Measurement of Space-Heating Emissions

Appendix H

Sierra Research Critique & OMNI Response

By request of the Fairbanks North Star Borough, this report was subject to a third-party review by Sierra Research. A memorandum summarizing this review is included in this appendix. The critique includes an analysis of the testing data, an enumeration of minor errors and errata found in the report draft reviewed, and general criticisms about the testing and reporting process. The minor issues and errata have all been addressed in the final version of the report, but the broader criticisms warranted further response. This response, in the form of a letter to Dr. James Connor of FNSB, is also included in this appendix.

January 24, 2012

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Memo to: Dr. James Conner, FNSB

From: Sierra Research

Subject: Critical Review of Draft Report "Measurement of Space-Heating Emissions," dated December 23, 2011, by OMNI-Test Laboratories, Inc.

Between March 8 and August 18, 2011, Omni-Test Laboratories, Inc., under contract to FNSB, conducted a series of 35 tests on nine space heating appliances, using six typical Fairbanks fuels. The main purposes of this study were to measure emissions and to provide detailed source profiles for chemical mass balance modeling. This memorandum summarizes the results of a review by Sierra Research of OMNI's draft report and data. Consistent with Borough priorities and SIP planning needs, our review has focused on $PM_{2.5}$ emission factors and the data collected by OMNI to develop those emission factors and corresponding source profiles.

Summary of Sierra's Findings and Recommendations

Testing, Analysis and Reporting Shortcomings

In several areas, OMNI's testing, analysis and/or reporting were, in our opinion, inadequate to meet Borough needs. These areas are outlined below and discussed in detail in the later sections entitled "Issues with OMNI Testing/Analysis/Reporting" and "Other Issues/Errata."

1. OMNI tested one emission control device installed on two different heating appliances. However, because of a failure to test the retrofit control device with the feedback air control attached, this supplemental control device testing did not meet the Borough's need for testing that is representative of Alaskan (or other "real world") conditions. Those test results, from run nos. 27 and 34, are of no use to the Borough.

2. OMNI's approach to measuring cold start effects using one integrated filter sample to capture ignition+kindling+coldstart preburn+hotstart testburn was flawed, in our opinion, because it did not provide the measurement of cold start emissions (only) required by the Borough. OMNI's initial analysis of its "cold start" test data was also flawed, in our opinion, for the same reason. Because of these problems, the results from OMNI's (5) cold start tests are of limited use.

3. OMNI found in its testing that the non-qualified (i.e., non-phase 2 certified) OWHH produced "an extreme amount of PM and heat in the flue…far beyond the capabilities of the sampling equipment." OMNI's steps to address the resulting problems were extensive. But OMNI did not, in our opinion, demonstrate that those measures were fully successful. Furthermore, in certain cases the test results were counterintuitive, raising further questions about their validity. For these reasons, Sierra does not believe that the results from nonqualified OWHH testing (run nos. 25-27 and 30-33) should be relied upon for regulatory purposes without further validation.

4. OMNI's analysis and review of its data and its reporting were insufficient to meet the Borough's needs. OMNI was selected by the Borough to perform this contract in part due to its anticipated understanding, experience, and qualifications in testing and interpreting test results for wood-burning and other space heating appliances. However, OMNI's analysis, interpretation, and reporting of test results, did not, in several areas, produce and properly identify much of what was critically needed by the Borough from the testing results. In particular, although OMNI's testing involved a specified matrix of fuels, appliance types, and other factors, and OMNI collected potentially valuable data, OMNI did little more than report the data—missing were the analysis and the insights.

Sierra has attempted to develop this information from an analysis of data in the report along with additional information provided by OMNI. Our summary of these insights is presented in the subsection below. Details are presented in the "Key Findings" section later in this memo, and reflected in the figures and tables appended to this memo.

Insights Gained from OMNI's Test Results

Notwithstanding the shortcomings described earlier, OMNI's testing of space heating appliances produced a dataset from which we were able to make several findings that should be useful to the Borough for its SIP planning and emission reduction strategy development. These include those outlined below.

1. EPA-certified wood stoves have a significantly lower PM emission factor (lbs of PM per ton of wood burned, dry basis) than non-certified stoves (see Figure 1, attached). This is important for two reasons. First, it confirms that the Borough's current strategy of providing incentives to remove non-certified wood stoves is an effective approach, even if such stoves are replaced by EPA-certified woodstoves (which were found to emit 70% less PM). Second, the developed emission factors allowed the quantification of the emission benefits per unit of fuel burned as well as per unit of useful heat output; this quantification provides support for the Borough's PM emissions inventory and for the evaluation of potential future emission reduction strategies that involve space heating.

2. EPA qualified (phase 2) OWHHs have a significantly lower emission factor than nonqualified OWHHs (see Figure 2). Although OMNI's testing of the

nonqualified OWHHs requires further validation in our opinion, a qualitative finding of much lower emissions is, we believe, supportable.

3. Emission factors for cordwood burned at" low" firing rate (about 35% of full load) are higher or much higher than at "high" (appliance maximum) firing rate, a result that has been reported by OMNI and others from previous measurement studies with other fuels. Emission factors were also found to be higher for birch than for spruce, which is contrary to the expectation of lower emissions for hardwoods compared to softwoods. These findings, which are detailed later and reflected in the 16 test runs shown in Figures 1 and 2, inform decisions about how and what to burn to minimize PM emissions and will assist both in the refinement of the Borough's emissions inventory and in providing guidance and technical support for the SIP.

4. Emission factors for coal in various forms (wet/dry, lump/stoker, low/high firing rate) resulted in a range of emission factors with no obvious systematic variation (results for six test runs, shown in Figure 3). While less satisfying than the simple, more systematic patterns observed for cordwood, these findings help to quantify the magnitude and variability of PM emissions from residential coal combustion. This is valuable because residential coal combustion is not explicitly represented in EPA's AP-42 emission factor compilation. The measurements shown also help to illustrate the substantial emission reduction possible when using augerfed coal compared to a conventional coal stove or coal-fired hydronic heater. (This and other comparisons of emission factors across fuel and appliance types are shown in Figures 4 and 5.)

5. The current OMNI study is the first systematic attempt to identify emission factors from Alaska-specific fuels and popular Alaska heating appliances, and results showed that emission factors with Alaska-specific fuels and appliances tend to be lower than EPA's AP-42 emission factors (see Attachment A). Better understanding and documenting the differences between the two will help guide the development of an effective and technically defensible SIP.

6. Firing with more homogeneously burned fuels—like oil, augerfed coal, and wood chips—tends to produce lower or dramatically lower PM emissions than cordwood. This observation, which was made by OMNI, lends credibility to the measurements because it is very reasonable to expect that more uniform fuel air mixtures will result in reduced emissions of unburned or partially burned fuel, which contribute to PM; more importantly, however, it is indicative of the large potential benefit of fuel switching. For example, on the basis of grams of PM emitter per megajoule of useful heat provided, OMNI's emission factors indicate that one conventional wood stove emits about 175 times as much PM as an oil burning appliance that produces the same amount of useful heat.

7. OMNI's speciated PM source profiles represent the first systematic sampling of the elemental composition of Alaska-specific fuels and space heating devices and, pending further review and comparisons with existing EPA profiles, they are expected to be used for CMB analysis as part of the SIP. However, at least one

profile (Run No. 1, the pellet stove test, which is discussed later) showed problems and should not, in our opinion, be relied upon without further analysis.

8. Waste lubricating oil, burned in a special purpose burner, was tested and found to have relatively low PM emissions compared to the non-homogenous fuels. However, the emissions profile for waste oil shows high concentrations of chlorine, phosphorous, potassium, and zinc, as well as a higher sulfur level than the conventional fuel oils, as shown later.

9. All of the mass profiles provided by OMNI have been compiled by Sierra into percentage mass profiles, and a subset of nine of those has been provided to the University of Montana for review. The subset was selected by Sierra to represent each major appliance type and fuels, as described in Table 1, below. In lieu of replicate tests (which are not available), the last two profiles were selected to provide backup for wood and coal burning in case problems were identified with the corresponding primary profiles above. All of these profiles are currently undergoing review.

Table 1
OMNI Profiles Selected to Represent Specified Source Categories

Run No.	Representation (and rationale)
5	EPA-certified Woodstove (low firing rate is most common, birch is highest emitting)
9	EPA-qualified OWHH (low firing rate, birch)
15	Conventional woodstove (low firing rate, birch)
17	Oil burner (no.2 fuel oil is most common)
18	Waste oil burner (only test of this source)
23	Coal stove (wet stoker coal and low firing rate are believed most common)
29	Coal OHH (wet stoker coal most common, augerfed showed low PM EF)
6	Backup profile for wood burning (EPA woodstove, spruce, low firing rate)
38	Backup profile for coal burning (coal stove, dry lump coal, low firing rate)

10. Emissions measurements for NH_3 collected by OMNI have no direct counterpart in EPA's AP-42 compilation of emission factors. However, Sierra has extracted the emission factor measurements from the OMNI testing and compared them (Table 2, below) with the most closely corresponding estimates contained in the preliminary emissions inventory for the SIP, which are based on estimates by Pechan[1] using molar ratios to CO. As the table shows, OMNI's emission factors, expressed as lbs of NH_3 per ton of fuel burned, tend to be less than the values estimated by Pechan but are generally within a factor of 4-5.

[1] Roe, Stephen, *et al*, "Estimating Ammonia Emissions from Anthropogenic Nonagricultural Sources - Draft Final Report)", prepared for Emission Inventory Improvement Program, by E.H. Pechan and Associates, Inc., April 2004.

Table 2
NH_3 Emission Factors by OMNI (draft report) Compared to Estimates by Pechan based on molar ratio to CO
(All emissions in lb/ton)

Pechan category and EF		OMNI description and EFs*	
Residential Wood, non-catalytic woodstoves, conventional	1.70	1 conventional, noncatalytic woodstove, avg (and range) of 4 tests: high and low firing rate, spruce and birch cordwood	0.386 (0.039 – 0.747)
Residential Wood, non-catalytic woodstoves, low-emitting	0.90	1 advanced (EPA-certified) noncatalytic woodstove, avg (and range) of 4 tests: high and low firing rate, spruce and birch cordwood	0.156 (0.053 – 0.322)
Residential wood, non-catalytic woodstoves, pellet fired	0.30	1 pellet stove, Alaskan wood pellets, low firing rate (~35%)	0.072
Residential wood, boilers and furnaces	1.8	1 non-qualified and 1 qualified OWHH, avg (and range) of 8 tests: 2 units, high and low firing rate, spruce and birch cordwood	0.202 (0.058 – 0.425)

* OMNI's measurements are based on M28 (hot start) tests and are expressed on the basis of dry tons burned; Pechan does not specify whether their measurements are on a dry basis.

The remainder of this memorandum provides additional background on the OMNI testing program and Sierra's review, including the limitations of our review; more detail about testing and reporting issues and about insights from the testing; and other issues/errata.

Background

Between March 8 and August 18, 2011, Omni-Test Laboratories, Inc., under contract to FNSB, conducted a series of 35 tests on nine space heating appliances, using six typical Fairbanks fuels. The testing matrix was specified by the Borough to meet its highest priority needs for preparation of the State Implementation Plan for $PM_{2.5}$. (A brief description and listing of results from each test is included in Attachment B.)

As specified by the Borough, filters were analyzed by RTI and liquid fuels were analyzed by SWRI. Solid fuels were analyzed by Twin Ports Testing. As of this writing, all of the planned testing has been completed, and essentially all test results have been received by Sierra[2] for review.

Previously, at the Borough's request, OMNI provided (partially complete) draft reports to the Borough dated September 1, 2011, and October 14, 2011, which described those

[2] As of this writing, we are still awaiting final minor formatting changes to the profiles for test runs that were reanalyzed by RTI and clarification of several items by OMNI and RTI.

portions of the test results from RTI and others that were available at the time. In November and December, OMNI provided the remainder of the test results and other requested information to Sierra, including a draft report dated December 23, 2011.

Limitations of This Review

Although Sierra received excellent cooperation from OMNI staff, our review has been limited by several factors, including the following: Sierra did not witness any of the testing; replicate testing was not conducted (or practical) for this limited test program; and, while OMNI performed many procedures and checks that are commonly a part of quality assurance, there was no quality assurance plan per se for the test program.

Issues with OMNI Testing/Analysis/Reporting

1. OMNI's supplemental testing of the retrofit control device did not meet the Borough's need for testing that is representative of Alaskan (or any other "real world") conditions.

A major focus of the Borough's contract with OMNI was to produce emissions measurements that represent typical Alaskan fuels, space heating appliances, and normal operations (consistent with standard measurement techniques, as specified). As part of this effort, OMNI received supplemental funding from the Borough in an amount of more than $25,000 to conduct two tests using a specified retrofit control device. Two supplemental tests were reported as reflected by the data and our conversations with OMNI, but there is essentially no description in the narrative portion of the report of either how tests were set up and conducted or what the results mean. Notably, the report does not state whether the feedback air control system for the retrofit control device was installed and operating during the tests.

It is Sierra's understanding, based on telephone conversations with both OMNI and the control device manufacturer,[3] that the control device manufacturer and/or its representative performed the control device installations and was present during both tests of the device, but that the feedback control system for the subject retrofit device was not connected or operating during the tests. If our understanding is correct that the air control system is, in fact, an integral part of the retrofit control device,[4] the associated test results would not be expected to represent any normal operating condition, nor would they be consistent with the pertinent objective of the project and OMNI's stated intent of measuring "real world" emissions. For these reasons, the results should not be used for emission inventory development, control technology assessment, or other regulatory purposes.

[3] Personal communications with OMNI and the control manufacturer, November and December 2011.
[4] The control device manufacturer has told Sierra that the furnace air control system is a part of the retrofit control system, and that they were instructed, either by the Borough directly or through OMNI, not to connect it. In contradiction, OMNI has told Sierra that the control device manufacturer was afforded all the time they required to install the control device completely and was present to witness the emissions testing that involved the control device.

2. OMNI's approach for measuring the effect of cold start on emissions represented a compromise between adherence to standard test methods, including Method 28 (which has no provision for cold-start testing) as specified by the Borough, and using a multi-test approach that, unavoidably, is subject to greater uncertainty. However, we believe the measurement as used and analyzed by OMNI to determine cold-start effect was flawed.

Briefly, OMNI used one integrated filter to capture emissions from four test phases: the cold start ignition, a kindling phase (which used a small charge of birch kindling), a high firing rate preburn charge (to prepare the hot coal bed for a Method 28 test), and a low firing rate test fuel charge. OMNI then used a modeling approach (initially suggested by Sierra after the testing was completed) of subtracting the emitted PM mass from the individual phases of the test to estimate the cold start effect. We view this approach as less than ideal because it requires taking differences from several tests, each of which unavoidably introduces additional (g/hr) uncertainties.

Subsequent to our most recent discussions with OMNI on this, we have a slightly revised, and we believe superior, approach to offer, whereby emissions for the ignition+kindling phase (together) are estimated by difference of the composite and two controlled (preburn and test) phases. However, neither this approach nor the one used by OMNI is able to fully compensate for the problematic integrated sampling approach used, which confounds the cold-start, high firing rate phase with the low firing rate main test phase.

Figure 6 provides an illustration of how we interpret the "cold start" tests. The two bars shown in the figure represent grams of PM emissions for the actual composite test (on the right), which had emissions of 38.73 grams, and an attempted reconstruction of that mass on the left, using emission factors from other low and high firing rate tests of the same unit and same fuel type, but using the fuel masses from the composite test. The difference of the reconstructed mass and the measured mass, which is shown lightly colored in the figure, is the mass attributed to the cold start—in this case, 4.67 grams out of the total of 38.73 grams, or 12.1% of the mass.

One may then ask, how do the mass emissions compare for a birch cordwood, low firing rate stove that is cold-started vs. one that is hot-started? The answer, from the figure, is that the hot start stove emits just 30.40 grams (time after time), whereas the cold started stove (after subtracting the preburn high firing rate charge, from the left hand bar), emits 35.07 (4.47+30.40) grams from start/kindling plus low firing rate test charge.

Similarly computed percentages are shown in Figure 7 for three other cold start tests, all of those 3 representing coal firing. The first two of those show relatively larger start effects, which may be real and caused by the relatively higher emission factor of the birch kindling compared to the coal pre-charge and test charge. In the case of augerfed coal (far right bar), the starting emissions are shown as negative, which is not true, but is a reflection of the uncertainty of the estimate showing them to be indistinguishable from zero. However, while not apparent from the figure, that also appears to be the case with the EPA certified wood stove (first bar), where the magnitude of the start effect is such that it likely is within the uncertainty of the measurement, and therefore indistinguishable from zero. This measurement is also far less than the several-fold difference suggested in

OMNI's 2009 report for Environment Canada.[5] OMNI's explanation of this to Sierra is that the Ontario report actually combines low firing rate and cold start and contrasts that result with high firing rate and hot start; thus, it too confounds the cold start effect. Sierra recommends that OMNI make a slight revision to its approach (as outlined above), include a more complete and detailed explanation in its report of how it analyzed the results, and provide a comparison of the current results with the results of Ontario (which appear to be the closest available comparison), explaining why the results are different.

One last interesting observation from Figure 6 is that it also permits an estimate of the effect of cold start upon mass emissions for a unit that burns birch cordwood at high (rather than low) firing rate. Here, we simply ignore (i.e., subtract out) the large contribution from the low firing rate main test charge and treat the preburn high firing rate phase as the main test charge. For this case, the mass emissions for a hot start are 3.66 grams and those for a cold start are 8.33 (4.67+3.66)—this represents a 128% increase, but results in relatively low emissions in either case because the relatively high emission factor associated with the low firing rate is eliminated.

3. Flow rates and filter loadings for the non-qualified OWHH testing (Run nos. 25-27 and 30-33, as listed in Attachment B) exceeded OMNI's testing system capabilities, requiring adaptations and non-standard test methods.

According to OMNI's assessment (p. 13):

> *The non-qualified OWHH used for testing required substantially modified procedures in order to generate meaningful results. This unit produced an extreme amount of particulate matter and heat in the flue. Combined with a low dilution factor, this resulted in excessively high particulate concentrations and temperatures in the dilution tunnel – far beyond the capabilities of the sampling systems described in Section 2.3*.

OMNI was required to take extraordinary steps (some, but not all of which are detailed in the report[6]) to address condensation problems, filter plugging, and filter overloading, yet, in the end, concluded that all of the provided test results, including those for the non-qualified OWHH, are valid.[7] We are less confident in this conclusion for the non-qualified OWHH results, in part because RTI found that filter overloading clearly did invalidate at least some of the XRF analyses (which had to be redone, as discussed in footnote 6), and also because of the somewhat surprising results for firing at low vs. high firing rate (discussed under the Cold Start issue, below), which tend to contradict the general pattern observed by OMNI and others in wood appliance testing.[8,9,10]

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[5] Pitzman, Lyrik, et al, "Verification of Emission Factors USEPA Certified Wood Heaters (Volume 1)", prepared for Environment Canada, by OMNI, September 8, 2009.

[6] OMNI should identify in the report which runs had filters that were overloaded to the point that RTI concluded that XRF analysis required calibration for individual elements. OMNI should also document in the report that spare duplicate filters were used for the reanalysis and which elements were reanalyzed. If not already done, the emission profile results for any elements that were not reanalyzed in this way for overloaded filters should be removed from the report.

[7] Personal communication with OMNI, December 2011.

[8] For example, in a 2005 study prepared for the Hearth and Patio Association ("PM2.5 Emission Reduction Benefits of Replacing Conventional Uncertified Cordwood Stoves with Certified Cordwood Stoves or

Accordingly, we recommend that test results for the non-qualified OWHH not be relied upon for regulatory purposes.

4. The amount of potassium in the PM emissions from the pellet burner was extraordinary—about 1/3 of the PM mass—and investigation into this by RTI revealed other significant problems with the pellet stove profile, namely "clearly low" mass reconstruction and "very poor" ion balance, according to RTI.[11]

These and other aspects of the Run 1 (pellet burner) test profile should be documented in a stand-alone section of the appendix that includes RTI's assessment. For the main report volume, it should suffice to say that quality control checks on the results for the pellet burner indicate that the profile cannot be relied upon for regulatory analysis, although the relatively high potassium measurement may be sound and is not without precedent, according to RTI.

Additional Detail on Insights Gained from OMNI's Test Results

1. Four tests were conducted with a conventional wood stove and four with an EPA-certified wood stove. Both were reported by OMNI to be popular and representative models in interior Alaska. Each model was tested with two permutations of firing rate (high and low) and with two fuels (birch and spruce), allowing for evaluation not only of the conventional vs. certified factor, but also the birch vs. spruce factor and low vs. high firing rate. A brief description of each test, and the corresponding emissions data are shown in Table 3.

Table 3
Summary of OMNI Test Results for Woodstoves

Run	Appliance	Fuel	Burn Rate	PM Emissions (g/MJ output)	PM Emissions (lb/ton)
2	EPA Certified Woodstove	Birch	High	0.041	0.977
3	EPA Certified Woodstove	Spruce	High	0.021	0.549
5	EPA Certified Woodstove	Birch	Low	0.331	8.16
6	EPA Certified Woodstove	Spruce	Low	0.079	1.90
12	Conventional Woodstove	Spruce	High	0.051	0.89
13	Conventional Woodstove	Birch	High	1.246	21.79
14	Conventional Woodstove	Spruce	Low	0.197	4.22
15	Conventional Woodstove	Birch	Low	0.581	12.13

Modern Pellet Stoves"), Houck et al of OMNI, appeared to suggest an average increase in PM emission factors (g/kg) of 344% when comparing a high and low burn rate for ten studies.

[9] Differences of <5 g/hr in emission rates might be interpreted as test to test variation, but the high to low firing rate PM emission difference observed for the nonqualified OWHH with birch was 75 g/hr.

[10] Sierra believes that variation in emission factors with load may be one of the key factors contributing to the uncertainty in the emission inventory for woodburning in Fairbanks.

[11] Personal communication with Dr. James Flanagan, RTI, December 2011.

For the woodstoves, Figure 1 shows an average emission factor from the four conventional stoves of 9.76 lbs/ton (dry basis) and an average of 2.90 lbs/ton for EPA-certified stoves, which is a 70% reduction. From the eight tests, all four of the pairwise comparisons (e.g. birch low-firing rate conventional vs. birch low-firing rate EPA certified) show a significant reduction. Similarly, with regard to birch vs. spruce, all four of the pairwise comparisons (e.g. birch low conventional vs. spruce low conventional) show a significant reduction. And finally, for low vs. high firing rate, three of the four pairwise comparisons (e.g. spruce low conventional vs. spruce high conventional) show a significant reduction. The exception is birch low conventional vs. birch high conventional, which shows an inversion of the usual pattern of higher emissions at low firing rate. We see no definitive explanation for this difference, although OMNI noted that the conventional stove had significant air leakage (which OMNI considered typical for an older, conventional stove) and, as a result, it was difficult to maintain tight air control for the "low" firing rate. Thus, if air could be more effectively controlled, the "true" emission factor for birch low conventional (and spruce low conventional) may be higher than was measured.

2. Similar to the woodstoves, four tests were run for each of two popular and believed representative outdoor wood hydronic heaters, a non-EPA-qualified unit and a qualified (Phase 2) unit, with the resulting lb/ton emission factors shown in Table 4 and Figure 2. Although we note a caution about the four nonqualified OWHH tests shown, we see an overall reduction of 84% from the 14.3 lb/ton 4-test average of the nonqualified unit to the 2.32 lb/ton average of the EPA qualified OWHH. Also, the patterns of wood type and firing rate are essentially identical to those observed for the woodstoves, including the inversion of the emission factors for high and low firing rates with birch of the nonqualified OWHH. The reasons in this case are also unknown.

Table 4
Summary of OMNI Test Results for OWHHs

Run	Appliance	Fuel	Burn Rate	PM Emissions (g/MJ output)	PM Emissions (lbs/ton)
8	EPA Qualified OWHH	Birch	High	0.057	1.61
9	EPA Qualified OWHH	Birch	Low	0.212	5.32
10	EPA Qualified OWHH	Spruce	High	0.027	0.769
11	EPA Qualified OWHH	Spruce	Low	0.065	1.576
25	Non Qualified OWHH	Spruce	High	0.789	10.89
30	Non Qualified OWHH	Spruce	Low	2.315	25.70
31	Non Qualified OWHH	Birch	High	0.757	11.85
32	Non Qualified OWHH	Birch	Low	0.757	8.82

3. There was no replicate testing performed that would permit rigorous statistical comparisons of the emission factors reported by OMNI. However, we view the

relative consistency of the results outlined above as a positive measure of their reliability. In addition, Sierra performed a simple multiple regression analysis of the above 16 emission factor test results using a log-linear model. The results, on average, showed the following:

- The lb/ton emission factor (EF) for conventional models was 390% compared to that for advanced (either qualified or certified), i.e., higher by nearly a factor of four;
- The EF for birch was 148% that of spruce;
- The EF for low firing rate vs. high was 134% (and only marginally significant statistically); and
- The EF for woodstove vs. OWHH was not statistically significant.

4. The emission factors for coal burning in a coal stove averaged 8.65 lbs/ton for the six tests shown in Table 5 and Figure 3. They ranged from a low of 2.3 lb/ton for dry stoker coal at low firing rate to 15.1 for wet stoker coal at a low firing rate. However, neither the effects of firing rate, nor pulverized vs. lump coal, nor even wet vs. dry coal were consistent. This may be due to high test variability, a more complex pattern of interactions than can be discerned by six tests, or other factors.

Table 5
Summary of OMNI Test Results for Coal Stoves and Augerfed HH

Run	Appliance	Fuel	Burn Rate	PM Emissions (g/MJ output)	PM Emissions (lbs/ton)
20	Coal Stove	Dry Stoker Coal	High	0.459	13.22
21	Coal Stove	Dry Stoker Coal	Low	0.085	2.32
23	Coal Stove	Stoker Coal	Low	0.589	15.07
29	Augerfed HH	Coal (hot start)	Single	0.030	0.96
35	Coal Stove	Stoker Coal	High	0.252	6.75
37	Coal Stove	Lump Coal	Low	0.142	3.98
38	Coal Stove	Dry Lump Coal	Low	0.377	10.57

This uncertainty in the emission factor for coal stoves is not, however, of much significance for the Borough's emission inventory, as the number of coal stoves is much smaller than the numbers of oil or wood-burning heating appliances. What the uncertainty does show, both for coal stoves and wood stoves, is that there is broad overlap of the two categories, i.e., despite the minor differences in average lb/ton values between woodstoves and coal stoves, there is no real difference between the two with regard to the amount of primary (i.e., direct) PM emissions per mass of fuel burned, and that both coal- and wood-burning produce far more PM than oil-burning.

The one exception to this pattern was the relatively low 0.96 lb/ton PM emission factor for the augerfed coal OHH (also shown in Table 5), which is nearly an order of magnitude below the average for the six coal stove test runs and only a factor of four greater than oil burning. Figure 4 illustrates these and other comparisons between emission factor test means, expressed as lbs/ton for the various fuel/appliance combinations. Figure 5, taken directly from OMNI's draft report, extends the comparison by showing, for each test, the g/MJ of heat output.

5. It would be difficult to overstate the significance of the OMNI study as the first systematic attempt to identify Alaska-specific emission factors representing both Alaska-specific fuel samples and heating appliances that were specifically selected to be popular and representative for interior Alaska. These two simple facts greatly increase the confidence associated with using the OMNI test results for Alaska's PM SIP.

It is also interesting to compare the OMNI test results, where possible, with EPA's compilation of emission factors as represented in EPA publication AP-42.
This comparison is attempted in Attachment A, where it may be seen that for six out of eight comparisons shown, the current OMNI lb/ton test results shown in column 1 are less than the AP-42 results shown in column 3. Exceptions are the coal stove (for which the AP-42 emission factor is really for a boiler, which is not directly comparable), and for the waste oil burner, where results depend (according to AP-42) on the specific ash content of the fuel.

6. There is, as demonstrated in Figure 5, a wide range of PM emissions from the various fuels and space heating appliances that represent Fairbanks. Furthermore, it's clear from the listing of these same emission factors in Attachment B that for the same useful heat output, the most extreme PM emitters can produce as much as 1,000 times higher PM emissions than at the cleaner end, and that even the next cleanest technology produces 3-4 times as much PM as fuel oil. The simple conclusion from this comparison is that a shift from burning wood to burning fuel oil would achieve PM emission reductions as soon as possible.

Other Issues/Errata

p. 3, Table 1. EPA Methods 28 and 28 OWHH are mentioned on subsequent pages but are not shown in Table 1. They should be.

p. 8, Section 2.4. It should be noted somewhere in the report, and this may be a logical place, that all tests with wood burning used cordwood of the specified types, which are popular in interior Alaska, rather than the crib wood of other types (which are specified in the respective test methods). Furthermore, birch kindling was used for the cold starts. Lastly, for reasons of practicality, the testing of each stove/fuel/condition used only one or two firing rates (low and high), as specified by the Borough, rather than four as specified in Method 28.

p. 9, Table 2. Run 27 is identified as a cold start, which is incorrect. It was a hot start (as implied in Table 10, pg 14).

p. 10, Section 2.4.2. The reference to Table 3 should be to Table 4, and in the same sentence, the word "load" should be inserted after "fuel." A sentence should also be added to describe briefly the cold start of Run 41, which is a deviation from Method 28 and is listed in the table.

p. 15, Sections 2.5 and 2.6. Two sections should be added to describe the retrofit control device testing and the cold start testing, respectively. For the retrofit control device, the report should document the conditions of the device setup and testing as described above.

p. 16, Section 3.3. Regarding the number 1 fuel oil and CO concentration below detection limit, it is suggested that the corresponding entries in Tables 12 and 16 be changed from "0" to "ND" (not detected), which matches the other tables and better describes the results, and that a footnote be added at the bottom of each table to describe "ND", "N/A" (not applicable), and ">" (exceeded instrument limit).

pp. 17-20, Tables 12-20. We understand that the data contained in the tables (and shown elsewhere in the report) used the initial (erroneous) lab analysis results for liquid fuels, and that these would be updated with the results from SWRI when available. Please confirm that the updated values have been incorporated throughout the report, including in the revised calculations of emission factors, etc. (and not just in Appendix B).

p. 25, Table 20. There is no reference or mention in the narrative of this important summary table. It should be referred to and briefly described in Section 3.1 (pg 16) in place of the reference to Appendix A. Similarly, the reference to Appendix B in Section 3.2 would be more useful if it referred instead to Tables 12 through 19.

p. 26, Section 4.1. It is stated here that "Emissions from eight appliances…were sampled…," whereas it was stated earlier (p. 1, Section 1), "…nine heating appliances were selected and operated…" There were nine, and p. 26 should be corrected.

p. 27. At Sierra's suggestion, OMNI provided graphs showing PM emissions per unit of useful heat output. Subsequently, EPA identified a problem with the measurements used to compute the efficiency of qualified OWHHs, and the agency removed the corresponding reported values from its website. OMNI should note this fact in its report, and state that it used the measurement and analysis procedures that were specified in Method 28 as of the time of its report.

On the same page, OMNI correctly notes that spruce generally burned cleaner (g/MJ) than birch, which Sierra also observed to be true on a lb/ton basis. This result is contrary to the general observation from prior testing that combustion of softwoods tend to have higher PM emissions than from hardwoods. OMNI should address this apparent contradiction between its test results and those in the literature.

p. 29. The reference to low amounts of particulate matter from waste oil needs to be qualified. In particular, the large fractions of chlorine, phosphorous, potassium and zinc on this filter, which are probably attributable to fuel oil additives, are noteworthy. The

resulting profile from this test (Run 18) appears to be limited to certain elements. (Is this a rerun of a previously overloaded filter? Are there no other filter results which are a rerun of a previous filter and therefore limited in the elements listed?)

p. 31. The emissions bars in Figure 12 should be labeled and, in Sierra's opinion, the results for the non-qualified OWHH should be identified as a subject to confirmatory testing.

pp. 32 and 33. Figures 13 and 14 should instead be labeled as Tables 21 and 22, respectively.

Appendix A. Several tests show blank fields for elemental and organic carbon for the quartz fiber filter sample. It is understood that these are due to filter overloadings that prevented the analyses. That explanation should be included in the report, and indicator, e.g. "NA" (not available) should be used in place of the blank on the pertinent test summary sheets. The same indicator should be used for those elements on the Teflon filter samples that were not reanalyzed by XRF when backup filters were reanalyzed by RTI due to filter overloading.

Appendix C. The real time graphs for several tests show results for several tests that are strongly modulated periodically. This is understood to be due to the automatic OWHH control of combustion air. For several other appliances, it is understood that combustion air was manually adjusted in an attempt to achieve the targeted burn rates. Both explanations should be included in the report.

Appendix E. There is conflicting information about how ignition was performed for the five cold start tests, with one source indicating that a propane torch was used for all, while another statement indicated that a lighter (butane) was used in at least one case. This should be clarified.

Figure 1

(Preliminary) $PM_{2.5}$ Emission Factors from OMNI Testing for Conventional and EPA-Certified Wood Stoves, Using Birch or Spruce and Low or High Firing Rates (lbs/ton of dry fuel)

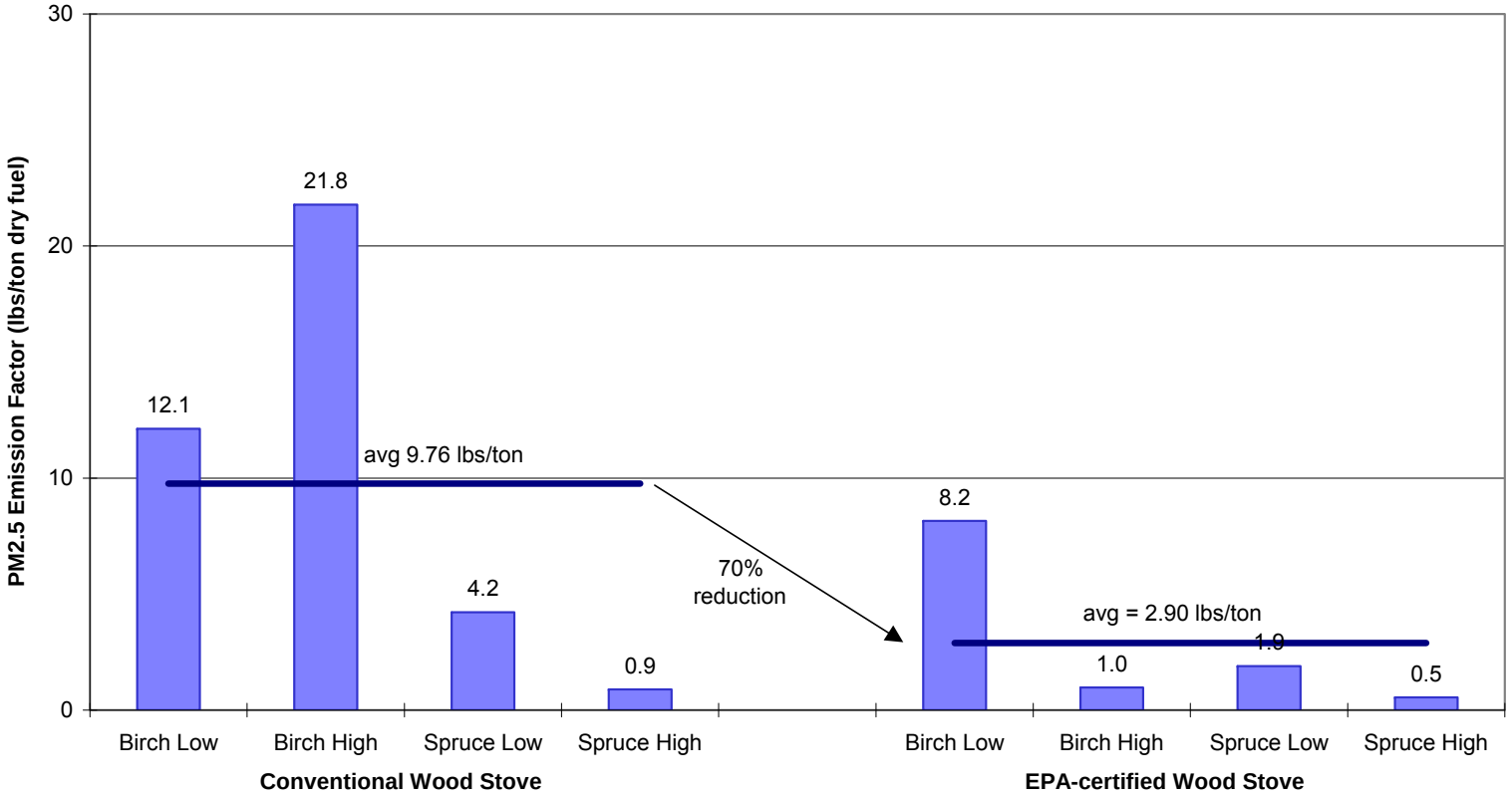


Figure 2

(Preliminary) Outdoor Wood Hydronic Heaters $PM_{2.5}$ Emission Factors from OMNI Testing for "Non-Qualified" and EPA-Qualified OWHHs using Birch or Spruce and Low or High Firing Rates (lbs/ton of dry fuel)

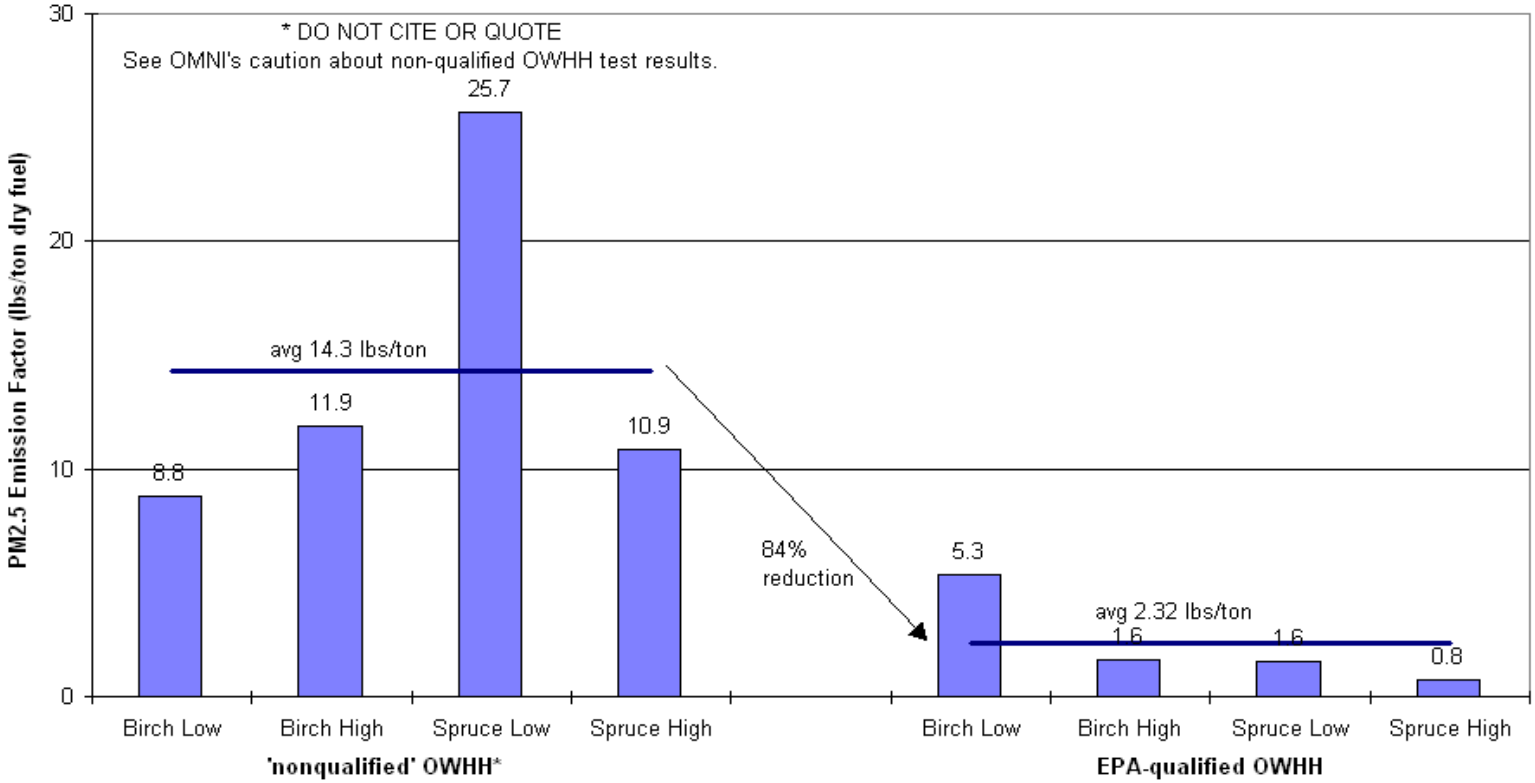


Figure 3

(Preliminary) Coal $PM_{2.5}$ Emission Factors from OMNI Coal Stove Testing for Wet or Dry Stoker and Lump Coal; Low and High Firing Rates; (lbs/ton of dry fuel)

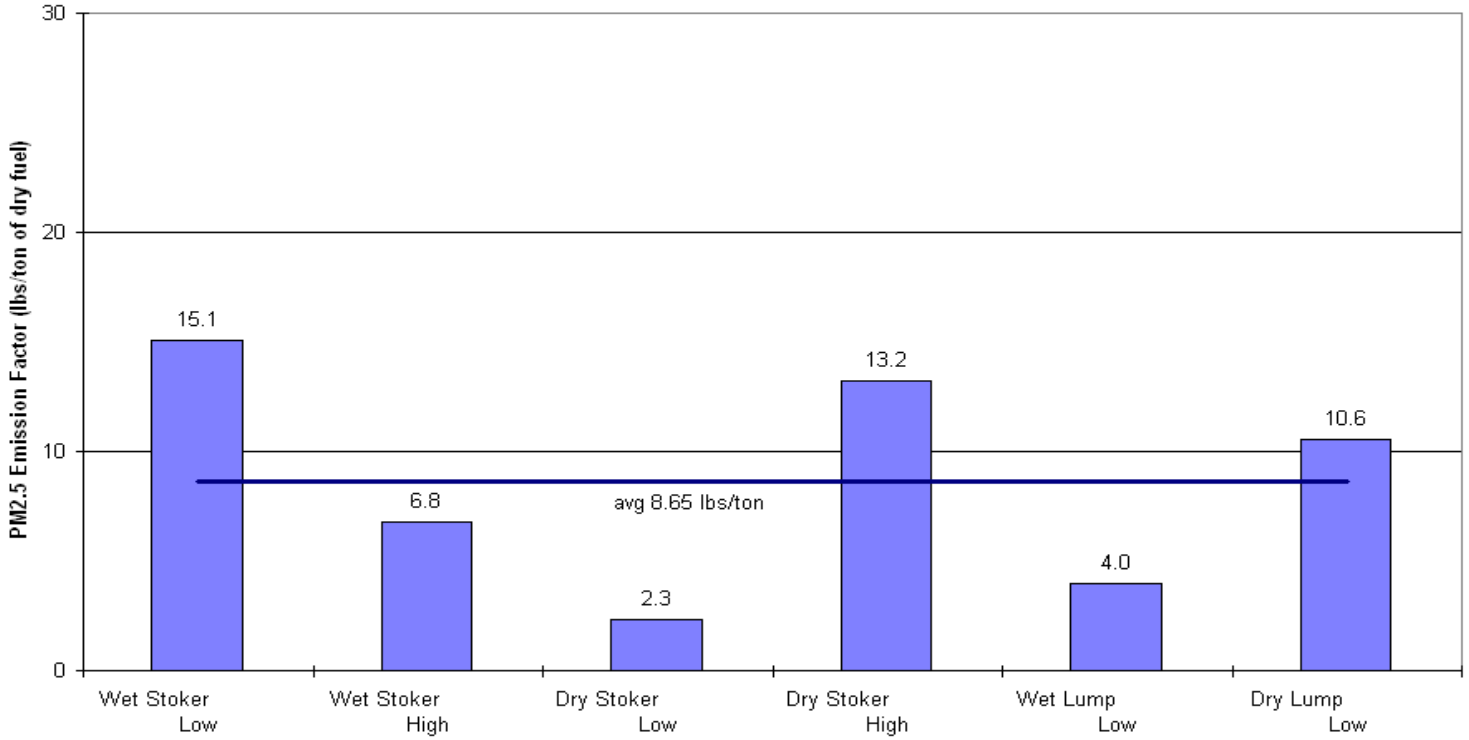


Figure 4

Preliminary Min, Max, and Average $PM_{2.5}$ Emission Factor by Appliance Type from OMNI Testing
(lbs $PM_{2.5}$ emitted per ton of fuel burned)

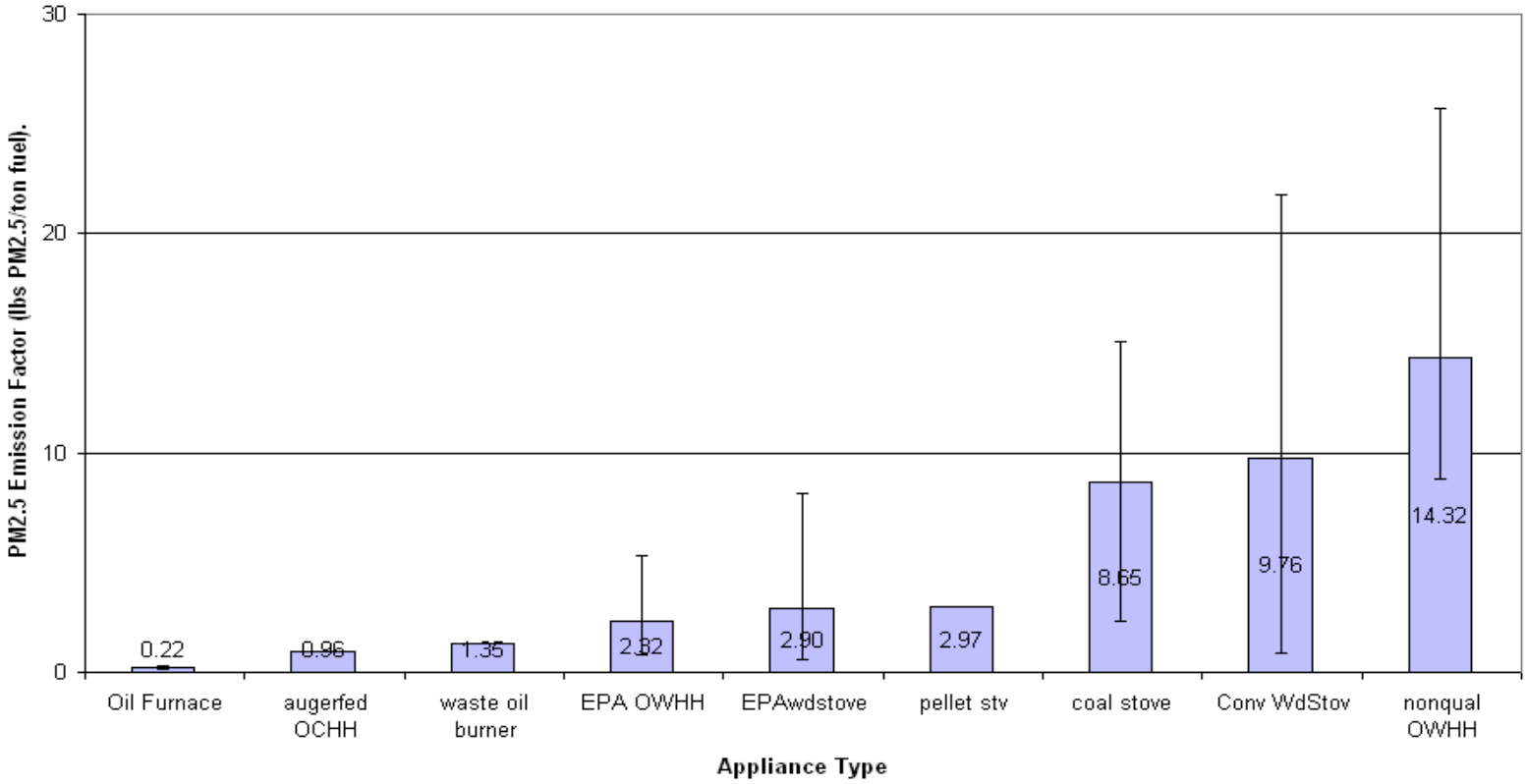


Figure 5

OMNI Preliminary Testing Results as $PM_{2.5}$ Emissions per Unit of Useful Heat Output (grams per megajoule)
(IMPORTANT – raw measurement results, see narrative for caveats)

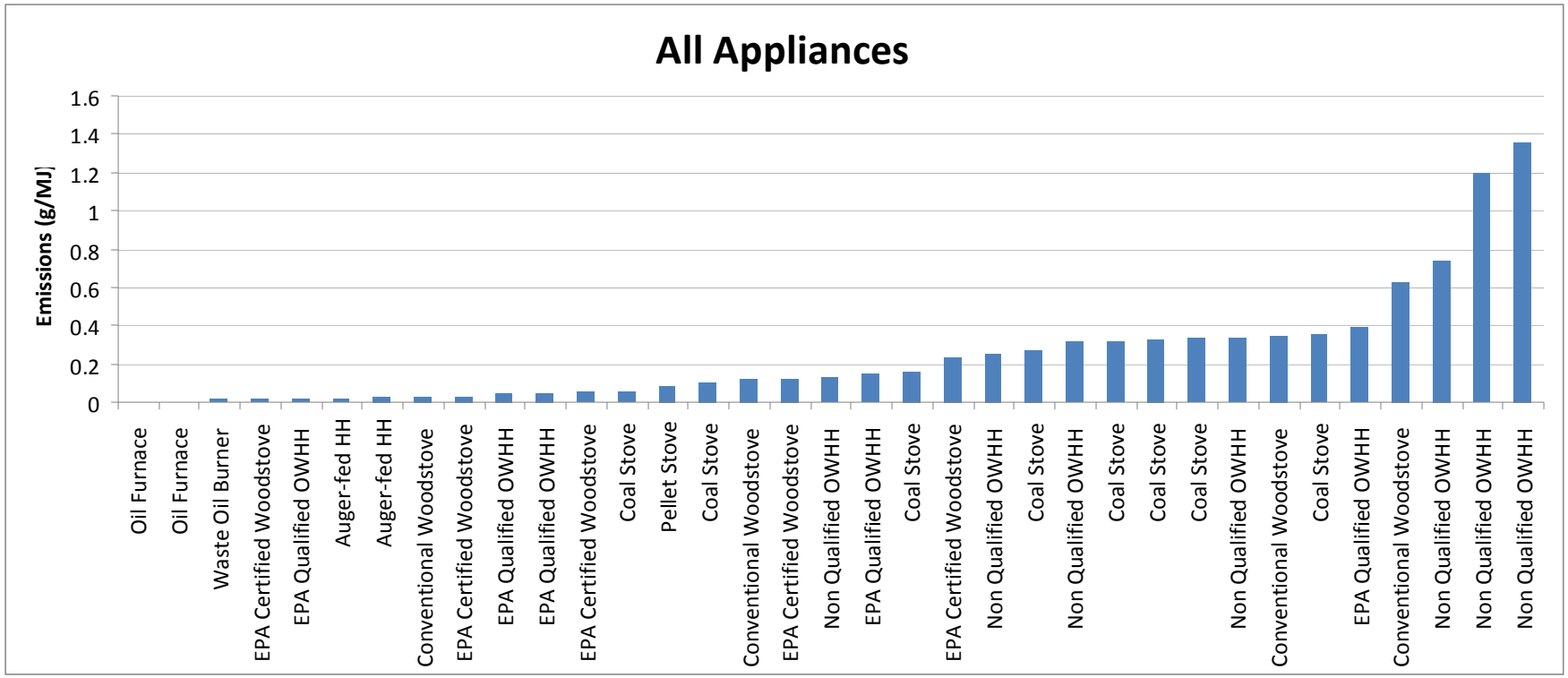


Figure 6

Cold Start Emissions for EPA Certified Wood Stove Burning Birch with Estimated Contribution from Each Test Phase

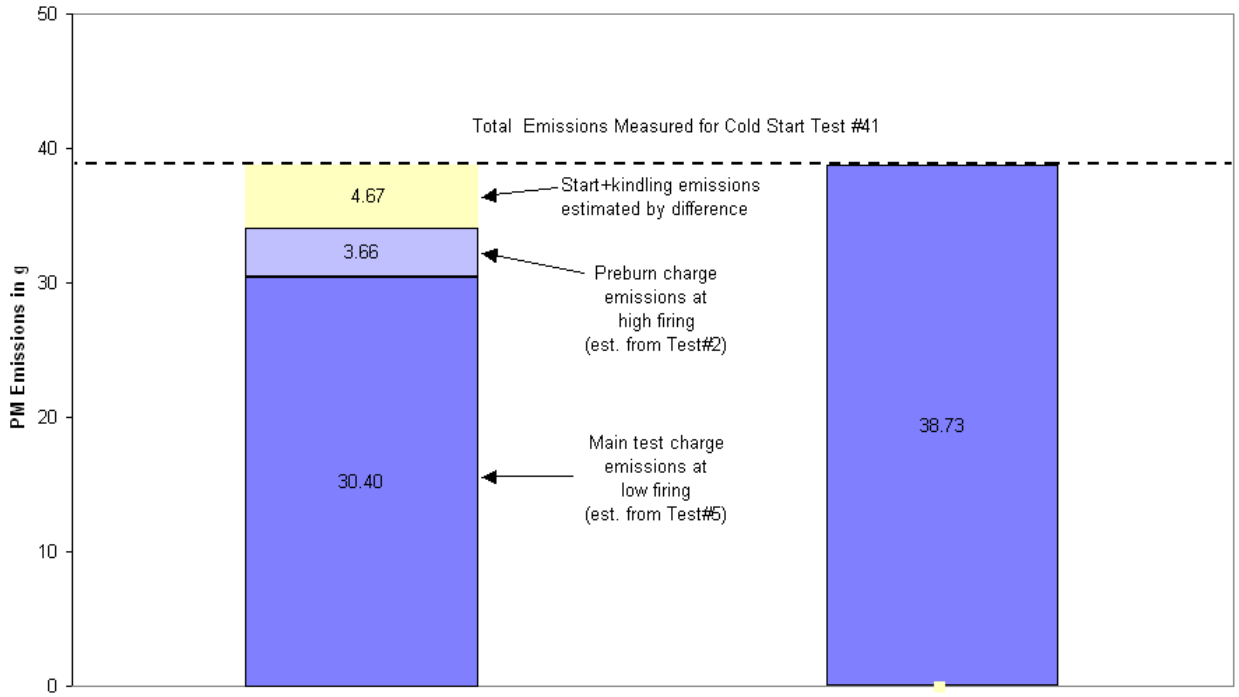
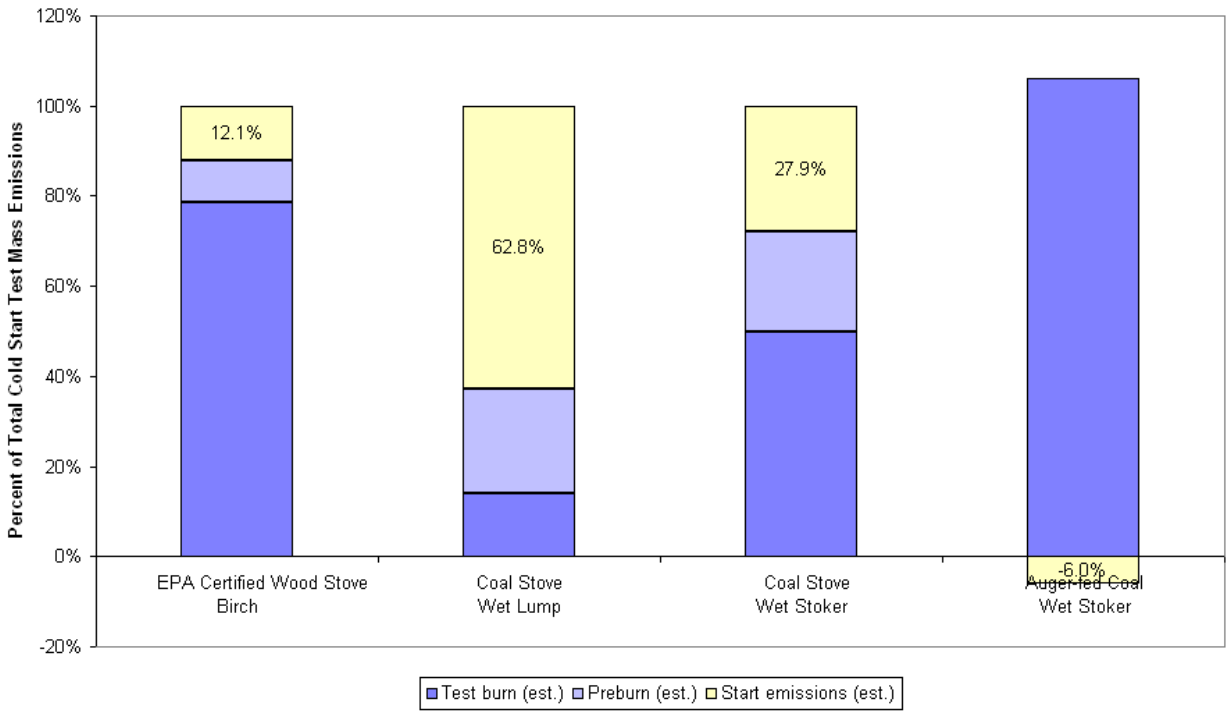


Figure 7

Estimated Contribution of Start+Kindling Emissions to Total Cold Start Test Emissions



Attachment A
Comparison of Selected OMNI PM Emission Factors Measurements (lbs/ton) with Prior Study Results & AP-42

Appliance Type	Current OMNI Testing Avg (range of conditions)	Earlier OMNI Testing of Same Model (fuel & method may vary)	AP-42 EFs (w. assumed or measured fuel properties)
Stove			
• Conventional, wood	9.8 (8.9 - 12.0)	7.1	30.6
• EPA-certified, wood	2.9 (2.4 - 5.3)	-	14.6 – 16.2
• Coal	8.7 (2.3 - 15.1)	-	-
OHH			
• Nonqualified, wood	14.3 (8.8 - 25.7)	-	-
• EPA Ph2 Qualified, wood	2.3 (0.77 – 5.3)	2.4	-
• Augerfed coal	0.96	-	3.8 (boiler)
Pellet Stove	3.0	-	4.2 - 8.8
Coal Stove	8.7 (2.3 – 15.1)	-	3.8 (boiler)
Oil burner			
• No. 1	0.33	-	0.55
• No.2	0.12	-	0.58
• Waste oil	2.97	-	0.17

Attachment B
List of Tests Performed by OMNI and Summary of Test Results

Run	Appliance	Fuel	Burn Rate	PM2.5 Emissions (g/hr)	Emissions (g/MJ output)	PM2.5 Emissions Factor (g/kg)
1	Pellet Stove	Alaskan Pellets	Single	3.31	0.111	1.48
2	EPA Certified Woodstove	Birch	High	1.84	0.041	0.49
3	EPA Certified Woodstove	Spruce	High	1.17	0.021	0.27
5	EPA Certified Woodstove	Birch	Low	6.12	0.331	4.08
6	EPA Certified Woodstove	Spruce	Low	1.68	0.079	0.95
8	EPA Qualified OWHH	Birch	High	10.72	0.057	0.81
9	EPA Qualified OWHH	Birch	Low	14.07	0.212	2.66
10	EPA Qualified OWHH	Spruce	High	5.12	0.027	0.38
11	EPA Qualified OWHH	Spruce	Low	4.32	0.065	0.79
12	Conventional Woodstove	Spruce	High	2.89	0.051	0.45
13	Conventional Woodstove	Birch	High	94.56	1.246	10.89
14	Conventional Woodstove	Spruce	Low	13.16	0.197	2.11
15	Conventional Woodstove	Birch	Low	44.02	0.581	6.06
17	Central Heating Indoor Furnace	No. 2 Heating Oil	Single	0.13	0.002	0.06
18	Waste Oil Burner	Waste Motor Oil	Single	10.41	0.021	0.67
20	Coal Stove	Dry Stoker Coal	High	17.45	0.459	6.61
21	Coal Stove	Dry Stoker Coal	Low	1.74	0.085	1.16
23	Coal Stove	Stoker Coal	Low	11.13	0.589	7.09
25	Non Qualified OWHH	Spruce	High	130.10	0.789	5.45
26	Non Qualified OWHH	Coal	Single	294.60	4.522	27.05
27	Non Qualified OWHH	Coal w/ retrofit control	Single	120.10	2.924	21.18
28	Augerfed HH	Coal (cold start)	Single	7.17	0.027	0.45
29	Augerfed HH	Coal (hot start)	Single	7.78	0.030	0.48
30	Non Qualified OWHH	Spruce	Low	174.00	2.315	12.85
31	Non Qualified OWHH	Birch	High	119.30	0.757	5.93
32	Non Qualified OWHH	Birch	Low	44.47	0.757	4.41
33	Non Qualified OWHH	Birch (cold start)	Low	34.75	0.376	2.33
34	EPA Qualified OWHH	Birch w/ retrofit control	Low	33.82	0.592	6.79
35	Coal Stove	Stoker Coal	High	7.83	0.252	3.18
36	Coal Stove	Lump Coal (cold start)	Low	16.32	0.453	6.48
37	Coal Stove	Lump Coal	Low	2.75	0.142	1.99
38	Coal Stove	Dry Lump Coal	Low	8.19	0.377	5.28
39	Coal Stove	Stoker Coal (cold start)	Low	14.49	0.431	6.36
40	Central Heating Indoor Furnace	No. 1 Heating Oil	Single	0.31	0.004	0.16
41	EPA Certified Woodstove	Birch (cold start)	Low	6.86	0.180	2.18

2/16/12

Dr. Jim Conner
Fairbanks North Star Borough

RE: Response to Sierra Critique

Dear Dr. Conner:

The following has been prepared by OMNI in response to the critical review submitted to you by Frank DiGenova of Sierra Research on January 25, 2012. Overall OMNI does not strongly disagree with any of the points made in the critique, but we would like to take this opportunity to comment on a couple of items.

Retrofit Device

The retrofit emissions control device was installed by representatives from its manufacturer. The decision not to enable feedback control was not made by OMNI and testing began only after the manufacturer's representatives indicated that their task had been completed. Any questions on the applicability of the tested installation to real-world usage should be directed to the device manufacturer.

Non-qualified OWHH

The uncertainly of data collected during the testing of the non-qualified OWHH was not reported. This is an oversight by OMNI, as it leads to the conclusion that despite the difficulties during testing, the data is as certain as that of other test runs. This is not the case. OMNI's calculations and comparisons to other data suggest that the reported particulate and gas emissions data sets for the non-qualified OWHH are only accurate to an order of magnitude. While this represents a large range, the results can still be of utility to the borough. Hypothetically, if reported emissions were reduced by a factor of ten, the results still show that emissions from the non-qualified unit are dramatically higher than those of the EPA Phase II certified OWHH. The report will be updated to include a description of the uncertainties in the data for the non-qualified OWHH.

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Fax: (503) 643-3799
Email: sbutton@omni-test.com

Lack of Analysis

OMNI was contracted to perform testing, report data, and perform quantitative analysis on those data. Neither the borough's proposal request, nor the proposal submitted by OMNI, included subjective analysis as a deliverable.

AP-42

OMNI urges caution when comparing data from OMNI's testing to the EPA's AP-42 emissions factors. The AP-42 report is intended to realistically report field-use emissions. Therefore, its sources are primarily field use studies that did not use standard operating methods. OMNI's testing relied primarily on EPA Method 28, the woodstove fueling and operation method. Method 28's intent is not to provide accurate field-use data; rather, its purpose is to ensure consistent results from one appliance to the next.

Replicate Testing

Though not discussed in the critique, OMNI's primary concern with the results of the study is the lack of repeated test runs. Many subjective conclusions can be drawn from the data, and much of the data makes intuitive sense. However, the fact that no two test runs were exactly the same means that the data has no scientific or statistical significance. The first step to improving the data for any appliance or fuel is to repeat the test runs performed.

In addition to the critical comments, Mr. DiGenova also pointed out some errors, as well as some opportunities for better clarification, which OMNI will work on addressing for a final draft. If you have any questions, please let don't hesitate to contact ***OMNI***.

Sincerely,

Sebastian Button
Emissions Testing Manager

Cold Climate Housing Research Center

CCHRC

Wood Storage Best Practices in Fairbanks, Alaska

June 27, 2011

A project report prepared by CCHRC for:
Sierra Research

CCHRC Web Site: http://www.cchrc.org
P.O. Box 82489, Fairbanks, AK 99708 Phone: (907)457-3454 Fax: (907)457-3456

Contents

Executive Summary

It is a common notion that firewood takes multiple years to fully cure in Fairbanks, Alaska, however, there is a lack of documented evidence to refute or confirm this belief. To determine the storage methods and time necessary to fully cure firewood in Fairbanks, CCHRC studied the moisture content of firewood stored using a variety of methods for spring and fall tree harvests. The spring harvest was conducted in April and May 2010; the fall harvest was conducted in September 2010. All firewood was monitored for moisture content from the harvest until May 2011, unless a full cure (20% moisture content) was reached before that time.

This study shows that if firewood from a spring harvest is split, several firewood storage methods allow for rapid curing over the summer months, achieving moisture contents equal to or less than 20% in 6 weeks to 3 months. When firewood was kept as whole logs, it was unable to fully cure over the summer under any storage scenario. Whole logs contained between 21% and 43% moisture content by late summer 2010; however, some storage scenarios with whole spruce logs cured fully by May 2011. The type of wood and storage method were important variables, but less so than whether the firewood was split or unsplit. Aspen tended to dry more slowly than birch or spruce, and uncovered firewood was at risk of gaining moisture from rain.

In contrast, firewood harvested in fall did not cure fully by any means of storage or preparation throughout the study period. However, it is notable that split firewood stored in a simulated wood shed dried significantly throughout the winter.

The method of firewood storage was more significant during the winter than the summer. While all storage methods allowed for rapid drying of the spring-harvested firewood over summer, the tarp-covered and uncovered firewood dried slower than firewood stored in a simulated wood shed over the winter. Some tarp-covered and uncovered firewood accumulated a significant amount moisture over the winter. Firewood in a simulated wood shed from the spring harvest only showed a small increase of moisture content over the winter, while firewood from the fall harvest cured significantly.

The results of this study clearly demonstrate that it is possible to dry firewood cut in the spring in Fairbanks over a single summer to moisture content levels that optimize wood burning efficiency and minimize emissions. This finding deserves some caution in generalizing to all locations in the Fairbanks vicinity, as the wood was stored in an open field with minimal obstruction of solar radiation and air movement.

Introduction

The use of firewood for space heating is a significant contributing factor to winter-season PM2.5 in the Fairbanks airshed. Furthermore, it is suspected that burning inadequately cured firewood is a contributing factor that could be partially mitigated by changes in firewood storage and curing methods. Burning dry wood provides immediate benefit for homeowners by optimizing heat output while reducing the release of particulate air pollutants. However, ensuring an adequate supply of dry firewood requires preparation and planning, including knowledge of appropriate storage methods and duration of storage to achieve a full cure.

This project is designed to study the time necessary to achieve an adequate cure of firewood (i.e. 20% moisture content) for common storage scenarios in Fairbanks, Alaska. The data generated from this study are intended for use in an educational campaign to teach homeowners best practices for firewood storage.

Project Structure

This report documents work conducted by CCHRC from Spring 2010 through early Summer 2011. The primary phases completed for this project are summarized below:

Spring Harvest

This project phase simulates the practice of homeowners planning ahead for the winter by allowing the firewood to dry over the summer months.

a. Work plan preparation;
b. Spring harvest of trees;
c. Cutting trees to length and segregation of piles;
d. Initial moisture content sampling and analysis;
e. Splitting and stacking of firewood in various storage scenarios;
f. Interim reporting (June 30, 2010);
g. Periodic sampling of storage scenarios for moisture content.

Fall Harvest / Continuation of Spring Harvest Monitoring

The fall harvest simulates the practice of homeowners who have not planned ahead for the needs of the upcoming heating season, or are preparing for long-term storage for subsequent heating seasons.

a. Fall harvest of trees;
b. Fall firewood preparation and storage;
c. Cutting of trees to length and segregation of piles;
d. Initial moisture content sampling and analysis;

e. Splitting and stacking of firewood in various storage scenarios;

f. Periodic sampling of storage scenarios for moisture content over the winter and spring;

g. Interim reporting (April 18, 2011);

h. Final project reporting.

CCHRC expected the moisture content of birch and aspen trees to be at a relative maximum in the spring and early summer, and a relative minimum in fall. As discussed in the results below, this anticipated standing tree moisture content variation was not observed. White spruce trees were not expected to show a strong seasonal variation in moisture content, which was observed in the moisture content data.

Study Variables

The following variables in wood storage and preparation were included in this study to determine how homeowners can achieve a moisture content of 20% or less of from an initial green wood condition.

Wood species

- White spruce
- Birch
- Aspen

Storage condition

- Covered on top and stacked on pallets (a simulated wood shed)
- Covered completely and stacked on the ground (covered with a tarp)
- Uncovered and stacked on the ground
- Within a solar kiln and stacked on the ground

Preparation

- Whole logs
- Split at least once

Season

- Spring tree harvest
- Fall tree harvest
- Drying over summer
- Drying over winter

CCHRC chose multiple means of storing firewood to study the effect of different storage methods on drying rates. Because of the large number of variables identified above, only some combinations could be studied directly. A total of 16 storage scenarios were studied from the spring harvest, and 10 storage scenarios were studied from the fall harvest, as detailed below.

Each storage scenario from the spring and fall harvests are comprised of approximately 0.75 to 1.0 cords of firewood, respectively, where a cord is defined as 128 cubic feet of stacked wood. Each of the firewood storage scenarios have subsets for whole and split logs, stored together in roughly equal volumes. Photographs of the storage scenarios are provided in Appendix A.

While referred to as “aspen,” the poplar trees included in this study are a mix of white and black poplar trees. In common language, these trees are referred to as “aspen” and “cottonwood”, respectively. Both poplar trees are common in Fairbanks vicinity, are similar in their heat content, and are commonly less desired as a fuel wood.

Acquisition and Storage of Firewood

Spring Harvest

CCHRC obtained a firewood cutting permit from the Environmental Division of the Fort Wainwright Directorate of Public Works, U.S. Army Alaska on April 23, 2010. This permit allowed CCHRC to harvest trees from specified areas on base through April 23, 2011. From April 27 through May 7, CCHRC cut approximately 5 to 6 cords of white spruce, birch and aspen trees from Fort Wainwright, which were brought to CCHRC's Research and Testing Facility. The trees cut were in the base's northwest corner within the lowlands and hillsides close to Birch Hill. All trees harvested were live, standing trees.

CCHRC secured an additional firewood gathering permit from the U.S. Army Corps of Engineers, Chena Flood Control Project on May 20, 2010. Firewood freshly cut for maintenance of the Flood Control Project was made available to the public. The permit allowed for only a single truck load of firewood, which CCHRC acquired on May 20. Approximately 0.75 cords of white spruce was hauled to CCHRC's Research and Testing Facility.

From mid- to late-May 2010, CCHRC prepared, sampled, and established the storage scenarios for the spring firewood harvest. The 8 storage scenarios are summarized below in Table 1, and documented by photographs included in Appendix A.

Table 1 – *Spring Firewood Sample Scenarios**

Wood Storage Method	**Birch**	**Spruce**	**Aspen**
Simulated wood shed	X	X	X
Covered with a tarp	X	X	
On ground and uncovered	X	X	
In a solar kiln			X

**Each scenario consists of approximately 0.75 cords of firewood*

First, CCHRC cut the firewood into approximately 12 – 16 inch lengths and divided the accumulated firewood into 8 roughly equal piles. These piles were then sampled to characterize the initial wood moisture content. Approximately half of each pile was then split at least once with an electric log splitter. The split and remaining whole logs were then stacked to be comingled. Each pile was then covered in accordance with the storage scenario plan, comprising a total of 16 different storage scenarios within 8 piles.

Fall Harvest

Under the same permit acquired previously from the U.S. Army Alaska, in mid-September 2011 CCHRC harvested approximately 5 cords of white spruce, birch, and aspen from the hillside area of the former Birch Hill Tank Farm. All trees harvested were live, standing trees. From mid- to late-September, CCHRC prepared, sampled, and established storage scenarios for the fall firewood harvest. The 8 storage scenarios are summarized below in Table 2, and documented by photographs in Appendix A.

Table 2 – *Fall Firewood Sample Scenarios*			
Wood Storage Method	**Birch**	**Spruce**	**Aspen**
Simulated wood shed	X	X	X
Covered with a tarp	X	X	

**Each scenario consists of approximately one cord of firewood*

CCHRC cut the firewood into approximately 12 – 16 inch lengths and divided the accumulated firewood into 5 roughly equal piles. These piles were then sampled to characterize the initial wood moisture content. Approximately half of each pile was then split at least once with an electric log splitter. The split and remaining whole logs were then stacked to be comingled and covered in accordance with the storage scenarios, comprising a total of 10 different storage scenarios within 5 piles.

Deviations from Study Plan

The birch and spruce wood piles from the spring harvest intended to be fully covered were found in early May to be mostly uncovered due to the tarps being carried in the wind. The duration for which these 2 wood piles were uncovered is unknown, but potentially could have extended from mid-April through early-May 2011.

Sampling and Analysis

Sample Collection

Throughout the process of dividing the firewood into separate piles, whole logs were collected to characterize the initial wood moisture content. Each storage scenario was represented with a primary sample that filled a container approximately 4 cubic feet in volume, consisting of 4 to 8 whole logs, depending on log diameter.

Whereas the first sampling event for a harvest characterized the firewood's initial moisture content, all subsequent sampling events differentiated between split and whole logs stored under varying conditions. After the initial sampling event, each primary sample from a wood pile included 2 whole logs or 4 split logs. Final sampling events, such as August 2010 and May 2011 had larger primary samples (3 – 4 whole logs or 6 – 8 split logs). For each sampling event, logs were selected from throughout the pile.

When a monthly sampling event indicated that the moisture content of a specific storage scenario was at or under 20%, then the subsequent sampling event was conducted as a final sampling (i.e. more logs in the primary sample) to ensure accurate documentation of the final firewood condition.

During sampling of the firewood piles in winter, bulk snow and frost was brushed from the logs prior to subsampling and analysis; however, this sample preparation would not remove ice and hardened frost. This methodology was adopted to simulate the most probable user behavior in handling firewood.

Sample Preparation

The logs collected from the firewood piles constitute the primary samples, which require subsampling to allow for moisture content analysis. After collection, primary samples were stored as whole logs at CCHRC's Research and Testing Facility; subsamples were prepared from the primary samples within a few days of sample collection. Because firewood moisture content can vary within different zones of the wood, e.g. sapwood versus heartwood, cross-sectional discs approximately one inch thick were cut from the logs to ensure that each zone was represented proportionally in the analysis. Two cross-sectional discs were cut from each log in the primary sample: one from a log end and one from the log center. For large diameter logs, these discs were halved or quartered to facilitate subsequent drying and weighing. Subsamples were stored in a sealed plastic bag until ready for analysis. The determination of the wood disc mass before drying took place within 10 minutes to an hour after the discs were cut. Photographs of example firewood subsamples are provided in Appendix A.

Sample Analysis

CCHRC analyzed all firewood subsamples for moisture content following Method B of ASTM Standard Test Method D4442-07 (*Direct Moisture Content Measurement of Wood and Wood-Base Materials*). This method provides an absolute measure of firewood moisture content on a dry-weight basis. The drying oven used was a Quincy Lab convection oven model 40 GC. The mass balance used was an Acculab VICON with readability to 0.1 g. No attempt was made to differentiate the mass loss of water versus that of any other volatile constituents within the wood samples. All firewood moisture content

data presented are on a dry-weight basis. The moisture content results of individual subsamples, per ASTM D4442-07 Method B, are estimated to have a precision of ±1%.

The duration of oven time for each subsample varied based on practical considerations, such as drying overnight during the weekdays versus over weekends. Therefore drying time was not standardized for the subsamples, but was evaluated based on the stability of multiple mass measurements over time. When each subsample had changed approximately 0.5 grams or less in mass from the prior mass determination, the drying was considered complete. This provides a conservative determination of the drying endpoint following Method B of ASTM D4442-07.

Data Analysis

Because the goal of the primary sampling is to represent the entire firewood pile, and the intent of the subsampling is to represent the primary sample with a fraction amenable to analysis, the chosen method for calculating the average moisture content is:

$$Average\ moisture\ content_x = \frac{(\sum_{i=1}^{n} Initial\ mass_i) - (\sum_{i=1}^{n} Oven\ dry\ mass_i)}{\sum_{i=1}^{n} Oven\ dry\ mass} \ (100\%)$$

where $x = specific\ wood\ and\ storage\ scenario$

$$n = number\ of\ subsamples$$

This method accounts for the contribution of each subsample towards the total sample mass, and also allows for splitting large wood discs without over representing the disc as several subsamples. If it were practical to weigh the entire cord of stacked wood over time, that approach would be ideal (i.e. a census of the entire population available for sampling). Instead, the chosen approach was to collect a fragment of the entire pile mass to represent the whole mass. In other words, the moisture content of the individual subsamples isn't of interest, but rather the moisture content of the subsamples in aggregate as a representation of the entire wood pile.

Results for Firewood Moisture Content

The results from the moisture content monitoring for the spring firewood harvest are tabulated in Table 3 and illustrated in Figures 1a-d. The results for the fall firewood harvest are tabulated in Table 4 and illustrated in Figures 2a-b. The complete record of the moisture content data is contained in an electronic spreadsheet provided to Sierra Research.

The findings come with the caveat that the wood was stored in an open field with minimal obstruction of solar radiation and air movement. Wood piles stored in shade-covered areas will presumably require more time to cure, and large continuous firewood piles (e.g. multiple cords) may dry faster on the edges than within the pile.

Simulated Wood Shed

As shown in Figure 1a, the moisture content of spring harvest firewood stored in the simulated wood shed dropped rapidly over the summer months of 2010. Split firewood met the 20% moisture content criteria for a full cure within approximately 6 weeks to 3 months. Whole firewood logs dried less rapidly during the summer and did not dry over the winter. When grouped as “split” and “whole” logs, spruce dried most rapidly, followed by birch and aspen. The difference between the drying times for the different wood types was accentuated for whole logs.

The moisture content of the firewood from the fall harvest dropped steadily over the winter, but at a much slower rate than spring-harvested firewood over the summer (Figure 2a). As noted with the spring harvest, split wood dried substantially more than wood left as whole logs. However, none of the wood harvested in fall dried to 20% moisture content by the final sampling event in May 2011. The significance of wood types in the drying over the winter was much less distinct than for the spring harvest.

Fully (Tarp) Covered

The moisture content of the spring-harvest firewood covered by tarps lowered rapidly over the summer months (Figure 1b). Split firewood met the 20% moisture content criteria for a full cure within approximately 6 weeks to 3 months. The rate of drying was similar to the firewood stored in the simulated wood sheds, although it appears the wood covered by a tarp dried at a slightly lower rate. While the whole log moisture content remained approximately constant over the winter, the split spruce firewood gained some moisture by absorption or frost accretion. There is no data for the split birch covered with a tarp over winter, as that firewood reached a full cure by August 2010, therefore sampling was discontinued.

As shown in Figure 2b, the moisture content of fall-harvest firewood stored under tarps over the winter varied depending on wood type and preparation. Birch tended to decline in moisture content slowly, and without much difference in split and whole logs until the beginning of Summer 2011. Spruce firewood as whole logs dried over winter slightly, then regained some moisture content at the beginning of Summer 2011, whereas split spruce showed the opposite trend. None of the wood harvested in fall dried to 20% moisture content by the final sampling event in May 2011.

Uncovered

This storage method was studied only for the spring firewood harvest. The moisture content of the spring harvest firewood left uncovered fell rapidly over the summer months (Figure 1c). Split firewood met the 20% moisture content criteria for a full cure within approximately 6 weeks. The rate of drying was similar to the firewood stored in the simulated wood sheds. However, the uncovered firewood was highly susceptible to absorption of moisture from rain, snow, and frost. For example, the split birch had dried from an initial moisture content of 57% to 19% by early July, then had increased to 35% by late August, presumably due to rain immediately prior to the August sampling event. The moisture regained by the firewood over the late summer and winter had dissipated by the final sampling event in early summer 2011.

Solar Kiln

This storage method was studied only for the spring firewood harvest. The moisture content of the spring harvest firewood enclosed within a solar kiln dropped rapidly over the summer months (Figure 1d). The firewood stored in the solar kiln dried to lower moisture contents than the firewood stored in simulated wood sheds. However, due to heterogeneity of the moisture content amongst the various firewood piles, the initial condition of the aspen stored in the solar kiln was substantially lower than the aspen stored in the simulated wood shed. The rates of moisture loss in the aspen were very similar for the solar kiln and simulated wood shed storage methods.

Table 3 - Spring Wood Harvest, Summary of Moisture Content Data

Simulated Wood Shed						
Wood Type	**Late May**	**Early July**	**Late Aug**	**Jan**	**March**	**May**
Birch – split (PBS –S)	52%	20%	18%	Dry	Dry	Dry
Birch – whole (PBS – W)	52%	30%	25%	29%	28%	24%
Spruce – split (PSS – S)	86%	16%	17%	Dry	Dry	Dry
Spruce – whole (PSS – W)	86%	28%	21%	23%	24%	17%
Aspen – split (PAS – S)	76%	26%	20%	Dry	Dry	Dry
Aspen – whole (PAS – W)	76%	49%	44%	40%	--	26%

Tarp Covered						
Wood Type	**Late May**	**Early July**	**Late Aug**	**Jan**	**March**	**May**
Birch – split (TBS – S)	49%	21%	20%	Dry	Dry	Dry
Birch – whole (TBS – W)	49%	28%	31%	32%	--	25%
Spruce – split (TSS – S)	86%	22%	22%	35%	--	18%
Spruce – whole (TSS – W)	86%	67%	30%	29%	--	23%

Table 3 - Spring Wood Harvest, Summary of Moisture Content Data (continued)

Uncovered						
Wood Type	**Late May**	**Early July**	**Late Aug**	**Jan**	**March**	**May**
Birch – split (UBS – S)	57%	19%	35%	46%	38%	17%
Birch – whole (UBS – W)	57%	29%	32%	52%	39%	25%
Spruce – split (USS – S)	77%	17%	19%	Dry	Dry	Dry
Spruce – whole (USS – W)	77%	29%	27%	47%	29%	17%

Solar Kiln						
Wood Type	**Late May**	**Early July**	**Late Aug**	**Jan**	**March**	**May**
Aspen – split (KAS – S)	59%	24%	16%	Dry	Dry	Dry
Aspen – whole (KAS – W)	59%	38%	32%	34%	31%	27%

Table 4 - Fall Wood Harvest, Summary of Moisture Content Data

Simulated Wood Shed				
Wood Type	**Mid Sept**	**Jan**	**March**	**May**
Birch – split (PBF – S)	80%	49%	42%	30%
Birch – whole (PBF – W)	80%	55%	56%	47%
Spruce – split (PSF – S)	85%	63%	40%	37%
Spruce – whole (PSF – W)	85%	77%	72%	51%
Aspen – split (PAF – S)	83%	63%	51%	34%
Aspen – whole (PAF – W)	83%	65%	--	48%

Tarp Covered				
Wood Type	**Mid Sept**	**Jan**	**March**	**May**
Birch – split (TBF – S)	78%	63%	70%	49%
Birch – whole (TBF – W)	78%	67%	--	57%
Spruce – split (TSF – S)	92%	117%	--	84%
Spruce – whole (TSF – W)	92%	80%	--	89%

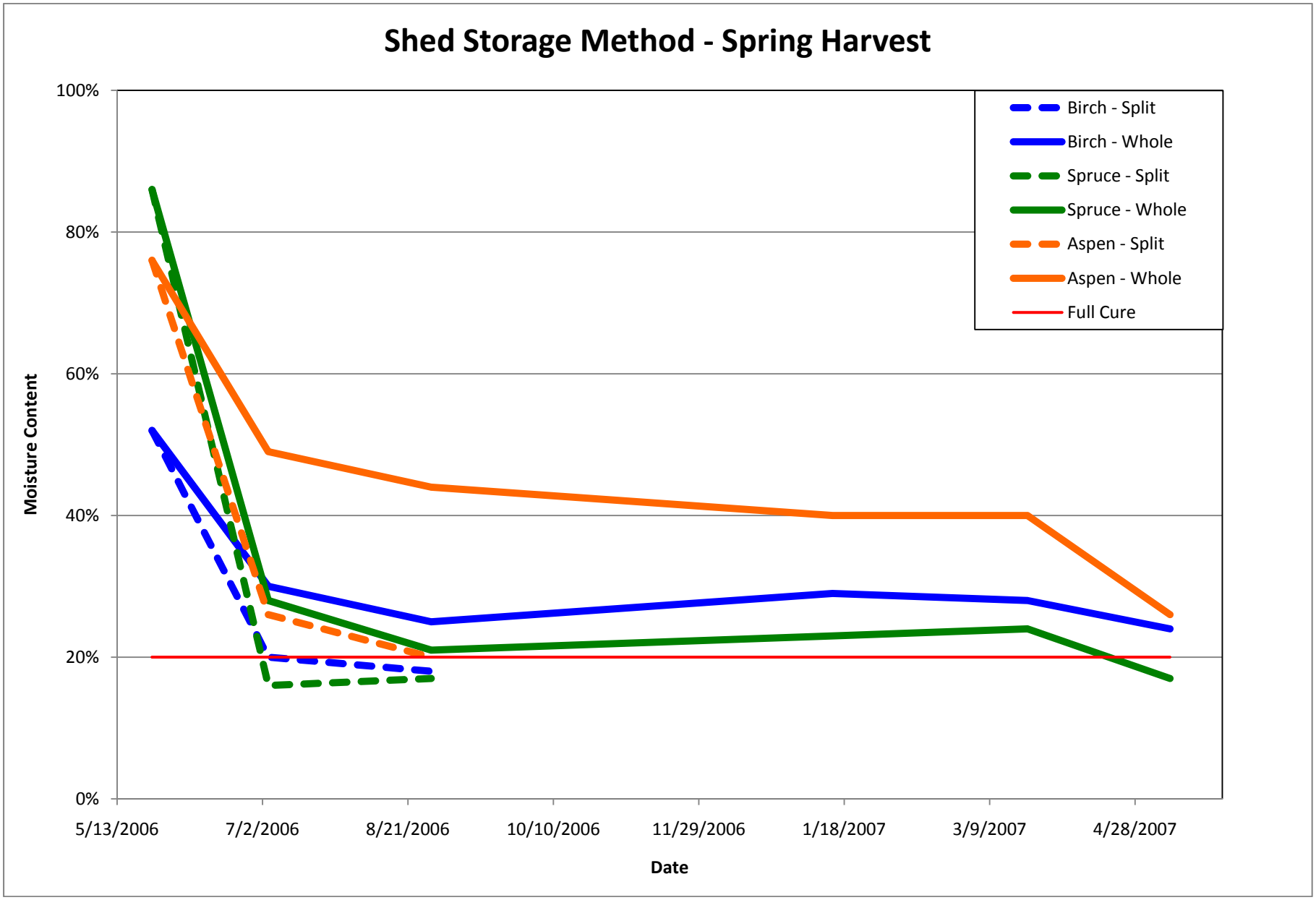


Figure 1a – Moisture content of spring harvest firewood over time for the different wood types and preparation methods.

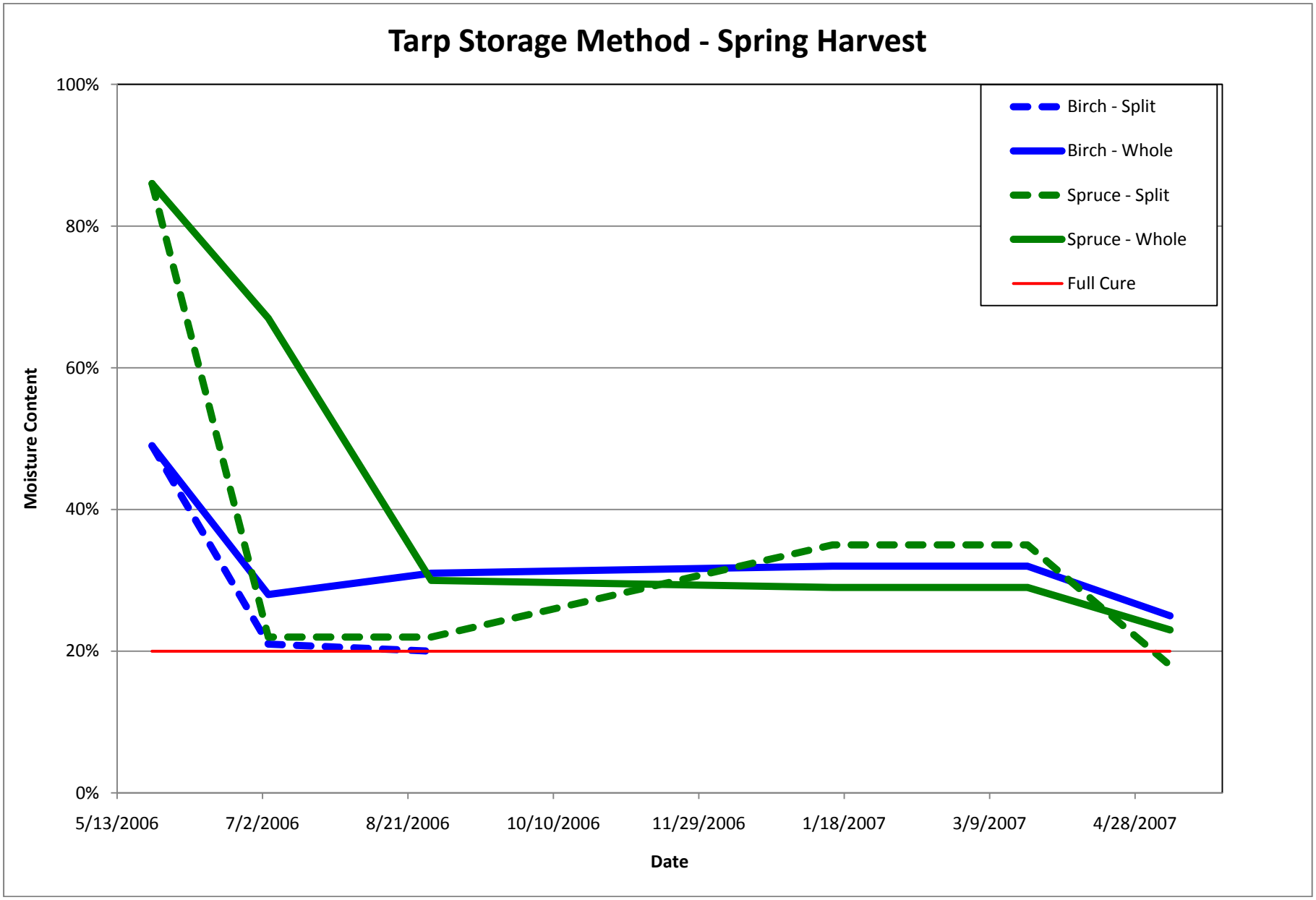


Figure 1b – Moisture content of spring harvest firewood over time for the different wood types and preparation methods.

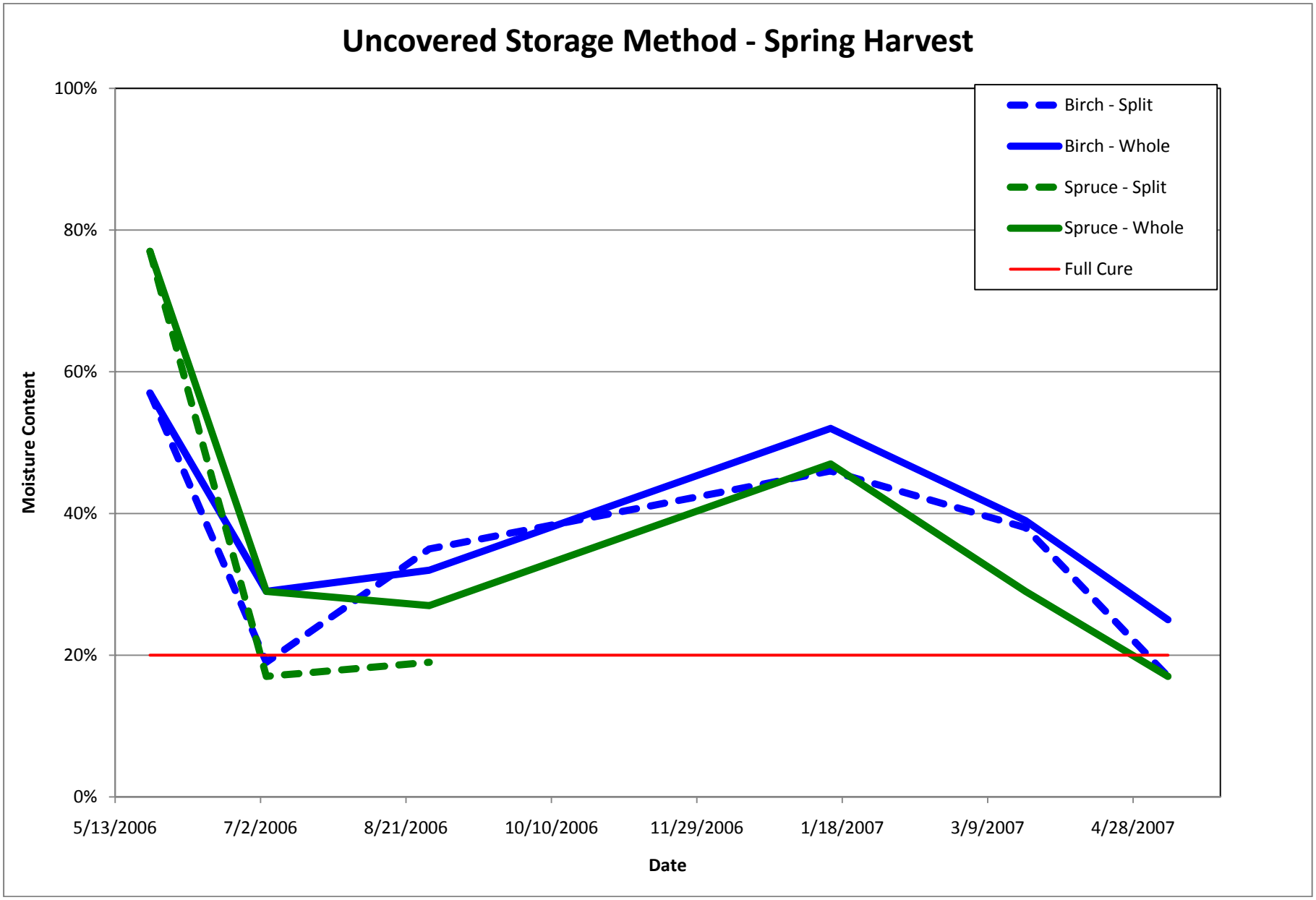


Figure 1c – Moisture content of spring harvest firewood over time for the different wood types and preparation methods.

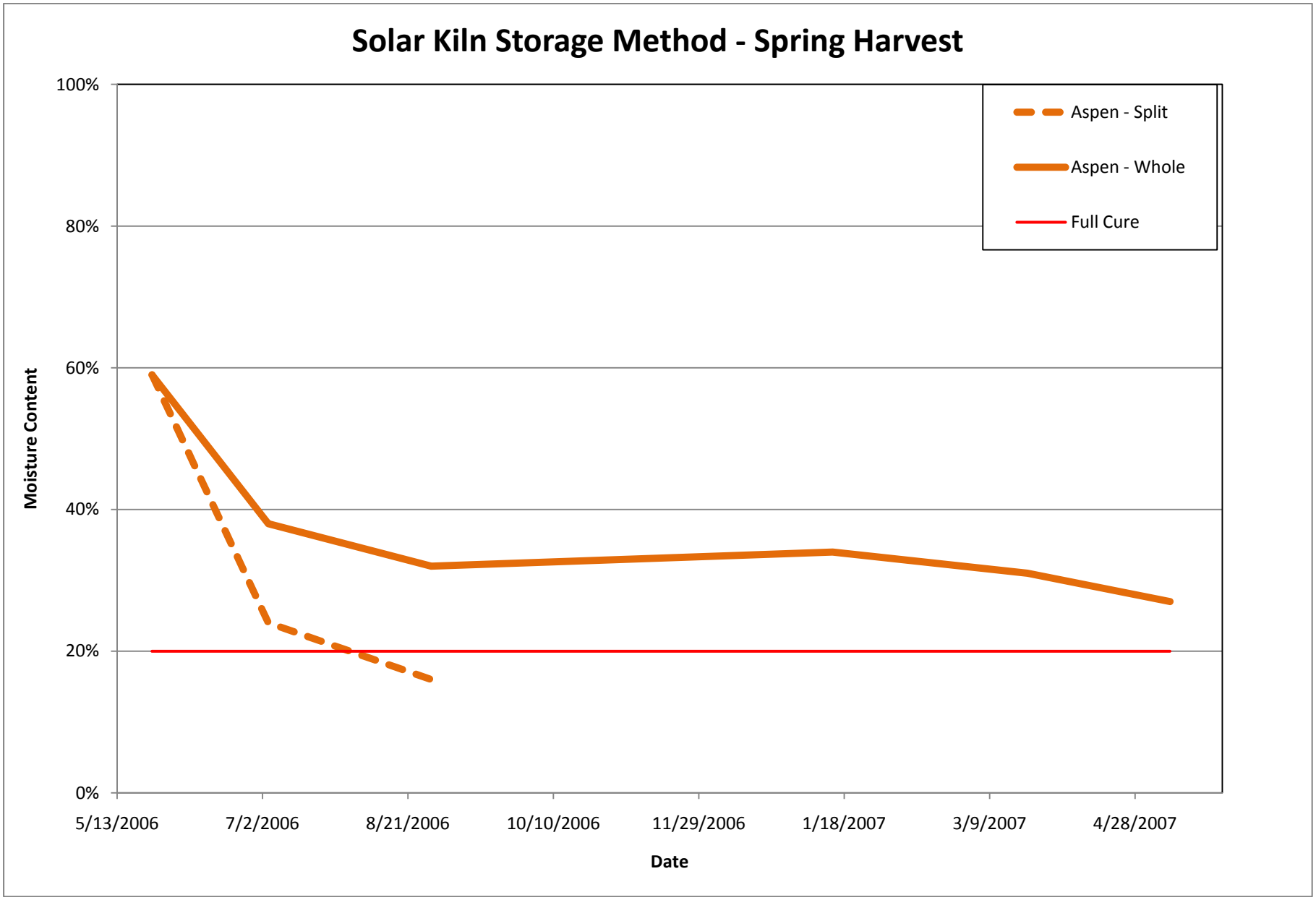


Figure 1d – Moisture content of spring harvest firewood over time for the different wood types and preparation methods.

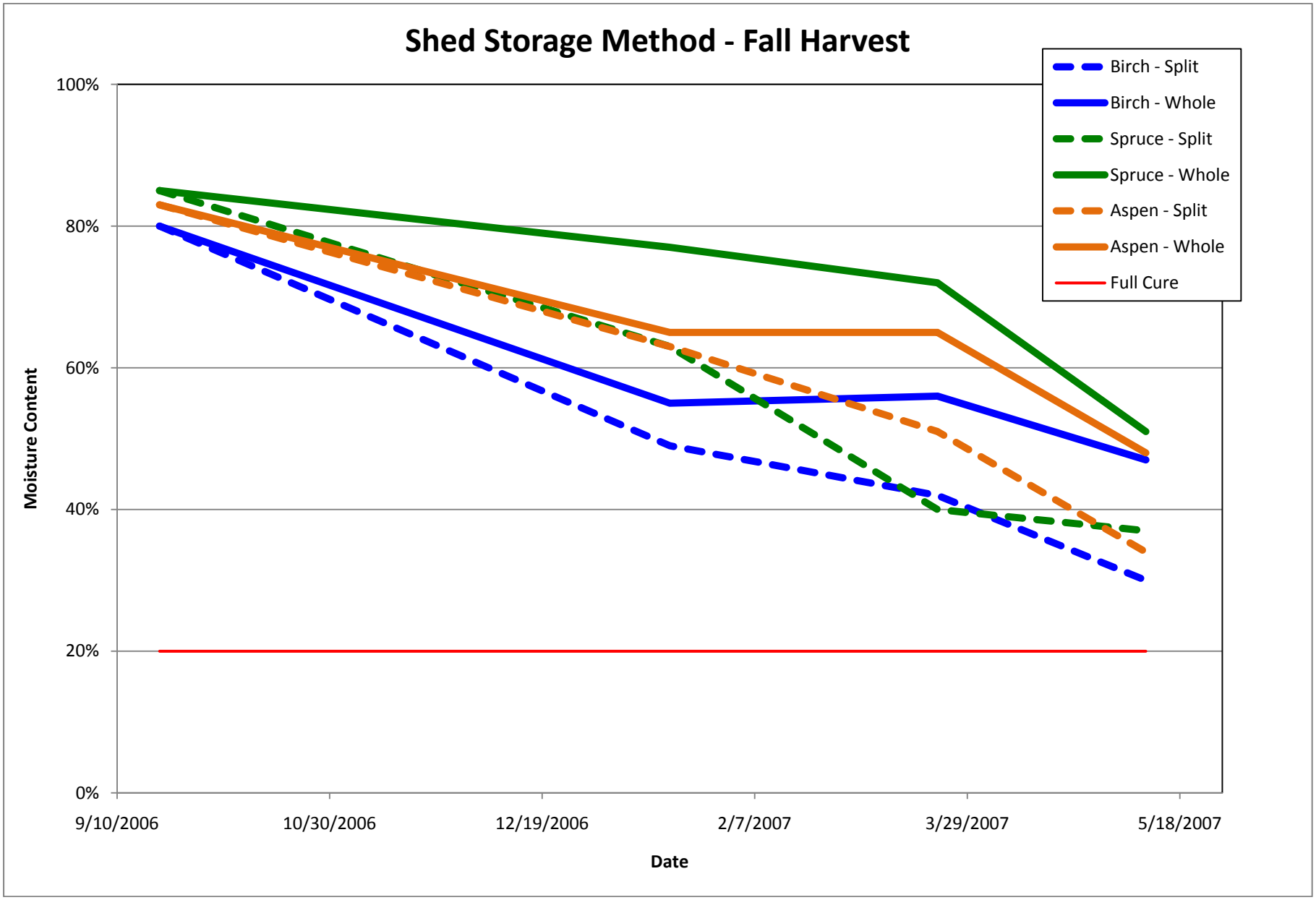


Figure 2a – Moisture content of fall firewood over time for the different wood types and preparation methods.

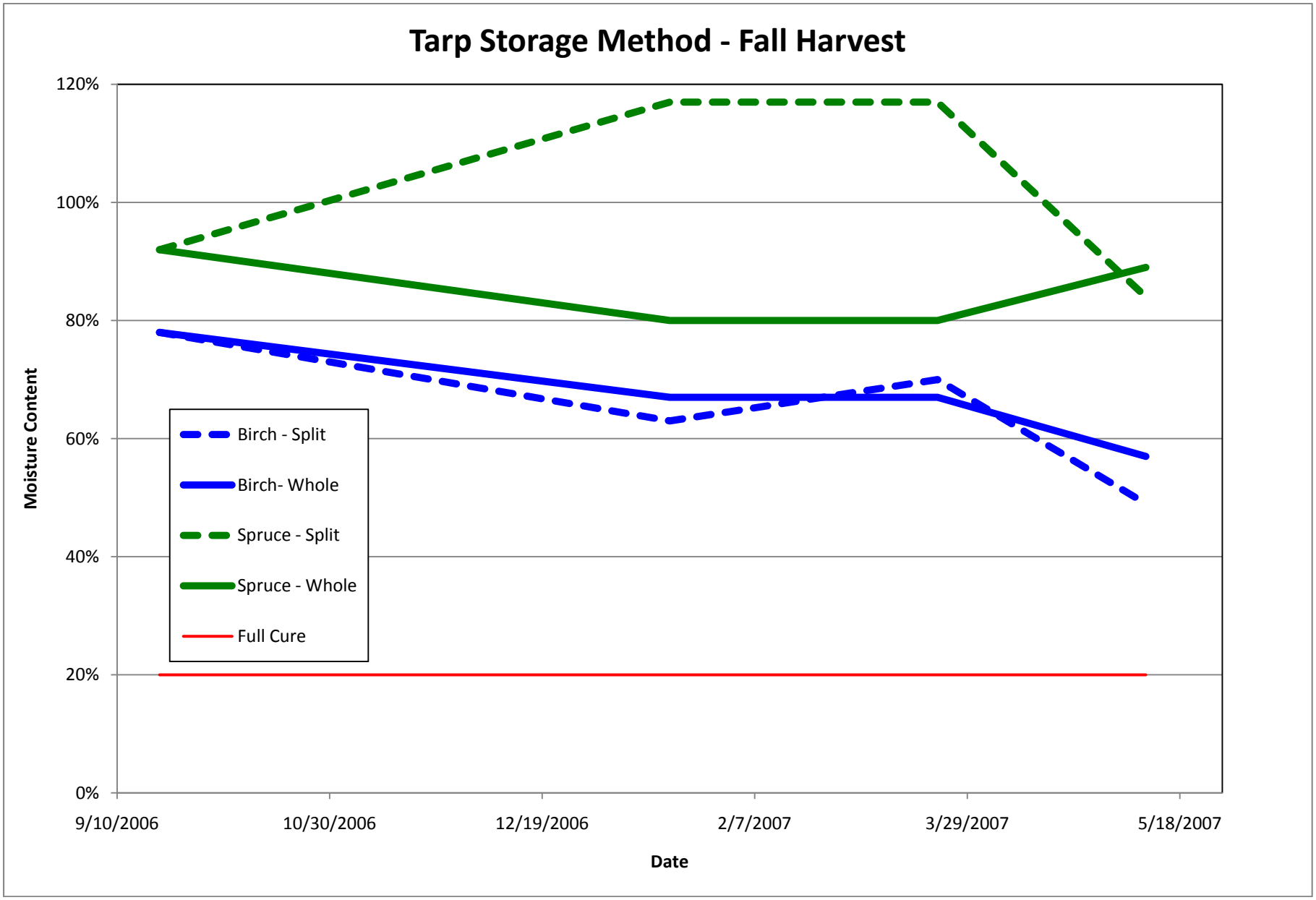


Figure 2b – Moisture content of fall firewood over time for the different wood types and preparation methods.

Appendix A – Photographs

The firewood storage scenarios initiated in May 2010 in the field west of the CCHRC Research and Testing facility.

The firewood storage scenarios initiated in May 2010.

Example of the simulated wood shed (top-covered and off-ground) storage scenario.

Example of the tarp-covered (fully-covered and on-ground) storage scenario.

Example of the uncovered and on-ground storage scenario.

Simple solar kiln storage scenario with wood placed on the ground.

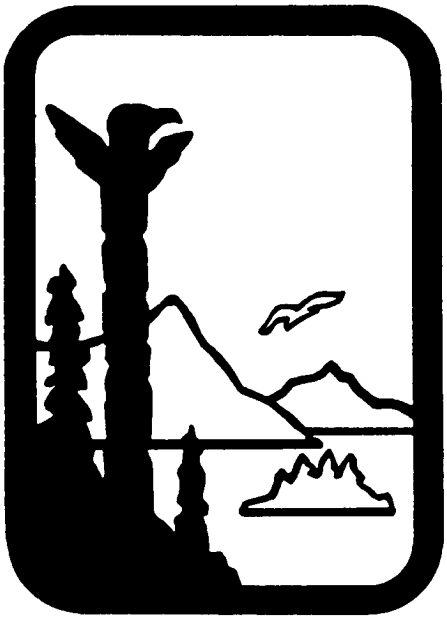
The firewood storage scenarios initiated in May 2010 (left side of picture) and September 2010 (right side of picture).

The firewood storage scenarios initiated in September 2010 (foreground) and May 2010 (background).

Firewood subsamples stored at CCHRC's Research and Testing Facility

Close-up of firewood subsamples.

Alaska Department of Environmental Conservation



Amendments to:
State Air Quality Control Plan

Vol. III: Appendix III.D.5.7

{Appendix to Volume II. Analysis of Problems, Control Actions; Section III. Area-wide Pollutant Control Program; D. Particulate Matter; 5. Fairbanks North Star Borough PM2.5 Control Plan}

Adopted

December 24, 2014

Bill Walker
Governor

Larry Hartig
Commissioner

(This page serves as a placeholder for two-sided copying)

Reasonably Available Control Measure (RACM) Analysis

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5.7. APPENDIX

5.7.1. BACKGROUND

In November 2009, Fairbanks was designated as a Moderate nonattainment area for the 2006 24-hour $PM_{2.5}$ National Ambient Air Quality standard.[1] The design value[2] is 44.7 µg/cubic meter.[3] The difference between this value and the ambient standard is 9.7 µg/cubic meter, which means that 98th percentile concentrations (the form of the standard) need to be reduced by 22% to demonstrate attainment.

The purpose of this document is to describe the process of identification and selection of Reasonably Available Control Measures (RACM) for the $PM_{2.5}$ Attainment Plan for the Fairbanks North Star Borough (FNSB, or Fairbanks) in Alaska.

5.7.1.1. Requirements for RACM Analysis

CAA section 172(c)(1) describes the general attainment plan requirement for reasonably available control measures (RACM). Attainment plan submissions must "provide for the implementation of all reasonably available control measures as expeditiously as practicable (including such reductions in emissions from existing sources in the area as may be obtained through the adoption, at a minimum, of reasonably available control technology) and shall provide for attainment" of the NAAQS.

Section 189 (a)(1)(C) requires that RACM measures in Moderate nonattainment areas be implemented no later than four years after designation.

Guidance on the steps to be followed in making RACM determinations for $PM_{2.5}$ were specified in the final Clean Air Fine Particulate Implementation Rule issued in 2007.[4] Additional guidance was provided in a subsequent EPA guidance document.[5] The rule was based on based on CAA Part D, Subpart 1. A court decision[6] in January 2013 remanded the $PM_{2.5}$ rule back to EPA to be re-promulgated to be consistent with Subpart 4. EPA withdrew the Subpart 1-based guidance document and new Subpart 4 based guidance has not been issued.

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[1] 74 FR 58688, November 13, 2009.
[2] The design value is a statistic that describes the air quality status of a given location, for purposes of comparison with the relevant NAAQS. The goal of the attainment plan is to bring the design value to a level at or below the standard.
[3] EPA, *$PM_{2.5}$ Detailed information;* available at http://www.epa.gov/airtrends/values.html (accessed September 8, 2014)
[4] 72 FR 20586, April 25, 2007
[5] Stephen Page, *Implementation Guidance for the 2006 24-Hour Fine Particulate (PM2.5) National Ambient Air Quality Standards,* March 2, 2012
[6] Natural Resources Defense Council (NRDC) v. EPA, No. 08-1250 (D.C. Cir., Jan. 4, 2013)

The steps in the RACM analysis followed in this report were developed based on a review of CAA provisions. In addition, this analysis incorporates the requirement in subpart 4[7] that RACM must be implemented within four years after designation. The RACM analysis steps are outlined below.

5.7.1.2. Process for Identification and Evaluation of Control Measures

Listed below are the steps that were followed in evaluating control measures.

- Step 1: Identify source categories with non-trivial emissions of $PM_{2.5}$ or its precursors.
- Step 2: **For each source category, source, or activity from Step 1**, develop a list of technologically feasible emission control technologies and/or measures
- Step 3: **For each technologically feasible control measure,** evaluate emission reductions and costs, identify and exclude economically infeasible measures.
- Step 4: Determine whether control measure can be implemented within four years of designation.
- Step 5: Identify Reasonably Available Control Measures.

5.7.2. STEP 1: IDENTIFY SOURCES OF $PM_{2.5}$ AND PRECURSORS IN FAIRBANKS

The first step in the RACM identification and evaluation process is to identify candidate control measures. In this step, all source categories with non-trivial emissions of $PM_{2.5}$ or its precursors are identified. A list of control measures potentially applicable to each source category is then developed for consideration as RACM.

"Primary" particulates (i.e., directly emitted $PM_{2.5}$) are emitted directly into the air as a solid or liquid particle (e.g., elemental carbon from diesel engines or fire activities, or condensable organic particles from gasoline engines). "Secondary" particulates (e.g., sulfate and nitrate) form in the atmosphere as a result of various chemical reactions. The main precursor gases associated with secondary fine particle formation are SO_2, NOX, volatile organic compounds (VOC), and ammonia.

Evaluation of monitoring data indicates that directly emitted $PM_{2.5}$ is the principle contributor to exceedances of the $PM_{2.5}$ NAAQS in Fairbanks. Figure 5.7-1 shows that directly emitted $PM_{2.5}$ comprises 63.2% of the measured concentration. Sulfates comprise 29.1%, nitrates comprise 7.6%, and secondary organic aerosols (SOAs) comprise 0%.

[7] Clean Air Act Section 189(a)(1)(C)

The most current estimate of directly emitted $PM_{2.5}$ and precursor emissions in the nonattainment area is the 2015 emission inventory shown in Table 5.7-1. It shows the average daily emissions across the two episodes (Jan-Feb, 2008 and Nov 2008) selected to represent conditions associated with exceedances of the 24-hour ambient $PM_{2.5}$ standard in Fairbanks.

Pollutant emissions from a source category were used as a proxy for its contribution to the ambient $PM_{2.5}$ concentration[8] (e.g., a source category's contribution to the fraction of ambient $PM_{2.5}$ attributed to directly emitted $PM_{2.5}$ was assumed to be the same as its emissions, expressed as a percentage of the total regional $PM_{2.5}$ inventory). Table 5.7-2 shows the contributions of each source category to ambient concentrations on the average episode day using this simplified technique.

Source category contributions to ambient concentrations were also estimated using photochemical modeling, and the results are compared with the results using the simplified estimate described above in Table 5.7-3. The modeling indicates that the contribution of wood combustion to ambient concentrations is greater than would be estimated from emissions alone. Presumably, this is because wood smoke is emitted close to the ground, below the mixed layer and dispersed throughout the Borough. Similarly, the contribution of pollutants from the combustion of gasoline is greater than share of emissions would suggest. Point sources, on the other hand, typically have tall stacks that release emissions well above the inversion layer; as a result, their contribution to ambient pollutant concentrations is relatively low.

Point sources are subject to Reasonably Available Control Technology (RACT) requirements, which is a specialized subset of RACM. Point sources are evaluated for RACT in a different part of this report.

[8] This is a simplified approach, used only to identify and eliminate source categories and/or control measures with insignificant contributions to ambient $PM_{2.5}$ concentrations. The contribution of each RACM control measure to attainment is subsequently quantified using photochemical modeling.

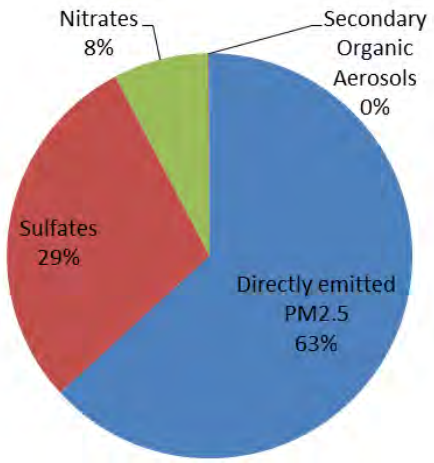

Figure 5.7-1. Constituents of Ambient $PM_{2.5}$ on High Concentration Days

Notes:
- Data are from the SANDWICH calculation spreadsheet that contains data over all winters from 2006- 2010 for the 98% days. They have been post processed through the SANDWICH method.
- Sulfates include primary and secondary sulfate + ammonium + particle bound water.
- Nitrates include primary + secondary nitrate + ammonium + particle bound water.
- Secondary organic aerosols were estimated from CMAQ.

Table 5.7-1. Average Daily Emissions by Source Category in 2015 for Episodes Selected for Fairbanks $PM_{2.5}$ Attainment Modeling

Source Category	Emissions (Tons per day)				
	Direct $PM_{2.5}$	SOx	NOx	VOC	NH_3
Point Sources					
Point Sources–all	1.59	22.97	27.39	1.15	0.00
Area Sources					
Space Heating–Wood	2.72	0.09	0.00	0.00	0.00
Central Oil–Residential	0.04	2.94	0.00	0.00	0.00
Central Oil–Commercial	0.02	1.14	0.00	0.00	0.00
Other Heating	0.05	0.12	0.00	0.00	0.00
Airport	0.01	0.08	0.76	0.26	0.00
Other Area Sources	0.06	0.00	0.00	0.60	0.00
Mobile Sources					
On-Road Vehicles (gasoline)	0.00	0.00	0.00	0.00	0.00
On-Road Vehicles (Diesel)	0.00	0.00	0.00	0.00	0.00
Non-Road Vehicles	0.01	0.01	0.30	0.15	0.00

Table 5.7-2. Estimated Source Category Contribution to Ambient $PM_{2.5}$ Concentration[a] (2015 Average Episode Day)

	$PM_{2.5}$			SOx			NOx			VOC			TOTAL
Source Category	%	Weighting[b] 63%	% of Ambient	%	Weighting[b] 29%	% of Ambient	%	Weighting[b] 8%	% of Ambient	%	Weighting[b] 0%	% of Ambient	% of Ambient[a]
Point Sources													
Point Sources–All	31%	63%	20%	84%	29%	24%	87%	8%	7%	19%	0%	0%	51%
Area Sources													
Space Heating–Wood	54%	63%	34%	0%	29%	0%	0%	8%	0%	0%	0%	0%	34%
Central Oil–Residential	1%	63%	1%	11%	29%	3%	0%	8%	0%	0%	0%	0%	4%
Central Oil–Commercial	0%	63%	0%	4%	29%	1%	0%	8%	0%	0%	0%	0%	1%
Other Heating	1%	63%	1%	0%	29%	0%	0%	8%	0%	0%	0%	0%	1%
Airport	0%	63%	0%	0%	29%	0%	2%	8%	0%	4%	0%	0%	0%
Other Area Sources	1%	63%	1%	0%	29%	0%	0%	8%	0%	10%	0%	0%	1%
Mobile Sources													
On-Road Vehicles (gasoline)	10%	63%	6%	0%	29%	0%	5%	8%	0%	60%	0%	0%	7%
On-Road Vehicles (Diesel)	1%	63%	1%	0%	29%	0%	5%	8%	0%	4%	0%	0%	1%
Non-Road Vehicles	0%	63%	0%	0%	29%	0%	1%	8%	0%	7%	0%	0%	0%
TOTAL													100%

Notes:

[a] No modeling involved. Estimated contributions of source categories to ambient concentrations were calculated by assuming that contribution to ambient PM subspecies ($PM_{2.5}$, nitrate, sulfate, VOC aerosol) concentration is proportional to emissions.

[b] Weighting factor for each PM subspecies ($PM_{2.5}$, nitrate, sulfate, VOC aerosol) is its measured fraction of the ambient $PM_{2.5}$ concentration across 2006 – 2010 winter period.

Table 5.7-3. Comparison of Estimated Source Category Contribution to Ambient $PM_{2.5}$ Concentration with Modeling Results (Projections to 2015)

Source Category	% of Ambient $PM_{2.5}$	
	Estimated[a]	Modeled
Point Sources		
Point Sources–All	51%	6%
Area Sources		
Space Heating–Wood	34%	66%
Central Oil–Residential	4%	3%
Central Oil–Commercial	1%	1%
Other Heating	1%	0%
Airport	0%	1%
Other Area Sources	1%	3%
Mobile Sources		
On-Road Vehicles (gasoline)	7%	18%
On-Road Vehicles (Diesel)	1%	2%
Non-Road Vehicles	0%	2%
TOTAL	100%	102%

Notes:
a. Estimated contributions of source categories to ambient concentrations were calculated by assuming that contribution to ambient PM subspecies ($PM_{2.5}$, nitrate, sulfate, VOC aerosol) concentration is proportional to emissions. The contribution of each subspecies is its measured fraction of the ambient $PM_{2.5}$ concentration on the episode day.

Based on the information in Table 5.7-2 and Table 5.7-3, the following source categories were evaluated for RACM.[9]

- Wood burning
  - Outdoor Wood-burning boilers (hydronic heater)
  - Wood Stoves
  - Fireplaces
  - Burn barrels
  - Open burning

- Residential Fuel Oil Combustion

[9] A number of control measures were not considered because emissions from this category of sources are *de minimis* in Fairbanks (either the number of such sources was too small to consider, or the seasonality of emissions means that reductions would not contribute to attainment). A list of such sources and control measures is provided in Appendix A.

- Transportation
  - Automobiles
  - Heavy-duty Vehicle

5.7.3. STEP 2: FOR EACH SOURCE CATEGORY, IDENTIFY TECHNOLOGICALLY FEASIBLE EMISSION CONTROL TECHNOLOGIES AND/OR MEASURES

An initial list was compiled that included all of the categories/measures identified by EPA in various guidance documents as likely candidates for RACM. To this list were added control measures that were suggested by public comments during Alaska's SIP development process. Some control measures on EPA's list (e.g., control of emissions from commercial charbroiling/cooking operations)[10] were eliminated because emissions from the source category make an insignificant contribution to PM concentrations in Fairbanks.

Additionally, $PM_{2.5}$ SIPs from other jurisdictions were reviewed for lists of control measures. Of the 35 areas originally designated to be nonattainment for the 2006 federal $PM_{2.5}$ standard, 23 also either had been or currently are an ozone nonattainment area; 6 of the remaining 12 have acquired a Clean Area Determination for $PM_{2.5}$, and therefore have not prepared a RACM analysis. The RACM analyses for each of the remaining six SIPs were reviewed for candidate control measures.

Controls applicable to stationary sources (large industrial facilities) were also eliminated because such facilities are subject to RACT review, and are addressed elsewhere in the SIP.

Table 5.7-4 lists the candidate control measures that were evaluated as potential RACM.

Table 5.7-4. Candidate Control Measures Considered for RACM

Source Category	Control Measure	Sources of Candidate Control Measure(s)[a]
Dry Wood Measures	Education and Outreach	1, 2, 4
	Regional kiln	7
	Ban on green wood sales	1

[10] The estimated $PM_{2.5}$ emission rate from conveyorized charbroilers in FNSB is about 0.0069 tons per day during the winter season. If all of these sources were controlled, the reduction (at an assumed 80%) would equal about 11 pounds per day.

Source Category	Control Measure	Sources of Candidate Control Measure(s)[a]
Hydronic Heaters	Education and Outreach	1, 2, 4
	Voluntary curtailment on air quality advisory days	1, 2
	Mandatory curtailment on air quality advisory days	1, 3, 5, 6
	All new units must be certified	7
	All units must be certified	7
	Ban new installations	5, 6
	Remove at time of home sale	3
	Subsidize heater change outs	2
	Ban use	7
Wood Stoves	Education and Outreach	1, 2, 3, 4
	Voluntary curtailment on air quality advisory days	1, 2
	Mandatory curtailment on air quality advisory days	1, 3, 5, 6
	All new units must be certified	2, 3, 4, 5, 6
	All new units must meet more stringent standards	7
	All units must be certified	3
	Replace uncertified stoves at time of home sale	3, 4
	Replace uncertified stoves at time of significant remodeling	7
	Replace uncertified stoves in rental units	3
	Require alternate heat source in rental units	3
	Require alternate heat source in new construction	7
	Ban new installations	7
	Subsidize stove change outs	3, 4
	Disincentives for resale of used stoves	7
	Ban use	3
	Use stove change outs to generate NSR offsets	3

Source Category	Control Measure	Sources of Candidate Control Measure(s)[a]
Fireplaces/Fireplace Inserts	Education and Outreach	1, 2, 3, 4
	Voluntary curtailment on air quality advisory days	1, 2, 5
	Mandatory curtailment on air quality advisory days	1
	Subsidize fireplace insert change outs	2
Open Burning	Reinstate open burning ban	1, 2, 3
Burn Barrel	Prohibit use of burn barrels (seasonal or year-round)	7
Residential Fuel Oil Combustion	Provide economic incentives to switch to low-sulfur fuel	7
	Increase coverage of District heating systems	3
Energy Efficiency Measures	Subsidize heating upgrades and weatherization	1, 3, 4, 5
Transportation	Improved public transit	1
	HOV lanes	1
	Traffic flow improvement programs	1
	Create non-motorized traffic zones	1
	Restrict truck idling	1
	Reduce cold start emissions	1
	Employer-sponsored flexible work schedules	1
	Retrofit diesel fleet (school buses, transit fleets)	1, 3
	Onroad vehicle I&M program	1
	Heavy-duty vehicle I&M program	1
	State LEV Program	1, 3

a. Control Measure Sources:
1 – EPA guidance
2 – FNSB programs and proposals
3 – Klamath Falls, Oregon SIP
4 – Oakridge, Oregon SIP
5 – Provo, Utah SIP
6 – Logan, Utah SIP
7 – Other

The identified control measures for area sources fall into four broad categories:

- Education and outreach;
- Voluntary curtailment;
- Mandatory curtailment; and
- Device upgrade and/or replacement.

Each control measure listed in Table 5.7-4 was evaluated for technological feasibility. Listed below are the criteria used. These criteria were developed based on a review of CAA provisions, past RACT and RACM guidance issued by EPA, the1992 general preamble for the implementation of Title of the 1990 CAA amendments and the addendum to the preamble..[11]

1. A measure is technologically infeasible if it is "absurd, unenforceable, or impractical."

2. A measure is technologically infeasible if it would cause severe socioeconomic impacts.

3. A measure is technologically infeasible if, considering the availability of mitigating adverse impacts of that control on other pollution media, the control would not, in the State's reasoned judgment, provide a net benefit to public health and the environment.

4. A measure may be determined to be technologically infeasible upon consideration of other relevant factors:

    a. The capability of effective implementation and enforcement of the measure; and

    b. Local circumstances, such as the condition and extent of needed infrastructure, population size, or workforce type and habits, which may prohibit certain potential control measures from being implementable.

The capability of effective implementation and enforcement are relevant considerations in the RACM analysis, even though public "unpopularity" is not. The General Preamble[12] states:

> *... the SIP submittal to EPA should contain a reasoned justification for partial or full rejection of any available control measures, including those considered or presented during the state's public hearing process, that explains, with appropriate documentation, why each rejected control measure is infeasible or otherwise unreasonable.*

[11] Federal Register, Vol. 57, No. 74, April 16, 1992.
[12] Page 13541 of the April 16, 1992 Preamble

5.7.3.1. Background Information

Education and Outreach Programs and Voluntary Curtailment

Education and outreach programs are necessary for successful implementation of curtailment programs. It is necessary that the target audience be aware of the reasons for, and means of implementing, curtailment of the specific behavior. Education and outreach should precede the implementation phase so that individuals may prepare for curtailment events. Education and outreach should continue through the program, to reinforce the message and to reach individuals who may have missed the previous outreach efforts.

Education and outreach efforts and voluntary curtailment programs may help increase community support for mandatory programs. Education and outreach increases the number of people who are aware of the air pollution problem, and explains the contribution that individuals can make to reduce the problem. Voluntary curtailment programs can help individuals understand the level of effort and cost needed to reduce the problem. Voluntary curtailment programs decrease opposition to mandatory programs by reducing the number of people who must change their behavior, and by demonstrating the feasibility of curtailment.

The State of Alaska and the FNSB have significant experience in educational programs that help citizens reduce their emissions. Public outreach is an important component of the Fairbanks air quality program with respect to improving residents' use of solid-fuel heating devices, thereby reducing $PM_{2.5}$ emissions. Public outreach efforts focus on measures residents can take to protect themselves and to reduce $PM_{2.5}$ emissions from activities like wood and coal burning. For example, the Borough and DEC have developed and implemented an extensive outreach effort to encourage residents to employ "best burning" practices when using wood heating devices. The Borough has also developed and implemented a program to support and encourage voluntary efforts to encourage residents who can to shift away from wood burning on advisory days and use their primary fuel oil heating systems instead.

Emission reductions from voluntary curtailment are potentially significant. However, because the reductions are not enforceable, EPA policy limits the amount of credit that may be taken for planning purposes to 6% of the total reductions needed for attainment.[13]

Mandatory Curtailment Programs

Mandatory curtailment programs that affect home heating are currently not feasible in Fairbanks North Star Borough because the community has, on several occasions, indicated that it would not accept such a program. The community has indicated this by

[13] http://www.epa.gov/ttn/caaa/t1/memoranda/evm_ievm_g.pdf

approving, and renewing, a referendum that prohibits the Borough from imposing or enforcing any limits on fuels used to heat homes.[14]

Under Alaskan laws, voter-approved ordinances cannot be amended by local officials for two years. In 2012, more than two years after the 2009 initiative passed, the Borough proposed "moderate" regulations affecting home heaters. In response, the proponents of the 2009 proposition circulated a new proposition, renewing and strengthening the previous measure. On October 2, 2012, the voters of the Fairbanks North Star Borough approved Proposition 3, the Home Heating Initiative:

> *The borough shall not, in any way, regulate, prohibit, curtail, nor issue fines or fees associated with, the sale, distribution, or operation of heating appliances or any type of combustible fuel.*
>
> *'Heating Appliances' is defined as, but not limited to: oil furnaces, gas furnaces, wood stoves, coal stoves, wood-fired hydronic heaters, wood-fired furnaces, coal-fired hydronic heaters, coal-fired furnaces, masonry heaters, pellet stoves, cook stoves, and fireplaces.*

Continuation of the four-year voter ban against Fairbanks North Star Borough regulation of air pollution from home heaters and fuels failed on October 14, 2014 when Proposition 2, the Home Heating Initiative, was defeated. The ban will be lifted when the vote is certified by the Borough Assembly. Although the Borough once again has the authority to develop local control measures, it has not had time to make decisions about any additional control measures to be implemented in the wake of the vote.
The Borough assembly interpreted the above language to require a repeal of its ban on open burning. This resulted in the DEC implementing its existing statewide open burning regulations within the nonattainment area.

This October, Fairbanks voters considered another initiative renewing the ban on local adoption of restrictions on combustion sources. And, although the initiative failed (giving the Borough the authority to establish local regulations for home heating devices) community opposition to limits on options for home heating is also grounded in the economics of home heating in the far north. Fairbanks experiences extremely and persistently cold temperatures during the winter, and the cold temperatures coincide with strong inversions that result in high 24-hour $PM_{2.5}$ concentrations. In summary, although a majority of Fairbanks voters now supports local development of home heater regulations, the margin of that majority is slim. Opposition to such controls remains widespread. Because effective measures that seek to change the behavior of the general public require the cooperation and support of the public as a whole, the existing level of opposition remains an obstacle to many mandatory measures. The resources to enforce an unpopular regulation affecting the daily behavior of hundreds or thousands of individuals are simply not available. This plan will develop public support for behavior

[14] FNSB Code 8.21.025 "The borough shall not, in any way, regulate, prohibit, curtail, nor issue fines or fees associated with, the sale, distribution, or operation of heating appliances or any type of combustible fuel."

change through education and outreach. For this reason, such measures continue to be considered technologically infeasible for now.

While fuel oil is the dominant source of home heating in Fairbanks, with roughly two thirds of the market, many homes are equipped to burn multiple fuels to ensure that a backup is available in the event of a supply disruption in an arctic environment. The cost of fuel has risen from a low point of $2.25/gallon in Nov. 2006, to a high of $4.12 in January 2013. Current prices are roughly $4/gallon. The increase in fuel oil prices has stimulated a shift towards increase use of wood and coal as a way to conserve home heating expenses. Any perceived constraint on limiting the use of lower priced fuels is a significant concern in the community.

To illustrate the magnitude of home heating expenses in Fairbanks, information on the cost of living associated with energy use was assembled for PM nonattainment communities and northern tier (cold climate, high energy cost) communities located in states with wood burning controls. The Council for Community and Economic Research (C2ER) publishes a Cost of Living Index for 279 urban areas.[15] A total of 57 indices are provided for grocery items, housing, utilities, transportation, health care and miscellaneous goods and services. The utility categories include those described below.

- *Total Home Energy Cost* – monthly cost, at current rates, for average monthly consumption of all types over the previous 12 months for a 2,400 sq. ft. living area new house on an 8,000 sq. ft. lot (i.e., four bedrooms and two baths)

- *Electricity* – the average monthly cost for all electric homes

- *Other Home Energy* – average monthly cost, at current rates for natural gas, fuel oil, coal and any other forms of energy except electricity

- *Telephone* – not relevant to this discussion

It is important to note that these indices do not represent the average energy cost of all homes in each community and they do not include the cost of all fuels (e.g., wood is not included in the cost estimates). The collection of this level of detail across 279 communities on a quarterly basis is impractical. Instead, the indices provide a consistent metric to contrast utility- based energy costs of same size homes in each of the surveyed communities. The concept is that while smaller and larger homes may have different fuel use and fuel mixes, the relative cost observed in the indexes should provide a representative estimate of the cost of utility based fuels used in homes. Thus, the absolute value of the energy costs expressed in the index are less important the relative cost among participating communities.

[15] Council for Community and Economic Research (C2ER),*Cost of Living Index, Comparative Data for 279 Urban Area, Second Quarter 2014, August 2014*

A summary of the *Other Home Energy* and *Total Home Energy* indices for the second quarter of 2014 is presented below in Table 5.7-5 for 24 urban areas. The table also shows the percentage of each listed community's index relative to Fairbanks. It shows that Fairbanks had the highest energy costs of any of the listed urban areas. The C2ER data also show that Fairbanks has the highest home energy costs in the U.S. Juneau, Alaska had home energy costs closest to those of Fairbanks at roughly 50% (i.e., one half). Outside of Alaska and Hawaii[16], the community with the highest energy costs

Table 5.7-5. Comparison of the Cost of Living Indices for *Other Home Energy and Total Home Energy* for Communities with Home Heating Particulate Control Measures

[16] Hilo and Honolulu, Hawaii have the second and third highest *Total Home Energy* cost in the U.S. (96.0% and 81.3%, respectively). While the State of Hawaii has outdoor burning restrictions, neither Hilo nor Honolulu community has wood burning restrictions and they have no PM nonattainment designations, so their values were not included in the Fairbanks comparisons.

Urban Area & State	Other Energy		Total Energy	
	Index	% Relative to Fairbanks	Index	% Relative to Fairbanks
Fairbanks, AK	426.93	100.0%	566.36	100.00%
Juneau, AK	223.11	52.3%	309.99	54.7%
Anchorage, AK	79.57	18.6%	162.30	28.7%
Phoenix, AZ	-	-	184.66	32.6%
Fresno, CA	79.30	18.6%	223.83	39.5%
Los Angeles, CA	70.71	16.6%	184.89	32.6%
Sacramento, CA	38.28	9.0%	215.80	38.1%
Denver, CO	69.21	16.2%	165.84	29.3%
Stamford, CT	129.19	30.3%	247.60	43.7%
Boise, ID	58.52	13.7%	148.85	26.3%
Boston, MA	122.55	28.7%	229.83	40.6%
Portland, ME	53.35	12.5%	136.28	24.1%
Detroit, MI	67.25	15.8%	183.32	32.4%
St. Paul, MN	71.76	16.8%	149.01	26.3%
Bozeman, MT	90.47	21.2%	154.02	27.2%
Manchester, NH	97.64	22.9%	205.55	36.3%
Newark, NJ	78.11	18.3%	206.39	36.4%
Buffalo, NY	70.01	16.4%	160.36	28.3%
Ithaca, NY	80.40	18.8%	179.24	31.6%
Manhattan, NY	148.24	34.7%	277.18	48.9%
Portland, OR	74.95	17.6%	158.73	28.0%
Burlington-Chittenden, VT	133.58	31.3%	234.60	41.4%
Salt Lake City, UT	76.03	17.8%	146.75	25.9%
Seattle, WA	-	-	173.47	30.6%
Tacoma, WA	79.94	18.7%	135.66	24.0%

(both categories) is Manhattan, NY, with 34.7% of the *Other Home Energy* index and 48.0% of the *Total Home Energy* index. Stamford, CT is second with 30.3% of the *Other Home Energy* index and 43.7.0% of the *Total Home Energy* index. Burlington-Chittenden, VT is third with 31.3% of the *Other Home Energy* index and 41.4.0% of the *Total Home Energy* index. Boston, MA is in fourth place, with 40.6% of the *Total Home Energy* index and 28.7% of the *Other Home Energy* costs.

Four communities (Fresno, Sacramento, Manchester, and Newark) had *Total Home Energy* indices falling between 33% and 40%. The rest of the listed communities had had energy costs that are one third or less than those incurred in Fairbanks. This

information demonstrates that home heating expenses are two to three times higher in Fairbanks than any other community with wood burning controls. The magnitude of this expense directly influences the public's willingness to comply with controls that increase the cost of home heating. The cost data also demonstrate the limited economic impact of wood burning controls in the other PM nonattainment areas, which influences public willingness to bear the cost of those controls.

Finally, in addition to the economic issues described above, some residences that are equipped with alternative sources of heat may find those sources inadequate on some of the coldest days of the year. In these cases, supplemental heating with a wood-fired device may be necessary when the fuel oil-fired heater does not provide enough heat.

For this reason, control measures that require the use of an alternative fuel source to wood have a much greater cost to the consumer in Fairbanks (a factor of two or three) than to consumers in other parts of the United States. The magnitude of this expense directly influences the public's willingness and ability to comply with controls that further increase the cost of home heating. A ban on use of woodstoves during high pollution days in Fairbanks has a dramatically different effect than such a ban in Sacramento.

As demonstrated by the Home Heating Initiative described above, the community resistance in Fairbanks to measures that would increase home heating costs has been carried over to other measures affecting the fuel supply, such as prohibitions on the use of wet wood.
While the initiative failed in October 2014, it will take some time to establish locally effective controls. For the reasons outlined above, such a program would still face resistance by many in the community, which remains opposed to limits on residential fuel use. Because of this opposition, candidate control measures that fall within the scope of the referendum's ban have been determined to be not practically enforceable at this time.

5.7.3.2. Dry Wood Programs

The Cold Climate Housing Research Center estimated in 2009 that residential wood burning accounted for slightly over 560 tons of $PM_{2.5}$ emissions per year in the FNSB.[17] As shown in Table 5.7-2, emissions from wood combustion are responsible for 2.99 tons per day of direct $PM_{2.5}$ emissions on episode days. Based on photochemical modeling, wood combustion is responsible for 66% of the ambient $PM_{2.5}$ concentration on episode days.

Dry wood programs reduce emissions from all categories of wood burning equipment by reducing the moisture content of the wood fuel mix. Reducing wood fuel moisture content reduces emissions of $PM_{2.5}$ and its precursors by (1) improving combustion, burning more cleanly and reducing emissions on a per pound of fuel basis; and (2) by burning more efficiently. Less moisture means less water needs to be evaporated, and

[17] Cold Climate Housing Research Center, *Reducing PM2.5 Emissions from Residential Heating Sources in the Fairbanks North Star Borough*, February 23, 2009. p. 14.

therefore more heat is available as useful heat. Because less fuel is required to provide the same amount of useful heat, emissions of all combustion pollutants is reduced. A secondary effect is that less energy is required to transport fuel, resulting in a modest reduction in onroad emissions.

Fuel wood can be dried actively in kilns. It can also be dried by letting cut wood season before being burned. Freshly cut "wet" wood may contain as much as 40% to 60% moisture, depending on the type of wood.[18] Wood that has been allowed sufficient time to dry (usually six months or more, for split wood that is air-dried) typically contains 20% moisture or less.[19] According to a 2008 report by the Northeast States for Coordinated Air Use Management (NESCAUM), for every 10 percentage point increase in the moisture content of wood, the $PM_{2.5}$ emissions increase by 65% to 167%.[20] Part of this increase is due to the increased amount of wood fuel needed to evaporate the extra water, but a larger part of this increase is due to poor combustion conditions that lead to reduced heat transfer efficiency and to more particulates in the smoke.

If only wet wood is burned, the total wood volume used for an entire winter may be as much as 100% more than if seasoned wood were used.[21]

Education and Outreach

The State of Alaska and the FNSB have significant experience in educational programs that help citizens reduce their emissions.[22] The agencies publish a brochure, *Split Stack Store and Save!*, that encourages the use of only dry wood, explains methods for ensuring that wood is dry (seasoning after cutting,), and explains some of the benefits (less wood needed, cleaner burning). EPA publishes a similar brochure, *Wet Wood is a Waste*, as part of its Burn Wise program. Burn Wise materials are also available from the FNSB and Alaska DEC. Because it involves voluntary efforts on the part of the public, and is implemented as a state program, community resistance to the FNSB and Alaska DEC's outreach programs has been minimal.

A more comprehensive program that encourages the use of only dry wood, explains the methods for ensuring that wood is dry (seasoning after cutting, use of inexpensive moisture meters), and explains the benefits (less wood is needed, wood is lighter/easier to carry, less creosote is formed) has been developed and is in the process of being implemented.

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[18] EPA, *Subpart AAA—Standards of Performance for New Residential Wood Heaters, Revised Draft Review Document,* December 30, 2009, p. 35

[19] EPA, *Subpart AAA—Standards of Performance for New Residential Wood Heaters, Revised Draft Review Document,* December 30, 2009, p. 35

[20] NESCAUM, *Source Characterization of Outdoor Wood Furnaces,* September 9, 2008, p. 4-1

[21] Bureau of land Management, *Wood Heat as a Comparison* http://www.blm.gov/ca/st/en/fo/alturas/woodheatcomparison.html ("Wet wood alone can reduce the efficiency of a wood stove by an additional 50%.")

[22] As discussed in the introduction to this Section.

Examples of other elements that may be included as part of this control measure include:

- Certifying dealers who commit to providing dry wood for sale.
- Making free or inexpensive wood moisture sensors to consumers

Overall effectiveness of voluntary measures as an emission reduction measure depends upon the extent of implementation, as well as the actual steps taken by the public. Education and outreach measures can reduce opposition to future efforts to implement mandatory measures.

This control measure is technologically feasible.

Increased availability—regional kiln

Of the wood burned in FNSB, 26.2 % is purchased from firewood dealers (the rest is harvested by the user).[23] Less than 20% of the wood sold in FNSB is dry wood; the rest is sold green, or self-cut, and contains a considerable amount of moisture.[24]

As discussed above, wet wood does not burn as efficiently as dry wood. One of the barriers to use of dry wood is availability. Construction of a regional kiln is one way to increase the availability of dry wood. A regional kiln would allow wet firewood to be dried quickly. Depending on the source of heat[25] for drying, substantial reductions in PM emissions could be achieved. The source of drying heat would also affect the cost of the process, and therefore the premium charged for kiln-dried wood.

This measure would reach only a portion of the wood supply. More than 75% of the wood burned in residential heaters is self-cut or comes from unlicensed wood suppliers; this wood could not be processed in a regional kiln.

As discussed above, dry wood provides several advantages for the consumer: it burns hotter and cleaner, each log weighs less, and less fuel is needed for the same amount of heat. Depending upon the cost of drying heat, the premium for dry wood may be less than the consumer's savings due to the reduced need for fuel.[26] Economic incentives from government agencies may therefore be necessary to kickstart construction of a regional kiln.

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[23] 2013 Tag survey.

[24] Most wood sold in the area comes from trees that have been cut down, but not sectioned and split until purchased by the consumer. As a result, the wood is still wet when sold.

[25] Sources of heat could include kiln-dried firewood produced in the facility, fuel oil or LNG, or low pressure steam or recovered heat from an industrial process.

[26] The current premium for dry vs. wet wood is $50 per cord ($375 per cord vs. $325 per cord). The moisture content of kiln-dried firewood must be similar to that of air-dried firewood in order for certified stoves to work properly.

There is no evidence that the current demand for sales of dry firewood is sufficiently high to require construction of a regional kiln.[27] As discussed below, adoption of a ban on the sale of green wood would increase demand, possibly justifying construction of a kiln; however, such a ban has not been feasible in FNSB. Furthermore, regional emissions from kiln-dried firewood are much higher than from air-dried firewood, because of the fuel needed to operate the kiln.

This measure is not technologically feasible.

Ban on green wood sales

A ban on the sale of green wood would require wood vendors to have access to facilities to dry wood. This would be either a kiln (such as a regional kiln described in the previous section) or sufficient storage space to store and dry all of the fuel wood to be sold in the following year. The amount of dry wood storage needed for one year of wood fuel sales in FNSB is 42,300 cords.[28]

This measure would reach only a portion of the wood supply. As discussed in the previous section, more than 70% of the wood burned in residential heaters is self-cut or comes from unlicensed wood suppliers; this would not be affected by a ban on sale of green wood.

As discussed above, the referendum prohibiting the Borough's regulation of home heating and fuels has prevented the Borough from implementing this program. Any such program would have to be implemented by the State, in the face of opposition from the local community.

This measure is not technologically feasible.

5.7.3.3. Residential Wood Burning: Outdoor Wood-burning Boilers (hydronic heaters)

A hydronic heater (also called an outdoor wood heater or outdoor wood boiler) burns wood to heat liquid flowing through pipes in the combustion chamber. The hot liquid is then piped to provide heat and hot water to occupied buildings. The number of units in

[27] At least one firewood vendor is constructing a kiln, based either on current demand or anticipation of demand. If this venture is successful, other vendors may choose to do the same. A much larger unmet demand for dry wood would be needed to justify a regional kiln, however.

[28] A 2011 home heating survey (Sierra Research, June 10, 2011) indicated average wood fuel use of 3.57 cords/year per installation for stoves and inserts, and 1.80 cords/year for fireplaces. The SIP inventory for 2015 projects a total of 11,510 stoves, inserts, and hydronic heaters, and 660 fireplaces. Total estimated annual wood fuel consumption = 3.57 * 11,510 + 1.80 * 660 = 42,300 cords

FNSB has been estimated[29] at about 480: 380 are uncertified, and 100 are Phase 2 Qualified units (see below).

Emissions from wood boilers are currently not regulated at the national level, but EPA has initiated a voluntary program for manufacturers of hydronic heaters.[30] The program encourages manufacturers to produce and sell cleaner, more efficient devices. Hydronic heaters that are "Phase 2 Qualified" under the EPA program must meet an emissions limit of 0.32 lbs per million BTU output.[31] This represents a reduction of about 90% compared to unqualified units.

Direct $PM_{2.5}$ emissions from hydronic heaters are estimated to be 350 tons per year.[32]

Education and Outreach

The State of Alaska and the FNSB have significant experience in educational programs that help citizens reduce their emissions.[33] The agencies publish a brochure, *Split Stack Store and Save!*, that encourages the use of only dry wood, explains methods for ensuring that wood is dry (seasoning after cutting,), and explains some of the benefits (less wood needed, cleaner burning). EPA publishes a similar brochure*, Wet Wood is a Waste,* as part of its Burn Wise program. Burn Wise materials are also available from the FNSB and Alaska DEC. In order to maximize the effectiveness of this control measure, additional materials that target hydronic heaters should be developed, containing the information currently available on the EPA website.[34]

Because it involves voluntary efforts on the part of the public, and is implemented as a state program, community resistance to the FNSB and Alaska DEC outreach programs has been minimal.

Examples of other elements that may be included as part of this control measure include:

- Making free or inexpensive wood moisture sensors to consumers
- Use wood sellers to distribute outreach materials (either voluntary or required)
- Use wood burning appliance vendors to distribute outreach materials
- Use agency resources to distribute outreach materials
- Make information available to consumers
    - Advantages to burning dry wood
    - How to tell if wood is dry
    - How to dry wood
    - Restrictions on burning (no burn days)

[29] Sierra Research, projected 2015 (attainment year) inventory based on 2011 home heating survey
[30] EPA, *EPA's Phase 2 Voluntary Partnership Program: Hydronic Heaters*
[31] Ibid.
[32] Cold Climate Housing Research Center, *Reducing $PM_{2.5}$ Emissions from Residential Heating Sources in the Fairbanks North Star Borough*, February 23, 2009. p. 14.
[33] As discussed in the introduction to this Section.
[34] http://www.epa.gov/burnwise/woodboilers.html.

- How to improve operation and maintenance
- Use a certified installer
- Resources for more information

Overall effectiveness of voluntary measures as an emission reduction measure depends upon the extent of implementation, as well as the actual steps taken by the public. Education and outreach measures can reduce opposition to future efforts to implement mandatory measures.

This control measure is technologically feasible.

Voluntary curtailment on air quality advisory days

Under a voluntary curtailment program, owners of wood burning devices are asked to voluntarily reduce or avoid operation of the devices on days when air quality is poor. Such a program relies on agency efforts to predict poor air quality days, agency efforts to make the public aware of predictions, agency efforts to educate the public about reducing emissions, and public cooperation with requests to minimize emissions.

The FNSB Air Quality Division provides daily air quality information on its website and by telephone. Alaska DEC also provides air quality advisories when circumstances call for them. FNSB has developed a voluntary burn cessation program that includes direct notification of participants when an advisory is called. Advisories are called when $PM_{2.5}$ concentrations above 35 micrograms per cubic meter are predicted.

Under this control measure, the agencies will develop and distribute additional educational materials. They will increase efforts to publicize the program, beginning with links on the existing Air Quality Index webpages to the FNSB's existing AQ Advisory program webpages.

In February, 2014, the FNSB adopted an ordinance[35] to create a voluntary burn cessation program with the following elements:

- Provide incentives (sign-up bonus, yard sign, or other form of public acknowledgment) to households that agree to voluntarily avoid use of wood-burning appliances during air quality advisories.

- Establish methods, such as automated phone calls, to notify participants when an advisory is called.

- Allow the Borough to contract with an agency to promote the program.

This control measure is technologically feasible.

[35] http://co.fairbanks.ak.us/meetings/ordinances/2014/2014-11.pdf

Mandatory curtailment on air quality advisory days

Mandatory curtailment on air quality advisory days would prohibit use of some hydronic heaters on days of poor air quality. This prohibition could be implemented to affect all hydronic heaters, or only those that do not meet EPA qualification standards. An exemption from the ban for units that are the sole source of a residence's space heating would be included in either case. Approximately 4% of households in Fairbanks use wood as the sole source of heat.

State law currently prohibits the operation of wood-fired heating devices on episode days:

> *18 AAC 50.075 (b) A person may not operate a wood-fired heating device in an area for which the department has declared an air quality episode under 18 AAC 50.245.*

The criteria for declaring an air quality episode do not currently include $PM_{2.5}$ concentrations. Alaska DEC has proposed[36] to revise the criteria for declaring an air quality episode to include $PM_{2.5}$, but at a concentration well above the federal standard. At the same time, Alaska DEC proposed a revision to Section 50.075 to give the agency discretion about declaring an episode. The revision would benefit public health by reducing $PM_{2.5}$ concentrations on the worst episode days. Advisories are called when $PM_{2.5}$ concentrations above 35 micrograms per cubic meter are predicted.

As discussed above, the Borough has not been able to implement this measure because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such measure would have to be implemented by the State, in the face of opposition from the local community and would not be practically enforceable.

This measure is not technologically feasible.

All new units must be certified

Alaska DEC has already proposed a more stringent standard. See next section.

This control measure is technologically feasible.

All new units must meet a more stringent state standard of 2.5 gram/hour

EPA has initiated a voluntary program for manufacturers of hydronic heaters. EPA's primary intent is to first encourage manufacturers to produce cleaner hydronic heater models. EPA also wants those who buy a hydronic heater to buy the cleanest models

[36] Alaska DEC, *Proposed Regulation changes Pertaining to: Open Burning, Wood-fired Heating Device Visible Emission Standards, Solid Fuel-Fired Heating Device Fuels, Wood Fired Heating Device Standards, & Fine Particulate Matter (PM-2.5) Air Episode and Advisories, Public Review Draft*, September 19, 2013.

available, which are those that qualify for the EPA voluntary program. EPA maintains a list of qualifying models, of which there are many.

Many local agencies have developed ordinances that ban unqualified hydronic heaters and establish minimum distances to neighbors and minimum stack heights. EPA has provided technical and financial support for the NESCAUM to develop a model rule that state and local agencies can use to regulate hydronic heater emissions.

Alaska DEC has proposed[37] to adopt a new regulation, 18 AAC 50.077(b)(1), that would require that all new hydronic heaters meet an emission limit of 2.5 gm/hr. While this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels, the State could implement the measure. Since it would only affect the supply of wood stoves offered for sale and not impact homeowner fuel choice decisions, enforceability limitations and concerns would not apply.

This measure is technologically feasible.

All units must be certified, requiring retrofits/replacement of existing units

Adoption of a performance standard for all hydronic heaters would require replacement or retrofit of existing heaters that do not meet the standard (e.g., qualified under the EPA program described above).

As discussed above, this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such measure would have to be implemented by the State, in the face of opposition from the local community and would not be practically enforceable.

This control measure is not technologically feasible.

Ban on new installations

A ban on new installations would not reduce emissions from hydronic heaters in the near term, but would ultimately reduce emissions as hydronic heaters were retired. However, this approach could have the negative effect of prolonging the use of existing, dirty units because replacing them with newer, much cleaner units would not be allowed. As a result, this measure would not result in quantifiable reductions in the four years after designation.

As discussed above, this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such

[37] Alaska DEC, *Proposed Regulation changes Pertaining to: Open Burning, Wood-fired Heating Device Visible Emission Standards, Solid Fuel-Fired Heating Device Fuels, Wood Fired Heating Device Standards, & Fine Particulate Matter (PM-2.5) Air Episode and Advisories, Public Review Draft*, September 19, 2013.

measure would have to be implemented by the State, in the face of opposition from the local community and would not be practically enforceable. Since the measure has been recently defeated in October 2014. This information became available after the preparation of this document, there is insufficient time to prepare revisions and meet the schedule for delivering the SIP to EPA by the end of 2014. Moreover, the Borough has not had time to make decisions about any additional control measures to be implemented in the wake of the vote.

This control measure is not technologically feasible.

Remove at time of home sale

A requirement to replace hydronic heaters at the time of home sale would not reduce emissions from hydronic heaters in the near term, but would ultimately reduce emissions as hydronic heaters were retired when residential property changed hands. As a result, this measure would not result in quantifiable reductions in the four years after designation. The cost of the measure would be borne by the seller, because the home's sale price would be diminished by the value of the heater that must be removed.

As discussed above, this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such measure would have to be implemented by the State, in the face of opposition from the local community would not be practically enforceable.

This control measure is not technologically feasible.

Subsidize heater change outs

FNSB has a solid fuel burning appliance (SFBA) change out program. Qualifying residents can be reimbursed for replacing, removing, or repairing solid fuel burning devices (wood and coal-stoves, wood and coal-fired furnaces, hydronic heaters, fireplace inserts, etc.). FNSB offers reimbursement of 100% of the cost (up to $10,000) of a new qualifying hydronic heater. There is also a bounty program for dismantling an old device without replacement.

This control measure is technologically feasible.

Ban use

A ban on the use of hydronic heaters would require those with access to alternate heat sources to use them. Unless an exemption were offered, those with no alternate heat source would be required to install one. As discussed above, on very cold days some residences with alternate heat sources find those sources to be inadequate, and need to supplement with heat from wood combustion. An enforcement mechanism is required to implement this measure. Such a mechanism does not currently exist.

As discussed above, this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such measure would have to be implemented by the State, in the face of opposition from the local community would not be practically enforceable.

This control measure is not technologically feasible.

5.7.3.4. Residential Wood Burning: Wood Stoves

The number of units in FNSB has been estimated[38] at about 11,000: 3,645 (33%) are uncertified; 3,811 (35%) are EPA-certified non-catalytic units; 2,497 (23%) are EPA-certified catalytic units; and 412 (4%) are pellet stoves

Direct $PM_{2.5}$ emissions from wood stoves are estimated to be 214 tons per year.[39]

Education and Outreach

The State of Alaska and the FNSB have significant experience in educational programs that help citizens reduce their emissions.[40] The FNSB and State of Alaska have programs focused on woodstoves. Program materials include brochures on woodstoves, catalytic woodstoves, and non-catalytic woodstoves; *Split Stack Store and Save!*, that encourages the use of only dry wood, explains methods for ensuring that wood is dry (seasoning after cutting,), and explains some of the benefits (less wood needed, cleaner burning). EPA publishes a similar brochure, *Wet Wood is a Waste,* as part of its Burn Wise program. Burn Wise materials are also available from the FNSB and Alaska DEC. Because it involves voluntary efforts on the part of the public, and is implemented as a state program, community resistance to the FNSB and Alaska DEC outreach programs has been minimal.

Examples of other elements that may be included as part of this control measure include:

- Making free or inexpensive wood moisture sensors to consumers
- Use wood sellers to distribute outreach materials (either voluntary or required)
- Use wood burning appliance vendors to distribute outreach materials
- Use agency resources to distribute outreach materials
- Make information available to consumers
    - Advantages to burning dry wood
    - How to tell if wood is dry
    - How to dry wood
    - Restrictions on burning (no burn days)
    - How to improve operation and maintenance
    - Use a certified installer
    - Resources for more information

[38] Sierra Research, projected 2015 (attainment year) inventory based on 2011 home heating survey

[39] Cold Climate Housing Research Center, *Reducing PM2.5 Emissions from Residential Heating Sources in the Fairbanks North Star Borough*, February 23, 2009. p. 14.

[40] As discussed in the introduction to this Section.

Overall effectiveness of voluntary measures as an emission reduction measure depends upon the extent of implementation, as well as the actual steps taken by the public. Education and outreach measures can reduce opposition to future efforts to implement mandatory measures.

This control measure is technologically feasible.

Voluntary curtailment on air quality advisory days

Under a voluntary curtailment program, owners of wood burning devices are asked to voluntarily reduce or avoid operation of the devices on days when air quality is poor. Such a program relies on agency efforts to predict poor air quality days, agency efforts to make the public aware of predictions, agency efforts to educate the public about reducing emissions, and public cooperation with requests to minimize emissions.

The FNSB Air Quality Division provides daily air quality information on its website and by telephone. Alaska DEC also provides air quality advisories when circumstances call for them.

In February, 2014, the FNSB adopted an ordinance[41] to create a voluntary burn cessation program with the following elements:

- Provide incentives (sign-up bonus, yard sign, or other form of public acknowledgment) to households to agree to voluntarily avoid use of wood-burning appliances during air quality advisories.

- Establish methods, such as automated phone calls, to notify participants when an advisory is called

- Allow the Borough to contract with an agency to promote the program.

This measure is technologically feasible.

Mandatory curtailment on air quality advisory days

Mandatory curtailment on air quality advisory days would prohibit use of some woodstoves. This prohibition could be implemented to affect all woodstoves, or only those that do not meet EPA certification standards. An exemption from the ban for units that are the sole source of a residence's space heating would be included in either case.

State law currently prohibits the operation of wood-fired heating devices on episode days:

> *18 AAC 50.075 (b) A person may not operate a wood-fired heating device in an area for which the department has declared an air quality episode under 18 AAC 50.245.*

[41] http://co.fairbanks.ak.us/meetings/ordinances/2014/2014-11.pdf

The criteria for declaring an air quality episode do not currently include $PM_{2.5}$ concentrations. Alaska DEC has proposed[42] to revise the criteria for declaring an air quality episode to include $PM_{2.5}$, but at a concentration well above the federal standard. At the same time, Alaska DEC proposed a revision to Section 50.075 to give the agency discretion about declaring an episode. The revision would benefit public health by reducing $PM_{2.5}$ concentrations on the worst episode days.

As discussed above, this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such program would have to be implemented by the State, in the face of opposition from the local community would not be practically enforceable. Since the measure has been recently defeated in October 2014. This information became available after the preparation of this document, there is insufficient time to prepare revisions and meet the schedule for delivering the SIP to EPA by the end of 2014. Moreover, the Borough has not had time to make decisions about any additional control measures to be implemented in the wake of the vote.

This control measure is not technologically feasible.

<u>All new units must be certified</u>

Alaska DEC has proposed a more stringent measure. Please see next section.
This control measure is technologically feasible.

<u>Only stoves meeting more stringent state standards (2.5 gram/hr) may be sold</u>

Alaska DEC has proposed[43] to adopt a new regulation, 18 AAC 50.077(b)(2), that would require that all new woodstoves meet an emission limit of 2.5 gm/hr and be certified by EPA. The short-term effectiveness of this measure is low, as the turnover of wood stoves built before 1992 is very slow; however, the measure would stop the projected growth in the number of uncertified wood stoves (~1.3% per year).[44] Changeover to newer units could be accelerated with a wood stove change-out program.

This control measure is technologically feasible.

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[42] Alaska DEC, *Proposed Regulation changes Pertaining to: Open Burning, Wood-fired Heating Device Visible Emission Standards, Solid Fuel-Fired Heating Device Fuels, Wood Fired Heating Device Standards, & Fine Particulate Matter (PM-2.5) Air Episode and Advisories, Public Review Draft*, September 19, 2013.
[43] Alaska DEC, *Proposed Regulation changes Pertaining to: Open Burning, Wood-fired Heating Device Visible Emission Standards, Solid Fuel-Fired Heating Device Fuels, Wood Fired Heating Device Standards, & Fine Particulate Matter (PM-2.5) Air Episode and Advisories, Public Review Draft*, September 19, 2013.
[44] Sierra Research, projected 2015 (attainment year) inventory based on 2011 home heating survey

Replace uncertified stoves at time of home sale

A requirement to replace uncertified stoves at the time of home sale would not reduce emissions from wood stoves in the near term, but would ultimately reduce emissions as wood stoves were retired when residential property changed hands. As a result, this measure would not result in quantifiable reductions in the four years after designation. The cost of the measure would be borne by the seller, because the home's sale price would be diminished by the value of the stove that must be removed.

As discussed above, this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such measure would have to be implemented by the State, in the face of opposition from the local community would not be practically enforceable. Since the measure has been recently defeated in October 2014. This information became available after the preparation of this document, there is insufficient time to prepare revisions and meet the schedule for delivering the SIP to EPA by the end of 2014. Moreover, the Borough has not had time to make decisions about any additional control measures to be implemented in the wake of the vote.

This control measure is not technologically feasible.

Replace uncertified stoves at time of significant remodeling

This measure would require replacement of stove when significant remodeling occurred. It would probably be enforced during the building permit review and issuance process. The scope and impact of this measure could be controlled by definition of "significant;" it could also be limited to situations where the remodeled room contains a stove. A requirement to replace uncertified stoves at the time of significant remodeling would not reduce emissions from wood stoves in the near term, but would ultimately reduce emissions as wood stoves were retired when residential property was remodeled. As a result, this measure would not result in quantifiable reductions in the four years after designation. The cost of the measure would be borne by the homeowner.

As discussed above, this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such measure would have to be implemented by the State, in the face of opposition from the local community would not be practically enforceable. Since the measure has been recently defeated in October 2014[45]. This information became available after the preparation of this document, there is insufficient time to prepare revisions and meet the schedule for delivering the SIP to EPA by the end of 2014. Moreover, the Borough has

[45] 51.57% to 48.43%. *Election Summary Report, 2014 Regular Election,* October 30, 2014

not had time to make decisions about any additional control measures to be implemented in the wake of the vote.

This control measure is not technologically feasible.

Replace uncertified stoves in rental units

A requirement to replace uncertified stoves in rental units would result in emission reductions upon replacement. The cost of the measure would be borne by the landlords, and presumably passed on to the renter.

As discussed above, this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such measure would have to be implemented by the State, in the face of opposition from the local community would not be practically enforceable. Since the measure has been recently defeated in October 2014. This information became available after the preparation of this document, there is insufficient time to prepare revisions and meet the schedule for delivering the SIP to EPA by the end of 2014. Moreover, the Borough has not had time to make decisions about any additional control measures to be implemented in the wake of the vote.

This control measure is not technologically feasible.

Require alternate heat source in rental units

Emission reductions occur to the extent that the renter uses the alternate heat source during air pollution advisories. The availability of an alternate heat source allows the renter to participate in curtailment programs. It is not clear what fraction of the rental housing stock is physically able to install an alternate heat source. The cost of the measure would be borne by the landlords, and presumably passed on to the renter.

As discussed above, this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such measure would have to be implemented by the State, in the face of opposition from the local community would not be practically enforceable. Since the measure has been recently defeated in October 2014. This information became available after the preparation of this document, there is insufficient time to prepare revisions and meet the schedule for delivering the SIP to EPA by the end of 2014. Moreover, the Borough has not had time to make decisions about any additional control measures to be implemented in the wake of the vote.

This control measure is not technologically feasible.

Require alternate heat source in new construction

A requirement to include alternate heat sources in new construction would not reduce emission; it would, however, potentially reduce the magnitude of new emissions associated with population growth. Emission minimization occurs to the extent that the resident uses the alternate heat source during air pollution advisories. The availability of an alternate heat source allows the resident to participate in curtailment programs. This measure would not result in quantifiable reductions in the four years after designation.

As discussed above, this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such measure would have to be implemented by the State, in the face of opposition from the local community would not be practically enforceable.

This control measure is not technologically feasible.

Ban on new installations

A ban on new installations would not reduce emissions from wood stoves in the near term, but would ultimately reduce emissions as wood stoves were retired; however, this approach could have the negative effect of prolonging the use of existing, dirty units because replacing them with newer, much cleaner units would not be allowed. This measure would not result in quantifiable reductions in the four years after designation.

An alternative proposal would be to limit the number of new installations allowed in new homes or under construction (i.e., construction of new homes or remodeling of existing homes) to some number greater than zero, and prohibit any more. This would allow the agency to effectively control the number of wood stoves in the area, rationing the number of new stoves that would be allowed. This would require a method for determining what the quota would be; how it would be distributed between developers and homeowners; and a significant enforcement effort.

Another alternative proposal would allow new installations, but only if one or more existing stoves were retired first. This would either be replacement of the existing stove with a new one, or would require the contractor to locate and buy the existing stove of another homeowner. Reduction in the inventory of stoves would be achieved by requiring more than one stove to be retired per new installation. This variation would almost certainly require a registration or permit system for existing stoves to be enforceable.

The short-term effectiveness of this measure is low, as the turnover of wood stoves built before 1992 is very slow. Changeover to newer units could be accelerated with a wood stove change-out program.

As discussed above, this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such measure would have to be implemented by the State, in the face of opposition from the local community would not be practically enforceable. Since the measure has been

recently defeated in October 2014. This information became available after the preparation of this document, there is insufficient time to prepare revisions and meet the schedule for delivering the SIP to EPA by the end of 2014. Moreover, the Borough has not had time to make decisions about any additional control measures to be implemented in the wake of the vote.

This control measure is not technologically feasible.

Subsidize woodstove change outs

FNSB has a SFBA change out program. Qualifying residents can be reimbursed for replacing, removing, or repairing solid fuel burning devices (wood and coal-stoves, wood and coal-fired furnaces, hydronic heaters, fireplace inserts, etc.). FNSB offers reimbursement of 100% of the cost (up to $4,000) of a new certified wood stove. There is also a bounty program for dismantling an old device without replacement.

This control measure is technologically feasible.

Discourage the resale of used stoves through taxes, fees, or other disincentives

This control measure would impose a financial penalty on the sale of a used stove to another user. This measure could apply to all sales of used stoves, or limited to uncertified stoves. There is little environmental benefit to discouraging the sale of a used certified stove; most of the incremental benefit of stove changeout is the difference between uncertified and certified stove emissions.

Enforcement of this measure would be much more difficult than enforcement of the requirement that all new stoves be certified. Enforcement of the latter measure requires that vendors be monitored. Enforcement of a penalty on resale would require that transactions involving individual sellers be monitored. This, in turn, might be addressed using a permit or registration system for stove owners.

The short-term effectiveness of this measure is low, as the turnover of wood stoves built before 1992 is very slow.

As discussed above, this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such measure would have to be implemented by the State, in the face of opposition from the local community would not be practically enforceable. Since the measure has been recently defeated in October 2014[46]. This information became available after the preparation of this document, there is insufficient time to prepare revisions and meet the schedule for delivering the SIP to EPA by the end of 2014. Moreover, the Borough has

[46] 51.57% to 48.43%. *Election Summary Report, 2014 Regular Election,* October 30, 2014

not had time to make decisions about any additional control measures to be implemented in the wake of the vote.

This control measure is not technologically feasible at this time.

Ban on all use

A ban on the use of woodstoves would require those with access to alternate heat sources to use them. Unless an exemption were offered, those with no alternate heat source would be required to install one. As discussed above, on very cold days some residences with alternate heat sources find those sources to be inadequate, and need to supplement with heat from wood combustion.

An enforcement mechanism is required to implement this measure. The mechanism would need to be much larger than needed to enforce a ban on hydronic heaters, due to the larger number of stoves and the fact that stoves are less conspicuous. Such a mechanism does not currently exist.

This control measure is not technologically feasible.

Incentive program: use stove change outs to generate New Source Review (NSR) offsets

Incentive programs provide cash incentives to equipment owners to retire or replace old, dirty equipment. Proposals for incentive programs focus on the source of funds, the amount of subsidy per transaction, and the amount of funds available.

This measure would allow applicants for new major industrial sources to obtain emission offsets by funding stove change outs. Emissions from woodstoves would be reduced, and some fraction of the reduction would be made available to offset emissions from the new industrial source.

Based upon discussions with Alaska DEC permitting staff, the likelihood of an industrial project in FNSB triggering PM offset requirements is small. Because no projects have been proposed that might find this option useful, no reductions will occur in the four years following designation.

This measure is not technologically feasible.

5.7.3.5. Residential Wood Burning: Fireplaces

The number of units in FNSB has been estimated[47] at about 1,275; 610 (48%) do not have inserts; 234 (18%) have uncertified inserts; 245 (19%) are EPA-certified non-catalytic units; 160 (13%) are EPA-certified catalytic units; and 24 (2%) are pellet-burning inserts.

[47] Sierra Research, projected 2015 (attainment year) inventory based on 2011 home heating survey

Education and Outreach

The State of Alaska and the FNSB have significant experience in educational programs that help citizens reduce their emissions.[48] The agencies publish a brochure, *Split Stack Store and Save!*, that encourages the use of only dry wood, explains methods for ensuring that wood is dry (seasoning after cutting,), and explains some of the benefits (less wood needed, cleaner burning). EPA publishes a similar brochure, *Wet Wood is a Waste,* as part of its Burn Wise program. Burn Wise materials are also available from the FNSB and Alaska DEC. Because it involves voluntary efforts on the part of the public, and is implemented as a State program, community resistance to the FNSB and Alaska DEC outreach programs has been minimal.

Examples of other elements that may be included as part of this control measure include:

- Making free or inexpensive wood moisture sensors to consumers
- Use wood sellers to distribute outreach materials (either voluntary or required)
- Use wood burning appliance vendors to distribute outreach materials
- Use agency resources to distribute outreach materials
- Make information available to consumers
    - Advantages to burning dry wood
    - How to tell if wood is dry
    - How to dry wood
    - Restrictions on burning (no burn days)
    - How to improve operation and maintenance
    - Use a certified installer
    - Resources for more information

Overall effectiveness of voluntary measures as an emission reduction measure depends upon the extent of implementation, as well as the actual steps taken by the public. Education and outreach measures can reduce opposition to future efforts to implement mandatory measures.

This control measure is technologically feasible.

Voluntary curtailment on air quality advisory days

Under a voluntary curtailment program, owners of wood burning devices are asked to voluntarily reduce or avoid operation of the devices on days when air quality is poor. Such a program relies on agency efforts to predict poor air quality days, agency efforts to make the public aware of predictions, agency efforts to educate the public about reducing emissions, and public cooperation with requests to minimize emissions.

The FNSB Air Quality Division provides daily air quality information on its website and by telephone. Alaska DEC also provides air quality advisories when circumstances call for them.

[48] As discussed in the introduction to this Section.

In February 2014, the FNSB adopted an ordinance[49] to create a voluntary burn cessation program with the following elements:

- Provide incentives (sign-up bonus, yard sign, or other form of public acknowledgment) to households that agree to voluntarily avoid use of wood-burning appliances during air quality advisories.

- Establish methods, such as automated phone calls, to notify participants when an advisory is called.

- Allow the Borough to contract with an agency to promote the program.

This program is technologically feasible.

Mandatory curtailment on air quality advisory days

Mandatory curtailment on air quality advisory days would prohibit use of some fireplaces. This prohibition could be implemented to affect all fireplaces, or only those that do not meet EPA certification standards (e.g., certified inserts; chimney abatement systems). An exemption from the ban for units that are the sole source of a residence's space heating would be included in either case.

State law currently prohibits the operation of wood-fired heating devices on episode days:

> *18 AAC 50.075 (b) A person may not operate a wood-fired heating device in an area for which the department has declared an air quality episode under 18 AAC 50.245.*

The criteria for declaring an air quality episode do not currently include $PM_{2.5}$ concentrations. Alaska DEC has proposed[50] to revise the criteria for declaring an air quality episode to include $PM_{2.5}$, but at a concentration well above the federal standard. At the same time, Alaska DEC proposed a revision to Section 50.075 to give the agency discretion about declaring an episode. The revision would benefit public health by reducing $PM_{2.5}$ concentrations on the worst episode days. However, because the proposed threshold for calling an advisory is well above the federal standard, this revision will not result in emission reductions on many violation days, and therefore will not contribute to attainment in FNSB.

This control measure is not technologically feasible.

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[49] http://co.fairbanks.ak.us/meetings/ordinances/2014/2014-11.pdf

[50] Alaska DEC, *Proposed Regulation changes Pertaining to: Open Burning, Wood-fired Heating Device Visible Emission Standards, Solid Fuel-Fired Heating Device Fuels, Wood Fired Heating Device Standards, & Fine Particulate Matter (PM-2.5) Air Episode and Advisories, Public Review Draft*, September 19, 2013.

Subsidize fireplace insert change outs

FNSB has an SFBA change out program. Qualifying residents can be reimbursed for replacing, removing, or repairing solid fuel burning devices (wood and coal-stoves, wood and coal-fired furnaces, hydronic heaters, fireplace inserts, etc.). FNSB offers reimbursement of 100% of the cost (up to $4,000) of a new certified fireplace insert. There is also a bounty program for dismantling an old device without replacement.

This control measure is technologically feasible.

5.7.3.6. Residential Wood Burning: Burn Barrels, Open Burning

Reinstate seasonal open burning ban

Open burning is currently banned between November 1 and March 31 in Wood Smoke Control Areas (18 AAC 50.065(f)). FNSB is not currently a Wood Smoke Control Area. Alaska DEC has proposed adding $PM_{2.5}$ non-attainment areas to the areas covered by this regulation as a proactive measure to prevent additional smoke during winter months.[51]

Alaska DEC's regulation 18 AAC 50.065(e) prohibits open burning during an air quality advisory. Advisories are called when $PM_{2.5}$ concentrations above 35 micrograms per cubic meter are predicted.

Since the 1970s, the Fairbanks North Star Borough had an ordinance to restrict wintertime open burning. In 2013, the Borough Assembly repealed that ordinance in response to a voter initiative that restricted the Borough's authority to regulate fuel burning.

Although the voters of FNSB have clearly indicated opposition to local regulations affecting home heating, there is no indication of similar widespread opposition to the FNSB's historical open burning control program.

The cost of such a program is the increased administrative cost of enforcing the ban. Most of this cost can be recovered through fines imposed on violators.

This control measure is technologically feasible.

Burn barrel prohibition

Although the voters of FNSB have clearly indicated opposition to local regulations affecting home heating, there is no indication of similar widespread opposition to the

[51] Alaska DEC, *Proposed Regulation changes Pertaining to: Open Burning, Wood-fired Heating Device Visible Emission Standards, Solid Fuel-Fired Heating Device Fuels, Wood Fired Heating Device Standards, & Fine Particulate Matter (PM-2.5) Air Episode and Advisories, Public Review Draft*, September 19, 2013.

FNSB's historical open burning control program. Burn barrels are used by some residents to dispose of combustible waste, not to provide useful heat.

Many states and localities ban the use of burn barrels, mostly because these devices are prone to creating a nuisance. If used only to burn clean, dry wood, they can be operated in a smokeless, odor-free manner. Combustion of almost any other materials will result in both smoke and odors.

Burn barrels are covered by the State's open burning regulation, which bans open burning between November 1 and March 31 in Wood Smoke Control Areas (18 AAC 50.065(f)). FNSB is not currently a Wood Smoke Control Area. Alaska DEC has proposed adding $PM_{2.5}$ nonattainment areas to the areas covered by this regulation as a proactive measure to prevent additional smoke during winter months.[52]

Alaska DEC's regulation 18 AAC 50.065(e) also prohibits open burning during an air quality advisory. Advisories are called when $PM_{2.5}$ concentrations above 35 micrograms per cubic meter are predicted.

This control measure is technologically feasible.

5.7.3.7. Residential Fuel Oil

The number of units in FNSB has been estimated at about 27,000.[53] Direct $PM_{2.5}$ emissions from fuel oil combustion in residential heaters are estimated to be 42 tons per year.[54] Additionally, fuel oil combustion contributes to secondary particulate formation because virtually all (99%) of the sulfur in fuel oil is oxidized to SO_2 when combusted, and a portion of the SO_2 reacts to form sulfate aerosols, a form of $PM_{2.5}$. SOx emissions from fuel oil combustion are estimated to be about 770 tons per year,[55] equivalent to 130 tons per year of direct $PM_{2.5}$ emissions.

Economic incentives to switch to low sulfur fuel

The most effective strategy for reducing SO_2 emissions from residential oil use is lowering the sulfur content of heating oil. Currently in the U.S. (and in the FNSB),

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[52] Alaska DEC, *Proposed Regulation changes Pertaining to: Open Burning, Wood-fired Heating Device Visible Emission Standards, Solid Fuel-Fired Heating Device Fuels, Wood Fired Heating Device Standards, & Fine Particulate Matter (PM-2.5) Air Episode and Advisories, Public Review Draft*, September 19, 2013.

[53] Sierra Research, projected 2015 (attainment year) inventory based on 2011 home heating survey

[54] Cold Climate Housing Research Center, *Reducing PM2.5 Emissions from Residential Heating Sources in the Fairbanks North Star Borough*, February 23, 2009. p. 15.

[55] Cold Climate Housing Research Center, *Reducing PM2.5 Emissions from Residential Heating Sources in the Fairbanks North Star Borough*, February 23, 2009. p. 15. SOx emissions are calculated by dividing the reported sulfate formation (232 TPY) by the assumed conversion rate (30%).

heating oil for residential use has an average sulfur content of about 0.20–0.25% (about 2,500 ppm). Switching to low sulfur content fuel (500 ppm) could eliminate 75–80% of the SO_2 emissions generated by residential oil heating systems, as well as 80% of direct $PM_{2.5}$ emissions.

The American Society for Testing and Materials (ASTM), an international voluntary standards development organization, has approved a Low-Sulfur No. 2 Heating Oil specification. Also, the Oilheat Manufacturers Association has been promoting low-sulfur heating oil, both to improve air quality and to reduce equipment maintenance costs. Low-sulfur heating oil reduces the level of residue build-up on the surfaces of boilers and furnaces, improving equipment performance and reducing maintenance costs.

The control measure would consist of providing an economic incentive (in the form of a cash rebate[56]) to consumers to purchase low-sulfur fuel oil instead of their current supply. Because participation in the program would be voluntary, it would not conflict with the fuel regulation ban in the Home Heating Initiative.

This control measure is technologically feasible.

5.7.3.8. District Heating System

Many residential, commercial, and institutional buildings within the FNSB are connected to district heating systems that supply low pressure steam or hot water for space heating and domestic hot water use. Use of the district heating systems allows for the widespread use of energy produced by a central steam generating unit that is well controlled. These systems essentially eliminate the need for the operation of individual fuel combustion units by the facilities connected to them.

Even considering transmission losses, a well maintained and operated central unit can be much more efficient that individual combustion units, especially those that burn wood, coal, or oil. Pollutants from a central unit are emitted at a much higher elevation, and as a result are more dispersed.

Increased usage/coverage of district heating systems

Individual combustion units—especially those that burn wood, coal, or oil—are often much less efficient than a well maintained and operated central power plant. Individual combustion units also produce pollutants that are emitted to the atmosphere very near ground level, rather than from tall stacks. Because of the difference in release points, pollutants from individual combustion units have a greater impact on ground-level $PM_{2.5}$ concentrations.

[56] Because Alaska has no state income or sales tax, a tax credit or exemption would not work as a mechanism for implementing this program. A property tax offset is another possible mechanism, but would not be available to renters.

An increase in the coverage of the district heating systems would therefore result in a decrease in measured $PM_{2.5}$ concentrations.

This control measure is technologically feasible.

5.7.3.9. Energy Efficiency and Weatherization

Home Improvement Rebate Program

EPA recognizes the benefits of including energy efficiency programs in SIPs as a low cost means of reducing emissions.

The Alaska Housing Finance Corporation (AHFC) implements several energy programs that are designed to make homes more energy efficient. As homeowners make energy efficiency improvements, they reduce the amount of fuel and electricity needed for power and heat, leading to corresponding air quality benefits due to the reduced fuels being burned for space heating and power generation.

This control measure is technologically feasible and already implemented.

5.7.3.10. Transportation

Listed below are the transportation-related programs currently being implemented in Fairbanks.

- Expanded availability of plug-ins; electrical outlets were installed on 1,500+ parking spaces between 2008 & 2015
- Ordinance mandating—for employers with 275+ parking spaces—electrification of outlets at temps < 21° F between November 1 and March 31
- Public education focused on the benefits of plugging-in and using the transit program called Metropolitan Area Commuter System (MACS)
- Expanded transit service includes improved service frequency on high ridership routes, new routes and better bus stop facilities; ridership increased 61% between 2008 & 2013
- Commuter Van Pool program, includes Van Tran program for elderly and disabled
- Anti-idling program for heavy-duty diesel vehicles started as a ADOT&PF program focused on dump trucks and tractors and has been expanded to a CMAQ-funded pilot program focused on the purchase and installation of auxiliary heaters to reduce idle time
- Federal Motor Vehicle Control Program

With the exception of the anti-idling program, the programs listed above have been in place for well over a decade and are working to reduce motor vehicle emissions under extreme winter operating conditions.

Measures focused on reducing traffic congestion offer limited benefits as the Fairbanks road network has few roads operating at Level of Service (LOS) levels D, E, or F.

Community-wide ridesharing programs offer few potential emission reduction benefits because of the low population and employment density in the nonattainment area (employer programs are operated where sufficient density supports participation).

Travel reduction programs have been found to have limited benefits on a national basis, with principal reductions coming from commute trips, which require high density employment to be successful.

EPA's motor vehicle emissions model MOVES, including the recently released version MOVES2014, does not provide a PM benefit for either light- or heavy-duty I/M programs. Thus, there is no way to quantify a particulate benefit from I/M, and EPA clearly does not recognize I/M as an appropriate PM control measure.

Given these constraints, no additional TCMs appear viable for Fairbanks. Because TCMs are not expected to provide additional reductions, all TCMs are classified as "not technologically feasible."

5.7.3.11. Measures Deemed Technologically Infeasible

A summary of the assessment of technological feasibility for candidate control measures is presented below in Table 5.7-6. It shows that a number of candidate control measures are not technologically feasible at this time: two of those—construction of regional kilns and use of stove change outs to generate NSR credits—are not feasible because there is no evidence of demand, so no emission reductions are expected; the remainder are infeasible because they are not practically enforceable in the Borough at this time.

Table 5.7-6. Candidate Control Measures Considered for RACM

Source Category	Control Measure	Technologically Feasible?	
Dry Wood Measures	Education and Outreach	Yes	
	Regional kiln		No
	Ban on green wood sales		No
Hydronic Heaters	Education and Outreach	Yes	
	Voluntary curtailment on air quality advisory days	Yes	
	Mandatory curtailment on air quality advisory		No

Source Category	Control Measure	Technologically Feasible?	
	days		
	All new units must be certified	Yes	
	All new units must meet more stringent standards	Yes	
	All units must be certified		No
	Ban new installations		No
	Remove at time of home sale		No
	Subsidize heater change outs	Yes	
	Ban use		No
Wood Stoves	Education and Outreach	Yes	
	Voluntary curtailment on air quality advisory days	Yes	
	Mandatory curtailment on air quality advisory days		No
	All new units must be certified	Yes	
	All new units must meet more stringent standards	Yes	
	All units must be certified		No
	Replace uncertified stoves at time of home sale		No
	Replace uncertified stoves at time of significant remodeling		No
	Replace uncertified stoves in rental units		No
	Require alternate heat source in rental units		No
	Require alternate heat source in new construction		No
	Ban new installations		No
	Subsidize stove change outs	Yes	
	Disincentive to sell used stoves		No
	Ban use		No
	Use stove change outs to generate NSR offsets		No
Fireplaces/Fireplace Inserts	Education and Outreach	Yes	
	Voluntary curtailment on air quality advisory days	Yes	
	Mandatory curtailment on air quality advisory days		No
	Subsidize fireplace insert change outs	Yes	
Open Burning	Reinstate open burning ban	Yes	
Burn Barrel	Prohibit use of burn barrels (seasonal or year-round)	Yes	
Residential Fuel Oil	Provide economic incentives to switch to low-	Yes	

Source Category	Control Measure	Technologically Feasible?	
Combustion	sulfur fuel		
	Increase coverage of District heating systems	Yes	
Energy Efficiency Measures	Subsidize heating upgrades and weatherization	Yes	
Transportation	Improved public transit	Yes	
	HOV lanes		No
	Traffic flow improvement programs		No
	Create non-motorized traffic zones		No
	Restrict truck idling	Yes	
	Reduce cold start emissions	Yes	
	Employer-sponsored flexible work schedules		No
	Retrofit diesel fleet (school buses, transit fleets)		No
	Onroad vehicle I&M program		No
	Heavy-duty vehicle I&M program		No
	State LEV Program		No

5.7.4. STEP 3: EVALUATE EMISSION REDUCTIONS AND COSTS FOR EACH TECHNOLOGICALLY FEASIBLE CONTROL MEASURE

In this section, technologically feasible control measures are evaluated for emission benefits and cost effectiveness. Measures with negligible potential for emission reductions were screened out in previous steps.

The process used to evaluate the economic feasibility of candidate control measures is outlined below. Some of the control measures determined to be RACM in this analysis are already implemented in the FNSB. Because the economic feasibility of these measures does not need to be established, a qualitative analysis has been performed.

1. **For each technologically feasible emission control technology or measure**, provide best estimates of the following:

    a. the control efficiency by pollutant;
    b. the possible emission reductions by pollutant;
    c. the estimated cost per ton of pollutant reduced; and
    d. the date by which the technology or measure could be reasonably implemented.

2. Determine if any technologically feasible control measures are economically infeasible:

a. Consider the cost of reducing emissions and the difference between the cost of an emissions reduction measure at a particular source and the cost of emissions reduction measures that have been implemented at other similar sources.

b. Economic feasibility of RACM/RACT is thus largely determined by evidence that other sources in a source category have in fact applied the control technology, process change, or measure in question.

c. For each technologically feasible control measure or technology, a state must determine the capital costs, annualized costs, and cost effectiveness (i.e., cost per ton of pollutant reduced by that measure or technology).[57]

d. A state may not reject a technologically feasible control measure or technology as being economically infeasible if such a measure or technology has been implemented at other similar sources, unless the state provides a detailed justification that clearly explains the specific circumstances of the source or sources in the nonattainment area that make such a measure or technology economically infeasible.

Table 5.7-7 presents the list of candidate control measures that were determined to be technologically feasible.

Table 5.7-7. Technologically Feasible Control Measures

Source Category	Control Measure	Economically Feasible?	RACM?	Potential Implementation Date
Dry Wood Measures	Education and Outreach	Yes	RACM	Already in place
Hydronic Heaters	Education and Outreach	Yes	RACM	Already in place
	Voluntary curtailment on air quality advisory days	Yes	RACM	1st Qtr 2016
	All new units must be certified to more stringent standards	Yes	RACM	1st Qtr 2016
	Subsidize heater change outs	Yes	RACM	Already in place

[57] Note that this is not a cost/benefit analyis. The health benefits (reduction in number of premature deaths and/or avoided health costs) are not quantified or considered in this analysis.

Source Category	Control Measure	Economically Feasible?	RACM?	Potential Implementation Date
Wood Stoves	Education and Outreach	Yes	RACM	Already in place
	Voluntary curtailment on air quality advisory days	Yes	RACM	Already in place
	All new units must be certified	Yes	RACM	1st Qtr 2016
	Subsidize stove change outs	Yes	RACM	Already in place
Fireplaces/Fireplace Inserts	Education and Outreach	Yes	RACM	Already in place
	Voluntary curtailment on air quality advisory days	Yes	RACM	Already in place
	Subsidize fireplace insert change outs	Yes	RACM	Already in place
Open Burning	Reinstate open burning ban	Yes	RACM	1st Qtr 2016
Burn Barrel	Prohibit use of burn barrels (seasonal or year-round)	Yes	RACM	1st Qtr 2016
Residential Fuel Oil Combustion	Provide economic incentives to switch to low-sulfur fuel	No	No	Not cost effective
	Increase coverage of District heating systems	No	No	Not cost effective
Energy Efficiency Measures	Subsidize heating upgrades and weatherization	Yes	RACM	Already in place
Transportation	Improved Public Transit	Yes	RACM	Already in place
	Restrict Truck Idling	Yes	RACM	Already in place
	Reduce Cold Start Emissions	Yes	RACM	Already in place

5.7.4.1. Dry Wood Programs

As shown in Table 5.7-2, residential wood combustion in Fairbanks is responsible for 2.72 tons per day, or 60% of total direct $PM_{2.5}$ emissions on episode days. About 60% of the wood burned in residential wood combustion units is green wood, on a volume basis.[58] According to a 2008 NESCAUM report, for every 10 percentage point increase in the moisture content of wood the $PM_{2.5}$ emissions increase by 65% to 167%.[59] If dry wood (20% moisture content) is burned instead of all of the wet wood, a reduction of between 1.2 and 1.8 ton/day of $PM_{2.5}$ could result.

Education and Outreach

The overall effectiveness of voluntary measures depends upon the extent of implementation, as well as the actual steps taken by the public. Actual quantification of emission reduction is difficult to do. However, these programs are considered pivotal to the acceptance of any wood smoke control program.[60]

Costs associated with this measure are small. Costs include the cost to the State and/or Borough to develop educational materials (small, because educational materials for this purpose have already been developed) and the cost to homeowners to store wood for a season. (In order to have dry wood all year, a full year's supply of wood would need to be purchased at least six months before it is to be used, and split and stored in a manner that would allow it to dry. The average amount of wood burned per year in Fairbanks is 3.57 cords/year per household,[61] which would require 460 cubic feet of storage. Although construction of this much storage would not be a trivial expense, the cost would go down after the first year by as much as 30% because less dry wood is needed for the same useful heat production.[62])

- Control efficiency by pollutant: N/A

[58] Based on a 2011 sample of 20 households, 40% of the households sampled had moisture contents at or below 20%.
[59] NESCAUM, *Source Characterization of Outdoor Wood Furnaces,* September 9, 2008, p. 4-1
[60] Hearth, Patio and Barbecue Association, *Clearing the Smoke: The Wood Stove Changeout in Libby, Montana*, January 2008, p. 20; see also Canadian Council of Ministers of the Environment, Code of Practice for Residential Wood Burning Applicances, 2012, p. 28.
[61] A 2011 home heating survey (Sierra Research, June 10, 2011) indicated an average wood fuel use of 3.57 cords/year per installation for stoves and inserts, and 1.80 cords/year for fireplaces.
[62] Useful heat energy from a typical wood fuel is 5,000 btu/lb at 20% moisture, and 3,500 btu/lb at 40% moisture (the difference is due to the heat required to evaporate the extra water). The fuel savings due to burning dry wood (20% moisture) is 30% [(5,000-3,500)/5,000].

- Possible emission reductions by pollutant: Potentially large. However, EPA guidance allows only a small amount of SIP credit for voluntary measures.

- Estimated cost per ton of pollutant reduced: small

- Date by which the measure could be reasonably implemented: already implemented

This measure is economically feasible.

5.7.4.2. Residential Wood Burning: Outdoor Wood-burning Boilers (hydronic heater)

Education and Outreach

Overall effectiveness of voluntary measures depends upon the extent of implementation, as well as the actual steps taken by the public. Costs associated with this measure are small. Costs include the cost to the State and/or Borough to develop educational materials (small, because educational materials for this purpose have already been developed).

- Control efficiency by pollutant: N/A

- Possible emission reductions by pollutant: Potentially large. However, EPA guidance allows only a small amount of SIP credit for voluntary measures.

- Estimated cost per ton of pollutant reduced: small

- Date by which the measure could be reasonably implemented: already implemented

This measure is economically feasible.

Voluntary curtailment on air quality advisory days

Under a voluntary curtailment program, owners of wood burning devices are asked to voluntarily reduce or avoid operation of the devices on days when air quality is poor. Such a program relies on agency efforts to predict poor air quality days, agency efforts to make the public aware of predictions, agency efforts to educate the public about reducing emissions, and public cooperation with requests to minimize emissions.

The FNSB Air Quality Division provides daily air quality information on its website and by telephone. Alaska DEC also provides air quality advisories when circumstances call for them

Under this control measure, the agencies will develop and distribute additional educational materials. They will increase efforts to publicize the program, beginning

with links on the existing Air Quality Index webpages to the FNSB's existing AQ Advisory program webpages.

- Control efficiency by pollutant: N/A
- Possible emission reductions by pollutant: Potentially large. However, EPA guidance allows only a small amount of SIP credit for voluntary measures.
- Estimated cost per ton of pollutant reduced: not estimated because already implemented
- Date by which the measure could be reasonably implemented: 1st Qtr 2016

This measure is economically feasible.

All new units must meet 2.5 gm/hr

This control measure reduces the rate of growth of emissions due to the increased number of installations by minimizing the emissions from new equipment. In addition, it reduces emissions as old units are retired and replaced by new ones.

Because of the small rate of projected growth, and the low rate of replacement of old units, emission reductions from this measure are small. Cost of control is also small, because there is no incremental cost between a certified unit and a non-certified unit.

Alaska DEC has proposed[63] to adopt a new regulation, 18 AAC 50.077(b)(2), that would require that all new woodstoves meet an emission limit of 2.5 gm/hr and be certified by EPA.

- Control efficiency by pollutant: small
- Possible emission reductions by pollutant: small.
- Estimated cost per ton of pollutant reduced: small
- Date by which the measure could be reasonably implemented: 1st Qtr 2016

This measure is economically feasible.

Subsidize hydronic heater change outs

The FNSB's hydronic heater change out program is a voluntary program initiated by FNSB to promote the use of cleaner-burning heating appliances. It uses a cash rebate, combined with public outreach and education, to encourage consumers to replace their

[63] Alaska DEC, *Proposed Regulation changes Pertaining to: Open Burning, Wood-fired Heating Device Visible Emission Standards, Solid Fuel-Fired Heating Device Fuels, Wood Fired Heating Device Standards, & Fine Particulate Matter (PM-2.5) Air Episode and Advisories, Public Review Draft*, September 19, 2013.

old, inefficient, and high-polluting woodstoves with new clean-burning EPA-certified woodstoves, or other heating appliances such as pellet stoves or gas/electric stoves.[64] EPA has provided estimates of control effectiveness and costs for such a program.[65] These are summarized below.

- Control efficiency by pollutant: 60%
- Possible emission reductions by pollutant: small
- Estimated cost per ton of pollutant reduced: $10,000
- Date by which the measure could be reasonably implemented: already implemented

This measure is economically feasible.

5.7.4.3. Residential Wood Burning: Wood Stoves

Education and Outreach

Overall effectiveness of voluntary measures depends upon the extent of implementation, as well as the actual steps taken by the public. Costs associated with this measure are small. Costs include the cost to the State and/or Borough to develop educational materials (small, because educational materials for this purpose have already been developed).

- Control efficiency by pollutant: N/A
- Possible emission reductions by pollutant: Potentially large. However, EPA guidance allows only a small amount of SIP credit for voluntary measures.
- Estimated cost per ton of pollutant reduced: small
- Date by which the measure could be reasonably implemented: already implemented

This measure is economically feasible.

Voluntary curtailment on air quality advisory or alert days

Under a voluntary curtailment program, owners of wood-burning devices are asked to voluntarily reduce or avoid operation of the devices on days when air quality is poor. Such a program relies on agency efforts to predict poor air quality days, agency efforts to make the public aware of predictions, agency efforts to educate the public about reducing emissions, and public cooperation with requests to minimize emissions.

[64] Guidance for Quantifying and Using Emission Reductions from Voluntary Woodstove Changeout Programs in State Implementation Plans.
[65] EPA, *Menu of Control Measures* (8/6/2013), p. 52

The FNSB Air Quality Division provides daily air quality information on its website and by telephone. Alaska DEC also provides air quality advisories when circumstances call for them. Advisories are called when $PM_{2.5}$ concentrations above 35 micrograms per cubic meter are predicted.

Under this control measure, the agencies will develop additional educational materials. They will increase efforts to publicize the program, beginning with links on the existing Air Quality Index webpages to the FNSB's existing AQ Advisory program webpages.

- Control efficiency by pollutant: N/A
- Possible emission reductions by pollutant: Potentially large. However, EPA guidance allows only a small amount of SIP credit for voluntary measures.
- Estimated cost per ton of pollutant reduced: small
- Date by which the measure could be reasonably implemented: already implemented

This measure is economically feasible.

Only certified stoves may be sold

This control measure reduces the rate of growth of emissions due to the increased number of installations by minimizing the emissions from new equipment. In addition, it reduces emissions as old units are retired and replaced by new ones.

Because of the small rate of projected growth, and the low rate of replacement of old units, emission reductions from this measure are small. Cost of control is also small, because there is no incremental cost between a certified unit and a non-certified unit.[66]

Alaska DEC has proposed[67] to adopt a new regulation, 18 AAC 50.077(b)(2), that would require that all new woodstoves meet an emission limit of 2.5 gm/hr and be certified by EPA.

- Control efficiency by pollutant: small
- Possible emission reductions by pollutant: small.
- Estimated cost per ton of pollutant reduced: small
- Date by which the measure could be reasonably implemented: 1st Qtr 2016

This measure is economically feasible.

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[66] An analysis of the 2012 List of EPA Certified Wood Stoves shows there is essentially no correlation between retail price and the EPA certification emission rate, with a R2 of 0.023. The List was accessed at (www.lrapa.org/downloads/publications/**certifiedwood**.pdf *)*

[67] Alaska DEC, *Proposed Regulation changes Pertaining to: Open Burning, Wood-fired Heating Device Visible Emission Standards, Solid Fuel-Fired Heating Device Fuels, Wood Fired Heating Device Standards, & Fine Particulate Matter (PM-2.5) Air Episode and Advisories, Public Review Draft*, September 19, 2013.

Subsidize stove change outs

The FNSB's woodstove change out program is a voluntary program initiated by FNSB to promote the use of cleaner-burning heating appliances. It uses a cash rebate, combined with public outreach and education, to encourage consumers to replace their old, inefficient, and high-polluting woodstoves with new clean-burning EPA-certified woodstoves, or other heating appliances such as pellet stoves or gas/electric stoves.[68] EPA[69] has provided estimates of control effectiveness and costs for such a program, as summarized below.

- Control efficiency by pollutant: 60%
- Possible emission reductions by pollutant: small
- Estimated cost per ton of pollutant reduced: $9,900 (2010$)
- Date by which the measure could be reasonably implemented: already implemented

This measure is economically feasible.

5.7.4.4. Residential Wood Burning: Fireplaces

Education and Outreach

Overall effectiveness of voluntary measures depends upon the extent of implementation, as well as the actual steps taken by the public. Costs associated with this measure are small. Costs include the cost to the State and/or Borough to develop educational materials (small, because educational materials for this purpose have already been developed).

- Control efficiency by pollutant: N/A
- Possible emission reductions by pollutant: Potentially large. However, EPA guidance allows only a small amount of SIP credit for voluntary measures.
- Estimated cost per ton of pollutant reduced: small
- Date by which the measure could be reasonably implemented: already implemented

This measure is economically feasible.

[68] Guidance for Quantifying and Using Emission Reductions from Voluntary Woodstove Changeout Programs in State Implementation Plans.
[69] EPA, *Menu of Control Measures* (8/6/2013), p. 52

Voluntary curtailment on air quality advisory days

Under a voluntary curtailment program, owners of wood burning devices are asked to voluntarily reduce or avoid operation of the devices on days when air quality is poor. Such a program relies on agency efforts to predict poor air quality days, agency efforts to make the public aware of predictions, agency efforts to educate the public about reducing emissions, and public cooperation with requests to minimize emissions.

The FNSB Air Quality Division provides daily air quality information on its website and by telephone. Alaska DEC also provides air quality advisories when circumstances call for them. Advisories are called when $PM_{2.5}$ concentrations above 35 micrograms per cubic meter are predicted.

Under this control measure, the agencies will develop additional educational materials. They will increase efforts to publicize the program, beginning with links on the existing Air Quality Index webpages to the FNSB's existing AQ Advisory program webpages.

- Control efficiency by pollutant: N/A
- Possible emission reductions by pollutant: Potentially large. However, EPA guidance allows only a small amount of SIP credit for voluntary measures.
- Estimated cost per ton of pollutant reduced: small
- Date by which the measure could be reasonably implemented: already implemented

This measure is economically feasible.

Subsidize fireplace insert change outs

The FNSB's fireplace change out program is a voluntary program initiated by FNSB to promote the use of cleaner-burning heating appliances. It uses a cash rebate, combined with public outreach and education, to encourage consumers to retrofit fireplaces with devices that reduce emissions.

EPA[70] has provided estimates of control effectiveness and costs for such a program, as summarized below.

- Control efficiency by pollutant: 70%
- Possible emission reductions by pollutant: small
- Estimated cost per ton of pollutant reduced: $9,500 (2012$)
- Date by which the measure could be reasonably implemented: already implemented

[70] EPA, *Menu of Control Measures* (8/6/2013), p. 43

This measure is economically feasible.

5.7.4.5. Residential Wood Burning: Burn barrels, open burning

Open burning (including the use of burn barrels) is currently banned between November 1 and March 31 in Wood Smoke Control Areas (18 AAC 50.065(f)). FNSB is not currently a Wood Smoke Control Area. Alaska DEC has proposed adding $PM_{2.5}$ nonattainment areas to the areas covered by this regulation as a proactive measure to prevent additional smoke during winter months.[71]

Alaska DEC's regulation 18 AAC 50.065(e) prohibits open burning (including the use of burn barrels) during an air quality advisory. Advisories are called when $PM_{2.5}$ concentrations above 35 micrograms per cubic meter are predicted.

Open burning ban

Open burning is not considered a large contributor to air pollution episodes. However, a ban on open burning on air quality advisory days could prevent such activities from contributing to unhealthful air, and is relatively inexpensive to implement. Because the expected reductions are small and variable, they are difficult to quantify.

- Control efficiency by pollutant: N/A
- Possible emission reductions by pollutant: small
- Estimated cost per ton of pollutant reduced: small
- Date by which the measure could be reasonably implemented: 1st Qtr 2016

This measure is economically feasible.

Burn barrel prohibition

Burn barrels are not considered a large contributor to air pollution episodes. However, a ban on burn barrels could prevent such activities from contributing to unhealthful air, could avoid nuisance situations, and is relatively inexpensive to implement. Because the expected reductions are small and variable, they are difficult to quantify.

- Control efficiency by pollutant: N/A
- Possible emission reductions by pollutant: small
- Estimated cost per ton of pollutant reduced: small
- Date by which the measure could be reasonably implemented: 1st Qtr 2016

This measure is economically feasible.

[71] Alaska DEC, *Proposed Regulation changes Pertaining to: Open Burning, Wood-fired Heating Device Visible Emission Standards, Solid Fuel-Fired Heating Device Fuels, Wood Fired Heating Device Standards, & Fine Particulate Matter (PM-2.5) Air Episode and Advisories, Public Review Draft*, September 19, 2013.

5.7.4.6. Residential Fuel Oil

Economic incentives to switch to low sulfur fuel

The sulfur in fuel oil is emitted as SOx when the fuel is burned. SOx emissions contribute to the formation of secondary particulate matter in the form of sulfate aerosols. Ambient sampling and modeling in FNSB indicates that reduction of six tons of SOx emissions result in the same reduction in ambient $PM_{2.5}$ concentration as the reduction of one ton of directly emitted $PM_{2.5}$.[72] Additionally, fuel oil combustion contributes to secondary particulate formation because virtually all (99%) of the sulfur in fuel oil is oxidized to SO_2 when combusted, and a portion of the SO_2 reacts to form sulfate aerosols, a form of $PM_{2.5}$.

Reducing six tons of SOx emissions results in the same ambient PM concentration that would result from about a one ton reduction of directly emitted PM. SOx emissions from fuel oil combustion are estimated to be about 770 tons per year,[73] equivalent to 130 tons per year of direct $PM_{2.5}$ emissions.

Using low-sulfur fuel (500 ppm sulfur) instead of current fuel oil (2,000 ppm sulfur) would reduce SOx emissions from this source category by 1500/2000 = 75%, or 580 tons per year. This is equivalent to 96 tons per year of $PM_{2.5}$ reductions.

The incremental cost of low sulfur fuel oil is assumed to be $0.10 per gallon;[74] the resulting reduction in SO_2 emissions is 0.011 lb/gal. The cost effectiveness of control is therefore $0.10/0.011 lb of SO_2, or $18,000 per ton of SO_2. Because SO_2 reductions are 1/6 as effective as $PM_{2,5}$ reductions as a control measure, this is equivalent to more than $100,000 per ton of $PM_{2.5}$.

In addition to the increased cost of fuel, there are potentially capital costs involved in switching fuels as well. Because the physical characteristics of low-sulfur fuel oil are different, changes may be needed to storage, pumps, and burners to accommodate the new fuel.

- Control efficiency by pollutant: 75% reduction of SO_2
- Possible emission reductions by pollutant: 580 tons per year of SO_2
- Estimated cost per ton of pollutant reduced: $18,000
- Date by which the measure could be reasonably implemented: Not cost effective

This control measure is not cost effective, and is therefore not RACM.

[72] Appendix III.D.5.7 Precursors
[73] Ibid.
[74] Personal communication, Sourdough Fuel, October 2, 2014

5.7.4.7. District Heating System

Increased usage/coverage of district heating systems

The costs and benefits of potential increases in the coverage of the district heating systems are highly variable and depend on the number and types of individual combustion units replaced.

Aurora Energy operates a coal-fired power plant that cogenerates steam for heating use. Aurora Energy also provides district heating (in the form of low-pressure steam or hot water) to approximately 180 customers. Customers range in size from small residential to large commercial/institutional loads. In the last nine years, Aurora Energy has added 35 new district heat customers, with a total load of approximately 45 million btu/hr.

Aurora Energy has prepared a study of the feasibility of increasing the size of the district heat program by 210 MMBtu/hr, to serve an additional 1,989 individual buildings.[75] The increased cost associated with this measure is the capital cost of constructing the steam distribution infrastructure; no additional capital costs are needed for the heating plant. The total cost of the expanded distribution system and building conversions to hot water heat exchanger is estimated to be $238 million. The resulting cost per connection is estimated to be $120,000.

The average amount of wood used for home heating in a home that relies on a wood stove for home heating in Fairbanks is 3.57 cords/year.[76] The emission factor for burning air-dried wood in an uncertified wood stove is 20.3 lb $PM_{2.5}$ per cord. The emissions from each household would therefore average 72.5 lb/year. Over 30 years, the emissions would total 2175 lb, or 1.1 tons.

Even without taking into consideration increased emissions at the power plant, the cost effectiveness of this proposal would be no less than $120,000/1.1 tons, or $109,000/ton of $PM_{2.5}$.

This control measure is not cost effective.

5.7.4.8. Transportation

Improved Public Transit

While Fairbanks has expanded its transit service in recent years and continues to experience increased ridership, a review of the MOVES-based emission factors for transit buses and motor vehicles operating in Fairbanks conditions shows that PM and NOx

[75] PDC, Inc. Engineers, *Aurora Energy District Heat Capacity Study, Phase 2,* December 2008

[76] A 2011 home heating survey (Sierra Research, June 10, 2011) indicated an average wood fuel use of 3.57 cords/year per installation for stoves and inserts, and 1.80 cords/year for fireplaces.

emissions from buses are higher than passenger vehicles. Thus, new bus routes need to take enough passenger vehicles off the road to offset the emissions associated with increased bus operations. Information on the transit program operations obtained from the Borough[77] indicates that current average winter ridership over the entire transit system is 1,725 passengers per day at a cost of $16,370 per day (this cost includes the cost of both bus service operation and ADA-required para-transit services).[78] Using an estimated average trip length of 6.9 miles per trip replaced (i.e., for passenger vehicles trips), an average 1,800 miles of transit VMT per day, and 2014 MOVES-based emission factors, it is estimated that 1 lb of $PM_{2.5}$ is eliminated through transit operations each winter day service is provided (i.e., Monday through Saturday, transit service is not provided on Sundays). The cost per ton of this reduction is $32.7 million dollars.

The control measure is not cost effective.

Restrict Truck Idling

Alaska DEC recently received approval for a CMAQ program that is intended to reduce heavy-duty diesel emissions through anti-idling, maintenance, and other emission reduction opportunities. The focus of the program is to expand the use of auxiliary heaters to reduce idle time, thereby reducing emissions and providing an associated cost savings due to less diesel fuel needed. The program has the following elements:

- Provide support for the existing anti-idling pilot project currently underway at DOT in Fairbanks by assisting with Telemetric purchase and installation, installing additional heaters, and assisting with education and training. With assistance from this program, the DOT pilot program will be fully functional and will be able to provide additional information to assist in expanding anti-idling programs to others.

- Expand anti-idling to other heavy-duty vehicles within the FNSB nonattainment area: state fleets, local government fleets, private fleets, and commercial fleets. This includes working with the heavy-duty fleet owners by providing education material and training; contracting for installations of auxiliary heaters; and providing incentives for participation, including purchasing of heaters and auxiliary equipment.

- During installation of program auxiliary heaters, conduct an inspection of the vehicle to identify where implementation of additional emission reductions may be possible, such as maintenance (filter, tune-up), retrofit technologies or repower, and/or additional emission reduction equipment (particulate matter traps). Partnership and incentive opportunities with vehicle fleet owners will be explored to further emission reduction benefits while the vehicle is in shop.

[77] Email communication from Glenn Miller to Bob Dulla, October 7, 2014.
[78] *http://www.ecfr.gov/cgi-bin/text-idx?SID=3387a7533c3134e09c52ac1170a185d7&tpl=/ecfrbrowse/Title49/49tab_02.tp*l

CMAQ funding in the amount of $750,000 has been approved for the program, which will be implemented by Alaska DEC. While CMAQ funding will not support continued operation of a project, the bulk of the funding cover the cost of procurement and installation of equipment which can continue to operate after the project has ended.

This program is economically feasible.

Reduce Cold Start Emissions

The Borough recently received approval for CMAQ project funding that continues a long-standing practice of expanding the number of parking spaces in both public and private lots equipped with electrical outlets. This program will add a total of 975 outlets to four community facility parking lots.

CMAQ funding in the amount of $2,912,000 has been approved and the Borough will implement the program.

Since the project will cover the cost of the outlet installation and the Borough Plug-In Ordinance[79] requires parking lot owners with 275+ parking spaces to supply electricity to outlets at temperatures below 21° F, the outlets will continue to operate after the CMAQ project has ended.

This program is economically feasible.

5.7.5. STEP 4: DETERMINE WHETHER CONTROL MEASURES CAN BE IMPLEMENTED WITHIN FOUR YEARS OF DESIGNATION

Five of the technologically feasible and cost effective control measures have not already been implemented.

- Hydronic heaters: voluntary curtailment on air quality advisory days
- Hydronic heaters: All new units must be certified to 2.5 gm/hr
- Wood stoves: All new units must be certified to 2.5 gm/hr
- Open burning: Reinstate open burning ban
- Burn barrels: Prohibit use of burn barrels (seasonal or year-round)

All of these measures may be implemented within four years of designation, with a target implementation date of 1st Qtr 2016.

5.7.6. STEP 5: IDENTIFY REASONABLY AVAILABLE CONTROL MEASURES

[79]http://yosemite.epa.gov/r10/airpage.nsf/283d45bd5bb068e68825650f0064cdc2/fa36e96da9630a5588256da20070d1c1/$FILE/Ordinance%20No.%202001-17.pdf

Table 5.7-8. Reasonably Available Control Measures

Source Category	Control Measure	Potential Implementation Date
Dry Wood Measures	Education and Outreach	Already in place
Hydronic Heaters	Education and Outreach	Already in place
	Voluntary curtailment on air quality advisory days	1st Qtr 2016
	All new units must be certified to 2.5 gm/hr	1st Qtr 2016
	Subsidize heater change outs	Already in place
Wood Stoves	Education and Outreach	Already in place
	Voluntary curtailment on air quality advisory days	Already in place
	All new units must be certified to 2.5 gm/hr	1st Qtr 2016
	Subsidize stove change outs	Already in place
Fireplaces/Fireplace Inserts	Education and Outreach	Already in place
	Voluntary curtailment on air quality advisory days	Already in place
	Subsidize fireplace insert change outs	Already in place
Open Burning	Reinstate open burning ban	1st Qtr 2016
Burn Barrel	Prohibit use of burn barrels (seasonal or year-round)	1st Qtr 2016
Energy Efficiency Measures	Subsidize heating upgrades and weatherization	Already in place
Transportation	Restrict truck idling	Already in place
	Reduce cold start emissions	Already in place

Note:
a. Implementation dates are targets for planning purposes, not commitments.

APPENDIX A

CONTROL MEASURES NOT CONSIDERED

- Stationary Diesel Engine (prime) retrofits (insignificant contribution to ambient concentrations)
- Charbroilers (insignificant contribution to ambient concentrations)
- Reduced solvent usage or solvent substitution (insignificant contribution to ambient concentrations)

Appendix III.D.5.7

Individual Emission Unit RACT Determinations

Introduction

This appendix provides the detailed Reasonably Available Control Technology (RACT) analyses performed to support the RACT determinations contained in the Fairbanks $PM_{2.5}$ SIP. All facilities with emissions exceeding 100 TPY of $PM_{2.5}$, or one of its precursors SO_2 and NO_x, were included. An individual RACT determination was made for each emission unit with emissions equal to or exceeding 5 TPY of one of these pollutants, for that pollutant.

The U.S. EPA has defined RACT as "the lowest emission limitation that a particular source is capable of meeting by the application of control technology that is reasonably available considering technological and economic feasibility."[1] EPA has also defined "presumptive RACT" as the norm achievable by the source category.[2] EPA interprets the term "reasonably available" to allow consideration of both the costs and benefits of applying the measure.[3]

> *RACT and RACM are those measures that a State finds are both reasonably available and contribute to attainment as expeditiously as practical in the specific nonattainment area.*[4]

The individual RACT analysis in this document follows the steps outlined below.

1. Identify baseline RACT[5] for the source category. This involves a review of current practice within the category.
2. Determine whether the emission unit meets baseline RACT.
3. If the emission unit does not meet baseline RACT, determine whether site-specific considerations preclude implementation of baseline RACT.

The emission units, and affected pollutants, are shown in Table 1.

[1] 44 FR 53762 (September 17, 1979)
[2] 72 FR 20610 (April 25, 2007)
[3] 72 FR 20610 (April 25, 2007)
[4] 72 FR 20612 (April 25, 2007)
[5] "Baseline RACT," as used in this analysis, is intended to be conceptually similar to "presumptive RACT"—it is the norm achievable by the source category, and serves as the starting point for the individual RACT evaluation. However, because it has not been established with the rigor utilized by EPA to determine presumptive RACT in the ozone and NO_2 programs, the term "presumptive RACT" is not utilized in this report.

Table 1. Emission units, located at major stationary sources, with actual emissions of $PM_{2.5}$, or a precursor, greater than 5 TPY.

Facility	Source	Source Category	Unit Size[a]	Actual Emissions[b]			Current Controls	Proposed RACT
				$PM_{2.5}$	SO_2	NO_x		
Fort Wainwright	Boiler 3	Coal-fired boiler	230 MMBtu/hr	2	**109**	**101**	Baghouse	Baghouse
Fort Wainwright	Boiler 4	Coal-fired boiler	230 MMBtu/hr	2	**101**	**99**	Baghouse	Baghouse
Fort Wainwright	Boiler 5	Coal-fired boiler	230 MMBtu/hr	2	**126**	**117**	Baghouse	Baghouse
Fort Wainwright	Boiler 6	Coal-fired boiler	230 MMBtu/hr	1	**87**	**91**	Baghouse	Baghouse
Fort Wainwright	Boiler 7	Coal-fired boiler	230 MMBtu/hr	3	**171**	**197**	Baghouse	Baghouse
Fort Wainwright	Boiler 8	Coal-fired boiler	230 MMBtu/hr	2	**122**	**168**	Baghouse	Baghouse
Aurora Energy, Chena	Boiler 1, 2, 3, 5[c]	Coal-fired boiler	5 MW each (Boilers 1,2,3); 20 MW (Boiler 5)	**7.81 (total)**	**838.9 (total)**	**792.7 (total)**	Baghouse	Baghouse
North Pole Refinery	H-2001 Crude Heater	Liquid Fuel Fired Process Heater	325.6 MMBtu/hr	5.1	3.3	**62.0**	Ultra low NO_x burners	No additional controls
North Pole Refinery	H-241 Crude Heater	Liquid Fuel Fired Process Heater	120 MMBtu/hr	2.0	1.0	**44.6**		Note (d)
North Pole Refinery	H-1001 Crude Heater	Liquid Fuel Fired Process Heater	62.5 MMBtu/hr	0.3	0.8	**20.6**		Note (d)
North Pole Refinery	B-401 Steam Generation	Liquid Fuel Fired Boiler	25 MMBtu/hr	0.3	0.1	**11.8**		Note (d)
North Pole Power Plant	Gas Turbine #1	Gas Turbine	60.5 MW	**15.5**	**42.3**	**50.3**		Continued use of HAGO
	Gas Turbine #2	Gas Turbine	60.5 MW	**131**	**326**	**464**		Continued use of HAGO
	GT #3	Gas Turbine	43 MW	**16.8**	**1.86**	**367**		Continued use of naptha and LSR
Zehnder	GT#1	Gas Turbine		**16.05**	**39.83**	**54.3**		Continued use of HAGO
	GT#2	Gas Turbine		**10.77**	**25.73**	**36.4**		Continued use of HAGO
UofA, Fairbanks	Boiler #1	Coal-fired boiler	84.5 MMBtu/Hr	3.62	**123.8**	**250**	Baghouse	Baghouse
	Boiler #2	Coal-fired boiler	84.5 MMBtu/Hr	3.77	**128.93**	**260**	Baghouse	Baghouse
	Boiler #3	Dual Fuel-fired Boiler	180.9 MMBtu/Hr	2	**17.7**	**5.72**		Continued use of No. 2 Distillate
	Boiler #4	Dual Fuel-fired Boiler	180.9 MMBtu/Hr	1.27	**11.23**	3.63		Continued use of No. 2 Distillate

NOTES:
[a]From each facility's Title V Permit Application.
[b]Actual emissions are based on information submitted in by facility operators 2013 for operations in 2011. The information was requested by Alaska Department of Environmental Conservation to satisfy the requirement to prepare a statewide point-source emission inventory (40 CFR 51.30). The inventory report has not been completed.
[c]Emissions shown for the Chena boilers, which share a common stack, are the combined emissions for all four boilers.
[d]No RACT determined for this source because the only pollutant above the threshold is NO_x.

The emission units for which determinations were made fall into three source categories:

- Coal-fired boilers (12; excludes dual fuel-fired boilers), evaluated for $PM_{2.5}$ (1), SO_2 (12)
- Dual Fuel-fired Boilers (2), evaluated for SO_2 (2)
- Gas Turbines (5), evaluated for $PM_{2.5}$ (5), SO_2 (5)

Control of NO_x as a $PM_{2.5}$ Precursor

NO_x is a precursor for $PM_{2.5}$ in the form of nitrates, especially ammonium nitrate. Atmospheric phenomena involving NO_x are very complex. Dispersion and transport of NO_x emissions, atmospheric chemistry, and other factors affect the ultimate fate of NO_x emissions.

NO_x is widely controlled in many parts of the United States as a precursor for ozone. Current and former ozone nonattainment areas have NO_x control requirements for many source categories. Some of these regulations reflect RACT, while others go beyond RACT.

The definition of RACT includes consideration of both costs and benefits of candidate controls. A control technique that is widely used for some other purpose because the emission reduction contributes towards attainment or maintenance of the standard (as an ozone precursor, for example) may still not be RACT for PM control, if the costs of control greatly outweigh the benefits of control.

EPA's policy towards control of NO_x as a precursor for $PM_{2.5}$ includes a strong presumption in favor of requiring controls; this presumption may be overcome, however, if controls are very expensive, and the local conditions are such that NO_x reductions are will not advance attainment by one year. The cost/benefit element of RACT review is commonly expressed as cost effectiveness for a proposed control. Cost effectiveness is expressed in units of dollars per ton of emissions avoided. A lower value for cost effectiveness means that the control technology is more efficient from a cost perspective at reducing emissions.

No threshold has been set for acceptable cost effectiveness for RACT review.[6] Instead, cost effectiveness is used as an indicator of the relative value of the costs and benefits of control. A very high cost effectiveness value may mean that a candidate control technology, even if commonly used and affordable, is not RACT for a specific emission unit because the costs of control outweigh the benefits from control. Whether a particular control technology is cost-effective as RACT for a specific emission unit is a case-by-case determination made by states and EPA.

As part of this analysis, the effectiveness of NO_x emission reduction as a strategy to reduce ambient $PM_{2.5}$ concentrations in Fairbanks has been evaluated relative to reductions of directly emitted $PM_{2.5}$. The evaluation was based on the contribution that nitrates make to $PM_{2.5}$ concentrations in the design case for the region's attainment demonstration, and the regional NO_x emissions that contribute to them.[7]

Based upon ambient sampling, nitrates comprise about 4% of the measured $PM_{2.5}$ concentrations in Fairbanks.[8] This corresponds to hydrated ammonium nitrate concentration of 3.4 $\mu g/m^3$. This represents the theoretical upper-bound of $PM_{2.5}$ reductions that could be achieved by elimination of NO_x emissions.

Regional emissions of NO_x from point sources are 13.45 TPD.[9] Assuming that all of the ambient nitrate $PM_{2.5}$ can be attributed to emissions from point sources establishes an upper bound for the effectiveness of NO_x reductions as a strategy for reducing $PM_{2.5}$ concentrations.[10] Using this assumption, a reduction of 13.45 TPD of NO_x would result in a reduction, at most, of 3.4 $\mu g/m^3$, or 0..25 $\mu g/m^3$ (= 3.4/13.45) per TPD.

For comparison, a wood stove change out program implemented by Fairbanks North Star Borough to reduce directly emitted $PM_{2.5}$—is expected to achieve a reduction in ambient $PM_{2.5}$ of 10.62 $\mu g/m^3$ through a reduction of 3.18 TPD of $PM_{2.5}$ emissions, or 3.34

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[6] Some states and local agencies use cost effectiveness thresholds when evaluating the economic feasibility of controls that have been proposed as Best Available Control Technology (BACT). Some states and some local agencies, notably several in California, establish "bright line" thresholds above which controls are considered too costly to apply. Current typical practice at Alaska DEC from reviewing BACT analyses is to deem any control that costs more than $10,000 per ton of reduction it may be too expensive to require for BACT. EPA has not established such cost-effectiveness thresholds. Both states and EPA also may use cost effectiveness in prioritizing post-RACT control measures for plans to attain and maintain National Ambient Air Quality Standards. For this reason, any control technique deemed too expensive for RACT may still be required as part of the attainment demonstration.

[7] This analysis is not as precise as one based, for example, on atmospheric modeling. However, the results are being used here as an indicator of the relative cost/benefit of requiring reduced emissions of a given pollutant. For this limited purpose, the level of approximation provided by the analysis is reasonable.

[8] Appendix III.D.5.7 Precursors

[9] Fairbanks PM 2.5 SIP Chapter III.D.5.8

[10] This is a conservative assumption. Region-wide, 60% of all NOx emissions are from point sources (the other 40% come from mobile, area, non-road, and miscellaneous other sources). It would therefore be reasonable to apportion 60% of the NOx-originated PM2.5 to point sources. This apportionment would still be conservative because the plumes from industrial sources frequently penetrate the inversion layer that is a common feature of local meteorology, and as a result the NOx in those plumes does not contribute as significantly to local $PM_{2.5}$ concentrations as the emission inventory would suggest. However, neither of these adjustments is necessary to demonstrate that NOx control is not an effective strategy for reducing ambient $PM_{2.5}$ concentrations in Fairbanks.

(=10.62/3.18) µg/m^3 per TPD. Based on this measure, control of a ton of directly emitted $PM_{2.5}$ is about 13 times more effective[11] than control of a ton of NO_x.

Survey of NO_x Controls in $PM_{2.5}$ SIPs

In order to ensure that the RACT determinations in this analysis are consistent with those made by other jurisdictions in similar circumstances, a survey of $PM_{2.5}$ SIPs was performed.

All areas designated nonattainment for the 2006 $PM_{2.5}$ standard[12] were identified. Areas that are currently nonattainment for ozone were eliminated from further review. This was done because control requirements for NO_x in current ozone nonattainment areas are already well beyond RACT levels. PM SIPs in such areas cannot provide insight into NO_x RACT in ozone attainment areas.

Next, areas that have been redesignated attainment for the 2006 $PM_{2.5}$ standard, or that have Clean Area determinations, were eliminated from further review. The plans for these areas were not expected to include NO_x control measures as strategies for attaining the PM standard because the standard has already been attained.

Six jurisdictions, including Fairbanks, were left. SIPS for these other areas were reviewed for information useful in establishing RACT. The results of this review were:

- Klamath Falls, Oregon: Klamath Falls point sources emit a total of 755 lb/day (138 TPY). Point source control measures identified as RACT: 20% opacity limitation (direct PM control). No NO_x control measures were identified as RACT.
- Oakridge, Oregon: Nitrates contribute less than 0.4% of the PM mass on exceedance days. As a result, Oakridge did not evaluate RACT for NO_x sources in its plan.
- Logan, Utah: Total NO_x inventory from point sources = 7.3 TPY. [13] No NO_x RACT proposed.
- Provo, Utah: Unlike Fairbanks, secondary particulate is most responsible for Provo's PM exceedances.[14] However, due to previous efforts to attain the federal PM_{10} standard, most point sources were already controlled at RACT/BACT levels. Additional control measures for point sources are listed with Salt Lake City, below.

[11] 13.2 = 3.97 tons of NOx emissions / 0.3 tons of woodsmoke emissions
[12] EPA, *Area Designations for 2006 24-Hour Fine Particle ($PM_{2.5}$) Standards,* http://www.epa.gov/airquality/particlepollution/designations/2006standards/state.htm
[13] *Utah State Implementation Plan, Control Measures for Area and Point Sources, Fine Particulate Matter, PM2.5 SIP for the Logan, UT-ID Nonattainment Area* (November 6, 2013), p. 24
[14] *Utah State Implementation Plan, Control Measures for Area and Point Sources, Fine Particulate Matter, PM2.5 SIP for the Provo, UT Nonattainment Area* (November 6, 2013), p. 43

- Salt Lake City, Utah: Unlike Fairbanks, secondary particulate is most responsible for Provo's PM exceedances.[15] However, due to previous efforts to attain the federal PM_{10} standard, most point sources were already controlled at RACT/BACT levels. The State identified the following additional point source control measures:[16]
    - Ultra-Low NO_x Burners (liquid fuel-fired process heaters), $1,813-$7,200 per ton
    - Low NO_x Burners and Flue Gas Recirculation (FGR): $8,340 per ton
    - Combustion Controls, $1,357 per ton

The methodology used by Utah to establish the levels that it characterized as RACT went beyond RACT requirements.[17] Utah identified feasible control methods for each source it reviewed; it then evaluated expected reductions in its air quality model, in an effort to achieve attainment of the NAAQS as expeditiously as practicable. Finally, it determined which control measures would be included in the overall control strategy for the SIP.

The last two steps utilized by Utah are not part of a RACT analysis. They are the steps used in evaluating and prioritizing control measures for attainment. In other words, Utah blended the RACT evaluation process and the attainment planning process. Utah skipped making RACT determinations and efficiently proceeded directly to identification of the controls needed to demonstrate attainment. These control requirements are certainly *at least stringent as* RACT would be for the affected sources. In many cases, however, the controls go beyond RACT, as indicated by the cost effectiveness calculations included in the analysis.

For this reason, Utah's RACT determinations were considered, but in the end not used, in the RACT determinations for Fairbanks.

Methodology

As discussed above, NO_x controls are not an efficient method for reducing PM concentrations in Fairbanks. This conclusion is based upon the relatively small contribution that secondary particulate (specifically nitrates) make to ambient PM concentrations on episode days, and the relatively large reductions in NO_x emissions needed to have the same benefit (as measured by ambient PM concentrations) as a modest reduction in PM emissions.

Because the purpose of this analysis is to determine whether expenditures are reasonable for reduction of ambient $PM_{2.5}$ concentrations, the cost-effectiveness threshold for this analysis has been selected by taking the relative effectiveness of NO_x control for PM reductions into account. This adjustment is necessary in order to ensure that control dollars are spent effectively. As discussed elsewhere in this report, a NO_x reduction of 13 tons was determined to have the same effect as reduction of a single ton of directly-

[15] *Utah State Implementation Plan, Control Measures for Area and Point Sources, Fine Particulate Matter, PM2.5 SIP for the Provo, UT Nonattainment Area* (November 6, 2013), p. 43
[16] *PM2.5 Technical Support Documentation For the Salt Lake City and Provo PM2.5 Nonattainment Areas*
[17] *PM2.5 Technical Support Documentation For the Salt Lake City and Provo PM2.5 Nonattainment Areas*, p. 5.c.i-1

emitted PM, for the purposes of reducing ambient concentrations of PM. After reviewing several past ADEC BACT determinations for various pollutants, staff determined that $10,000 per ton was a representative threshold for BACT for all pollutants. For this analysis, the RACT cost-effectiveness threshold for PM was set at the same level as the BACT threshold.

In order to maximize the environmental benefit for the amount of money spent, the cost RACT cost-effectiveness for NO_x reductions for the purpose of reducing ambient PM concentrations was derived by taking into account the relative benefits of reducing NO_x and direct PM. As discussed above, a reduction of PM emissions is about 13 times more effective than a reduction of the same amount of NO_x emissions.

In order to be conservative, a cost effectiveness threshold of $1,000 per ton of NO_x has been used in this RACT review. Any technology with a lower bound of more than $1,000 per ton of NO_x reduction was eliminated from further consideration.

Control technologies considered

All of the point sources under review emit NO_x as a combustion product. There are two approaches to the control of NO_x from combustion: combustion controls, and post-combustion controls. Combustion controls include use of water injection, low NO_x burners, and other combustion modifications to reduce the formation of NO_x during combustion. Post-combustion controls include catalyst systems that convert NO_x to nitrogen in the stack.

The control techniques evaluated are presented in Table 1, along with the estimated cost effectiveness.

Table 1 shows that the screening estimate of the cost effectiveness[18] (based on the low end of the dollar-per-ton range, if one was provided) of all identified control technologies except one is higher than (i.e., less cost-effective than) the $1,000 per ton threshold established above. As a result, none of these control technologies are considered cost effective for the control of NO_x as a precursor of $PM_{2.5}$ in Fairbanks.

The exception is the use of low NO_x burners and flue gas recirculation (FGR) to control NO_x emissions from oil-fired process heaters. The only oil-fired process heaters under review are the heaters at the North Pole refinery. The largest of these units, the H-2001 Crude Heater, is already equipped with ultra low-NO_x burners. The other three heaters are not currently equipped with low NO_x burners. Installation of low NO_x burners was considered as a possible RACT measure for these units. However, the cost effectiveness value shown in Table 1 is the low end of the range of estimated costs, and it is just barely below the RACT threshold. Installation costs in Alaska are not expected to be at the low

[18] The values shown in Table 1 are the low values in the range, if a range was given in *EPA Menu of Control Options.* The cost of controls in Fairbanks is expected to be above the middle of the range of costs in the lower 48 states. Additionally, some of the cost effectiveness values do not take equipment size into account. Many of the sources are relatively small, at or below the range for which cost estimates are valid. Smaller units generally cost more per ton than larger units. As a result, the values shown are conservatively low. Actual costs would be expected to be much higher.

end of the range of costs; additionally, the costs of installation on small units are almost never at the low end of the range—economies of scale usually result in the low end of the cost scale being associated with large units. For these reasons, the cost effectiveness of installation of low NO_x burners at North Pole Refinery are expected to be sufficiently higher than the value shown in Table 1 to be above the cost effectiveness threshold, and installation of low-NO_x burners was determined to not be RACT for these units.

Because none of the identified NO_x control measures will result in a cost-effective reduction of ambient PM concentrations, existing controls are deemed to meet RACT requirements for NO_x for each of the identified sources.

Table 1. NO_x Control Techniques[a]

Source Category	Control Technique	Cost Effectiveness ($/ton of NO_x removed)[b]	Additional Information
Coal-Fired Boilers (and Dual Fuel-Fired Boilers)[c]			
Industrial Boilers firing coal (stoker)	Low NO_x burner	$1,526	<250 MMBtu/hr
Industrial Boilers firing coal (stoker)	Low NO_x burner and overfire air	$1,077	
EGU boiler firing coal	SCR	$1,550	
EGU Boilers firing coal	SNCR	$1,370	
Liquid Fuel-Fired Process Heaters[d]			
Industrial Fuel Oil Combustion	Low NO_x Burner	$1,894	
Process Heaters	Low NO_x burner and FGR	$915	
Oil combustion in Process Heaters	Low NO_x burner retrofit & SNCR	$3,691	
Gas Turbines[e]			
Turbines, oil fired	Water Injection & SCR	$3,691	
Turbines, oil fired	Water Injection	$2,070	

[a]Data from *EPA Menu of Control Options* (Updated 4/12/2012). The values shown are the bottom of the range, if a range was provided.
[b]2006 dollars
[c]Fort Wainwright Boilers 3-8; Chena Power Plant Boilers 1,2,3,5; UofA Fairbanks Boiler 1-2.
[d]North Pole Refinery Crude Heaters and Steam Generation.
[e]North Pole Power Plant GT1-3; Zehnder GT 1-2.

Conclusion: Reducing NO_x emissions is a relatively inefficient strategy for reducing $PM_{2.5}$ in Fairbanks. Using the analysis discussed and cited above, our assessment of the cost and effectiveness of NO_x controls concludes that available controls are not cost effective and would not advance attainment of the $PM_{2.5}$ standard by a year. Based on the fact that controlling for direct $PM_{2.5}$ is approximately 13 times more effective, on a per-pound basis, than controlling for NO_x emissions, any cost effectiveness analysis for NO_x control equipment would need to reflect this factor and still be shown to be cost effective.

Our analysis did not find any NO_x controls that are cost effective for reducing $PM_{2.5}$ emissions in the nonattainment area.

For this reason, NO_x reductions, for the purposes of $PM_{2.5}$ reductions within the context of RACM and RACT, will not be considered at this time.

Coal-Fired Boilers

The following is considered baseline RACT for coal-fired boilers in Fairbanks:

- $PM_{2.5}$: Fabric Filters
- SO_2: Use of low-sulfur coal

The basis for each baseline RACT determination is described below.

$PM_{2.5}$ (Direct Emissions)

Candidate Control Technologies – The following control technologies were considered for this source category:

- Fabric Filters;
- Electrostatic Precipitators; and
- Wet Scrubbers.

All of the coal-fired boilers under evaluation are currently equipped with fabric filters. If properly designed and maintained, fabric filters generally reflect the best performing control technology available for emissions of PM from coal-fired boilers.

Conclusion: RACT for PM for each of the coal-fired boilers is a properly designed and operated fabric filter system. A design review will be conducted for each boiler to confirm that the existing baghouses are properly designed and operated.

SO_2

Candidate Control Technologies – The following control technologies were considered for this source category:

- Scrubber (Wet, Spray Dry, and Dry); and
- Fuel sulfur content reduction.

Scrubbers[19] – Scrubbers are used extensively to control emissions of inorganic contaminants, including acid gases such as sulfur dioxide (SO_2). Scrubbers are capable of reduction efficiencies in the range of 50% to 90%. In a wet system, the exhaust gas is contacted in a scrubber with a wet solution. Acid components (SO_2 and HCl) are absorbed into the liquid, and a liquid waste must be disposed of. Dry systems involve injection of dry alkali substances (usually some form of lime), which is removed from the exhaust by a fabric filter or ESP. Spray dry systems introduce the absorbent in a slurry that is fully evaporated by the exhaust stream, resulting in particulates that are removed by fabric filter or ESP. Approximately 85% of the Flue Gas Desulfurization (FGD) systems installed in the U.S. are wet systems, 12% are spray dry, and 3% are dry systems.

[19] Information in this section is from: EPA, *Air Pollution Control Technology Fact Sheet: Flue Gas Desulfurization (FGD) - Wet, Spray Dry, and Dry Scrubbers*, EPA-452/F-03-034

SO_2 scrubbers have been applied to combustion units as small as 5 MW (~50 MMBtu/Hr). Dry and spray dry scrubbers are generally applied to units less than 300 MW (~3,000 MMBtu/Hr).[20] However, there are relatively few installations on units smaller than 300 MMBtu/hr. All 14 of the units in Fairbanks are smaller than 300 MMBtu/hr; 6 of them are smaller than 100 MMBtu/hr. See Table 1. The strategy for control of SO_2 emissions under the Acid Rain program provides an incentive to invest in controls for large to very large sources while leaving smaller sources without controls. EPA has characterized the range of "realistic values" for unit size for scrubber installations as between 100 and 2000 MW_e.[21]

Capital costs for all SO_2 scrubbers were reported to be approximately $100/kW in 2001.[22] Retrofit costs vary significantly between sites and depend on space limitations, requirements for duct modifications, and operating conditions (temperature, flow rate); retrofit of scrubbers on existing units can increase the capital costs up to 30%.

The addition of a scrubber to an existing combustion device causes a loss of energy due to evaporation of water and the energy required to drive the reaction.[23] New scrubber designs result in energy penalties of less than 1% of total plant energy.

Wet scrubbers rely primarily on the absorption process to remove these soluble contaminants from the exhaust gas stream. Wet scrubbing devices that are based on absorption principles include packed towers, plate (or tray) columns, venturi scrubbers, and spray chambers. Removal efficiencies for gas absorbers vary for each pollutant-solvent system and with the type of absorber used. Pollutant removal may also be enhanced by manipulating the chemistry of the absorbing solution so that it reacts with the pollutant(s), e.g., caustic solution for acid-gas absorption vs. pure water as a solvent. Chemical absorption may be limited by the rate of reaction, although the rate-limiting step is typically the physical absorption rate, not the chemical reaction rate.

Most absorbers have removal efficiencies in excess of 90%, and packed tower absorbers may achieve efficiencies as high as 99.9% for some pollutant-solvent systems.

EPA considers dry scrubbers to be a promising emerging technology.

> *Dry scrubbers have significantly lower capital and annual costs than wet systems because they are simpler, demand less water and waste disposal is less complex. Dry injection systems install easily and use less space, therefore, they are good candidates for retrofit applications. SO_2 removal efficiencies are significantly*

[20] For the purposes of this analysis, a nominal plant heat rate of 10,000 Btu/kwhr is assumed for boilers producing steam for electricity where a heat rate is required site specific information is not available.
[21] Srivastava, *Controlling SO_2 Emissions: A Review of Technologies, EPA/600/R-00/093* (November 2000) , p. 44.
[22] Smith, *SO_2 Controls: Cost of SO_2 Scrubbers Down to $100/kW,* Power Engineering (September 2001).
[23] Although there is no evaporation, there is still an energy penalty associated with the use of dry scrubbing. EPA, *Air Pollution Control Technology Fact Sheet: Flue Gas Desulfurization (FGD) - Wet, Spray Dry, and Dry Scrubbers*, EPA-452/F-03-034, p. 2.

lower than wet systems, between 50% and 60% for calcium based sorbents. Sodium based dry sorbent injection into the duct can achieve up to 80% control efficiencies (Srivastava 2001). Dry sorbent injection is viewed as an emerging SO_2 control technology for medium to small industrial boiler applications. Newer applications of dry sorbent injection on small coal-fired industrial boilers have achieved greater than 90% SO_2 control efficiencies.[24]

The available information for cost effectiveness for scrubbers is summarized below.

Table 2. Cost of SO_2 Scrubbers

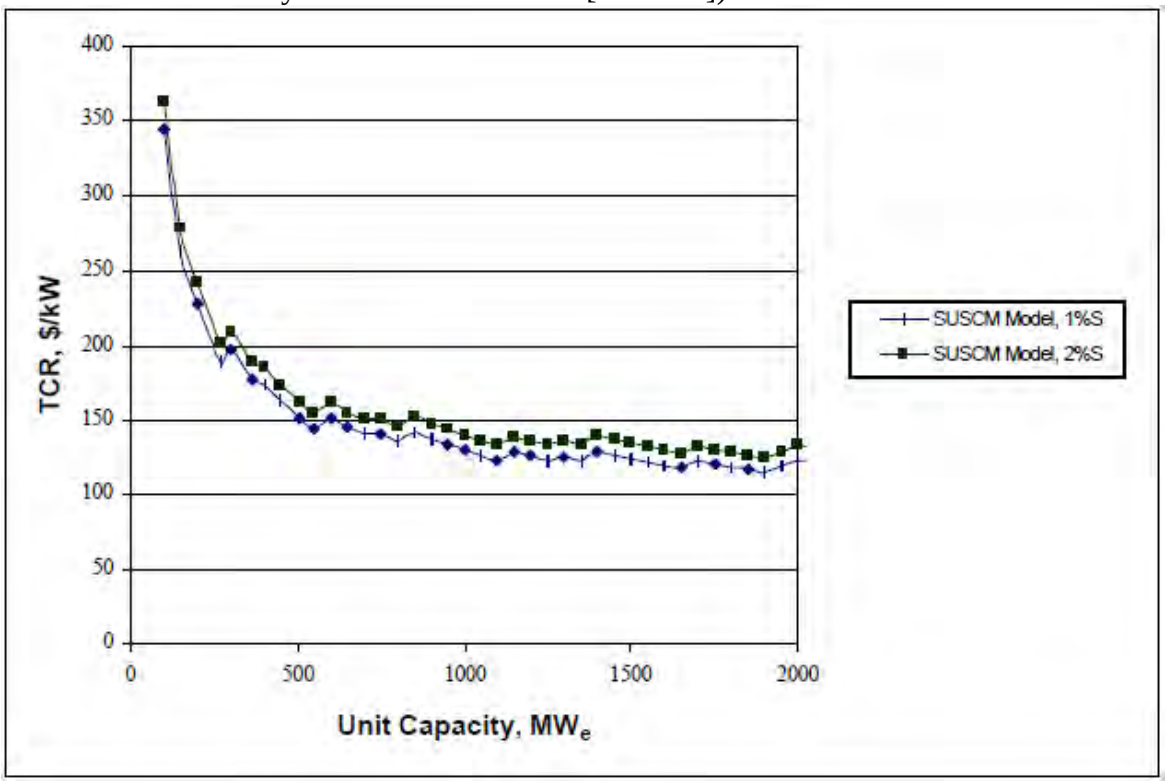
Scrubber Type	Unit Size (MW)	Cost per Ton of Pollutant Removed ($\$_{2001}$/ton)
Wet	>400	200-500
	<400	500-5000
Spray Dry	>200	150-300
	<200	500-4000
Dry Scrubbers	All	Not Available

Source: EPA, *Air Pollution Control Technology Fact Sheet: Flue Gas Desulfurization (FGD) - Wet, Spray Dry, and Dry Scrubbers*, EPA-452/F-03-034. EPA does not provide cost information for dry scrubbers.

By far the most significant factor determining cost effectiveness of controls is the size of the unit. This is illustrated in Figure 1.

[24] EPA, *Air Pollution Control Technology Fact Sheet: Flue Gas Desulfurization (FGD) - Wet, Spray Dry, and Dry Scrubbers*, EPA-452/F-03-034

Figure 1. Total Capital Requirement for Lime Spray Drying System (as calculated by State-of-the-Art Utility Scrubber Cost Model [SUSCM])[25]



NOTE: 100 $MW_e \approx$ 1,000 MMBtu/hr

In order to better refine this cost estimate, EPA's tool for estimating the cost of controls for coal-fired boilers, CUECost,[26] was utilized to estimate the cost of wet scrubbers for coal-fired equipment in Fairbanks. CUECost is the Coal Utility Environmental Cost workbook, an interrelated set of spreadsheets that "produces rough-order-of-magnitude cost estimates (+/- 30% accuracy) of the installed capital and annualized operating costs for air pollution control systems installed on coal-fired power plants."[27] As noted above, EPA has determined realistic values for unit size for scrubber installations as between 100 and 2000 MW_e. Consistent with this determination, the minimum unit size for which CUECost is valid is 100 MW_e whereas the largest example in the nonattainment area are the 40 MWe associated with the combines exhaust from the Chena power plant.

Default values were used for most user-specified inputs. Non-default values, and the basis for their selection, are shown in Table 3. The analysis was performed using values for the largest boiler under review (the combined emissions of the four boilers at Aurora Energy's Chena facility). This exhaust stream was selected because it is expected to have the best cost effectiveness value for capital costs; operating costs for sulfur controls are roughly

[25] Taken from Srivastava, *Controlling SO_2 Emissions: A Review of Technologies, EPA/600/R-00/093* (November 2000) , p. 74.
[26] CUECost Model Version 3.0, downloaded from *http://www.epa.gov/ttn/catc/products.html*. This is the most current version of CUECost available.
[27] Yelverton, *Coal Utility Environmental Cost (CUECost) Workbook User's Manual, Version 1.0,* p. 1. This is the version of the user's manual that accompanies CUECost Version 3.0.

proportional to actual throughput, so unit size does not affect overall operating costs as strongly.

Table 3
CUECost Estimate of Cost of Sulfur Scrubbers for 100 MW Coal-fired Boiler—Input

Description	Units	Range	Default	Case 2
Location - State	Abbrev.	All States	PA	AK
MW Equivalent of Flue Gas to Control System	MW	100-2000	500	100[a]
Net Plant Heat Rate (w/o APC)	Btu/kWhr		10,500	10,500
Plant Capacity Factor	%	40-90%	65%	40%[b]
Percent Excess Air in Boiler	%		120%	120%
Air Heater Inleakage	%		12%	12%
Air Heater Outlet Gas Temperature	°F		300	300
Inlet Air Temperature	°F		80	26.7[c]
Ambient Absolute Pressure	In. of Hg		29.4	29.4
Pressure After Air Heater	In. of H2O		-12	-12
Moisture in Air	lb/lb dry air		0.013	0.0026[d]
Ash Split:				
Fly Ash	%		80%	80%
Bottom Ash	%		20%	20%
Seismic Zone	Integer	1-5	1	4[e]
Retrofit Factor (1.0 = new, 1.3 = medium, 1.6 = difficult)	Dimensionless	1.0-3.0	1.3	1.3 – 3
Coal Cost	$/MMBtu		1.50	3.30[f]
Coal Moisture	wt%		30.24	30.00[g]
Coal Carbon	wt%		48.18	45.00[g]
Coal Sulfur	wt%		0.37	0.13[h]
Ash	wt%		5.32	9.23[h]
Electricity cost	mills/kwh		25	60[i]
2013 Chemical Engineering Price Index			388 (1998)	585.7 (2012)

NOTES:
[a] Largest boiler in the study is 37 MW (combined exhaust of boilers at Aurora Energy's Chena Facility). Used minimum value in the tool's range (i.e., 100 MW).
[b] The analysis was run using the lowest value for capacity factor within the tool's allowed range (i.e., 40%)
[c] U.S. Climate Data *http://usclimatedata.com/climate.php?location=USAK0083*, accessed 9/19/13.
[d] Vapor pressure of water over ice at 32F.
[e] Seismic zone = 4 ("Areas within Zone 3 close to major fault systems"), based on information from this website: *http://seismic.alaska.gov/seismic_hazards_earthquake_risk.html*
[f] Cost of coal ~$50/st
[g] Adjusted from default to compensate for ash content.
[h] From Emission Inventory 2011
[I] Source: Alaska Electric Light and Power Company, Large Commercial Tariff

Information about the estimates is provided in Table 4. Based on the model, the cost effectiveness of wet scrubbers and spray dryer systems to control SO_2 from these boilers is

between $24,000 and $58,000 per ton of SO_2. This is much higher than the cost effectiveness values provided by the EPA Fact Sheet, shown in Table 2. However, this outcome is expected, given the small size and low sulfur content of the unit being evaluated. Furthermore, it is important to bear in mind that the definition of "small" for coal-fired units is 500 MWe, and that EPA considers installation of scrubbers on units smaller than 100 MW_e to be "unrealistic."

Table 4
CUECost Estimate of Cost of Sulfur Scrubbers for 100 MW Coal-fired Boiler—Output

Description	Units	Limestone Forced Oxidation[a]	Lime Spray Dryer[b]
Total Capital Requirements	$\$_{2012}$	$77-176 million	$57-131 million
Levelized Constant Dollars			
Fixed O&M	$\$_{2012}$/year	$4.0 million/year	$3.0 million/year
Variable O&M	$\$_{2012}$/year	$0.6 million/year	$0.8 million/year
Fixed Charges	$\$_{2012}$/year	$9.0-20.6 million/year	$6.7-15.3 million/year
Total	$\$_{2012}$/year	$13.6-25.0 million/year	$10.4-19.1 million/year
Total	$\$_{2012}$/ton SO_2	$29,600-57,600/ton	$23,900-46,100/ton

[a]Limestone Forced Oxidation is a type of wet scrubber.
[b]Lime Spray Dryer is a type of spray dryer.

In summary, available cost information for wet scrubbers and spray dry systems indicate that these systems are not cost effective for small units (smaller than 500 MW_e).

As for dry scrubbers, the most recent EPA guidance indicates that EPA considers dry scrubbers to be a promising, but still emerging, technology, with potentially lower capital costs, particularly for medium to small installations. An emerging technology may be a candidate for evaluation in a top-down BACT analysis, but cannot be considered to be the "norm." Efforts to find cost data for dry scrubbers were largely unsuccessful. After searching various literature sources and vendor websites, one article comparing circulating dry scrubbers with other wet scrubber systems was found.[28] The report compared units designed for 400-500 MW coal-fired power plants. The report concluded that, for that size at least, the cost of a dry scrubber was essentially a tie with the cost of a lime spray-dry system.

The Sargent & Lundy report compares capital and operating costs for power plants of two sizes: 400 MW and 500MW. The report also evaluated the effect of fuel sulfur content on cost. The cost calculations were developed for the purpose of comparing the relative cost effectiveness of the various technologies on power plants of the selected sizes. The report cautions that costs should not be used to plan the cost of a FGD project. Taking these cautions into account, the report still contains information relevant to the RACT analysis. What follows is an attempt to scale the cost data for a 400 MW plant down to the 20-40 MW units in Fairbanks.

[28] Sargent & Lundy, *Flue Gas Desulfurizaiton Technology Evaluation: Dry Lime vs. Wet Limestone FGD,* March 2007.

Effect of fuel sulfur content on cost

Table 5 presents the cost information from the Sargent & Lundy report (Cases 1-6), as well as an extrapolation of the costs to a hypothetical 400 MW power plant burning Alaska coal. The costs shown are retrofit costs.

The defining characteristic of Alaska coal is very low sulfur content. For this reason, uncontrolled sulfur emissions are 4 times lower than occur at a plant burning "low sulfur" coal in the lower 48 states.

Table 5. Cost of Circulating Dry Scrubber for SO_2 Controls (400 and 500 MW Coal-fired Power Plant)

		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Unit Size	MW	400	500	400	500	400	500
boiler fuel capacity	MMBtu/hr	4000	5000	4000	5000	4000	5000
Coal HHV	btu/lb	8,335	8,335	13,100	13,100	13,100	13,100
Sulfur content	wt%	0.6	0.6	1.3	1.3	2	2
SO_2 generation	lb/MMBtu	1.44	1.44	2.0	2.0	3.1	3.1
Annual fuel use	ton/year	1,681,584	2,101,980	1,069,924	1,337,405	1,069,924	1,337,405
Capacity Factor		80%	80%	80%	80%	80%	80%
Control efficiency		97.2%	97.2%	98%	98%	98%	98%
Capital Cost	M$	110.2	139.3	107.9	135.9	111.9	140.6
Annualized Cap Cost	M$/year	10.40	13.15	10.18	12.83	10.56	13.27
Fixed Operating Cost	M$/year	2.08	2.45	2.05	2.40	2.11	2.47
Variable Operating Cost	M$/year	5.13	6.41	7.03	8.79	10.46	13.07
Total Operating Cost	M$/year	7.21	8.86	9.08	11.19	12.57	15.54
Total cost	M$/year	17.61	22.00	19.27	24.02	23.13	28.81
Cost per kwh	¢/kwh	0.63	0.63	0.69	0.69	0.83	0.82
SO_2 removed	ton/year	19,614	25,224	27,818	34,773	42,797	53,496
Cost effectiveness	$/ton SO_2	898	872	693	691	540	539

Notes:
[a]All data from Sargent & Lundy, *Flue Gas Desulfurizaiton Technology Evaluation: Dry Lime vs. Wet Limestone FGD,* March 2007.
[b]Annual capital cost calculated using a 7% discount rate and a 20-year equipment life.

A direct result of this is that the cost effectiveness of any sulfur emission reduction strategy is much poorer for facilities firing Alaskan coal. The estimated cost effectiveness of retrofitting a 400 MW baseload (80% capacity factor) firing Alaskan coal is $2,800 per ton; this is more than 3 times the cost of retrofitting a similar unit in the lower 48 states. This value is based on an assumption that the control efficiency of the control device will be 95%. It is likely that the control efficiency will be lower, because a lower inlet pollutant loading usually results in a lower overall control efficiency.

Effect of unit size on cost

Extrapolating costs from data at 400-500 MW to units that are 5-40 MW in size is unreliable, at best. Generally, economies of scale result in capital costs (expressed as dollars per unit of capacity) being higher for smaller units.

The Sargent & Lundy capital cost data were evaluated to determine a capital cost factor of $0.276 million per MW for scrubber units applied to boilers in the 400-500 MW range

The linear factor above does not take into account economies of scale. Small units are more expensive (on a dollar per unit capacity basis) than larger units. A scaling equation to account for the non-linearity of construction costs, adjusting equipment cost estimates for size, is provided by the National Energy Technology Library.[29]

$$SC = RC * (\frac{SP}{RP})^{Exp}$$

Where

SC = Scaled Cost
RC = Reference Cost
SP = Scaling Parameter
RP = Reference Parameter
Exp = exponent

For the components comprising the desulfurization system (sorbent handling, injection, collection, etc.) the exponents range from 0.5 to 0.72. An exponent value of 0.64 was used to calculate the costs presented in Table 4. Costs were calculated by scaling the estimated cost of a 400 MW unit burning Alaska coal (Case 7 in Table 4) by the ratio of the boiler capacity (in MW) to 400 MW, raised to the power of 0.64.

Operating and maintenance (O&M) costs can be separated into two components: fixed costs (overhead costs that are insensitive to usage; these include labor and maintenance materials) and variable costs (costs that are tied to production, including cost of consumable, by-product management, water and power). Fixed costs were estimated by evaluating the Sargent & Lundy cost data to get a fixed cost factor of $5,036 per MW. Variable costs were based on a variable cost factor of $252 per ton of SO_2 recovered.

[29] US Department of Energy, *Capital Cost Scaling Methodology*, January 2013.

Results of Cost Calculations

Table 6 presents the cost estimates for dry scrubbers using the methodology described above. Estimated site-specific cost effectiveness are $2,200 per ton of SO_2 removed (Chena power plant); $2,200 per ton of SO_2 removed (University of Alaska 1 & 2); and over $5,000 per ton of SO_2 removed (Wainwright, University of Alaska 3 & 4).

Table 6. Cost of Circulating Dry Scrubber for SO_2 Controls (Fairbanks Facilities)

		Case 7 (Alaska coal)	Wainwright 3-8	U of A 1, 2[c]	Chena (combined)[d]
Unit Size	MW	400	23	8.5	42
boiler fuel capacity	MMBtu/hr	4000	230	85	420
Coal HHV	btu/lb	7,545	7,545	7,545	7,545
Sulfur content	wt%	0.14	0.14	0.18	0.14
SO_2 generation	lb/MMBtu	0.4	0.4	0.5	0.4
Annual fuel use	ton/year	1,857,654	50,391	36,950	234,251
Capacity Factor		80%	38%	75%	96%
Control efficiency		95%	95%	95%	95%
Capital Cost	M$	110.4	12.0	4.5	22.0
Annualized Cap Cost	M$/year	10.42	1.14	0.42	2.08
Fixed Operating Cost	M$/year	2.01	0.12	0.04	0.21
Variable Operating Cost	M$/year	1.24	0.04	0.03	0.16
Total Operating Cost	M$/year	3.26	0.15	0.08	0.37
Total cost	M$/year	13.68	1.29	0.50	2.45
Cost per kwh	¢/kwh	0.49	1.70	0.89	0.69
SO_2 removed	ton/year	4,941	141	133	656
Cost effectiveness	$/ton SO_2	2,769	9,140	3,734	3,732

Notes:
[A]All costs are estimates based on cost factors derived from Sargent & Lundy, *Flue Gas Desulfurizaiton Technology Evaluation: Dry Lime vs. Wet Limestone FGD,* March 2007. The values in this table are extrapolated from 400 and 500 MW examples.
[b]Annual capital cost calculated using a 7% discount rate and a 20-year equipment life.
[c]University of Alaska Units 3 & 4 are not included. These dual fuel-fired units did not burn coal in the inventory year.
[d]Chena Units are combined because they share a common stack. Unit 4 capacity was adjusted upward (from 20 MW to 27 MW) to match actual physical capacity as demonstrated by historical firing rate data.

In interpreting these values, it is important to note that they are very likely low estimates. They are based on cost factors for much larger facilities, and do not take economies of scale into account. The Wainwright boilers have relatively low capacity factors, which contributes to poor cost effectiveness. All of them use low-sulfur Alaska coal, which also contributes to poor cost effectiveness. Additionally, the low sulfur loading may result in much lower abatement efficiencies than assumed in this analysis, further increasing the cost per ton of SO_2 controlled, and reducing the effectiveness of the control strategy.

Other observations

The Sargent & Lundy report indicates that the cost of a circulating dry scrubber is very similar to that of a spray dryer.[30]

Information in the Sargent & Lundy report creates concerns about cost estimates using older sources.

> FGD prices have seen a minimum of 25% inflation in the last year [CY2006]. Some recent contracts have been signed at prices over 300% higher than the market of 5 years ago.[31]

The EPA fact sheet used to describe and estimate costs for other SO_2 removal technologies uses cost data from 2000 and 2001.

Sargent & Lundy indicated that, at least in 2007, the scrubber marketplace was a "seller's market."

> [E]ven when the seller's costs agree with the costs that these tables were based on, the seller's price may include a factor of 20% that reflects his diminished desire to capture the contract. This diminished desire may alternatively be expressed as a refusal to offer any price. Many suppliers are declining to bid on contracts they deem too small, too different from their experience base, to short a schedule, too difficult a labor environment, or too commercially risky.[32]

Conclusions

The cost effectiveness of controlling SO_2 from coal-fired units in Fairbanks using dry scrubbing technology has been estimated. The estimated costs exceed $3,700 per ton for all facilities, and range as high as $9,100 per ton. For a number of reasons, these cost estimates are considered to be underestimates of the actual costs.

- The capital cost per unit capacity is extrapolated from 400 MW examples to units smaller than 40 MW.
- A control efficiency of 90% was assumed. However, this level of control may not be achievable due to the much lower inlet sulfur loading.
- Actual vendor costs may be higher, or even unavailable, because the projects are too small or too challenging to be attractive.

These control costs are too high for this technology to be considered RACT for the small units operated in Fairbanks.

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[30] Sargent & Lundy, *Flue Gas Desulfurizaiton Technology Evaluation: Dry Lime vs. Wet Limestone FGD,* March 2007, p. 53.

[31] Sargent & Lundy, *Flue Gas Desulfurizaiton Technology Evaluation: Dry Lime vs. Wet Limestone FGD,* March 2007, p. 33.

[32] Sargent & Lundy, *Flue Gas Desulfurizaiton Technology Evaluation: Dry Lime vs. Wet Limestone FGD,* March 2007, p. 33.

The Sargent & Lundy report indicates that the cost of dry scrubbing is very similar to that of a spray dryer, characterizing them as a "tie" from a cost standpoint. The report also indicates that the costs of controls have increased substantially since the EPA guidance on sulfur control technologies was issued, and the costs in that guidance may underestimate control costs by a factor of 3 or more.

For the reasons presented above, the use of scrubbers (wet, spray-dry, or dry) on boilers smaller than 100 MW_e cannot be considered to be the norm for SO_2 control, and therefore scrubbers are not considered RACT for these units

Reduced Sulfur in Fuels – Perhaps the simplest and, in many cases, the most cost effective SO_2 emission reduction technology that can be employed for fuel combustion sources is to switch to a lower sulfur content fuel. Reducing the sulfur content in the fuel will reduce the sulfur emissions linearly.

For coal-fired boilers, this means either cleaning the coal to remove sulfur, or switching to a coal source with a lower sulfur content.

Alaskan coal has very low sulfur content.[33] As a result, switching to a coal with a lower sulfur content is not an option. The low sulfur content makes fuel cleaning uneconomical as well, because of the higher volume of fuel that must be cleaned to achieve a given reduction in sulfur.

Conclusion: In order to establish baseline RACT for this source category, data collected by EPA during development of the Boiler NESHAPS were reviewed. Very few coal-fired boilers are currently equipped with exhaust gas SO_2 controls—certainly not enough to be able to say that exhaust gas scrubbers are the norm for this source category. EPA guidance states that use of scrubbers on units smaller than 100 MW is unrealistic. Wet scrubbers and spray dry scrubbers are too expensive to be cost effective. Dry scrubbers may be less expensive than other scrubbers, but the available information on control costs is extremely sparse, and extrapolation to estimate the cost of very small units is unreliable. However, costs have been estimated using available information, and the result appears to indicate that dry scrubbers are too costly to be deemed RACT.

Alaskan coal has a very low fuel content, making fuel switching ineffective and fuel cleaning uneconomical. For these reasons, baseline RACT for SO_2 for each of the coal-fired boilers is use of low-sulfur coal, with no additional controls.

[33] "Alaskan coal resources have a lower sulfur content (averaging 0.3 percent) than most coals in the conterminous United States and are within or below the minimum sulfur value mandated by the 1990 Clean Air Act Amendments." USGS, *Alaska Coal Geology, Resources, and Coalbed Methane Potential* ,(2004) p. 1.

Individual RACT: Fort Wainwright Boilers 3-8

Fort Wainwright has a Central Heat and Power Plant (CHPP) that generates steam and electricity to meet the heating and electricity demands of the base. The CHPP has six identical 230 MMBtu/hr coal-fired boilers (identified as boiler 3 through 8). The boilers were built in 1953 and each is controlled with a full stream baghouse.

$PM_{2.5}$ – Actual PM emissions from each of these boilers were less than the 5 TPY threshold used to screen sources for inclusion in this analysis.

Conclusion: RACT for PM for each boiler is properly designed and operated fabric filters. A design review will be conducted to confirm that the existing fabric filter controls are properly designed.

SO_2 – Actual emissions from each of these boilers was between 87 and 171 tons in 2011. The boilers are currently not equipped with SO_2 controls.

Each boiler's capacity of about 23 MW is above the size of the smallest commercial scrubber installations, yet is below the bottom of the size range (i.e., 100-2,000 MW) for cost estimates. The capacity of each boiler is well below the "realistic range" EPA has determined for scrubbers. As explained above, Aurora Energy's Chena Facility was selected for detailed cost calculations because it was expected to be the most economical to control. Based on the CUECost evaluation of the larger boiler exhaust stream at the Chena facility, the cost effectiveness of wet or spray dry sulfur scrubbing is expected to be higher than $24,000/ton. Efforts to find cost data for dry scrubbers were largely unsuccessful. After searching various literature sources and vendor websites, one article comparing circulating dry scrubbers with other wet scrubber systems was found.[34] The report compared units designed for 400-500 MW coal-fired power plants. The report concluded that, for that size at least, the cost of a dry scrubber was essentially a tie with the cost of a lime spray-dry system.

Conclusion: RACT for SO_2 for each boiler is use of low-sulfur coal, with no additional controls. The boilers are already using low-sulfur coal.[35]

Individual RACT: Aurora Energy Chena Boilers 1, 2, 3, 5

The Chena facility has four coal-fired boilers: three overfeed traveling grate stokers and one spreader stoker. The three traveling grate boilers (identified as Chena 1, 2, and 3) were installed in the 1950s and the maximum design power production of each is 5 megawatts (MW); fuel capacity is 76 MMBtu/Hr.[36] The spreader stoker unit (identified as Chena 5) was installed in 1970 and has a maximum power production rating of 20 MW; fuel capacity is 269 MMBtu/hr. The four coal-fired boilers are controlled with a single

[34] Sargent & Lundy, *Flue Gas Desulfurization Technology Evaluation: Dry Lime vs. Wet Limestone FGD,* March 2007.
[35] 0.14 wt% sulfur content (Data submitted to ADEC for 2011 Emission Inventory).
[36] Aurora Energy Company, *Application, Title V Permit No. AQ0315TVPO2 Revision 1* (October 2010) Table 2-1

full stream baghouse (installed in 2007) through which all of the combined exhaust gas flows.

Because the four boilers share a common stack and exhaust control system, the RACT analysis will be based on the combined capacity and exhaust characteristics.

$PM_{2.5}$ – Actual emissions from all four of these boilers combined was 7.81 TPY in 2011.

Conclusion: RACT for PM for each boiler is properly designed and operated fabric filters. A design review will be conducted to confirm that the existing fabric filter controls are properly designed.

SO_2 – Actual emissions from all four of these boilers combined was 838.9 TPY in 2011. The boilers are currently not equipped with SO_2 controls.

The combined capacity of 35 MW (500 MMBtu/hr) is above the size of the smallest commercial scrubber installations, yet is below the bottom of the size range (i.e., 100-2,000 MW) for cost estimates. The capacity of each boiler is well below the "realistic range" EPA has determined for scrubbers. Based on the CUECost evaluation of this facility, described above, the cost effectiveness of wet or spray dry sulfur scrubbing is expected to be higher than $24,000/ton. Efforts to find cost data for dry scrubbers were largely unsuccessful. After searching various literature sources and vendor websites, one article comparing circulating dry scrubbers with other wet scrubber systems was found.[37] The report compared units designed for 400-500 MW coal-fired power plants. The report concluded that, for that size at least, the cost of a dry scrubber was essentially a tie with the cost of a lime spray-dry system.

Fuel sulfur content is very low (0.13 weight%). As discussed above, this makes fuel switching ineffective and fuel cleaning uneconomical.

Conclusion: RACT for SO_2 for each boiler is use of low-sulfur coal, with no additional controls.

Individual RACT: University of Alaska, Fairbanks Campus Power Plant
Boilers 1, 2, 3 and 4

The University of Alaska's Utilities Division operates a combined heat and power plant that provides electric power, steam heat, domestic water, and chilled water to campus. The power plant has two 140 MMBtu/Hr coal-fired boilers (identified as Boilers 1 and 2) that were installed in 1962 and two 181 MMBtu/Hr dual-fired (gas, liquid, or coal slurry) boilers (identified as Boiler 3, installed in 1970, and Boiler 4, installed in 1987) that generate the steam that powers the three turbines. The coal-fired boilers are controlled by a multi-cyclone separator that came as part of the unit followed by an add-on baghouse installed in 1982. The dual-fired boilers both have low NO_x burners. The University is

[37] Sargent & Lundy, *Flue Gas Desulfurization Technology Evaluation: Dry Lime vs. Wet Limestone FGD,* March 2007.

planning to construct a new coal-fired boiler and that will be controlled with lime injection and a fabric filter.[38] The new boiler will replace boilers 1 and 2 while greatly reducing the need for boilers 3 and 4. It is scheduled to start operations in 2017.

$PM_{2.5}$ – Actual PM emissions from each of these boilers were less than the 5 TPY threshold used to screen sources for inclusion in this analysis.

Conclusion: RACT for PM for each boiler is properly designed and operated fabric filters. A design review will be conducted to confirm that the existing fabric filter controls are properly designed.

SO_2 – Actual emissions from all four of these boilers combined was 281.7 TPY in 2011. The boilers are currently not equipped with SO_2 controls.

The individual boiler capacity (~14-18 MW) is above the size of the smallest commercial scrubber installations, yet is below the bottom of the size range (i.e., 100-2,000 MW) for cost estimates. The capacity of each boiler is well below the "realistic range" for scrubbers. Based on the CUECost evaluation of the larger boiler exhaust stream at Aurora Energy's Chena facility, the cost effectiveness of wet or spray-dry sulfur scrubbing is expected to be higher than $24,000/ton. Efforts to find cost data for dry scrubbers were largely unsuccessful. After searching various literature sources and vendor websites, one article comparing circulating dry scrubbers with other wet scrubber systems was found.[39] The report compared units designed for 400-500 MW coal-fired power plants. The report concluded that, for that size at least, the cost of a dry scrubber was essentially a tie with the cost of a lime spray-dry system.

Fuel sulfur content is very low (0.18 weight%). As discussed above, this makes fuel switching ineffective and fuel cleaning uneconomical.

Conclusion: RACT for SO_2 for each boiler is use of low-sulfur coal, with no additional controls.

Dual Fuel-fired Boilers

Because only two identical units are included in this category, baseline RACT was not established. Instead, the relevant factors were considered as part of the individual emission unit analysis, presented below.

Individual RACT: U of Alaska, Fairbanks Boilers 3, 4

Boilers 3 and 4 are 181 MMBtu/Hr dual-fired (gas, liquid, or coal slurry) boilers. The dual-fired boilers both have low NO_x burners. The University is planning to construct a new coal-fired boiler and that will be controlled with lime injection and a fabric filter.

[38] The University has obtained permits to construct two units; however, only one has been scheduled for construction.

[39] Sargent & Lundy, *Flue Gas Desulfurizaiton Technology Evaluation: Dry Lime vs. Wet Limestone FGD,* March 2007.

The new boiler will replace boilers 1 and 2 while greatly reducing the need for boilers 3 and 4. It is scheduled to start operations in 2017. See the previous section for more details.

$PM_{2.5}$ – Actual PM emissions from each of these boilers were less than the 5 TPY threshold used to screen sources for inclusion in this analysis.

Conclusion: RACT for PM was not determined for these boilers, because emissions are below the threshold for evaluation.

SO_2 – Actual emissions from combustion of fuel oil were 17.7 tons (Boiler 3) and 11.2 tons (Boiler 4) in 2011.[40] Based on the analyses prepared for the coal-fired boilers, use of wet or spray-dry scrubbers to control SO_2 from the dual-fuel fired boilers is not expected to be cost-effective. Since the only available cost information for dry scrubbers indicates that the costs are similar to those for spray dry scrubbers, dry scrubbers are not expected to be cost-effective.

The fuel used in these boilers is #2 Distillate Oil. The fuel sulfur content of this fuel, 0.43 wt%, is considered typical for this fuel. The feasibility of achieving cost-effective SO_2 reductions at this facility by replacing this fuel with a low-sulfur alternative is discussed below.

Table 5 shows fuel characteristics of the fuels included in this analysis. Information in this table was provided by Golden Valley Electric Association in a site specific analysis prepared by CH2MHill to evaluate the costs associated with fuel switching at GVEA North Pole and Zehnder Peaker Units.[41] HAGO is Heavy Atmospheric Gas Oil, a relatively inexpensive heavy fuel oil produced at the North Pole refinery.

Table 5
Fuel Characteristics

Fuel Type		HAGO	No. 2 fuel oil	Naphtha	ULSD
Sulfur[a]	wt%	1	0.5	0.05	0.0015
Density	lb/gal	7.12	7.05	6.43	7.1
Heat value	BTU/gal	141,000	138,000	116,000	138,500
Cost	$/gal	$2.79	$3.28	$2.41	$3.66
$PM_{2.5}$ emissions	lb/MMBtu	0.043	0.012	0.012	0.012
SO_2 emissions	lb/MMBtu	1.01	0.51	0.06	0.00
Cost	$/MMBtu	$19.79	$23.77	$20.78	$26.43

Notes:
[a]Fuel sulfur content is based on fuel specifications rather than actual current fuel content.

Tables 6 and 7 show the fuel costs associated with switching fuels. This is just the cost of buying the new fuel instead of the old one. Capital investment will be required for some

[40] Data submitted to ADEC for 2011 Emission Inventory.
[41] CH2MHill, *Evaluation of Fuel Switching for Potential PM2.5 Reduction for GVEA North Pole and Zehnder Peaker Units*, January 2014

units to be able to switch fuels due to fuel physical characteristics such as viscosity. Additionally, some units will require onsite storage in order to meet system reliability requirements.

Table 6
Fuel Cost of Switching Fuels ($/ton $PM_{2.5}$ Reduced)

	To this fuel		
From this fuel	No. 2 fuel oil	Naphtha	ULSD
HAGO	$25,683.11	$6,378.25	$42,830.70
No. 2 fuel oil		no benefit	no benefit
Naphtha			no benefit

Table 7
Fuel Cost of Switching Fuels ($/ton SO_2 Reduced)

	To this fuel		
From this fuel	No. 2 fuel oil	Naphtha	ULSD
HAGO	$15,951.27	$2,071.36	$13,166.10
No. 2 fuel oil		-$13,140.10	$10,436.72
Naphtha			$209,679.08

Table 6 shows that the cost of fuel, by itself, is above ADEC's $10,000/ton BACT cost effectiveness threshold for $PM_{2.5}$ for all fuels except naphtha. Table 7 shows that the cost of fuel, by itself, is above typical ADEC's $10,000/ton BACT cost effectiveness threshold for SO_2 for all fuels except naphtha. For this reason, fuel switching to fuels other than naphtha is ruled out as RACT.

Switching from #2 distillate to naphtha would significantly reduce fuel costs for these units. However, naphtha has significantly different combustion characteristics that would require substantial equipment modification. Naphtha is significantly more flammable than heavier fuels, potentially requiring significant construction costs for storage and structures. Fuel systems would need to be modified or replaced. Although the costs of these modifications would be very site-specific, and are not currently available, it is clear that switching to naphtha is a costly effort for a facility not currently equipped to burn this fuel.

Conclusion: Use of low-sulfur naphtha as a fuel would result in PM and SO_2 emission reductions. However, because of the relatively low use/low emissions of these boilers, and the fact that usage is expected to be even lower in 2017 when the new boiler begins operating, the significant capital investment needed to convert Boilers 3 and 4 to naphtha is not justified. RACT is continued use of #2 distillate.

Gas Turbine

Because only five units are included in this category, baseline RACT was not established. Instead, the relevant factors were considered as part of the individual emission unit analysis, presented below.

Individual RACT: North Pole Power Plant GTs 1, 2, and 3

The North Pole Power Plant has three generating units. One unit (GT#3) is a base load unit and operates continuously except for periods of repair or maintenance. This unit was installed in 2006 and is a 455 MMBtu/hr GE Gas Turbine fueled with low sulfur naphtha and LSR fuel and equipped with water injection for NO_x control and a CO oxidation catalyst. The other two units at the North Pole Power Plant are 672 MMBtu/hr GE fuel oil-fired regenerative Gas Turbines, installed in 1976 and 1977, and are now operated in peak load periods only. The fuel used in Units 1 and 2 is HAGO. The two units operated a combined total of about 123 days during 2011. This facility also has a permit to install a fourth gas turbine similar to the base unit, but the unit has not yet been installed.

$PM_{2.5}$ – Actual PM emissions from the gas turbines were 16 TPY for GT #1, 131 TPY for GT#2, and 16 TPY for GT#3.[42]
SO_2 – Actual SO_2 emissions from the gas turbines were 42 TPY for GT #1, 326 TPY for GT#2, and 1.9 TPY for GT#3.[43]

Candidate Control Technologies – The following control technologies were considered for this source category:

- Use of gaseous fuels
- Use of low sulfur liquid fuels

Gaseous fuels such as natural gas or propane have much lower sulfur content than liquid distillate fuels. Gas turbines burning gaseous fuels have lower particulate emissions than those burning liquid fuels. However, none of the gas turbines under evaluation are currently capable of burning gaseous fuels. Furthermore, a supply of pipeline natural gas is not available in Fairbanks. The only natural gas currently used in Fairbanks is brought in by truck for supply to a network of 1100 customers. This network does not extend to North Pole. For this reason, use of gaseous fuel is not an option.

Table 5 shows fuel characteristics of the fuels included in this analysis. Information in this table was provided by Golden Valley Electric Association in a site specific analysis prepared by CH2MHill to evaluate the costs associated with fuel switching at GVEA North Pole and Zehnder Peaker Units.

[42] Data submitted to ADEC for 2011 Emission Inventory.
[43] Data submitted to ADEC for 2011 Emission Inventory.

Tables 6 and 7 show the fuel costs associated with switching fuels. This is just the cost of buying the new fuel instead of the old one. Capital investment will be required for some units to be able to switch fuels due to fuel physical characteristics such as viscosity. Additionally, some units will require onsite storage in order to meet system reliability requirements.

Table 6 shows that the cost of fuel, by itself, is above the typical ADEC $10,000/ton BACT cost effectiveness threshold for $PM_{2.5}$ for all fuels except naphtha. Table 7 shows that the cost of fuel, by itself, is above typical ADEC BACT cost effectiveness for SO_2 for all fuels except naphtha. For this reason, fuel switching to fuels other than naphtha is ruled out as RACT.

Switching from HAGO to naphtha would significantly reduce fuel costs for Units 1 and 2 (Unit 3 already uses naphtha). However, naphtha has significantly different combustion characteristics that may require substantial modification before it can be used as a fuel. Naphtha is significantly more flammable than heavier fuels, potentially requiring significant construction costs for storage and structures. Fuel systems would need to be modified or replaced. Switching to naphtha is a costly effort for a facility not currently equipped to burn this fuel. GVEA has stated that, due to the age of its turbines, a requirement to retrofit the turbines to use naphtha would likely result in replacement of the turbines. Additionally, GVEA has indicated that it would probably need to demolish and rebuild structures in order to meet safety requirements. Finally, GVEA has indicated that it would need to replace all fuel systems.

Conclusion: Use of low-sulfur naphtha as a fuel would result in PM and SO_2 emission reductions from Units 1 and 2. However, because of the relatively low use/low emissions of these boilers, the significant capital investment needed to Units 1 and 2 to naphtha is not justified. RACT for directly emitted $PM_{2.5}$ and SO_2 control is continued use of current fuels: HAGO in Units 1 and 2, and naphtha and LSR in Unit 3.

Individual RACT: Zehnder, GTs 1 and 2

The Zehnder Power Plant has two GE Frame 5 fuel oil-fired gas turbines, which were installed in 1971 and 1972. The two gas turbines ran a combined total of about 53 days during 2011.

$PM_{2.5}$ – Actual PM emissions from the gas turbines were 16 TPY for GT #1 and 11 TPY for GT#2.[44]

SO_2 – Actual SO_2 emissions from the gas turbines were 40 TPY for GT #1 and 26 TPY for GT#2.[45]

[44] Data submitted to ADEC for 2011 Emission Inventory.
[45] Data submitted to ADEC for 2011 Emission Inventory.

Candidate Control Technologies – The following control technologies were considered for this source category:

- Use of gaseous fuels
- Use of low sulfur liquid fuels

Gaseous fuels such as natural gas or propane have much lower sulfur content than liquid distillate fuels. Gas turbines burning gaseous fuels have lower particulate emissions than those burning liquid fuels. However, none of the gas turbines under evaluation are currently capable of burning gaseous fuels. Furthermore, a supply of pipeline natural gas is not available in Fairbanks. The only natural gas currently used in Fairbanks is brought in by truck for supply to a network of 1100 customers. This network does not extend to Zehnder. For this reason, use of gaseous fuel is not an option.

Table 5 shows fuel characteristics of the fuels included in this analysis. Information in this table was provided by Golden Valley Electric Association in a site specific analysis prepared by CH2MHill to evaluate the costs associated with fuel switching at GVEA North Pole and Zehnder Peaker Units.

Tables 6 and 7 show the fuel costs associated with switching fuels. This is just the cost of buying the new fuel instead of the old one. Capital investment will be required for some units to be able to switch fuels due to fuel physical characteristics such as viscosity. Additionally, some units will require onsite storage in order to meet system reliability requirements.

Table 6 shows that the cost of fuel, by itself, is above the typical ADEC's $10,000/ton BACT cost effectiveness (based on reviewing BACT analyses) threshold for $PM_{2.5}$ for all fuels except naphtha. Table 7 shows that the cost of fuel, by itself, is above ADEC's $10,000/ton BACT cost effectiveness threshold for SO_2 for all fuels except naphtha. For this reason, fuel switching to fuels other than naphtha is ruled out as RACT.

Switching from HAGO to naphtha would significantly reduce fuel costs for Units 1 and 2. However, naphtha has significantly different combustion characteristics that may require substantial modification before it can be used as a fuel. Naphtha is significantly more flammable than heavier fuels, potentially requiring significant construction costs for storage and structures. Fuel systems would need to be modified or replaced. Switching to naphtha is a costly effort for a facility not currently equipped to burn this fuel. GVEA has stated that, due to the age of its turbines, a requirement to retrofit the turbines to use naphtha would likely result in replacement of the turbines. Additionally, GVEA has indicated that it would probably need to demolish and rebuild structures in order to meet safety requirements. Finally, GVEA has indicated that it would need to replace all fuel systems.

Conclusion: Use of low-sulfur naphtha as a fuel would result in PM and SO_2 emission reductions from Units 1 and 2. However, because of the relatively low use/low emissions of these boilers, the significant capital investment needed to Units 1 and 2 to naphtha is

not justified. RACT for directly emitted $PM_{2.5}$ and SO_2 control is continued use of current fuels: HAGO in Units 1 and 2.

Process Heater, Oil-fired

The only emission units at the facility with emissions above the screening level are the Crude Heaters at the North Pole Refinery. NO_x emissions from these units are already controlled using an Low NO_x Burners. As discussed above, NO_x controls are not an effective way to reduce $PM_{2.5}$ in Fairbanks.

SO_2 emissions for these units are less than 5 TPY each, and are therefore below the threshold used in this analysis for RACT determinations for SO_2.

At 5.1 TPY $PM_{2.5}$ emissions for one unit (H-2001 Crude Heater) are just above the threshold for evaluation for RACT. This unit burns a very low sulfur distillate fuel and refinery fuel gas. In fact, particulate emissions from oil combustion are below the 5 TPY threshold; emissions from natural gas combustion bring the unit's emissions above 5 TPY. The unit is equipped with ultra low-NO_x burners.

Control of PM emissions from units firing gas and/or distillate fuels is accomplished by improving burner servicing and improving oil atomization and combustion aerodynamics (i.e., burner design).[46]

The H-2001 Crude heater is already equipped with ultra low-NO_x burners. The burner design incorporates features that improve combustion dynamics, with the result that the uncontrolled PM emissions (as measured by source test) are very low (0.5 lb/thousand gallons,[47] compared with the uncontrolled emission factor of 2.0 lb/thousand gallons in AP-42). It is not expected that further PM reductions can be achieved through design changes.

Based on the low uncontrolled emission factor; the small amount of particulate to be controlled (less that 5 TPY from oil combustion); the type of oil burned (low sulfur distillate fuel); and commonly applied controls as described in AP-42, RACT for $PM_{2.5}$ for H-2001 Crude Heater is best practices for burner maintenance.

[46] AP-42 (May 2010) p. 1.3-6
[47] 2011 Emission Inventory

State of Alaska Department of Environmental Conservation

Evaluation of Reasonably Available Control Technologies (RACT) to Support the Development of the Fairbanks $PM_{2.5}$ SIP

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I. Executive Summary

The purpose of this report is to present an evaluation of emission control technologies that are candidates for selection as reasonably available control technologies (RACT) that could be implemented to advance the timeframe for attaining the annual Fine Particulate Matter ($PM_{2.5}$) National Ambient Air Quality Standard (NAAQS)[1] in the Fairbanks North Star Borough (FNSB). Section I (this section) provides a brief discussion of the results of the evaluation. Section II discusses FNSB's designation by the U.S. Environmental Protection Agency (EPA) as a nonattainment area for $PM_{2.5}$ and refers to the statutory requirements that Alaska must meet in response to this designation. Section III describes the major point source facilities found in the FNSB. Section IV provides additional information on individual emission units at these facilities as well as the control technologies currently in use. Section V describes the control technologies that were considered to be candidates for RACT for each source category, and analysis discussion of the estimated costs and benefits of each candidate technology. Section VI presents the recommended RACT for each emission source type. Detailed individual RACT determinations are provided in Appendix III.D.5.7

Information supplied by the Alaska Department of Environmental Conservation (ADEC) was used to identify individual emission units that comprise the significant sources of $PM_{2.5}$, SO_2, and NO_x emissions at the FNSB major point source facilities. These emission units were grouped by source category types (i.e., coal-fired boilers, gas turbines, process heaters, etc.). For each of the source category types, emission control technologies were identified that could be potential candidates for selection as RACT. A review of available literature, including RACT analyses performed by other States, was performed to gather information on the expected efficiency, capital cost, and cost-effectiveness for each of the candidate technologies. Other site-specific factors, such as the availability of various types of clean fuel in Fairbanks, were also considered in evaluating the candidate technologies.

RACT determinations were made for those emission units at major point source facilities having actual emissions greater than 5 tons per year of any one of the following pollutants: $PM_{2.5}$, NO_x, or SO_2. Emission units at area sources were not included in this RACT analysis; such units will be addressed, if necessary, during the development of Reasonably Available Control Measures (RACM). Emission units with actual emissions below 5 TPY were not evaluated, because EPA guidance, described below, indicates that that further control of such sources, individually, is inefficient in reducing area-wide concentrations of PM.

[1] 40 CFR 50.13

The emission units for which RACT determinations were made include boilers, process heaters, and turbines. The $PM_{2.5}$ RACT is a fabric filter system for boilers. Additional $PM_{2.5}$ controls are considered unreasonable for process heaters and turbines. RACT for the SO_2 emissions is the use of low sulfur fuel for all of the fuel combustion sources. RACT controls were not recommended for NO_x because control of NO_x is not an efficient method for reducing ambient $PM_{2.5}$ in Fairbanks.

All of the emission units that were reviewed are already implementing the emission control techniques identified as RACT. All of the coal-fired units are already equipped with fabric filters, and Alaskan coal has a very low sulfur content. The costs associated with switching from high- to low-sulfur liquid fuels were too high to be deemed to be source specific RACT for those sources currently using liquid fuels.

II. Background

On November 13, 2009 the U.S. Environmental Protection Agency (EPA) designated a portion of the FNSB as a nonattainment area[2] for the 2006 24-hour $PM_{2.5}$ National Ambient Air Quality Standards (NAAQS). This designation obligates the State to develop an approvable State Implementation Plan (SIP) to demonstrate attainment of the NAAQS. Requirements for the preparation, adoption, and submittal of a SIP are outlined under 40 CFR 51, Subpart Z. Paragraph (a) of section 51.1010 states:

> *(a) For each $PM_{2.5}$ nonattainment area, the State shall submit with the attainment demonstration a SIP revision demonstrating that it has adopted all reasonably available control measures (including RACT for stationary sources) necessary to demonstrate attainment as expeditiously as practicable and to meet any RFP requirements. The SIP revision shall contain the list of the potential measures considered by the State, and information and analysis sufficient to support the State's judgment that it has adopted all RACM, including RACT.*

As defined in 40 CFR 51.100(o), RACT "means devices, systems, process modifications, or other apparatus or techniques that are reasonably available taking into account: (1) The necessity of imposing such controls in order to attain and maintain a national ambient air quality standard, and (2) The social, environmental, and economic impact of such controls." The State's SIP for demonstrating attainment with the $PM_{2.5}$ NAAQS must, therefore, include analyses of the emission control technologies currently in use at the applicable stationary sources and whether there are additional emissions reductions that could be achieved by applying other controls that are found to be reasonable. This report presents the results of these analyses.

As described in more detail in Section III, there are six major point source facilities in the FNSB. These six major point source facilities are all operating under Title V permits. A modeling analysis[3] was performed by the State using a dispersion model to evaluate the impact of the point source facilities on the observed $PM_{2.5}$ values at the monitor located at the Fairbanks state office building. Cumulatively, according to information provided by ADEC, these six major point source facilities are estimated to contribute approximately 5 percent of the direct $PM_{2.5}$ on the state office building monitor filter[4] and up to an additional 15 percent of the secondary sulfate.[5] Nitrates account for less than 5

[2] 74 FR 58688 (November 13, 2009); Designations effective December 14, 2009.
[3] Appendix III.D.5.8 Weight of Evidence/ Using the CALPUFF dispersion model to characterize Fairbanks power plant plumes.
[4] Appendix III.D.5.7 Precursors.
[5] Fairbanks PM 2.5 SIP Chapter III.D.5.8 Modeling

percent of the overall mass collected on the filters.[6] Therefore, although NO_x control technologies are discussed in this analysis, the installation of additional NO_x controls on the point source facilities would have little impact on ambient $PM_{2.5}$ concentrations.

Some of the FNSB major point source facilities include numerous small, low emitting sources of $PM_{2.5}$, SO_2, and NO_x.[7] Several other emission units that would have large uncontrolled emissions are already so well controlled that their potential emissions of $PM_{2.5}$ are very low.[8] Additional PM controls for these emission units would not be cost effective because of the very low emission reductions that could be achieved. For example, an annualized capital cost of as low as $30,000 to reduce particulate emissions from a small oil-fired process heater that emits 3 tons of $PM_{2.5}$ per year would have a cost effectiveness of over $10,000 per ton even without considering any operating cost for the controls. Most viable emissions control techniques actually cost at least an order of magnitude more than the $30,000 used in the hypothetical example. In its 2006 Regulatory Impact Analysis for the Particulate Matter National Ambient Air Quality Standards, EPA stated that sources emitting less than 5 tons per year "were likely to have existing controls in place, and further control was typically not cost-effective and inefficient in reducing area-wide concentrations of PM." [9] In light of this statement by EPA, only those emission units having the potential to emit greater than 5 tons per year of $PM_{2.5}$ (or one of its precursors, SO_2 or NO_x, for which the same rationale applies) were evaluated individually for RACT.[10]

[6] Appendix III.D.5.7 Precursors.
[7] Title V Permit applications for Fort Wainwright, North Pole Refinery, and University of Alaska. See Section IV below.
[8] Title V Permit applications for Fort Wainwright, Chena Power Plant, Zehnder Power Plant, and University of Alaska. See Section IV below.
[9] EPA, *Regulatory Impact Analysis for 2006 National Ambient Air Quality Standards for Particle Pollution* (October 2006). p. 1-12
[10] This conclusion does not rule out the possibility that the cumulative impact of numerous small sources may be considerable, and worth controlling as a group. For example, reduction of SO_2 emissions from area combustion sources by means of stringent limit on fuel sulfur content may be a cost effective control technique. Evaluation of such measures is beyond the scope of this analysis.

III. Description of Major Point Source Facilities

As mentioned earlier, the FNSB includes six major point source facilities that are estimated to contribute approximately 5 percent of the direct $PM_{2.5}$ and an additional 15 percent of the secondary sulfate measured at the Fairbanks state office building monitoring site. Of the six major point source facilities, five are operating power plants that produce electricity and, in some cases, provide steam and hot water for comfort heating in nearby commercial/residential buildings. The sixth facility is a refinery that has numerous emission points related to its process operations. The following paragraphs present brief descriptions of each of the six major point source facilities. Additional information on the major point source facilities' emissions and emission controls is presented in Section IV of this report.

Discussion and assessment of non-major point source facilities (also known as "area sources") is beyond the scope of this analysis.

A. Aurora Energy, LLC, Chena Power Plant[11]

Aurora Energy, LLC, owns and operates the Chena Power Plant, which provides steam and electrical power to the City of Fairbanks. The facility not only produces electricity for the Fairbanks area but also operates two district heat systems (one steam and the other hot water) to provide heat to nearby commercial/residential buildings. The Chena facility has four coal-fired boilers, with three being overfeed traveling grate stokers and one being a spreader stoker. The three traveling grate boilers (identified as Chena 1, 2, and 3) were installed in the 1950s and the maximum design power production of each is 5 megawatts (MW_e). The spreader stoker unit (identified as Chena 5) was installed in 1970 and has a maximum power production rating of 20 MW_e. The four coal-fired boilers are controlled with a single full stream baghouse (installed in 2007) through which all of the combined exhaust gas flows.[12]

B. Doyon Utilities, LLC, Ft. Wainwright Power Plant

Fort Wainwright has a Central Heat and Power Plant (CHPP) that generates steam and electricity to meet the heating and electricity demands of the base. The CHPP has six identical 230 MMBtu/hr (23 MW_e) coal-fired boilers (identified as Boiler 3 through 8).[13] The boilers were built in 1953 and each is controlled with a full stream baghouse.[14] The

[11] The following information comes from *Title V Statement of Basis, Revision 1* (October 9, 2006) p. 2.
[12] *Renewal Application for Title V Permit* (October 2010). p. 2.
[13] *Revised Title V Renewal Permit Application Package for Fort Wainwright, Alaska* (March 2008), p. 4
[14] *Revised Title V Renewal Permit Application Package for Fort Wainwright, Alaska* (March 2008), p. 8

facility also operated a coal preparation plant that prepares the coal for the boilers.[15] The emission units at the coal preparation plant are controlled by baghouses. [16] Fort Wainwright's CHPP also has a 2 megawatt Black Start generator that meets the EPA Tier II requirements.[17]

Fort Wainwright also has several insignificant sources that emit $PM_{2.5}$, NO_x, and SO_2. The insignificant sources are not controlled and are spread out across the base. The insignificant units include 16 generator sets, 5 lift stations, 4 well pumps, and wind erosion and drop loading at the coal pile.[18]

C. Flint Hills Resources, North Pole Refinery

The North Pole Refinery processes North Slope crude oil and supplies gasoline, jet fuel, heating oil, diesel, gasoil and asphalt to Alaska markets. Most of the current combustion emission units at the facility were installed either in the mid-1980s or during renovations in 1998.[19] There are four combustion devices with actual emissions greater than 5 TPY (three crude heaters and one steam generator), as well as a number of smaller combustion devices..[20] The combustion units burn light straight run (LSR)[21], fuel gas, waste gas, or diesel depending on the unit. In addition, the refinery has numerous VOC sources.

D. Golden Valley Electric Association (GVEA)

Golden Valley Electric Association (GVEA) operates two electric generating facilities within the Fairbanks North Star Borough; the North Pole Power Plant and the Zehnder Power Plant.

D.1. The North Pole Power Plant has three generating units. One unit is a base load unit and operates continuously except for periods of repair or maintenance.[22] This unit was installed in 2005 and is a GE LM6000 Gas Turbine fueled with low sulfur naphtha and LSR fuel and equipped with water injection for NO_x control and a CO oxidation

[15] *Revised Title V Renewal Permit Application Package for Fort Wainwright, Alaska* (March 2008), p. 4
[16] 2011 Emission Inventory
[17] 2011 Emission Inventory
[18] *Revised Title V Renewal Permit Application Package for Fort Wainwright, Alaska* (March 2008), p. 42
[19] *Department of Environmental Conservation Air Quality Operating Permit No. AQ0071TVP02* (April 23, 2010) Section 2, Table A
[20] 2011 Emission Inventory
[21] LSR is a very low sulfur (0.0025 wt. percent sulfur) liquid fuel, with properties similar to gasoline. See 2011 Emission Inventory
[22] *Application for Renewal of Title V Permit AQ0110TVP02, Golden Valley Electric Association North Pole Power Plant* (May 2013), Form A3

catalyst.[23] The other two units at the North Pole Power Plant are GE Frame 7 fuel oil-fired regenerative Gas Turbines, installed in 1976 and 1977, and are now operated in peak load periods only.[24] This facility also has a permit to install a fourth gas turbine similar to the base unit, but the unit has not yet been installed.[25]

D.2. The Zehnder Power Plant has four units. Two of the units are GE Frame 5 fuel oil-fired gas turbines installed in 1971 and 1972.[26] The other two units are GE fuel oil-fired electro-motive diesel engines, installed in 1970, that are used for emergency power and also serve as black start engines for the GVEA generation system.

E. University of Alaska, Fairbanks Campus Power Plant

The University of Alaska's Utilities Division operates a combined heat and power plant that provides electric power, steam heat, domestic water and chilled water to campus. The power plant has two 84.5 MMBtu/hr coal-fired boilers (identified as Boilers 1 and 2) that were installed in 1962 and two 181 MMBtu/hr dual-fired (gas, liquid, or coal slurry) boilers (identified as Boiler 3, installed in 1970, and Boiler 4, installed in 1987) that generate the steam that powers the three turbines.[27] The coal-fired boilers are controlled by a multi cyclone separator that came as part of the unit followed by an add-on baghouse installed in 1982.[28] The dual-fired boilers both have low NO_x burners.[29] The power plant also has one 13,226 hp diesel generator, two backup 125 kW diesel generators, and one backup oil-fired boiler.[30] The generator was originally designed to burn a coal slurry and was installed with an SCR unit.[31] The SCR is still in operation; however, the generator burns diesel fuel instead of the coal slurry.[32]

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[23] *Application for Renewal of Title V Permit AQ0110TVP02, Golden Valley Electric Association North Pole Power Plant* (May 2013), Form A2
[24] *Application for Renewal of Title V Permit AQ0110TVP02, Golden Valley Electric Association North Pole Power Plant* (May 2013), Form A3
[25] *Application for Renewal of Title V Permit AQ0110TVP02, Golden Valley Electric Association North Pole Power Plant* (May 2013), Form A2
[26] *Revision to Application for Renewal of Title V Permit AQ0109TVP02, Golden Valley Electric Association Zehnder Power Plant* (October 2013), Form B
[27] *Application for Renewal of an Air Quality Control Operating Permit, University of Alaska--Fairbanks Campus Power Plant* (June 2012), Section 5, Table A
[28] *Application for Renewal of an Air Quality Control Operating Permit, University of Alaska--Fairbanks Campus Power Plant* (June 2012), Section 1, Table 1-1
[29] *Application for Renewal of an Air Quality Control Operating Permit, University of Alaska--Fairbanks Campus Power Plant* (June 2012), Section 4, Page 21
[30] *Application for Renewal of an Air Quality Control Operating Permit, University of Alaska--Fairbanks Campus Power Plant* (June 2012), Section 4, Table A
[31] *Application for Renewal of an Air Quality Control Operating Permit, University of Alaska--Fairbanks Campus Power Plant,* Section 4, Table A, Note 3
[32] *Application for Renewal of an Air Quality Control Operating Permit, University of Alaska--Fairbanks Campus Power Plant* (June 2012), Section 4, Table A, Note 3

The University is planning to construct two new coal and biomass-fired boilers that will be controlled with lime injection and a fabric filter.[33] The new boilers will replace boilers 1 and 2 while greatly reducing the need for boilers 3 and 4.[34] They are scheduled to start operations in 2017.[35]

The University also operates a diesel fired medical waste incinerator that is mostly used for pathological waste.[36] The University also has several insignificant sources that emit $PM_{2.5}$, NO_x, and SO_2. The insignificant sources are not controlled and are spread out across the campus. The insignificant units include fifteen (15) boilers, two (2) generators, three (3) furnaces, one (1) grain dryer, one (1) hot water heater, one (1) classroom engine.[37] All of the insignificant sources burn diesel fuel. The sulfur content in the fuel is not regulated directly and the facility does not burn low sulfur diesel fuel, but SO_2 emissions from these sources are limited to 500 ppm averaged over three hours.[38]

[33] *Application for a Prevention of Significant Deterioration Air Quality Construction Permit* (January 2013), p. 1
[34] *Application for a Prevention of Significant Deterioration Air Quality Construction Permit* (January 2013), p. 1.
[35] *Application for a Prevention of Significant Deterioration Air Quality Construction Permit* (January 2013), p. 8.
[36] *Application for Renewal of an Air Quality Control Operating Permit, University of Alaska--Fairbanks Campus Power Plant* (June 2012), Section 4, Table 2-4
[37] *Application for Renewal of an Air Quality Control Operating Permit, University of Alaska--Fairbanks Campus Power Plant* (June 2012), Section 4, Table 2-4
[38] *Application for Renewal of an Air Quality Control Operating Permit, University of Alaska--Fairbanks Campus Power Plant, Section 4* (June 2012), Permit Conditions13 and 24

IV. Emission Units and Current Emission Levels

This section presents information on the significant emission units (defined in this analysis as those that have the potential to emit greater than 5 tons of $PM_{2.5}$, SO_2, or NO_x emissions per year) found at each of the FNSB major point source facilities. In the first subsection, each facility is addressed in a separate table that shows the facility's emission units current control technology, control efficiency, and the actual and potential emissions of $PM_{2.5}$, NO_x and SO_2. All of this information except the actual reported emissions was taken from the facilities' Title V permits and applications. The actual emissions are those reported by the facilities in their 2011 annual emissions inventory report. In a few cases, the reported actual emissions are higher than the calculated potential to emit (PTE) in the Title V permit information.

For some emission units, the PTE is the maximum allowable emissions, and reflects enforceable emission limits. For such units, actual emissions cannot exceed the PTE without being out of compliance. However, there are many units for which the PTE is an estimate, not an enforceable limit, calculated for the sole purpose of determining applicability of certain programs, including the Title V permit program. One option recommended by EPA to calculate PTE is to use of average emission rates from agency references such as AP-42, and assume continuous operation at full capacity. See, e.g., EPA Potential to Emit: A Guide for Small Businesses, (October 1998).

If subsequent source tests indicate that the actual emission factor is higher than the one used to calculate PTE, then the actual emissions may exceed the PTE without resulting in noncompliance. This is the situation for all but one of the emission units where actual emissions exceed PTE.

The one exception is Chena Boiler #5, which reported an actual annual average firing rate 20% above the boiler's rated capacity. After investigation, it was determined that this unit has not been modified. The boiler's rated capacity is simply much lower than its actual physical capacity.

The second subsection presents the emission units grouped by source category types. This allows a comparison of the different control technologies for the existing sources in the FNSB.

EMISSION UNITS BY FACILITY

A. Aurora Energy, LLC, Chena Power Plant

Description	Control Device	$PM_{2.5}$			NO_x			SO_2		
		Control Efficiency	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)
Coal-fired boilers (units 1, 2, 3, & 5, combined)	Baghouse	99.9%[f]	7.81[e]	5.0[d]	None	792.7[e]	744.6[c]	None	838.9[e]	1,294.7[a,c]
Coal preparation plant	Baghouse	99.9%[f]	0.28[e]	0.34[d]	NA[b]	NA	NA	NA	NA	NA
Ash vacuum pump exhaust	Baghouse	99.9%[f]	0.197[e]	0.23[d]	NA	NA	NA	NA	NA	NA

[a] Based on average sulfur content of coal of 0.26 wt. percent (Title V Permit Application Table 2-8); reported sulfur content in 2011 emission inventory was 0.13 wt. percent

[b] NA means that the pollutant is not emitted by the source type

[c] Data from 2010 Title V Permit Application Table 2-2.

[d] Data from 2010 Title V Permit Application Table 2-6d.

[e] Data from 2011 Emission Inventory (2011 EI SS-315_Chena)

[f] $PM_{2.5}$ Control Efficiency is from Chapter 6, OAQPS Control Cost Manual (Sixth Edition), EPA, Office of Air Quality Planning and Standards, Emissions Standards Division, January 2002 (EPA 452/B-02-001).

Note that actual 2011 emissions exceed the reported PTE for the coal-fired boilers. This discrepancy is due to two things. First, the PTE calculations are based on emission factors developed from a 2007 source test, while the actual emissions are based on emission factors developed from a 2011 source test. Second, Unit 5, the largest boiler, reported an annual average firing rate 20% above its rated capacity. After investigation, it was determined that this unit has not been modified. The boiler's rated capacity is simply much lower than its actual physical capacity.

B. Doyon Utilities, LLC, Ft. Wainwright Power Plant

Description	Control Device	$PM_{2.5}$			NO_x			SO_2		
		Control Efficiency	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)
Coal-fired boiler 3	Baghouse	99.9%[a]	2[d]	5.4[c]	None	101[d]	767.9[c]	None	109[d]	2,352.0[c]
Coal-fired boiler 4	Baghouse	99.9%[a]	2[d]		None	101[d]		None	99[d]	
Coal-fired boiler 5	Baghouse	99.9%[a]	2[d]		None	117[d]		None	126[d]	
Coal-fired boiler 6	Baghouse	99.9%[a]	1[d]		None	91[d]		None	87[d]	
Coal-fired boiler 7	Baghouse	99.9%[a]	3[d]		None	197[d]		None	171[d]	
Coal-fired boiler 8	Baghouse	99.9%[a]	2[d]		None	168[d]		None	122[d]	
Coal Preparation Plant South	Baghouse	99.9%[a]	0.596[d]	14[c]	NA[b]	NA	NA	NA	NA	NA
Ash Handling	Baghouse	99.9%[a]	None reported[d]	11.8[c]	NA	NA	NA	NA	NA	NA

[a] $PM_{2.5}$ Control Efficiency is from Chapter 6, OAQPS Control Cost Manual (Sixth Edition), EPA, Office of Air Quality Planning and Standards, Emissions Standards Division, January 2002 (EPA 452/B-02-001).

[b] NA means that the pollutant is not emitted by the source type

[c] *Revised Title V Renewal Permit Application Package for Fort Wainwright, Alaska* (March 2008), p. 9.

[d] 2011 Emission Inventory

Note that actual 2011 $PM_{2.5}$ emissions exceed the reported PTE for the coal-fired boilers. This discrepancy is because, the PTE calculations are based on emission factors developed from a 2005 source test, while the actual emissions are based on emission factors from EPA's WebFIRE database.

C. Flint Hills Resources, North Pole Refinery

Description	Control Device	$PM_{2.5}$			NO_x			SO_2		
		Control Efficiency	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)
H-241 Crude Heater (120 MMBtu/hr)		None	2.0[b]	3.0[c]	None	44.6[b]	65.4[c]	None	1.0[b]	1.5[c]
H-1001 Crude Heater (70 MMBtu/hr)		None	0.3[b]	0.5[c]	None	20.6[b]	38.6[c]	None	0.9[b]	1.6[c]
B-401 Steam Generator		None	0.3[b]	0.6[c]	None	11.8[b]	23.5[c]	None	0.1[b]	0.2[c]
H-2001 Crude Heater[a]	ULNB	None	5.1[b]	6.7[c]	None	62.0[b]	81.5[c]	None	3.3[b]	4.3[c]

[a] The crude heater was grouped with H-3700 Asphalt Heater which had an actual NO_x emissions of 0.81 tpy compared to 52.2 tpy from H-2001. In the analysis we assumed that the crude heater was the significant unit and included in the RACT analysis.

[b] 2011 Emission Inventory

[c] PTE Calculations based on rated capacity and emission factors in Emission Inventory, and operation at full capacity for 8760 hours per year.

D.1 Golden Valley Electric Association (GVEA), North Pole Plant

Description	Control Device	$PM_{2.5}$[a]			NO_x			SO_2		
		Control Efficiency	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)
GT#2 Gas Turbine	None		131[c]	141[d]	Limited to 7,992 hr/yr	464[c]	3,733[d]	Combined limit of 24,500 lb/day[e]	326[c]	4079[d]
GT#1 Gas Turbine	None		15.5[c]	290[d]		50.3[c]			42.3[c]	
GT#3 Gas Turbine	NO_x - Water Injection CO - Oxidation Catalyst[f]		16.8[c]	25.6[d]	Limited to 1,600 tpy[d]	367[c]	1,600[d]	Limited to naphtha or LSR to .05%S[e]	1.86[c]	192[d]
GT#4 Gas Turbine[b]	NO_x - water injection[f]		--	1.2[d]		--		Limited to Jet A to 0.3%S[e]	--	31[d]

[a] Assume that PM_{10} equals $PM_{2.5}$ since no other data is available in the permit application.

[b] This unit is included in the pending permit application but had not yet been installed in 2011.

[c] 2011 Emission Inventory

[d] *Application for Renewal of Air Quality Operating Permit North Pole Power Plant* (2007), Attachment 1, Table 1.

[e] *Application for Renewal of Air Quality Operating Permit North Pole Power Plant* (2007), Attachment 1, Table 5.

[f] *Application for Renewal of Air Quality Operating Permit North Pole Power Plant* (2007), Attachment 2, Table 1.

D.2 Golden Valley Electric Association (GVEA), Zehnder Power Plant

Description	Control Device	$PM_{2.5}$[a]			NO_x			SO_2		
		Control Efficiency	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)
Diesel Generator #2	None	None	0.007[c]	8.5[b]	None	0.393[c]	392[b]	None	0.012[c]	580 TPY total facility permit limit
Diesel Generator #1	None	None	0.028[c]	8.5[b]	None	1.58[c]	392[b]	None	0.048[c]	
Combustion Gas Turbine #1	None	None	16.05[c]	14.1[b]	None	54.3[c]	1033[b]	None	39.83[c]	
Combustion Gas Turbine #2	None	None	10.77[c]	14.1[b]	None	36.4[c]	1033[b]	None	25.73[c]	

[a] Assume that PM_{10} equals $PM_{2.5}$ since no other data is available in the permit application.

[b] *Application for Renewal of Air Quality Operating Permit Zehnder Power Plant (2007),* Attachment 1, Table 1

[c] 2011 Emission Inventory

E. University of Alaska, Fairbanks Campus Power Plant

Description:	Control Device	$PM_{2.5}$			NO_x			SO_2		
		Control Efficiency [a]	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)
Coal-fired Boiler #1	Multicyclone with a Baghouse	99.9%	3.62[g]	7.3[c]	None	250[g]	212.9[b]	Limited to 500ppm S[e]	123.8[g]	220.1[d]
Coal-fired Boiler #2	Multicyclone with a Baghouse	99.9%	3.77[g]	7.3[c]	None	260[g]	212.9[b]		128.9[g]	220.1[d]
Dual Fuel-Fired Boiler #3	Low NO_x Burners	None	2[g]	11.6[c]	30-50%[f]	5.72[g]	138.8[b]		17.7[g]	410.6[d]
Dual Fuel-Fired Boiler #4	Low NO_x Burners	None	1.27[g]	11.6[c]	30-50%[f]	3.63[g]			11.23[g]	410.6[d]

[a] $PM_{2.5}$ Control Efficiency is from Chapter 6, OAQPS Control Cost Manual (Sixth Edition), EPA, Office of Air Quality Planning and Standards, Emissions Standards Division, January 2002 (EPA 452/B-02-001).

[b] *Application for Renewal of an Air Quality Control Operating Permit* (June 2012) Table 2-4

[c] *Application for Renewal of an Air Quality Control Operating Permit* (June 2012) Table 2-6c

[d] *Application for Renewal of an Air Quality Control Operating Permit* (June 2012) Table 2-8

[e] *Application for Renewal of an Air Quality Control Operating Permit* (June 2012) Permit Condition 13

[f] EPA, *Technical Bulletin: Nitrogen Oxides (NO_x), Why and How They Are Controlled* (November 1999), Table 16

[g] 2011 Emission Inventory

V. Candidates for Reasonably Available Control Technology

This section presents discussions of the various control technologies that were considered as candidates for selection as RACT for the applicable source categories. The first subsection (A) presents those technologies that primarily control emissions of direct $PM_{2.5}$. Subsections B and C present technologies that primarily control emissions of $PM_{2.5}$ and precursors SO_2 and NO_x, respectively.

A. $PM_{2.5}$ Control Technologies

The $PM_{2.5}$ control technologies that were identified as potentially applicable to the sources being evaluated for RACT are presented below in a top down order: the technology with the theoretically highest potential $PM_{2.5}$ reduction being first and the remaining technologies in descending order of reduction effectiveness:

- Fabric Filters
- Electrostatic Precipitators
- Wet Scrubbers
- Controls for Stationary Diesel Engines

Provided below is a general description of each of these technologies, as well as a rough assessment (~+/- 30%) of the associated costs. The technical feasibility of each control device, as it specifically applies to the Fairbanks area will be discussed in Section VI. The cost and cost effectiveness values presented below were taken from EPA publications available on the Clean Air Technology Center at EPA's website: www.epa.gov/ttn/catc/products.[39] The cost information presented here is intended to be representative of the typical costs of the control technologies but does not account for numerous variables that may be encountered by a specific facility. In addition, the cost effectiveness values are typical of those that would be expected when applying the control technologies to an uncontrolled source. For these reasons, a more detailed assessment was made, as appropriate, for each of the emission units being evaluated for RACT. This detailed assessment is provided in Appendix XXX.

[39] *Chemical Engineering*, May 2012, p. 64. Costs were first determined using the methods described in the EPA publications, then adjusted to 2012 dollars using the ratio of the CE Composite Index for 2012 and the reference year for the cost calculations. The index in 2002 (most of the costs in the EPA references were reported in 2002 dollars) was 395.6. The index value used for 2012 was 584.6. Costs in 2002 dollars were adjusted to 2012 dollars using a factor of 584.6/395.6 = 1.48.

A1. Fabric Filters[40]

Fabric filters consist of one or more isolated compartments containing rows of fabric bags in the form of round, flat, or shaped tubes, or pleated cartridges. Particle laden gas passes through the fabric, particles are retained on the upstream face of the bags, and the cleaned gas stream is vented to the atmosphere. Fabric filters collect particles with sizes ranging from submicron to several hundred microns in diameter at efficiencies generally in excess of 99 percent. Fabric filter removal efficiency is relatively level across the particle size range, so that excellent control of PM_{10} and $PM_{2.5}$ can be obtained. The layer of dust, or dust cake, collected on the fabric is primarily responsible for such high efficiency. Gas temperatures up to about 500°F, with surges to about 550°F can be accommodated routinely in some configurations. Most of the energy used to operate the system appears as pressure drop across the bags and associated hardware and ducting. Typical values of system pressure drop range from about 5 to 20 inches of water.

Fabric filters are used where high efficiency particle collection is required. Limitations are imposed by gas characteristics (temperature and corrosivity) and particle characteristics (primarily stickiness) that affect the fabric or its operation and that cannot be economically accommodated. Fabric filter costs vary depending on the type of fabric filter, the air to cloth ratio, and the filter type used. According to cost information presented in EPA publications "EPA-452/F-03-025 and EPA-452/F-03-026," typical capital costs for pulse jet and reverse air fabric filters range from $9 to $128 per standard cubic feet per minute (scfm) of air flow. Annualized costs range from $9 to $75 per scfm and the cost effectiveness ranges from $63 to $508 per ton of PM controlled.

A2. Electrostatic Precipitators[41]

Electrostatic precipitators (ESPs) use electrical fields to remove particulate from flue gas. In an ESP, an electric field is maintained between high-voltage discharge electrodes, typically wires or rigid frames, and grounded collecting electrodes, typically plates. A corona discharge from the discharge electrodes ionizes the gas passing through the precipitator, and gas ions subsequently ionize particles in the gas stream. The electric field then drives the negatively charged particles to the collecting electrodes. Because ESPs act only on the particulate to be removed and only minimally hinder flue gas flow, they have very low pressure drops and low energy requirements and operating costs. While several factors determine ESP removal efficiency, size is of paramount

[40] Information in this section is from EPA, *Air Pollution Control Technology Fact Sheet: Fabric Filter – Pulse-Jet Cleaned Type (EPA-452/F-03-025)* and *Air Pollution Control Technology Fact Sheet: Fabric Filter – Reverse Air Cleaned Type (EPA-452/F-03-026).*
[41] Information in this section is from EPA, *Air Pollution Control Technology Fact Sheet: Dry Electrostatic Precipitator (ESP) –Wire-Plate Type (EPA-452/F-03-028).*

importance. Size determines treatment time: the longer a particle spends in the ESP, the greater its chance of being collected, other things being equal.

Factors limiting ESP performance are flow non-uniformity and re-entrainment. More uniform flow will ensure that there are no high gas velocities, short treatment time paths through the ESP. Attaining flow uniformity also will minimize gas flows bypassing the electrical fields.

ESP overall (mass) collection efficiencies can exceed 99.9%, and efficiencies in excess of 99.5% are common. ESPs with high overall collection efficiencies will have high collection efficiencies for particles of all sizes, so that excellent control of PM_{10} and $PM_{2.5}$ will be achieved with well-designed and operated ESPs. According to EPA publication "EPA-452/F-03-028," typical ESP capital costs range from $15 to $50 per scfm of exhaust gas. The annualized cost ranges from $6 to $57 per scfm and the cost effectiveness for PM control ranges from $57 to $355 per ton. In general, smaller units controlling a low concentration waste stream will be towards the high end of the cost range.

A3. Wet Scrubbers[42]

Wet scrubbers control particulates by bringing them in contact with a liquid (in the form of droplets, foam, or bubbles) and then collecting the liquid along with the adhering particulates. There are several wet scrubber designs available commercially, including the venturi, spray tower, packed bed, and impingement plate scrubbers. Collection efficiencies for wet scrubbers are highly variable. Most conventional scrubbers can achieve high collection efficiencies for particles greater than 5-10 micrometers in diameter but they are generally much less effective for particles less than 5 micrometers. Properly designed venturi scrubbers, however, are capable of controlling fine particulate matter and typically provide high removal efficiencies of particles between 0.5 and 5.0 micrometers in diameter. In most applications, venturi scrubbers achieve reductions of 80 to 90% of $PM_{2.5}$ emissions. Although the capital cost for venturi scrubbers is much lower than the costs for fabric filters and ESPs, the high pressure drop through venturi scrubber systems typically results in relatively high energy use. In addition, the operation of scrubbers generates large volumes of water that must be properly treated or disposed.

EPA publication "EPA-452/F-03-017" indicates that the capital costs of venturi scrubbers range from $4 to $32 per scfm. Annualized costs range from $9 to $291 per scfm, and the cost effectiveness values range from$105 to $3600 per ton of PM.

[42] Information in this section is from EPA, *Air Pollution Control Technology Fact Sheet: Packed-Bed/Packed Tower Wet Scrubber (EPA-452/F-03-015)* and *Air Pollution Control Technology Fact Sheet: Venturi Scrubber (EPA-452/F-03-017).*

EPA publication "EPA-452/F-03-015" indicates that the capital costs of packed bed scrubbers range from $17 to $83 per scfm. Annualized costs range from $26 to $117 per scfm, and the cost effectiveness values range from $166 to $828 per ton of PM.

B. SO_2 Control Technologies

There are limited SO_2 control technologies options available for consideration for the Fairbanks Area. The control technologies considered are:

- Wet scrubber
- Dry scrubber
- Spray dry scrubber
- Fuel sulfur reduction

Provided below is a general description of each of these options. The technical feasibility of each control device, as it specifically applies to the Fairbanks area will be discussed in Section VI.

B1. Wet Scrubbers[43]

In addition to their use as particulate control devices (discussed above), wet scrubbers are used extensively to control emissions of inorganic contaminants, including acid gases such as sulfur dioxide (SO_2). Wet scrubbers rely primarily on the absorption process to remove these soluble contaminants from the exhaust gas stream. Wet scrubbing devices that are based on absorption principles include packed towers, plate (or tray) columns, venturi scrubbers, and spray chambers. Removal efficiencies for gas absorbers vary for each pollutant-solvent system and with the type of absorber used. Pollutant removal may also be enhanced by manipulating the chemistry of the absorbing solution so that it reacts with the pollutant(s), e.g., caustic solution for acid-gas absorption vs. pure water as a solvent. Chemical absorption may be limited by the rate of reaction, although the rate limiting step is typically the physical absorption rate, not the chemical reaction rate.

Most absorbers have removal efficiencies in excess of 90%, and packed tower absorbers may achieve efficiencies as high as 99.9% for some pollutant-solvent systems. As discussed above, typical capital costs for wet scrubbers average from about $4 to $83 per scfm. Operating costs for wet scrubbers used to control SO_2 are somewhat higher than for scrubbers used strictly for PM control because of the added cost of the caustic

[43] Information in this section is from EPA, *Air Pollution Control Technology Fact Sheet: Packed-Bed/Packed Tower Wet Scrubber (EPA-452/F-03-015)* and *Air Pollution Control Technology Fact Sheet: Venturi Scrubber (EPA-452/F-03-017).*

solution that is typically added and because of the additional treatment that may be required for the wastewater.

B2. Dry Scrubbers[44]

Dry systems involve injection of dry alkali substances (usually some form of lime), which is removed from the exhaust by a fabric filter or ESP. Sorbent may be mixed with the fuel or injected in the exhaust. Dry scrubbing is not commonly used for coal-fired power plants. EPA considers dry scrubbers to be a promising technology, but one that becomes less cost effective as the boiler size decreases.

An even distribution of sorbent across the reactor and adequate residence time at the proper temperature are critical for high SO_2 removal rates.

> "Dry scrubbers have significantly lower capital and annual costs than wet systems because they are simpler, demand less water and waste disposal is less complex. Dry injection systems install easily and use less space, therefore, they are good candidates for retrofit applications. SO_2 removal efficiencies are significantly lower than wet systems, between 50% and 60% for calcium based sorbents.
>
> "Sodium based dry sorbent injection into the duct can achieve up to 80% control efficiencies (Srivastava 2001). Dry sorbent injection is viewed as an emerging SO_2 control technology for medium to small industrial boiler applications.[45] Newer applications of dry sorbent injection on small coal-fired industrial boilers have achieved greater than 90% SO_2 control efficiencies."[46]

Cost information for dry scrubbers is not readily available.

B3. Spray Dry Scrubbers[47]

Spray dry systems introduce the absorbent in a slurry that is fully evaporated by the exhaust stream, resulting in dry particulates that are removed by fabric filter or ESP. They differ from dry systems because the absorbent is introduced in liquid form. They differ

[44] Information in this section is from EPA, *Air Pollution Control Technology Fact Sheet: Packed-Bed/Packed Tower Wet Scrubber (EPA-452/F-03-015)* and *Air Pollution Control Technology Fact Sheet: Venturi Scrubber (EPA-452/F-03-017).*
[45] Although this statement is based on EPA guidance that is 11 years old, it remains EPA's current guidance.
[46] EPA, *Air Pollution Control Technology Fact Sheet: Flue Gas Desulfurization (FGD) - Wet, Spray Dry, and Dry Scrubbers*, EPA-452/F-03-034
[47] Information in this section is from EPA, *Air Pollution Control Technology Fact Sheet: Packed-Bed/Packed Tower Wet Scrubber (EPA-452/F-03-015)* and *Air Pollution Control Technology Fact Sheet: Venturi Scrubber (EPA-452/F-03-017).*

from wet systems because the water is fully evaporated, so the absorbed sulfur is removed from the exhaust as a sold by a fabric filter or ESP.

The capital and operating cost for spray dry scrubbers are typically lower than the costs for similarly-sized wet scrubbers because equipment for handling wet waste products is not required. However, the operation of a spray dry scrubber is more sensitive than a wet scrubber to operating conditions. Excess moisture causes wet solids to deposit on the absorber and downstream equipment. .

B4. Reduced Sulfur in Fuels

Perhaps the simplest and, in many cases, the most cost effective SO_2 emission reduction technology that can be employed for fuel combustion sources is to switch to a lower sulfur content fuel. Reducing the sulfur content in the fuel will reduce the sulfur emissions linearly.

The emission units subject to this evaluation burn a variety of fuels. The sulfur content of these each fuel is limited either by regulation or by permit condition. Additionally, some of the emission units are subject to mass emission limits; others are subject to limitations on exhaust SO_2 concentration.

Current limits on liquid fuel sulfur content range from 500 ppm (for naphtha/LSR burned in GT#3 at the North Pole power plant) to 10,000 ppm (for other liquid fuels burned in the same gas turbines).[48]

In recent years, EPA has reduced the permissible level of sulfur in highway diesel fuel to 15 ppm.[49] This ultra-low sulfur fuel is becoming increasingly available on a widespread basis. Tables available on the EIA website (www.eia.gov) show that the average price differential (not including taxes) in Alaska between No. 2 heating oil and ultra-low sulfur No. 2 diesel fuel was about 25 cents per gallon in 2010.[50] Reducing the fuel sulfur content from 500 ppm to 15 ppm results in reduction of 0.0067 lb SO_2 emissions per gallon. Thus, switching from heating oil to an ultra-low sulfur fuel oil would cost about $75,000/ton. This is clearly not a cost-effective strategy for reduction of ambient PM concentrations.

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[48] North Pole Power Plant Title V Operating Permit, Condition 12.
[49] USEPA, Heavy-Duty Highway Diesel Program, http://www.epa.gov/oms/highway-diesel, accessed October 25, 2013
[50] Annual Average No. 2 Fuel Oil (residential) price in 2010 in Alaska was $2.95/gal (EIA website http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMA_EPD2_PRT_SAK_DPG&f=M accessed October 28, 2013).
Annual Average No. 2 Diesel Fuel price in 2010 in Alaska was $3,20/gal (EIA website http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMA_EPD2D_PTC_SAK_DPG&f=M accessed October 28, 2013).

Fuel switching to low sulfur liquid fuels was evaluated as a strategy for reducing both direct PM emissions and SO_2. Switching from high sulfur fuel oil to any fuel but naphtha will increase fuel costs well beyond ADEC's threshold for acceptable costs. Switching from high sulfur fuels to naphtha would significantly reduce fuel costs. However, naphtha has significantly different combustion characteristics from currently used fuels Naphtha is significantly more flammable than heavier fuels, potentially requiring significant construction costs for storage and structures. Fuel systems would need to be modified or replaced. The combustion units themselves would require significant modifications or possibly retirement and replacement. Switching to naphtha is a costly effort for a facility not currently equipped to burn this fuel.

As a result, fuel switching was ruled out as RACT for all combustion sources.

C. NO_x Control Technologies

Based upon ambient sampling, nitrates comprise about 4% of the measured $PM_{2.5}$ concentrations in Fairbanks.[51] Atmospheric conditions in Fairbanks do not lead to a high rate of conversion from NO_x emissions to ambient $PM_{2.5}$. As a result, the installation of additional NO_x controls on the point source facilities would have little impact on ambient $PM_{2.5}$ concentrations. Controlling for direct $PM_{2.5}$ is approximately 13 times more effective, on a per-pound basis, than controlling for NO_x emissions.[52] Any cost effectiveness analysis for NO_x control equipment would need to reflect this factor and still be shown to be cost effective. This is extremely unlikely.

For this reason, NO_x controls are not being considered as RACT for $PM_{2.5}$ planning for Fairbanks.

[51] Appendix III.D.5.7 Precursors.
[52] See Appendix III.D.5.7 Precursors, for supporting calculations.

VI. Recommended RACTs for each Source Category Type

The following paragraphs present the recommendations for baseline RACT for the source category types found in the FNSB. RACT is addressed for each of the pollutants of concern ($PM_{2.5}$ and SO_2) for each source category type. NO_x controls are not discussed because NO_x reduction is not an especially effective method for reducing ambient $PM_{2.5}$ in Fairbanks. As a result, these controls are not considered to be economical or reasonable for the purposes of the RACT analysis.

The baseline RACT determinations below are the starting point for the individual emission unit RACT determinations, details of which are provided in Appendix III.D.5.7.

A. Boilers

$PM_{2.5}$ emissions from coal and dual-fuel fired boilers can be most effectively controlled by the installation and operation of a properly sized fabric filter system. While other types of control devices such as electrostatic precipitators (ESPs) and high pressure drop venturi wet scrubbers may achieve comparable control efficiencies, there are drawbacks to their selection as RACT in the FNSB geographical area. ESPs typically require a larger initial investment than fabric filters and often require more space for installation than a fabric filter system. Venturi scrubbers are less costly than fabric filters but they typically achieve lower control efficiencies unless they are designed to operate at very high pressure drops, which increases the operating costs and, therefore, the total annualized costs to levels exceeding the costs for fabric filters. Also, freezing is a potential disadvantage of any type of wet scrubber in a location where ambient temperatures are well below freezing for many months of the year.[53] Although in-stack temperatures are elevated and would accommodate wet scrubber systems, the auxiliary piping that is required for the operation of a wet system would require heating or greatly increased amounts of insulation, which would further increase the operating cost. Wet scrubbers also typically generate a dense plume of water vapor, which could lead to downstream icing issues. Because fabric filter systems achieve emission reductions comparable to ESPs, and because they tend to be less costly to purchase and install and they typically require less space, they are considered to be RACT for $PM_{2.5}$ control for coal-fired boilers. Fabric filter systems have been used to control PM emissions from large coal-fired boilers in a range of geographical setting, including Alaska, for many years and there is significant precedent for selecting the technology as RACT for the control of $PM_{2.5}$.

While effective control of SO_2 emissions from boilers can be accomplished through the use of wet scrubbers, the cost per pound of sulfur removal rises dramatically as boilers

[53] The Stationary Source Control Techniques Document for Fine Particulate Matter (EPA, 1998), p. 5.4-1

get smaller, and as the sulfur content of the fuel gets lower. Because all of the coal-fired boilers in Fairbanks are relatively small (i.e., below 300 MW capacity) and because they already use very low sulfur coal, the use of scrubbers for SO_2 control unreasonably expensive for the sources being reviewed. See Appendix III.D.5.7 for more details.

The use of low sulfur content fuel is, therefore, recommended as baseline RACT for controlling emissions of SO_2 from combustion devices. For coal-burning units, this means use of low-sulfur Alaskan coal. For the oil-burning units in Fairbanks, the cost of switching to low-sulfur liquid fuels is not cost effective, because of complex physical changes that must be made in order to accommodate a fuel which the equipment cannot currently utilize. Case-by-case evaluations of the effectiveness of SO_2 emission reductions by switching to a lower sulfur fuel are provided in Appendix III.D.5.7.

B. Process Heaters

Process heaters are combustion devices that heat process materials. All of the units included in this analysis are refinery heaters that are fired with diesel fuel or a high grade of fuel oil (such as No. 2 fuel oil or kerosene). One process heater has actual PM emissions slightly above the review threshold (at 5.1 TPY). This process heater burns a very low sulfur distillate fuel.[54] The commonly applied PM control for boilers that burn distillate fuel is best operating practices for boiler maintenance. The combination of best operating practices and the use of very low sulfur distillate fuel constitutes RACT for this source category.

None of the other process heaters included in this evaluation have PM or SO_2 emissions above the review threshold, and NO_x control is not effective for reducing ambient PM. For these reasons, no controls are proposed for process heaters.

C. Turbines

Combustion turbines used to generate electricity generally emit relatively low levels of particulate matter and have very high exhaust gas flow rates. AP-42 states: "PM emissions are negligible with natural gas firing and marginally significant with distillate oil firing because of the low ash content."[55] Consequently, direct PM controls are not considered feasible for existing turbines. For the reasons discussed above, the cost of switching to more expensive low-sulfur fuels is not cost-effective; use of current fuels is recommended as RACT for SO_2 controls.

[54] Fuel sulfur content = 0.00146 wt%
[55] EPA, *Compilation of Air Pollutant Emission Factors (AP-42),* p. 3.1-4

ADEC

Addressing the precursor gases for Fairbanks $PM_{2.5}$ State Implementation Plan

Deanna Huff

9/25/2014

As part of requirements for subpart 4 Non-Attainment Area (NAA) PM2.5 State Implementation Plan (SIP), all of the precursor gases that contribute to PM2.5 (NOx, SO2,NH3 and VOCs) are addressed for potential controls in addition to the primary PM2.5 components (organic carbon, elemental carbon, ammonium, sulfate, nitrate, other).

Executive Summary

This document explains how the precursor gases (sulfur dioxide, nitrogen oxides, ammonia, and volatile organic compounds) contribute to $PM_{2.5}$ in the Fairbanks, Alaska NAA. The Clean Air Act (Subpart 4 of Part D of Title I, id. 7513-7513b (Subpart 4)) calls upon states to develop an analysis called RACM (Reasonable Available Control Technologies) for all source sectors for $PM_{2.5}$ including all precursor gases. The major source sectors are points, area (home-heating), and road and non-road vehicles. The precursor gases that must be addresses as part of the analysis are nitrogen oxides, sulfur dioxide, ammonia and Volatile Organic Compounds (NO_x, SO_2, NH_3 and VOCs). Fairbanks is designated a non-attainment area for exceeding the $PM_{2.5}$ 24-hour NAAQS of 35 $\mu g/m^3$. The designation was calculated from the 98%-tile of 3 years of data from 2006-2008 and 2008 is the design year. The baseline design value of 44.7 $\mu g/m^3$, that the attainment demonstration is based on, was derived from 5 years (2006-2010) of FRM monitor data at the State Office Building, monitored data is found in Appendix III.D.5.4.

Particulate Matter ($PM_{2.5}$) is directly emitted into the atmosphere or formed by secondary chemical reactions from precursor gases. The largest component of $PM_{2.5}$ in the Fairbanks area is organic carbon, primarily from direct emission with less resulting from secondary formation. The major components of atmospheric aerosols formed by secondary chemistry are nitrate (NO^{-3}), sulfate (SO_2^{-4}) and ammonium (NH_4^+). These species are formed mostly from chemical reactions in the atmosphere involving the precursor's nitrogen oxides (NO_x), sulfur dioxide (SO_2) and ammonia (NH_3).

SO_2: ADEC's analysis shows that sulfates comprise approximately 18% of the total mass of Fairbanks $PM_{2.5}$. Direct emissions and atmospheric formation of particulate sulfate contribute to measured sulfate concentrations. Most of the sulfate is in the form of ammonium sulfate and the total mass contribution including particle bound water is 8.69 $\mu g/m^3$. Comparing SO_2 controls that lead to a reduction in ammonium sulfate would be 3.2 times less effective than wood stove controls.

NO_x: Aerosol processes play a dominant role in the formation of nitrate. Most nitrate is formed in the atmosphere from NO_x emissions that transform into from secondary processes. Assuming that all of the moles of nitrate are balanced by any equivalent molar amount of ammonium the observations show that ammonium nitrate accounts for 4% of the total $PM_{2.5}$. In order to reduce NO_x emissions effectively, it is necessary to understand the formation of nitrate in the atmosphere and how NO_x controls influence nitrate formation in $PM_{2.5}$. The total amount of nitrate that can be removed as ammonium nitrate including particle bound water, according to filter-based measurements is 3.39 $\mu g/m^3$ $PM_{2.5}$. Comparing NO_x controls to reduce ammonium nitrate, wood stove controls are 13.2 times more effective.

NH_3: The processes that emit ammonia (biomass burning, mobile, home heating) differ in Fairbanks from those in the lower 48, where ammonia from agricultural activities, vehicles, and other industrial activities form ammonium nitrate. In the Fairbanks nonattainment area, there is only a limited about of PM-nitrate formed from on the measurement filters. The maximum reductions of the 2.44 $\mu g/m^3$ of ammonium in the $PM_{2.5}$ would come from the reductions in nitrate and sulfate in the form of ammonium nitrate and ammonium sulfate that were formed from precursor gases NO_x and SO_2 (some ammonium is associated with primarily emitted sulfate that is not from precursor gases).

VOCs: The VOCs emissions contribute to $PM_{2.5}$ by condensing after being emitted from a high temperature stack and through photochemistry forming secondary organic aerosols (SOA). The VOC emissions are 14.8 TPD, but according to model results on 0.00062 $\mu g/m^3$ are from SOA. The model performance shows good agreement between organic carbon observed and organic carbon + SOA modeled. For this reason we believe the contribution from VOCs to $PM_{2.5}$ is very small.

Fairbanks Chemistry Overview

Addressing the precursor gases and how they are related to $PM_{2.5}$ requires understanding the Fairbanks wintertime characteristics that lead to the formation of $PM_{2.5}$ from both direct and secondary formations. Precursor gases form secondary $PM_{2.5}$ and this component of $PM_{2.5}$ is addressed through reviewing current knowledge of the chemistry involved in the secondary formation in the Fairbanks airshed

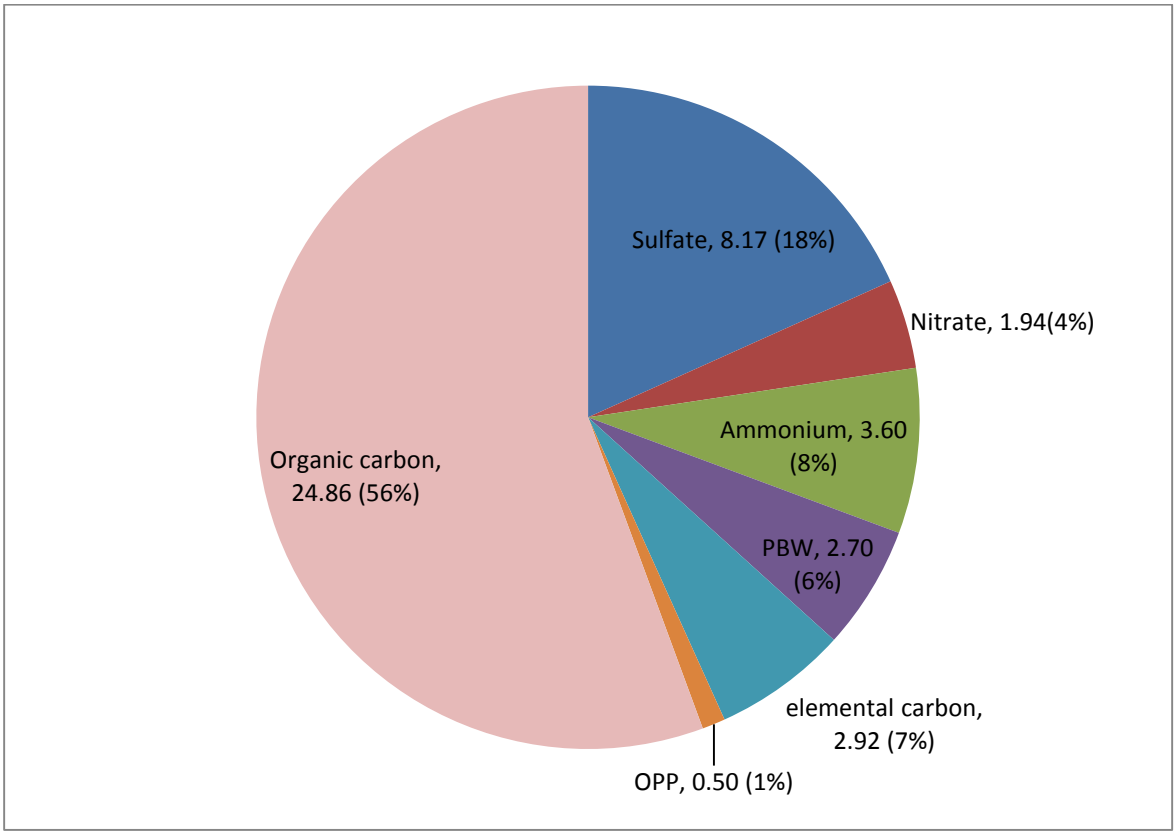

Figure 1: 24-hr average FRM-derived PM $_{2.5}$ speciation concentrations based on the design value (DV) of 44.7 µg/m^3 for the top 25% of wintertime days from the years 2006 -2010 at the Fairbanks State Office Building.

Particulate Matter ($PM_{2.5}$) is directly emitted into the atmosphere or formed by secondary chemical reactions from precursor gases. The major components of atmospheric aerosols formed by secondary chemistry are nitrate (NO^{-3}), sulfate (SO_2^{-4}) and ammonium (NH_4^+). These species are formed primarily from chemical reactions in the atmosphere involving the gas-phase precursors, nitrogen oxides (NO_x), sulfur dioxide (SO_2) and ammonia (NH_3). The major component of Fairbanks $PM_{2.5}$ is organic carbon and is directly emitted as particles, condenses to existing particles, or contributes to the formation of new particles from gaseous molecules.

Speciation of the Fairbanks winter $PM_{2.5}$ components (Figure 1) are derived from the top 25% of wintertime high $PM_{2.5}$ days from the years 2006-2010. The speciation concentrations that represent the

breakdown of the components of $PM_{2.5}$ in the Fairbanks area are measured from the SASS speciation instrument. The two different instruments both measure $PM_{2.5}$ but have different measurement artifacts. The goal is to derive concentrations of chemical species as they would be found on the official Federal Reference Method (FRM) monitor filter, not as they are found through the SASS instrument. To convert the concentrations of each chemical species from the measurement by the SASS to what would have been found on the FRM filter, we use the SANDWICH method (Frank, 2006). A detailed account of the adjustments made to compare speciation measurements to FRM total $PM_{2.5}$ measurements are found in Appendix III.D5.8. The speciation results in Figure 1 are post-SANDWICH and thus represent speciation on the FRM filter that is used to calculate regulatory design values.
Conversion of precursor gas emissions of nitrogen oxides (NO_x) and sulfur dioxides (SO_2) are constrained by atmospheric conditions including photochemical reactions from sunlight, the pH and the ambient temperature.

pH is an important aspect of atmospheric chemistry and has strong baring on the formation of ammonium sulfate and ammonium nitrate in particulate matter. One method to estimate the pH of the particulate matter is to balance the charge of major ions including ammonium (NH4+, Na+, K+, nitrate $(NO_3)^-$, Sulfate $(SO_4)^{2-}$ and Chloride (Cl^-). Figure 2 was completed by an ion mass balance approach using NH_4^+, Na^+, K^+ for the cations and NO_3^- , SO_4^{2-} and Cl^- as the anions for the Fairbanks State Office Building speciation data for 2006-2010. The net equivalent charge of all the speciation days from 2006-2010 are plotted verses the total FRM $PM_{2.5}$. If the net charge is 0, greater than 0 or less than 0; then the particulate matter is neutral, basic or acidic, respectively.

Our analysis finds neutral to basic aerosol pH on high $PM_{2.5}$ days, which is in general agreement with Dr. Peltier's analysis (2011, 2012) of Fairbanks $PM_{2.5}$. His 2011 white paper compares net charge in $\mu eq/m^3$ for observed winter speciation from 2007-2010 from the State Office Building, using only sulfate, nitrate and ammonium. Peltier found basic conditions during the winter, but did not break down the speciation data by high $PM_{2.5}$ days. In his 2012 analysis, he obtained a more time resolved analysis of two months of hourly sampling for aerosols using a PILS (Particle In Liquid Sampler) instrument, which collects airborne particles into a liquid vial for analysis on hourly speciation, and was used for net equivalent charge comparison. Peltier used the ion molar ratio method using the anions, cations and organic acid measurements to calculate a resulting net particle charge. The results showed that the aerosol is slightly acidic to neutral at high organic carbon hours. The hourly data is only representative of 280 hours during the time period from February 11- March 11th, 2011. There were only two $PM_{2.5}$ days greater than $30\mu g/m^3$during the study and no days were at or above the design value of $44.7\mu g/m^3$.

Although the first Peltier analysis concludes Fairbanks $PM_{2.5}$ is basic and the second analysis finds slightly acidic to neutral particles, they agree that particles on less polluted days are neutral. Both data sets have net equivalence charges between -0.1 and 0.1, which is considered to be in the category of neutrally charged (Peltier, 2012). The basic conditions in the first Peltier analysis occurred at high $PM_{2.5}$ loadings not experienced during collection of the second dataset. It is possible that the denuder on the SASS instrument used at the State Office Building could allow for excess ammonia gas penetration and an overrepresentation of ammonium. Another factor to consider is the presence of sulfur in non-sulfate forms, but Peltier (2012) found only 10% non-sulfate sulfur in Fairbanks $PM_{2.5}$. To within the degree we

can trust the measurement techniques and compare datasets across time, the three analyses are in reasonably good agreement that $PM_{2.5}$ in Fairbanks is not noticeably acidic.

In addition to the net equivalence charge using observed data, a modeling study was conducted in the Fairbanks area using local NO_x, O_3 and particulate matter data to understand the formation of ammonium (Joyce et. al., 2012). The results indicated that ammonium nitrate would only form downwind of downtown and no secondary formation of nitrate or sulfate occurred in the downtown Fairbanks area. Figure 3 shows the process analysis results from a CMAQ model run for the Jan. 23th- Feb. 10th representative episode for the formation of nitrate. “Aerosol Processes” play a dominant role in the formation of nitrate, which means that nitrate is being formed from NO_x precursors rather than being directly emitted from emission sources. It is not possible to understand control strategies for nitrate without understanding the emissions and fate of NO_x.

Forming nitrate downwind from the Fairbanks area has important implications for whether ammonia controls would reduce $PM_{2.5}$ or not. With neutral to basic pH in the particles, this suggests there may be enough ammonium to neutralize the sulfate and excess ammonium to form ammonium nitrate under the right conditions. For nitrate, the excess ammonium denoted by the neutral particles suggests that we are limited by nitrate formation under the dark and cold conditions and by fresh injection of NO hindering the nitrate production. For the sulfate secondary formation, reductions in SO_2 will yield a proportional reduction in $PM_{2.5}$ rather than simply replace ammonium sulfate with ammonium nitrate. The photochemistry in downtown Fairbanks due to the low to no sunlight and cold conditions during the winter, limits the photochemical production of nitric acid from the daytime processes of OH and NO_2. In addition at night, NO titrates the ozone removing the main oxidant to form nitrate (Joyce et. al, 2012). Joyce showed that ammonium nitrate is formed downwind of downtown, adding to the probability that aerosol nitrate from nitric acid is not being formed in downtown Fairbanks. Heterogeneous nighttime chemistry from N_2O_5 is thought to be responsible for 80% of the nitric acid formation at high latitudes (Crutzen et al, 2000), but in polluted areas the fast reaction of excess NO with the nitrate radical, nitric acid formation is hindered at night (Seinfeld and Pandis, 1999).

The largest component of $PM_{2.5}$ in the Fairbanks area is organic carbon. Organic carbon is primarily due to direct emission with very little resulting from secondary formation. The CMAQ modeling results show the fraction of secondary organic aerosols formed are 6.2 x 10^-4 $\mu g/m^3$ for the State Office Building grid cell. The observed organic carbon mass is in good agreement with modeled organic carbon mass (Table 1) at 17.1 observed and 25.1 $\mu g/m^3$ of organic carbon modeled for the average of the two modeling episodes (details can be found in Appendix III.D.5.8).

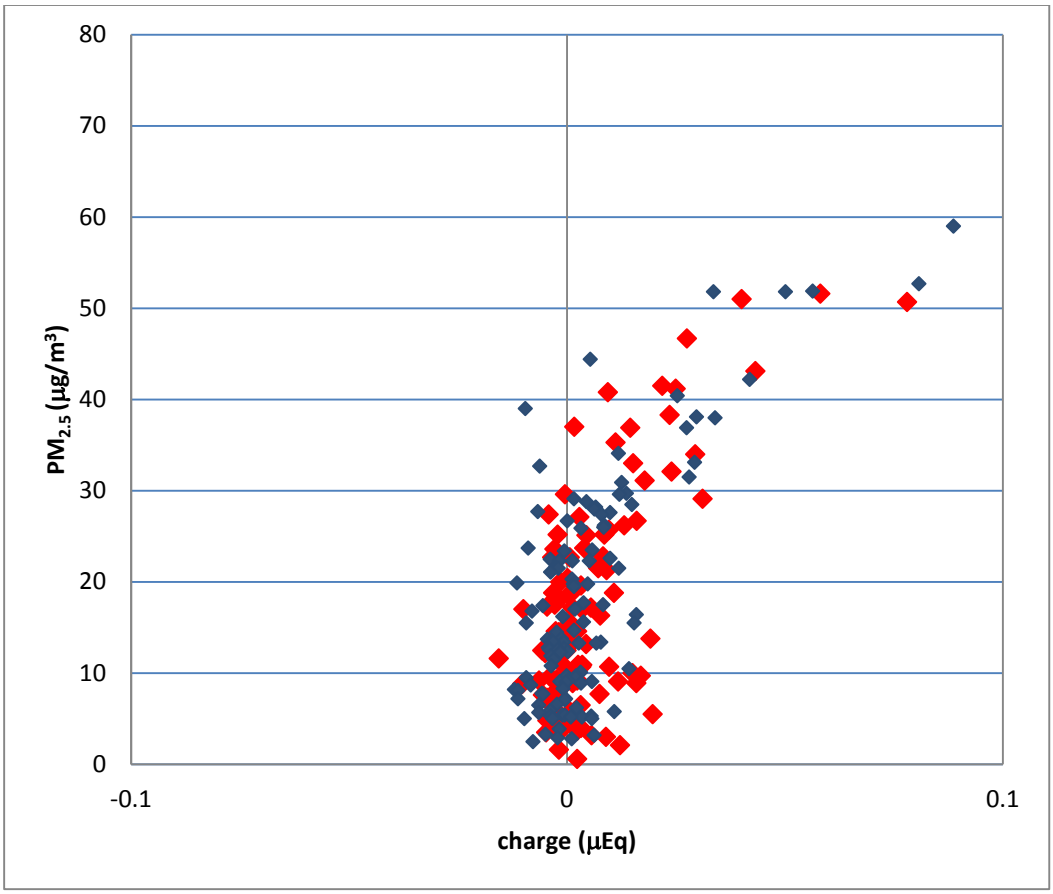

Figure 2: Aerosol charge vs. high $PM_{2.5}$ concentrations measured by FRM from 2006-2010 concentrations. Charge less than zero is acidic and greater than zero is basic.

Table 1. CMAQ and Observed Species Comparison from the State Office Building Monitor-FRM days Averaged for both modeling episodes.

Species	**Observed** (µg/m^3)	**Modeled** (µg/m^3)
$PM_{2.5}$ Total	36.1	35.7
OC	17.0	24.5
EC	2.3	4.3
SO_4	6.2	2.1
NO_3	1.6	1.3

NH_4	3.1	1.2
OTH	6.3	2.3

The CMAQ model run for Fairbanks performs well for nitrate and is in agreement with the State Office Building observed concentrations of nitrate and the modeled state office building grid cell concentration. Table 1 represents the observed verses simulated concentrations for the chemical components of $PM_{2.5}$ during two representative design episodes, episode 1 (Jan. 23-Feb 11th) and episode 2 (Nov. 2nd to the 17th) used for simulated control strategy model runs for the impracticability demonstration. The observed and modeled speciation components are 24-hr averages of the FRM days only and when speciation measurements were available.

The model adequately represents the organic carbon, elemental carbon and nitrate components. The CMAQ model runs do not well represent ammonium, sulfate or other primary particulates. Details on the model performance are found in Section 5.8.

Satisfying the EPA guideline for RACM requires the validation of all controls to advance attainment for year. In the case of Fairbanks, an estimate of 2 $\mu g/m^3$ per year is needed to advance attainment by 1 year. The design value of 45 mg/m^3 minus the $PM_{2.5}$ NAAQS of 35.0$\mu g/m^3$ is a 10 $\mu g/m^3$ reduction needed to reach attainment. If we have 5 years to reach attainment then a 10 $\mu g/m^3$ reduction over 5 years is estimated to be 2 $\mu g/m^3$. After each precursor discussion section, RACM applicability follows.

Nitrogen oxide precursors and nitrates

Nitrogen oxides are referred to as the chemical family NO_x (NO_2+NO), NO and NO_2 with primary emissions coming from combustion processes, home heating, vehicles and industry. Typically, during the day, NO_x is oxidized by reacting with ozone and OH radical chemistry and forms nitric acid (HNO_3) and during the night NO_x is oxidized to form $N_2O_{5\ (g)}$, which reacts on aerosol surfaces to form $HNO_{3\ (aq)}$ and deposition to snowpack. Particles containing nitrate are neutralized via reaction with ammonia gas (NH_3) to form ammonium nitrate.

Winter time chemistry is well represented by the model from a comparison of simulated to observed concentrations of nitrates. The modeled 24-hr mean NO_x concentration for both episodes near the surface at the State Office Building is 30ppm or 51$\mu g/m^3$. The State Office Building simulated grid cell mean 24-hr average NO_x of 51 $\mu g/m^3$ and simulated 1.3 $\mu g/m^3$ for the nitrate mass concentrations on FRM days (FRM days are a 1/3 schedule and used to compare observed filters directly to modeled days, not the same concentrations that are used for model performance all modeled days) only and converted to molar concentrations leads to a nitrate/ NO_x molar ratio of 0.031. The production of nitrate compared to NO_x emissions is very low at 3.1%. The molar ratio of 0.031 assumes that the NO_x at the State Office Building grid cell has not undergone chemical reactions (some NO has already converted to NO_2), but equivalent observed 24-hr nitrate measurement on FRM days used for performance evaluation of CMAQ is 1.6

μg/m^3, meaning that the simulated nitrate mass concentration of 1.3 μg/m^3 is in good agreement with the observed measurement almost all of the NO_x converting to nitrate is captured by the model (Table 1). This is good model agreement and gives weight to CMAQ's analysis of nitrogen chemistry during polluted wintertime episodes. The aerosol process or secondary formation of nitrate is the driving process (Figure 3) from our modeled analysis and shows that CMAQ is representing nitrate with an acceptable bias and error (section 5.8.4 "Basecase Model Performance"). All of the PM-nitrate is considered secondary and primary emitted nitrate quantity is very small (10^ (-5) μg/m^3).

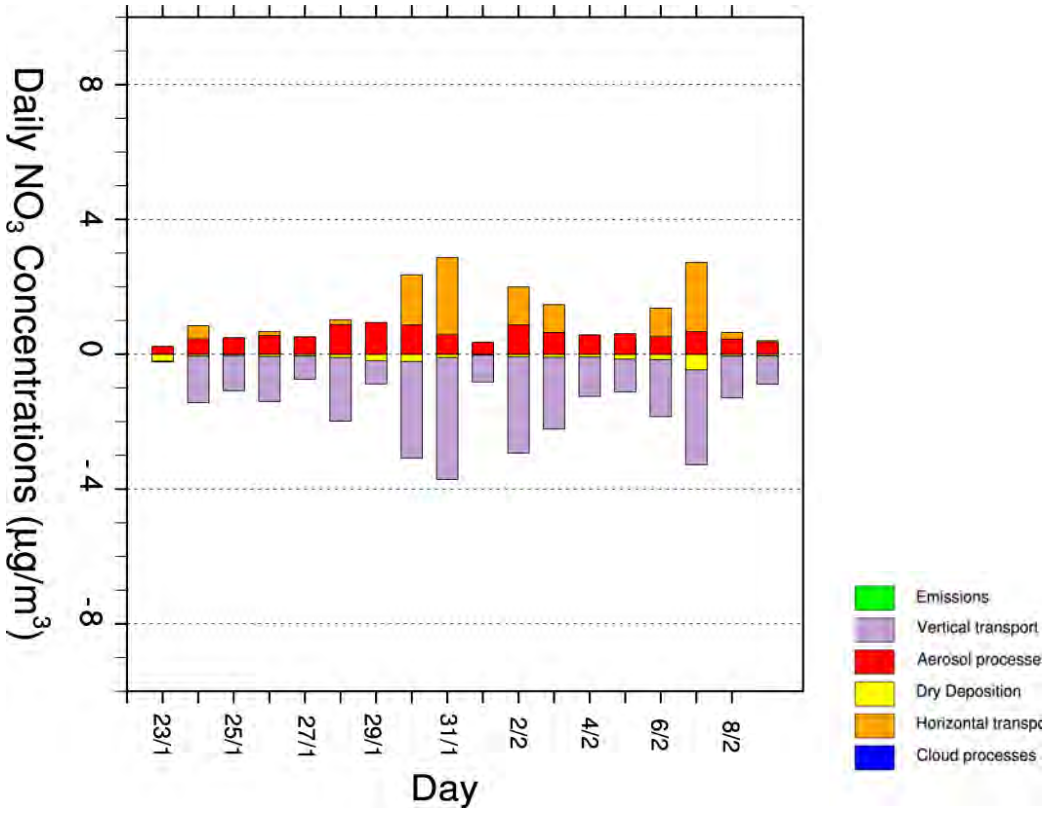

Figure 3. Process analysis results for nitrate from CMAQ for Jan. 23rd to Feb. 10th from the State Office Building grid cell.

The contribution from point sources is an important factor for NO_x emissions, because they contribute to the nitrate component of $PM_{2.5}$. The NO_x emissions by source category are 60% point sources, 20% mobile, 15% area, 4% non-road and less than 1% for all other sources combined. The total NO_x emissions from point sources are 13.45 Tons per Day (TPD).

In the winter, nitrate composes 4.33% (Figure 1) of the total $PM_{2.5}$ at the Fairbanks State Office Building on the top 25% most polluted days. For Fairbanks' baseline design value of 44.7 μg/m^3, this corresponds to 1.93 μg/m^3 of nitrate. In the CMAQ modeling, nitrate is 3.6% whereas the nitrate was 4.33 % of the observed $PM_{2.5}$.

Assuming that all of the moles of nitrate are balanced by any equivalent molar amount of ammonium the observations show that ammonium nitrate accounts for 4% of the total $PM_{2.5}$. This percentage is calculated based on an observed 1.94 $\mu g/m^3$ nitrate (Figure 1) and equivalent to 2.5 $\mu g/m^3$ ammonium nitrate (1.94 x (80 g/mol NH_3NO_3/ 62 g/mol NO_3). The observed ammonium nitrate originates from 13.45 TPD of NO_x emitted by point sources and we are assuming that all the nitrate is formed from point source emissions alone for this example. In addition to ammonium nitrate, a certain amount of water is associated with the ammonium nitrate, called particle bound water. The amount of water depends the acidity of the aerosol, the components, relative humidity and temperature. These parameters are hard to measure of an individual aerosol and there is an assumption that the water is bound in a 1/3 to 2/3 ratio, 1/3 for ammonium nitrate and 2/3 for ammonium sulfate (Frank, 2006). Taking the particle bound water (PBW) into account as part of the ammonium nitrate, then 0.89 $\mu g/m^3$ addition to the 2.5 $\mu g/m^3$ ammonium nitrate, for total of 3.39 $\mu g/m^3$ of ammonium nitrate + PBW. The 0.89 $\mu g/m^3$ (2.70 x 0.33) estimate is from the Frank (2006) paper where the ratio of PBW of 0.12 for ammonium nitrate or 1/3 (0.33) of the 2.70 $\mu g/m^3$ that is PBW (Figure 1).

Next, the observed ammonium nitrate and emitted NO_x are translated into a \$/ton NO_x metric to assess the NO_x control reduction. Dividing through the emitted tons by the observed ammonium nitrate (13.45 TPD / 3.39 $\mu g/m^3$ ammonium nitrate + PBW) it is determined that 3.97 Tons of NO_x makes 1 $\mu g/m^3$ of $PM_{2.5}$. Assuming that the conversion of NO_x to nitrate is linear throughout the range of nitrate concentrations, every ton of NO_x controls would reduce $PM_{2.5}$ nitrate by 1/3.97 $\mu g/m^3$, or 0.295 $\mu g/m^3$. In comparison, the total emissions for woodstoves are 3.18 TPD and the modeled reduction of $PM_{2.5}$ from woodstoves is 10.62 $\mu g/m^3$ (details on the emissions inventory and modeling for wood stoves can be found in Appendix III.D.5.6). Every ton of wood smoke emissions yields, by dividing the through the emitted tons by the modeled wood smoke $PM_{2.5}$ (3.18 Tons/ 10.62 $\mu g/m^3$), 0.3 tons of wood smoke $PM_{2.5}$ emissions makes 1 $\mu g/m^3$ of $PM_{2.5}$. Recalling that 3.97 tons of emissions makes 1 $\mu g/m^3$ of $PM_{2.5}$, wood smoke emissions are 13.2 (3.97/0.3) times more efficient at producing 1 $\mu g/m^3$ $PM_{2.5}$ than NO_x emissions are.

When it comes to the economic feasibility of various control strategies, NO_x controls will need to be 13.2 (3.97/0.30) times less expensive to be cost effective relative to controls on wood stove emissions. If wood stove emissions reductions are \$10,000/ton (from pg 41, EPA wood stove change outs), NO_x controls would need to be less than ~\$758/ton (\$10,000/13.2) to be considered cost effective relative to wood stove change outs.

Sulfur Dioxide precursor gas and Sulfate

Sulfates are a major component of the $PM_{2.5}$ mass; estimates show that sulfates comprise approximately 18% (8.17 $\mu g/m^3$) of the total mass of Fairbanks $PM_{2.5}$. Direct emissions and atmospheric formation of particulate sulfate contribute to measured sulfate concentrations. The bulk of the primary sulfate results from the combustion of fossil fuels, and to a lesser extent wood combustion also contribute. The speciation profiles used for the different emission categories show that primary sulfate is emitted by point, area (home heating) and mobile sources. Direct emissions of sulfate are not enough to account for the amount of sulfate observed at the State Office Building. It is very likely that SO_2 is converted into sulfate in the atmosphere after being emitted and thus accounts for the remainder of the observed sulfate. The

direct emissions of sulfate do not account for all of the sulfate found on the filters and even though the mechanism is not known, secondary sulfate formation is important. As control strategies are adopted, for example to reduce wood stove use by switching to fuel oil, fuel oil has higher SO_2 and primary sulfate emissions. Due to the complex nature of the sulfate chemistry a white paper on sulfur chemistry was written by Rick Peltier of UMass, Division of Environmental Health Science (Peltier, 2011). As discussed in the introduction, the white paper concludes that the lack of oxidants available in the dark and cold conditions would impede production of sulfate by the most common photochemical pathways(Peltier, 2011), and the chemical mechanisms to convert SO_2 to sulfate under the Fairbanks wintertime conditions are unknown. Unlike nitrate, the CMAQ model does not capture the sulfate concentrations found at the State Office Building speciation filters resulting in a need to parameterize the conversion of SO_x to sulfate with a blend of observations and model results.

The CMAQ inventory for point and area sources reveal that point sources are a majority of primary sulfate (Dulla, 2010c, Elleman, 2010) emissions. After further refinements based on source apportionment modeling and locally derived emissions factors (Appendix III.D.5.6), the latest emissions inventory break down shows 65.4 % of SO_2 is linked to point sources and 42.1% of SO_2 is linked to area-space heating fuel oil sources. Fairbanks total $PM_{2.5}$ speciation at the surface is composed of 18% sulfates by mass or 8.17 $\mu g/m^3$ (Figure 1).

Sulfate and sulfur dioxide as precursor gas are significant when addressing sulfate in the attainment demonstration as well as in the RACM analysis. In the case of sulfate, the modeled concentrations of primary and secondary sulfate are 2.03 $\mu g/m^3$ from both episodes, 24-hr average concentration at the State Office Building grid cell on modeled FRM days (Table 1). The observed FRM values from the representative modeling episodes are 5.25 $\mu g/m^3$, leaving an unexplained secondary sulfate contribution not represented by the model of 3.22 $\mu g/m^3$ (Table 2).

Table 2. Sulfate Average ($\mu g/m^3$) from FRM days for our two representative modeling episodes

	Episode 1	Episode 2	Weighted Average
Observed	5.38	5.08	5.25
Modeled	2.03	2.03	2.03
Remainder	3.35	3.04	3.22

The modeled concentrations in Table 2 are the sulfate average days from the two representative episodes. Evaluating the reduction in PM-sulfate for RACM, the design value, a 5-yr rolling average of the 98%-tile concentrations from years 2006-2010 of 44.7 $\mu g/m^3$ is used instead the modeling episode days which are only 14 day periods. Taking the weighted average column of observed, modeled and remainder concentrations in Table 2, multiplying by the ratio of design value observed sulfate (8.17 $\mu g/m^3$) by the observed sulfate during the episodes (5.25 $\mu g/m^3$) the sulfate fraction from all sources modeled is 3.16 $\mu g/m^3$and 5.01$\mu g/m^3$ is the unexplained sulfate remainder:

2.03 (modeled sulfate $\mu g/m^3$) * (8.17/5.25) = 3.16 $\mu g/m^3$
3.22 (remainder sulfate $\mu g/m^3$) *(8.17/5.25) = 5.01 $\mu g/m^3$

The model runs have very little secondary sulfate (average of 0.2 μg/m^{3}of secondary sulfate formed for both episodes), but the main chemical reactions in the model are photochemical and a function of OH and H_2O_2 (Molders, 2012). There are no observed measurements of OH or H_2O_2 for daytime winter conditions to prove that the mechanism is not favorable, but background OH concentrations at high latitudes in remote areas are measured to be extremely low even in the summertime (Mao et al., 2010). Sulfate is not well represented in the CMAQ model runs (Table 2). The observed average sulfate concentrations at the State Office Building during all days in both episode 1 and episode 2 is 6.2μg/m^3 and the simulated concentration is 2.1 μg/m^3 (Table 1).

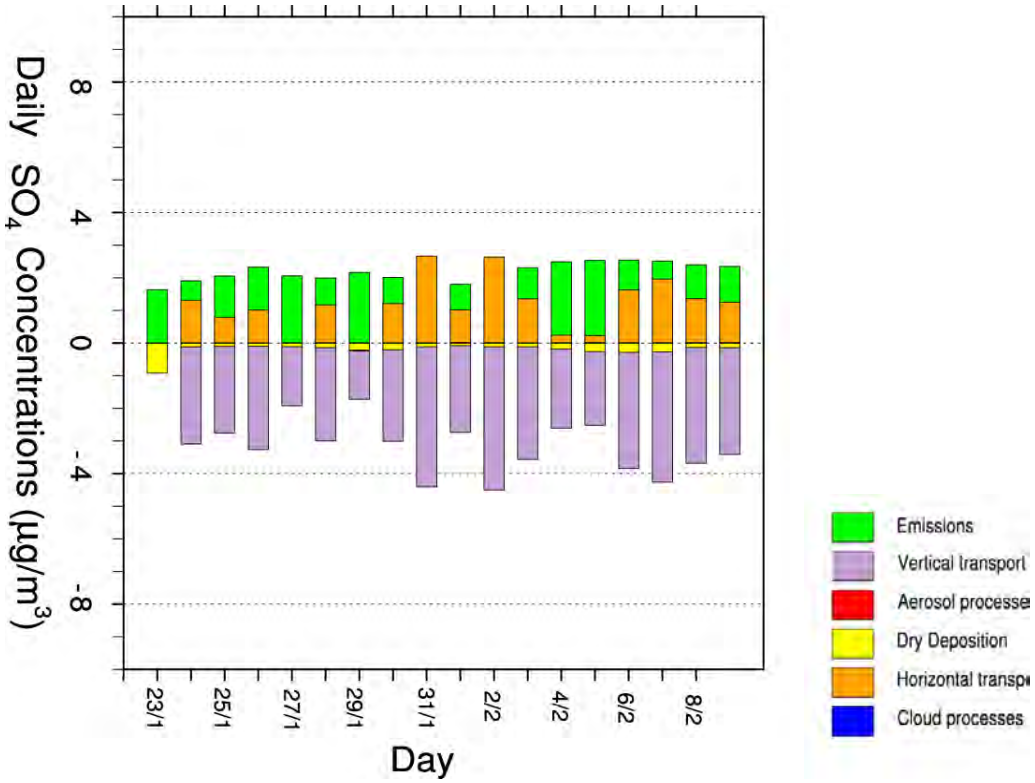

Figure 4. Process analysis for SO_4 concentrations from the CMAQ model for Jan. 23rd to Feb. 10th at the State Office Building grid cell (Molders, 2012).

The CMAQ process analysis results for sulfate show the sulfate emissions are nearly entirely primarily emitted and no aerosol processes are responsible for secondary formation of sulfate (Figure 4) in the model. CMAQ under predicts sulfate formation when compared to the total sulfate of the $PM_{2.5}$ speciation concentrations (Figure 1).

Understanding why CMAQ performs poorly for secondary sulfate in Fairbanks, several changes were made to the CMAQ model to investigate secondary sulfate, from increasing the water available for the Fe/Mn catalyst conversion reaction of SO_2 to SO_4, changing the pH and combining meteorological inputs of ice and water (Molders, 2012). The percentage of sulfate increased from 4.2 to 5.3% and from 3.9 to 5.0% for the November and January episodes. The increase in the percentage of SO_4 increased NH4 and the percentage of NO_3 and organic compounds decreased. The increase of sulfur dioxide and sulfate

affected the thermodynamic equilibrium of the aerosol and allowed further neutralization of the sulfate and nitrate into ammonium sulfate and ammonium nitrate (Seinfeld, 2006). The 1% increase in sulfate in the model results did not account for 34% missing secondary sulfate from the observed sulfate to the modeling sulfate (Table 1) and sulfate model performance is still poor.

In order for the Fe/Mn catalyst reaction to take the place, the pH and the amount of water available are important. One idea for the underrepresentation of sulfate in the model is that the anthropogenic water not represented in the model that comes from the point sources could be enough to initialize the conversion of Fe/Mn catalyst reaction. This chemical mechanism was presented by Grgic et al. (1993) in a laboratory setting and she found that under the right pH and available water that the conversion to sulfate could be accounted for by Fe/Mn. The anthropogenic water that is not represented in the model has not been calculated and an additional box model study is needed to predict if this mechanism is responsible for the under representation in the CMAQ model. Since this study is not conducted, we currently parameterized the upper and lower bound of the sulfate conversion. The CMAQ inventory SO_2 precursor gas and primary sulfate emission estimates are total emissions into the entire modeling domain, not specifically what sources contribute to the high $PM_{2.5}$ surface concentrations.

Another determination for SO_2 precursor gas benefits is the possibility of forming ammonium nitrate and in fact increasing the $PM_{2.5}$. We have evidence from the understanding of wintertime Fairbanks chemistry that this would not occur and the details are in the ammonia precursor gas section. A total of 8.38 TPD of SO_2 are emitted. After source elimination CMAQ model results (Hixson, 2012c), it is estimated that 5% of primary emitted sulfate is from the point sources and up to 15% of secondary sulfate (assuming the entire unexplained sulfate portion is formed from point source emissions). These CMAQ model results were corroborated by running CALPUFF, a dispersion model. The CALPUFF model (Huff, 2012) results showed minimal impact for directly emitted $PM_{2.5}$, less than 5%. The CALPUFF model was also run for SO_2 emissions from point sources and found 21% of the SO_2 at the State Office Building was from point sources for the November modeling episode. More detailed calculations on the SO_2 forming sulfate predications are discussed below.

CMAQ has been used in a series of source elimination runs to determine the contributions of different source sectors to the primary SO_4 and SO_2 gas at the monitor grid cell. It was found that 22% of the SO_2 originates from points, 78% from central oil and <1% is from mobile source. Using the design value day unexplained sulfate remainder and assuming that each source contributes linearly to the unexplained sulfate remainder of 5.01 $\mu g/m^3$ ((8.17 obs sulfate design value/5.25) *3.22 remainder sulfate on FRM days), then an estimate of the secondary SO_4 attributable to point sources would be calculated to be 1.10 $\mu g/m^3$ as shown below.

> 5.01 $\mu g/m^3$ Unexplained SO_4 Total x 0.22 (fractional SO_2 from point sources) = 1.10 $\mu g/m^3$ Unexplained SO_4 from point sources

The sulfate reduction of 1.10 $\mu g/m^3$ is a mid-range estimated benefit of 100% SO_2 controls on all point sources based on the modeled source contributions to SO_2 at the monitor assuming a linear relationship between SO_2 reductions and unexplained, measured sulfate. This sulfate reduction benefit was calculated only for our model episodes, but this secondary sulfate reduction can also be calculated on a design value basis. In the context of the design value of 5.01$\mu g/m^3$ of unexplained (secondary) sulfate in question as a

portion of the total design concentration of 44.7μg/m^3. There are three scenarios for the unexplained sulfate (Hixson, 2013, sulfate elimination):

1) 61.3% (5.01 μg/m^3) Upper bound - All of the unexplained sulfate is from point sources
2) 13.5% (1.10 μg/m^3) Middle/Estimated - 22% of modeled contribution from points
3) 0% (0 μg/m^3) Lower bound- None of the unexplained sulfate is from the point sources

In addition to CMAQ modeling results, the CALPUFF dispersion model was run for the same November episode when SO_2 measurements were available at the State Office Building and used to corroborate the CMAQ model results. Hourly SO_2 measurements for Nov. 2-17th were averaged to 24-hour measurements and then to an episode average of 46 μg/m^3. The CALPUFF surface layer at the State office Building grid cell for all point sources combined was 9.7 μg/$m^3$of SO_2. Comparing the CMAQ total point source apportionment results for SO_2 above to actual SO_2 measurements for the November episode using CALPUFF:

> 9.7 μg/m^3 SO_2 modeled concentration at SOB / 46 μg/m^3 SO_2 OBS at the SOB = 21 % point source contribution of total SO_2 (Huff, 2012).

Considering the cost effectiveness for SO_2, the most conservative scenario 1) was used or all of the unexplained sulfate remainder of 5.01 μg/m^3 is from the point sources. Adding in the mass of ammonium that provides the charge balance within the particles, the concentration of ammonium sulfate is calculated to be 6.89 μg/m^3 (5.01 + 1.89 μg/m^3 (using the ratio132 g/mol of ammonium sulfate/96 g/mol ammonium). Using the same methodology as for comparing SO_2 emissions to $PM_{2.5}$ sulfate, it takes 1.21 TPD (8.38 SO_2 TPD / 6.89 μg/m^3 sulfate) of SO_2 to form each 1 μg/$m^3$of $PM_{2.5}$. Assuming the SO_2 to sulfate to be linear and a source the total that could be removed by SO_2 controls is 1.22 Tons (8.38 TPD/6.89 ammonium sulfate). Recalling that 0.3 tons of wood smoke $PM_{2.5}$ emissions makes 1 μg/m^3 of $PM_{2.5}$, SO_2 controls would need to be 4.1 times (1.22 / 0.3) cheaper than wood stove controls in order to provide the same air quality benefit as wood stove controls.

If we take particle bound water (PBW) into account as part of the ammonium sulfate, then 1.8 μg/m^3 addition to the 6.89 μg/m^3 for total ammonium sulfate and particle bound water of 8.69 μg/m^3 would be included in the cost effectiveness. The 1.8 μg/m^3 estimate is from the Frank (2006) paper where the ratio of PBW of 0.12 for ammonium nitrate or 1/3 of the PBW and therefore 2/3rds is bound to ammonium sulfate (2.70 x 0.66 = 1.8).Using the above equations there are 0.96 Tons of SO_2 removed (8.38 SO_2 TPD emitted/ (6.89 μg/m^3 ammonium sulfate + 1.8 μg/m^3 PBW)). The SO_2 control cost effectiveness would then be 3.2 (0.96/0.30) or less than $3,125/ton ($10,000/3.2).

In conclusion if the RACT controls for point sources and woodstoves are the same at $10,000/ton and all of the secondary sulfate is from point sources, then SO_2 controls would need to be 3.2 times more efficient (than primary $PM_{2.5}$ in wood stoves) to be cost effective (0.96/0.30). SO_2 controls would need to be less than $3,125/ton ($10,000/3.2) to be considered cost effective.

Ammonia precursor gas and ammonium

Ammonia gas (NH_3) reacts with acid aerosols containing nitrate (NO_3^-) and sulfate (SO_4^{2-}) to from ammonium nitrate (NH_4NO_3) and ammonium sulfate ($(NH_4)_2SO_4$). Nitrate is assumed to be all ammonium nitrate. Sulfates are partially neutralized to form ammonium sulfate and are associated with a degree of neutralization. Speciation data shows that 3.6 µg/m^3 (8 %) of total $PM_{2.5}$ mass 44.7 µg/m^3 on violation days is ammonium (Figure 1). In locations that are ammonium limited, reductions in sulfate make an ammonium available to nitrate. Controls on sulfate have the net effect of decreasing ammonium sulfate but increasing ammonium nitrate. Since nitrate is heavier on a per mole basis than sulfate, sulfate controls in an ammonium-limited environment increase $PM_{2.5}$ mass. There is no indication this would occur in Fairbanks since the observed $PM_{2.5}$ appears to be well-balanced in charge and because we have other evidence that nitrate does not readily form from NO_x in Fairbanks in the winter. With an approximately neutral particle acidity in Fairbanks, there is no indication that particle formation is ammonia limited. If sulfate is reduced in Fairbanks, $PM_{2.5}$ is reduced by the weight of the sulfate reduced and also by the weight of the ammonium.

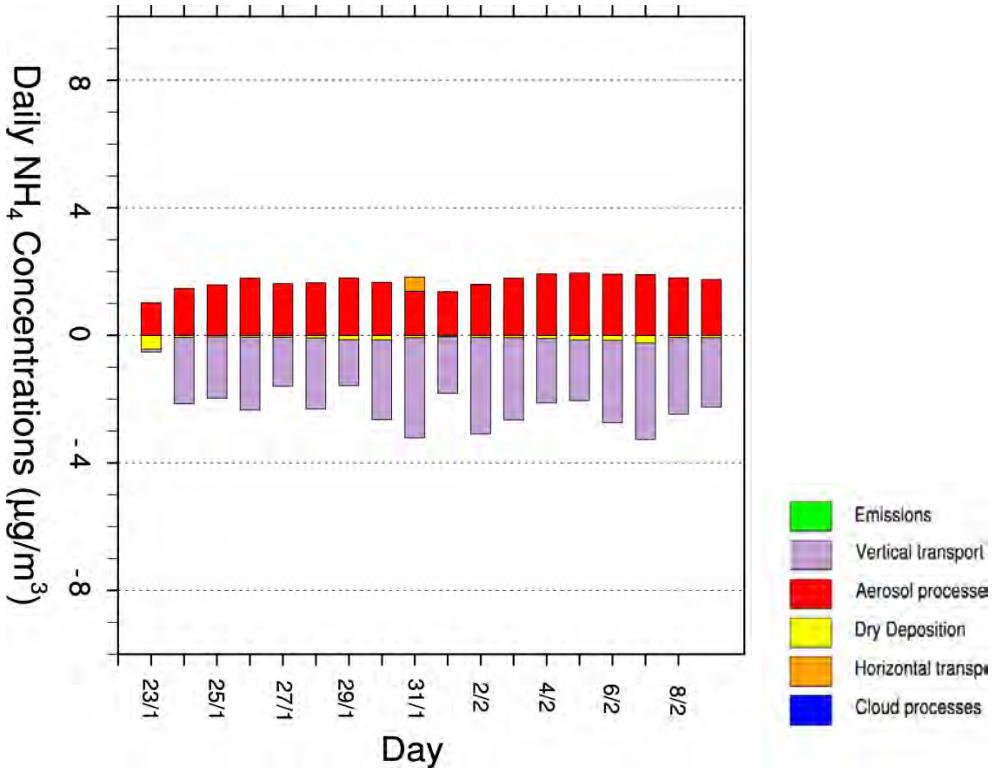

Figure 5. Ammonium concentration process analysis for episode 1 using the CMAQ model (Molders, 2012) at the State Office Building grid cell.

The modeling process analysis Figure 5 shows that the driving process for the production of ammonium is aerosol processes. The model does not accurately represent ammonium and is linked to the under prediction of secondary formation of sulfate and possible missing chemical mechanisms to convert SO_2 to

sulfate. In addition, the ammonia emissions are measured and observed poorly due to measurement techniques. Figure 5 shows that there is enough ammonium to neutralize the sulfate, but in the model the amount of secondary ammonium sulfate production is very low, approximately 0.4 $\mu g/m^3$ of 2 $\mu g/m^3$ of sulfate (Molders, 2012).

Ammonia as a precursor gas is emitted from area sources at 60.7% (mostly home heating), mobile is 38.7% and non-road is 0.7%. Because ammonium in the Fairbanks $PM_{2.5}$ is dictated by the availability of sulfate and nitrate, this analysis accounts for ammonium decreases as part of sulfate and nitrate control strategies. If control strategies were to remove all 6.89 $\mu g/m^3$ of ammonium sulfate (1.88 $\mu g/m^3$ is ammonium) and 2.5 $\mu g/m^3$ of ammonium nitrate (0.56 $\mu g/m^3$ is ammonium), 2.45 $\mu g/m^3$ of ammonium (1.89 + 0.56 = 2.45) would be removed. The remainder of ammonium of 1.15 $\mu g/m^3$ (3.6 observed – 2.45 removed = 1.15) is associated with sulfate that is primarily emitted and not formed from the precursor gas emissions of SO_2.

Volatile Organic Compounds

The emissions of Volatile Organic Compounds (VOCs) are precursor gas emissions that contribute to the secondary formation of $PM_{2.5}$ by forming particulate organic carbon through condensing in the cold air after emission and through photochemistry to form secondary organic aerosols (SOA). The VOC emissions for home heating are 14.8 TPD. The condensable fraction of PM from point sources, gases that are emitted and form particles right out of the high temperature stack could be a significant from the condensation due to low temperature. After analyzing the CMAQ modeling results from the VOC emitted tons per day, the VOC fraction of secondary organic aerosols formed are 6.2 x 10^-4 $\mu g/m^3$ for the State Office Building grid cell. Some VOCs are temperature driven by higher temperatures and greater vaporization, but in Fairbanks winter the temperatures are routinely as low -40 with a winter time average temperature of -10° F, this pathway is not expected to add VOC emissions. As mentioned in the introduction, the observed organic carbon mass (particles primarily emitted and those formed from VOCs) is in good agreement with modeled organic carbon mass (Table 1) at 17.1 observed and 25.1 $\mu g/m^3$ of organic carbon modeled for the average of the two modeling episodes. The observed organic carbon mass is mostly accounted by primary particle contribution with no unexplained secondary organic aerosol. The relationship between modeled vs. observed concentrations and the very small modeled SOA leads us to believe that VOCs forming SOA are miniscule in the Fairbanks area and will be not be dealt with in detail in further RACT or RACM analysis.

The largest contributor to $PM_{2.5}$ in Fairbanks is organic carbon mass (OCM) at 21.47 $\mu g/m^3$ or 48% (Figure 1). Both organic carbon (OC) and elemental carbon (EC) are from combustion processes. Elemental carbon (EC) is a primary particulate emitted and is 17% of total. Elemental carbon is not involved in precursor chemistry and will not be addressed. Organic carbon is a primary and secondary particulate and calculated as the organic mass fraction of the total using the SANDWICH method (Frank, 2006) for the design value on high days (Figure 1). The major sources for EC/OC components are home heating. This includes wood stoves, fireplaces, inserts and wood boilers as the main component of OC and EC. Primary $PM_{2.5}$ emitted from point sources is 1.38 tons/day, not considering what fraction reaches the surface. The wood home heating primary $PM_{2.5}$ emitted is 3.18 tons/day and is emitted near the surface. Woodsmoke is found to be a major source contributor to $PM_{2.5}$ in Fairbanks and from the

receptor model CMB (chemical mass balance), woodsmoke is shown to have 60-80% of total $PM_{2.5}$ (Ward, 2013). Carbon-14 testing can identify the aging of the carbon particles. Newer particles are associated with wood burning and aged carbon with fossil fuels (34-62%) (Ward, 2013).

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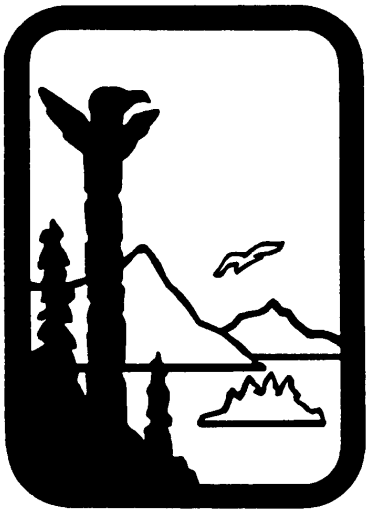

18 AAC 50 AIR QUALITY CONTROL

Proposed Regulation Changes Pertaining to:

Wood-Fired Heating Device Standards

&

Fine Particulate Matter (PM-2.5) Air Episode and Advisories.

Adopted

November 14, 2014

Sean Parnell
Governor

Larry Hartig
Commissioner

ALASKA ADMINISTRATIVE CODE

TITLE 18- DEPARTMENT OF ENVIRONMENTAL CONSERVATION

Chapter 50. Air Quality Control

Article 1. Ambient Air Quality Management

Proposed regulation amendments:

Adding a new section: Section 50.077 Wood-fired heating device standards;

Amending Section 50.245: Air quality episodes and advisories;

Amending Section 50.990: Definitions.

18 AAC 50 is amended by adding a new section to read:

18 AAC 50.077. Wood-fired heating device standards. (a) These regulations apply to a person who owns or operates a hydronic heater, woodstove, or wood-fired heating device, in an area identified in 18 AAC 50.015(b)(3), or a person intending to sell, lease, distribute, market or convey a hydronic heater, woodstove, or wood-fired device for use in an area identified in 18 AAC 50.015(b)(3), if the hydronic heater, woodstove, or wood-fired device is installed after {*effective date of regulation*} and not otherwise exempted in this section.

(b) Except as provided in (d) and (e) of this subsection, a person may not use, operate, supply, distribute, lease, sell, convey, or install in an area identified in 18 AAC 50.015(b)(3)

(1) a new hydronic heater unless the model has been

(A) listed on EPA's Phase 2 Qualified White Tag Model list, provided the unit meets the particulate matter annual average emission rate in (B) of this subsection and its rated size is under 350,000 BTU per hour, as of {*the effective date of regulation*}; or

(B) tested by an EPA-accredited lab to meet an annual average emission level of 0.32 pound per million BTU of heat output, a particulate matter annual average emission rate of 2.5 grams per hour, and a maximum individual test run emission rate of 18.0 grams of fine particles per hour using the appropriate EPA hydronic heater test procedures for the specific device from the EPA Voluntary Phase 2 Hydronic Heater Program, "Test Method 28 WHH, for Measurement of Particulate Emissions and Heating Efficiency of Wood-Fired Hydronic Heating Appliances", American Standard Testing Manufacturing Method E2618, "Standard Test Method for Measurement of Particulate Emissions and Heating Efficiency of Outdoor Solid Fuel-fired Hydronic Heating

Appliances," and American Standard Testing Manufacturing Method E2515, "Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel," approved by EPA as of October 12, 2011 and adopted by reference with test results submitted to and approved by the department as described in (c).

(2) a new woodstove unless the model has been

(A) listed on EPA's certified woodstove list, provided the unit meets the emission standard in (B) of this subsection and its rated size is under 350,000 BTU per hour, as of six months after the {*effective date of regulation*}; or

(B) tested by an EPA-accredited lab to meet the particulate matter emission limit of 2.5 grams per hour using the applicable EPA Test "Method 28" and appropriate emission concentration measurement procedures "5G" or "5H" found in 40 C.F.R. 60, Appendix A, revised as of December 23, 1991 and adopted by reference with test results submitted to and approved by the department as described in (c).

(3) a new wood-fired heating device greater than 350,000 BTU per hour unless the model has been tested by an EPA-accredited lab to meet the particulate matter emission limit of 2.5 grams per hour using American Standard Testing Manufacturing test procedures E2515-11, approved as of November 1, 2011, and E2618-09, approved as of February 15, 2009, and adopted by reference with test results submitted to and approved by the department as described in (c).

(c) Prior to selling, conveying, installing, distribution, supplying or leasing of a wood-fired heating device covered under this section, proof of EPA certification or test results demonstrating compliance with the emission standards listed in (b)(1) - (3) shall be submitted by the manufacturer to the department for review and acceptance if the wood-heating device is not already listed by the department. Heating devices certified by the department shall be included on

a list and made publically available on the Internet, at the department's Division of Air Quality offices in Anchorage, Fairbanks, and Juneau, and upon request. A person who disputes a certification decision by the department under this section may request review under 18 AAC 50.185 or 18 AAC 15 Article 6.

(d) A person may supply, distribute, lease, sell, convey or install a new wood-fired heating device where that person has confirmed in writing with the buyer or user of the device that the device will be installed and used in an area other than the air quality and special protection areas identified in 18 AAC 50.015(b)(3).

(e) Subsection (b) does not apply to wood-fired heating devices located in a fine particulate non-attainment area classified as "moderate" by the Environmental Protection Agency pursuant to 42 U.S.C. 7513 and identified in 18 AAC 50.015(b)(3); where the device is being sold, leased or conveyed as part of an existing building or other property and the device was installed in that building or on that property prior to {*effective date of regulation*}.

(Eff.__/__/____, Register ___)

Authority: AS 46.03.020 AS 46.14.020 Sec. 30, ch. 74, SLA 1993
AS 46.14.010 AS 46.14.030

Editor's Note: The documents, procedures, and methods adopted by reference in 18 AAC 50.015 may be reviewed at the department's Anchorage, Fairbanks, or Juneau office. For information on how to obtain a copy of the ASTM documents referred to in 18 AAC 50.015, contact the American Society for Testing and Materials (ASTM), Publications Department, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania, 19428-2959, phone (610) 832-9585, fax (610) 832-9555. The list of EPA-certified woodstoves may be found at,

http://www.epa.gov/compliance/resources/publications/monitoring/caa/woodstoves/certifiedwood.pdf

18 AAC 50.245(a) is amended to read:

18 AAC 50.245. Air quality episodes and advisories. (a) The department **or a local air quality control program** may declare an air **quality** episode and prescribe and publicize curtailment action if the concentration of an air pollutant in the ambient air has reached, or is likely in the immediate future to reach, any of the concentrations established in Table 6 in this subsection. **Nothing in this regulation alters a local government's powers or obligations under a local air quality control program established under AS 46.14.400 and other governing local laws, as applicable.**

The title of 18 AAC 50.245(a) Table 6 is changed to read:

Table 6

Concentrations Triggering an Air **Quality** Episode

(Eff. 1/18/97, Register 141; am 10/1/2004, Register 171; am__/__/____, Register ___)

Authority: AS 46.03.020 AS 46.14.020 Sec. 30, ch. 74, SLA 1993
AS 46.14.010 AS 46.14.030

18 AAC 50.245(b) is amended to read:

(b) The department **or a local air quality control program** will declare an air quality advisory if, in its judgment, air quality or atmospheric dispersion conditions exist that might threaten public health.

18 AAC 50.245(c) is amended to read:

(c) If the department **or a local air quality control program** declares an air quality advisory under (b) of this section, the department **or a local air quality control program** will

• • •

(Eff. 1/18/97, Register 141; am 10/1/2004, Register 171; am__/__/____, Register ___)

Authority: AS 46.03.020 AS 46.14.020 Sec. 30, ch. 74, SLA 1993
AS 46.14.010 AS 46.14.030

18 AAC 50.990(123) is amended to read:

(123) "wood-fired heating device" means a device designed **or used** for wood combustion so that usable heat is derived for the interior of a building; “wood-fired heating device” includes wood-fired **or pellet-fired** stoves, woodstoves, fireplaces, **wood-fired forced air furnaces, masonry heaters,** wood-fired **or pellet-fired** cooking stoves, **hydronic heaters** and combination fuel furnaces or boilers that burn wood; “wood-fired heating device” does not include a device that is primarily a part of an industrial process and incidentally provides usable heat for the interior of a building.

18 AAC 50.990 is amended by adding new paragraphs to read:

(135) “hydronic heater” means an outdoor or indoor fuel burning device, which may be equipped with a heat storage unit, designed to burn wood, biomass or other solid fuels that heats building space via the distribution, typically through pipes, of fluid heated in the device, typically water or a water/antifreeze mixture. A forced air furnace is not a hydronic heater.

(136) "solid fuel-fired heating device" means a device designed or used for wood or coal combustion so that usable heat is derived for the interior of a building; “solid fuel-fired heating device” includes wood-fired heating devices, coal stoves, coal forced air furnaces, coal-fired cooking stoves, coal-fired hydronic heaters and combination fuel furnaces or boilers that burn wood and coal; “solid fuel-fired heating device” does not include a device that is primarily a part of an industrial process and incidentally provides usable heat for the interior of a building.

(137) “woodstove” or “wood heater” has the meaning given to “wood heater” in 40 C.F.R. 60.531, revised as of October 17, 2000 and adopted by reference.

(138) “masonry heater” means a heating appliance constructed of concrete or solid masonry which is designed to absorb and store heat from a solid fuel fire built in the firebox by routing the exhaust gases through internal heat exchange channels in which the flow path downstream of the firebox may include flow in a horizontal or downward direction before entering the chimney and which delivers heat by radiation from the masonry surface of the heater, or as otherwise defined in the current version of the International Building Code and compliant with the requirements of ASTM E1602 or UL1482.

(Eff. 1/18/97, Register 141; am 6/14/98, Register 146; am 6/21/98, Register 146; am 9/4/98, Register 147; am 11/4/99, Register 152; am 1/1/2000, Register 152; am 2/2/2002, Register 161; am 5/3/2002, Register 162; am 11/15/2002, Register 164; am 8/8/2003, Register 167; am 10/1/2004, Register 171; am 12/3/2005, Register 176; am 12/30/2007, Register 184; am 7/25/2008, Register 187; am 4/1/2010, Register 193; am 12/9/2010, Register 196; am 9/17/2011, Register 199; am 9/14/2012, Register 203; am __/__/____, Register ___)

Authority: AS 44.46.025 AS 46.14.140 AS 46.14.250
AS 46.03.020 AS 46.14.150 AS 46.14.255
AS 46.03.710 AS 46.14.160 AS 46.14.280

AS 46.14.010	AS 46.14.170	AS 46.14.285
AS 46.14.020	AS 46.14.180	AS 46.14.290
AS 46.14.030	AS 46.14.210	AS 46.14.300
AS 46.14.120	AS 46.14.230	AS 46.14.560
AS 46.14.130	AS 46.14.240	Sec. 30, ch. 74, SLA 1993

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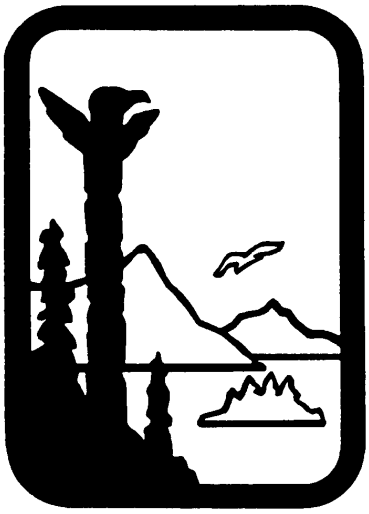

18 AAC 50 AIR QUALITY CONTROL

Purpose and Applicability of Chapter,
Open Burning,
Wood-fired Heating Device Visible Emission Standards,
Solid Fuel-Fired Heating Device Fuels,
Commercial Wood Seller Disclosure Program,
Wood-fired Heating Device Standards,
&
Fine Particulate Matter (PM-2.5) Air Episode and Advisories

Adoption

December 24, 2014

Bill Walker
Governor

Larry Hartig
Commissioner

ALASKA ADMINISTRATIVE CODE

TITLE 18- DEPARTMENT OF ENVIRONMENTAL CONSERVATION

Chapter 50. Air Quality Control

Article 1. Ambient Air Quality Management

Proposed regulation amendments:

Amending Section 50.005: Purpose and applicability of chapter;

Amending Section 50.065: Open burning;

Amending Section 50.075: Wood-fired heating device visible emission standards;

Adding a new section: Section 50.076 Solid fuel-fired heating device fuel requirements;

Amending Section 50.077: Wood-fired heating device standards;

Adding a new section 50.246: Air quality episodes and advisories for PM-2.5;

and

Amending Section 50.990: Definitions.

18 AAC 50.005 is amended by adding a new subsection to read:

(c) Nothing in this Article alters a local government's powers or obligations under a local air quality control program established under AS 46.14.400 and other governing local laws, as applicable. (Eff. 1/18/97, Register 141; am 10/1/2004, Register 171; am__/__/____, Register ___)

Authority: AS 46.03.020 AS 46.14.030 Sec. 30, ch. 74, SLA 1993
AS 46.14.010

18 AAC 50.065(f) is amended to read:

(f) **Wood Smoke Control and PM-2.5 Non-Attainment Areas**. Open burning is prohibited between November 1 and March 31 in **all** [A] wood smoke control **areas** [AREA] identified in 18 AAC 50.025(b) **and in all PM-2.5 non-attainment areas identified in 18 AAC 50.015(b)(3). In PM-2.5 non-attainment areas, a local air quality open burn permit program may replace the seasonal open burning prohibition in this section provided the program does not cause or contribute to violations of the PM-2.5 ambient air quality standards adopted in 18 AAC 50.010 and the open burn program is part of a local air quality plan included in the State Air Quality Control Plan adopted under 18 AAC 50.030**. (Eff. 1/18/97, Register 141; am__/__/____, Register ___)

Authority: AS 46.03.020 AS 46.14.010 AS 46.14.030
AS 46.03.710 AS 46.14.020 Sec. 30, ch. 74, SLA 1993

The introductory language at 18 AAC 50.075 is amended to read:

18 AAC 50.075. Wood-fired heating device visible emission standards.

18 AAC 50.075 (a) is amended to read:

(a) A person may not operate a wood-fired heating device in a manner that causes

(1) black smoke; or

(2) visible emissions that exceed 50 percent opacity for more than **six [15]** minutes in any one hour**, except during the first 15 minutes after initial firing of the unit,** in an area for which an air quality advisory is in effect under 18 AAC 50.245 **or 18 AAC 50.246. Visible emissions are measured following opacity reading procedures as required by Vol. 3., sec. IV-3, Appendix IV-3, of the state air quality control plan, adopted by reference in 18 AAC 50.030 or EPA's approved Method 9 Alternative Method, ALT-082, Revised 5/17/2012.**

18 AAC 50.075 is amended by adding a new subsection to read:

(d) A person may operate a wood-fired heating device in an area for which the department has declared a PM-2.5 air quality episode under 18 AAC 50.246 or under emergency episode provisions included in a local air quality plan incorporated in the *State Air Quality Control Plan* adopted under 18 AAC 50.030, only if:

(1) visible emissions or opacity from the wood-fired heating device is below the opacity limits identified in the episode announcement for that area as defined in the *State Air Quality Control Plan* adopted by reference in 18 AAC 50.030 or

(2) the owner or operator of the wood-fired heating device obtains a written temporary waiver from the department or local air quality program from the opacity limits identified in the episode announcement; the department or local air quality program may grant a temporary waiver after considering:

(i) financial hardship information provided by the owner or operator

(ii) technical feasibility information provided by the owner or operator;

(iii) potential impacts to sensitive locations including hospitals, schools, day care centers, health clinics, nursing homes, and senior centers;

(iii) mitigation measures implemented by the owner or operator to prevent adverse health impacts to sensitive individuals; and

(iv) the contribution of the device to the exceedance of the PM-2.5 concentration triggering the episode announcement.

(Eff. 1/18/97, Register 141; am 5/6/2009, Register 190; am__/__/____, Register ___)

Authority: AS 46.03.020 AS 46.14.020 Sec. 30, ch. 74, SLA 1993
AS 46.14.010 AS 46.14.030

18 AAC 50 is amended by adding a new section to read:

18 AAC 50.076. Solid fuel-fired heating device fuel requirements. (a) A person operating a solid fuel-fired heating device in areas identified in 18 AAC 50.015(b)(3) may only use the following fuels:

(1) For wood-fired heating devices:

(A) wood;

(B) wood pellets, manufactured compressed wood logs, bricks, or pucks made from clean wood;

(C) manufacturer recommended starter fuels including home heating oil, propane, natural gas or wood-based material for dual-fuel fired hydronic heaters; and

(D) biomass fuels approved by the manufacturer.

(2) For coal burning devices:

(A) coal; and

(B) coal pellets.

(3) For all solid fuel-fired heating devices:

(A) a fuel that is approved by the manufacturer that is not prohibited by the department in (3)(B);

(B) persons are prohibited from burning or incinerating the following items: wood that has paint, stains, or other types of coating, wood that has been treated with preservatives including copper chromium arsenate, creosote, or pentachlorophenol, asphalt, rubber or tar products including materials contaminated with petroleum, petroleum derivatives, oily wastes or oil cleanup materials; chlorinated or halogenated organic compounds including plastics, polyurethane products, pesticides, herbicides, fungicides; compounds containing cyanide or asbestos; animal carcasses; or putrescible garbage.

(b) Effective October 1, 2015, between October 1 and March 31 each year, a person operating a wood-fired heating device in areas identified in 18 AAC 50.015(b)(3) may only use the following fuels:

(1) dry wood;

(2) wood pellets, manufactured compressed wood logs, bricks, or pucks made from clean wood;

(3) manufacturer recommended starter fuels including home heating oil, propane, natural gas or wood-based material for dual fuel-fired hydronic heaters;

(4) biomass fuels approved by the manufacturer; and

(5) a fuel that is approved by the manufacturer, other than wet wood or a fuel that is not prohibited by the department under (a)(3).

(c) Commercial Wood Seller Registration Program:

(1) a commercial wood seller, an individual or business who sells wood for use in space heating, is required to register in the commercial wood seller registration program and is subject to all requirements of this section, except 18 AAC 50.076(c)(7), if they sell or provide wood to entities located in a fine particulate matter non-attainment area classified by the Environmental Protection Agency as "serious" pursuant to 42 U.S.C. 7513 and identified in 18 AAC 50.015(b)(3) where the department has issued a finding that wood smoke is a significant component of the fine particulates leading to an area being designated as "non-attainment";

(A) requirements on wood sellers shall become effective on the sixty-first day after the department publishes a notice identifying the need for and establishment of the program for the serious fine particulate matter non-attainment area;

(B) that departmental notice shall be published, no less than 60 days before the implementation of a wood seller registration program, in a newspaper of general circulation, posted in the local air pollution control program office, and on the state online public notice system;

(C) wood pellets, manufactured compressed wood logs, bricks, or pucks made from clean wood are exempt from the requirements of the commercial wood seller registration program;

(D) retailers whose principle business is not selling wood for space heating and that sell only wood pellets, manufactured, compressed wood logs, bricks, or pucks made from clean wood or seasoned split wood bundles sized 0.75 cubic feet or less are not considered "commercial wood sellers".

(2) a commercial wood seller subject to this section shall:

(A) prior to selling or providing wood, initially register with the department by submitting a registration application and required documentation to the department in a format provided by the agency;

(B) have available for use a department-approved wood moisture content meter;

(C) have a valid Alaska business license as required under AS 43.70 and 12 AAC 12;

(D) renew registration by submitting a renewal application and required documentation to the department, in a format provided by the agency, 30 days before the expiration date of the existing registration.

(3) upon receipt of a complete registration application and associated documentation, the department may:

(A) issue a unique registration identification number to the wood seller;

(B) identify the time period covered by the registration, not to exceed three years;

(C) issue a batch of uniquely numbered three-part moisture disclosure forms for use in this program; and

(D) add the registered wood seller to the publically available registration list.

(4) a registered commercial wood seller shall:

(A) upon sale or point of delivery of wood to the consumer,

(i) test the moisture content of the wood in accordance with 18 AAC 50.076 (c)(6);

(ii) fully complete and sign the uniquely numbered moisture content disclosure form;

(iii) obtain the buyer's signature or mark on the form that the buyer is 'unavailable'; and

(iv) provide the buyer with a copy of the signed form.

(B) after sale or delivery of wood to the consumer:

(i) submit to the department the ADEC copy of the fully completed forms no later than the fifteenth day of the month for sales conducted during the preceding month; and

(ii) retain the seller copy of the completed forms for two years after date of sale or delivery.

(C) provide the seller copy of completed forms for inspection at the request of the department;

(D) account for all of the moisture content disclosure forms received from the department. At the time of the monthly submittal under (B)(i), any moisture content

disclosure forms not given to a customer due to damage or errors must be submitted, and for any forms lost, the unique number must be reported;

(E) upon loss of registration or non-renewal of registration return to the department any unused moisture content disclosure forms;

(F) failure to comply with the requirements of (4)(A) - (E) may result in any or all of the following actions:

(i) remedial training on program requirements;

(ii) notice of violation;

(iii) removal from publically available registration list until deemed in compliance;

(iv) revocation of registration; or

(v) enforcement under AS 46.03.020, AS 46.03.760, AS 46.03.761, or AS 46.03.790.

(5) the department shall approve commercially-available moisture test meters for use by commercial wood sellers and provide a list of approved devices on the ADEC Division of Air Quality Internet web site and upon request.

(6) the commercial wood seller shall test the moisture content of the wood in the delivered or purchased load, except as provided by 18 AAC 50.076(c)(6)(B), (C),and (D), using a moisture meter approved by the department under (5) as follows:

(A) for split wood, wood rounds, or logs that are cut at the time of, or prior to, sale, and are marketed, sold, or provided as dry wood,

(i) moisture content shall be measured in a minimum of three pieces of wood for each cord of wood purchased;

(ii) the commercial wood seller shall randomly select the wood to be tested from differing locations throughout the entire load; and

(iii) each selected piece of wood shall undergo a fresh cut, be tested in the center of the fresh cut end and the measured moisture content documented on the department-provided form;

(B) for frozen wood, wood cut and sold or delivered at freezing temperatures below 32 degrees Fahrenheit, the commercial wood seller shall note on the moisture content disclosure form that the wood is frozen and assumed to be wet with greater than 20 percent moisture content;

(C) for wood marketed, sold, or provided as wet wood, the commercial wood seller shall note on the moisture content disclosure form that the wood is wet and assumed to be greater than 20 percent moisture content; and

(D) for wood split prior to freezing, provided the split wood is covered and stacked for ventilation, a commercial wood seller may report the wood to the consumer as dry provided that

(i) the moisture content of the wood sold is measured randomly after splitting while stacking and storing and meets the definition of dry wood;

(ii) the moisture content and the date of the measurements are recorded and saved; and

(iii) upon actual sale or delivery, if the temperature is at or below 32 degrees Fahrenheit, the commercial wood seller documents the previously recorded moisture content and date on the department-provided form.

(7) a registered commercial wood seller may be certified as a "Certified Dry Wood Seller" provided:

(A) the department has reviewed the registered commercial wood seller's business practices and determined that the business is capable of consistently providing dry wood or manufactured compressed wood logs;

(B) the registered commercial wood seller commits to consistently providing buyers dry wood or manufactured compressed wood logs; and

(C) the registered commercial wood seller signs an acknowledgement form that failure to provide dry wood or accurately provide moisture content information for wood sold is subject to 18 AAC 50.076(c)(4)(f) and revocation of certification as a "Certified Dry Wood Seller". (Eff. __/__/____, Register ___)

Authority: AS 46.03.020 AS 46.14.020 Sec. 30, ch. 74, SLA 1993
AS 46.14.010 AS 46.14.030

18 AAC 50.077(b) is amended to read:

(b) **Prohibitions**. Except as provided in (d) [AND]**,** (e) **and (f)** of this subsection, no person subject to (a) of this section may supply, distribute, lease, sell, convey, or install in an area identified in 18 AAC 50.015(b)(3)

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18 AAC 50.077 is amended by adding a new subsection to read:

(f) the prohibitions in subsection (b) do not apply to the following wood-fired heating devices located in a fine particulate matter non-attainment area classified by the Environmental

Protection Agency as "Serious" pursuant to 42 U.S.C. 7513 and identified in 18 AAC 50.015(b)(3):

(1) a wood stove certified by the Environmental Protection Agency or the department to be compliant with federal and state performance standards applicable to fine particulate emissions from that device and in effect prior to {*effective date of regulation}* or the date of installation of the device at its present location, whichever is later; or

(2) a hydronic heater approved or certified by the Environmental Protection Agency or the department to be compliant with federal and state performance standards applicable to fine particulate emissions from that device and in effect prior to {*effective date of regulation}* or the date of installation of the device at its present location, whichever is later; or

(3) a wood-fired heating device for which the owner has received a written temporary waiver from the prohibitions in subsection (b) from the department or a local air quality program. The department or local air quality program may grant a temporary waiver after considering:

(i) financial hardship information provided by the owner or operator

(ii) technical feasibility information provided by the owner or operator; and

(iii) potential impacts to sensitive locations including hospitals, schools, day care centers, health clinics, nursing homes, and senior centers.

(Eff.__/__/____, Register ___)

Authority: AS 46.03.020 AS 46.14.020 Sec. 30, ch. 74, SLA 1993
AS 46.14.010 AS 46.14.030

18 AAC 50 is amended by adding a new section to read:

18 AAC 50.246. Air quality episodes and advisories for PM-2.5. (a) The department or a local air quality control program may declare an air quality episode and prescribe and publicize the actions to be taken if the concentration of PM-2.5 in the ambient air has reached, or is likely in the immediate future to reach, any of the concentrations established in Table 6a in this subsection. The episode thresholds and actions prescribed for any area that has a local air quality plan included in the State Air Quality Control Plan adopted under 18 AAC 50.030 shall be consistent with the emergency episode provisions included in that plan.

Table 6a

Concentrations Triggering an Air Quality Episode for PM-2.5

Episode Type	Air Pollutant	Concentration in micrograms per cubic meter
Air alert	PM-2.5	35.5 (24-hour average)
Air warning	PM-2.5	55.5 (24-hour average)
Air emergency	PM-2.5	150.5 (24-hour average)

(b) The department or a local air quality control program authorized by the department under AS 46.14.400 will declare a PM-2.5 air quality advisory if, in its judgment, PM-2.5 air quality or atmospheric dispersion conditions exist that might threaten public health.

(c) If the department or a local air quality control program declares a PM-2.5 air quality advisory under (b) of this section, the department or a local air quality control program will

(1) request voluntary emission curtailments from any person issued a permit under this chapter whose stationary source's emissions might impact the area subject to the advisory; and

(2) publicize actions to be taken to protect public health. (Eff. _/__/____, Register ___)

Authority: AS 46.03.020 AS 46.14.020 Sec. 30, ch. 74, SLA 1993
AS 46.14.010 AS 46.14.030

18 AAC 50.990(65) is amended to read:

(65) "open burning" means the burning of a material that results in the products of combustion being emitted directly into the ambient air without passing through a stack, flare, vent, or other opening of an emission unit from which an air pollutant could be emitted**; camp fires as defined in 18 AAC 50.990(140), barbeques, candles, tobacco, and celebratory fireworks are not considered open burning.**

(Eff. 1/18/97, Register 141; am 6/14/98, Register 146; am 6/21/98, Register 146; am 9/4/98, Register 147; am 11/4/99, Register 152; am 1/1/2000, Register 152; am 2/2/2002, Register 161; am 5/3/2002, Register 162; am 11/15/2002, Register 164; am 8/8/2003, Register 167; am 10/1/2004, Register 171; am 12/3/2005, Register 176; am 12/30/2007, Register 184; am 7/25/2008, Register 187; am 4/1/2010, Register 193; am 12/9/2010, Register 196; am 9/17/2011, Register 199; am 9/14/2012, Register 203; am __/__/____, Register ___)

Authority: AS 44.46.025 AS 46.14.140 AS 46.14.250

AS 46.03.020	AS 46.14.150	AS 46.14.255
AS 46.03.710	AS 46.14.160	AS 46.14.280
AS 46.14.010	AS 46.14.170	AS 46.14.285
AS 46.14.020	AS 46.14.180	AS 46.14.290
AS 46.14.030	AS 46.14.210	AS 46.14.300
AS 46.14.120	AS 46.14.230	AS 46.14.560
AS 46.14.130	AS 46.14.240	Sec. 30, ch. 74, SLA 1993

18 AAC 50.990 is amended by adding new paragraphs to read:

(139) “dry wood” means wood with a moisture content of 20 percent or less.

(140) "camp fire" means any open fire less than 3 feet in diameter used for cooking, personal warmth, lighting, ceremonial or aesthetic purposes that is hand built and that is not associated with any debris disposal activities.

(141) "wet wood" means wood with moisture content of more than 20 percent.

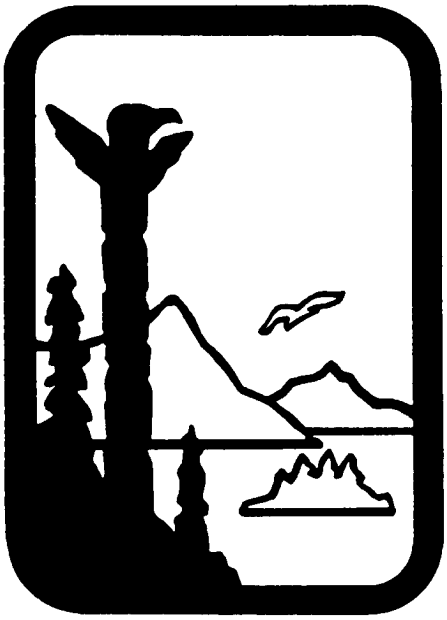
(142) “manufactured compressed wood logs” means logs that have been made from 100 percent compressed sawdust, wood chips, and/or other organic material with no additive.

(Eff. 1/18/97, Register 141; am 6/14/98, Register 146; am 6/21/98, Register 146; am 9/4/98, Register 147; am 11/4/99, Register 152; am 1/1/2000, Register 152; am 2/2/2002, Register 161; am 5/3/2002, Register 162; am 11/15/2002, Register 164; am 8/8/2003, Register 167; am 10/1/2004, Register 171; am 12/3/2005, Register 176; am 12/30/2007, Register 184; am 7/25/2008, Register 187; am 4/1/2010, Register 193; am 12/9/2010, Register 196; am 9/17/2011, Register 199; am 9/14/2012, Register 203; am __/__/____, Register ___)

Authority:	AS 44.46.025	AS 46.14.140	AS 46.14.250
	AS 46.03.020	AS 46.14.150	AS 46.14.255
	AS 46.03.710	AS 46.14.160	AS 46.14.280

AS 46.14.010	AS 46.14.170	AS 46.14.285
AS 46.14.020	AS 46.14.180	AS 46.14.290
AS 46.14.030	AS 46.14.210	AS 46.14.300
AS 46.14.120	AS 46.14.230	AS 46.14.560
AS 46.14.130	AS 46.14.240	Sec. 30, ch. 74, SLA 1993

Alaska Department of Environmental Conservation



Amendments to:
State Air Quality Control Plan

Vol. III: Appendix III.D.5.8

{Appendix to Volume II. Analysis of Problems, Control Actions; Section III. Area-wide Pollutant Control Program; D. Particulate Matter; 5. Fairbanks North Star Borough PM2.5 Control Plan}

Adopted

December 24, 2014

Bill Walker
Governor

Larry Hartig
Commissioner

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5.8. Modeling Appendix

5.8.1 Introduction

This appendix provides the supplemental details of the photochemical transport modeling required as part of the Species Modeled Attainment Test (SMAT). Modeling efforts using PMF and CMB describe the early efforts to quantify the contributions to particulate matter concentrations in Fairbanks. Dispersion modeling results are presented to quantify the potential influence of point sources. Scientific analysis of sulfur formation and organic components of ambient aerosols provide further understanding related to contributing activities and atmospheric processes to $PM_{2.5}$ formation. The photochemical transport modeling sections provide the methodology for converting meteorological model outputs and emission inventories to model-ready inputs. Photochemical model outputs are then presented in the form of episode averaged concentrations of $PM_{2.5}$ components and gaseous SO_2. The resulting future design value concentrations are then calculated for the attainment tests.

5.8.3 Emissions Processing

Emission inventories were processed through the Sparse Matrix Operator Kernel Emissions (SMOKE) model version 2.7.5. The emissions sources were grouped into 8 different source sectors: point, home heating, onroad rate per vehicle (starting exhaust), onroad rate per distance (running exhaust, tire, and brake), onroad rate per profile (evaporative), nonroad including railroad, airport, and other area. All source sectors with the exception of the onroad mobile sources were processed through the following SMOKE program workflow: SMKINVEN, GRDMAT, SPCMAT, TEMPORAL, and SMKMERGE. An additional layer step is needed for point, home heating and airport sources with vertical distributions above the ground level.

Meteorological Data Processing

Before the emissions processing can be initiated the meteorological data from the WRF model and the emissions inventory are converted to inputs for both the SMOKE and CMAQ models. The meteorological outputs from WRF are used to define the modeling grid (GRIDDESC) for both SMOKE and CMAQ. The Meteorology-Chemistry Interface Processor (MCIP) program version 3.6 was used to prepare the WRF outputs for use with SMOKE and CMAQ. The SMOKE model as configured in 5.8.4 was used to process episodic inventories for the 2008 baseline, 2015 projected baseline, 2015 control scenario, 2019 projected baseline, and 2019 control scenario.

5.8.3.1 Processing of Emissions Source Sectors

After processing the meteorological data files the emission inventories for the eight source sectors above were imported into SMOKE using the SMKINVEN program. SMKINVEN imports the raw inventory data that is described in III.D.5.06. Point sources and home heating area sources were both imported with hourly and spatially defined emissions. The modifications required to permit the importing of home heating area emissions in this manner are described in

the area source modifications sub section below. All other source sectors were imported as described in the SMOKE manual documents[1].

The methodology for spatial allocation and temporal allocations of sectors varied by source. A more detailed accounting of the spatial and temporal variation of sources is described in the emissions inventory Appendix III.D.5.6. Point sources and area sources were provided as inventory inputs (PTINV) and hourly inputs (PTHOUR)[2]. These inputs contain spatial and temporal information meaning that separate allocation inputs are not required. For the mobile source sector the spatial variation of population (rate-per-vehicle and rate-per-profile) and vehicle miles traveled were used to allocate emissions to the modeling grid. Hourly temperature and speed profiles are used to make diurnal allocations of mobile source emissions with monthly variations based on VMT. Spatial gridding Airport emissions was defined based on the locations of airports in the Fairbanks area. Other Area emissions were assumed to vary spatially based on population. The Nonroad sector's rail road emissions are gridded based on the locations of rail lines and yards; snow mobile allocations for running exhaust are assumed to largely occur outside of the Fairbanks North Star Borough with some maintenance activity allocated within the Borough by population. Temporal allocations for Nonroad, other area and airport emissions were applied to represent average winter hourly activity from the annual average daily inventory files.

Vertical allocation of emissions was performed for the point source, home heating, and airport sources. Point source vertical profiles were calculated within SMOKE using the laypoint program. Home heating and airport vertical profiles were calculated outside of SMOKE and applied using the layalloc program. All other sources were assumed to emit into the first layer.

Default speciation profiles from EPA's SPECIATE database[3] compatible with the CMAQ cb05cl_ae5_aq mechanism (Carbon Bond 5 gas-phase mechanism, fifth-generation CMAQ aerosol mechanism[4]) were used for all source sectors with the exception of the home heating wood burning and oil burning sources particulate matter profiles. $PM_{2.5}$ profiles developed from the OMNI-labs Measurement of Space-Heating Emissions sources were supplemented to provide a more representative particulate matter composition.

For each source sector SMOKE completes the following steps: inventory importing, spatial allocation, temporal allocation, vertical allocation, and speciation. The final step in emissions processing is the merging of the intermediate files produced in each of the above steps using the smkmerge (or movesmrg for the onroad mobile source sector) program. Individual source sector emissions are then combined with the mrggrid program to produce a single input file to the CMAQ-model. The steps above are repeated for each of the emissions scenario modeled for the SIP.

[1] SMOKE v2.7 User's Manual: section 6.16 pages 283-294

[2] SMOKE v2.7 User's Manual: section 8.2.7, 8.2.8 pages 398-413

[3] http://www.epa.gov/ttnchie1/software/speciate/

[4] "Community Multiscale Air Quality (CMAQ) Modeling System Version 4.7.1 (June 2010)" accessed from *https://www.cmascenter.org/cmaq/documentation/4.7.1/Operational_Guidance_ Document.pdf*

5.8.3.2 SMOKE Emissions Processing Modifications for Fairbanks, AK $PM_{2.5}$ SIP

In support of $PM_{2.5}$ SIP modeling efforts in Fairbanks, Alaska, Sierra Research has created a modified version of the SMOKE-model. Model modifications were made in order to generate highly resolved home heating emissions and address bugs in the processing of onroad mobile source emissions from the MOVES model. The baseline source codes used in these projects were SMOKE version 2.7.5, MOVES 2010a, and SMOKE-MOVES 0.20 and 0.31. Processed emissions were evaluated using Verdi 1.31, custom NCL scripts, custom BASH and CSH SHELL scripts, and NCO programs on a custom-built computer (Intel i7 950 4 core/8 thread, 8 GB system memory, 1 TB hard disk drive) running Ubuntu 10.04 OS.

The modeling episodes span January 23 through February 11 and November 7 through November 22. The modeling domain covers 199x199 grid cells of 1.33x1.33km size comprising the bulk of the Fairbanks North Star Borough and 38 vertical layers up to 20km.

5.8.4 Area Source Modifications

Home heating emissions inputs to the SMOKE model were generated using a Fairbanks-specific heating demand model developed by Sierra Research. The home heating model is informed by multiyear phone surveys, in-home instrumentation data, device measurement studies, local land parcel data, census records and local day-specific meteorology. The home heating model can produce highly spatially resolved, hourly emissions for the 199x199 gridded model domain. To best preserve the temporal and spatial resolution of this inventory, an alternative approach to the standard SMOKE area source processing via spatial and temporal surrogates schemes was developed. The most efficient approach was to treat the home heating source input file as a large point source emissions inventory with hourly specified emissions.

Both an inventory input and hourly emissions input file were created to meet SMOKE's point source processing requirements: PTINV[5] and PTHOUR. The PTINV input was formatted per the ORL formatting guidelines[6]. Descriptive, dummy text was applied to the facility information fields with the exception of the FIPS, SCC codes, pollutant CAS number, X location and Y location. In this instance, the PTINV file ultimately serves as a spatial allocation file. The PLANTID field is given a name specific to the grid cell where the home heating activity is located and which corresponds to the latitude and longitude specified by the X and Y location fields. Since hourly emissions data are imported with PTHOUR, the emission levels in the PTINV file are set to dummy values and not ultimately used. PTHOUR follows the EMS95 Wide format per the SMOKE guidelines.[7]

Changes to the SMOKE code were made to allow for the home heating sources to be processed using the PTINV and PTHOUR inputs while preserving the sector's identity as an area source. Code sections that received changes are noted below and comments were added within the

[5] Variables, subroutines, and inputs are presented in all capitalized form for clarity.
[6] SMOKE v2.7 User's Manual: section 8.2.8.3 pages 408-412
[7] SMOKE v2.7 User's Manual: section 8.2.7.2 pages 300-401

source code. The initial code changes were made to the inventory importing routines within the smkinven[8] program. Lines of code were added to read the HOUR_SPECIFIC_YN environment variable on lines 201 to 205 within the area source subsection of smkinven.f. Modifications were subsequently required on lines 249, 256, 273, 275, 401, and 424 related to the source category variable CATEGORY. For simplicity when the hour-specific emissions variable was set to true, the source category was changed from AREA to POINT before calling certain subroutines. The old category was stored in a separate variable and then recalled after these subroutines were completed. This category swapping was preferable to rewriting each of the subroutines to allow both POINT and AREA categories to use the PTHOUR emissions and PTINV inventory files. Subroutines impacted by this category swapping were the following: RDINVSRCS, PROCINVSRCS, PROCINVEN, OPENINVOUT, WRINVCHR, SRCMEM, and WRINVEMIS.

Several other subroutines were impacted by the point as area and hourly emissions changes. The INITFINFO subroutine in file initinfo.f was modified on lines 61, 67 and 76 to read the hourly emissions flag. Conditional statements were placed or modified to correctly initialize variables associated with processing the hourly area source emissions and inventory data as for the treatment of the hourly area source emissions on lines 77, 112, 120, 166, 176, 187, 201, 203, 219, and 237.

The OPENINVIN subroutine was altered on line 121 to allow for hourly specified emissions outside of POINT sources. Conditional statements were added on lines 340 and 347 to avoid opening certain point source related files that were not required for the area source category. RDINVDATA was updated to add logic around the instances where hourly specific emissions were to be used and area source category inventories were being read. Line 225 was modified to determine whether the hourly specific emissions flag was set. Lines 362, 669, 691, 795, 855, 1171, 1188, 1389, 1393, 1458, 1460, 1479, and 1495 received modifications to their conditional statement logic to have the hourly specific area source files process more like point source files when the hourly specific emissions flag was set.

Due to the 8-character, SCC length limitations of the EMS95 Wide Format, the RDEMSPD subroutine in rdemspd.f had to be altered to extend the SCC size from 8 to 10 characters for EMS95 Wide emission files. Extending the SCC field width requires shifting all of the proceeding fields by the number of characters added to the SCC field. Changes occurred on lines 273 and 274 where the position of the field following the SCC code is defined: DATNAM. Both the start and end positions of the DATNAM field were increased by two, 381 to 383 and 396 to 398. There are no other fields that follow these in the EMS95 Wide format. Lines 680 and 721 are responsible for reading the SCC code from each line in the PTHOUR file. The values indicating the ending position of the SCC code were increased by two digits from 380 to 382.

Additional precision was also sought in the reading of the latitude and longitude entries, XLOC and YLOC, of the PTINV file. The RDINVDATA subroutine was modified to accept two additional digits of precision when reading latitude and longitude, line 214 in the file rdinvdata.f.

[8] Executable programs and their source code files are presented in lowercase to distinguish them from variables, subroutines, and inputs.

Lines 1502 and 1503 were revised to preserve the desired precision of the XLOC and YLOC by using a formatted read statement instead of the existing code's usage of the function STR2REAL. Subroutine RDDATAORLPT in file rddatantipt.f was modified on lines 75 and 76 to extend the LAT and LON dimensions from 9 to 11.

A section of the subroutine WRPDEMIS that checks for missing emissions data and fills in those data with values based on annual emissions data was modified since the area emissions are now using hourly data only. An error would result due to the inability of the code to differentiate between missing emissions data and a zero emissions value. Line 319 was modified to set null emissions to zero.

Following changes to the smkinven source code, the smkinven program was compiled and tested with PTINV and PTHOUR area source inputs. Debug statements, log files for the smkinven program, and intermediate data files were inspected as part of the QA process to address any coding errors and resolve any bugs. The resulting intermediate files from the imported inventory and emission files were then passed to the grdmat, spcmat, and temporal programs.

The gridding program, grdmat, was updated to use the latitude and longitude information from the imported inventory file to grid the emissions. Sections of code were added on lines 172 and 199 to read the hourly-specific emissions flag and conditionally branch into point source spatial allocation subroutines even when the area category was being processed. Conditional statements were modified on lines 254, 299, 303, 641, 706, 726, and 756 to allocate sufficient memory for the number of sources and to call subroutines to convert the latitude and longitude to gridded outputs. Source code in opengmat.f was modified on lines 87, 110 and 120 to setup the correct headers for the area source as points gridding matrix. Grdmat was then compiled and tested similarly to the smkinven program.

The speciation program, spcmat, received updates to the correct for problems with processing the hourly area sources. Changes occurred on lines 152 and 166 to add reading of the hourly specified flag and a temporary variable for storing the source category. A line of code was added on line 186 to read the hourly emissions environment flag. Source code was added on line 271 to artificially switch the source code to POINTS before running the RDINVCHR subroutine that reads inventory characteristics. This is a more efficient solution than modifying the RDINVCHR code. A conditional statement in file asgntag.f line 179 was changed to allow both hourly point and area sources to use a set of SCC storage arrays required for the number of sources being processed. The profile assignment subroutine in asgnspro.f was modified on lines 129, 190, 224, 234, 242, 314 and 361 to accommodate the changes to the rest of the spcmat program. Spcmat was compiled and tested using the existing intermediate files from smkinven.
No modifications were required to the temporal allocation program within SMOKE. Temporal was tested as is with some additional debug statements to ensure clean processing of the hourly area sources. Intermediate files and log files were also checked to determine the successful operation of the program.

With the completion of the smkinven, grdmat, spcmat, and temporal programs some minor changes to the smkmerge program was made to merge together the spatial, temporal, and speciated intermediate data files. Code was written on lines 206 and 219 to determine if hourly

specific data were being merged. Next conditional statements on lines 393, 401, 404, 419, 429, 433, 452, 561, 565, 625, 657, 661, 666, 719, 720, 761, 766, 795, 924, 925, 939, and 951 were written to correctly call point source or area source subroutines depending on the state of the hourly specific data variable. The resulting code was compiled and extensively bug tested using intermediates generated from the previously mentioned intermediate programs. The outputs from smkmerge were plotted using the Verdi program and exported to both Excel and ArcGIS compatible file formats for spatial and temporal assessments. NCO software, ncl scripts, and BASH scripts were utilized in creating data summaries of the inventories generated from this process.

5.8.5 SMOKE-MOVES code changes, bug fixes, daily meteorology

The MOVES 2010a model was used to create onroad emissions inventory lookup tables for the Fairbanks $PM_{2.5}$ nonattainment area. Local data was used for the configuration of the MOVES model for the two separate modeling episodes. Details on the operation of MOVES and post processing are described in the Emission Inventory Data CMAQ/SMOKE 2008 sections.
The meteorological processing routines in the MET4MOVES code was changed to allow for daily processing of meteorology for use in the MOVES model and the MOVESMRG program. Lines 293 and 312 of met4moves.f were modified to indicate daily averaging methods were being used. Lines 163, 262, 266, and 269 of rdmetmoves.f were modified to allow for day specific averaging and storing of minimum and maximum while reading the MCIP processed meteorology fields.

Revisions to the SMOKE source code were made for the processing of the MOVES mobile source emissions inventory. These changes were necessary due to bugs from the preliminary nature of the releases of the software available at the time: SMOKE 2.7.5b and the SMOKE-MOVES processing tools version 0.20 – 0.31.

The MOVESMRG source code was modified to correct for errors that occurred during the reading and processing of the mobile source emissions inventory. These errors included the exceeding of arrays. The BLDSRCCELL subroutine in file bldsrccell.f allocates the source fractions to each grid cell. Conditional statements were added on line 82 and 87 to ensure the SRC variable falls between 1 and NSRC (the maximum number of sources) to prevent the NSRCCELLS array from exceeding its bounds.

For the core MOVESMRG source code a bug was addressed with the discrepancy between county codes used in movesmrg.f and in other subroutines resulting in an error in the arrays AVGMIN and AVGMAX. Parameter CNTYCOD was added on line 78 and used on line 546 to correctly address the county number for determining MINVAL and MAXVAL. Additional debug statements and warning messages were added to movesmrg.f on lines 546, 717 and 720.

5.8.6 Photochemical Modeling

Model outputs were extracted for the State Office Building grid cell in the modeling domain for all episode days. The episode averages and multi-episode averages are shown in tables below for

the 2008 baseline, 2015 projected baselines, 2015 control scenarios. The 2015 year emissions are presented both with actual point source emissions (Actuals) and PTE-level point source emissions (PTE). Outputs are shown as for $PM_{2.5}$ total, OC (organic carbon), EC (elemental carbon), SO_4 (sulfate), NO_3 (nitrate), NH_4 (ammonium), OTH (other), SOA (secondary organic aerosol), and SO_2 (gaseous sulfur dioxide).

Table 5.8-1. 2015 PM Species Concentrations Episode Averages and Multi-Episode Averages

Scenario	Averaging Period	$PM_{2.5}$ ($\mu g/m^3$)	OC ($\mu g/m^3$)	EC ($\mu g/m^3$)	SO_4 ($\mu g/m^3$)	NO_3 ($\mu g/m^3$)	NH_4 ($\mu g/m^3$)	OTH ($\mu g/m^3$)	SOA ($\mu g/m^3$)	SO_2 (ppm)
2008 Baseline	Ep1 & Ep2	35.72	24.47	4.34	2.13	1.30	1.17	2.31	0.01	0.02
	Ep1	42.01	29.24	5.13	2.40	1.25	1.25	2.73	0.01	0.02
	Ep2	28.53	19.01	3.44	1.83	1.35	1.07	1.83	0.01	0.01
2015 Baseline Actuals	Ep1 & Ep2	33.91	23.36	3.82	2.20	1.23	1.17	2.13	0.01	0.02
	Ep1	39.59	27.66	4.52	2.48	1.20	1.27	2.47	0.01	0.02
	Ep2	27.42	18.44	3.01	1.88	1.27	1.07	1.73	0.00	0.01
2015 Baseline PTE	Ep1 & Ep2	36.90	23.48	3.91	2.72	1.26	1.35	4.18	0.01	0.02
	Ep1	42.82	27.81	4.65	3.02	1.21	1.44	4.69	0.01	0.02
	Ep2	30.12	18.53	3.07	2.37	1.32	1.25	3.59	0.01	0.02
2015 Controls Actuals	Ep1 & Ep2	30.80	20.70	3.46	2.18	1.18	1.15	2.13	0.01	0.02
	Ep1	36.04	24.61	4.11	2.46	1.15	1.24	2.47	0.01	0.02
	Ep2	24.82	16.23	2.72	1.86	1.22	1.05	1.73	0.00	0.01
2015 Controls PTE	Ep1 & Ep2	33.77	20.82	3.56	2.70	1.20	1.32	4.18	0.01	0.02
	Ep1	39.24	24.76	4.25	2.99	1.14	1.40	4.69	0.01	0.02
	Ep2	27.51	16.32	2.78	2.36	1.26	1.22	3.58	0.01	0.02

Relative response factors for each of the components of $PM_{2.5}$, gaseous SO_2, and SO_4* are calculated for 2015. SO_4* RRF represents the combined impacts of primary and secondary sulfate on $PM_{2.5}$ using both modeled and measured estimates of sulfur. The method for calculating SO_4* is explained below. $PM_{2.5}$ and SO_2 RRFs are calculated by dividing the modeled concentrations in the 2015 multi-episode 24-hour averaged concentration of a species by the 2008 multi-episode 24-hour averaged concentration:

$$RRF_i = \frac{[i_{2015}]}{[i_{2008}]}$$

where *RRF* is the relative response factor of species *i* and [*i*] is the concentration of *i* for 24-hours averaged over all episode days in 2008 and 2015.

The SO_4* RRF is calculated as the weighted average of the SO_4 and SO_2 RRFs. A process analysis study of the CMAQ-model for both the modeling episodes by Leelasakultum and Mölders found that nearly all of the sulfate is derived from primary emissions.[9] Any RRF derived from the modeled SO_4 concentrations would overestimate the impacts of changes to primary SO_4 while ignoring the impacts of changes to gaseous SO_2. In order to estimate the likely impacts of changes to SO_2 emissions on $PM_{2.5}$ a method was developed to account for the secondary formation of sulfate:

$$RRF_{SO_4{}^*} = \frac{\left(\left[SO_{4(FRM)}\right] - \left[SO_{4(CMAQ)}\right]\right) \times RRF_{SO_2}}{\left[SO_{4(FRM)}\right]} + \frac{\left[SO_{4(CMAQ)}\right] \times RRF_{SO_4}}{\left[SO_{4(FRM)}\right]}$$

Where the variables are defined as follows:

- $RRF_{SO_4{}^*}$ is the relative response factor for both primary and secondary sulfate
- $[SO_{4(FRM)}]$ is the measured concentration of SO_4 averaged over FRM days for both episodes in $\mu g/m^3$
- $[SO_{4(CMAQ)}]$ is the modeled concentration of SO_4 averaged over FRM days for both episodes in $\mu g/m^3$
- RRF_{SO_2} is the relative response factor of gaseous SO_2
- RRF_{SO_4} is the relative response factor of primary SO_4.

This method assumes that the sulfate concentrations calculated by CMAQ are due only to primary emissions and transport of sulfate. This assumption seems reasonable given the results of the process analysis study by Leelasakultum and Mölders.[10]

[9] *Fairbanks North Star Borough PM 2.5 Non-Attainment Area CMAQ Modeling Final Report Phase II* DEC 2012 By Prof. Nicole Mölders (PhD, PhD) and Ketsiri Leelasakultum (MS) University of Alaska Fairbanks, Geophysical Institute, College of Natural Science and Mathematics, Department of Atmospheric Sciences

[10] IBID

Table 5.8-2. 2015 PM and SO_2 Relative Response Factors - Episode Averages and Multi-Episode Averages

Scenario	Averaging Period	OC	EC	SO_4	NO_3	NH_4	OTH	SO_2	SO_4*
2008 Baseline	Ep1 & Ep2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Ep1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Ep2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2015 Baseline Actuals	Ep1 & Ep2	0.95	0.88	1.03	0.95	1.00	0.92	1.06	1.05
	Ep1	0.95	0.88	1.03	0.96	1.01	0.90	1.06	1.05
	Ep2	0.97	0.88	1.03	0.94	1.00	0.95	1.06	1.04
2015 Baseline PTE	Ep1 & Ep2	0.96	0.90	1.27	0.97	1.15	1.80	1.29	1.28
	Ep1	0.95	0.91	1.26	0.97	1.15	1.72	1.26	1.26
	Ep2	0.97	0.89	1.30	0.97	1.16	1.96	1.33	1.32
2015 Controls Actuals	Ep1 & Ep2	0.85	0.80	1.02	0.91	0.98	0.92	1.05	1.04
	Ep1	0.84	0.80	1.02	0.92	0.99	0.90	1.05	1.04
	Ep2	0.85	0.79	1.02	0.90	0.98	0.95	1.05	1.04
2015 Controls PTE	Ep1 & Ep2	0.85	0.82	1.26	0.92	1.13	1.80	1.28	1.27
	Ep1	0.85	0.83	1.25	0.92	1.12	1.72	1.26	1.25
	Ep2	0.86	0.81	1.29	0.93	1.13	1.96	1.33	1.31

Ammonium and particle bound water RRFs are calculated based on the changes to sulfate and nitrate RRFs. Calculated future ammonium concentrations are fixed at 0.29*[NO_3] + 0.37*[SO_4]. The ratios of 0.29 for NH_4:NO_3 and 0.37 for NH_4:SO_4 are fixed based on the 2006 – 2010 winter average (quarters 1 and 4) values used for SANDWICH. Particle bound water RRFs are calculated by attributing 1/3rd of the PBW to ammonium nitrate and 2/3rd of the PBW to ammonium sulfate as discussed in the precursors document in Appendix III.D.5.7. The equation to calculate the PBW RRF is shown below:

$$RRF_{PBW} = \frac{2}{3} \times RRF_{SO_4} + \frac{1}{3} \times RRF_{NO_3}$$

Where RRF_{PBW}, RRF_{SO4}, and RRF_{NO3} are the relative response factors for PBW, SO_4 and NO_3 respectively. The RRFs from model outputs averaged over both episodes are used to calculate the future design values for 2015 emissions scenarios.

Future design values calculated from the RRFs above with a 0.5 µg/m^3 credit for voluntary measures are presented in table 5.8-3. Scenarios for the baseline projections and controls were simulated with actual point source emissions (Actual) and potential to emit levels (PTE). Three sets of design values are shown for each scenario depending on the treatment of sulfate: FDV, FDV SO_4, and FDV SO_4*. The FDV column calculates the design value based on RRFs for OC, EC, NO_3 and OTH with PBW and NH_4 RRFs derived as stated above. Per discussions with EPA

regarding the model performance of SO_4 the sulfate RRF is held to 1.0. FDV SO_4 and FDV SO_4* present scenarios where the sulfate RRF is used in the design value calculations. FDV SO_4 uses the RRF calculated from the model outputs for [SO_4] with no modifications. Based on the model performance and process analysis assessment this approach likely does not account for secondary sulfate. FDV SO_4* uses the RRF for SO_4* in the design value calculation. This treatment of the design value should more accurately capture the influence of both secondary and primary sulfate on $PM_{2.5}$ concentrations.

Voluntary measure benefits are calculated as the weighted average of a 3% credit in onroad mobile source contributions and a 6% reduction in the remaining sources. The total needed reductions based on the baseline design value of 44.7 $\mu g/m^3$ and 24-hour $PM_{2.5}$ NAAQS of 35 $\mu g/m^3$ would be calculated as 44.7 – 35 = 9.7 $\mu g/m^3$. Using the inventory for the 2008 baseline onroad mobile sources contribute 13.7% of the direct $PM_{2.5}$ in the nonattainment area with all other sources contributing 86.7%. A 3% voluntary measure credit from mobile source would yield a reduction of 3%*13.7%*9.7 $\mu g/m^3$ = 0.04 $\mu g/m^3$. A 6% voluntary measure benefit from all other sources would yield a reduction of 6%*86.7%*9.7 $\mu g/m^3$ = 0.5 $\mu g/m^3$. A total voluntary credit of 0.5 $\mu g/m^3$ is taken when rounding to the first decimal.

Table 5.8-3. Future Design Values for 2015 baselines (Actual and PTE) and Control Scenarios (Actual and PTE)

Scenario	FDV ($\mu g/m^3$)	FDV SO_4 ($\mu g/m^3$)	FDV SO_4* ($\mu g/m^3$)
2015 Baseline Actual	42.4	42.8	43.0
2015 Baseline PTE	43.2	46.6	46.8
2015 Control Scenario Actual	39.6	39.8	40.1
2015 Control Scenario PTE	40.1	43.4	43.5

The treatment of Actual and PTE point sources along with the influence of sulfate can produce a range of results for the control run between 39.6 $\mu g/m^3$ and 43.5 $\mu g/m^3$. The PTE bias alone can cause the results to shift by 0.5 $\mu g/m^3$ to 3.6 $\mu g/m^3$ depending on the treatment of sulfate. This range of bias is caused by the significant contributions of sulfate and sulfur dioxide from point sources. The most realistic approximation of the FDV in 2015 would be 40.1 $\mu g/m^3$ from the 2015 Control Scenario Actual with SO_4*.

CMAQ-modeled outputs for 2019 baseline and control scenarios are shown in tables 5.8-4. Similar to 2015 the outputs are shown as averaged over both episodes and for individual episodes across $PM_{2.5}$ total, OC, EC, SO_4, NO_3, NH_4, OTH, SOA, and SO_2. Simulations for 2019 are presented only for the case where point sources are held to PTE levels. A 2019 baseline and control scenario are shown along with the 2008 baseline for comparison. The control scenario package contains the ARA OHH, WSCO, State standards, natural gas expansion, dry wood, and natural turnover. Credit for voluntary measures is taken following the RRF calculations below.

Table 5.8-4. 2019 PM Species Concentrations Episode Averages and Multi-Episode Averages

Scenario	Averaging Period	$PM_{2.5}$ ($\mu g/m^3$)	OC ($\mu g/m^3$)	EC ($\mu g/m^3$)	SO_4 ($\mu g/m^3$)	NO_3 ($\mu g/m^3$)	NH_4 ($\mu g/m^3$)	OTH ($\mu g/m^3$)	SOA ($\mu g/m^3$)	SO_2 (ppm)
2008 Baseline	Ep1 & Ep2	35.72	24.47	4.34	2.13	1.30	1.17	2.31	0.01	0.02
	Ep1	42.01	29.24	5.13	2.40	1.25	1.25	2.73	0.01	0.02
	Ep2	28.53	19.01	3.44	1.83	1.35	1.07	1.83	0.01	0.01
2019 Baseline PTE	Ep1 & Ep2	37.16	23.84	3.79	2.76	1.26	1.36	4.15	0.02	0.01
	Ep1	43.02	28.14	4.49	3.07	1.21	1.46	4.64	0.02	0.01
	Ep2	30.47	18.91	2.99	2.41	1.31	1.26	3.59	0.02	0.00
2019 Controls PTE	Ep1 & Ep2	26.87	14.70	2.57	2.78	1.29	1.39	4.13	0.02	0.00
	Ep1	31.29	17.80	3.12	3.08	1.19	1.47	4.62	0.03	0.00
	Ep2	21.81	11.16	1.95	2.43	1.40	1.30	3.57	0.02	0.00

Relative response factors for 2019 are calculated in the same manner as for 2015 using 2008 as the base year with 2019 as the future year. Again no Actual level point source outputs are presented here.

Table 5.8-5. 2019 PM and SO_2 Relative Response Factors - Episode Averages and Multi-Episode Averages

Scenario	Averaging Period	OC	EC	SO_4	NO_3	NH_4	OTH	SO_2	SO_4*
2008 Baseline	Ep1 & Ep2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Ep1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Ep2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2019 Baseline PTE	Ep1 & Ep2	0.97	0.87	1.29	0.97	1.17	1.79	1.32	1.31
	Ep1	0.96	0.88	1.28	0.97	1.17	1.70	1.30	1.29
	Ep2	1.00	0.87	1.32	0.97	1.17	1.96	1.37	1.35
2019 Controls PTE	Ep1 & Ep2	0.60	0.59	1.30	0.99	1.19	1.79	1.43	1.38
	Ep1	0.61	0.61	1.28	0.95	1.17	1.69	1.39	1.35
	Ep2	0.59	0.57	1.33	1.03	1.21	1.95	1.50	1.43

Design values for 2019 are derived from the above RRFs with the same considerations for sulfate presented for each scenario in Table 5.8-6: FDV, FDV SO_4, and FDV SO_4*. The bias from PTE emissions is not calculated in the 2019 scenarios, but the influence is again expected to range from 0.5 $\mu g/m^3$ to 3.6 $\mu g/m^3$ depending on the sulfate RRF calculations. The previously calculated voluntary measure credit of 0.5 $\mu g/m^3$ is also applied to the FDV values for 2019 in the table below.

Table 5.8-6. Future Design Values for 2019 baseline (PTE) and Control Scenarios (PTE)

Scenario	FDV ($\mu g/m^3$)	FDV SO_4 ($\mu g/m^3$)	FDV SO_4* ($\mu g/m^3$)
2019 (PTE)	43.4	47.1	47.4
2019 Control Scenario (PTE)	33.5	37.3	38.3

5.8.7 Unmonitored Area Analysis

Areas in the nonattainment region away from the monitor sites require additional analysis to show attainment under a control scenario. These unmonitored areas are reviewed using a technique described as unmonitored area analysis (UMAA). The UMAA methodology blends photochemical model predicted concentrations of $PM_{2.5}$ with interpolated ambient monitor data to produce a map of future concentrations throughout the nonattainment area. This approach takes advantage of modeled $PM_{2.5}$ gradients between grid cells while making use of the existing monitor network's spatial fields. Three steps are recommended for UMAA; 1) interpolate ambient data, 2) adjust ambient spatial fields with modeled outputs, 3) adjust model-modified spatial fields with modeled cell-by-cell RRFs. [11]

5.8.7.1 Interpolation of Measured Ambient Concentrations

The interpolation of ambient monitored $PM_{2.5}$ concentrations relies on data from monitor sites over the design period of 2006 – 2010 to produce a five year weighted average design value as described in the SMAT section of the SIP (Chapter 5.8.9.2). The only available monitor with FRM-derived speciated concentrations covering all winters for 2006 through 2010 was the State Office Building monitor. Several other temporary monitor sites were operated during that period.

Table 5.8-7 summaries the sites used, their locations, and the ratio of observed $PM_{2.5}$ against the State Office Building monitor. The monitors are a mix of temporary installations operating for a few winters and the Borough's Relocatable Air Monitoring System (RAMS) trailers which may operate for a single season. To be consistent across all sites the BAM (beta attenuation monitor) concentrations were used as FRM (Federal Reference Monitor) data was not available at some locations. These sites were ultimately selected as they were in operation for periods during the design value calculation time frame of 2006 to 2010 and contained enough measurements to capture a range of air quality conditions. Ratios for total 24-hour $PM_{2.5}$ were calculated for each site against the State Office Building monitor.

Table 5.8-7. Future Design Values for 2019 baseline (PTE) and Control Scenarios (PTE)

[11] Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze U.S. Environmental Protection Agency Office of Air Quality Planning and Standards Air Quality Analysis Division Air Quality Modeling Group Research Triangle Park, North Carolina - EPA - 454/B-07-002 April 2007

Site Name	Monitors	Latitude	Longitude	Observed Ratio
State Office Building	FRM & BAM	N 64° 50.45'	W 147 ° 43.3822'	1:1
Peger Road	FRM & BAM	N 64° 49.154'	W 147° 46.685'	0.94:1
Woodriver	FRM & BAM	N 64° 50.348'	W 147° 52.339'	0.62:1
North Pole Elementary	FRM & BAM	N 64° 45.140'	W 147° 20.8325'	0.99:1
Landfill	BAM	N 64° 48.307'	W 147° 42.116'	0.81:1
UAF Farm	BAM	N 64° 51.200'	W 147° 51.606'	0.44:1
West Farmers Loop	BAM			0.38:1
UAF Thompson Road	BAM			0.62:1
Mid Badger Road	BAM			0.95:1
East Farmer's Loop	BAM			0.12:1
Ester Dome	BAM	N 64° 50.706'	W 148° 0.553'	0.17:1

These sites were then used in lieu of more permanent monitors to spatially interpolate $PM_{2.5}$ concentrations. Since the data from these sites were not all speciated the total $PM_{2.5}$ was used to establish the ratios between the State Office Building and the rest of the sites in the nonattainment area.

5.8.7.2 Adjusting Ambient Spatial Fields with Modeled Outputs

The spatial information from the monitors is adjusted with modeled outputs using the Voronoi Neighbor Averaging (VNA) technique. The VNA technique was applied in Excel as described in the BenMAP: Environmental Benefits Mapping and Analysis Program User's Manual.[12] BenMAP software was not used due to the limited monitor availability during the modeling episodes. VNA operates as an inverse-distance weighted average of monitor values. The VNA method was coded to match the default options in BenMAP with no distance cutoff or maximum number of monitors. The $PM_{2.5}$ weighted average is calculated in a given grid cell as follows,

$$PM_{2.5_i} = \frac{\frac{1}{d_1} * \frac{[obs_1]}{[model_1]} + \frac{1}{d_2} * \frac{[obs_2]}{[model_2]} + \cdots + \frac{1}{d_n} * \frac{[obs_n]}{[model_n]}}{\frac{1}{d_1} + \frac{1}{d_2} + \cdots + \frac{1}{d_n}} * [model_i]$$

Where $PM_{2.5i}$ is the adjusted $PM_{2.5}$ concentration in a grid cell i; d_1, d_2, and d_n are the distances between the grid cell i and 1st, 2nd, and nth monitors; obs_1, obs_2, and obs_n are the observed $PM_{2.5}$ concentrations at the 1st, 2nd, and nth monitors; $model_1$, $model_2$, and $model_n$ are the modeled

[12] BenMAP: Environmental Benefits Mapping and Analysis Program User's Manual, September 2008, Prepared for Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency by Abt Associates Inc.

concentrations at the 1st, 2nd, and nth monitor grid cells; $model_i$ is the modeled concentration in the grid cell i. The adjusted grid cells are calculated over the nonattainment area grid cells using the 2008 baseline model outputs.

5.8.7.3 Relative Response Factor Adjustments of Spatial Fields

Cell by cell RRFs were calculated for total $PM_{2.5}$ in the modeling domain for the 2015 and 2019 control scenarios. The total $PM_{2.5}$ RRF was used instead of the individual components due to the lack of speciated measurements away from the State Office Building monitor site. To be consistent with the methodology used in the FDV calculations the total $PM_{2.5}$ RRF in each grid cell was calculated as follows:

$$RRF_{PM} = \frac{OC_{future} + EC_{future} + NO3_{future} + NH4_{future} + OTH_{future} + SO4_{baseline}}{OC_{baseline} + EC_{baseline} + NO3_{baseline} + NH4_{baseline} + OTH_{baseline} + SO4_{baseline}}$$

Where the RRF_{PM} is the relative response factor for $PM_{2.5}$ for a future year control scenario in a grid cell; OC, EC, NO3, NH4, OTH, and SO_4 are concentrations of individual $PM_{2.5}$ species for either the future year or the baseline year. Note the SO_4 contribution to the RRF is held constant to match the RRF_{SO4} calculation used in the attainment demonstration.

SMAT (Speciated Modeled Attainment Test)

EPA model guidance, "Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze" (USEPA, 2007), recommends the Species Modeled Attainment Test (SMAT) to estimate future concentrations of daily $PM_{2.5}$ concentration. The method combines monitoring data with outputs from simulation models to estimate future $PM_{2.5}$ concentrations. It can be used to determine whether emission reductions will bring ambient concentrations to or below the National Ambient Air Quality Standard (NAAQS) (<=35 $\mu g/m^3$ for 24-hr $PM_{2.5}$). The SMAT is combined with other modeling techniques and relevant supplemental evidence to develop a technically-sound, weight-of-evidence recommendation on whether the proposed control strategies will meet the goal of pollution levels below the NAAQS.

SMAT recommends a nine-step process to take historically-measured $PM_{2.5}$ concentrations, apply factors to represent changes from the historical period to a future year, and estimate the future $PM_{2.5}$ design value (DV). The historically-measured $PM_{2.5}$ concentrations are sampled from the top 25% of polluted wintertime days within a five-year period. For each major chemical component of $PM_{2.5}$ (sulfates, nitrates, ammonium, organic carbon, elemental carbon; particle bound water, other primary particulate matter (Figure 1)), an air pollution model projects the change in concentration from the historical period to the future year. For instance, if the organic carbon concentration is projected to be in 2014 half of what it was in 2008, then the organic carbon concentration from the polluted days in the historical period is divided by two. The process is done for each chemical species and then summed across species to the get the projected future $PM_{2.5}$ after implementation of control strategies.

One important aspect of SMAT is how speciated $PM_{2.5}$ measurements from the Speciated Trends Network (STN) monitor are melded with the standard federal reference method (FRM) measurement of total $PM_{2.5}$ concentration. Care must be taken in this step because the STN monitor and FRM monitor use different measurement techniques. As the NAAQS are based on FRM monitored values, the speciated data from the STN monitor must be transformed into the values that would have been recorded by the FRM monitor. EPA modeling guidance in Section 5.1.4 describes this transformation technique, called Sulfate, Adjusted Nitrate, Derived Water, Inferred Carbonaceous material balance approach (SANDWICH), which follows the peer-reviewed, scientific methodology of Frank (2006) and references therein.

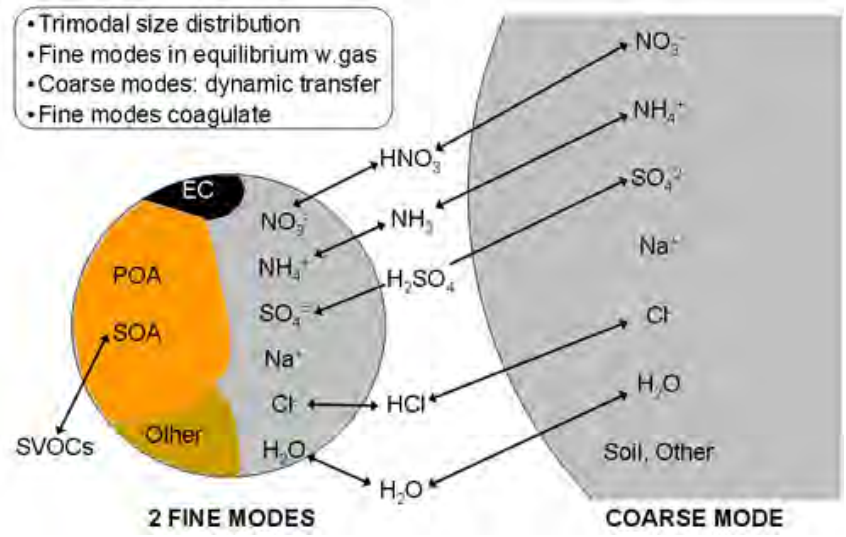

Figure 1: Major Components of $PM_{2.5}$
http://www.epa.gov/AMD/ModelDevelopment/aerosolModule.html

STEP 1:

The first step in the SMAT analysis is to identify the high observed $PM_{2.5}$ days at each monitoring site for each year used for the baseline design value (DV). The baseline design value represents the pollution levels at the time the area violated the NAAQS and was designated nonattainment. In Fairbanks, the State Office Building is the only monitoring station that was used to determine a non-attainment area (NAA). Following the EPA emission inventory guidance (USEPA, 2005), 2008 was chosen as the base year, and following Section 3.1 of the EPA modeling guidance the baseline design value was calculated as an average of the 2006-2008, 2007-2009, and 2008-2010 three-year design values. The three-year design value is the same one as in the calculation of compliance with the PM2.5 NAAQS: an average of three consecutive years' worth of 98th percentiles. The baseline design value for the Fairbanks non-attainment area the design value is 44.7μg/m^3 (Table 1).

The baseline design value is not directly used in the calculation of the future year design value. Rather, the species-specific changes from the base (historical) year to the future year are applied to all the individual 24-hour averages in the 2006-2010 period and then the same procedure as used to calculate the baseline design value (98th percentiles for each year, three year design values, average of three year design values) is used to calculate the future design value (USEPA Update to the 24 hour PM2.5 NAAQS model attainment test, 2011). The baseline design value is not useless, however. The difference between the baseline design value and the NAAQS determines the overall reductions needed to reach attainment. After the amount of pollution reduction needed to reach attainment (9.2 μg/m^3) is divided by the number of years between designation of nonattainment and the Moderate Area attainment date (5), we arrive at the one year's worth of progress value relevant for Reasonable Further Progress and Contingency Measures (1.84 μg/m^3).

Table 1: The 98%-tile $PM_{2.5}$ (μg/m^3) concentration days and resulting 5-year rolling average DV for Fairbanks, excluding Exceptional Events[1].

Year	High Concentrations	98th Percentile	3- year design value
2006	51.9	42.2	
	42.2		
2007	51.6	33.1	
	34.1		
	33.1		
2008	114.5	46.7	40.7
	50.7		
	46.7		
2009	59.0	51.0	43.6
	52.7		
	51		
2010	83.2	51.8	49.8
	57.1		
	51.8		
5-yr Baseline Design Value			44.70

[1]Exceptional Events for the 2009 data have been flagged by DEC and concurred by EPA. 2010 Exceptional Events have been flagged by DEC and are in the EPA concurrence process. If the 2010 data is not concurred on by EPA, the baseline design value will be 51.8 $\mu g/m^3$. These Exceptional Events become official when EPA acts on them in the Federal Register, which will come when the EPA acts upon this SIP revision.

STEP 2:

The intent of Step 2 to is to develop the average $PM_{2.5}$ chemical speciation for representative polluted days. For Fairbanks we designated the top 25% of winter days during Quarter 1 and 4 of 2006-2010—as indicated by the $PM_{2.5}$ concentration from the FRM filter -- for this task as a balance of choosing the relevant polluted days and having a statistically strong dataset to use (Table 2). We develop a post-SANDWICH average speciation for Quarter 1 (January, February, and March) and Quarter 4 (October, November, and December) separately, according to EPA modeling guidance. We then use the average of the Quarter 1 and Quarter 4 speciated concentration because Fairbanks experiences polluted days across all winter months.

We developed the species concentration fractions from the STN monitor located at the same State Office Building location as the violating FRM monitor. As mentioned previously, the speciated concentration from the STN measurement cannot be directly used as the speciated concentration from the FRM. The speciated concentration must be converted into the concentration that would have been measured by the FRM monitor after accounting for the differences between the instruments. For example, the FRM measurements do not capture all ambient particles, loss of ammonium nitrate, and addition of particle bound water (PBW) from the STN speciation measurement. The SANDWICH method (Frank, 2006) carries out this conversion process and is described briefly below. We followed the SANDWICH method described from Frank and by EPA modeling guidance exactly in most cases, but made a couple changes specific to woodsmoke-dominated areas in consultation with the EPA Regional Office and in collaboration with other states with woodsmoke issues.

Table 2: The top 25% of high $PM_{2.5}$ ($\mu g/m^3$) days at the State Office Monitor for the years 2006-2010 for Quarter 4 (Q4) and Quarter 1 (Q1).

Q4 Date	Q4 FRM Concentration ($\mu g/m^3$)	Q1 Date	Q1 FRM Concentration ($\mu g/m^3$)
20081229	114.5	20100126	83.2
20071220	51.6	20090107	59
20091209	51	20090110	52.7
20081114	50.7	20060117	51.9
20081202	46.7	20100102	51.8
20091230	43.1	20100105	51.8
20091221	41.5	20100108	44.4
20101201	41.2	20060111	42.2
20091212	40.8	20080209	40.4
20081214	38.3	20090104	39
20081108	37	20100120	38.1
20101207	36.9	20060105	38
20091124	35.3	20100111	36.9
20081217	34	20070205	34.1
20071223	33	20070223	33.1
20061219	32.1	20060129	32.7
20061125	31.1	20100204	31.5
20071129	29.6	20100213	30.9
20081223	29.1	20070220	29.7
20081111	27.4	20070127	29.6
20081205	27.1	20090113	29.1
20071217	26.7	20100201	28.8
20091121	26.2	20100123	28.5
20081220	25.7	20070301	28.2
20091227	25.2	20090215	28
20101210	25.2	20090101	27.7
20091206	25.1	20060123	27.6
20061119	23.7	20100129	27.4
20081123	23.6	20070112	26.7
20061207	22.8	20090125	26.2
20071111	22.7	20100216	26

SANDWICH addresses the 7 major measured components of $PM_{2.5}$:

- Measured sulfate [$SO4_{STN}$]
- Adjusted nitrate [$NO3_{FRM}$] (retained on the FRM filter)
- Adjusted ammonium [$NH4_{FRM}$] (retained on the FRM filter)
- Measured elemental carbon [EC_{STN}] (corrected IMPROVE to NIOSH analysis)
- Organic carbonaceous mass estimated from a mass balance [OCMmb]
- Estimated particle bound water [PBW]
- Estimated other primary $PM_{2.5}$ components [OPP]

Measured sulfate

There are no major differences in how the STN and FRM instruments measure sulfate. It is assumed that the sulfate measured by the STN is equal to what was captured by the FRM.

Retained Nitrate Mass

Nitrate volatilizes from the FRM filter but not the STN measurement. SANDWICH calculates the amount that would have volatilized if the amount of nitrate measured by STN had been deposited on the FRM filter. The volatilized nitrate mass concentration, delta NO_3, in units of μg/m^3 is

$$\Delta NO_3 = \frac{745.7}{T_R(K)} x \frac{1}{24} \sum_{i=1}^{24} K_i^{1/2}$$ Eq. 5.2 (USEPA, 2007) ;(Eq. 5, (Frank, 2006)).

The dissociation constant for ammonium nitrate (K_i) is evaluated for every hour of every day of nitrate measurements we are using for the analysis. The hourly temperature and relative humidity data used for the associated equations (Frank, 2006) in determining K_i are from the Fairbanks Airport (PAFA). The reference temperature T_R in Eq. 5.2 is the daily average ambient temperature and then ΔNO_3 averaged to 24-hour. The retained nitrate [$NO3_{FRM}$] is estimated by

$NO3_{FRM} = NO3_{STN} - \Delta NO_3$.

A limit was applied to $NO3_{FRM}$ as follows,

If $NO3_{FRM} < 0$, then $NO3_{FRM} = 0$.

The potential nitrate loss using local Fairbanks meteorology is shown in Figure 2. The graph is labeled as potential nitrate loss, because the loss of nitrate is bound by the nitrate on the filter ($NO3_{FRM}$). The amount of nitrate volatilization during the winter in Fairbanks is low. The maximum nitrate loss of all the days analyzed from 2006-2010 was 1.2 μg/m^3 and was during the summer on exceptional event day.

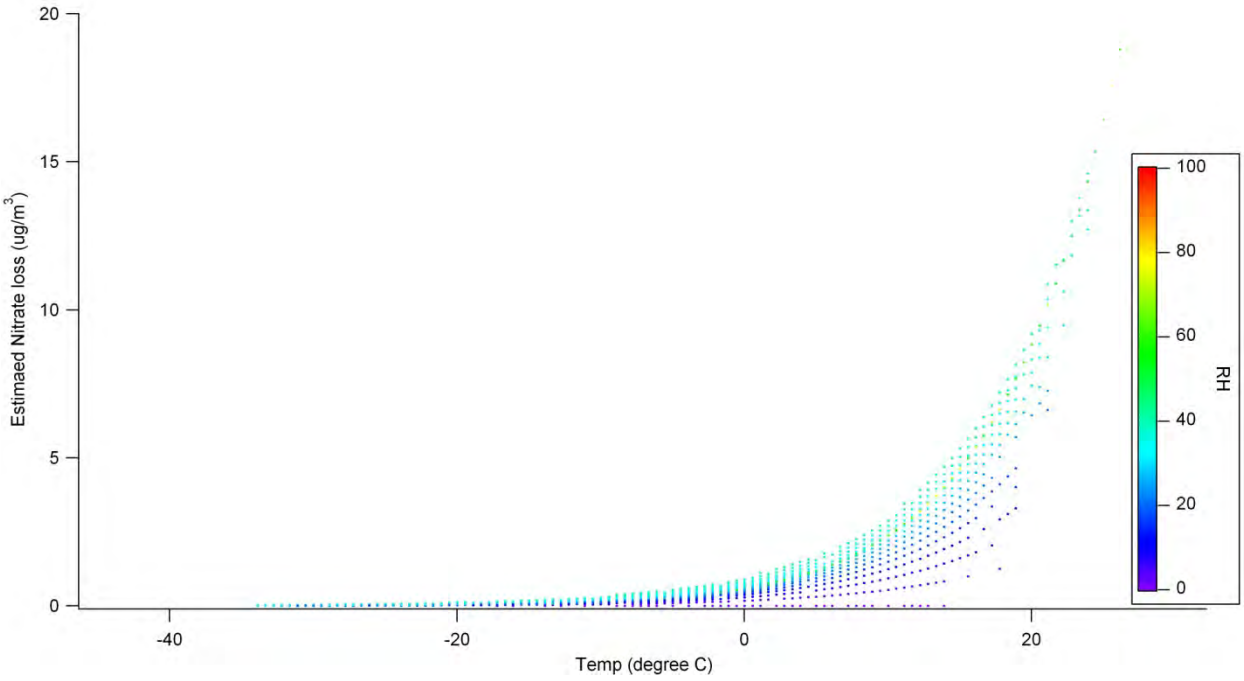

Figure 2: Fairbanks Potential 1-hr NO_3 loss as a function of temperature and relative humidity.

Adjusted Ammonium Mass

EPA modeling guidance recommends using the measured STN ammonia (NH_4) as the measured FRM ammonia. Many of the questions raised in the guidance about the validity of such a recommendation are not problems in Fairbanks because Fairbanks winters are very cold and the amount of ammonium nitrate volatilization is very small. Thus,

$[NH_{4FRM}] \cong [NH_{4STN}]$.

In cases where the ammonia concentration exceeds the amount necessary to neutralize the FRM sulfate and nitrate, the ammonia concentration was adjusted to ensure charge balance. This is a deviation from the USEPA recommended adjustment, but has been noted in other adjusted ammonium concentration calculations (Turner, 2010). The adjustment used was:

$NH_{4FRM} = 2 \times SO_4^{2-} + NO_{3FRM} - H^+$ when $H^+ > 0$ or else $H^+ = 0$

The hydrogen ion concentration results from the calculation of particle bound water, as described below.

Elemental Carbon Mass

Elemental carbon (EC) concentrations as measured by the STN instrument are used directly as the concentrations for the FRM measurement. In October 2009, the STN instrument at the Fairbanks State Office Building changed its technique for measuring elemental and organic carbon; the MetOne SASS using the NIOSH analysis method was replaced with the URG 3000N using the IMPROVE analysis method. Since most of the measurements were made on the SASS sampler and NIOSH method and evidence of high wood smoke $PM_{2.5}$ areas are more accurately measured by the NIOSH method, the EC

measurements from October 2009 on were corrected to reflect the NIOSH method (Hixson, 2011). Traditionally in the Lower 48 the NIOSH data is corrected to reflect the IMPROVE method, but the opposite makes sense for the particular case of a wood smoke dominated area with primarily NIOSH data in the 2006-2010 analysis timeframe.

$EC_{FRM} = EC_{SASS/NIOSH}$ (Before October 2009)
$EC_{FRM} = (EC_{URG/IMPROVE}*0.5722) + 0.2509$ (After October 2009)

Other primary $PM_{2.5}$ components

We calculate the other primary $PM_{2.5}$ (OPP) directly as recommended by EPA modeling guidance:

OPP= 3.73 x [*Si*] + 1.63 x [*Ca*] + 2.42 [*Fe*] + 1.94 x [*Ti*].

Particle Bound Water Mass

Because the STN speciation does not measure the particle bound water (PBW) that would be present in the $PM_{2.5}$ if it were being measured by a FRM monitor, we calculate the PBW with the Aerosol Inorganic Model II (http://www.aim.env.uea.ac.uk/aim/model2/model2a.php). Inputs to the model are using the ammonia, nitrate, and sulfate concentrations as calculated above. As suggested by Frank (2006), the model is evaluated at 295K and 35% RH because these are the equilibrium atmospheric conditions under which the FRM filter is weighed in the laboratory. In the model we assume there is no ammoniated compound solid formation and us the following ion mass balance equation:

$H^+ = [2 \times SO_4^{2-}] + NO_3^- - NH_4^+$.

The measured sulfate, retained nitrate mass and adjusted ammonium mass allowed an estimated hydronium ion proton molar concentration and a PBW water mass was directly calculated from the AIM model.

Organic Carbonaceous Mass

SANDWICH estimates organic carbonaceous mass, [OCMmb], as the amount that is not explained by other chemical species:

$OCMmb = [PM2.5_{FRM}] - \{[SO_{4STN}] + [NO_{3FRM}] + [NH_{4FRM}] + [EC_{FRM}] + [OPP] + [PBW] + 0.5$

The STN instrument measures organic carbon directly, but the techniques to quantify the organic mass have considerable uncertainties. The mass balance technique is reasonable since all other species can be well-quantified and it is likely the remaining mass is organic carbon. As a benefit mass closure is assured. To guard against spurious results, the organic carbon mass is bound on the lower end by 70% of the measured organic carbon and on the upper end by 80% of the total mass. As with the elemental carbon concentration, organic carbon concentrations obtained with the URG/IMPROVE method were converted using the correlation in Hixon (2011) to the SASS/NIOSH method. When a bound is applied, the speciated concentration no longer adds up to the total concentration. When this happens all species are adjusted proportionally such that they add up to the total measured concentration by the FRM instrument. The upper bound was never invoked by the Fairbanks data set, while the lower bound was used on three

occasions (5% of the total dataset). The concentration closure adjustment in these three cases modified the sum of the species' concentration by less than 10%.

Quarterly average FRM-derived species concentration fractions

The SANDWICH process is done separately for every 24-hour measurement in the dataset. The top 25% polluted days in 2006-2010 for Quarter 1 and Quarter 4 represent 31 and 27 samples, respectively. The average speciation for Quarter 1 and Quarter 4 is presented in Table 3 and Figures 4-5. These values represent the chemical composition of $PM_{2.5}$ on polluted wintertime days in Fairbanks for the baseline 2006-2010 period.

Table 3: Quarterly average percentage of SANDWICH'ed $PM_{2.5}$, calculated from the top 25% of $PM_{2.5\ days}$ for years 2006-2010

	SO_{4STN}	NO_{3FRM}	NH_{4FRM}	PBW	$EC_{URG/IM>SASS/NI}$	OPP	$OCMmb_{URG/IM>SASS/NI}$
Q4	17.40%	3.64%	7.57%	5.82%	6.89%	1.25%	57.43%
Q1	19.15%	5.0%	8.54%	6.27%	6.19%	1.01%	53.82%

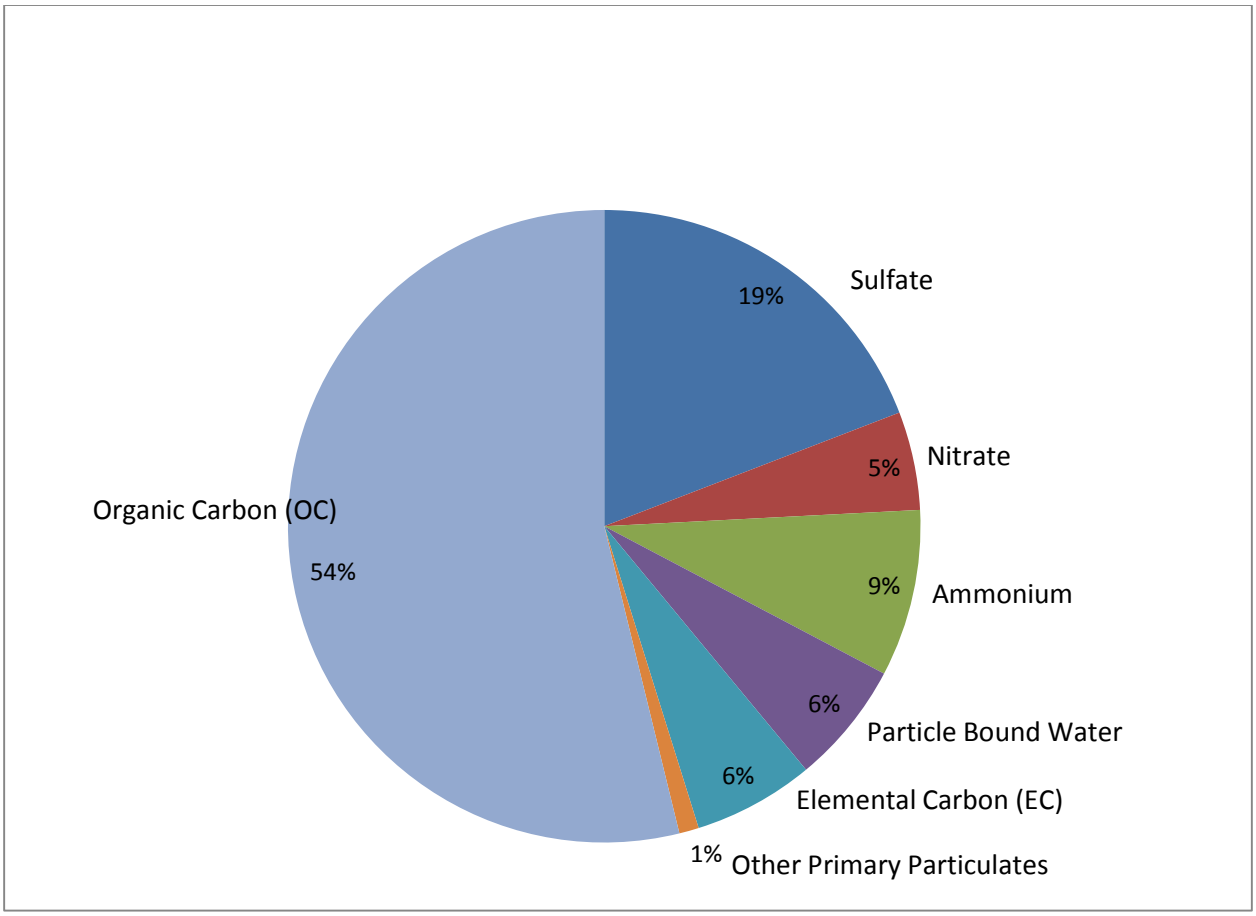

Figure 4: Quarter 1, FRM-derived species percentage of high 24-hr average $PM_{2.5}$ days from the Fairbanks State Office Building for years 2006-2010.

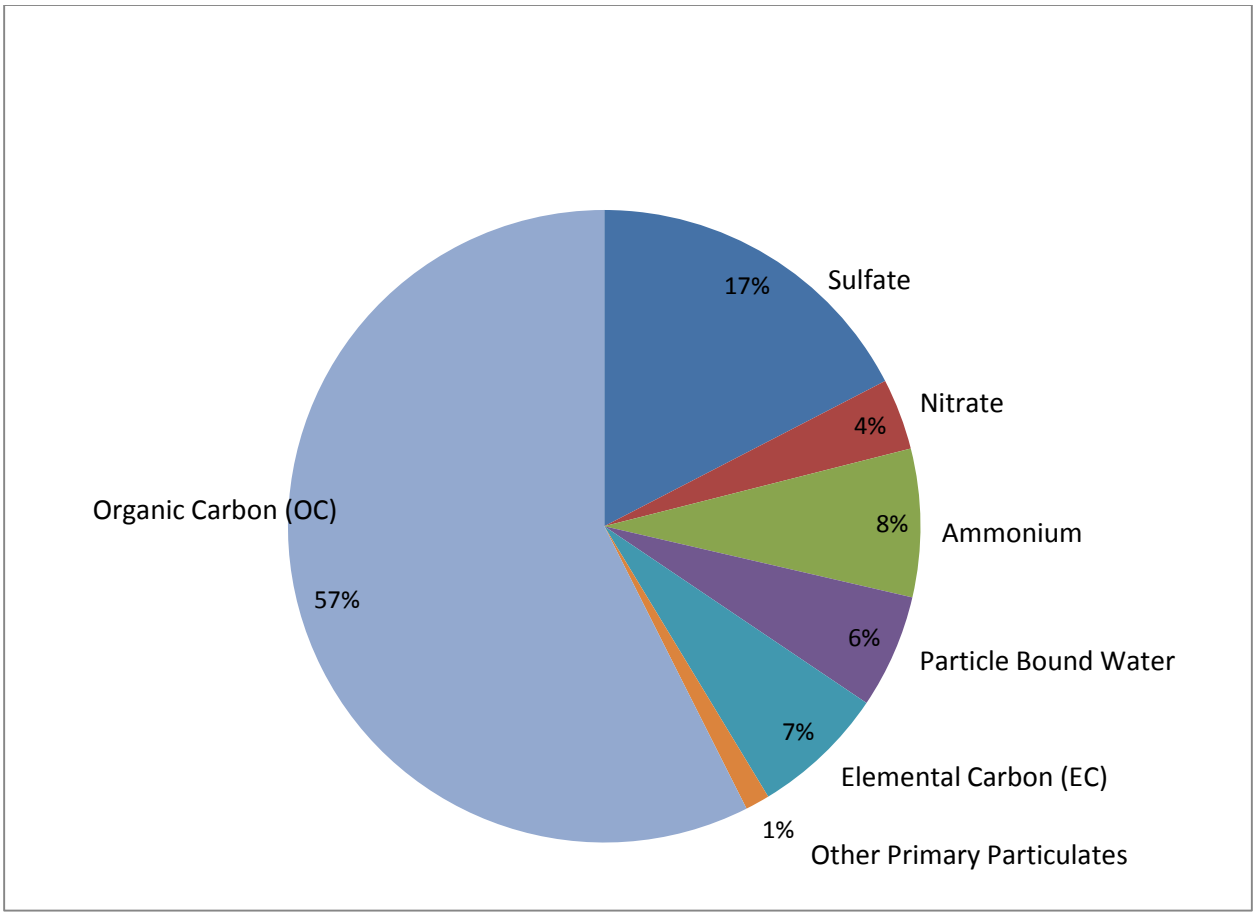

Figure 5: Quarter 4, FRM-derived species percentage of high 24-hr average $PM_{2.5}$ days from the Fairbanks State Office Building for years 2006-2010.

After SANDWICH was complete and the Q1 and Q4 average species concentrations and percentages were calculated (Table 4), the average species percentage was multiplied by the baseline design value of 44.7 $\mu g/m^3$ from Step 1. While not necessary for the model attainment test, this information has been helpful in guiding other parts of the attainment plan.

Table 4: Averaged Quarter 1 and 4, FRM-derived species percentage of high $PM_{2.5}$ days and average concentration based on the baseline design value (DV) of 44.7$\mu g/m^3$.

Species	Sulfate	Nitrate	Ammonium	Water	elemental carbon	OPP	Organic carbon
Q4 %	17.40	3.64	7.57	5.82	6.89	1.25	57.43
Q1 %	19.15	5.03	8.54	6.27	6.19	1.01	53.82
Average of Q1 and Q4 %	18.28	4.34	8.05	6.05	6.54	1.13	55.62
Average DV($\mu g/m^3$)	8.17	1.94	3.60	2.70	2.92	0.50	24.86

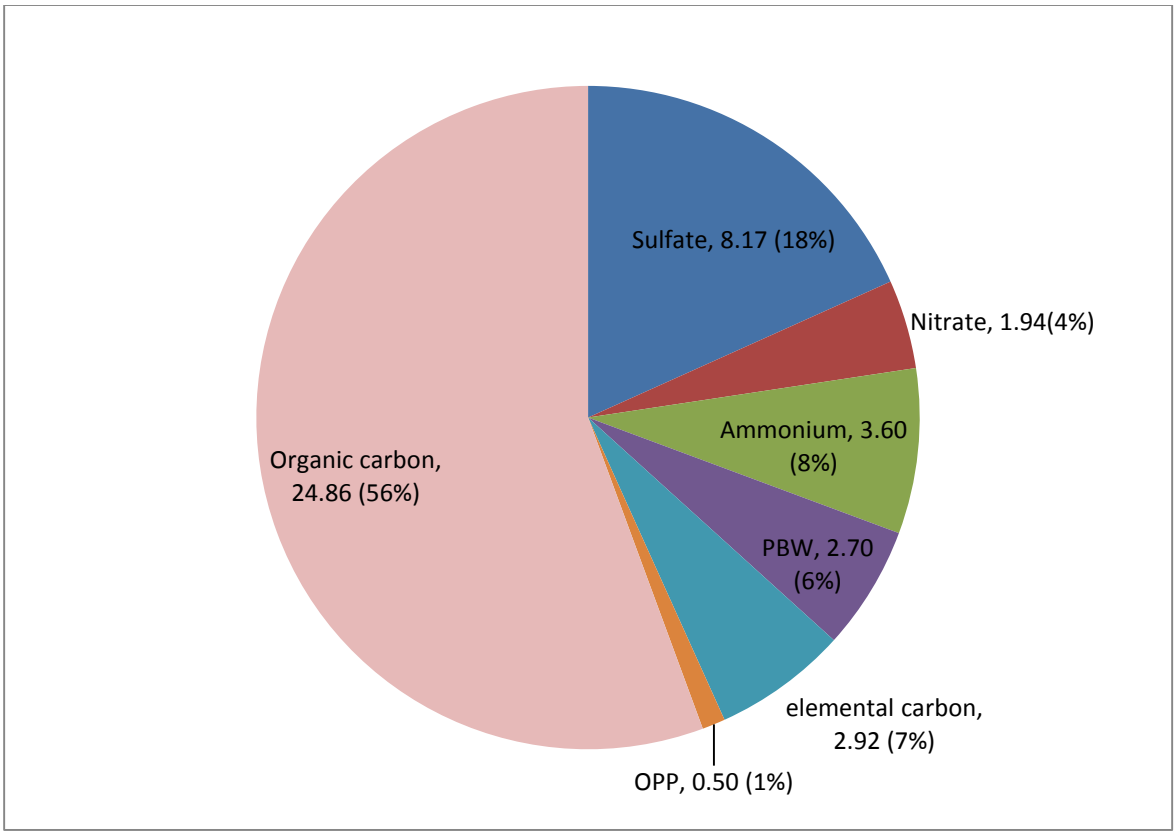

Figure 6: Averaged Quarter 1 and 4, FRM-derived species percentage of high PM2.5 days from years 2006-2010 and average concentration based on the baseline design value (DV) of 44.7 $\mu g/m^3$.

Step 3: Calculate species concentration for each of the high ambient days

Step 3 calculates the concentration of chemical species on each of the high ambient days in 2006-2010. For example, the highest $PM_{2.5}$ from 2006 was 51.9 $\mu g/m^3$ on January 17th (see Table 1,STEP1), Using the Quarter 1 average speciation percentages (Table 4), we calculate the species concentrations in $\mu g/m^3$on that day at the Fairbanks State Office Building in Table 5:

Example for sulfate:

51.9 $\mu g/m^3$ - 0.5 $\mu g/m^3$ (blank filter) = 51.4 $\mu g/m^3$ x 0.1915 (SO4, Q1 % from Table 3) = 9.84 $\mu g/m^3$

Table 5: $PM_{2.5}$ Species concentrations in $\mu g/m^3$ for the highest day in the year 2006

Date	FRM PM2.5	Blank	Non blank FRM	Sulfate	Nitrate	Ammonium	Water	Elemental Carbon	OPP	Organic Carbon
1/17/06	51.9	0.50	51.40	9.84	2.58	4.39	3.22	3.18	0.52	27.66

The same process is done for the top 25% of high days during the winter (Quarter 1 and 4) and all of these high days are listed in Table 2, STEP 2.

STEP 4: Calculate the component specific RRFs (Relative Response Factor)

The relative response factor is a ratio between the modeled projected concentrations divided by the present baseline modeled concentration for each species. Two episodes from 2008 are modeled using emissions from 2008 (present baseline) and then using emissions from 2015 (future baseline) plus emission reductions from emission reduction strategies (future control). The modeled concentrations from the 2015 future control case are divided by the modeled concentrations from the 2008 present baseline. This is done for each chemical species and for every grid cell of the modeling domain. The result is a table of RRFs similar to Table 5, which is just an illustration for explanatory purposes. The RRFs for the emission reductions proposed in this attainment plan are presented in Chapter 5.9. Concentrations in the both the present and future model runs are calculated as 24-hour average values for each component of PM for the baseline and each component of the future. Then the future components were divided by the baseline for the episode-long 24-hour PM species averages for all episode days except for the two model spin up days at the start of each episode. The resulting RRFs for the modeled State Office Building grid cell are in Table 6. Table 7 shows an example of data from the high days of 2008 with the species-specific RRFs applied in order to calculate the concentration of each $PM_{2.5}$ chemical species in 2015 given a scenario of emission controls.

Example calculation:

Sulfate RRF = 2015 future modeled concentration x 2008 baseline modeled concentration = 0.89 RRF

Sulfate RRF = 8.78/9.82 = 0.89 RRF

Table 6: Relative Response Factor (RRF) example averaged over days in episode 1 and 2 derived from a present baseline 2008 simulation and future year control strategies.

Species	Sulfate	Nitrate	Ammonium	Water	Element Carbon	OPP	Organic Carbon
RRF	0.89	0.95	0.94	1.00	0.88	0.99	0.77

There are no RRFs for particle bound water or the blank, they do not change as control strategies changes. For example, in Table 6, the OCMmb (organic carbon mass balance) RRF is 0.77 and a large decrease in OC is observed from controls that largely only affect organic carbon.

STEP 5-6: Apply the component specific RRFs to the observed air quality by quarter

Step 5-7 are represented as an example in Table 7 for the year 2008, high $PM_{2.5}$ days and the species are added together to calculate the future year $PM_{2.5}$ species (step6). The left side of the Table 7 follows the exact same method as shown in Table 5 for January 17th, 2006. The FRM derived species concentrations based on the Sandwich method on the left and the right side is the future species concentrations based on the example RRFs in Table 6.

Example calculation for future sulfate:

Future Sulfate = 2008 FRM-derived species concentration x 2015 sulfate RRF = 17.66 $\mu g/m^3$

Future Sulfate = 19.84 x 0.89 = 17.66 $\mu g/m^3$

Table 7: Example RRF future year concentrations based on the RRFs in Table 5 and the top high days in year 2008.

Observed FRM PM 2.5	Blank	Non blk FRM	Observed Sulfate	Observed Nitrate	Observed Ammonium	Water	Observed Elemental Carbon	OPP	Observed Organic Carbon		Future Sulfate	Future Nitrate	Future Ammonium	Water	Future Elemental Carbon	Future OPP	Future Organic Carbon	Blank	Future FRM
114.5	0.50	114.00	19.84	4.16	8.62	6.64	7.85	1.42	65.47		17.66	3.95	8.11	6.64	6.91	1.41	50.41	0.50	95.58
50.7	0.50	50.20	8.74	1.83	3.80	2.92	3.46	0.63	28.83		7.78	1.74	3.57	2.92	3.04	0.62	22.20	0.50	42.37
46.7	0.50	46.20	8.04	1.68	3.50	2.69	3.18	0.58	26.53		7.16	1.60	3.29	2.69	2.80	0.57	20.43	0.50	39.03
40.4	0.50	39.90	7.64	2.01	3.41	2.50	2.47	0.40	21.47		6.80	1.91	3.20	2.50	2.17	0.40	16.54	0.50	34.02
40.4	0.50	39.90	6.94	1.45	3.02	2.32	2.75	0.50	22.91		6.18	1.38	2.84	2.32	2.42	0.49	17.64	0.50	33.78
38.3	0.50	37.80	6.58	1.38	2.86	2.20	2.60	0.47	21.71		5.86	1.31	2.69	2.20	2.29	0.47	16.72	0.50	32.03
37	0.50	36.50	6.35	1.33	2.76	2.13	2.51	0.46	20.96		5.65	1.26	2.60	2.13	2.21	0.45	16.14	0.50	30.94
34	0.50	33.50	5.83	1.22	2.53	1.95	2.31	0.42	19.24		5.19	1.16	2.38	1.95	2.03	0.41	14.81	0.50	28.44
32.6	0.50	32.10	5.59	1.17	2.43	1.87	2.21	0.40	18.43		4.97	1.11	2.28	1.87	1.95	0.40	14.19	0.50	27.27
25.9	0.50	25.40	4.86	1.28	2.17	1.59	1.57	0.26	13.67		4.33	1.21	2.04	1.59	1.38	0.25	10.53	0.50	21.84
23.7	0.50	23.20	4.44	1.17	1.98	1.45	1.44	0.23	12.49		3.95	1.11	1.86	1.45	1.26	0.23	9.61	0.50	19.99
23.5	0.50	23.00	4.40	1.16	1.96	1.44	1.42	0.23	12.38		3.92	1.10	1.85	1.44	1.25	0.23	9.53	0.50	19.82
23.4	0.50	22.90	4.39	1.15	1.96	1.44	1.42	0.23	12.32		3.90	1.09	1.84	1.44	1.25	0.23	9.49	0.50	19.74
21.5	0.50	21.00	4.02	1.06	1.79	1.32	1.30	0.21	11.30		3.58	1.00	1.69	1.32	1.14	0.21	8.70	0.50	18.14
19.8	0.50	19.30	3.70	0.97	1.65	1.21	1.19	0.19	10.39		3.29	0.92	1.55	1.21	1.05	0.19	8.00	0.50	16.71
19.5	0.50	19.00	3.64	0.96	1.62	1.19	1.18	0.19	10.23		3.24	0.91	1.53	1.19	1.03	0.19	7.87	0.50	16.46
14.4	0.50	13.90	2.22	0.00	0.80	0.77	0.76	2.07	7.28		2.22	0.00	0.80	0.77	0.76	2.07	7.28	0.50	14.40

Step 7: Sum the species components to get total $PM_{2.5}$ concentrations for each day

The species concentrations from the future year are added together to arrive at the modeled projected concentrations given changes in emissions between 2015 and 2008 plus changes from emission controls. Table 7 is the result of this process for when or example RRFs (from Step5) are applied to our high ambient days (from Step1). It is an estimate of the $PM_{2.5}$ concentration that would have been observed in 2006-2010 if the area had the pollutant emissions from 2015 and from the proposed emission control strategy. The result of this process for the emission controls proposed in this attainment plan is in Section Chapter 5.6 and Appendix 5.6.

Step 8: Determine future year 98th percentile concentrations for each site year.

The 98th percentile concentration is usually the 3rd highest concentration from a year for the sampling schedule followed in 2006-2010 but it depends on how many valid samples were obtained from the year [Appendix N reference]. For the 2006 $PM_{2.5}$ data, the 2nd highest concentration is the 98th percentile and is the 3rd highest for 2007 through 2010. Table 8 identifies the 98th percentile for the future year control case.

Step 9: Calculate future 5 year 24-hr DV.

The future year control design value is calculated as an average of the 3-year design values from 2006-2008, 2007-2009, and 2008-2010. For our example case:

Table 8: Baseline and Future 5-year Design Values based example RRFs (Table 5)

Year	**98%-tile**	**98%-tile**
2006	42.2	36.6
2007	33.1	28.7
2008	46.7	39.0
2009	51.0	45.6
2010	51.8	44.9
Design Values	**44.70**	**38.6**

References

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USEPA (2007): Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze, EPA-454/B-07-002,United States Environmental Protection Agency, Office of Air Quality Planning and Standards, April 2007.

USEPA (2011): Attachment A and B. http://www.epa.gov/ttn/scram/guidance/guide/Update_to_the_24-hour_PM25_Modeled_Attainment_Test.pdf

USEPA(1993): Appendix N.

Using the CALPUFF Dispersion Model to Characterize the Fairbanks Power Plant Plumes.

Fairbanks has a significant $PM_{2.5}$ nonattainment problem with design values increasing, in excess of 50 µg/m^3 in recent years. Chemical speciation shows organic carbon (OC) levels amount to approximately 60% and sulfate levels of about 20% of the mass of $PM_{2.5}$. The dominant source of CO is thought to be from the wood burning and sources of sulfur from space heating oil, power plant fuel oil and coal. Upon analysis of the monitoring site filters, it is not clear whether the SO_2 and sulfate emissions are from fuel oil or from the coal because of the presence of winter time inversion layers.

The air quality model CMAQ, configured with the Penn State developed meteorological model WRF runs showed approximately 20% of the particulate matter composed of sulfate. It was not known whether the sulfur contribution to the $PM_{2.5}$ was from fuel oil or from the coal. EPA region 10 suggested running a dispersion model to assess the plumes from the point sources located at the adjacent areas. ADEC and EPA agreed that CALPUFF would be an appropriate model to run to characterize the plumes from the power plants located within the vicinity of the nonattainment area.

CALPUFF is a non-steady-state meteorological and air quality modeling system used by the EPA for studies that include long range transport of pollutants. The model was configured with WRF inputs using mesoscale model interface program (MMIF) and was modified to handle 38 vertical layers representing Fairbanks with the lowest layer being 4 meters above ground level on a 1.33 x 1.33 km grid cell. Six point sources that are in the Fairbanks $PM_{2.5}$ nonattainment area were modeled for the design episode January 23- February 10, 2008. These six point sources were:

1- Fort Wainwright (Facility ID 1121) – Coal is the fuel source, hourly emissions provided.
2- University of Alaska Fairbanks (Facility ID 315) Coal is the base fuel and distillate fuel oil is the secondary fuel used to satisfy increased loads, hourly emissions were provided.
3- GVEA is the electric utility and has two facilities Zehnder (Facility ID 109). Zehnder peaking facility north of downtown which burns high sulfur distillate fuel oil on an intermittent basis.
4- North Pole (Facility ID 110). North Pole is a larger facility and burns a mixture of high sulfur distillate fuel oil and naptha (very low sulfur), hourly emissions provided for both.
5- Aurora Energy (Facility ID 315) is a power plant owned by the coal company, located in downtown Fairbanks, which burns a mixture of coal and distillate fuel oil. They sell the power to GVEA and they sell hot water and steam to office buildings and a limited number of homes in the downtown area. Only constant yearly emissions were provided.
6- Flint Hills Refinery (Facility ID 71) – is located in North Pole. It is a distillation refinery, no cracking; all heavy ends go back into the pipeline. Hourly emissions were provided.

Figure XX represents the modeling domain 201 x 201 in the X and Y direction with a grid cell size of 1.33 x 1.33 km. In addition to the gridded receptors, the model used discretely placed receptors at specific locations with vertical resolution of the WRF data's first 12 layers to obtain the average surface concentration of the entire domain. Summary of the six major point sources average surface concentration of $PM_{2.5}$and SO_2 is tabulated below.

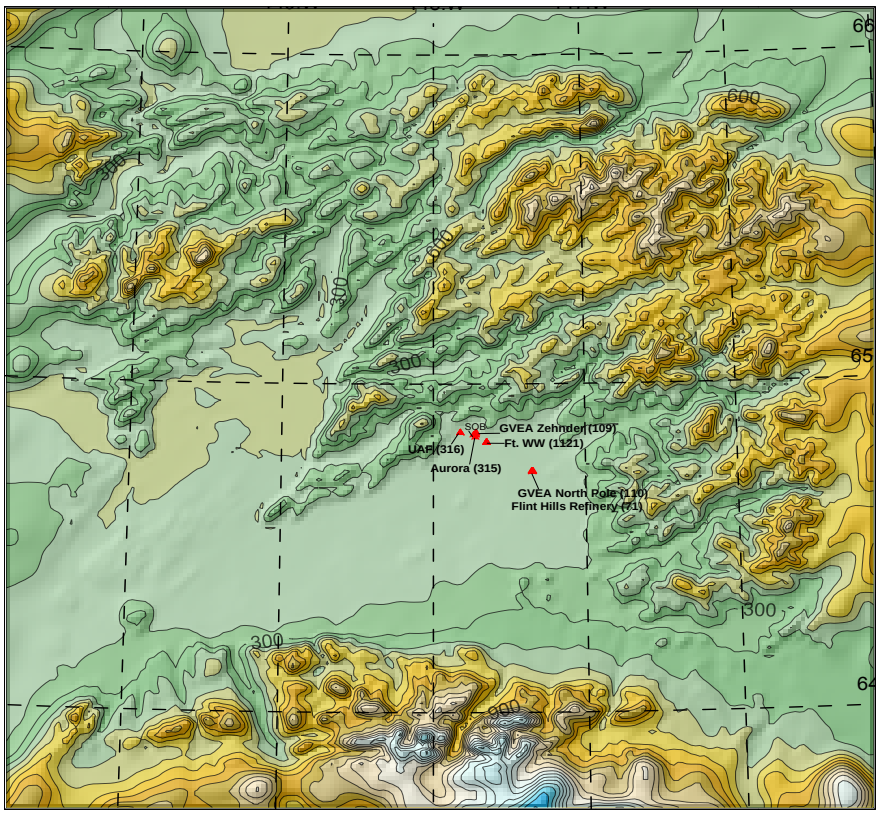

Figure XX: Fairbanks point source locations are represented by red triangles and are labeled by facility ID number and abbreviated name. The SOB (state office building) that houses the FRM (Federal Reference Method) monitor is labeled with a red triangle. The domain represented is 201 x 201, 1.33 km grid cells.

Table 1. Summary of six major Fairbanks point source plumes from CALPUFF for the episode (Jan. 23rd to Feb. 9th, 2008) average surface concentrations of $PM_{2.5}$ and SO_2 in $\mu g/m^3$.

Power Plant	Episode average SO_2 ($\mu g/m^3$)	Episode average $PM_{2.5}$ ($\mu g/m^3$)
UAF- 316	2.75	0.16
Aurora- 315	0.75	0.02
Zehnder-109	0.48	0.19
Flint Hills-071	0.016	0.38
GVEA NP-110	3.8	1.45
Ft. WW- 1121	14	1.6
Total surface concentration	21.8	3.8

CALPUFF modeling showed two largest sources that influence $PM_{2.5}$ concentration at the downtown state office building site were, the GVEA North Pole and Ft. Wainwright power plants. Monitoring data from the state office building was selected for comparison because it was the only location for which January 2008 episode data was available. Average SO_2 concentration from all sites for the entire episode was 4.4 $\mu g/m^3$ and the highest were from the two sources aforementioned. The cumulative effect of all six plants according to model output is estimated to be less than 10% of the $PM_{2.5}$ surface concentration. In overall, whether use of vertical profiles, episode surface concentration averages for all power plants, or SOB specific concentrations, there was not more than 10% influence on the surface concentrations from the six power plants.

Aerosol Chemistry in Fairbanks: A Summary of Prevailing Conditions

May 27, 2011

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1. Introduction

Atmospheric particulate matter (PM) is comprised of a variety of chemicals across a range of sizes and is nearly ubiquitous in the environment. It is also a dynamic component of the atmosphere that can undergo rapid chemical or physical transformation from a variety of stimuli. This leads to highly complex aerosol climatology that is dependent on a variety of contextual variables and therefore must be characterized with high precision and specificity.

The Fairbanks region in Alaska is a region of specific concern because of the relatively high concentrations of PM, especially in the winter. In recent years, the Fairbanks community has experienced a number of exceedances in which PM concentrations were above the federally-mandated standard. This paper will describe the current state of understanding of the conditions observed in the Fairbanks region. A specific focus of this document entails a detailed discussion of a specific component of PM – sulfur-containing aerosol – that is found in significant quantities of aerosol measured in this community.

2. General Overview on Particulate Matter

Ambient PM is ubiquitous in the lower troposphere and results from a variety of physical and chemical transformations. It can be formed as a primary pollutant from combustion and biogenic sources, as well as by resuspension of dust from crustal surfaces [2-4]. Secondary aerosol sources, i.e. those formed by precursor gases and/or particles, are substantially more complex, however. PM has also been shown to form as a secondary product from a variety of chemical reactions in the atmosphere [3, 5], with the most important reactions involving the secondary formation from petroleum combustion exhaust, biomass burning, and coal fired emissions. The diversity of possible atmospheric reactions makes unequivocal identification of aerosol sources quite complex, and thus, our understanding of aerosol formation is also incomplete. PM is chemically complex in different regions of the world. Figure 1, adapted from Jimenez et al [1] confirms significant spatial variability of aerosol chemical components at the global and continental scale. In general, ammonium, sulfate, and secondary fractions of organic carbon comprise the majority of observed $PM_{2.5}$ mass near the East coast of North America. In contrast, aerosol on the West Coast is more chemically variable, but is driven by nitrate, ammonium, and more volatile fractions of organics. Thus on continental scales,

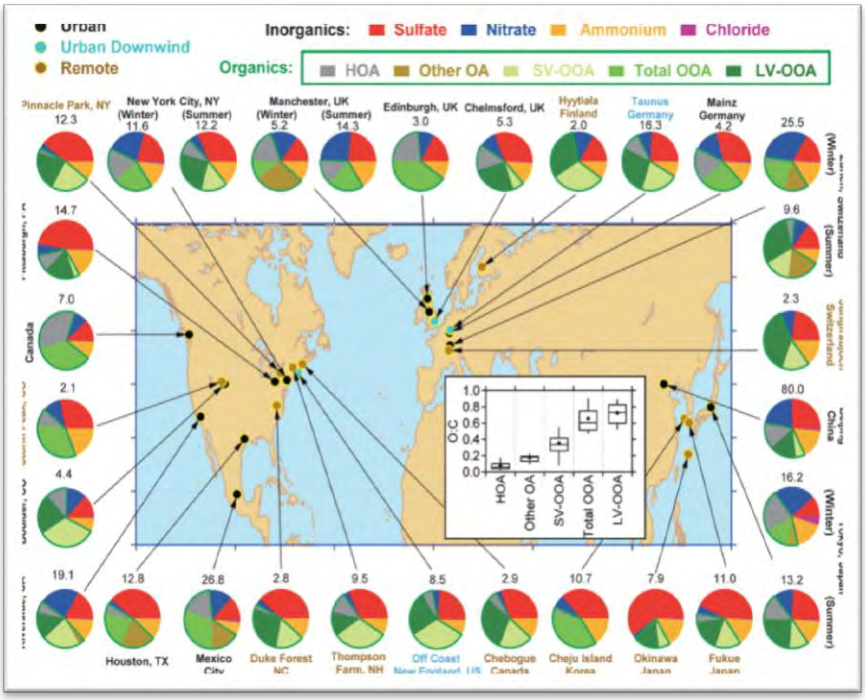

Figure 1: Measured worldwide distribution of aerosol composition, including differences in inorganic and organic components. Figure adapted from Jimenez, et al [1]

significant spatial variability is observed in aerosol chemical composition. This implies that when assessing aerosol chemical exposure in different regions of North America, a $PM_{2.5}$ measure of exposure in one region is chemically different from a $PM_{2.5}$ measure of exposure in another region.

In general, particulate matter in Fairbanks is comprised of a mixture of ions, crustal material, and carbonaceous components, with relative levels of each component dependent, in part, on prevalent local sources and sinks, long-range transport of chemicals, and chemical processing. However, because of its geography and prevailing meteorology, we currently lack a full understanding of the chemical processing that typically occurs, especially during the winter months when there is a high demand for residential heating, strong inversions, and extremely cold temperatures. This white paper attempts to provide a summary of the current state of knowledge, provides an initial analysis of some of the existing data, and proposes some mechanisms for future study. A specific focus of this paper expands the understanding of sulfur chemistry, which drives a significant fraction of the aerosol composition in Fairbanks.

2 Sources of Aerosol Sulfur in Fairbanks

2.1 Sulfur Precursors

Sulfur is emitted into the atmosphere typically as gas-phase constituents from both biogenic and anthropogenic sources. Biogenic sources of sulfur include hydrogen sulfide (H_2S), carbonyl sulfide, dimethyl sulfide and a variety of mercaptans, all of which contain sulfur in the lowest oxidation state (-2). Anthropogenic sources of sulfur are extensive, though the largest source (by mass) is the release of sulfur dioxide stemming from the combustion of petro-fuels such as heating oil, diesel, and coal.

Observed particulate sulfur in Fairbanks comprises a significant fraction of total PM, though our understanding of sulfur sources remains incomplete. Sulfur can be present in three broad forms: as part of an organosulfur compound, as a sulfate salt, or other sulfur-metal or sulfur–metalloid complexes. The latter complexes are atypical and usually only found as a result of specific industrial sources and are often only of limited consequence for an urban community.

Atmospheric processing of these sulfur sources is equally diverse and includes a number of relevant pathways the lead to sulfur-containing particulate matter. There are a number of primary emission sources, such as the release of sea spray laden with sulfate, that do contribute to primary sources of sulfur to the atmosphere, though these are likely to have an insignificant impact on the Fairbanks regions since few sources are located nearby. This leaves secondary formation mechanisms that lead to the bulk of observed sulfur in particulate matter.

Specific sources of sulfur in Fairbanks are thought to include emissions from the three coal-fired power generation facilities (Atkinson Power Plant at UAF, the Chena Power Plant, and the Fort Wainwright Power Plant – a fourth plant in Eielson AFB also exists), on-road diesel fuel, and home heating oil. Long-range transport is not thought to contribute significantly to sulfur loading in Fairbanks because there are very few upwind regional sources of sulfur. Wood-burning does contribute to the overall loading of particulate matter, but it is not likely to directly contribute to the sulfate burden typically observed in Fairbanks. Thus, the available sulfur sources in Fairbanks are probably limited to these three main categories, though recent regulations have sharply reduced the quantity of sulfur in on-road diesel; the mechanisms of formation are also not yet fully understood, and thus a discussion of these mechanisms follows.

2.2 Secondary Sources of Sulfur: Homogeneous nucleation

Gas-to-particle conversion of precursor sulfur-containing gases can be a significant source of particulate laden with sulfate. Briefly, this process is initiated when a gas, such as SO_2, is present in supersaturated conditions and spontaneously forms agglomerates (e.g. molecular clusters). These agglomerations, which are inherently unstable and continuously disintegrate, can interact with one another if an adequate number of agglomerates are formed. In a process similar to coagulation, these agglomerates can form larger particles that exceed (albeit briefly) a critical diameter that allows for vapor equilibrium between the newly-formed particle and the surrounding vapor. In this case, condensation is encouraged and allows for rapid growth of the particle governed by Kelvin theory, a complex ratio of saturation vapor pressure over a flat plane compared to that over a spherical particle.

Homogeneous nucleation typically depends on point sources of sulfur (usually SO_2) that are emitted in high concentrations in order for optimal conditions to be present for gas-to-particle formation to occur. Such sources might include coal- or residual oil-fired power generation facilities, high sulfur fuel use (mainly for heating purposes) or fugitive sulfur emissions from refining activities. This is relevant for Fairbanks because all of these sources are thought to have an impact on local aerosol climatology, though these processes are not yet fully understood. Even less empirical data are available on nucleation in extremely cold environments such as what Fairbanks experiences each winter, though nucleation events at cold temperatures would require higher vapor pressures than an equivalent event at warmer temperatures; essentially, this makes this process less likely a player in aerosol formation in Fairbanks. However, an open mind would be prudent in future assessment of homogeneous nucleation in this community because of the unusual and unique environmental conditions (rapid cooling, ice fog formation, rapid sublimation) that these gases meet soon after emission.

2.3: Heterogeneous nucleation

Heterogeneous nucleation, that is, the formation of sulfur-containing particles that involves precursor gases and other reactants, is a far more complex formation mechanism and likely to be a significant source of particulate-bound sulfur. Heterogeneous reactions are usually mediated by compounds that can either directly oxidize sulfur, or participate as catalysts in oxidation processing. Though gas-phase heterogeneous chemistry involving common oxidants (e.g. hydroxyl radical, ozone, organic peroxides, etc.) is typically quite slow, aqueous phase reactions are greatly accelerated and contribute to the bulk of the observed heterogeneous chemistry. Thus, the importance of available water is crucial for facilitating the formation of particle-bound sulfur compounds.

Heterogeneous formation of sulfur-containing particles likely plays at least some role in the climatology of aerosol chemistry in Fairbanks, however, this formation mechanism is poorly, if not at all, understood. Under more typical conditions, water droplets, or seed particles coated with liquid water (from vapor condensation, deliquescence, etc) serve as the reactor vessels that lead to sulfate aerosol formation. Sulfur dioxide, a common emission source of sulfur, is dissolved in these droplets and allows for much more rapid rates of conversion compared to typical gas-phase reactions. Oxidants, either formed in-situ or directly released, play an important role in mediating this oxidation, and they include ozone, peroxyradicals, hydroxyl groups, formaldehyde, oxides of nitrogen, and some metals and are summarized in Table 1.

Table 1: Possible oxidant reactions that may play a role in sulfur chemistry in Fairbanks

Oxidant component	Likely Local Source of oxidant in Fairbanks	Estimated relative reaction efficiency in Fairbanks winter	Consideration of future measurement to better understand sulfur conversion?
Ozone	Photochemical production of ozone	low	Perhaps. Easy to do with instrumentation already in place.
Hydrogen peroxide	Mainly found dissolved in clouds/fog resulting from photochemistry	Unknown, likely moderate	yes
Organic Peroxides	VOC oxidation due to NO3 radical chemistry	low	Yes, surveys of representative organic peroxides might yield important information on sulfur conversion pathway.
Dissolved Oxygen	Naturally-occurring	Probably trivial	No, yield not likely to be significant and O2 concentration already known.
Metal catalysis (Fe^{3+}, Cu^{2+}, and Mn^{2+})	Direct emission of metals	Unknown, possible synergy in presence of both metals.	Yes, but these metals already measured in speciation network; consider additional study of metal oxidation states.
Hydroxyl radical	Photochemical production from water vapor/droplets/crystals	Probably low	No, technically challenging to directly measure OH
Oxides of nitrogen	Direct emission	Low	Yes, despite low theoretical yield, research infrastructure already in place by investigators at UAF. Also, many local sources, especially in winter.
Formaldehyde (and other aldehydes)	Direct emission and secondary formation from VOC oxidation	unknown	Yes

Of these typical oxidant pathways, most are pH dependent, with lower sulfur conversion yields at higher pH [6]. They also vary depending on the precursor chemical concentrations present in the ambient environment. An exception to this is the pathway involving hydrogen peroxide which is relatively insensitive to changes in acidity, and maintains a high sulfur conversion yield independent of pH (assuming typical urban concentrations of constituent gases).

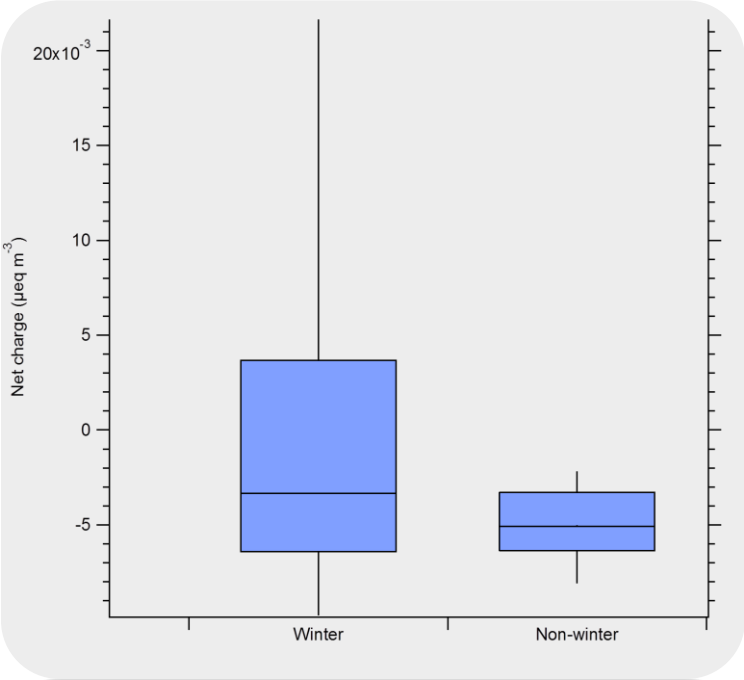

Figure 2: Net charge on aerosol resulting from sulfate (-2), nitrate (-1), and ammonium (+1) by season. Winter is defined as November- March; non-winter is all other months. Measurements less than zero suggest an apparently acidic aerosol.

Using data of fine sulfate, ammonium, and nitrate collected by FNSB from 2007-2010, we observe a somewhat different apparent aerosol acidity profile in the winter compared to the non-winter periods (Figure 2). While this approach only includes a fraction of the components that comprise a molar balance of aerosol (e.g. other aerosol species may change this balance), it appears that aerosol is generally acidic in both the winter periods (defined as November – March) and the non-winter periods (April – October). There is no significant difference between the two seasons, though there is a skewing of data during the winter towards more alkaline conditions that is not observed in the summer. This indicates an apparent excess of positively-charged components (e.g. ammonium ion) during the winter. In the case of positively charged aerosol, previous work [7, 8] has shown this to likely be a result of biomass burning influence and suggests the presence of unmeasured organic acids as the anionic pair.

The majority of the scientific understanding on sulfur chemistry has been studied under acidic conditions. Only limited information on heterogeneous chemistry is available and seems to suggest that typical sulfur conversion reactions are not highly favored. Nonetheless, sulfur (mainly as sulfate) is most certainly observed in significant quantities in Fairbanks. Most research has investigated alkaline sulfate formation of sea salt in the presence of ozone, though this process is not expected to play any significant role in Fairbanks. Thus at present, the mechanism of heterogeneous sulfate formation in the winter in Fairbanks is not understood.

Of the mechanisms described in Table 1, the most likely candidates to play a significant role in sulfur conversion in Fairbanks appears to be that induced by hydrogen peroxide, organic peroxides, metal catalysis, oxides of nitrogen, and formaldehyde. This does not exclude the other sources of sulfur conversion chemistry, but they are not likely to play a large role in contributing to the observed sulfur in the region. While there are plausible primary sources of these components, there may also be unusual secondary chemistry at play that forms these reagents in-situ. A number of arctic studies [9-11] (and references therein) have suggested that halide chemistry, specifically interactions with chlorine and bromine species, play an important role in catalyzing oxidant formation, specifically in the presence of snowpack. Most existing studies, again, have taken place in remote areas (e.g. Barrow, AK, northern Finland, Greenland, etc), and have centered on investigating the fundamental mechanistic chemistry principles under pristine conditions and may not be fully transferable to a more complex urban

environment characterized by multiple sources of aerosol. However, this pathway may still be an important determinant in the formation of atmospheric constituents that can lead to sulfur conversion.

A unique possibility for further study of sulfur chemistry in the Fairbanks area relates to the widespread presence of ice fog in the vicinity of the Chena River during the winter. With low winter temperatures, most water bodies in the region freeze to solid ice (surfaces at least). The Chena River, which winds through the central downtown region, is injected by waste heat produced by the Chena Power Plant, a 29MW coal-fired facility. Coupled with winter dew points well below zero and low ambient temperatures, artificially warm river water rapidly evaporates, condenses, and freezes each day. This represents a significant mass transfer of water and dissolved components into the air, and may suggest a possible source for direct formation of aerosol from this process [12-14]. It also likely provides a large number of small particles, which in total, create a large surface area suitable for reactive chemistry. This is particularly important because it occurs in the immediate vicinity of the power plant; in the presence of a looping or fumigating plume, there is the potential for significant sulfur chemistry.

2.4 Sulfur losses

Particulate sulfur is lost through one of two ways: via transport out of the measurement domain (e.g. long-range meteorological transport), or loss to the surface by deposition (through direct contact with surfaces or induced by precipitation). Because it is very stable, sulfur bound as sulfate aerosol generally does not undergo further chemical processing that reduces concentration. Other sulfur species (e.g. organosulfur components) may be subjected to further chemical processing though this mechanism is not understood and depends on the initial chemical conditions, aerosol sources, and available atmospheric reactants. Because the region has relatively low annual precipitation, it is likely that sulfur losses in Fairbanks are most likely a result of long range transport out of the region.

3. Current Investigations and Open Questions

The Fairbanks region is characterized by almost entirely locally-generated particulate matter, with relatively low concentrations in summer and much higher concentrations in winter. For much of the United States, this seasonal pattern is reversed (with highest PM concentrations observed in the summer) and reflects the importance of photochemistry in the formation of PM. Fairbanks, however, lacks significant photochemistry in the winter suggesting that unique, alternative formation mechanisms drive the chemistry. While a number of studies have looked at atmospheric chemistry in arctic regions, to our knowledge, no studies have examined in detail the processing of urban pollutants in arctic regions. This is, in part, because there are relatively few cities located in arctic regions and there are comparatively few opportunities to conduct such investigations.

The Division of Air Quality of Fairbanks North Star Borough, has had a presence monitoring ambient particulate matter since 1999. It currently operates 4 monitoring stations, and includes measurements of PM_{10} and $PM_{2.5}$, as well as measurements of carbon monoxide, SO_2, and chemical speciation. Recent efforts have begun the attempt to characterize the chemistry conditions prevalent in the Fairbanks region beyond the scope and capacity of the FNSB borough, and these are now summarized. As of the date of this document, many of the results summarized below are in progress and final data and analyses are not yet completed.

3.1 Measurements by FNSB

Measurements of elemental sulfur and particulate sulfate have been collected in Fairbanks since 2003. Figure 3 shows a simple time series of sulfate concentration. Of note, significant wintertime spikes in sulfate are apparent, with summer minima more typical. Also plotted on this figure is the ratio of directly measured elemental sulfur that is predicted stoichiometrically by sulfate (e.g. removal of four moles of oxygen per mole of sulfate), including a box-plot smoothed line to more clearly identify any patterning in the data. Despite the seasonal spikes in sulfate concentration, no

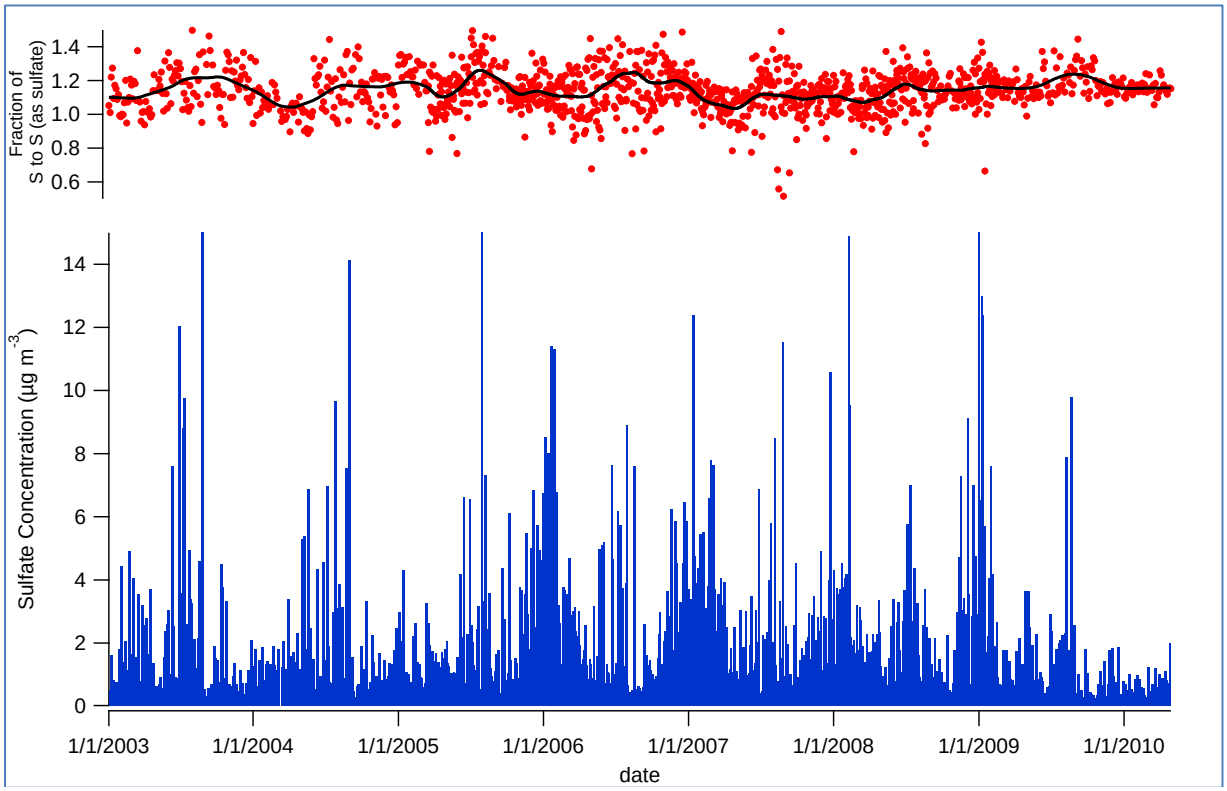

Figure 3: Time series of sulfate concentration (lower frame) and sulfur-to-sulfur ratio (upper frame, including box-smoothed line for visual aid) from Jan 2003-Jan 2010, as collected by FNSB.

pattern in this ratio is apparent, although it appears there is an unmeasured source of sulfur in Fairbanks that is not measured as sulfate. On the whole, the sulfur-to-sulfur (as sulfate) ratio is 1.15 and suggests an addition ~15% of sulfur cannot be attributed to sulfate. The ratio and sulfate concentration measurements are not correlated, suggesting that an independent factor is associated with this additional sulfur. Possible sources for this include organosulfur compounds or sulfur gases preferentially-adsorbed and reacted onto elemental filters. Additional work is continuing to understand this process.

3.2 Modelling approaches

Investigators from the University of Montana, Center for Environmental Health have recently concluded an intensive effort to characterize aerosol chemistry from 2008-2009 using modeling approaches. This study, which employs a Chemical Mass Balance model to identify relative sources of aerosol, utilized existing data provided by FNSB from five monitoring locations in the region. A secondary approach used archived filters for a chemical analysis of isotopes of carbon as well as levoglucosan, a marker for

biomass burning. Their results were recently summarized in a final report by Dr. Tony Ward (Ward, 2010).

Their CMB analysis identified 5 prevailing source profiles of aerosol representative of the Fairbanks region. While there was some site-to-site variability, winter time aerosol loading was most significantly impacted by woodsmoke (range: 62.7%-79.8%, depending on location). Sulfate aerosol was the second most prevalent component of PM (range: 9.8%-20.0%). Their findings also suggest that ammonium nitrate was also substantial (range: 5.1%-10.5%), with lesser contributions from automobile exhaust (range: not detected to 6.8%), diesel exhaust (range: not detected to 7.3%), and Unexplained (range: 0.5%-1.2%). While CMB modeling does not provide insight into specific chemistry, is does provide information towards the more important chemical processes that might be at play in the Fairbanks region.

This study also provided an analysis of 14C carbon isotope ratio analysis that provides information on the sources of the observed carbon. 14C analyses are particularly powerful because they can identify, at the atomic level, the likely age of the carbon elements. In this case, Ward's investigation provides confirmatory evidence that woodsmoke, or 'modern carbon' is a significant contributor to the aerosol loading in the Fairbanks region. This project investigated an additional dataset of levoglucosan, a sugar associated with woodsmoke. Their results were, again, consistent with the notion that woodsmoke contributes significantly to the aerosol mass loading for the Fairbanks airshed.

3.3 Denuder studies

Work at the Washington University in St Louis has begun to investigate the nature of denuder function in cold-weather environments. This study explores three main objectives: whether extreme cold temperate allows for SO_2 penetration through a denuder, whether water vapor interferes with denuder functionality, and whether long-term denuder loading plays a deleterious role in denuder efficiency. This work is still under development and not yet completed, but early results suggest that there is no significant effect on denuder function based on cold-temperate operating conditions, and that water vapor does, in fact, inhibit the denuder from efficient functioning.

3.4 Winter intensive characterization

In February and March of 2011, investigators from the University of Massachusetts established an intensive field monitoring site to provide a broad spectrum of chemical characterization measurements at a fast time resolution. This was an effort to establish more advanced chemical measurements throughout typical wintertime conditions in Fairbanks, and to capture both typical and atypical PM climatology in the region. The study collected hourly aqueous samples of dissolved $PM_{2.5}$ (including all typical ions), daily high-volume filter samples (for trace metal analysis), and hourly measurements of organic carbon and elemental carbon.

Preliminary data, which has not yet been validated, shows a time series of organic and elemental carbon during the study period (Figure 4). The data are characterized by highly distinct spikes of both organic and elemental carbon, with a good correlation between the two measurements ($r^2 = 0.53$). This suggests that a periodic event that leads to this chemistry consistently occurs and lowers the likelihood of industrial sources of OC or EC (such as power plant emissions or refinery effluent, which normally do not have a significant diurnal emissions profile). Ion measurements and trace metal results are still

pending.

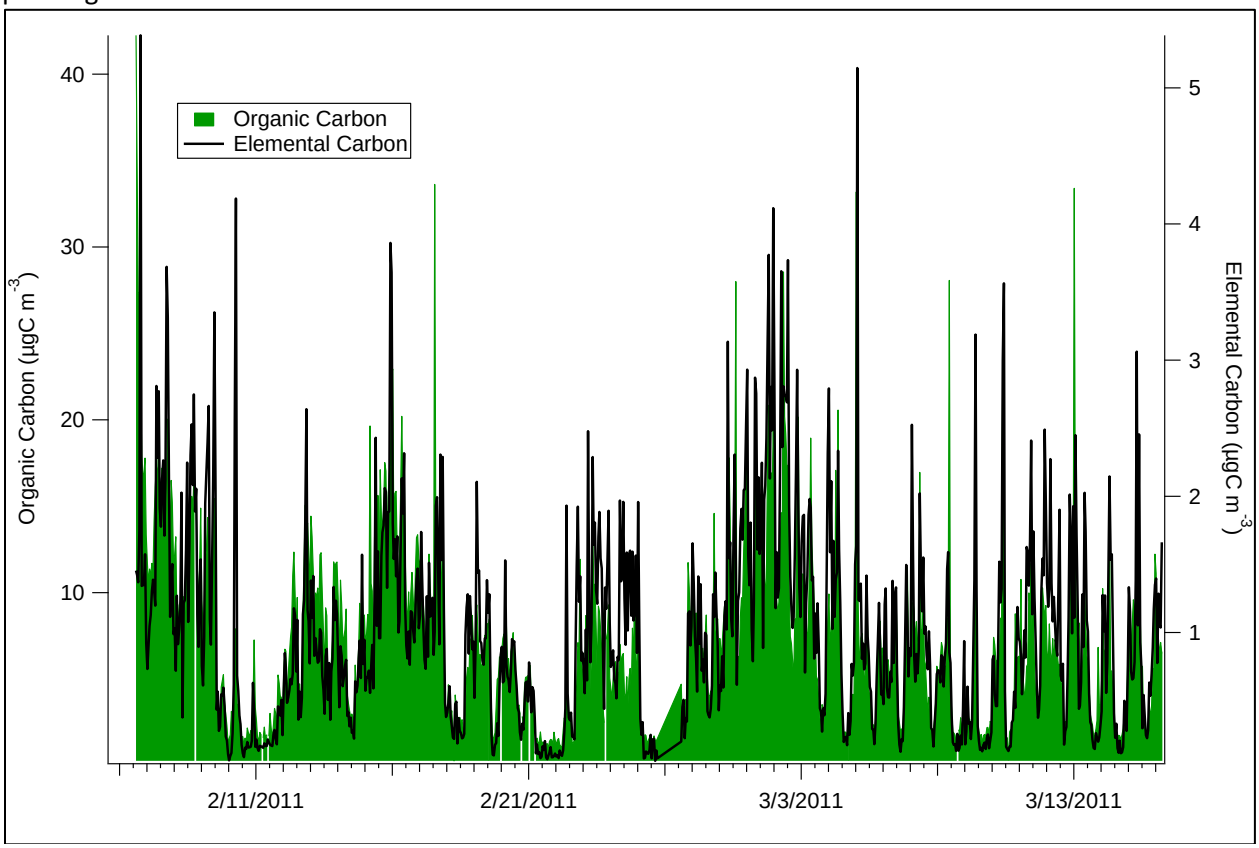

Figure 4: Time series of organic carbon and elemental carbon measured during this study in Feb-Mar 2011 in Fairbanks.

There appears to be a wintertime pattern of highly enhanced EC and OC, as well as a precipitous drop in the same concentration. Figure 5 presents the same data in an alternative approach, with all of the OC and EC data presented as box plots across each hour of the day. Both EC and OC exhibit a clear bimodal distribution, with apparent spikes in the late morning and the hours before midnight during the study period. There are several possible explanations for this finding, though the most probable one involves a link to residential heating using wood and/or oil. The latter possibility is important in the context of sulfur chemistry, since wood burning does not normally emit significant quantities of sulfur, and these data may be useful for further study of home heating oil use in that this emits both sulfate precursor as well as organic and elemental carbon, and thus their variability is likely to have a high degree of association.

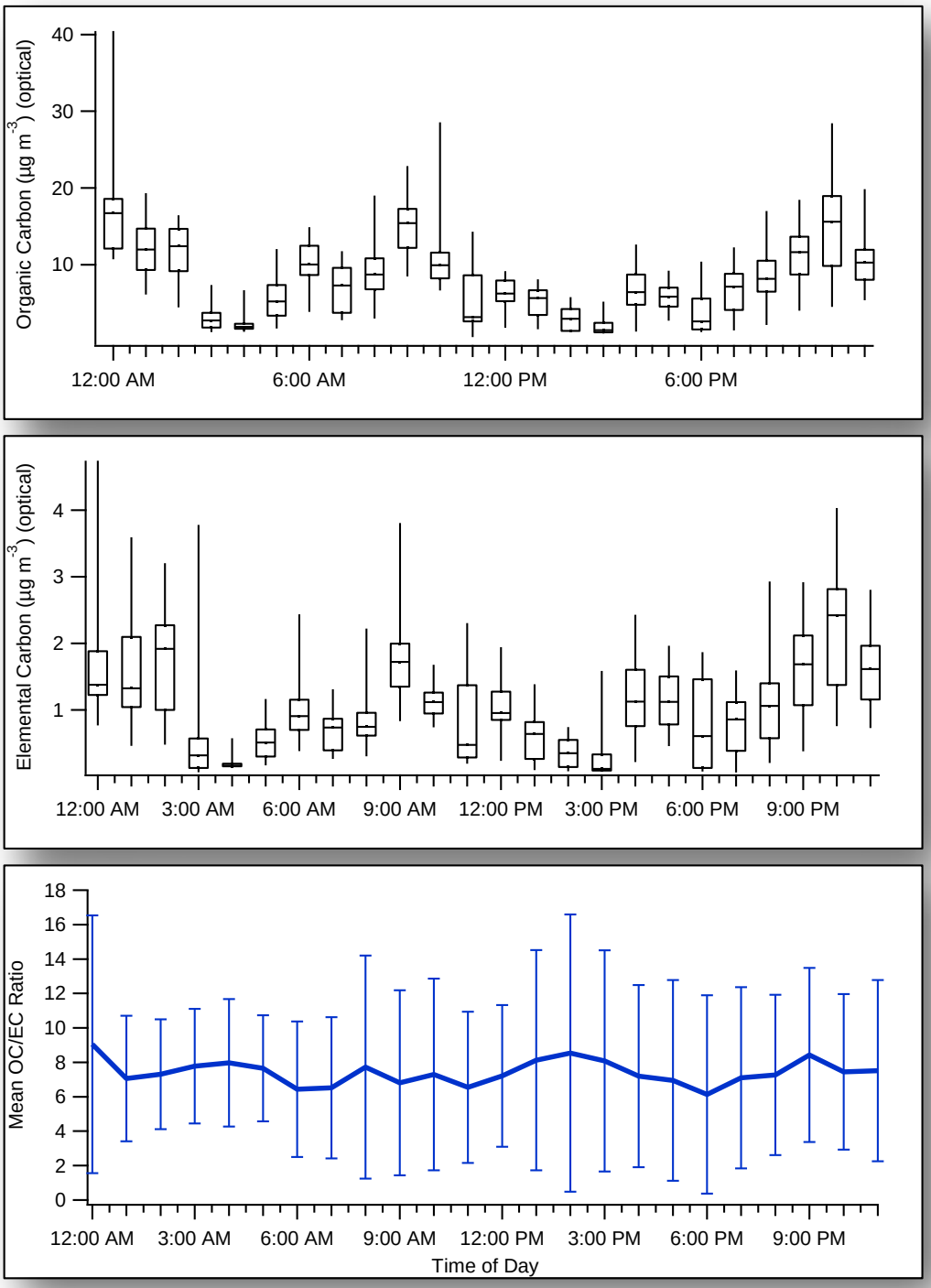

Figure 5: Hourly measurements of organic carbon (top), elemental carbon (middle), and mean OC/EC ratio (bottom). Box plots consist of median and 25th and 75th percentile; whiskers denote 10th and 90th percentiles. Data was collected over approximately 40 days in Feb-Mar 2011 in Fairbanks.

The data also include the mean OC-to-EC ratio for each hour. Overall, these ratios are quite large, with mean ratios approaching 8. The included error bars denote that there is no significant patterning in the data across the diurnal profile, which is inconsistent with the concentration plots of OC and EC. The EC

tracer method of estimating secondary organic aerosol [15, 16], which is an admittedly imperfect analytical approach, would suggest that the majority of the observed OC in the atmosphere is primarily emitted since the ratios are much higher than typical environments with active secondary organic aerosol formation mechanisms. It should be noted that the primary emissions profile of wood and oil burning, on-road diesel combustion, and other local sources of particulates in Fairbanks is not yet known. Additional work (described below) will inform whether the empirically measured ratio is entirely consistent with primary emissions, or if, in fact, secondary formation processes have an important role.

3.5 Fuel feedstock characterization studies

FNSB has recently contracted with Omni Environmental (Portland, OR) to chemically characterize a variety of local fuel feedstocks, including firewood, local on-road and heating oil fuel, and coal. By doing so, it is hoped that a chemical signature profile can be developed for each source indigenous to Fairbanks which, in turn, can be used to study and better understand the observed ambient conditions. As of the date of this paper, no results are yet available.

3.6 Open Questions

Several specific open questions remain that have not yet been addressed by the current efforts. It would be worthwhile to investigate the approaches to answering these questions, and to determine whether these efforts would inform FNSB in the best approach to establishing attainment status. These questions include:

1) To what degree does wintertime ice fog play a role in secondary aerosol chemistry?
2) Can the current emissions inventory of sulfur account for the observed sulfur (as sulfate or non-sulfate sulfur-containing components?)
3) Can PM be better apportioned to on-road diesel, home heating fuel oil, home heating biomass, and coal-fired power plant emissions, which likely comprise the bulk of PM emissions in Fairbanks?
4) How does extreme cold temperatures influence gas-to-particle conversion in the context of stack emissions (e.g. how does a rapidly cooling wet emissions stack perform)?
5) Can existing (or new) air quality models be better calibrated to on-the-ground observations? Are these model assumptions valid?

4.0 Future Plans on Attainment in Fairbanks

Currently, Sierra Research is working with FNSB staff to develop a comprehensive Implementation Plan to ensure compliance with federal air quality standards. Data from these, and future, investigations will provide significant guidance in the best approaches to developing efficient, and effecting plans to reduce the burden of particulate matter.

There are two complimentary approaches to a better understanding of air quality issues in the Fairbanks region, and both are equally important. The first approach includes better empirical understanding of local aerosol conditions through additional field characterization studies. This approach will result in a direct understanding of the critical mechanisms at play in this unique environment, and will do so with the least amount of scientific uncertainty. However, over the long term, additional field studies are probably unsustainable in that they are technically challenging, often limited to answering only a few, specific questions, and can be cost-prohibitive. Thus, computational chemistry modeling is an outstanding extension to field studies. They are cost-effective, highly repeatable, and can be adapted to changing conditions. By themselves however, models – especially those developed to operate in an

atypical aerosol milieu such as that of Fairbanks – need to be compared with on-the-ground measurements to provide operational efficacy and validation to ensure high confidence in their results. A number of these possible future studies are listed in Appendix A, though not all are specific to improving model guidance.

5.0 Summary and Conclusions

This paper has summarized the current state of the science associated with aerosol chemistry during the winter in Fairbanks, Alaska. It has also provided a brief summary of the studies to-date, and these results appear to be consistent with significant issues related to sulfur chemistry, as well as chemistry related to carbon (organic and elemental). Further, it identified likely and unlikely oxidation mechanisms for secondary formation (mainly in the context of sulfur conversion, though this process is not necessarily limited to this element).

Attainment of the National Ambient Air Quality Standards in Fairbanks will only be achieved with a better understanding of aerosol formation chemistry specific to the winter in Fairbanks. Without this understanding, most attempts to reduce emissions – e.g. through regulatory action – may be misguided and not achieve the intended targets. At his point, the understanding of chemical conditions in Fairbanks, specifically related to sulfur chemistry, is quite poor and needs significant improvement.

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Appendix A

Future Research Initiatives: Fairbanks North Star Borough Region

Ice Fog Sample Collection

Method Summary: Develop highly mobile, high volume TSP samplers suitable for quick deployment to collect and characterize ice fog samples for a chemical analysis of potential aerosol formation processes. Samples could be collected and compared across periods of local wood- and fuel-burning influence, when gas-phase power plant emissions have a stronger downwelling impact, or when relatively clean air advects through the region. Samples would be taken in the immediate vicinity of the fog formation near the Chena River, as well as downwind of this fog after the crystals have phase sublimation.

Rationale: Because the chemical processing and formation mechanisms are, at this point, not fully understood, it has been hypothesized that ice fog crystals provide suitable reactive surface area for heterogeneous nucleation in the absence of known oxidant components. Collecting in-situ measurements with newly-formed fog crystals (and pre-existing particles and gases near the river), we can provide baseline concentration measurements of sulfur-containing fine particles. Additional measurements may provide insight into sulfur oxidation processes by assessing differential sulfur-containing particle concentrations downwind of the aerosol/fog mixture.

Spatial profiling of aerosol composition: Stationary Approaches

Method Summary: Develop and simultaneously deploy a set of 15-20 (or more) autonomous filter samplers capable of unattended, low-flow PM2.5 aerosol collection on Teflon filter media. Typical deployment schemes include weekly (or bi-weekly) filter changes with a ½ hour on, ½ hour off cycle that collects samples at low flow (4 lpm) throughout the week. Alternative approaches include more frequent filter changes (e.g. every 48 hours) with a continuous sample collected during each time period. Spatially distributed measurements can be scaled against 2-3 reference site measurements for components thought to have limited local variation (TBD) in order to account for instrument variability, instrument precision, or local emission effects. Study length will be 6-8 weeks during the winter, and can be coupled with 6-8 weeks during the summer for comparative purposes. Filter analysis by gravimetry and high resolution XRF for ~35 metals.

Rationale: The ability to discern spatial and temporal characteristics of particle composition, coupled with meteorological data, may provide important insight into the specific sources of aerosols in the region. Further, it will provide a dense dataset which may inform spatial models currently under production and use in the region with improved chemistry profiles and temporal variations.

Model Validation Studies

Method Summary: Chemical speciation measurements guided by the chemical modeling currently used by FNSB to identify predicted PM concentrations and future attainment. Speciation measurements depend on elements identified by the model as predictive of model efficacy and uncertainty and would be measured in different locations and across different times (e.g. different seasons, diurnal variations). Measurements could include chemical elements such as those measured by XRF, PM2.5 mass, or gas-

phase tracers. Both high spatial resolution models (e.g. smallest grid cells) and low spatial resolution models can be validated.

Rationale: Because of increased reliance on models to efficiently provide estimates or predictions of current and future aerosol climatology, it is essential to characterize the performance of these models in terms of precision and uncertainty through robust field measurements. This approach will provide either a) a mechanism to assess and possibly improve model performance for local conditions; b) provide evidence to invalidate model results based on field testing; or c) provide insight into reasons and locations where model predictions and field measurements are de-coupled.

Spatial profiling of aerosol composition: Mobile Approaches

Method Summary: Expand and enhance the analytical capabilities of the FNSB "Sniffer" vehicle with a wider range of chemical and physical characterization capacity (either permanently or for a specific study period). Relevant instruments for such an application might include high time resolution measurements of carbon monoxide, sulfur dioxide, particle size distribution (by SMPS and/or aerosol laser spectrometer), and short time integrated, high volume filter samplers.

Rationale: Expansion of analytical capacity provides FNSB staff with the capacity to better investigate aerosol chemical characteristics across a wide range of conditions, often in response to short-term prevailing environmental conditions (e.g. presence of strong or weak inversion, periodically located downwind of specific sources of interest, etc). The current Sniffer vehicle has yielded important findings, but is currently limited by analytical capacity and specificity.

Characterizing Organic Carbon (and tracers of combustion) in Fairbanks

Method Summary: Simultaneously characterize carbonaceous aerosol at three or more locations to provide chemical evidence describing multiple facets of carbon. A set of instrumentation will be established at each site, and will include aethelometers, Sunset Labs EC/OC (field instruments), and a custom-built filter sampler capable of multiple sample collections on quartz filters through either denuded or undenuded sample lines. The latter would be collected and analyzed (after extraction) by suitable speciation methods (e.g. GC/MS) for organic speciation, ^{14}C isotopic dating, and levoglucosan analysis. Measurements to be conducted in the winter and summer.

Rationale: Organic carbon accounts for a large fraction of $PM_{2.5}$ (and is even larger when converted to organic matter) and thus represents an important subject of study in order to move FNSB towards attainment. By undertaking more comprehensive chemical analyses with a specific focus on carbon-containing aerosol, FNSB is likely to better understand source contributions to this complex component, whether from fuel oil combustion, on-road diesel/gasoline, or wood-burning.

Final Report

To

Alaska Department of Environmental Conservation (ADEC)

Grant Number 127617

Reporting Period: 8 March 2011 – 31 January 2012

'Fairbanks, North Star Borough AK PM2.5 Non-Attainment Area WRF-ARW'

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2 Apr 2012

EXECUTIVE SUMMARY

This final report describes work performed by the Department of Meteorology at the Pennsylvania State University under Grant Number 127617, 'Fairbanks North Star Borough PM2.5 Non-Attainment Area WRF-ARW Modeling', supported by the Alaska Department of Environmental Conservation (ADEC) and the Fairbanks / North Star Borough. The purpose of this project was to perform meteorological modeling of the region around Fairbanks and North Pole, AK, as part of the State Implementation Plan for fine particulate matter (PM2.5) analysis of the region. The Fairbanks / North Star region was designated a non-attainment area for the daily National Ambient Air Quality Standard (NAAQS) for PM2.5 by the Environmental Protection Agency (EPA); high PM2.5 concentrations for the area predominantly occur within stable boundary layers during periods of extreme cold and weak winds during the winter season. The air quality modeling component of the SIP utilizes atmospheric analyses generated by a meteorological model; therefore it is important to select a meteorological model configuration that can properly represent the structure and evolution of the local stable boundary layer in these conditions.

The simulations were to be performed with the Weather Research and Forecasting (WRF), Advanced Research WRF (WRF-ARW) model, a globally used and freely-available meteorological model. Initial WRF-ARW simulations for a period in Jan. – Feb. 2008 were performed by Penn State under the Regional Applied Research Effort (RARE) project funded by the EPA. During the RARE project an optimal set of physics options, grid configuration, and data assimilation strategy was developed and tested. For physics sensitivity tests data assimilation was only performed on the coarser two domains (12-km and 4-km horizontal grid spacing), while the finest domain (1-km horizontal grid spacing) was used for assessing sensitivity. It was concluded, however, that a final meteorological analysis to be provided to EPA should also have data assimilation on the finest domain, to provide a better fit to the observations.

For the current contract, the model setup from the RARE project was to be applied to the production of a new meteorological analysis covering the period 2-17 Nov. 2008. As in the final meteorological analysis of the RARE project, data assimilation for the current project uses data assimilation on all three domains. However, a few modifications to the data assimilation procedure were implemented to take advantage of data and source code not used in the RARE project: 1) the effective vertical resolution of the observations as seen by the data assimilation modules was increased; 2) a more vertically-consistent objective analysis procedure was used; 3) additional surface observations from non-standard sources (i.e., stations not present in the standard METAR-format database typically used for hourly meteorological reporting) were used

both for verification and in the data assimilation, in order to supplement the METAR observations in this relatively data-sparse region.

A test period (5 – 9 Nov 2008) was used to perform some initial evaluations of possible modified procedures. In particular, during the RARE project the data assimilation on Grid 3 for the final meteorological analysis only used the temperatures from the METAR surface stations, and not the winds. For the RARE project it was thought that, since the surface winds during the coldest episode would be expected to be weak and poorly sampled, and since the surface winds in these conditions might be expected to be thermally-driven, the best chance of accurately reproducing existing flows would be to only use the temperature (and moisture) fields from surface observations in data assimilation, while relying on the model itself to generate the proper wind fields. This led to realistic low-level flow patterns and generally satisfactory wind error statistics at non-calm locations. There did tend to be a positive near-surface temperature bias during periods of extreme cold and weak winds, which could have been a result of overestimated vertical mixing due to the model's positive near-surface wind speed bias. The extended surface dataset used in the current study provided an opportunity to determine if improved statistics could result if 1-km grid data assimilation of near-surface winds was included. This was one of the initial sensitivity tests performed for the test period.

The major findings of the current project are as follows:

- The use of near-surface winds in data assimilation during the test period, when compared to a control simulation, led to about a 20 degree improvement in the mean absolute error (MAE) of wind direction. Temperature and wind speed statistics were also improved, but the improvements were modest. The modest size of these improvements was hypothesized to be due to either insufficient horizontal resolution of the model topography, or too large of a region of influence of particular observations in the data assimilation procedure.

- A new simulation was performed in which the radius of influence of observations on the 1-km grid was reduced from 75 km to 30 km, and the strength of the relaxation coefficient was doubled. These experiments produced slightly better temperature statistics on average, but slightly worse wind speed statistics. Wind direction errors, however, were further reduced by the new simulation procedure by a substantial amount (about 19 degrees in MAE). It was decided to make this model configuration (experiment TWIND2X30) the basis of a simulation of the entire 2-17 Nov. 2008 episode.

- Previous experiments did not make use of calm wind observations in the data assimilation procedure; the possible presence of missing data or high instrument response thresholds imply that it might be preferable to retain model-generated flows in weak-

wind conditions rather than relax the flows towards a zero-magnitude wind vector by data assimilation. However, because it was desired to further reduce the model positive wind speed bias, an additional set of simulations over the 2-17 Nov. 2008 episode was performed, for which data assimilation did make use of calm wind reports (henceforth experiment TWIND2X30CALM). While the use of calm wind reports did reduce the positive near-surface wind bias of the model, the improvement was only on the order of 0.1 m s^{-1}. Meanwhile, TWIND2X30CALM had wind direction MAE scores that were about 14 degrees worse. Since wind direction by necessity can only be verified with non-calm wind observations, the implication was that the use of near-surface calm wind observations in data assimilation was degrading wind direction statistics at other observation locations without making a substantial improvement in wind speed statistics. Therefore, it was decided to deliver the results of TWIND2X30, rather than TWIND2X30CALM, to ADEC for use in subsequent air quality modeling.

- The Jan-Feb 2008 episode simulated during the RARE study was re-simulated using the TWIND2X30 procedure, and compared with corresponding statistics using the RARE configuration. Little statistical difference was found between the RARE and TWIND2X30 for variables other than wind direction, for which the TWIND2X30 configuration was about 12 degrees better in terms of MAE.

- Qualitatively, it was found that the meteorological analysis produced realistic topographical flows, and was capable of reproducing observed surface temperatures below -40 °C in locations such as Woodsmoke. However, the model did tend to have a positive near-surface temperature bias during the coldest episodes at valley locations that could not be well-resolved by the model (e.g., Goldstream Creek). This was counteracted by periods when the model had a negative temperature bias, such as during the initial precipitation event of the 2-17 Nov. 2008 episode, such that the overall model temperature bias was quite small (less than a degree Celsius) for both simulated episodes.

1. INTRODUCTION

The region around Fairbanks and North Pole, AK, was designated by the Environmental Protection Agency (EPA) as a non-attainment area for fine particulate matter (PM2.5, referring to particles with aerodynamic diameters equal to or less than 2.5 microns). This designation required that a State Implementation Plan (SIP) be developed. The violations occur predominantly during the cold season, when the meteorological conditions frequently become ideal for achieving high concentrations of any tracer released into the atmosphere. These ideal conditions, often present in combination, include the presence of extremely strong inversions capping a shallow layer of extremely cold air, light and variable winds, and very weak, intermittent turbulence (e.g., Benson 1970; Serreze et al. 1992; Mölders and Kramm 2010). These conditions, which frequently occur in the winter over inland Alaska, can be exacerbated in the region around Fairbanks, where a rough semicircle of ridges tends to isolate the airflow around Fairbanks from its surroundings, restricting the dispersal of pollutants.

2. EPA RARE STUDY BACKGROUND

The Regional Applied Research Effort (RARE) study was sponsored by the EPA to help the Fairbanks North Star Borough and the Alaska Department of Environmental Conservation (ADEC) develop a State Implementation Plan for the Fairbanks / North Pole PM2.5 non-attainment area. This project included meteorological modeling, meteorological observational, and trace gas and aerosol analysis modeling components. Penn State conducted the meteorological modeling component of this study from 1 Sep 2008 – 31 Jan 2010, with the specific focus being the extremely cold stable boundary layers in winter in the Fairbanks region. The meteorological portion of the project consisted of selecting and performing two twenty-day simulations down to 1-km horizontal grid spacing for two episodes from the 2007-2008 winter season characterized by high PM2.5 exceedance events in the Fairbanks region. One episode was to be characterized by near total darkness, while the second was to contain partial sunlight.

There were two components of the atmospheric modeling portion of the study. One was to produce the best possible analysis of the atmosphere (at approximately 1-km grid spacing) that could be used in conjunction with the parallel chemical and emissions modeling efforts to better understand the nature of the PM2.5 exceedance events of the Fairbanks / North Star Borough area. The other was to perform physics sensitivity studies on turbulence and land surface model parameterizations to determine the best-performing modeling configuration and physics suite for representing the stable atmospheric boundary layers in these conditions.

The tool used for the meteorological modeling component of the RARE project was the Weather Research and Forecasting (WRF) model (Skamarock et al. 2008), more specifically, the Advanced Research WRF dynamic core (WRF-ARW, henceforth simply called WRF). WRF contains separate modules to compute different physical processes such as surface energy budgets and soil interactions, turbulence, cloud microphysics, and atmospheric radiation. Since turbulent eddies in the SBL are typically much smaller than mesoscale model horizontal grid spacing (e.g., ten meters vs. a thousand or more meters), they cannot be modeled directly (e.g., Wyngaard 2004), but typically their effect is parameterized by a planetary boundary layer (PBL) scheme that predicts turbulent kinetic energy (TKE). Within WRF the user has many options for selecting the different schemes for each type of physical process. There is also a WRF Preprocessing System (WPS) that generates the initial and boundary conditions used by WRF, based on topographic datasets, land use information, and larger-scale atmospheric and oceanic models.

The RARE simulations used three one-way nested horizontal grids with horizontal grid spacing of 12 km, 4 km and 1.3 km, respectively. Grid 1 covers the entirety of Alaska and extends from Siberia to the northwestern continental United States (Figure 1). Grid 2 closely coincides with the extent of the Alaskan landmass south of the Brooks range; it includes the Anchorage region and the Gulf of Alaska in the south (Figure 2). Grid 3, centered around Fairbanks and extending south to the Alaska Range and north past the White Mountains and other uplands just north of Fairbanks, includes all of the non-attainment area within the Fairbanks North Star Borough (Figure 3 - Figure 4).

Many of the WRF namelist parameters used in the RARE study were taken directly from modeling studies performed by Penn State for studying the nocturnal stable boundary layers of central Pennsylvania (Stauffer et al. 2009; Seaman et al. 2012) using version 3.1 of WRF-ARW. Many of the grid-independent parameters are listed in Table 1. In particular, the extremely fine vertical grid spacing of the model levels near the surface is in order to adequately resolve the depth of stable boundary layers that may be only tens of meters deep, and within which the scale of the turbulent eddies may be even less. However, the near-surface vertical grid spacing in the RARE study was coarsened slightly from that of the central Pennsylvania studies both in order to prevent numerical instabilities from occurring over the extremely steep elevation gradients on the north edge of the Alaska Range, and to alleviate concerns about the model atmospheric grid spacing being on the order of the vegetation canopy height. The final near-surface vertical grid spacing was 4 m, increasing gradually with height above the surface (refer to Gaudet and Stauffer 2010).

Grid-dependent namelist parameters and WRF Preprocessing System (WPS) namelist parameters are listed in Table 2 and Table 3, respectively.

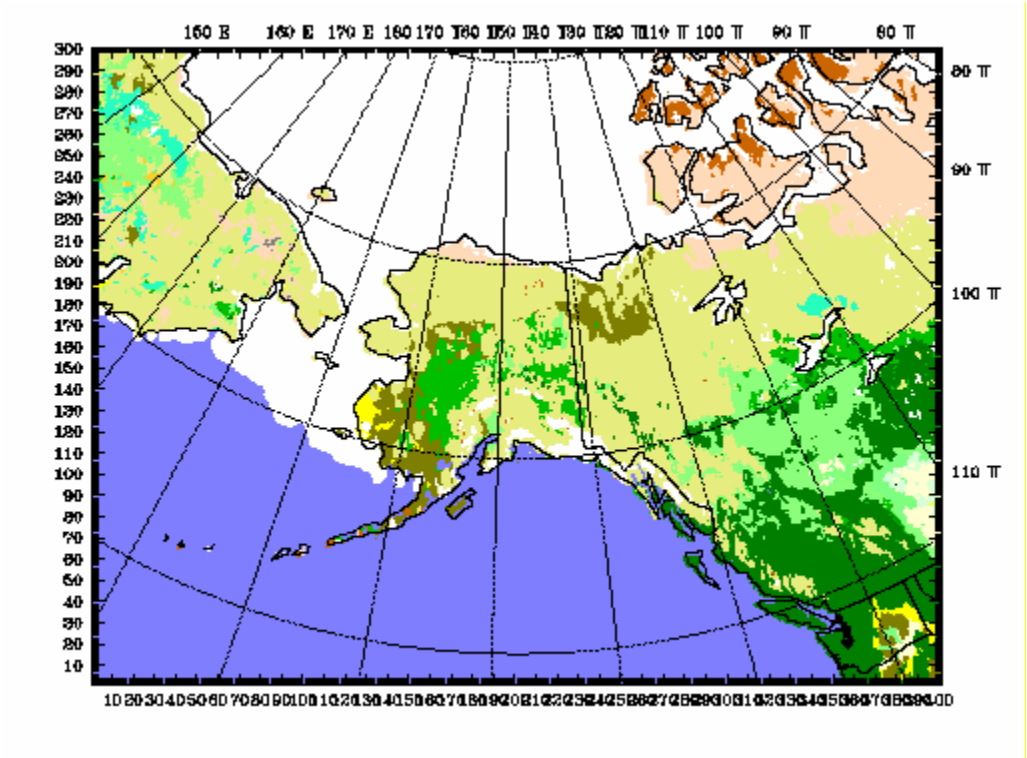


Figure 1: Grid 1 domain, showing land use variation. Colors indicate: light green – cropland/woodland mosaic; yellow – grassland; dark yellow – shrubland; mustard – mixed shrubland/grassland; leaf green – deciduous broadleaf forest; dark green – deciduous or evergreen needleleaf forest; forest green – mixed forest; light blue – water body; brown – herbaceous wetland; surf green – wooded wetland; tan – barren or sparsely vegetated; light gray – herbaceous tundra; avocado – wooded tundra; peach – mixed tundra; medium gray – bare ground tundra; white – snow or ice.

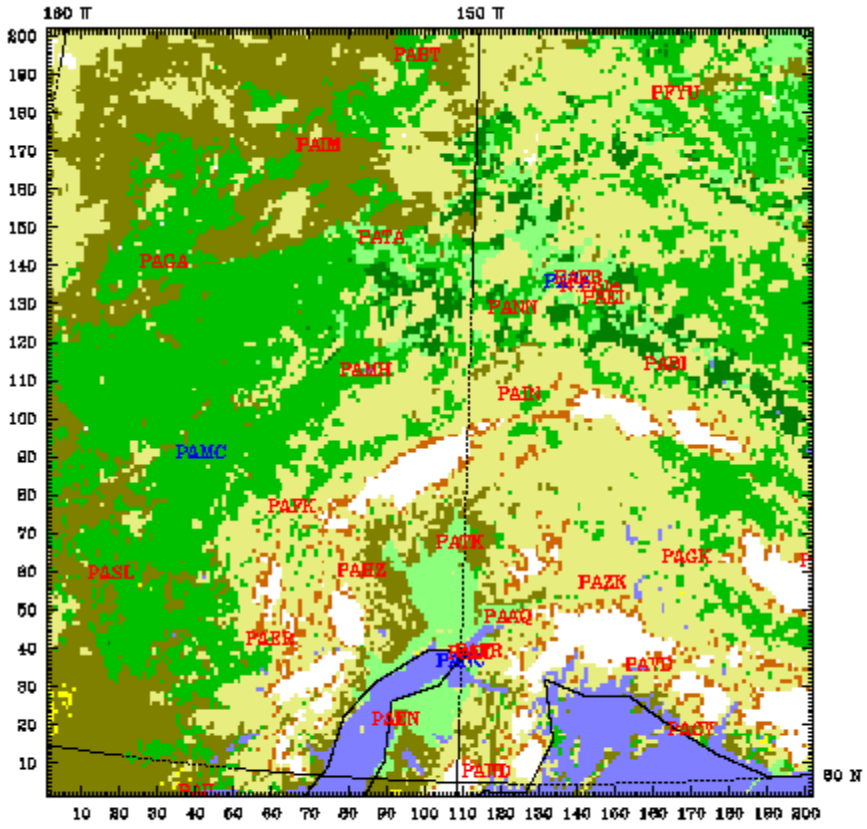


Figure 2: Grid 2 domain, showing land use variation. Color scale same as in Figure 1.

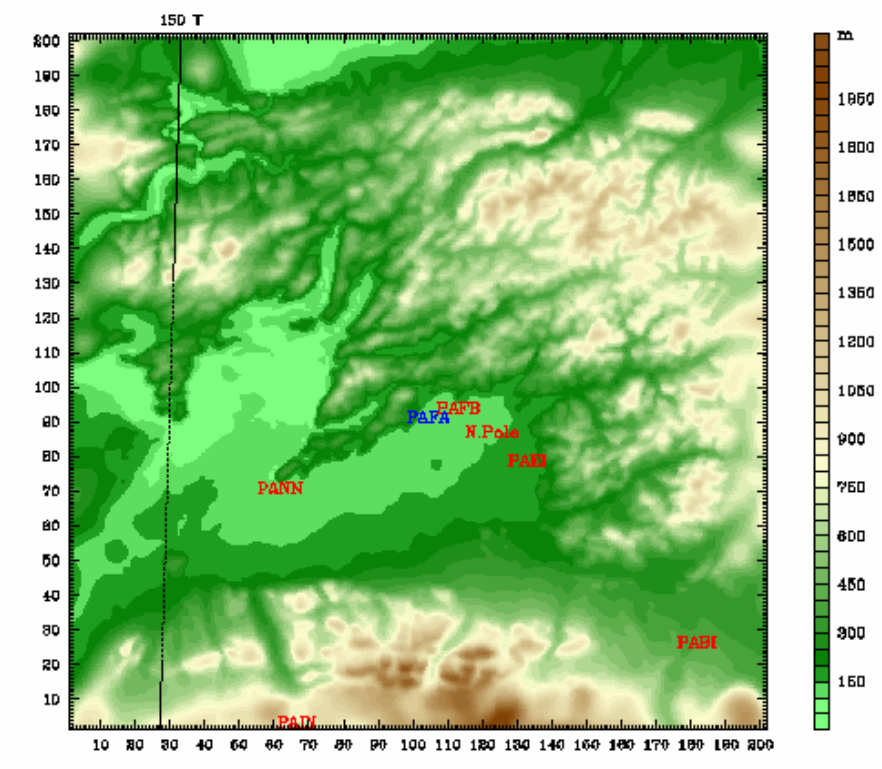


Figure 3: Grid 3 domain, showing topographic relief. METAR stations are shown in red; rawinsonde stations are shown in blue. Eielson AFB is denoted by PAEI; Fort Wainwright is denoted by PAFB. Location of community of North Pole is also indicated.

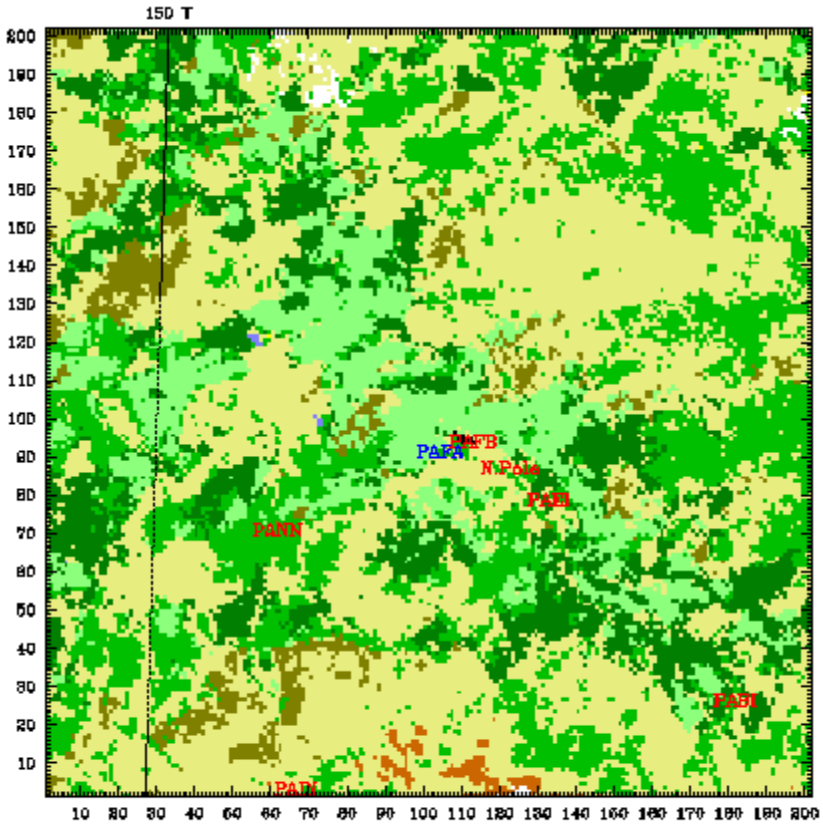


Figure 4: Grid 3 domain, showing land use variation. Color scale same as in Figure 1.

Table 1: Grid-independent features of WRF simulations.

nesting procedure	one-way concurrent
model top (hPa)	50
number of vertical layers	39
eta value of full levels	1.0, 0.9995, 0.999, 0.9984, 0.99705, 0.99415, 0.99155, 0.986, 0.78, 0.966, 0.95, 0.034, 0.918, 0.902, 0.886, 0.866, 0.842, 0.814, 0.78, 0.74, 0.694, 0.648, 0.602, 0.556, 0.51, 0.464, 0.418, 0.372, 0.326, 0.282, 0.24, 0.2, 0.163, 0.128, 0.096, 0.066, 0.04, 0.018, 0
approximate height above ground level of half levels (m)	2.0, 6.0, 10.5, 18.4, 35.5, 57.8, 90.9, 146.2, 228.3, 344.5, 478.7, 614.8, 752.7, 892.5, 1052.3, 1251.1, 1491.2, 1785.4, 2148.4, 2587.7, 3079.8, 3598.2, 4146.0, 4727.3, 5346.7, 6010.4, 6725.8, 7502.6, 8333.4, 9208.6, 10135.5, 11190.6, 12139.8, 13234.2, 14408.4, 15652.1, 16921.7, 18193.7
exclude nudging from the boundary layer	no
G for analysis nudging, when used (s^{-1})	0.0003
G for obs nudging, when used (s^{-1})	0.0004
obs nudging half-time window (hr)	2
specified, relaxed zone width	1, 9

Table 2: Grid-Dependent features of baseline model configuration

	Grid 1	Grid 2	Grid 3
horizontal extent	401 x 301	202 x 202	202 x 202
horizontal Δx (km)	12	4	1.33
i parent start	-	156	103
j parent start	-	106	106
time step (s)	24	8	4
sound step ratio	8	8	4
dampcoef	0.0	0.0	0.0
analysis nudging	yes	no	no
obs nudging	yes	yes	yes
surface obs nudging xy radius (km)	100	100	75
topographic dataset	USGS 10 m	USGS 2 m	USGS 30 s

Table 3: Grid-independent WRF Preprocessor System (WPS) features

projection	Lambert conformal
reference latitude, longitude	64.8, -148.0
true latitudes	50.0, 70.0
standard longitude	-148.0
initial conditions	0.5 degree GFS analyses
analysis interval (hr)	6

Two twenty-day episodes from the 2007-2008 winter season were selected in the RARE study. One episode was from 14 Dec 2007 to 03 Jan 2008, a time of year when there is little solar radiation in the Fairbanks area (approximately three hours of daylight per day near the solstice). During this episode the temperature rapidly decreased to near -40°C by 21 Dec, accompanied by rapid increases in PM2.5 concentrations, and then temperatures generally increased and PM2.5 decreased for the remainder of the episode. The second episode was from 23 Jan 2008 to 12 Feb 2008, when solar insolation was more significant (between five and eight hours of sunlight per day), and provides an example of 'partial sunlight' conditions. During this episode temperatures were initially relatively warm (near 0°C), decreased briefly to near -35°C by 27 Jan, rebounded slightly, and then decreased during the most extensive period of sub -35°C weather of the season. Consistent with the prolonged period of cold temperatures were recurring violations of the PM2.5 standard in the Fairbanks area.

In the initial period of a regional model simulation there is generally a period of several hours when the atmospheric state, whose initial conditions are usually provided by a global or coarser regional model, is still dynamically adjusting to the finer scale resolution and topography of the regional model. Therefore the model output from this initial 'spin-up' period is not completely reliable as an indicator of the true atmospheric state. However, if a regional model simulation is allowed to progress for too long without re-initialization (normally several days), it tends to drift away from the actual observed atmospheric state. Therefore, our method of obtaining realistic regional atmospheric analyses over an entire twenty-day episode was to divide each episode into four overlapping simulation segments. Each segment was around five days long with a twelve-hour overlap between each segment to avoid spin-up effects. (Specifically, the near total darkness episode was divided into successive segments of 6 days, 5.5 days, 5.5 days, and 4.5 days; the partial sunlight episode was divided into successive segments of 5 days, 5.5 days, 5.5 days, and 5.5 days). Initial conditions and most of the Grid 1 lateral boundary conditions were obtained from the half-degree Global Forecast System (GFS) zero-hour analyses (except for a few particular times during the near total darkness episode when the half-degree GFS product was unavailable, when one-degree GFS analysis was used).

Even with the overlapping simulation segment strategy, it is difficult to ensure that the interior of a regional model simulation remains close to observations for simulations of more than a day or so. Therefore, dynamic analyses of historical cases are often performed, in which a Four-Dimensional Data Assimilation (FDDA) strategy is applied throughout the model integration. Relaxation terms based on the differences between actual observations and the corresponding model fields at the observation sites (also known as the 'innovations') are added to the model's predictive equations. In this way the model error is constrained based on available observations while the model still provides dynamic consistency and finer mesoscale structure not present in the observations. The version of FDDA used in these simulations is the multiscale, multigrid

nudging FDDA strategy developed by Stauffer and Seaman (1994) for the MM5 mesoscale model, and implemented in WRF as described in Deng et al. (2009). Nudging is also known as Newtonian relaxation, where the nudging relaxation terms are proportional to the innovation divided by a characteristic e-folding time inversely proportional to a nudging coefficient *G*. Nudging does not perform a direct insertion of observational information at a single point in space and time, but rather it applies the correction or innovation gradually in time and space based on the model terrain influences and prescribed / assumed weighting functions. For example, when a well-mixed PBL is present, one would generally want the influence of surface observations to be extended throughout the PBL, because in these conditions there is high correlation between errors in atmospheric fields at the surface and those anywhere within the PBL.

The multiscale multigrid FDDA method uses a combination of two forms of nudging: analysis nudging and observation ('obs') nudging. Analysis nudging is performed in model grid space where an objective analysis of observations (e.g., a modified Cressman scheme, Benjamin and Seaman 1985) is performed using the interpolated global analyses (e.g., from the GFS) as a background field. The resultant 'enhanced analysis' can then be used as the basis for analysis nudging. Analysis nudging is generally applied on coarser model domains where synoptic data can be used to produce a reasonable gridded analysis. Obs nudging is more attractive for finer-scale domains and asynoptic data. It is particularly effective where observational data density is sparse and corrections are applied only in the neighborhood of the observations, allowing the model to still add value in regions without any data by advecting observation information into the data-sparse regions and creating mesoscale structure not in the observations. In this case the nudging is performed in observation space, and the model field is interpolated to the observation site to compute the innovation that is then analyzed back to the model grid over some three-dimensional neighborhood in space, and over some time window. Quality control (QC) of observations is critically important for the success of both analysis nudging and observation nudging.

In the multiscale multigrid FDDA method applied in the RARE study, 3D-analysis nudging, as well as surface analysis nudging using higher temporal frequency surface data within the PBL (e.g., Stauffer et al. 1991), were performed on the outermost 12-km domain. Obs nudging is applied on at least the 12-km and 4-km domains. (Obs nudging is not applied on the finest 1.33-km model nest for the physics sensitivity studies described further below.) The finer domains thus have the benefit of improved lateral boundary conditions from the coarsest 12-km domain using both types of nudging, as well as the obs nudging performed directly on the 4-km nested domain. This project was one of the first applications of the multiscale FDDA strategy of Stauffer and Seaman (1994) in WRF. The newly developed OBSGRID module was used to produce gridded objective analyses similar to those produced by Rawins / Little_r in the MM5 system. The output files of OBSGRID can be used for 3D and surface analysis nudging and obs

nudging within WRF. OBSGRID takes as input raw WMO observations (both surface and upper air) and the output from WPS, which consists of large-scale gridded data (e.g., GFS output) horizontally interpolated to the model grid to be used in WRF. The outputs of OBSGRID relevant to this study include 1) pressure-level and surface objective analyses of the WMO observations (passing internal QC checks) using the GFS output interpolated to the model grid as background fields; the resultant analyses are then vertically interpolated to the WRF terrain-following "sigma" layers to be used for 3D analysis nudging; 2) surface analysis nudging files that can be directly used by WRF; 3) observation nudging files usable by WRF, and 4) files of the WMO observations including those passing the QC tests for use in the statistical verification software.

As mentioned above, for the physics sensitivity portion of the RARE study, 3D analysis nudging, surface analysis nudging, and obs nudging were performed on the 12-km domain (Grid 1); obs nudging was performed on the 4-km domain (Grid 2); and no nudging was performed on the 1.33- km domain (Grid 3). Thus Grid 3 has no direct FDDA tendencies and could be used to determine physics sensitivities, while still benefiting from improved lateral boundary conditions derived from the coarser grids that did have FDDA.

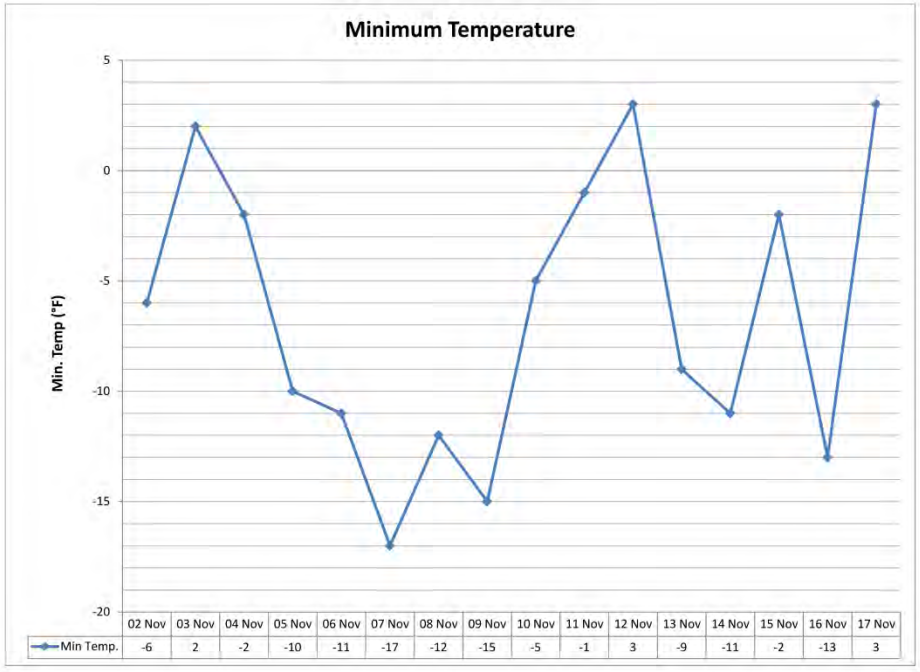
The following modifications were made to the WRF FDDA schemes for use in the baseline Alaska simulations. 1) The verification software was rewritten so that surface wind observations are verified against the third model half-layer from the ground (level closest to the 10-m observation level), while surface moisture and temperature observations are verified against the lowest model half-layer (level closest to the 2-m observation level). 2) A portion of the verification software that uses an assumed lapse rate to adjust model temperatures based on the difference between modeled and actual elevation was disabled, because this can lead to large errors in very stable conditions. 3) The surface analysis nudging and obs nudging codes were modified so that surface innovations for wind are computed and applied directly at the third model level. 4) Because surface wind observations directly relate to the third model layer and surface temperature and moisture observations directly relate to the lowest model layer, the similarity-based adjustments normally performed on model output for surface innovation computation was also disabled. 5) Hardwired vertical weighting functions for surface innovations were implemented into the surface analysis nudging and obs nudging codes, replacing the default functions that extend surface corrections to the model-predicted PBL height. The new functions had a vertical extent hardwired at about 150 m, which is a reasonable order of magnitude estimate for the maximum depth of nocturnal radiatively-driven stable boundary layers (SBL).

As a result of the physics sensitivity studies, the selected physics parameterizations included the Morrison cloud microphysics scheme (specifically designed for high-latitude simulations; Morrison et al. 2005), the RRTMG longwave / shortwave radiation package (Mlawer et al. 1997; Chen and Dudhia 2001), the Mellor-Yamada-Janjic PBL turbulence parameterization

(Janjic 2002) (as modified to be appropriate for the weak-turbulence conditions of very stable boundary layers), and the Rapid Update Cycle (RUC) land surface model (Smirnova et al. 2000). In particular, this physics suite seemed to have the best (least positive) temperature bias and best statistics during the periods when the surface temperatures were coldest and PM2.5 concentrations were the greatest. However, even with this physics configuration, the model's positive temperature bias could not be completely removed; furthermore, during other periods (such as the falling temperature periods in advance of a number of extremely cold episodes) the selected model physics suite seemed to have a negative temperature bias. It was thus strongly suggested that the actual meteorological analysis provided to the EPA be obtained from a final dynamic analysis simulation in which FDDA was also used to constrain the 1.33-km Grid 3 to the observations. However, there was concern that data assimilation of wind fields on Grid 3 would produce spurious low-level circulations in the model; furthermore, it was expected that the low-level circulations in both the actual atmosphere and the model would be driven by the low-level temperature fields. Thus, it was decided that in the delivered final dynamic analysis, that FDDA on Grid 3 would be done within all layers for temperature and moisture fields, but only within layers more than 150 m above the surface for wind fields. Also, the radius of influence for obs nudging on Grid 3 was reduced from the 100 km used on Grids 1 and 2 to 75 km. This value was obtained by computing the characteristic Grid 3 surface temperature innovation length scale through a correlation procedure that will be described in more detail in the next section.

3. WORK PLAN FOR NOV 2008 EPISODE

The current study covers the period 2-17 Nov 2008. Temperatures were relatively mild during the initial portion of this period (Figure 5), but then decreased to -17 °F (-27.2 °C) by the 7th, as recorded by a portable Beta Attenuation Mass (BAM) monitoring unit in the Fairbanks / North Star Borough region. Temperatures then rebounded for about 5 days before the next cold outbreak which bottomed out again at (-11 °F) (-24 °C)by the 14th. The low temperature periods corresponded to high PM2.5 concentrations as expected, especially towards the end of the study episode. However, the extremely cold temperatures, below (-22 °F) -30 °C, recorded during the Jan-Feb 2008 RARE episode did not occur during the Nov 2008 episode, and so the extreme effect of ice fog was not a factor. The final simulation of the episode was divided into four overlapping segments (12 UTC 01 Nov – 00 UTC 05 Nov; 12 UTC 04 Nov – 12 UTC 09 Nov; 00 UTC 09 Nov – 00 UTC 14 Nov; 12 UTC 13 Nov – 12 UTC 18 Nov). In order to facilitate the performance of initial sensitivity studies, an initial test period of 00 UTC 05 Nov – 12 UTC 09 Nov, encompassing one of the colder times during the Nov 2008 episode, was chosen.



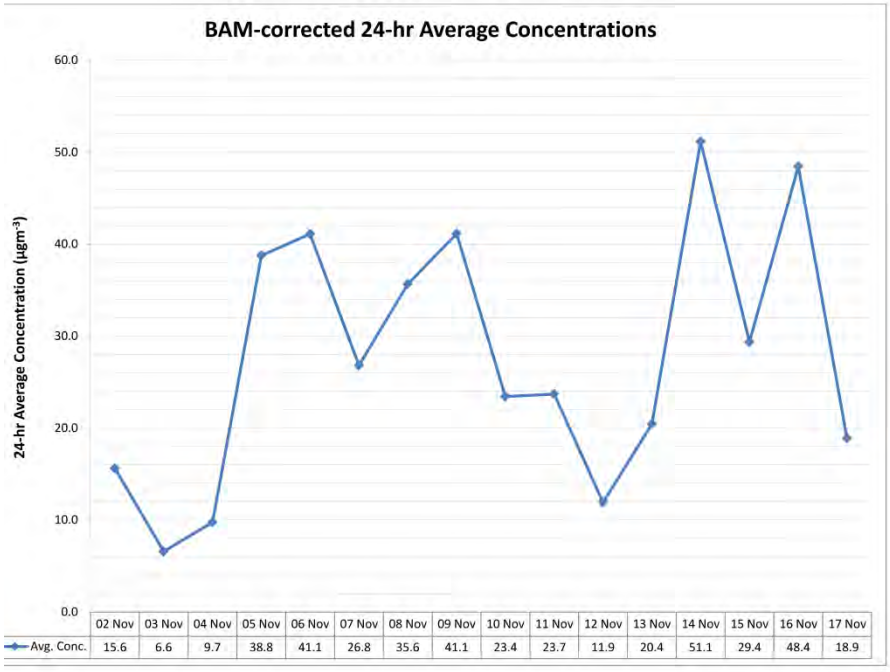


Figure 5 – Plot showing the daily minmun temperatures for the November episode in the Fairbanks region in Farenheit (top) and the BAM-corrected 24-hr average concentration of PM2.5 (bottom). Courtesy Bob Dulla, Sierra Research.

The grid configuration was taken directly from the EPA RARE study, although there are a few modifications relating to the use of observations for the November case as compared to the RARE study. The first involves the effective vertical resolution of the quality control procedure performed on the observations. The OBSGRID pre-processing software package compares point observations of a field such as temperature (either at a single level such as the surface or at multiple levels such as in a sounding) to the background analysis values of that field. For surface observations a direct comparison is performed between observed values of temperature and the background surface values. For sounding observations, if a vertical pressure level of the background analysis does not correspond to one of the pressure levels of that sounding, the observed sounding is interpolated in pressure space to the background pressure levels prior to the objective analysis and the values at the original observed sounding pressure levels are not retained. The result of this procedure is that the effective vertical resolution of sounding observations in the verification dataset and as used in the model is limited by the vertical resolution of the background analysis. In the GFS background fields the pressure levels are spaced 25 hPa apart near the surface, which corresponds to a distance in physical space of approximately 250 m. To alleviate this issue for the current study, a modified version of the GFS decoder, obtained from NCAR, permitted the generation of a background analysis with enhanced vertical resolution, with pressure levels spaced 5 hPa (~50 m) apart near the surface. It was hoped that the increased vertical resolution would improve the representation of the extremely shallow stable boundary layers characteristic of the winter season.

Another modification dealt with the specific objective analysis procedure used by OBSGRID. During the RARE project OBSGRID used either a Cressman scan procedure or a multiquadric analysis (Nuss and Titley 1994) depending on the number of observations at each vertical level. Since the RARE project, NCAR modified the OBSGRID code to provide the user with more flexibility in the objective analysis procedure. It was decided to use the Cressman method at each vertical level in order to produce more vertical consistency in the analysis; furthermore, each successive scan radius was set using the same method present in the Mesoscale Model version 5 (MM5) developed by the co-PI and others at Penn State.

Finally, a decision was made to make use of observations beyond those from the standard METAR observational dataset, in order to enhance the sparse local observational dataset. The total number of surface METAR stations within the Grid 3 domain is eight: Fairbanks (code PAFA), Eielson Air Force Base (PAEI), Ft. Wainwright (PAFB), Nenana (PANN), Delta Junction / Ft. Greely (PABI), McKinley Park (PAIN), Healy (PAHV), and Manley Hot Springs (PAML). Of these, only three could be said to lie in the focus region of the non-attainment area (Fairbanks, Eielson AFB, Ft. Wainwright). However, data from non-METAR surface stations for the period of Nov 2008 were located in the focus region during this project. The data quality from these stations is sometimes uncertain, and often standard METAR meteorological fields

(such as dewpoint) may be absent, but some of the data may be quite valuable, and many of them are used in the Meteorological Assimilation Data Ingest System (MADIS) that is run operationally by the National Weather Service. Stations from the non-METAR database are shown in Table 4.

Table 4: Non-METAR stations used for data assimilation and verification in current study. APRSWXNET – Automatic Position Reporting System as a WX NETwork; RAWS – Remote Automated Weather Station; AKDOT – AK Department of Transportation; MADIS – Meteorological Assimilation Data Ingest System

Station	Database	Latitude	Longitude	Elevation (m)
Woodsmoke	Other MADIS	64.781	-147.284	145
Goodpasture	RAWS	64.238	-145.267	463
Healy (near Otto Lake Rd.)	APRSWXNET	63.839	-149.068	594
Two Rivers	APRSWXNET	64.873	-147.174	229
Fairbanks, near Farmer's Loop Rd. & Ballaine Rd.	APRSWXNET	64.879	-147.824	152
Goldstream Creek	APRSWXNET	64.894	-147.876	176
Livengood	RAWS	65.424	-148.722	137
Ester Dome	APRSWXNET	64.879	-148.055	708
Parks Hwy at Antler Creek	AKDOT	63.810	-148.965	462

A qualitative examination of the data from the non-METAR stations suggested that the temperature data are quite reasonable, although data gaps are more common than for most of the METAR stations. Most of these stations also provide wind data; while the actual values often seem quite plausible, the non-METAR stations overwhelmingly report zero wind speeds during the time period of this study. This is probably due to the relatively high start-up measurement threshold of the instruments used, making them inadequate to measure the very weak winds in the stable meteorological conditions. The one exception to this is Ester Dome, located 710 m above sea level on a ridge to the west of Fairbanks, which normally records a stronger flow. Many of the non-METAR stations also report pressure, but it was discovered that in some cases the pressure seemed to be reduced to the 1000-hPa level, whereas in other cases actual pressure was used. The value of pressure has some significance in that WRF uses potential temperature

as an internal variable, which is the temperature that would result if an air parcel is adiabatically compressed or expanded from its current pressure to the standard sea level pressure. An incorrect or misinterpreted pressure would lead to an erroneous potential temperature and thus an erroneous sense of the 'warmth' of a station. Thus, a decision was made to disregard any reported pressures from the non-METAR surface stations, and effectively use the model-predicted surface pressures to generate a self-consistent potential temperature field from the surface observations.

4. NEAR-SURFACE WIND ASSIMILATION

In the original RARE project a decision was made not to assimilate low-level wind data from surface stations on the 1.33-km (Grid 3). The reasoning was that the near-surface flow in these conditions was weak and predominantly thermally-forced (i.e., much of the existing wind circulation likely consists of topographically-forced drainage flows induced by air masses of varying temperatures). Thus, a numerical model may actually do a better job at capturing these flows than an observational network, especially a sparse observational network, and any data assimilation of observed near-surface winds within the model may erroneously override the development of these flows. The use of this data assimilation strategy in the RARE project did lead to realistic low-level flow patterns and produced generally satisfactory wind error statistics. However, the reported wind speed and wind directions statistics excluded cases where the observation wind report was calm. Including calm wind reports in the wind speed verification, by necessity, makes the wind speed bias more positive, because the model generated wind is never exactly zero. On the one hand, calm or near-calm conditions are common in extremely cold stable boundary layers, so representing them properly is of importance to this study. On the other hand, it is not clear how much of the positive model wind speed bias during calm wind reports is an artifact of insufficient instrument sensitivity. (More discussion on this issue will appear in the next section.) The reported surface temperature biases in the RARE project were also reasonable, but did tend to be positive during the periods of the weakest winds, which could be a direct consequence of positive model wind speed biases leading to too much turbulent mixing in the model. Because the extended dataset to be used in Nov 2008 case provided the potential for more surface data coverage over the Fairbanks region than that used in the Jan-Feb 2008, the possible use of near-surface wind data assimilation was revisited.

A comparison for the 5-9 Nov test period was performed between a simulation that used the RARE FDDA strategy on Grid 3, only nudging temperature and moisture near the surface (henceforth experiment T), and a simulation where additionally nudging of winds near the surface was performed (henceforth experiment TWIND). Statistics for the three local METAR stations are shown in Table 5. The wind speed statistics here include calm wind observations, but the wind direction statistics still do not, because wind direction cannot be defined in calm conditions. It can be seen that in experiment TWIND the wind speed RMSE statistics for all stations are reduced in comparison with experiment T; the reduction is modest but is about 10%

for Ft. Wainwright. The positive wind speed biases are also reduced, though their reduction is even more modest (no more than 0.02 m s^{-1}). Temperature statistics show a small sensitivity, although again Ft. Wainwright shows the greatest improvement in RMSE score. The biggest statistical difference between experiments T and TWIND resides in the wind direction RMSE scores, for which there is a 20 degree improvement for TWIND relative to T when the statistics for all stations are combined.

Table 5: Surface METAR statistics for experiments T and TWIND

Temperature (°C)	T RMSE (MAE for wind direction)	TWIND RMSE (MAE for wind direction)	T Bias	TWIND Bias
Fairbanks	1.71	1.72	-0.07	-0.15
Eielson AFB	1.83	1.80	1.20	1.18
Ft. Wainwright	1.36	1.32	0.05	-0.05
Three Stations	1.70	1.68	0.42	0.36
Relative Humidity (%)				
Fairbanks	4.21	4.31	-0.54	-0.59
Eielson AFB	7.39	7.50	3.59	3.70
Ft. Wainwright	17.55	17.89	-16.59	-16.96
Three Stations	9.31	9.49	-2.06	-2.11
Wind Speed (m s^{-1})				
Fairbanks	0.98	0.95	0.54	0.16
Eielson AFB	1.20	1.16	0.71	0.70
Ft. Wainwright	0.82	0.75	0.18	0.53
Three Stations	1.05	1.01	0.54	0.53
Wind Direction (degrees)				
Fairbanks	49.1	32.6	26.2	22.4
Eielson AFB	66.2	37.6	42.0	16.7
Ft. Wainwright	93.1	74.2	35.8	36.2
Three Stations	73.1	53.8	33.2	28.4

This statistical improvement in wind direction statistics suggested that using near-surface wind FDDA on the 1.33-km Grid 3 should be recommended, once a subjective analysis of the wind field in simulation TWIND revealed no irregularities.

Though the wind direction improvement in experiment TWIND was encouraging, the relatively small improvement in surface wind speed statistics, and the lack of substantial improvement in surface temperature statistics, was puzzling. An examination of the time series of the statistics during the test period (Figure 6 - Figure 13) suggests that while at Eielson AFB positive temperature biases are the norm during the early morning hours, this is not true at Fairbanks on 06 Nov, within one of a couple of prolonged periods of negative surface temperature biases at Fairbanks. (The time axes on the plots are in Coordinated Universal Time (UTC), so 00 UTC is 1500 Alaska Standard Time while 12 UTC is 0300 Alaska Standard Time, which correspond closely to the typical times of daily maximum and minimum temperatures, respectively.) Note that the location of the Fairbanks METAR is at the airport near the west end of the semi-circular topographical bowl in the region, while Eielson AFB is at the east end of this bowl and somewhat more distant from the neighboring ridges (Figure 3). If the time series of actual observed and modeled surface temperatures at the METARs are examined (Figure 14), it can be seen that for Eielson AFB and apparently for Ft. Wainwright the model is significantly too warm during the night (approximately -22 °C versus the observed -25 °C), consistent with the findings from the RARE study. (The gap during the night in the Ft. Wainwright observations is due to the fact that observations from that location are not typically reported during the night or on weekends.) However, on 06 Nov the Fairbanks observation reports a much warmer temperature (near -18 °C) than the other stations, and it shows significant oscillations but no trend of decreasing temperatures during the night. The modeled temperature time series in Figure 14 shows much less variability among the three stations; however, there is a warm spike in the modeled temperature at Fairbanks near 12 UTC 06 Nov that is reflective of the observations.

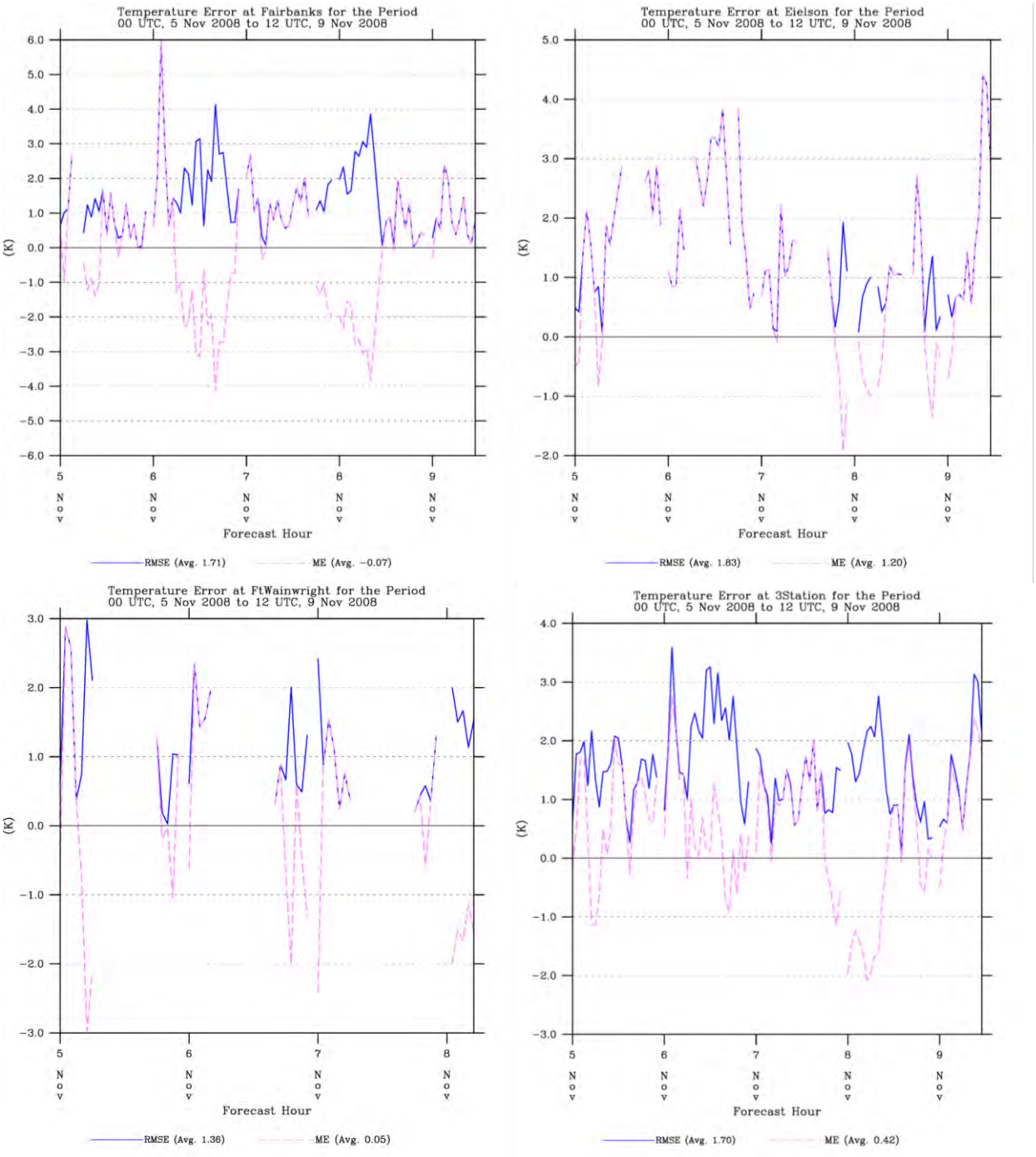


Figure 6: Temperature root mean square error (RMSE) and bias or mean error (ME) statistics for experiment T during the 00 UTC 5 Nov 2008 – 12 UTC 9 Nov 2008 test period at the local METAR surface stations. Statistics are for Fairbanks (top left), Eielson AFB (top right), Ft. Wainwright (bottom left) and all three stations combined (bottom right).

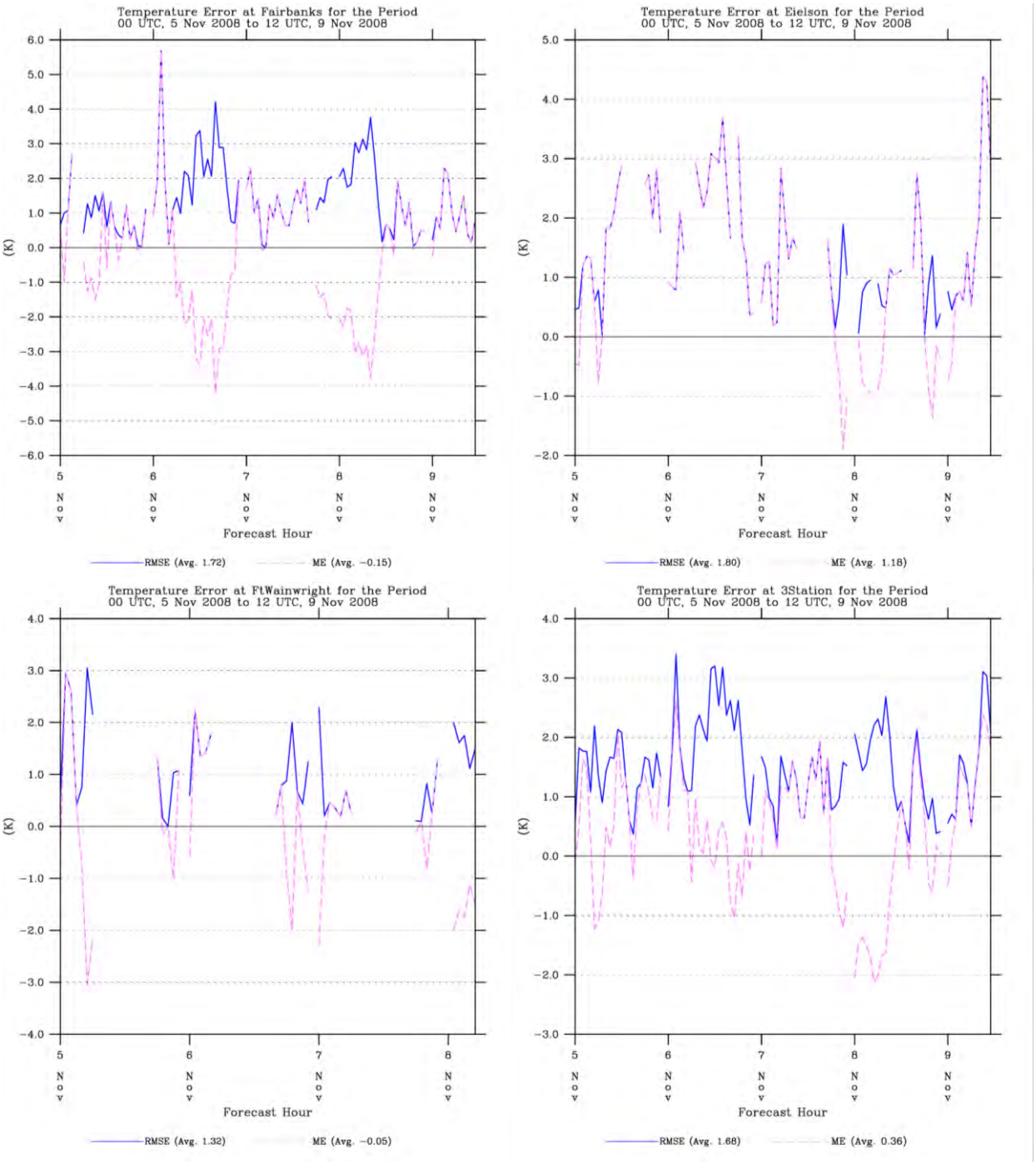


Figure 7: Same as Figure 6, but for experiment TWIND.

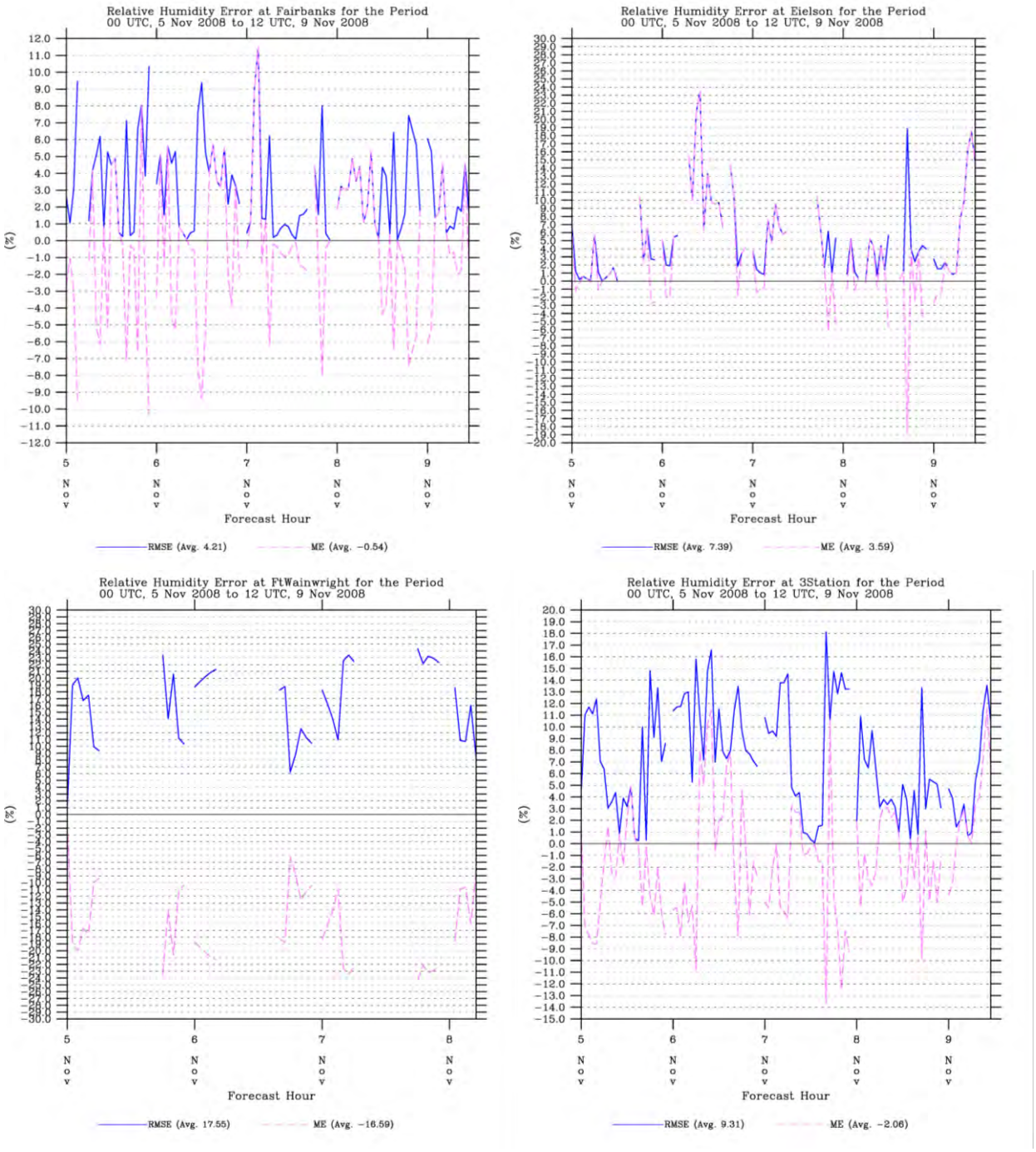


Figure 8: Relative humidity root mean square error (RMSE) and bias or mean error (ME) statistics for experiment T during the 00 UTC 5 Nov 2008 – 12 UTC 9 Nov 2008 test period at the local METAR surface stations. Statistics are for Fairbanks (top left), Eielson AFB (top right), Ft. Wainwright (bottom left) and all three stations combined (bottom right).

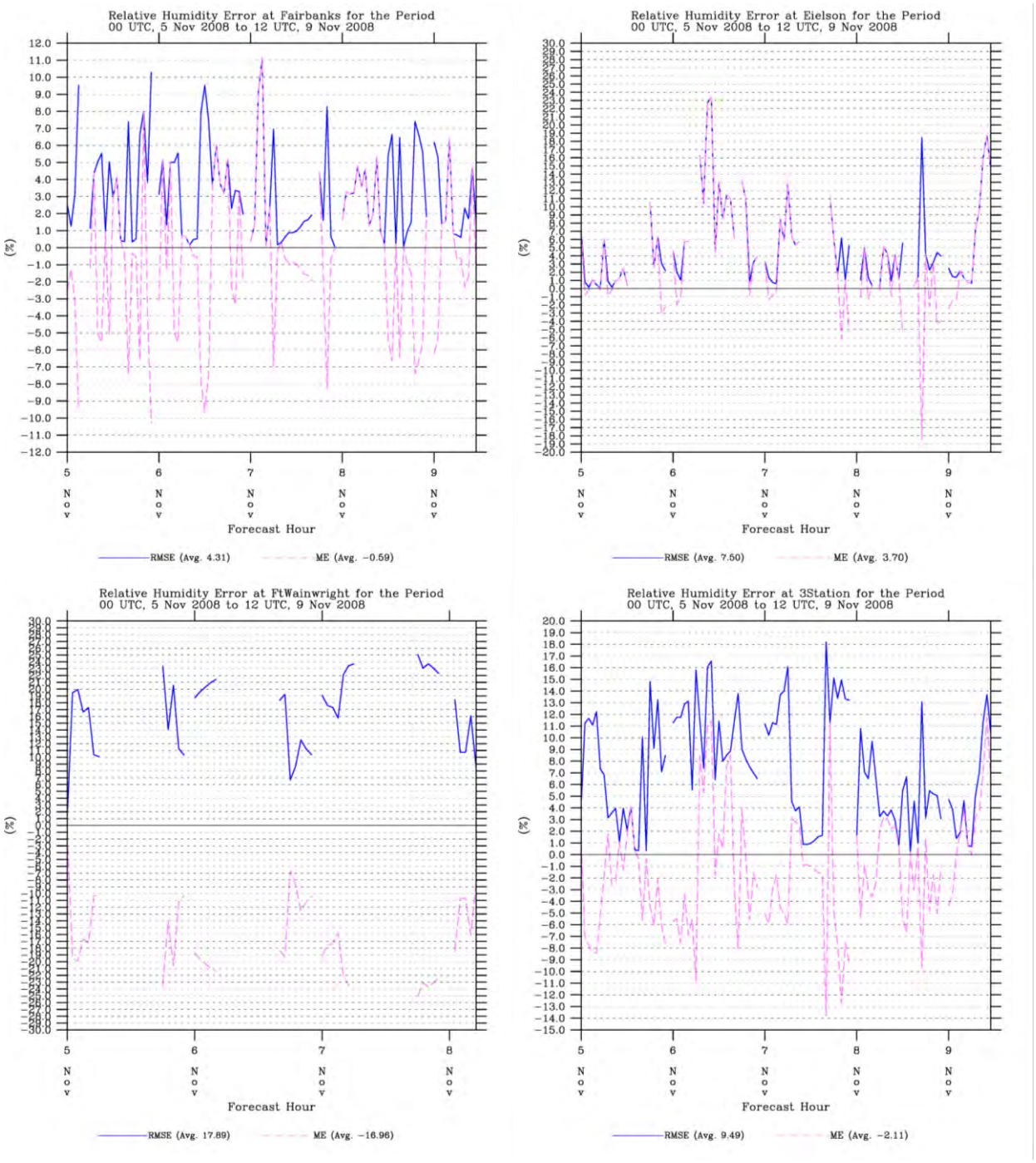


Figure 9: Same as Figure 8, but for experiment TWIND.

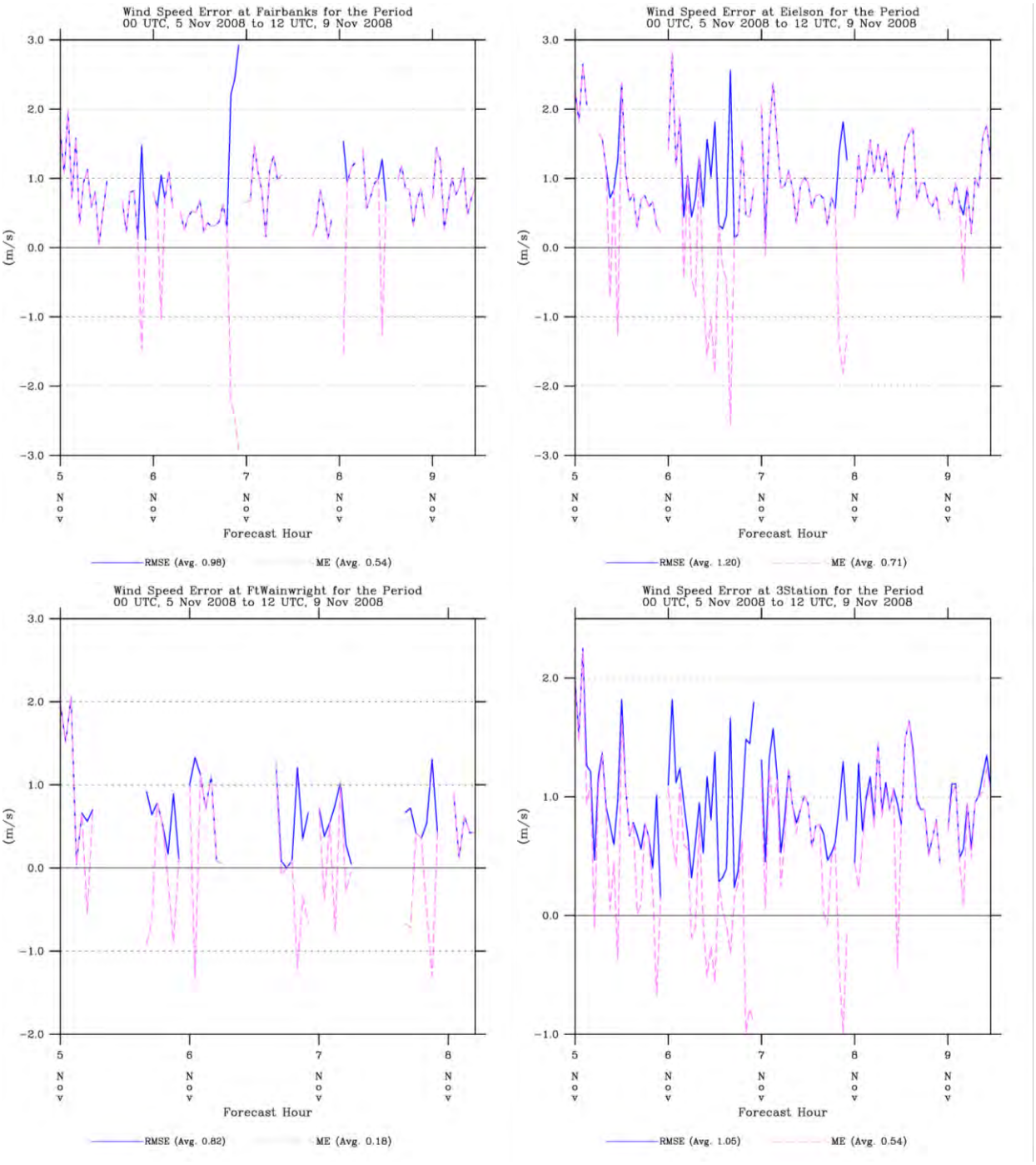


Figure 10: Wind speed root mean square error (RMSE) and bias or mean error (ME) statistics for experiment T during the 00 UTC 5 Nov 2008 – 12 UTC 9 Nov 2008 test period at the local METAR surface stations. Statistics are for Fairbanks (top left), Eielson AFB (top right), Ft. Wainwright (bottom left) and all three stations combined (bottom right).

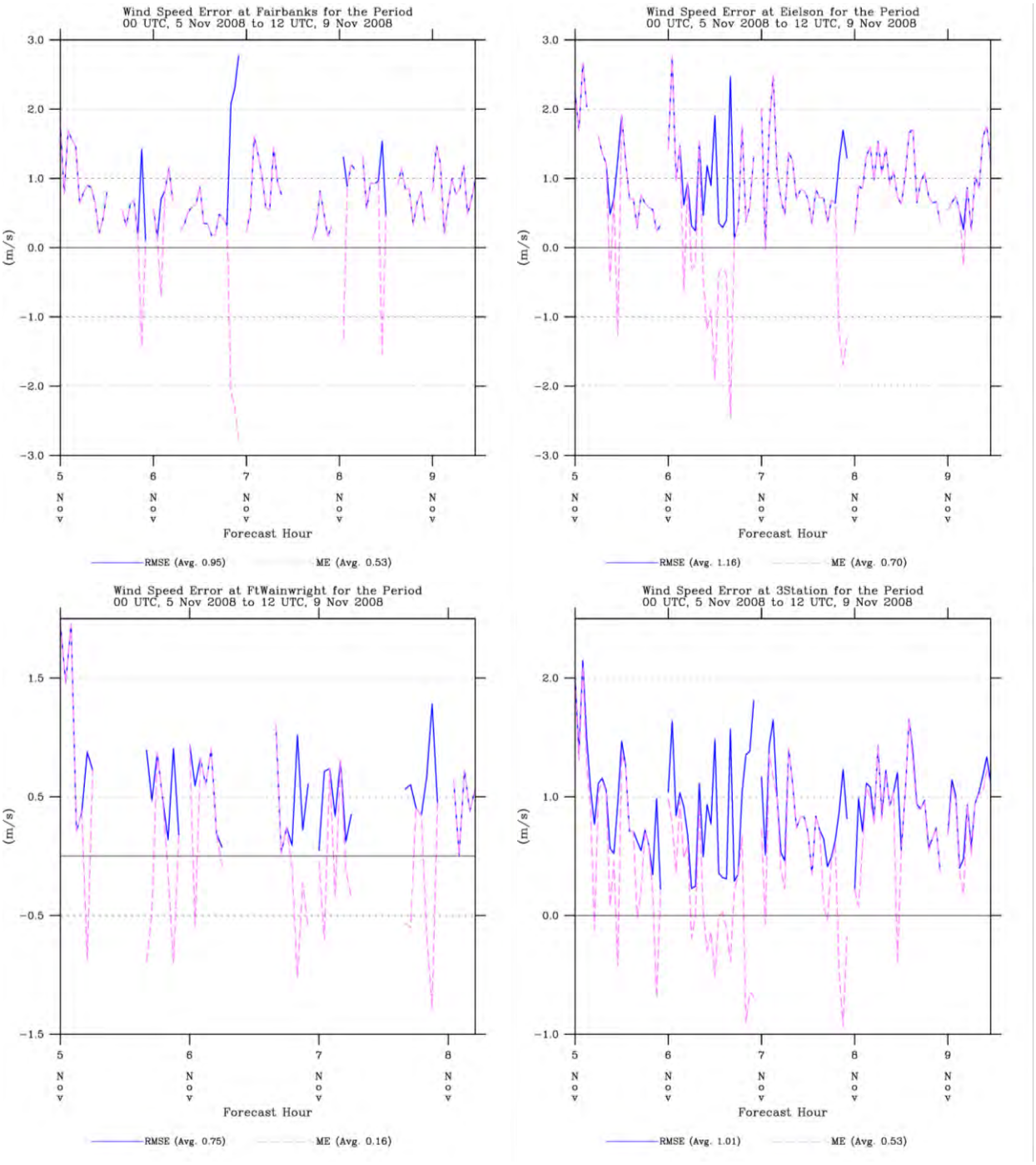


Figure 11: Same as Figure 10, but for experiment TWIND.

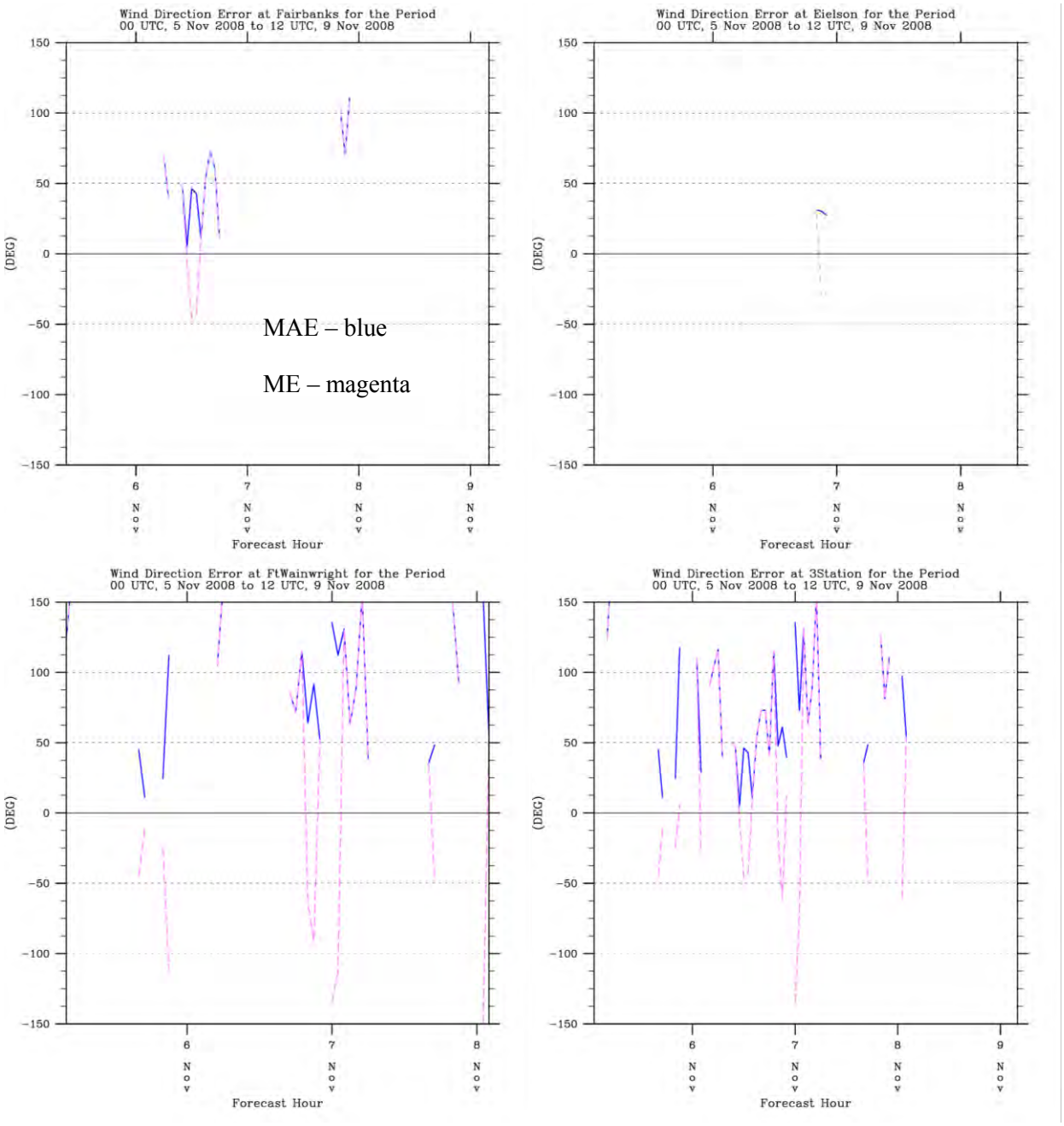


Figure 12: Wind direction mean absolute error (MAE) and bias or mean error (ME) statistics for experiment T during the 00 UTC 5 Nov 2008 – 12 UTC 9 Nov 2008 test period at the local METAR surface stations. Statistics are for Fairbanks (top left), Eielson AFB (top right), Ft. Wainwright (bottom left) and all three stations combined (bottom right).

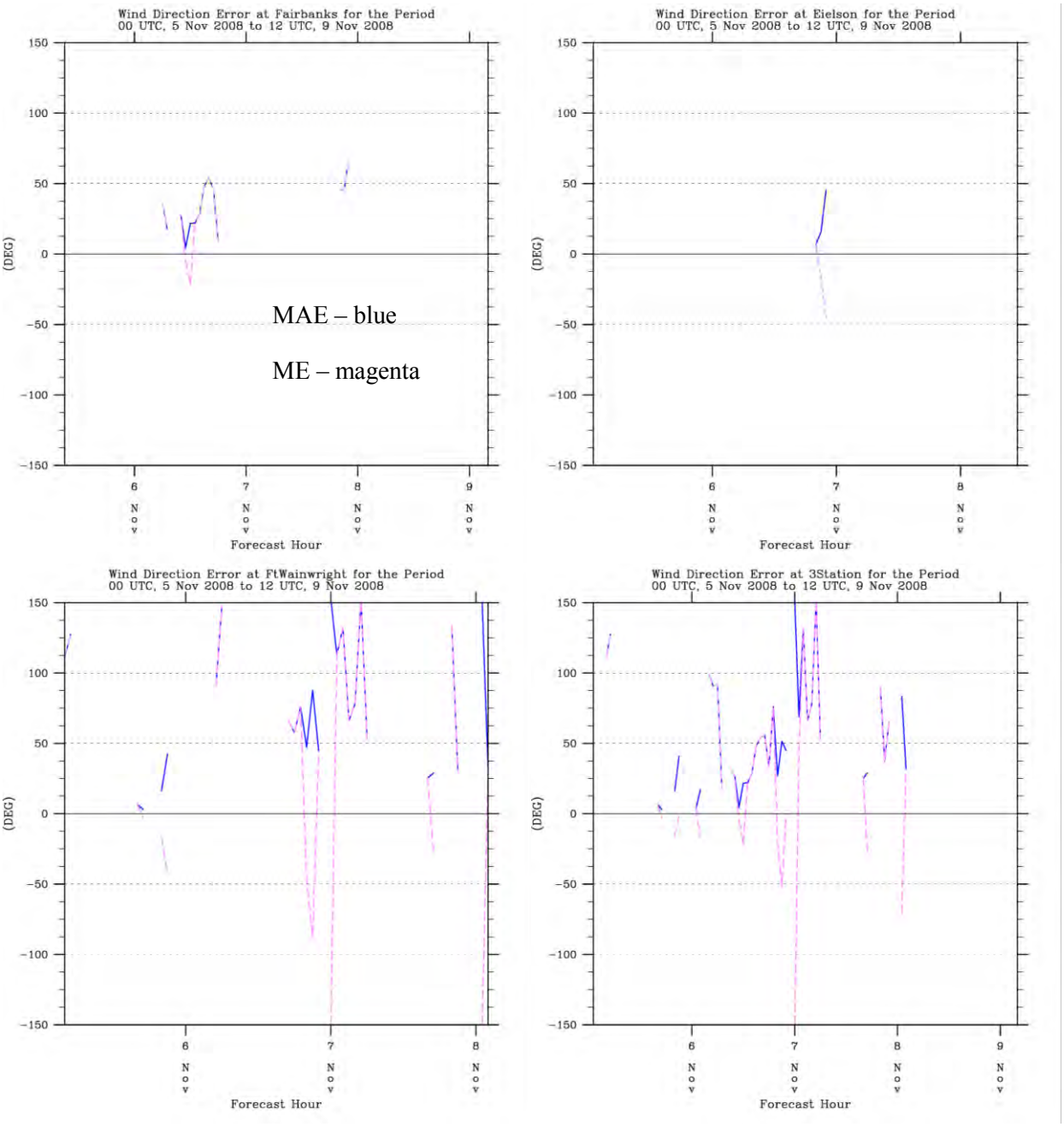


Figure 13: Same as Figure 12, but for experiment TWIND.

The corresponding time series of observed and modeled wind speeds (Figure 15) reveal that 06 Nov exhibits fairly strong wind speeds at Fairbanks (to about 4 m s^{-1} or about 8 knots), especially compared to the other stations, which is probably due to the fact that the Fairbanks station is

closest to the perimeter of the stagnant air within the topographic semicircle. The model successfully reproduces some of the increased wind speed at Fairbanks at this time (2.2 – 2.8 m s^{-1}), but the maximum wind speed of 4.0 m s^{-1} is underestimated. It is plausible that the anomalously warm temperatures at Fairbanks for this case are a direct consequence of increased wind speeds at this location, which lead to increased turbulent mixing and prevent the occurrence of the cold surface temperatures shown at the more stagnant locations at Ft. Wainwright and Eielson AFB. A plausible explanation of the errors in the model predictions is that the model is insufficiently resolving the differences in topography and location among the three stations, and effectively blending the effects of the observations of all three stations. The conclusion, then, is that surface wind data assimilation on Grid 3 seems to be beneficial, especially for wind direction, but that the radius of influence of wind observations should probably be reduced.

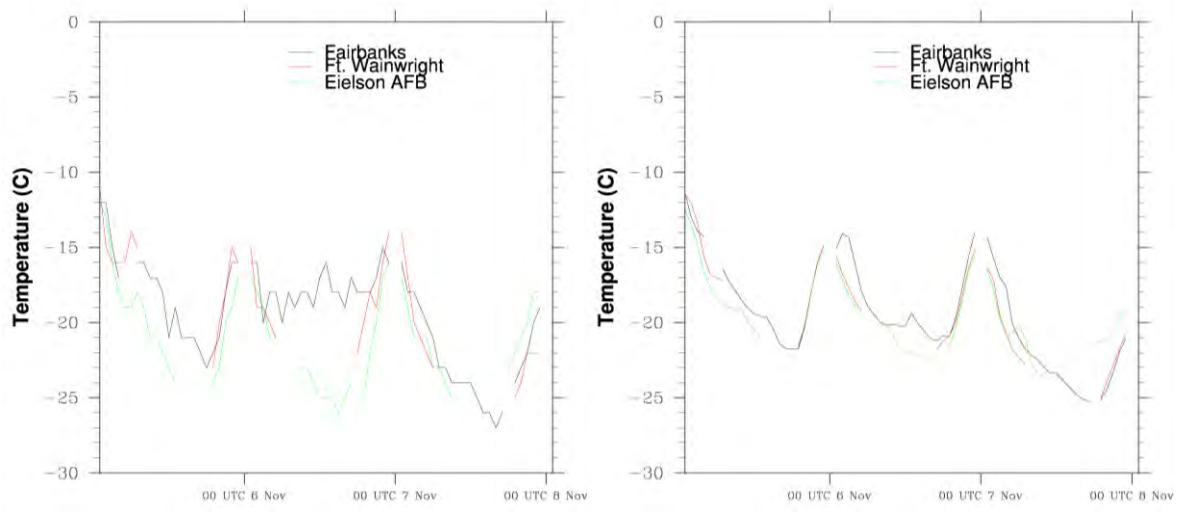


Figure 14: Time series of temperature for Fairbanks, Ft. Wainwright, and Eielson AFB from observations (left) and experiment TWIND (right)

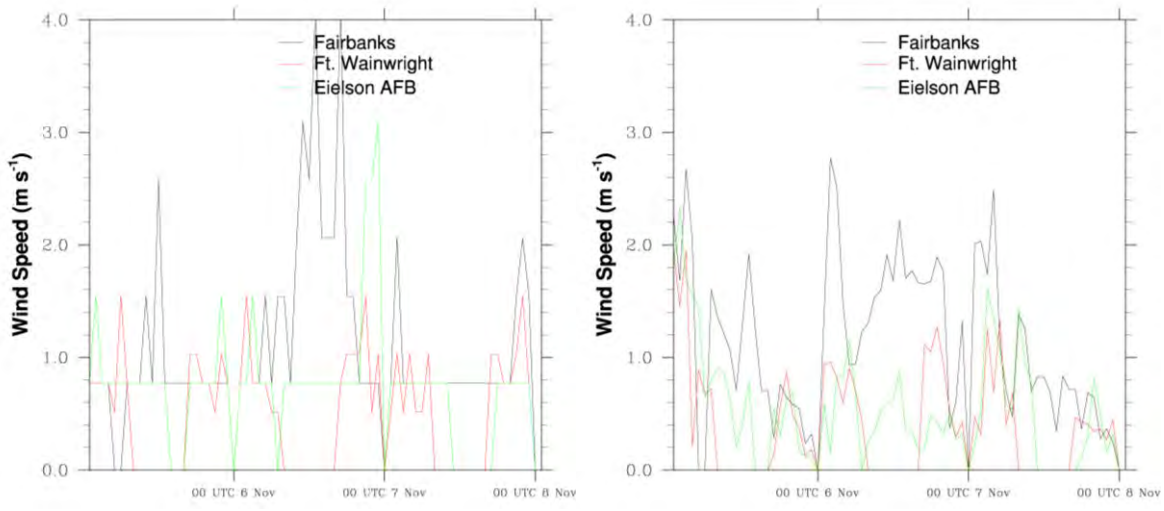


Figure 15: Same as Figure 14, but for wind speed

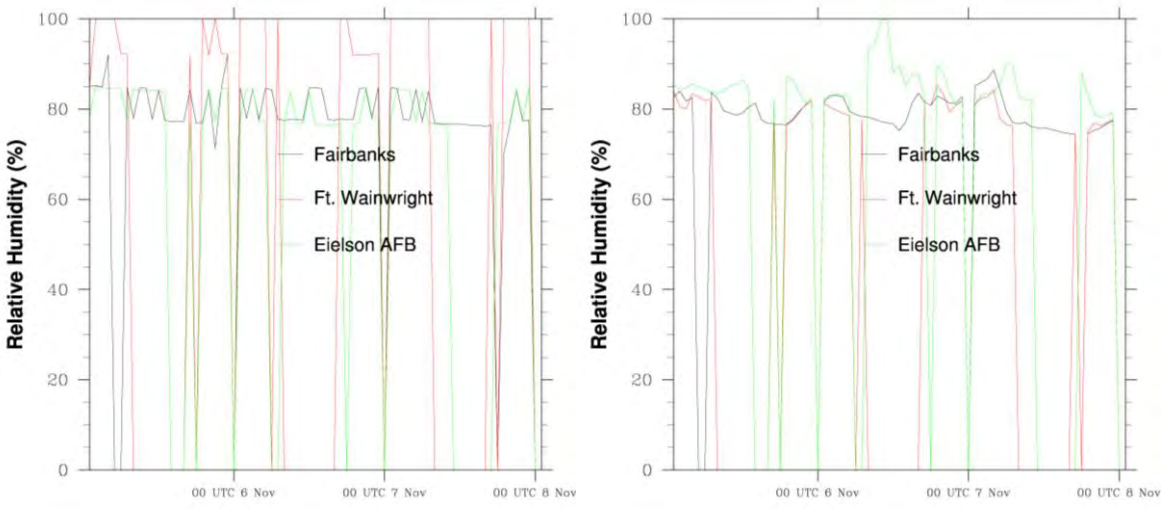


Figure 16: Same as Figure 14, but for relative humidity

Some insight into the characteristics of the relative humidity statistics can be found in Figure 16. The observations for stations other than Ft. Wainwright indicate relative humidity values are consistently near 80%. This is consistent with conditions near saturation with respect to ice but with relative humidity reported with respect to water saturation, when temperatures are on the order of -20 °C. However, Ft. Wainwright always reports relative humidity near 100% in these conditions. The model output at the Ft. Wainwright location tends to be closer to 80%, leading to the large positive relative humidity bias found in the Ft. Wainwright relative humidity

statistics. This could reflect the fact that Ft. Wainwright is erroneously reporting 100% relative humidity, based on the occurrence of ice crystals and other water condensate in the atmosphere, when in reality the atmosphere is ice saturated. However, it is interesting that the model does in fact produce conditions closer to water saturation near Eielson AFB during the day of 07 Nov, though the observations do not reflect this. Water saturation at temperatures as cold as -20 °C is difficult to maintain because of the large numbers of ice nuclei at these temperatures; after nucleation, ice crystals tend to deplete all water vapor above the ice saturation value and deplete all remaining liquid water via the Bergeron-Findeisen process. However, it is possible to maintain water saturation at these temperatures if the air is pristine. So a full explanation of these differences is not known at present.

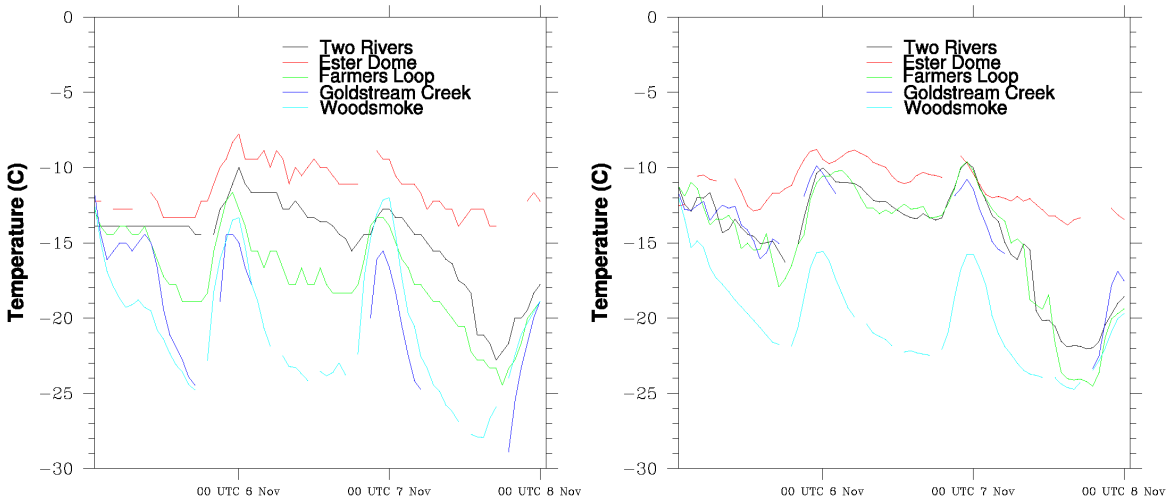


Figure 17: Time series of temperature for the local non-METAR surface stations from observations (left) and experiment TWIND (right).

Figure 17 shows the time series of observed and TWIND temperature at five non-METAR surface stations in the immediate Fairbanks region. The observed temperatures show that Woodsmoke and presumably Goldstream Creek behave like Eielson AFB and Ft. Wainwright, approaching -25 °C at night. The location near Farmer's Loop Rd. behaves somewhat like the Fairbanks METAR station in that it has temperatures decreasing to only about -18 °C at night. Two Rivers has even less of a nocturnal decrease of temperature, while Ester Dome remains near -10 °C for most of the period. This seems to confirm that the warmest temperatures during these episodes occur on the ridges while the coldest temperatures occur within the low spots of local valleys. Of these stations, Ester Dome is predicted very well by the model, helping corroborate the model skill for the atmosphere above the near-surface stable boundary layer. Two Rivers and Woodsmoke are also fairly well predicted by the model; the latter performance is notable because it confirms that the model configuration is capable of reproducing observed surface

temperatures at least as low as about -23 °C. These two stations also happen to be located at the east end of the Fairbanks / North Star Borough valley, near Eielson AFB. The model predicts approximately the same temperatures at Goldstream Creek and Farmer's Loop Rd. as at Two Rivers, but for Farmer's Loop Rd. and Goldstream Creek the resultant temperature is much too warm. It should be pointed out that these two stations are only about 2 km apart in physical distance, so it cannot be expected that a numerical model with 1.33-km horizontal grid spacing would be able to differentiate the temperature behavior between the two. All of the results considered together suggest that the model is able to predict the temperature evolution well in places both along the ridges and in the valley, but in other places the model is insufficiently resolving the actual difference in meteorological conditions between stations, whether the insufficient resolution is in the model terrain or in the way the model is treating observations in the data assimilation.

Statistics for wind speed are shown in Figure 18 for the non-METAR stations. This is an example of the fact that, other than Ester Dome, the wind instrumentation at these stations is generally not capable of recording what little wind is present. For Ester Dome itself, however, the magnitude of the wind speed peaks are well represented at the beginning of the test period. It can be seen that at the Woodsmoke station, the appropriately low model temperatures are accompanied by model wind speeds generally about 1 m s^{-1} or less, while the other stations have model wind speeds that are usually above 1 m s^{-1}.

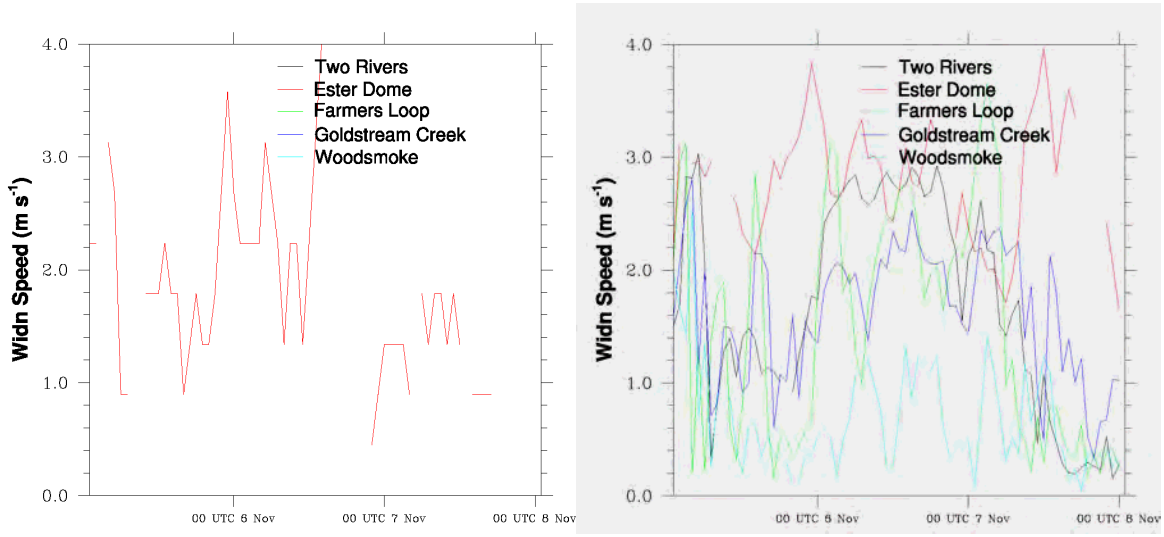


Figure 18: Same as Figure 17, but for wind speed.

Based on these results, it was decided to re-apply a procedure performed during the RARE study to derive an observation nudging correlation length scale based on the near-surface temperature field, and to use that radius of influence in subsequent model simulations. The procedure

consists of repeating the simulation with the same configuration, but with no FDDA of any sort performed on Grid 3. For each station on Grid 3, the temperature innovation (value of the observation minus the value of the model at that location) is computed at one hour increments. The correlation coefficient was then calculated between pairs of stations separated by known horizontal distances. Since the innovation for a variable is proportional to the nudging tendency for that variable, the typical distance over which innovations are correlated gives an indication of what the radius of influence should be. When this analysis was performed for the November case, it was discovered that the typical correlation distance was on the order of 30 km, substantially smaller than the 75 km value derived in the RARE project. (The ability to calculate a smaller radius of influence for the current study was aided by the presence of a denser surface observational network after the inclusion of the non-METAR stations.) It was thus decided to try a combination of a reduced radius of influence from 75 km to 30 km on Grid 3, along with a doubled value of the wind nudging strength on Grid 3 (from 4×10^{-4} s^{-1} to 8×10^{-4} s^{-1}). The temperature nudging strength was left unaltered, because the extreme horizontal variability in the temperature field and its strong dependence on the local topography argue for a more conservative approach.

When the new experiment (henceforth TWIND2X30) was run on the test period, the results (Table 6 and Figure 19 - Figure **22**) showed even more improvement in surface wind direction errors for the three local METAR stations, with an average decrease in MAE of 19 degrees. Temperature RMSE scores were slightly better for Fairbanks, somewhat worse for Ft. Wainwright, but substantially better for Eielson AFB. Since Eielson AFB is relatively distant from most of the other stations, this is an indication that the reduced radius of influence was in fact an improvement. Relative humidity errors are also generally improved. On the other hand, wind speed RMSE scores were made slightly worse, by up to 0.16 m s^{-1} for Ft. Wainwright.

Though there was no completely unambiguous choice, based on the test period results, for the optimal model configuration to produce the dynamic analysis for the entire 2-17 Nov 2008 episode, it was decided that, since the degradation in wind speed errors was slight while the improvement in wind direction errors was substantial, we would select the TWIND2X30 setup as the basis for further simulations.

Table 6: Surface METAR statistics for experiments TWIND and TWIND2X30

Temperature (°C)	TWIND RMSE (MAE for wind direction)	TWIND2X30 RMSE (MAE for wind direction)	TWIND Bias	TWIND2X30 Bias
Fairbanks	1.72	1.68	-0.15	0.33
Eielson AFB	1.80	1.45	1.18	0.95
Ft. Wainwright	1.32	1.43	-0.05	0.63
Three Stations	1.68	1.55	0.36	0.62
Relative Humidity (%)				
Fairbanks	4.31	4.46	-0.59	-0.61
Eielson AFB	7.50	5.43	3.70	2.49
Ft. Wainwright	17.89	16.22	-16.96	-15.33
Three Stations	9,49	8.36	-2.11	-2.26
Wind Speed (m s^{-1})				
Fairbanks	0.95	1.01	0.16	0.60
Eielson AFB	1.16	1.24	0.70	0.82
Ft. Wainwright	0.75	0.91	0.53	0.27
Three Stations	1.01	1.10	0.53	0.63
Wind Direction (degrees)				
Fairbanks	32.6	21.0	22.4	9.5
Eielson AFB	37.6	19.3	16.7	3.1
Ft. Wainwright	74.2	48.9	36.2	10.7
Three Stations	53.8	34.5	28.4	9.2

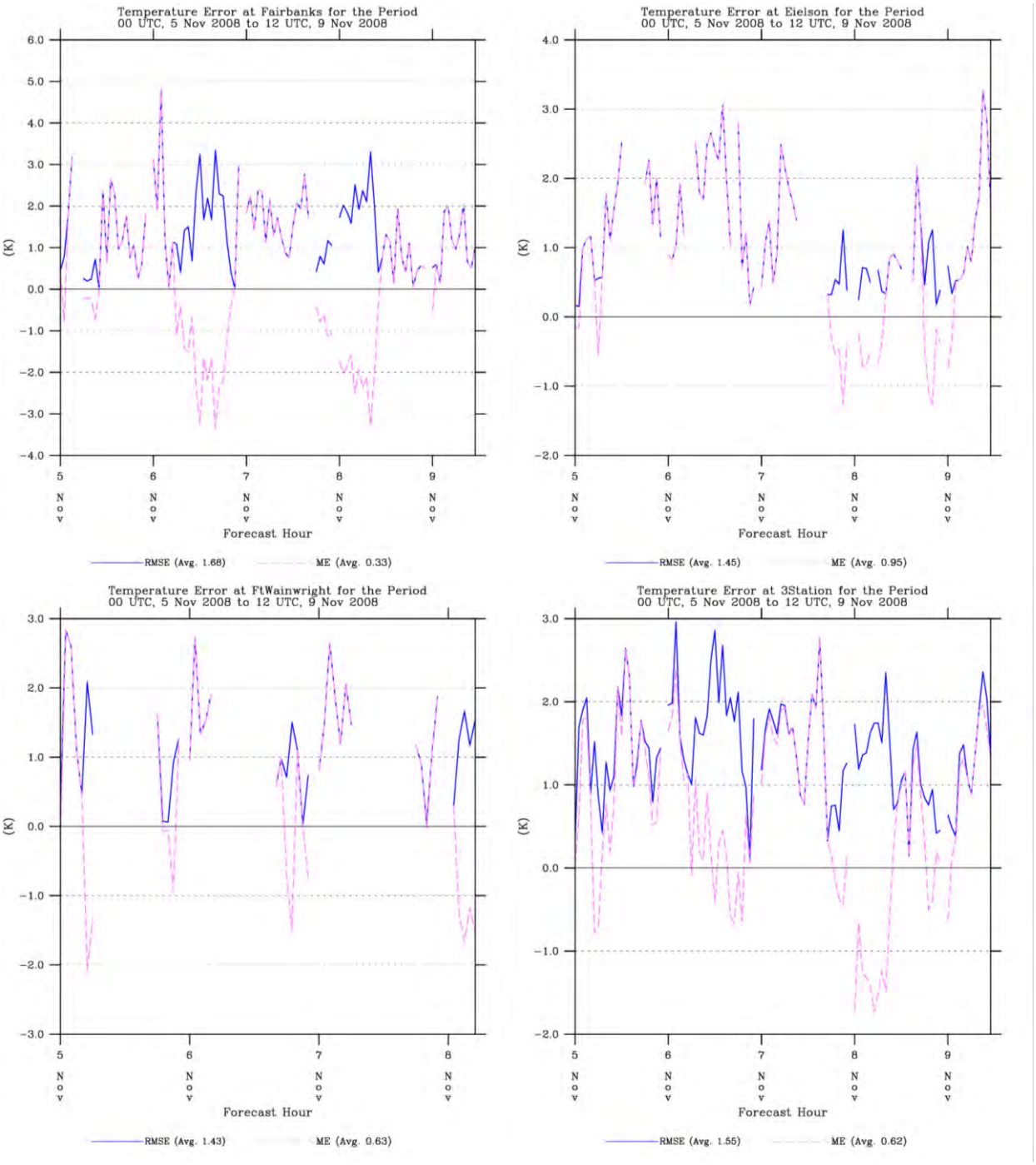


Figure 19: Same as Figure 6, but showing temperature statistics for experiment TWIND2X30.

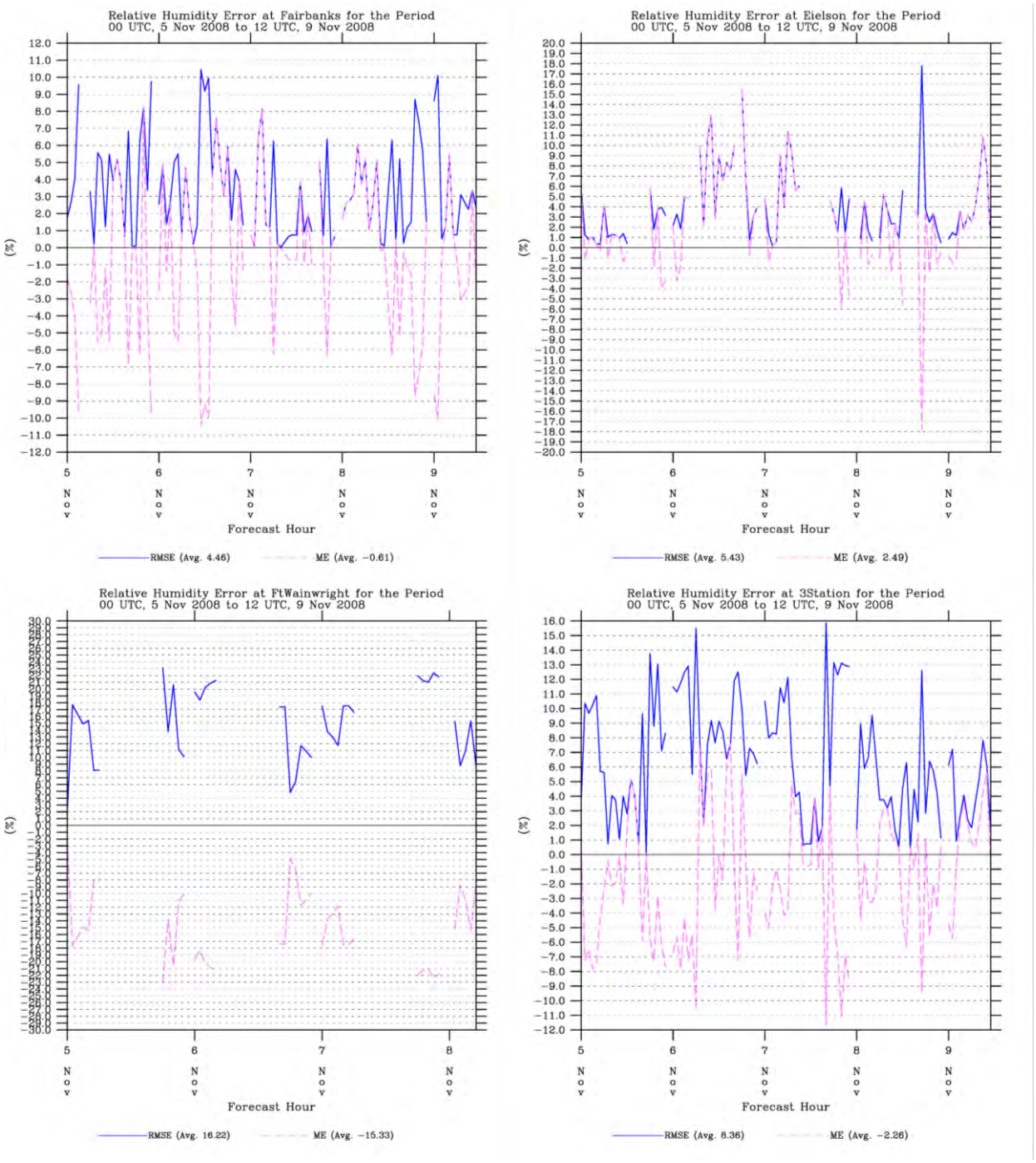


Figure 20: Same as Figure 8, but showing relative humidity statistics for experiment TWIND2X30.

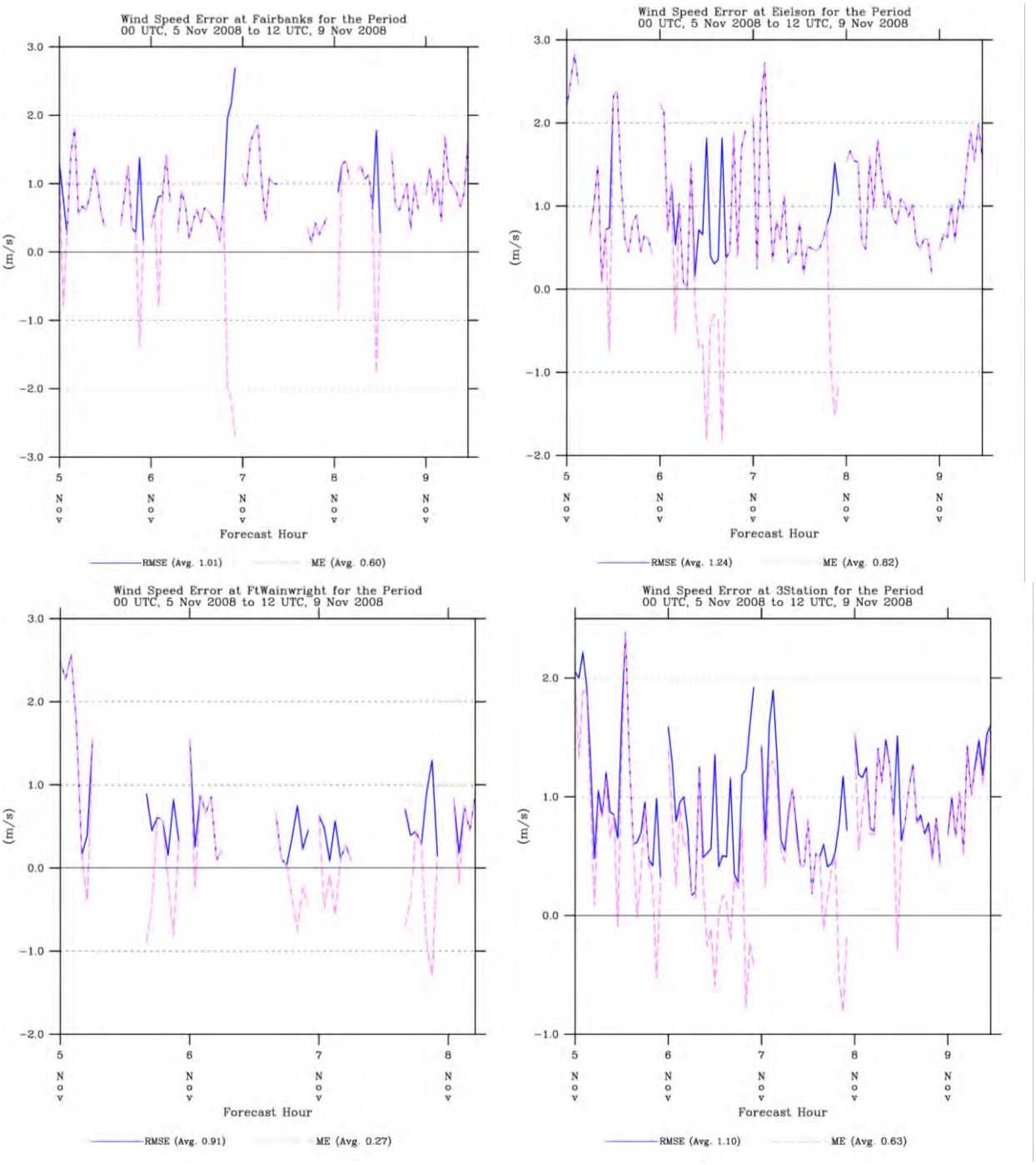


Figure 21: Same as Figure 10, but showing wind speed statistics for experiment TWIND2X30.

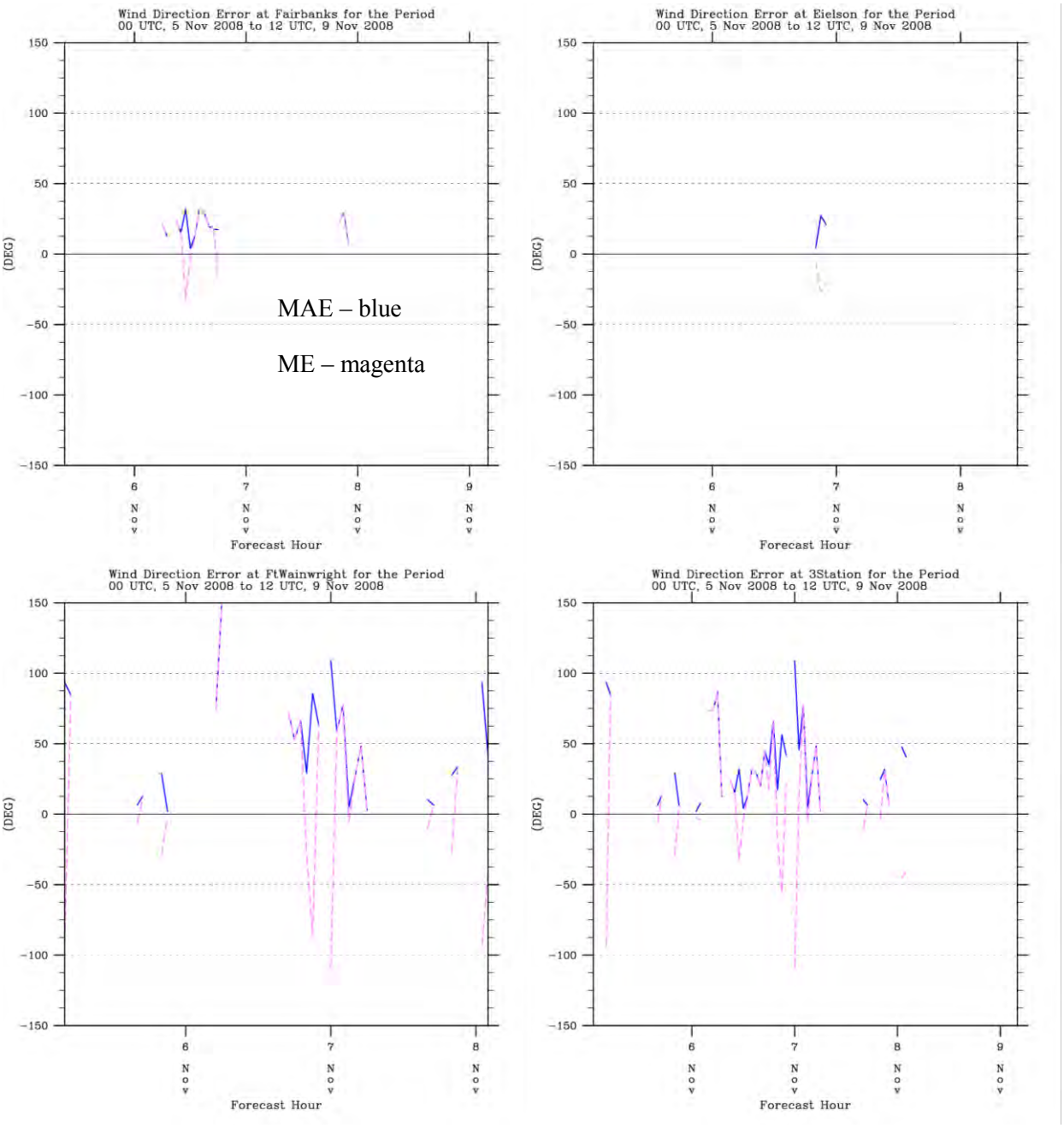


Figure 22: Same as Figure 12, but showing wind direction MAE and ME statistics for experiment TWIND2X30.

5. USE OF CALM WIND OBSERVATIONS

One issue of particular importance lies in the treatment of observations that report zero wind speed. It is often not clear, especially for non-METAR data, whether a report of zero wind speed indicates calm conditions, or indicates missing or faulty data. Furthermore, even if it is accepted that the data correctly represents calm conditions, in practice a report of calm generally indicates an actual wind speed that could have any value up to some minimum detection threshold. For automated METAR surface stations such as Fairbanks this threshold is 3 knots (=1.543 m s^{-1}). This is on the order of the model positive wind speed biases, which suggests that a (not-well-known) component of the model positive wind speed bias may be due to the model capturing actual atmospheric flows that are below the observational threshold. Furthermore, observations of calm winds do not provide usable guidance on the direction of the flow that does exist, which is of great importance for dispersion applications, and for which the model may be the only reliable source of information.

Because of these considerations, the default obs nudging data assimilation strategy is not to use calm wind reports. For the typical case of dense surface observing networks and non-stagnant meteorological conditions, this is entirely satisfactory. However, in the particular application of near-surface transport under very stable conditions, when only a few meters per second of flow can have a great effect on the transport of pollutants, and where the presence of non-calm surface wind observations are infrequent, the assimilation of near-surface calm winds should be considered.

As noted above, the great majority of the surface wind observations for these stable episodes are calm reports. Since the model appears to have a positive wind speed bias in these conditions, nudging towards a zero velocity wind vector near the surface may have a beneficial effect on reducing a positive wind speed bias. On the other hand, also as noted above, an unknown portion of the positive wind speed bias in near-calm conditions is an artifact of the model always having a wind speed above zero while observations indicate a wind speed of exactly zero when the wind speed is below the instrument threshold. Furthermore, since a calm wind observation does not provide guidance as to the wind direction, within the radius of influence of a calm surface observation there is the potential to degrade model predictions of wind direction at locations where the wind speed is not actually calm.

Table 7: Surface METAR statistics for experiments TWIND2X30CALM and TWIND2X30 for the November test period.

Temperature (°C)	TWIND2X30CALM RMSE (MAE for wind direction)	TWIND2X30 RMSE (MAE for wind direction)	TWIND2X30CALM Bias	TWIND2X30 Bias
Fairbanks	1.51	1.68	0.22	0.33
Eielson AFB	1.43	1.45	0.93	0.95
Ft. Wainwright	1.50	1.43	0.70	0.63
Three Stations	1.48	1.55	0.57	0.62
Relative Humidity (%)				
Fairbanks	4.55	4.46	-0.87	-0.61
Eielson AFB	5.44	5.43	2.46	2.49
Ft. Wainwright	16.21	16.22	-15.30	-15.33
Three Stations	8.37	8.36	-2.38	-2.26
Wind Speed (m s^{-1})				
Fairbanks	0.97	1.01	0.54	0.60
Eielson AFB	1.18	1.24	0.72	0.82
Ft. Wainwright	0.96	0.91	0.29	0.27
Three Stations	1.07	1.10	0.57	0.63
Wind Direction (degrees)				
Fairbanks	31.4	21.0	20.9	9.5
Eielson AFB	31.0	19.3	4.97	3.1
Ft. Wainwright	83.7	48.9	5.9	10.7
Three Stations	57.1	34.5	11.3	9.2

A final sensitivity test to the effect of including calm wind reports in the data assimilation procedure of experiment TWIND2X30, henceforth experiment TWIND2X30CALM, was performed. Statistics for the two experiments performed over the test period are shown in Table 7. The assessment of the comparison is mixed. Overall temperature biases and wind speed biases are improved by about 10% in experiment TWIND2X30CALM (note however that a 10% improvement of wind speed bias in this case amounts to less than 0.1 m s^{-1} which is certainly less than the instrumentation precision), and temperature RMSE scores are improved by about 5%. However, both statistics are actually degraded for the Ft. Wainwright station. Furthermore, overall wind direction MAE statistics are over 20 degrees worse in experiment TWIND2X30CALM than in experiment TWIND2X30. Recall that in wind direction statistics calm wind observations are excluded from the verification dataset; therefore, a degradation of wind direction statistics in experiment TWIND2X30CALM means that the inclusion of calm wind reports in the data assimilation is having an adverse affect on the model-generated winds at other locations that are not reporting calm winds.

The decision between using simulation TWIND2X30CALM and TWIND2X30 was even more challenging than the decision between simulation TWIND and TWIND2X30. However, despite the beneficial reduction in the positive wind speed bias in TWIND2X30CALM, because of the importance of wind direction prediction to dispersion calculations in these conditions, and because wind direction was the variable that showed the most statistical variability between different experiments, a final decision was made to simulate the whole 2-17 Nov 2008 episode using the TWIND2X30 setup (although a parallel simulation of the entire episode using TWIND2X30CALM was also performed). The time series of the entire episode are presented in Figure 23 - Figure **26**. It appears that the statistics for the whole 2-17 Nov 2008 episode are somewhat worse than the statistics for just the test period, particularly for the temperature statistics during 2-5 Nov, 13-14 Nov, and 17-18 Nov. These three periods of greater-than-typical temperature RMSE scores are actually characterized by negative temperature biases, and meteorologically are characterized by extensive cloudiness and frequent reports of snow. Failure of the model to properly represent these events and the cloudiness in particular could explain the negative temperature biases. The periods of coldest temperatures adjacent to these events have positive temperature biases at these stations, but these are generally of the order of 2 °C or less. The overall three-station temperature bias for the whole episode is negative (-0.9 °C), and the overall temperature RMSE of 2.4 °C is comparable to what was obtained in the RARE project. The overall wind speed bias for the whole Nov 2008 episode for the three METAR stations is almost exactly the same as it is for just the test period (+1.0 m s^{-1}). The overall wind direction MAE of 41 degrees for these stations is slightly better than what we have observed in SBLs over central Pennsylvania using unfiltered wind data. These results give us confidence that our general model configuration is performing as intended, though possibilities for improvement still exist.

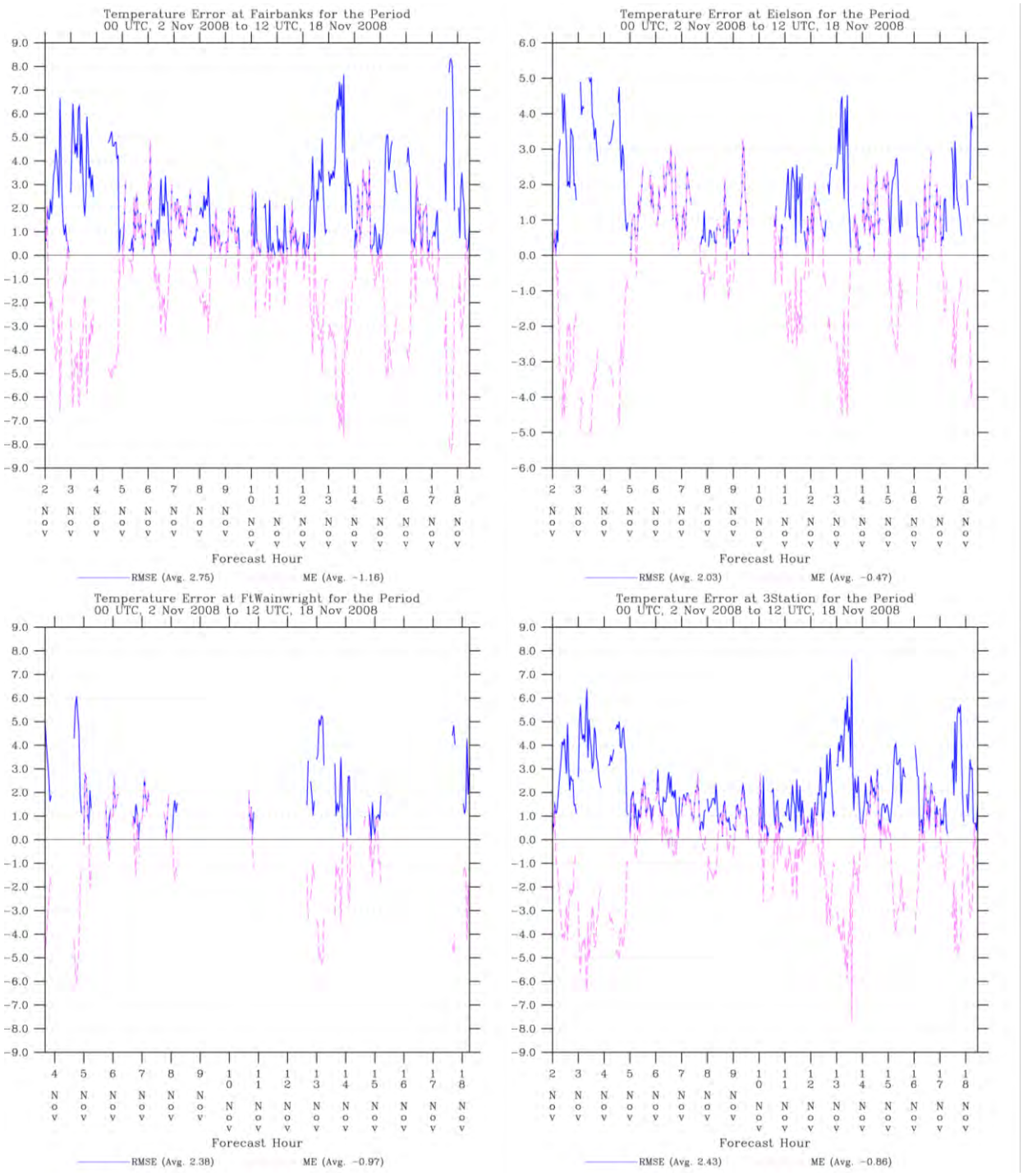


Figure 23: Temperature statistics for experiment TWIND2X30 over the entire 00 UTC 2 Nov 2008 – 12 UTC 18 Nov 2008 test episode at the local METAR surface stations.

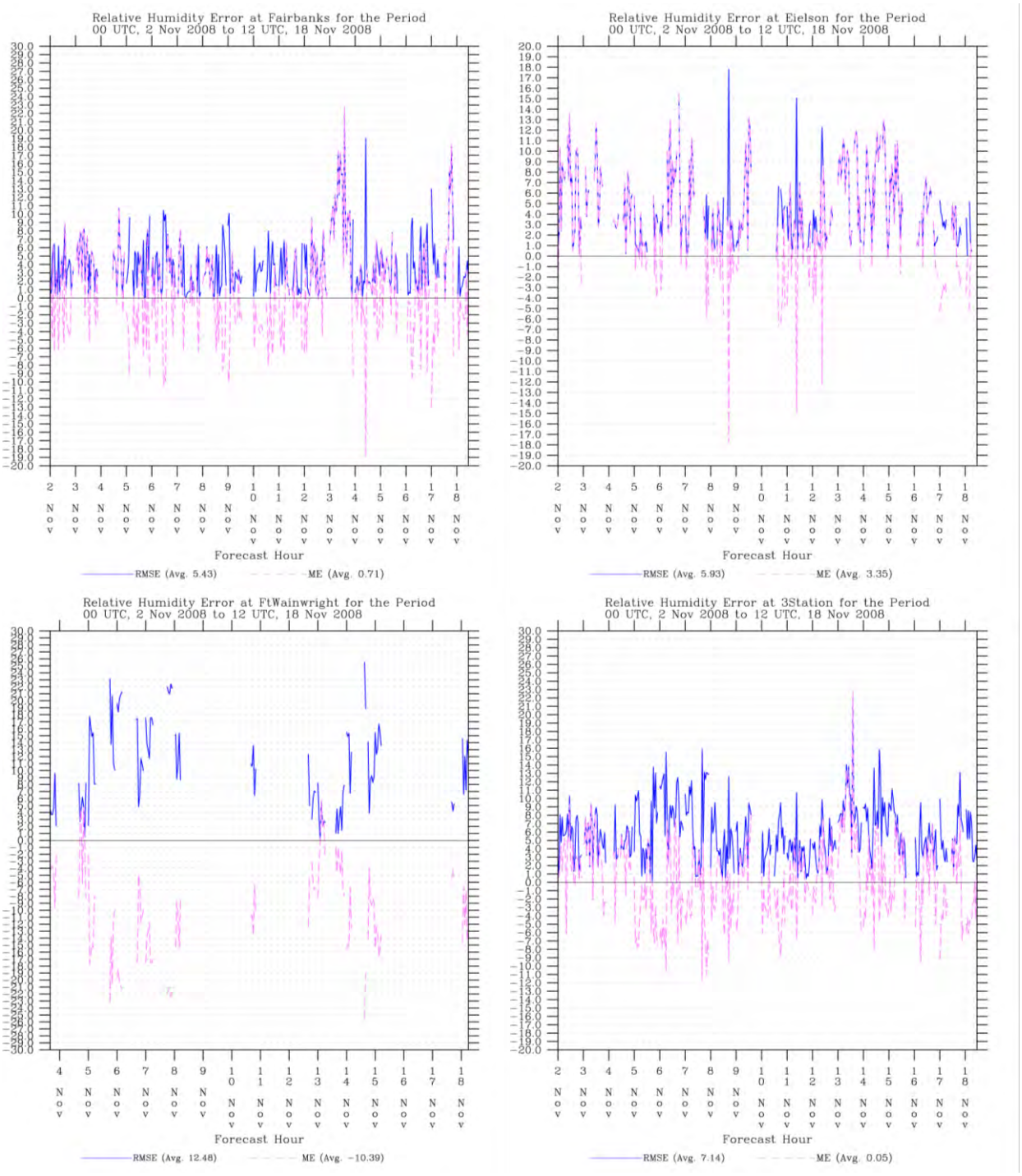


Figure 24: Same as Figure 23, but showing relative humidity statistics.

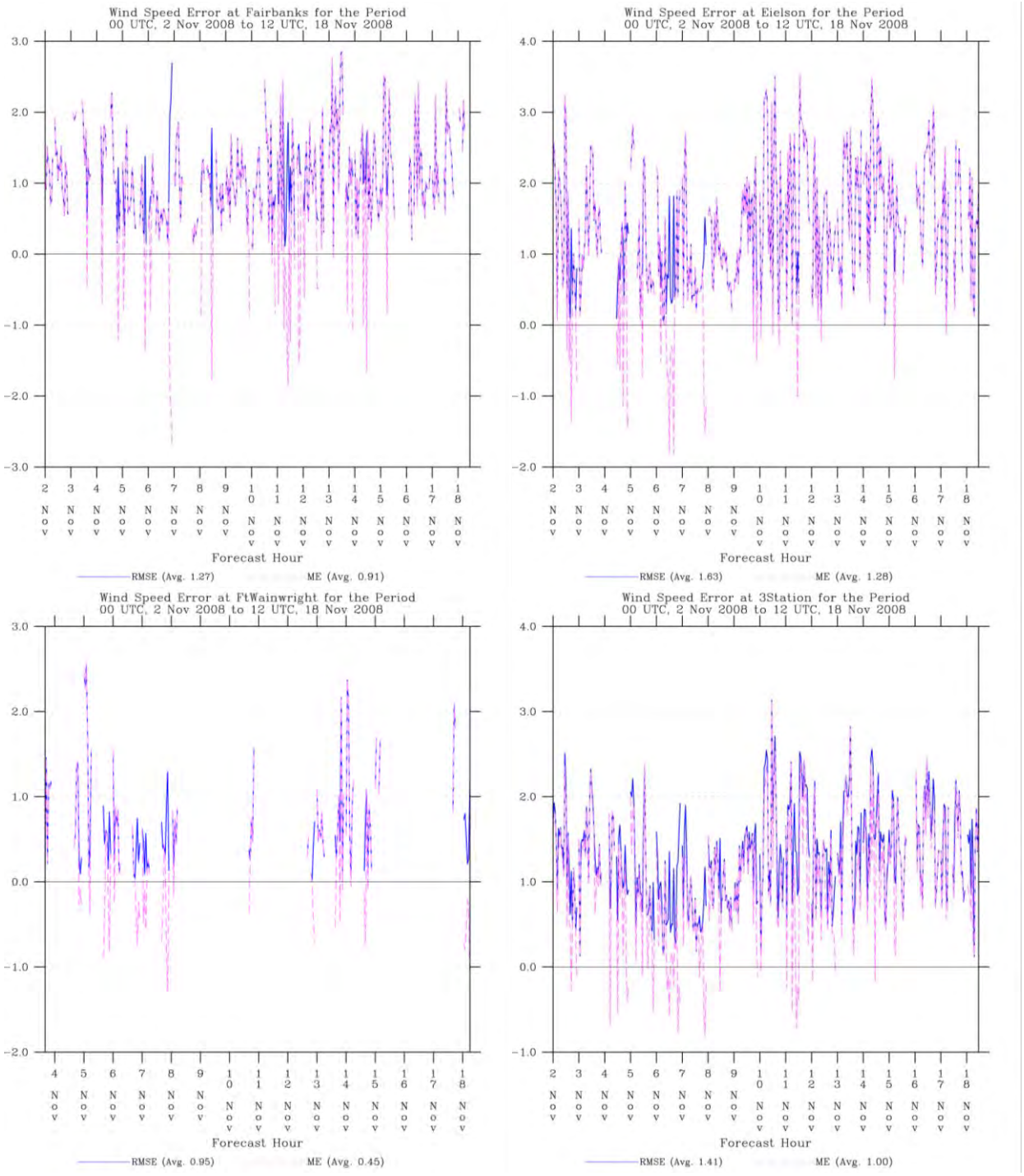


Figure 25: Same as Figure 23, but showing wind speed statistics.

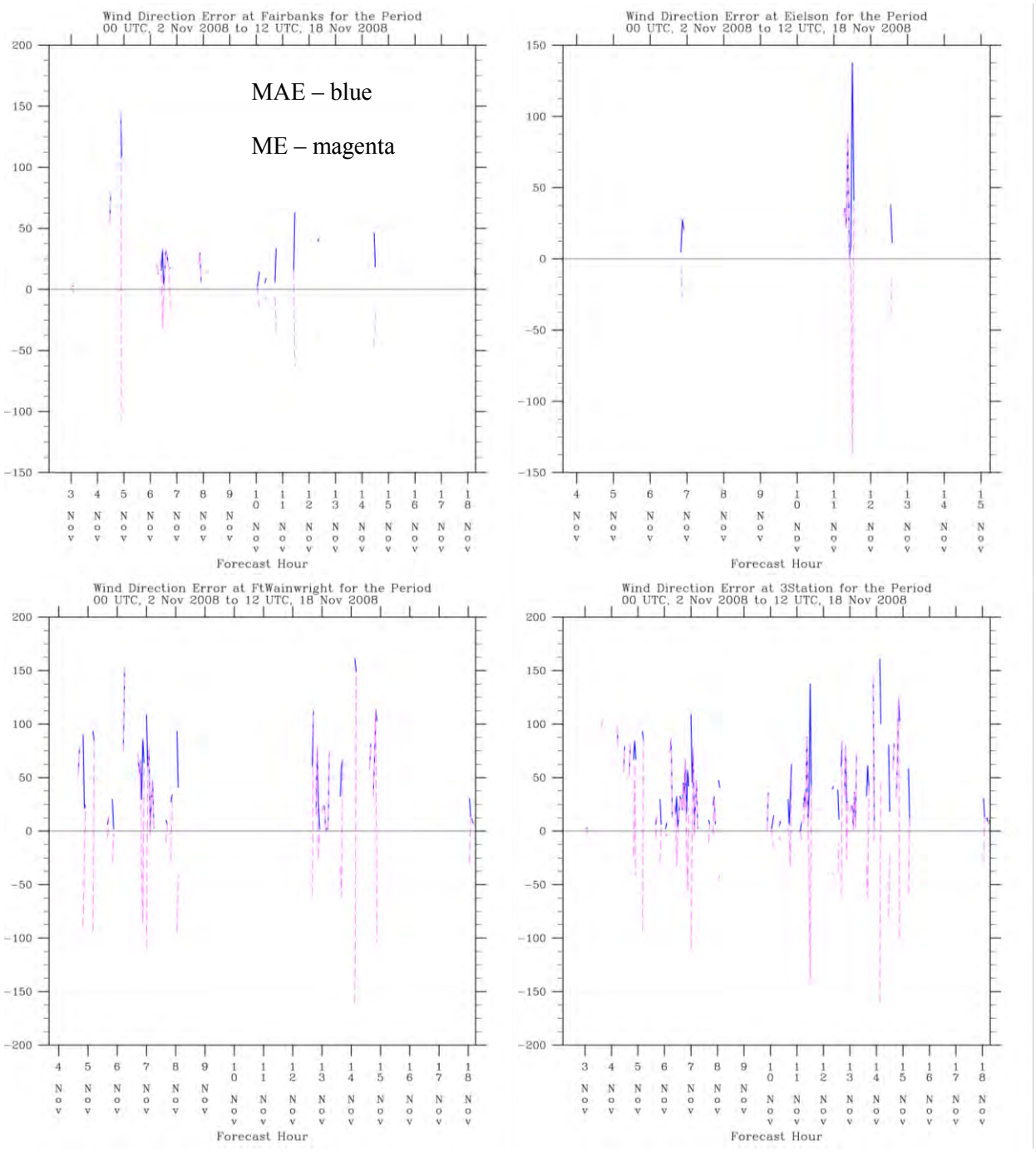


Figure 26: Same as Figure 23, but showing wind direction statistics.

For reference, a comparison between the statistics for the TWIND2X30CALM and TWIND2X30 model configurations for the entire November episode are presented in Table 8. Essentially, the same tendencies found for the November test period apply to the entire November episode as a whole. The superior configuration for temperature depends on statistic and station, and in all cases the sensitivity to calm wind inclusion is never more than about 0.15 °C. Positive wind speed biases are reduced by the inclusion of calms by on the order of 0.1 m s^{-1} for Fairbanks and Eielson, but are actually increased at Ft. Wainwright. Again, the one substantial sensitivity is in wind direction error, for which TWIND2X30 has the better performance.

Finally, detailed time series of the statistics and modeled and observed values of surface meteorological variables, for both METAR and non-METAR stations, are presented in Appendix A for the TWIND2X30 simulation of the November episode that was provided to ADEC.

Table 8: Same as Table 7, but over entire November episode.

Temperature (°C)	TWIND2X30CALM RMSE (MAE for wind direction)	TWIND2X30 RMSE (MAE for wind direction)	TWIND2X30CALM Bias	TWIND2X30 Bias
Fairbanks	2.64	2.75	-1.30	-1.16
Eielson AFB	2.03	2.03	-0.46	-0.47
Ft. Wainwright	2.44	2.38	-0.94	-0.97
Three Stations	2.38	2.43	-0.92	-0.86
Relative Humidity (%)				
Fairbanks	5.49	5.43	0.75	0.71
Eielson AFB	6.01	5.93	3.42	3.35
Ft. Wainwright	12.39	12.48	-10.40	-10.39
Three Stations	7.17	7.14	0.10	0.05
Wind Speed (m s^{-1})				
Fairbanks	1.22	1.27	0.84	0.91
Eielson AFB	1.51	1.63	1.16	1.28
Ft. Wainwright	1.00	0.95	0.49	0.45
Three Stations	1.33	1.41	0.93	1.00
Wind Direction (degrees)				
Fairbanks	46.6	32.8	6.5	6.1
Eielson AFB	45.7	38.6	22.0	18.2
Ft. Wainwright	69.7	50.8	17.1	17.9
Three Stations	55.7	41.3	14.2	13.6

6. JAN-FEB 2008 EPISODE

The episode from 23 Jan – 12 Feb 2008 was re-simulated using the final model setup used for the 2-17 Nov 2008 episode (i.e., model configuration TWIND2X30, using the supplemental surface stations and enhanced vertical resolution in data assimilation). As mentioned previously, the Jan-Feb 2008 episode was considerably colder than the Nov 2008 case, with an extended period of temperatures reaching -35°C (see Figure 27**)**. A comparison between the METAR station statistics for the TWIND2X30 re-simulation with the statistics from the original RARE project simulation is shown in Table 9. Generally the difference between the re-simulated and original statistics were slight for temperature, wind speed, and relative humidity (although at Ft. Wainwright the temperature RMSE increased by 0.5 °C in the re-simulated case). Wind direction errors were substantially reduced in the re-simulated Jan – Feb 2008 episode, though, because in the original RARE configuration there was no assimilation of any surface wind observations on the finest domain. It appears that either model configuration has little, if any, overall temperature bias for the Jan-Feb episode. However, this reflects a cancellation between periods of positive temperature bias (generally the coldest temperature episodes) and periods of negative temperature bias (generally before the coldest episodes, often when precipitation is occurring).

A comparison of the METAR statistics between the TWIND2X30 versions of the Nov 2008 and Jan-Feb 2008 episodes (Table 10) shows that the TWIND2X30 version of the Jan-Feb 2008 episode arguably has better statistics than the Nov 2008 episode, despite the more extreme cold present in the former. However, the more negative temperature bias in the Nov 2008 versus the Jan-Feb 2008 episode is consistent with the relative absence of extreme cold periods in Nov 2008 and the configurations general tendency to have a negative temperature bias in milder winter conditions for the Fairbanks region. While the model tends to be too warm during the periods of the coldest temperatures, the coldest temperature periods also tend to be of short duration.

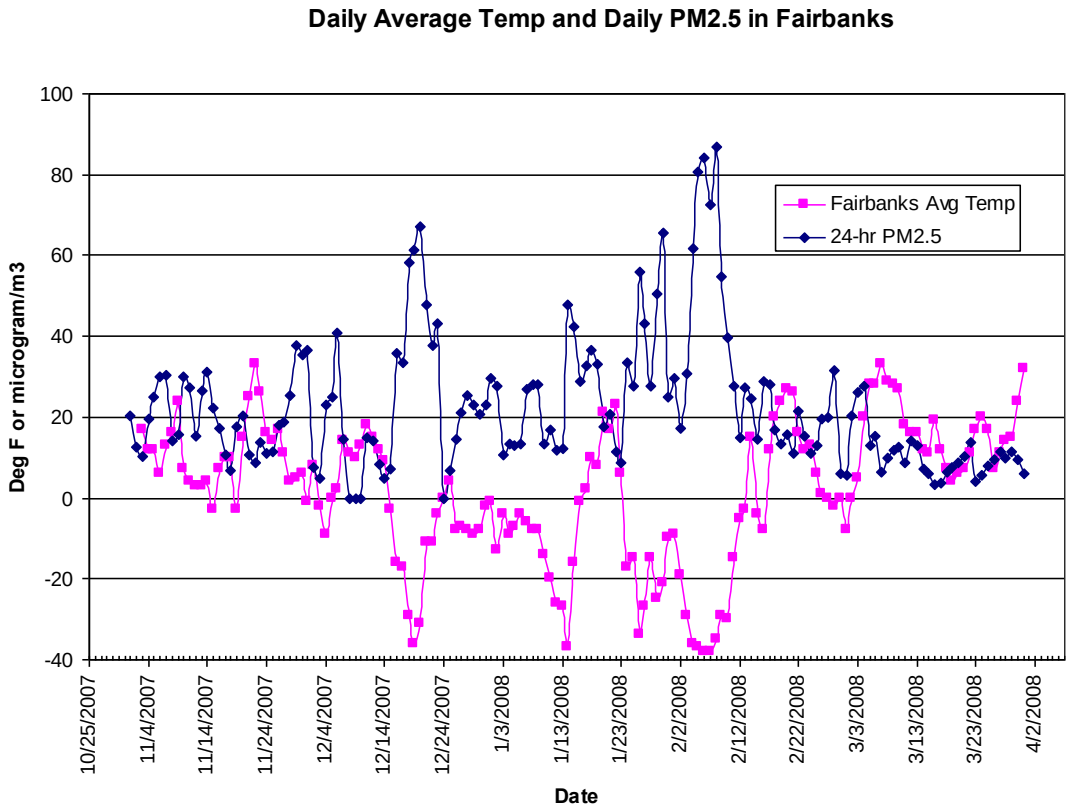


Figure 27: Measured daily average temperature (Fahrenheit) and 24-hr PM2.5 concentration in Fairbanks region during 2007-2008 winter season. Courtesy Robert Dulla, Sierra Research.

Temperatures for some of the local non-METAR stations are shown in Figure 28. Although the data record is a bit erratic, it is apparent that for the coldest period between 00 UTC on the 4th and 00 UTC on the 9th, the temperatures in Woodsmoke can be 10 °C or more colder than those in Two Rivers, which in turn can be 10 °C colder than those on Ester Dome. While the model surface temperature forecasts are not perfect (daytime temperatures at Two Rivers in particular seem to be too warm) the model configuration is certainly capturing a large part of the temperature variability and magnitude across these stations

Time series of statistics for the METAR stations for the rerun of the Jan – Feb 2008 case are shown in Figure 29 – Figure **32**. While there are significant gaps in the data, it seems clear that the period from about 28 January through 31 January, as well as from about 4 – 11 February, exhibit positive temperature bias, corresponding to periods of low actual temperatures, while other periods tend to have a negative temperature bias (Figure 29). The largest temperature RMSE values for the positive and negative temperature bias periods are roughly comparable (exceeding 4 °C at times, but usually less than 3 °C). Wind speed biases tend to be positive

(Figure 31), but wind speed RMSE values seem to vary little on average between the warm and cold periods. These results are broadly consistent with those from the RARE project.

Appendix B contains more detailed time series of the statistics and modeled and observed surface field values for the Jan-Feb 2008 episode.

Table 9: Comparison of statistics for Jan-Feb 2008 between RARE configuration and TWIND2X30 configuration.

Temperature (°C)	Jan-Feb RARE RMSE (MAE for wind direction)	Jan-Feb RARE Bias	Jan-Feb TWIND2X30 RMSE (MAE for wind direction)	Jan-Feb TWIND2X30 Bias
Fairbanks	2.20	-0.03	2.22	-0.12
Eielson AFB	1.81	-0.07	2.05	-0.23
Ft. Wainwright	1.33	0.23	1.83	0.51
Three Stations	1.87	0.02	2.07	0.00
Relative Humidity (%)				
Fairbanks	8.07	2.74	8.15	2.55
Eielson AFB	11.45	-1.38	12.45	-2.49
Ft. Wainwright	16.85	-13.87	17.09	-13.67
Three Stations	11.98	-2.89	12.44	-3.32
Wind Speed (m s^{-1})				
Fairbanks	1.58	0.87	1.51	0.86
Eielson AFB	1.17	0.69	1.18	0.69
Ft. Wainwright	1.31	0.32	1.21	0.25
Three Stations	1.38	0.69	1.34	0.68
Wind Direction (degrees)				
Fairbanks	43.6	0.3	21.6	-5.6
Eielson AFB	55.7	-19.4	26.0	-10.3
Ft. Wainwright	66.4	18.9	40.3	3.4
Three Stations	54.6	1.9	29.2	-3.6

Table 10: Comparison of statistics for Nov 2008 and Jan-Feb 2008 episodes for TWIND2X30 model configuration.

Temperature (°C)	Nov 2008 RMSE (MAE for wind direction)	Nov 2008 Bias	Jan-Feb 2008 RMSE (MAE for wind direction)	Jan-Feb 2008 Bias
Fairbanks	2.75	-1.16	2.22	-0.12
Eielson AFB	2.03	-0.47	2.05	-0.23
Ft. Wainwright	2.38	-0.97	1.83	0.51
Three Stations	2.43	-0.86	2.07	0.00
Relative Humidity (%)				
Fairbanks	5.43	0.71	8.15	2.55
Eielson AFB	5.93	3.35	12.45	-2.49
Ft. Wainwright	12.48	-10.39	17.09	-13.67
Three Stations	7.14	0.05	12.44	-3.32
Wind Speed (m s^{-1})				
Fairbanks	1.27	0.91	1.51	0.86
Eielson AFB	1.63	1.28	1.18	0.69
Ft. Wainwright	0.95	0.45	1.21	0.25
Three Stations	1.41	1.00	1.34	0.68
Wind Direction (degrees)				
Fairbanks	32.8	6.1	21.6	-5.6
Eielson AFB	38.6	18.2	26.0	-10.3
Ft. Wainwright	50.8	17.9	40.3	3.4
Three Stations	41.3	13.6	29.2	-3.6

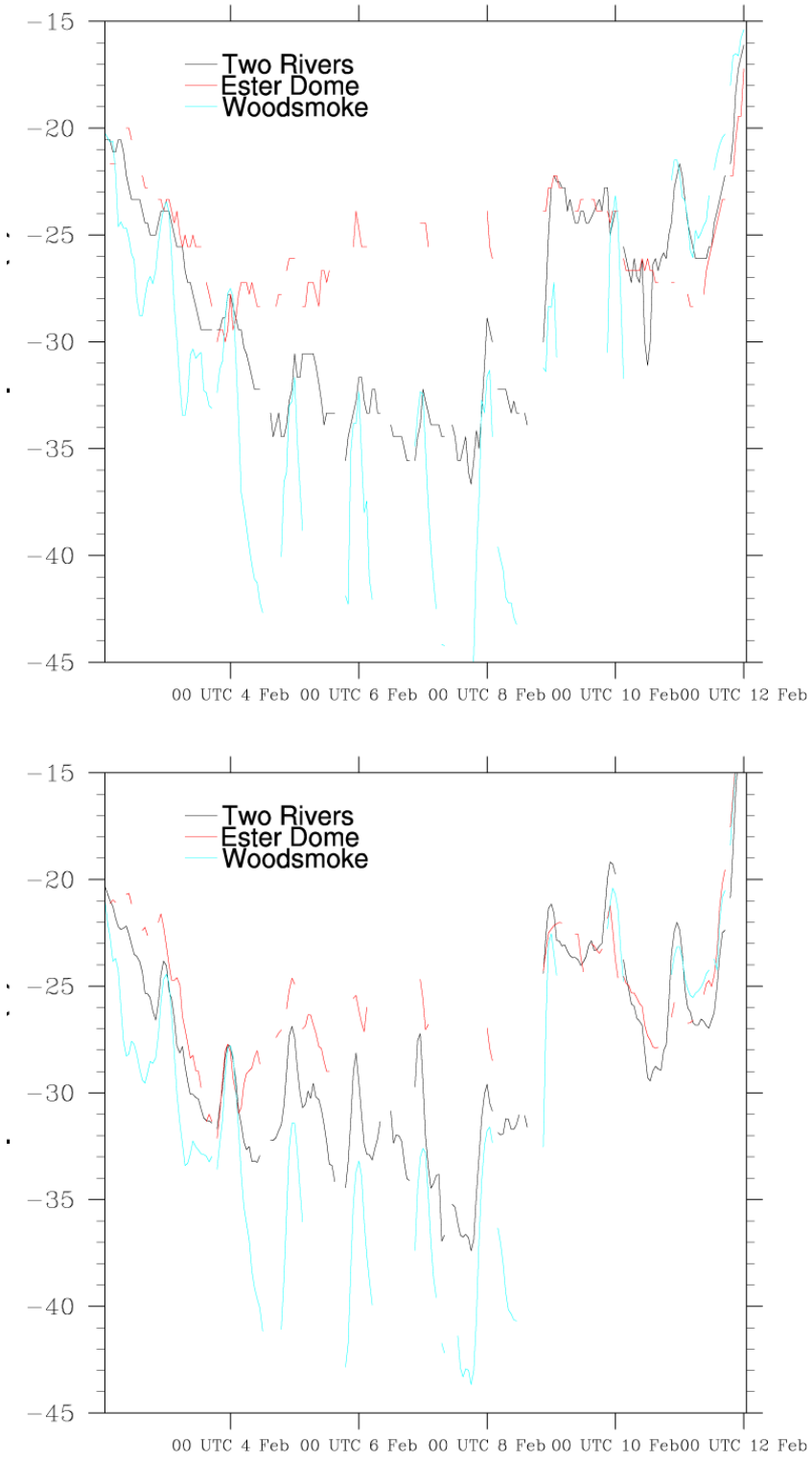


Figure 28: Observed (top) and model (bottom) surface temperatures (degrees Celsius) at non-METAR stations for 00 UTC 3 Feb -- 00 UTC 12 Feb

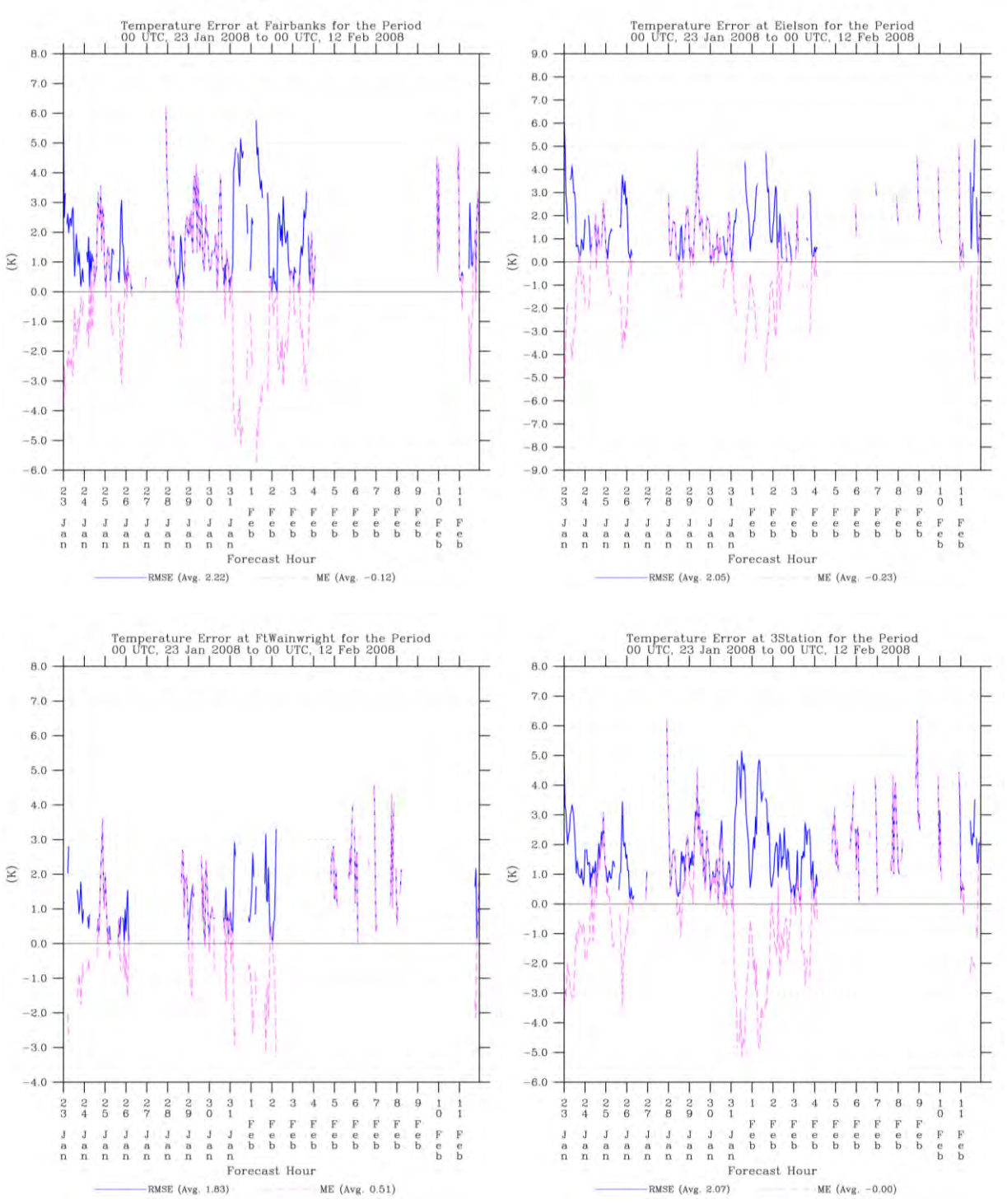


Figure 29: Temperature RMSE and Bias statistics for Jan-Feb 2008 episode at the local METAR surface stations using TWIND2X30 configuration.

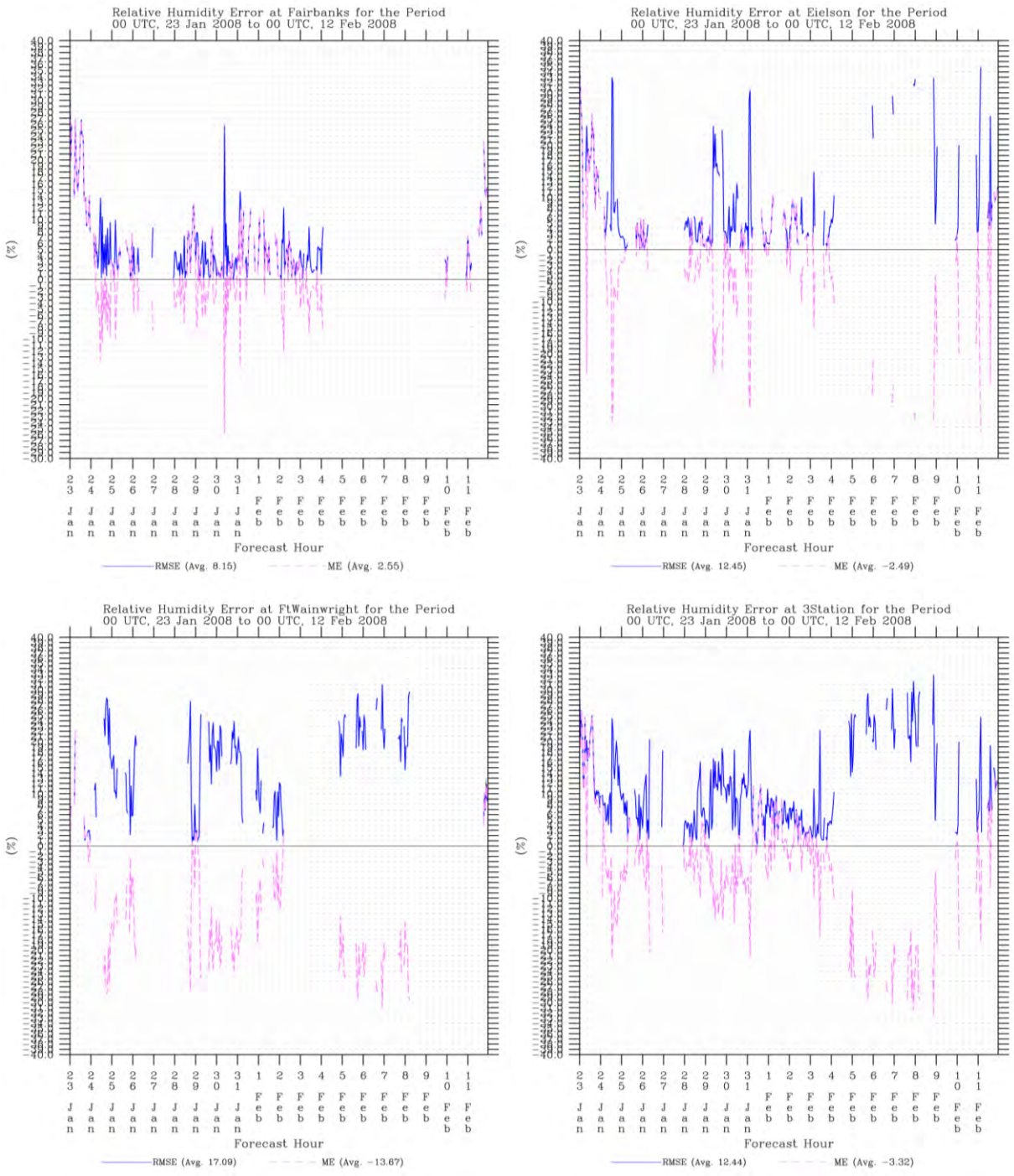


Figure 30: Same as Figure 29, but for relative humidity.

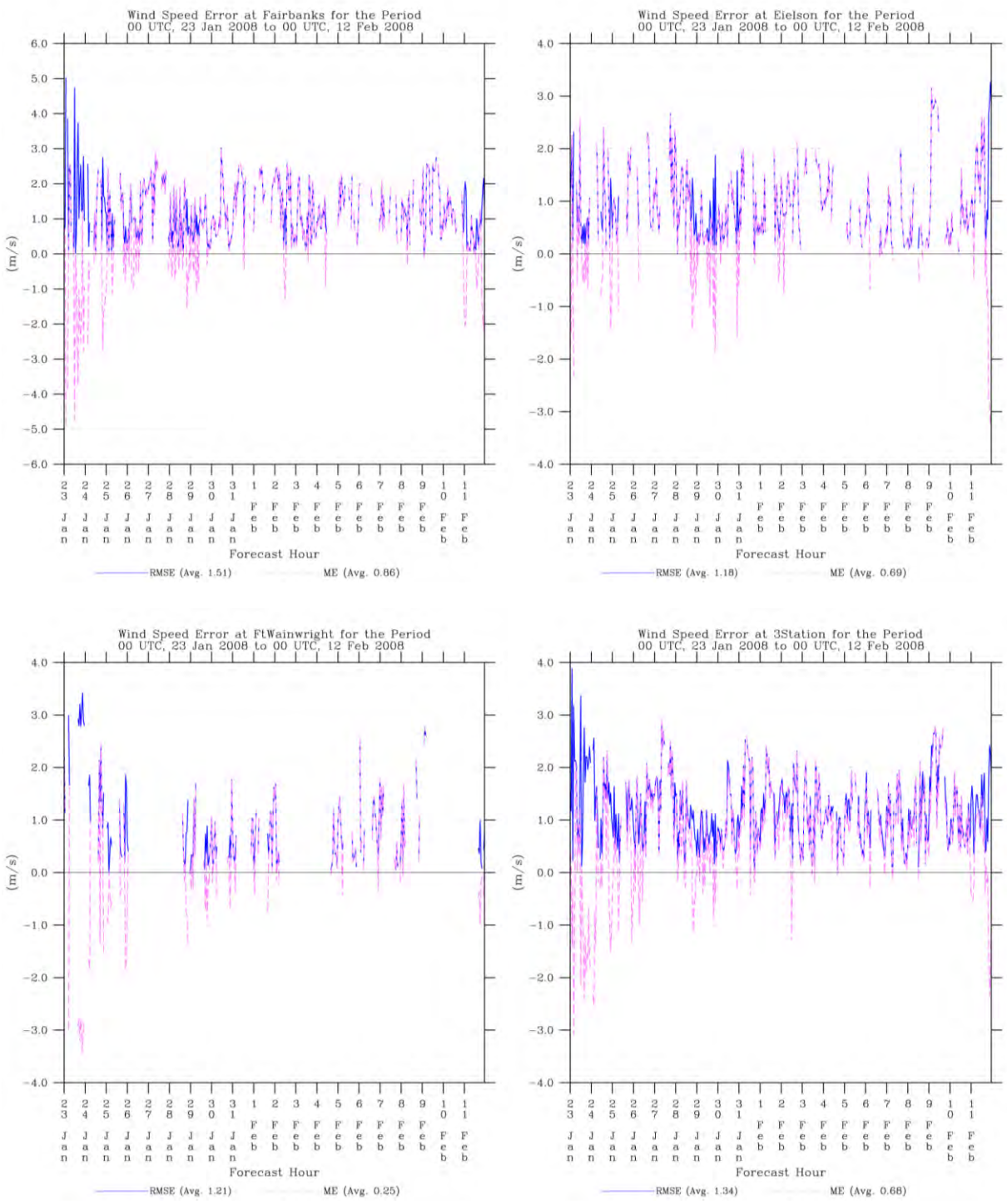


Figure 31: Same as Figure 29, but for wind speed.

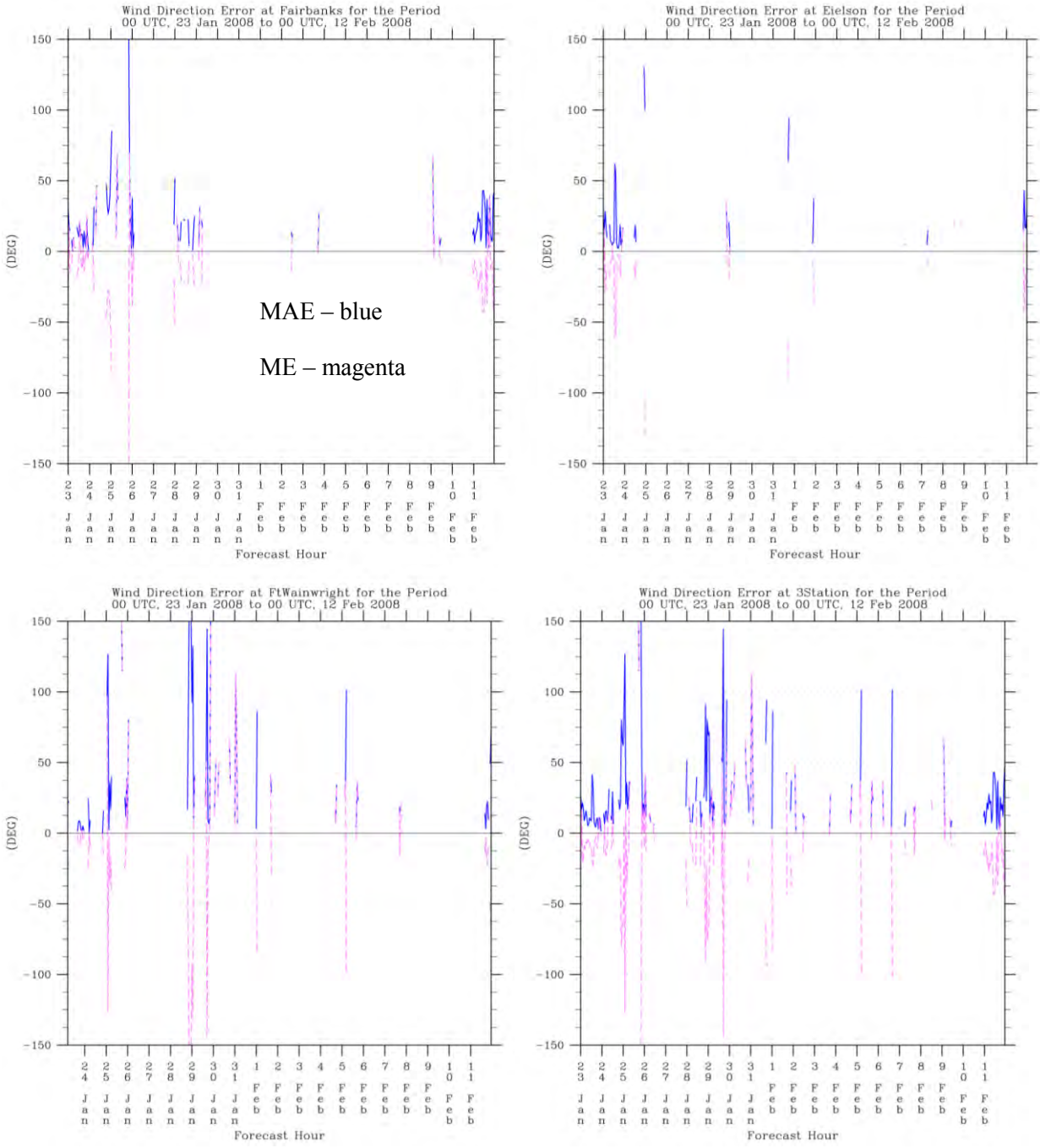


Figure 32: Same as Figure 29, but for wind direction MAE and ME statistics.

7. CONCLUSIONS

An episode extending from 2-17 November 2008 was simulated as part of the State Implementation Plan for the Fairbanks / North Star non-attainment region. The simulations were performed using the WRF-ARW model with essentially the same configuration as that used in the preliminary RARE study. However, initial decisions were made to increase the effective vertical resolution of the data assimilation near the surface, to use observation nudging towards surface wind observations even on the 1.33-km finest grid, and to make use of both standard METAR and non-METAR surface observations that were available for the period. These alterations to the procedure of the RARE study were made because, even though the statistics from that study were reasonably good, the model displayed a warm bias during the coldest, most stagnant conditions from that study, and concurrently the model wind speed bias was consistently positive. It was felt that these modifications would lead to the creation of a dynamic analysis that would be a closer fit to the actual state of the atmosphere.

The November episode was divided into four overlapping simulation segments using the discussed model configuration. A test period from 5-9 November was chosen for model sensitivity tests, including a comparison between the RARE study methodology and the proposed method of enhancing the data assimilation capabilities. Statistics indicated the benefits of the new data assimilation configuration, especially for wind direction. This configuration was then used for all subsequent simulations. However, the statistics also suggested that the model data assimilation was effectively blending the influence of neighboring observations in the Fairbanks region, leading to model simulations that did not possess all of the horizontal variability of the observations. A procedure taken from the RARE study was performed to determine an effective correlation length scale for surface temperature observation innovations; this led to new simulations in which the radius of influence was reduced from 75 km to 30 km, while the strength of the nudging coefficients was doubled. The new configuration (indicated by the label TWIND2X30) was then used to simulate the entire November episode, and generated the atmospheric analysis delivered to ADEC.

A positive wind speed model bias remained during stagnant, cold temperature conditions, though a portion of that bias is an artifact of the threshold of instrument detection, causing observations to frequently report dead calm conditions while model simulations produce non-zero wind speeds near the surface. While one procedure to reduce the positive wind speed bias would be to explicitly nudge towards the calm wind observations, it was found that this led to only minimal reductions in the wind speed bias, and using these reports in nudging had the undesirable effect of creating large increases in wind direction error at nearby stations not reporting dead calm conditions. Therefore, the decision was made to use the default procedure of not making explicit use of calm surface wind observations in the data assimilation procedure.

The Jan-Feb 2008 episode was then re-simulated using the TWIND2X30 configuration. Wind direction statistics for the METAR stations were improved with respect to the original simulations from the RARE project. Other fields did not show much change statistically. While model output at the location of the non-METAR station at Woodsmoke confirmed that the model could produce temperatures (nearly) as cold as observed temperatures around -45 °C, at other locations the model had difficulty producing sufficient cooling, especially if the horizontal resolution was insufficient (e.g., Goldstream Creek).

At the METAR stations, overall temperature bias for both episodes was quite low (less than a degree Celsius), while the temperature RMSE was on average 2 – 2.5 °C, which seemed reasonable given the occasionally extreme meteorological conditions. Wind speed RMSE values seemed to be fairly consistent at 1.3 – 1.4 m s^{-1}, while wind direction MAE values were on the order of 30 – 40 degrees with the TWIND2X30 configuration.

APPENDIX A – Detailed Time-Series Figures of 2-17 November 2008 Episode, for TWIND2X30 Configuration

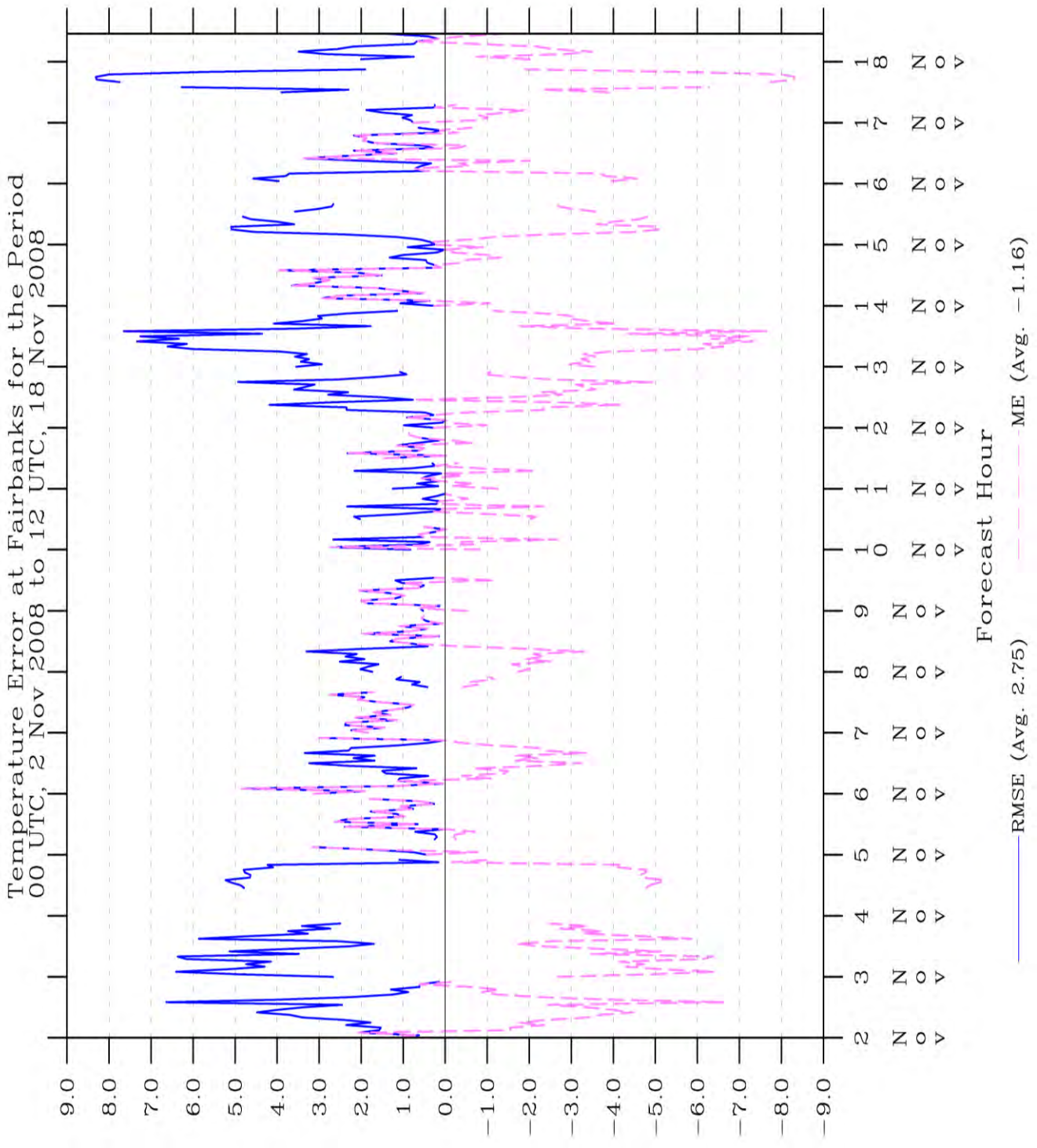


Figure 33: Time series of temperature statistics for Fairbanks in TWIND2X30.

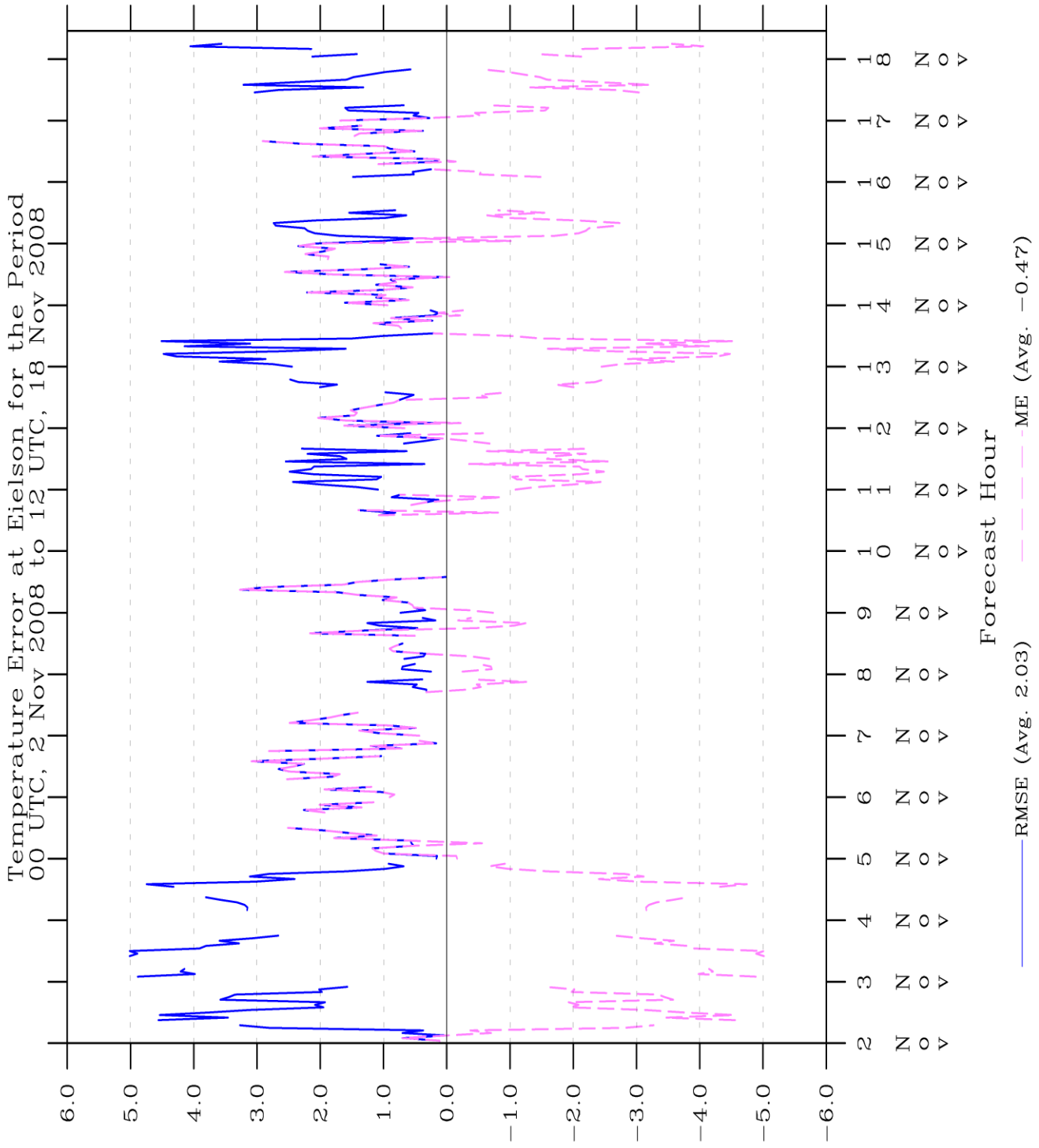


Figure 34: Time series of temperature statistics for Eielson in TWIND2X30.

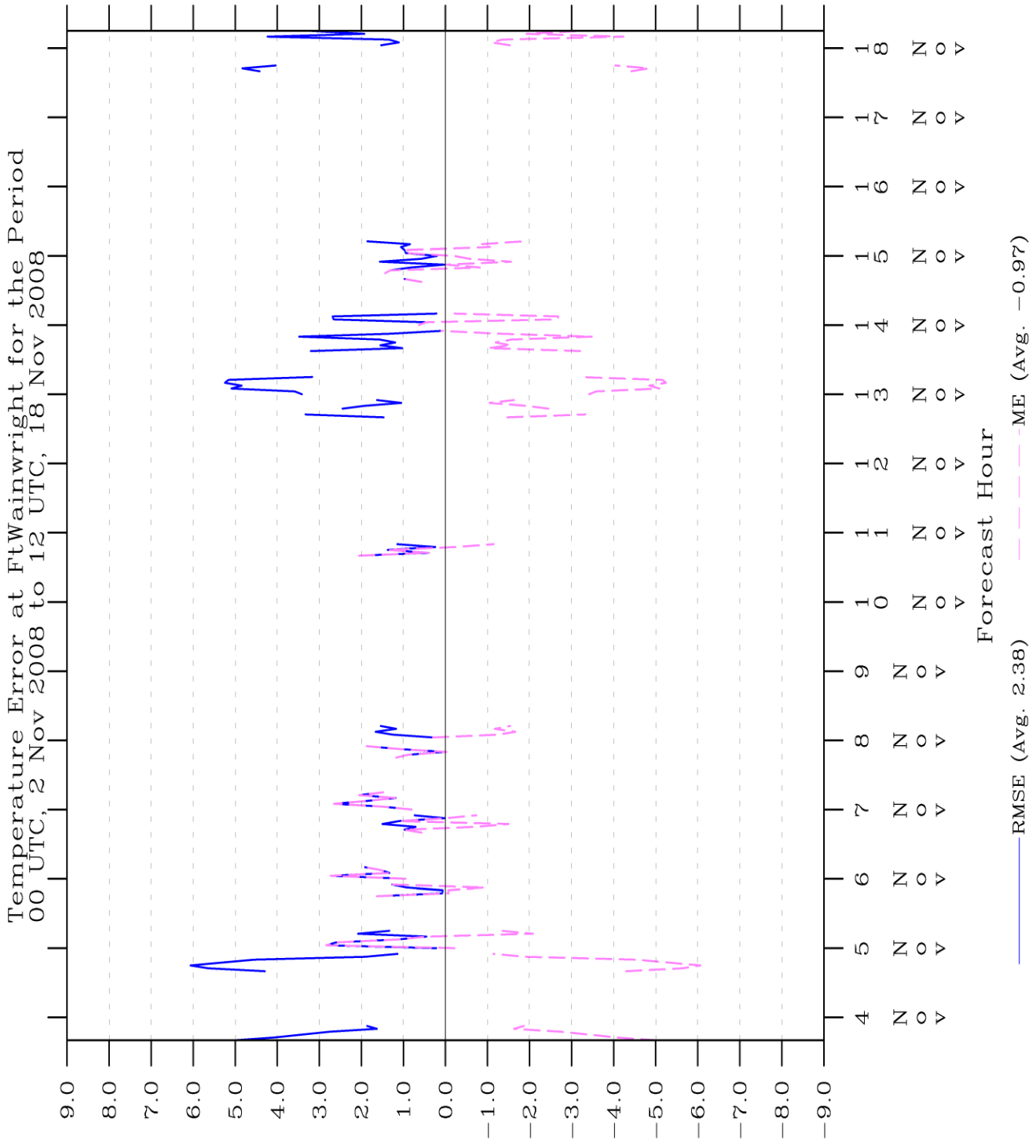


Figure 35: Time series of temperature statistics for Ft. Wainwright in TWIND2X30.

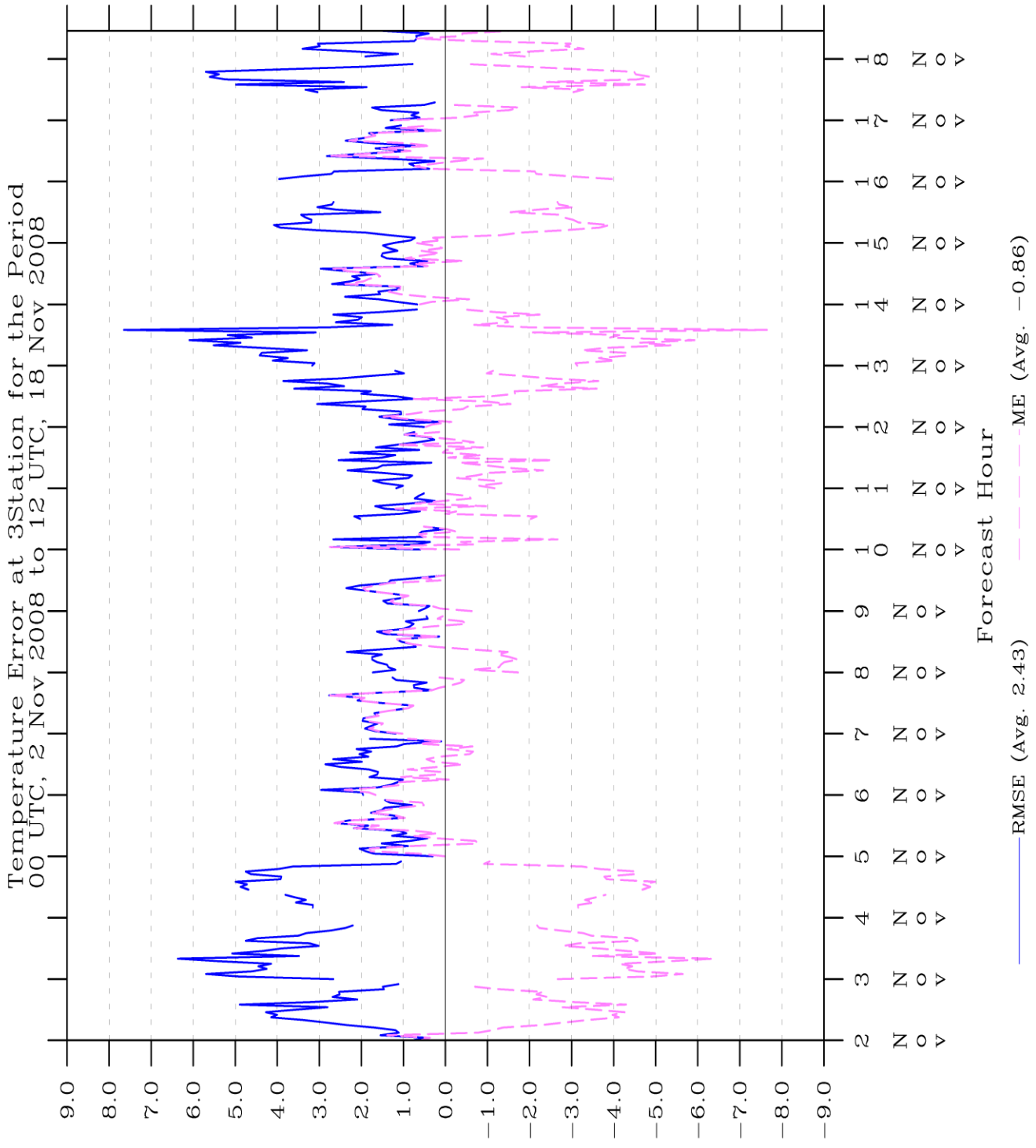


Figure 36: Time series of temperature statistics for all three stations in TWIND2X30.

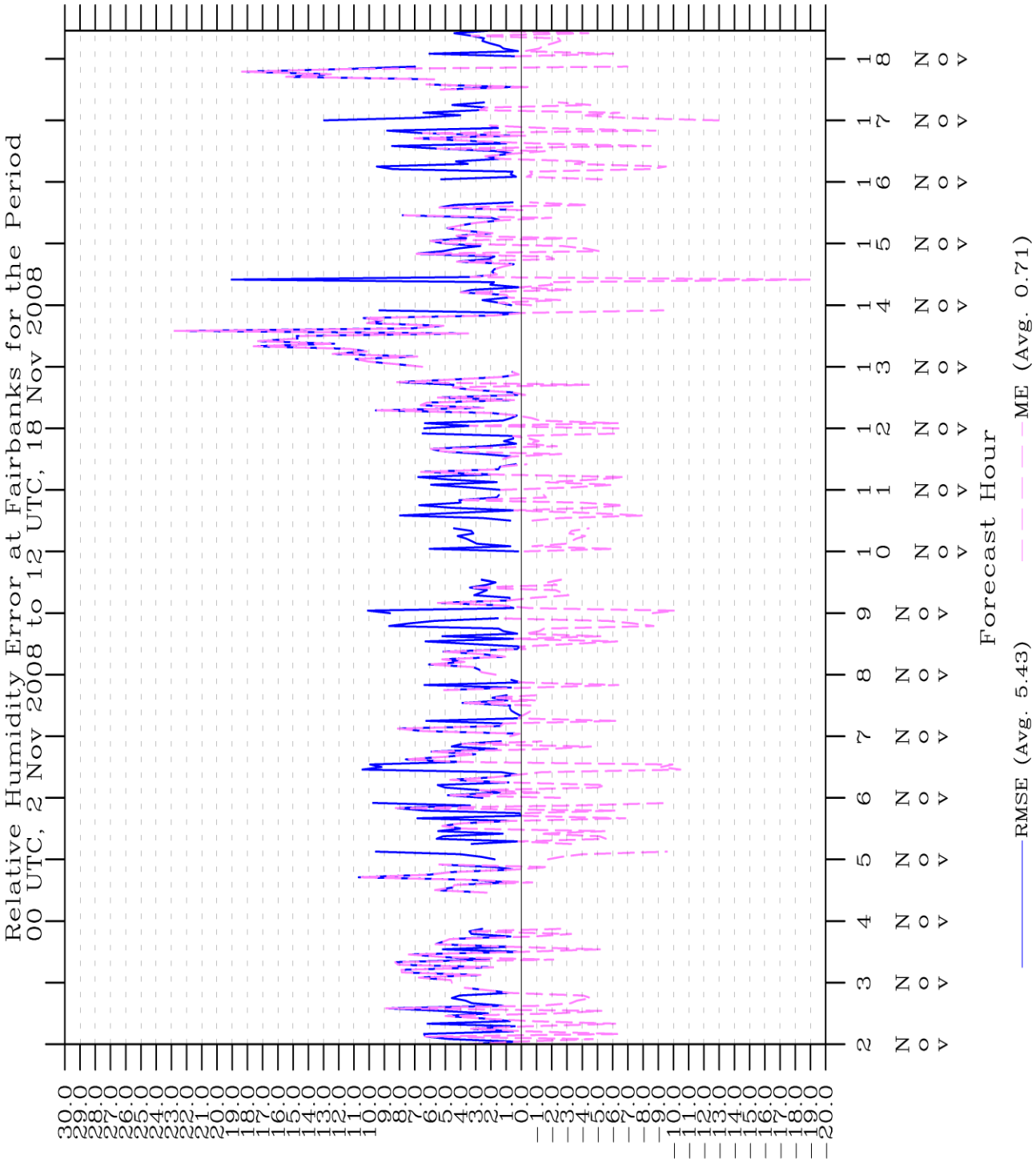


Figure 37: Time series of relative humidity statistics for Fairbanks in TWIND2X30.

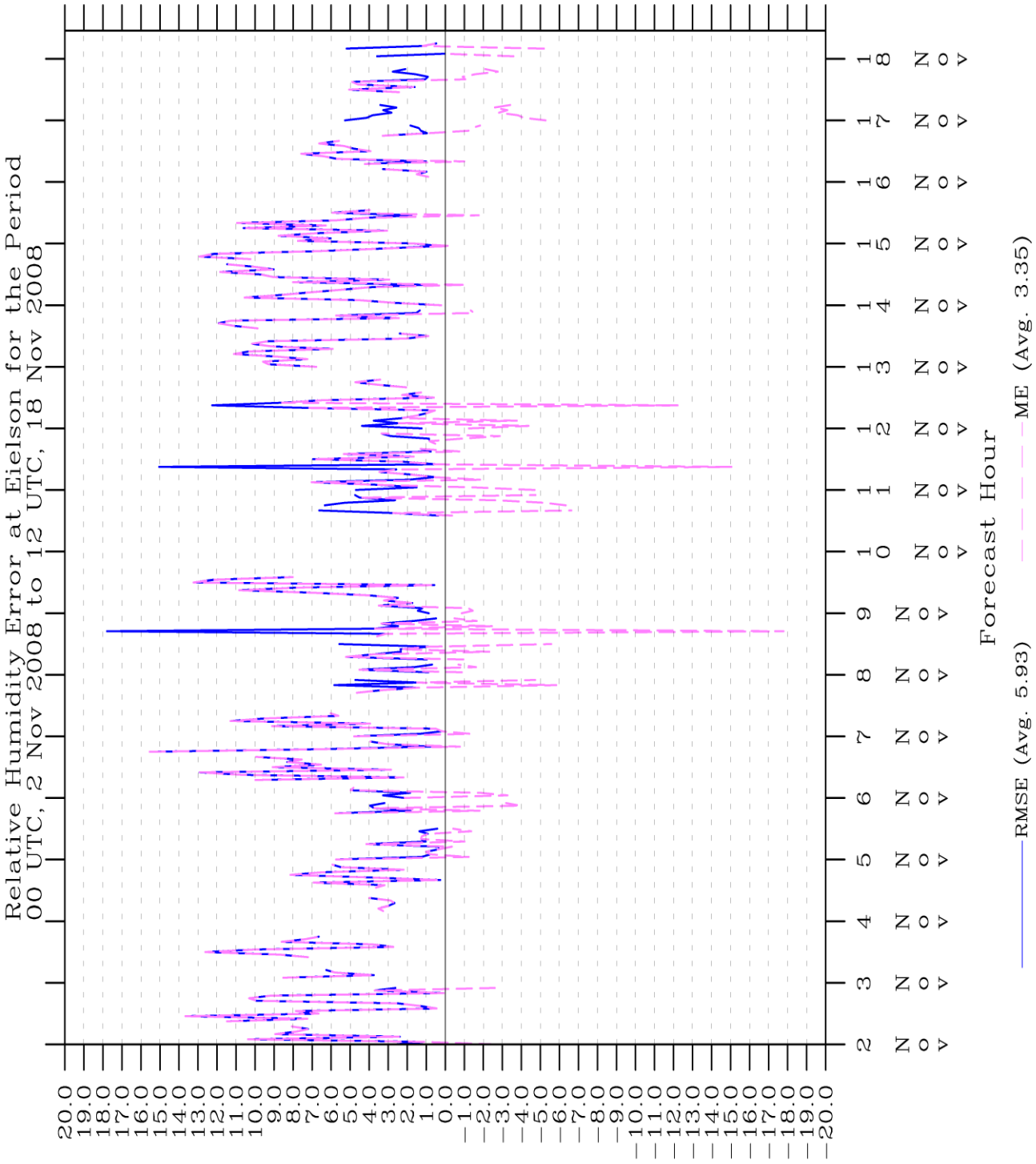


Figure 38: Time series of relative humidity statistics for Eielson in TWIND2X30.

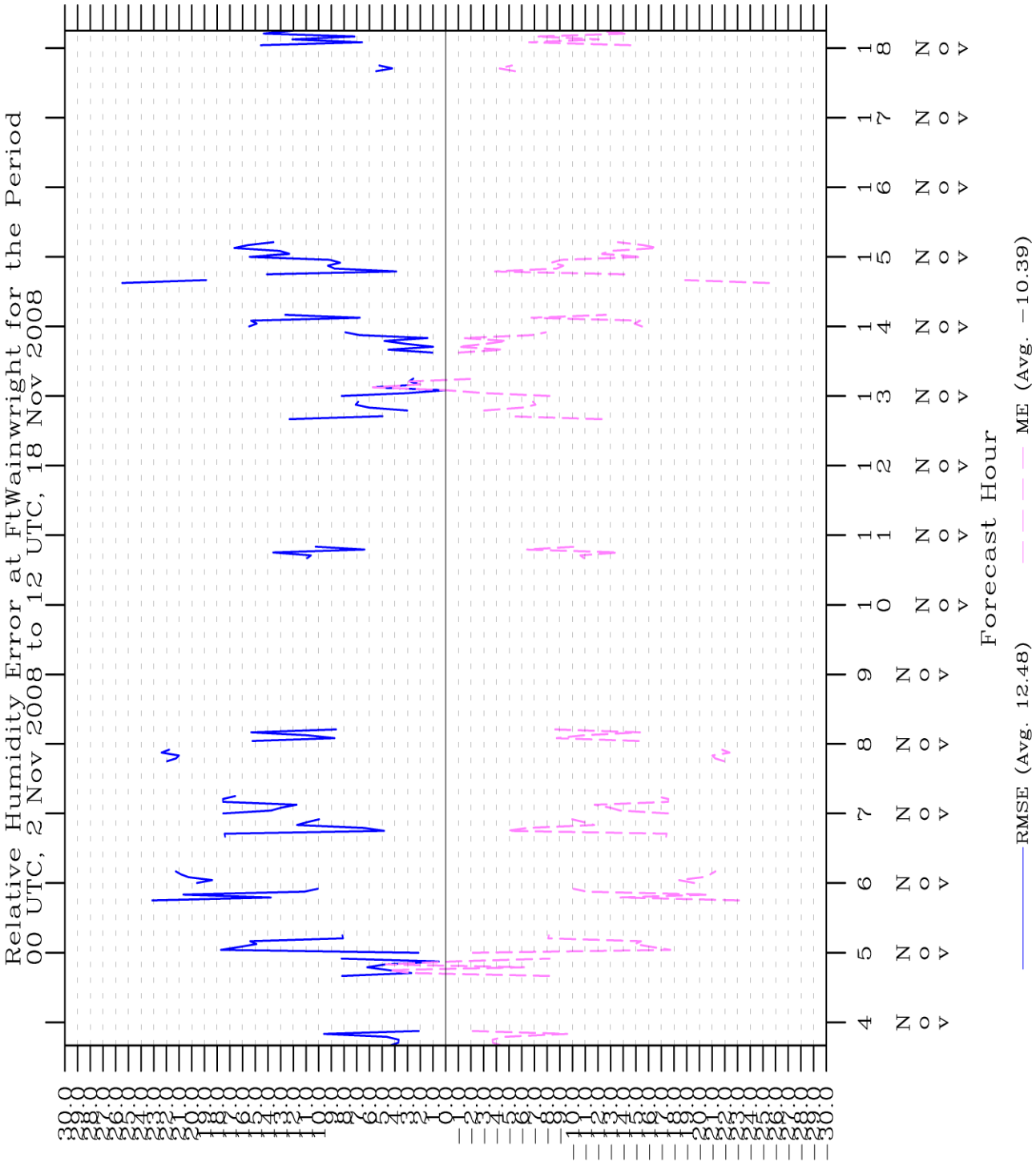


Figure 39: Time series of relative humidity statistics for Ft. Wainwright in TWIND2X30.

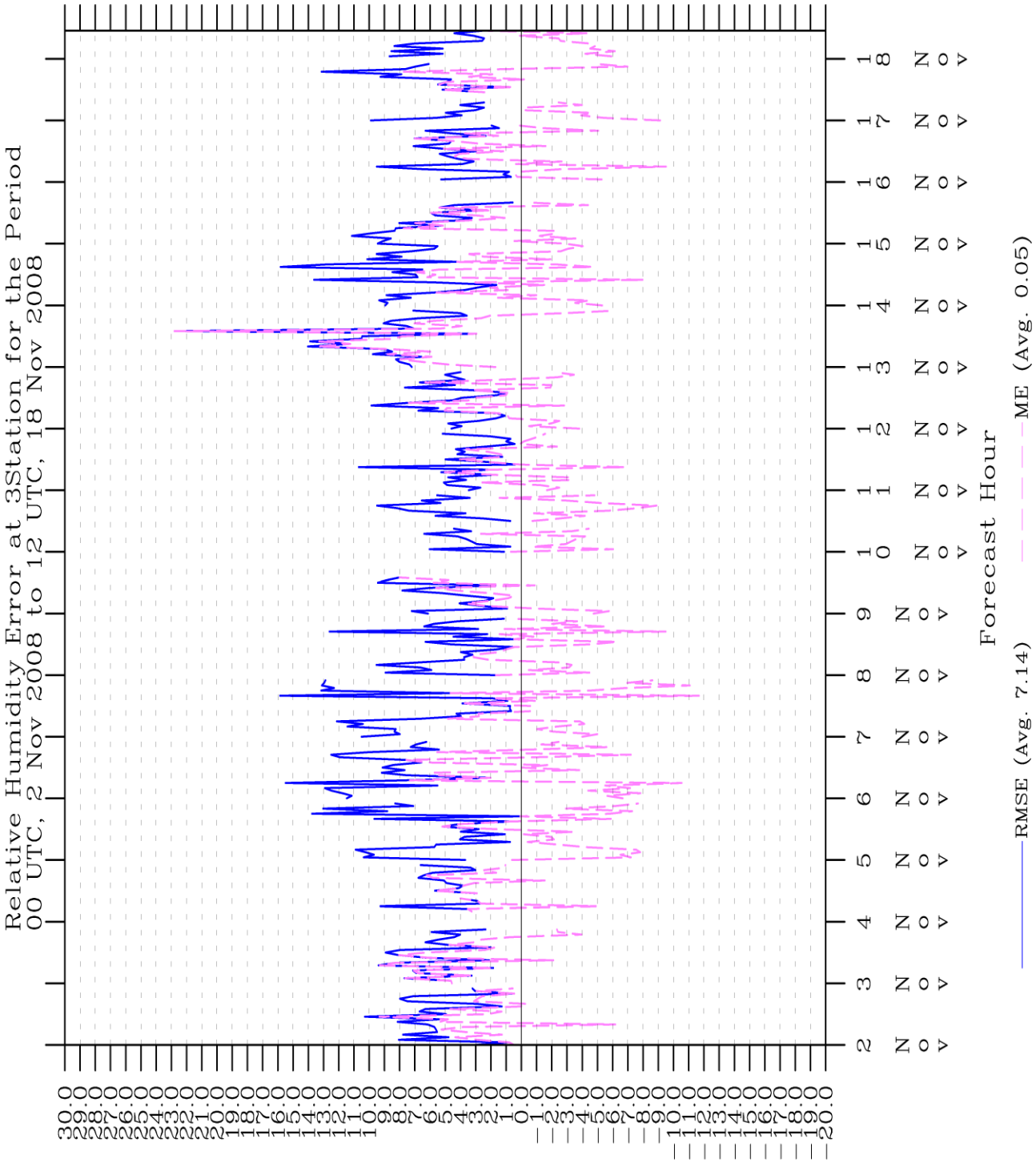


Figure 40: Time series of relative humidity statistics for all three stations in TWIND2X30.

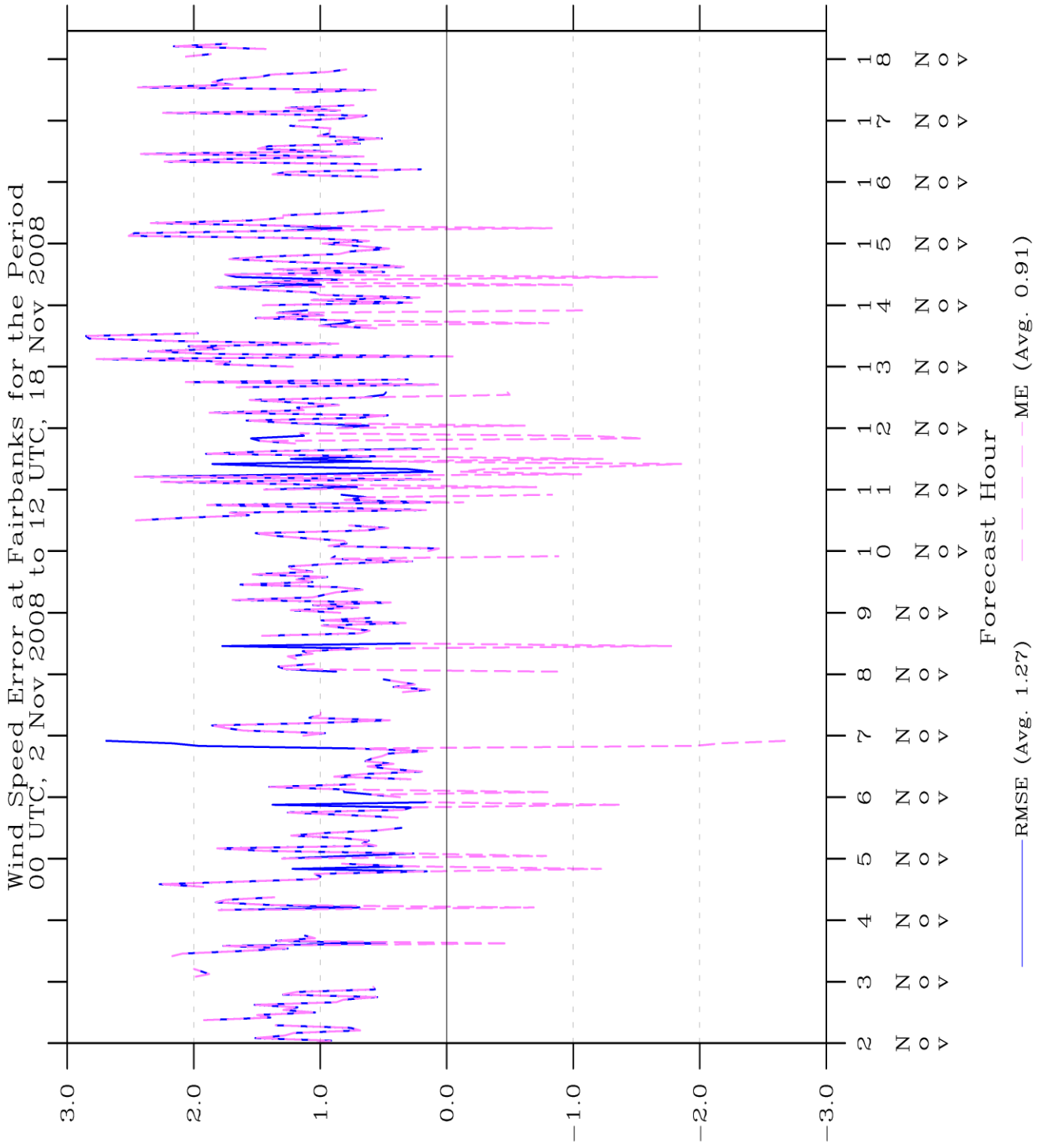


Figure 41: Time series of wind speed statistics for Fairbanks in TWIND2X30.

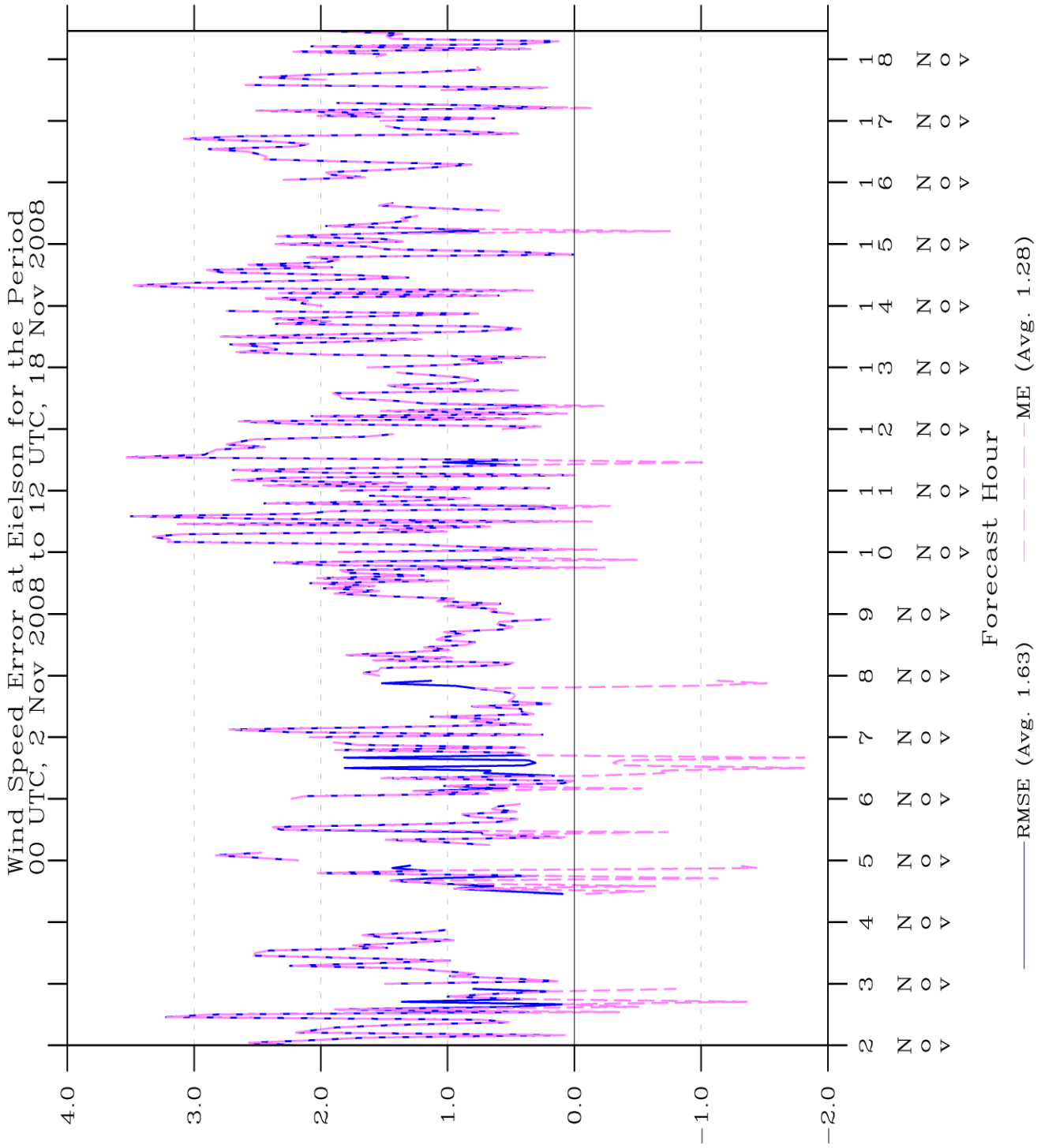


Figure 42: Time series of wind speed statistics for Eielson in TWIND2X30.

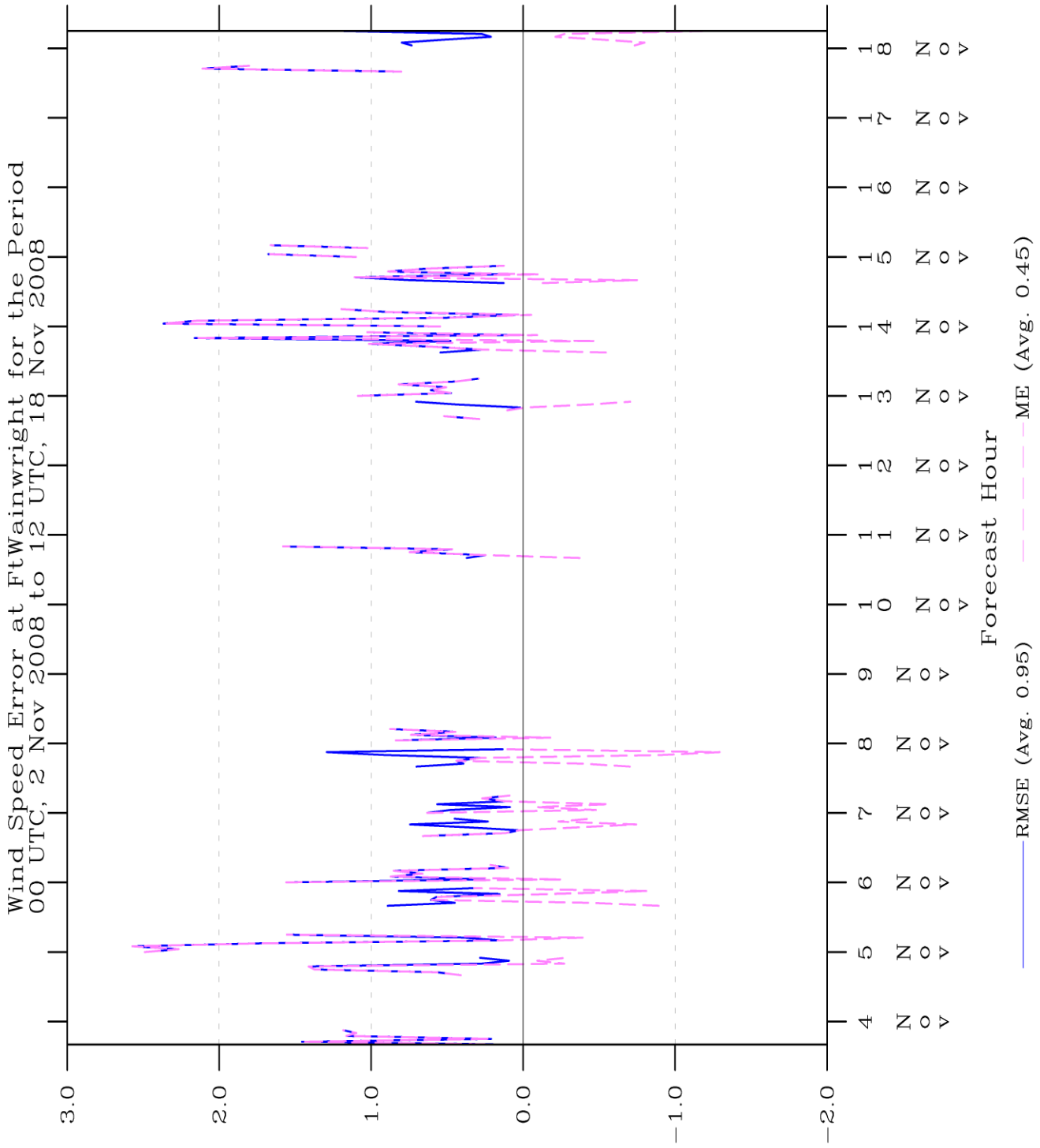


Figure 43: Time series of wind speed statistics for Ft. Wainwright in TWIND2X30.

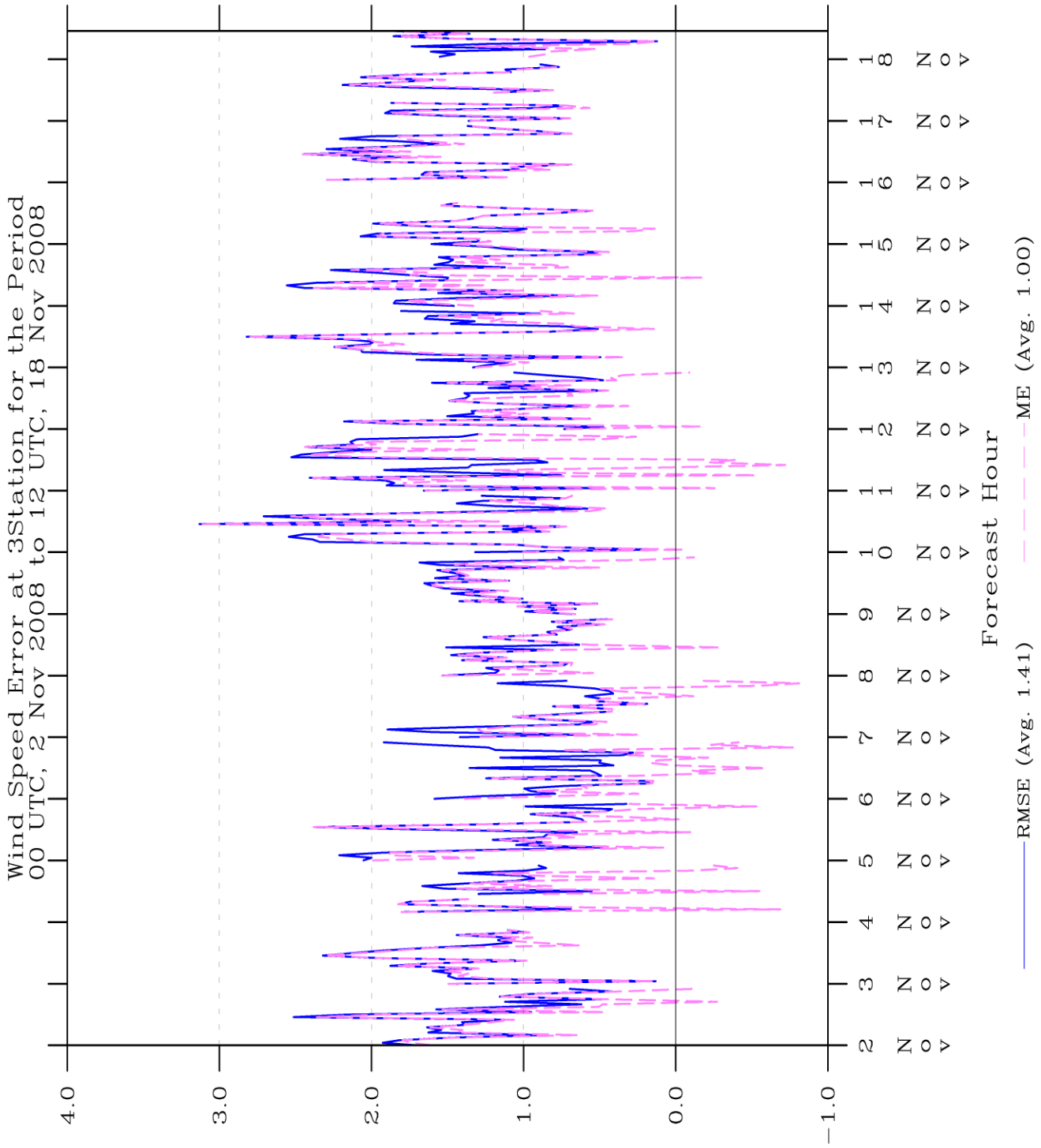


Figure 44: Time series of wind speed statistics for all three stations in TWIND2X30.

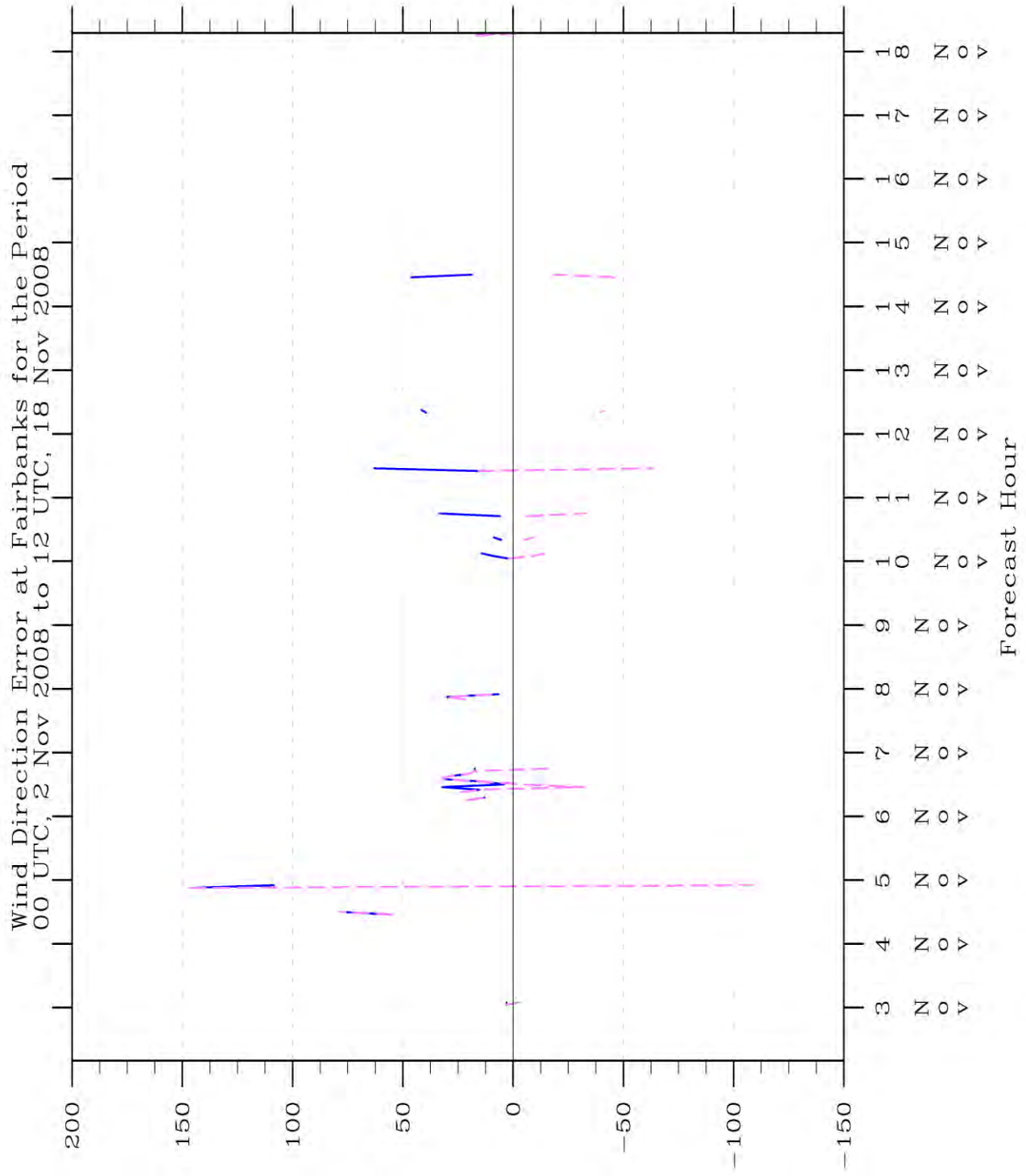


Figure 45: Time series of wind direction mean absolute error (blue) and mean error (magenta) statistics for Fairbanks in TWIND2X30.

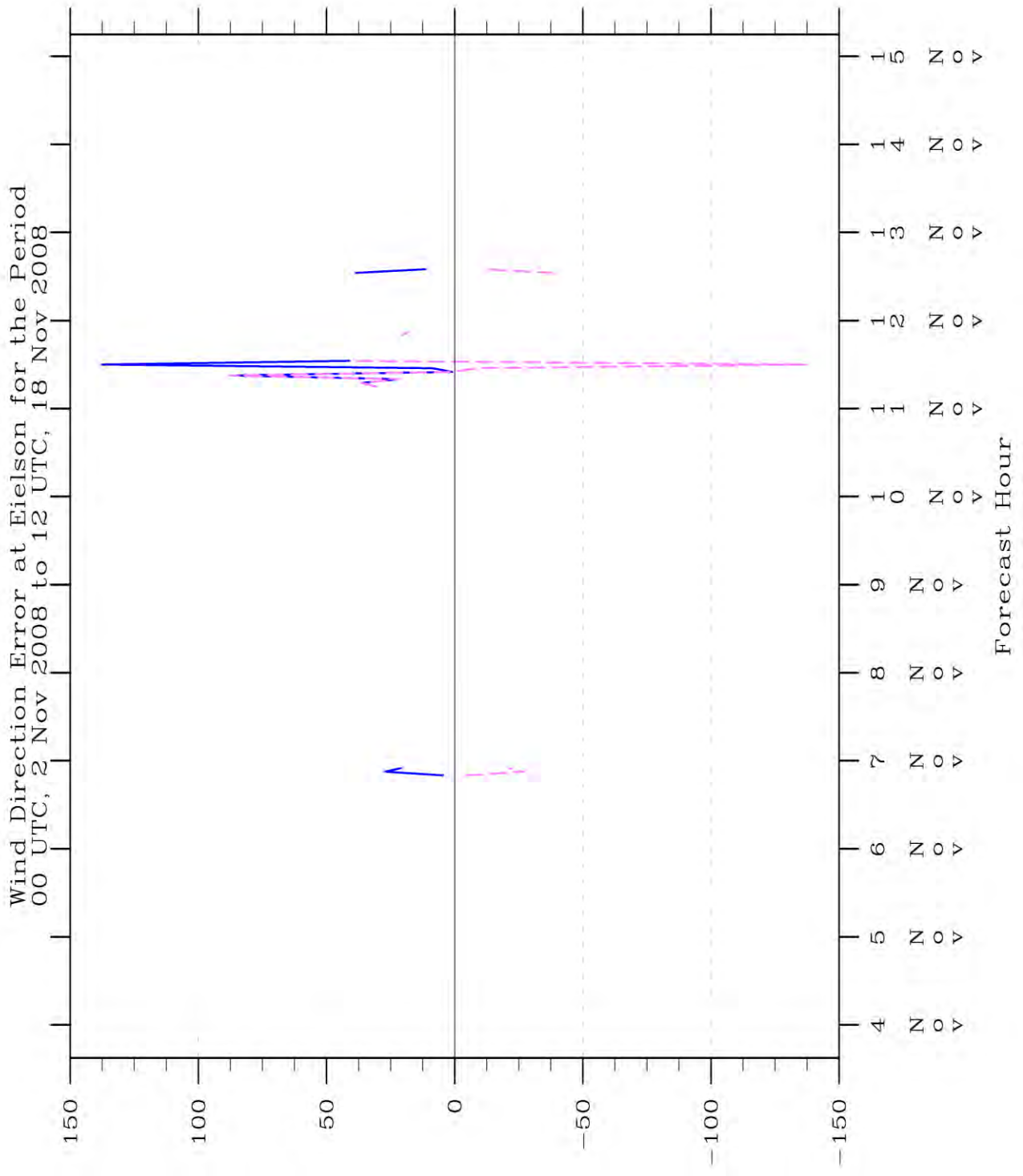


Figure 46: Time series of wind direction mean absolute error (blue) and mean error (magenta) statistics for Eielson in TWIND2X30.

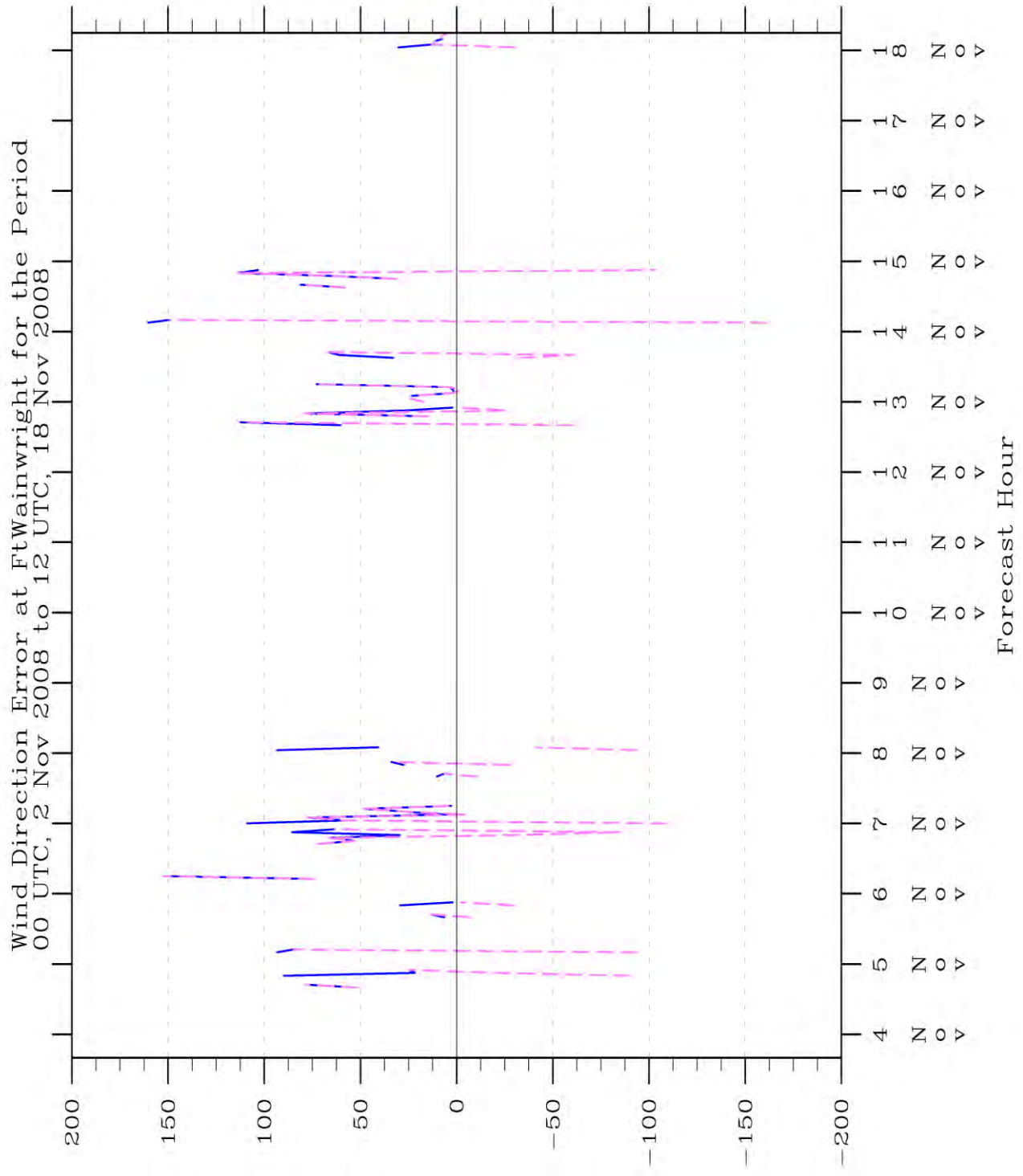


Figure 47: Time series of wind direction mean absolute error (blue) and mean error (magenta) statistics for Ft. Wainwright in TWIND2X30.

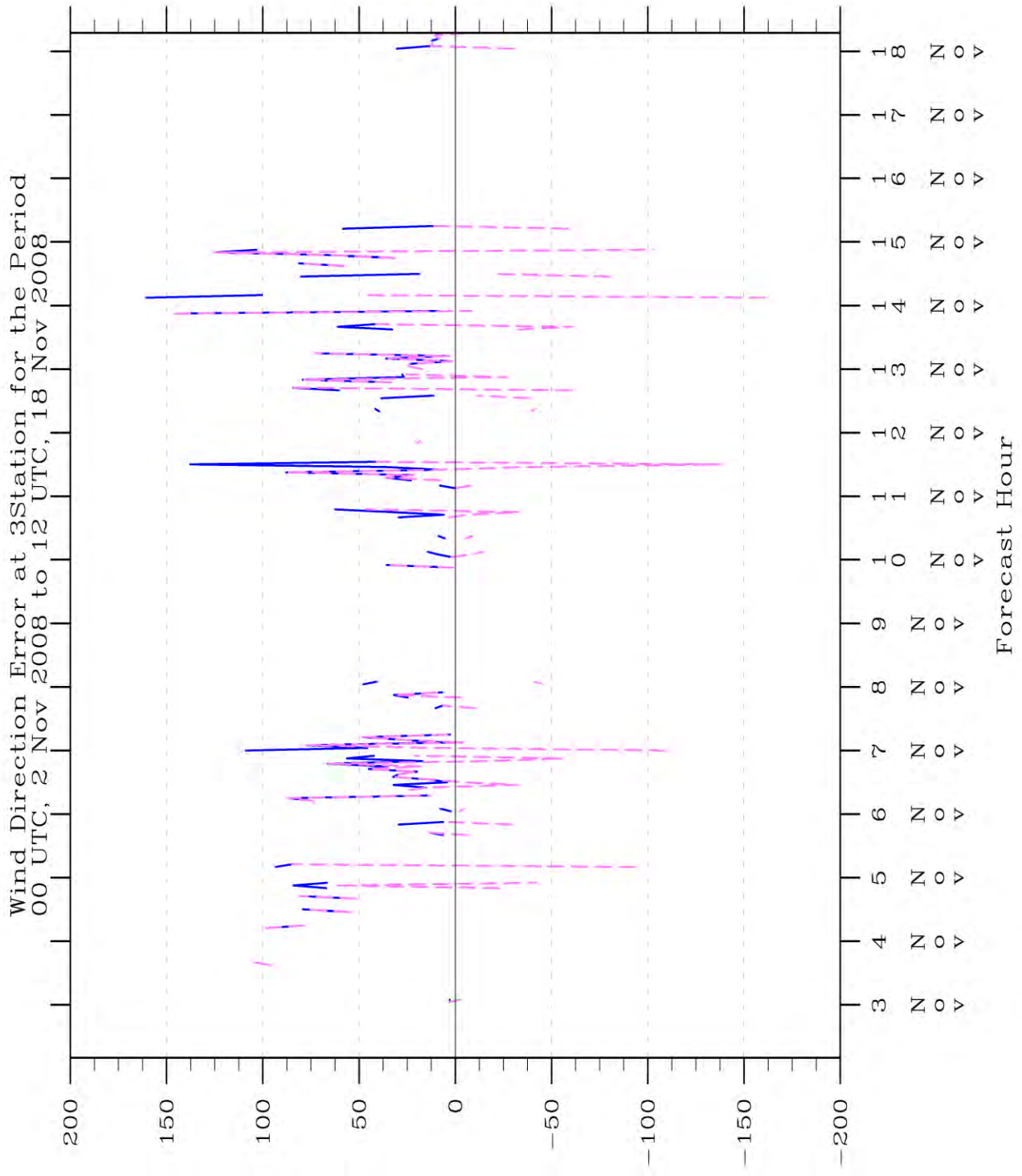


Figure 48: Time series of wind direction mean absolute error (blue) and mean error (magenta) statistics for all three stations in TWIND2X30.

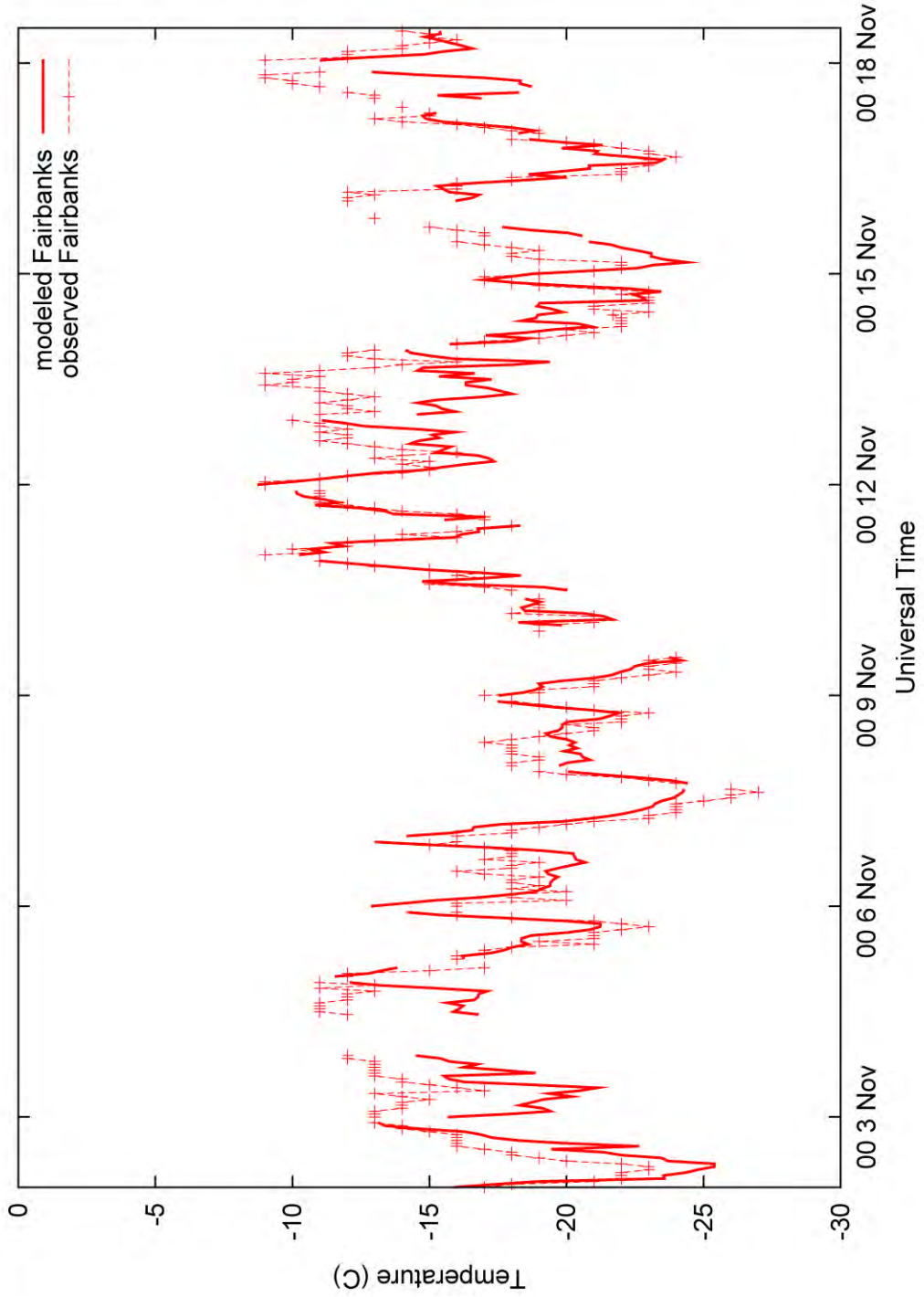


Figure 49: Time series of modeled and observed temperature for Fairbanks in TWIND2X30.

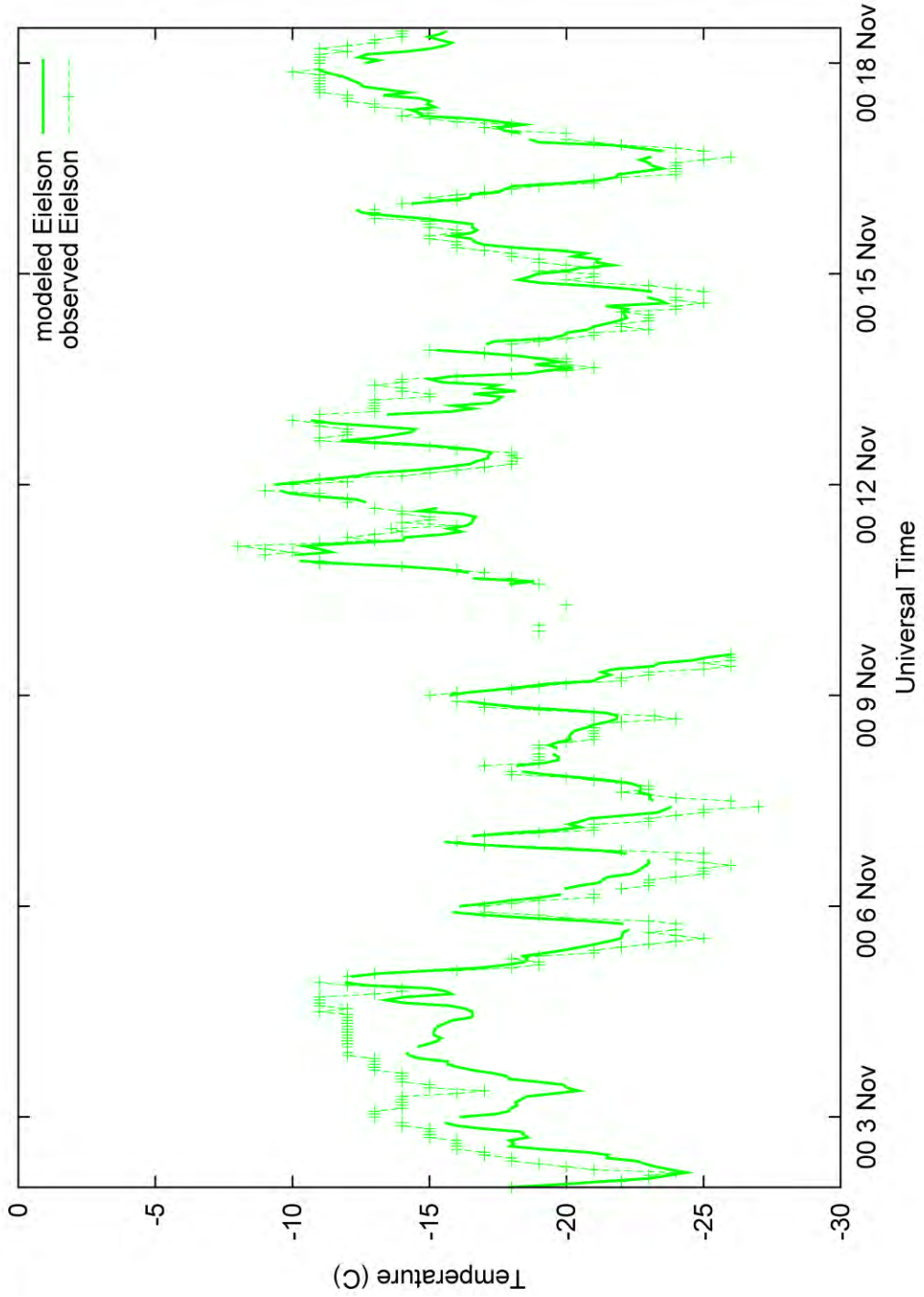


Figure 50: Time series of modeled and observed temperature for Eielson in TWIND2X30.

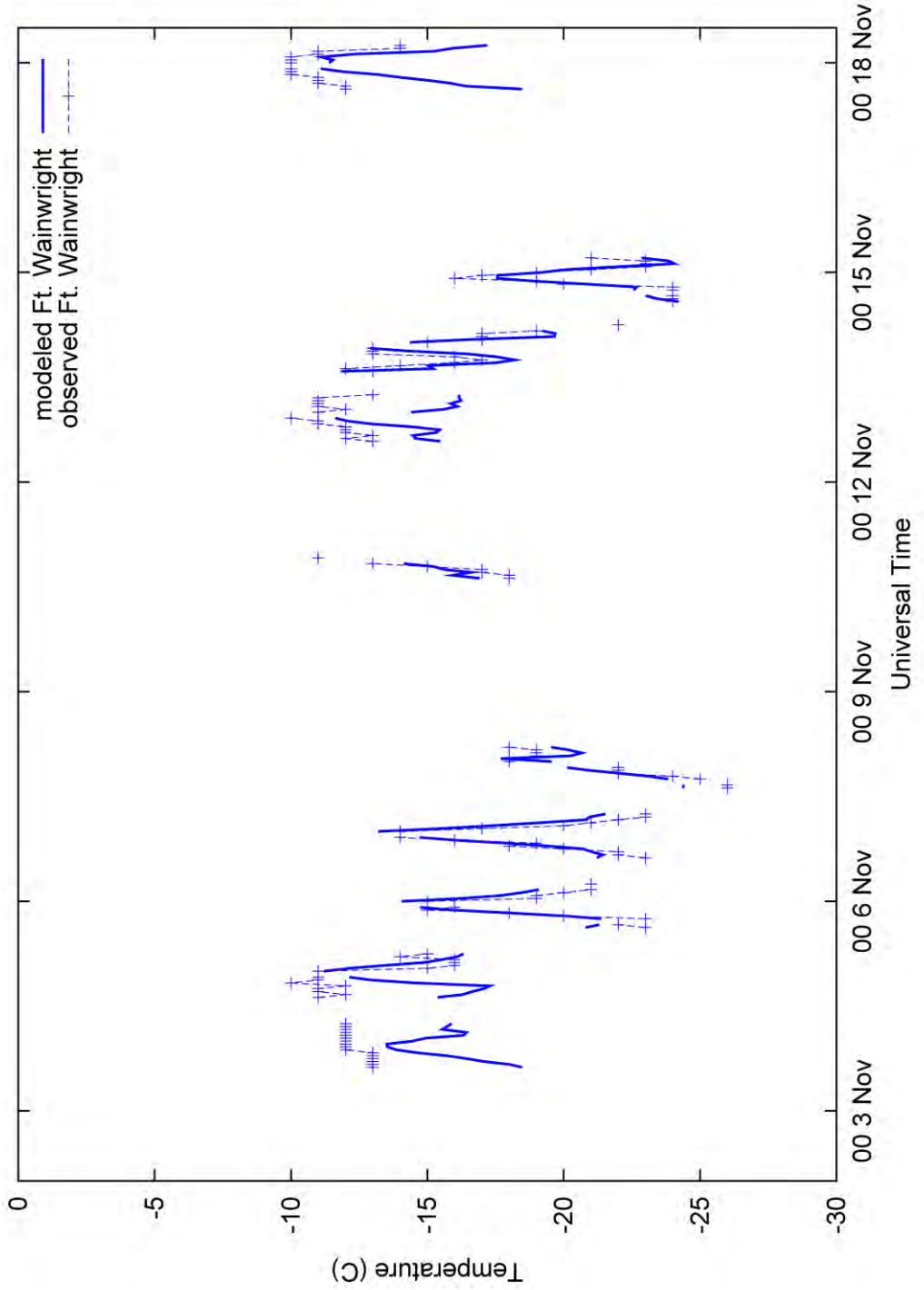


Figure 51: Time series of modeled and observed temperature for Ft. Wainwright in TWIND2X30.

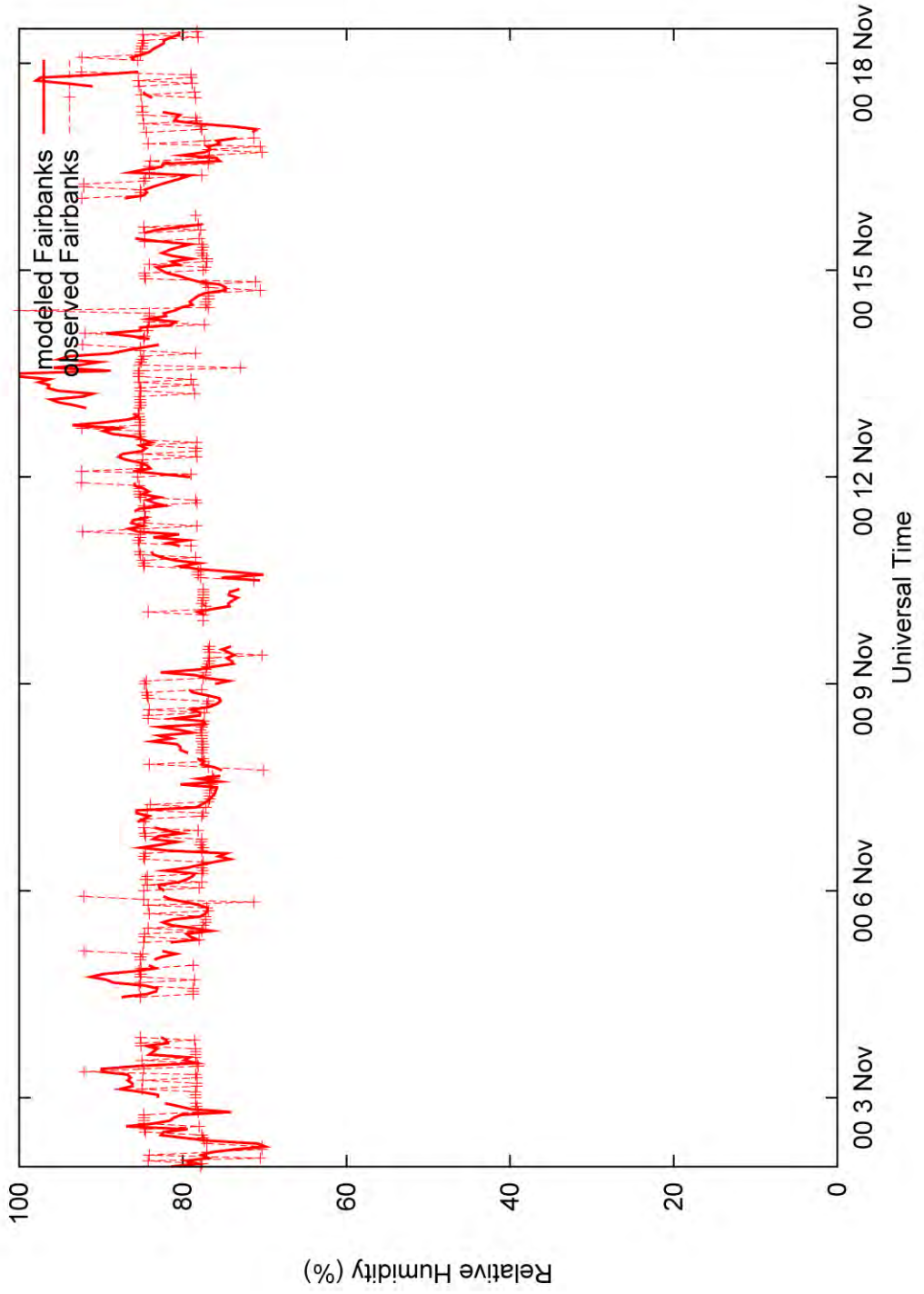


Figure 52: Time series of modeled and observed relative humidity for Fairbanks in TWIND2X30.

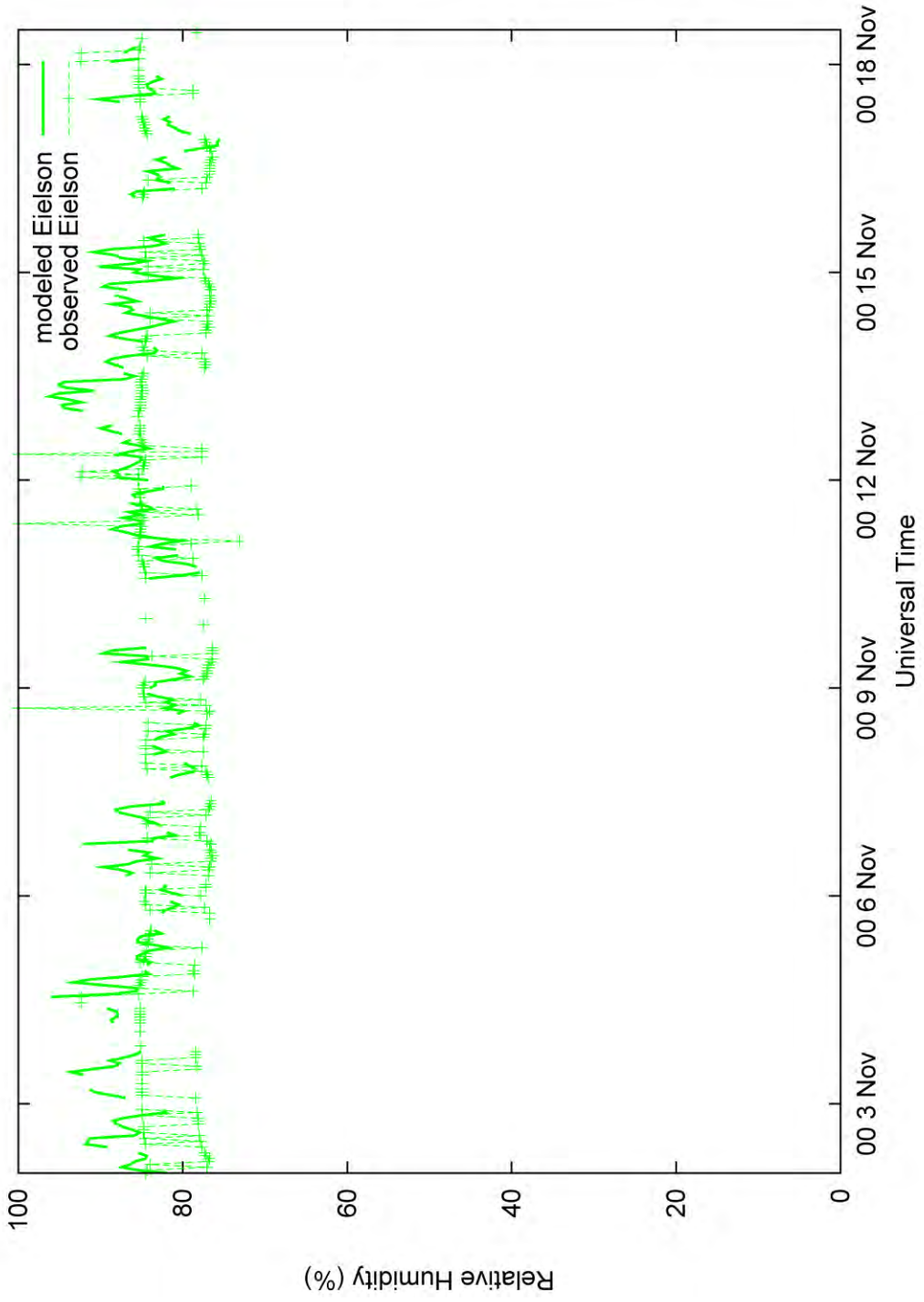


Figure 53: Time series of modeled and observed relative humidity for Eielson in TWIND2X30.

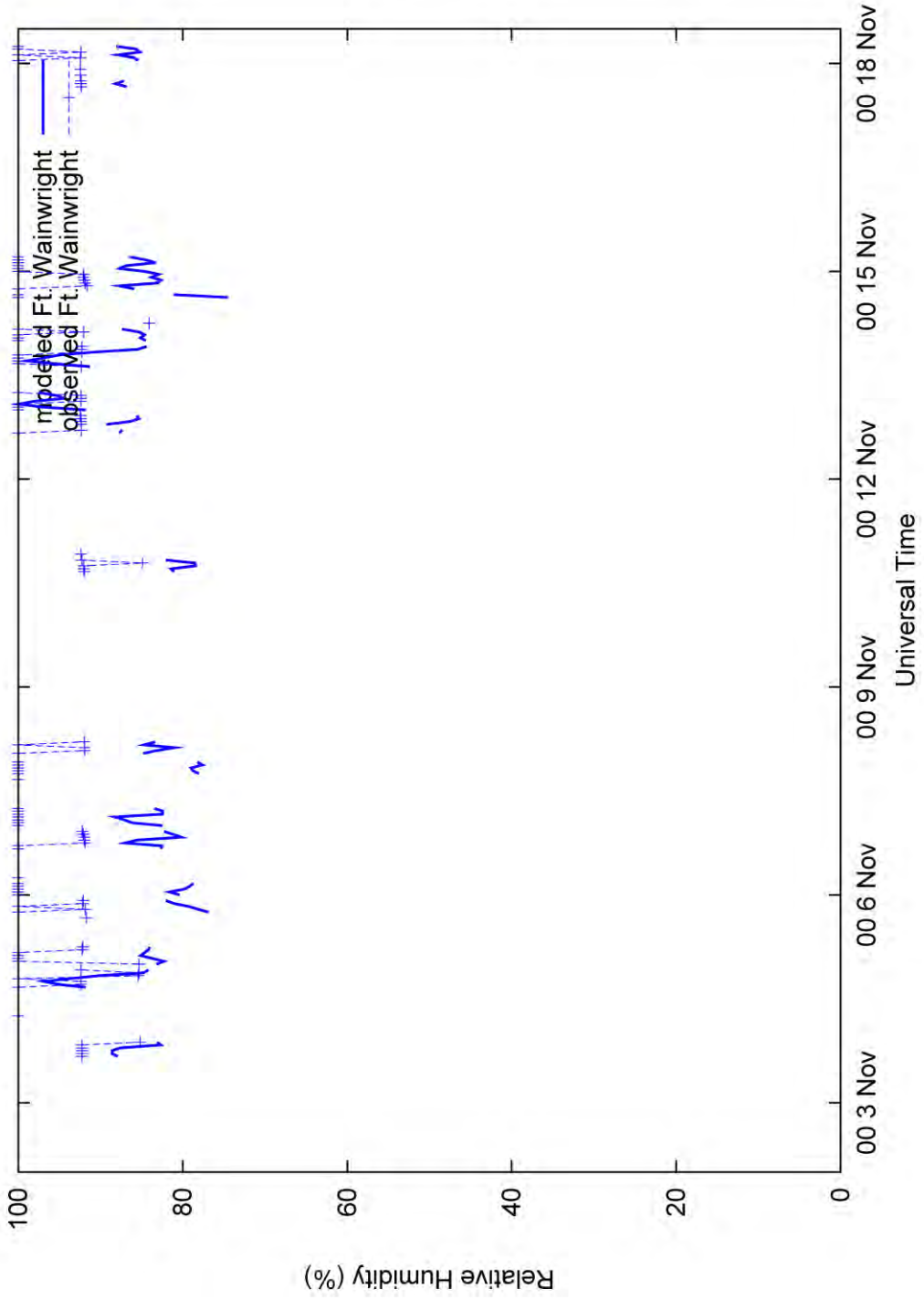


Figure 54: Time series of modeled and observed relative humidity for Ft. Wainwright in TWIND2X30.

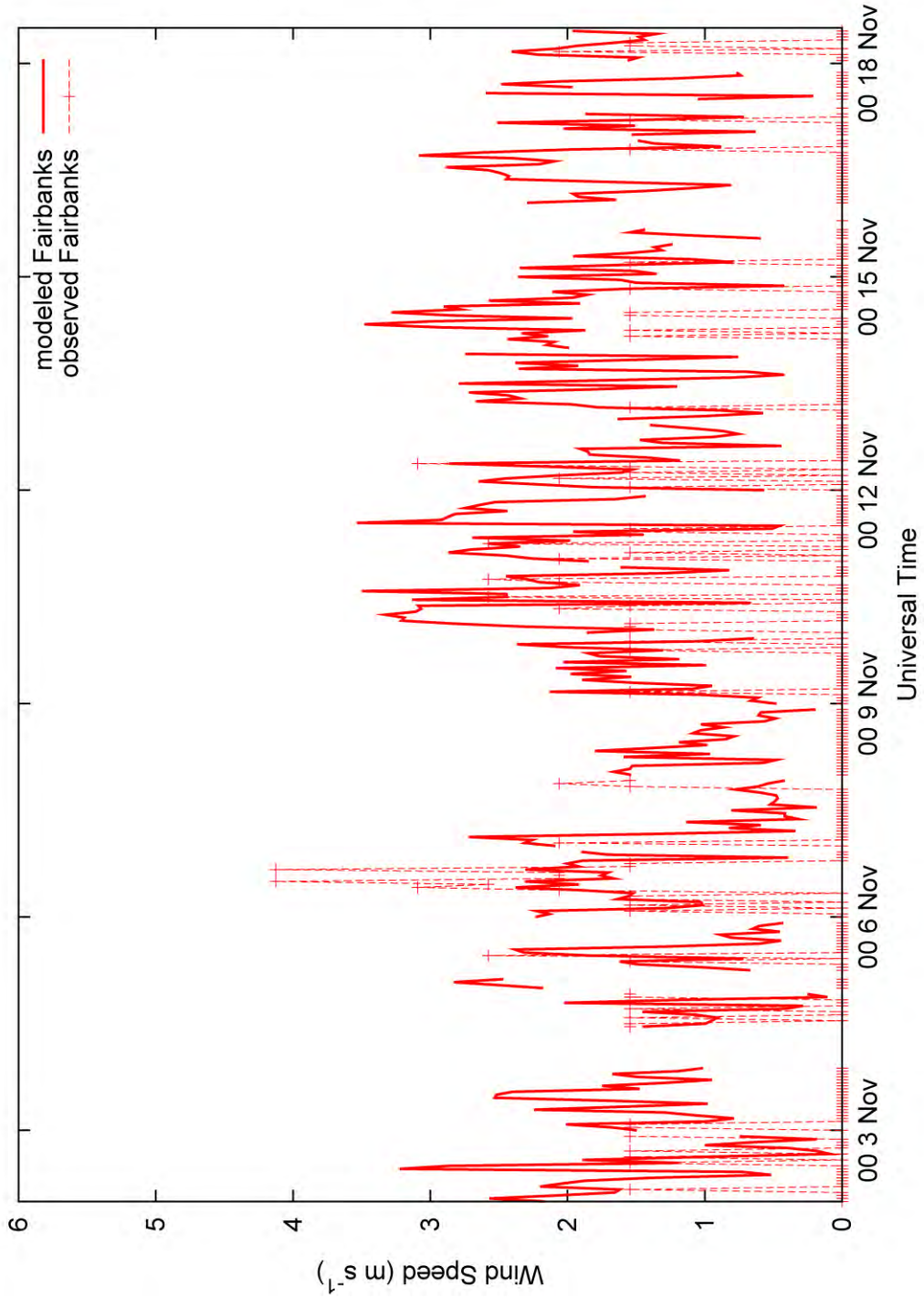


Figure 55: Time series of modeled and observed wind speed for Fairbanks in TWIND2X30.

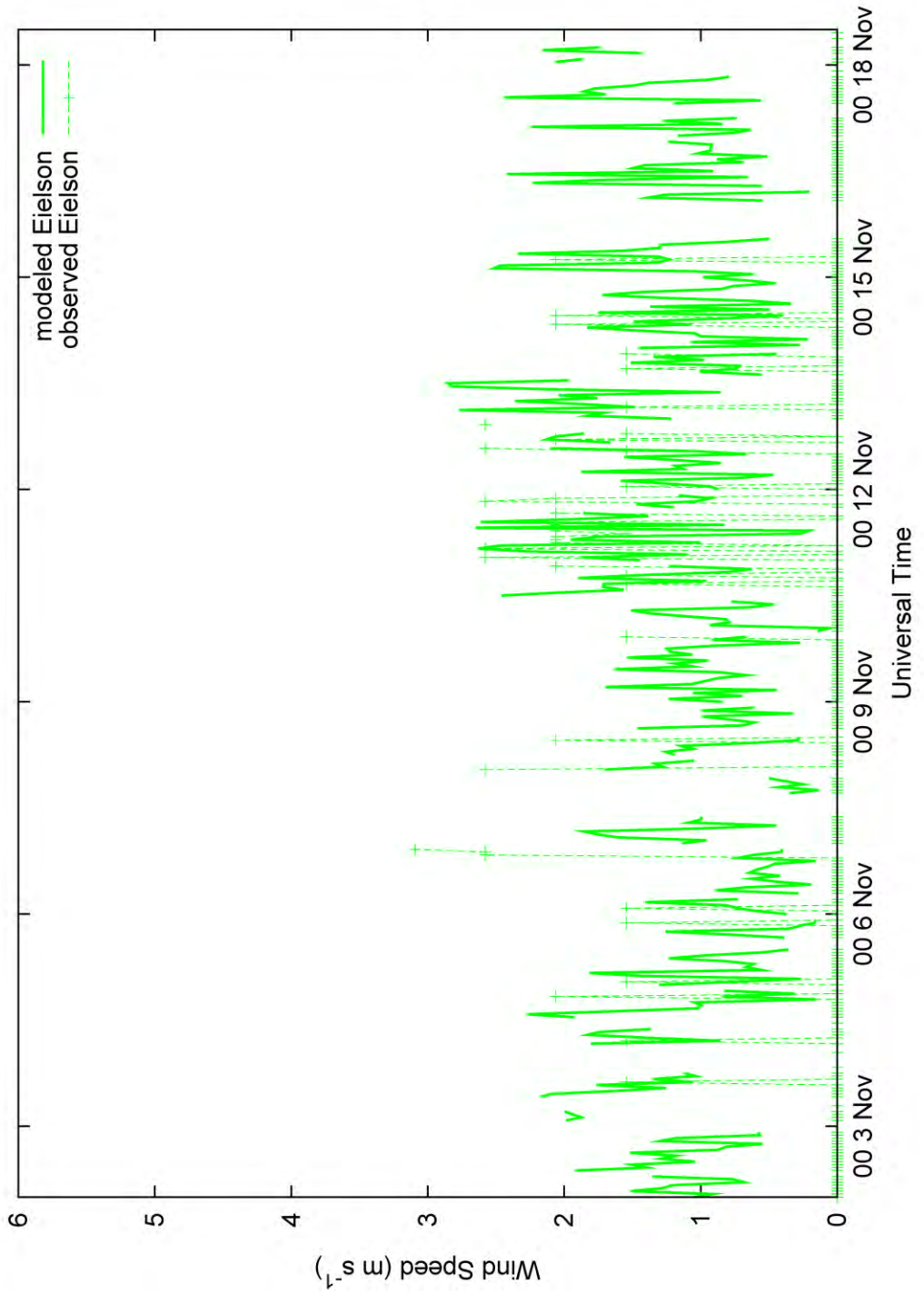


Figure 56: Time series of modeled and observed wind speed for Eielson in TWIND2X30.

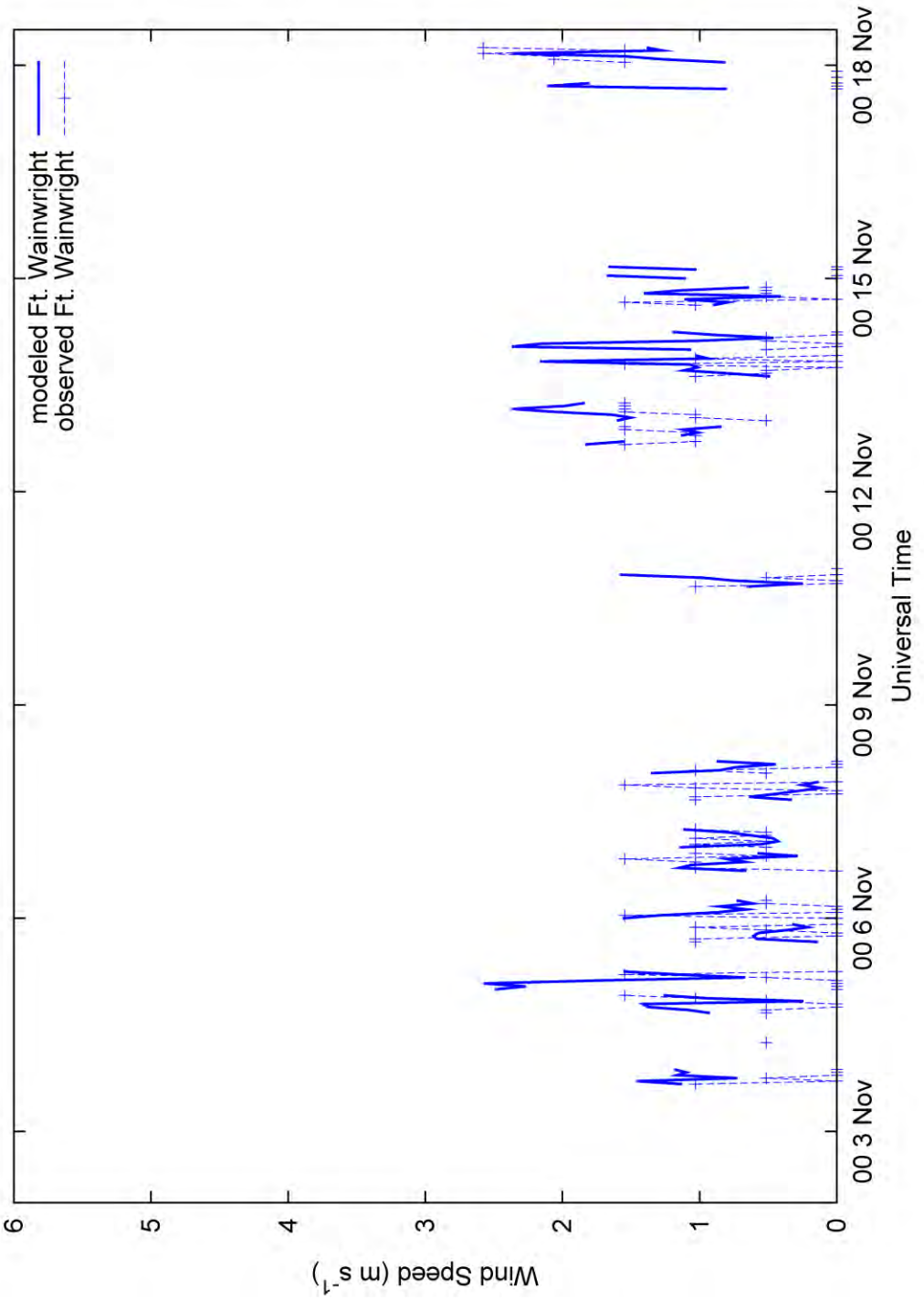


Figure 57: Time series of modeled and observed wind speed for Ft. Wainwright in TWIND2X30.

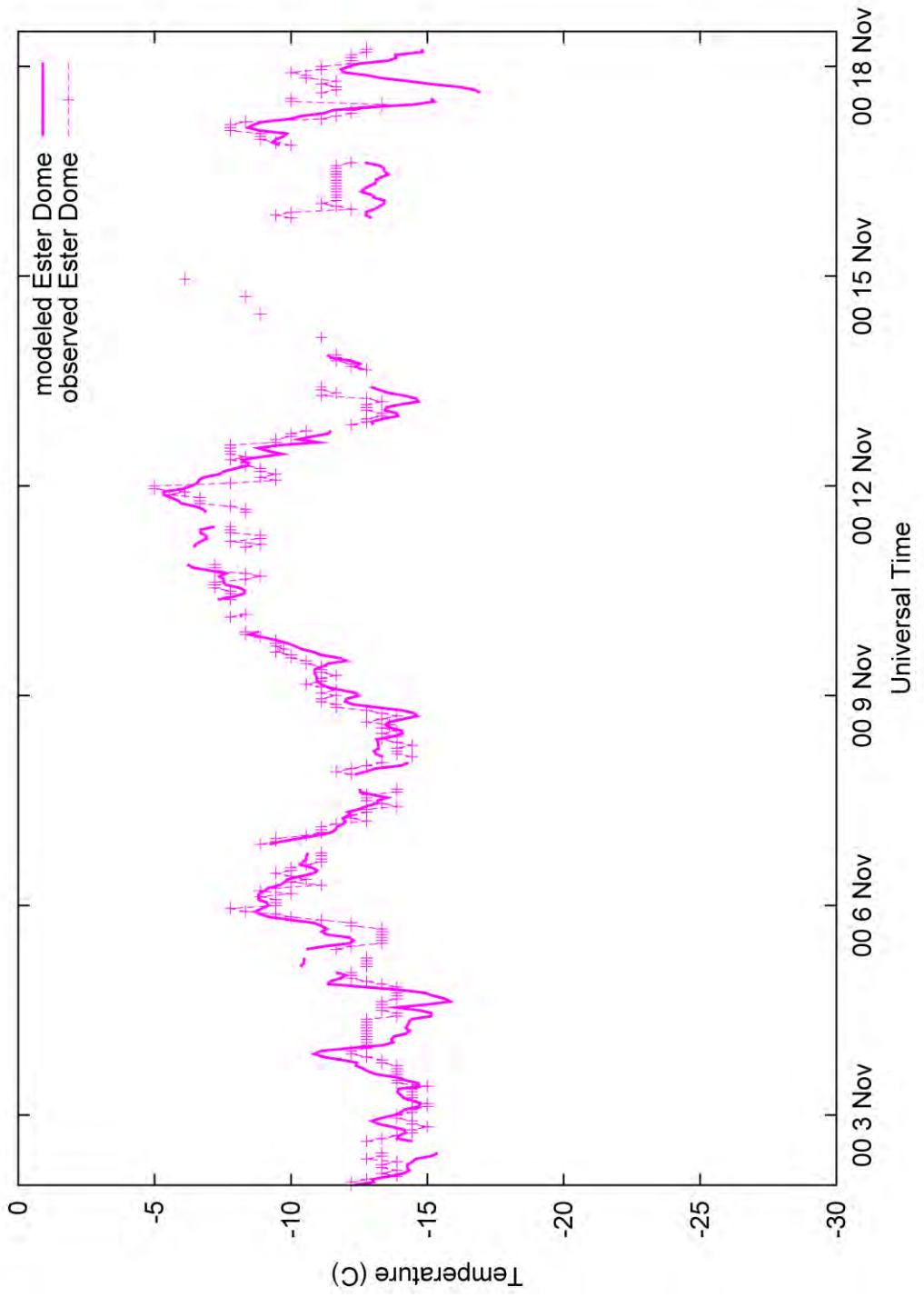


Figure 58: Time series of modeled and observed temperature for Ester Dome in TWIND2X30.

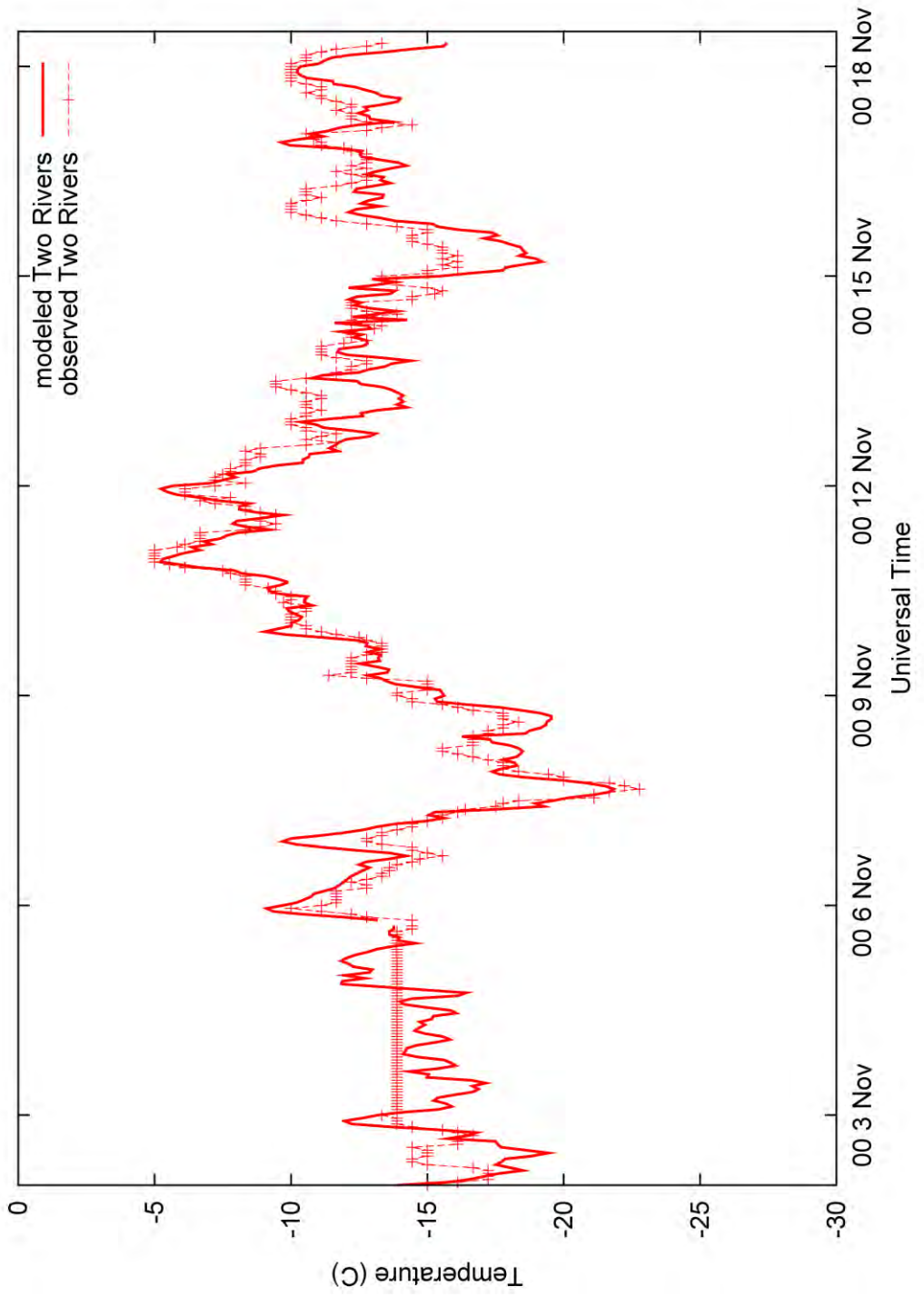


Figure 59: Time series of modeled and observed temperature at Two Rivers in TWIND2X30.

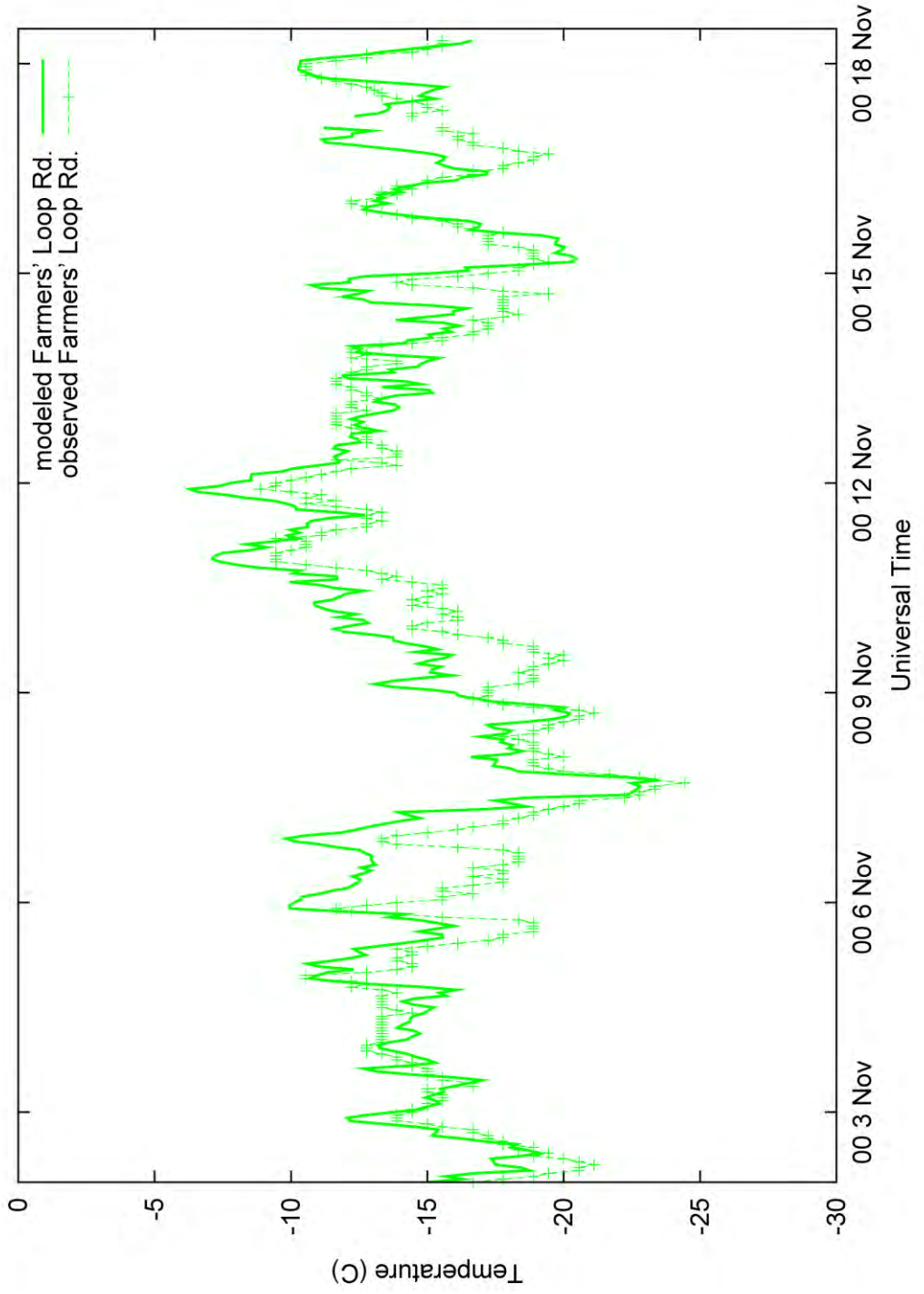


Figure 60: Modeled and observed time series of temperature for Farmers' Loop Rd. in TWIND2X30.

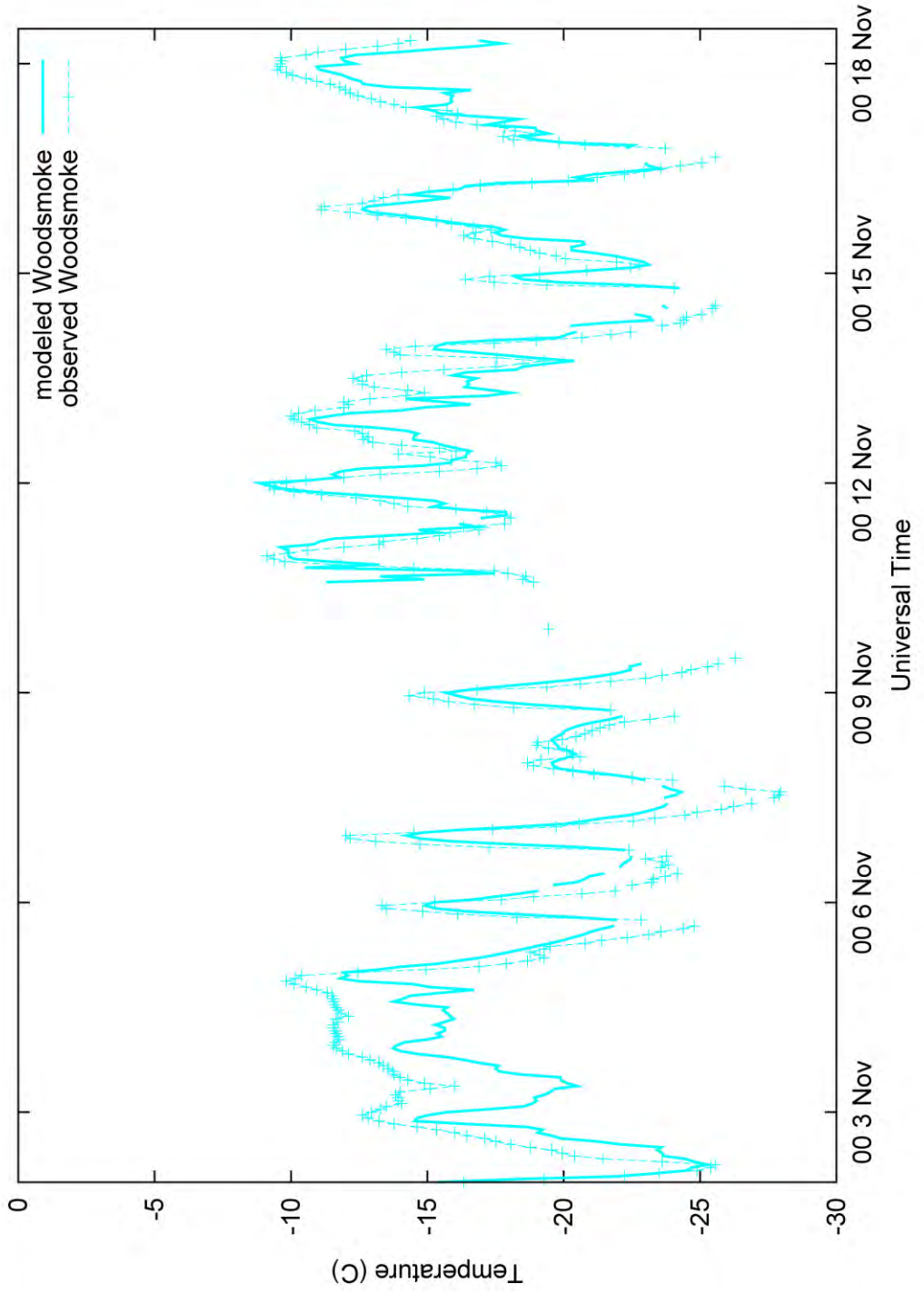


Figure 61: Time series of modeled and observed temperature for Woodsmoke in TWIND2X30.

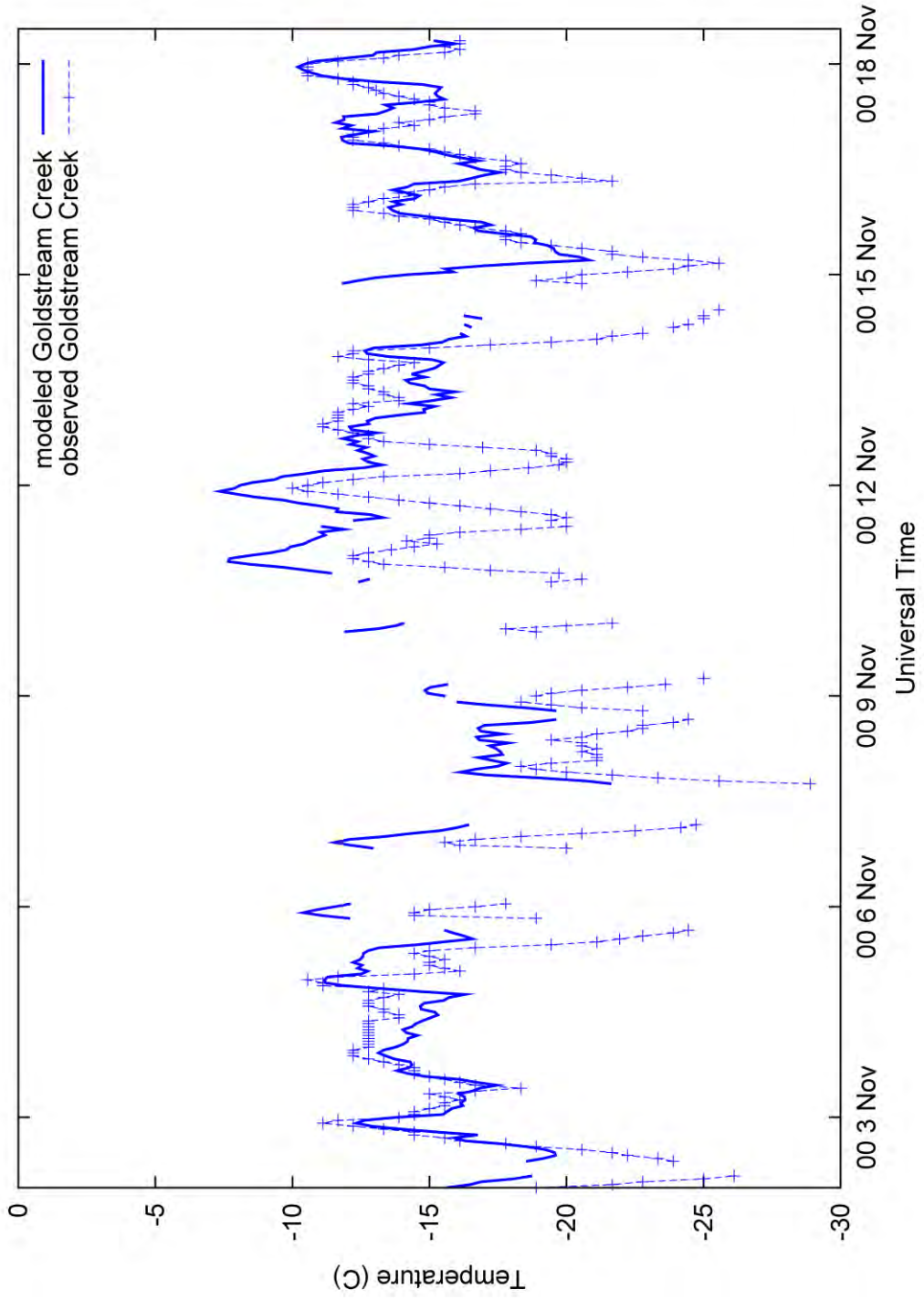


Figure 62: Time series of modeled and observed temperature for Goldstream Creek in TWIND2X30.

APPENDIX B – Detailed Time-Series Figures of 23 Jan – 12 Feb 2008 Episode, for TWIND2X30 Configuration

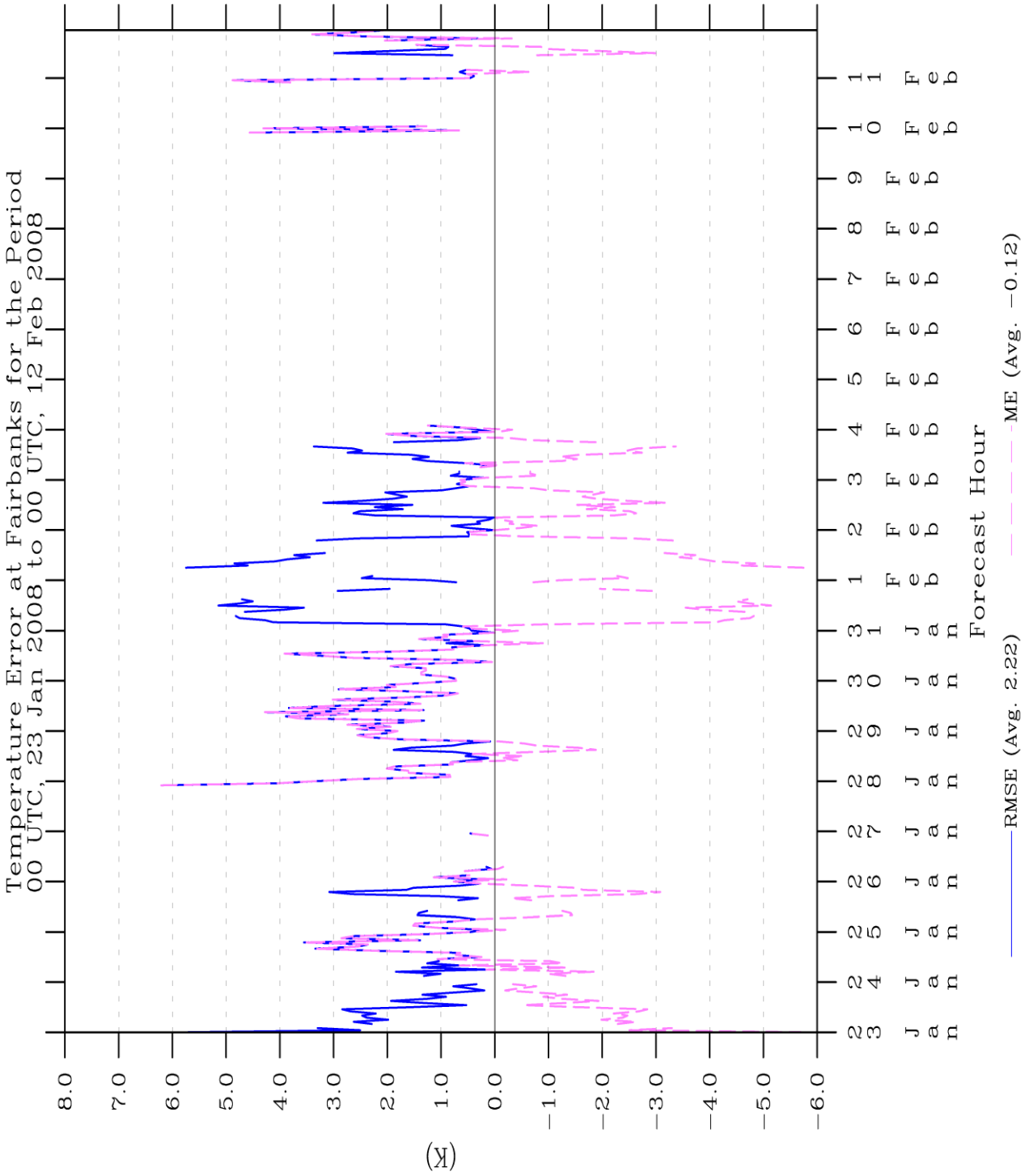


Figure 63: Time series of temperature statistics for Fairbanks in TWIND2X30

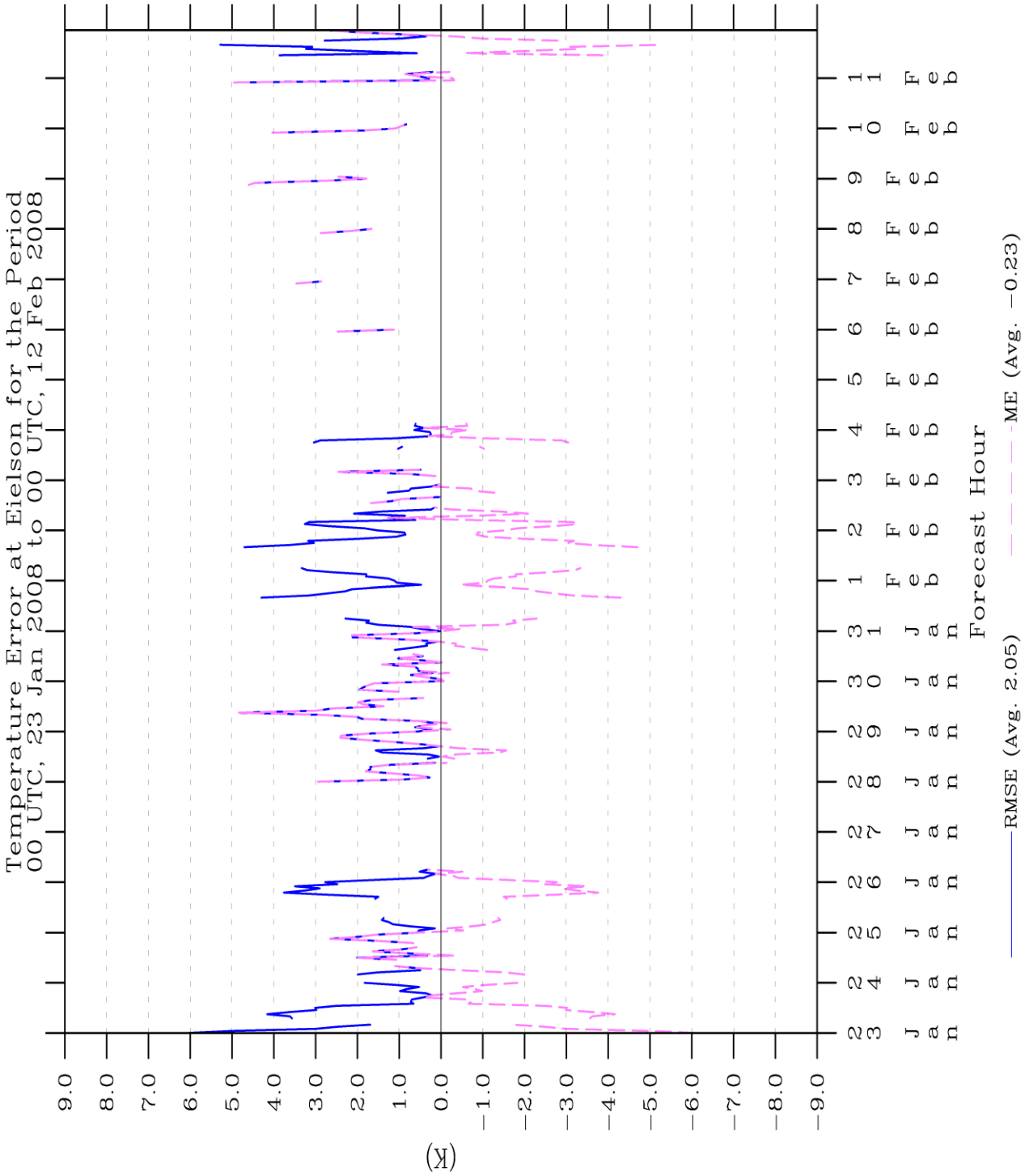


Figure 64: Time series of temperature statistics for Eielson in TWIND2X30.

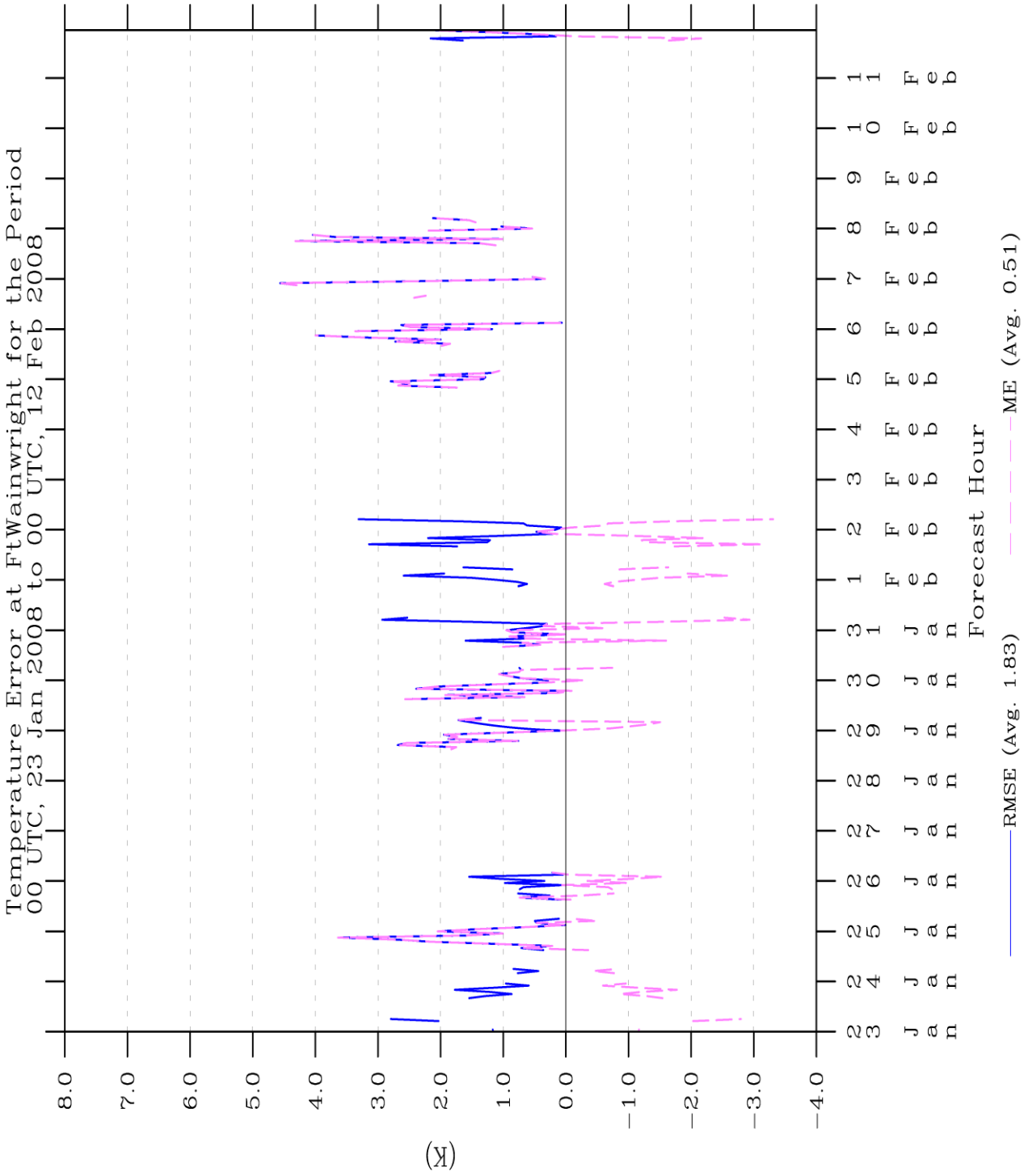


Figure 65: Time series of temperature statistics for Ft. Wainwright in TWIND2X30.

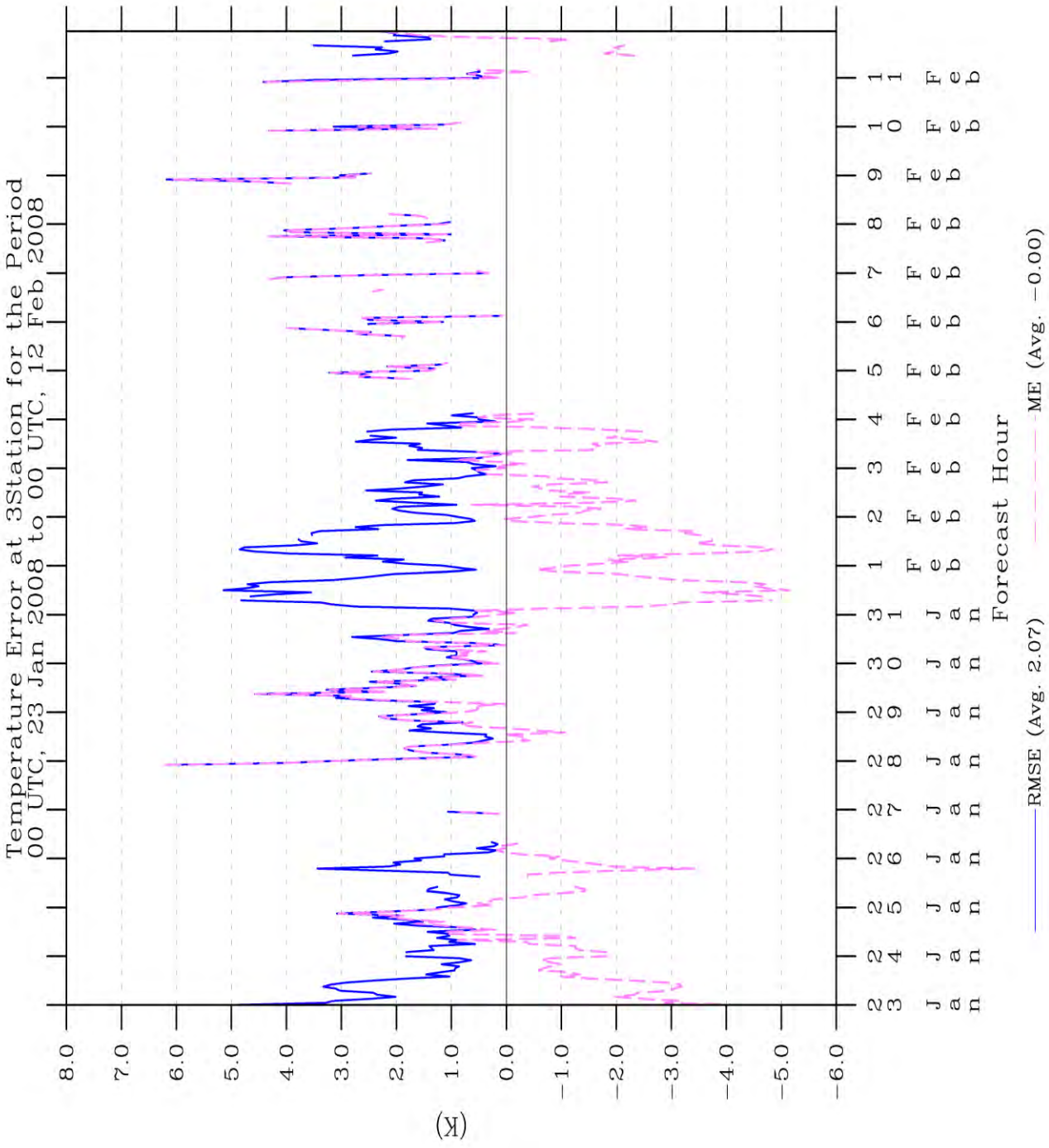


Figure 66: Time series of temperature statistics for all three stations in TWIND2X30.

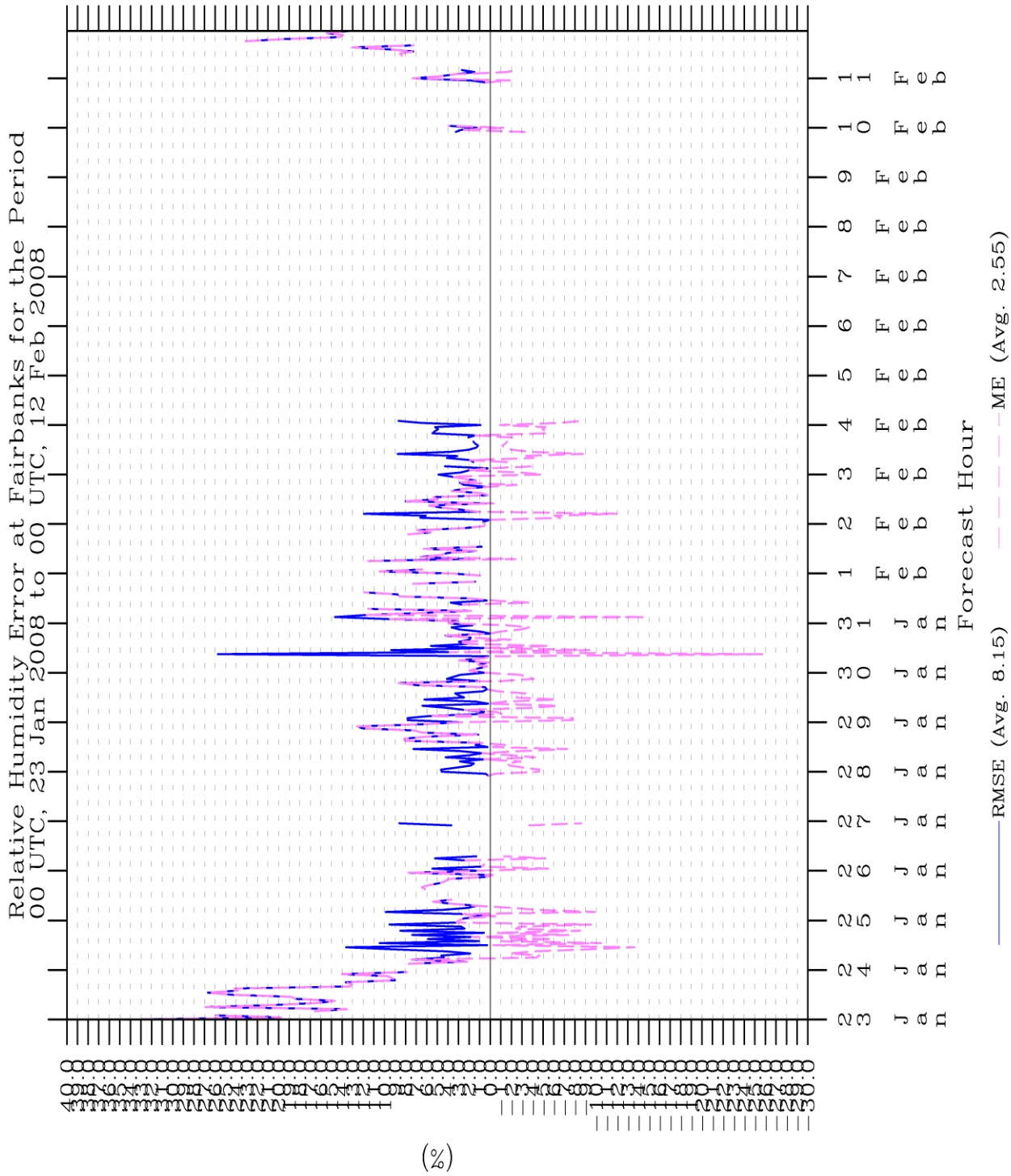


Figure 67: Time series of relative humidity statistics for Fairbanks in TWIND2X30.

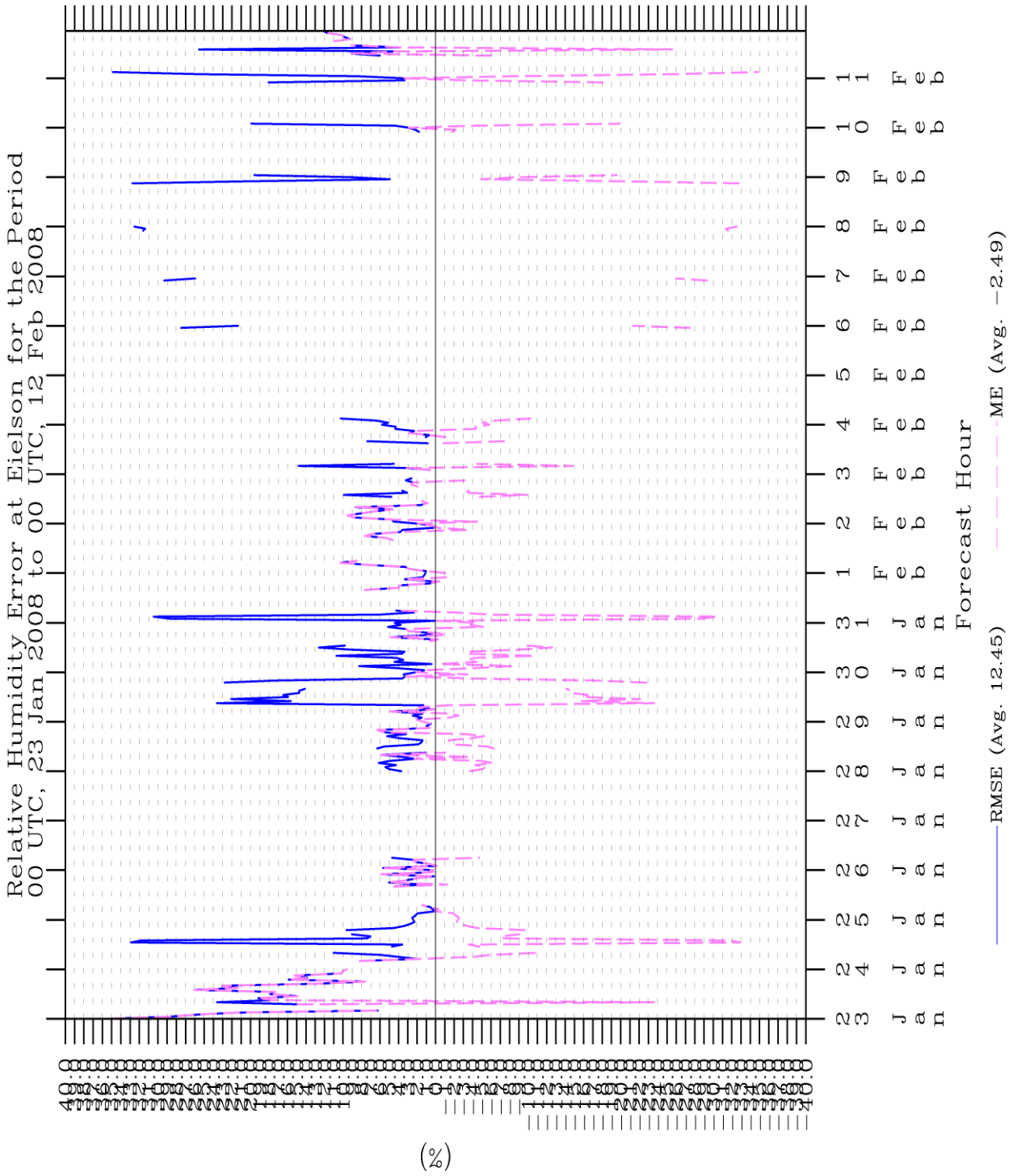


Figure 68: Time series of relative humidity statistics for Eielson in TWIND2X30.

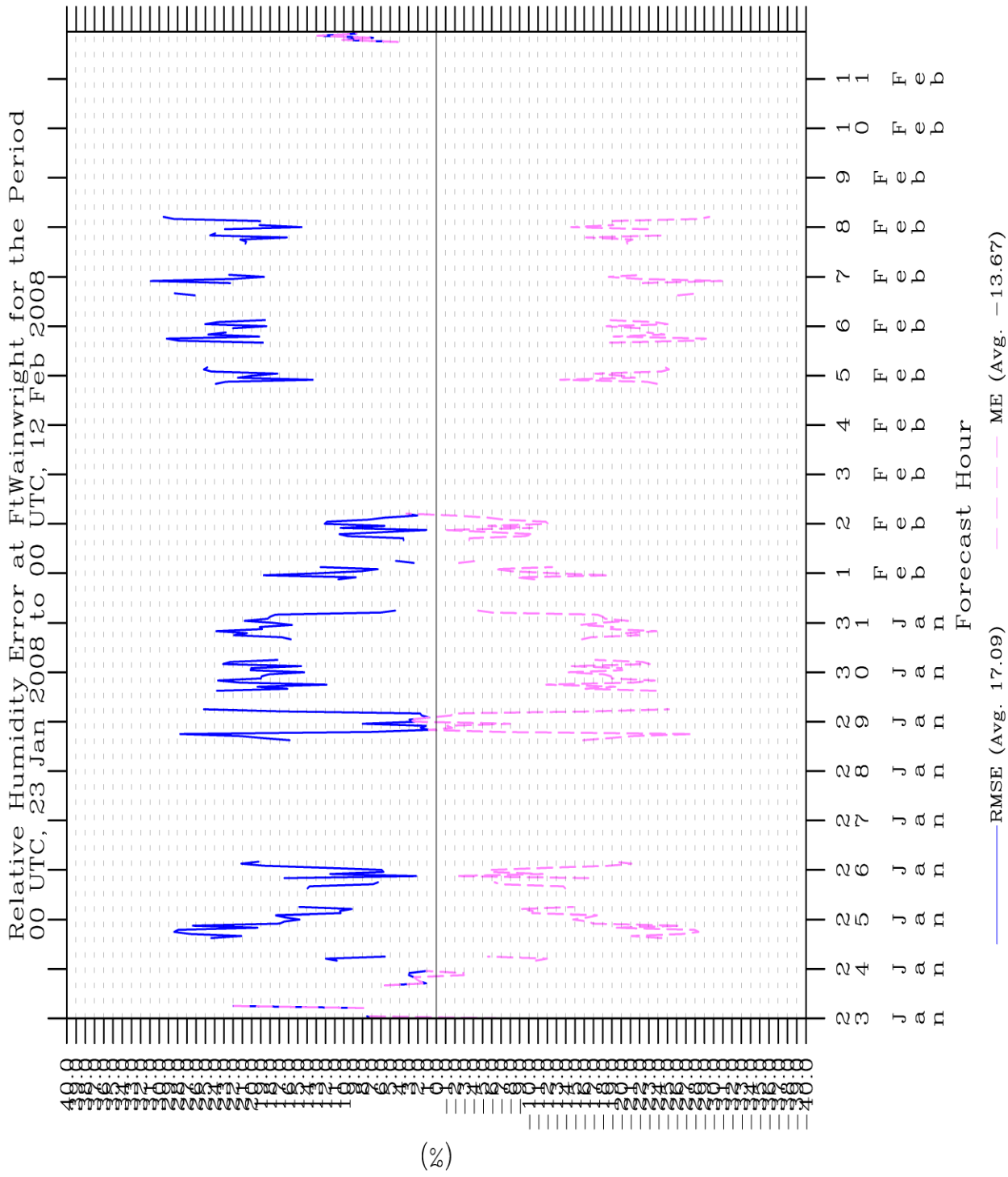


Figure 69: Time series of relative humidity statistics for Ft. Wainwright in TWIND2X30.

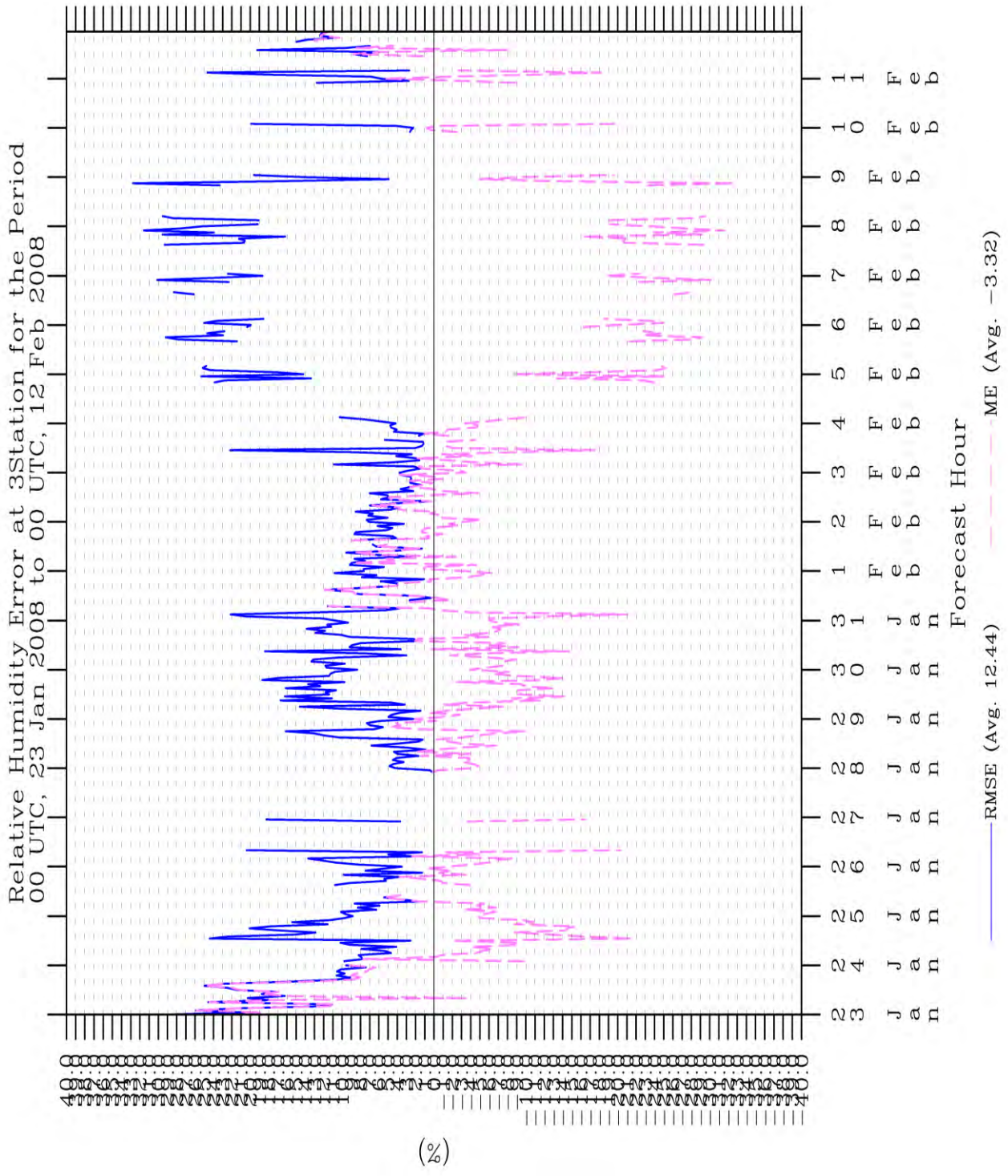


Figure 70: Time series of relative humidity statistics for all three stations in TWIND2X30.

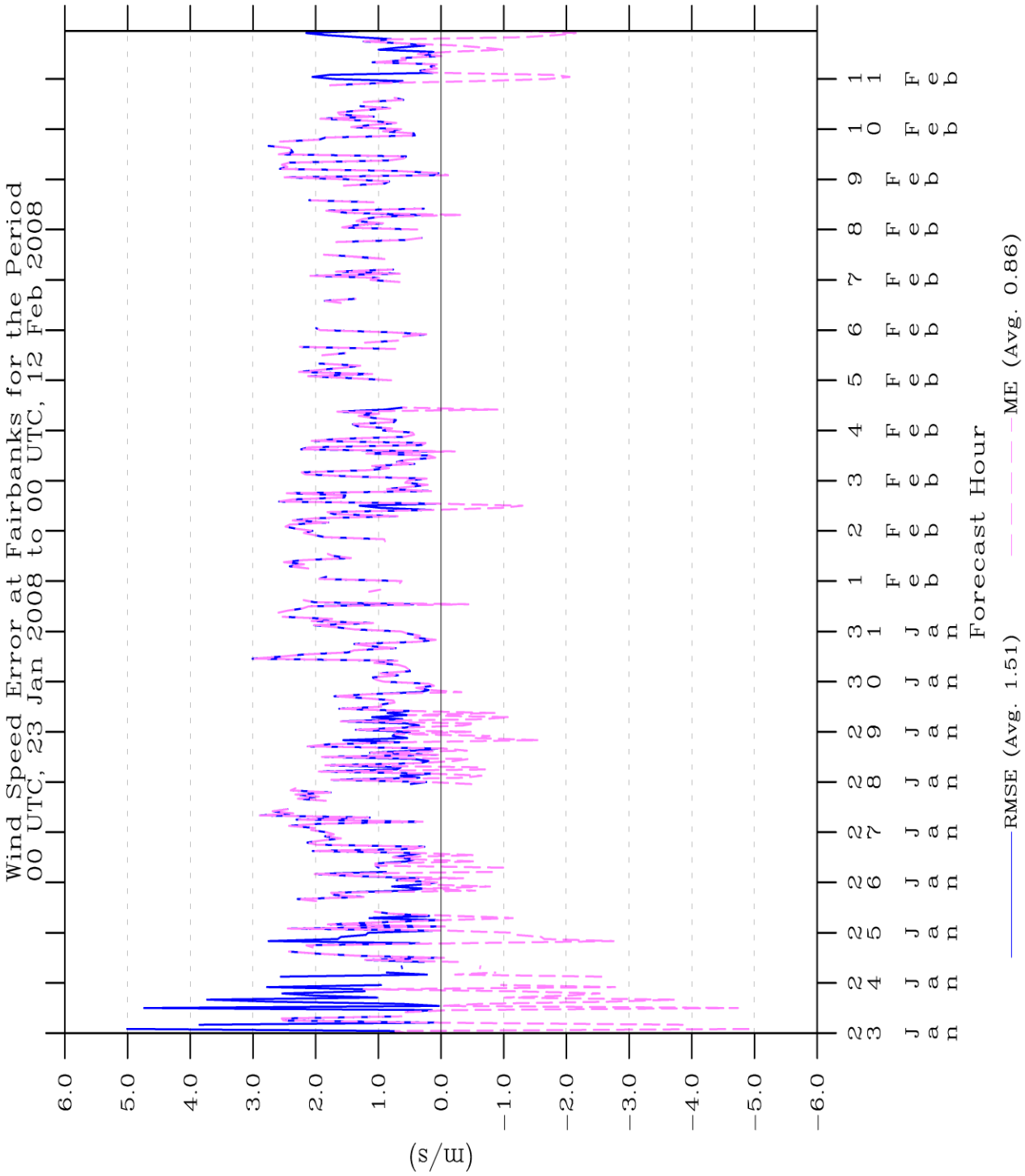


Figure 71: Time series of wind speed statistics for Fairbanks in TWIND2X30.

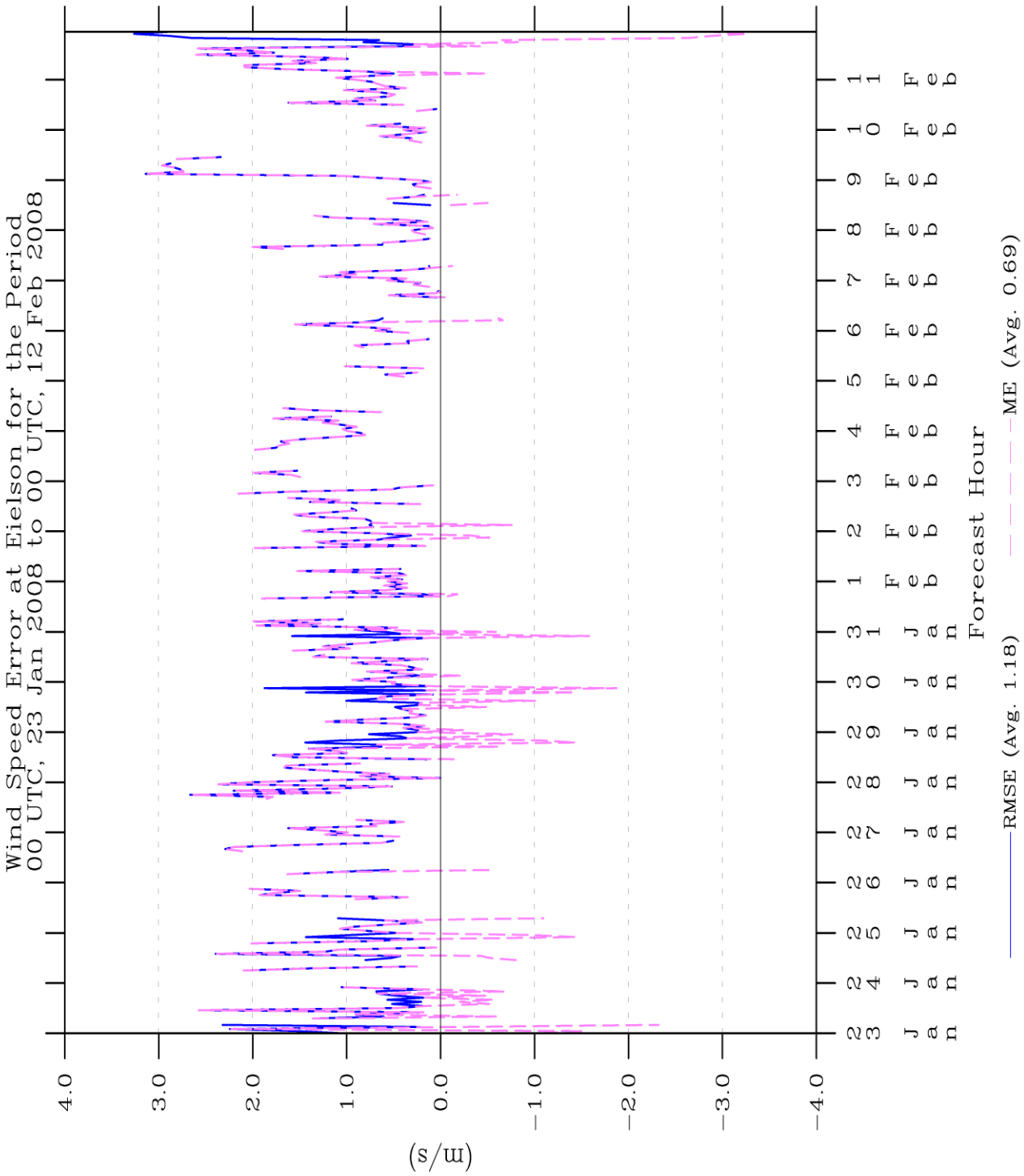


Figure 72: Time series of wind speed statistics for Eielson in TWIND2X30.

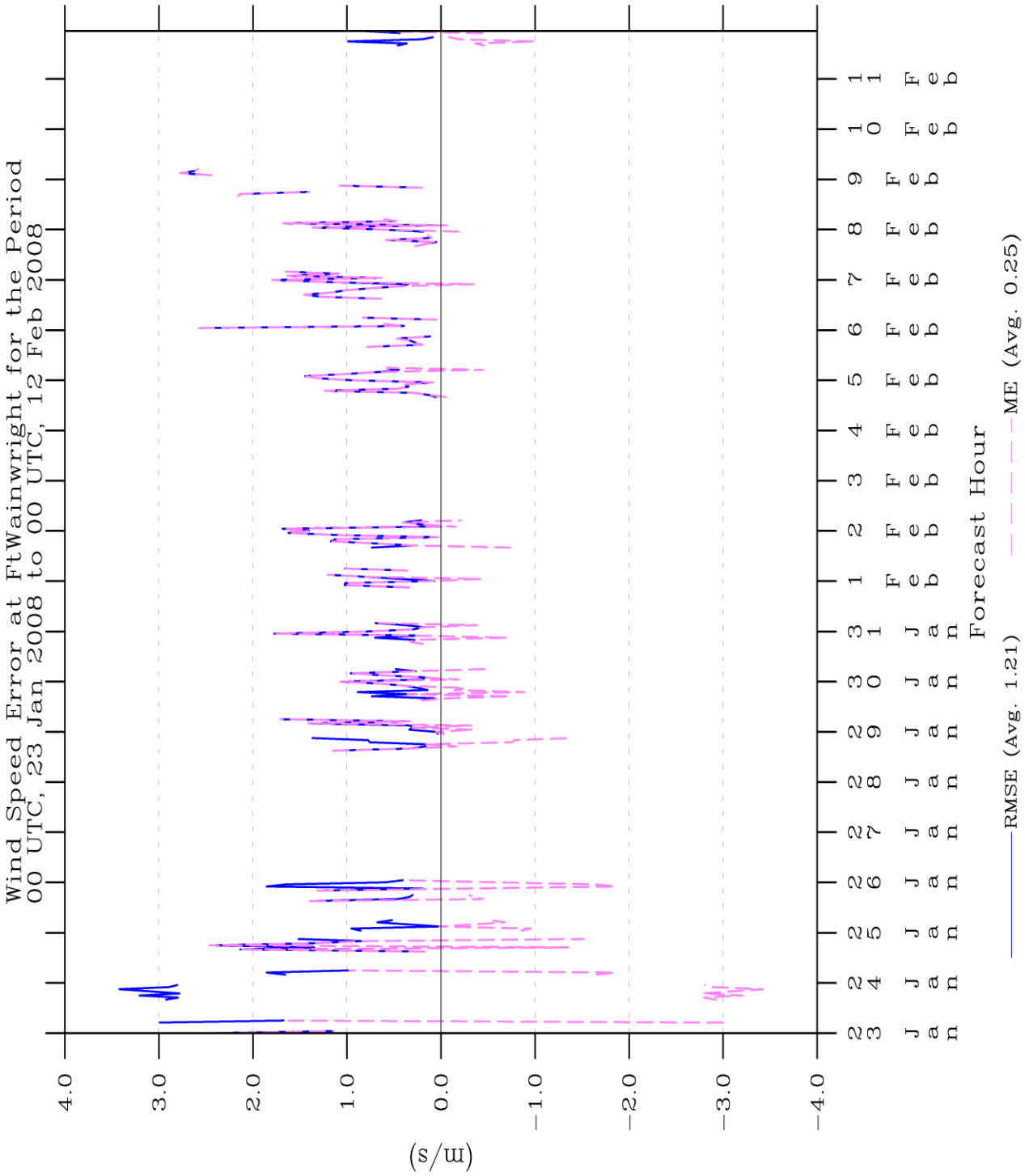


Figure 73: Time series of wind speed statistics for Ft. Wainwright in TWIND2X30.

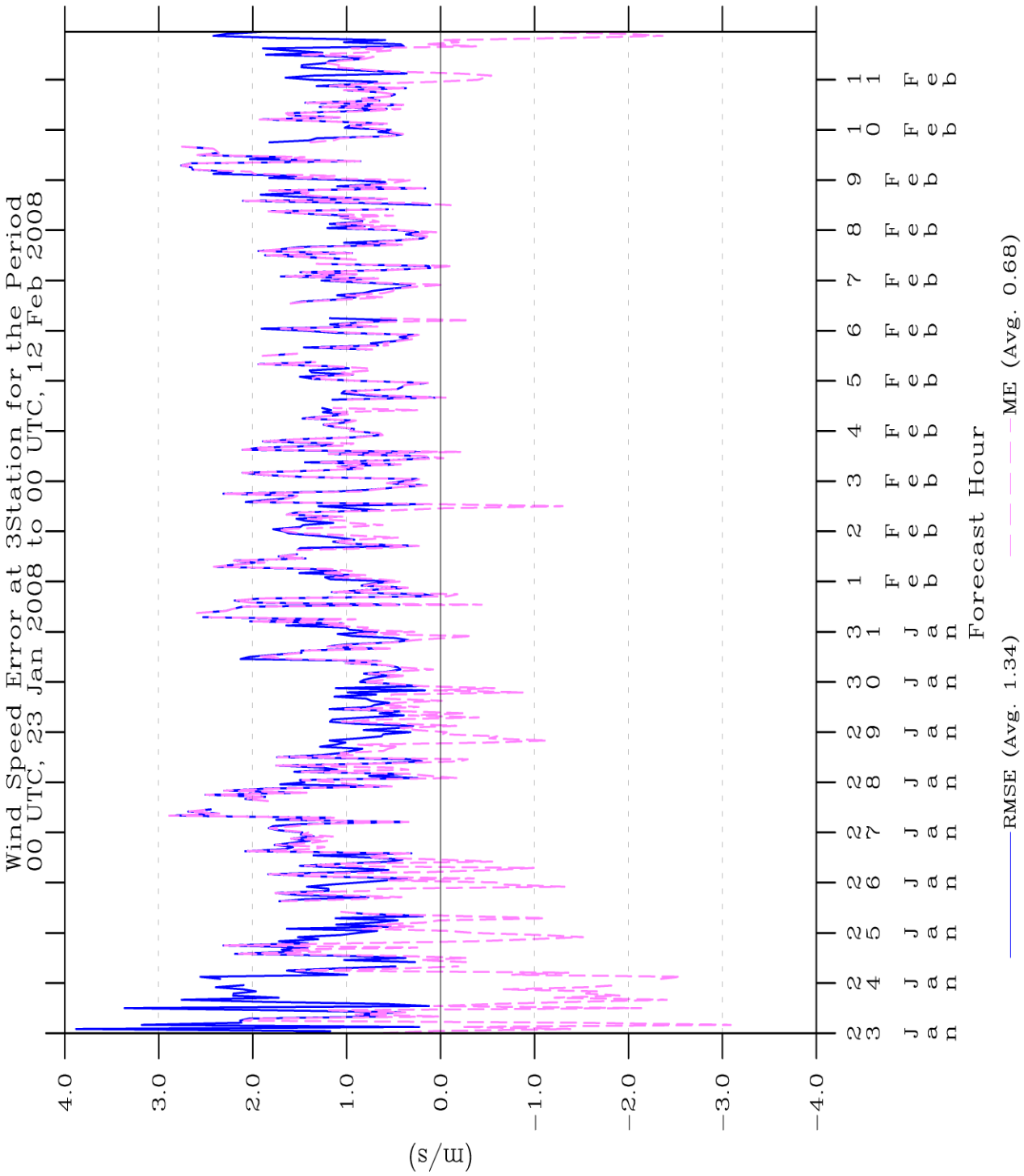


Figure 74: Time series of wind speed statistics for all three stations in TWIND2X30.

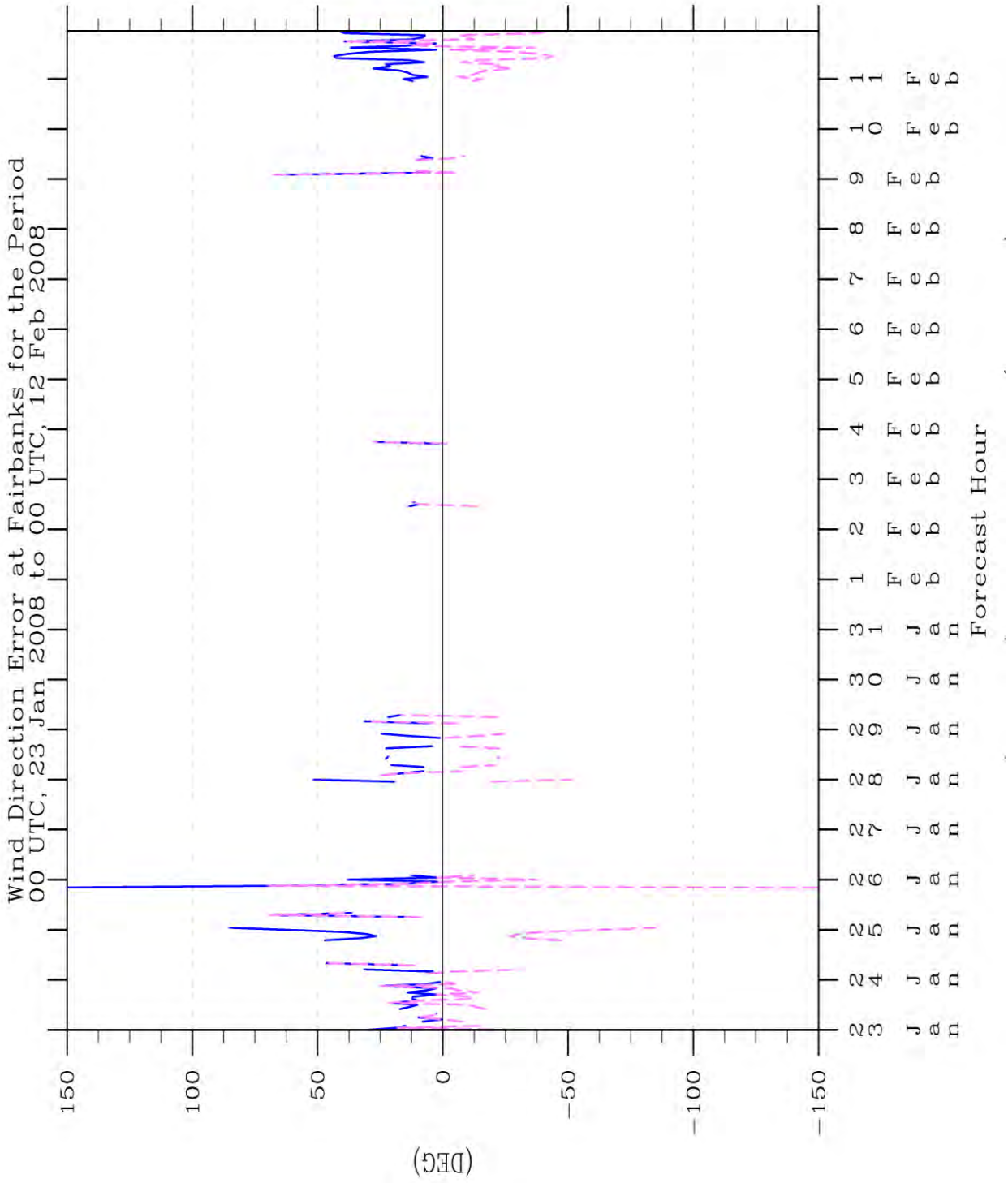


Figure 75: Time series of wind direction mean absolute error (blue) and mean error (magenta) statistics for Fairbanks in TWIND2X30.

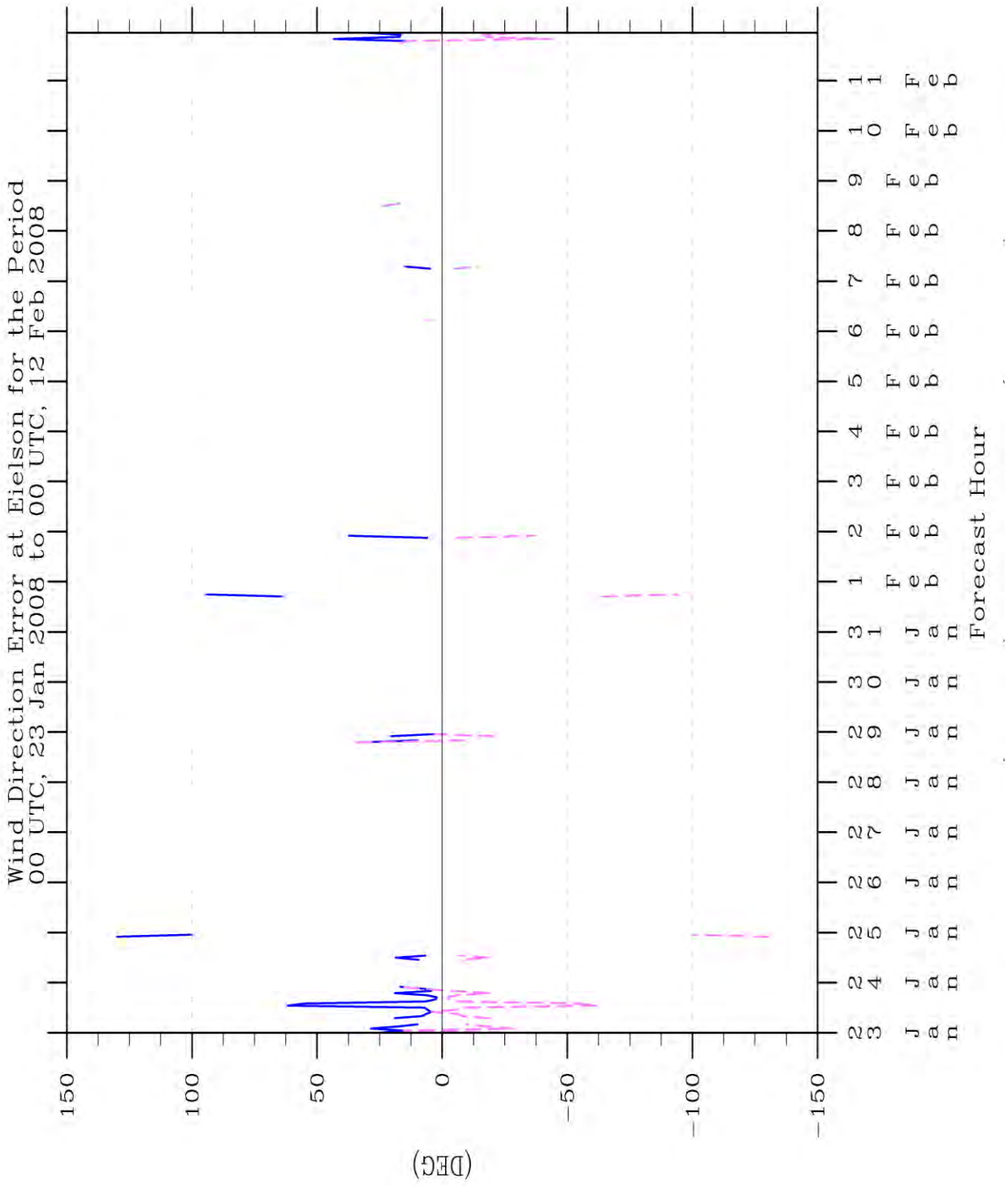


Figure 76: Time series of wind direction mean absolute error (blue) and mean error (magenta) statistics for Eielson in TWIND2X30.

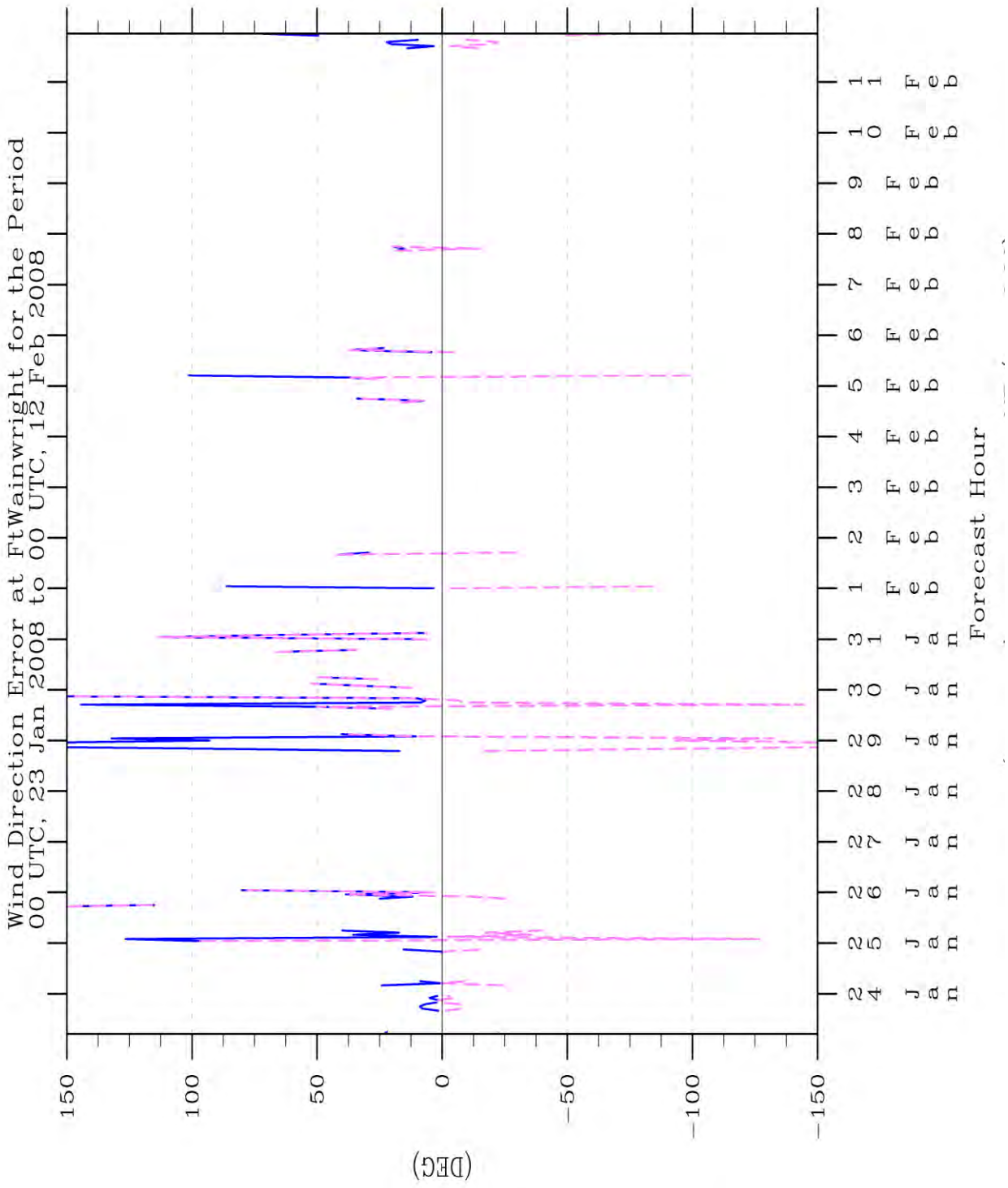


Figure 77: Time series of wind direction mean absolute error (blue) and mean error (magenta) statistics for Ft. Wainwright in TWIND2X30.

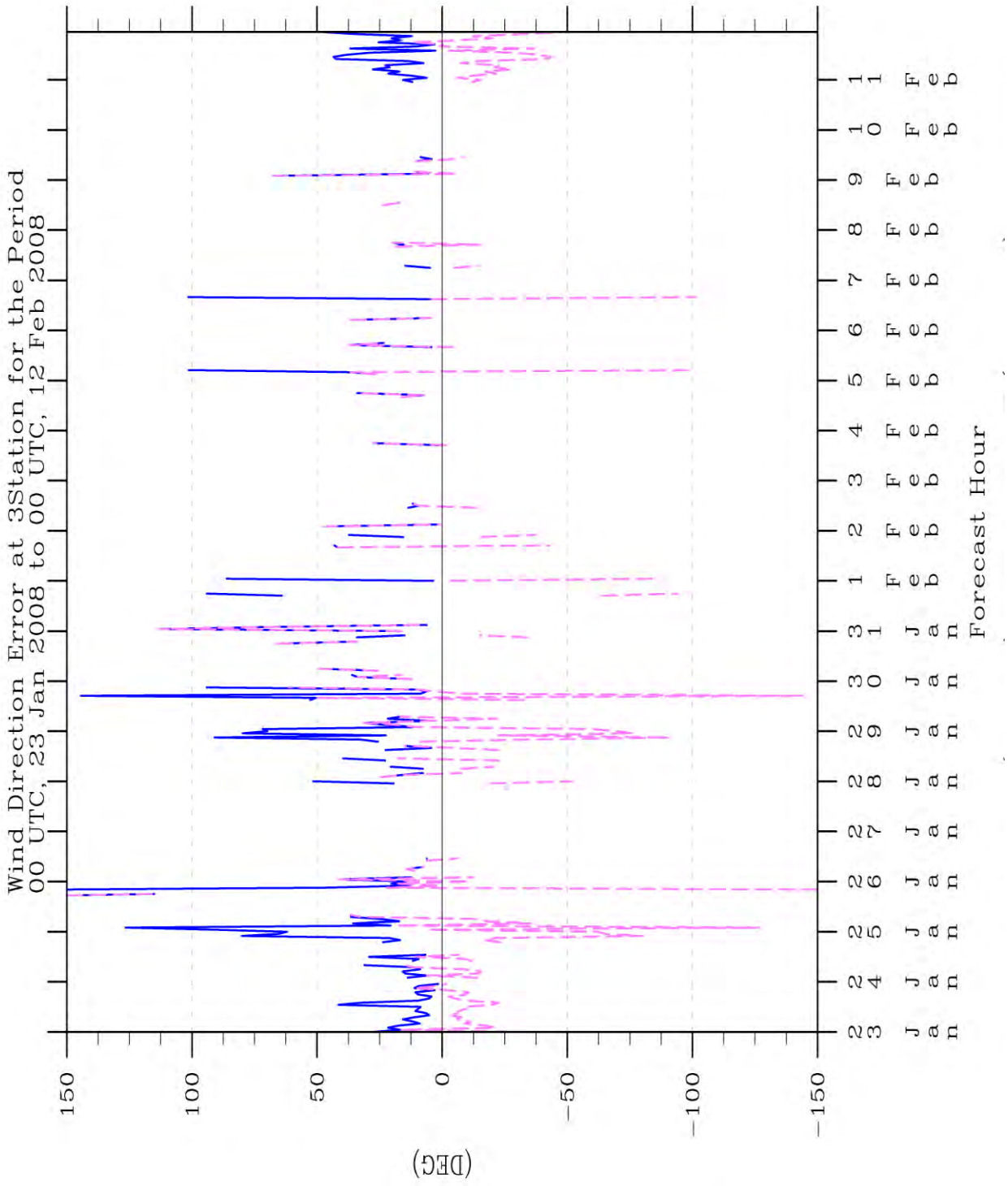


Figure 78: Time series of wind direction mean absolute error (blue) and mean error (magenta) statistics for all three stations in TWIND2X30.

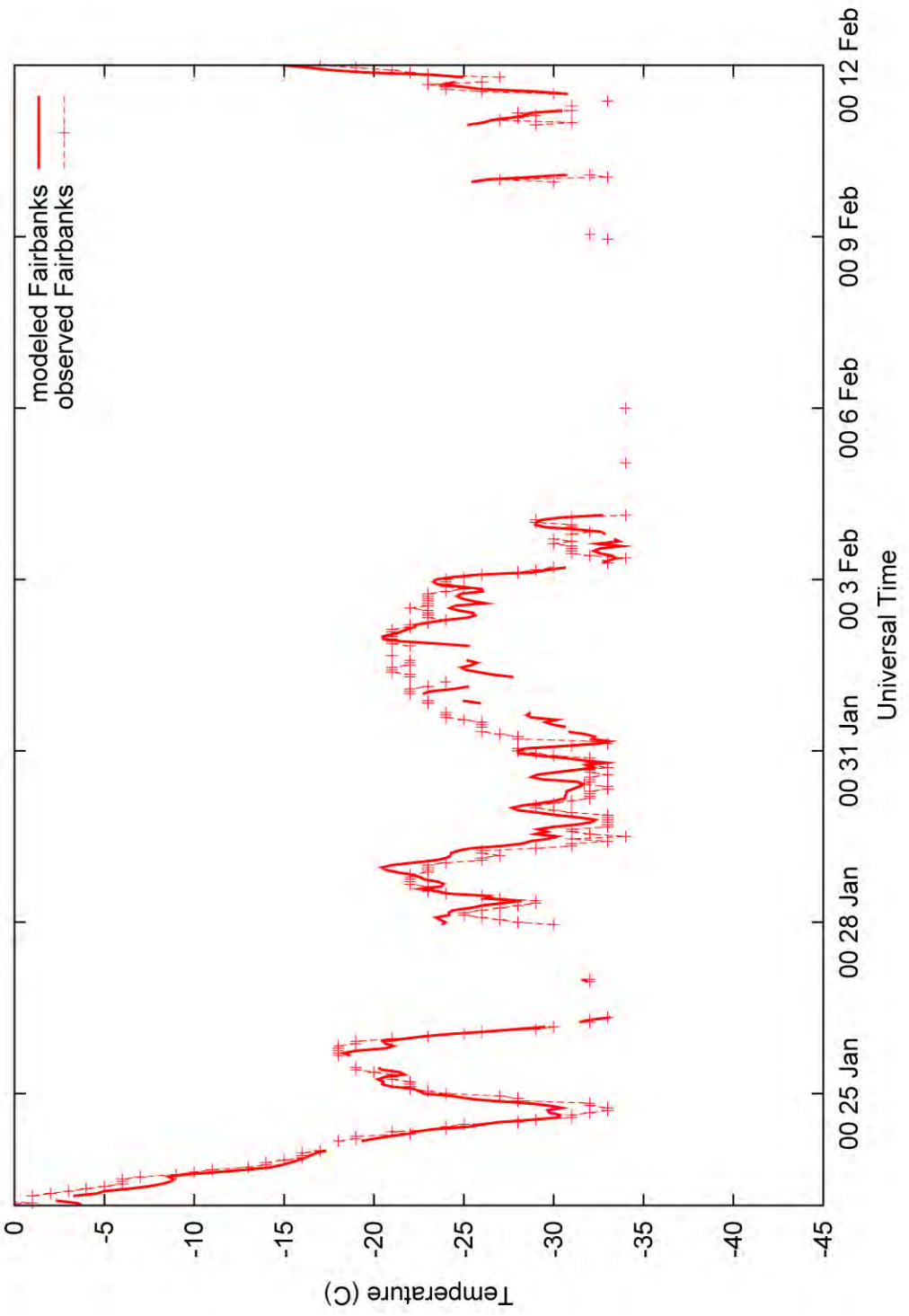


Figure 79: Time series of modeled and observed temperature for Fairbanks in TWIND2X30.

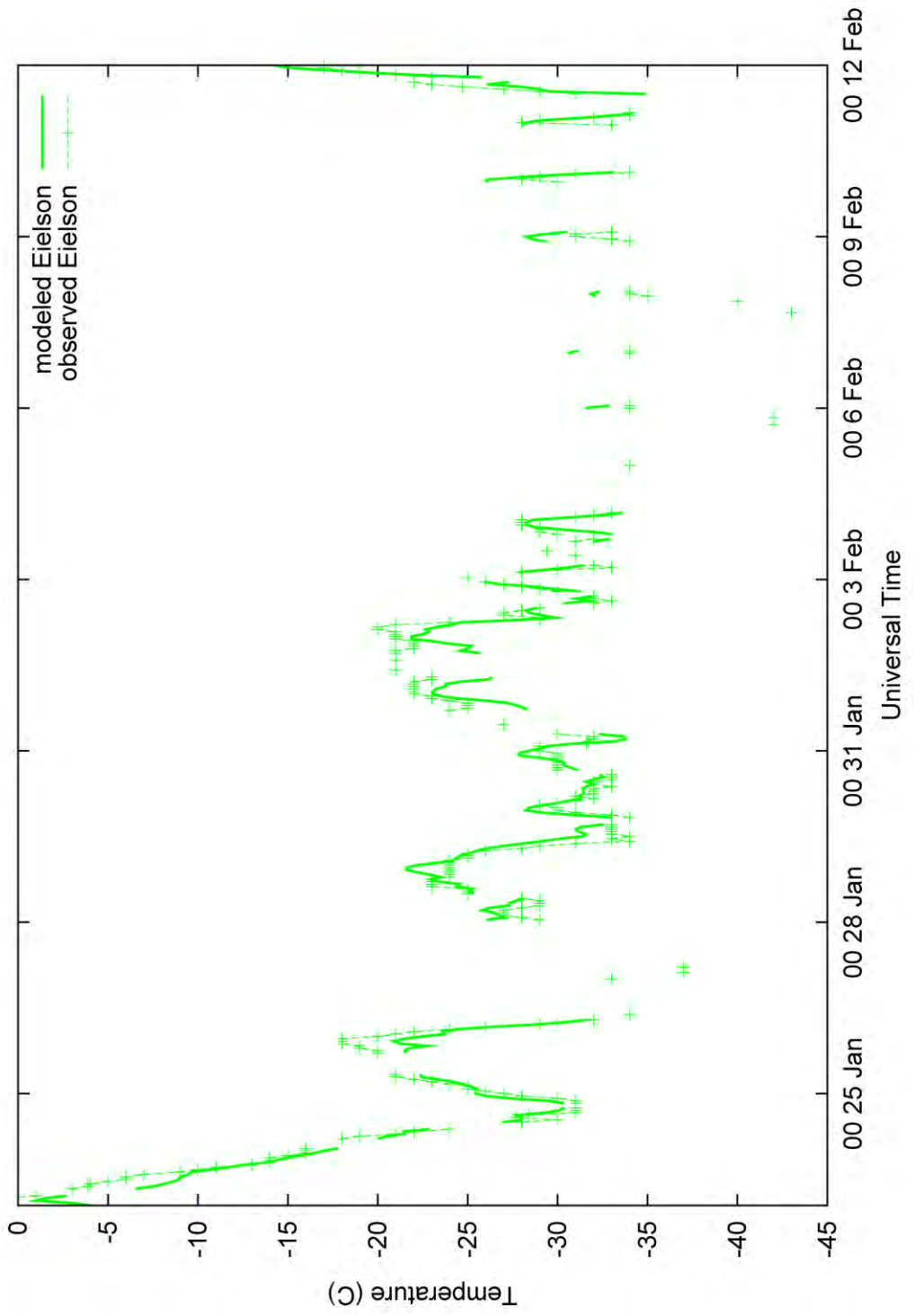


Figure 80: Time series of modeled and observed temperature for Eielson in TWIND2X30.

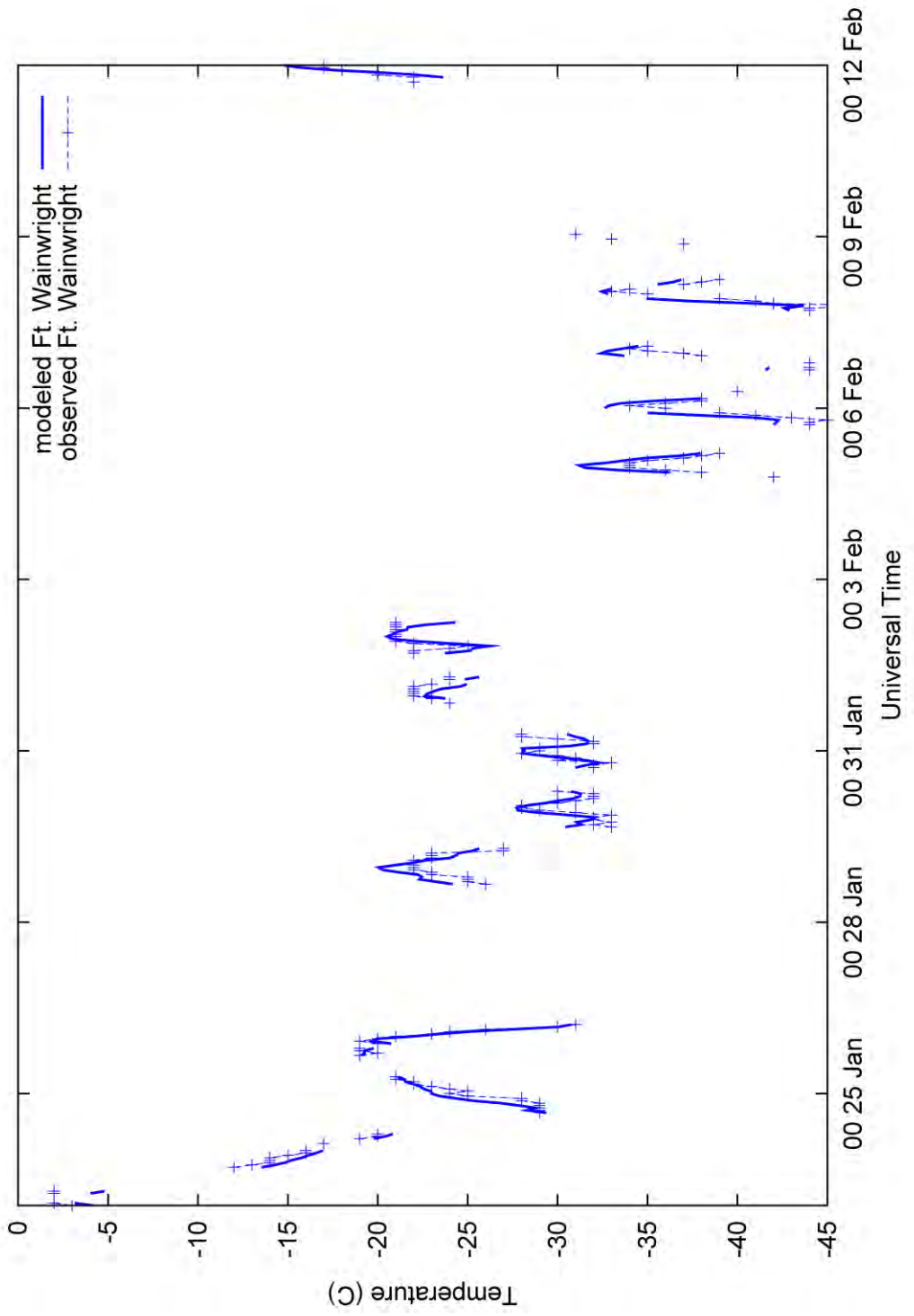


Figure 81: Time series of modeled and observed temperature for Ft. Wainwright in TWIND2X30.

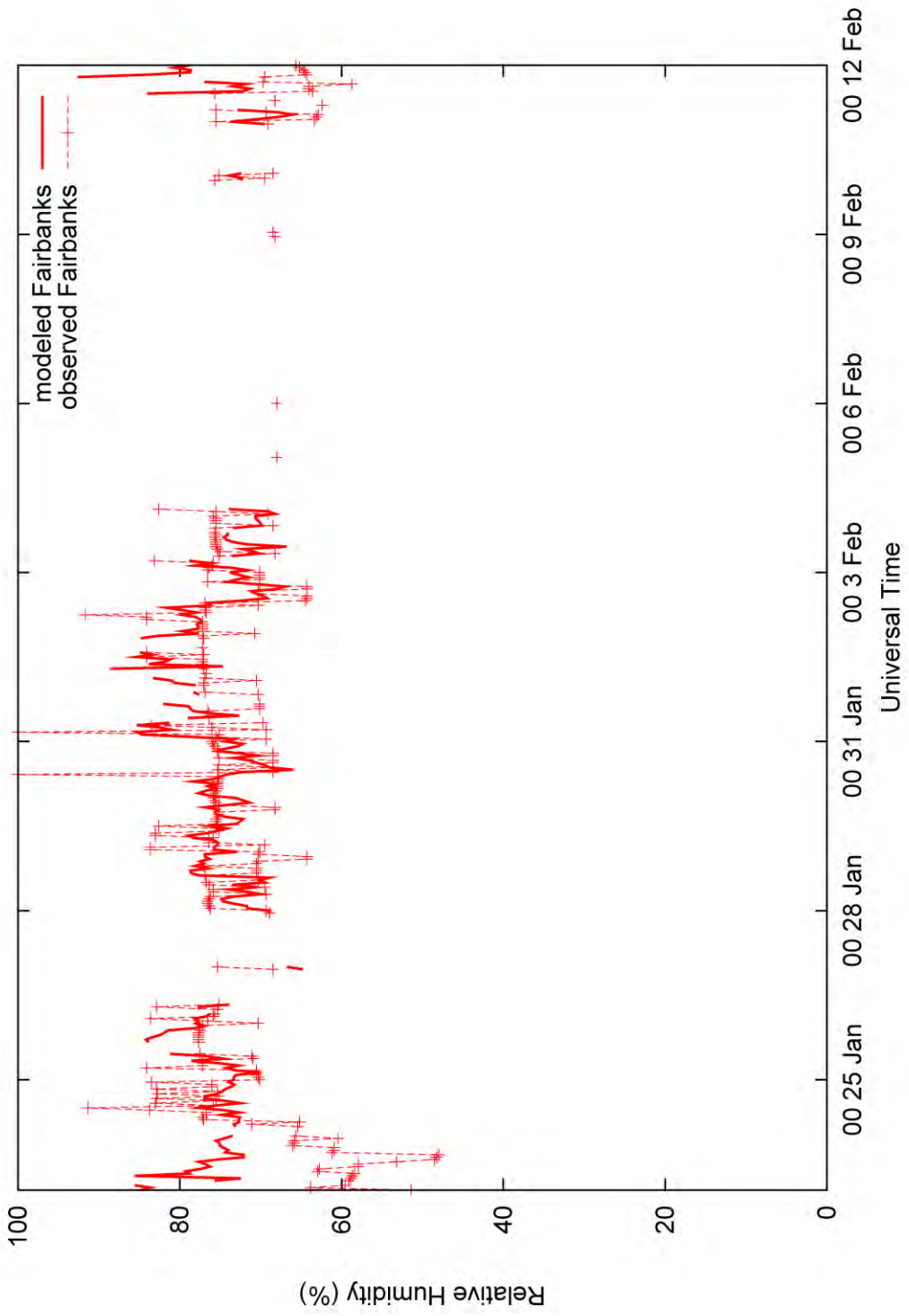


Figure 82: Time series of modeled and observed relative humidity for Fairbanks in TWIND2X30.

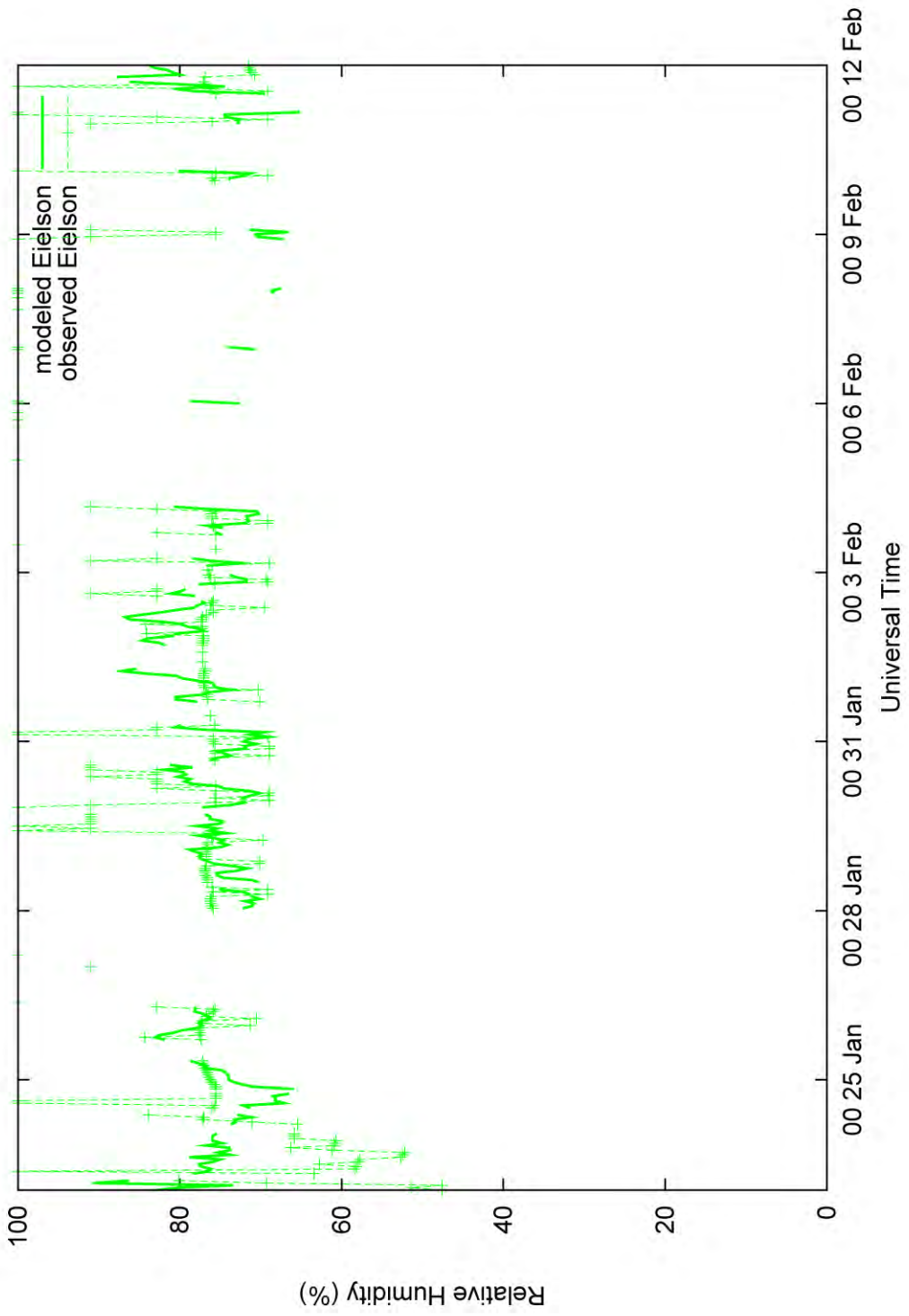


Figure 83: Time series of modeled and observed relative humidity for Eielson in TWIND2X30.

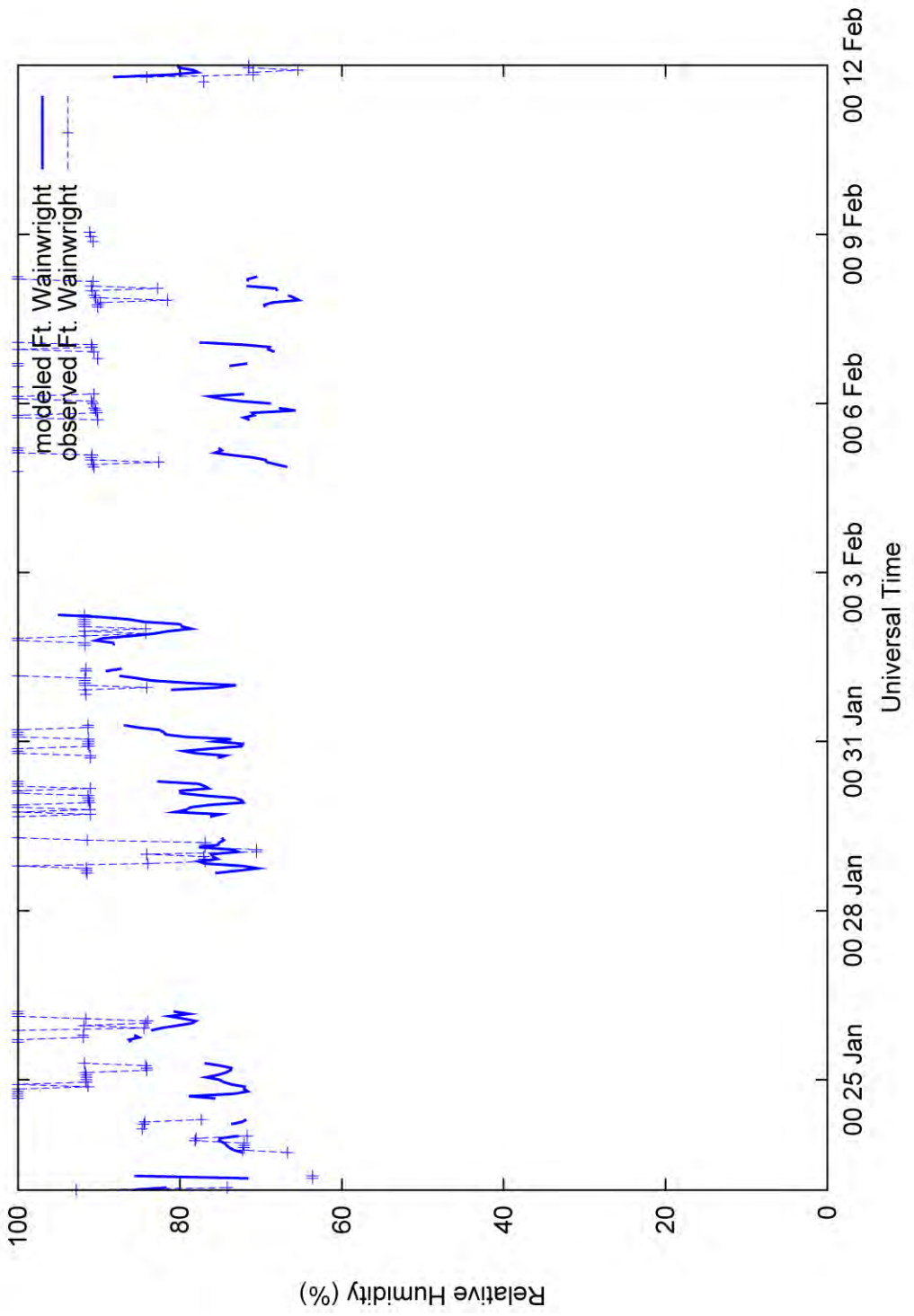


Figure 84: Time series of relative humidity for Ft. Wainwright in TWIND2X30.

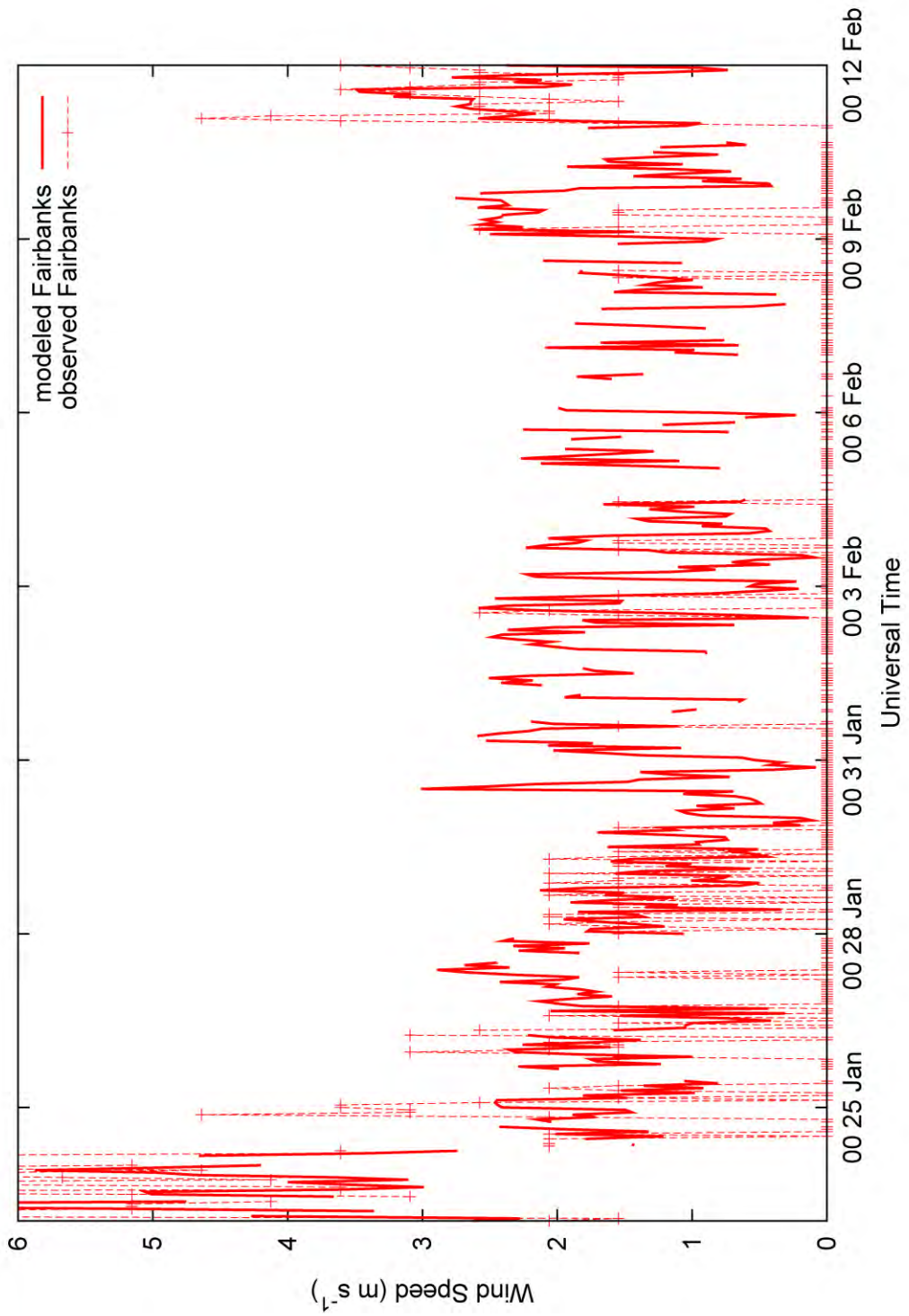


Figure 85: Time series of modeled and observed wind speed for Fairbanks in TWIND2X30.

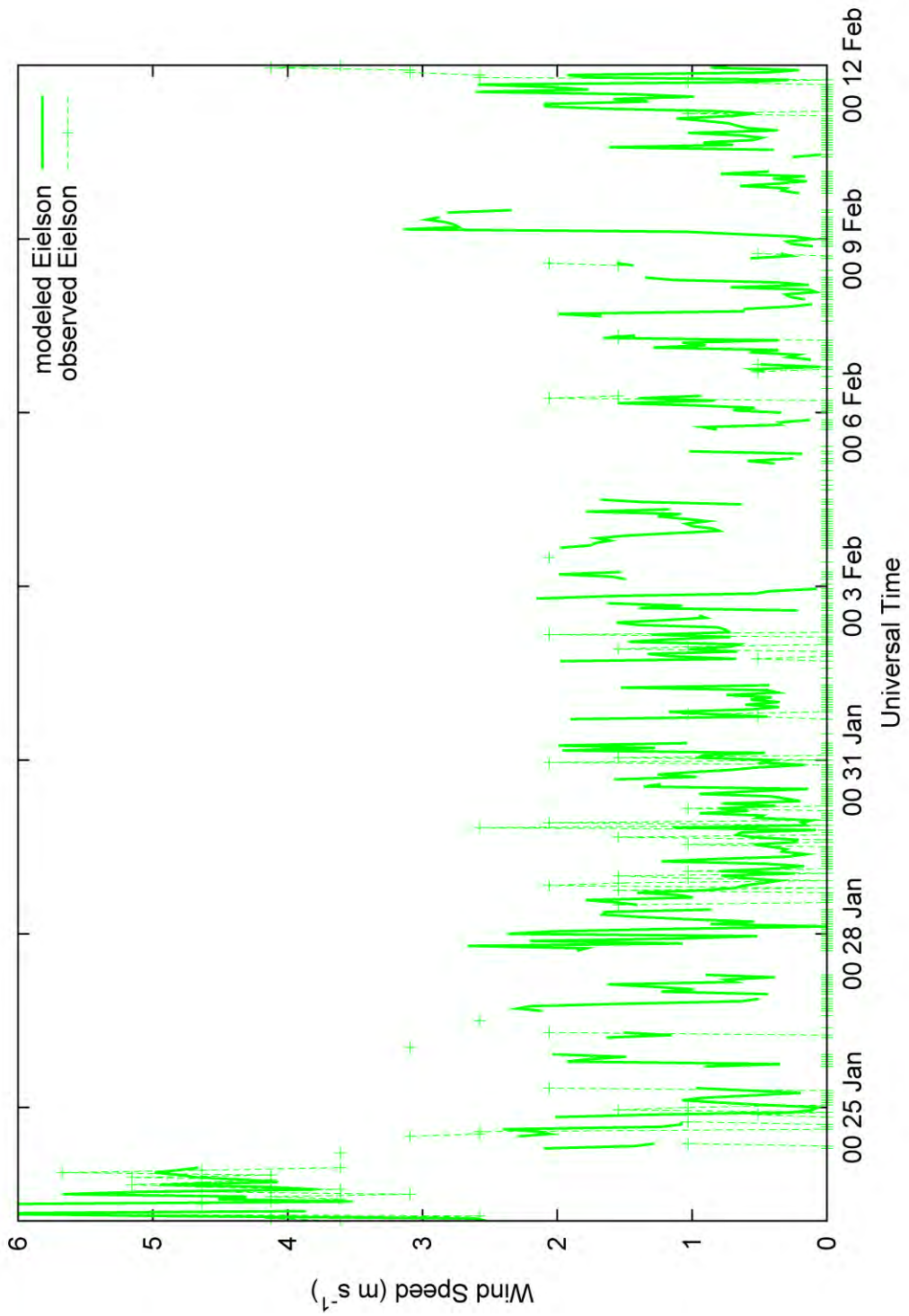


Figure 86: Time series of modeled and observed wind speed for Eielson in TWIND2X30.

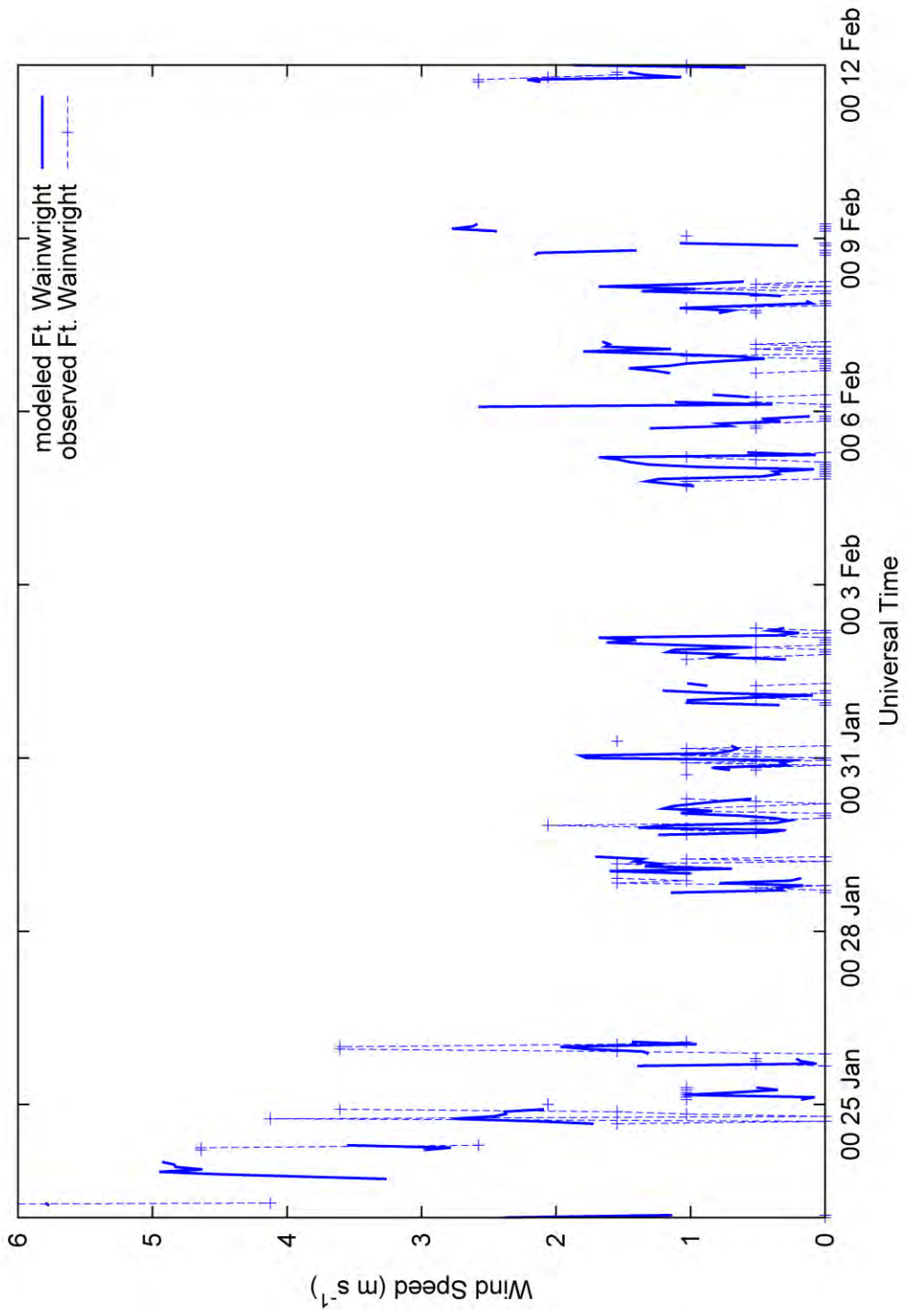


Figure 87: Time series of modeled and observed wind speed for Ft. Wainwright in TWIND2X30.

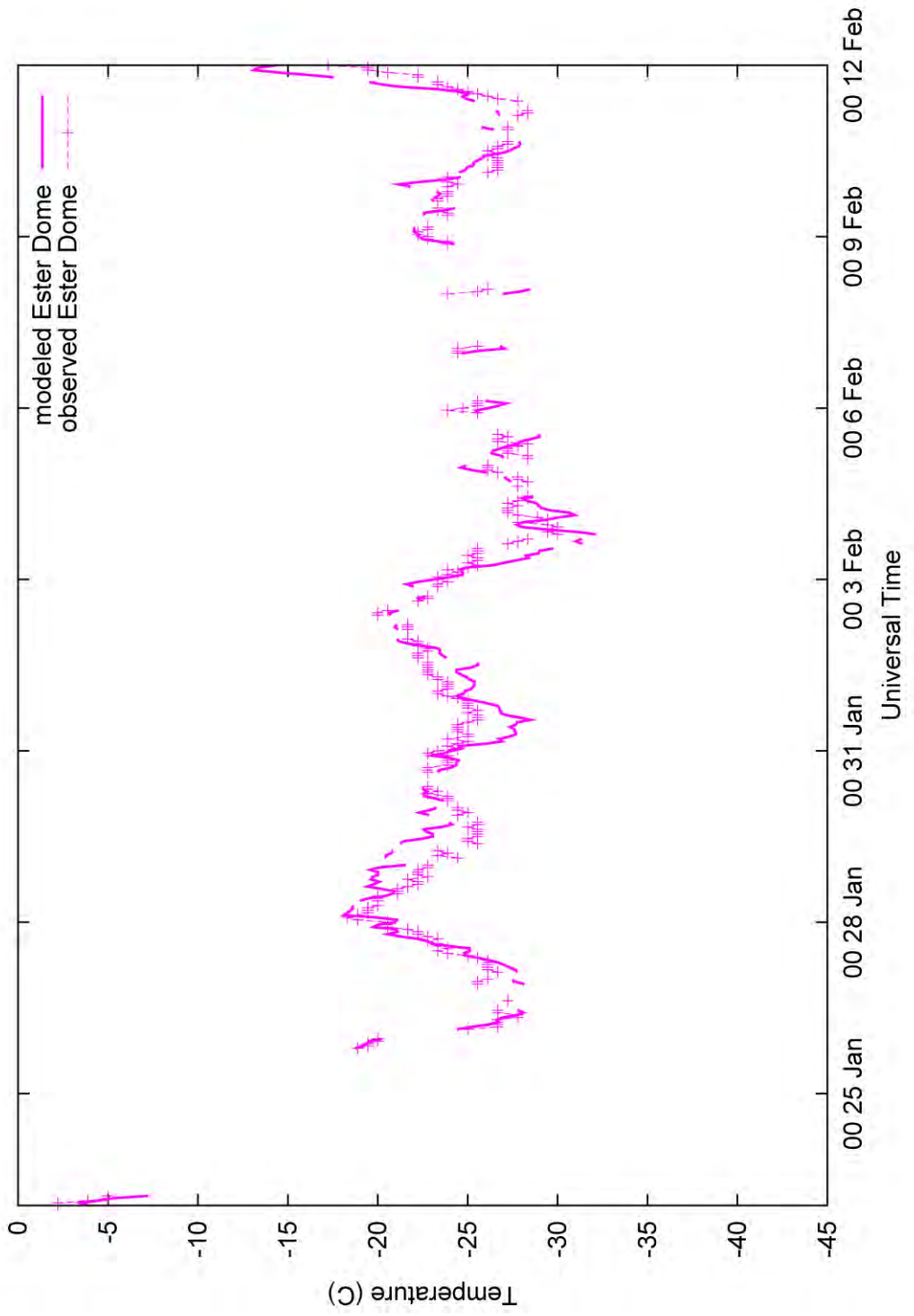


Figure 88: Time series of modeled and observed temperature for Ester Dome in TWIND2X30.

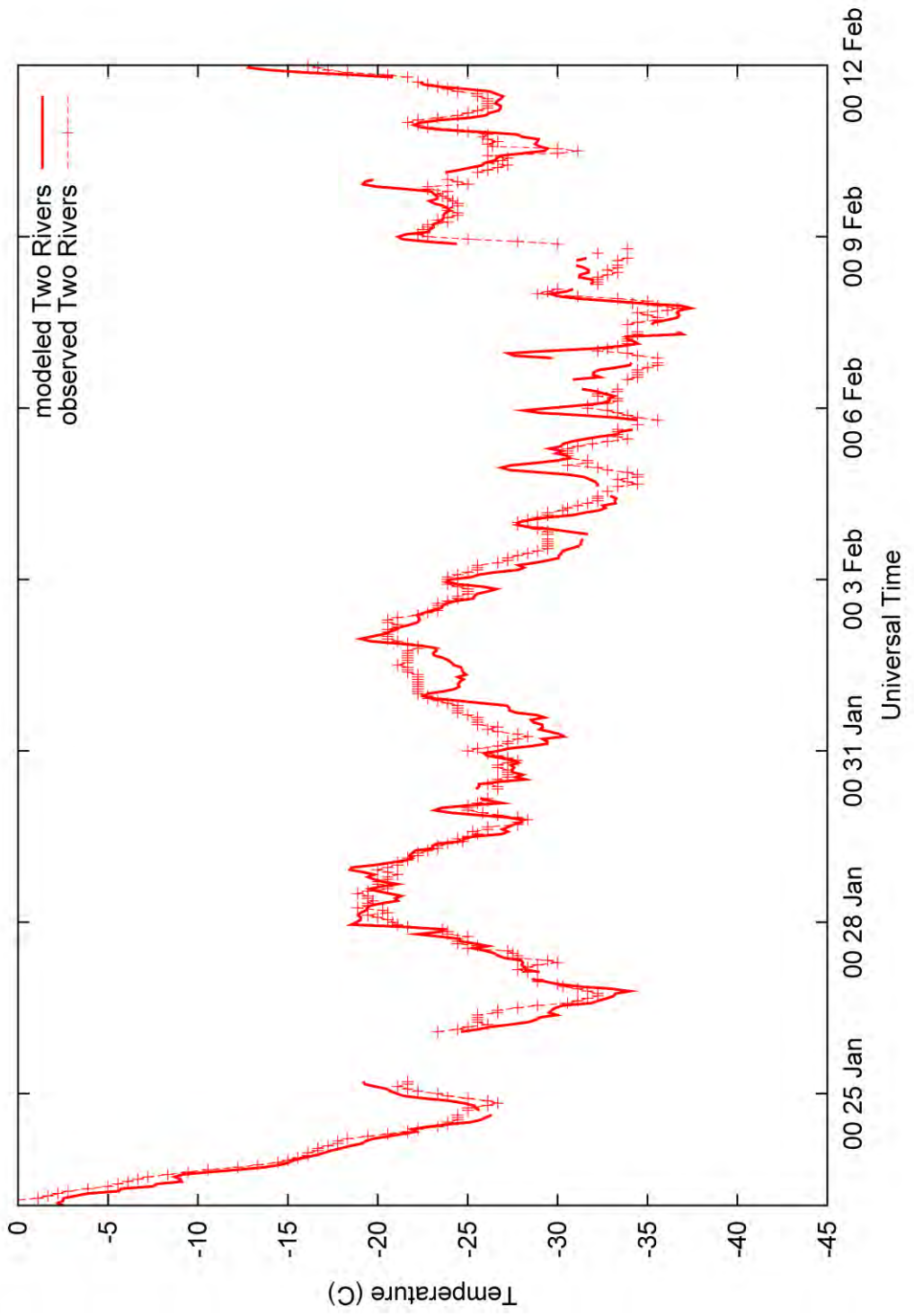


Figure 89: Time series of modeled and observed temperature for Two Rivers in TWIND2X30.

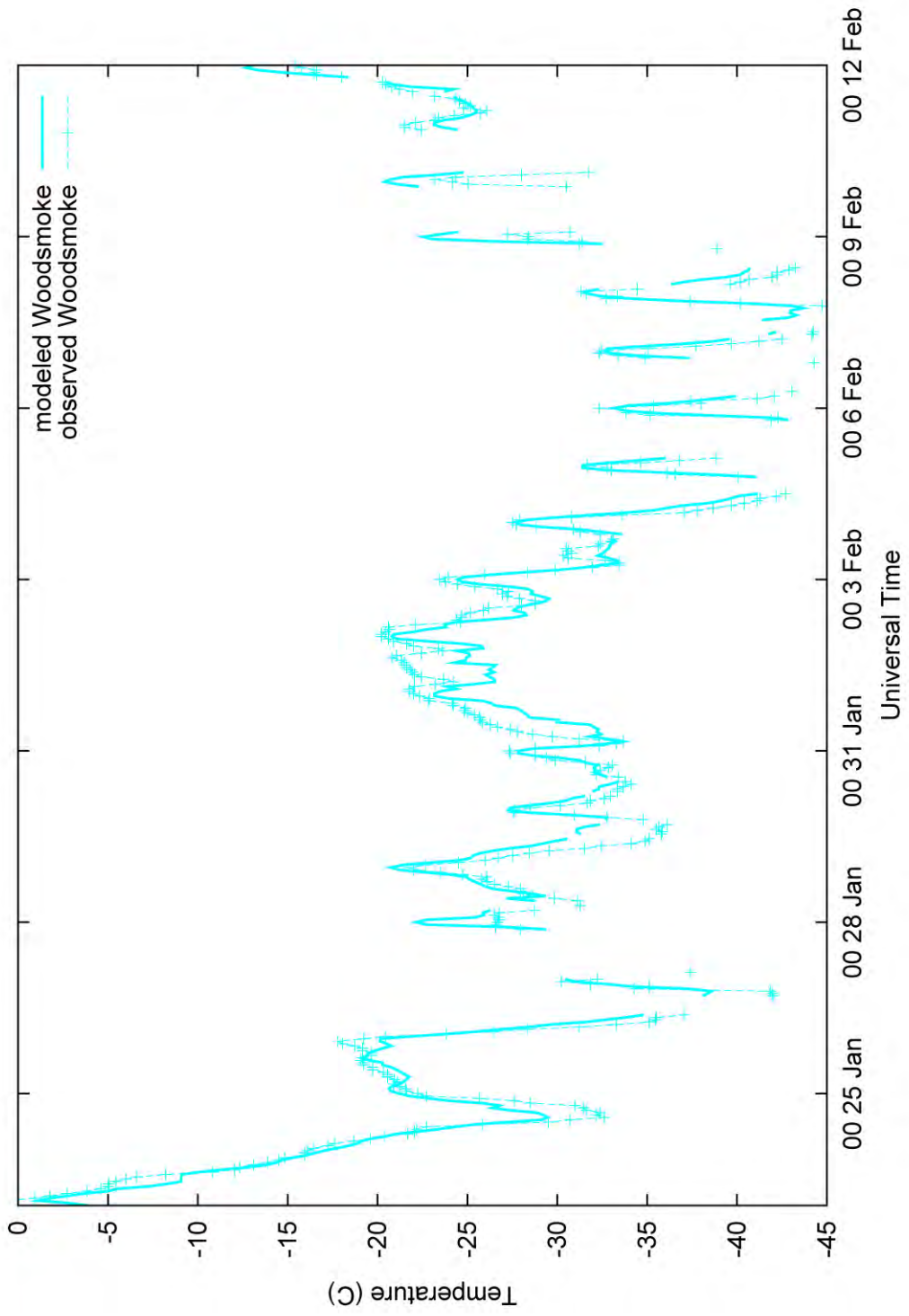


Figure 90: Time series of modeled and observed temperature for Woodsmoke in TWIND2X30.

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Reconciling Trends in Carbon Measurements for Fairbanks 2006-2010

Summary

A February 2009 change from the Met One SASS sampler using a NIOSH analysis methodology to the URG3000N sampler using an IMPROVE analysis methodology has resulted in an inconsistency in the particulate carbon measurement history for Fairbanks, Alaska. In order to develop a consistent history of speciated particulate matter for the region, these two carbon data sets must be reconciled. A number of journal articles and presentations have attempted to address this issue across a number of regions (Cheng 2011a, Chow 2010, Frank 2010, Schichtel 2010). Reconciliation of the total carbon (TC) and organic carbon (OC) across measurement techniques and analysis techniques proves difficult due to sampling artifacts and analysis methodology differences (McDow 1990). The elemental carbon (EC) discrepancies only occur due to the latter (McDow 1990). The design period for Fairbanks spans the years 2006 through 2010. Due to the long history of measurements with the Met One SASS sampler using a NIOSH analysis protocol, the continued usage of the Met One SASS sampler at other sites in the region, and given that the modeling episodes both occur in 2008, the best practice would be to correct the newer URG3000N IMPROVE measurements of EC/OC to reflect NIOSH-like values.

Sampler Differences

A comparison of the two samplers used in Fairbanks has shown that the higher face velocity and smaller filter area of the URG3000N reduce a positive artifact present in the SASS sampler from adsorbed OC. The positive artifact reduction reduces the overall total carbon. However, the higher face velocity of the URG3000N also results in a negative artifact due to evaporative losses of semi-volatile materials (McDow 1990). The overall difference in carbon is therefore a reduction of a positive artifact from SASS and introduction of a negative artifact from URG3000N. The magnitude of these changes is difficult to assess even with collocated samples (Chow 2010). There are multiple sites in and around Fairbanks that continue to use the Met One SASS sampler. At this time, however, there is no quantitative comparison of the magnitude of these sampling artifacts for Fairbanks, so direct comparisons cannot be made between the samplers at different sites. A value judgment of which sampler is best suited for conditions in Fairbanks is not possible as the URG3000N is not collocated with any of the Met One SASS samplers.

Analysis Differences

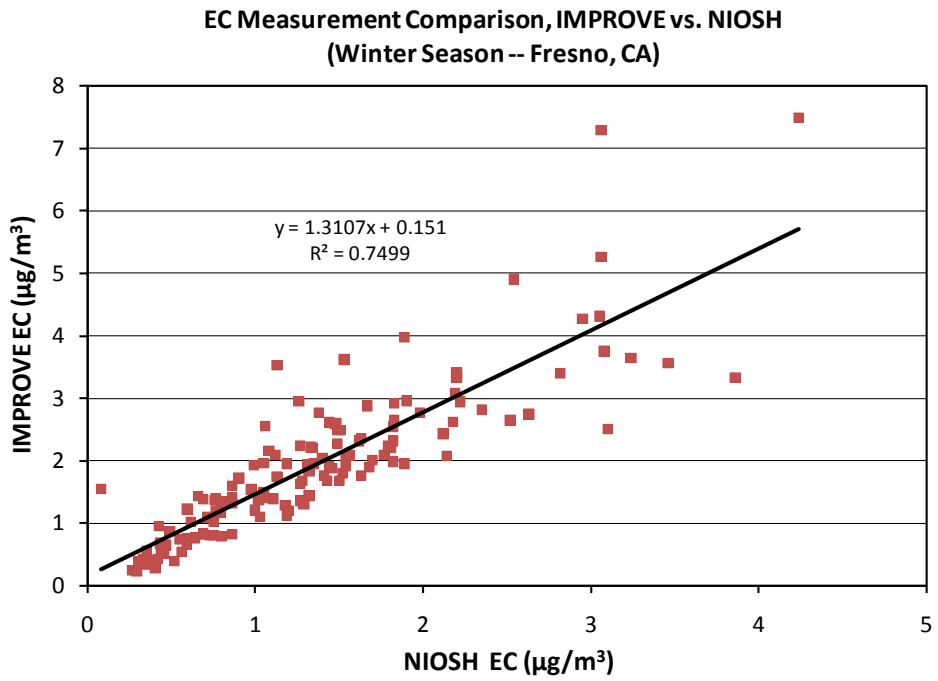
A further complication is the ongoing debate about the merits of the NIOSH and IMPROVE protocols for representing EC and OC. While the OC can be influenced by the sampler itself due to adsorption and evaporation, the EC should remain relatively the same between two samplers (McDow 1990). However, the EC (as well as OC) will vary depending on the analysis technique employed (IMPROVE, NIOSH, TOT, TOR). The literature suggests that the EC shift seen when comparing NIOSH and IMPROVE techniques is largely driven by the products of wood

combustion (Schauer 2003, Chow 2001). The choice of TOR versus TOT can also have a significant impact on the measurement of EC (Chow 2004, Cheng 2011b).

Proposed Changes

Using collocated IMPROVE and CSN sampler data from Fresno, CA from the years 2004 through 2009 an IMPROVE to NIOSH correction factor for EC has been developed. Figure 1 shows the EC concentrations as measured for the winters in Fresno, CA. The emissions source mix for Fresno, CA in the winter seems the most comparable to Fairbanks as it does include a significant amount of wood smoke as compared to other sites with collocated samplers. The conversion for IMPROVE EC to NIOSH EC would follow the equation y=1.3107x + 0.151, where y is the IMPROVE EC and x represents NIOSH EC. In this context, IMPROVE implies the use of the URG3000N sampler and NIOSH implies the Met One SASS. Corrected EC values would then be used to derive the corrected OC.

Figure 1
EC Correlation between the Collocated IMPROVE and CSN Samplers



Conclusion

Considering the unsettled nature of these debates, it seems the best course of action is to rely on the weight of the historical measurement data which used the Met One SASS sampler and NIOSH protocol to correct the newer IMPROVE data. This sampler and analysis technique were employed for the bulk of the design period 2006 through early 2009 and also cover the episodes in 2008 for which CMAQ simulations are already underway. An additional concern is the ability to compare the carbon measurements at the downtown site with the other monitor sites in and around Fairbanks. At present, there are no other sites using the URG3000N with IMPROVE analysis in the region. Adjusting the IMPROVE carbon measurements represents a more efficient means of comparing data gathered at multiple sites in Fairbanks. Considering that EC should differ only from the change in analysis protocol, not the change in samplers, an EC correction factor should be devised based on collocated sampler data from a region with comparable sources and meteorology to Fairbanks. Thus far the best data set appears to be from a site in Fresno, CA. The corrected EC can then be used to derive a corrected OC concentration for the period of 2009 through 2010. Going forward, the Fairbanks North-Star Borough will maintain a collocated Met One SASS sampler at the downtown site. Filters from the collocated sampler will be analyzed using the NIOSH protocol to provide a basis for comparing against the URG3000N IMPROVE sampler as well as other monitor sites in Fairbanks.

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Investigation of means for $PM_{2.5}$ mitigation through atmospheric modeling

Final report Phase I
12/1/08 – 12/31/10

Prepared for the Fairbanks North Star Borough

By

Nicole Mölders, Huy N.Q. Tran and Ketsiri Leelasakultum

Geophysical Institute and College of Natural Sciences and Mathematics
Department of Atmospheric Sciences

April 2011

Summary

The Alaska adapted Weather Research and Forecasting model incline coupled with a chemistry package is used to assess the situation of $PM_{2.5}$ concentrations in the Fairbanks $PM_{2.5}$-nonattainment area in the winter months, to explore two mitigation scenarios and to assess the role of point-source emissions for the $PM_{2.5}$ concentrations at breathing level. The evaluation of the model results by the few data available suggests overall acceptable performance of WRF/Chem. WRF/Chem was chosen, as this research model was an air-quality model that was already adapted and tested for Alaska conditions.

Simulations were performed with WRF/Chem with and without consideration of point-source emissions for November 2005 to February 2006. The results suggest that point-source emissions contribute to the $PM_{2.5}$-nonattainment problem, but are not the main cause.

Two mitigations scenarios were performed for October 2008 to March 2009. The first mitigation scenario was a direct one as it assumed reduction of $PM_{2.5}$-emissions by replacing non-certified wood-burning devices with certified wood-burning devices while keeping emissions from all non-wood burning sectors the same. Comparison of the reference simulation that assumes business-as-usual, with the various simulations assuming replacement of non-certified wood-burning devices indicates that such replacements reduce the $PM_{2.5}$-concentrations at breathing level. However, a small replacement program that leads to only 6% reduction of $PM_{2.5}$-emissions on average is insufficient to achieve attainment. According to sensitivity studies, the magnitude of $PM_{2.5}$-concentration reductions at breathing level depends strongly on the number and kind of devices replaced, and the assumed partitioning of heating among devices in households with more than one heating device. Further uncertainty results from the unknown location of wood-burning devices.

Since $PM_{2.5}$ is not only emitted, but also can form by physio-chemical processes (gas-to-particle conversion) in the atmosphere from precursor gases, the second mitigation scenario addressed an indirect strategy to achieve mitigation of the $PM_{2.5}$ problem by reducing an important precursor of $PM_{2.5}$ namely sulfur. This emission-reduction scenario assumed the introduction of low sulfur fuel for domestic heating and use in all oil-burning facilities (e.g. oil-burning power plants) if they did not already use low sulfur fuel. This simulation was also performed for October 2008 to March 2009. Comparison of the results of the simulations suggest that on average over the entire winter and nonattainment area, a slightly higher reduction of $PM_{2.5}$-concentrations can be achieved when introducing low sulfur fuel than for the small wood-burning device replacement program assumed in the other emission reduction scenario. However, the results also suggest that locally and temporally $PM_{2.5}$-concentrations may increase after introduction of low sulfur fuel due to shifts in the equilibria of precursor concentrations. The increase is due to a shift towards more formation of nitrate that has a higher mass than sulfate. Note that introduction of low sulfur fuel not only changes the emissions of SO_2, but also the emissions of other species released during the combustion of oil and hence causes a shift in the distribution of precursors. The effect of such shifts in precursors on the equilibria depends on temperature, light and moisture conditions. The aforementioned meteorological conditions all affect gas-to-particle conversion and hence the production of $PM_{2.5}$ in the atmosphere. Since introduction of low sulfur fuel may, under certain conditions, lead to increased, instead of decreased $PM_{2.5}$-concentrations, a woodstove replacement program seems to be the safer way to achieve mitigation than a measure that tries to achieve mitigation indirectly.

Calculation of the relative response factors and new design values suggests that none of the scenarios assumed in this study may alone lead to attainment. Therefore, combined measures and/or other measures like enhancement of the use of gas should be examined in the future.

1. Brief description of Fairbanks' nonattainment problem

In 2006, the Environmental Protection Agency (EPA) tightened the previous 24h National Ambient Air Quality Standard (NAAQS) for particulate matter (PM)[1] with diameter <2.5µm ($PM_{2.5}$) from 65µg/m^3 to 35µg/m^3. The annual $PM_{2.5}$ standard of 15µg/m^3 remained. Data collected by the Fairbanks North Star Borough (FNSB) and faculty at the Geophysical Institute (GI) indicate that in the past years 24h-average $PM_{2.5}$ concentrations[2] exceeded the new standard frequently (cf. Fig. 1). Since in previous years, the measurements at the official PM measurement site of the FNSB at the State Building exceeded the new NAAQS for $PM_{2.5}$ repeatedly, a $PM_{2.5}$ nonattainment area was assigned.

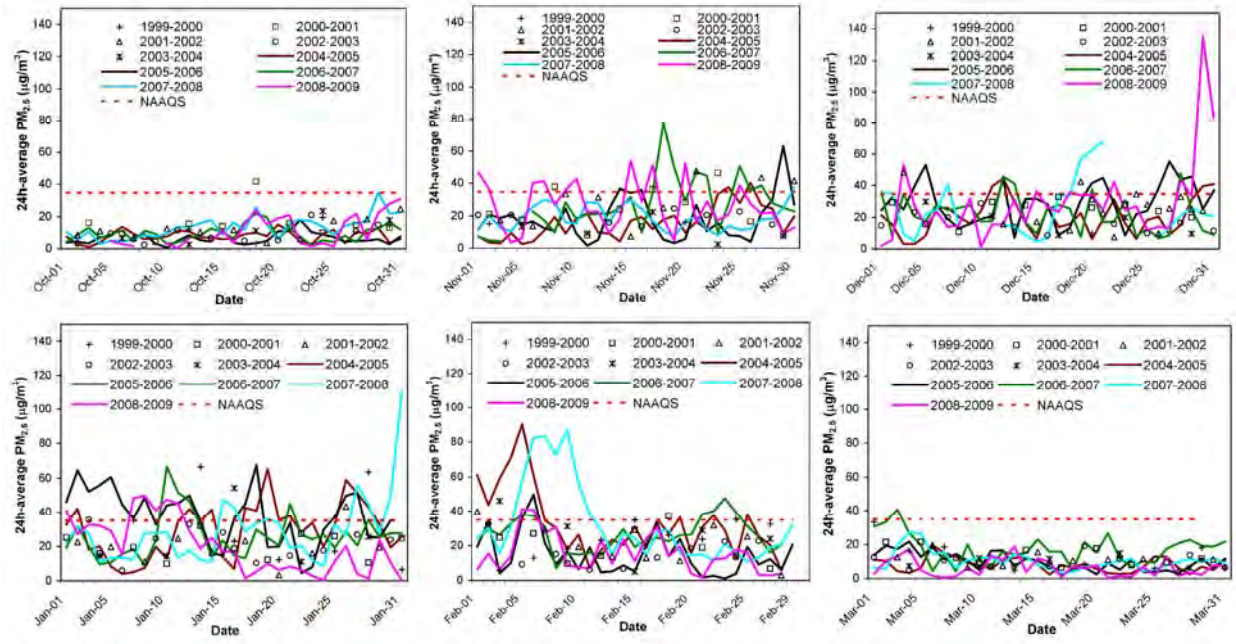

Fig. 1. $PM_{2.5}$ concentrations measured in downtown Fairbanks from October 1 to March 31 in various years from 1999 to 2009. Modified after *Tran and Mölders* [2011]

In Fairbanks, exceedances typically occur during the cold season (October to March) hereafter referred to as winter, and the fire season (summer) [*Tran and Mölders*, 2011]. In Alaska summer, fire events frequently create $PM_{2.5}$ concentrations well in excess of levels deemed "unhealthy". However, these events may be excluded from being considered as an exceedance if it can be proven that the exceedance was due to a particular event [*EPA*, 2007]. While exceedances due to fires may be considered as "natural events" under the aforementioned circumstances, the exceedances in winter are due to anthropogenic activity.

Analysis of available data showed that there are various factors contributing to the $PM_{2.5}$ exceedances in winter: topography, weather, and emissions[3] [*Tran and Mölders*, 2011].

[1] Particulate matter is often also called particulates. Here PM are tiny subdivisions of solid matter suspended in the atmosphere.
[2] Concentration refers to the amount of a substance per defined volume. Typically, concentration is expressed in terms of mass per unit volume (e.g. µg/m^3).
[3] Emission refers to the release of gases and/or particulate matter into the atmosphere, i.e. a flow. Typically, emissions are expressed in terms of mass per unit area per time (e.g. kg/(m^{2}s)).

Fairbanks' being located at the edge of an air-mass source region[4] yields low wind-speeds, and cold air that remains in place over long time [*Tran and Mölders*, 2011]. In addition, wintertime radiative cooling leads to inversions, i.e. a temperature increase with height[5]. Fairbanks experiences strong semi-permanent inversions with temperature differences of 5-10K from the basis close to the earth's surface to the top of the inversion during the period from November to February [*Bourne et al.*, 2010]. Such inversions hinder the vertical exchange of air. Consequently, if an inversion is present, $PM_{2.5}$ and other pollutants will accumulate in the air underneath the inversion, and will potentially lead to $PM_{2.5}$ exceedances [*Tran and Mölders*, 2011]. The fact that Fairbanks is surrounded by hills further contributes to the low exchange of polluted and clean air masses. Other meteorological factors affecting concentrations are mixing height, atmospheric stability, longevity and strength of inversions [*Mölders and Kramm,* 2010].

Heat and energy production as well as traffic are the main sources for $PM_{2.5}$ emissions. In winter, roughly 30% of the $PM_{2.5}$ in downtown Fairbanks may stem from traffic [*Johnson et al.*, 2009]. Pervious studies [*Davies et al.*, 2009] indicate that non-certified woodstoves and wood-boilers strongly contribute to the $PM_{2.5}$ emissions from the heating sector. Another source for $PM_{2.5}$ is gas-to-particle conversion a process that occurs naturally in the atmosphere [e.g. *Kumar et al.*, 2010].

Trace gases that are emitted are referred to as primary pollutants. Pollutants resulting from reaction of primary pollutants and other naturally available gases are called secondary pollutants. Particulate matter that is emitted is called primary PM. Secondary PM forms already in the plumes, but also elsewhere in the atmosphere, from gas-to particle conversion. Any $PM_{2.5}$ that results from gas-to-particle-conversion is called secondary $PM_{2.5}$ hereafter.

The term aerosol refers to solid and liquid particles suspended in the atmosphere. Aerosols can exist in the nucleation, accumulation and coarse mode. Aerosols in the coarse mode typically stem from mineral dust and ash fly from biomass burning. The terms *nucleation mode* and *accumulation* mode denote the mechanical and chemical processes that produce aerosol particles in these two size ranges.

In the nucleation mode, the aerosols are the smallest. They are produced by *gas-to-particle conversion*. Gas-to-particle conversion produces particles when trace gases react with other gases or particles that exist in the atmosphere or when trace gases absorb solar radiation that leads to photochemical reactions. In the nucleation mode, most aerosol particles consist of sulfuric compounds, and stem from the oxidation of sulfur containing precursor gases (like SO_2, H_2S, CS_2, COS, CH_3SCH_3, and CH_3SSCH_3) to sulfate (SO_4^{2-}), and subsequent condensation into particle form. This process is called homogenous gas-to-particle conversion. These tiny highly mobile sulfate aerosol particles can coagulate. Much of the sulfate aerosol from gas-to-particle conversion finally ends up in the 0.1-1.0µm size range. Sulfur dioxide (SO_2), for instance, can yield the formation of various sulfates in the presence of ammonia (NH_3) and water vapor via gas-to-particle conversion. Sources for SO_2 in the atmosphere are volcanic emissions, and emissions from fires, traffic, power-production and combustion for heating. Important anthropogenic sources for ammonia are domesticated animals and fertilizer.

[4] An air-mass source region is a region over which air remains frequently for a long enough time that the surface affects the air mass' temperature and moisture properties substantially.

[5] Under normal conditions, temperature decreases with height in the troposphere. Temperature inversion means that temperature increases with height. Inversion layer refers to the atmospheric layer within that such an increase exists.

Gas-to-particle-conversion forms ammonium (NH_4^+) $PM_{2.5}$ by the reaction of ammonia in the gas-phase with sulfur, nitrogen, and other acidic species forming ammonium nitrate and ammonium-sulfate particulate matter. $PM_{2.5}$ ammonium nitrate, for instance, forms from the NO_x-reaction by-product nitric acid and ammonia.

Nitrate (NO_3^-) containing aerosols typically exceed 1µm in diameter, i.e. they do not form by homogenous, but heterogeneous gas-to-particle conversion processes. They also may stem from evaporation of droplets, among other things.

In the accumulation mode (0.1-2.5µm in diameter), *coagulation* of smaller particles and/or *heterogeneous condensation* of gases onto existing particles produce particles. The largest mass and amount of particles occur in the accumulation mode due to the lack of efficient removal mechanisms for these particles.

The term secondary aerosol refers to particles that are produced by precursor gases, condensation and other processes in the atmosphere. This means that $PM_{2.5}$ can be released in the atmosphere from emissions, or be produced in the plume of stacks or in the atmosphere by gas-to-particle conversion. Primary aerosol refers to particles directly emitted into the atmosphere as particles. Primary aerosols produced by combustion span all three size ranges.

Measurements by the FNSB show a large spatial and temporal variability in $PM_{2.5}$ concentrations (e.g. Figs. 2, 3). The reasons for the observed spatial variability in $PM_{2.5}$ concentrations are manifold. In business districts dominated by central heating, traffic usually contributes more than in low-traffic residential areas dominated by heating with coal, wood or oil. $PM_{2.5}$ emissions from traffic, power plants and home heating with oil also depend on sulfur content [e.g. *Johnson et al.*, 2009]. $PM_{2.5}$ concentrations at breathing level depend on the emissions and meteorological factors like temperature, mixing height, atmospheric stability, longevity and strength of inversions [*Dawson et al.*, 2007; *Mölders and Kramm*, 2010; *Tran and Mölders*, 2011].

Fig. 2. $PM_{2.5}$ concentrations as measured in Fairbanks by the mobile platforms (lines of dots) on 12-29-2008 during the drive starting at 1523 AST (Alaska Standard Time). Measurements have been also made in the hills and the North Pole area (not shown here). Single dots are the $PM_{2.5}$ concentrations as measured at the stationary sites. Color code: deep green 0-35 $\mu g/m^3$, olive 35-105 $\mu g/m^3$, orange 105-210 $\mu g/m^3$, red 210-350 $\mu g/m^3$, and >350 $\mu g/m^3$ grey. Courtesy to *F. di Genova* [2009]

Due to the temperature dependency of chemical reaction [e.g. *Seinfeld and Pandis*, 1997] secondary pollutants, gas-to-particle-conversion and the emissions from energy and heat production differ for warm and cold atmospheric conditions. For $PM_{2.5}$ ammonium nitrate formation not only the NO_x reaction by-product nitric acid and ammonia have to be available, but also temperatures must be low and relative humidity must be high [*Wexler and Seinfeld*, 1992]. This means that the local change rate $\partial[C]/\partial X$ in concentration [C] with changes in the meteorological quantity X can differ in winter from those in summer or in other words is different for Fairbanks' winter conditions as compared to winter conditions in a warmer climate.

As previously indicated, $PM_{2.5}$ is a complex mixture of components − nitrate, sulfate, organic carbon, elemental carbon (EC) other primary particulate matter, ammonium and water − that show strong seasonal variations (Fig. 3) due to differences in sources, temperature and humidity. Analysis of previous measurements suggests that the burning sector and especially wood-burning strongly contribute to the high $PM_{2.5}$ concentrations in the FNSB (e.g. Fig. 3).

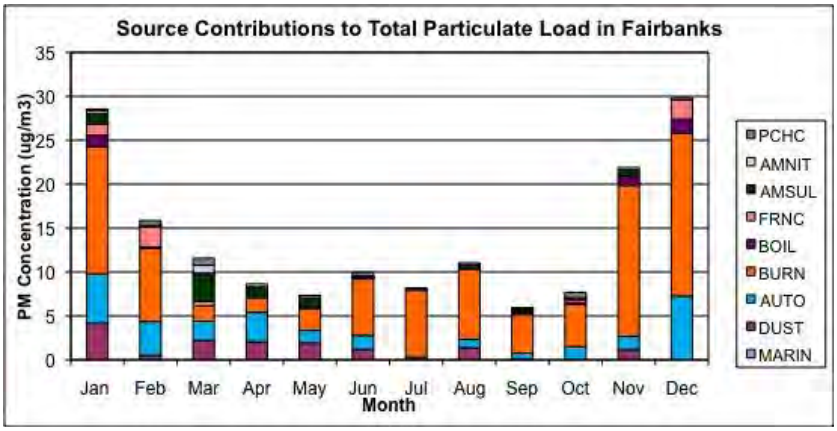

Fig. 3. $PM_{2.5}$ composition in Fairbanks. PCHC, AMNIT, AMSUL, FRNC, BOIL, BURN, AUTO, DUST and MARINE stand for coal-fired power plant, ammonium nitrate, ammonium sulfate, furnace, industrial boilers, biomass burning, automobiles, soils, and marine $PM_{2.5}$. Courtesy to *C.F. Cahill and A.N. Wallace* [2010]

If no action is taken to reduce the $PM_{2.5}$ concentrations in Fairbanks, Fairbanks will likely exceed the $PM_{2.5}$ standard in winters in the future. Such non-compliance is expected to have significant social, health and/or economic impacts on Fairbanks, the FNSB and their citizens.

The EPA, FNSB, Alaska Department of Environmental Conservation (DEC), Alaska Health & Social Services and scientists are concerned about the $PM_{2.5}$ concentrations in Fairbanks as $PM_{2.5}$ has various known health adverse effects. For instance, exposure to airborne $PM_{2.5}$ is associated with cardiovascular events and mortality in elderly and cardiac patients [*Riediker et al.*, 2004]. Various studies indicate that people − especially children − living in close proximity to roadways show more respiratory symptoms, decreased lung function, more respiratory hospitalizations and increased incidence of asthma than their peer groups in other environmental conditions [e.g. *McCreanor et al.*, 2007]. Climate-geographical location plays no role and a pre-existing family history of asthma is not required, i.e. living close to heavy traffic or heavily industrialized areas is the important factor [*Gordian* 2010; pers. communication]. Investigations on healthy young men who were exposed to $PM_{2.5}$ from road traffic suggest that these men experienced pathophysiological changes that involve inflammation, coagulation and cardiac rhythm [*Riediker et al.*, 2004].

2. Selection of the air quality model

Obviously, no exposure to any pollutants would avoid adverse health impacts from air pollution, but this is impossible to realize. The current NAAQS were set according to the best scientific knowledge to protect human health. These values are re-evaluated from time to time to adjust to newest scientific findings if required. Often tightening the NAAQS requires emission regulations. Such emission regulations may have enormous socio-economic impacts for both public and private stakeholders. Therefore, it is helpful to assess the effectiveness of a potential regulation and/or the contribution of an emission source sector being under suspicion to strongly contribute to the exceedance of the new NAAQS.

Photo-chemical models of various complexity have been used for a long time to examine (1) the relation between meteorological conditions and air quality, (2) the formation and distribution of acid rain, (3) air-quality issues, and (4) the role of long-range transport of pollutants for air quality [e.g. *Chang et al.*, 1989; *Mölders et al.*, 1994; *Grell et al.*, 2000, 2005; *Tetzlaff et al.*, 2002; *Otte et al.*, 2005; *Yu et al.*, 2008; *Eder et al.*, 2009; *Mölders et al.*, 2010]. The use of such air-quality models for emissions permits and/or for regulatory purposes has a long tradition not only at EPA [*EPA*, 2009]. Recently, ambient air-quality modeling has been used successfully to estimate individual and population exposure for human health research in mid-latitudes [e.g. *Bell* 2006].

The great advantage of photo-chemical models is that they permit easily to change emissions in the model world. The model then provides the atmospheric response, i.e. the concentrations that result in response to the altered emissions. This means photo-chemical models permit us to answer "What …if" questions like

- "What will happen to the $PM_{2.5}$ concentrations at breathing level if we replace a certain amount of non-certified wood-burning devices by EPA certified wood-burning devices?"
- "What will happen if we reduce the sulfur content in fuel used for domestic heating and power productions?"

They also permit us to assess the contribution of an emission source of interest to the $PM_{2.5}$ concentrations at breathing level, and answer questions like

- "What do the power plants contribute to the $PM_{2.5}$ concentrations at breathing level?"

Modeling is a useful tool to access in which direction emission-reduction efforts will go, how the altered emissions in combinations with the various chemical and meteorological processes affect the concentrations, and what the impact of emissions sources are. To answer such questions it is necessary to perform at least two simulations. One simulation considers the emissions as they are currently (business-as-usual). This simulation is the reference simulation and provides the baseline. The second simulation that is applied for the same meteorological condition as the first one, considers the emissions of the altered emission scenario (e.g. the change in emissions in response to a "woodstove exchange program"). Comparison of the results of the simulations permits us to assess how much the concentrations change in response to the altered emissions.

The goal of this study was to conduct photo-chemical model simulations with a complex state-of-the-art research model to quantify numerically the potential impacts of various emission reduction scenarios on the $PM_{2.5}$ concentrations at breathing level in Fairbanks, the Fairbanks nonattainment area and its adjacent land. These modeling studies in combination with various

other investigations related to Fairbanks' nonattainment problem [e.g. *Davies et al.*, 2009; *Carlson et al.*, 2010], ongoing studies and measurements are to help policy makers in the decision making process on which measures to apply to decrease the $PM_{2.5}$ levels in the future and to inform the public.

The Weather Research and Forecasting model inline coupled with a chemistry model commonly known as WRF/Chem [*Grell et al.*, 2005] is a state-of-the-art photo-chemical research model[6] based on the newest scientific knowledge. It simulates the meteorology and the trace-gas and aerosol cycles from emission, through a variety of chemical reactions, to transport, and finally removal from the atmosphere by wet or dry deposition. WRF/Chem can consider feedbacks between chemistry and meteorology.

WRF/Chem was chosen as it was the only photo-chemical model that was already adapted for application in Alaska [*Mölders et al.*, 2010, 2011]. These modifications, among other things, ensure Alaska-typical values of the vertical profiles of initial background concentrations (e.g., acetylene, CH_3CHO, CH_3OOH, CO, ethane, HCHO, HNO_3, H_2O_2, isoprene, NO_x, O_3, propene, propane, SO_2) and boundary conditions. The modifications also ensure that Fairbanks and other settlements are included in the land-use data and that winter typical vegetation parameters are used from Mid-October to Mid-April. In addition, modifications concerning the stomatal behavior of Alaska vegetation and dry deposition of trace gases on snow were included [*Mölders et al.*, 2010, 2011]. Furthermore, first evaluations studies of the Alaska adapted WRF/Chem already existed that showed accepatble performance for Alaska [*Mölders et al.*, 2010, 2011]. Such studies did not exist for other photo-chemical models yet.

We used the following model setup that was capable of capturing Alaska winter conditions well in previous studies [*Mölders*, 2008; *Mölders and Kramm*, 2010; *Mölders et al.*, 2010; *Yarker et al.*, 2010]. The WRF-Single-Moment six-class scheme that allows the coexistence of super-cooled water droplets and ice-crystals and processes among the solid and liquid phase cloud and precipitation components, served to simulate resolvable cloud- and precipitation-formation processes [*Hong and Lim*, 2006; *Hong et al.*, 2006]. It is able to simulate falling snow crystals and ice fog, which are of relevance for Fairbanks in winter. To consider the impact of the cumulus convection even though it rarely occurs in Fairbanks winters, we used the cumulus-ensemble scheme [*Grell and Dévényi*, 2002] as it is well suitable for the grid-resolution at which WRF/Chem was run for this study. The Goddard two-stream multi-band scheme was used to calculate shortwave radiation processes. It considers, among other things, the impacts of clouds and ice fog on shortwave radiation. This is important as the shortwave radiation affects photolysis rates. Long-wave radiation was calculated with the **R**apid **R**adiative **T**ransfer **M**odel [*Mlawer et al.*, 1997] that takes into account multiple spectral bands, trace gases, and cloud microphysical species (cloud-droplets, rain drops, ice-crystals, etc.), among other things. It allows considering the effects that pollution, ice fog and clouds have on long-wave radiation. The 1D-prognostic scheme by Janjić [2002] was applied to determine turbulent processes[7] in the atmospheric boundary layer[8] (ABL), i.e. the first 1000m or so above ground level (AGL). For the

[6] Note that WRF/Chem is a complex state-of-the-art research model, not a regulatory model.
[7] Turbulence refers to rapid fluctuations.
[8] The ABL is the lowest part of the atmosphere that is directly influenced by its contact with the surface. In the ABL, turbulence and vertical mixing can be strong.

atmospheric surface layer[9], i.e. the first 100m or so, Monin-Obukhov similarity hypotheses were used to describe the turbulent processes; the so-called Zilitinkevich thermal roughness-length concept was considered for the underlying viscous sublayer [*Janjić*, 1994]. Previous studies showed that out of various parameterizations available in WRF/Chem these parameterizations of ABL and surface layer processes provide the best results most of the time for Interior Alaska [e.g. *Mölders and Kramm*, 2010]. Simulating the ABL processes adequately is required to capture inversions and their strength and hence the accumulation of pollutants underneath. *Smirnova et al.*'s [2000] land-surface model (LSM) was used to determine the exchange of heat and moisture at the land-atmosphere interface. This LSM calculates, among other things, the soil-temperature and moisture states including frozen soil, snow conditions at various depths in the snow-pack, and vegetation impacts on the atmosphere. The LSM was chosen as it considers permafrost and snow processes. Simulating these processes adequately is important to capture the strength of inversions.

The chemical mechanism by *Stockwell et al.* [1990] served to calculate gas-phase chemistry, i.e. reactions among trace gases. This mechanism considers the chemical reactions that occur in the polluted and non-polluted atmosphere at day and night. Inorganic reactions and constants involve 14 stable inorganic compounds, four inorganic short-lived intermediates and three abundant stable species (oxygen, nitrogen, water). The organic chemistry scheme considers 26 groups of stable organic compounds and 16 groups of organic short-lived intermediates (peroxy radicals). Photolysis frequencies were calculated in accord with *Madronich* [1987] as even at winter solstice Fairbanks still experiences 3.7h of sunlight. These frequencies were used in the calculation of photochemical processes. Photolysis calculation considered 21 photo-chemical reactions. In mid latitudes, the chemical processes during daylight (daytime chemistry) differ from those at night (nighttime chemistry). In Fairbanks, however, the fraction of the day with daylight strongly differs over the winter. In Fairbanks, the sun is only a few hours above the horizon in January and December, while it is appreciably longer above the horizon to provide energy for photochemical processes in October, November, February and March. Thus, the importance of photochemical processes and their contribution to chemical transformations differs strongly over the winter due to the large differences in available shortwave radiation (see Fig. 11c). Thus, "daytime" and "nighttime" chemistry play a different role in January and December than the other winter months. Therefore, it was considered necessary to simulate several months rather than a short episode in the coldest month.

Various processes (transport, turbulence, evapotranspiration, sorption, desorption, biogenic activity, emission, settling, chemical reactions) are involved in the dry deposition process, i.e. the removal of trace gases from the atmosphere. Thus, dry deposition not only depends on the physical and chemical states of the atmosphere, but also on the surface on which the trace gases and particles deposit. The formulation of dry deposition [*Wesely*, 1989] with the modifications introduced by *Mölders et al.* [2011] considers these processes. The modifications serve to treat dry deposition of trace gases more realistically under low temperature conditions and consider dry deposition on snow. Since the stomata of Alaska vegetation often are still open at $-5^{o}\mathrm{C}$, the threshold for total stomata closure was lowered accordingly in the LSM and deposition module.

[9] In the atmosphere, surface layer refers to the layer where the turbulent air is most affected by interaction with the surface. The characteristics of the turbulence depend on the distance from the surface. The surface layer is characterized, among other things, by large concentration gradients of any substances transported to or from the surface.

Aerosol chemistry and physics was treated based on a modified version of the Regional Particulate Model [*Binkowski and Shankar*, 1995], where the vertical transfer of particulate matter is treated in accord with *Kramm et al.* [1992]. Among other things, the aerosol module considers aerosol chemistry and physics, and aerosol formation by gas-to-particle conversion, and Secondary Organic Aerosol (SOA) formation processes [*Schell et al.*, 2001] and the removal of particulate matter from the atmosphere by wet and dry deposition of aerosols. These aerosol chemistry modules have been well tested for mid latitudes. A through evaluation for Alaska is still missing due to lack of observational data. First evaluations with the limited data available [*Mölders et al.*, 2010, 2011] suggest acceptable performance most of the time.

3. Model domain, initial and boundary conditions

The Alaska Emission allocation Model (AkEM) [*Mölders* 2009, 2010] and WRF/Chem were set up for a domain covering most of Interior Alaska with a horizontal grid increment of $4\text{km} \times 4\text{km}$. Since Alaska available land-use data did not consider any urban areas, we introduced Fairbanks, North Pole, Eielson and the villages into the WRF/Chem land-use data file (Fig. 4) based on satellite data using Google Earth. Relevant WRF/Chem-simulated concentrations and meteorological quantities were written out hourly as a function of time and space for the domain of interest. The domain of interest for the analysis encompasses 89,600km^2 centered around Fairbanks up to 100hPa (Fig. 4).

WRF/Chem used logarithmically increasing vertical grid increments with the smallest increment being located above the ground and the largest increment reaching to the top of the model located at 100hPa. In total, there are 28 layers. In the lower troposphere, the tops of the layers were at 8, 16, 64, 113, 219, 343, 478, 632, and 824m AGL. The lowest atmospheric model layer represents the "breathing level". This vertical and horizontal grid is a compromise to ensure still sufficient vertical and horizontal resolution, and allow for several months long simulations in a reasonable amount of time.

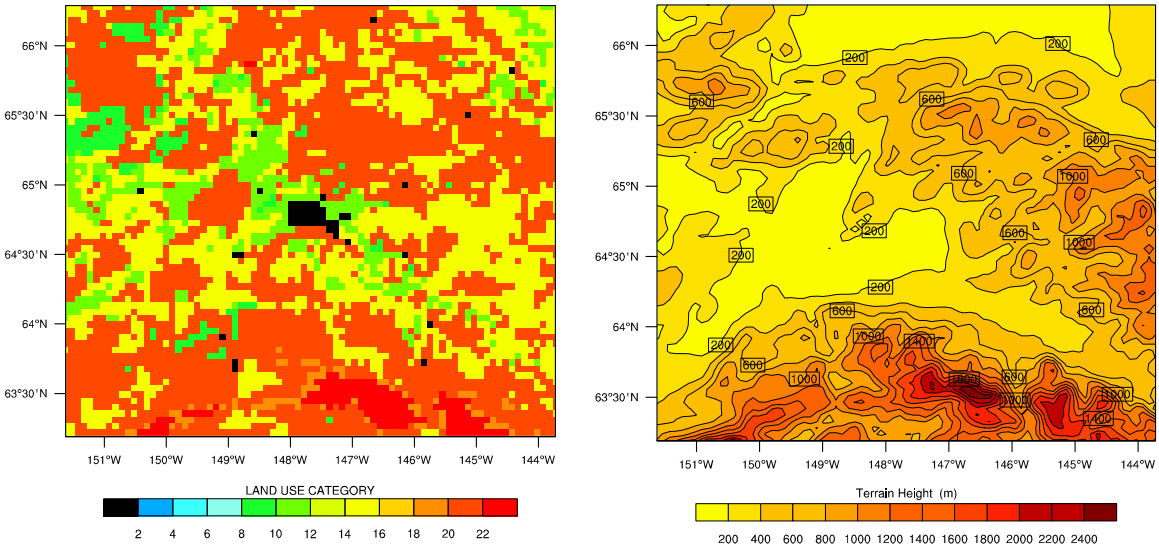

Fig. 4. Land-use (left) and topography (right) in the domain of interest for the analysis of this study. The land-use category code is 1 urban and built-up land, 2 dryland cropland and pasture, 3 irrigated cropland and pasture,4 mixed dryland/irrigated cropland and pasture, 5 cropland/grassland mosaic, 6 cropland/woodland mosaic, 7 grassland, 8 shrubland, 9 mixed shrubland/grassland, 10 savanna, 11 deciduous broadleaf forest, 12 deciduous needleleaf forest, 13 evergreen broadleaf, 14 evergreen needleleaf, 15 mixed forest, 16 water bodies, 17 herbaceous wetland, 18 wooden wetland, 19 barren or sparsely vegetated, 20 herbaceous tundra, 21 wooded tundra, 22 mixed tundra, 23 bare ground tundra, 24 snow or ice.

The meteorological fields were initialized every five days using data downscaled from the $1^o \times 1^o$, 6h-resolution National Centers for Environmental Prediction global final analyses (FNL). At the beginning of the simulations, WRF/Chem was initialized with idealized vertical profiles of Alaska background concentrations for each chemical specie (e.g., acetylene, CH_3CHO, CH_3OOH, CO, ethane, HCHO, HNO_3, H_2O_2, isoprene, NO_x, O_3, propene, propane, SO_2). For all further days, the simulated chemical fields of the previous day served as initial conditions to simulate the next day.

Since Fairbanks is far remote from any emission sources, Alaska background concentrations were used for the chemical lateral boundary conditions. The meteorological boundary conditions were downscaled and interpolated from the FNL-data.

WRF/Chem was run in forecast mode, i.e. no nudging or data assimilation was applied. The reference simulation and the simulation that was to assess the contribution of point sources to the $PM_{2.5}$ concentrations at breathing level, start with the same meteorological and chemical initial conditions on November 1, 2005 0000 UTC (see Table 1). In the mitigation investigations, the reference simulation and all mitigation scenarios start with the same meteorological and chemical initial conditions on October 1, 2008 0000 UTC (see Table 1). This procedure ensures that differences in simulated concentrations only result in response to the changes in assumed emissions.

Emissions were considered as a function of time (month, weekday, and hour) and space (latitude, longitude and height). Various types of emission sources are considered. Point sources are fixed (immobile) facilities that emit gaseous or particulate atmospheric pollutants (e.g. smokestacks, power plants, industrial plants, steel mills). A line source is one-dimensional emission source (e.g., vehicle traffic on a highway). An area source is a two-dimensional source of diffuse emissions (e.g. the emissions from domestic heating, landfills, fires). For more details, see e.g. *http://en.wikipedia.org/wiki/Air_pollution_dispersion_terminology* [2011].

In the case of point sources, emissions are released into the model levels that are calculated depending on stack parameters (stack height, stack diameter, flow temperature, flow velocity, etc.). WRF/Chem, among other things, also includes plume rise [*Peckham et al.*, 2009]. In the case of area and line sources, the model level in which the emissions are released depends on the kind of emission source. For instance, emissions from city or highway traffic are released into the first model layer above ground (Fig. 5).

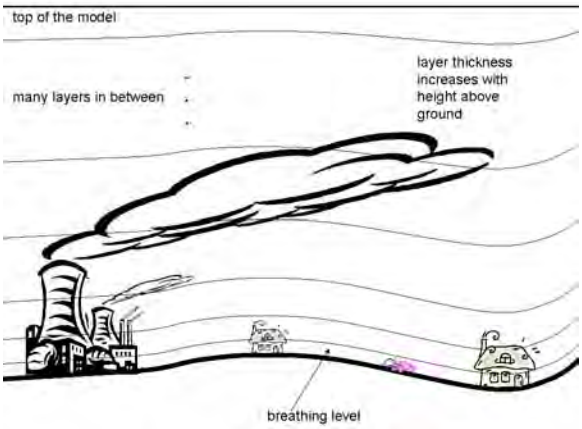

Fig. 5. Schematic view of the vertical grid structure and consideration of various emission sources. The spacing of vertical model layers increases logarithmically with height. Note that not all model layers and potential emission sources considered by WRF/Chem are pictured here.

Some Alaska plant species remain photosynthetically active up to temperatures as low as -5°C (23°F). Thus, we considered biogenic emissions of isoprenes, monoterpenes, and volatile organic compounds (VOC) by plants, and nitrogen emissions by soil as calculated by the **M**odel of **E**missions of **G**ases and **A**erosols from **N**ature [*Guenther et al.*, 1994; *Simpson et al.*, 1995] if the ground is not covered by snow.

4. Meteorological episodes simulated

At the start of the project in 2008, the most recent emission data available for the FNSB were the National Emission Inventory (NEI[10]) data of 2005. In December 2008, the FNSB expected that a gridded emission-data inventory with 400m spatial and hourly resolution representing the winter 2007/08 would be available for Fairbanks and its vicinity in April 2009 [*Conner* pers. communication, 2008]. Therefore, it was planned to switch to a more recent episode for the simulations on the impact of introduction of low sulfur fuel and a "woodstove replacement program" despite doing so would require producing an additional reference (baseline) simulation (Table 1).

4.1 Emissions

All NEI data were annual values for the various species and emission sectors in the FNSB. These emission data were allocated for use in WRF/Chem using the AkEM [*Mölders*, 2009; 2010]. Input data to AkEM are the EPA NEI data, stack parameters, data for the split of $PM_{2.5}$ and VOC, allocation data of annual, daily, hourly emission percentages for area, line, and point sources, population density data, land-use and street network data as well as meteorological data. The split of $PM_{2.5}$ emissions into ammonium (NH_4), carbon, nitrate (NO_3), potassium, sodium, and sulfate (SO_4) was made based on observations provided by the FNSB [*Conner,* 2009]. Due to the lack of observational data, we split the total anthropogenic VOC emissions into the various species like ethane, butane, formaldehyde, pentane, hexane, ethylene, propylene, acetylene, benzene, toluene, xylene, tri-methylbenzene, and other aromatics depending on emission-source types in accord with *Mölders et al.* [2011].

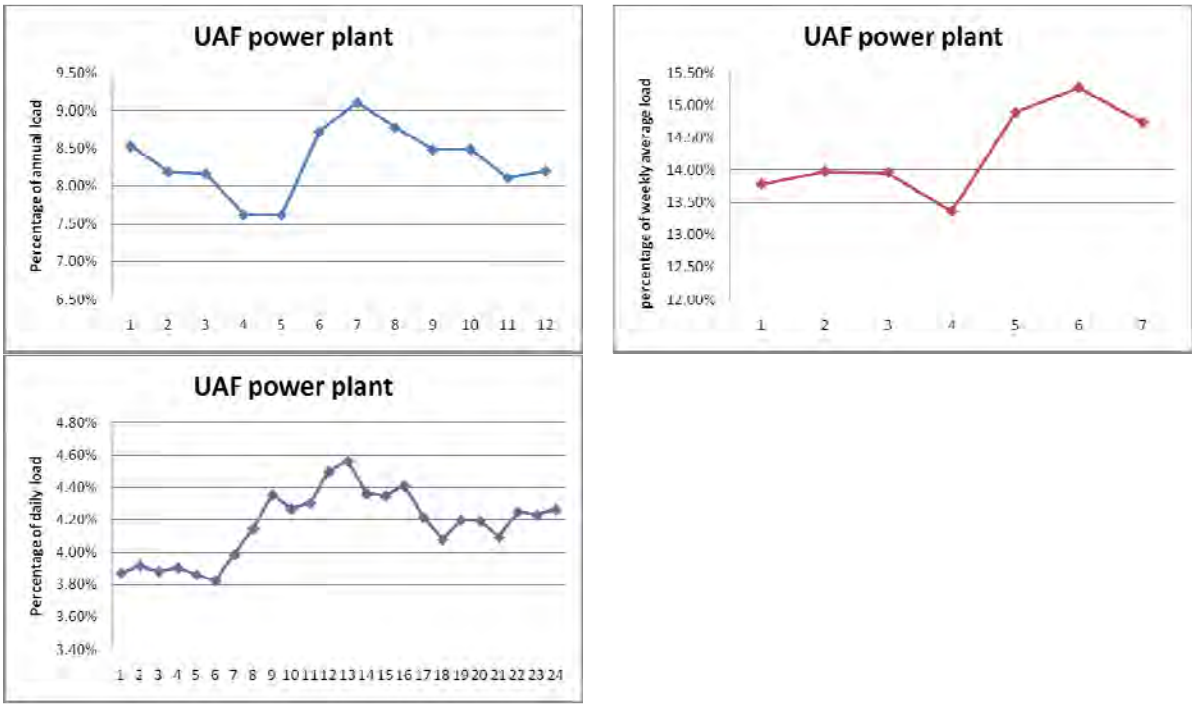

Fig. 6. Activity allocation as derived for the UAF power plant for (from upper left to lower left) monthly, weekday and hourly activity. Data courtesy by *Waard* [2008]

[10] Typically the National Emission Inventory is abbreviated as NEI and the year is added, e.g. NEI1999 would be the NEI for 1999.

AkEM calculates hourly emission rates for each grid-cell from the annual emission E_{total} given by the NEI. In doing so, AkEM uses the spatial and temporal activity allocation functions for the various emission sources that have been recommended by EPA for Alaska with the modifications that have been derived in collaboration with local partners. Figure 6 exemplarily shows the emission-allocation functions as derived from data for the UAF power plant. Area emissions from the burning sector, for instance, are distributed spatially depending on specie, activity, population, and/or land-use, and time. The model level and grid cell into which point sources emit, depends on stack parameters, latitude, and longitude and plume raise that is calculated using Biggs formula [*Peckham et al.*, 2009].

4.1.1 Emission data for 2005/06

We performed a quality assessment and quality control (QA/QC) on the NEI2005 data for the FNSB. The QA/QC showed that for some point sources stack parameters were missing and/or the coordinates were incorrect or vice versa. We worked with the respective facility operators and EPA to fill in and/or replace the data with the correct data.

We worked with Golden Valley Electricity Association and UAF's power plant employees to obtain Alaska specific annually, daily and hourly emission profiles for 2005 (e.g. Fig. 6) and implemented them into the AkEM. We used the population-density data provided by the FNSB from the Census 2000 [data provided by *Duncan*, 2009] and projected them onto the model domain. AkEM requires these data for determining/distributing the area emissions.

For the winter 2005/06 simulations AkEM [*Mölders*, 2009] used allocations functions depending on space and time. Allocation differed with time of the day, day of the week and month. For 2006, an increase in annual emissions of 1.5% was assumed across the board.

4.1.2 Emission data for 2008/09

In December 2008, the FNSB expected that gridded spatially high resolved hourly emission data for winter 2007/08 would be available in April 2009 from SRL. The FNSB wanted to have the option to switch to a more recent episode (probably 2008/09) than 2005/06 for the "woodstove replacement" and "low sulfur emission" simulations. The reasons for this request were manifold. More observational data for model evaluation are available for this more recent winter. Moreover, since 2007, the number of woodstoves has increased notably and 2008 was discussed as a potential design year.

Early in 2010, the anticipated SRL-emission inventory for winter 2007/08 was still not available[11] due to unforeseen delays and difficulties in collecting the data that were beyond the control of SRL and/or the FNSB. Moreover, the QA/QC had still to be performed by EPA. Early, in 2010, the FNSB decided that we should perform the "woodstove replacement" and "low sulfur scenarios" for winter 2008/09. Meanwhile, namely, the NEI2008 became available except for point-source emissions. The NEI2008 more closely represents the current emission situation in the FNSB, as it considers emission changes between 2005 and 2008 and hence is more recent than the NEI2005. Therefore, we did a new reference simulation and the mitigation scenarios for winter 2008/09 (Table 1).

Note that the main difference between the emission data that we used for this study and those of the anticipated SRL-inventory is that the NEI2008 in combination with AkEM treat emission

[11] As of January 2011, we have no access to the SRL-compiled 2007/08 emission data.

data for the FNSB in a top-down approach, while the SRL-inventory treats emissions in a bottom-up approach. A top-down approach assesses emission rates based on aggregated-statistical methodologies, while the bottom-up approach compiles a site-specific emission inventory based on the detailed information for each area [e.g. *Kim et al.*, 2010]. Inter-comparison analysis suggests that standard emissions data from a top-down approach are appropriate for atmospheric model simulations [e.g. *Kannari et al.*, 2008]. The differences, advantages and disadvantages between these two types of approaches have been widely discussed in the literature [e.g. *Kannari et al.*, 2008; *Kim et al.*, 2010] and are therefore not repeated here.

Emissions of mobile and several nonpoint-emission sectors were available from the NEI2008. The NEI2008 considered aircraft emission as point sources. Other point-source sectors were not yet available in the NEI2008 and were not expected to be available before 2011. Therefore, we updated the point-source emission inventory (EI) by personal communications with the facilities holders in the FNSB whom we contacted with this request. Note that not all facilities contacted did respond. For those facilities without reported emission data, we used estimates on point-source emissions based on the previous inventory assuming a 1.5% increase per year.

The mobile emissions in the NEI2008 are less than what they were in the NEI2005, which is consistent with the lower traffic activity in 2008 as compared to 2005 [*DOT*, 2009]. Some nonpoint-emission sectors were required to be updated with the latest borough employment data. We performed these updates using the respective data from the Alaska Department of Labor and Workforce Development [*http://laborstats.alaska.gov/cgi/dataanalysis/?PAGEID=94*].

However, there were some nonpoint-emission sectors that EPA was not planning to estimate unless additional resources became available. Those sectors included industrial/commercial/ institutional fuel combustion and the residential wood combustion. The latter make up a large portion of the emission in the FNSB according to the NEI2005. Therefore, the emissions from these sectors were included in the emission database used for our simulations of winter 2008/09 to obtain realistic emission conditions. For industrial/commercial/institutional fuel combustion, we assumed the 2008 emissions to be the same as in NEI2005 because they were expected to have just marginally changed over 2005-2008. Emissions from residential wood combustions were taken from *Davies et al.* [2009] as was requested by the FNSB. The outcome showed much higher emissions from residential wood combustion in 2008 as compared to that category in the NEI2005. This increase in woodstove emissions, however, is expected given the situation in the FNSB in winter 2008/09. Note that in the NEI2005, EPA estimated emissions from residential wood combustions based on the small partition of wood-burning devices as obtained from the Census 2000. Meanwhile, in response to the increasing oil prices, many residents had added wood-burning devices to reduce heating costs. The wood-cutting permits have increased threefold in 2009 as compared to 2007 [*Conner* 2010, pers. communication]. To derive the annual emissions for 2009 from those of 2008, an increase in annual emissions of 1.5% was assumed across the board.

For allocation of the winter 2008/09 emissions a modified version of AkEM [*Mölders*, 2010] was used that applied allocations functions depending on space, time and temperature. Allocation differs with time of the day, day of the week; month and deviation of the daily mean temperature from the 30-year monthly average mean temperature. This modification (calibration) of the emission model was introduced to improve the allocation functions based on our experience with the simulations for winter 2005/06 and several sensitivity studies paid from other sources. This

modification of the emission allocation permits to better consider the temperature dependency of cold start enhanced emissions (CSEE) and the increase in energy consumption for heating for temperatures below 18°C (64.4°F) using a modified equation of *Hart and de Dear* [2004]. The temperature dependency for production of electrical power was determined assuming that freezers, refrigerators and hot water production consume equal amounts of energy. The same allocation functions and temperature correction as for power plants is assumed for emissions from fuel combustion for electricity production by nonpoint sources, but these emissions are considered dependent on population density [*Mölders*, 2010]. AkEM assumed that the non-temperature corrected allocation function is valid for the mean temperature of the month [*Mölders*, 2010]. Thus, the inclusion of temperature dependency increases (decreases) the emission factors for temperatures below (above) the monthly mean temperature. The temperatures used in these corrections are the 2m-temperatures read in from the WRF/Chem initialization data. Figure 7 exemplarily shows the impact of temperature-dependent emissions for March 3, 2005 where the domain average temperature was -22.1°C (-7.8°F).

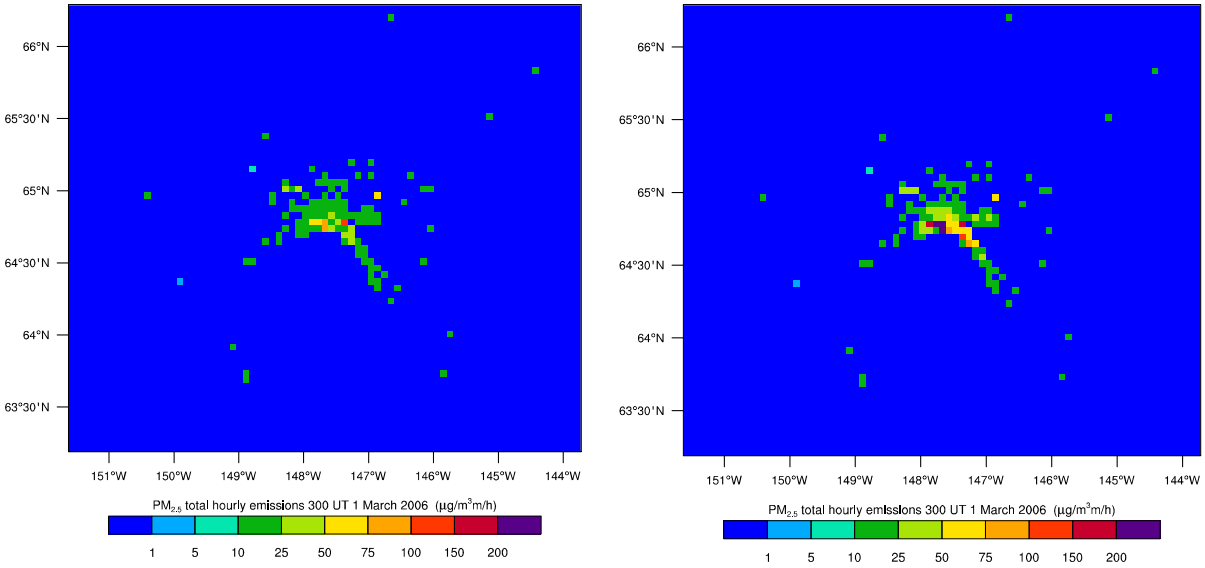

Fig. 7. Emissions of $PM_{2.5}$ without (left) and with consideration of temperature correction. This day is colder – the daily average temperature is 22.1°C (-7.8°F) - than the climatological average March temperature of -11.7°C (10.9°F) for which the original allocation functions were valid. As expected, emissions increase in response to the low temperatures. *Davies et al.*'s [2009] emission data were used.

4.2 Emission scenarios

This section describes the emission scenarios used in the mitigation simulations. Table 1 summarized the simulations performed for this study. Throughout this report, the simulations as their results are referred to as REF and NPE, or REF, WSR and LSF, respectively.

4.2.1 Emission scenario for investigation of point source contribution

The 2005/2006 winter was chosen because at the start of the project in 2008, the most recent available emission-data inventory was the NEI2005. Since the concentrations resulting from point-source (PS) emissions alone were so low that $PM_{2.5}$ concentrations were governed mainly by background chemistry, we performed simulations with emissions from all sectors as the reference simulation (REF). In a further simulation, we considered emissions from all sectors

except point-source emissions (NPE). This means emissions of all species emitted by point-sources were set to zero in the NPE scenario. Simulations with consideration of point-source emissions were performed for October 1, 2005 to February 28, 2006. The first 15 days performed for October 2005 served for calibration. The rest of October 2005 served to spin-up the chemical fields. Simulations without consideration of point sources were performed from November 1, 2005 to February 28, 2006. The simulations with and without consideration of point-source emissions start with the same initial conditions of the meteorological fields and chemical components on November 1, 2005 as obtained from the spin-up. Comparison of the concentrations obtained by the REF and NPE simulations for November 1, 2005 to February 28, 2006 served to quantify the contribution of the point sources (e.g. power plants) to the $PM_{2.5}$ concentrations at breathing level.

Table 1. List and names of simulations performed with WRF/Chem for this study. Note that LSF and WSR have the same reference simulation.

Simulation name	Description	episode simulated
REF	Reference simulation with all emissions using the NEI2005	October 1, 2005 to February 28, 2006
NPE	Simulation using the NEI2005, but excluding emissions of all species from all point sources	November 1, 2005 to February 28, 2006
REF	Reference simulation with all emissions using the NEI2008 with the updates as described in the emission section	October 1, 2008 to March 31, 2009
WSS1	"Woodstove replacement" sensitivity study that assumes non-certified wood-burning devices are replaced by modern EPA-certified woodstoves using *Davies et al.*'s [2009] numbers of wood-burning devices, while keeping emissions from all other emission sectors the same as in the respective reference simulation	October, 1 2008 to October 15, 2008
WSS2	as WSS1, but using the numbers wood-burning devices from SRL's draft report	October, 1 2008 to October 17, 2008
WSR	as WSS2, but using the numbers of *Carlson et al.*'s [2010] final report	October 1, 2008 to March 31, 2009
LSF	"Introduction of low sulfur fuel for heating and power generation", while keeping emissions from all other emission sectors the same as in the respective reference simulation	October 1, 2008 to March 31, 2009

4.2.2 Emissions for the "woodstove replacement" scenarios

A set of simulations addressed the influence of a "woodstove-replacement action" on the $PM_{2.5}$ concentrations at breathing level. The reference simulation (REF) considered emissions from all sectors available in the NEI2008 and the additional information described before. The simulation assuming "woodstove replacements" considered the same emissions as in REF minus the emissions from non-certified wood-burning devices that were assumed to be replaced plus the emissions that stem from the certified wood-burning devices that replaced the non-certified wood-burning devices. The reference and "woodstove replacement" simulations started with the same initial conditions of the meteorological fields and the same Alaska-typical chemical background concentrations for October 1, 2008.

To compile the emission data for the "woodstove-replacement" simulations, we analyzed *Davies et al.*'s [2009] results. We searched the literature and collected data on other species than $PM_{2.5}$ emitted by EPA-certified woodstoves and other wood-burning devices. These data were required as not only the $PM_{2.5}$ emissions from wood-burning devices, but also the emissions of the other species emitted by these devices will change if non-certified wood-burning devices are replaced by EPA-certified wood-burning devices. This means all species emitted by wood-burning were changed in the "woodstove-replacement scenarios". The consideration of changes for all species emitted by wood-burning devices is required because some $PM_{2.5}$ can form from gas-to-particle conversions once the species are in the atmosphere as explained before.

Davies et al.'s [2009] data only provide the total number of certified woodstoves (6912), but not the split between certified woodstoves with catalytic and non-catalytic equipment. The same is true for masonry heaters and pellet stoves. We assumed the same emission rates for wood-burning devices with catalytic and non-catalytic equipment.

Table 2. Number of households in Fairbanks. Data courtesy of *T. Duncan* [2010]

Year	Pre-2005	2005	2006	2007	2008	2009
Number of households	33970	34946	35910	36952	37550	38292

The number of households changed over the years (Table 2). As obvious from the sum of the devices listed in *Davies et al*. [2009] report, some households have at least two heating devices. We assumed that in the case of households with more than one heating device, woodstoves co-exist with oil furnaces. For fire-safety reasons it is unlikely that a woodstove exists in a household with gas. It is unlikely that woodstoves co-exist with hydronic or masonry heaters or pellet stoves as well. The category "others" is most likely central heating which also has a low likelihood to co-exist with woodstoves. Coal and woodstoves are unlikely to co-exist as typically people who burn coal also burn wood in the same stove. To avoid double counting of households in their emission contribution, we determined the number of households with at least two heating devices

$$N_{two} = N_{devices} - N_{households} \quad (1)$$

Where $N_{devices}$ and $N_{households}$ are the number of heating devices and households in that particular year. After studying *Davies et al.*'s [2009] data, it seemed reasonable to assume that households with two devices use the woodstove to other device in a ratio 33.5:66.5 of the time. Sensitivity studies indicated that the total emission reduction is very sensitive to how households split their heating among their available devices. Thus, we recommend collecting data on the "split" behavior to reduce uncertainty in future modeling studies.

We determined the actual number of devices contributing at a time to wood-burning emission as

$$N_x^{'} = N_x\left(1 - 0.665\frac{N_{two}}{N_1 + N_2 + N_3}\right) \quad (2)$$

Where the x stands 1, 2 and 3, with 1 to 3 representing non-certified woodstoves, EPA-certified woodstoves with catalytic equipment, and EPA-certified woodstoves without catalytic equipment, respectively. Analogously, the number of devices contributing at a time to emissions from oil furnaces is determined as

$$N_7^{'} = N_7\left(1 - 0.335\frac{N_{two}}{N_7}\right) \quad (3)$$

Where the index 7 denotes oil furnaces. After this procedure, the sum $\sum_{k=1}^{11} N_k^{'}$ equals the number of households.

Davies et al.'s [2009] data for Fairbanks' wood-burning emissions differ from those assumed in the compilation of the NEI2008. We used *Davies et al.*'s [2009] data for all wood-burning devices and oil furnaces as requested by the FNSB. We used EPA's data for the other categories, as data for these devices were not included in *Davies et al.*'s [2009] report.

The total annual emission rate of the i^{th} specie from heating after "woodstove replacement" is given by

$$E_{NEIyyyy,WSR} = E_{NEI,yyyy} + N_{exchange}E_2 - \sum_j N_j E_j \quad (4)$$

Where $N_{exchange}$ and E_2 are the number of wood-burning devices replaced and emission rates per certified wood-burning device, E_j are N_j the emission rates and numbers of noncertified wood-burning devices, and the index j stands for noncertified wood-burning devices, respectively.

In all "woodstove replacement" emission scenarios, we assumed emissions from all sectors to remain the same as in the reference simulation except for the heating sector. For the heating sector, we assumed the emissions from all heating devices but wood-burning devices to remain the same as in the reference simulation too. This means that in all "woodstove replacement" simulations, we only altered the emissions from the wood-burning sector.

In a first sensitivity study on "woodstove replacement", we determined the emissions remaining from wood-burning after the replacement of non-certified devices by assuming the number of residential wood-burning devices as reported in *Davies et al.* [2009]. We calculated the emissions from residential wood combustion, subtracted the contribution from non-certified devices (assumed to be replaced) and added the contribution that the certified device (that replaced the non-certified devices) would have. The simulation with this emission scenario is referred to as WSS1 hereafter. In total, 15 days (10-1-2008 to 10-15-2008) were simulated assuming this scenario.

In a second sensitivity study on "woodstove replacement", we determined the emissions remaining from wood-burning after the replacement of non-certified devices by assuming the number of wood-burning devices that became available from a draft by the Sierra Research Laboratories (SRL) group. This data based on a survey of 300 households in the nonattainment area carried out by SRL. The number of wood-burning devices reported in the draft and in the final report by *Carlson et al.* [2010] is lower than the estimates used in *Davies et al.*'s [2009] report. Note that there is high uncertainty in the actual number of wood-burning devices that exist in the nonattainment area [*Conner* 2011; pers. communication]. The draft SRL report did not include pellet stoves. *Carlson et al.*'s [2010] data only provide the total of certified woodstoves, but not the split between certified woodstoves with catalytic and non-catalytic equipment. We assumed the same emission rates for both. Again, we calculated the emissions from residential wood combustion, subtracted the contribution from non-certified devices

(assumed to be replaced) and added the contribution that the certified device (that replaced the non-certified devices) would have. The simulation performed using the emission scenario obtained this way is called WSS2 hereafter. We run this set of "woodstove-replacement" simulation from 10-01-2008 to 10-17-2008.

The final SRL report by *Carlson et al.* [2010] included pellet stoves as a separate category in the wood-burning sector. For the third "woodstove replacement" simulation, we determined the emissions remaining from wood-burning after the replacement of non-certified devices by assuming the number of wood-burning devices that were given in *Carlson et al.*'s [2010] final report. Using these numbers, we calculated the emissions from residential wood combustion, subtracted the contribution from non-certified devices (assumed to be replaced) and added the contribution that the certified device (that replaced the non-certified devices) would have. *Carlson et al.*'s [2010] data only provide the total of certified woodstoves, but not the split between certified woodstoves with catalytic and non-catalytic equipment. We assumed the same emission rates for both. A full winter simulation was performed assuming this emission scenario. This simulation is called WSR hereafter (Table 1).

Figure 8 exemplarily shows the hourly emission rates from all heating sectors for the Fairbanks area prior to and after the assumed three different "woodstove-replacement scenarios". In all "woodstove-replacement scenarios", we considered the impact on emissions of all species, not only $PM_{2.5}$.

The policy options recommended by *Davies et al.* [2009] estimated to reduce $PM_{2.5}$ emissions from residential heating from 874 tons/year to 422 tons/year, or 52% for their base year. The "woodstove replacement" scenario assuming *Davies et al.* [2009] numbers of wood-burning devices reduces the emissions for 2008 to 40%, while those with the SRL draft and *Carlson et al.*'s [2010] numbers reduce the emissions much less (Fig. 8). Note that changing out non-certified wood-burning devices to certified ones would reduce theoretically both primary and secondary $PM_{2.5}$ emission at the same order. In *Davies et al.* [2009], $PM_{2.5}$ accounts for both primary and secondary aerosol that forms after the emissions. WRF/Chem considers primary $PM_{2.5}$ from emissions and calculates the secondary $PM_{2.5}$ that builds in stacks and in air [*Peckham et al.*, 2009].

Note that if primary $PM_{2.5}$ emission were reduced greatly by changing noncertified wood-burning devices to oil furnaces, the secondary $PM_{2.5}$ emission might increase. Oil furnaces namely have higher emission rates of SO_x and NO_x than wood-burning devices. SO_x and NO_x are the main precursors of secondary $PM_{2.5}$ that forms through gas-to-particle conversion. Therefore, exchanging noncertified wood-burning devices to oil furnaces with current fuel sulfur content will be less effective in reducing $PM_{2.5}$ emission than exchanging them with certified wood-burning devices.

Obviously there is uncertainty in our study due to the unknown number of woodstoves that exist and that can be replaced. Unfortunately, no data were available, where what wood-burning devices are operated and when they were operated and how they were operated and how often. We simply assumed the distribution of wood-burning devices to be proportional to the distribution of population density. This assumption holds uncertainty in the spatial distribution that may affect local maximum concentrations as well as 24h-averages of $PM_{2.5}$ concentrations. *Fortun and Mölders* [2009] showed that uncertainty in the diurnal course of emission marginally affects the 24h-average $PM_{2.5}$ concentrations. However, uncertainty in the spatial distribution can

provide notable differences in the 24h-average $PM_{2.5}$ concentrations. Sensitivity studies on the emissions indicate that uncertainty in emission rates also results from the unknown partitioning of the use of wood-burning and other heating devices in households having more than one heating option. Note that the simulations on "woodstove replacement" do not consider that additional wood-burning devices have been added since 2008.

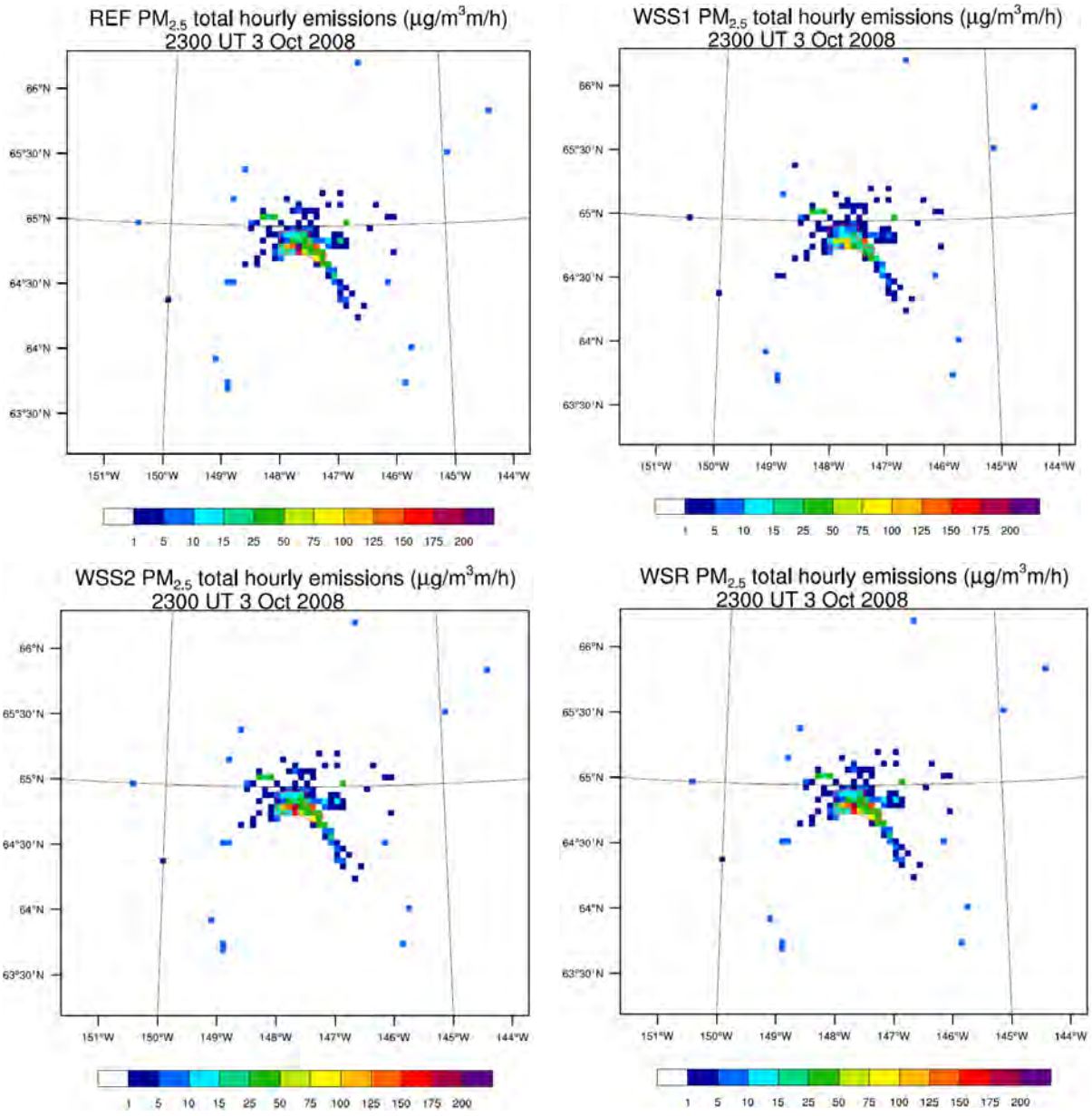

Fig. 8. Emissions of $PM_{2.5}$ as obtained with AkEM (upper left to lower right) before (REF) and after the assumed "woodstove replacement" assuming *Davies et al.*'s [2009] (WSS1), SRL's draft report (WSS2), and *Carlson et al.*'s [2010] (WSR) data on the numbers of heating devices. All "woodstove-replacement scenarios" result in reduced emissions over the nonattainment area. The nonattainment area is schematically superimposed in red.

As pointed out above, there is uncertainty in any emission data. This uncertainty is related to the approaches used and assumptions made. *Davies et al.* [2009] developed the emission rates for wood-burning devices using the operation-emission limits of the device (grams/hour) issued by EPA multiplied with the total hours of heating per year per household. Doing so, provided a

$PM_{2.5}$-emission rate of 60lb/yr.hh for noncertified and of 17lb/yr.hh for certified woodstoves. *Carlson et al.* [2010] list the amount of wood used annually as 3.95 cords wood/yr.hh. If one takes the EPA AP-42 emission factors of noncertified and certified woodstoves (30.6 and 14.6lb/short tons of dry wood, respectively), one obtains for the emission rates of noncertified and certified woodstoves 145lb/yr.hh and 69lb/yr.hh, respectively. *Davies et al.*'s [2009] study is based on heating hours and emission limits, while *Carlson et al.*'s [2010] study is based on fuel used. This means *Davies et al.*'s [2009] and *Carlson et al.*'s [2010] studies use different approaches. We used the AP-42 emission factors to compare their data. Depending on the approach, one will for each replaced woodstove reduce the emissions by (60-17) lb/yr.hh = 43lb/yr.hh and (145-69) lb/yr.hh = 76lb/yr.hh, respectively.

We used *Davies et al.*'s [2009] emission-rate data for all wood devices and oil furnaces as requested by the FNSB, but used *Carlson et al.*'s [2010] data for number of devices. Note that using this data seemed to be "safer" because the amount of reduction in response to a "woodstove replacement" program is smaller than using *Carlson et al.*'s [2010] emission rates. This means that the relative response factors that we obtained from our "woodstove replacement" simulations may underestimate the actual reduction that a woodstove replacement program can provide. In the sensitivity study WSS1, we used EPA's data for the "others" category, as data for these devices were not included in *Davies et al.*'s [2009] report. In the sensitivity study WSS2, we used *Carlson et al*.'s [2010] number of devices without consideration of pellet-stoves.

4.2.3 Emission scenario for introduction of low sulfur fuel for heating oil and power generation and other oil-burning point sources

The third scenario (LSF) represents a measure that aims at mitigation of $PM_{2.5}$ concentrations indirectly by reduction of precursors. As pointed out above sulfur can contribute to $PM_{2.5}$ formation in the atmosphere. Thus, the third emission scenario performed for winter 2008/09 assessed the impact of the introduction of low sulfur fuel for use as heating oil and in oil-burning power plants and other point-sources on the $PM_{2.5}$ concentrations at breathing level. The target emission categories that we considered in the "low sulfur fuel" scenario are heating oil, point source facilities and power plants that burn oil. The emissions from domestic and industrial combustion (including power plants) used in the reference simulation (REF) represent the emissions from relatively sulfur-rich fuel.

In the LSF simulation, the emissions from all sectors were kept the same as in the reference simulation except for emissions from domestic heating with heating oil, and oil-burning point sources and power plants with sulfur-rich fuel. The emissions from these sectors were replaced by emissions one would obtain with low sulfur content fuel for the same combustion amount.

To determine the amount of emission reduction due to a change from high to low sulfur-content fuels we reviewed the literature. Since the fuel-sulfur content may affect other emissions than just $PM_{2.5}$, we adjusted the emissions of these other species as well. Doing so is required as particles and hence $PM_{2.5}$ may form due to gas-to-particle conversion from various species as explained earlier.

NESCAUM [2005] reported the emission reduction due to reducing the sulfur content of No. 2 distilled heating oil from 2,000-3,000ppm to 500ppm for SO_2, PM and NO_x as 75%, 80% and 10% respectively. In our study, we assumed the same transition of sulfur content in heating fuel in Fairbanks, and applied the same reduction found by *NESCAUM* [2005]. Since no reduction

benefits were reported for VOC and CO, we assumed that lowering of sulfur content in heating oil does not affect the VOC and CO emissions.

From personal communication with several power-plant operators in the FNSB, we learned that almost all power plants in the FNSB are burning No. 2 fuel oil having sulfur content about 4,000ppm. This fuel is similar to the fuel used for household heating. For the LSF simulations, we modified the point-source emissions with respect to low sulfur-fuel emissions for those oil-burning facilities that did not yet use low sulfur fuel already.

To our best knowledge, no report exists on the effects of low sulfur-fuel usage on the emissions of power plants. Therefore, we assumed a similar transition of sulfur content in heating fuel in the FNSB as reported in *NESCAUM* [2005] and applied the reduction given for power plants. Note that the actual reduction would be higher than the assumed reduction since the emission control devices in power plants become more effective as the sulfur content decreases.

In the low sulfur fuel (LSF) scenario, the emission reductions due to low sulfur fuel are only applied to those power plants and point sources that burn No. 2 fuel oil. For these facilities, a reduction rate of 75%, 80% and 10% was applied to the SO_x, PM and NO_x emissions, respectively. For power plants burning both fuel oil and coal, only emissions from burning oil were subject to the emission reduction. We only got the break-down of the fuel-type consumption for the UAF power plant. Since the UAF power plant works on economic principles as the other power-plant operators do, we assumed a similar break-down of fuel types used for those facilities that burn different fuel types. No changes in emissions were made for power plants burning only coal.

4.3 Analysis methods

We compared the results of the simulations performed with modified emissions with the results of their respective reference simulation to assess the impact of the various emission mitigation measures or the contribution of point-source emissions on the $PM_{2.5}$ concentrations in the nonattainment area and in the grid-cell holding the FNSB official measurement site. This site is located on top of the State Building.

We used the Student t-test [*von Stroch and Zwiers*, 1999] to test the $PM_{2.5}$-concentration differences between REF and NPE for winter 2005/06, and REF and WSR or LSF for winter 2008/09 for their statistical significance at the 95% confidence level. The null hypothesis was that concentrations in REF and NPE, or REF and WSR or REF and LSF do not differ. In the following, we only use the word significant when data fail to pass this test.

Note that from a scientific point of view, it is important whether an emission source causes significant differences in the $PM_{2.5}$-concentrations. However, from a regulation point of view it is not of relevance whether or not, an emission source contributes significantly (in a statistical sense) to the concentrations of $PM_{2.5}$. Instead, it is important whether the emission-sources' contributions are the main contributor, i.e. dominate the concentration values, and whether reducing the emissions of these sources may lead to compliance.

If a certain kind of emission sources is the dominating one, regulation on the emission may help solve the exceedance problem. Here again distinctions have to be made. An emission source far away from the nonattainment area and/or far away from any settlements will typically dominate the concentrations in its surroundings, as it is most likely the only emission source out there. Thus, the large percentage contribution of such an emission source will not be worrisome as long

as the concentrations do not exceed the NAAQS. If an emission source is located in an unpopulated area close to populated areas, its contribution also may percentagewise be the main contributor. Then one has to consider how large the impact is on the adjacent populated areas and whether this impact leads to exceedances of the NAAQS. These facts have to be kept in mind in the following discussion.

For all scenarios, we determined the relative response factors and new design values.

4.3.1 Analysis of point source contribution

Differences between the highest 24h average $PM_{2.5}$-concentration obtained by REF and NPE were investigated to assess the impact of PS-emissions on the $PM_{2.5}$-concentrations at breathing level. The number, frequency and locations of grid-cells with 24h-average $PM_{2.5}$ exceedances were determined for both simulations to assess the contribution of PSs to exceedances. In addition, we examined the radius of impact of the point sources on the $PM_{2.5}$ concentrations at breathing level. Grid-cells affected by PS-emission will have non-zero $PM_{2.5}$-concentration difference between REF and NPE. Therefore, the influence of PS-emissions on the $PM_{2.5}$-concentration at breathing level was investigated by analyzing the correlation between the PS-emissions at each emitting level with the $PM_{2.5}$-concentration-difference. In the domain of interest, 27 PSs emit into the second (8-16m) to the seventh model layer (343-478m) due to plume raise.

The impact of each individual PS on the perturbation of $PM_{2.5}$-concentration is difficult to identify unambiguously because in WRF/Chem, like other photochemical models, all PSs located within the same grid cell are lumped but emit into the levels into which the individual PSs would emit. After lumping, there are nine grid columns holding PSs. Due to the lumping we cannot investigate individual PS impacts on $PM_{2.5}$-concentration at breathing level, but the cumulative impact of all PSs within a grid-column on the downwind $PM_{2.5}$ concentrations of that column. We examined the impact for each grid column holding PSs and denote these PS1 to PS9, hereafter. See Figure 14 for locations.

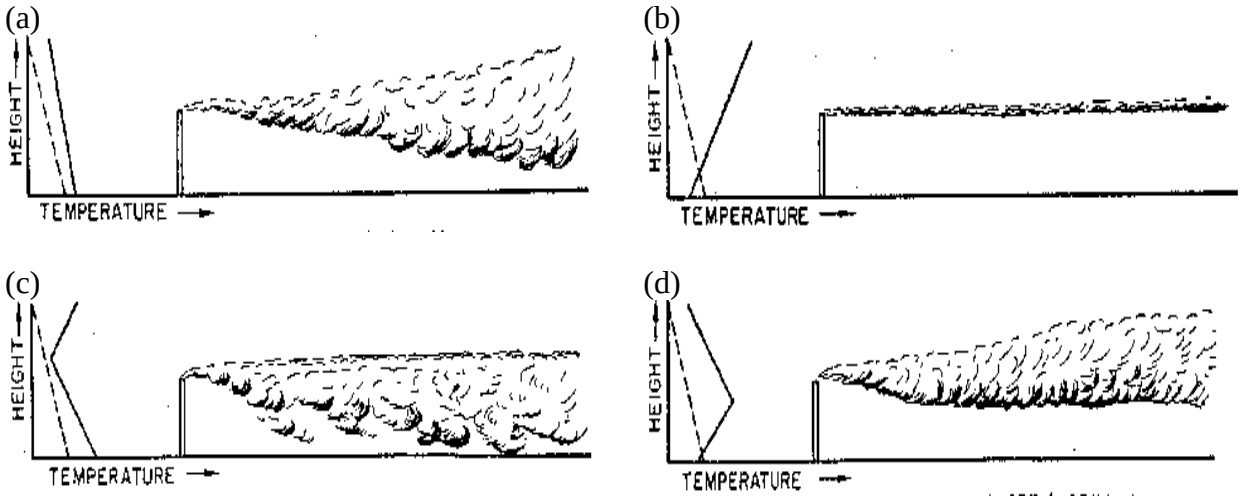

Fig. 10. Schematic view of temperature profiles and plume behavior for emissions in the case of (a) no inversion layer, (b) into an inversion layer, (c) below an inversion layer, and (d) above an inversion layer. From: *http://www.iitap.iastate.edu/gcp/acid/images/plume.gif.*

We only considered the $PM_{2.5}$-concentration-difference distribution at grid cells located downwind of a grid-cell with PSs. At each PS1 to PS9, we used the wind direction from the first level above ground to the uppermost emitting level to identify the downwind grid cells of each level in each simulation hour. This treatment ensured that not all grid cells around the PSs, but only the grid cells impacted by the PS are considered. These $PM_{2.5}$-concentration-difference values were used to calculate the correlation with the PS-emissions for November to February (NTF). All correlations were tested for their statistical significance at the 95% or higher confidence level using a Student-t test.

PSs in the downwind sectors of a PS-holding column may affect the $PM_{2.5}$-concentrations in its downwind. Therefore, the correlation behavior of each PS1 to PS9 was investigated under consideration of potential impacts by other PS holding grid-columns. As atmospheric temperature inversion and wind speed affects the dispersion of the PS emissions, we investigated separately the correlation between PS-emissions and $PM_{2.5}$-concentration-difference for different wind-speed classes at the emitting level and under conditions when PSs emitted below, above and into inversion layer (Fig. 10). We applied different time lags in determining the correlations to account for the lag in time between the actual emission and the time when the $PM_{2.5}$ reaches the downwind grid-cells at breathing level.

4.3.2 Analysis of the "woodstove replacement" scenario

We used the Student t-test to examine the $PM_{2.5}$-concentration differences (REF-WSR) for their significance at the 95% level of confidence. To verify that the differences are really due to replacing "woodstoves", we adopted a False Ensemble Analysis method (FEA) which was developed and applied successfully in climate model data analysis [*Carpenter et al.*, 1989; *Werth and Avissar*, 2002]. We performed the analysis for each month of the REF and WSR simulations. First, the true difference of 24h-average $PM_{2.5}$-concentration between REF and WSR was determined for each month. Secondly, a set of false "REF" and "WSR" ensembles was created by randomly replacing results of simulation days of REF (WSR) with the results of the corresponding simulation days of WSR (REF). Because the emission strengths are allocated depending on the hour of the day, day of the week and month of the year, and daily mean temperature [*Mölders,* 2010], each randomly selected REF-day had to be replaced by the corresponding WSR-day. In this way, emissions only differ with respect to the emission changes in response to the wood-burning devices exchanged. A random generator was used to create an index array, which days of the month were to be chosen to create the false ensemble, and REF (WSR) files were replaced accordingly. The replacement was completed as the number of WSR (REF) simulation days makes up 50% of the total days of the false "REF" ("WSR") ensemble by which the false "REF" and "WSR" can be considered as having no net difference in the mean emission.

Theoretically, $n!/[(n/2)!]\times 2$ numbers of false ensembles can be generated from n simulation days in the way described above. However, considering the time constrains and computational limitation, we generated 400 false "REF-WSR" ensembles randomly for each month. For each set of false "REF" and "WSR" ensemble the difference of 24h-average $PM_{2.5}$-concentration was determined as was done for the true difference REF-WSR. Finally, the true and 400 false concentration differences were ranked. The above procedure was applied for each grid cell. If at a grid cell, the true difference falls in the top 5% of all values, we can conclude that the true $PM_{2.5}$-concentration difference is real, i.e. the "woodstove replacement" actually reduced the $PM_{2.5}$-concentration in the grid cell of interest.

4.3.2 Analysis of the “low sulfur” scenario

Emissions of $PM_{2.5}$, PM_{10}, SO_2, NO and VOC from the current sulfur content fuel (REF) and the use of low sulfur fuel (LSF) were analyzed and compared on a monthly and daily basis. Note that these pollutants were selected as they are primary particular matter and precursors for secondary aerosols, i.e. they can affect the $PM_{2.5}$-concentrations at breathing level. Since the emissions were considered temperature-dependent, the mean temperatures and their deviation from the long-term mean temperature were analyzed and used to elucidate the variations in emission reductions.

Concentrations of $PM_{2.5}$ and other pollutants (PM_{10}, sulfate, nitrate, VOC) in the nonattainment area obtained by REF and LSF were compared. The monthly, daily, and hourly variations of $PM_{2.5}$-concentration reductions after introduction of low sulfur fuel were quantified and analyzed. The variations in the aerosol composition were also identified. Furthermore, mean meteorological quantities (temperature, dewpoint temperature, relative humidity, wind-speed, shortwave radiation fluxes, atmospheric boundary layer height, precipitation and cloudiness) were used in the analysis of $PM_{2.5}$-concentration reductions as there were feedbacks of aerosols on the meteorology.

Furthermore, we also applied the FEA to the REF and LSF data.

5. Evaluation

As pointed out above, we used the results of the WRF/Chem simulations of the first 15 days October 2005 for calibration. Within the framework of another project, WRF/Chem was evaluated by data from a Doppler SOund Detection And Ranging (SODAR) device, twice-daily radiosondes, 33 surface meteorological and four aerosol sites [*Mölders et al.* 2011].

The evaluation used the following performance skill-scores (root-mean-square error [RMSE], bias, standard deviation of error [SDE], correlation coefficient [R]) following *von Storch and Zwiers* [1999] for the meteorological quantities, and the fractional bias ($FB = \left(\overline{C_s} - \overline{C_o}\right) \Big/ \left[0.5\left(\overline{C_s} + \overline{C_o}\right)\right]$), normalized mean-square error ($NMSE = \left(\overline{C_s} - \overline{C_o}\right)^2 \Big/ \left(\overline{C_s} \cdot \overline{C_o}\right)$), geometric mean bias ($MG = \exp\left(\overline{\ln C_s} - \overline{\ln C_o}\right)$), and the fraction of simulated concentrations C_s being within a factor of two of the observed concentrations C_o (FAC2) following *Chang and Hanna* [2004] for the chemical quantities. These are standard measures typically used in the evaluation of photochemical models and hence allow us to assess how good the Alaska adapted WRF/Chem performs for Alaska winter relative to models applied for cases in mid latitudes.

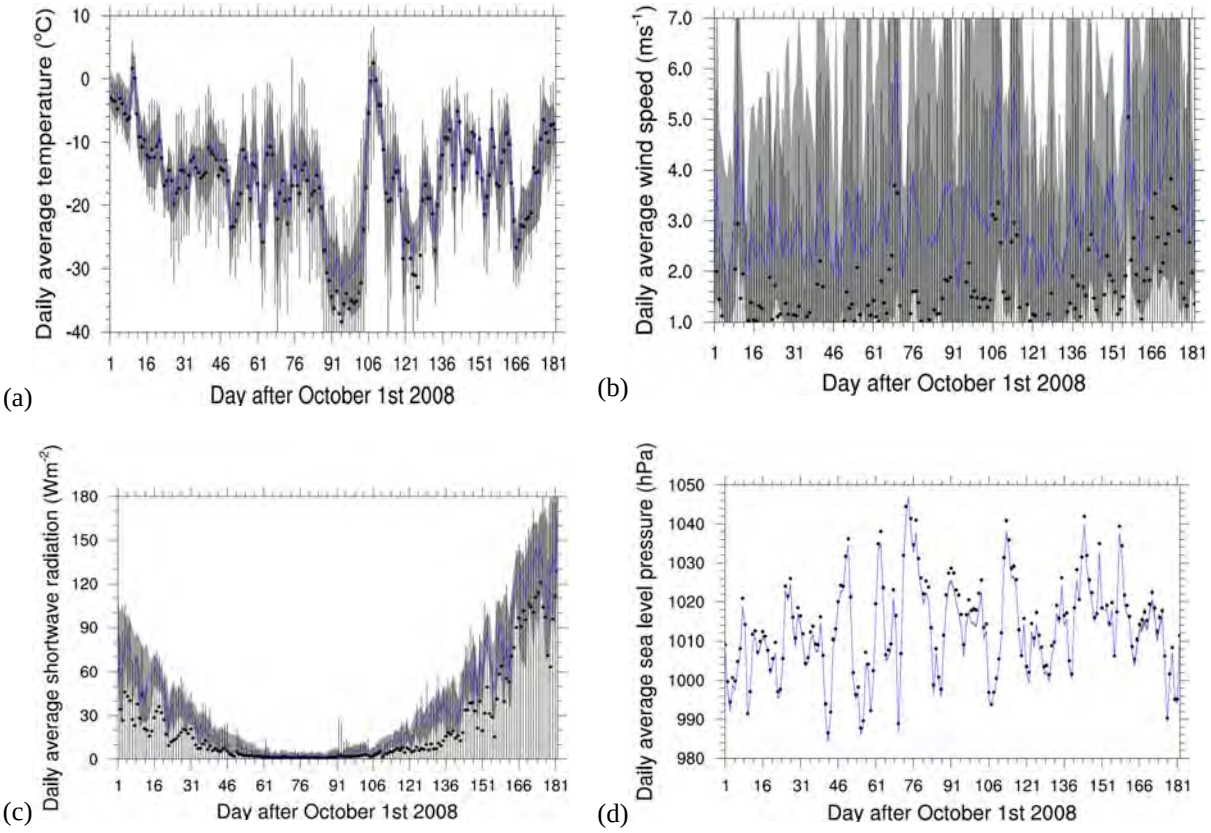

Fig.11. Temporal evolution of daily averaged of (a) air-temperature, (b) wind-speed, (c) downward shortwave radiation, and (d) pressure averaged over all sites for which data were available as simulated (blue line) and observed (dots). Plots for dewpoint (not shown) and air-temperatures look similar. Grey-shading and vertical bars indicate variance of simulated and observed quantities, respectively. Note that there were only two sites with pressure data Fairbanks International Airport and Eielson Air Force Base. Due to their relative close location, there is not much spatial variance. Therefore, no bars on the spatial variance of pressure are plotted.

All our simulations were run in"forecast" mode, i.e. no nudging or data assimilation was applied. *Mölders et al.* [2011] found that biases determined based on all available data from the 33 sites over NTF are 1.6K, 1.8K, 1.85m/s, -5^{o}, and 1.2hPa for temperature, dewpoint temperature, wind-speed, wind-direction, and sea-level pressure, respectively, in NTF 2005/06. Figure 11 shows the average temporal evolution of simulated and observed meteorological quantities as obtained for October 2008 to March 2009 (OTM) on average over all 23 sites within the domain of interest for which data were available for that time. Note that there were less meteorological sites operating in the area covered by the domain of interest for analysis in winter 2008/09 than 2005/06. Over OTM 2008/09, the overall biases over all sites are 1.3K, 2.1K, 1.55m/s, -4^{o}, and -1.9hPa for temperature, dewpoint temperature, wind-speed, wind-direction, and sea-level pressure, respectively. The 2005/06 temperature bias is only marginally higher than that reported by *Gaudet and Staufer* [2010] for their WRF short-term study with a 4km grid increment performed for Fairbanks using data assimilation. The wind-speed RMSE is slightly higher than the RMSE reported for their short study. Note that it is relatively easy to optimize a model for a short period of several days, while it is rather difficult to achieve a generally acceptable performance over an episode as long as four or six months like in our study.

The evaluation by means of SODAR-data revealed that WRF/Chem slightly over(under)estimates wind-speed in the lower (upper) ABL. WRF/Chem captures the frequency of low-level jets well, but overestimates the strength of moderate low-level jets [*Mölders et al.* 2011].

As aforementioned there are hardly any chemical data available for winter 2005/06. While $PM_{2.5}$ concentration data exist only at two sites (Fairbanks State Building, Denali Park) for winter 2005/06, measurements exist at 12 sites in Fairbanks for winter 2008/09. Based on the limited data available WRF/Chem simulated the maximum $PM_{2.5}$-concentration about 6% too low for winter 2005/06. Data from four aerosol sites suggest large underestimation of PM_{10}, and NO_3 at the remote sites outside of the nonattainment area and underestimation of $PM_{2.5}$ at the State Building in winter 2005/06 [*Mölders et al.* 2011].

Averaged over the two $PM_{2.5}$- and SO_4-sites, 41% and 50% of the simulated values, respectively, fell within ±50% of the observed concentration value for winter 2005/06. The low data density – for 2005/06 only one $PM_{2.5}$ observational site exists in the nonattainment area – may falsely indicate errors due to local effects [*Mölders et al.* 2011].

The hourly $PM_{2.5}$ evaluation of winter 2008/09 shows that 29%, and 36% of the simulated and observed concentrations agree within ±50% for the fixed sites FNSB (site at the State Building), and Peger Road, respectively. The performance for the 24h-average $PM_{2.5}$ is better – 46% of the fixed sites agree within ±50%. At the FNSB State Building, Peger Road, North Pole, Sadler and Denali site 35%, 58%, 38%, 39% and 58% of the simulated 24-average $PM_{2.5}$ concentrations are within ±50% of the observations, respectively. The scientific community considers photo-chemical models with fractional biases within ±30%, random scatter being within a factor of two or three of the mean, and 50% of the predictions falling within a factor of two of the observations to perform well [e.g. *Chang and Hanna* 2004]. Thus, our WRF/Chem simulations for 2005/06 fall in the lower end of acceptable performance, while those for 2008/09 are slightly better. The better performance for 2008/09 than 2005/06 may be due to the introduction of a temperature-dependency of traffic, power generation and domestic heating emissions in AkEM in response to the evaluation for 2005/06.

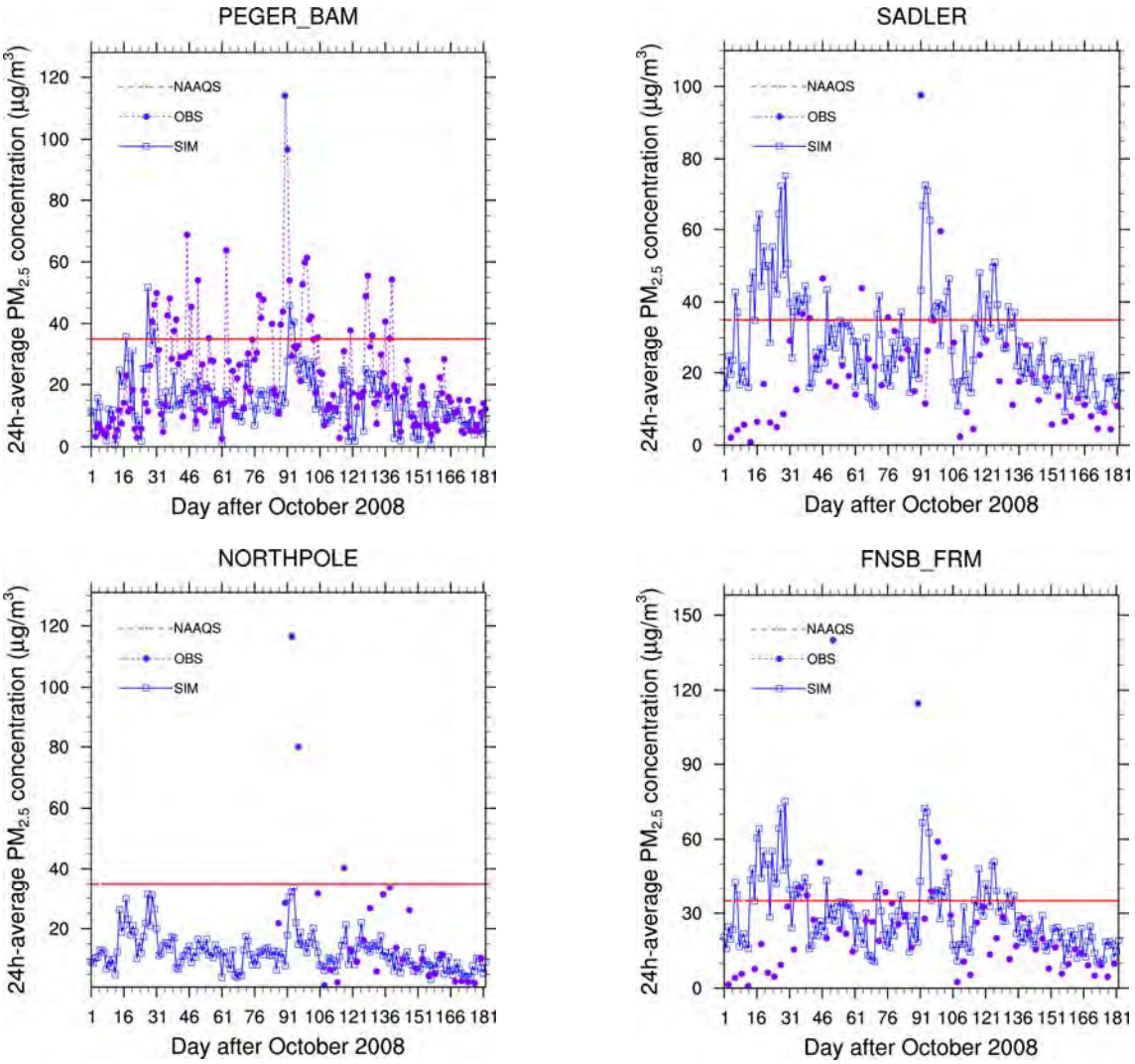

Fig. 12. Comparison of simulated and observed concentrations as obtained for winter 2008/09 for various sites. FNSB is the site at the State Building.

The evaluation of both winters indicates that WRF/Chem captures the temporal evolution of $PM_{2.5}$ concentrations well except during sudden temperature changes, underestimation of inversion-strengths and timing of frontal passages (e.g. Fig. 12). In October, WRF/Chem underestimates the $PM_{2.5}$ concentrations appreciably at all sites for which data are available. This behavior suggests that the assumed emissions for October 2008 are too low. Note that there are hardly any Alaska specific emission allocation functions. We used the allocation functions recommended by EPA for Alaska, which we modified to avoid obviously unreasonable emissions (e.g. emissions from lawn mowing in October), when no Alaska specific allocation functions could be obtained.

Errors in $PM_{2.5}$-concentrations relate strongly to temperature errors, i.e. to WRF rather than its chemical package [see also *Mölders et al.* 2011]. In October 2008, WRF/Chem underestimates the concentrations strongly at some sites (e.g. Sadler). It should be examined whether emissions are underestimated in October. On the contrary, in other months simulated and observed concentrations agree better in magnitude. The discrepancies found may also result from

channeling effects in streets or slight offsets of dispersion plumes. The occasional much higher observed than simulated concentrations are most likely due to contamination of the measurements by mobile sources at the site (e.g. busses idling at the Peger site upwind of the sampler). All these discrepancies are common in and known to occur for all photochemical models of the scale deployed here [e.g. *Chang and Hanna,* 2004].

The evaluation of winter 2005/06 suggested that simulated $PM_{2.5}$-concentrations may be slightly too low on average over the polluted and unpolluted site. However, averaging of polluted and non-polluted sites may be misleading due to the strong concentration differences of polluted and non-polluted sites. In both winters, WRF/Chem seems to overestimate the concentration slightly at the polluted sites. In winter 2005/06 and 2008/09, the mean biases over all available sites are 4.2 and 4.0$\mu g/m^3$, respectively. However, this bias affects the reference as well as the simulations with the emission scenarios. Since we are examining concentration differences in this study, the impact of the aforementioned errors can be considered as small.

6. Results

We examined the meteorological conditions on days with $PM_{2.5}$ exceedances. We found three distinct local circulation patterns at breathing level and five different circulation patterns higher above ground between 100 and 200 m that lead to exceedances of the NAAQS at breathing level (Fig. 13). If at breathing level, wind is very calm (<1m/s) and comes from various directions and the air remains in town, local exceedances will occur within the nonattainment area. The same will be true if slight drainage of the Fairbanks air occurs towards southwest, down the Tanana Valley or if air moves into town from southeast under calm wind conditions in Fairbanks. Obviously, in this case, advection of polluted air from the Salcha air shed and North Pole can contribute to causing the exceedances.

Exceedances are also related to what happens at heights between 100 and 200m or so. If at these levels, air moves out of town slowly down the Tanana Valley, air slowly travels through Fairbanks down the Tanana Valley, air moves towards North Pole and Eielson Air Force Base up the Tanana Valley, or air drains to both sides of the Tanana Valley (Fig. 13), exceedances will occur at some places in the nonattainment area at breathing level. This behavior is especially true when at the same time, winds are relatively calm over Fairbanks or the air circulates slowly over the town.

In the following, $PM_{2.5}$-concentrations at breathing level are discussed if not mentioned otherwise.

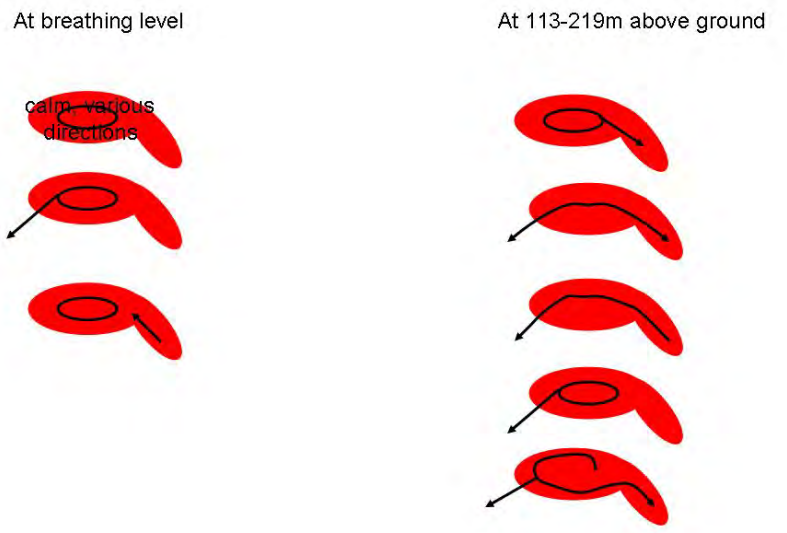

Fig. 13. Circulation pattern associated with violations at breathing level. The red area schematically illustrates Fairbanks, North Pole and Salcha air sheds. Wind-speeds must be very low.

Note that winter 2008/09 except for February and in particular October 2008 were colder than the 30-year average (Table 3).

Table 4 compares the results of the WSR, LSF and REF simulations. The results suggest that in October 2008, January, February and March 2009 the assumed “woodstove replacement” yields a stronger reduction of the $PM_{2.5}$-concentrations at breathing level than the introduction of low sulfur fuel. In November and December 2008, introduction of low sulfur fuel, on average,

provides the higher mitigation of the $PM_{2.5}$-concentrations. The results suggest that "woodstove replacement" provides a temporally more constant percentage reduction of around 6% averaged over the nonattainment area than does the introduction of low sulfur fuel (Table 4).

Table 3. Monthly mean temperatures at Fairbanks International Airport in Fahrenheit. Courtesy to *H. Angelhoff* [2011]. The 30-average for 1971-2000 is taken from *Shulski and Wendler* [2007]. Values for the episode simulated in this study are high-lighted.

	Oct	Nov	Dec	Jan	Feb	Mar	Oct-Mar
2007	21.2	11.5	-3.4	-6.6	-6.7	-6.5	1.6
2008	15.1	-1.4	-7.8	-9.2	-5.9	15.4	1.0
2009	30.7	-1.2	-2.8	-12	-1.5	5.6	3.1
2010	27.5	11.9	-17.9	-13.7	2.9	10.8	3.6
2007-2009	22.3	3.0	-4.7	-9.3	-4.7	4.8	1.9
2008-2010	24.4	3.1	-9.5	-11.6	-1.5	10.6	2.6
1971-2000	24	2	-6	-10	-4	11	2.8

Table 4. Monthly average $PM_{2.5}$-concentration as obtained for the grid-cell holding the State Building and averaged over the nonattainment area for October 2008 to March 2009. The percentage reduction is given in brackets.

	$PM_{2.5}$ ($\mu g/m^3$)					
	State Building			Nonattainment area		
	REF	WSR	LSF	REF	WSR	LSF
OCT	40.2	38.5 (4.2%)	39.2 (2.5%)	12.9	12.2 (5.4%)	12.5 (3.1%)
NOV	30.3	28.8 (5.0%)	28.5 (5.6%)	11.0	10.3 (6.3%)	10.0 (9.0%)
DEC	25.8	24.5 (5.0%)	24.4 (5.4%)	9.2	8.6 (6.5%)	8.5 (7.6%)
JAN	33.9	32.2 (5.0%)	32.7 (3.5%)	11.0	10.3 (6.4%)	10.4 (5.5%)
FEB	27.1	25.5 (5.9%)	26.0 (4.1%)	9.8	9.2 (6.1%)	9.3 (5.1%)
MAR	17.1	16.1 (5.8%)	16.2 (5.3%)	5.7	5.3 (6.4%)	5.3 (7.0%)

6.1 Impact of point-source emissions

This section discusses findings from the simulations performed for winter 2005/06. See Table 1 for details on the simulations.

The influence of emissions from elevated point sources on the $PM_{2.5}$ concentration at breathing level was investigated by analyzing the correlation between the PSs' emissions at each level with the $PM_{2.5}$-concentration at the breathing level. The highest effective level reached by the plume from point-source emissions is the model layer representing the conditions between 343 and 478m. Note that the buoyancy, depending on temperature of the plume, velocity at release etc. and the environmental conditions, determine which levels the emissions from PSs can reach.

Table 5. Monthly average of $PM_{2.5}$-concentration at the State Building and averaged over the nonattainment area as obtained from the simulations for winter 2005/06. The percentage reduction is given in brackets.

	$PM_{2.5}$ ($\mu g/m^3$)			
	State Building		Nonattainment area	
	REF	NPE	REF	NPE
NOV	30.5	29.2 (4.2%)	14.4	13.4 (6.9%)
DEC	26.4	25.4 (3.8%)	12.5	12.0 (4%)
JAN	40.9	39.7 (2.9%)	15.9	14.9 (6.3%)
FEB	21.6	20.9 (3.2%)	9.6	9.2 (4.2%)

Since no emissions from PSs are considered in NPE, the monthly total emission strength does not differ between REF and NPE from November 2005 to February 2006 except at the locations of the PSs. Since most of the PS and the strongest PSs are located in the highly populated

Fairbanks area, here the largest differences between REF and NPE in emissions as well as concentrations occur. Emission and concentration differences are larger in December and January as during these months emissions from PSs are higher than in November and February. The majority of the PSs are facilities that emit more in December and January to cover the higher heating and/or energy demands during the darker, colder December and January than the relatively warmer and less dark November and February.

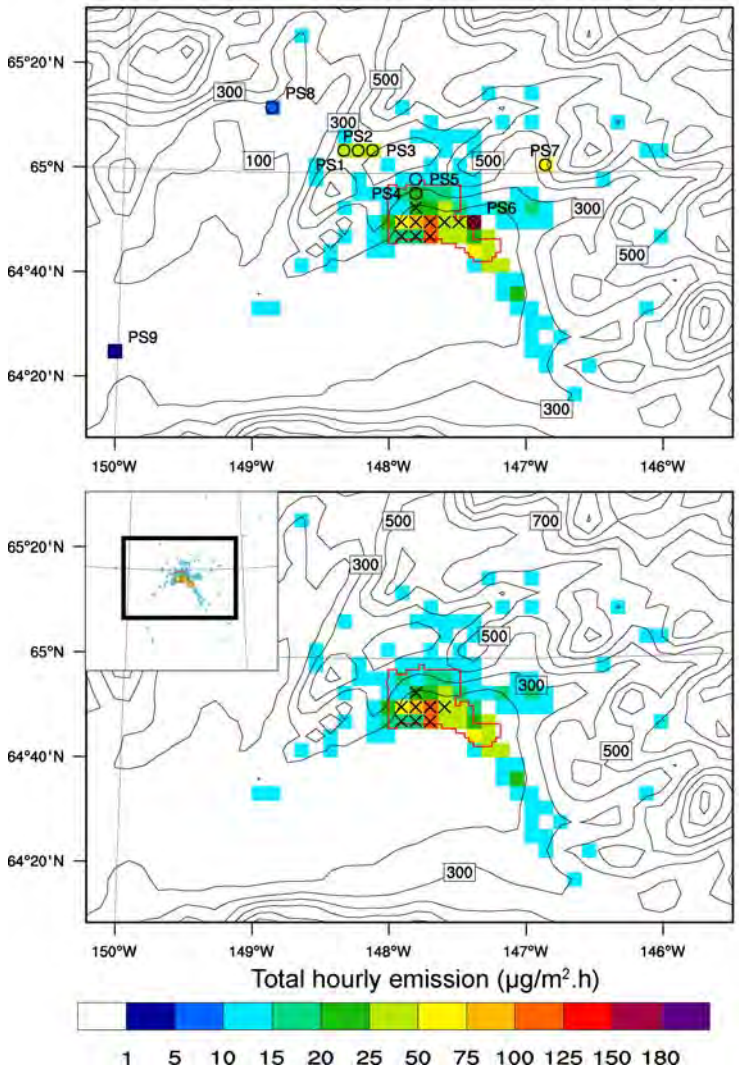

Fig. 14. Zoom-in on the spatial distribution of areas experiencing $PM_{2.5}$-concentration exceeding the NAAQS (grid cells with crosses) in REF (top) and NPE (bottom) exemplarily superimposed on the map of total hourly emission on 0200 UTC December 1, 2005. The black box indicates the location of the zoom-in area. PS1 to PS9 indicate locations of grid columns with point sources.

$PM_{2.5}$-concentration obtained by REF and NPE differ hardly with respect of the number of NAAQS exceedances. Within the domain of interest, the NAAQS is exceeded 10 (7), 6 (5), 22 (21) and 1(1) times in REF (NPE) in November, December, January, and February, respectively. The locations of exceedances within the nonattainment area are identical in both REF and NPE except at PS6 and the adjacent grid cell to its west (Fig. 14). Except for two events in November

2005 in REF, the grid-cell holding the State Building monitoring station experienced exceedances on all exceedance events in REF and NPE.

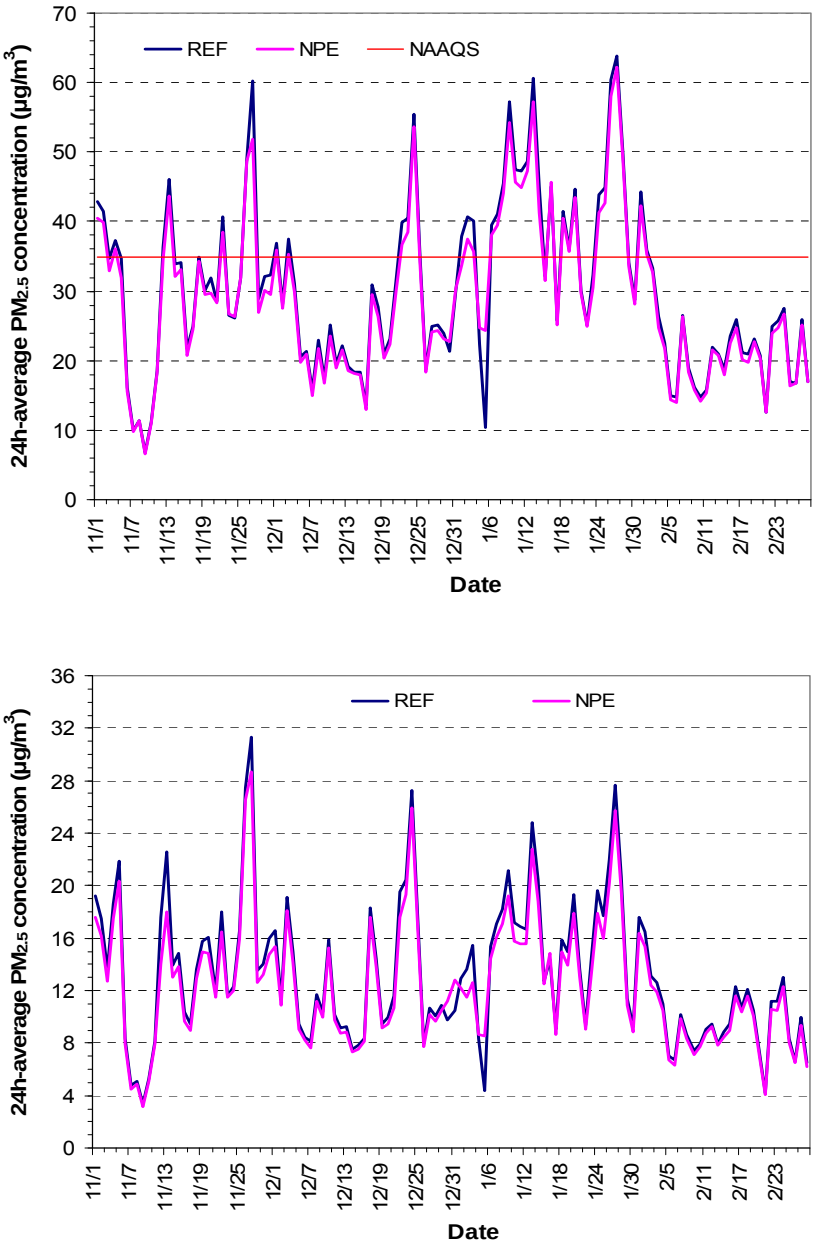

Fig. 15. Temporal evolution of 24h $PM_{2.5}$-concentrations as obtained for the grid-cell that holds the State Building (top) and the 24h $PM_{2.5}$-concentration averaged over the nonattainment area (bottom) for the simulations with (REF) and without (NPE) inclusion of point sources. NAAQS is the National Ambient Air Quality Standard of 35µg/m^3.

Despite the number of exceedances in REF exceeds that in NPE occasionally, the days with exceedances in REF, but not in NPE show almost the same magnitude of $PM_{2.5}$-concentration (Fig. 15). Over the entire simulation period, the average differences of between REF and NPE 24h-average $PM_{2.5}$-concentration are 0.04µg/m^3, 0.8µg/m^3 and 1.0µg/m^3 over the entire analysis domain, the nonattainment area and at the State Building, respectively. The average difference of

highest concentrations between REF and NPE were as low as 1.3µg/m^3 and barely exceeded 3µg/m^3. The most notable differences occurred at locations close to the PS-holding columns. The highest concentration differences occurred for PS6 and on 47% of 120 simulation days and amounted 7µg/m^3 on average. Note that PS6 has the strongest $PM_{2.5}$ emissions among the PS-holding columns.

These findings suggest that PS-emissions do not strongly increase the $PM_{2.5}$-concentration within the nonattainment area except for the grid-cell PS6. In the nonattainment area, on days and at the locations of exceedances, emission from PSs accounted for 4% of the 24h-average $PM_{2.5}$-concentration on average and barely exceeded 10%. These findings mean that emissions from area sources induced high $PM_{2.5}$-concentration in the nonattainment area and the emissions from the PSs just added the small amount needed to exceed the NAAQS. This also means that emissions from PSs play a minor role for the $PM_{2.5}$ exceedances in the nonattainment area.

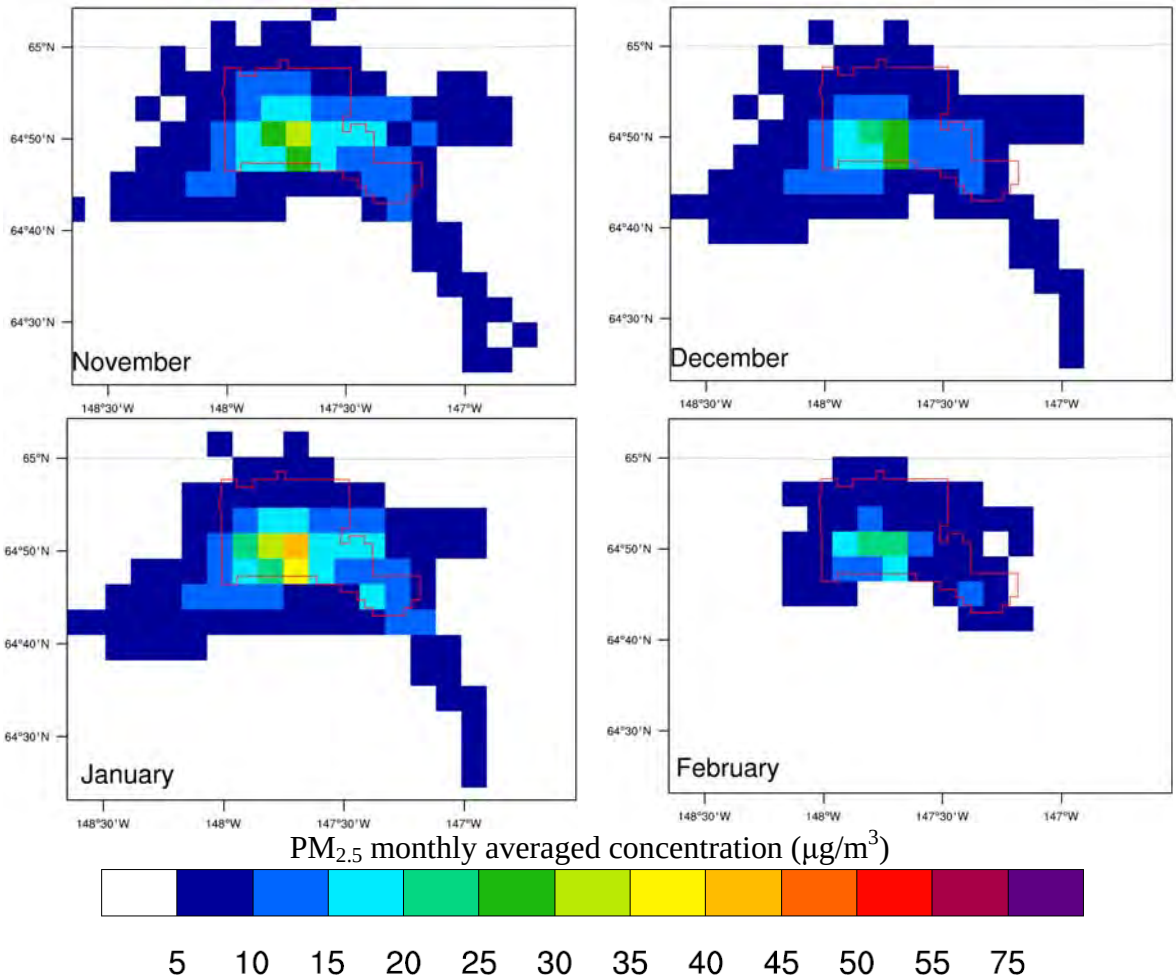

Fig. 16. Zoom-in on monthly mean 24h-average $PM_{2.5}$ concentration in NTF as obtained by REF for winter 2005/06.

Figure 16 shows a zoom on the spatial distribution monthly mean 24h-average $PM_{2.5}$-concentrations at breathing level. The hot spots remain the same over all four months, but with different magnitude. The hot spots remain the same in the simulation without consideration of point source emissions (Fig. 17). The concentrations are only slightly lower in the simulation without consideration of point source emissions. These facts indicate that area and line sources

(e.g. domestic combustion, traffic) are the main cause emission wise for the high $PM_{2.5}$ concentrations.

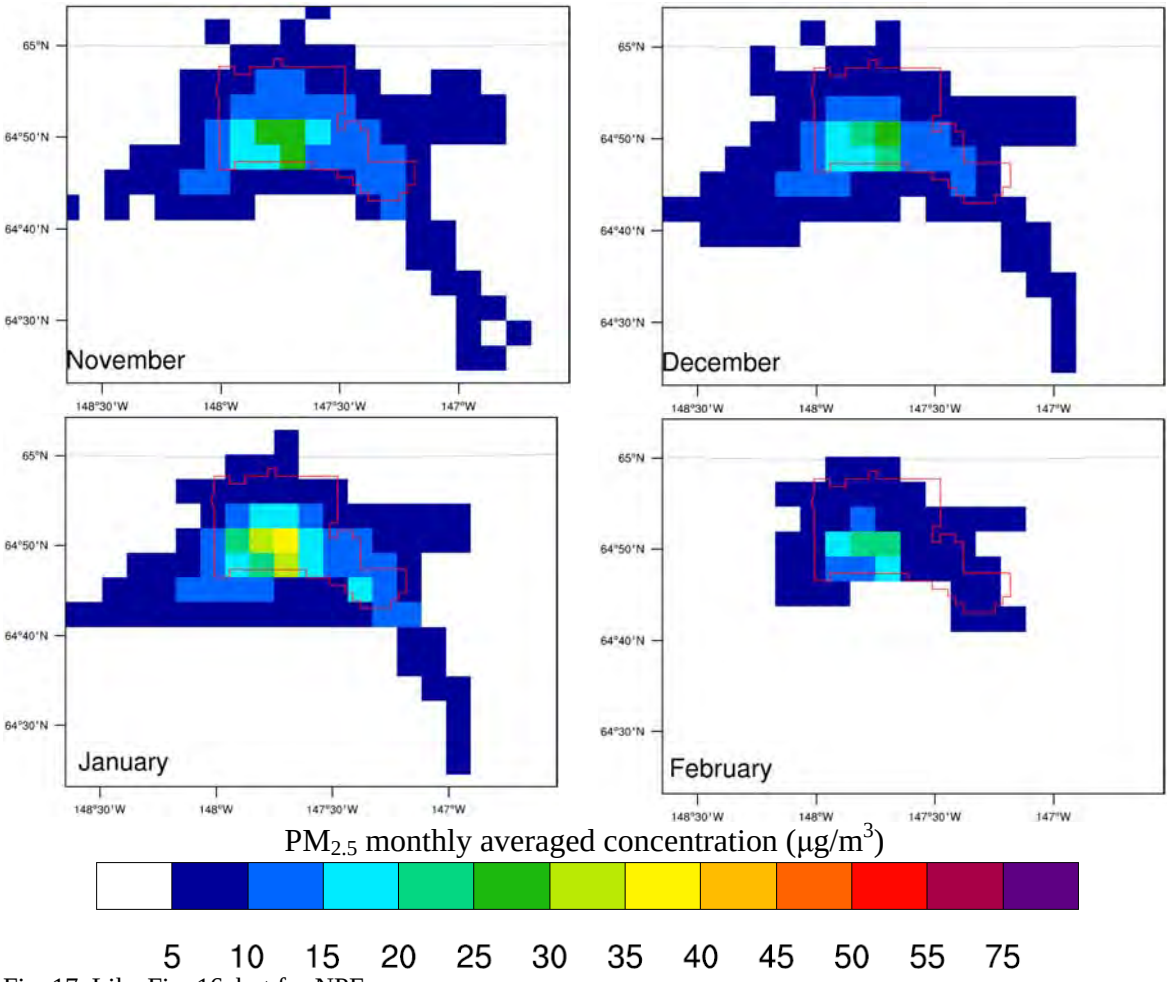

Fig. 17. Like Fig. 16, but for NPE.

Theoretically, higher $PM_{2.5}$-concentration at breathing level are expected with higher PS-emission rates, and under normal atmospheric conditions (no inversion), the location having the highest concentration at breathing level will be farther away from the PS as the effective emission level increases. Our analysis showed statistically significant correlations between emissions and $PM_{2.5}$-concentrations, but the correlation values are low and vary highly among PS-holding columns due to PS characteristics, location and co-location effects. In the downwind of PSs, the impact of point-source emissions on the $PM_{2.5}$-concentration decreases rapidly with increasing distance from the PS.

Investigations show that the total emissions within a grid-column and the simulated $PM_{2.5}$-concentrations at breathing level correlate highly in populated areas. This finding is true for both REF and NPE. The correlation between the total emissions within a grid-column and the simulated $PM_{2.5}$-concentrations at breathing level will only marginally differ if no point-source emissions are considered in the calculation of the $PM_{2.5}$ concentrations. This finding suggests that PS emissions are not the main causes for high $PM_{2.5}$ concentrations.

We evaluated the impact-radius of PS-emissions on the $PM_{2.5}$ concentrations at breathing level. Correlation values between PS-emissions and $PM_{2.5}$-concentration-differences at downwind grid-cells differ generally with wind-speed. Overall, under low wind-speed (<2ms^{-1}) conditions, the highest correlation values at breathing level occur within 2km from the PS; correlations under stronger wind-speed decrease, but are highest farther downwind (e.g. Fig. 18). The occurrence of highest correlation also shifts farther downwind when the emission-level height increases. Nevertheless, regardless of emission level and wind-speed, the highest correlations occurred within 10km from the PS. Beyond 10km from the PS, correlations are small and non-significant and small for low wind-speeds, but significant for moderate wind-speeds (≥5m/s). The strongest correlations are obtained typically with time lags of 0 or 1h.

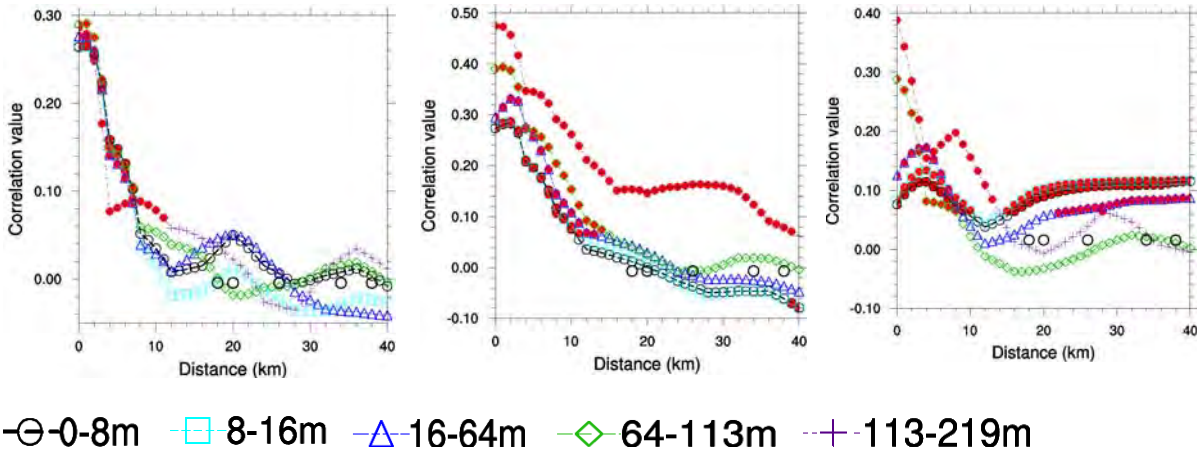

Fig. 18. Correlation of emissions at PS6 with the $PM_{2.5}$-concentration-difference (REF-NPE) at downwind grid-cells in subsequently lower levels from the emitting level (113-219m) to the breathing level (0-8m) under wind-speeds <2m/s (left), 2-5m/s (middle) and ≥5m/s (right). The emitting level is the highest level displayed in the figure. Open black circles indicate the relative position of grid columns holding other PSs near the PS-holding grid-column of interest. Closed red circles represent statistically significant (at the 95% confidence level) correlations.

Atmospheric temperature inversions influence the dispersion of PS-emissions (Fig. 10). As can be easily derived from Figure 10, theoretically, PS-emissions emitting into levels above, in-between and below inversion layers would have their impact on the breathing level from the lowest to highest magnitude, respectively. In the following, we talk about “no-inversion conditions” when the bottom of any inversion layer aloft is 200m above the emitting-level. “Below-inversion” refers to when the bottom of any inversion aloft is less than 50m above the highest emitting-level. On average, WRF/Chem predicted in-between-inversion, above-inversion, below-inversion and no-inversion conditions for PS-emissions in 64%, 18%, 10% and 8% of the time, respectively. Note that WRF/Chem for 2005/06 predicted the frequency of inversions acceptably [*Mölders et al*., 2011].

In general, WRF/Chem reproduced successfully the emission-inversion relationship at all PSs. Here we only show the correlation at PS6 as an example. The strongest and significant correlations between PS-emissions and $PM_{2.5}$-concentration-difference at breathing level occurred under “below-inversion” conditions and the highest correlation values typically occurred at 8-10km downwind depending on emission level and wind speed (e.g. Fig. 19). The second strongest (significant) correlations occurred under “in-between-inversion” conditions. Then the highest correlation values occurred within 0-12km downwind depending on wind-speed, emission level and inversion strength. The location of highest correlation typically shifts

farther downwind as the inversion strength increases and vice versa. Under both "no-inversion" and "above-inversion" conditions, PS-emissions correlate marginally and insignificantly with the breathing level $PM_{2.5}$-concentration. Based on these finding we conclude that PSs have their highest impact on the $PM_{2.5}$-concentration at breathing level within 10km of their location.

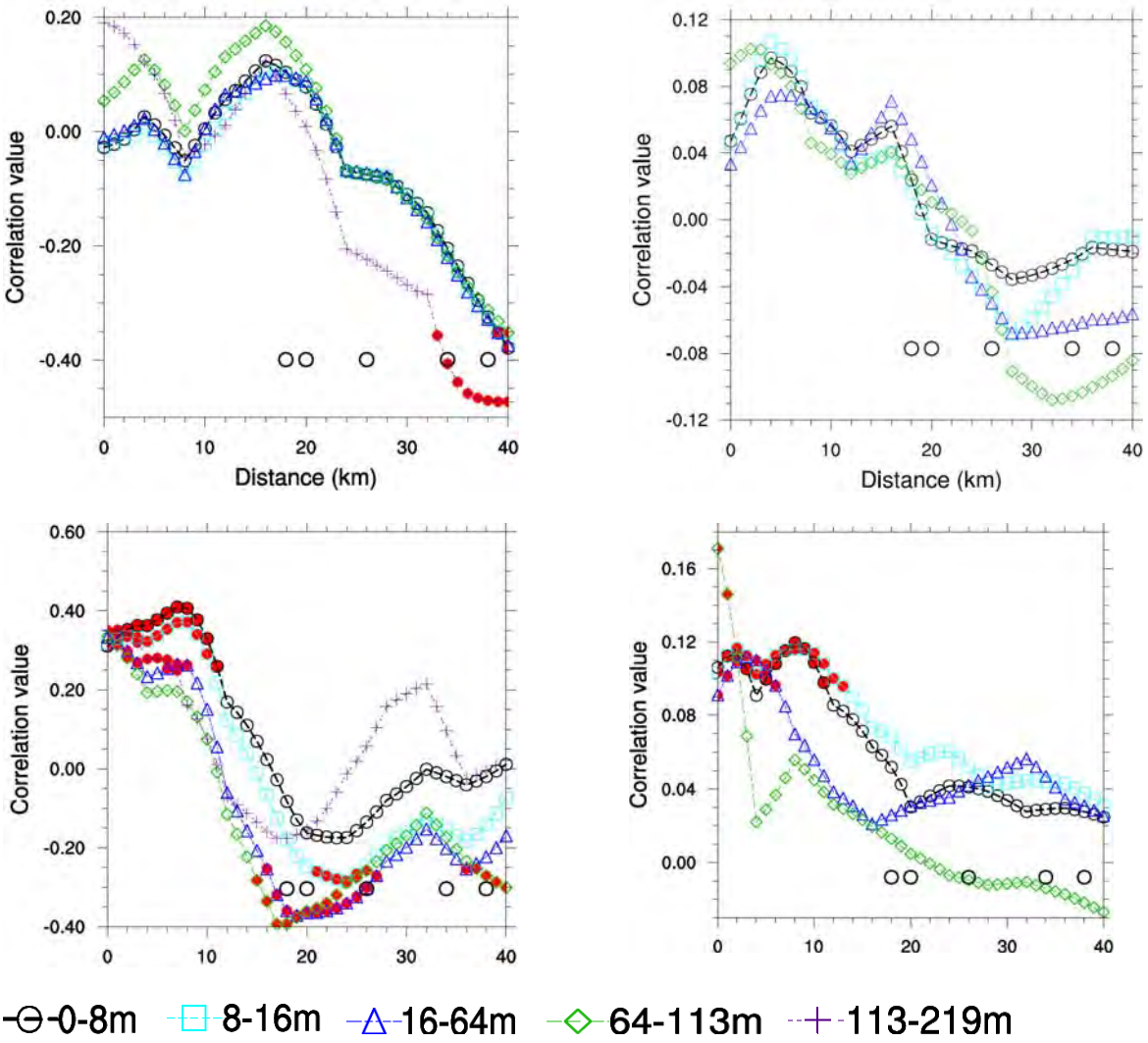

Fig. 19. Correlation of $PM_{2.5}$ emissions at PS6 with $PM_{2.5}$-concentration-difference at downwind grid-cells in subsequently lower levels from the emitting-level to the breathing level (0-8m) under conditions when there was "no inversion", emission into levels above, just below and in between inversion layers (top-left to bottom-right, respectively). The emitting-level is the highest level displayed in the figure. Open black circles indicate the relative position of grid columns holding other PSs in the vicinity of the PS-holding grid-column of interest. Closed red circles represent statistically significant (at the 95% confidence level) correlations.

6.2 Potential impact of "woodstove replacement" programs

As pointed out above, WSR is a very moderate "woodstove replacement" scenario in comparison with the sensitivity simulation that assumed a replacement of all non-certified wood burning devices based on the number of devices given in *Davies et al.*'s [2009] report (WSS1). The emission reduction in WSR was much lower than in WSS1 (cf. section 4). Within the nonattainment area, the emission strength in WSR was 6$\mu gm^{-2}h^{-1}$ (6%) less than in REF on

average whereas in WSS1 the emission strength was 40% lower than in REF. Because of the comparably small emission difference between REF and WSR, simulated $PM_{2.5}$-concentration of REF and WSR differ typically only slightly (Figs. 20, 21).

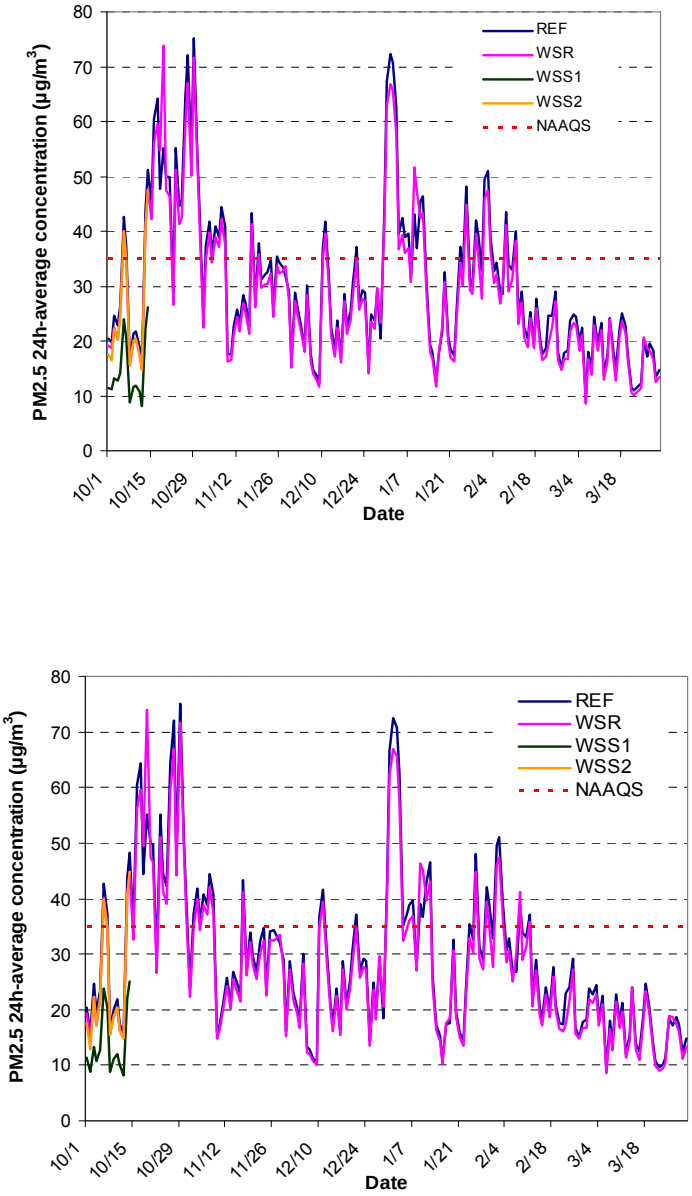

Fig. 20. Highest 24h-average $PM_{2.5}$ concentration as obtained anywhere in the model domain (top) and the 24h-average concentration at the grid-cell holding the State Building (bottom) in REF, WSR, WSS1, and WSS2. Note that the highest concentrations within the model domain occurred in the nonattainment area.

In comparison with the emissions in REF, the average $PM_{2.5}$-emission reductions in the nonattainment area are 6%, 36%, and 7% in WSR, WSS1, WSS2, respectively. The highest 24h-average $PM_{2.5}$-concentration difference anywhere in the domain amounts 5.7µgm^{-3} on February 22, 2009 (Fig. 20). Averaged over the nonattainment area, the highest (2.1µg/m^3) and the second highest (2.0µg/m^3) difference in 24h-averaged $PM_{2.5}$-concentrations were simulated for October 27, 2008 and January 1, 2009, respectively, and the average difference over time and the nonattainment area amounts 0.6µg/m^3. About 45% and 33% of the concentration differences fall

between 0.5-1µg/m^3 and 0-0.5 µg/m^3, respectively (Fig. 22). All grid-cells with the highest concentrations are located in the nonattainment area.

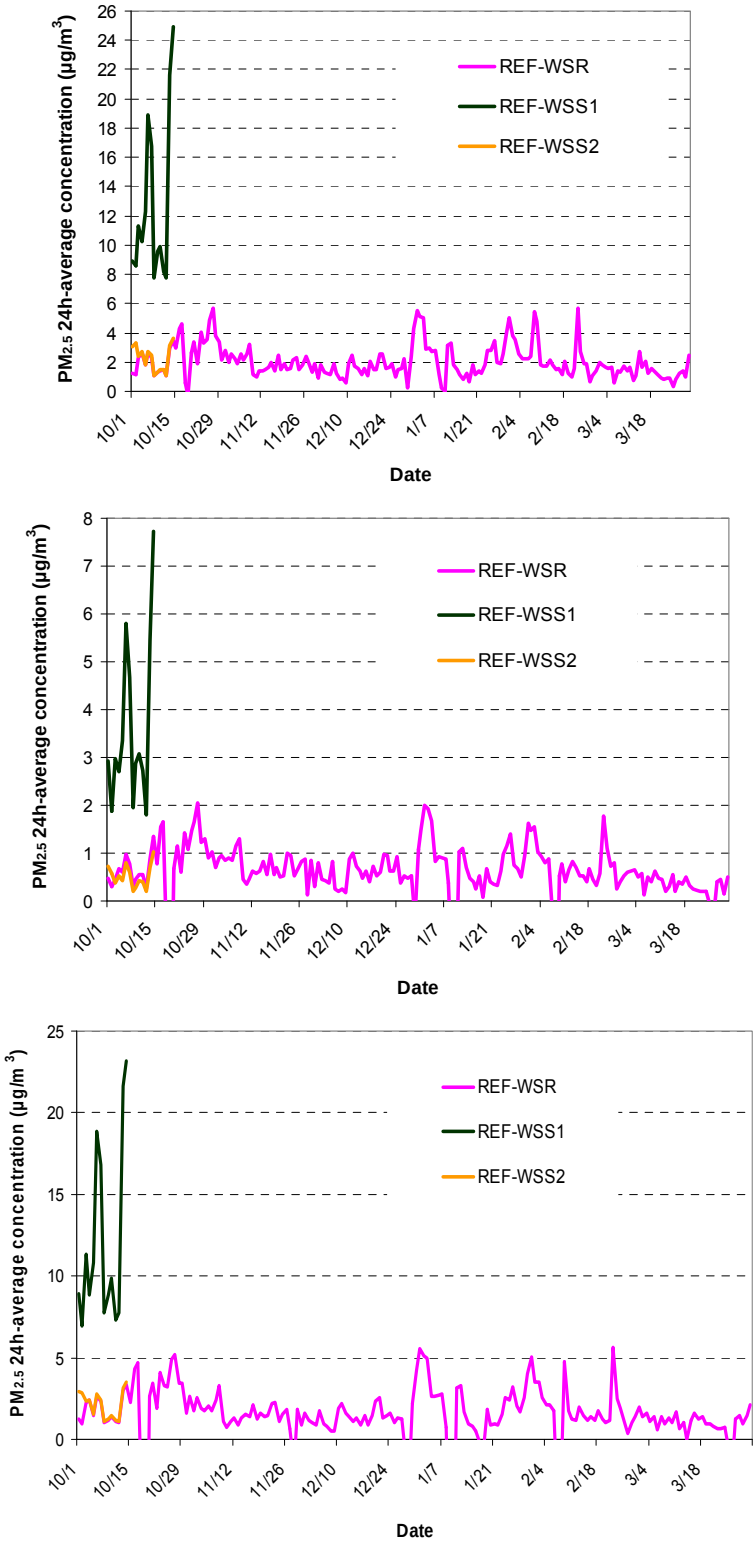

Fig. 21. Highest 24h-average $PM_{2.5}$-concentration difference from REF for WSR, WSS1, WSS2 as obtained in the domain (top), on average over the nonattainment area (middle) and the grid-cell with the State Building (bottom).

In the nonattainment area, the monthly average $PM_{2.5}$-concentration differences amount to $0.7\mu g/m^3$, $0.7\mu g/m^3$, $0.6\mu g/m^3$, $0.7\mu g/m^3$, $0.6\mu g/m^3$ and $0.3\mu g/m^3$ in October, November, December, January, February and March, respectively. We calculated the 24h-averaged $PM_{2.5}$-concentration difference for each day of the 182 simulation days and sorted them from high to low differences. We picked the 20% highest and 20% lowest concentration differences from this list. Note that 20% corresponds to 36 days in our study. The investigation showed that 14 and 13 of the top 20% highest and lowest concentration differences occurred in October and January, respectively. Off the 20% lowest, nine days occurred in March. This means the highest differences typically occurred in October and January whereas the lowest differences occurred in March. This finding means that the highest mitigation of $PM_{2.5}$-concentrations can be achieved in the months that are coldest.

The Student t-test showed statistically significant $PM_{2.5}$-concentration differences only within the nonattainment area and some adjacent grid-cells (Fig. 23). Outside the nonattainment area, the $PM_{2.5}$-concentration differences are very low and non-significant. Although the Student t-test shows that the concentration differences are significant, there is still a possibility that the $PM_{2.5}$-concentration difference at a given grid-cell is not due to the reduced emission, but rather due to some variable random effects between the two simulations (e.g. truncation errors, model sensitiveness). This is especially true for very small differences in $PM_{2.5}$-concentration. We adopted the FEA analysis [*Carpenter et al.*, 1989; *Werth and Avissar*, 2002] to verify that the differences are really due to the "woodstove replacement".

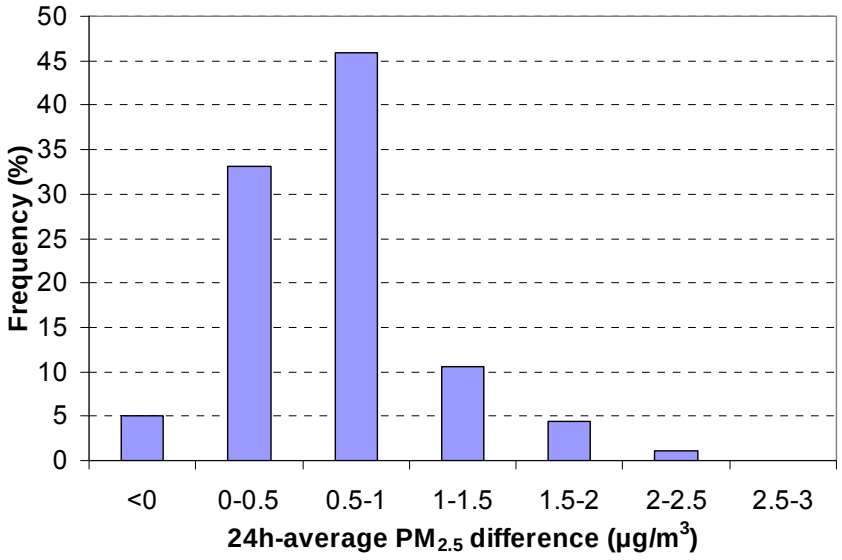

Fig. 22. Frequency distribution of 24h-average $PM_{2.5}$-concentration difference as obtained for WSR.

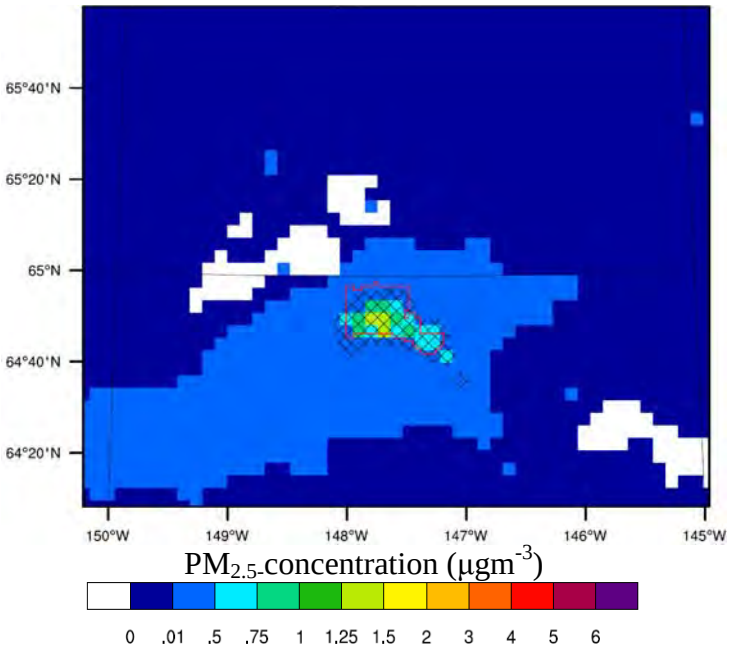

Fig. 23. Zoom-in showing the average difference of $PM_{2.5}$-concentration between REF and WSR for October 1, 2008 to March 31, 2009. The hashed shading indicates grid cells where the difference is statistically significant at 95% or higher level of confidence

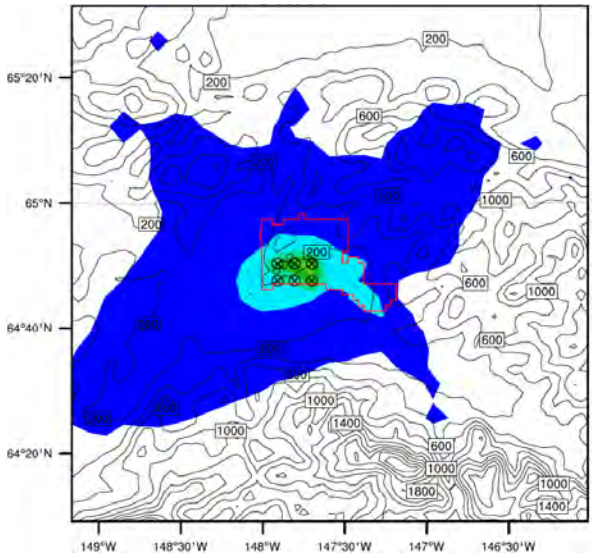

Fig. 24. Zoom-in map of grid-cells for which exceedances were simulated during October 1, 2008 to February 28, 2009 in REF. The 24h-average $PM_{2.5}$ concentration on October 1, 2008 is superimposed. The crossed circles indicate grid cells for which exceedance were simulated during OTM; the red polygon indicates schematically the nonattainment area. Grid-cells for which exceedances were simulated in WSR are identical to those for which exceedances occurred in REF (therefore not shown).

In February 2009, several grid-cells exist in the northwest of the nonattainment area that have ranks lower than the top 5%. Some of them have non-significant concentration-differences according to the Student-t test (Fig. 24). For November and December 2008, the ranks of true

concentration differences are relatively uniform anywhere in the whole model domain whereas they vary strongly in other months. This behavior coincides with the temporal evolution of the 24h-average $PM_{2.5}$-concentration difference (Fig. 21) that indicates low variation of the difference in November and December 2008, but strong variation in the other months.

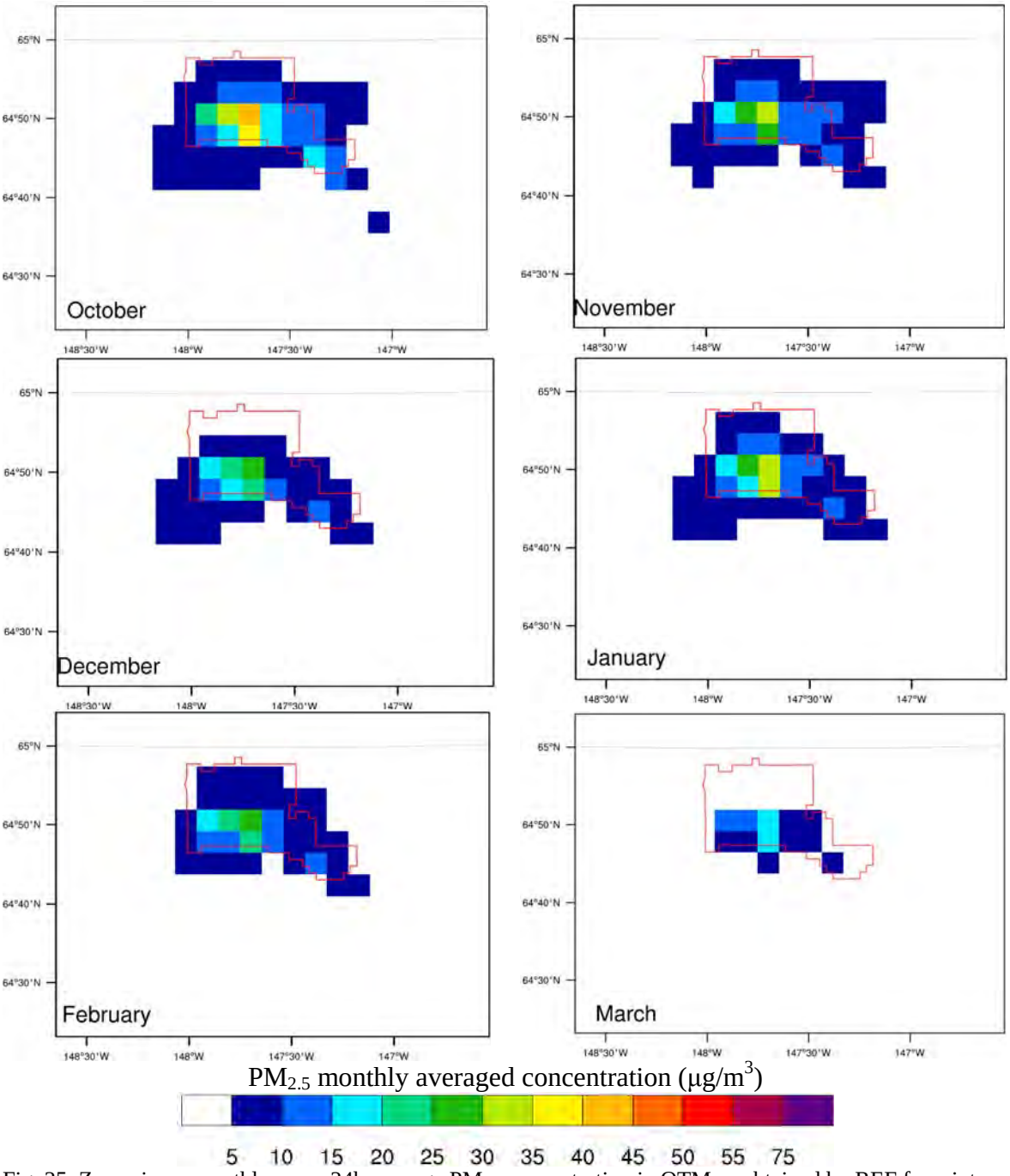

Fig. 25. Zoom-in on monthly mean 24h-average $PM_{2.5}$ concentration in OTM as obtained by REF for winter 2008/09.

According to the FEA, exchanging the noncertified wood-burning devices helped to reduce the number of exceedance days during OTM. The number of exceedance days anywhere in the nonattainment area are 20 (19), 10 (7), 5 (3), 15 (14), and 5 (5) in REF (WSR) for October,

November, December, January, February respectively. All exceedance events of OTM occurred at grid-cells in the nonattainment area. At the grid-cell holding the State Building monitoring site, exceedances were simulated for 52 (44) days in REF (WSR). At grid-cells other than that holding the official site, exceedances were simulated for 40 (34) days by REF (WSR). Despite the different number of exceedance days, locations (grid-cells) that experienced exceedances are identical in REF and WSR during OTM (Fig. 25). Days and grid-cells having the highest $PM_{2.5}$-concentrations during simulated exceedance events during OTM are also identical. This fact indicates that there are no offsets in the temporal and spatial distribution of exceedance events between REF and WSR.

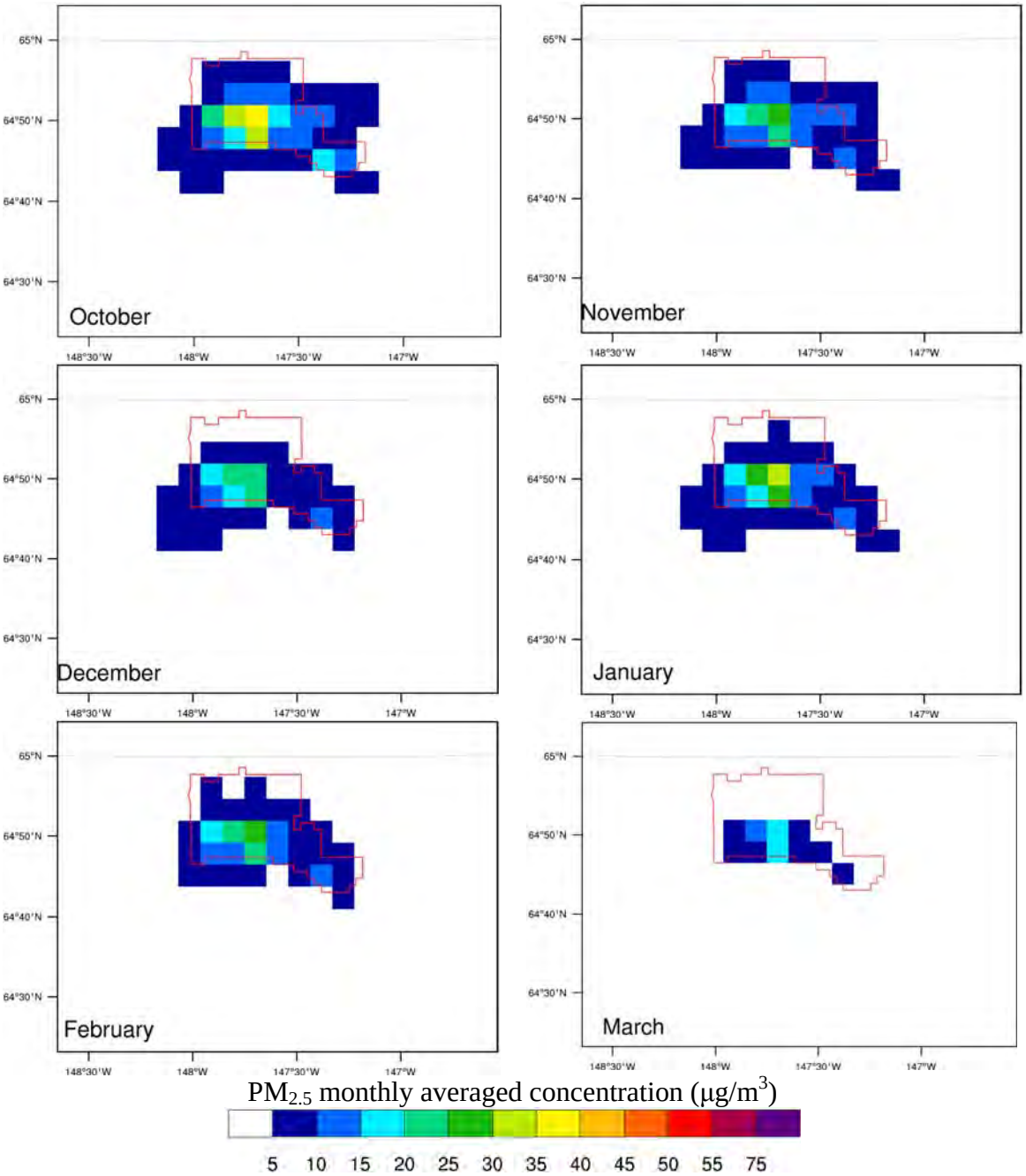

Fig. 26. Like Fig. 25, but for WSR.

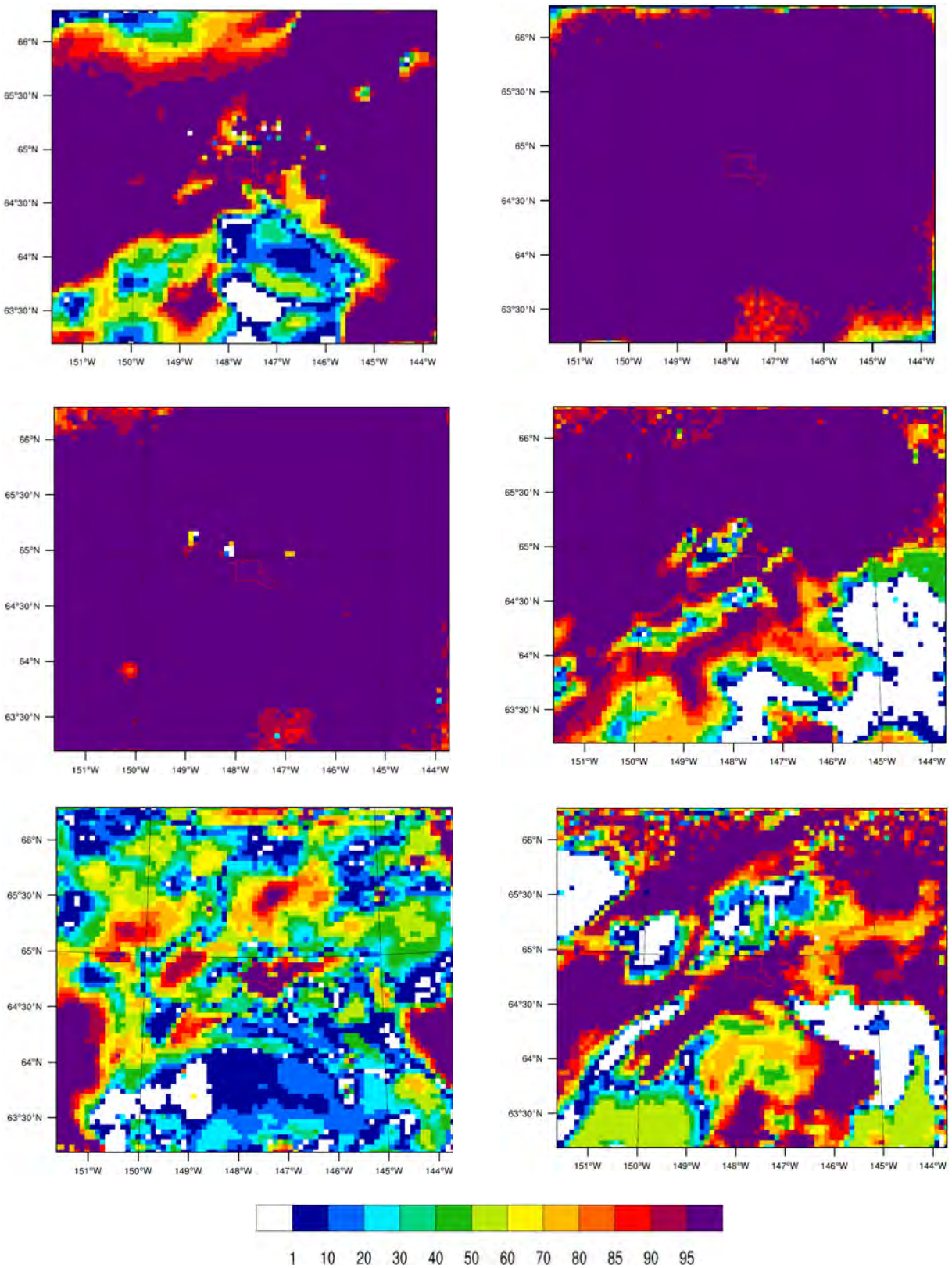

Fig. 27. Monthly rank of "true" differences over "false" differences of $PM_{2.5}$-concentration for October 2008 to March 2009 (from top left to bottom right). At grid-cells ranking higher than the 95% percentile, the "woodstove replacement" can be considered as the factor that actually reduced the $PM_{2.5}$ concentrations at breathing level.

Comparison of the monthly mean 24h-average $PM_{2.5}$ concentrations obtained with REF and WSR (Figs. 25, 26) indicates that the hot spots remain the same, but with slightly lower concentrations.

The FEA was applied for every month from October 2008 to March 2009. The ranks of the true-difference concentrations varied highly at all grid-cells throughout OTM except for those in the nonattainment area (Fig. 27). The ranks of true concentration difference at grid-cells in the nonattainment area lay consistently in the top 5% of the false ensembles. This means that exchanging the non-certified wood-burning devices does really help to reduce the $PM_{2.5}$-concentrations in the nonattainment area.

The results of the Student-t test and FEA (Fig. 27) indicate that exchanging the noncertified wood-burning devices does really help to reduce the $PM_{2.5}$-concentration in the nonattainment area. This outcome results from the fact that wood-burning devices emit into low levels of the atmosphere. Therefore, the emitted species are not transported far away from their sources. This behavior is especially true for conditions with low wind-speeds, as they frequently exist during winter in Fairbanks [cf. *Tran and Mölders*, 2010]. Thus, the impact of emissions from wood-burning on the $PM_{2.5}$-concentrations at breathing level remains local compared to the impacts of elevated point sources.

6.2.1 Sensitivity studies on "woodstove replacements"

We compared the emission reductions that related only to the different numbers of heating devices in WSS1, WSS2 and WSR with each other as well as with the reference simulation. Recall that the reference simulation, and the simulations assuming the "woodstove replacement" using *Davies et al.*'s number of devices, and the "woodstove replacement" using the SRL draft report and *Carlson et al.*'s number of devices were denoted as REF, WSS1, WSS2, and WSR, respectively (Table 1). Due to the tremendous CPU time required for a half-year long simulation the WSS1 and WSS2 simulations were carried out only for a limited time. While WSS1 reduces the $PM_{2.5}$ concentrations in the nonattainment area greatly, WSS1 is much less doing so (Figs. 20, 21). Within the 15 days of simulation, WSS2 reduces the 24h-average $PM_{2.5}$ concentrations by 3.6μg/m^3 to the highest, while WSS1 reduces them by as much as 25μg/m^3. WSS1's reduction helped efficiently to avoid four exceedances encountered locally in REF. On the contrary, the reduction in WSS2 was not sufficient to do so. The locations of exceedances do not differ between REF, WSS1 and WSS2 and they all occur in the nonattainment area. The reduction benefit of WSS1 was higher when local exceedances existed, while the reduction obtained in WSS2 differed marginally with time.

The sensitivity studies suggested large uncertainty in the magnitude of the efficiency of a "woodstove replacement" program. This uncertainty mainly results from (1) the unknown number of wood-burning devices that exist in the nonattainment area and could be replaced, (2) the unknown partitioning of the use of wood-burning and other heating devices in households with more than one heating option, (3) the unknown temporal use of wood-burning devices, and (4) the unknown spatial distribution of wood-burning devices.

6.3 Potential impact of usage of low sulfur fuel for heating oil, power generation and in oil-burning facilities

Introducing low sulfur fuel decreased the total monthly $PM_{2.5}$-emissions in the nonattainment area from October to March by 15.666, 17.448, 15.407, 15.447, 14.294, and 13.381 kg/km^2,

respectively from 140.130, 94.184, 94.118, 101.265, and 98.398 kg/km^2, respectively. The percentage total daily $PM_{2.5}$-emission reductions from October to March were 11.1%, 18.5%, 16.4%, 13.0, 14.1, and 13.6%, respectively. The decreases in monthly emissions of SO_2, NO and VOC were approximately 23%, 1% and 0%, respectively.

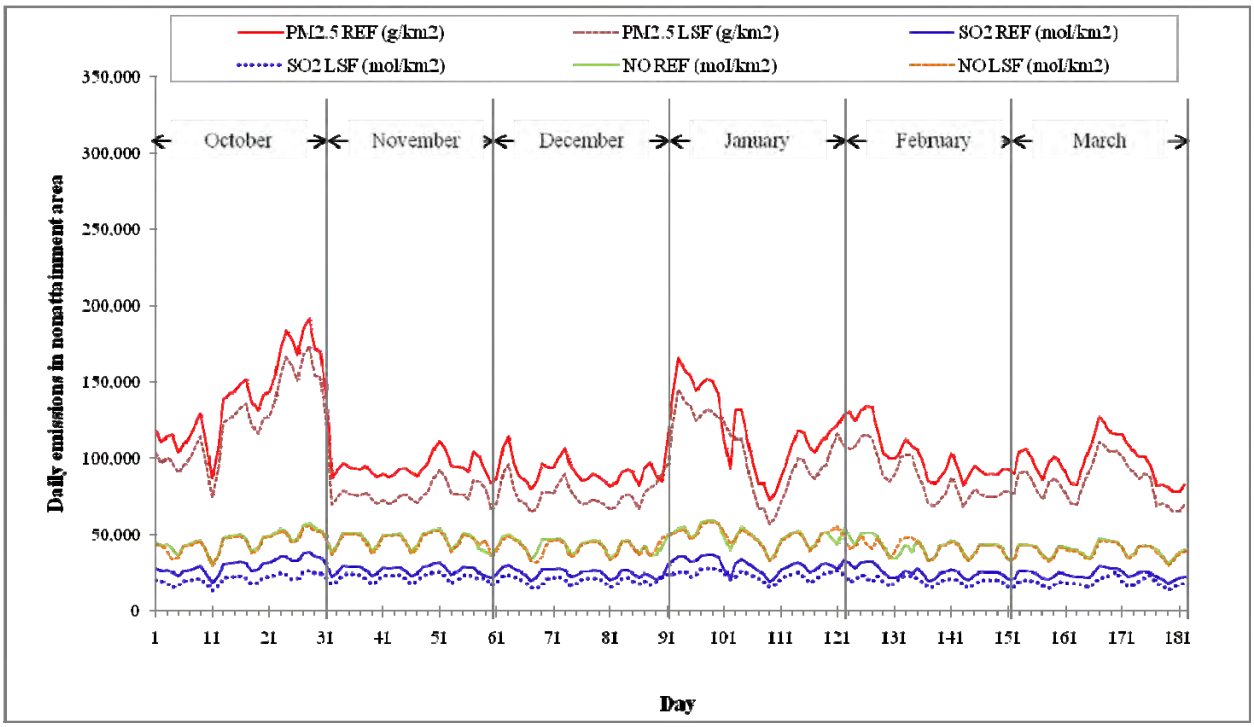

Fig. 28. Temporal evolution of daily emissions averaged over the nonattainment area for October 2008 to March 2009 as assumed in REF and LSF. The day refers to the day since start of the simulation (1 October 2008).

The daily mean temperatures are a main factor that affects the efficiency of utilizing low sulfur fuel. Low temperatures cause incomplete combustion and support the gas-to-particle conversion. During OTM, October 2008 had the highest frequency of days with daily near-surface temperatures below the 1971-2000 30-year monthly mean temperature (Table 3). Consequently, October 2008 had high emissions of particulate matter. Daily emissions in the nonattainment area with the current fuel sulfur content and after introduction of low sulfur fuel are compared in Figure 28.

In the nonattainment area, the monthly average $PM_{2.5}$-concentration amounted to 13.0, 11.6, 9.2, 11.0, 9.8 and 5.7µg/m^3, respectively, and 9.9µg/m^3 on average over OTM. The monthly average $PM_{2.5}$-concentration difference (REF-LSF) amounts to 0.4, 1.0, 0.7, 0.6, 0.5 and 0.4µg/m^3 in October, November, December, January, February and March, respectively, and 0.6µg/m^3 on average over the entire winter. The percentage reductions varied from 3% to 9% (Table 4). November had the highest assumed emission reduction and simulated concentration reductions. The daily reduction in emissions does not yield to a linearly corresponding reduction in the daily average $PM_{2.5}$ concentrations at breathing level in the nonattainment area (cf. Figs. 28, 29).

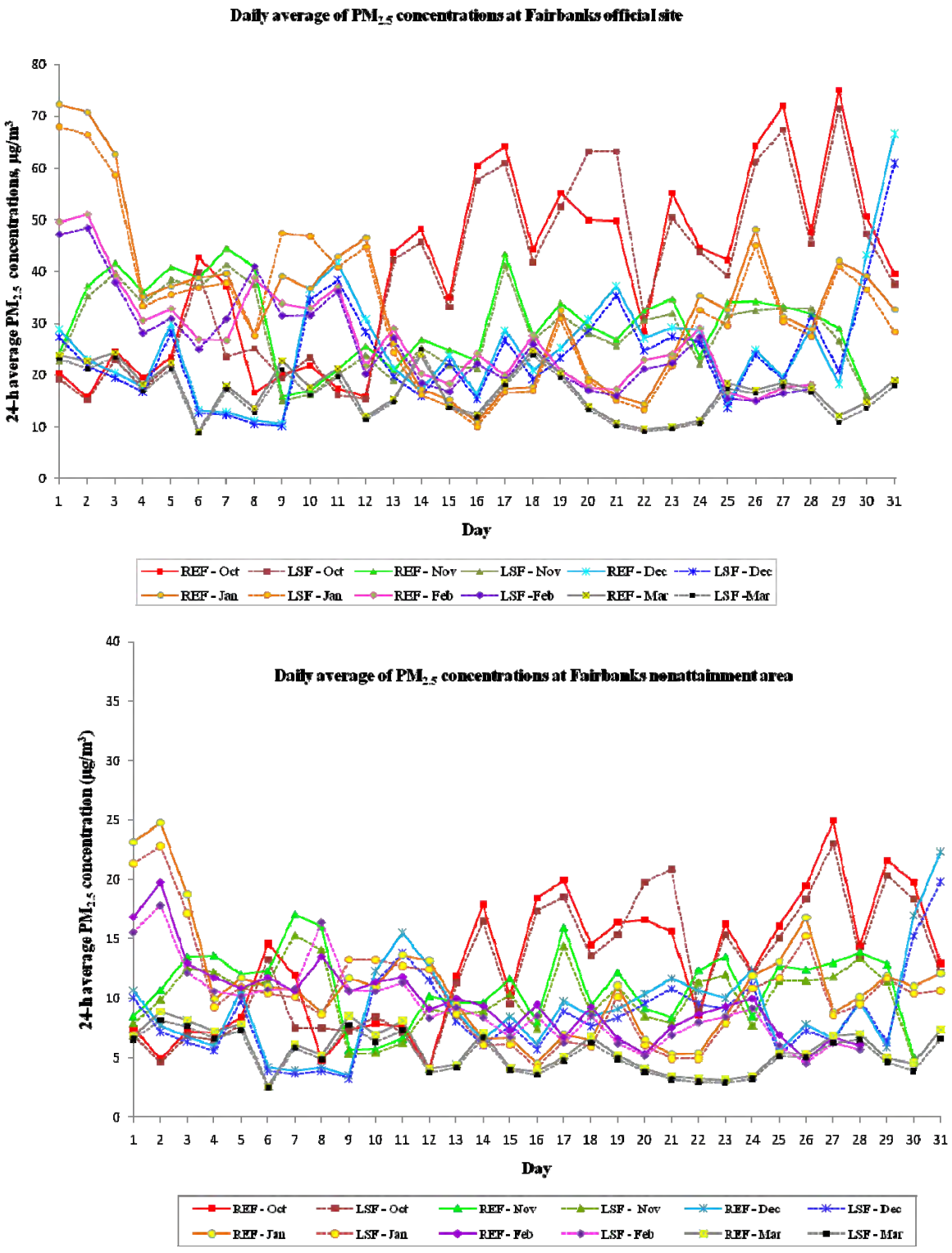

Fig. 29. Temporal evolution of simulated 24h-average $PM_{2.5}$ concentrations as obtained for the grid-cell that holds the State Building (top) and the 24h-average $PM_{2.5}$ concentrations averaged over the nonattainment area (bottom) in the various months of winter 2008/09. REF and LSF refer to the reference simulation and the simulation assuming the introduction of low sulfur fuel for heating oil, power generation and facilities burning oil (see Table 1).

On average, the simulated reduction of 24h-average $PM_{2.5}$ concentrations during OTM was 0.6µg/m^3. The maximum 24h-average $PM_{2.5}$-concentrations reduction of 4.4µg/m^3 occurred in October (Fig. 29). Focusing on the values simulated for the grid-cell holding the official $PM_{2.5}$-monitoring site in the nonattainment area at the State Building, the average daily concentrations reduction was 1.2µg/m^3 for OTM. The maximum 24h-average $PM_{2.5}$-concentration reduction at the State Building site was 13.6µg/m^3 and was simulated for October 2008. In comparison with the $PM_{2.5}$-concentrations obtained for other grid-cells in the nonattainment area, this site had the highest frequency of exceedance days (19, 8, 5, 15, 5, and 0 exceedance days for October to March, respectively), and most of them had the highest $PM_{2.5}$-concentrations, when compared to other grid-cells in the nonattainment area on the same day.

We calculated the 24h-averaged $PM_{2.5}$-concentration difference between REF and LSF for each day of the total 182 simulation days and sorted them from high to low differences. We picked the 20% highest and 20% lowest concentration differences from this list. Note that 20% corresponds to 36 days in this case. Investigation of the top 20% showed that 14 of the highest concentration differences occurred in November. Off the 20% lowest, most days (14) occurred in March. This means the highest differences typically occurred in November whereas the lowest differences occurred in March. The highest differences were mainly due to the concentration values. In this scenario, high monthly average concentrations mostly translated into high monthly average reductions. Table 4 shows that high $PM_{2.5}$ concentrations occurred in October, January, and November from the first to the third rank, respectively. In October and January, the concentrations were high, but there were some days for which $PM_{2.5}$ concentrations increased after introduction of low sulfur fuel. Therefore, in October and January, the $PM_{2.5}$-concentration reduction was not as high as in November. The lowest difference for $PM_{2.5}$-concentrations occurred for March as this month had the lowest $PM_{2.5}$-concentrations.

The daily reductions in $PM_{2.5}$-concentrations vary strongly with the meteorological conditions and over the months (Fig. 29). By reducing the fuel sulfur content of oil, the number of simulated exceedance days in October 2008 to March 2009, which amounted to 20, 10, 5, 15, 5 and 0 in REF were reduced to 19, 8, 4, 14, 5 and 0 in LSF, respectively. The simulations suggested that in total, five exceedance days could have been avoided by introduction of low sulfur fuel.

Remarkably, on several days, the 24h-average $PM_{2.5}$-concentrations increased in the nonattainment area after introduction of low sulfur fuel. Note that similar was found also in another sulfur reduction study carried out over the North Pacific for January with another configuration of WRF/Chem [*T.T. Tran*, 2011; pers. communication]. In our study, on some simulated days, the increase of $PM_{2.5}$-concentrations stemmed from the increase of $PM_{2.5}$ emissions, for example at the end of December and in mid-January (Fig. 28). The emissions increased due to the non-linear temperature dependency of emissions from power generation and domestic combustion considered in AkEM.

However, the increase of $PM_{2.5}$ concentrations on October 8, 10, 20-22, and February 7-9 and March 14 did not coincide with increased $PM_{2.5}$ emissions. These increases despite of decreased $PM_{2.5}$ emissions are due to gas-to-particle conversion. Recall that the usage of low sulfur fuel leads to a different emission spectrum for various other species. Increases of $PM_{2.5}$ concentrations occurred both inside and outside the nonattainment area (e.g. Fig. 30). The increases were related to the atmospheric chemistry of NO_x that affected the thermodynamic equilibria of sulfate-nitrate-ammonia-water in aerosols.

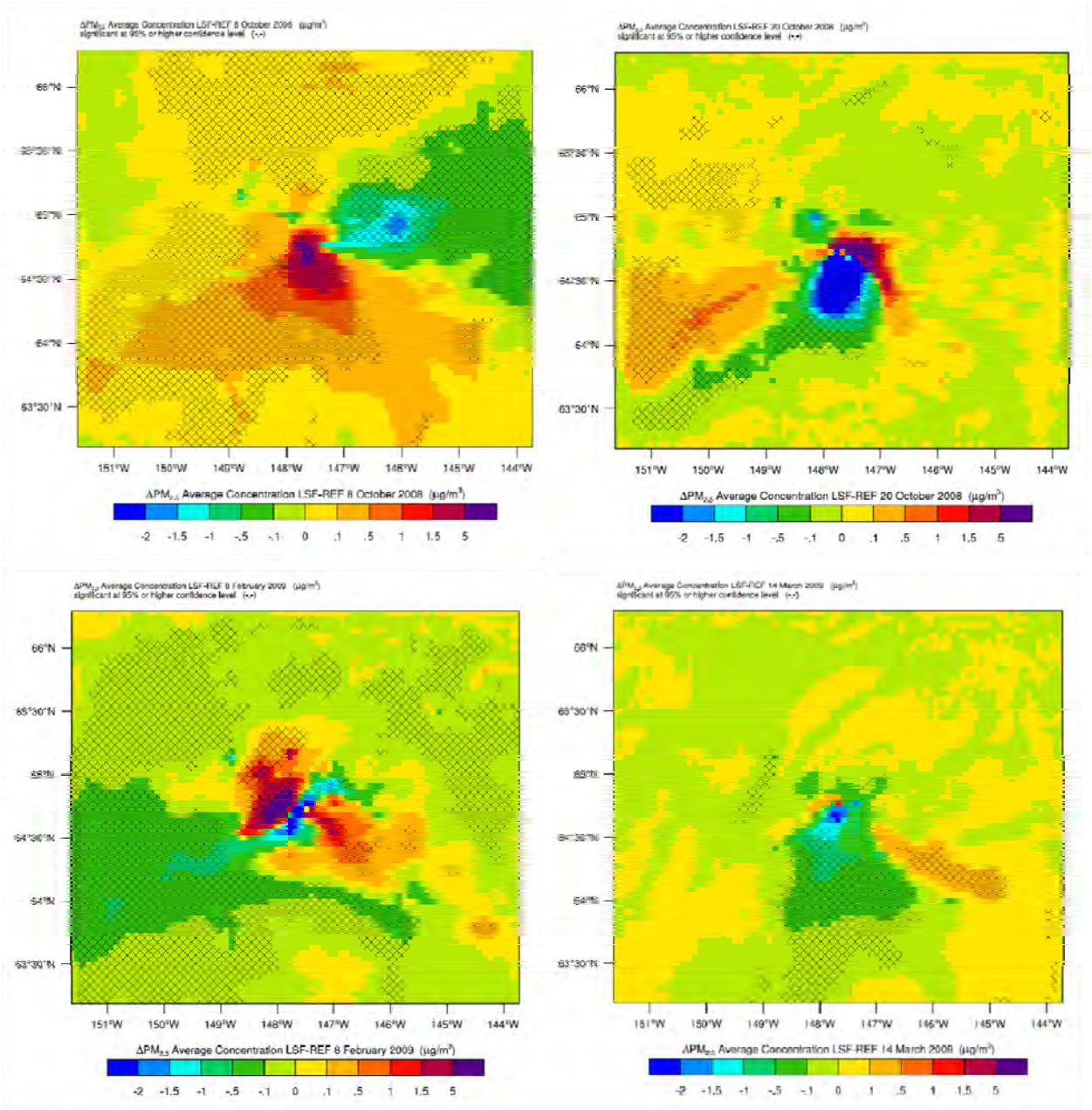

Fig. 30. Examples of $PM_{2.5}$-concentration difference distributions on days with days with locally increased $PM_{2.5}$ concentrations after introduction of low sulfur fuel. The hashed shading indicates grid cells wherein the difference (REF-LSF) is statistically significant at 95% or higher level of confidence.

The large number of days (12 days in the nonattainment area, 13 days for the grid-cell holding the State Building) with increased $PM_{2.5}$-concentrations and the emission-concentration relationship (Figs. 28, 29) suggest that the locally increased $PM_{2.5}$-concentrations after introduction of low sulfur fuel are most likely not a model artifact, but real. The reduction of SO_2 emissions and lower SO_2-concentrations in LSF reduced the sulfate-aerosol concentrations. This circumstance further resulted in partial replacement of the reduced aerosol mass by available nitric acid. The percent fraction of nitrate increased, but sulfate decreased on days with increased $PM_{2.5}$ concentrations (Fig. 31). Note that nitrate has more mass than sulfate.

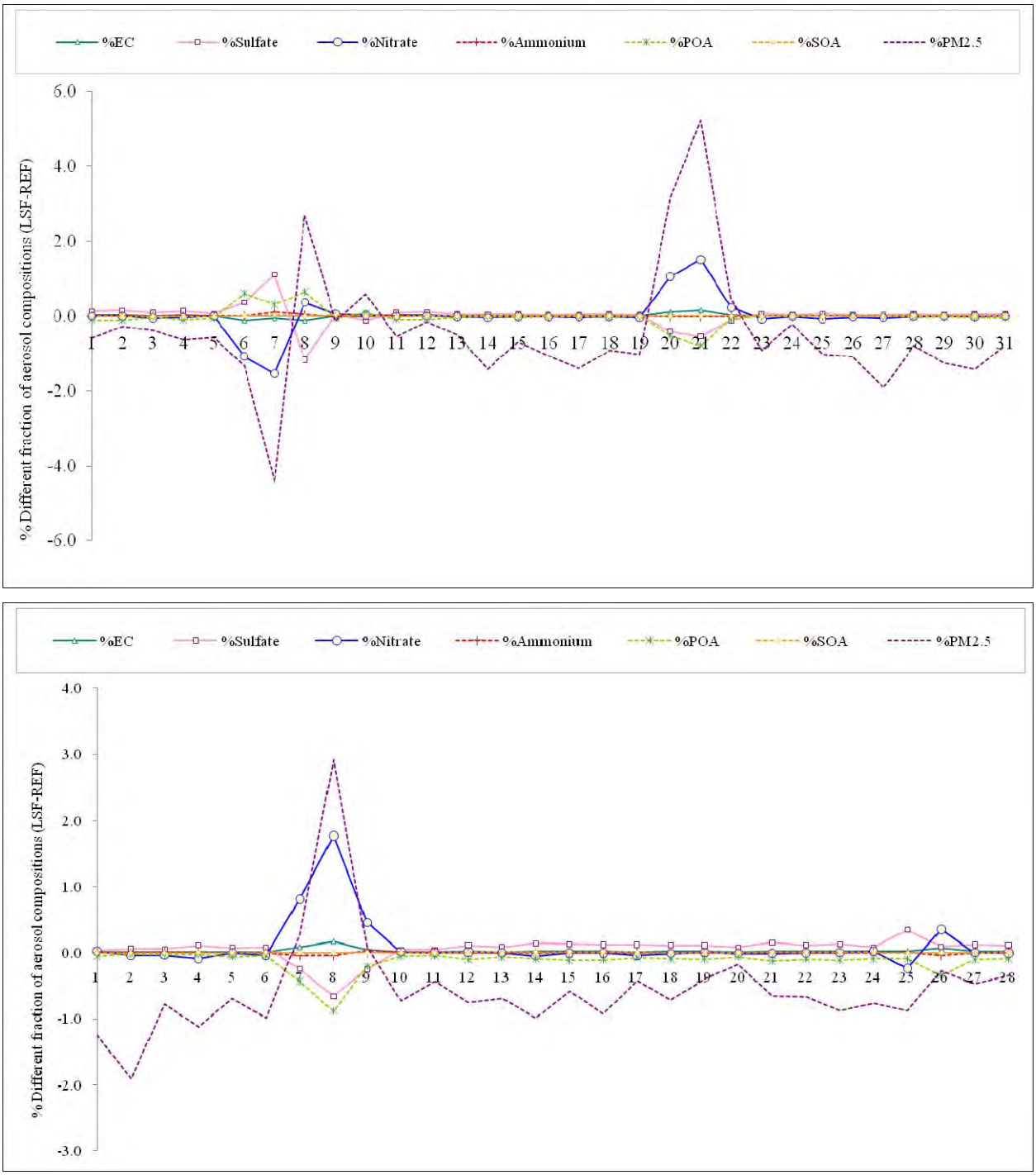

Fig. 31. Temporal evolution of daily average percentage difference of aerosol composition in the nonattainment area as obtained for October (top) and February (bottom).

The investigation of the reasons is beyond the scope of this study. However, preliminary analysis within the framework of a PhD thesis suggests that less transformation and removal of NO_x after introduction of low sulfur fuel during months with still relatively high solar radiation led to an increase of the nitrate concentrations, and increased the particulate matter concentrations accordingly (Fig. 31). The replacement of nitrate brought about a shift of the NH_4NO_3 equilibrium toward the gas-phase. Consequently, the NO_3-concentrations increased in the

atmosphere after introducing low sulfur fuel. The fact that no such increase occurs during the months with lowest insolation (e.g. December, January) suggests that chemical processes initiated by photolysis play an important role. As explained earlier, during October, February, and March, photolysis plays a stronger role as photolysis rates are higher than in December or January. Consequently, NO, NO_2 and NO_3 concentrations increase during October, February, and March, and $PM_{2.5}$ concentrations increased accordingly. The high aerosol concentrations fed back to meteorology. The simulated atmosphere became more stable and air quality became worse in the Fairbanks nonattainment area. The increase of nitrate, which means an increase of aerosols in the atmosphere, and the effect of chemistry on meteorology, should be analyzed for full understanding, but both tasks are beyond the scope of this study.

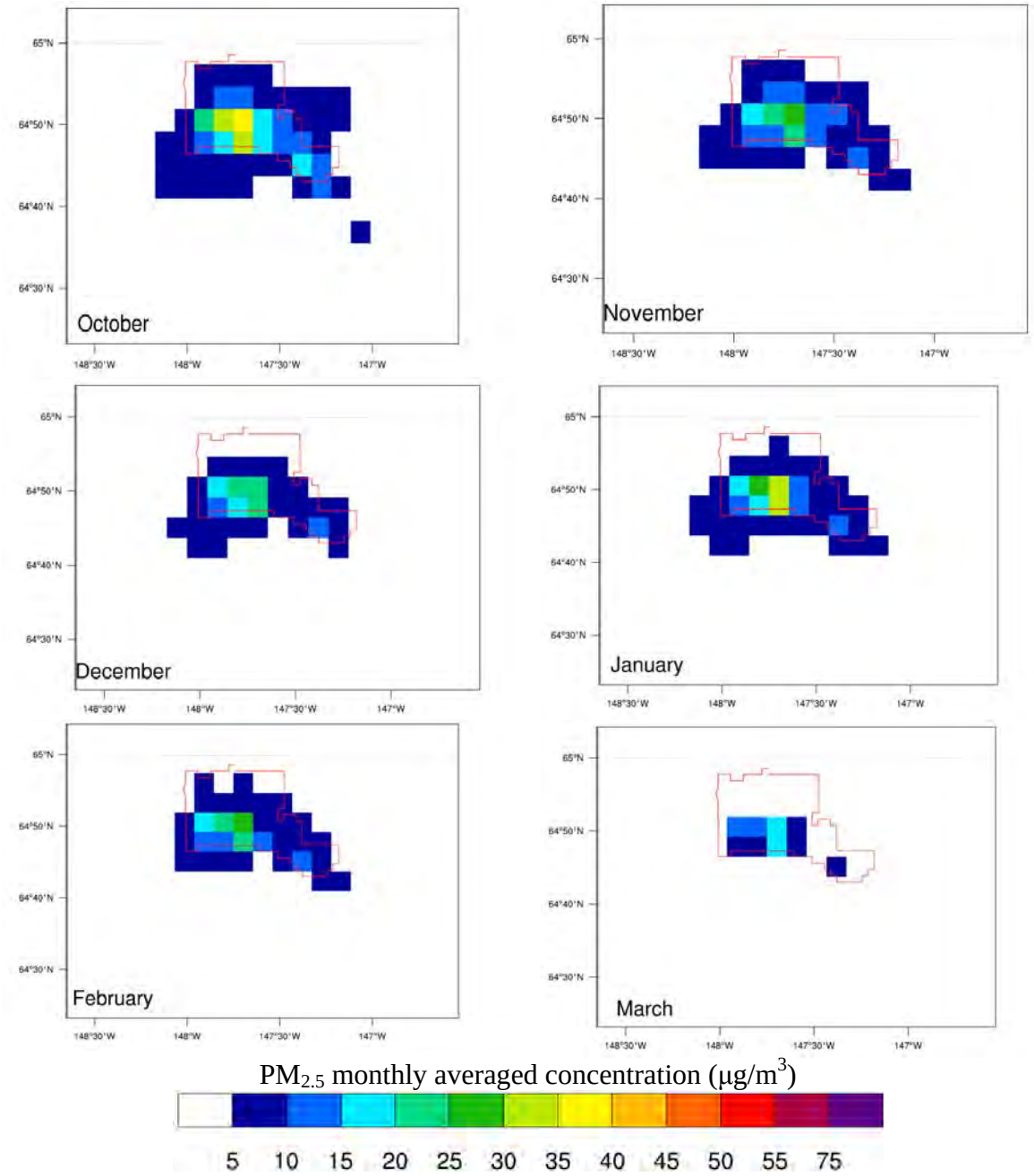

Fig. 32. Like Fig. 25 but for LSF.

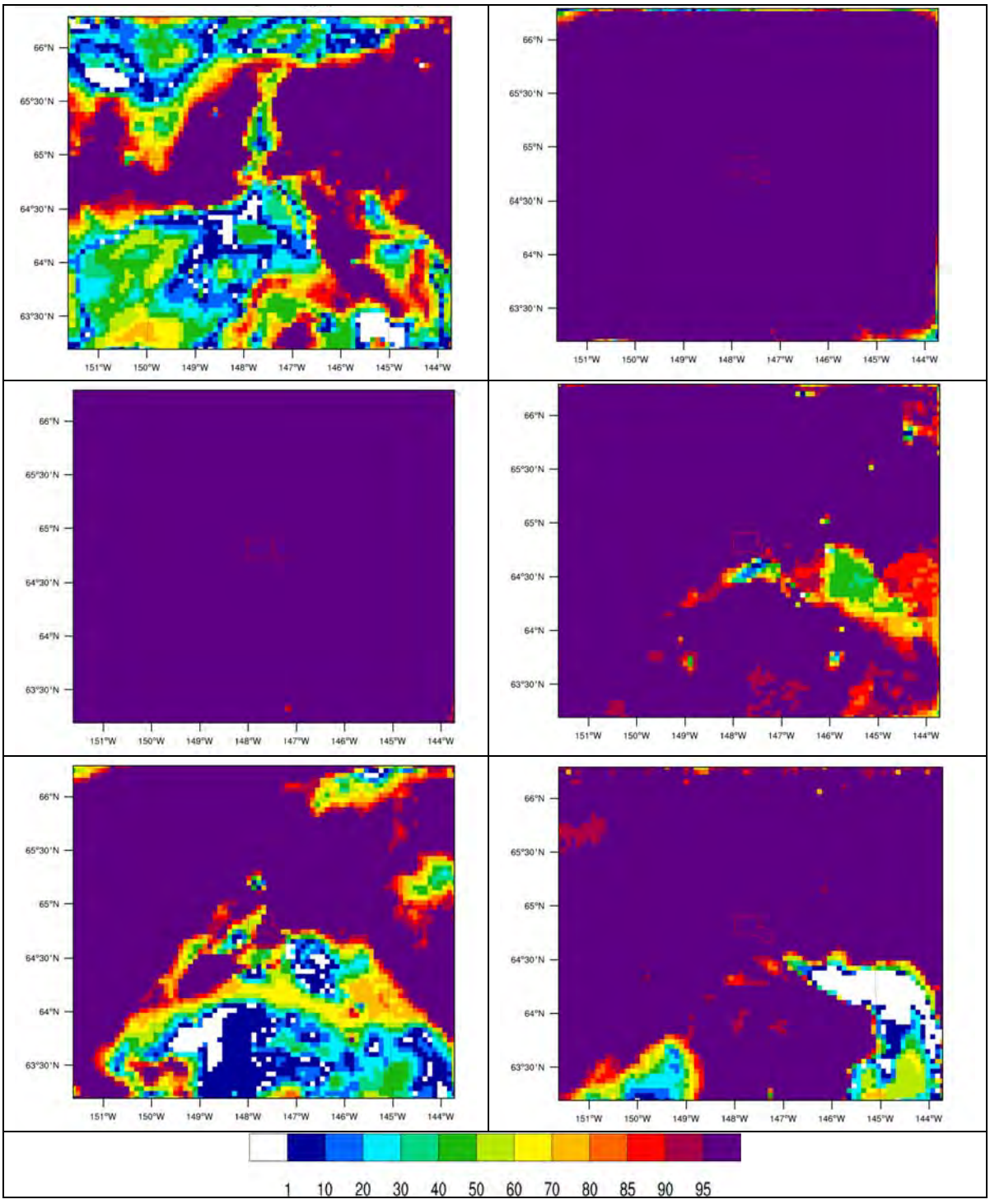

Fig. 33. Monthly rank of "true" differences over "false" differences of $PM_{2.5}$-concentration for October 2008 to March 2009 (from top left to bottom). At grid-cells ranking higher than the 95% percentile, the low sulfur fuel scenario has high efficiency in reducing concentrations in nonattainment area only in November, December, January and March.

Comparison of the monthly mean 24h-average $PM_{2.5}$ concentrations (Figs. 25, 32) shows the same hot spots in October, January, February and March than for REF, but these hotspots have

lower values in LSF. The local reduction is smaller in February and March than in the relatively cold October. The distribution-patterns of $PM_{2.5}$ concentrations change notably for November and December. These spatial changes suggest that gas-to-particle conversion to changes in the concentrations. Note that these processes depend on the concentrations of precursor gases, photolysis rates, temperature and humidity in non-linear ways. Thus, small changes in the concentrations of precursors may lead to much higher or lower gas-to-particle conversion rates.

Like for NPE and WSR we applied the FEA method to the data of LSF and REF. The FEA results indicate that the concentration differences (REF-LSF) in November, December, January, February and March are due to the introduction of low sulfur fuel (Fig. 33). In October, obviously random effects may play a role.

6.3 Comparison of the mitigation measures relative to each other

EPA's Office of Air Quality Planning and Standards in conjunction with the EPA Regional Offices compute design values based on observations in previous years, and review and publish them annually [*EPA*, 2011]. Design values are expressed as a concentration instead of an exceedance. These design values describe the air-quality status of a given area relative to the NAAQS. Consequently, design values can be used to classify nonattainment areas, develop control strategies, and assess progress towards meeting the NAAQS [*EPA*, 2011]. The design value for the baseline year 2008 for the Fairbanks nonattainment area is 44.5μg/m^3 [*Huff,* 2011; pers. communication]. The design values of 2005-2007, 2006-2008, and 2007-2009 were 39, 41, and 57, respectively [*EPA*, 2011]. These values partly reflect the decreasing air quality in response to the increase in wood burning.

Emissions are temperature dependent – more heating is required when it is colder than warmer outside. The winter episode 2007-2009 was about 0.7^{o}F colder than that of 2008-2010 (Table 3). This fact explains why the 2008-2010 design value is smaller than the 2007-2009 design value. The average temperature OTM for winter 2008/09 was 0.3^{o}F, i.e. much colder than winter 2007/08 (4.9^{o}F) or winter 2009/10 (4.5^{o}F).

An easy way to compare the impacts of the altered emissions on the $PM_{2.5}$ concentrations and their composition at breathing level is to determine the relative response factors (RRF). The RRF for each simulated particulate matter component j at site i is given by [*EPA*, 2007]

$$RRF_{ij} = \frac{\lfloor C_{j,projected} \rfloor}{\lceil C_{j,current} \rceil} \qquad (5)$$

Where in our study $\lfloor C_{j,projected} \rfloor$ is the mean concentration obtained from the various simulations with altered emissions (e.g. WSR or LSF), and $\lfloor C_{j,current} \rfloor$ is the respective mean concentration obtained from the reference simulation for the episode simulated. Note that the lower the RRF value is the higher is the response to the measure (e.g. “woodstove replacement”, “introduction of low sulfur fuel”).

Table 6 summarizes the RRFs for the grid-cell holding the State Building, i.e. the official monitoring site. The RRFs suggest that point sources contribute slightly to the $PM_{2.5}$ concentration and its composition at the State Building. This finding is not surprising because several point sources are in the immediate vicinity of this site. However, as discussed above, on average over the non-attainment area, the contribution of point sources to the total $PM_{2.5}$ concentration is relatively low. The very low RRF for NH_4 obtained for January results from the

very low NH_4 concentrations in both REF and NPE as compared to the other months. Speciation data did not become available before the end of this project. Therefore, no through analysis and interpretation of simulated vs. observed speciation is included in this report. A first screen of this data, however, supports that simulated NH_4 concentrations are too low (Fig. 34). A detailed analysis of simulated speciation was beyond the scope of our study, but should be done in the future to improve forecasts. Future studies should investigate the role of NH_4 and the emission sources of NH_3 that seem to be missing in the NEI2008 for Fairbanks.

Table 6. Relative response factors for $PM_{2.5}$ and the particulate matter composition as obtained for the scenarios without point source emissions (NPE), with woodstove replacement (WSR) and low sulfur fuel (LSF) at the grid-cell holding the official $PM_{2.5}$ site at the State Building for various periods. EC, ORG and PBW stand for elemental carbon, organic compounds, and particle bound water, respectively. Note that for the NPE scenario investigations were only to be carried out for November through February (cf. Table 1). Note that the baseline (reference) for the response factors of NPE (winter 2005/06) differs from that of WSR and LSF. WSR and LSF both use the same baseline of winter 2008/09.

	$PM_{2.5}$	SO_4	NO_3	NH_4	EC	ORG	PBW
			NPE				
Nov	0.957	0.961	0.858	0.976	0.961	0.961	0.949
Dec	0.964	0.963	0.954	1.019	0.962	0.962	0.971
Jan	0.973	0.978	0.849	0.247	0.977	0.977	0.959
Feb	0.970	0.971	0.954	0.810	0.970	0.970	0.971
Nov-Dec	0.960	0.962	0.901	0.996	0.961	0.961	0.960
Jan-Feb	0.972	0.976	0.865	0.254	0.975	0.975	0.963
Winter 05/06	0.966	0.969	0.892	0.965	0.969	0.969	0.961
			WSR				
Oct	0.958	0.959	0.865	1.003	0.959	0.959	0.954
Nov	0.950	0.952	0.898	1.005	0.951	0.951	0.948
Dec	0.950	0.952	1.001	1.001	0.950	0.951	0.949
Jan	0.953	0.952	0.887	1.075	0.952	0.952	0.951
Feb	0.944	0.940	1.041	0.891	0.939	0.939	0.944
Mar	0.941	0.943	0.855	1.005	0.941	0.941	0.941
Oct-Dec	0.954	0.955	0.880	1.004	0.954	0.954	0.951
Jan-Mar	0.946	0.947	0.935	0.976	0.945	0.945	0.946
Winter 08/09	0.950	0.951	0.897	0.991	0.950	0.950	0.949
			LSF				
Oct	0.975	0.974	1.023	1.016	0.973	0.973	0.976
Nov	0.943	0.944	0.937	0.998	0.943	0.943	0.944
Dec	0.945	0.946	0.925	0.999	0.944	0.944	0.945
Jan	0.966	0.966	0.947	1.074	0.965	0.965	0.965
Feb	0.957	0.955	1.129	0.887	0.955	0.955	0.961
Mar	0.953	0.954	0.926	1.002	0.952	0.952	0.953
Oct-Dec	0.957	0.957	0.970	1.004	0.956	0.956	0.958
Jan-Mar	0.960	0.959	1.006	0.973	0.959	0.959	0.961
Winter 08/09	0.958	0.958	0.981	0.990	0.957	0.957	0.959

The RRFs also indicate that there is not much wiggle room related to point-source emission. Recall that in the real world, point sources cannot be “switched off”. Power plants, for instance, ensure the supply of energy. Thus, if “switching them off” in the model world does not reduce the concentration much – as indicated by the RRFs – introduction of filters to reduce the point-source emissions will not solve the problem either as the point sources still will emit even though at a lower rate.

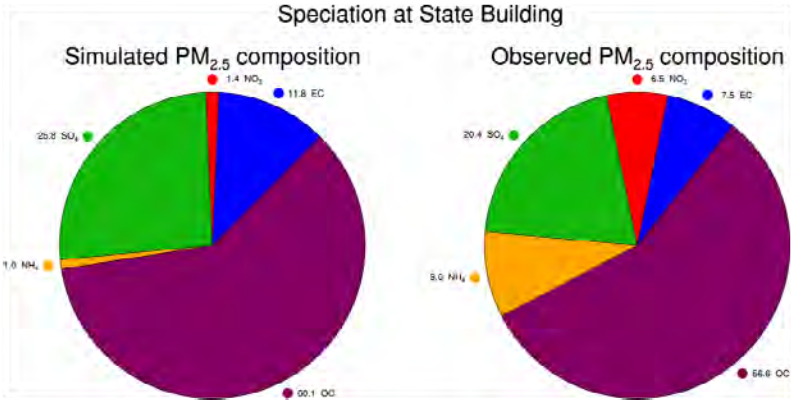

Fig. 34. Comparison of simulated and observed $PM_{2.5}$ components for winter 2005/06. Observed data courtesy of *D. Huff* [2011].

The RRFs for the "low sulfur fuel" and "woodstove replacement" scenarios are of similar magnitude, but on average over the entire winter slightly favor a "woodstove replacement" program. The RRFs to the introduction of low sulfur fuel show a higher variability among months than to the woodstove replacement. This means that for individual months "introduction of low sulfur fuel" may yield a stronger mitigation than "woodstove replacement". However, the latter seems to be the more temporally reliable measure as it more stably provides similar RRFs.

The RRFs of the various compounds of $PM_{2.5}$ indicate shifts in the composition in response to the altered emissions (Table 6). This means that both measures ("woodstove replacement", "introduction of low sulfur fuel" for heating and use in oil burning facilities) strongly affect the atmospheric chemistry and secondary aerosol formation via gas-to-particle conversion. The composition changes differ for the two measures. The "woodstove replacement" yields a shift towards more NH_4 and less NO_3 aerosols in most months. The composition shifts in response to "introduction of low sulfur fuel" vary more strongly among months than in response to "woodstove replacement".

To calculate the future design values we multiplied the observed design value with the RRFs obtained for the various measures tested. The resulting new design values are listed in Table 7.

Table 7. Calculated $PM_{2.5}$ "design values" ($\mu g/m^3$) in response to the tested measures for the grid-cell holding the State Building for various periods. Here "winter" refers to November 2005 to February 2006 for the NPE scenario and October 2008 to March 2009 for the "woodstove replacement" and "low sulfur fuel" scenarios.

	No point source emissions	small woodstove replacement program	introduction of low sulfur fuel
Oct	-.-	42.6	43.4
Nov	42.6	42.3	42.0
Dec	42.9	42.3	42.1
Jan	43.3	42.4	43.0
Feb	43.2	42.0	42.6
Mar	-.-	41.9	42.4
Oct-Dec	-.-	42.5	42.6
Jan-Mar	-.-	42.1	42.7
Nov-Dec	42.7	-.-	42.6
Jan-Feb	43.3	-.-	43.4
Winter	43.0	42.3	42.0

The introduction of low sulfur fuel results in a slightly lower new design value than the small "woodstove replacement program" assumed in WSR. The results also showed that such a small "woodstove replacement program" reduces the design value already by 2.2μg/m^3. The sensitivity studies performed on "woodstove replacement" suggested that a more rigorous replacement (WSS1) than assumed in WSR may yield much higher mitigation. Since the introduction of low sulfur fuel is very expensive, since a further reduction of sulfur content costs even more, and since the RRF and resulting new design values vary strongly among months when introducing low sulfur fuel, it seems that a rigorous replacement of non-certified wood-burning devices is the more promising way to achieve compliance.

Comparison of Figs. 25, 26, and 32 suggests that both "woodstove replacement" as well as "introduction of low sulfur fuel" reduce the concentrations in the nonattainment area. However, while hot spots remain in the same areas in the case of a "woodstove replacement" for all months, this is not the case when introducing low sulfur fuel.

7. Conclusions

We performed simulations for November 2005 to February 2006 with and without consideration of point-source emissions (Table 1) using the Alaska-adapted WRF/Chem[12] to assess the contribution of point-source emissions on the $PM_{2.5}$-concentrations at breathing level. The emission data for the reference simulation (business-as-usual) based on the NEI2005. The simulation without consideration of point-source emissions was run with the same meteorological input data and same emission data except that all point-source emissions were set to zero (NPE). Based on the comparison of the results of these simulations, we conclude that point sources are not the major cause for Fairbanks' wintertime $PM_{2.5}$-pollution problem. This conclusion is also supported by the results of the other mitigation scenarios. Eliminating the point-source emissions – as it is practically done in the NPE simulation – only led to marginal decreases in $PM_{2.5}$ concentrations at breathing level and only five avoidances of exceedances at locations in the nonattainment area. The highest $PM_{2.5}$-concentrations obtained in REF and NPE only differ 1.3μg/m^3 on average. The locations where simulated $PM_{2.5}$ exceeds the NAAQS occur in the nonattainment area. According to the results of REF and NPE, PS6[13] is the point source that often contributes to exceedances in the nonattainment area. However, in these cases concentrations without that point source were already high. Note that this point source has the highest emission rate. Emissions from point sources located in the nonattainment area may influence the $PM_{2.5}$-concentration at breathing level within 10km or so from the point-source-holding air column. This phenomenon is a combined effect of extreme atmospheric stable condition, weak circulation, and for some point sources the low-level in which they emit. These meteorological conditions altogether inhibit transport of the pollutants out of the area. It would be worth examining how increases in stack height and emission temperature (which also would lead to emissions into higher levels) would affect the point-sources' radius of impact and the $PM_{2.5}$ concentrations at breathing level.

Based on or simulations with and without consideration of point-source emissions we conclude that when "switching off" of the point sources does not solve the problem, reducing point-source emissions by new techniques will not solve the problem either as the point sources still emit even though at a lower rate. For days that are close to the NAAQS, just a marginal increase in area emission would lead to an exceedance.

Some of the $PM_{2.5}$ in the air is formed in the air from gases that transform to particles via physico-chemical processes called gas-to-particle conversion. Since gas-to-particle conversion non-linearly depends on temperature and vapor pressure of species and introducing measures to further clean the exhausts of point sources alters the composition of the point-source emission plumes, it may be worth examining whether in combination with other measures such additional filtering may nevertheless be beneficial.

In addition to the investigation on the impact of point sources on $PM_{2.5}$-concentrations in the nonattainment area, we performed a suit of simulations for October 2008 to March 2009 with the Alaska optimized WRF/Chem (Table 1). This suit of simulations assumed the same meteorological initial input data and boundary conditions. The reference simulation (REF) used the NEI2008 updated with point-source emissions (for details see section on emissions). Two scenarios were run. One scenario assumed a replacement program for non-certified wood-

[12] Note that WRF/Chem is a complex state-of-the-art research model, not a regulatory model.
[13] Privacy law forbids naming facilities.

burning devices. With the assumptions made on how households with several heating devices partition heating among devices and the burning behavior and number of non-certified burning devices replaced, the $PM_{2.5}$ emissions from heating were reduced by 4% on average over the nonattainment area over the six months (WSR). Two sensitivity studies were performed assuming different numbers of non-certified wood-burning devices that could be replaced (WSS1, WSS2). In addition, sensitivity analysis was made how emissions change with the assumptions on the burning behavior (partitioning among devices, time of burning). The second scenario mitigation for winter 2008/09 assumed the use of low sulfur fuel for domestic combustion, oil-burning point-source facilities and that part of power generation that used oil-fuel in accord with the 2008 allowances for fuel-sulfur content (LSF).

The LSF and WSR mitigation studies (like the study on the contribution of point-source emissions on the $PM_{2.5}$-concentrations at breathing level) suggest that emissions from area sources (e.g. domestic heating) and/or traffic are the main contributors to the $PM_{2.5}$ NAAQS exceedances occurring in the nonattainment area.

The "woodstove replacement" simulations indicate that a program for replacement of wood-burning devices can reduce the $PM_{2.5}$-concentrations at breathing level in the Fairbanks $PM_{2.5}$-nonattainment area. The study suggests that the highest mitigation of $PM_{2.5}$-concentrations with a "woodstove replacement" can be achieved in the months that are coldest. The sensitivity studies suggest that the reduction effectiveness depends on the number of wood-burning devices exchanged and on what kinds of devices are replaced (see results of WSR, WSS1, WSS2). The average emission reduction in the heating sector calculated for October 1 to October 15, 2008 amounts 40%, 7% and 6% on average over the nonattainment area under the assumption made for the "woodstove replacement" in WSS1, WSS2, and WSR, respectively. Note that we are here talking about the emission reduction of primary $PM_{2.5}$, not the emission reductions for other species (e.g. SO_2, NO_x, VOC) that go along with a "woodstove replacement".

Unfortunately, no data are available, where and what wood-burning devices are operated and when and how intensively. In our study, we simply assumed the distribution of wood-burning devices as being proportional to the population density. This assumption holds uncertainty in the spatial distribution that may affect local maximum concentrations as well as 24h-averages of $PM_{2.5}$-concentrations according to sensitivity studies. Further uncertainty is due to the unknown number of wood-burning devices that exist and that can be replaced. Sensitivity studies on the emissions indicated that uncertainty results from the unknown partitioning of the use of wood-burning and other heating devices in households with more than one heating option. Despite these uncertainties, all simulation studies on "woodstove replacement" show in common a mitigation of $PM_{2.5}$-concentrations on average at breathing level. Note that the simulations on "woodstove replacement" do not consider that additional wood-burning devices may have been added since 2008 or might be added in the future.

Based on the studies performed on the replacement of wood-burning devices we can conclude that exchanging noncertified wood-burning devices can help to reduce the number of exceedance days during October to March. The full benefit of exceedance reduction due to the "woodstove replacement" may be underestimated by WSR because the number of woodstoves exchanged may be on the lower end of the number of woodstoves that actually could/will be exchanged. Nevertheless, the concentration offsets between the baseline simulation REF and the "future" simulation WSR (Table 6, Figs. 25, 26) imply that replacement of non-certified wood-burning devices alone when only preformed in low numbers will not be sufficient to avoid all $PM_{2.5}$

exceedances. If emissions of area and point sources only slightly increase due to increasing of traffic, population, etc. the benefit due to the "woodstove replacement" will be set off quickly. This means a high number of non-certified wood-burning devices has to be replaced.

We further conclude that there is an urgent need to collect data on the location and kind of wood-burning devices used in the nonattainment area and to obtain additional information on how households with wood-burning devices and another heating device partition their heating among these heat sources. Information is also needed on the diurnal burning behavior on weekdays, weekends and holidays. Since emissions also depend on the dryness of the wood, data on the fraction of seasoned and non-seasoned wood typically burned will be helpful in better assessing the contribution from wood-burning devices to the $PM_{2.5}$-concentrations at breathing level. Furthermore, it would be good to know how accurate data from surveys may be if people fear, their information could later lead to measures that may be of disadvantage to them. This means it has to be examined whether we do obtain the correct information in surveys.

Our study suggests that the introduction of low sulfur fuel can reduce the number of exceedance days. The simulations suggest that introduction of low sulfur fuel as assumed in LSF leads occasionally to higher reductions than achieved by the "woodstove replacement" (WSR) assumed in this study. However, the results also suggest that up to 20% of the days in months with relatively long daylight hours (October, February, March) may experience increases in $PM_{2.5}$-concentrations at breathing level in response to introduction of low sulfur fuel due to gas-to-particle conversion. This increase is related to shifts in the thermodynamic equilibrium of sulfate-nitrate-ammonia-water in aerosol during months with still or already again enough daylight. The highest temporal and local differences in simulated $PM_{2.5}$ concentrations in response to introducing low sulfur fuel typically occurred in November whereas the lowest differences occurred in March. The reason is that October had high and February, March small increases in $PM_{2.5}$-concentrations after introducing low sulfur, while there were no increases in November.

The results of the simulation on the introduction of low sulfur fuel also suggest that in the case of measures aiming at mitigation indirectly by reduction of precursors it is important to simulate an entire winter emission season. Otherwise one could by accident just be lucky to have chosen a period where reduction occurs and oversee that there may be cases where despite reduced emissions of precursors the concentrations go up. Moreover, only in the case of the statistics over the entire winter it is possible to judge whether, on average, mitigation can be reached. Our study also suggests that care has to be taken in the judgment of the representativeness of the winter examined.

The simulation results showed that "introduction of low sulfur fuel" (LSF) results in a slightly lower new design value than the small "woodstove replacement program" assumed in WSR. The results also showed that a small "woodstove replacement program" such as assumed in WSR already reduces the design value by 2.2$\mu g/m^3$. The sensitivity studies performed on "woodstove replacement" (WSS1, WSS2) suggested that a more rigorous replacement of wood-burning devices (WSS1) may yield much higher mitigation than the small exchange program assumed in WSR. Since the introduction of low sulfur fuel is very expensive and further reduction costs even more, and since the relative response factors and new design values vary strongly among months when introducing low sulfur fuel, it seems that a rigorous replacement of non-certified wood-burning devices is much more promising to achieve compliance.

The results of all the simulations performed for this study suggest that a single pollution-control policy may not be sufficient to help comply with the 24h-average $PM_{2.5}$ NAAQS. Due to the high nonlinearity of chemical processes, we cannot assume that a combined "woodstove replacement" and "low sulfur fuel" program will lead to the goal. An additional study considering both measures would be required because precursors for gas-to-particle conversion are changed by both measures and interaction among the impacts of the two measures may yield to diminution or enhancement of wanted or even unwanted effects. Since changes in emissions of precursors lead to changes in gas-to-particle conversion, combinations of different control methods (i.e. "woodstove replacement" and concurrent "low sulfur fuel" programs) and other mitigation strategies (i.e. replacement of oil furnaces by gas, replacement of oil furnaces and wood-burning devices by gas) should be investigated. Future studies should also examine the impact of introducing other energy sources and/or expansion the use of gas for heating and energy generation.

The results of our study also show a stronger percentage mitigation of $PM_{2.5}$-concentrations on average over the entire nonattainment area than at the grid cell holding the State Building. In the future, it should be examined whether observations also show differences in changes of air quality at various sites in the nonattainment area. If so, local sources may play a role and they should be identified.

Unfortunately, the speciation data did not become available during the time of the project. Thus, an evaluation of the simulated composition of $PM_{2.5}$ is still pending, but planned for the future. Such an evaluation of simulated speciation is an urgent need to assess the role of ammonia. Based on speciation data of prior years and a first screen of the data that became available after the end of the project (Fig. 34), various scientists are concerned that the NEI2008 may underestimate the NH_4 emissions in the FNSB.

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Fairbanks North Star Borough $PM_{2.5}$ Non-Attainment Area CMAQ Modeling

Final Report Phase II

Reporting Period: January 1, 2012 – December 31, 2012

Project: 398831 CMAQ-DEC 2012

By Prof. Nicole Mölders (PhD, PhD) and Ketsiri Leelasakultum (MS)

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1. Background

The Community Multiscale Air Quality (CMAQ) model version 4.7.1 was adapted to simulate the $PM_{2.5}$-concentrations in Fairbanks, Interior Alaska in phase I [*Mölders and Leelasakultum*, 2011]. The adapted CMAQ was applied to a two-week episode in January/February, 2008 and November, 2008 each for investigations on and understanding of the $PM_{2.5}$-situation in the Fairbanks nonattainment area.

According to the final report of phase I [*Mölders and Leelasakultum*, 2011], the CMAQ model was configured to use the global mass-conserving Yamartino advection scheme, the eddy vertical diffusion module, the Carbon Bond Five (CB05) lumped gas phase chemistry mechanism, which uses the Euler Backward Iterative (EBI) as solver, the AERO5 aerosol mechanism, the photolysis inline module, and the Asymmetric Convective Method (ACM) cloud processor to compute convective mixing (cloud_acm_ae5). As described in the final report of phase I, we had made several changes to the CMAQ code to improve the prediction of $PM_{2.5}$-concentrations and to represent the conditions in the Fairbanks domain. Those changes were the development of Alaska specific initial and boundary conditions, modification of the dry deposition code, reducing of the minimum mixing height, replacing the minimal stomata resistances, decreasing the lowest and highest eddy diffusivity coefficients by half and scaling them according to the fraction of land-use, and reducing the wind-speed by half in valleys within the domain. The latter step has been abandoned in the further studies. This step was only done only for investigation of the magnitude of the impact of the overestimated wind-speeds obtained from the Alaska adapted WRF (see *Gaudet and Staufer* [2012] for details on this WRF version). This means all results reported in the current report use the original simulated wind-speed as obtained from WRF.

Based on the CMAQ's output in phase I, Sierra Research Inc. had improved the emission input data generated by using the Sparse Matrix Operator Kernel Emission (SMOKE). Penn State [*Gaudet and Staufer*, 2012] had updated the meteorological input data generated for the Alaska adapted CMAQ model (called adapted CMAQ hereafter) by using the Weather Research and Forecasting (WRF; *Skamarock et al*. [2009]) in its version adapted for Fairbanks by *Gaudet and Staufer* [2011]. Hereafter, we refer to the January/February episode data before and after the update as January v1 and January v2, respectively. Without the reducing wind-speed in the valleys by half, the new version of the emission inventory data and the meteorological input data brought an increase in the simulated $PM_{2.5}$-concentrations at the grid-cell holding the State Office Building site. Here CMAQ underestimated the $PM_{2.5}$-concentrations previously. Therefore, the reduction of the wind-speeds in the valleys by half is not required for the January v2 and November episode.

2. Activities

Building upon the Alaska adapted CMAQ described in the final report of phase I and the results of phase I, we incorporated the final Penn State WRF output files and the first complete emissions inventory from SMOKE which accounts for Fairbanks specific temporal and spatial variations that we obtained from Sierra Research Inc.. We prepared an assessment of the CMAQ performance, which includes using metrics established by *Boylan and Russell* [2006] and running CMAQ Process Analysis (PA). In the following sections, we describe and assess the results of these activities.

2.1 Configuration of CMAQ for the November 2008 Episode

The November episode covers November 2 to November 16, 2008. The emissions developed for the November episode were updated by Sierra Research Inc. for the emissions from mobile sources. They also included the emissions from airports. The temporal evolutions of 24h-average of simulated $PM_{2.5}$-concentrations show that the model overestimates the 24h-average $PM_{2.5}$-concentrations at the State Office Building site at the beginning of the episode (November 2-4); the adapted model failed to capture the peaks on November 6, 9 and 16, and shows a nonexistent temporal minimum on November 7 (Fig. 1).

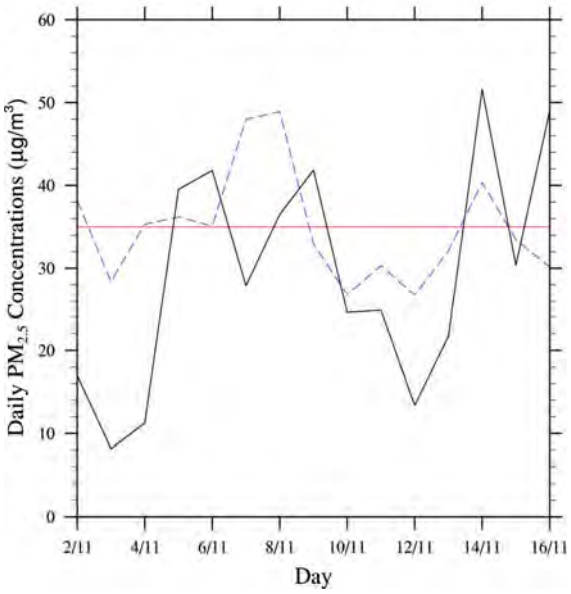


Fig. 1 Time series of simulated (blue dashed line) and observed (black solid line) 24h-average $PM_{2.5}$-concentrations as obtained with the adapted CMAQ simulation that used the revised WRF and SMOKE input for the November episode at the State Office Building site.

The 24h-average $PM_{2.5}$-concentrations obtained from the adapted CMAQ simulations with the observations have a correlation coefficient of 0.31. The scatter between simulated and observed 24h-average $PM_{2.5}$-concentrations is shown in Figure 2. We also found that allowing for a time lag of one between the simulation results and the observations increases the correlation

coefficient from 0.31 to 0.37. According to the observations, there are nine days in the November episode that have $PM_{2.5}$-concentrations below the National Ambient Air Quality Standard (NAAQS) of 35 µg/m^3, and there are six days with $PM_{2.5}$-concentrations above the NAAQS. For most of the days of the episode, the simulated and observed 24h-average $PM_{2.5}$-concentrations agree well; there are two days with false alarm, two days of missed events and three pairs of data outside the factor of two agreement (Fig. 2).

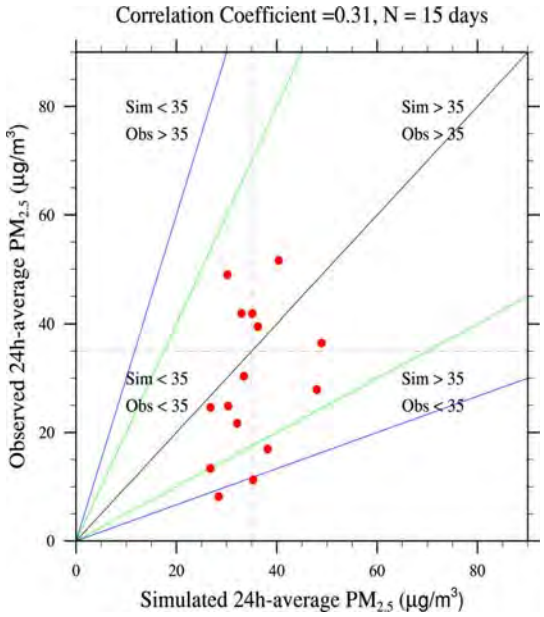
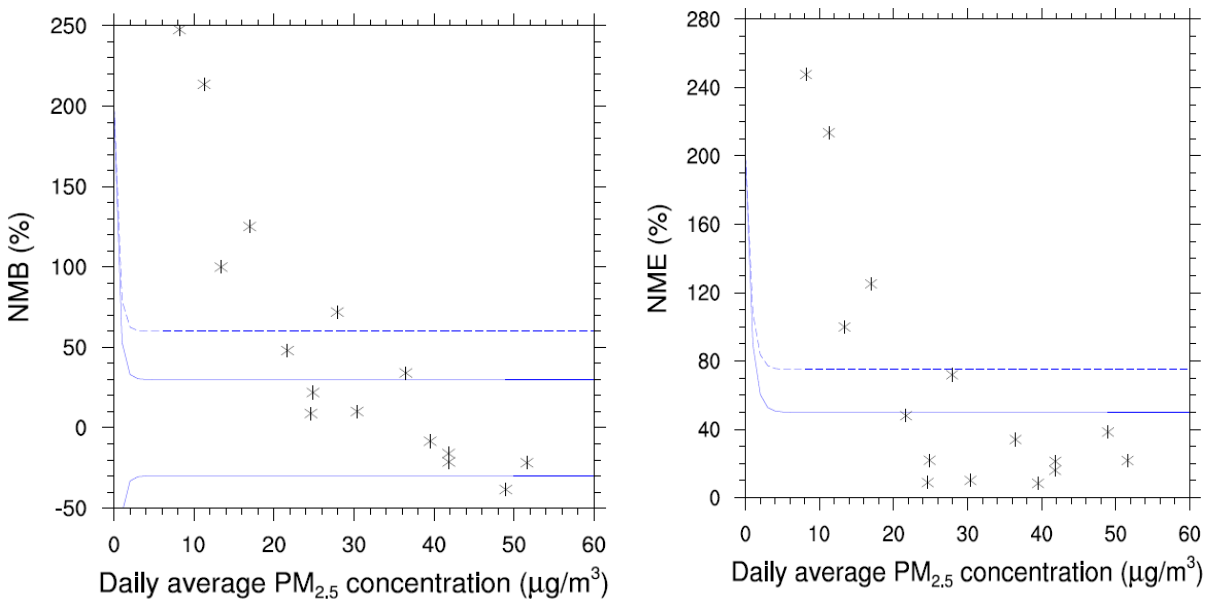


Fig.2 Scatter plot of 24h-average $PM_{2.5}$-concentrations as obtained from the adapted CMAQ simulation that used the revised WRF and SMOKE input for the November episode and the observations at the State Office Building site. The green line indicates the factor of two and the blue line indicates the factor of three agreement.

The bugle plots and soccer plots show that the adapted CMAQ simulation has five days outside the performance criteria (Fig. 3, a-c). Three of five days are the days in the beginning of the episode, which are probably due to spin-up effects in the CMAQ model itself. Moreover, all of those five days have very low (below NAAQS) 24h-average $PM_{2.5}$-concentrations.

(a) (b)



(c)

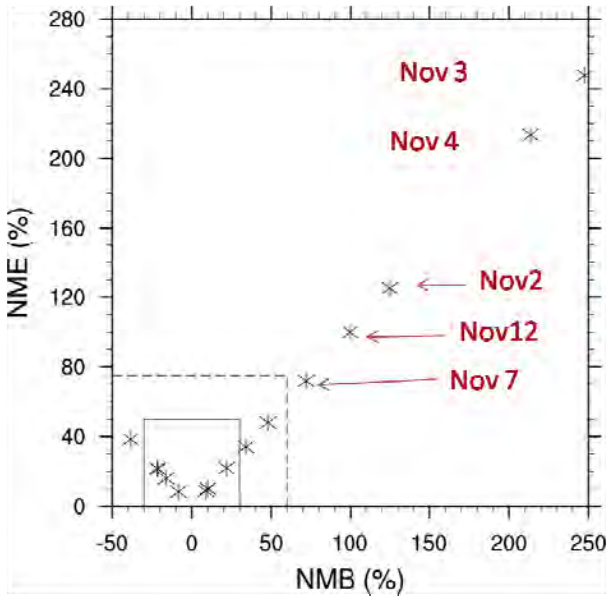


Fig. 3 Bugle plots of (a) normalized mean biases, (b) normalized mean errors, and soccer plots of (c) normalized mean errors and biases of simulated 24h-average $PM_{2.5}$-concentrations as obtained from the adapted CMAQ simulations that used the revised WRF and SMOKE input for the November episode at the State Office Building site.

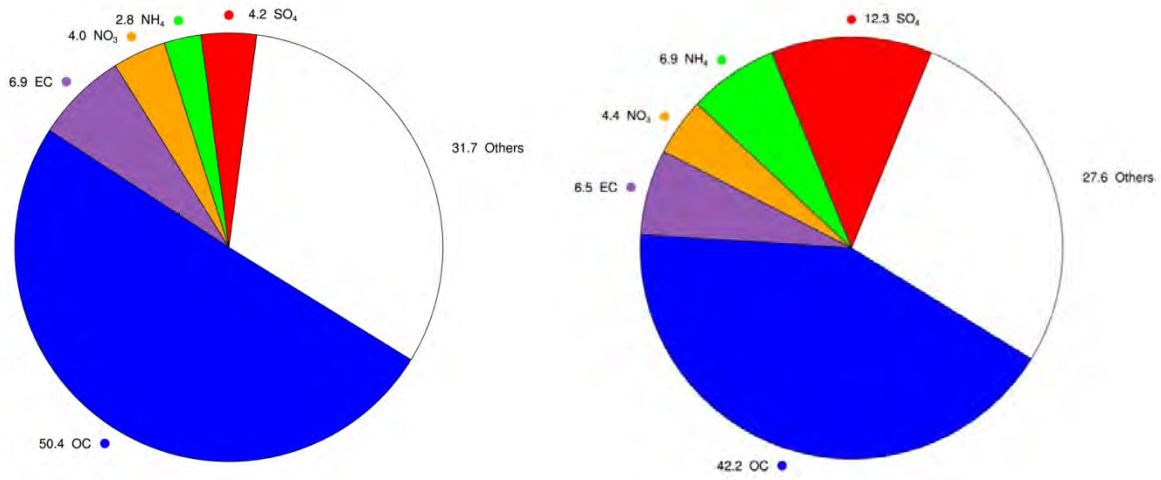


Fig. 4 Composition of simulated 24h-average total $PM_{2.5}$ as obtained by the CMAQ with modifications on average over the November episode (left), and as observed on average over the 3 days, for which data was available during that episode, at the State Office Building site. In the observations, the category "others" includes Al, Br, Ca, Na, Cl, Cu, Fe, Pb, Ni, K, Se, Si, S, Sn, Ti, V, Zn. In the simulations, the category "others" refers to unspecified anthropogenic mass (A25i+A25j), Na and Cl.

Comparing the simulated and observed composition of 24h-average $PM_{2.5}$ aerosol showed that the adapted CMAQ overestimated the percentage of organic carbon, but underestimated the percentage of sulfate and ammonium (Fig. 4).

Data of observed $PM_{2.5}$-composition data are available on a 1-in-3 day basis. The 24h-average $PM_{2.5}$-composition as simulated by the Alaska adapted CMAQ for the November episode were compared for each day that had observations (Fig. 5). On November 8 and 14 (with respect to Alaska Standard Time; AST), which have observed $PM_{2.5}$-composition data, there are small contributions from transport from outside the domain into the area [*Mölders and Leelasakultum*, 2012]. Note that typically advection from outside Alaska does not increase $PM_{2.5}$-concentrations by more than 2 $\mu g/m^3$ [e.g. *Cahill*, 2003; *Tran* et al., 2011; *Mölders* et al., 2012]. For details, see discussion later in this report. The simulations are not able to capture the peak on November 14 well.

Simulated sulfate and ammonium are underestimated on all three days (Fig. 5). Sodium and chloride are both underestimated. A possible reason for the underestimation of sodium (Na) and chloride (Cl) is that no sea-salt is emitted into the domain as there is no ocean and that some sodium and chlorine might be advected during the episode. However, this shortcoming has no big impact on the concentrations of total $PM_{2.5}$ as Na and Cl make up only a small amount of $PM_{2.5}$-composition (<1%). Simulated organic, nitrate and elemental carbon are almost in the same order of magnitude as observed.

We also conducted a process analysis. Process analysis is a technique that provides information about the impacts of individual processes on the change in a species' concentration. In the following, we refer to horizontal transport as the sum of horizontal advection and diffusion, and to vertical transport as the sum of vertical advection and diffusion. In our discussion, the term aerosol processes represents the net effects of aerosol thermodynamics, new particle formation, condensation of sulfuric acid and organic carbon on preexisting particles, and the coagulation within and between the Aitken and accumulation modes of particulate matter. Cloud processes represent the net effects of cloud attenuation of photolytic rates, aqueous-phase chemistry, below-and in-cloud mixing with chemical species, cloud scavenging and wet deposition [*Liu et al.*, 2010].

According to the process analysis, emissions were the dominant contributor to the $PM_{2.5}$ and SO_4 concentrations, and the horizontal transport contributed to and removed $PM_{2.5}$ and SO_4 at the grid-cell holding the State Office Building site (Fig. 6a-b). The aerosol processes played a small role here. This means $PM_{2.5}$ is mainly composed of primary PM and SO_4 at this site. $PM_{2.5}$ and SO_4 were mainly vented out through vertical transport. Dry deposition played a small role in the removal of $PM_{2.5}$ and cloud process did not play any role here. Note that cloud processes are irrelevant when there are not clouds as these processes then do not occur.

Different from the findings for sulfate, the aerosol processes played the main role for nitrate formation. At the grid-cell holding the State Office Building site, horizontal transport contributed strongly to nitrate. Note that the nitrate concentrations also show an offset like found for $PM_{2.5}$ (see discussion above). The major removal process was vertical transport, i.e. vertical mixing. Note that various studies performed with WRF for Alaska indicated that WRF has difficulties to simulate the strength of inversions with temperature gradients greater than 8K/100m and that WRF tends to overestimate vertical mixing [e.g. *Mölders et al.,* 2011, 2012, *Tran*, 2012]. An overestimation of the vertical transport of pollutants may lead to diluted concentrations and underestimation of the concentrations as particles are too quickly removed from the breathing level. The process analysis also revealed that dry deposition caused a small loss to nitrate. Cloud processes neither produced nor removed nitrate in this grid-cell (Fig. 6c).

For ammonium, the aerosol processes are the dominant contributor at the grid-cell of the State Office Building site. Horizontal transport contributed to ammonium on some days. The major removal process was vertical transport, and dry deposition caused only a small loss to ammonium. Cloud processes did not play a role here similar to what was found for both sulfate and nitrate (Fig. 6d).

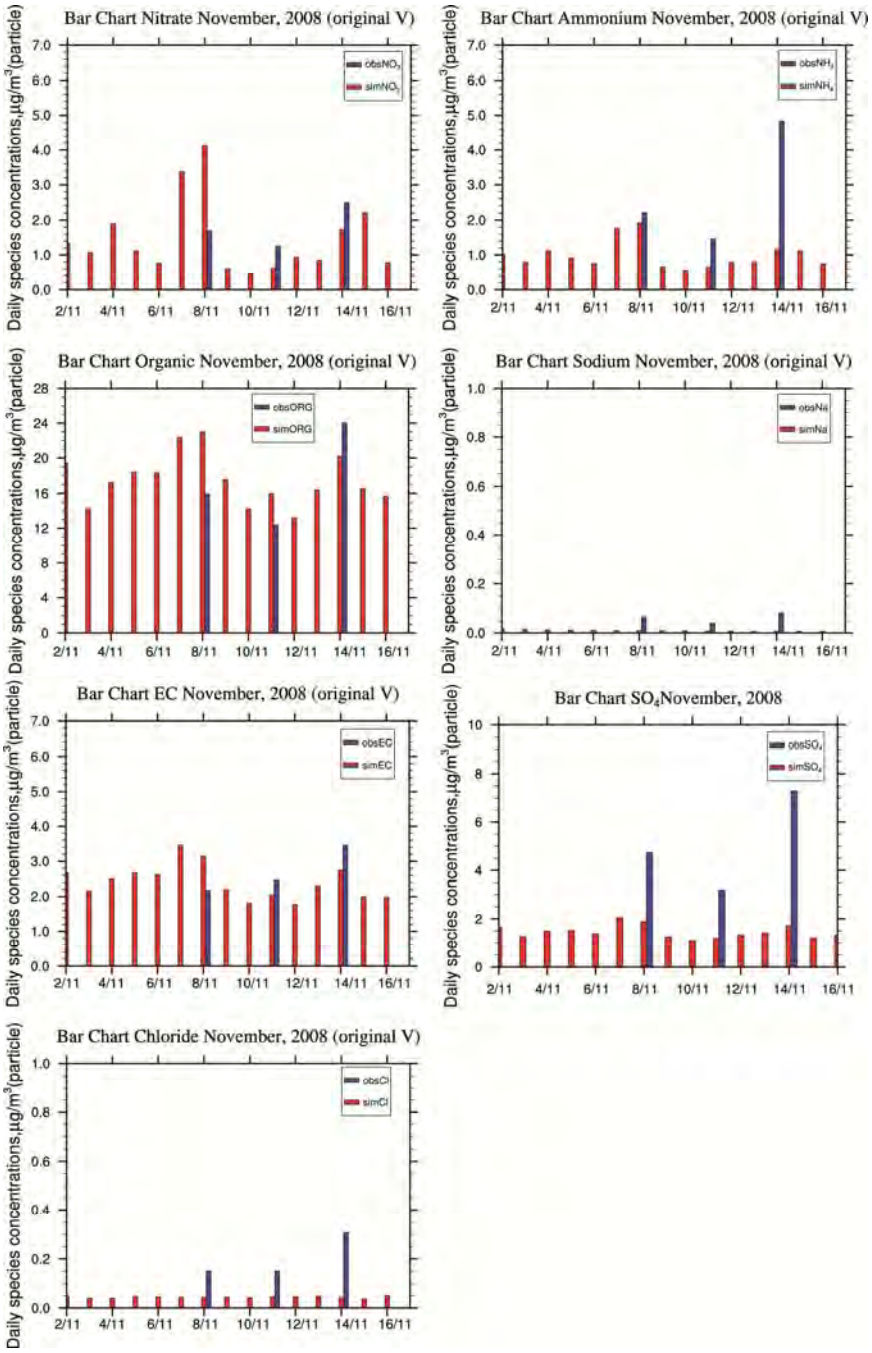


Fig. 5 Bar charts of simulated (red) and observed (blue) 24h-average $PM_{2.5}$-composition for NO_3, NH_4, EC, OC, Na, Cl, SO_4 as obtained for the November episode at the State Office Building site.

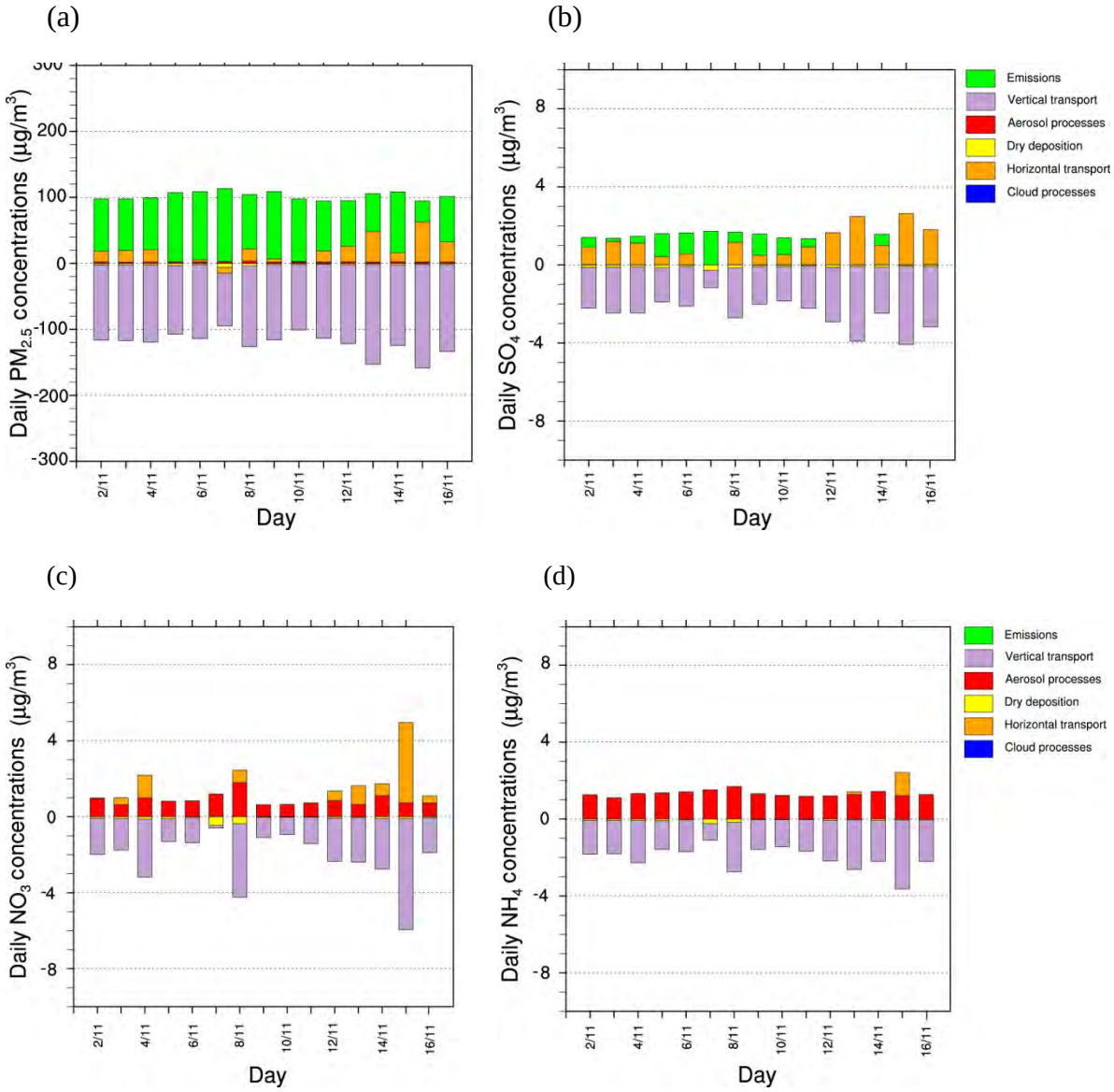


Fig. 6 Daily mean hourly contributions of individual processes to the (a) $PM_{2.5}$-concentrations, (b) SO_4-concentrations, (c) NO_3-concentrations and (d) NH_4-concentrations as obtained from the process analysis at the State Office Building site for the November episode. Simulations were performed using the revised WRF and SMOKE input.

2.2 Configuration of CMAQ for the January/February 2008 Episode (January v2)

The January episode covers January 23 to February 9, 2008. The temporal evolutions of 24h-average simulated $PM_{2.5}$-concentrations show that the model mostly overestimates the 24h-average $PM_{2.5}$-concentrations at the State Office Building site; the model fails to capture the peak on February 8 (Fig. 7). The model predicts a non-existing temporal minimum on February 2 (Fig. 7). The CMAQ model seems to be ahead in predicting 24h-average $PM_{2.5}$-concentrations by about 24 hours.

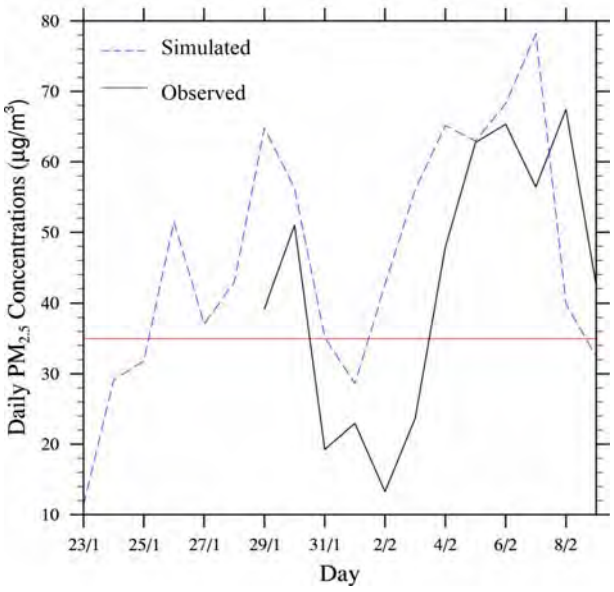


Fig. 7 Timeseries of simulated (blue dashed line) and observed (black solid line) 24h-average $PM_{2.5}$-concentrations at the State Office Building site as obtained from the adapted CMAQ simulation that used the revised WRF and SMOKE input for the January episode.

The 24h-average $PM_{2.5}$-concentrations obtained from the adapted CMAQ simulations correlate with the observations with a correlation coefficient of 0.52. Figure 7 shows the scatter of the simulated and observed values. To examine the reasons for the relatively low correlation we examined the timeseries. The temporal evolutions of simulated and observed hourly and 24h-average $PM_{2.5}$-concentrations suggested an offset. To quantify the offset we calculated the correlation with various time lags. We found that allowing for a time lag for one day increases the correlation coefficient from 0.52 to 0.84 [*Mölders and Leelasakultum*, 2012]. Allowing a 24h-time lag can increase the correlation coefficients of the hourly average $PM_{2.5}$-concentrations at the State Office Building site from 0.23 to 0.50, and the correlation increases even more to 0.59 when we allow a time lag of 26 hours. This means that some of the low correlation is caused by a temporal offset between simulated and observed 24h-average $PM_{2.5}$-concentrations.

It also means that if this shift in timing would not exist, the adapted CMAQ would perform better.

According to the observations, there are four days in the January episode that have $PM_{2.5}$-concentrations below the NAAQS, and there are eight days with $PM_{2.5}$-concentrations above this standard. On most of the days of the January episode, the simulated and the observed 24h-average $PM_{2.5}$-concentrations agree well; there are two days with false alarm, one day of a missed event, and two pairs of data outside the factor of two agreement (Fig. 8).

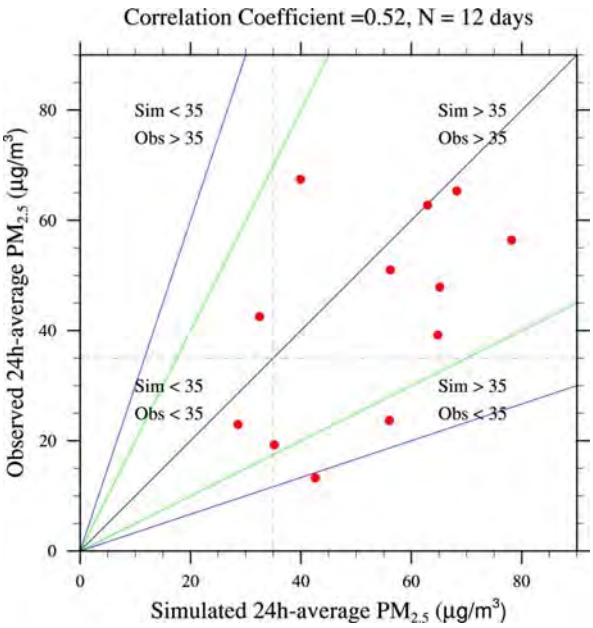
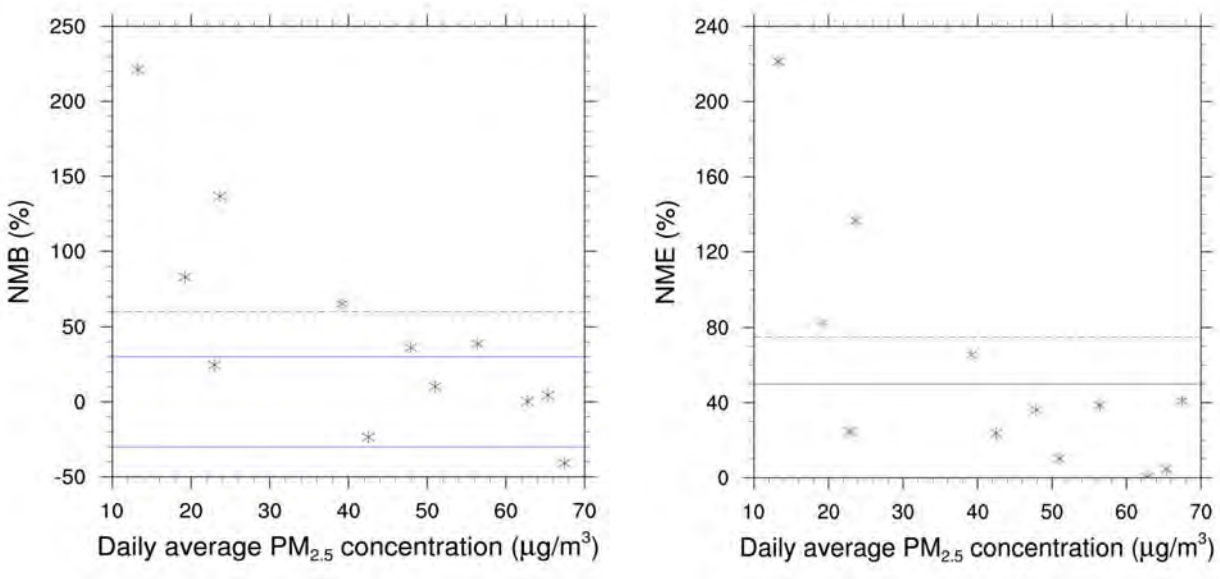


Fig.8 Scatter plots of 24h-average $PM_{2.5}$-concentrations as obtained from the adapted CMAQ simulation that used the revised WRF and SMOKE input during the January episode at the State Office Building site. The green line indicates the factor of two and the blue line indicates the factor of three agreement.

(a) (b)



(c)

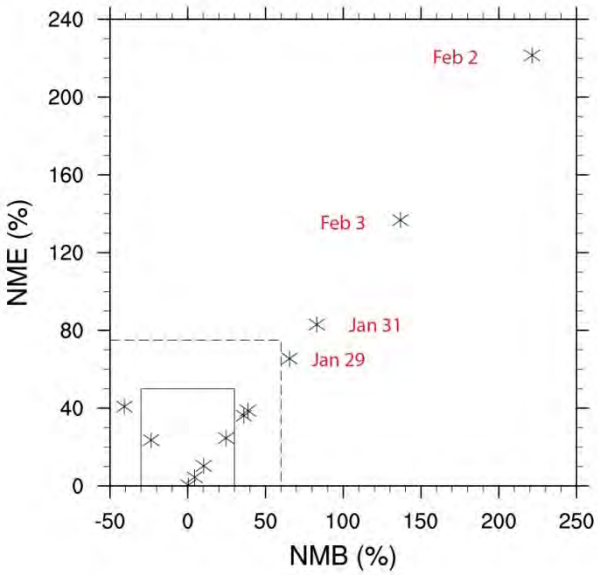


Fig. 9 Bugle plots of (a) normalized mean biases (NMB), and (b) normalized mean errors (NME) and soccer plot of normalized mean errors and biases of 24h-average $PM_{2.5}$-concentrations at the State Office Building site as obtained from the adapted CMAQ simulations that used the revised WRF and SMOKE input for the January episode.

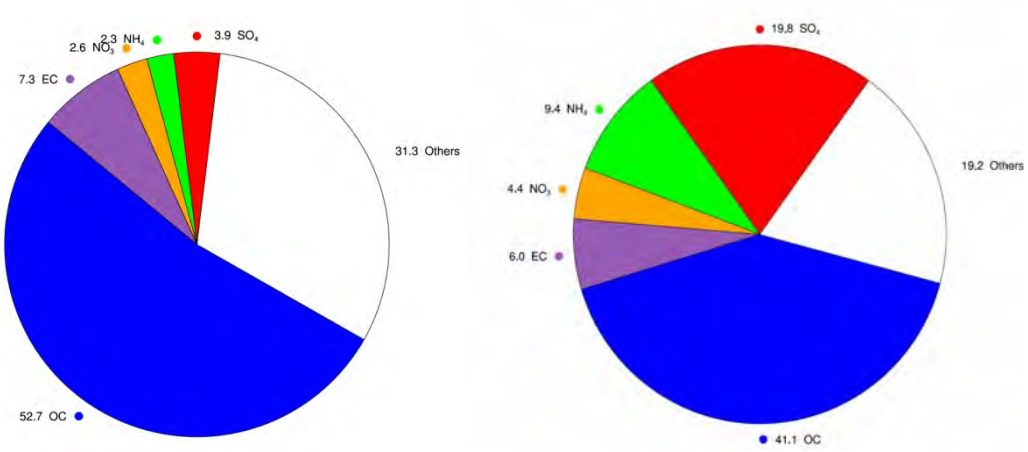


Fig. 10 Composition of simulated 24h-average total $PM_{2.5}$ as obtained by CMAQ with the modifications on average over the January episode (left), and as observed on average over the six days, for which data was available at the State Office Building site. In the observations, the category "others" includes Al, Br, Ca, Na, Cl, Cu, Fe, Pb, Ni, K, Se, Si, S, Sn, Ti, V, Zn. In the simulations, the category "others" refers to unspecified anthropogenic mass (A25i+A25j), Na and Cl.

The bugle plots and soccer plots show that on four days the adapted CMAQ simulation provides results outside the performance criteria (Fig. 3, a-c). Three of these four days are days, on which the 24h-average $PM_{2.5}$-concentrations are below the NAAQS. Therefore, we conclude that the adapted CMAQ model has difficulties to capture extremely low $PM_{2.5}$-concentrations well. Note that it is harder to predict very low than high concentrations correctly. Thus, this behavior is typical in air-quality modeling [e.g. *Boylan and Russell*, 2006].

Comparison of the simulated and observed composition of 24h-average $PM_{2.5}$ aerosol showed that the adapted CMAQ overestimated the percentage of organic carbon, but underestimated the percentage of sulfate, ammonium, nitrate and elemental carbon at the State Office Building site for the January episode (Fig. 10).

The 24h-average $PM_{2.5}$-composition as simulated by the Alaska adapted CMAQ for the January episode was compared for each day that had observed data (Fig. 11). During February 5-10, there was higher sulfur content, and on February 6 and 9 (AST), there were small contributions from long-range transport [*Mölders and Leelasakultum*, 2012]. Simulated sulfate (SO_4) and Ammonium (NH_4) are underestimated on all six days (Fig. 11). Sodium and chloride are both underestimated (see earlier discussion for reasons). Simulated organic, nitrate (NO_3) and elemental carbon (EC) concentrations are almost of the same order of magnitude as the observations and well follow the temporal evolution of the observations.

Similar to the findings of the November episode, in the January episode, emissions were the dominant contributor to the $PM_{2.5}$- and SO_4-concentrations at the grid-cell holding the State

Office Building (Fig. 12a-b). Horizontal transport contributed to and removed $PM_{2.5}$ and SO_4 at this site. The aerosol processes played a small role here. This fact indicates that $PM_{2.5}$ is composed mainly of primary PM and SO_4 at this site. $PM_{2.5}$ and SO_4 were mainly vented out through vertical transport. Dry deposition played a small role in the removal of $PM_{2.5}$ and cloud process did not play any role here. Note that if there are no clouds cloud processes cannot contribute to/affect the concentrations.

Like for the November episode, the findings obtained for nitrate differed from those for sulfate. The aerosol processes played the main role for nitrate formation. High contributions of nitrate also came from horizontal transport, i.e. neighbored grid-cells, but could not capture the conditions on February 9. The major removal process was vertical transport, and dry deposition caused a small loss to nitrate. Cloud processes neither produced nor removed nitrate in this grid-cell (Fig. 12c).

For ammonium, the aerosol processes are the dominant contributor at this site. Horizontal transport form neighbored grid-cells contributed to the ammonium concentrations on some days. The major removal process was vertical transport, and dry deposition caused only a small loss to ammonium. Cloud processes did not play a role here similar to what was found for both sulfate and nitrate (Fig. 12d).

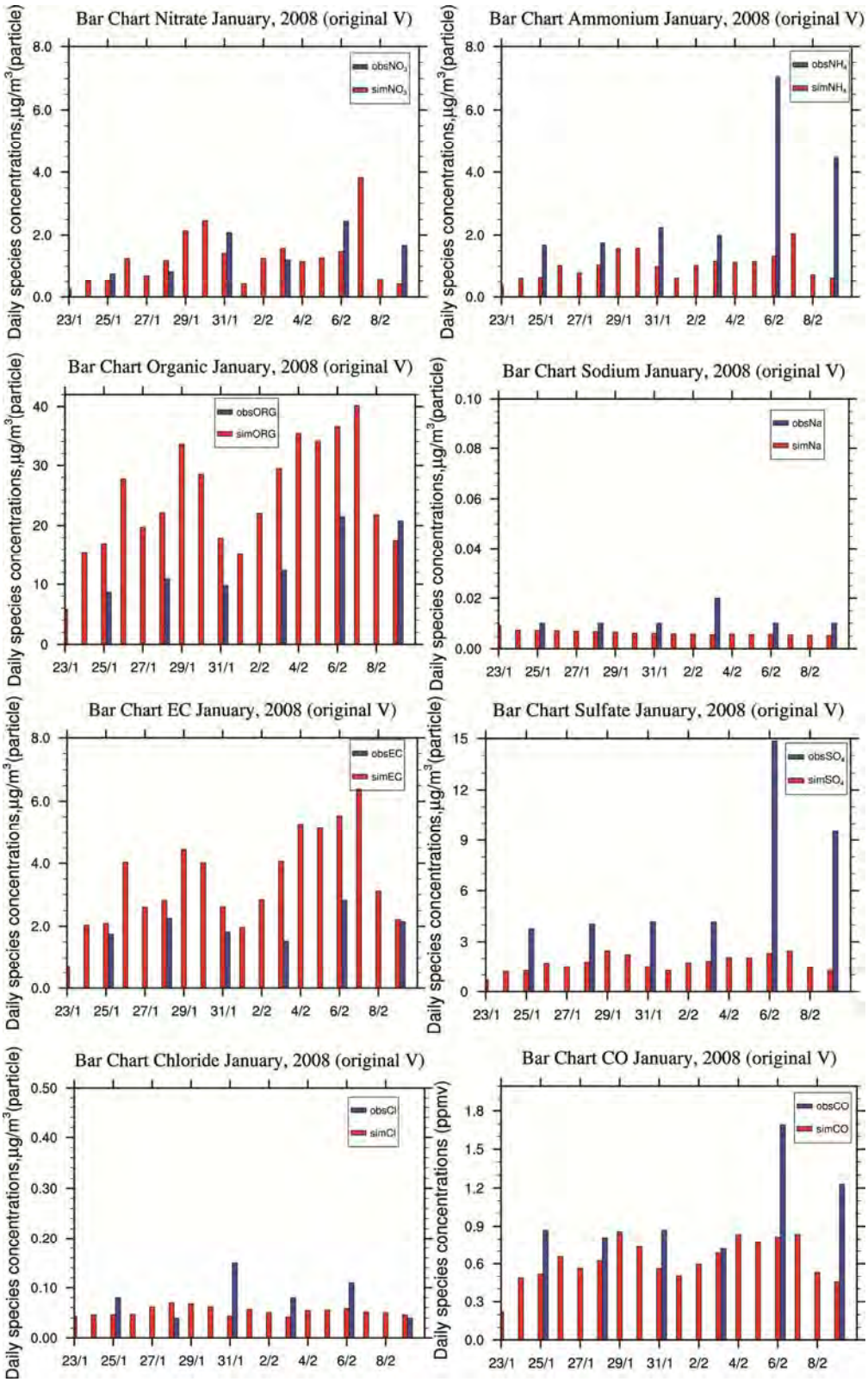


Fig. 11 Bar charts of simulated (red) and observed (blue) 24h-average $PM_{2.5}$-composition for NO_3, NH_4, EC, OC, Na, Cl, SO_4 as obtained at the State Office Building for the January episode.

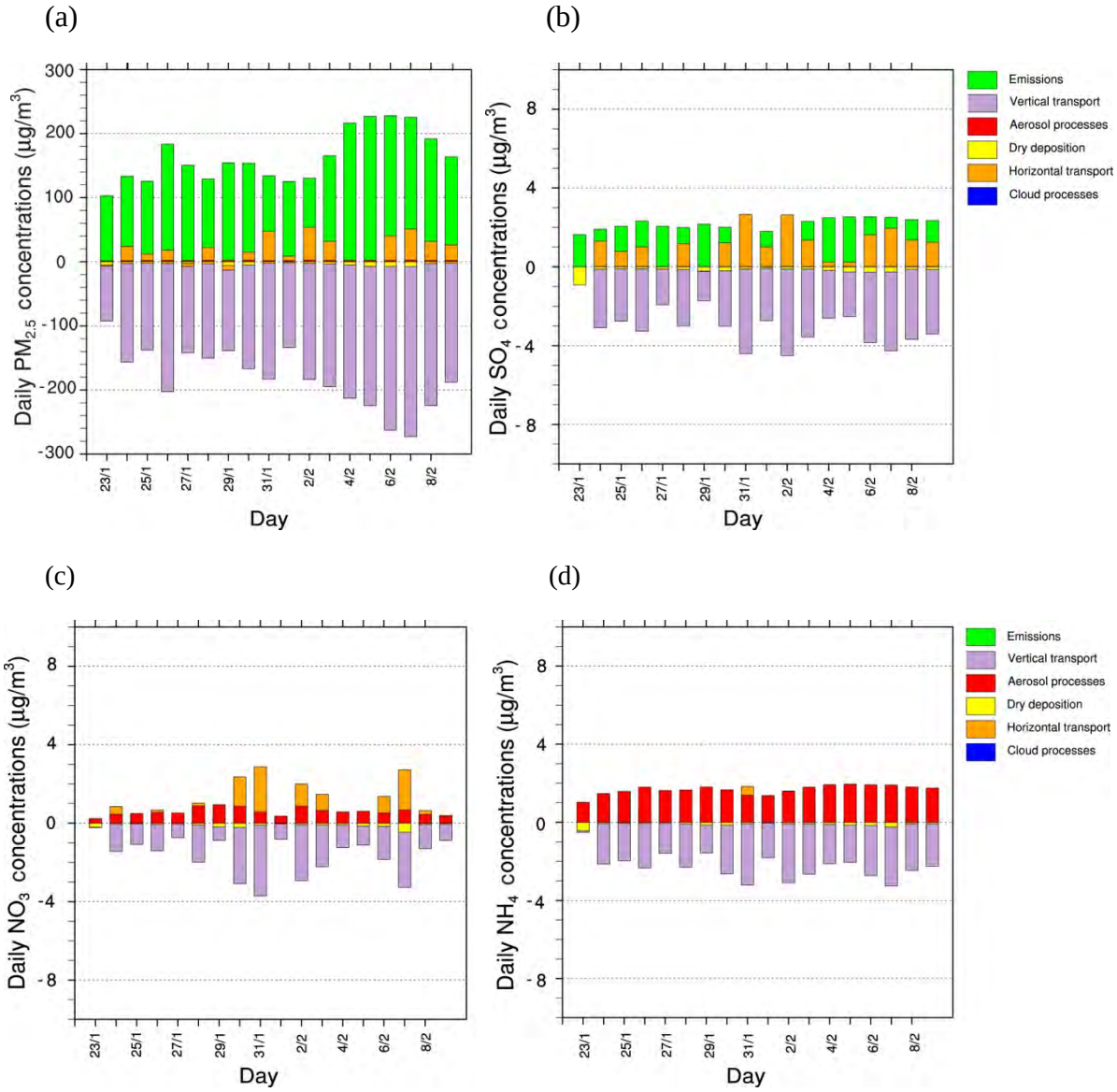


Fig. 12 Daily mean hourly contributions of individual processes to the (a) $PM_{2.5}$-concentrations, (b) SO_4-concentrations, (c) NO_3-concentrations, and (d) NH_4-concentrations as obtained at the State Office Building site from the adapted CMAQ simulation that used the revised WRF and SMOKE input for the January episode.

2.3 Documentation of Changes in CMAQ and Performance Improvements Made during Phase II

The simulations of the Alaska adapted CMAQ model underestimated sulfate (SO_4). Sulfate is the second major component in the composition of $PM_{2.5}$ in the Fairbanks nonattainment area. The simulations of the Alaska adapted CMAQ model also showed a time lag of ~24 hours in comparison with the observations at the State Office Building site for both the January and November episodes.

2.3.1 Improvements Implemented to Reduce the Sulfate-Underestimation

The performance of CMAQ in predicting fine particulate matter ($PM_{2.5}$) and its species has been evaluated in many studies [e.g. *Appel et al.*, 2008; *Eder and Yu*, 2006; *Mathur et al.*, 2008]. Obviously, according to these studies, CMAQ's performance tends to be lower in winter than summer for $PM_{2.5}$ and most species. CMAQ is also likely to underpredict sulfate during winter [*Appel et al.*, 2008; *Eder and Yu*, 2006; *Mathur et al.*, 2008].

The statistical performance skills for sulfate are poorer for the Fairbanks domain than for other US states (Table 1). Slightly lower performance skills were also found for Alaska than the Lower 48 for WRF/Chem simulations [*Mölders et al.*, 2012]. Thus, based on the literature, we may conclude that air-quality models may generally have difficulty with relatively lower temperature conditions. Thus, the extremely low temperature during the winter in Fairbanks might be a reason of the sulfate underestimation. This conclusion is backed by the evaluation studies for the Lower 48 that report weaker performance for $PM_{2.5}$-prediction winter than summer episodes [e.g. *Appel et al.*, 2008]. Therefore, we made several changes to the code of CMAQv4.7.1 to improve the sulfate simulation.

We performed various studies to examine the reasons for and to reduce the underestimation of sulfate and $PM_{2.5}$. In the following, first, the changes are described and later their impact will be discussed.

1) Increase of the Default Values for Fe and Mn in AQ_PAEAMS.EXT

In aerosol and aqueous chemistry, iron and manganese can play important roles for sulfate formation. Therefore, we updated the background values of Fe (III) and Mn (II) from $0.010\mu g/m^3$ to $0.040\mu g/m^3$ and decreased Mn (II) from $0.005\mu g/m^3$ to $0.001\mu g/m^3$following the measurement made in Fairbanks during winter 2011-2012 by *Peltier* [2012].

2) Increase of Sulfate and SO_2-concentrations for the Initial and Background concentrations (IC/BC)

The concentrations of sulfate and SO_2 of the previous initial and background concentrations were suspected to be too low. We now use the concentrations from the Clean Air Status and Trends Network (CASTNet) at the Denali site of winter 2008/09 (October–February). Thus, at the near-surface level the new SO_2-concentration is now 3.50×10^{-4} ppm. This value is closer to the default values that are used in the Eastern US. Modifying the near-surface concentration lead to ~1.7 increased near-surface SO_4-concentrations as compared to the total SO_4-concentrations obtained with the old values. The vertical profiles of SO_2 and sulfate are still based on *Jaeschke et al.* [1999] as no other vertical profile data is available to our best knowledge.

3) Change the dry deposition code back to the CMAQ v.4.7.1 original code

The modifications introduced for the dry deposition of SO_2 in phase I (deposition onto tundra, which was switched off in the original CMAQ, revised vegetation parameters for Alaska, formulations for dry deposition onto snow; see *Mölders and Leelasakultum* [2012]) led to increased removal of sulfate as compared to the original CMAQ. Therefore, we changed the parameterization of the SO_2 dry deposition processes back to their original version as it was in CMAQv.4.7.1 except that we kept the dry deposition on tundra. Note that if we would change this back to the original code it would mean that no deposition would be considered over most of the domain. Note that tundra covers most of the domain. In the original version of CMAQ, the code run over all vegetation types except for tundra to save computational time. This procedure is justifiable and makes sense for regions without tundra vegetation. However, in regions where tundra occurs, it would mean that no deposition is calculated over these tundra areas.

We want to point out that the changes that we originally made in phase I, are valid from a scientific point of view. The dry deposition over snow is quite different than over snow-free surfaces and should be dealt with similar as described in *Zhang et al.* [2003], i.e. likea we introduced it into CMAQ during phase I. The change back to the original formulation was only made to come closer to the observations and because of the philosophy to stay with the original code when changes do not lead to improvement for Alaska.

4) Reduction of the liquid-water threshold for resolvable scale clouds

Mueller et al. [2006] found that CMAQ underestimated sulfate because of a problem in the diagnosis of cloud cover. They found that reducing the liquid-water threshold values by 50% can decrease the cloud bias and lead to better results for sulfate predictions. Therefore, we decreased these threshold values by 50% in “rescld.F” of CMAQ model. The response will be discussed later.

5) Improved parameterization for the sulfuric acid – water nucleation rates

In CMAQ, the parameterization of the homogeneous nucleation rate of sulfuric acid and water is based on *Kulmala et al.* [1998]. *Vehkamaki et al.* [2002] published an extension of the formulation by *Kulmala et al.* [1998] to lower temperatures and a wider relative humidity range. CMAQ model v4.7.1 had not yet been updated to include this extension. Its formulas hold for temperatures between -43^{o}C and 32^{o}C, relative humidity between 0.01% and 100%, nucleation rates between 10^{-7} and $10^{10}cm^{-3}s^{-1}$, and sulfuric acid concentrations of 10^{4} to $10^{11}cm^{3}$. We coded and implemented this extended parameterization for the calculation of the nucleation rates based on *Vehkamaki et al.* [2002] and presented the results in the secondary quaterly report phase II. Later on, we updated the calculation based on personal communication with *Vehkamak* [2012]. This updated calculation is basically similar to what we have done, but the numbers include more digits. Furthermore, there are more conditions considered [*Vehkamaki,* 2012; pers. comm.]. The fortran code can be found at

http://www.atm.helsinki.fi/~hvehkama/publica/vehkamaki_hi_t_binapara.f90.

2.3.2 Response to the Improvements Made to Reduce the Sulfate-Underestimation

The introduction of the above improvements led to an increase in the percentage sulfate concentrations of total $PM_{2.5}$ at the grid-cell of the State Office Building site. The percentage of sulfate increased from 4.2 to 5.3% and from 3.9 to 5.0% for the November and January episode, respectively (Fig. 13). The increase in the percentage of SO_4 affected the partitioning of other species. This means concurrently the percentage of NH_4 increased, while the percentage of NO_3 and organic compounds decreased. These shifts in percentage may be explained as follows. The enhancement of sulfur dioxide and sulfate affected the thermodynamic equilibrium of the aerosol system. The sulfate-related aerosol acidity may be further neutralized by NH_3 to form ammonium sulfate aerosol ($(NH_4)_2SO_4$) [*Lovejoy*, 1996; *Seinfeld*, 2006]. The rest of ammonia can also neutralize nitric acid (HNO_3), and forms ammonium nitrate aerosol (NH_4NO_3).

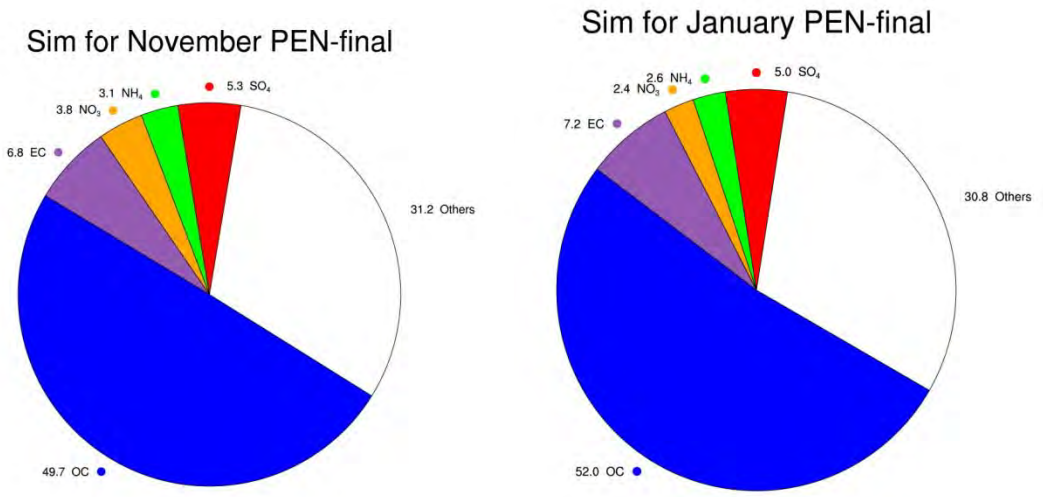


Fig. 13 Composition of simulated 24h-average total $PM_{2.5}$ as obtained by the CMAQ simulations with the final modifications and using the PennState provided meteorology (PEN-final) on average over the November episode (left), and the January episode (right) at the grid-cell of the State Office Building site. In the simulations, the category "others" refers to unspecified anthropogenic mass (A25i+A25j), Na and Cl. In the observations, the category "others" includes Al, Br, Ca, Na, Cl, Cu, Fe, Pb, Ni, K, Se, Si, S, Sn, Ti, V, Zn.

The comparison of the absolute differences between the simulations before and after the improvements shows increases in sulfate, and ammonium and decreases in nitrate on every simulated day for both episodes (Figs. 14, 15). On average, the absolute increase of sulfate is 0.4 $\mu g/m^3$ or 28-29% for both episodes. The improvements did not bring a change in the organic concentrations (Figs. 14, 15); the decreased percentage of organic compounds is due to the increase of the percentage of SO_4 and NH_4. Note that the final modifications did not change the

temporal evolutions of sulfate and $PM_{2.5}$-concentrations, and the final version of Alaska adapted CMAQ still underpredicts sulfate aerosol.

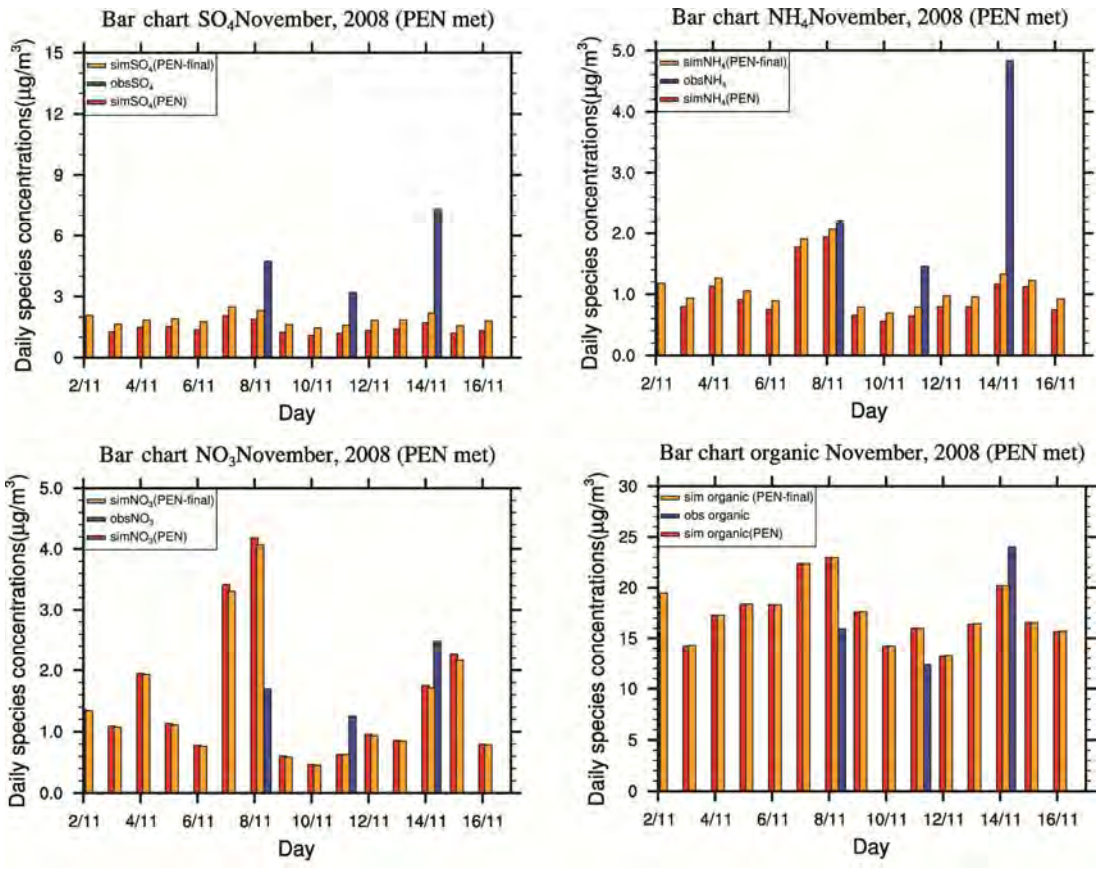


Fig. 14 Bar charts of simulated species as obtained from the previous CMAQ modification described in the final report of phase I (red), and as obtained from the final CMAQ modification described above (orange) and observed species (blue) of the 24h-average $PM_{2.5}$-composition for SO_4, NH_4, NO_3, and organic carbon for the November episode.

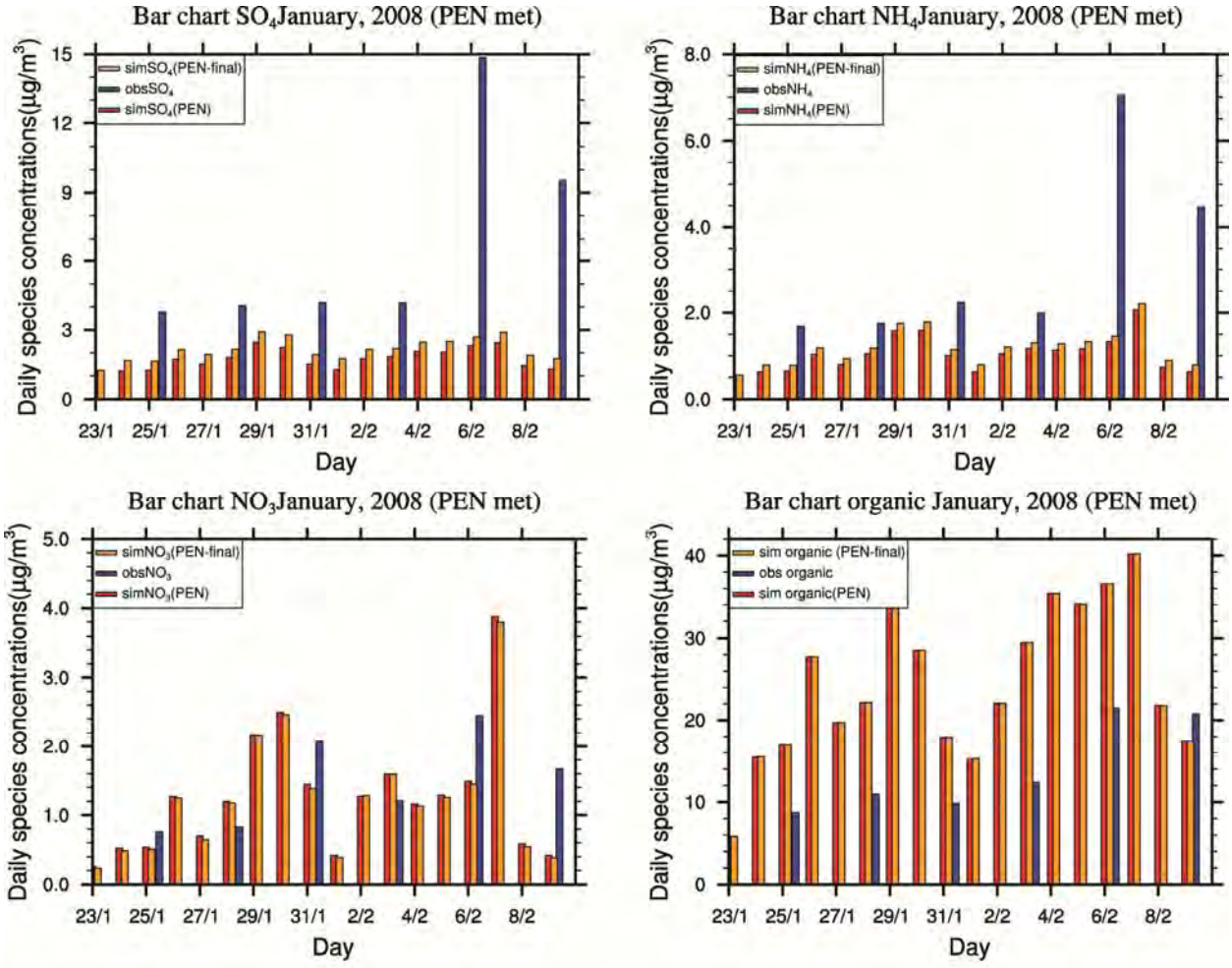


Fig. 15 Bar charts of simulated species as obtained from the previous CMAQ modification described in the final report of phase I (red), and as obtained from the final CMAQ modification described above (orange) and observed species (blue) of the 24h-average $PM_{2.5}$-composition for SO_4, NH_4, NO_3, and organic carbon for the January episode.

The process analysis of sulfate concentrations at the grid-cell of the State Office Building site shows that the final modifications caused changes in the horizontal and vertical transport (Fig. 16). This means that the modifications led to changes in neighbored grid-cells. These changes then led to advection of slightly modified (composition wise) air. On average in the November episode, the final CMAQ modification increased the contribution of sulfate from horizontal transport, cloud and aerosol processes by 0.39, 8.4×10^{-7} and 4.8×10^{-4}µg/m^3, respectively. The contributions to sulfate from removal by dry deposition and vertical transport decreased by -0.02 and 0.28µg/m^3. There was no change in the emissions as we used the same emission inventory.

On average over the January episode, the final CMAQ modification led to increased contributions of sulfate from horizontal transport, cloud and aerosol processes by 0.30, 1.1×10^{-6} and 5.6×10^{-4} µg/m^3, respectively. In the runs with the modifications, the removal of sulfate by

dry deposition and by vertical transport decreased by -0.02 and 0.37μg/m^3, respectively, as compared to the run without the modifications.

Table 1. Performance statistics for sulfate species simulated by the CMAQ model that did not employ the revised WRF and SMOKE input (January v1 episode), the CMAQ model with the previous modification (January v2 episode, PEN-WRF) described in the final report of phase I, and with the CMAQ model version with the final modification (PEN-WRFfinal) for the January and November episode on the days. Statistics are based on the observed sulfate data was available at the Fairbanks State Office Building site. The statistics of the annual simulations of sulfate in other states in US as reported by *Eder and Yu* [2006] are included for comparison. Here "No." stands for the number of days with observations. Furthermore, r, MB, RMSE, NMB and NME are the correlation skill score, mean bias, root-mean-square error, normalized mean bias, and normalized mean error.

Sulfate	**No.**	**Mean model**	**Mean observed**	**r**	**MB**	**RMSE**	**NMB (%)**	**NME (%)**
	January v1 episode							
PEN-WRF	6	1.3	6.8	0.36	-5.4	6.8	-80.3	80.3
	January v2 episode							
PEN-WRF	6	1.7	6.8	0.56	-5.1	6.4	-75.4	75.4
PEN-WRFfinal	6	2.1	6.8	0.61	-4.7	6.1	-69.6	69.6
	November episode							
PEN-WRF	3	1.6	5.1	0.61	-3.5	3.8	-68.5	68.5
PEN-WRFfinal	3	2.0	5.1	0.66	-3.1	3.4	-60.0	60.0
Eder and Yu, 2006	6970	3.33	3.40	0. 77	-0.77	2.25	-2.0	42.0

The statistical performance of the Alaska adapted CMAQ version that did not employ the revised WRF and SMOKE input (January v1), the CMAQ with the modifications that employs the revised WRF and SMOKE (January v2), and from the final CMAQ modification in simulating sulfate are compared in Table 1. Introducing the changes in the parameterizations increased the mean sulfate concentrations on the days, which had observed sulfate concentrations at the State Office Building site, in the range of 1.7 to 2.1μg/m^3 and 1.6 to 2.2μg/m^3 for the January and November episode, respectively. The mean biases (MB) were -4.7 and -3.1 μg/m^3 for the latest changes in the parameterization for the January and November episode, respectively. The

normalized mean bias (NMB) and normalized mean error (NME) from all simulations are high (exceed 50%) in comparison with the annual NMBs in the study by *Eder and Yu* [2006]. The examination the NMB and NME for the two episodes reveals better performance in simulating sulfate with the latest modifications. Our analysis of the performance also revealed that the correlation coefficients between the observed and simulated sulfate data increase as the concentrations of sulfate increase (Table 1).

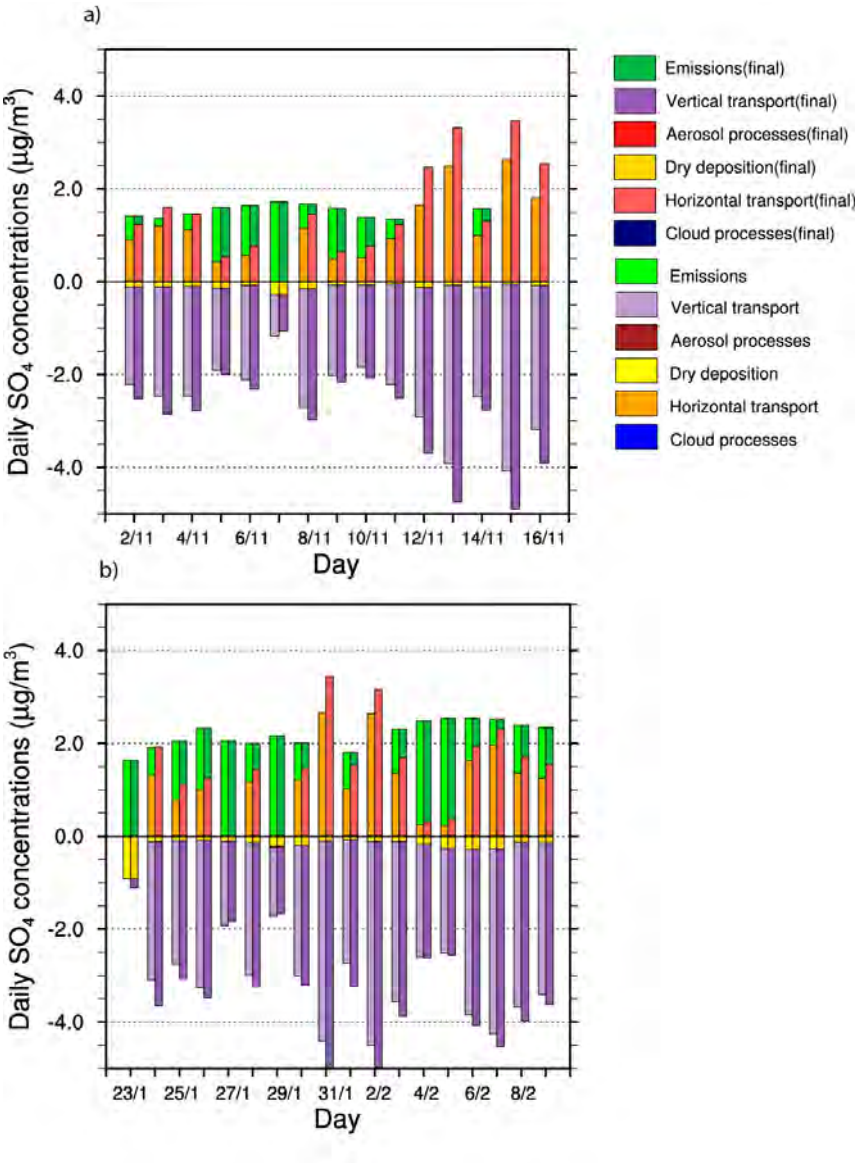


Fig. 16 Comparison of the daily contributions of individual processes to the SO_4-concentrations as obtained by CMAQ with the previous modifications and with CMAQ with the modifications described in this report at the grid-cell of the State Office Building site for the (a) November and (b) January episode.

Table 2. Performance statistics for the 24h-average $PM_{2.5}$-concentrations as obtained from the Alaska adapted CMAQ with the previous modifications and the CMAQ with the final modifications at the grid-cell of the State Office Building site for the January v1, January v2 and November episodes. The small differences as compared to the 1st quarterly report of phase II are due to the use of the SMVGEAR solver instead of the EBI solver that is needed for the process analysis.

24h-average $PM_{2.5}$-concentrations	**January v1**	**January v2**	**November**	**Final modifications**	
				January	**November**
Number of pairs used in the calculation of the statistics	12	12	15	12	15
Mean simulated($\mu g/m^3$)	35.0	52.6	34.9	53.1	35.5
Mean observed ($\mu g/m^3$)	42.6	42.6	29.3	42.6	29.3
Mean bias ($\mu g/m^3$)	-3.0	6.6	5.6	7.0	6.2
Mean fractional bias (%)	-1	17	26	18	31
Mean error ($\mu g/m^3$)	9.2	10.8	12.1	11.0	15.7
Mean fractional error (%)	24	26	42	27	54
Average difference (sim-obs)	-4.5	9.9	5.6	10.5	6.2
Simulated min| max ($\mu g/m^3$)	26.6 | 49.7	28.6 | 78.2	26.8 | 49.0	29.3 | 78.8	27.3 |49.4
Observed min|max ($\mu g/m^3$)	13.3 | 67.4	13.3 | 67.4	8.2 | 51.6	13.3 | 67.4	8.2 | 51.6
Number of simulated exceedance days	7	10	7	10	7
Number of observed exceedance days	8	8	6	8	6
STDEV of simulation ($\mu g/m^3$)	7.3	16.2	6.8	16.2	6.7
STDEV of observation ($\mu g/m^3$)	19.0	19.0	13.7	19.0	13.7
Variance of simulation$(\mu g/m^3)^2$	52.8	262.2	46.0	262.0	45.5
Variance of observation$(\mu g/m^3)^2$	362.8	362.8	188.3	362.8	188.3
Correlation coefficient	0.38	0.52	0.31	0.52	0.31

The Alaska adapted CMAQ with the final modifications given in this report is still not able to simulate sulfate concentrations as high as the observations suggest. As the process analysis indicated that the emission process is the main source of sulfate at the grid-cell of the State

Office Building site, we performed simulations with the same CMAQ configuration, but used an earlier version of the emission inventory. The comparison showed that the model showed better performance in simulating sulfate at the State Office Building site with the earlier version of the emission inventory. Therefore, we compared the emission inventories to examine what changes in the emissions led to these differences in model performance. Our investigations showed that in the latest version of the emission inventory there was a decrease of sulfate from 7% to 2-3% in the partitioning of the $PM_{2.5}$-emissions in comparison with the earlier version of the emission inventory (see also discussion in *Mölders and Leelasakultum* [2012]). Therefore, the decrease of sulfate in the partitioning of the $PM_{2.5}$-emissions is probably the main cause of underestimation of sulfate concentrations. The main differences we see in these WRF-CMAQ runs that only differ by the emission inventory used, show us the sensitivity of the model to the emissions and their partitioning. However, the latest version of the emission inventory reflects the latest inventory accuracy with new woodstove changeout, census and mobile numbers. Therefore, the latest emission inventory has to be considered superior over the earlier versions from a from a research standpoint.

Finally, we compared the performance statistics of the 24h-average $PM_{2.5}$-concentrations from Alaska adapted CMAQ version that did not employ the revised WRF and SMOKE input, the CMAQ modification that employed the revised WRF and SMOKE, and the CMAQ with the final modifications (Table 2). The final modifications did not increase the correlation coefficient or change the temporal evolution. The results of soccer plot and bugle plot are similar as prior to introducing the latest changes. As the differences are not statistically relevant, they are not shown here.

2.3.3 Investigation of the Causes for the Temporal Offset

As discussed above, the time-lag effect caused the model to fail to capture the temporal evolution of $PM_{2.5}$-concentrations well. Consequently, the correlation coefficients between the simulated and observed $PM_{2.5}$-concentrations for both episodes are lower than they should be. We run a hierarchy of simulations to test the causes for the temporal offset found at the grid-cell of the State Office Building site.

In the earlier simulations, the time-steps for the operator splitting were set as follows: maximum sync time-step = 12 min, minimum sync time-step=1.5 minute, and up to sigma = 0.9. We hypothesized that the CMAQ model might be too slow in updating the chemistry, which consequently could lead to the temporal offset at the grid-cell of the State Office Building site. Therefore, we reduced the time step for the operator splitting to be as follows: maximum sync time-step = 6 min, minimum sync time-step=1minute, and up to sigma =0.7. The temporal evolution of $PM_{2.5}$-concentrations for the longer time-step (PEN-WRF) and the shorter time-step (PEN-WRFfinal) were compared. The comparison showed no difference in the temporal evolutions for both the January and November episode (Figs. 17, 18). The differences in concentrations might be due to the improvement of parameterizations in the PEN-final version.

Additionally, we also run the simulations by using the emission of the next day (PEN-Eshift), i.e. we shifted the emissions by one day. The temporal evolutions of simulated $PM_{2.5}$-concentrations showed only marginal differences from those simulations that used the emissions in sync with the meteorological data (Fig. 17).

Another reason for the temporal offset between simulated and observed $PM_{2.5}$-concentrations was hypothesized to be an offset in the simulated meteorology. Therefore, we ran WRF for the two episodes in a different configuration than the PennSate WRF. In the following, we refer to these simulations as "UAF-WRF". Our WRF-simulations differ in the model configuration from the WRF-simulations performed and provided by PennState. Note that the simulations provided by PennState are called "PEN-WRF", hereafter. The new WRF simulations served to examine whether an offset in meteorology is the cause for the time lag in the $PM_{2.5}$-concentrations.

The domains for the simulations with the UAF-WRF are based on the domains used in the PEN-WRF for easy comparison. Our model configuration like theirs used three one-way nested horizontal grids with horizontal grid spacing of 12km, 4km and 1.3km, respectively. Domain 3 that has a 1.3km grid increment was used to provide the meteorological input data to simulate the chemical transport and transformation of species with the CMAQ model. For the UAF-WRF simulations, the initial meteorological conditions were downscaled from the $1^o \times 1^o$, 6h-resolution National Centers for Environmental Prediction global final analyses. The simulations were performed in forecast mode (turning off nudging) for January 23, 2008 0000UTC to February 12, 2008 0000UTC and November 02, 2008 0000UTC to November 18, 2008 0000UTC. The selection of options in the first simulations of the UAF-WRF (UAF-WRFv1) bases on long-year experience of the PI and her research group with meteorological simulations for Alaska [e.g. *Mölders and Olson*, 2004; *Mölders and Walsh*, 2004; *Mölders and Kramm*, 2007; 2010; *Chigullapalli and Mölders*, 2008; *Yarker et al.*, 2010; *Mölders et al.*, 2011; 2012]. The selection of options in the second set of simulations with the UAF-WRF (UAF-WRFv2) for domain 3 is the same as those in the PEN-WRF except that we turned off the OBS nudging. The meteorological fields were initialized every day. The model configurations for both the PEN-WRF and UAF-WRFv1 and UAF-WRFv2 are compared in Table 3.

Nudging to observations (OBS nudging) is a technique that adds artificial forcing functions to a model's prognostic equations to nudge the solutions toward the observations. Those individual observations are spread in space and time. In domain 3, there is a limited number of radiosonde sounding sites [*Mölders et al.*, 2011]. Thus, OBS nudging might cause a temporal offset, as obviously the WRF model was unable to capture the temperature inversion at the right time and place. Therefore, we turned off the OBS nudging for a sensitivity study for both UAF-WRFv1 and UAF-WRFv2. Note that in Fairbanks, many inversions are locally forced when the right synoptic conditions exist [*Mayfield*, 2012].

The comparison of the temporal evolutions of the $PM_{2.5}$-concentrations as obtained by CMAQ with the UAF-WRFv1 and UAF-WRFv2 with those obtained with the PEN-WRF indicates that

the meteorological input data led to changes in the temporal evolutions of $PM_{2.5}$-concentrations. However, none of the obtained changes in $PM_{2.5}$-concentrations led a perfect fit with the observed $PM_{2.5}$-concentrations (Figs.17, 18). The UAF-WRFv1 simulations with the *Lin et al.*'s [1983] microphysics scheme seem to provide the highest $PM_{2.5}$-concentration peaks in the beginning of the November episode and the lowest dip in the $PM_{2.5}$-concentrations on November 11 as compared with the other simulations (Fig. 17). For the January episode, the simulation with the *Lin et al.* [1983] microphysics scheme showed the smallest temporal shift as compared to the PEN-WRF, but still showed the offset (Fig. 18). The simulations with the Morrison 2-moment [*Morrison et al.*, 2005] scheme tend to smooth the peak and dip. As a result, the simulations with the UAF-WRFv2 clearly brought the 24h-average $PM_{2.5}$-concentrations down.

Table 3. WRF-model configurations of the PennState University (PEN-WRF) and University of Alaska Fairbanks simulations for domain 3 version 1 (UAF-WRFv1) and version 2 (UAF-WRFv2). The main differences of model configurations are indicated in bold letters.

Model Configurations	PEN-WRF	UAF-WRFv1	**UAF-WRFv2**
Cumulus Parameterization	None	Grell G3	None
Microphysics	Morrison 2-moment	Lin et al.	Morrison 2-moment
Longwave radiation	RRTMG	RRTM	RRTMG
Shortwave radiation	RRTMG	Goddard	RRTMG
PBL scheme	Mellor-Yamada-Janjic (Eta)	Mellor-Yamada-Janjic (Eta)	Mellor-Yamada-Janjic (Eta)
Surface Layer scheme	Monin-Obukhov (Janjic Eta)	Monin-Obukhov (Janjic Eta)	Monin-Obukhov (Janjic Eta)
Land-surface scheme	RUC Land-Surface Model	RUC Land-Surface Model	RUC Land-Surface Model
Urban model	No urban physics	No urban physics	No urban physics
Land use classification	USGS	USGS	USGS
3D analysis nudging	OFF	OFF	OFF
SFC analysis nudging	OFF	OFF	OFF
OBS nudging	**ON**	**OFF**	**ON**

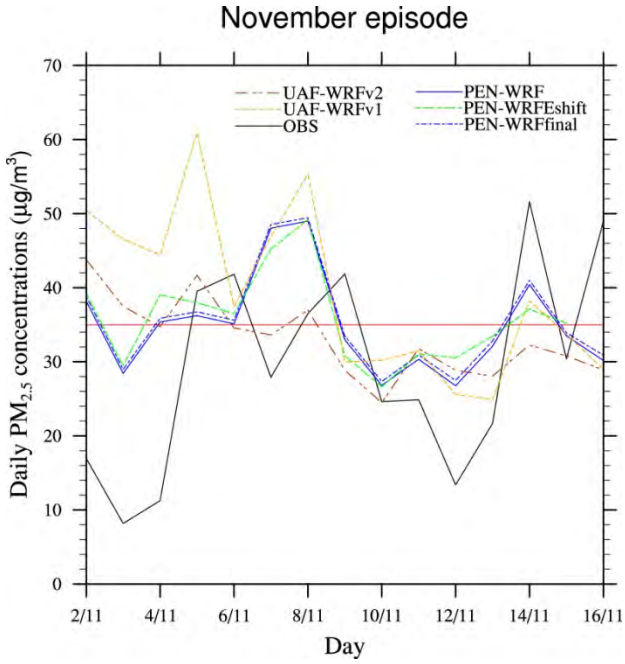


Fig. 17 Temporal evolutions of 24h-average $PM_{2.5}$-concentrations as simulated at the grid-cell of the State Office Building site by the Alaska adapted CMAQ that uses a longer time-step (PEN-WRF) and the shorter time-step (PEN-final), emission on the next day, with the UAF-WRF version 1 (UAF-WRFv1) and version 2 (UAF-WRFv2) and as observed (OBS) at the State Office Building for the November episode.

The correlation coefficients between the simulated $PM_{2.5}$-concentrations obtained with CMAQ using the PEN-WRF, PEN-WRFEshift, PEN-WRFfinal, UAF-WRFv1 and UAF-WRFv2 and the observations are 0.31, 0.26, 0.31, -0.01 and -0.12, respectively for the November episode. For the January episode, the correlation coefficients were all 0.52 no matter whether CMAQ used the PEN-WRF, PEN-WRFfinal and UAF-WRFv1 meteorology. It can be clearly seen that the PEN-WRF is providing the best correlation coefficient of simulated and observed $PM_{2.5}$-concentrations. However, the temporal offset of the model still exists even when we run the WRF with the OBS nudging turned off, but otherwise with the same options as used by PennState. Therefore, we recommend to do more tests and find a WRF-setup that better represents the temporal evolution of 24h-average $PM_{2.5}$-concentrations at the State Office Building site.

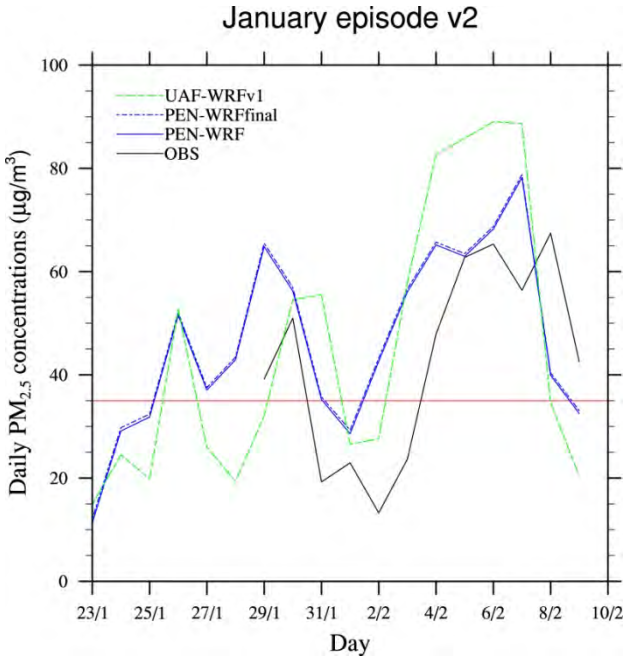


Fig. 18 Temporal evolutions of 24h-average $PM_{2.5}$-concentrations as simulated by the Alaska adapted CMAQ that uses a longer time-step (PEN), a shorter time-step (PEN-final), emission of the next day, with the UAF-WRF version 1 (UAF-WRFv1) and version 2 (UAF-WRFv2) and observed at the State Office Building site (OBS) for the January episode.

2.4 Investigation on the Boundary and Initial Conditions

To create the boundary conditions (BC) for domain 3, we would have had to run CMAQ on domain 2 at least. However, emission data for domain 1 and 2 were never created as various studies with WRF/Chem [*Tran et al.*, 2011; *Mölders et al.*, 2012] and observational analysis [*Cahill*, 2003] showed that the contribution by transport of $PM_{2.5}$ towards Alaska are more than an order of magnitude smaller than the concentration of the NAAQS. This means that there were no issues related to the BC. Consequently, the Alaska Department of Environmental Conservation did not request Sierra Research Inc. to create an emission inventory for Alaska and did not ask us to perform CMAQ simulations on domain 2. Note that typically, the chemical fields predicted on domain 2 at the boundaries of domain 3 would serve as the BC for domain 3. For these reasons, we could not investigate the impact of the BC on the concentrations in domain 3 directly. Nevertheless, we performed a work intensive series of tests to investigate the impact of the BC on the concentrations simulated in domain 3 indirectly. These tests as their results are discussed in the following.

In the final report of phase I [*Mölders and Leelasakultum*, 2012], we already reported on potential impacts of BC when comparing the results at the boundaries of the smaller 66×66 domain with concentrations at these places in simulations on a 199×199 domain. The interested reader is referred to this document for further reading on BC impacts.

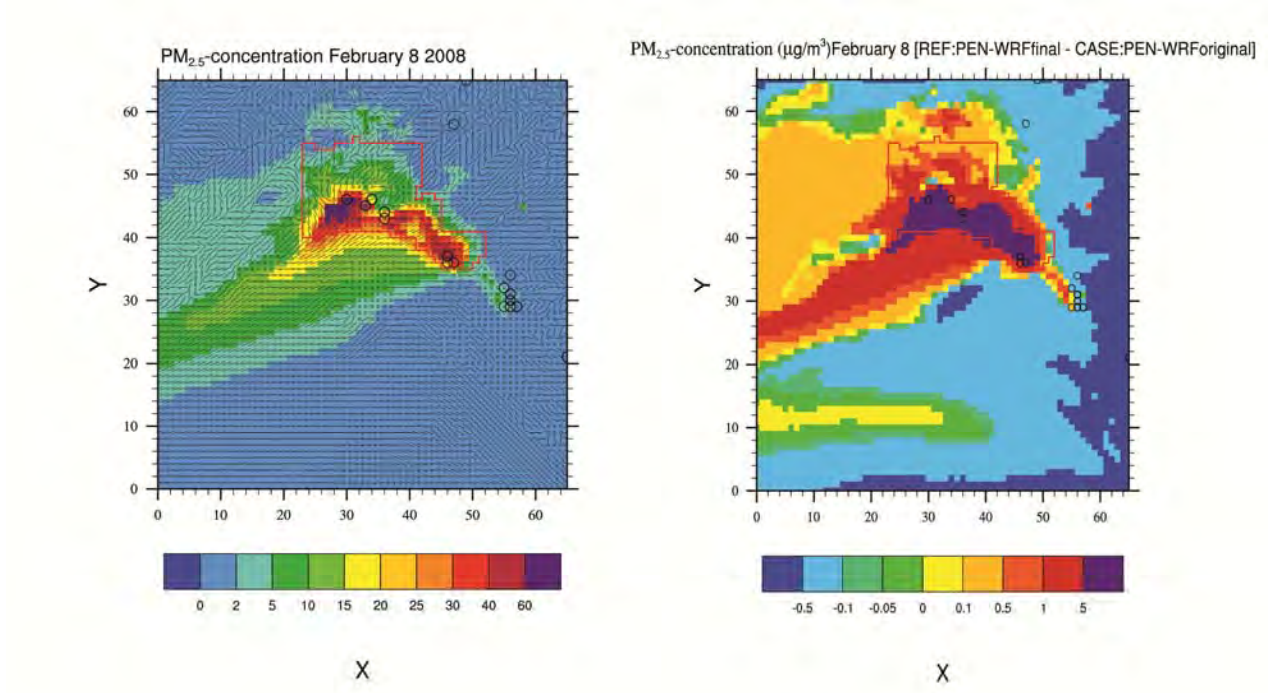


Fig. 19 Exemplary plot of (a) 24h-average $PM_{2.5}$-concentrations as simulated by CMAQ with the PEN-WRF meteorology (PEN-WRFfinal) with the wind barbs and (b) 24h-average $PM_{2.5}$-concentration differences at breathing level between the simulations with the final CMAQ and the PEN-WRF meteorology that uses the cleaner IC/BC conditions (see text for details) and the original CMAQ with that uses the default initial and boundary condition and PEN-WRF meteorology (PEN-WRForiginal). Differences are PEN-WRFfinal-PEN-WRForiginal.

To determine the impact of the initial conditions (IC) and BC, we compared the results from the final Alaska adapted CMAQ simulation that was generated with the PennState meteorological data (PEN-WRFfinal) with the results from the original CMAQ version with the default initial and boundary conditions that represent the background concentrations in the eastern United States. We assumed that the initial and boundary conditions developed for Alaska are "clean" background conditions. The boundary-condition impacts on the 24h-average $PM_{2.5}$-concentrations make a difference of less than 0.5µg/m^3 outside the nonattainment area (Fig. 19). For the January episode, the maximum difference due to the boundary conditions amounts 1.4 µg/m^3. However, on some days, effects of the boundary conditions can be found inside the nonattainment area in the range of 0.1 to 0.5µg/m^3. The magnitude of the BC impacts depends on wind-speed and direction.

For example on February 8, the northeast wind blows the $PM_{2.5}$ to the southwest. This consequently results in an impact of the boundary condition on the concentrations inside the nonattainment area (Fig. 19). The difference between the clean background condition and the default BC also shows in a difference in the 24h-average $PM_{2.5}$-concentrations about 0.1-0.5

$\mu g/m^3$. The results for the impact of recirculation pattern on the $PM_{2.5}$-concentrations in the domain are shown in the Appendix.

Using IMPROVE network observations of winter 2008/09 combined with HYSPLIT [*Draxler et al.*, 2009] backward meteorological trajectories simulations at 0000 UTC on days with high $PM_{2.5}$-concentrations ($>2\mu g/m^3$) at the Denali IMPROVE site and heights of 1000m to 8500m in steps of 500m above ground showed transport of particles from Asia to Denali Park at several levels. However, at the Denali IMPROVE site the $PM_{2.5}$-concentrations are still far away from the NAAQS and typically below $3\mu g/m^3$. This means long-range transport may contribute to the $PM_{2.5}$-concentrations in the nonattainment area by a couple of $\mu g/m^3$, but is not the reason for the exceedances. In winter, the advected amount of $PM_{2.5}$ is too small to cause an exceedance unless the $PM_{2.5}$-concentrations are already close to the NAAQS.

Photochemical modeling with WRF/Chem, for which various emission datasets were available, showed that the region receives only minor amounts of pollution from long-range transport [*Tran et al.*, 2011; *Mölders et al.*, 2012]. The major sources of primary particulate matter are within the nonattainment area. Typically, $PM_{2.5}$-exceedances occur during strong temperature-inversions on calm-wind days when the inversion traps local emissions from heating and vehicles near the surface [*Tran and Mölders*, 2011; *Mölders et al.*, 2012]. On these days, wind-speeds are low and advection from outside the nonattainment area is marginal.

2.5 Assessment of CMAQ Sensitivity to Secondary Chemistry

We investigated the sensitivity of the Alaska adapted CMAQ model version to chemistry before the final improvements were made for the January v1 and November episode. In the nonattainment area, the overall and average concentrations of sulfate, nitrate and organic for turning on and turning off chemistry were compared (Table 4).

The comparison of the sulfate, nitrate and organic concentrations of the two episodes shows that the concentrations of all three species are higher in the January than November episode. Turning off the chemistry decreases the sulfate concentrations by 9% and 3% for the January and November episode, respectively. Doing so, decreases the organic compound concentrations by 1% and less than 1%, and decreases the nitrate concentrations by 90% and 95% for the January and November episode, respectively (Table 4). The nitrate-aerosol production is related to the neutralization of HNO_3 vapor, which is a by-product of photochemical reactions. In the November episode, there is more sunlight than January episode. Thus, gas-phase and aerosol chemistry of nitrate play a greater role than in the January episode. For sulfate and organic compounds, the lower temperatures and dry conditions of the January episode support more gas-to-particle conversion than in the November episode. Consequently, those aqueous vapors tend to convert into particles and increase the mass of sulfate and organic particulate matter.

Table 4. Overall mass and average mass of sulfate, nitrate and organic compounds in the nonattainment area for the case of turning off the chemistry (chem_noop and aero_noop in CMAQ), turning off the gas chemistry (chem_noop), turning off the aerosol chemistry (aero_noop), and turning on the chemistry.

Nonattainment area	**Sulfate (μg/m^3)**	**Nitrate(μg/m^3)**	**Organic(μg/m^3)**
Overall mass			
January			
Turn on chemistry	152,490	103,508	713,109
Turn off gas-chemistry	148,521 (-3%)	40,787(-61%)	712,325(N)
Turn off aero-chemistry	139,856(-8%)	10,764(-90%)	708,086(-1%)
Turn off chem.	139,317(-9%)	10,161(-90%)	707,934(-1%)
November			
Turn on	125,201	189,067	1,354,795
Turn off gas-chemistry	125,413(N)	30,136(-84%)	1,354,053(N)
Turn off aero-chemistry	121,161(-3%)	10,489(-94%)	1,351,743(N)
Turn off chemistry	122,050(-3%)	10,069(-95%)	1,351,745(N)
Average mass			
January			
Turn on	0.85	0.57	3.96
Turn off gas-chemistry	0.82(-3%)	0.23(-61%)	3.95(N)
Turn off aero-chemistry	0.78(-8%)	0.06(-90%)	3.93(-1%)
Turn off chemistry	0.77(-9%)	0.06(-90%)	3.93(-1%)
November			
Turn on	0.88	1.33	9.53
Turn off gas-chemistry	0.88(N)	0.21(-84%)	9.52(N)
Turn off aero-chemistry	0.85(-3%)	0.07(-94%)	9.51(N)
Turn off chemistry	0.86(-3%)	0.07(-95%)	9.51(N)

At the grid-cell of the State Office Building site, the ratios of simulated to observed sulfate, nitrate and organic carbon and of precursors to concentrations were also investigated. On average over the January episode, the ratios of modeled SO_2/modeled aerosol sulfate are 189.0 and 154.1 for the Alaska adapted CMAQ model before and after the improvements, respectively. For the November episode, the average ratios of modeled SO_2/modeled aerosol sulfate are 184.8 and 147.5 for the Alaska adapted CMAQ model before and after the improvements, respectively. These findings mean that introducing the improvements led to more conversion of SO_2 to sulfate at the grid-cell of the State Office Building site. The ratios of emitted SO_2/emitted sulfate are 248.6 and 227.8 for the January episode v2 and for the November episode, respectively. The ratios of modeled SO_2/modeled aerosol sulfate divided by emitted SO_2/emitted sulfate are 0.62 and 0.65 for the final improvements of CMAQ for the January v2 and November episode, respectively. Note that there is no observed SO_2 data for the two episodes.

Furthermore, for the simulations that did not employ the revised WRF and SMOKE inputs, the ratio of modeled SO_2/modeled aerosol sulfate divided by emitted SO_2/emitted sulfate are very close (0.63 and 0.62). However, the ratio of emitted SO_2/emitted sulfate for the January v1 is 380.1, which is higher than for the January v2 case. The ratio of modeled SO_2/modeled aerosol sulfate divided by emitted SO_2/emitted sulfate is close to one. This finding indicates that the concentrations of SO_2 and sulfate at the grid-cell of the State Office Building site are mainly from emissions.

For organic carbon, the averaged ratios of modeled VOC/modeled organic carbon are 0.20 for both the Alaska adapted CMAQ model before and after the improvements for the January v2 episode. For the November episode, the average ratio of modeled VOC/modeled organic carbon is 0.18 for the Alaska adapted CMAQ model both before and after the improvements, i.e. it stayed the same. The introduction of the improvements does not lead to a difference in the organic carbon concentrations at the gri-d-cell of the State Office Building site. The ratios of emitted VOC/emitted organic carbon are 72.2 and 94.4 for the January episode v2 and for the November episode, respectively. The ratios of modeled VOC/modeled organic carbon divided by emitted VOC/emitted organic carbon are 0.19 and 0.18 for the final improvements of CMAQ for the January v2 and November episode, respectively. The simulations that did not employ the revised WRF and SMOKE inputs, have a ratio of modeled VOC/modeled organic carbon divided by emitted VOC/emitted organic carbon of 0.66. For the January v1 episode, the ratio of emitted VOC/emitted organic carbon is 30.1, which is lower than for the January v2 case. The low ratio of modeled VOC/modeled organic carbon divided by emitted VOC/emitted organic carbon indicates that there is higher gas-to-particle conversion of VOC to organic carbon than sulfate at the grid-cell of the State Office Building site.

For nitrate, the averaged ratios of modeled NO_2/modeled aerosol sulfate are 175.4 and 179.2 for the January v2 episode before and after implementation of the improved parameterizations. For the November episode, the averaged ratios are 137.8 and 140.7 before and after implementation of the improved parameterizations. The increase of sulfate concentrations after the improvement

brought about a decrease of the modeled nitrate aerosol concentrations. The averaged ratios of modeled NO_2/modeled aerosol sulfate for the January v1 episode is 180.7.

The temporal evolutions the ratios of modeled SO_2/modeled aerosol sulfate divided by emitted SO_2/emitted sulfate agree with the temporal evolutions of the meteorological variables such as 2m-temperatures and 2m-water mixing ratios clearly in both episodes (Fig. 20). Lower temperature and lower water mixing ratio conditions lead to more gas-to-particle conversion. We found that on the first day of the simulations, the ratios are very low. These low ratios might be the effect of the spin-up of the chemistry in CMAQ.

a)

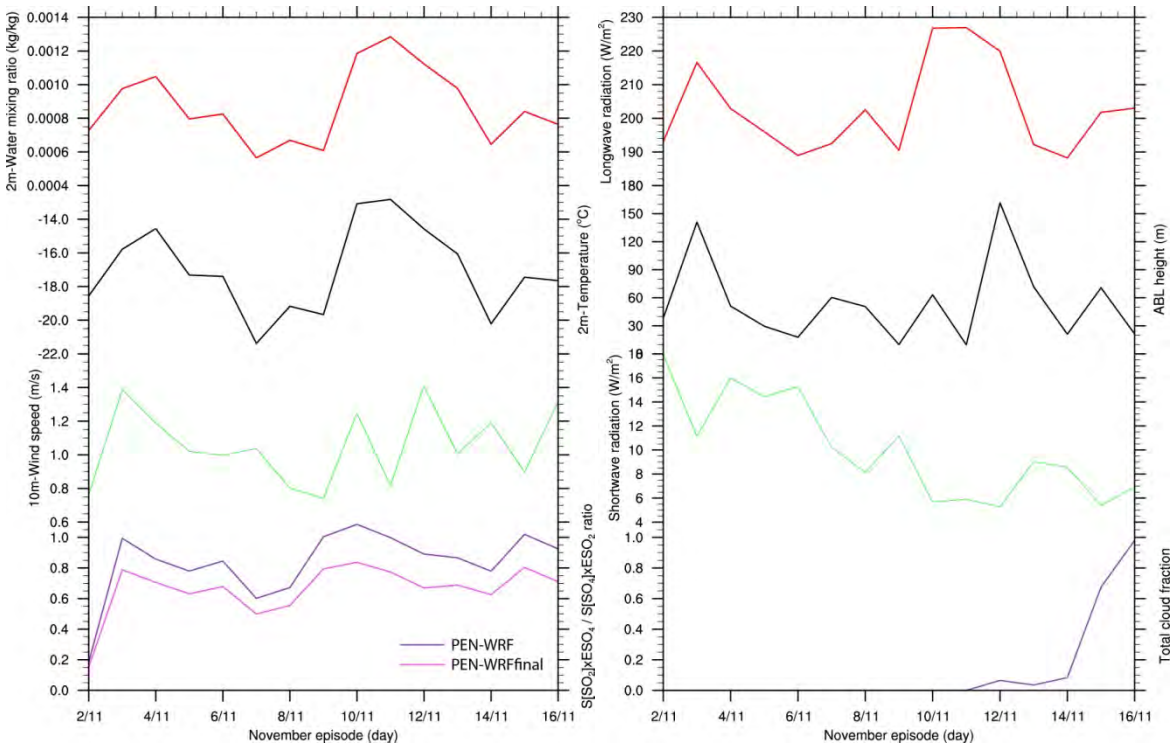


Fig. 20 continued

b)

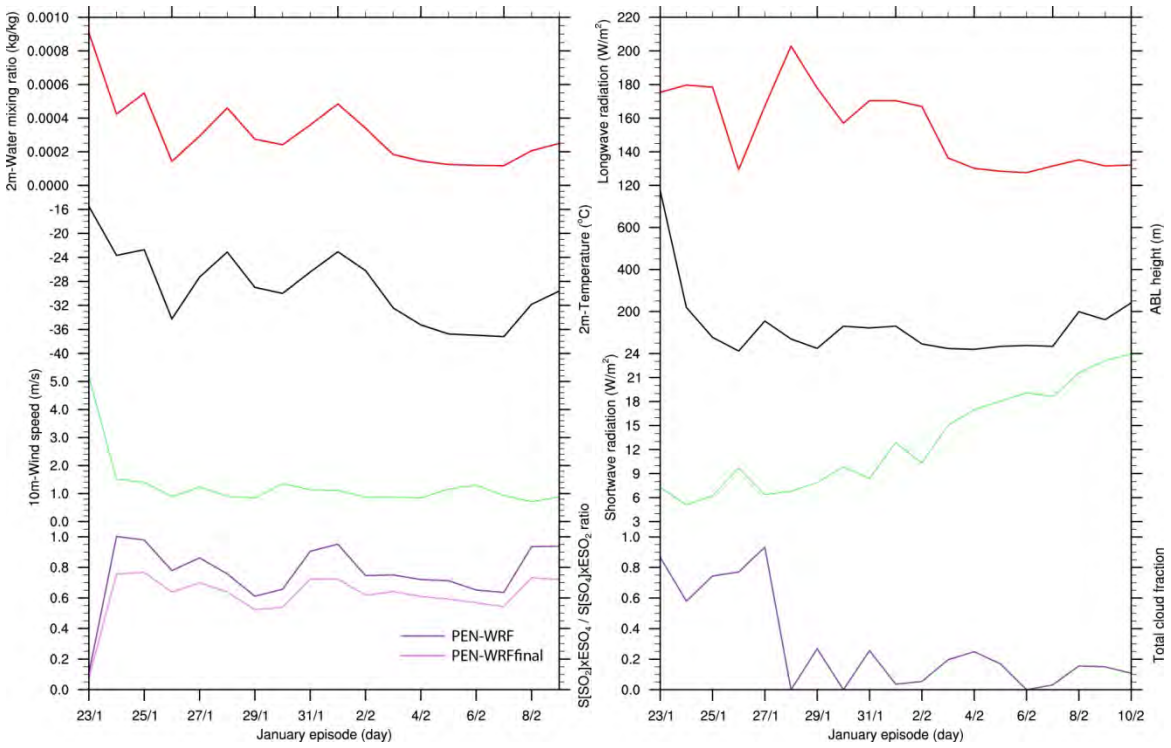


Fig. 20 Temporal evolutions of ratios of modeled SO_2/modeled aerosol sulfate divided by emitted SO_2/emitted sulfate as obtained from the CMAQ simulations prior to the improvements (PEN-WRF) and after the CMAQ improvements (PEN-WRFfinal) described in this report and the temporal evolutions of the meteorological variables generated by MCIP for the CMAQ model, which include 2m-water mixing ratio, 2m-temperature, 10m-windspeed, long-wave radiation, atmospheric boundary layer (ABL) height, shortwave radiation and total cloud fraction as obtained at the grid-cell of the State Office Building site for the (a) January and (b) November episode.

3. Conclusions and Recommendations

With the final improvements of the parameterizations and parameters made within the framework of this contract, the Alaska adapted CMAQ model showed an increase in the simulated sulfate concentrations at the grid-cell of the State Office Building site. Despite this success, the adapted CMAQ model still underpredicts the sulfate concentrations at the grid-cell of the State Office Building site. The normalized mean errors are 60% and 70% for the November and January episode, respectively.

We made various sensitivity simulations and tests to examine the reasons for the underestimation. These investigations and the process analysis provide strong evidence that most likely the partitioning of the emitted $PM_{2.5}$ is part of the reason for the underestimation of sulfate at the grid-cell of the State Office Building site. However, we have to use the emissions as they

partitioned in the newest version of the emission inventory as it is based on the most current insights on the emission situation in Fairbanks. Therefore, we strongly recommend further assessing and/or improving the percent partitioning of total particulate matter emissions into sulfate and other species.

Our results support the findings from other authors [e.g. *Appel et al.,* 2008] for winter cases in the Lower 48 that CMAQ underpredicts sulfate compared to observations. At UAF, currently further research is performed within the framework of a dissertation why CMAQ underestimates sulfate at low temperatures. Thus, it has to be expected that possible changes to CMAQ will become available in the future to better capture the sulfate concentrations for subarctic conditions.

Another reason for the underestimation that we cannot exclude is that in the subarctic there may be physical/chemical processes in the sulfate chemistry that are of relevance at low temperatures, low water vapor mixing ratios or both. These conditions rarely exist in the Lower 48. Thus, if such processes exit in the subarctic they may have been overlooked in studies for mid-latitudes. It is obvious that when a relevant process has not yet been found/identified, it, of course, is not considered in the code. Thus, the model cannot simulate the process and its impact on sulfate concentrations. The detection of missing processes would require long laboratory studies. Eventually, it would require long test series to derive parameterizations of the processes from the data and to implement and test the parameterizations in the model.

Our investigations and sensitivity studies also showed that the input meteorology and temporal offsets therein strongly determine the temporal evolutions of simulated 24h-average $PM_{2.5}$-concentrations. Therefore, we recommend further tests for the best options in the WRF setup for producing meteorological data with less temporal offset.

Our investigations suggest that the CMAQ for these episodes needs about three days to spin up the chemical fields. Therefore, we recommend to discard the first three days of simulations as spin up time and to not consider them in any assessment for the State Implementation Plan development. We further recommend that the simulation results of the first three days should be discarded from any evaluation as the chemical fields still spin-up.

We recommend that the final Alaska adapted CMAQ version presented here is tested for other episodes that have more observational data that the January and November episodes. The low data density does not permit assessment whether the occasional weak performance is related to model, emission and/or observational errors. Furthermore, with data available at just one site it is impossible to assess whether CMAQ captures the spatial distribution right. Some of the discrepancies might be just spatial offsets due to the overestimation of wind-speed. Low data availability always bears the risk to adapt a model in the wrong direction, as one can be easily right for the wrong reason at one place. This risk decreases when the amount of data increases.

A revised version of the emission inventory just became available [*Hixson*, 2012; pers. comm.]. It has to be examined how much the updated emissions will impact the simulated $PM_{2.5}$-concentrations and affect the simulated sulfate concentrations.

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Appendix 1

The following pages show an hourly sequence of plots illustrating how polluted Fairbanks air that left the nonattainment area enters the nonattainment area as aged polluted air. The wind barbs indicate wind direction. Circles mean zero wind speed and hence no wind direction. The color gives the $PM_{2.5}$-concentrations as indicated in the legend.

Fairbanks $PM_{2.5}$ Source Apportion Estimates Winter 2008/2009

The University of Montana is under contract to ADEC to conduct a multi-year study of $PM_{2.5}$ monitoring data collected in Fairbanks. The initial analysis focused on monitoring data collected during the 2008/2009 winter to determine the percent distribution of emission sources impacting each monitoring site. This information is critical to the Borough's efforts to identify which sources need to be controlled in order to reduce wintertime $PM_{2.5}$ concentrations in Fairbanks. It is also needed to determine if the emission source contributions are consistent throughout the Borough or vary by location.

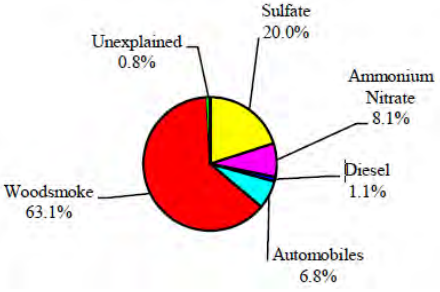
Up until the winter of 2008/2009, chemical speciation $PM_{2.5}$ monitoring data were collected only at the State Office Building in downtown Fairbanks. To expand coverage of the Borough, three additional sites were added that winter: (1) North Pole; (2) Peger Road at the Borough Transportation Center; and (3) a field located to the northwest of the intersection between Geist Road and the Parks Highway, known as the Reindeer site. Because of delays in getting the monitors installed and operating, data collection did not begin until January 25, 2009. Thus, measurements collected at these sites did not capture the elevated concentrations recorded earlier in the winter. The State Office Building, however, collected data all winter (November 8, 2008, through April 7, 2009). A map of the location of each of the sites within the Borough is displayed in Figure 1.

The University of Montana employed several methods to analyze the data collected at each monitoring site. They first used a statistical analysis procedure, which is approved by EPA, called Chemical Mass Balance or CMB to assess relationships in the chemical compounds collected at each site to chemical compounds emitted from each emission source (e.g., automobiles, wood smoke, etc.). The second approach used was Carbon-14, which looks at the age distribution of carbon molecules found at each site. The newer carbon is generally, but not completely, associated with wood burning, while the older carbon is associated with petrochemicals or fossil fuels. The third method used was to measure an organic chemical compound known as levoglucosan, which is a unique byproduct of wood burning. Since there is some uncertainty with each method, this approach provides a broader range of insight into emission source contributions and greater comfort that the findings are correct and defensible.

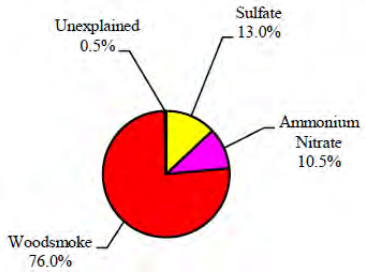
The CMB analysis results for each site are displayed in Figure 2. It shows that wood smoke is estimated to be the dominant emissions source at each site, with a contribution uniformly exceeding 60% of the measured $PM_{2.5}$ mass. The contributions of other emission sources are more variable; the second largest contributor was found to be sulfate (a compound that includes particles directly emitted during combustion and secondary particles formed in the atmosphere) and the third largest contributor to be ammonium nitrate (also a secondary particle). Generally speaking, sulfate is a function of the sulfur content of the fuels burned in the community. Recent regulations have all but eliminated sulfur from gasoline and Diesel fuel in Alaska. Therefore, the fuels contributing sulfur to the atmosphere include distillate fuel oil used in space heating and coal. Similarly,

Figure 1
Location of $PM_{2.5}$ Monitors in Fairbanks

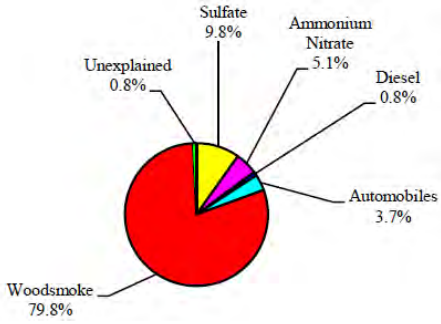
Figure 2
Emission Source Contribution Estimated from CMB Analysis



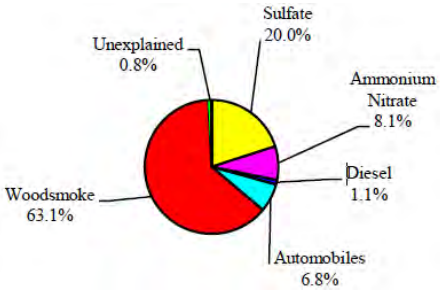
State Building



RAMS



North Pole



Peger Road

ammonium nitrate comes from ammonia and nitrogen oxide (NO_x) emissions. Sources of ammonia include waste treatment and motor vehicles. NO_x emissions come from all combustion sources.

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The Carbon-14 analysis was performed on a limited sample of measurements at the three new sites and more extensively for the State Office Building. The results, which are expressed as a range, found that wood smoke values stretch from a low of 34–62% at Peger Road to high of 50–60% at North Pole. While these estimates of the wood smoke contribution are lower and more variable than the CMB results, they also support the finding that wood smoke is a major source of the $PM_{2.5}$ mass measured at each of the monitoring sites in Fairbanks.

Levoglucosan was found to comprise 3% of the $PM_{2.5}$ mass measured at the State Office Building, 2% at Peger Road, and 6% at the North Pole and the Reindeer sites. These values are consistent with and generally higher than those measured in other urban areas in the northwest of the U.S., including Seattle and Spokane, WA and Missoula and Libby MT. CMB analyses for the latter communities estimated the wood smoke contribution to $PM_{2.5}$ to range from 56–82% of the wintertime $PM_{2.5}$ mass.

In summary, the contribution of wood smoke to $PM_{2.5}$ mass varies depending on the method used to prepare the estimate and the location. Nevertheless, three separate chemical analysis methods consistently estimate wood smoke to be a very significant source of $PM_{2.5}$ in all areas of Fairbanks and to be potentially the largest single contributor.

Measurements of $PM_{2.5}$ collected at monitors in Fairbanks during the entire 2009/2010 winter are currently being analyzed (i.e., chemically speciated). The results will be forwarded to the University of Montana for source apportionment analysis shortly; findings from that effort are expected to be available in October. For additional information on the results presented above, please contact Dr. James Conner at the Borough.

###

Characterization of $PM_{2.5}$ from Fairbanks, AK: Organics Analysis for Residential Oil Burner Emissions

Interim Report: 6/2011

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1. Executive Summary

Fairbanks, AK experiences very high levels of ambient $PM_{2.5}$ during the winter months. Studies are currently under way to determine the sources of the $PM_{2.5}$ so that the issue might be addressed. Possible sources of the $PM_{2.5}$ include residential heating (wood, fuel oil, and/or natural gas combustion), transportation (diesel and gasoline engines), and coal combustion.

The current project is to provide a more complete characterization of the organic chemical composition of $PM_{2.5}$ from Fairbanks with the goal of identifying and quantifying chemical species that can be used to indicate and monitor $PM_{2.5}$ emissions from fossil fuel combustion.

A comprehensive chemical analysis for hopanes, steranes and PAHs has been performed on eight PM samples from Fairbanks, selected to represent typical or high $PM_{2.5}$ days. The results of these analyses have been examined with special attention to compounds reported by previous authors as emissions from fossil fuel sources. Emphasis has been placed on sulfur-containing compounds (dibenzothiophene and benzo naphtho thiophene) which are known emissions of diesel vehicles and residential oil burners and a polynuclear aromatic hydrocarbon (picene) which has been reported as a unique marker for coal combustion.

The results indicate that the levels of selected hopanes, steranes, picene and thiophenes, measured either as a concentration in air or as a fraction of $PM_{2.5}$, are very high. These concentrations are significantly higher than those reported in previous studies for coal, diesel or residential oil burner PM emissions or for airsheds in the United States and in Europe. Given that picene is a specific marker of coal emissions, the results indicate that coal combustion emissions are likely a significant contributor to Fairbanks $PM_{2.5,,}$ specifically the sulfate/sulfur fraction. Overall, the results indicate that fossil fuel combustion, particularly of emissions from coal and residential fuel oil combustion, is a significant contributor to Fairbanks $PM_{2.5}$.

2. Methods

2.1 Samples selected for analysis.

Eight Fairbanks $PM_{2.5}$ samples from the winter of 2009-2010 were selected in consultation with Alaska DEC and submitted to Desert Research Institute for comprehensive analysis of 83 PAHs (including substituted PAHs, dibenzothiophene and benzonaphthothiophene) and 23 hopanes and steranes. The samples, listed in Table 1, were all from the downtown sampling site and had a range of $PM_{2.5}$ levels from 15.7 to 54.4 ug/m^3. A laboratory blank filter was also sent for analysis, and the reported levels of all compounds are blank corrected.

Desert Research Institute (DRI) returned two spreadsheets with the analytical results for hopanes and steranes and for PAHs. The amount and estimated uncertainty of each compound found on the filter is reported in ng. These spreadsheets of the raw analytical results are included with this report.

2.2 Analysis of the Raw Results

The DRI results provide a great deal of information about the samples. However, these raw results are difficult to interpret or utilize without some context. Based on a review of relevant published studies, several specific chemical compounds were selected for further analysis. These compounds are listed in Tables 2 and 3 and are those reported as significant components of particulate matter from combustion of specific fossil fuels: residential heating oil, diesel vehicles, gasoline vehicles, and coal. Unfortunately, many of the published reports only provide levels for a subset of the compounds selected. It is not clear if those that are not reported were included in the original analysis but were not detected or if they were not subject to analysis. Blank cells indicate that no level was reported for those compounds in the cited publication, while "nd" indicates that those compounds were reported as not detected.

Table 1: Date, identity and $PM_{2.5}$ level of the filters selected for analysis.

Date	Cassette Number	$PM_{2.5}$ Level ug/m^3
11/15/2009	510	15.7
11/27/2009	773	20.9
12/10/2009	772	54.4
12/13/2009	215	44.4
12/27/2009	721	24.1
1/11/2010	615	38.5
1/17/2010	753	15.8
2/10/2010	735	22.1

The sampled volume and $PM_{2.5}$ levels for each Fairbanks sample were used to determine the concentrations of the selected compounds in the ambient air (ng/m^3) and as a fraction of the $PM_{2.5}$ (ppm). These results are also reported in Tables 2 and 3 as the median and maximum for those samples for which the compounds were detected. In most cases, the compounds were detected on all or nearly all samples. The exception is 20S-5α(H),14α(H),17α(H)-ergostane, which was detected on only two samples (510 and 735).

3. Results and Discussion

The results from literature review and calculated analytical results for fourteen selected compounds are presented in Tables 2^{1-6} and 3^{7-9}. These compounds are classified into hopanes and steranes, thiophenes, and PAHs.

3.1 Hopanes and Steranes

The hopanes and steranes are typically found and reported in distillate fossil fuel emissions, but have also been reported in coal emissions. The highest levels reported are for diesel auto emissions, and the lowest are for coal emissions. The second column of coal results, presented as mg/kg of fuel, indicate that these compounds are present in coal emissions but do not allow direct comparison with the other values reported. The hopanes and steranes are not present in emissions from biomass

Table 2: Levels of selected marker compounds as a fraction of particulate matter (ppm).

	Compound	Residential Oil Burner[3]	Diesel Vehicles[1,4]	Gasoline Vehicles[5]	Bituminite Coal[6]	Bituminite Coal[2,b]	Fairbanks Median (Maximum)
Hopanes/Steranes (petroleum products)	17α(H)-22,29,30-Trisnorhopane		5.3		0.4	67	16.6 (90.6)
	17α(H),21ß(H)-29-Norhopane	2.22	14.8	2.5		85	41.3 (152)
	17α(H),21ß(H)-Hopane	3.53	61.6	4.4	1.4	45	26.0 (79.8)
	22S-17α(H),21ß(H)-30-Homohopane	1.02		nd	1.1	10	17.7 (55.9)
	22R-17α(H),21ß(H)-30-Homohopane	0.64		nd	0.2	17	23.5 (129)
	22S-17α(H),21ß(H)-30,31-Bishomohopane	0.58		nd	nd	11	8.5 (34.5)
	22R-17α(H),21ß(H)-30,31-Bishomohopane	0.40		nd	nd	16	15.9 (39.5)
	20R-5α(H),14ß(H),17ß(H)-cholestane	2.03	4.2				39.2 (45.7)
	20S-5α(H),14α(H),17α(H)-ergostane	4.53	17.0				4.43 (4.97)
	20R-5α(H),14ß(H),17ß(H)-stigmastane	1.87	20.6				4.89 (6.36)
Thio-phenes	Dibenzothiophene		12.6 10.7[a]	43[a]			49.0 (65.8)
	2,3-Benzo[b]naphtha[1,2-d]thiophene		23.8				15.8 (29.7)
PAH	Picene				nd	94	36.2 (69.3)
	Retene				4.6	nd	44.2 (68.0)

[a]Found in the gas phase only. [b]Emission factors in mg/kg of fuel.

Table 3: Levels of selected marker compounds found in ambient air (ng/m^3)

	Compound	Ambient Air, Europe[8]	Mingo Junction, OH[7]	Zheng Southeastern USA[9]	Fairbanks Median (Maximum)
Hopanes/Steranes (petroleum products)	17α(H)-22,29,30-Trisnorhopane			0.06	0.53 (2.18)
	17α(H),21ß(H)-29-Norhopane		0.1-0.6	0.36	1.26 (3.67)
	17α(H),21ß(H)-Hopane		0.05-0.3	0.38	0.72 (1.92)
	22S-17α(H),21ß(H)-30-Homohopane			0.20	0.47 (1.17)
	22R-17α(H),21ß(H)-30-Homohopane			0.18	0.61 (3.11)
	22S-17α(H),21ß(H)-30,31-Bishomohopane			0.11	0.38 (0.72)
	22R-17α(H),21ß(H)-30,31-Bishomohopane			0.08	0.45 (0.95)
	20R-5α(H),14ß(H),17ß(H)-cholestane				0.88 (2.49)
	20S-5α(H),14α(H),17α(H)-ergostane				0.082 (0.086)
	20R-5α(H),14ß(H),17ß(H)-stigmastane				0.12 (0.24)
Thio-phenes	Dibenzothiophene	0.029 (0.095)			0.93 (2.92)
	2,3-Benzo[b]naphtho[1,2-d]thiophene	0.012 (0.082)			0.45 (0.72)
PAH	Picene		<0.0006 - 0.2		0.76 (1.67)
	Retene				1.08 (2.58)

combustion, and thus provide a general indication of the extent to which an air shed is affected by fossil fuel emissions. Unfortunately, however, none of the compounds provide a specific marker of any particular fossil fuel source.

The results for the Fairbanks samples show very high levels of the selected hopanes and steranes. This is clear from inspection of Table 2, which shows that the hopanes and steranes typically represent a much higher fraction of $PM_{2.5}$ than any of the reported fossil fuel sources. There are exceptions in which the Fairbanks levels are about the same as or lower than diesel emissions. These results are striking, however, since $PM_{2.5}$ in Fairbanks is expected to be a mixture of PM from various sources including non-fossil fuel sources.

The ambient air levels of hopanes and steranes in Fairbanks also far exceed those reported for other airsheds (Table 3). Since these airsheds are impacted by automobiles and Mingo Junction Ohio is also affected by coal emissions, the very high levels in Fairbanks are notable. Clearly, fossil fuel emissions have a substantial impact on Fairbanks $PM_{2.5}$.

An alternative approach for the analysis of hopane results is to calculate the ratio of 17α (H) 21β (H) hopane to 22R-17α (H), 21β (H) homohopane.[2, 6, 10] This value has been reported to be 3.7 for gasoline emissions and 2.5 for diesel emissions.[10] Unfortunately, conflicting results have been reported for coal combustion emissions, with Oros *et al.*[2] reporting values of 0.1-2.6 and Zhang *et al.*[6] reporting values of 4.28-9.19. The average value observed for Fairbanks is 1.2 ± 0.4. This relatively low value places the result for Fairbanks within the range reported by Oros *et al.*, which implies that coal emissions may have a significant impact on Fairbanks $PM_{2.5}$.

The hopane and sterane results indicate that fossil fuel emissions have a substantial effect on air quality in Fairbanks. However, the results are not very helpful in more clearly identifying the specific fossil fuel source. For this reason, regular further analysis of hopanes and steranes is not recommended unless it is conducted as part of a more in-depth comprehensive source apportionment based on organic compounds.

3.2 Thiophenes

Dibenzothiophene, napthobenzothiophenes and alkylated derivatives of these compounds are reported to be representative of diesel fuel vehicle emissions.[1, 4] These compounds make up a significant fraction of the sulfur content of diesel fuel (Table 4). Low sulfur diesel fuel has lower concentrations of these compounds, and vehicles utilizing low sulfur diesel fuel emit reduced quantities of these compounds. The values reported in Table 2 for diesel emissions are from vehicles utilizing low sulfur diesel fuel.[1, 4] Rogge *et al.*[3] did not report thiophenes in the emissions from residential fuel oil combustion, but Huffman *et al.* did report that typically 25-35% of the sulfur in residential fuel oil particulate is thiophenic sulfur.[11] Given the similar composition of # 2 fuel oil and diesel fuel, and the fact that the sulfur content of # 2 fuel oil is not regulated with respect to sulfur content, it stands to reason that these compounds may be found in the $PM_{2.5}$ emissions from #2 fuel oil as well. In fact, #2 fuel oil obtained from Fairbanks was found to have a level of dibenzothiophene much higher than that reported previously for high sulfur diesel fuel (Table 4). Waste oil fuel and and #1 fuel oil from Fairbanks were found to have dibenzothiophene levels between that of low and high sulfur diesel fuels. Dibenzothiophene has also been reported in the emissions from gasoline vehicles. In this and one report on diesel emissions, dibenzothiophene was found primarily in the gas phase. Given the ambient

Table 4: Dibenzothiophene levels in three fuel oils from Fairbanks and in diesel fuels.

Fuel	Dibenzothiophene (ppm)
Fuel #1	34.3
Fuel #2	461
Waste Fuel	21.7
LSDF[3]	15.2
HSDF[3]	84.0

temperatures in Fairbanks, it seems likely that the compound would be found in the particulate phase. These sulfur compounds are not present in wood smoke, and were not reported in coal studies. It is not clear, however, whether or not they are present in PM from coal combustion.

The results in Table 2 indicate that the Fairbanks PM has high levels of thiophenes in comparison to PM emitted from vehicles burning low sulfur diesel fuel. As with the hopane and sterane results discussed in section 3.1, these results are striking given that Fairbanks $PM_{2.5}$ is expected to be a mixture of PM from various sources and not only diesel fuel or residential fuel oil burners. The observed dibenzo- and benzonaphtho- thiophene levels do not, however, explain the relatively high levels of non-sulfate sulfur observed in Faribanks $PM_{2.5}$. These compounds represent only 7.7 and 2.5 ppm S in the $PM_{2.5}$ respectively.

The results in Table 3 show that the ambient levels of these thiophenes in Fairbanks are much higher than those reported for several European cities. The average $PM_{2.5}$ levels in those cities varied from 11 to 30 ug/m^3, and median concentration of dibenzo- and benzonaphtho- thiophenes as a fraction of the $PM_{2.5}$ was 1.3 and 0.48 ppm respectively. The very high levels observed in Fairbanks, considered either as ambient concentration or as a fraction of $PM_{2.5}$, are remarkable given that diesel powered automobiles and trucks are typically much more prevalent in European cities.

The thiophene results presented here point rather strongly to residential fuel oil burners utilizing #2 fuel oil obtained from Fairbanks (and/or possibly coal combustion) as a source of $PM_{2.5}$ in Fairbanks. Analysis of the $PM_{2.5}$ obtained from residential oil burner studies utilizing Fuel #2 will be especially useful in confirming this result. Fuel #2 from Fairbanks has exceptionally high levels of dibenzothiophene, suggesting that this and other thiophenes will be very useful markers of emissions from combustion of that oil. Further, combustion of this fuel in Fairbanks may explain some of the high levels of sulfur observed in the $PM_{2.5}$.

3.3 PAHs

Picene is a 5-ring PAH that has been reported as being representative of emissions from coal combustion.[2, 6, 7] Zhang *et al.* reported picene as being "unique to the organic carbon emissions from coal combustion," although picene was not detected in all coal particulate and was notably absent from bituminous coal emissions from industrial boilers.[6] Zhang *et al.* did report picene in brown and mixed coal emissions from residential boilers (3.7 and 2.0 ppm respectively) as well as much higher levels in the emissions from residential oil burners (72-284 ppm).[6] Oros et al. reported picene and methyl picenes as bituminous coal smoke markers , and C_2 substituted picenes as more general coal-specific markers.[2] As a large PAH, picene can be expected to be found primarily in the particulate phase.

Results for picene as a fraction of Fairbanks $PM_{2.5}$ (Table 2) are relatively difficult to interpret given the scarcity of relevant information in comparable units found in the literature. By comparison to the results of Zhang *et al.*[6], the levels in Fairbanks are much higher (by a factor of 10 or more) than would be expected from commercial boilers. The levels observed in Fairbanks are not as high as those reported by Zhang *et al.* for residential coal burners in China, but are of a similar magnitude for combustion of some types of coal in Chinese residential coal burners.

Results for ambient picene levels are also surprising. Fairbanks has much higher levels of picene than Mingo Junction, OH, which was specifically studied because of a significant impact of coal emissions. Source apportionment in Mingo Junction using organic marker profiles concluded that coal soot makes up 3 to 10% of the organic carbon in the $PM_{2.5}$, depending on season.[7]

Relatively high levels of picene are observed in Fairbanks when considered either as a fraction of $PM_{2.5}$ or as ambient concentration. This is a very strong indication that coal combustion, and very likely coal combustion in a poorly designed or operated boiler, is a significant contributor to Fairbanks $PM_{2.5}$.

Retene is an alkyl substituted 3-ring PAH that has commonly been associated with combustion of soft woods.[12] This compound is included in this report, however, because it has also been reported as a component of coal combustion emissions.[6] Levels in Fairbanks are relatively high compared with those reported by Zhang et al. for bituminous coal emissions from industrial boilers, similar to the level reported by these authors for brown coal emissions from industrial boilers (60 ppm) and much lower than those reported for residential coal burners (364-5000 ppm).[6] Ambient levels in Fairbanks are similar to or lower than those reported for southeastern US cities.[7] It is not clear whether the retene observed in Faribanks $PM_{2.5}$ is indicative of coal combustion, wood combustion, or both.

Table 5: Ratio of indeno[123-cd]pyrene to sum of indeno[123-cd]pyrene and benzo[ghi]perylene for various sources.

Source	IP/(IP+BghiP)
Gasoline autos	0.18
Diesel autos	0.37
Coal combustion	0.56
Wood combustion[12]	0.54
Fairbanks $PM_{2.5}$	0.39 ± 0.02

Another commonly used measure for sourcing PAH emissions is the ratio of indeno[123-cd]pyrene to the sum of indeno[123-cd]pyrene and benzo[ghi]perylene (IP/(IP+BghiP)).[6, 12, 13] Typical values for this ratio from various fossil fuel sources, woodsmoke and for Fairbanks are reported in Table 5. No value is available for residential oil combustion $PM_{2.5}$. The ratio for Fairbanks is quite consistent between samples, and is most similar to that reported for diesel fuel emissions.

4 Conclusions

The results of this preliminary study are very informative, but are not conclusive. It is not possible to draw unqualified or quantitative conclusions concerning the sources of Fairbanks $PM_{2.5}$ with the limited number of samples and compounds analyzed. However, the results do show that Fairbanks $PM_{2.5}$ is more complex chemically than was previously realized, and strongly suggest that fossil fuel combustion represents a measurable contribution to $PM_{2.5}$ in Fairbanks. The levels of hopanes and steranes, thiophenes, and picene are all high relative to previous reports whether considered as a fraction of PM or as ambient concentrations. These compounds are all representative of fossil fuel combustion sources.

The hopanes and steranes are not representative of any particular fossil fuel source, but do indicate the overall contribution of fossil fuels. Analysis of the ratio of 17α (H) 21β (H) hopane to 22R-17α (H), 21β (H) homohopane might suggest that coal combustion is a significant source of $PM_{2.5}$ in Fairbanks, but inconsistent literature values for this ratio cause significant uncertainty in this conclusion.

The relatively high levels of thiophenes observed in Fairbanks $PM_{2.5}$ are a strong indication of significant transportation diesel fuel or residential oil burner contributions. Again, the levels of these compounds are higher than those previously reported for diesel PM or in cities with many more diesel vehicles than Fairbanks. The #2 fuel oil used in residential oil burners in Fairbanks also contains a very high concentration of dibenzothiophene, implying that this is a likely source. The low sulfur diesel fuel used in Fairbanks should significantly limit the contribution of diesel transportation to the thiophene concentrations. Coal combustion emissions can not be ruled out as a source of some of the thiophenes, but few if any quantitative data exist concerning the presence or absence of thiophenes in coal combustion emissions. Although the concentrations of thiophenes are relatively high, their concentrations are not sufficient to explain the sulfur content of Fairbanks $PM_{2.5}$.

Picene is also observed at remarkably high levels whether considered relative to the $PM_{2.5}$ mass or as ambient concentration. This compound is considered to be a good and selective marker of coal combustion, so this result is strong evidence that coal combustion is a source of $PM_{2.5}$ in Fairbanks. Based on literature values, however, the concentrations of picene in Fairbanks can not be explained by

industrial boiler emissions alone. This begs the question of whether the boilers operating in the Fairbanks area are being operated under suboptimal conditions, or if there are other coal combustion sources contributing to Fairbanks $PM_{2.5}$.

The ratio of IP/(IP+BghiP) for Fairbanks $PM_{2.5}$ is lower than that reported previously for coal or wood combustion, and is indicative of diesel vehicle emissions. This may indicate either a significant contribution from diesel transportation, a significant contribution from residential heating oil, or a combination of wood/coal with diesel/residential heating oil and gasoline auto PM.

Further study of Fairbanks $PM_{2.5}$ needs to be conducted before any more quantitative or conclusive source apportionment using organic tracers can be conducted. This approach would be much more informative once analyses have been performed on $PM_{2.5}$ obtained from representative sources under controlled conditions. A comprehensive organic speciation of many more samples than were analyzed in the current study, combined with a source apportionment procedure using organic compounds as tracers ,[9, 14, 15] could lead to a more complete picture of the Fairbanks $PM_{2.5}$ problem.

Alternatively, analysis of Fairbanks $PM_{2.5}$ for a limited number of selected analytes could be informative. This is especially true if these analyses were used to evaluate the effects and efficacy of remediation efforts and/or in combination with local or regional mapping of concentrations. If this limited and less costly approach is to be pursued, the current study suggests that the most likely marker candidates for analysis are levoglucosan (wood smoke), picene (coal) and thiophenes (residential oil and/or diesel). Initial and preliminary studies in our laboratory indicate that these three compounds can be determined at relevant concentrations using a single extraction followed by two separate gas chromatographic separations.

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Fairbanks, Alaska $PM_{2.5}$ Organic Composition and Source Apportionment Research Study

Final Report

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by

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1. Executive Summary

Fairbanks, AK experiences very high levels of ambient $PM_{2.5}$ during the winter months. Studies are currently under way to determine the sources of the $PM_{2.5}$ so that the issue might be addressed. Possible sources of the $PM_{2.5}$ include residential heating (wood, fuel oil, and/or natural gas combustion), transportation (diesel and gasoline engines), and coal combustion.

The current project is to provide a more complete characterization of the organic chemical composition of $PM_{2.5}$ from Fairbanks with the goal of identifying and quantifying chemical species that can be used to calculate and apportion ambient $PM_{2.5}$, particularly from wood and fossil fuel combustion.

Comprehensive chemical analyses for levoglucosan, hopanes, steranes and PAHs have been performed on up to33 ambient $PM_{2.5}$ samples from Fairbanks. Analyses have also been performed on $PM_{2.5}$ generated at OMNI scientific using representative fuels and devices. The results of these analyses have been examined with special attention to compounds reported by previous authors as emissions from wood (levoglucosan) and fossil fuel sources. Emphasis has been placed on sulfur-containing compounds (dibenzothiophene and benzonaphthothiophene) which are known emissions of diesel vehicles and were hypothesized to be markers of residential oil burners and a polynuclear aromatic hydrocarbon (picene) which has been reported as a unique marker for coal combustion. A second polynuclear aromatic hydrocarbon, bibenzyl, has been identified as a potential marker for residential oil combustion.

In general, the results show that the ambient levels of levoglucosan and selected hopanes, steranes, picene and thiophenes, measured either as a concentration in air or as a fraction of $PM_{2.5}$, are high relative to previous studies. Levoglucosan results provide a reasonable estimate of the wood smoke contribution to ambient $PM_{2.5}$, and other markers provide a sense of upper bounds for the contribution of residential oil burners and coal combustion.

Levoglucosan results indicate that wood smoke contributes 26-35% of the $PM_{2.5}$ at the State Building site, 42-62% at the North Pole site, and 20-30% at the Peger Road site. These values are significantly lower than those reported by CMB analysis and similar to somewhat lower than those determined by ^{14}C analysis. The results show that wood smoke is a substantial contributor to ambient $PM_{2.5}$. The contribution of wood smoke to ambient $PM_{2.5}$ varies substantially within a season, but has had a fairly constant seasonal average or median over the past three seasons.

Polynuclear aromatic hydrocarbon results indicate that residential oil combustion is likely a minor contributor to ambient $PM_{2.5}$ levels with a median contribution of less than 1%. Sterane analysis indicates that the upper bound for the contribution from residential oil combustion is 15%, but this is likely to be an overestimate. There is significant but unquantifiable uncertainty in these results, which rely on a single sample of no. 2 fuel oil $PM_{2.5}$.

Analysis of picene levels indicates that coal combustion also contributes a minor fraction to ambient $PM_{2.5}$ of 2.7% or less. Analysis of hopanes suggests an upper bound for coal contribution of 13%, which is likely to be an overestimate. The picene and hopane shares of coal $PM_{2.5}$ are highly variable with device, however, and the contribution of coal combustion to ambient $PM_{2.5}$ could be less than 1% from coal stoves or much higher if from HH systems.

Thiophene analysis shows that these compounds are not present in residential oil emissions, and thus cannot be used as markers of residential oil combustion. The compounds do appear in the emissions from coal combustion at shares that result in estimated coal contributions to ambient $PM_{2.5}$ of 6.7% to over 100%. It is clear from this analysis that there is another significant source of thiophenes, particularly dibenzothiophene, other than residential heating. The most likely source is transportation, since thiophenes have been reported at significant levels in diesel fuel and gasoline emissions.

2. Levoglucosan

Levoglucosan, a product of incomplete cellulose combustion, has been recognized for many years as a marker of biomass combustion in $PM_{2.5}$. In winter urban environments such as Fairbanks, this can be equated with smoke from wood-fired residential heating devices.

The University of Montana has been analyzing ambient filters from Fairbanks for levoglucosan content since beginning in the 2008-2009 heating season and continuing through the 2010-2011 heating season. Measurements have been made on over 225 filters from four separate sampling sites during that period. This report will summarize these results, providing both the raw results and interpretation of those results in terms of the fractional contribution of wood smoke to total PM in Fairbanks.

2.1 Analytical Method and Quality Control

The Fairbanks ambient $PM_{2.5}$ sampling program is described in detail in "The Fairbanks, Alaska PM2.5 Source Apportionment Research Study Final Report," July 23, 2012, by Tony Ward. Levoglucosan analyses were performed on quartz filters obtained through this sampling program as described in this report for the ^{14}C analyses.

Ambient filters received from Fairbanks are stored at -10 C until analysis is performed. Each filter is halved before analysis to allow for a second half to be archived or analyzed for ^{14}C or other analytes. The filter half was placed in a 30 mL vial and spiked with deuterated levoglucosan as in internal standard. The vials were left at room temperature to allow the standard to be absorbed onto the filter. After half an hour or until the standard solvent had evaporated, 20 mL of ethyl acetate with 3.6 mM triethylamine (TEA) was added and the samples were sonicated for half an hour to extract the desired compounds. After sonication, the filter was removed and the extract was filtered through a Whatman 0.45 µm nylon filter to remove particulates. The volume of the solvent was adjusted to 0.5 mL through evaporation under a stream of air in a sand bath at 45 °C. The sample was evaporated to dryness under a stream of air at room temperature and then derivatized with 75 µL N-*O*-bis(trimethylsilyl)trifluoroacetamide (BSTFA), 10 µL trimethylchlorosilane (TMCS), and 10 µL trimethylsilylimidazole (TMSI). The samples were heated in a sand bath at 70 °C for 1 hour to allow the derivatization to go to completion. Upon removal from the sand bath, the samples were diluted to 500 µL with ethyl acetate containing 3.6 mM TEA and were transferred to a GC vial for analysis.

Analysis was performed on an Agilent 6890N Gas Chromatograph with an Agilent 5973 Mass Spectrometer. An HP-5MS column ((5%-Phenyl)-methylpolysiloxane) was used with dimensions of 0.25 mm ID x 30 m length x 0.25 μm film thickness. A volume of 2 μL was injected for each analysis into a Split/Splitless FocusLiner^{TM} for HP, single taper p/w quartz wool liner. Split injection was used to analyse for levoglucosan with a split ratio of 50:1. The inlet temperature was set to 250°C and the auxiliary transfer line temperature was set at 280°C. The temperature programme was started at 40˚C for 1.5 minutes, ramped at 30°C/min to 190°C, 20°C/min to 210°C, and then 50°C/min to a final temperature of 300°C, which was held for 1.5 minutes. The mass spectrometer was operated with a solvent delay of

4.00 minutes and the mass range from 40-450 was scanned. Single ion monitoring was also used during detection. Highly selective quantitation was performed using the signal for representative ions for levoglucosan (217 m/e) and D-levoglucosan (220 m/e) extracted from the total ion chromatogram.

Calibration standards were prepared containing variable concentrations of levoglucosan and a fixed concentration of D-levoglucosan internal standard. The fixed concentration of deuterated internal standard (20 ppm) was selected to match the concentration expected from extraction of internal standard spiked on the filters, assuming 100% recovery. The standards were derivatized and analysed on the GCMS. The ratio of the peak area of levoglucosan to the peak area of D-levoglucosan standard was found for each calibration standard. A calibration curve was prepared by plotting the ratio of the two peak areas versus the concentration of the levoglucosan. Linearity was determined for each calibration curve, and all had R^2 values of at least 0.95. The concentration of levoglucosan extracted from sample filters was determined by measuring the ratio of the peak area for the analyte to that of D-levoglucosan, and reading the concentration from the calibration curve. Filter blanks and spiked filters were analysed on a regular basis, at least once for every 10 filters. Recoveries were determined for blank filters spiked with the analytes at known amounts corresponding to typical levels seen in actual sample filters. Recovery was consistently in the range of 95-105%, and blank filters did not give significant signals.

Wood smoke particulate obtained from OMNI Scientific was also analysed for levoglucosan content using essentially the same procedure. These filters had very high loads of $PM_{2.5}$, which required adaptations to the method. Smaller portions of the filters, typically 1/8 rather than ½, and extracts were often diluted before derivatization. In each case where additional dilution was necessary, the filters were spiked before extraction with sufficient deuterated levoglucosan such that the final diluted concentration would match that of other samples and standards. This ensured that the area ratios could be interpreted using the same standard curve.

In order to interpret the results for levoglucosan as a share of wood smoke $PM_{2.5}$ on the OMNI-generated filters, it was necessary to estimate the total $PM_{2.5}$. OMNI reported total $PM_{2.5}$ for quartz filter 1 (PM_{Q1}) and flow rates for quartz filters 1 (FR_{Q1}) and 2 (FR_{Q2}) for each sampling event. Quartz filter 2 was sent to UM for levoglucosan analysis. We calculated total $PM_{2.5}$ on quartz filter 2 using these data:

$$PM_{Q2} = PM_{Q1}\frac{FR_{Q2}}{FR_{Q1}}$$

This calculation assumes that the sampling time and that the $PM_{2.5}$ level in the sampling region for the two quartz filters were the same for each experiment.

2.2 Results

Raw results for all measured levoglucosan levels in ambient air (in ng/m^3) and as levoglucosan share of total $PM_{2.5}$ (in %) are provided in a spreadsheet. These data are organized by sampling site and sampling date, and total reported $PM_{2.5}$ (in $\mu g/m^3$) are also included. Based on replicate measurements, typical relative error for reported levoglucosan levels is ± 10%.

Table 1 presents averages and 95% confidence intervals for levoglucosan levels and shares by sampling site and year. Data for the RAMS site is presented only for the 2009-2010 season since other seasons have either no or insufficient data. Confidence intervals in these results are affected by actual variations in levoglucosan levels and shares as well as variations due to analytical reproducibility.

Table 1: Average levoglucosan (LG) levels and shares for four sites over the three year study period.

	State Building		Peger Road		North Pole		RAMS	
	LG Level (ng/m^3)	LG Share (%)	LG Level (ng/m^3)	LG Share (%)	LG Level (ng/m^3)	LG Share (%)	LG Level (ng/m^3)	LG Share (%)
2008-09	573 ±203	3.1 ±1.1	628 ±120	2.18 ±0.24	833 ±480	3.8 ±1.2	NA	NA
2009-10	671 ±288	2.33 ±0.63	312 ±131	1.60 ±0.41	1720 ±470	4.80 ±0.51	NA	NA
2010-11	671 ±157	2.96 ±0.32	763 ±195	2.30 ±0.36	1150 ±490	4.85 ±0.53	2680 ±1160	4.67 ±0.70
3 yr	632 ±118	2.80 ±0.46	628 ±120	2.18 ±0.24	1400 ±300	4.59 ±0.40		

Levoglucosan levels range from 600 to 2700 ng/m^3 with levels at the State Building and Peger Road at the lower end and those at North Pole averaging 1400 ng/m^3.

Table 2: Levoglucosan shares for various devices, fuels and burn rates.

Filter ID	Burner Type	Fuel Type	Burn Rate	Levoglucosan Share (%)
FNB 1	pellet	Pellet	single	0.24
FNB 44	conv. WS	Birch	high	1.08
FNB 40	conv. WS	Spruce	high	0.88
FNB 52	conv. WS	Birch	low	1.18
FNB 48	conv. WS	Spruce	low	0.35
FNB 4	Cert. WS	Birch	high	0.27
FNB 7	Cert. WS	Spruce	high	1.80
FNB14	Cert. WS	Birch	low	6.12
FNB 18	Cert. WS	Spruce	low	6.05
FNB 87	NQ OWHH	Spruce	high	5.86
FNB 27	EPA OWHH	Birch	high	7.46
FNB 34	EPA OWHH	Spruce	high	2.48
FNB 28	EPA OWHH	Birch	low	5.73
FNB 36	EPA OWHH	Spruce	low	11.73

The RAMS site, with an average of 2700 ng/m^3 is very high, but the $PM_{2.5}$ levels are also very high at that site. Levoglucosan share range from 1.6 to 4.7%, with the State Building and Peger Road sites averaging 2.2-2.8% and the North Pole and RAMS sites averaging 4.6-4.7%. Significant differences in levoglucosan levels and shares are observed between sampling sites, with the North Pole and RAMS sites showing higher levels and shares and the State Building and Peger Road sites having lower levels and shares. There are no significant differences or trends in levoglucosan levels or shares for any given site as a function of heating season. Variability in the levoglucosan levels, expressed as relative 95% confidence intervals, are high, often exceeding 40%. This variation reflects the fact that levoglucosan levels increase

and diminish with $PM_{2.5}$ levels, which also vary significantly. Relative variations in levoglucosan as share of $PM_{2.5}$ are lower, and are typically 15% or less.

Fourteen filters generated by OMNI Scientific utilizing wood burning devices and two wood species representative of those from Fairbanks, and generated at different burn rates, were also analyzed for levoglucosan content and share. The results for levoglucosan share of the wood smoke $PM_{2.5}$ for these filters are presented in Table 2. Based on replicate analyses of some filters, the relative uncertainty in these numbers is estimated to be ±10%.

In general, these results indicate a relatively low share of levoglucosan in the wood smoke (3.7%) compared to published values[1-3]. No significant differences were observed in levoglucosan share based on wood species, which is also not consistent with previous studies[1-3]. Significant differences are observed as a function of burner type and within burner types as a function of burn rate.

2.3 Interpretation and Discussion

The levoglucosan results in Tables 1 and 2 have been analyzed in an effort to provide a quantitative measure of the contribution of residential wood combustion to ambient $PM_{2.5}$. Recent studies have made similar efforts[1]. The basic approach is to establish an experimental levoglucosan share in wood smoke, and to use this to convert levoglucosan share of ambient $PM_{2.5}$ to wood smoke fraction of ambient $PM_{2.5}$. Dividing the levoglucosan share of ambient $PM_{2.5}$ by the levoglucosan share of pure wood smoke generated using representative heating appliances and wood species should provide the fractional wood smoke contribution to the ambient PM. The levoglucosan share of wood smoke is established by analysis of PM from wood heaters and wood species used in the region of study. The levoglucosan share is generally observed to vary between wood species[1-3], so a representative value for the region is calculated as a weighted average based on a survey of the amount or fraction of each wood species consumed in the region[1].

There are several difficulties, however, in establishing the best conversion factor to apply to Fairbanks ambient levoglucosan results. The most relevant data for levoglucosan share of wood smoke $PM_{2.5}$ should be those reported in Table 2. However, those data include results only for spruce and birch, and a survey of wood consumption in Fairbanks has indicated 43% aspen, 52% birch, and 6% spruce. Further, average levoglucosan share reported in Table 2 is 3.7%, which is significantly lower than typical and average levoglucosan shares measured in ambient $PM_{2.5}$ at the North Pole and RAMS sites. Calculation of wood smoke contribution to ambient PM using these average numbers would result in average values of 124-126% for these two sites. This is clearly not a reasonable result.

There are experimental levoglucosan shares of PM reported in the literature for wood smoke from various species, including aspen, birch and spruce (Fine). These published data are generally accepted and have been used in multiple studies to interpret ambient PM levoglucosan results. The published numbers are generally higher than those reported in Tables 1 and 2, and employing them would result in more acceptable average wood smoke contributions of less than 100%. However, the published results are not specific for appliances and practices in Fairbanks, and their use thus introduces

significant uncertainty. Other published results for levoglucosan share do not include the same species as those burned in Fairbanks and/or are for PM_{10} rather than $PM_{2.5}$.

We have investigated multiple approaches to generate a conversion factor to allow the calculation of wood smoke contributions from levoglucosan fractions of ambient $PM_{2.5}$. Each of our conversion factors is a weighted average based on the survey data for wood species consumption in Fairbanks:

$$CF = \frac{1}{0.43L_A + 0.52L_B + 0.06L_S}$$

where CF is the desired conversion factor and L_A, L_B, and L_S are the levoglucosan share for aspen, birch and spruce wood smoke respectively. A value calculated from results published by Caseiro et al. (CF=11) was rejected because those published results did not include all of the species of interest and because they were for PM_{10}. The value calculated from the published results of Fine et al. (CF=9.01) is considered the industry standard, and is based only on the assumption that the Fine results are valid for Fairbanks devices and conditions. This "Fine conversion factor" was the lowest of the calculated conversion factors and is used here as a lower limit. Two conversion factor values were calculated using, in part, the results in Table 2 for the OMNI-generated filters. The first is calculated using the average values for L_B and L_S from Table 2 under all burn conditions and the value for aspen reported by Fine et al. (L_A=0.125). The resulting "OMNI conversion factor" (CF=13.3) is strongly influenced (43%) by the published value for aspen. Working with a lower value for aspen more in line with those measured for OMNI-generated filters would result in a larger conversion factor and in many days for which wood smoke contributions in North Pole would exceed 100%. The OMNI conversion factor as calculated results in only one day for which wood smoke contribution in North Pole exceeds 100%, and three days that exceed 90%. It is thus a reasonable upper limit for the conversion factor. Finally, device type data by zip code was utilized together with wood species survey data to generate site-specific conversion factors weighted for both wood species and device type. These conversion factors were calculated using L_A from Fine et al., and L_B and L_S from Table 2 and ranged from 12.2-12.4. There was significant concern that these conversion factors were based on too many data with significant uncertainties. Because of this, and because the values are intermediate, they were rejected and were not used for additional calculations.

Using the two conversion factors it is possible to calculate a low and a high estimate of wood smoke contribution to ambient $PM_{2.5}$ in Fairbanks. The high end estimates are nearly 48% higher than the low end estimates. Table 3 presents these results by site and season, along with results for the same sites and seasons from ^{14}C and CMB analysis. The levoglucosan results include analyses for many sampling periods when ^{14}C analysis was not performed. Average values are reported, but these do not differ significantly from median values. Errors are reported as presented in previous reports or as 95% confidence intervals for levoglucosan results. The results for ^{14}C analysis are based on a subset of the samples that were analyzed for levoglucosan, and those results may thus be biased if those samples were not selected at random. Still, results calculated using the OMNI conversion factor (which includes the published Fine result for Aspen) are within the range or are not significantly different from the

results reported from the ^{14}C results. Results calculated using the conversion factor generated using only the published Fine numbers are generally lower than, and often significantly lower than, the minimum value reported from the ^{14}C results. All of the results based on levoglucosan analysis are significantly lower than those reported using CMB modeling. It should be noted that some data were eliminated for a few low PM days, where the results for levoglucosan are either below the detection limit or near the detection limit and thus have considerable error. No more than two data points were eliminated for any heating season.

Table 3: Wood smoke contributions to ambient $PM_{2.5}$ as determined by ^{14}C analysis, levoglucosan analysis

	WS % $PM_{2.5}$ ^{14}C Minimum	**WS % $PM_{2.5}$ ^{14}C Maximum**	**WS % $PM_{2.5}$ Levoglucosan (Fine CF=9.01)**	**WS % $PM_{2.5}$ Levoglucosan (OMNI CF=13.3)**	**WS % $PM_{2.5}$ CMB Model (OMNI)**	**WS % $PM_{2.5}$ CMB Model**
State Bldng						
2008/2009	31.6 ± 8.0	38.0 ± 9.6	28.1±10.0	34.7±5.9	56.0	66.3 ± 10.1
2009/2010	36.7 ± 7.5	44.2 ± 9.1	21.0±5.6	31.0±8.3		69.9 ± 7.8
2010/2011	28.7 ± 4.3	34.5 ± 5.1	26.7±2.9	39.4±4.3		72.0 ± 6.3
3-yr avg	33.6 ± 7.7	40.4 ± 9.3	25.6±4.1	35.2±3.5		68.5 ± 8.6
North Pole						
2008/2009	42.9 ± 9.8	51.7 ± 11.8	36.8±10.0	54.3±14.7	73.4	72.1 ± 4.7
2009/2010	56.7± 6.3	68.3 ± 7.6	43.3±4.6	63.8±6.8		83.3 ± 10.3
2010/2011	58.4 ± 6.9	70.4 ± 8.3	43.7±4.8	64.3±7.0		73.8 ± 17.0
3-yr avg	55.0 ± 8.3	66.2 ± 10.0	42.0±3.4	61.8±5.1		79.4 ± 11.8
Peger Road						
2008/2009	23.6	28.4	14.3±3.7	21.1±5.4	51.0	62.9
2009/2010	33.9 ± 4.8	40.9 ± 5.8	21.5±2.9	31.7±4.3		69.9 ± 13.1
2010/2011	28.7 ± 6.6	34.6 ± 8.0	22.5±3.4	33.1±5.0		68.5 ± 11.3
3-yr avg	31.8 ± 5.6	38.3 ± 6.7	20.0±2.0	29.5±3.0		69.0 ± 12.1

The relatively low per sample cost of levoglucosan analysis allows multiple analyses to be run a single site in a single season and over several seasons. This, in turn, provides a means to monitor wood smoke contributions as a function of time as well as during and after efforts to reduce wood smoke emissions. A major caveat with this approach, however, is that source profiles would also need to be monitored if significant changes in fuels or devices are implemented. As an example of the approach, the wood smoke contribution to $PM_{2.5}$ at two sampling sites in Fairbanks as a function of time are presented in Figure 1. These plots show clearly that there is significant variability in the results, which is a combination of actual variability and random error in the measurements (if relative error in PM and levoglucosan measurements are each ±10%, the calculated levoglucosan share can be expected to be ±14%). The plots show no observable trend within any heating season. The data show a weak but

statistically insignificant trend of increasing contribution from wood smoke over time. Neither these plots nor the average seasonal data in Table 3 provide significant evidence of any trend of increased or diminished wood smoke contribution over this time period.

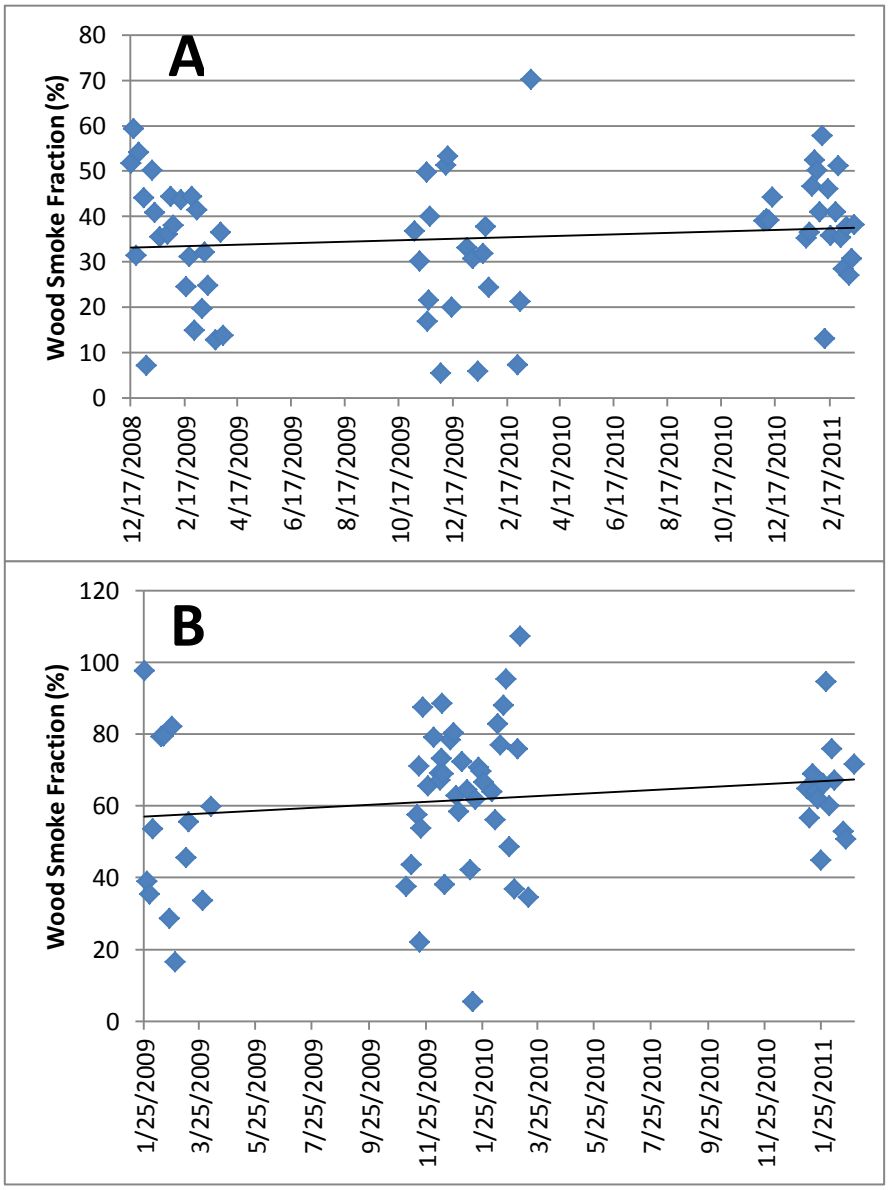

Figure 1: Wood smoke contribution to ambient $PM_{2.5}$ in Fairbanks North Star Borough, based on levoglucosan measurements and the OMNI conversion factor, at A. State Building and B. North Pole sites as a function of time.

2.4 Conclusions

Measurement of levoglucosan shares in ambient $PM_{2.5}$ in Fairbanks as well as in wood smoke particulate using representative devices and fuels allows an estimate of the residential wood smoke contribution to ambient $PM_{2.5}$. The final estimates include significant uncertainty due to both random measurement errors and lack of knowledge concerning the chemical composition of wood smoke. The effect of random measurement errors is reduced somewhat by the large number of measurements that can be made to generate averages. The effect of errors in estimation of the conversion factor is not diminished by making multiple measurements. Two conversion factors were generated that can be

reasonably expected to yield minimum and maximum wood smoke contributions, but as an indication of the uncertainty these two values differ by nearly 45%.

The resulting values for wood smoke contribution are similar to those determined from ^{14}C analysis. This lends some level of credence to both of these methods. Both of the approaches, however, yield results that are significantly lower than those obtained from CMB analysis.

Levoglucosan analysis is relatively inexpensive in comparison to either ^{14}C analysis or CMB analysis. This allows the wood smoke fraction of $PM_{2.5}$ to be determined and monitored many times over the course of a heating season or intervention program. Inspection of the data for the past three years in the Fairbanks area indicates that wood smoke contribution has not diminished but may have increased.

3. Polynuclear Aromatic Hydrocarbons

Polynuclear aromatic hydrocarbons (PAH) are found in the $PM_{2.5}$ from most combustion processes. Although the PAH are generally associated with combustion, certain PAH are reported to be strongly associated with combustion of specific fuels. Examples include retene, picene, and thiophenes, which are often associated with wood, coal and diesel fuel combustion, respectively.

Ambient and OMNI Scientific-generated $PM_{2.5}$ samples on quartz filters were submitted to the Desert Research Institute for analysis of PAH, including two thiophenes (dibenzothiophene and benzonaphthothiophene), on two dates. In the first round of analyses, eight ambient samples were analyzed for 62 PAH. In the second set, 25 ambient samples and 11 OMNI-generated samples were analyzed for 96 PAH. All of the ambient $PM_{2.5}$ samples are from the State Building site. The first eight samples were selected to be relatively high $PM_{2.5}$ days to ensure detection of the PAH, but the subsequent 25 ambient samples were selected considering meteorological conditions and represent a range of low to high $PM_{2.5}$ days. Most of the ambient samples are from the 2009-10 season. All of the raw and calculated results discussed in this report are provided in a spreadsheet.

The results for OMNI Scientific samples have been used to identify those PAH that appear at relatively high levels and shares of $PM_{2.5}$ in samples for specific fuels and devices. Those fuel-specific share data have then been used to set upper bounds on the contribution to ambient $PM_{2.5}$ from the combustion of those fuels.

3.1 OMNI Fuel and Device-Specific Samples

OMNI Scientific supplied UM with eleven quartz filter samples generated using various burners and fossil fuels. The identity of the filters, fuel and burner type are provided in Table 4. The $PM_{2.5}$ catch for each filter was calculated as described for OMNI-generated wood smoke filters as described in section 2.1. Unfortunately, no data were available to allow calculation of the $PM_{2.5}$ catch for two of the filters. Full PAH results for these filters, with analytical uncertainties, are provided in a spreadsheet.

Unfortunately, no replicate filters were provided for any fuel type or device, so it is not possible to estimate the repeatability of these experiments.

Table 4: OMNI Scientific-generated filters analyzed for PAHs.

Filter ID	Fuel	Device	$PM_{2.5}$ Catch (µg)
FNB56	No. 1 Fuel Oil	CHIF	NA
FNB59	No. 2 Fuel Oil	CHIF	474
FNB62	Waste Oil	Waste Oil Burner	9559
FNB66	Coal	Stove	NA
FNB69	Dry Coal	Stove	16340
FNB72	Dry Coal	Stove	2950
FNB79	Coal	Stove	7536
FNB89	Coal	OWHH	93786
FNB91	Coal	OWHH	59879
FNB95	Coal	HH Cold Start	3431
FNB96	Coal	HH Hot Start	3965

3.2 Fuel and Waste Oil

Insufficient data were provided by OMNI Scientific to calculate $PM_{2.5}$ catch for the filter generated with no. 1 fuel oil. The filter provided for no. 2 fuel oil has a relatively low catch of $PM_{2.5}$, and analysis was able to detect significant quantities and shares of only bibenzyl and 9-flourenone. Bibenzyl appears at a relatively high share of no. 2 fuel oil $PM_{2.5}$, at 0.2%. Although a higher quantity of $PM_{2.5}$ was caught for waste oil, analysis of this filter detected only 9-fluorenone and at a much lower share (0.0001%) compared with no. 2 fuel oil. The results for waste oil and no. 1 fuel oil do not identify any potential $PM_{2.5}$ markers for these fuels. It is possible, however, to consider 9-fluorenone and bibenzyl as markers of no. 2 fuel oil combustion.

9-Fluorenone made up a significant but small share (0.013%) of no. 2 fuel oil $PM_{2.5}$, but was also detected in the OMNI generated coal $PM_{2.5}$ samples at 0.0002% to 0.004% share. 9-Fluorenone was detected in ambient samples at similar to higher shares than in the no. 2 fuel oil $PM_{2.5}$ sample, implying that there is another significant source of this compound in ambient $PM_{2.5}$. This compound was thus not considered to be a unique or useful marker for no. 2 fuel oil $PM_{2.5}$.

Bibenzyl, however, was not detected in any other OMNI-generated fossil fuel $PM_{2.5}$ samples but was detected as a significant share (0.2%) in no. 2 fuel oil $PM_{2.5}$. Bibenzyl was not determined in the first set of eight ambient filter samples but was detected in 24 of the 25 samples submitted in the second set. Bibenzyl is found at much lower shares in ambient $PM_{2.5}$ than in $PM_{2.5}$ for no. 2 fuel oil. Bibenzyl was thus considered a potentially unique and useful marker for no. 2 fuel oil combustion.

An upper boundary for the contribution of no. 2 fuel oil $PM_{2.5}$ to the ambient $PM_{2.5}$ samples was calculated using the bibenzyl results for ambient shares and the experimental bibenzyl share in no. 2 fuel oil $PM_{2.5}$. **This analysis provided a median of 0.6% and a mean of 0.6 ± 0.4% (±1σ) contribution, suggesting that no. 2 fuel oil combustion is responsible for only a minor fraction of ambient $PM_{2.5}$.**

This is considered an upper boundary since the analysis does not take into consideration any other potential sources of bibenzyl. Further, there is significant but unquantifiable uncertainty in this result, since it is based on a single collection and analysis of $PM_{2.5}$ from no. 2 fuel oil.

3.3 Coal

OMNI Scientific provided $PM_{2.5}$ samples for coal combustion in various residential devices. These results provide some useful results for these devices. However, there are still no measured values for any PAH in coal emissions from power plants or other commercial facilities.

Inspection and analysis of the results for the OMNI coal $PM_{2.5}$ samples suggests eight possible PAH markers for coal combustion. These compounds were selected because they were detected in more than half of the OMNI coal $PM_{2.5}$ samples and because they showed at least a 200 ppm share for one or more coal $PM_{2.5}$samples. Table 5 lists the selected PAH with their median and average ± 1σ shares of $PM_{2.5}$ over the seven usable OMNI coal $PM_{2.5}$ samples. The very high standard deviations in these data reflect the large variability between different coal burning devices tested by OMNI scientific. In each case, $PM_{2.5}$ from the HH systems had the lowest shares of PAH compounds. Previous studies have identified picene as a unique marker for coal combustion,[4-6] and this compound is observed at relatively high shares in most of the coal $PM_{2.5}$ samples in this study (although not for the HH systems).

Table 5: PAH compound shares of coal $PM_{2.5}$ in OMNI Scientific-generated samples, and contributions of coal $PM_{2.5}$ to Fairbanks ambient $PM_{2.5}$ calculated using these shares.

Compound	**Share of Coal $PM_{2.5}$ (ppm)**		**Median Coal Fraction of Ambient $PM_{2.5}$ (%)**	
	Median	**Mean ± 1σ**	**by Median**	**by Mean**
Picene	1000	1000 ± 1200	2.7	2.7
Retene	56	250 ± 400	72	16
Indeno[1,2,3]pyrene	320	370 ± 350	19	16
Benzo[g,h,i]perylene	440	460 ± 430	26	24
Anthanthrene	210	190 ± 160	12	13
Dibenzo[a,l]pyrene	150	130 ± 120	4.4	4.9
Coronene	160	160 ± 150	21	21
Dibenzo(b,k)fluoranthene	160	160 ± 150	5.7	5.8
Dibenzothiophene	2.2	11 ± 14	234[1]	48[1]
Benzonaphthothiophene	6.4	19 ± 33	20[1]	6.7[1]

[1]Based on second set of 25 ambient $PM_{2.5}$ samples only.

Also included in Table 5 are the median percent contributions of coal $PM_{2.5}$ for the Fairbanks ambient $PM_{2.5}$ samples based on either the median or the mean share of that compound in OMNI-generated coal $PM_{2.5}$ samples. Most of these are determined for the full set of 33 ambient samples, but thiophene results are reported for only the latter 25 samples analyzed (this is discussed in detail below).

The results for coal $PM_{2.5}$ fraction based on the PAHs are highly variable, ranging from a median contribution of 2.7% to 72%. In fact, because these compounds are also produced by other combustion processes, each of the reported values is an upper boundary for coal $PM_{2.5}$ contribution. Retene, for example, is known to be emitted during wood combustion. Thus, the lowest of these calculated

contributions, 2.7%, which is based on picene shares, is most likely to be valid. Picene has been reported as unique to coal combustion emissions[7,8], lending additional confidence to this result.

Defining a coal PM fraction based on any of the markers is complicated, however, by the wide range of $PM_{2.5}$ shares observed for each marker with different coal burning devices. Picene is no exception; picene shares range from below the detection limit (5 ppm share of $PM_{2.5}$) for HH systems to 3300 ppm share of $PM_{2.5}$ for coal stoves. This suggests that the median coal $PM_{2.5}$ contribution to ambient $PM_{2.5}$ could range from 0.8% if the contribution were exclusively from coal stoves to >100% if the $PM_{2.5}$ were exclusively from HH systems. A value of greater than 100% indicates a substantial contribution from a separate source, although other sources of picene have not been reported. It is possible that a single coal stove in the vicinity of the sampling site contributing less than 1% to the sampled $PM_{2.5}$ could account for all of the observed picene.

3.4 Ratiometric Analysis

Another commonly used measure for sourcing PAH emissions is the ratio of indeno[123-cd]pyrene to the sum of indeno[123-cd]pyrene and benzo[ghi]perylene (IP/(IP+BghiP)).[6,9,10] Typical values for this ratio from various fossil fuel sources, woodsmoke, and for Fairbanks are reported in Table 6. No published value is available for residential oil combustion $PM_{2.5}$. The ratio for OMNI-generated coal $PM_{2.5}$ (average ± 1σ) is also included in Table 6. No value could be determined for oil burner samples since these PAH compounds were not detected. The ratio for Fairbanks ambient $PM_{2.5}$ is reasonably consistent between samples, and is most similar to that reported for diesel fuel emissions. The observed ratio is lower than all reported ratios except gasoline autos, which suggests a significant contribution from transportation.

Table 6: Ratio of indeno[123-cd]pyrene to sum of indeno[123-cd]pyrene and benzo[ghi]perylene for various sources.

Source	IP/(IP+BghiP)
Gasoline autos	0.18
Diesel autos	0.37
Coal combustion	0.56
Wood combustion[9]	0.54
OMNI-Coal	0.42 ± 0.05
Fairbanks $PM_{2.5}$	0.33 ± 0.05

3.5 Thiophenes

The thiophenes are unique sulfur-containing compounds related to the PAHs that have been reported in the emissions of fossil fuel combustion. Preliminary studies of Fairbanks ambient $PM_{2.5}$ showed high levels of these compounds. Thus, there was interest in further study of these compounds in ambient $PM_{2.5}$ and in $PM_{2.5}$ from fossil fuel sources.

Dibenzothiophene, benzonapthothiophenes and alkylated derivatives of these compounds are reported to be representative of diesel fuel vehicle emissions.[7,8] These compounds make up a significant fraction of the sulfur content of diesel fuel. Low sulfur diesel fuel has lower concentrations, and vehicles utilizing low sulfur diesel fuel emit reduced quantities of these compounds[7,8]. Rogge *et al.*[11] did not report thiophenes in the emissions from residential fuel oil combustion, but Huffman *et al.* did report that typically 25-35% of the sulfur in residential fuel oil particulate is thiophenic sulfur.[12] Analysis of no. 2 fuel oil from Fairbanks at the University of Montana detected dibenzothiophene at 443 ppm, a

level that is higher than that reported previously for high sulfur diesel fuel. Given the similar composition of # 2 fuel oil and diesel fuel, and the fact that the sulfur content of # 2 fuel oil is not regulated with respect to sulfur content, it was hypothesized by us that these compounds would be found in the $PM_{2.5}$ emissions from #2 fuel oil. Dibenzothiophene has also been reported in the emissions from gasoline vehicles[13]. In this and one report on diesel emissions[8], dibenzothiophene was found primarily in the gas phase. Given the ambient temperatures in Fairbanks, it seems likely that the compound would be found in the particulate phase. These sulfur compounds are not present in wood smoke $PM_{2.5}$.

Preliminary results for eight Fairbanks ambient $PM_{2.5}$ samples showed very high levels and shares of thiophenes when compared with published results for diesel emissions[7] or with ambient concentrations in European urban environments[14]. Results for the second set of 25 Fairbanks ambient $PM_{2.5}$ samples are much lower, however, and there is a large, statistically significant ($p<10^{-9}$), and inexplicable difference in thiophene shares of ambient $PM_{2.5}$ between the first eight and latter 25 samples. The share results for the latter 25 samples are lower than those reported for diesel emissions[7]. However, the ambient concentration results for the latter samples remain a factor of two to three higher than those reported for European cities[14]. This may be explained by different $PM_{2.5}$ concentrations and local environments. There is concern, therefore, that the thiophene results for the initial eight samples are invalid.

It is important to note that thiophenes were not detected in the OMNI-generated $PM_{2.5}$ from fuel oil samples. Our hypothesis that dibenzothiophene and benzonaphthothiopene might serve as markers for $PM_{2.5}$ from no. 2 fuel oil combustion is not supported by the results, and is invalidated.

Results for two thiophenes in OMNI-generated coal $PM_{2.5}$ are included in Table 5 and are used in subsequent calculations of coal contributions to ambient $PM_{2.5}$. Coal contributions based on thiophenes range from 6.7% to more than 100%. A value of greater than 100% indicates a substantial contribution from a separate source of dibenzothiophene, such as diesel or gasoline vehicle emissions.

It remains unclear what the sources of the thiophenes observed in Fairbanks ambient $PM_{2.5}$ are. None of the OMNI samples for residential oil heating devices had detectable levels of either thiophene, so this cannot be considered a significant source. Some fraction of the thiophene shares of Fairbanks ambient $PM_{2.5}$ may be explained by coal emissions, but these cannot explain all of the observed thiophenes. Previous studies have attributed thiophenes to diesel emissions, but this should be minimized with low sulfur diesel fuel. Previous studies have also reported relatively high concentrations of these thiophenes in the vapor phase emissions from gasoline automobiles[13]. It is possible in the winter climate in Fairbanks that these normally vapor phase emissions are associated with the $PM_{2.5}$, explaining a substantial fraction of the observed levels.

3.6 Conclusions

Polynuclear aromatic hydrocarbon and thiophene analysis of $PM_{2.5}$ generated using representative fuels and devices as well as ambient $PM_{2.5}$ does provide useful information regarding

potential contributions of fuel oil, coal and potentially other fossil fuels to Fairbanks $PM_{2.5}$. The results indicate no substantial contributions of fuel oil or coal combustion to ambient $PM_{2.5}$.

No. 2 fuel oil emissions and waste oil filters had low amounts of $PM_{2.5}$ and the levels of nearly all compounds were below the detection limits. Bibenzyl was identified as a potential marker based on its relatively high fraction in no. 2 fuel oil $PM_{2.5}$ and its absence in coal $PM_{2.5}$. Using this as a marker leads to the conclusion that combustion of no. 2 fuel oil contributes a negligible fraction to ambient $PM_{2.5}$ of less than 1% for the 33 samples analyzed.

Picene is accepted as a unique marker for coal combustion. Zhang *et al.* reported picene as being "unique to the organic carbon emissions from coal combustion," although picene was not detected in all coal particulate and was notably absent from bituminous coal emissions from industrial boilers.[6] Zhang *et al.* did report picene in brown and mixed coal emissions from industrial boilers (3.7 and 2.0 ppm shares respectively) as well as much higher levels in the emissions from residential coal burners (72-284 ppm shares).[6] Oros *et al*. reported picene and methyl picenes as bituminous coal smoke markers, and C_2 substituted picenes as more general coal-specific markers.[4] As a large PAH, picene can be expected to be found primarily in the particulate phase.

The current results for picene support its use as a specific marker for coal combustion. Picene appears as a relatively large share of coal $PM_{2.5}$ for certain devices. Other compounds found in the coal $PM_{2.5}$ were detected at lower $PM_{2.5}$ share and suggested higher contributions of coal combustion to ambient $PM_{2.5}$. These compounds are very likely found in the emissions of other combustion sources.

Using a median value of picene share in the various devices leads to 2.7% coal contribution to $PM_{2.5}$. The picene shares, however, are highly variable depending on the device. If coal combustion were primarily from devices that have a much lower $PM_{2.5}$ share of picene, then coal $PM_{2.5}$ would represent a much higher fraction of ambient $PM_{2.5}$. Alternatively, the observed picene share of ambient $PM_{2.5}$ could result from less than a 1% contribution from devices that generate high picene shares.

The OMNI Scientific $PM_{2.5}$ samples do not show detectable levels of thiophenes for fuel oil samples, and show only low shares for coal samples. Thiophenes are observed in ambient $PM_{2.5}$ at levels that cannot be explained using coal combustion sources alone. It remains unclear what the sources or these thiophenes are. A fraction of the observed thiophenes might be associated with coal emissions, but it seems likely that the majority is from transportation sources.

4. Hopanes and Steranes

The hopanes and steranes are typically found and reported in distillate fossil fuel emissions, but have also been reported in coal emissions. The highest levels reported are for diesel auto emissions, and the lowest are for coal emissions. The hopanes and steranes are not present in emissions from biomass combustion, and thus provide a general indication of the extent to which an air shed is affected by fossil fuel emissions. Unfortunately, however, none of the compounds have been reported to be a specific marker of any particular fossil fuel source.

Analytical results for 23 hopane and sterane compounds have been obtained for eight Fairbanks ambient $PM_{2.5}$ samples, and generally show high levels and shares (5-60 ppm) of certain compounds. These results, with analytical uncertainties, are presented in a separate spreadsheet. Levels of hopanes and steranes in Fairbanks are typically higher than those reported for ambient air in other airsheds[5,15], and Fairbanks hopane and sterane shares are greater than those reported for most specific fuel emissions[4,6,8,11,13]. Analytical results for the same hopanes and steranes were also obtained for fossil fuel $PM_{2.5}$ samples provided by OMNI Scientific. These results are also presented in a separate spreadsheet.

4.1 Coal

Of the compounds analyzed, several hopanes were selected as potentially useful markers of coal combustion. Compounds were considered potential markers if they were detected in all of the coal $PM_{2.5}$ samples, if shares of three or more of the seven samples exceeded 100 ppm, and if the compounds did not have comparable shares in fuel oil $PM_{2.5}$. These selected hopanes, and their median and mean shares of coal $PM_{2.5}$, are presented in Table 7. Shares of coal $PM_{2.5}$ are highly variable between devices, with the HH systems showing low shares and the coal stoves generally showing high shares. In comparison, previous studies have reported hopane shares of diesel $PM_{2.5}$ of 5-60 ppm[7,8] .

Table 7: Hopane compound shares of coal $PM_{2.5}$ in OMNI Scientific-generated samples, and contributions of coal $PM_{2.5}$ to Fairbanks ambient $PM_{2.5}$ calculated using these shares.

Compound	**Share of Coal $PM_{2.5}$ (ppm)**		**Median Coal Fraction of Ambient $PM_{2.5}$ (%)**	
	Median	**Mean ± 1σ**	**by Median**	**by Mean**
17α(H),21ß(H)-29-Norhopane	83	122 ± 133	50	34
17α(H),21ß(H)-Hopane	111	126 ± 121	23	21
22S-17α(H),21ß(H)-30-Homohopane	45	132 ± 135	39	13
22R-17α(H),21ß(H)-30-Homohopane	90	137 ± 156	26	17
22S-17α(H),21ß(H)-30,31-Bishomohopane	41	65 ± 62	21	13

The share data presented in Table 7 can be used to estimate coal contributions to the ambient $PM_{2.5}$ samples. These results are also presented in Table 7, and show median coal contributions to ambient $PM_{2.5}$ of 13 to 50%. Because the hopanes are not specific to coal emissions, these should be considered upper bounds to coal contribution. Further, the hopane shares are highly variable with coal burning device. Thus, ambient levels of $PM_{2.5}$ could suggest an upper bound of as little as 6% contribution of $PM_{2.5}$ from coal stoves that produce high hopane shares. Coal emissions from HH systems, on the other hand, cannot explain the shares observed in Fairbanks ambient $PM_{2.5}$.

4.2 Fuel Oil

The results for hopane and sterane shares of no. 2 fuel oil and waste oil $PM_{2.5}$ were also examined for potentially useful selective markers. Hopane and sterane shares of waste oil $PM_{2.5}$ were all less than 1.3 ppm and were equivalent or higher in coal $PM_{2.5}$, and thus could not be used to estimate waste oil contributions to ambient $PM_{2.5}$. One sterane, 20S-5α(H),14ß(H),17ß(H)-cholestane, did appear at a relatively high share of no. 2 fuel oil $PM_{2.5}$ (13 ppm) and at lower shares of coal $PM_{2.5}$ (0-6 ppm). Using this compound as a marker for no. 2 fuel oil generates an extreme upper bound of 15% for the contribution of no. 2 fuel oil combustion to ambient $PM_{2.5}$. This is very clearly an overestimate to fuel oil contribution, since substantial quantities of this sterane would also be produced by combustion of other fossil fuels, including coal. Further, there is significant but unquantifiable uncertainty in this result, since it is based on a single collection and analysis of $PM_{2.5}$ from no. 2 fuel oil.

4.3 Ratiometric Analysis

An alternative approach for the analysis of hopane results is to calculate the ratio of 17α (H) 21β (H) hopane to 22R-17α (H), 21β (H) homohopane.[4,6,16] This value has been reported to be 3.7 for gasoline emissions and 2.5 for diesel emissions.[16] Unfortunately, conflicting results have been reported for coal combustion emissions, with Oros *et al.*[4] reporting values of 0.1-2.6 and Zhang *et al.*[6] reporting values of 4.28-9.19. In the current study, the ratio for OMNI-generated coal emissions over all devices ranged from 0.76 to 1.63 with a median of 1.15 and an average ± 1σ of 1.13 ± 0.33. The ratios for no. 2 fuel oil and waste oil emissions were found to be 0.57 and 1.01 respectively, but the ratio for no. 1 fuel oil emissions could not be determined because 22R-17α (H), 21β (H) homohopane was not detected. The average value observed for Fairbanks is 1.2 ± 0.4. This relatively low result for Fairbanks is not significantly different from that observed for the OMNI-generated coal filters and is within the range reported by Oros *et al.* for coal. This analysis implies that coal or other low ratio emissions such as fuel oil may be a more substantial contribution to the hopanes in Fairbanks ambient $PM_{2.5}$ than the analyses above suggest.

4.2 Conclusions

Hopane and sterane analysis of Fairbanks ambient $PM_{2.5}$ shows levels and shares that are indicative of substantial contribution from fossil fuel combustion sources. Unfortunately, however, none of these compounds can be considered specific markers of any individual combustion source. This means that any simple calculations of contributions from a given source will overestimate the value and must be considered upper bounds. Upper boundaries for the contributions of coal and no. 2 fuel oil combustion to ambient $PM_{2.5}$ by this approach are estimated to be 13% and 15% respectively.

Analysis based on the ratio of levels for two specific hopanes indicate that a substantial share of hopanes in ambient Fairbanks $PM_{2.5}$ are from a low ratio source such as fuel oil or coal. This is inconsistent with the results based on hopane and sterane shares of $PM_{2.5}$.

A more comprehensive approach of source apportionment using full profiles of all sources and ambient $PM_{2.5}$ is much more appropriate for this analysis. This is not recommended with the limited data available for Fairbanks sources and ambient $PM_{2.5}$.

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Exploratory Research of Wintertime Aerosol Chemical Composition at a Ground Location in Fairbanks, Alaska

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EXECUTIVE SUMMARY

This report summarizes quantitative chemical composition data of ambient particulate matter of less than 2.5 μm (PM2.5) aerosol collected during a month-long study in Fairbanks, Alaska in February and March, 2011. The data collected include hourly measures of ions commonly found in aerosol, as well as hourly measurements of organic and elemental carbon. Daily filter samples were also collected for alternative chemical analyses. Data were collected in a small, insulated trailer that was located near the Fairbanks Borough North Star Administrative Office near 809 Pioneer Road.

Approximately 283 sets of ion samples were collected during this study, and just over 500 measurements of organic and elemental carbon were collected. 37 pairs of filters were collected as well, with one set consumed by analytical techniques and a second set collected for long-term storage and post-hoc analyses. Aerosol chemical composition appears to be dominated by organic carbon (mean = 6.5 $\mu gC\ m^{-3}$) and estimated organic matter, as well as elemental carbon (mean = 0.9 $\mu gC\ m^{-3}$and sulfate (mean = 2.02 $\mu g\ m^{-3}$). Lesser measurements included ammonium, nitrate, potassium, and several light organic acids.

The data show a clear diurnal profile that is likely attributed to anthropogenic activities. Wood burning appears the be a significant contributor to the high particle loading observed during the winter in Fairbanks as indicated by the enhanced levels of organic carbon and in the relative absence of other compounds that would indicate other emission sources of PM2.5. Ion information provides some confirmation of this, and a preliminary look at high time resolution XRF data provides additional confirmatory evidence in support of this hypothesis.

A particular focus of this work involved improving the understanding of sulfur in the Fairbanks airshed. Particulate sulfur (as sulfate) was detected throughout the study indicating that mechanisms that promote sulfur conversion (from gas phase to particle phase) are, in fact, present. We also examined chemical composition by complementary analytical methods – first by X-Ray Fluorescence (XRF) followed by ion chromatography for two measures of sulfur from the same filter. Results show that sulfur is measured at the same levels no matter the analytical method, which is in contrast to results reported by the United States Environmental Protection Agency (EPA) for chemical speciation measurements in Fairbanks. It is likely that a methodological difference explains the disagreement between the two methods of sulfur measurement used by the EPA speciation network.

INTRODUCTION AND RATIONALE FOR RESEARCH

Ambient fine particles are ubiquitous in the lower troposphere, and result from a variety of physical and chemical transformations. They can be formed as a primary pollutant through, among others, combustion and biogenic sources, as well as by resuspension of dust from crustal surfaces [1-3]. Secondary aerosol sources – that is, aerosol formed by a variety of secondary gas-phase chemical reactions in the atmosphere - are substantially more complex and can represent a significant fraction of ambient aerosol [2, 4]. The diversity of possible atmospheric reactions makes unequivocal identification of aerosol sources quite complex, and thus, our understanding of aerosol formation is also incomplete.

The Fairbanks region is an excellent example of unique and diverse chemical conditions that result in ambient particulates. The region is known to routinely exceed the National Ambient Air Quality Standards during the winter heating season. This is thought to arise both from significant local emissions, but also by meteorological enhancement due to strong inversions and poor regional ventilation. Aerosol source hypotheses include emissions from wood and fuel oil burning, and the formation of sulfur-containing particles from local coal-fired power generation. Because of its relatively remote location, regional transport of particle pollution is generally insignificant suggesting that most of the ambient pollution was generated within the local area. Thus, because of this unique complexity and the absolute need to maintain safe temperatures through residential heating during the winter, Fairbanks represents an excellent case for further study of ambient aerosol composition and formation.

Because of a history of demonstrated non-attainment for PM2.5 in the Fairbanks area, there exists a need for substantially increased expansion of fundamental understanding of aerosol chemical climatology for the community. This information will be useful in identifying suggested pathways to reduce air pollution levels in the most efficient and cost-effective manner, as well as reduce aerosol components of known health hazards for the citizens of the borough. Without this information, mitigation attempts are likely to be ineffective.

INSTRUMENTATION

A state-of-the-art instrumentation package was installed in a small, insulated utility trailer, which was situated near the NCORE site in Fairbanks, Alaska. Instrument integration was completed on February 6, 2011, and field data collection began on February 9th, 2011 at approximately 13:00 AST. The instrumentation package, described below, operated with periodic user intervention and maintenance, as described below. FNSB staff were immensely helpful in performing these duties for the duration of the study. The study continued until March 16th, 2011 at 07:05 AST when instruments were powered down and removed from the trailer.

PILS-IC

The Particle-Into-Liquid Sampler (PILS) is a device that captures all particles greater than ~10-15 nm by employing condensational growth of the particle in a supersaturated environment of water vapor. Prior to entering the PILS, a particle passes through a set of denuders which strip out gas phase organics, and any acidic or basic gases present in the aerosol stream. The particles and water vapor are adiabatically cooled, which promotes rapid particle growth to a size of 1-3 μm; these are then accelerated and collected on an impaction wall. This wall is continuously washed with a small amount of purified water, and the effluent is then diverted by syringe pump to any number of

analytical processes. Typical detection limits are described in Table 1, and a schematic representation of the PILS system is show in Figure 1. Rather than *in-situ* analytical chemistry, aqueous samples were collected in a semi continuous manner in 1.8ml plastic aliquots which were

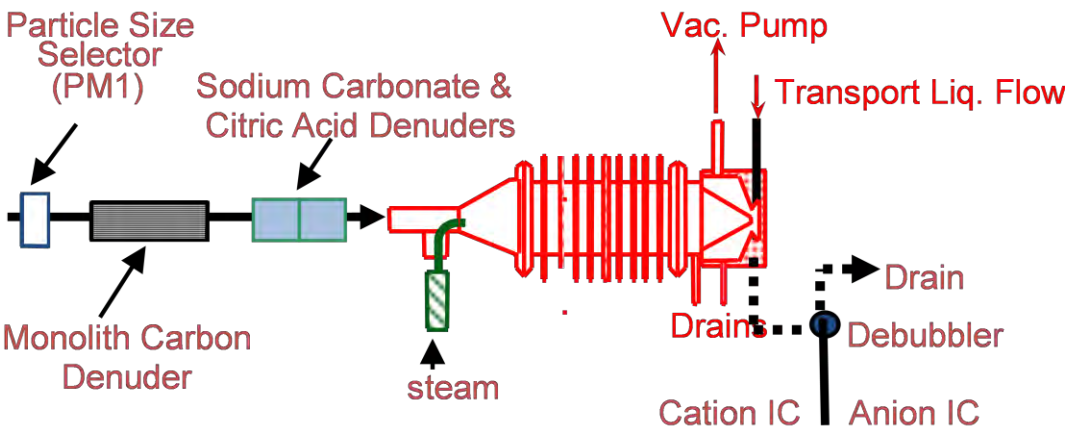

Figure 1: Schematic of Particle-Into-Liquid sampler. Aerosol enters from the leftm, is denuded and mixed with steam, abiabatically cooled, and collected on an impactor. Sample is then deposited into vials (not shown).

mounted on a computer-controlled rotating carousel. Filled aliquots were periodically collected and frozen by local assisting staff.

Maintenance activities performed by local staff included emptying of wastewater tanks (containing a non-hazardous dilute solution), replacement of purified water, retrieval and storage of samples and replacement of new plastic vials, and inspection and removal of any ice buildup at the pump exhaust. The instruments were checked daily for normal operation. Collected samples were organized according to unique barcodes, and shipped to the investigator's lab in Massachusetts for chemical analysis.

Table 1: This is a summary of analyses of aerosol chemical composition useful for this study. Data include typical concentrations in Fairbanks, estimated liquid concentration in the PILS effluent, and typical detection limits by a variety of analytical techniques.

Compound	Typical Winter Air Concentration at Fairbanks (Jan-Feb, 2006-2009), μg m^{-3}	Estimated Liquid Concentration (μg L^{-1})	Typical Detection Limit (μg L^{-1})
Sulfate	4.498	3748.33	0.01[a]
Elemental sulfur	1.63	1358.33	0.1[b]
Ammonium	2.021	1684.17	0.1[a]
Sodium	0.093	77.50	0.1[a]
Nitrate	1.121	934.17	0.5[a]
Potassium	0.150	125.00	0.2[a]
As	0.0015	1.25	0.1[c]
Se	0.0010	0.83	1.0[c]
Oxalate	n/a	n/a	0.2[a]
Zn	0.0520	43.33	0.2[c]

[a] by ion chromatography
[b] by ICP-MS
[c] by Flame ionization/ Atomic Absorption

Once defrosted, collected aliquots were removed from field vials and diluted to 4ml with precision pipettes and placed into 5ml autosampler vials (Environmental Express, Model K4300). Dilution matrix was 18.2M-Ohm or better purified water. The samples were then analyzed by ion chromatographic separation for 18 ion species (as a total of 13 anion and 5 cation peak) using a Dionex ICS-3000 Ion Chromatography System. In order of elution, the anion peaks are fluoride, acetate, formate, methanesulfonate, chlorite, chloride, nitrite, sulfate, bromide, oxalate, nitrate, chlorate, and phosphate. The 5 cation peaks are sodium, ammonium, potassium, magnesium, and calcium.

SUNSET LABS EC AND OC

Because of the multicomponent complexity of aerosol in Fairbanks, we also operated a Sunset Labs Model 4 semi continuous Organic Carbon and Elemental Carbon (OC/EC) analyzer. This instrument simultaneously and directly measures fine particle organic and elemental carbon at hourly integrated measurements and is a standalone instrument that requires almost no user support.

The instrument includes a sharp-cut cyclone to remove particles greater than 2.5 μm. The inlet also includes a parallel plate denuder consisting of laminar paper sheets impregnated with activated carbon which effectively removes organic vapors. The sample cycle typically includes 45 minutes of sample collection that begins on the hour, and a 12-13 minute analysis cycle. The instrument goes through a cooling cycle and then repeats an analysis at the next hour. With typical operating parameters, the detection limits of this analyzer are approximately 0.3 $\mu g\ m^{-3}$ for both organic carbon and elemental carbon. It requires several certified compressed gases for analysis, and this method is consistent with the NIOSH [5-7] method of OC and EC determination.

FILTER SAMPLES

37 filters samples (collected in duplicate, a total of 74 filters) were also collected for the duration of this study. The samples were collected over a nominal 24 hours (with filter changes initiated at approximately 13:00 AST), and were collected at ambient temperature and pressure and corrected to standard temperature and pressure. Samples were collected in conductive plastic filter holders than contained 37 mm ringed Teflon filters (Pall Corporation, model R2PJ037) that were sequentially labeled. Sample passed through a sharp-cut cyclone with a cut size of 2.5 μm, and through two stainless steel annular denuders in series, one of which was coated with a sodium carbonate/bicarbonate solution, and second coated with a citric acid solution. Sample flow was achieved by a 1/4hp vane pump that applied a strong vacuum to a critical orifice calibrated for choked flow at 15.0 $l\ min^{-1}$. After sampling, filters were returned to their original petri dish containers and sent to the investigator's lab in Massachusetts.

Filters were analyzed by high resolution X-ray Fluorescence Spectroscopy using analytical methods consistent with EPA speciation approaches. The method used in this analysis conforms to EPA Compendium Method IO-3.3: For the Determination of Metals in Ambient Particulate Matter Using X-Ray Fluorescence (XRF) Spectroscopy.

Filters were then returned to the lab and sent for further analysis by ion chromatography. This is a destructive technique that renders the remaining filters unusable for any further testing. Chromatographic separation methods were consistent with those described above, but filters were first digested in a vial of purified water under sonication, and then cooled for an hour to room temperature prior to analysis.

RESULTS AND DISCUSSION

AEROSOL IONS

Approximately 280 unique, hourly samples were collected over the course of this study. A number of samples were invalidated due to issues of contamination and instrument failure.

Table 2: Univariate statistics for the range of ions measured during this study. Reported values include mean, median, standard deviation, range, and the number of measurements collected during this study. Llod denotes measurements below the limit of detection.

	Mean, μg m^{-3}	Median, μg m^{-3}	Std Dev, μg m^{-3}	Range, μg m^{-3}	n
Ammonium	0.39	0.24	0.46	(llod, 3.22)	278
Potassium	0.75	0.63	0.42	(0.24, 3.5)	278
Magnesium	0.17	0.07	0.39	(0.03, 2.65)	278
Calcium	0.93	0.56	1.16	(0.17, 7.37)	273
Acetate	1.06	0.51	1.23	(llod, 8.8)	285
Formate	0.21	0.09	0.25	(0.02, 1.55)	285
Chloride	0.83	0.28	2.12	(0.08, 25.1)	285
Nitrite	0.08	0.03	0.12	(llod, 0.62)	285
Sulfate	2.02	1.55	1.56	(0.12, 12.25)	285
Oxalate	0.03	0.01	0.08	(llod, 0.56)	285
Nitrate	0.59	0.41	0.51	(llod, 2.9)	285

Table 2 shows univariate statistics describing the data collected at this location. Dominant ions throughout this study included ammonium, calcium, and potassium, as well as sulfate, nitrate and some chloride. All ions were detected at times over the course of this study. A number of light organic acids were detected, including acetate and formate; these are discussed further in the next section.

Aerosol chemical composition during this study could be characterized by high variability, as seen in relatively high reported standard deviations (Table 2) and graphically as in Figure 2. Figure 2 plots sulfate, one of the more dominant ions measured during this campaign, plotted on hourly intervals. Superimposed on this graph are measured sulfate concentrations determined from collocated 24-hour filter samples which were also analyzed by ion chromatography. Of particular note, sulfate appears with a quasi-diurnal cycle (more discussion of this follows) with minima typically in the 1-2 μg m^{-3} range, and short term maxima in the 4-5 μg m^{-3} range; there are notable deviations from this with clear spikes in sulfate approaching 10-12 μg m^{-3}. 24 hour filter measures show some variability in concentration data, but they lack substantial texture clearly seen with the higher time resolution data.

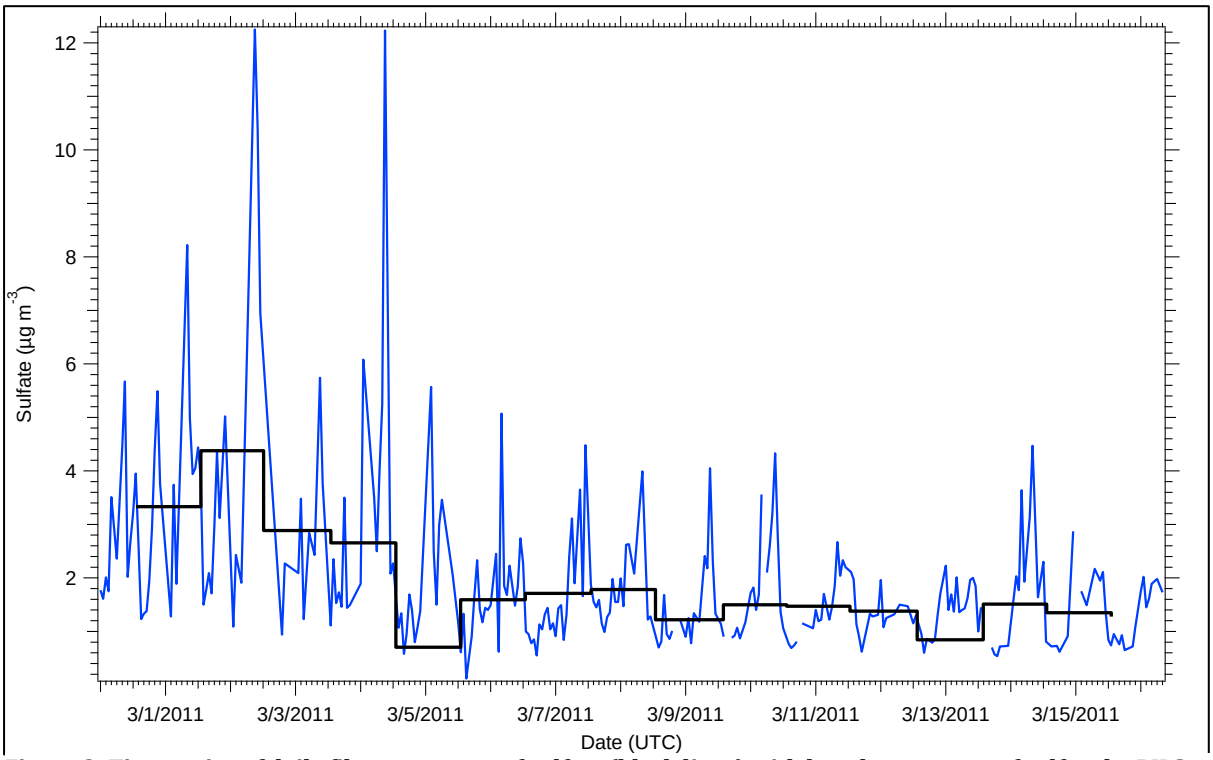

Figure 2: Time series of daily filter measures of sulfate (black lines) with hourly measures of sulfate by PILS (blue) superimposed on the figure.

Figure 3 depicts available ion data coupled with measured organic carbon, plotted against apparent charge, in microequivalents. Charge is calculated by taking the net valence charge for each measured ion, adjusted for molar concentration, and summing the positive and negative charges. This approach also includes (when available) the net charge resulting from a variety of measured light organic acids (including oxalate, formate, and acetate). If all elements are measured, one would expect a balanced charge of zero. Deviations towards a net negative charge indicate a missing cation; deviations towards a net positive charge indicate a missing anion. In typical studies, this missing cation (e.g. conditions with net negative charge) is presumed to be a hydrogen proton which can accompany acidic aerosol.

In the case of Figure 3, both positive and negative conditions appear in the data. While acidic conditions are often observed in air sheds that have significant influence from coal combustion (which normally leads to sulfuric acid formation in the aerosol), it is notable that these deviations occurred throughout a range of concentrations of OC – both high and low – and suggest that acidic influence is independent of OC concentration. Charge balance contributed by the measured light organic acids also appears to be relatively low during these periods suggesting that the aerosol climatology lacks a substantial light organic acid profile and further suggestion this acidity is linked more closely inorganic acids, such as sulfuric or nitric acid, rather than light organic acids. This does provide some weak evidence that inorganic acids are playing a role in determining aerosol charge in Fairbanks, but these results are not yet determinative; there are a number of possible explanations for this, though it does appears likely that the modest acidity results from a source unrelated to the source of organic carbon. It should also be noted that apparent acidity determined here is quite modest in the context of other studies which examined particle acidity arising from coal combustion. For example, in communities on the East Coast of the US, net charges are typically -0.25 µEq and lower [8, 9], which is twice as acidic as conditions observed here.

In contrast, a surprising result was that there were a number of cases where there were significant positive charges observed in the data, suggesting missing cations. This tended to occur during

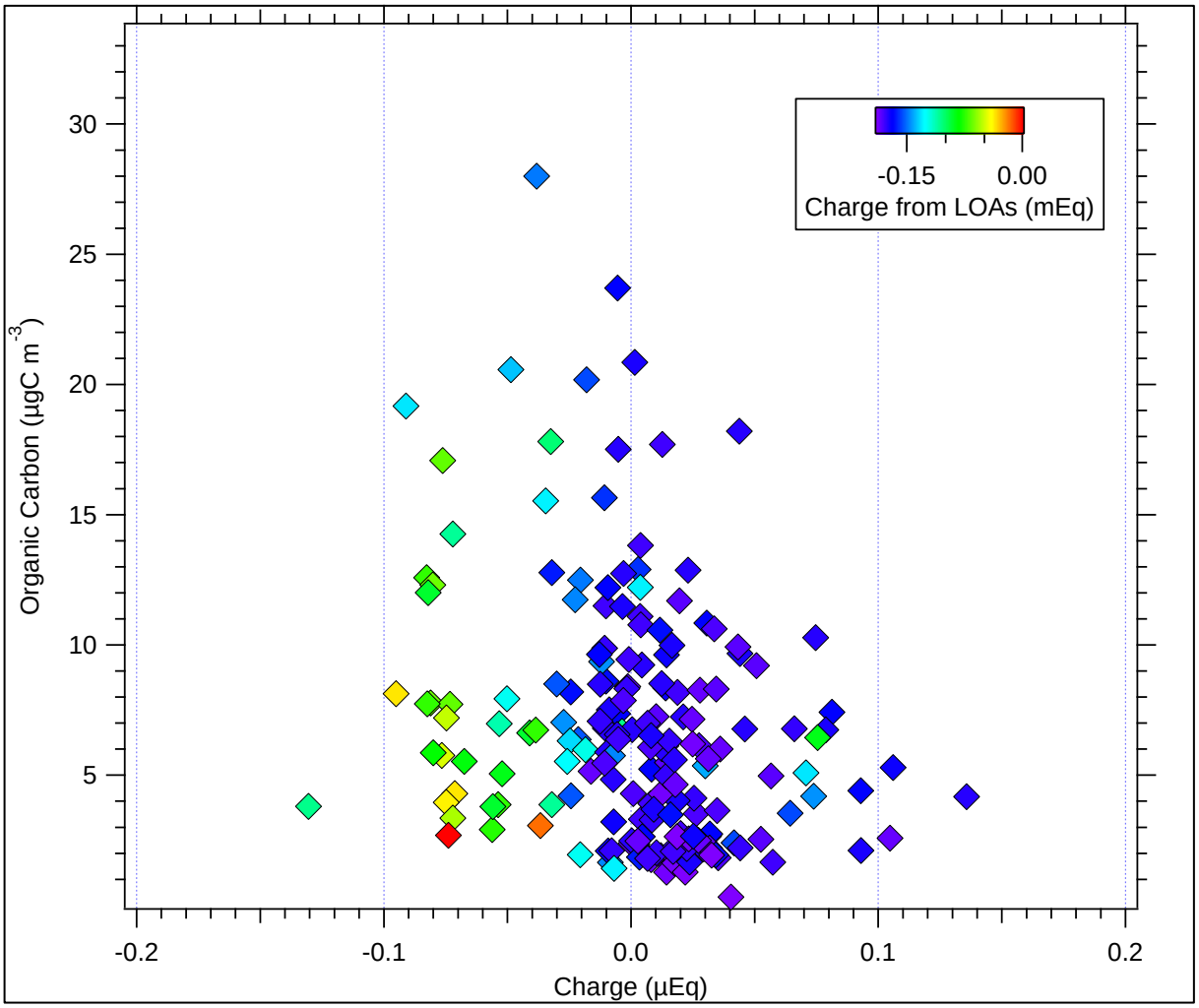

Figure 3: Net charge on aerosol plotted against organic carbon concentration. Markers are colored by apparent net charge resulting from three measured light organic acids, which include acetate, formate, and oxalate.

periods of lowest measured OC. While not yet determined, there are several possible explanations for this. For example, one explanation would be contamination of the system by a cation such as ammonium, though one would expect to see a systematic bias rather than only occasional influence. Another more likely explanation is that a negatively charged species, such as a light organic acid, may be present in aerosol only under conditions of limited OC, which is not accounted for in the charge calculation.

SULFUR STUDIES

Investigating the possible sources of sulfur was an a priori interest in this study and stems from the observation that local speciation measurements, which measure sulfate by chromatography and sulfur by XRF, suggest that there may be a non-sulfate source of sulfur present in the Fairbanks air shed. Of note, as illustrated by Figure 4, existing sulfate and sulfate data shows a substantially noisy

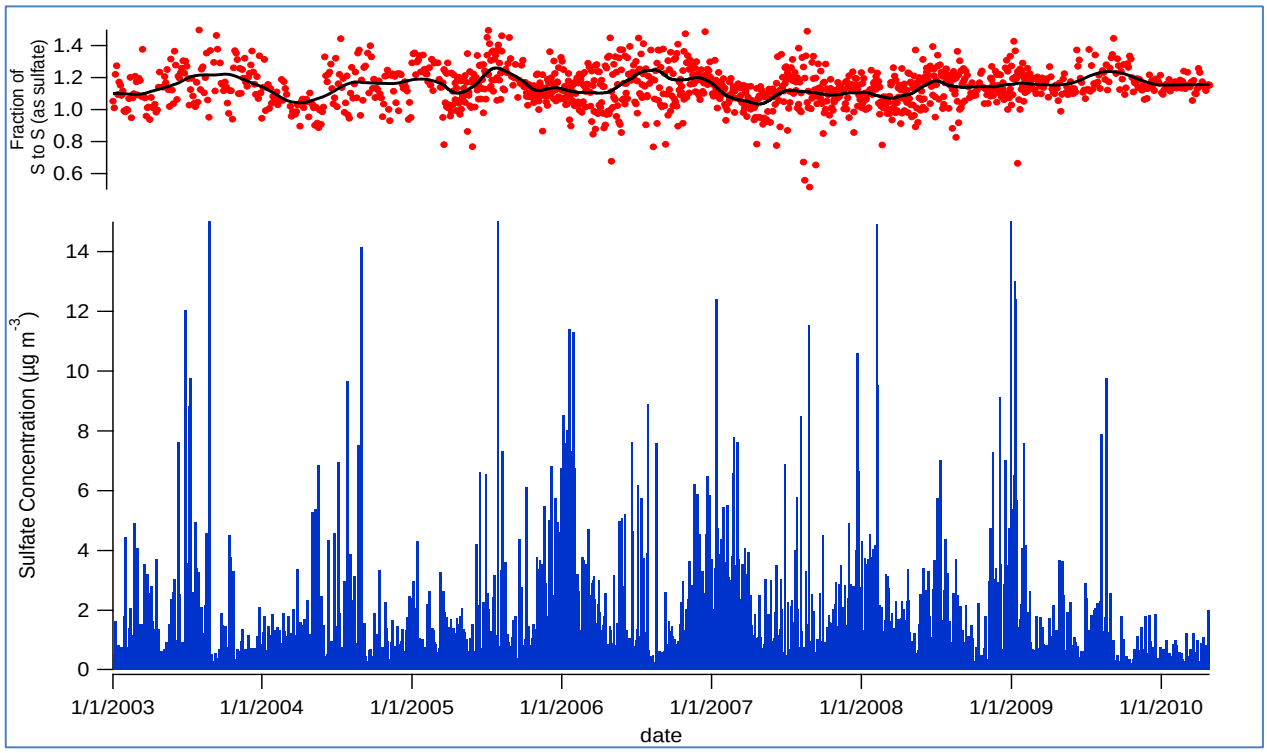

Figure 4: Time series of speciation data collected by FNSB staff since 2003. Data on bottom is daily sulfate measurements, and plot at top represents the fraction of total sulfur to sulfur calculated from measured sulfate. Total sulfur is measured directly by XRF, and sulfate is measured directly by ion chromatography.

pattern in the ratio of sulfur to sulfur (as sulfate). A clear divergence from unity can be observed suggesting that there is a possible unmeasured, stoichiometrically-adjusted sulfur source not captured in a collocated measure of sulfate. This ratio does have broad trends, but they do not appear to correspond with measured sulfate, which appears as highly variable in concentration and time.

Because this study collected its own filter measurements, we can empirically investigate the possibility of 'missing sulfur' by sequential analysis by non-destructive X-Ray Fluorescence Spectroscopy, followed by filter processing and chemical analysis of dissolved ions. The methods

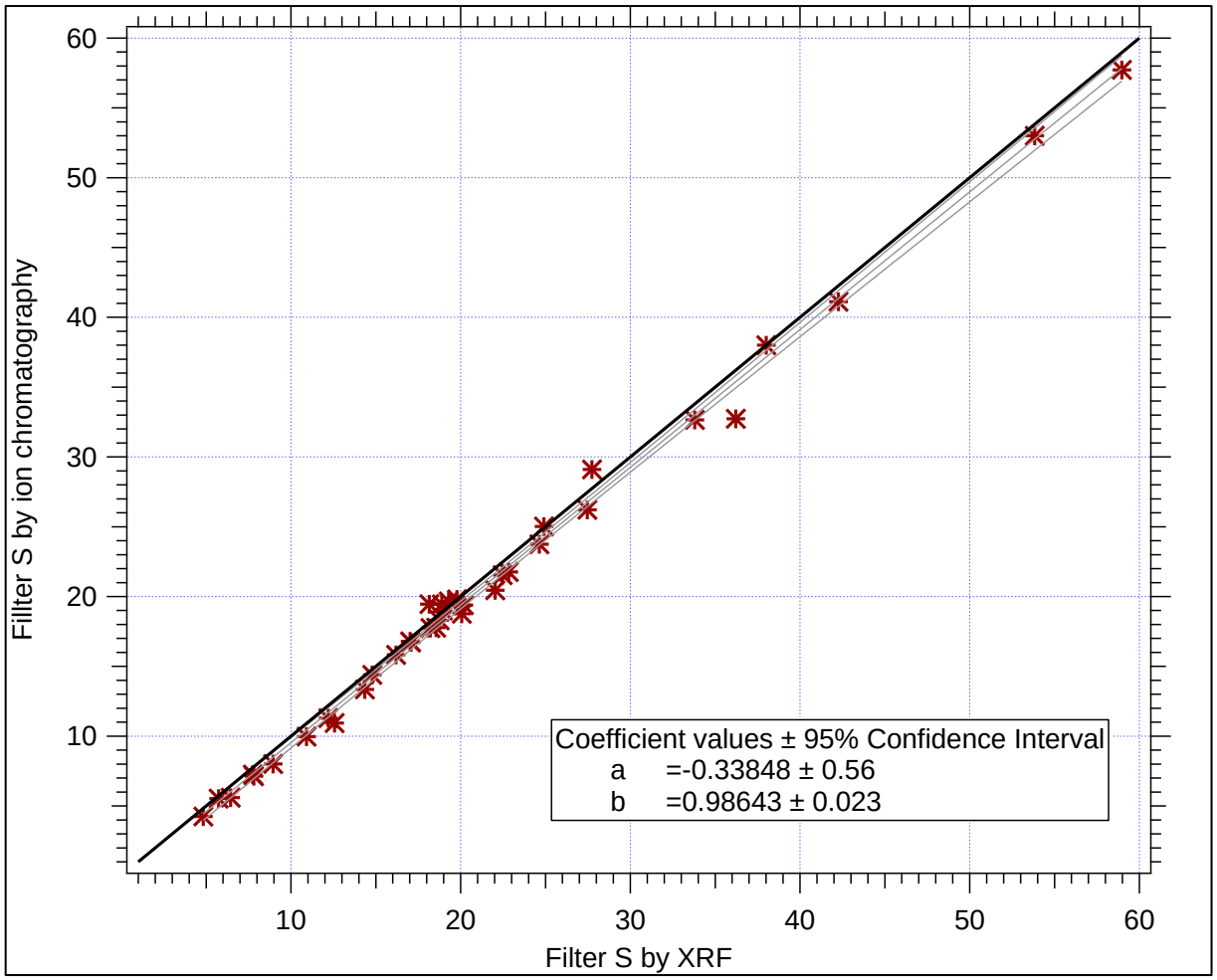

Figure 5: Regression plot of sequentially analyzed filters for sulfur concentration. Filters were first analyzed by XRF followed by ion chromatography for a measure of sulfate. Linear fit coefficients are also included and report a correlation coefficient of 0.97.

for this process were similar to the method used to analyze the aliquots collected by the PILS. The results, as shown in Figure 5, show a very high degree of correlation between measured S as sulfate and directly measured S by XRF. Regression slope approaches statistical unity, with a statistically insignificant intercept. These findings clearly suggest that any bias seen in the presence of sulfur across different measurements are not likely because of a unmeasured sources of ambient sulfur; the most likely explanation is that there is some bias introduced because of methodological reasons such as differential absorption related to different filter materials, systemic bias introduced by post-collection filter processing, or gas-phase intrusion resulting from the extreme cold experienced in Fairbanks. While the answer to this problem is still elusive, it should be noted that sulfur comprises a relatively small fraction of overall PM loading and this small bias, on average, may represent just a few tenths of percent of aerosol (by mass) in the Fairbanks region.

Further analysis follows in the section on preliminary analysis of XRF data.

EC AND OC

By mass, OC was one of the largest contributors to PM2.5 mass observed at this location during the study. EC, which was a much smaller fraction by mass, was well correlated with OC suggesting common sources. Of particular note as illustrated in Figure 6, OC and EC are generally well correlated with one another during this study. The OC to EC ratio was generally between 4-5,

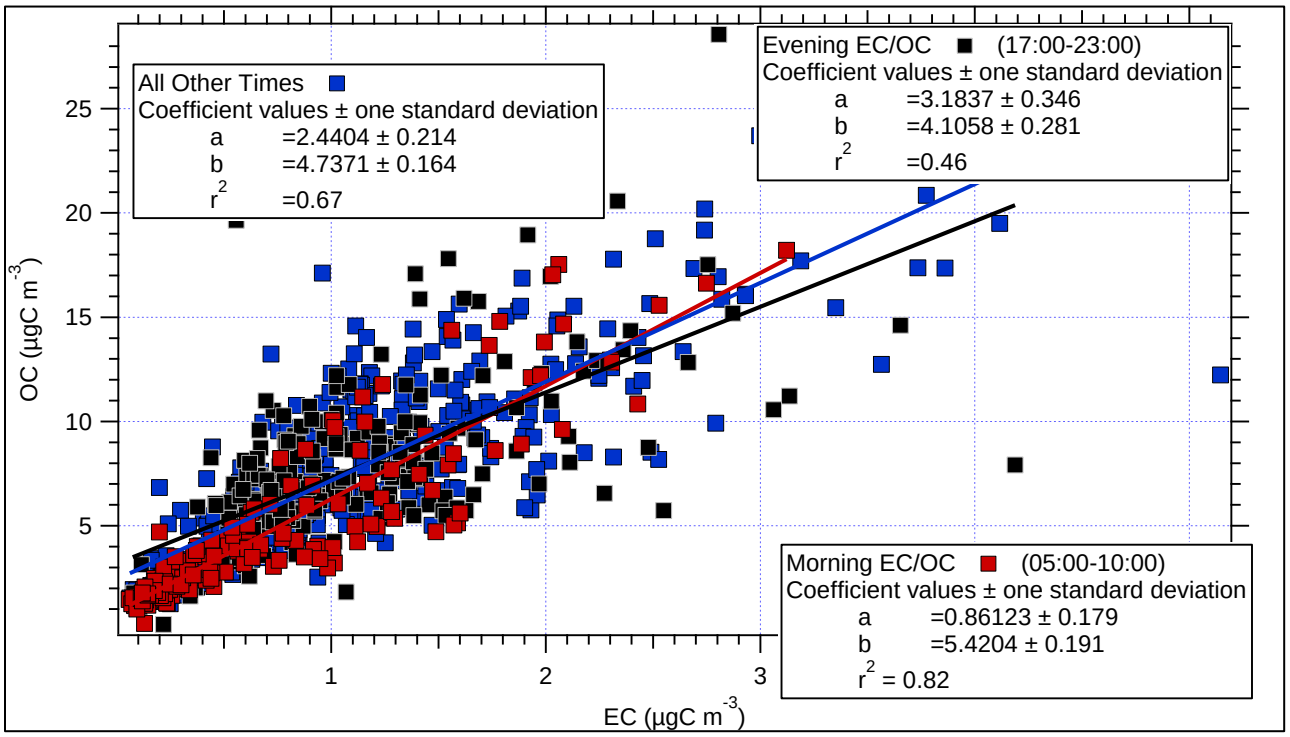

Figure 6: Measured organic carbon compared to measured elemental carbon (collected at same time). Data are binned to different time periods to show comparison between morning, evening, and all other times. Regression statistics are for a linear fit.

which is somewhat higher than urban values reported in the literature [10-14] and is more consistent with the higher values observed in biomass burning plumes [15-18], though this is an overly simplified analysis. More work is indicated to investigate these ratios further. A somewhat different regression was observed when the data were binned between morning, evening, and all other times. Tighter correlations and higher ratios were observed (Figure 6) in the morning compared to the evenings, suggested a different source process is occurring at this time. The lowest ratios and the less correlated data are observed in the evenings, with data from all other times falling between the two. This finding suggests that during morning periods, sources that are attributed to OC and EC (which themselves are tightly correlated) are more likely to emit OC per unit of EC than observed in the evenings. Possible explanations for this may include different combustion characteristics that emit OC and EC that are more conducive for OC formation in the morning compared to the evening. Likewise, combustion conditions in the evening appear to emit less OC per unit EC, providing another line of evidence suggesting different formation mechanisms.

Table 3: Univariate statistics for organic and elemental carbon measured during this study. Reported values include mean, median, standard deviation, range, and the number of measurements collected during this study. Llod denotes measurements below the limit of detection.

	Mean, µg m^{-3}	Median, µg m^{-3}	Std Dev, µg m^{-3}	Range, µg m^{-3}	n
Organic Carbon	6.47	5.92	4.62	(0.03, 33.4)	505
Elemental Carbon	0.90	0.78	0.69	(llod, 3.86)	509

While much remains to be analyzed, it appears that OC and EC in the Fairbanks region are most likely associated with biomass burning. A substantial residential heating demand is required in this community during the winter, and wood burning remains an economically efficient fuel source for the community. Unfortunately, this has resulting in a preponderance of OC and EC in the Fairbanks

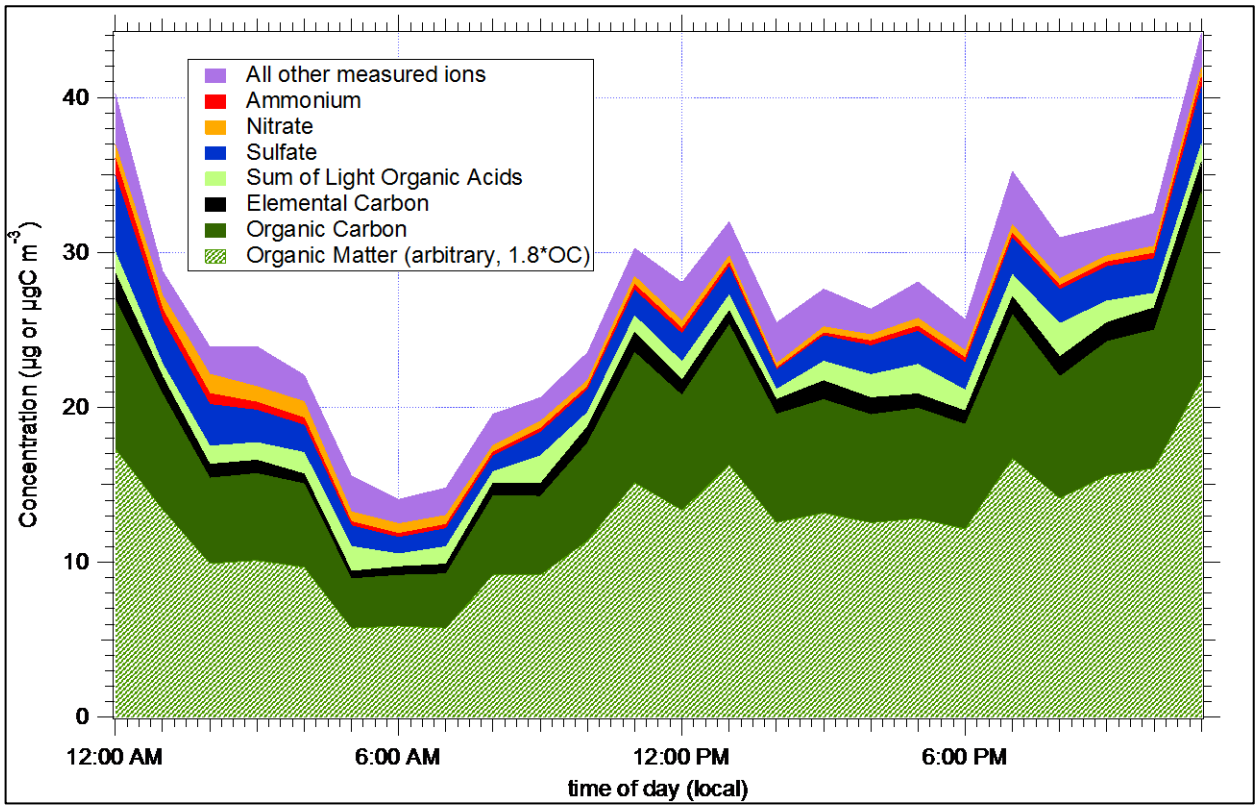

Figure 7: A composite diurnal profile for ~270 hourly measurements of OC, EC, and most ions. Organic matter is estimated as 1.8 times the measured OC value. Data are binned to each hour of the day and the mean value is presented here. Several lesser ions are binned into a separate composite group ('all other measured ions') to simplify this plot

air shed linked to these fuels, and it would be wise to investigate this issue further in hopes to better identify the mechanistic conditions leading to these different emissions profiles.

The data from this study were concatenated into a single, diurnal profile and plotted in Figure 7. While a number of components were measured during this study, organic matter – that is, the functional groups that are part of the organic particle, but not accounted for in the measure of carbon – is only estimated here. We use an arbitrary, but reasonable, value of 1.8 for the OM-to-OC ratio, and included this in the profile. Figure 7 shows a clear drop in concentration in the early

morning, with distinct peaks occurring around noon, 7PM, with highest observations around midnight local time. Ion composition is generally uniform throughout the day with some deviations in sulfate apparent throughout the day. Notable, however, is the dominance of OC and OM across the entire day, with these components reaching a minima around 6AM and a maxima at midnight.

This profile, at least subjectively, is consistent with wood burning as the dominant source of aerosol in this community. One might expect to see a declining emission rate between the evening and early morning as wood burning devices start to self-extinguish; a rapid increase in emissions follows in the morning as there is an increased demand for residential heating. The spike near midnight may be attributed to residential space heaters which are typically refueled to ensure continuous heating through the night and early morning.

XRF (PRELIMINARY)

As part of additional measurement efforts, the Borough has initiated a longer term study in the winter/spring of 2012 using a novel speciation instrument that provides hourly measurements of metal composition from PM2.5. This method is accomplished by way of a newly developed semicontinuous XRF installed at a ground location in Fairbanks. An initial look at this data is enclosed here, but does not represent a full analysis. Univariate statistics describing the dataset, as of 06 Jan 2012 are included in Table 4.

Table 4: Univariate statistics for the range of metals measured during the ongoing field study. Reported values include mean, standard deviation, max, and min values. All data are reported as nanograms per cubic meter, adjusted for standard temperature and pressure. Total number of measurements is 261 as of January 6, 2012, with data collection currently ongoing.

	Average	Stdev	Min	Max		Average	Stdev	Min	Max
SULFUR	868.169	760.360	0.076	3348.000	**ZINC**	42.448	42.982	0.116	254.743
POTASSIUM	158.202	100.821	0.941	568.123	**GERMANIUM**	0.129	0.102	*LLOD*	0.777
CALCIUM	24.719	93.944	*LLOD*	834.172	**ARSENIC**	0.117	0.500	*LLOD*	3.642
SCANDIUM	0.127	0.249	*LLOD*	1.486	**SELENIUM**	0.052	0.065	*LLOD*	0.372
TITANIUM	0.949	0.877	*LLOD*	4.754	**BROMINE**	3.291	3.250	0.049	24.975
VANADIUM	0.084	0.133	*LLOD*	0.729	**RUBIDIUM**	0.220	0.196	*LLOD*	1.122
CHROMIUM	0.087	0.240	*LLOD*	2.242	**STRONTIUM**	2.177	8.863	0.203	127.562
MANGANESIUM	0.525	0.821	*LLOD*	8.083	**SILVER**	54.473	178.273	0.204	1378.000
IRON	27.536	32.076	2.400	280.647	**CADMIUM**	19.157	52.453	1.096	588.461
COBALT	0.020	0.054	*LLOD*	0.504	**BARIUM**	0.930	1.547	*LLOD*	15.086
NICKEL	0.220	0.177	*LLOD*	1.645	**MERCURY**	0.001	0.010	*LLOD*	0.157
COPPER	3.997	3.263	0.918	46.591	**LEAD**	4.443	4.740	0.719	37.569

Transition metals are useful for source identification initiatives to provide quantitative information on elements that are released by specific sources, even if the overall concentrations of the elements are quite small. Figure 8 depicts a time series of concentration following elements with tracers through to mainly derive from coal combustion, although the important caveat that these

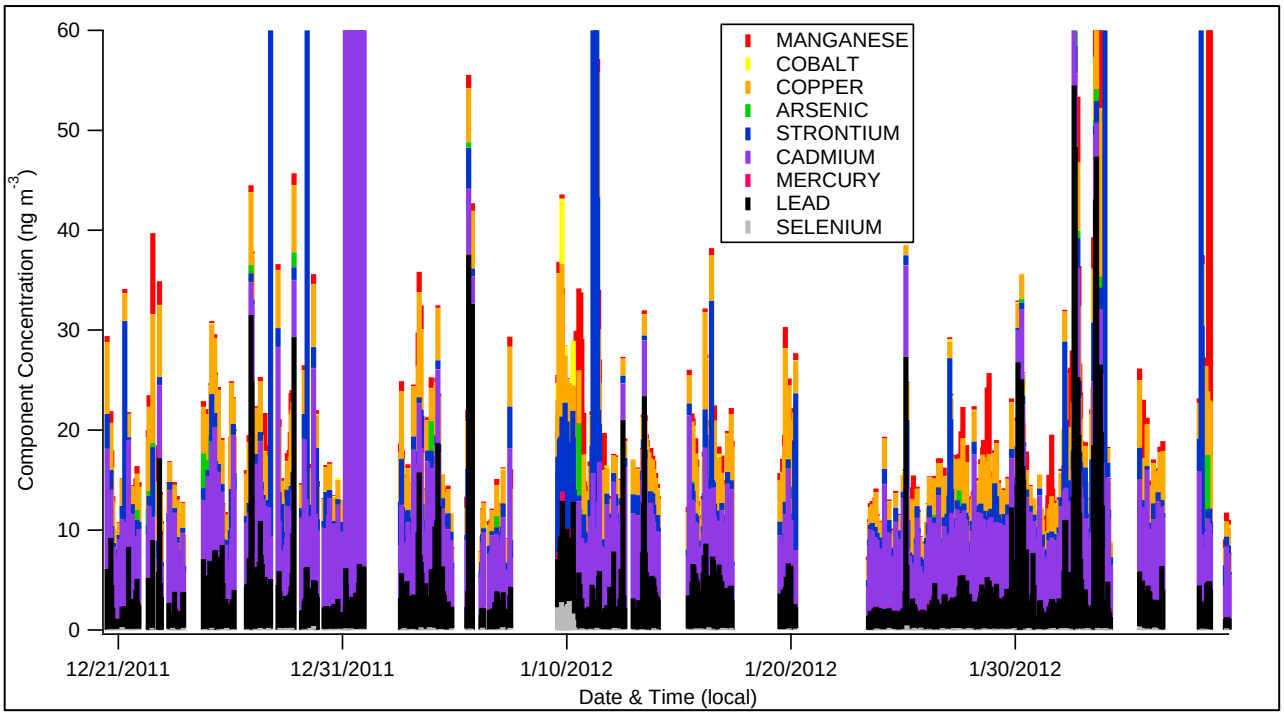

Figure 8: Time series of preliminary XRF data for selected metals thought to be linked to coal emissions. Gaps in data represent periods where the instrument was not reporting data.

components have not yet been confirmed as markers of coal combustion; further analyses to this effect are continuing.

Substantial texture in these elements suggests highly variable influence from coal combustion sources at this location. While overall elemental concentrations are in the single to 10's of nanogram per cubic meter range, some notable trends do appear in the data. For example, strontium has been anecdotally linked to spikes in PM concentration during times when air advection would suggest influence from the nearby coal power plant. Mercury and selenium also appear infrequently, but do so at clearly detectable levels well above a background concentration of less than ~0.5 ng m^{-3} and are generally throughy to be markers of coal combustion.

At least three distinct events are shown in this figure, occurring on January 1, January 12, and Feb 2-3 that warrant greater investigation. The event on January 1 was characterized by nearly 1 microgram per cubic meter of cadium; other elements were also substantially elevated during this time period. Because this event occurred just after midnight, it is likely that this is linked to local fireworks celebrations in the community. While this anecdote has little relevance for the broader air quality problems experienced by the borough, it does show the specificity and power of these measurements in the context of a complex aerosol setting. The other events are characterized by increases in strontium concentration, which is thought to be linked to coal emissions, though other sources may also be responsible for this emission.

It is important to point out that Figure 8 depicts a time series of densely-packed concentration for only a fraction of the elements. Though this approach provides a measure of concentration magnitude and temporal time scales, a more robust approach would be to use statistical modeling techniques to refine this data; such techniques include PMF, PCA, or other source apportionment approaches. It should also be noted that information on 13 additional elements (not plotted here) are also available, and these data are expected to be collected until the end of winter 2012. These approaches are forthcoming and not included in this report.

High time resolution data for sulfur was also exploited to begin investigating sulfur emissions and sulfate formation processes. The time period of study for this was from December 20th, 2011 through January 13th, 2012 and included 417 hourly data points measuring particulate sulfur by

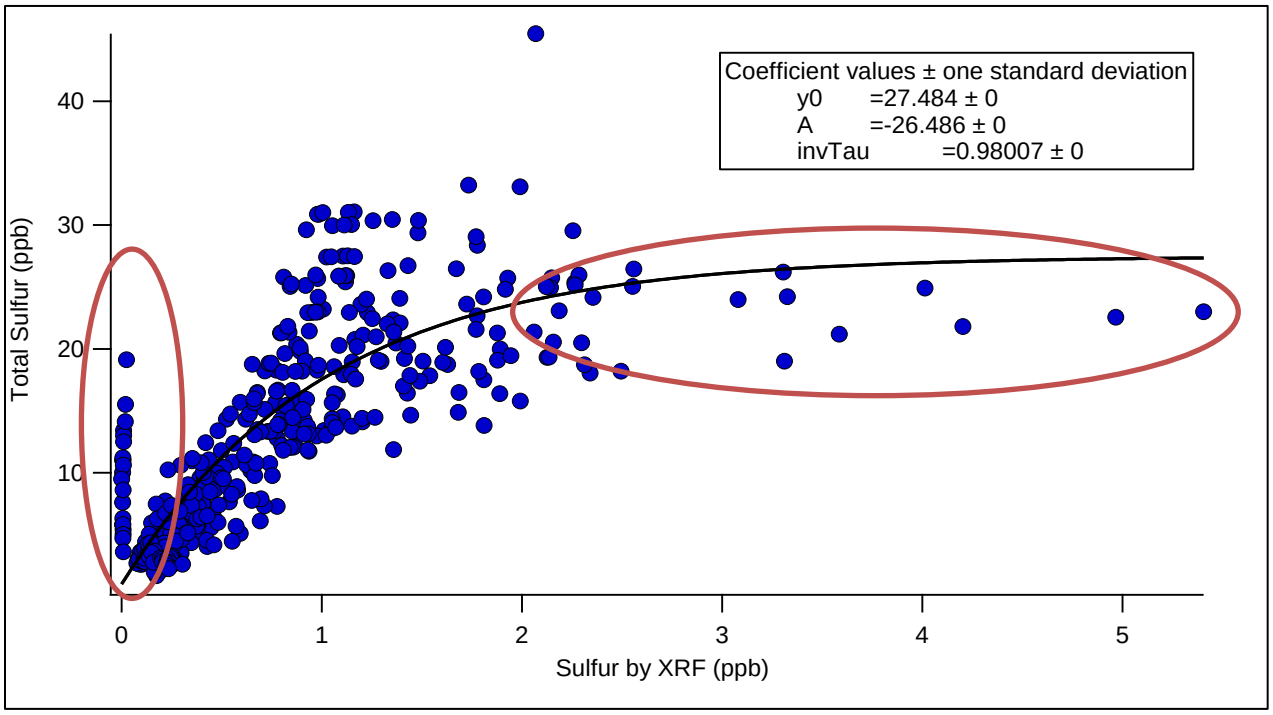

Figure 9: Total sulfur compared to sulfur measured by XRF. Total sulfur is defined as the sum of particulate sulfur by XRF with the sulfur observed in the gas phase as sulfur dioxide. Measurements are collocated. Circled regions highlight two distinct regimes; the left being a regime where particulate sulfate is absent even in the presence of gas-phase sulfur and the second regime (right) where total sulfur appears with a higher fraction in the particulate phase. This second regime may represent the most advantageous conditions for gas-to-particle conversion processes. Fit line is a simple exponential decay function.

XRF and sulfur as sulfur dioxide. Figure 9 plots total sulfur as defined by the sum of particulate sulfur by XRF and sulfur from SO2 compared against total particular sulfur by XRF. At least two different regimes are immediately apparent from this data; one that shows conditions where no aerosol is detected (presumably during precipitation events) and a second where sulfur conversion to particles is effective. In the latter case, an exponential decay appears to describe the latter where SO2 concentrations were generally limited to 25-30 ppb. An exponential curve fit to the data appears reasonable, but greater investigation is warranted. Under most conditions, sulfur conversion is a widely understand chemical process that occurs it he presence of sulfur dioxide, water vapor, and sunlight. The region lacks strong sunlight, and thus the typical mechanism for sulfate conversion is probably quite weak. Nonetheless, the presence of sulfate in the aerosol

stream in Fairbanks confirms that this conversion process exists, and appears to limit SO2 concentration to less than ~30ppb.

In terms of identification of sulfur sources, it is not yet clear where these sources can be attributed. Likely sources include coal power generation, coal residential heating, or combustion of fuel oils for residential heating. Much greater analysis is indicated to develop a more robust profile.

CONCLUSIONS AND FUTURE DIRECTIONS

While data from these studies continues to be collected at the time of writing this report, it is clear from the winter 2011 studies that aerosol chemical composition is complex and unlike any other air shed in the United States. With the exception of occupational environments, it is relatively rare that greater than 20 $\mu gC\ m^{-3}$ are observed at any time in US, yet this is typical on cold winter days in Fairbanks. Thus, Fairbanks is subjected to unique and important stressors on its airshed.

The data are consistent with a profile that fits a primary influence from biomass burning. High levels of OC and EC are routinely observed, and follow a pattern one might expect from a community that relies on wood burning to meet sizeable demands for residential heating. EC is well correlated with OC suggesting common sources, and the OC to EC ratio is consistent with sources derived from biomass combustion.

High temporal resolution measurements of ion concentrations showed relatively low (when compared with OC and EC) levels and suggest only a limited influence. Measured ions were dominated by sulfate, ammonium, and nitrate, but only at levels of approximately 10-20% of observed PM2.5 mass. While ions derive from a number of sources, sulfate is mainly derived from coal and non-road distillate combustion, the latter being defined mainly by home heating oil. Because we observed modest concentrations of sulfate (typically 2-4 $\mu g\ m^{-3}$), we cannot exclude these sources as contributors to the air quality concerns in Fairbanks, but they likely play only a minor role in PM2.5 loading in the community.

Combining these measurements, a strong diurnal profile was observed providing further evidence of anthropogenic influence on aerosol composition in Fairbanks. While there was some hour-to-hour variability in ion concentration, the vast majority of the diurnal profile was driven by OC, and the estimated organic material component that was not measured in this study. Further limited analysis examined sulfur concentrations in both gas and particle forms and suggest that there are at least two regimes related to sulfur conversion: one where sulfur remains in the gas phase with only trivial particulate sulfur, and another where sulfur conversion to particulate form appears to follow an exponential decay pattern. This suggests that the conditions necessary for this conversion are, in fact, present.

Future work on this data is extensive. One project includes a comparative analysis with fuel source profiles collected during another investigation by FNSB. By incorporating updated fuel profiles, which provide detailed chemical component information from each type of fuel used in the region, we hope to be able to statistically connect those profiles with the observations in Fairbanks. Another project will incorporate these results into the Chemical Mass Balance modeling currently performed by investigators at the University of Montana. Additional planned analyses include investigating the high time resolution XRF data in much greater detail, with a focus on chemical mass balance and positive matrix factorization modeling, as well as coupling this data with in-progress modification of the CMAQ model for purposes of refining and validation.

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Fairbanks North Star Borough $PM_{2.5}$ Non-Attainment Area CMAQ Modeling

First "Quarterly" Report Phase II

Reporting Period: January 1, 2012 – April 30, 2012

Project: 398831 CMAQ-DEC 2012

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1. Background

Due to deadlines that the Alaska Department of Environmental Conservation (DEC) had to meet with respect to the development of the Fairbanks State Implementation Plan (SIP), DEC had postponed the due date for the Quarterly Report. They wanted to provide time to UAF to perform investigations on questions DEC personnel needed to answer at their deadlines. Various phone conferences were held where UAF reported on the progress and the results of the investigations performed to answer DEC's urgent questions. Due to this DEC approved and requested later submission of the Quarterly Report, this report covers a longer period than three month.

The Community Multiscale Air Quality (CMAQ) model version 4.7.1 was adapted to simulate the $PM_{2.5}$-concentrations in Fairbanks, the interior of Alaska in phase I (Mölders and Leelasakultum 2011). In the time covered by the current report, we applied the adapted CMAQ to a two-week episode in January/February, 2008 and November, 2008 each for further improvement and investigations and understanding of the $PM_{2.5}$-situation in the Fairbanks nonattainment area.

The episode January, 2008 was first used to evaluate the performance of the CMAQ model. According to the final report of phase I (Mölders and Leelasakultum 2011), the model was configured to use the global mass-conserving Yamartino advection scheme, the eddy vertical diffusion module, the Carbon Bond Five (CB05) lumped gas phase chemistry mechanism which using the Euler Backward Iterative (EBI) as solver, the AERO5 aerosol mechanism, the photolysis inline module and the Asymmetric Convective Method (ACM) cloud processor to compute convective mixing (cloud_acm_ae5).

Several changes were made to the CMAQ code with the purpose of improving the prediction of $PM_{2.5}$-concentrations and for representing the Fairbanks domain conditions:

1. The default initial condition and boundary conditions were replaced with the developed Alaska specific initial and boundary condition.
2. The dry deposition code were modified to made the dry deposition occurred in the tundra-typed land-use, which is the major type of land-use in Fairbanks domain. Some other changes related to the dry deposition include the adjustment for the resistance to snow of SO_2, the soil resistance, the canopy cuticle resistance to be functioning with the low temperature, reducing of wet canopy resistance (see Mölders et al. 2011), reducing and scaling the area-to-volume ratio for buildings according to the urban fraction of Fairbanks, and increasing the pH value for snow/rain/wet surfaces to the average values found in Alaska.
3. The code in Meteorology-Chemistry Interface Processor (MCIP) version 3.6 for the minimum mixing height constant was reduced in accord with the observations in Fairbanks, and the minimal stomata resistances were also replaced.

4. The lowest and highest eddy diffusivity coefficients, which play an important role for the vertical distribution of concentrations, were decreased by half, and scaled according to the fraction of land-use.
5. The wind-speed in the valley of domain was reduced by half for calibrating the over-estimation of the simulated wind-speed by WRF.

The evaluations of the performance of the Alaska adapted CMAQ from phase I considered the January/February episode. It showed that the mean average of 24h-average $PM_{2.5}$-concentrations at the grid-cell that holds the official monitoring site is 38.07μg/m^3, whereas the mean average of observed data is 41.7μg/m^3. The ratio of means (sim/obs) is 1.13. The mean bias, mean fractional bias, mean error and mean fractional error are -3.76μg/m^3, -0.32%, 13.13μg/m^3, 34.51%, respectively. The CMAQ model overestimated during January 31 to February 2, and underestimated during February 5 to February 9. The correlation coefficient between the observed and simulated 24h-average $PM_{2.5}$-concentrations is 0.39 for 13 pairs of data. Bugle plots and soccer plots indicate weak performance on February 2 and February 8, 2008 (AKT). The Alaska adapted CMAQ model simulated the speciation of total dry $PM_{2.5}$ as 48% organic carbon (OC), 6% elemental carbon (EC), 4% nitrate, 3% ammonia, 2% sulfate and 36% others. The observed speciation of total dry $PM_{2.5}$ was 41% OC, 6% EC, 5% nitrate, 9% ammonia, 20% sulfate, and 19% others. The model obviously underestimated the sulfate compositions and ammonium, slightly overestimated OC and had very good performance for nitrate and EC.

Based on the CMAQ's output in phase I, Sierra Research Inc. had improved the emission input data, and Penn State had improved the meteorological input data for the CMAQ. Hereafter, we referred to the January/February episode data before the improvements as January v1 and we referred to the January/February episode data after the improvements as January v2. This first quarterly of Phase II will cover:

1. The simulations of the adapted CMAQ for the January v1 episode including the Relocatable Air Monitoring System (RAMS) data, $PM_{2.5}$ speciation and the sensitivity tests we performed
2. The comparison of simulations and the model performance for the November episode performed with and without reduction of the wind-speed in the valleys, including the simulations for $PM_{2.5}$ speciation and various sensitivity tests
3. The comparison of simulations and the model performance for the January v2 episode with and without CMAQ modifications
4. The statistical performance of the November and January v2 episodes with the CMAQ modifications and the performance evaluation for the $PM_{2.5}$-speciations in the January v2 episode
5. The process analysis results for the November episode and January v2 episode

2. Activities

2.1 Evaluations of the Alaska adapted CMAQ for the January v1 episode with RAMS data, $PM_{2.5}$ speciation and the sensitivity tests

The significance tests in the final report of phase I showed that the simulated and observed 24h-average $PM_{2.5}$-concentrations had statistical differences due to the low sample number. Therefore, the Relocatable Air Monitoring System (RAMS) data of the $PM_{2.5}$-concentrations were also included for evaluating the adapted CMAQ performance. The locations of the RAMS (Fig. 1) were Julie Shelton's house (N 64.88º W147.68º) for January 18 to January 24, David Leone's house (N 64.80º W147.45º) for January 24 to January 31, Anne Ruggle's house (N 64.88º W147.82º) for January 31 to February 7, Alaska Rubber (N 64.80º W147.70º) for February 7 to February 14 (see Fig. 1).

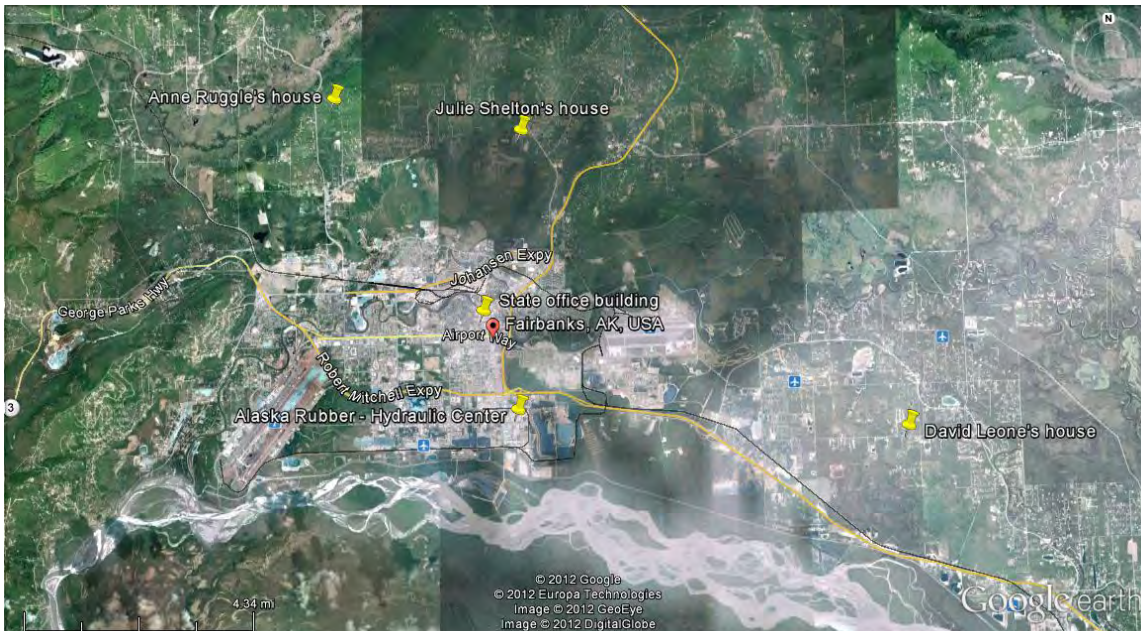


Fig. 1 Locations of the Relocatable Air Monitoring System (RAMS) and the State Building site.

The temporal evolution of the observed RAMS $PM_{2.5}$-concentrations were compared with the simulated $PM_{2.5}$-concentrations (Fig.2). The RAMS data suggested some spatial and temporal offsets during the local extremes, for instance, the adapted CMAQ model underestimated during January 26-January 28, and during February 8-10 (Fig. 2).

Combining the simulated and observed data of 24h-average $PM_{2.5}$-concentrations from both State Building and RAMS sites led to the increase of correlation coefficient to 0.51 for 29 pairs of data. There is no statistically significant difference at the 95% confidence level for both hourly and daily data. The scatter plot between the simulated and observed 24h-average $PM_{2.5}$-concentrations show the agreement of majority within the factor of two (Fig.3). For those pairs of data, that have agreement less than a factor of three, are the RAMS on January 27, February 2,

8, 9, which are sites above the inversion. Possibly, this is due to sub-grid scale effects, which are not resolved by the model.

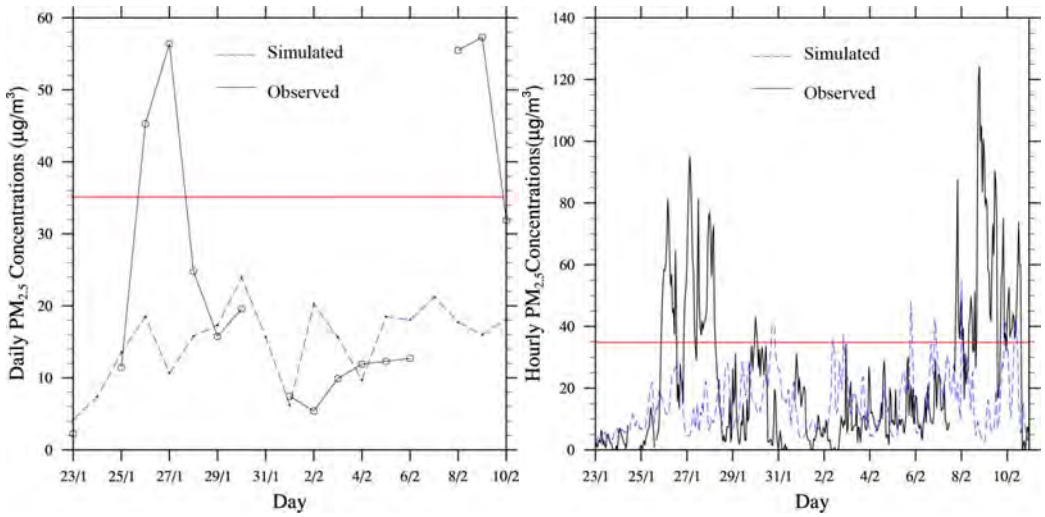


Fig. 2 Time series of the adapted CMAQ simulated (blue dashed line) and RAMS observed data (black solid line) for (a) 24h-average $PM_{2.5}$-concentrations and (b) hourly $PM_{2.5}$-concentrations (right) for January v1

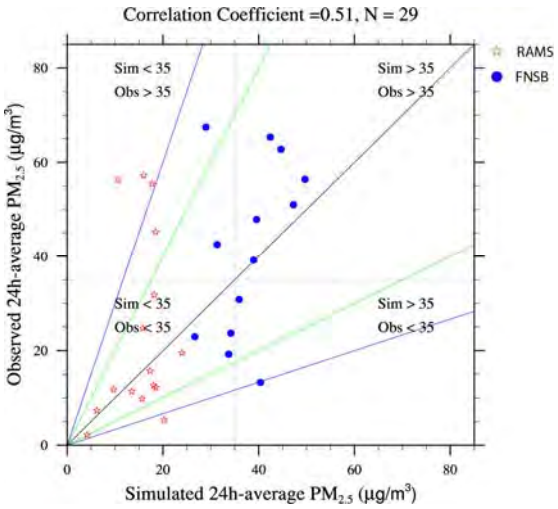


Fig. 3 Scatter plots of 24h-average $PM_{2.5}$-concentrations for January v1. The blue dots and red stars represent the data for the State Building and RAMS sites, respectively. The green line indicates the factor of two and the blue line indicates the factor of three agreement between simulated and observed values. Note that 30% of agreement within a factor of two is considered good performance (Chang and Hanna 2004).

The bugle plots and soccer plots show the similar results as the scatter plots i.e. that most pairs of data outside the performance criteria (see Boylan and Russell 2006 for a definition of the criteria) are from the RAM sites located above the inversion (Fig. 4). Note that it is common

knowledge that models like WRF have difficulties capturing inversions in very complex terrain as they use the mean terrain height within a grid-cell as the representative height, while the measurements capture the actual terrain impacts (Mölders and Kramm 2010). At the State Building site, there are two pairs outside the performance criteria. They occurred on January 31 and February 2, when the model overestimated the $PM_{2.5}$-concentrations and the observed data were extremely low.

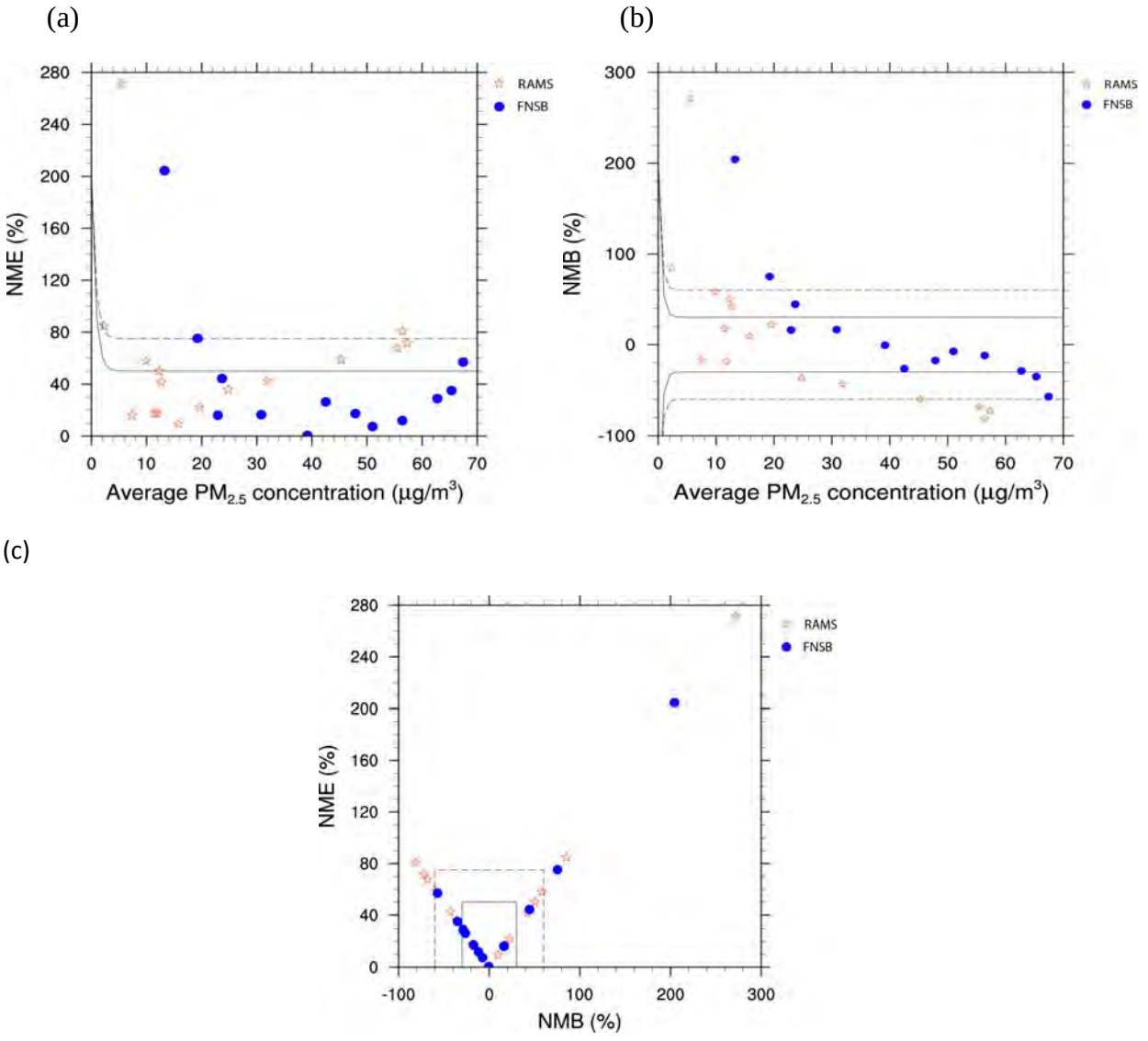


Fig. 4 Bugle plots of normalized mean (a) errors and (b) biases of simulated 24h-average $PM_{2.5}$-concentrations and (c) soccer plot of normalized mean errors and biases all determine with respect to the observations at the State Building site (blue dots) and RAMS sites (red stars) for January v1. The dashed and solid lines indicate the performance criteria and performance goals in accord with Boylan and Russell (2006).

The observed temperatures during January 31 to February 2 were the period when temperature rebounded slightly (PennState final report, 2011). WRF estimated too low surface temperatures on these days, for example, the WRF-simulated hourly surface temperature at 15 UTC on January 31 is about -30ºC (Fig. 5) in the Fairbanks nonattainment area, whereas the observed temperature at the Fairbanks International Airport at that time was about -24ºC. The too low temperatures would lead to enhanced gas-to-particle conversion than actually would occur with the correct temperature and lead to further over-prediction of the $PM_{2.5}$-concentrations at the State Building site.

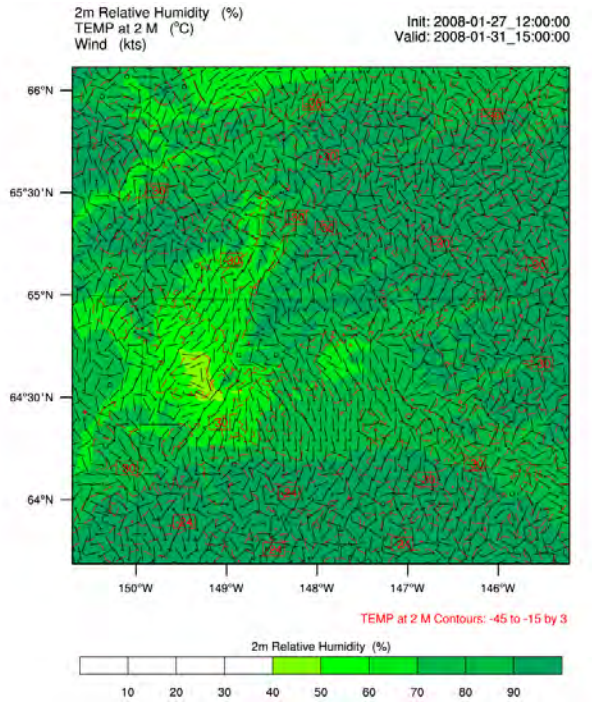


Fig. 5 Example of WRF simulated 2m temperatures (color), 2m relative humidity (contours) and 10m wind-speeds (barbs) in the Fairbanks domain on January 31 at 1500UTC.

The performance of the adapted CMAQ in simulating the $PM_{2.5}$-compositions was evaluated. The six days with pairs of observed and simulated $PM_{2.5}$-compositions were compared in bar charts and scatter plots (Figs. 6, 7). The adapted CMAQ model predicted best for OC and EC, which have high concentrations and make up large fractions of total $PM_{2.5}$. Simulated and observed sulfate and ammonium fail to agree within a factor of three. The bugle plots and soccer plots show similar results as the scatter plots, i.e., that most pairs of species data that fall outside the performance criteria are sulfate, ammonium and chloride (Cl) (Fig. 8). The Cl outlier occurred in the November episode as well (see later discussion), therefore we increased the initial and background Cl-concentrations at the lowest level according to the IMPROVE data in our simulations of January v2 and the November episode. The improved Cl-profiles are given in Appendix A. The NH_4-outlier may be due to underestimation of the NH_3 emissions (for a discussion on potential reasons for the NH3-emission underestimation see Mölders et al. (2012).

The adapted CMAQ underestimated SO_4 by five times the observed value, which requires improvement and further investigations. Some first results of these investigations are discussed later in this report, while other investigations are ongoing.

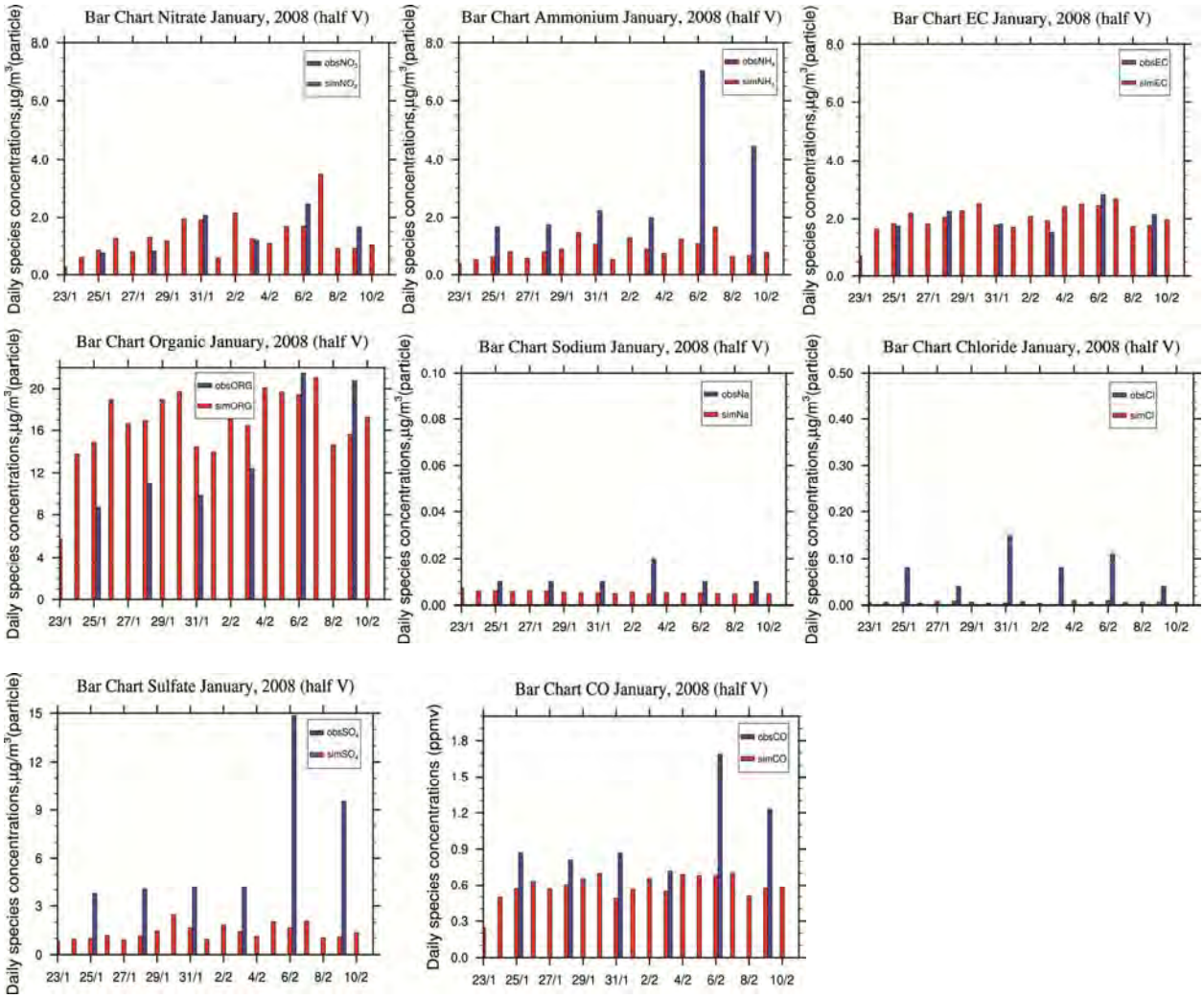


Fig. 6 Bar charts of observed (blue) and simulated (red) 24h-average $PM_{2.5}$-composition for NO_3, NH_4, EC, OC, Na, Cl, SO_4, CO for January v1. Note that this episode was run with 50% reduction of the near-surface wind speeds in the valleys (see Mölders and Leelasakultum 2011 for details on the simulation setup)

The 24h-average $PM_{2.5}$-concentrations at the State Building site were simulated for the case of without point source emissions, gas chemistry, aerosol chemistry, chemistry and compared with the observation data and the simulations, which include everything (reference/normal adapted CMAQ simulation), Fig. 9. It can clearly be seen that chemistry played a lesser role for the $PM_{2.5}$-concentrations than the emissions from point sources. The simulations wherein the point source emissions were turned off led to a decrease in $PM_{2.5}$-concentrations at State Building site of on average 3.9µg/m^3 (11%), whereas the simulation with turned off chemistry, aerosol

chemistry and gas chemistry led to decreased $PM_{2.5}$ concentrations by on average 2.0 (6%), 2.0 (6%) and 1.2µg/m^3 (4%), respectively. Note that in the adapted CMAQ model, turning off the aerosol chemistry resulted in the same results as turning off all chemistry. This behavior may be a hint that a process is missing in aerosol chemistry and/or aerosol chemistry is not taking place as too much water is in the ice phase.

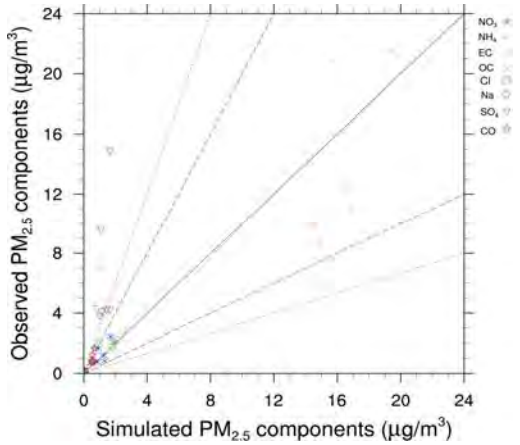


Fig. 7 Scatter plot of simulated and observed 24h-average $PM_{2.5}$-composition for January v1. See Mölders and Leelasakultum (2011) for details on the simulation setup

On the day which simulated the highest concentrations (49.7µg/m^3 on February 7), the chemistry process had the maximum contribution to the 24h-average $PM_{2.5}$ concentrations 4.9µg/m^3(10%) at the State Building. In this 4.9µg/m^3, the aerosol chemistry process contributed 3.9µg/m^3 (8%) to the total aerosol production of chemistry process.

(a) (b)

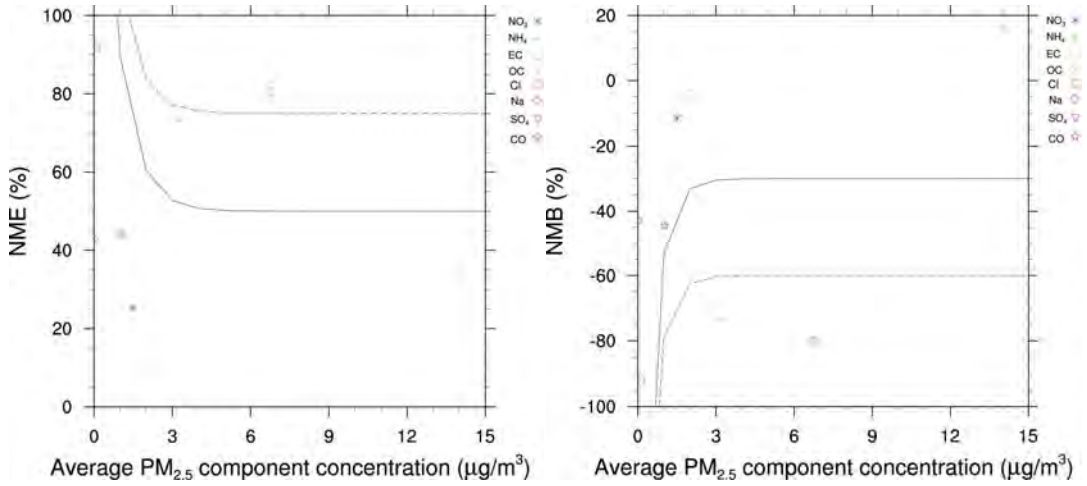


Fig. 8 continued on next page

(c)

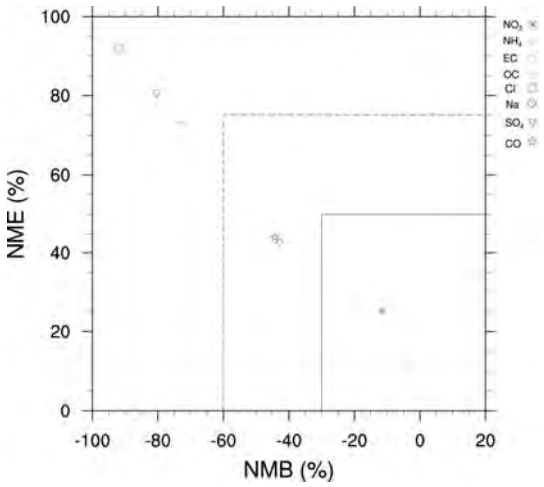


Fig. 8 Bugle plots of normalized mean (a) errors and (b) biases of simulated 24h-average $PM_{2.5}$-composition and (c) soccer plot of normalized mean errors and biases all determined with respect to the observations at the State Building site for January v1. The dashed and solid lines indicate the performance criteria and performance goals in accord with Boylan and Russell (2006).

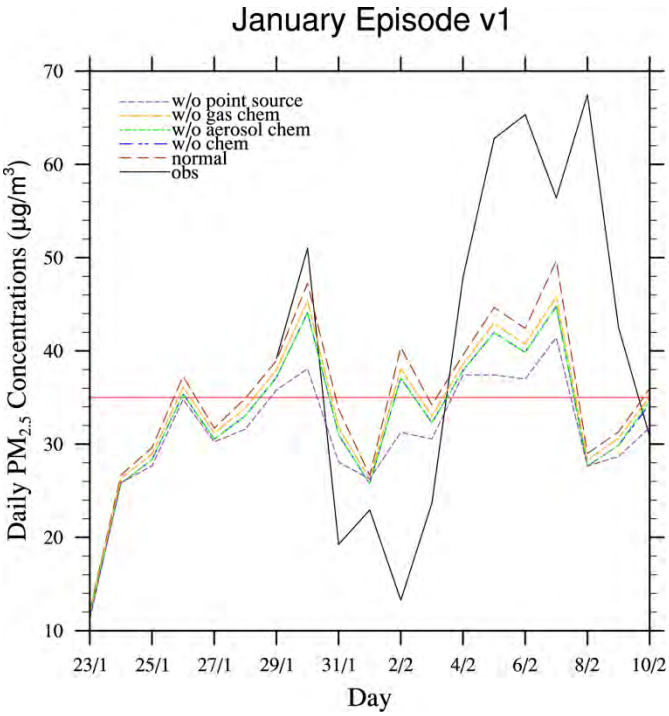


Fig. 9 Time series of observed (black solid line) and adapted CMAQ simulated data as obtained by various sensitivity tests that where performed without consideration of point sources, without consideration of gas chemistry, without consideration of aerosol chemistry, without consideration of chemistry and with consideration of all processes and emissions (reference/normal) for the 24h-average $PM_{2.5}$-concentrations at the State Building for January v1. The red solid line indicates the National Ambient Air Quality Standard of 35µg/m^3.

The highest and the second highest contribution from point source emission of 9.2 and 9.1µg/m^3 was simulated on January 30 and February 2. The percent contributions from point source emissions on these two days are 19% and 22%, respectively.

2.2 Comparison of simulations and their performance for the November episode with and without reduction of wind-speeds in the valleys

The November episode covers November 2 to November 16, 2008. The emissions developed for the November episode were updated by Sierra Research Inc. for the emissions from mobile sources, and include the emissions from airports. The comparison of the spatial distribution of emissions in the January v1 and November episode showed that the magnitudes of $PM_{2.5}$-emissions in the November episode are higher for the area north of the Fairbanks nonattainment area (Fig.10).

(a) (b)

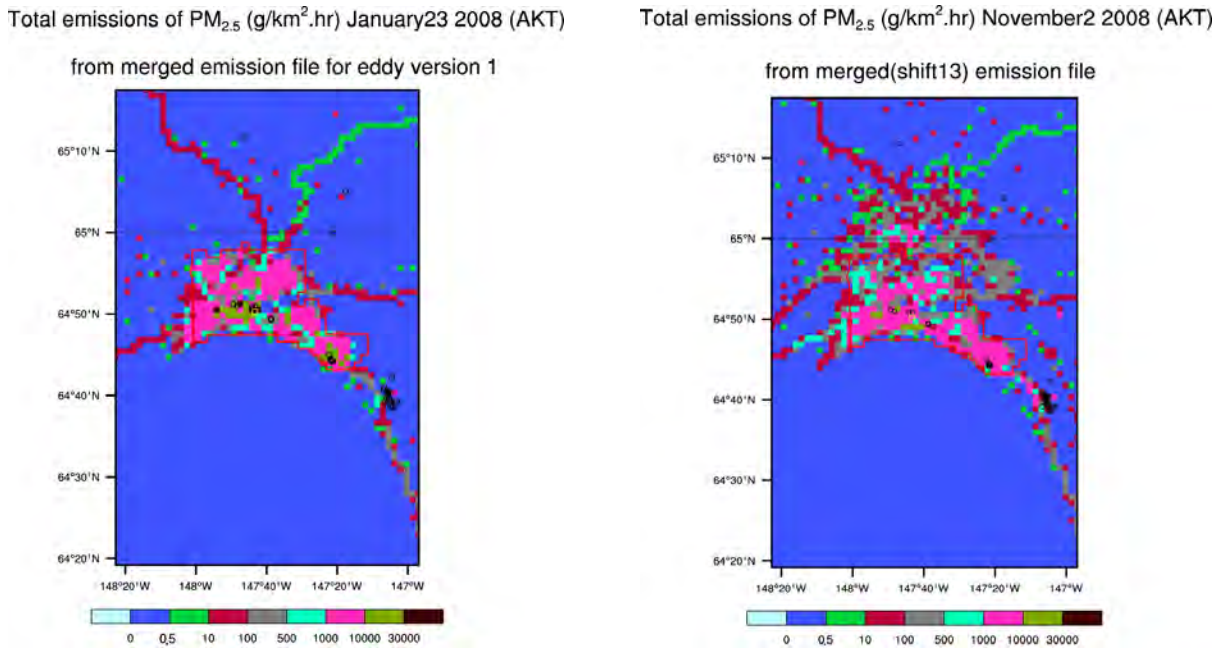


Fig. 10 Example of zoom in on the emissions as obtained from the Sierra Research Inc. emission inventory for Fairbanks for the (a) January v1 and (b) November episode. The red polygon indicates the Fairbanks nonattainment area.

In the January v1 episode, the wind-speeds in the valleys were reduced by half in order to increase the simulated $PM_{2.5}$-concentrations at the State Building site. As discussed by Mölders and Leelasakultum (2011) this reduction violates the continuity equation and was only a test to examine whether the strong overestimation of wind-speed is a potential cause for underestimation of $PM_{2.5}$-concentrations. Note that overestimation of near-surface wind-speeds

is a well known problem common to all meteorological models for simulations in areas with stagnant air conditions like in the Fairbanks area (see (Zhao et al., 2011), Mölders et al. 2012 for a discussion).

Our investigations showed that reducing the wind-speed by half is not required for the November episode as the emissions for November episode had been updated and increased by Sierra Research Inc. We therefore compare here the simulation results of the case study with reduction of wind-speed by half and the case study that used the original WRF-simulated wind-speeds.

The temporal evolutions of 24h-average $PM_{2.5}$-concentrations show that the case with reduction of wind-speed by half provides higher $PM_{2.5}$-concentrations at State Building site by on average 9.8µg/m^3 than the adapted CMAQ simulation with the original wind-speed. The impacts of the wind-speed reduction on the $PM_{2.5}$-concentrations varied with time. The highest difference in $PM_{2.5}$-concentrations was 14.1µg/m^3 on November 15, 2008 and the lowest differences in $PM_{2.5}$-concentrations were 6-7µg/m^3 during November 5 to 6 and 9 to 11 (Fig. 11). The simulated hourly $PM_{2.5}$-concentrations in the adapted CMAQ simulation with reduction of wind-speeds showed the higher concentrations as well (Fig. 12). The reduction of wind-speed during the relatively calm wind-periods probably resulted in the little differences.

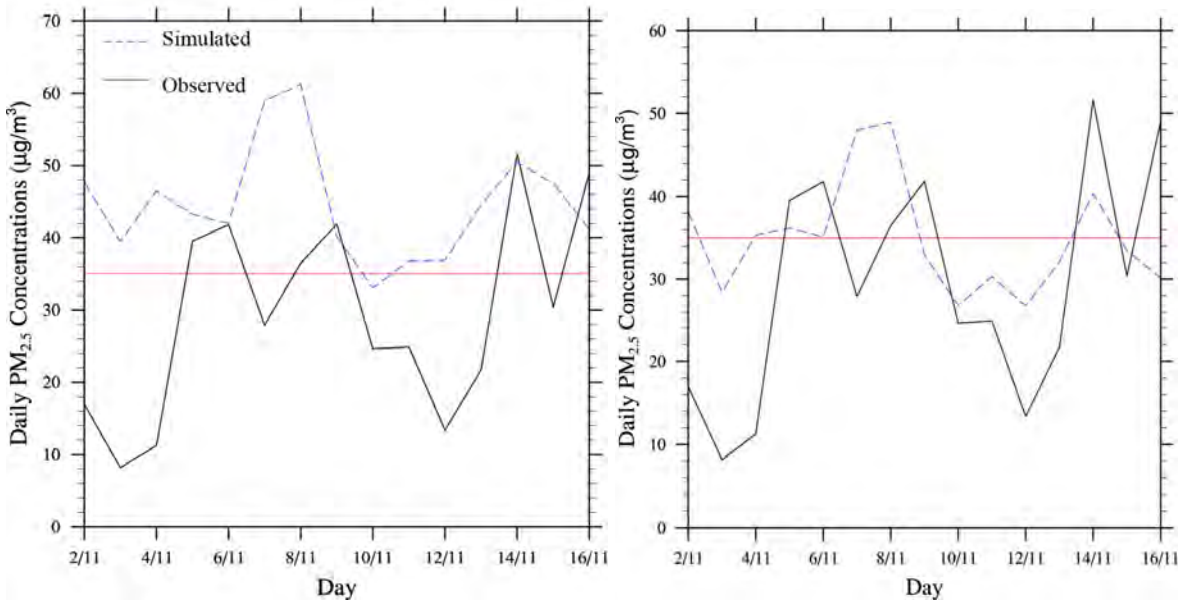


Fig. 11 Time series of simulated (blue dashed line) and observed (black solid line) 24h-average $PM_{2.5}$-concentrations as obtained with the adapted CMAQ simulation that used reduced wind-speeds in the valleys (left) and the adapted CMAQ simulation that used the original wind-speed from WRF (right) during the November episode at the State Building site.

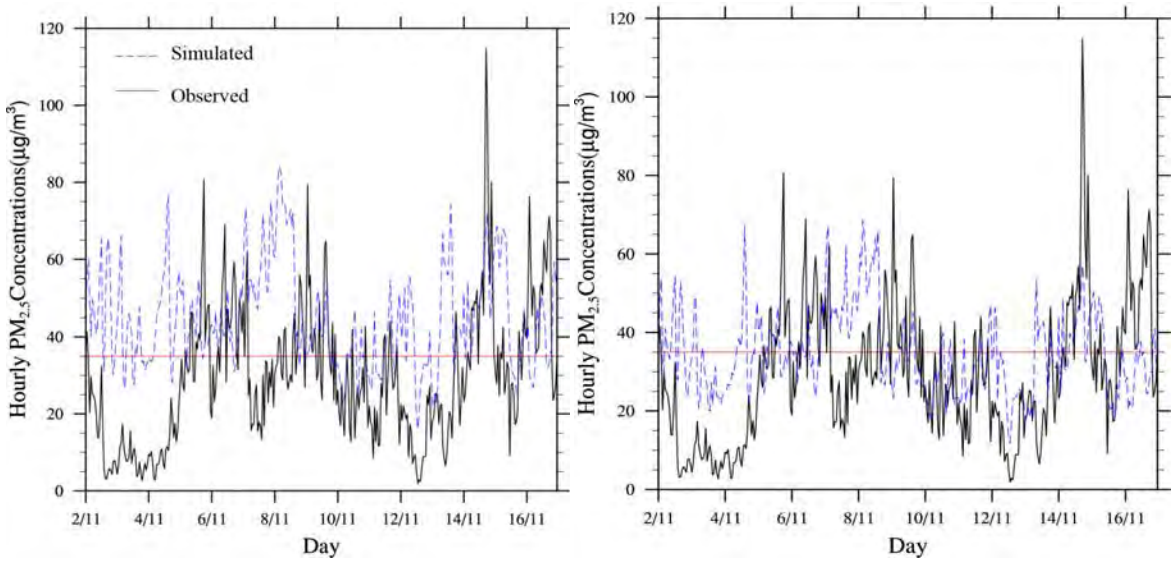


Fig. 12 Like Fig. 11, but for hourly $PM_{2.5}$-concentrations.

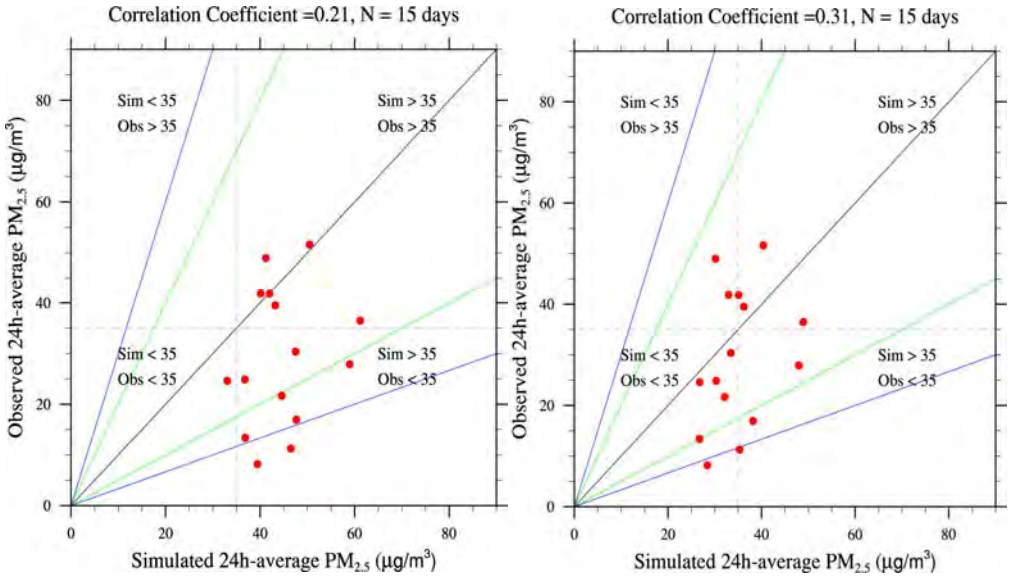


Fig.13 Scatter plots of 24h-average $PM_{2.5}$-concentrations as obtained from the adapted CMAQ simulation with reduction of wind speed (left) and the adapted CMAQ simulation with the original WRF simulated wind-speeds (right) for the November episode. The green line indicates the factor of two and the blue line indicates the factor of three agreement.

The scatter plots of 24h-average and hourly $PM_{2.5}$-concentrations obtained from the adapted CMAQ simulations with reduction of wind-speed and the adapted CMAQ simulation using the original WRF simulated wind-speeds have the correlation coefficients of 0.21and 0.31, respectively (Fig. 13). The reduction of the wind-speed in the valleys resulted in six pairs of data outside the factor of two agreement. For the adapted CMAQ simulations with the original WRF-

simulated wind-speed, there were four pairs of data outside of the factor of two agreement. The scatter plot of the hourly $PM_{2.5}$-concentrations obtained by from the adapted CMAQ simulation with the original WRF wind-speeds also shows a better correlation coefficient (0.2) for the 360 hours of data (Fig. 14).

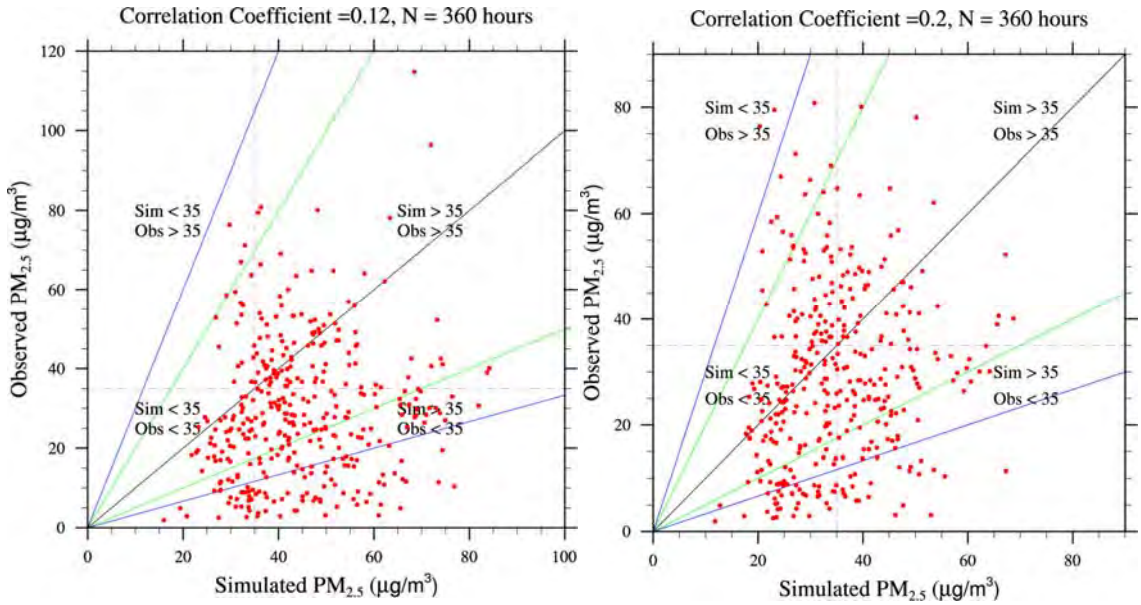


Fig.14 Scatter plots of hourly $PM_{2.5}$-concentrations as obtained from the adapted CMAQ simulations with reduction of wind-speeds in the valleys (left) and the adapted CMAQ simulation with the original WRF simulated wind-speed (right) for the November episode. The green line indicates the factor of two and the blue line indicates the factor of three agreement.

The bugle plots and soccer plots show that the adapted CMAQ simulation with the reduction of wind-speed has seven days outside the criteria, while the adapted CMAQ simulation with the original WRF-simulated wind-speeds has five days outside the criteria (Fig. 15-17).

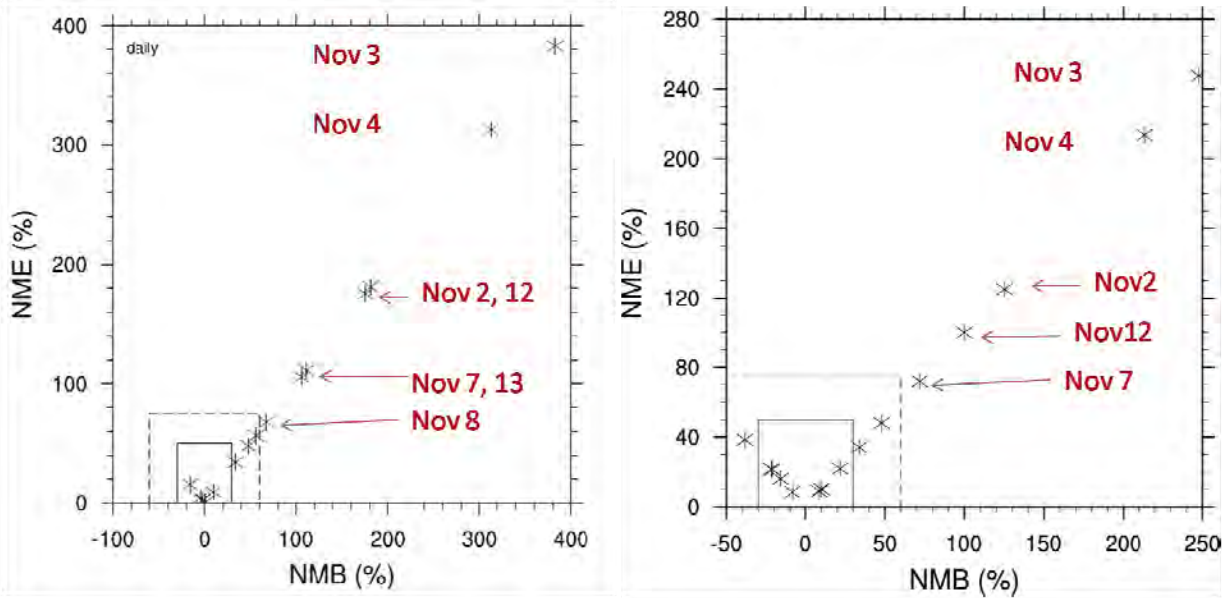


Fig. 15 Soccer plots of normalized mean errors and biases all determined with respect to the observations at the State Building site as obtained from the adapted CMAQ simulations with reduction of wind speed (left) and the adapted CMAQ simulations with the original WRF-simulated wind-speeds (right) for the November episode.

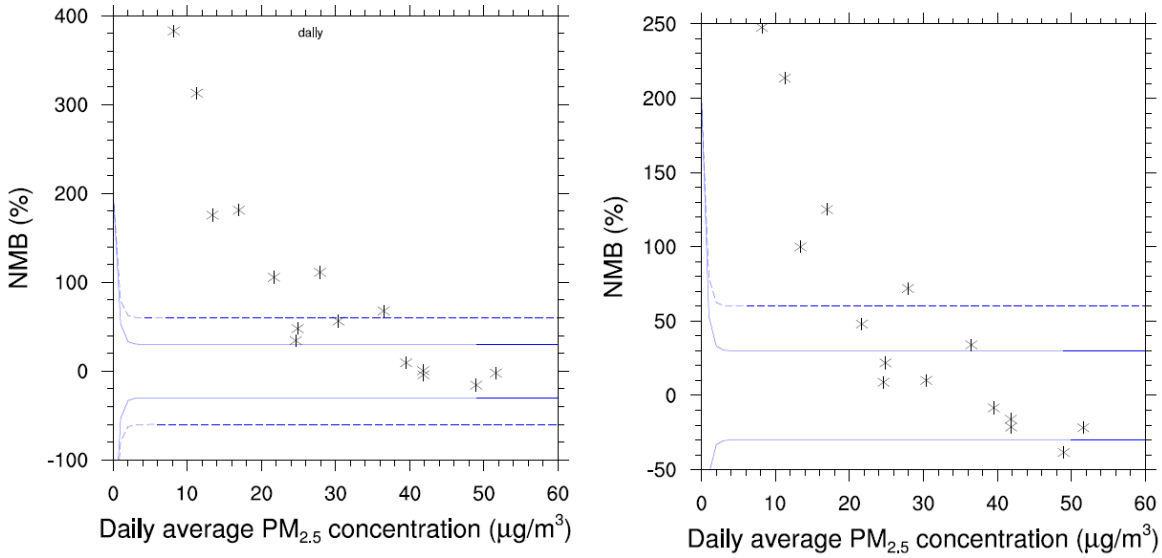


Fig. 16 Bugle plots of normalized mean biases of simulated 24h-average $PM_{2.5}$-concentrations at the State Building site as obtained from the adapted CMAQ simulations with reduction of wind-speed (left) and the adapted CMAQ simulation with the original WRF-simulated wind-speeds (right) for the November episode.

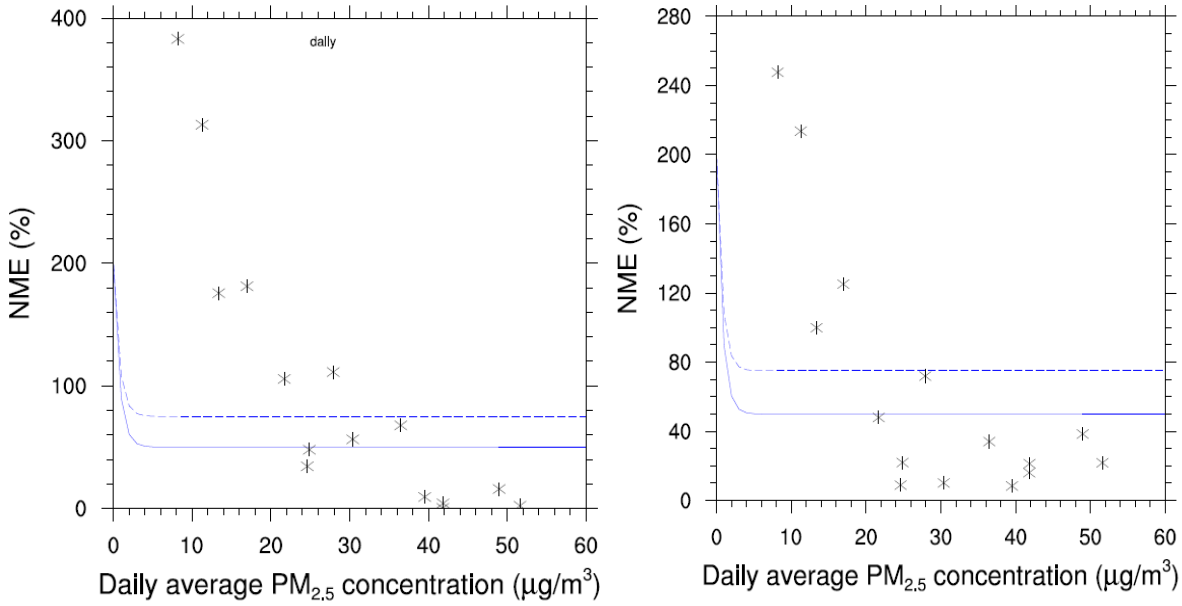


Fig. 17 Bugle plots of normalized mean errors of simulated 24h-average $PM_{2.5}$-concentrations at the State Building site as obtained from the adapted CMAQ simulation with reduction of wind-speed (left) and the adapted CMAQ simulation with the original WRF-simulated wind-speed (right) for the November episode.

The performance of adapted CMAQ in simulating the $PM_{2.5}$-composition during November was evaluated for both cases. The observed and simulated $PM_{2.5}$-compositions were compared in scatter plots (Fig. 18). The simulation, which used the original WRF-simulated wind-speeds, shows that sulfate and ammonium are outside of the factor of two agreement. The adapted CMAQ model predicted best for OC and EC, which have high concentrations and make up a large fraction of the total $PM_{2.5}$. The soccer plots for the adapted CMAQ simulation with wind-speed reduction show that sodium and chloride are outside the performance criteria. For the adapted CMAQ simulation with the original WRF-simulated wind-speeds show that sodium, chloride and sulfate are outside the performance criteria (Fig. 19). However, the increase of the Cl-concentrations for the initial/boundary conditions (IC/BC) for the adapted CMAQ simulation with the original WRF-simulated wind-speeds led to decreased NME and NMB for the Cl-species (Fig. 19) The new profile of Cl is included in the Appendix. The buggle plot of normalized mean bias for the adapted CMAQ simulations with the original WRF-simulated wind-speeds shows that sulfate is outside the criteria (Figs. 20, 21).

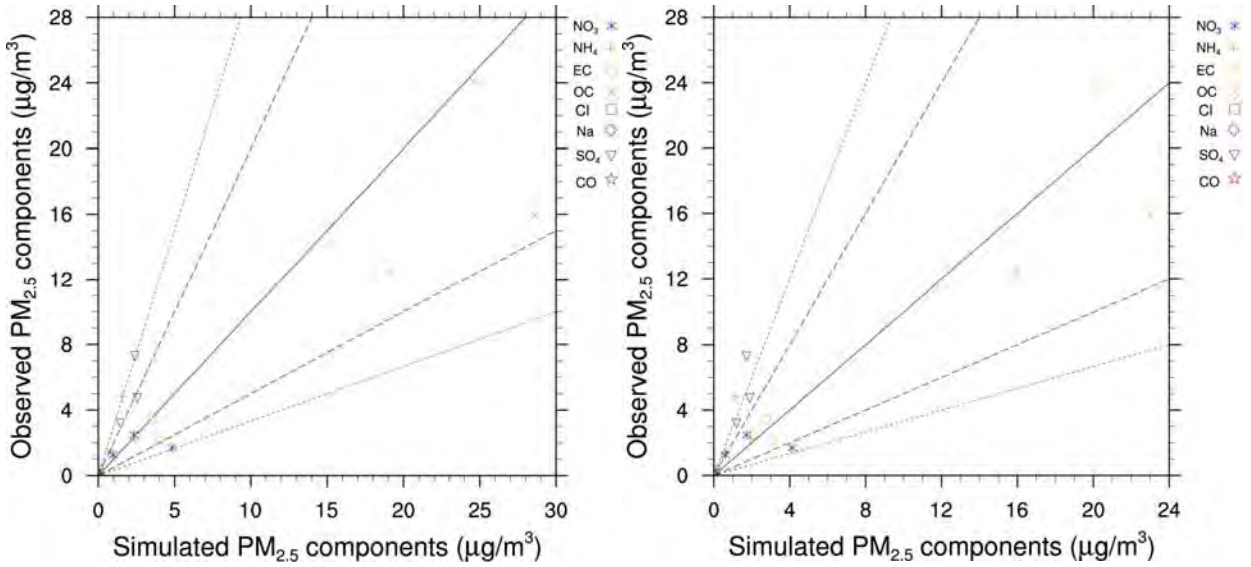


Fig.18 Scatter plot between simulated and observed 24h-average $PM_{2.5}$-composition at the State Building site as obtained for the adapted CMAQ simulation with reduction wind-speeds in the valley (left) and the adapted CMAQ simulations using the original WRF-simulated wind-speeds (right) for the November episode.

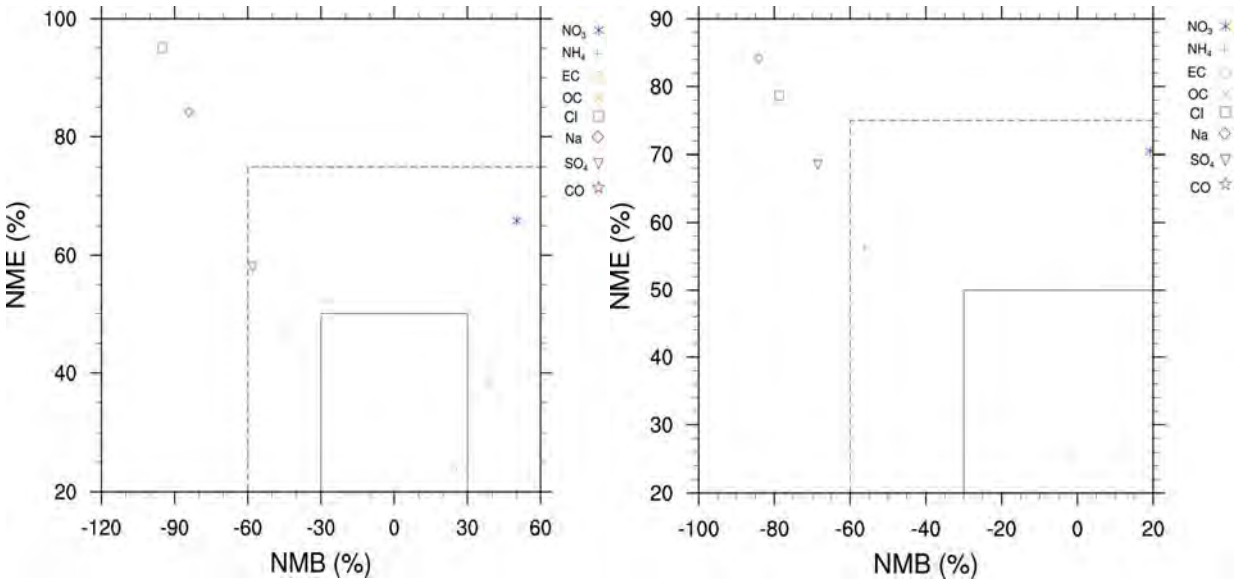


Fig. 19. Soccer plots of normalized mean errors and biases of simulated 24h-average $PM_{2.5}$-composition simulated and observed 24h-average $PM_{2.5}$-composition at the State Building site as obtained for the adapted CMAQ simulation with reduction wind-speeds in the valley (left) and the adapted CMAQ simulations using the original WRF-simulated wind-speeds (right) for the November episode. The dashed and solid lines indicate the performance criteria and performance goals in accord with Boylan and Russell (2006).

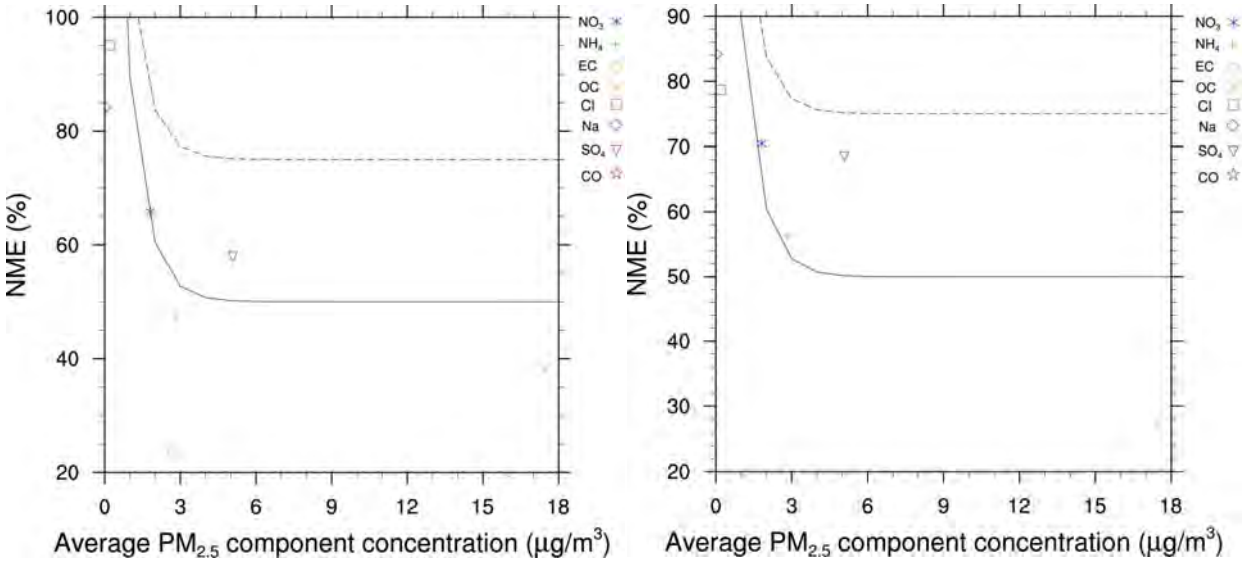


Fig. 20 Bugle plots of normalized mean errors of simulated 24h-average $PM_{2.5}$-composition simulated and observed 24h-average $PM_{2.5}$-composition at the State Building site as obtained for the adapted CMAQ simulation with reduction wind-speeds in the valley (left) and the adapted CMAQ simulations using the original WRF-simulated wind-speeds (right) for the November episode. The dashed and solid lines indicate the performance criteria and performance goals in accord with Boylan and Russell (2006).

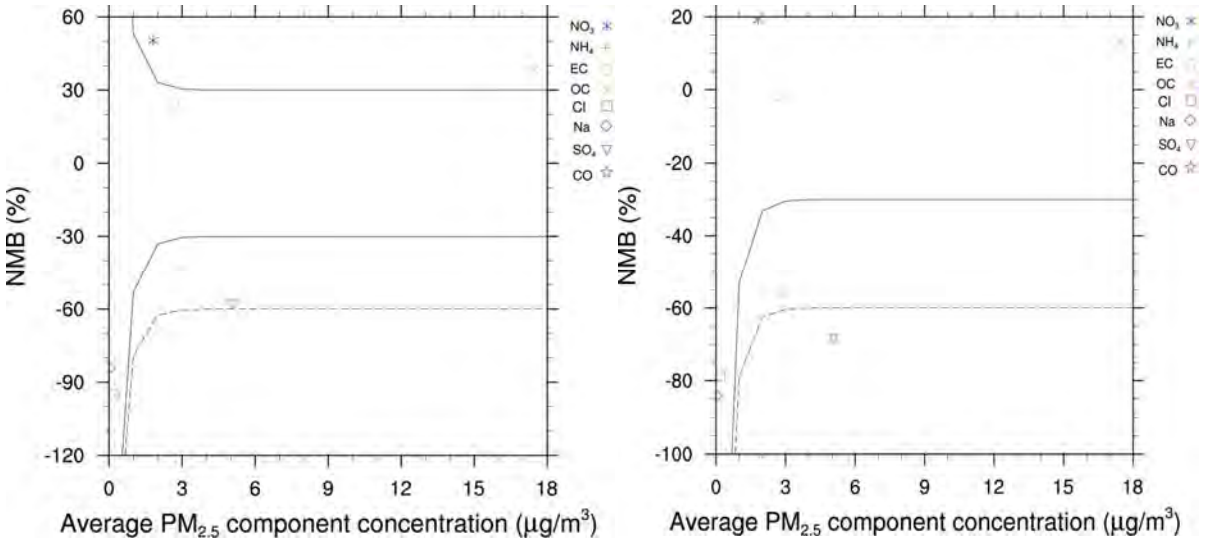
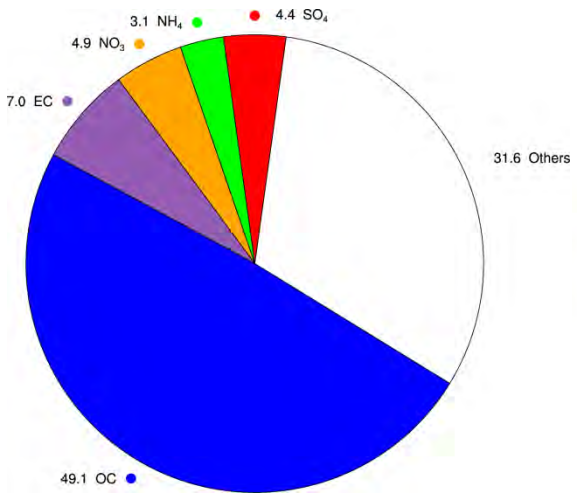
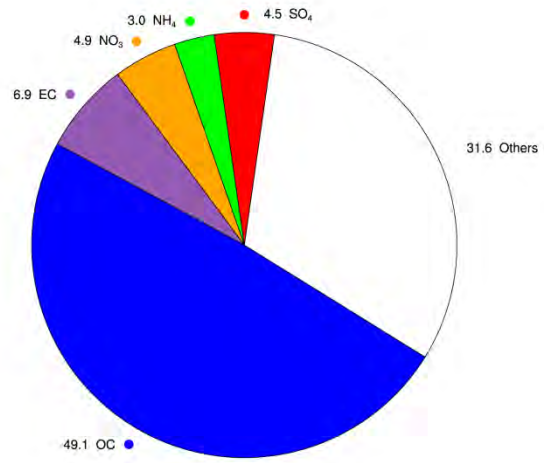


Fig. 21 Bugle plots of normalized mean biases of simulated 24h-average $PM_{2.5}$-composition simulated and observed 24h-average $PM_{2.5}$-composition at the State Building site as obtained for the adapted CMAQ simulation with reduction wind-speeds in the valley (left) and the adapted CMAQ simulations using the original WRF-simulated wind-speeds (right) for the November episode. The dashed and solid lines indicate the performance criteria and performance goals in accord with Boylan and Russell (2006).

(a)



(b)



(c)

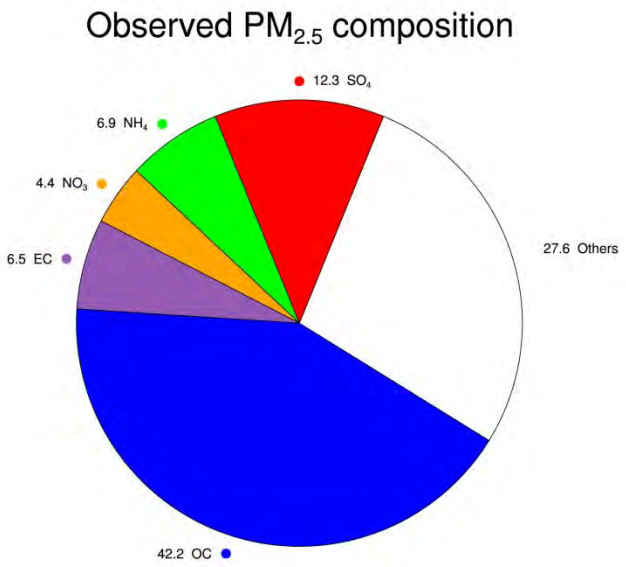


Fig. 22 The $PM_{2.5}$-composition at State Building site as obtained by (a) the adapted CMAQ simulation with reduction of wind-speeds in the valleys by half and (b) the adapted CMAQ simulations with modifications using the original WRF-simulated wind-speeds, and (c) observations of 24h-average $PM_{2.5}$-composition averaged over the 3 days with data available in the November episode. In the observations the category "others" includes Al, Br, Ca, Na, Cl, Cu, Fe, Pb, Ni, K, Se, Si, S, Sn, Ti, V, Zn. In the adapted CMAQ simulation results, the category "others" refers to unspecified anthropogenic mass (A25i+A25j).

In both case studies, in the simulated $PM_{2.5}$-composition, the percentage of organic carbon was overestimated, but the percentage of sulfate, and ammonium was underestimated (Fig. 32). The adapted CMAQ model predicted elemental carbon and nitrate well. Note that there were only 3 days, which had the available observed $PM_{2.5}$-composition data during the November episode.

Besides the normal case (reference simulations) with the adapted CMAQ, we performed adapted CMAQ simulations for the November episode without consideration of gas chemistry, without consideration of aerosol chemistry, and without consideration of chemistry. We compared the results of these sensitivity studies with the observed data (Fig. 23). We did not perform a sensitivity study without consideration of point-source emissions as the way Sierra Research Inc. provided the November emission data did not allow us this option. The emission file for November episode were in a merged file, not separately for area and point source emissions like the emission data provided for the January v1 episode. The interested reader is referred to Frost et al. (2006) and Tran and Mölders (2012) for a detailed discussion on point-source emission impacts.

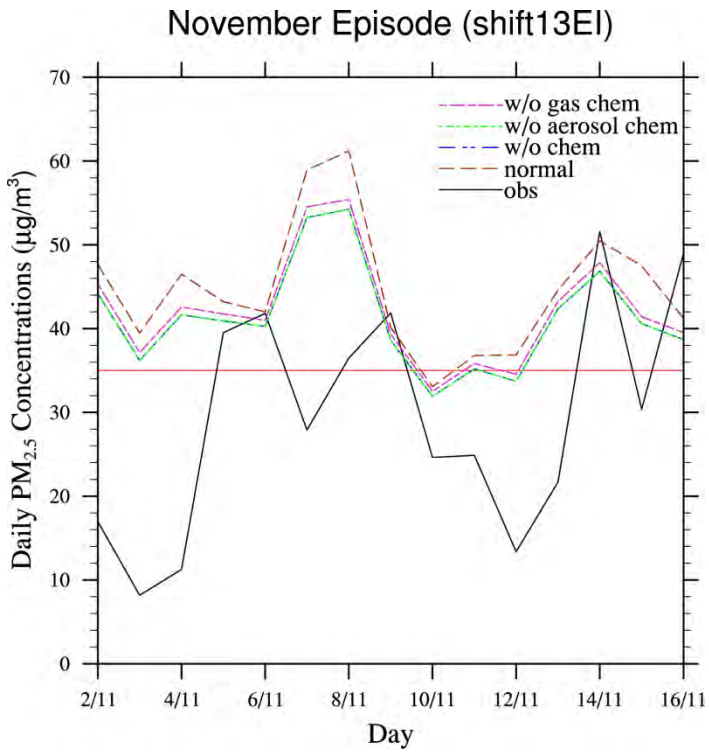


Fig. 23 Time series of observed (black solid line) and adapted CMAQ simulated 24h-average $PM_{2.5}$-concentrations at State Building site as obtained by the various sensitivity studies without consideration of gas chemistry, without consideration of aerosol chemistry, without consideration of chemistry, and with consideration of everything (reference/normal) for the November episode. The red solid line indicates the National Ambient Air Quality Standard of 35µg/m^3.

Similar to the January v1 episode, chemistry played a small role for the $PM_{2.5}$-formation. The simulations with turned off chemistry, turned off aerosol chemistry and turned off gas chemistry led to decreases in $PM_{2.5}$-concentrations of on average 2.2 (6%), 2.2 (6%) and 1.5µg/m^3 (4%), respectively. Turning off the gas chemistry led to the same results as turning off all chemistry.

On the day, for which the highest concentrations were simulated (48.9/m^3 on November 8), the chemistry processes had the maximum contribution to the 24h-average $PM_{2.5}$-concentrations 5.8µg/m^3 (12%) at the State Building site. In this 5.8µg/m^3, the aerosol chemistry processes contributed 4.9µg/m^3 (10%) to the total aerosol production by chemistry processes.

Since the times series of simulated and observed PM2.5-concentrations indicated a temporal offset, we correlated the simulated 24h-average $PM_{2.5}$-concentrations at State Building site with the observed data by allowing various time lags. We found that allowing a time lag of one day for the simulation results obtained with reduced wind-speed can increase the correlation coefficient from 0.21 to 0.46. For the reference simulation that uses the original WRF-simulated wind-speeds, allowing a time lag of one day increased the correlation coefficient from 0.31 to 0.37 (Fig. 24). This increasing of the correlation indicates that the adapted CMAQ model has a 24h delay in capturing the $PM_{2.5}$-concentrations at the State Building site for November episode.

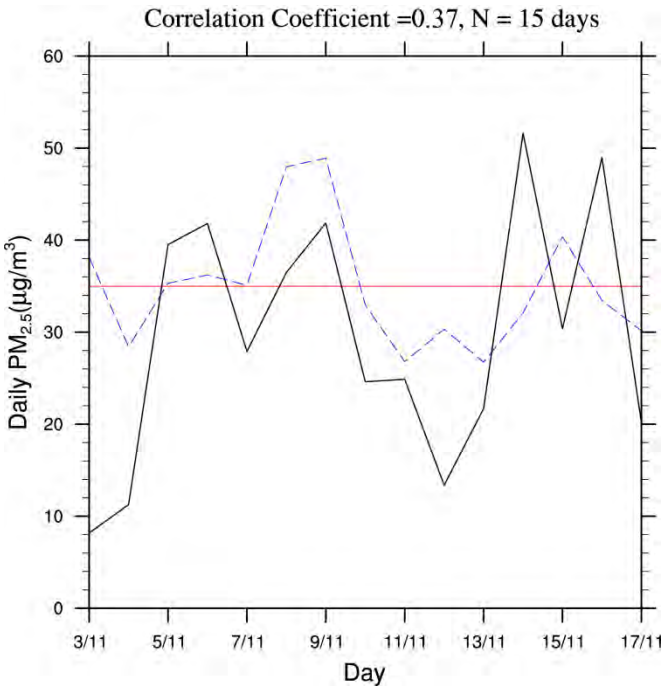


Fig. 24 Time series of simulated (blue dash line) and observed (black solid line) 24h-average $PM_{2.5}$-concentrations that allow a one day time lag for the adapted CMAQ simulation using the original WRF-simulated wind-speed for the November episode at the State Building site.

The reduction of the wind-speed by half might demolish the continuity equation (see discussion in Mölders and Leelasakultum 2011), but it led to a clear increase of $PM_{2.5}$-concentrations and better performance in simulating the sulfate compositions at the State Building site (Figs. 19-21). Although, the comparison with the observed data had lower correlation coefficients than 0.5 for both cases, allowing a time lag of one day increased the correlation coefficients in both cases.

2.3 Comparison of simulations and their performance for January v2 with and without CMAQ modifications

Like January v1, January v2 covers January 23 to February 9, 2008. The emissions used for the January episode v2 were developed by Sierra Research Inc. who updated the emission inventory for emissions from mobile sources, and included the emissions from airports like in the November episode (see their reports for details and the reasoning). The comparison of the spatial distribution of emissions as used for January v1 and January v2 shows that there is the increase in emissions from the mobile sectors for the January v2, mostly outside of the nonattainment area (Fig. 25). There are both increases and decreases in emissions inside the nonattainment area for the new version of emission inventory; the increase of the emissions is mostly south of the nonattainment area (Fig. 26).

Furthermore, January v1 and January v2 also differ by the meteorological data used (Fig. 27). January v2 uses WRF simulations provided by PennState that they created with an updated data assimilation procedure (see their final report for details). On the days, for which CMAQ overestimated the 24h-average $PM_{2.5}$-concentrations at the State Building site, the meteorological data in January v2 tend to have lower of relative humidity in the Fairbanks nonattainment area (64°40'N- 65°N, 147°W-148°W), and the area with low temperatures covers a larger area of the domain. These changes in the meteorology in the January v2 simulations results in an increase of $PM_{2.5}$-concentrations as it supports the gas-to-particle conversion process. For a discussion on the impact of errors in simulated meteorological quantities on simulated $PM_{2.5}$-concentrations see reader is referred to Mölders et al. (2011, 2012).

With the improvements in the emission inventory and the WRF meteorological data for January v2, the adapted CMAQ 24h-average $PM_{2.5}$-concentrations at the State Building site increased noticeably without the need for a wind-speed reduction (cf. Figs. 9, 28). The temporal evolution of $PM_{2.5}$-concentrations for January v2 with CMAQ modifications shows similar trends with that obtained without modifications. Note that CMAQ without modification would not consider deposition on snow or tundra-type land as well as would have unrealistic (for Alaska) pH-value thresholds, IC/BC and other important parameters. January v2 with modifications shows that most of the times both the 24h-average and hourly $PM_{2.5}$-concentrations at the State Building site are overestimated (Figs. 27, 28). Note that for SIP development this behavior is preferred over underestimation.

(a) (b)

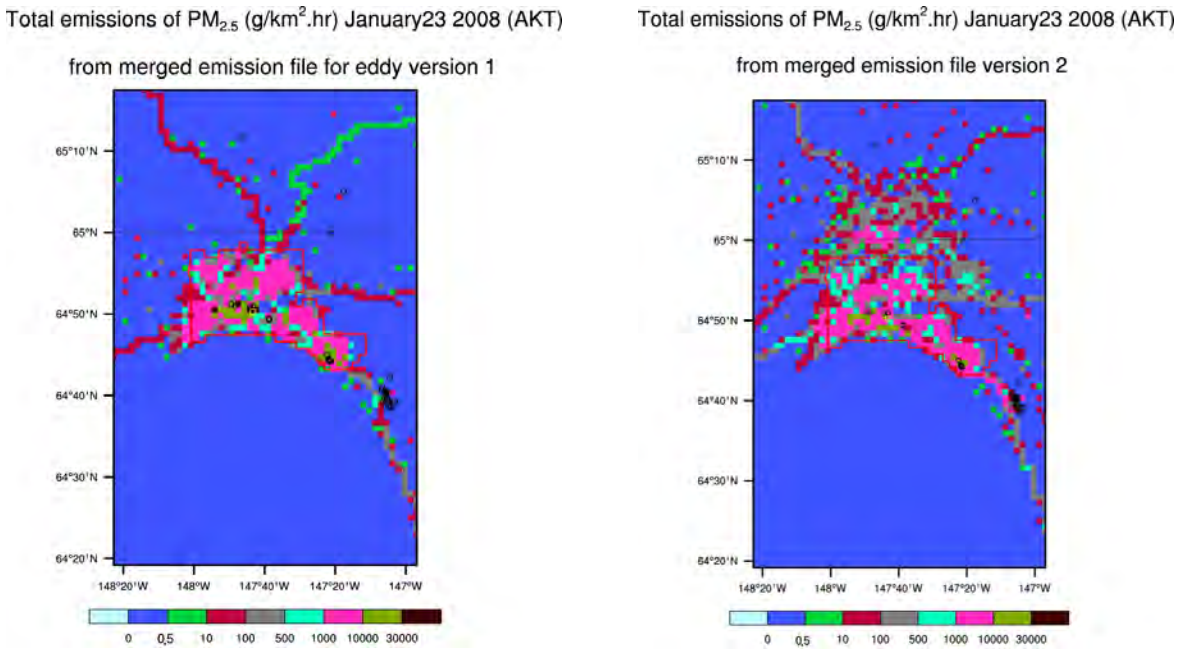


Fig. 25 Example of the emissions as obtained from the Sierra Research Inc. emission inventory for (a) January v1 and (b) January v2. The red polygon indicates the Fairbanks nonattainment area. The circles indicate point-source locations.

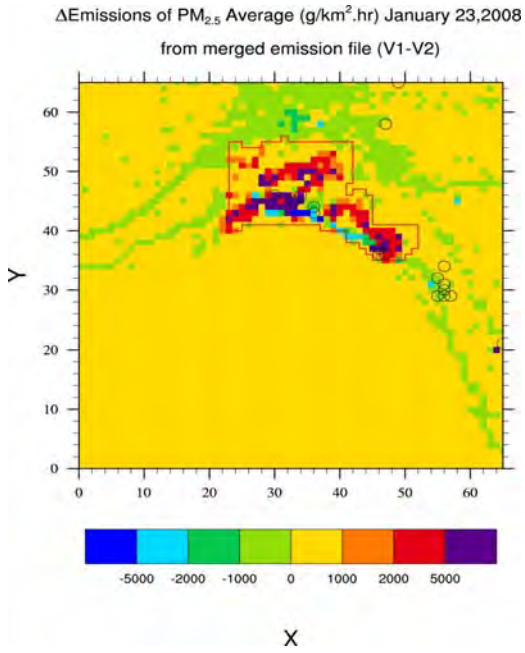


Fig. 26 Like Fig. 25, but for $PM_{2.5}$-emissions difference (January v1 minus January v2) at breathing level on January 23, 2008 as obtained from Sierra Research Inc. emission inventory.

(a) (b)

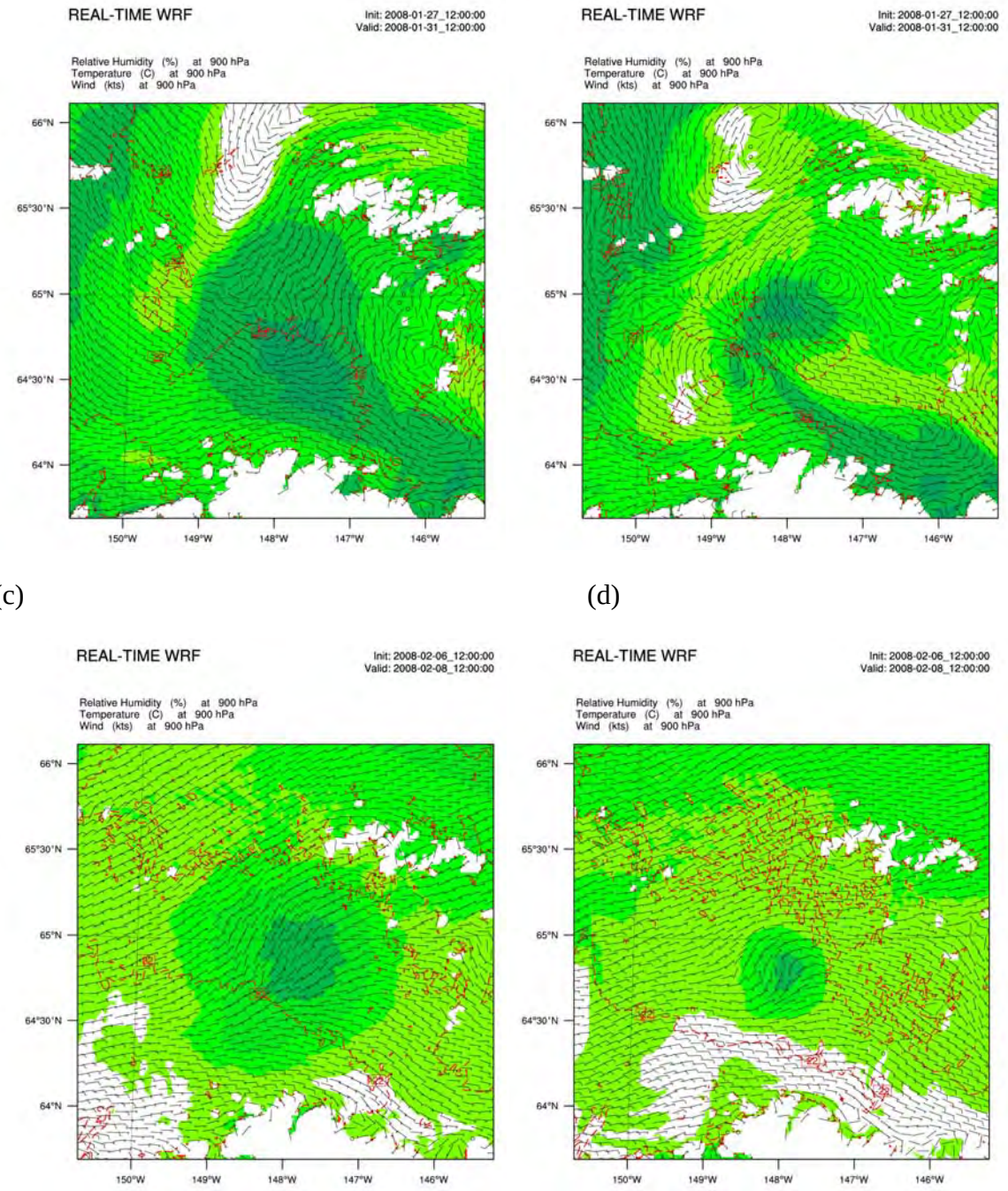


Fig. 27 Example of temperature (red contours), relative humidity (color), wind-speed and direction (barbs) at 900 hPa on January 31, 2008 1200UTC for (a) January v1 and (b) January v2, and on February 8, 2008 1200UTC for (c) January v1 and (d) January v2 as obtained from the PennState group.

The modifications of CMAQ resulted in a correlation coefficient of 0.52 for the 24h-average $PM_{2.5}$-concentrations, which is better than the correlation obtained for the simulation with the

CMAQ without modifications (Fig. 30). For the 12 pairs of data of the results from CMAQ with and without modifications, 83% of values lie within the factor of the two agreement (Fig. 30). However, the two points outside the factor of the two agreement for the CMAQ simulations without modifications are a "missed event" (Simulated<35µg/m^3 and Observed>35µg/m^3), and one value (simulated<35µg/m^3 and observed>35µg/m^3). Whereas, those two points in the CMAQ simulation with modifications are "false alarms" (simulated>35µg/m^3 and observed<35µg/m^3) (Fig. 30). The simulated hourly $PM_{2.5}$-concentrations of the CMAQ with modifications also yield a higher correlation coefficient with the observed data than those obtained without CMAQ modifications (Fig. 31).

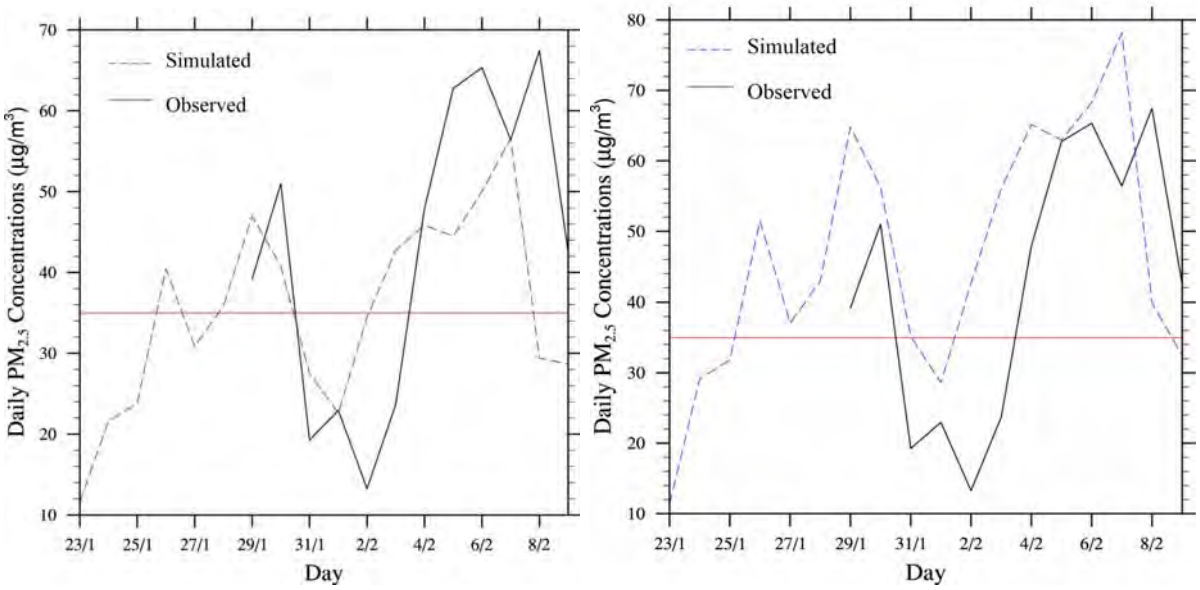


Fig. 28 Time series of simulated (blue dash line) and observed 24h-average $PM_{2.5}$-concentrations at the State Building site (black solid line) as obtained for January v2 without modifications (left) and January v2 with modifications (right).

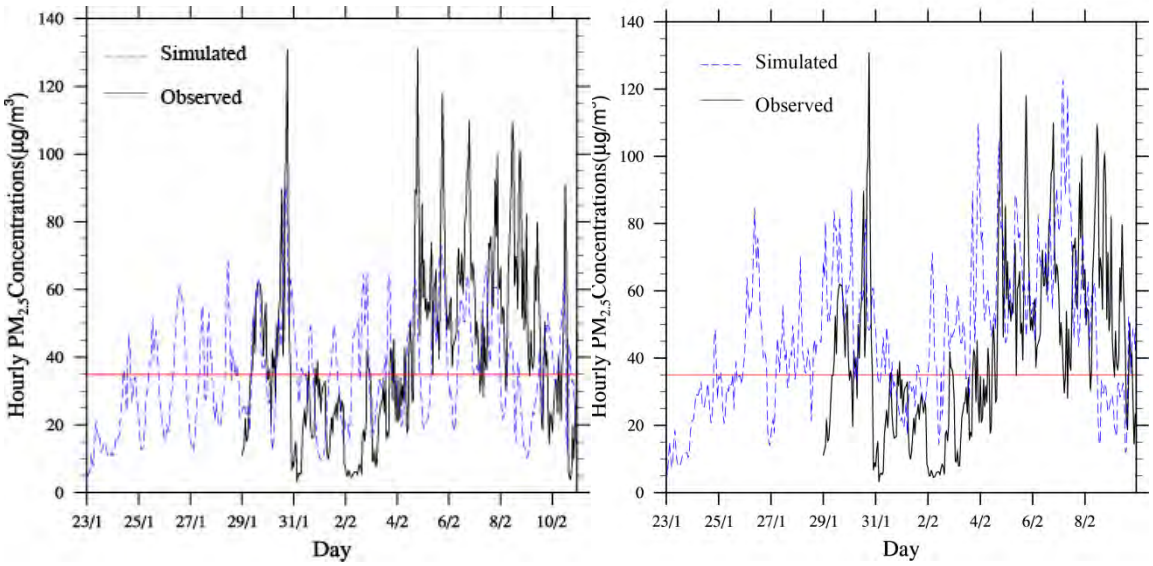


Fig. 29 Time series of simulated (blue dash line) and observed hourly $PM_{2.5}$-concentrations at the State Building site (black solid line) as obtained for January v2 without modifications (left) and January v2 with modifications (right).

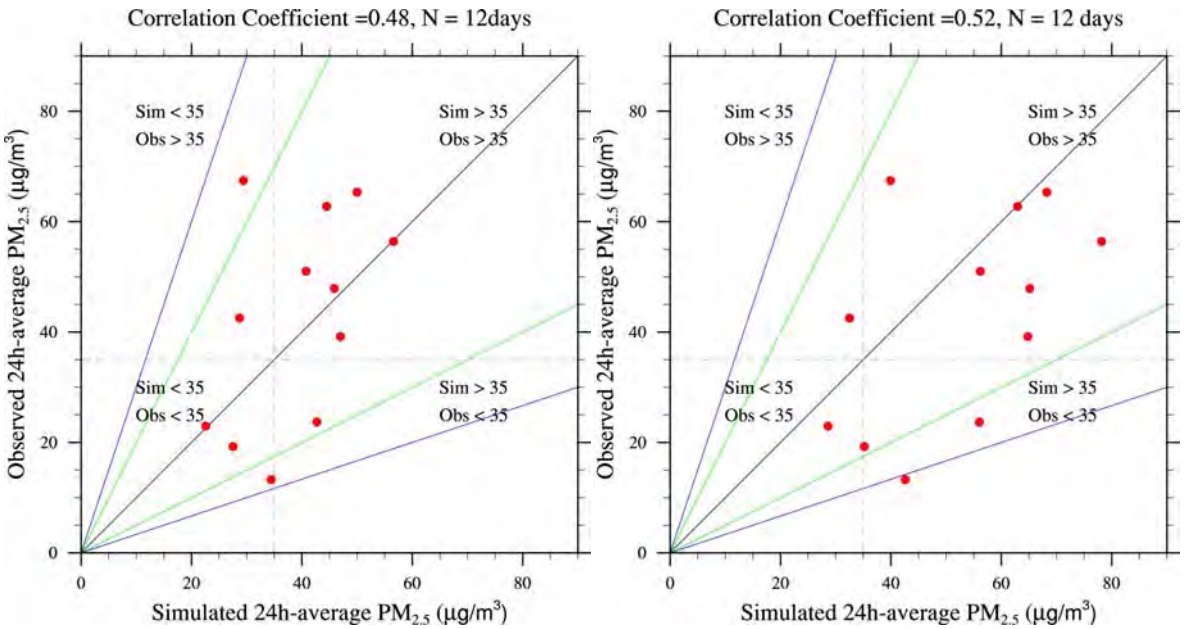


Fig. 30 Scatter plots of 24h-average $PM_{2.5}$-concentrations as obtained for January v2 without modifications (left) and January v2 with modifications (right). The green line indicates the factor of two agreement, and the blue line indicates the factor of three agreement.

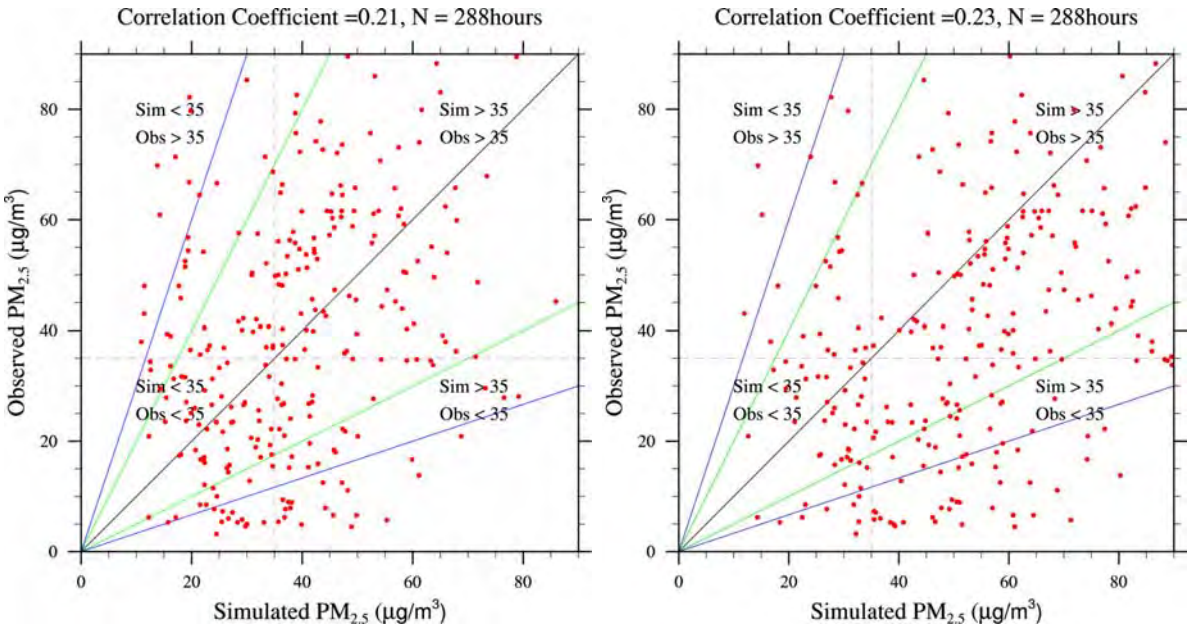


Fig. 31 Scatter plots of hourly average $PM_{2.5}$-concentrations as obtained by January v2 without modifications (left) and January v2 with modifications (right). The green line indicates the factor of two agreement, and the blue line indicates the factor of three agreement.

Furthermore, we run the CMAQ with modifications, but without the reduction of the lowest and the highest eddy diffusivity. The hypothesis of this test is that reductions of default eddy diffusivities by half caused the over-prediction and false alarms.

The temporal evolution of simulation with all modifications except the eddy diffusivity reduction shows similar result as the case of without these modifications (Figs. 28, 29, 31). The correlation coefficient between the simulated and observed 24h-average $PM_{2.5}$-concentrations obtained by the CMAQ with modifications, but without the reduction of the eddy diffusivity is 0.46. There are two values outside the factor of two agreement, which is similar to the CMAQ simulation of without these modifications (Fig. 31).

This means that the reduction of the default eddy diffusivities by half is the modification that led to the increase of $PM_{2.5}$-concentrations at the State Building site. It caused the over-prediction, and false alarms, however, setting the eddy diffusivities to the default does not lead to the improvement of the correlation between simulated and observed data. The CMAQ with the modifications and the reduction of the eddy diffusivities by half shows the best correlation coefficient (0.52). Thus, we recommend this setup.

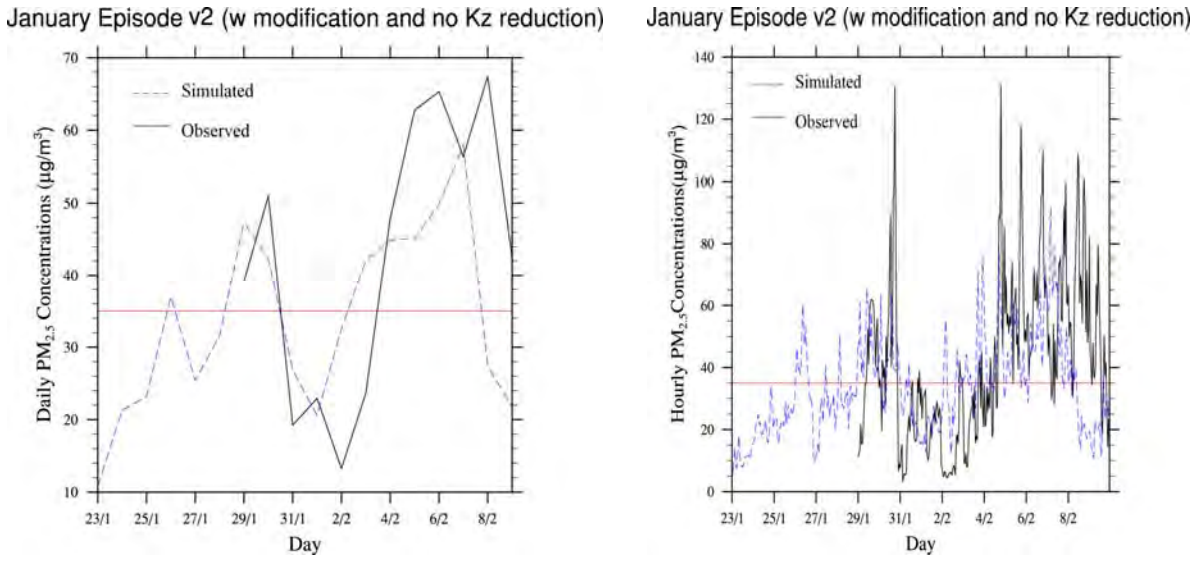


Fig. 32 Time series of simulated (blue dash line) and observed 24h-average $PM_{2.5}$-concentrations (left) and with modifications for hourly $PM_{2.5}$-concentrations (right) at the State Building site (black solid line) as obtained for January v2 with all modifications except the eddy diffusivity reduction.

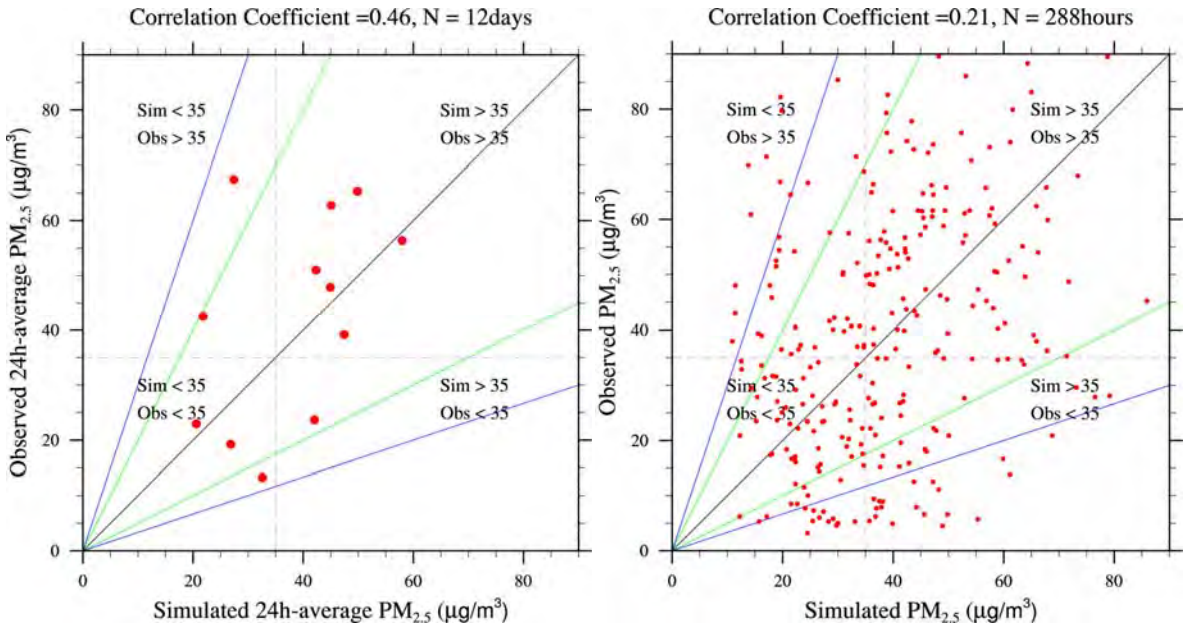


Fig. 33 Scatter plots of 24-h average $PM_{2.5}$-concentrations (left) and hourly average $PM_{2.5}$-concentrations (right) as obtained by January v2 with modifications, but without reduction of the eddy diffusivity. The green line indicates the factor of two agreement and the blue line indicates the factor of three agreement.

We also preformed simulations for January v2 without consideration of gas chemistry, without consideration of aerosol chemistry, and without consideration of chemistry. We compared the

results of these simulations to each other, the results of the simulation that considers all processes and with the observations (Fig. 34). Similar to the January v1episode, chemistry played a small role for the $PM_{2.5}$-formation. The simulations with turned off chemistry, turned off aerosol chemistry and turned off gas chemistry led to decreases in $PM_{2.5}$-concentrations of on average 2.0 (4%), 2.0 (4%) and 1.2µg/m^3 (3%), respectively. Note that in the CMAQ model turning off the gas chemistry resulted in the same result with turning off all chemistry.

On the day, for which the highest concentration was simulated (78.2/m^3 on February 7), the chemistry processes had the maximum contribution to the 24h-average $PM_{2.5}$-concentrations 5.6µg/m^3(7%) at the State Building. In this 5.6µg/m^3, the aerosol chemistry process contributed 4.4µg/m^3 (6%) to the total aerosol production of chemistry process.

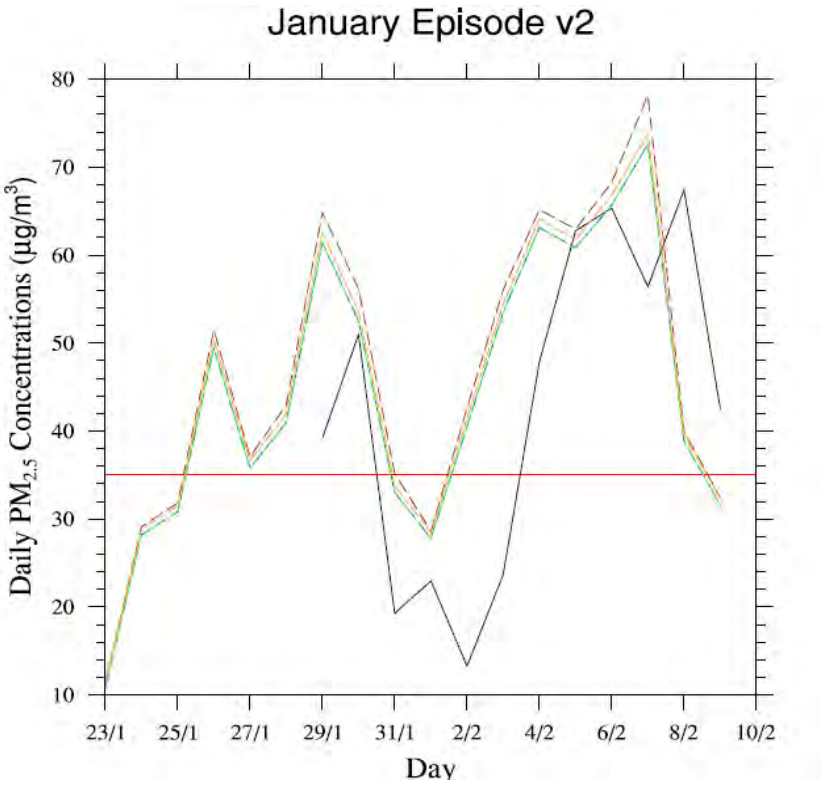
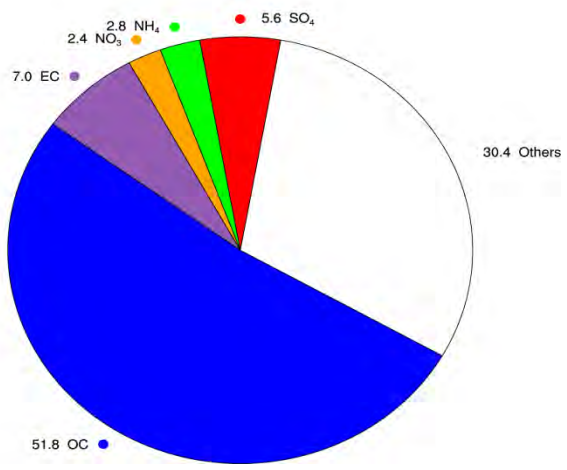


Fig. 34 Time series of CMAQ simulated and observed 24h-average $PM_{2.5}$-concentrations at State Building for the January episode v2 (black solid line). The sensitivity studies include simulations without consideration of gas chemistry, without consideration of aerosol chemistry, without consideration of chemistry and the simulation with consideration of everything (reference/normal). The red solid line indicates the National Ambient Air Quality Standard of 35µg/m^3.

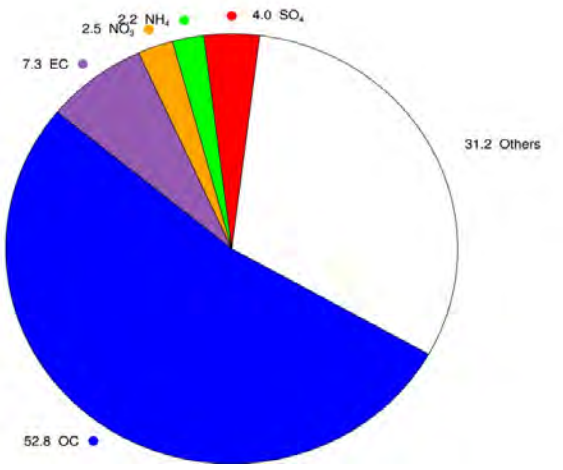
Comparing between the observed and the simulated composition of 24h -average $PM_{2.5}$ aerosol, showed that simulated $PM_{2.5}$ composition with the modifications and without the modifications

reveals that the adapted CMAQ overestimated the percentage of organic carbon, but underestimated the percentage of sulfate, ammonium, nitrate and elemental carbon (Fig. 35). Note that there were only 6 days, which had the observed $PM_{2.5}$-composition data during the study period.

(a)



(b)



(c)

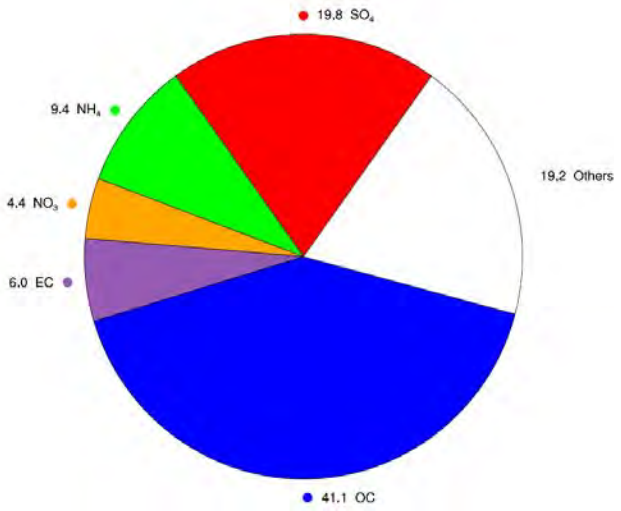


Fig. 35 Composition of simulated 24h-average total $PM_{2.5}$ as obtained by (a) CMAQ without modifications, (b) CMAQ with modifications, and (c) as observed on average over the 6 days for which data was available at the State Building site. In the observations, the category "others" includes Al, Br, Ca, Na, Cl, Cu, Fe, Pb, Ni, K, Se, Si, S, Sn, Ti, V, Zn. In the simulations, the category "others" refers to unspecified anthropogenic mass (A25i+A25j).

For the January v2 episode, we also correlated the simulated 24h-average $PM_{2.5}$-concentrations obtained by the Alaska adapted CMAQ model with the observed data by allowing a time lag. We found that allowing a time lag for one day increases the correlation coefficient from 0.52 to 0.84 (Fig. 36). Allowing a 24h time lag can increase the correlation coefficients of the hourly average $PM_{2.5}$-concentrations at State Building site from 0.23 to 0.50, and the correlation increases even more to 0.59 when we allow a time lag for 26 hours. These findings clearly indicate that the discrepancies between simulated and observed $PM_{2.5}$-concentrations are partly due to errors in simulated meteorology.

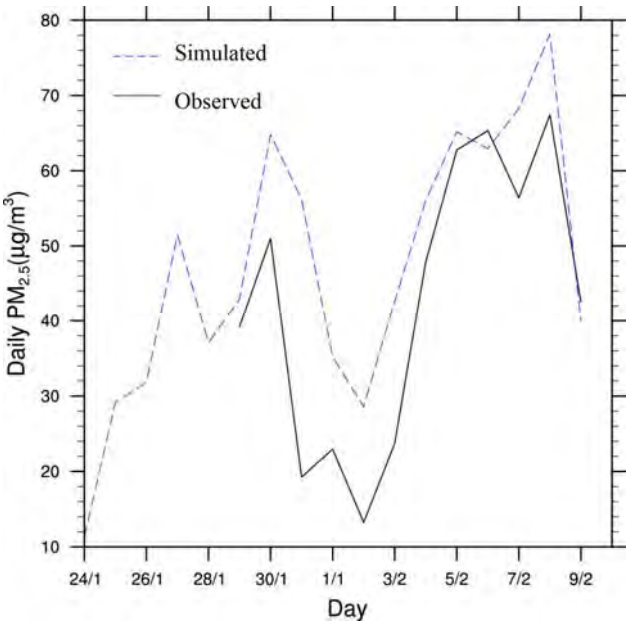


Fig. 36 Time series of simulated (blue dash line) and observed (black solid line) 24h-average $PM_{2.5}$-concentrations with a one day time lag for the January v2 episode at the State Building site.

2.4 Statistical performance for the November episode and January episode v2 with CMAQ modification

The statistical performance of the Alaska adapted CMAQ (Mölders and Leelasakultum 2011) for the November episode and January episode v2 was determined and is shown in Tables 1 and 2, respectively.

Table 1. Performance statistics for the Alaska adapted CMAQ at the State Building site for November episode. StDev is the standard deviation.

Fairbanks official monitoring Site	# of observ-ations	Mean CMAQ simulated (µg/m^3)	Mean observed (µg/m^3)	Ratio of Means (sim/obs)	Mean bias (µg/m^3)	Mean Fractional Bias (%)	Mean error (µg/m^3)	Mean Fractional Error (%)	Correlation coefficient
Hourly	360	34.9	29.3	1.92	5.56	30	15.51	53	0.21
24h-average	15	34.9	29.3	1.52	5.56	26	12.09	43	0.31
Fairbanks Official monitoring site	Average difference sim-obs (µg/m3)	Simulated exceedance days	Observed exceedance days	Simulated min|max (µg/m^3)	Observed min|max (µg/m^3)	STDEV of simulation (µg/m^3)	STDEV of observation (µg/m^3)	Variance of simulation (µg/m^3)^2	Variance of observation (µg/m^3)^2
24h-average	5.6	7	6	26.7 |48.9	8.17 |51.6	6.8	13.7	45.8	188.3

Table 2. Performance statistics for the Alaska adapted CMAQ at the State Building for the January v2 episode. Note that the statistics for the January v1 episode can be found in Mölders and Leelasakultum (2011).

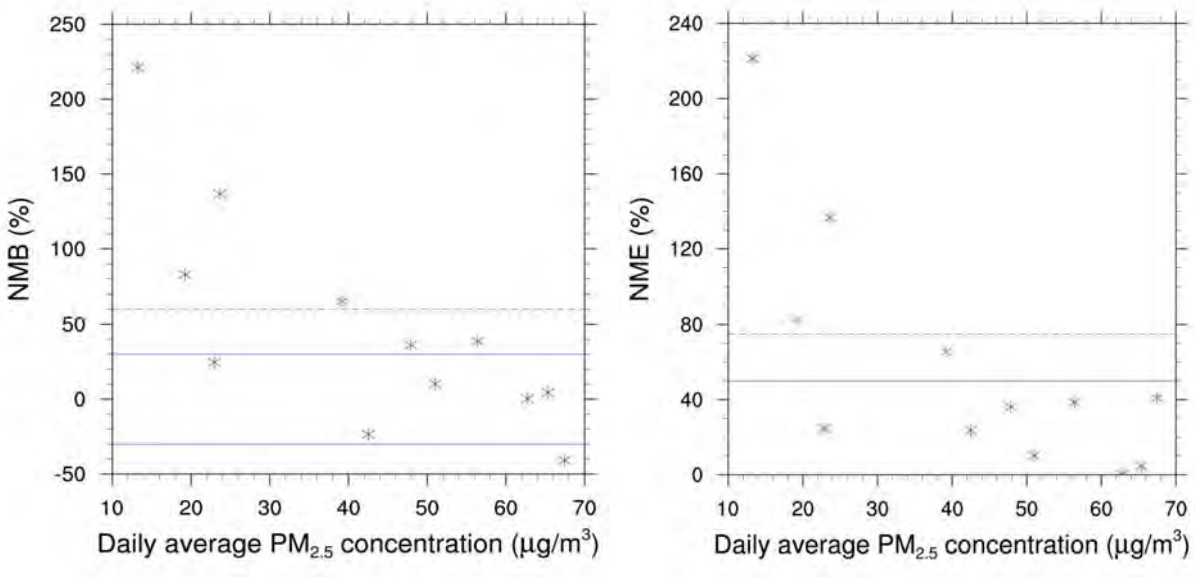
Fairbanks Official monitoring site	#of Observ-ations	Mean CMAQ simuled (µg/m^3)	Mean observed (µg/m^3)	Ratio of means (sim/obs)	Mean bias (µg/m^3)	Mean Fractional Bias (%)	Mean error (µg/m^3)	Mean Fractional Error (%)	Correlation coefficient
Hourly	288	46.3	42.6	1.34	6.59	20.23	16.33	38.39	0.23
24h-average	12	46.3	42.6	0.98	6.59	17.51	10.76	26.18	0.52
Fairbanks official monitoring site	Average difference sim-obs (µg/m3)	Simulated Exceedance days	Observed Exceedance days	Simulated min|max (µg/m3)	Observed min|max (µg/m3)	STDEV of simulation (µg/m3)	STDEV of observation (µg/m3)	Variance of simulation (µg/m^3)^2	Variance of observation (µg/m^3)^2
24h-average	9.9	10	8	28.6 |78.2	13.3 | 67.4	16.18	19.05	261.88	362.82

The Alaska adapted CMAQ model shows a better performance for the January episode v2 than the November episode. The mean simulated of 24h-average $PM_{2.5}$-concentration for the November episode is 34.9µg/m^3 and the mean observed 24h-average $PM_{2.5}$-concentration was 29.3µg/m^3. The higher means of simulated 24h-average $PM_{2.5}$-concentrations were for the January episode v2, which has lower temperatures and lower insolation. Although the average difference between the simulated and observed $PM_{2.5}$-concentrations in January v2 is as high as 9.9µg/m^3, the correlation coefficient, mean fractional bias, and mean fractional error indicate a better performance of the adapted CMAQ for the January v2 than November episode.

The performance metrics of Boyland and Rusell (2006) overlain in the soccer plot and bugle plots of the CMAQ performance for January v2 shows that four days are outside of the criteria (Fig. 37). Those four days are January 29, 31, and February 2, 3, which had 24h-average $PM_{2.5}$-

concentrations of 39.2, 19.2, 13.3, and 23.7µg/m^3, respectively. This means the adapted CMAQ captured well the air quality on those days that had high $PM_{2.5}$-concentrations, but not on those days with low concentrations. Similar was found for WRF/Chem (Mölders et al. 2012).

(a) (b)



(c)

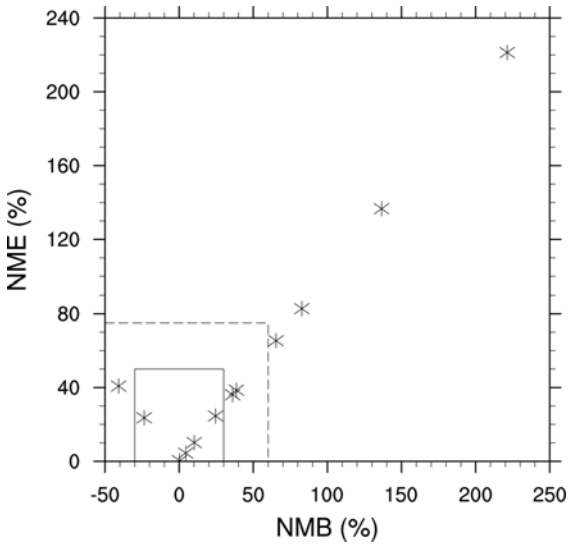


Fig. 37. Bugle plots of normalized mean (a) errors and (b) biases of simulated 24h-average $PM_{2.5}$-concentrations, and (c) soccer plot of normalized mean errors and biases all determined with respect to the observations at the State Building site for January v2 as obtained with the CMAQ with modifications. The dashed and solid lines indicate the performance criteria and performance goals in accord with Boylan and Russell (2006).

The RAMS data of the $PM_{2.5}$-concentrations were also included in the evaluation of the adapted CMAQ for January v2. The temporal evolutions of the RAMS-observed $PM_{2.5}$-concentrations were compared with the simulated $PM_{2.5}$-concentrations (Fig. 38). The RAMS data suggested some temporal offsets at times of local extremes, for instance, the adapted CMAQ model shows a drop on January 27, where the observed 24h-average $PM_{2.5}$-concentrations peaks (Fig. 38).

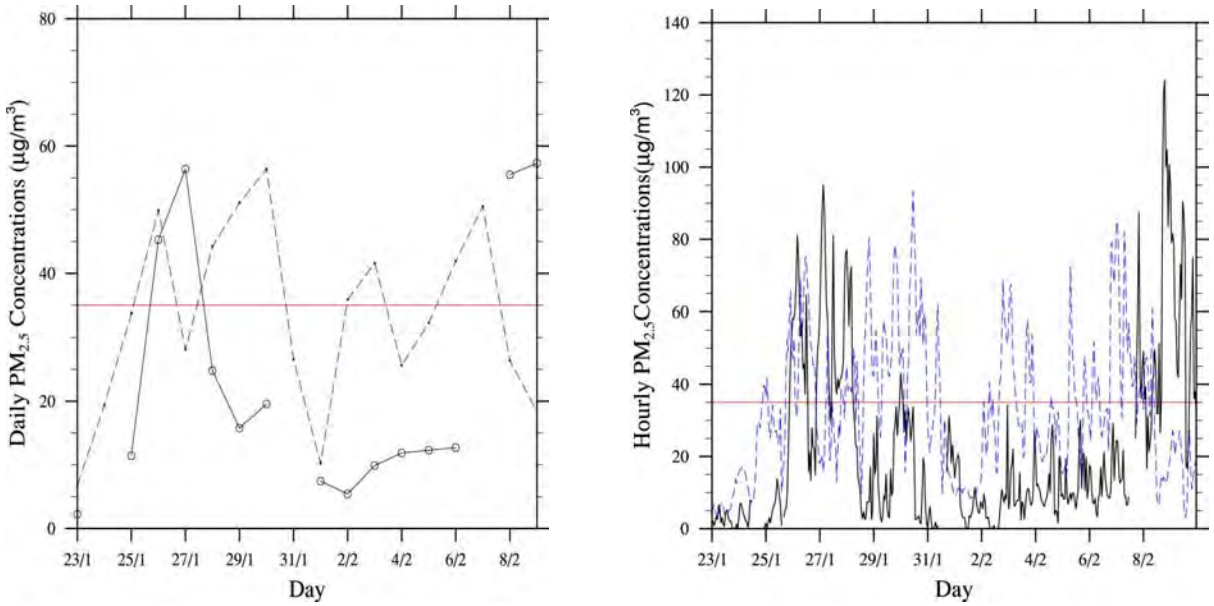


Fig. 38 Time series of simulated with the CMAQ with all modifications (blue dash line) and observed (black solid line) 24h-average $PM_{2.5}$-concentrations (left) and hourly $PM_{2.5}$-concentrations (right) at the State Building site as obtained for January v2.

The performance of CMAQ in simulating the $PM_{2.5}$-compositions for January v2 was evaluated. The scatter plot of simulated and observed $PM_{2.5}$-composition shows that one value for sulfate and one value for ammonium are not in the factor of three agreement (Fig. 39). The soccer plot and bugle plots indicate that the increased Cl-concentrations for the IC/BC led to the better performance for chloride. However, sulfate and ammonium are still outside of the criteria similar as it was found for the November episode (Fig. 40). Additionally, there was one value of OC and EC each that was outside the criteria.

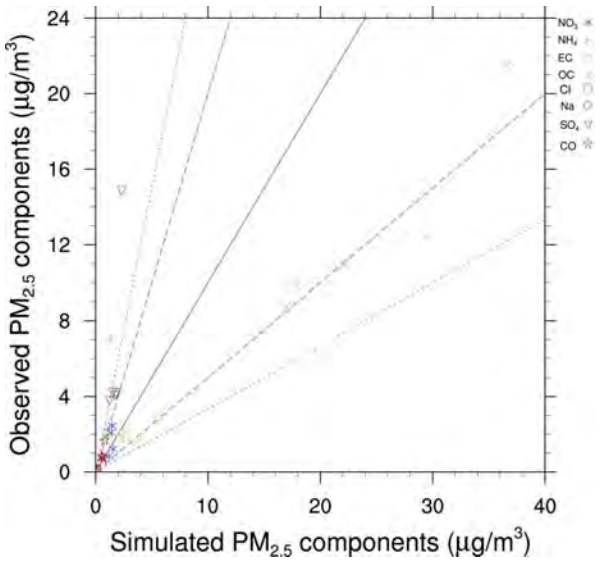


Fig.39 Scatter plot of simulated and observed 24h-average $PM_{2.5}$-composition at the State Building site for the January v2 episode.

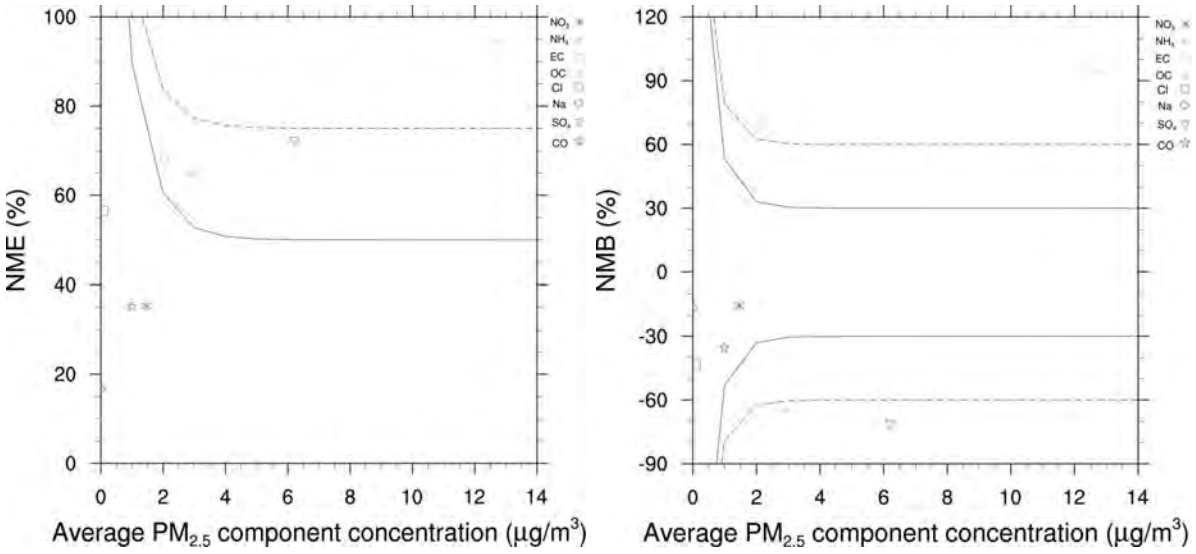


Fig. 40. Bugle plots of normalized mean (a) errors and (b) biases of simulated 24h-average $PM_{2.5}$-composition and (c) soccer plot of normalized mean errors and biases all determined with respect to the observations at the State Building site for January v2. The dashed and solid lines indicate the performance criteria and performance goals in accord with Boylan and Russell (2006).

2.5 Process analysis for the November and January v2 episodes and investigation on boundary conditions

The 24h-average $PM_{2.5}$-composition as simulated by the Alaska adapted CMAQ for the November episode and January v2 episode were compared for each day that had observed data (Figs. 41, 42). In the November episode, there were only three days, which had observed 24-haverage $PM_{2.5}$-composition data. Note that there was no observed CO data on these days. Overall, the Alaska adapted CMAQ model overestimated OC and EC, but underestimated SO_4, NH_4, Na and Cl. The adapted CMAQ model overestimated NO_3 on one day and underestimated NO_3 on two days.

In the January episode, there were six days with observed $PM_{2.5}$-composition data. The adapted CMAQ model shows similar results as for the November episode, i.e. it overestimated OC and EC, but underestimated SO_4, NH_4, Na, Cl and CO. The adapted CMAQ model overestimated NO_3 on two days and underestimated NO_3 on four days, but the trend of simulated NO_3-concentrations seemed to follow the observed data.

Ten-day backward trajectories (http://ready.arl.noaa.gov/HYSPLIT_traj.php) were run for the days, which had observed 24h-average $PM_{2.5}$-concentration data. The trajectories were determined starting at 00UTC and at 20m, 200m, 1000m above ground level over the Fairbanks meteorological station. The backward trajectories indicate that on the days, which had low observed 24h-average $PM_{2.5}$-composition concentrations, i.e. November 12 and February 4, the aerosols at the low levels (20m) were from the local sources (Fig. 43). Long-range transport contributed to the peak on the days, which had high observed 24h-average $PM_{2.5}$-composition concentrations, which CMAQ model seemed to be not able to capture. However, again the long-range is not the cause for the $PM_{2.5}$-problem. Note that a half year study with WRF/Chem for winter 2008/09 showed only a few days that had advection from outside Alaska (Mölders et al. 2012). Investigations by Cahill (2003) based on about a decade of observations also showed that the advection of $PM_{2.5}$ by long-range transport is not the reason for the $PM_{2.5}$-problem in Fairbanks. Investigations by Tran et al. (2011) performed for January 2000 also suggested only marginal advection of $PM_{2.5}$ from Asia to the Interior of Alaska and confirmed the results found here and by the afore cited authors.

The underestimations of SO_4 and NH_4 on every day of both episodes indicate errors, which need to be investigated and corrected. Some first steps in this direction are reported on later in this report.

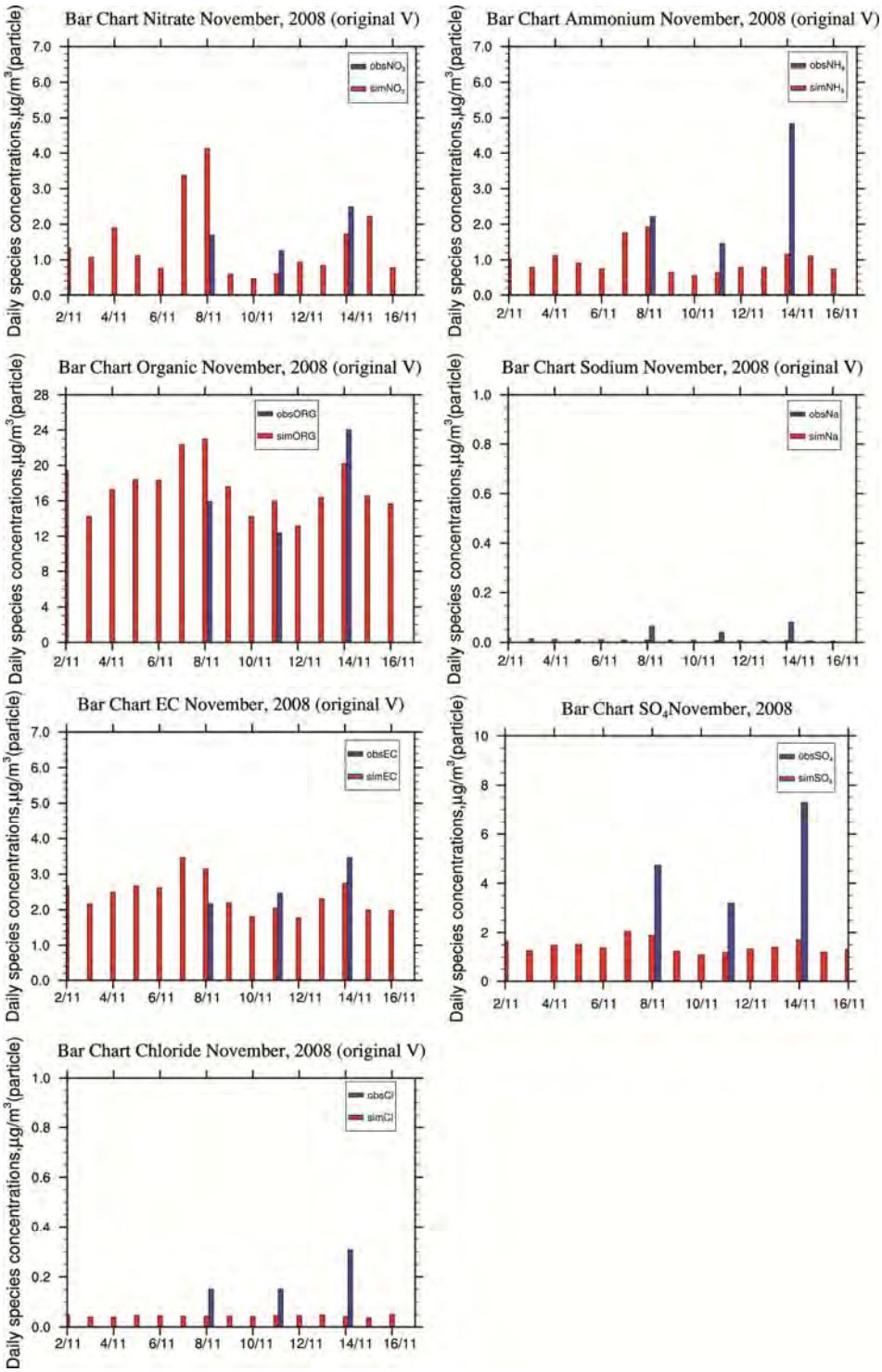


Fig. 41 Bar charts of simulated (red) and observed (blue) 24h-average $PM_{2.5}$-composition for NO_3, NH_4, EC, OC, Na, Cl, SO_4 as obtained for the November episode.

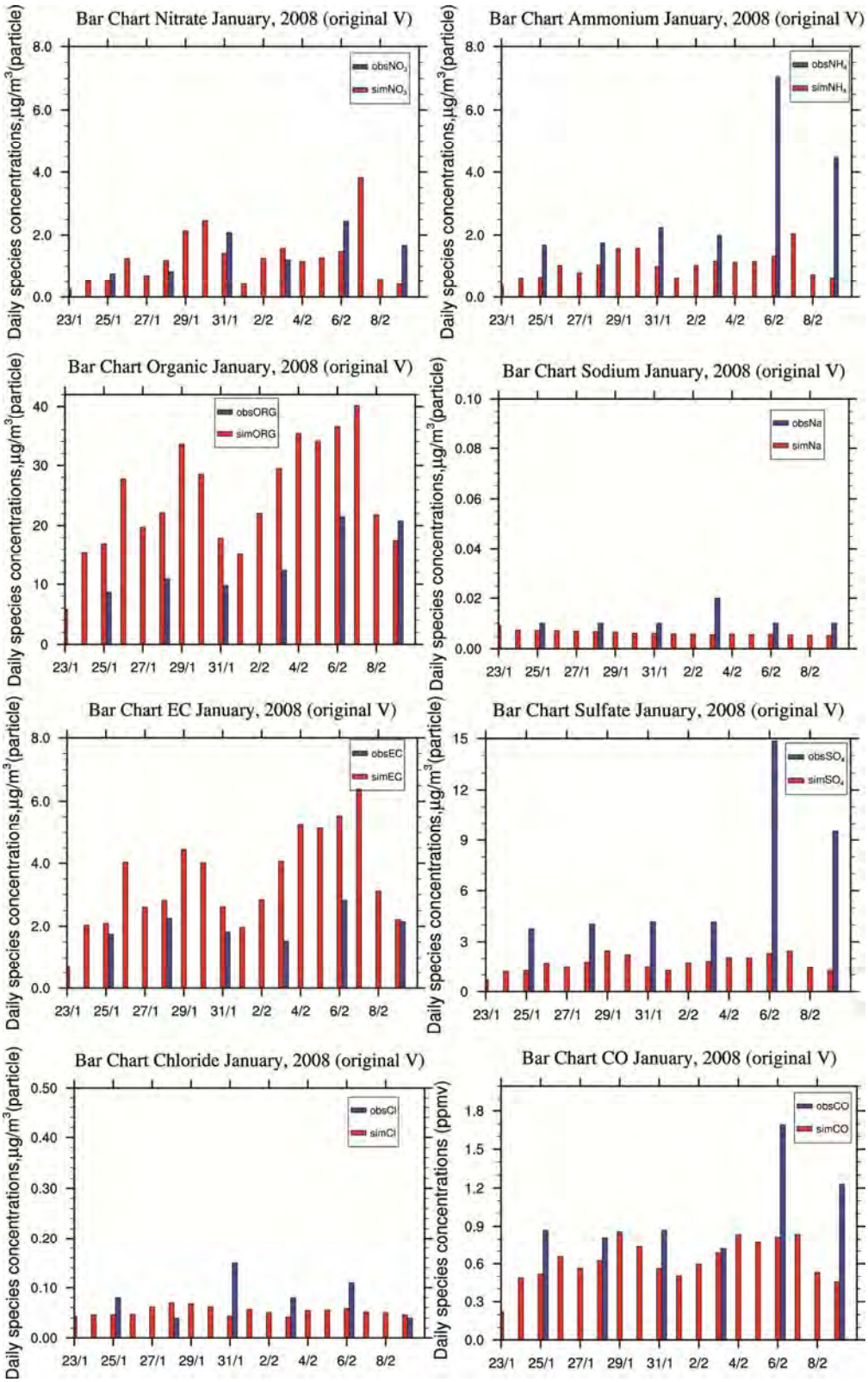


Fig. 42 Bar charts of simulated (red) and observed (blue) 24h-average $PM_{2.5}$-composition for NO_3, NH_4, EC, OC, Na, Cl, SO_4 as obtained for the January v2 episode.

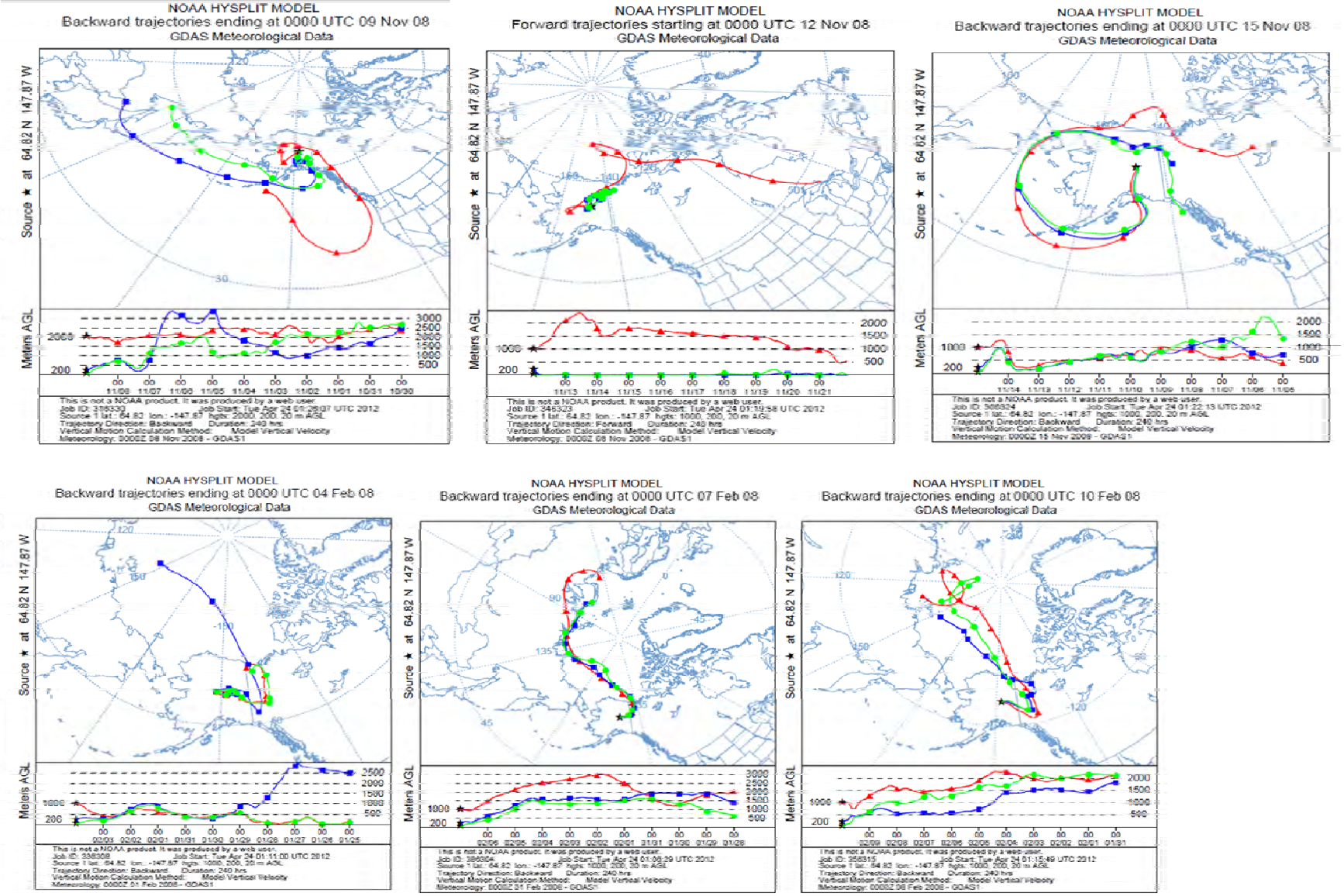


Fig. 43 Ten-day backward trajectories as calculated for November 9, 12, and 15, 2008, and February 4, 7, and 10, 2008 at 00 UTC.

To investigate the under-prediction of SO_4 at the State Building site, we conducted a process analysis. Process analysis is a technique that provides information about the impacts of individual processes on the change in a species' concentration. In the following, we refer to horizontal transport as the sum of horizontal advection and diffusion, and to vertical transport as the sum of vertical advection and diffusion. Aerosol processes represent the net effects of aerosol thermodynamics, new particle formation, condensation of sulfuric acid and organic carbon on preexisting particles, and the coagulation within and between Aitken and accumulation modes of particulate matter (PM). Cloud processes represent the net effects of cloud attenuation of photolytic rates, aqueous-phase chemistry, below-and in-cloud mixing with chemical species, cloud scavenging and wet deposition (Liu et al., 2010).

The hourly process analysis results for $PM_{2.5}$-concentrations and other species were analyzed for the domain. In the following, the results for the grid-cell holding the State Building site are discussed. Figure 44 shows the contributions of individual processes to the 24h-average $PM_{2.5}$-concentration in the first model layer (0-4m) at the grid-cell holding the State Building site. According to the process analysis, emissions were the dominant contributor to the $PM_{2.5}$-concentrations, and the horizontal transport contributed and removed $PM_{2.5}$ at this grid-cell. The aerosol processes played a small role here, which indicates that $PM_{2.5}$ is composed mainly of primary PM at this site. $PM_{2.5}$ was mainly vented out through vertical transport. Dry deposition played a small role in the removal of $PM_{2.5}$ and cloud process did not play any role here.

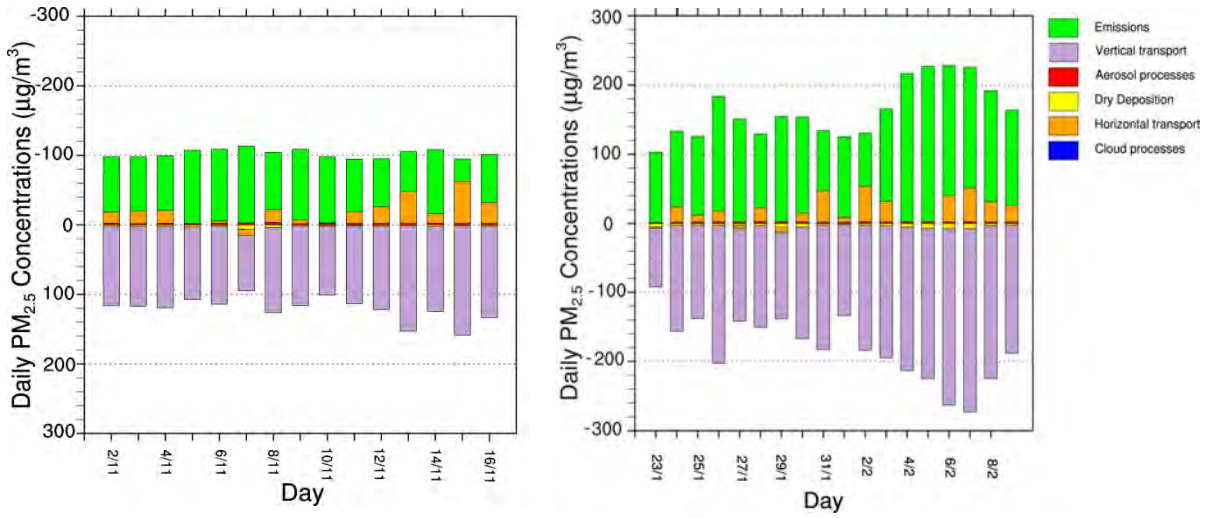


Fig. 44 Daily mean hourly contributions of individual processes to the $PM_{2.5}$-concentrations at the State Building site as obtained for the November episode (left) and January v2 episode (right).

For the sulfate species, the major contributors were emissions and horizontal transport. Comparing the observed sulfate bar chart (Fig. 42) with the process analysis plot (Fig. 45), it

could be verified that there was some offsets for the horizontal transport. For example, on November 14 or February 6, when the observed sulfate concentrations were highest, the horizontal transport in the process analysis (Fig. 45) dropped and peaked on the following day. Similar to $PM_{2.5}$, the major removal process for sulfate at the grid holding the State Building site was vertical transport. The dry deposition processes played a small role here, and aerosol processes and cloud processes did not play a role in sulfate formation. The latter may be a hint at overlooked sulfate forming processes or too low aqueous phase processes.

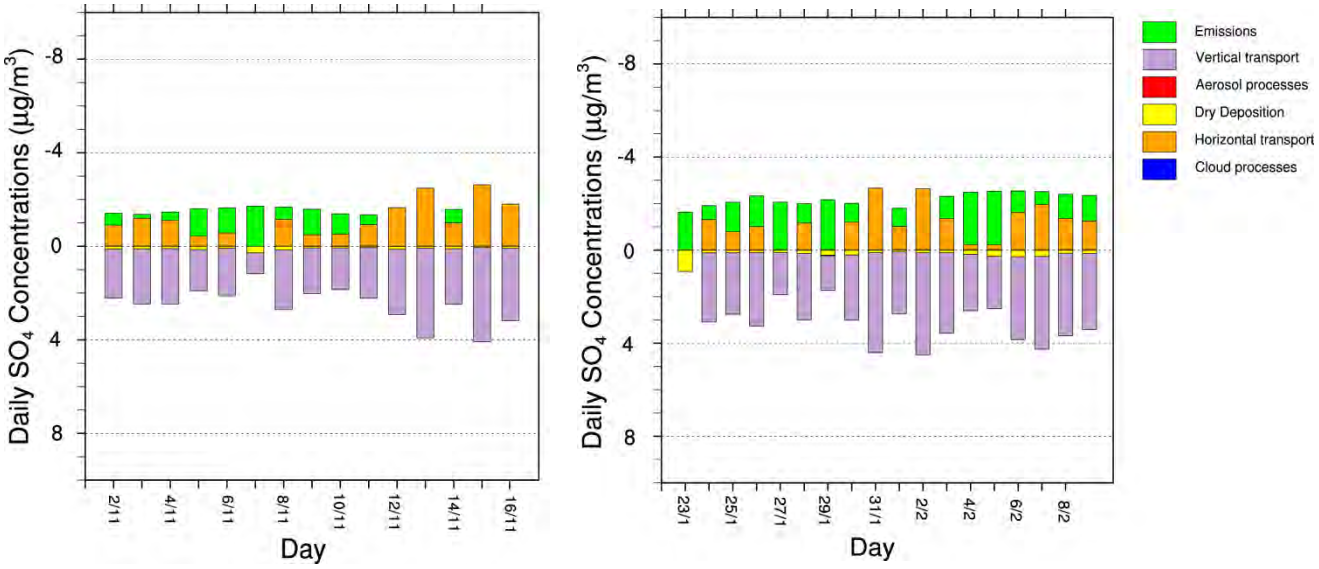


Fig. 45 Daily mean hourly contributions of individual processes to the SO_4-concentrations at the State Building site for the November episode (left) and January v2 episode (right).

Different from sulfate, the aerosol processes played the main role for nitrate formation. High production of nitrate also came from horizontal transport, which also shows an offset. The major removal process was vertical transport, and dry deposition caused a small loss to nitrate. Cloud processes neither produced nor removed nitrate in this grid-cell (Fig. 46).

For ammonium, the aerosol processes are the dominant contributor at this site. Horizontal transport contributed to ammonium on some days. The major removal process was vertical transport, and dry deposition caused only a small loss to ammonium. Cloud processes did not play a role here similar to what was found for both sulfate and nitrate (Fig. 47).

According to the process analysis results, cloud processes did not play a role for the formation or removal of aerosols at this grid cell. In general, the aqueous-phase oxidation of SO_2 in clouds is able to increase the SO_4-formation. Therefore, the average amount of water and ice mixing ratios simulated by WRF for both episodes were compared in vertical model column over the State Building site. Figure 48 shows that the cloud phase at this site is in the solid (ice) phase, which might affect the aqueous reactions and may be a cause for the low formation of SO_4-aerosol. The

water phase represents the integral sum of cloud water mixing ratios and rain-water mixing ratios, and the ice phase represents the integral sum of snow, ice and graupel mixing ratios. Note that the comparison of 120 WRF-simulations over Alaska showed that the Morrison-code used in the WRF-simulations tends to produce relatively higher ice phase than liquid phase (Chigullapalli and Mölders 2008).

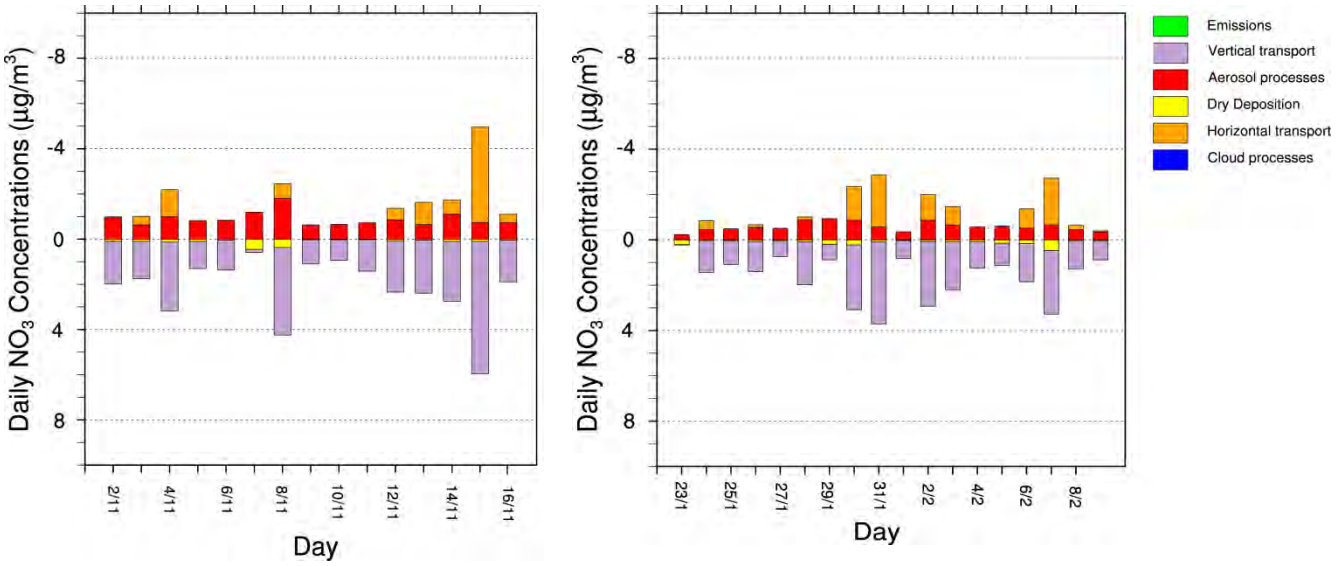


Fig. 46 Daily mean hourly contributions of individual processes to the NO_3-concentrations at State Building site as obtained for the November episode (left) and January v2 episode (right).

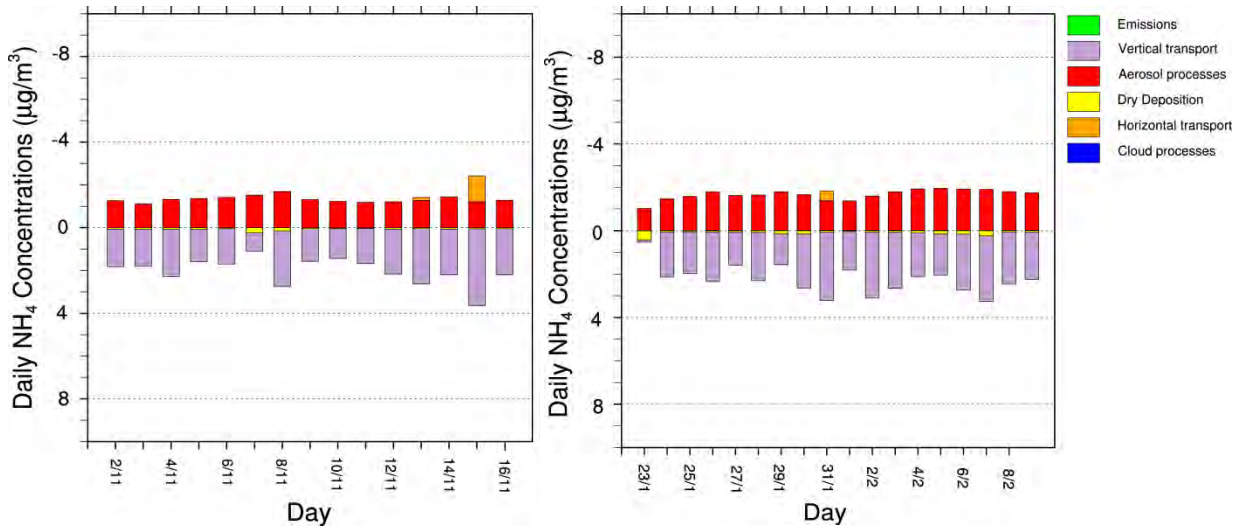
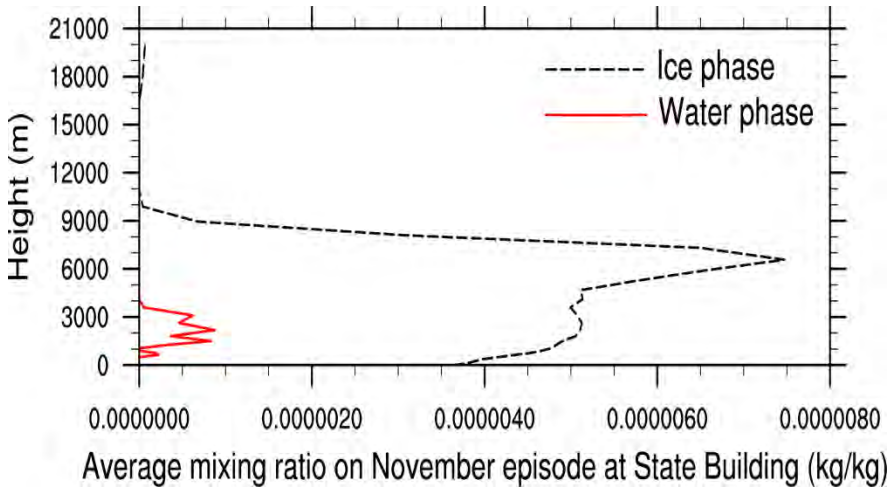


Fig. 47 Daily mean hourly contributions of individual processes to the NH_4-concentrations at the State Building site as obtained for the November episode (left) and January v2 episode (right).

(a)



(b)

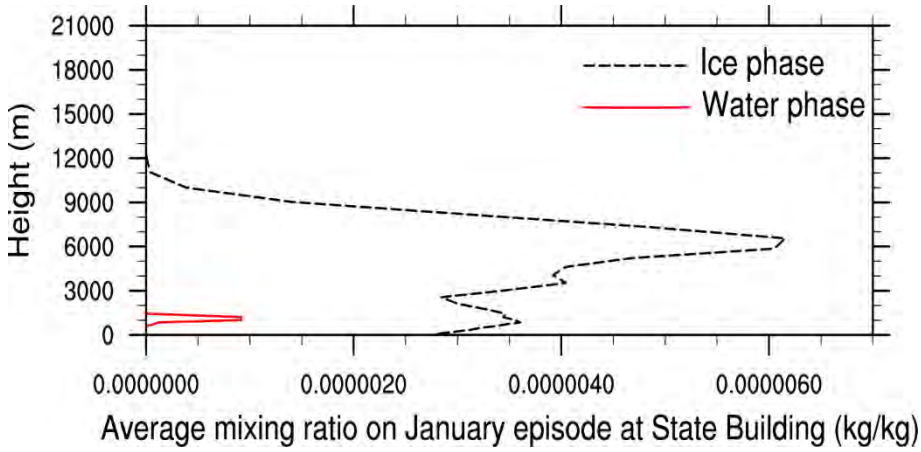


Fig. 47 Average ice phase and water phase mixing ratios at the State Building site as obtained for the (a) November episode and (b) January v2 episode.

Besides the effects from cloud processes, the underestimation of sulfate might come from too low SO_2-emissions. To test this hypothesis, we performed adapted CMAQ simulations wherein we doubled the SO_2-emissions that were given in the Sierra Research Inc. emission inventory. The results of this sensitivity study show that doubling the SO_2-emissions would increase the sulfate species concentrations, but not increase them (proportionally) two times (Fig. 48).

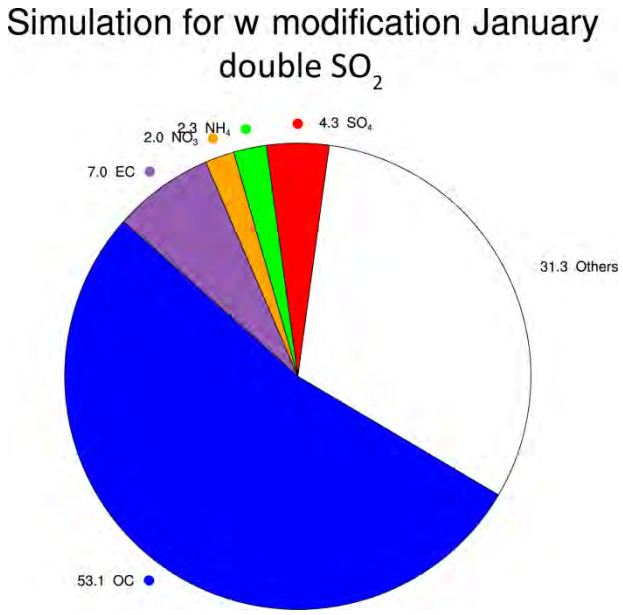


Fig. 48 Composition of total $PM_{2.5}$ averaged for the three days with observations as obtained by the adapted CMAQ for the January v2 episode and the sensitivity study with adapted CMAQ assuming doubled SO_2 emissions.

In a nutshell, the chemical processes have the dominant role in the formation of nitrate and ammonium, but not in the sulfate formation at the grid-cell holding the State Building site. Emissions are the main contributor to sulfate and $PM_{2.5}$-concentrations, and horizontal transport is another main contributor. The offset of the simulated meteorology led to the delay in prediction the $PM_{2.5}$ and its species of about 24 hours. The underestimation the sulfate composition is probably from the low amount of water in the liquid/water phase, i.e. low water content available to react with SO_2. Consequently, the cloud processes did not play a role for the aerosol formation. We recommend testing this hypothesis by adapted CMAQ simulations that use WRF simulations with a different cloud module. Studies on the impact of the parameterizations namely show that the partitioning between the solid and liquid phase in clouds differs strongly among parameterizations of cloud microphysical schemes (Mölders et al. 1995, 1997, Mölders 1999, Mölders and Kramm 2010) with consequences for the aqueous phase reactions (Mölders et al. 1994, Mölders and Laube 1994).

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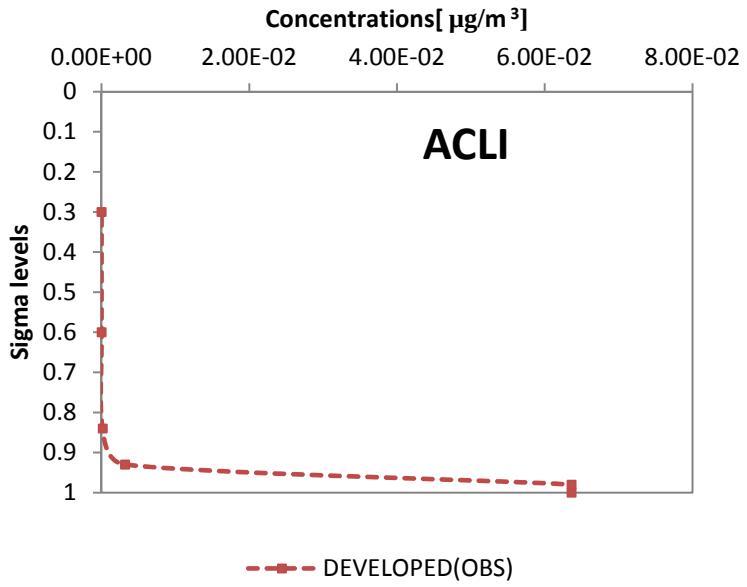
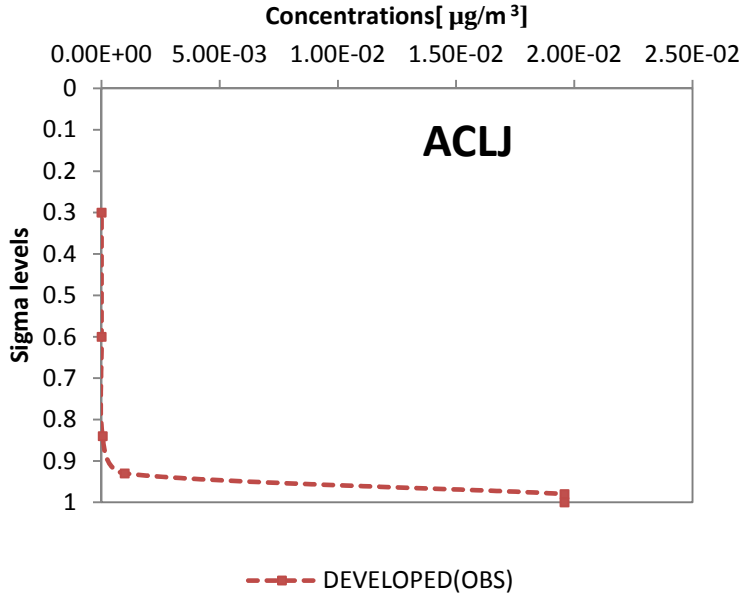
Appendix

The Cl-concentrations in the lowest level of the adapted CMAQ are now based on the average Cl-concentrations for January and November of 2003-2004 as observed at the Denali site (IMPROVE website). The vertical distribution assumed a reduction by 5% of the lower eta-level for every level between eta=0.93 and eta=0.30 (see panels below).





The Fairbanks, Alaska $PM_{2.5}$ Source Apportionment Research Study Winters 2005/2006-2012/2013, and Summer 2012

Final Report

Amendments 6 and 7

December 23, 2013

by

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1.0. Executive Summary

Fairbanks, Alaska has some of the highest measured ambient $PM_{2.5}$ (particulate matter less than or equal to 2.5 microns in diameter) concentrations in the United States, with wintertime levels often exceeding the 24-hour $PM_{2.5}$ National Ambient Air Quality Standard (NAAQS) of 35 $\mu g/m^3$. In an effort to understand the sources of $PM_{2.5}$ in the Fairbanks airshed, source apportionment using Chemical Mass Balance (CMB) modeling was conducted at multiple locations throughout Fairbanks each winter between 2005/2006 and 2012/2013. $PM_{2.5}$ source apportionment was also conducted at the NCORE and State Building sites during the summer of 2012 for comparison. Modeling for each of the sites/years was conducted using source profiles from both the Environmental Protection Agency (EPA) as well as Fairbanks-specific profiles developed by OMNI Environmental Services (OMNI).

Throughout the program, wintertime $PM_{2.5}$ average concentrations ranged from 8.2 $\mu g/m^3$ (RAMS, winter 2008/2009) up to 46.9 $\mu g/m^3$ (NPF3, winter 2012/2013), with many of the sites having frequent exceedances of the 24-hour NAAQS on the scheduled sample days. The results of the CMB modeling using source profiles developed by the EPA revealed that wood smoke (likely residential wood combustion) was the major source of $PM_{2.5}$ throughout the winter months in Fairbanks, contributing between ~60% to over 80% of the measured $PM_{2.5}$ depending on site and winter / year. The other sources of $PM_{2.5}$ identified by the CMB model were secondary sulfate (~7-21%), ammonium nitrate (3-11%), diesel exhaust (not detected-11%), and automobiles (not detected-7%). Approximately 1-2% of the ambient $PM_{2.5}$ was unexplained.

When conducting CMB modeling with Fairbanks-specific space heater source profiles developed by OMNI, final results were somewhat similar to the sources identified using EPA profiles. Consistent with the EPA modeling, wood smoke was identified as being a large source of $PM_{2.5}$ at the majority of the sampling sites, contributing from 30% to 77% to the ambient wintertime $PM_{2.5}$. In addition, the OMNI profile for No. 2 fuel oil combustion was frequently identified during the winter months, contributing anywhere from 10% to 47% to the ambient $PM_{2.5}$ throughout the winter months at each of the sites. Combustion of No. 2 fuel oil (and contribution to ambient $PM_{2.5}$) was determined to be especially high at the State Building and Peger Road sites.

Summer source apportionment revealed that ambient levels of $PM_{2.5}$ were very low at both the State Building and NCORE sites (~5.5 $\mu g/m^3$). CMB modeling using both the EPA and OMNI profiles identified wood smoke as the predominant source during the summer months, likely from residential outdoor biomass waste burning and regional controlled/wildfires. In summary, CMB modeling results using both the EPA and OMNI profiles support that residential home heating (residential wood stoves and heating with No. 2 fuel oil) are the major contributors to the ambient $PM_{2.5}$ in the Fairbanks airshed during the winter months. Wood smoke was also consistently identified during the summer months, albeit at much lower concentrations compared to winter concentrations.

2.0. Overview

The primary objective of this research study was to identify the major sources of ambient $PM_{2.5}$ in Fairbanks, Alaska using both EPA and OMNI (Fairbanks-specific) source profiles in a CMB model. Specifically, source apportionment was conducted for the following time periods/locations:

Winter 2005/2006: State Building.
Winter 2006/2007: State Building.
Winter 2007/2008: State Building.
Winter 2008/2009: State Building, North Pole, RAMS, Peger Road.
Winter 2009/2010: State Building, North Pole, RAMS, Peger Road.
Winter 2010/2011: State Building, North Pole, Peger Road.
Winter 2011/2012: State Building, NCORE, RAMS, North Pole, NPF3.
Summer 2012: State Building, NCORE.
Winter 2012/2013: State Building, NCORE, NPF3, NPE.

Within this report, the sampling, analytical, and computer modeling methodologies are described in Sections 3.0 through 5.0, respectively. Sections 6.0 and 7.0 present the results of the $PM_{2.5}$ sampling and CMB modeling program (using both EPA and OMNI source profiles), respectively, while Section 8.0 provides a discussion of all of the CMB modeling findings. Section 9.0 presents the results of the Quality Assurance / Quality Control (QA/QC) program. In Appendix A, the eight source profiles developed from the OMNI emissions testing are displayed, while Appendix B contains a listing of sample days excluded from CMB modeling. Finally, Appendix C presents the CMB results for each sample day (per site and season) using both EPA and OMNI profiles.

3.0. $PM_{2.5}$ Sampling Program

3.1. Sampling Program Experimental Method

For each of the winter sampling programs (November-March), $PM_{2.5}$ sampling was typically conducted every three days following the EPA"s fixed monitoring schedule. For the winters of 2005/2006, 2006/2007, and 2007/2008, sampling was conducted at the State Building site. $PM_{2.5}$ sampling was conducted at the State Building, North Pole, and Peger Road (also known as the Transit Yard) sites during the winters of 2008/2009, 2009/2010, and 2010/2011, respectively. A Relocatable Air Monitoring System (RAMS) collected $PM_{2.5}$ samples only during the winters of 2008/2009, 2009/2010, and 2011/2012. From January 14-March 19, 2009, the mobile RAMS was located at the Reindeer Site (i.e. University of Alaska Fairbanks Experimental Farm property between the Parks Highway and Geist Rd). From March 19 through the end of the program, the mobile RAMS was located at Woodriver Elementary School (Palo Verde Ave/ Univ. West). In this report, results for the Reindeer and Elementary School sites are presented as one location (i.e. the "RAMS Site").

In addition to the RAMS site, samples were also collected every three days at four additional sites (State Building, NCORE, North Pole, and NPF3) during the winter 2011/2012. For the winter of 2012/2013, the RAMS and North Pole sites were discontinued while the NPE site was added. Finally, $PM_{2.5}$ samples were collected at two locations during the summer of 2012 (State Building and NCORE) for a site comparison, as well as providing a comparison for summer results with winter results.

At each of the sites, 24-hour $PM_{2.5}$ sampling was conducted using a MetOne (Grants Pass, OR) Spiral Ambient Speciation Sampler (SASS). During each 24-hour sampling event at each of the sites, the SASS collected ~9.7 m^3 of air through Teflon, nylon, and quartz filter media, respectively (flow rate of 6.7 liters per minute (LPM)). Starting in the winter of 2009/2010, a URG 3000N Sequential Particulate

Speciation System was used to collect sample on a quartz filter at the State Building site for organics analyses. During each 24-hour event the URG collected air sample at a flow rate of 22.0 LPM.

3.2. Sampling Program Quality Assurance / Quality Control (QA/QC)

A stringent Quality Assurance / Quality Control (QA/QC) program was employed throughout this study. Prior to sampling, clean filters (Teflon, nylon, and quartz) were provided by Research Triangle Institute (RTI, Research Triangle Park, NC). Following the sampling events, exposed Teflon and nylon filters were sent back to RTI for laboratory analyses, while the exposed quartz filters were sent to Desert Research Institute (Reno, NV). During shipment of both clean and exposed filter sample media, all $PM_{2.5}$ filters remained in their protective containers and were FedEx overnighted in a cooler containing cold packs during transport.

Throughout the sampling program, the air samplers were maintained by Fairbanks North Star Borough (FNSB) Air Quality staff, with support from Alaska Department of Environmental Conservation (ADEC) staff. During each sampling event (24-hour period), the filters were subjected to temperatures that did not exceed the ambient temperature by more than five °C for more than 30 minutes continuously. Fairbanks site personnel removed the exposed filters from the samplers within 48 hours after the episode ended, and refrigerated the exposed filters immediately upon collection. The air samplers were also audited with an independent transfer standard during the program to verify the accurate measurement of air flow rates, ambient/filter temperatures, and barometric pressures. In addition, $PM_{2.5}$ filter field blanks were collected periodically throughout the program in an effort to determine any artifact contamination.

4.0. Analytical Program

4.1. $PM_{2.5}$ Speciation Data

The Met One Super SASS located at each of the sites collected ambient $PM_{2.5}$ on Teflon, nylon, and quartz filter media, respectively. The majority of the exposed SASS filter samples were analyzed by RTI. From the Teflon filter, a gravimetric analysis (RTI, 2008) was initially performed followed by an elemental analysis (RTI, 2009a) using energy-dispersive X-ray fluorescence (EDXRF) where 31 elements were quantified. From the nylon filter, ions (including ammonium, potassium, sodium, nitrate, and sulfate) were measured by ion chromatography (IC) (RTI, 2009b; RTI, 2009c). Depending on the site and year, quartz filters were either analyzed by RTI for Elemental Carbon and Organic Carbon (EC/OC) concentrations using Thermal Optical Transmittance (RTI, 2009d), or by Desert Research Institute using the IMPROVE_A method (Chow et al., 2007). Following the analyses, sample results (including analyte concentrations and uncertainties) were provided to the University of Montana for use in the CMB source apportionment model.

4.2. Analytical Program QA/QC

RTI and the Desert Research Institute were responsible for QA/QC activities within their laboratories.

5.0. Computer Modeling Program

In this project, the most recent version of the Chemical Mass Balance (CMB) computer model (Version 8.2) was utilized to apportion the sources of $PM_{2.5}$ in Fairbanks. The CMB receptor model (Friedlander, 1973; Cooper and Watson, 1980; Gordon, 1980, 1988; Watson, 1984; Watson et al., 1984; 1990; Hidy and Venkataraman, 1996) is based on an effective-variance least squares method, and consists of a solution to linear equations that expresses each receptor chemical concentration as a linear sum of products of source fingerprint abundances and contributions.

For each sample day (from the multiple sites), the CMB modeling process began by selecting from a combination of 91 sources (**see Table 1**) and 43 chemical species (36 elements, 5 ions, OC and EC, **Table 5**) in an effort to reconstruct the measured Fairbanks ambient $PM_{2.5}$ mass and chemical composition. As part of the CMB modeling procedure, multiple combinations would be tried for each sample run in an effort to select the best combination of sources and species, with an evaluation of the diagnostic performance measures conducted each time until an optimal fit could be obtained. The resulting output file contained the source contribution estimate (SCE) of each identified source, along with the associated standard errors (STD ERR). Unexplained concentrations were also calculated by taking the difference between the actual measured mass and the CMB predicted mass for each sample run.

5.1. CMB Model EPA Source Profiles

Discussions were held with Sierra Research, FNSB, and ADEC in an effort to identify all of the potential sources of $PM_{2.5}$ in Fairbanks prior to setting up the CMB model. Following these discussions, a comprehensive list of sources that could potentially contribute $PM_{2.5}$ to the Fairbanks airshed was developed. For each identified source, an attempt was made to locate a source profile. Source profiles are the fractional mass abundances of measured chemical species relative to primary $PM_{2.5}$ mass in source emissions, and are part of the input data loaded into the CMB model. Source profiles represent a general source category rather than any local, individual, $PM_{2.5}$ emission source.

The source profiles listed in **Table 1** (known throughout this report as "EPA Source Profiles") were either taken directly from the most recent version of SPECIATE 4.0 (USEPA, 2006) or from previous Missoula Valley (Montana) CMB applications (Carlson, 1990; Schmidt, 1996; Ward and Smith, 2005). SPECIATE 4.0 is EPA's repository of Total Organic Compound (TOC) and Particulate Matter (PM) speciated source profiles for use in source apportionment studies. For each source found in the database, both the compound fraction and uncertainty for the source-specific compounds are presented. The profiles in **Table 1** are listed together as source groups, and can be broken down into profiles for street sand and road dust (Profiles 1- 6), pure secondary source emissions (Profiles 7-9), gasoline and diesel exhaust emissions (Profiles 10 – 40), tire and brake wear (Profiles 41 - 48), meat cooking (Profiles 49 - 53), residential wood combustion (Profiles 54 – 78), and other local sources / industry in Fairbanks (Profiles 79-91). Multiple source profiles for each source were used because source compositions can vary substantially among sources, even within a single source over an extended period of time.

Since Missoula and Fairbanks have similar topographies (i.e. valley locations impacted by temperature inversions, cold winter temperatures, etc.) and many of the same sources of $PM_{2.5}$, several of the CMB source profiles developed in past Missoula CMB applications were included in the Fairbanks $PM_{2.5}$ source apportionment program. These include profiles for street sand (Profiles 1), secondary sulfate (Profile 7), secondary ammonium sulfate (Profile 8), secondary ammonium nitrate (Profile 9), diesel train (Profile 39) and diesel truck exhaust (Profile 40), and residential wood combustion (Profile 56). All SPECIATE and Missoula CMB profiles used in the Fairbanks CMB were reviewed before being loaded into the CMB model. For those chemical species known to be absent from specific source types, default values of zero for the mass fraction and uncertainty of 0.0001 were used.

One assumption of the CMB model is that compositions of source emissions are constant over the period of ambient and source sampling, and that chemical species do not react with each other. CMB is well suited for apportioning sources of primary aerosols (those emitted directly as particles). However, it is difficult to attribute secondary aerosols formed through gas-to-particle transformation in the atmosphere to specific sources. Sulfate, nitrate, and ammonium abundances in directly emitted particles are not sufficient to account for the concentrations of these species measured in the atmosphere. Therefore, to

account for secondary aerosol contributions to $PM_{2.5}$ mass, sulfate (Profile 7), ammonium sulfate (Profile 8), and ammonium nitrate (Profile 9) were expressed as "pure" secondary source profiles, and represented by their chemical form.

Table 1: $PM_{2.5}$ Source Profiles ("EPA Profiles") Used in the Fairbanks CMB.

Profile	Description
1	CITY STREET SANDING PILE, STREET SAND
2	SPECIATE 411302.5, PAVED ROAD DUST – COMPOSITE
3	SPECIATE 412202.5, UNPAVED ROAD DUST – COMPOSITE
4	SPECIATE 92053, PAVED ROAD DUST – SIMPLIFIED
5	SPECIATE 92088, UNPAVED ROAD DUST – SIMPLIFIED
6	SPECIATE 92073, SAND & GRAVEL – SIMPLIFIED
7	SULFATE (SO4 IS ONLY SPECIE, THEREFORE IS ONLY NONZERO CONCENTRATION)
8	AMMONIUM SULFATE (INCLUDES NH4)
9	AMMONIUM NITRATE (INCLUDES NH4)
10	SPECIATE 311052.5 LIGHT DUTY VEHICLE-LEADED COMPOSITE
11	SPECIATE 312022.5 LIGHT DUTY VEHICLE-UNLEADED
12	SPECIATE 321022.5 LIGHT DUTY VEHICLE-DIESEL
13	SPECIATE 321032.5 LIGHT DUTY VEHICLE-DIESEL (2ND PROFILE OF THIS TYPE)
14	SPECIATE 322032.5, HEAVY DUTY VEHICLE-DIESEL
15	SPECIATE 311082.5, LIGHT DUTY VEHICLE - NON CATALYST
16	SPECIATE 311072.5, LIGHT DUTY VEHICLE - WITH CATALYST
17	SPECIATE 322022.5, HEAVY DUTY DIESEL
18	SPECIATE 322082.5, HEAVY DUTY DIESEL TRUCKS
19	SPECIATE 312012.5, LIGHT DUTY VEHICLE – UNLEADED
20	SPECIATE 312032.5, LIGHT DUTY VEHICLE – UNLEADED
21	SPECIATE 3875, GASOLINE EXHAUST - WINTER, SMOKER
22	SPECIATE 3884, GASOLINE EXHAUST - WINTER, LOW EMITTER PROFILE 1
23	SPECIATE 3888, GASOLINE EXHAUST - WINTER, LOW EMITTER PROFILE 2
24	SPECIATE 3892, GASOLINE EXHAUST - WINTER, HIGH EMITTER PROFILE 1
25	SPECIATE 3896, GASOLINE EXHAUST - WINTER, HIGH EMITTER PROFILE 2
26	SPECIATE 3900, GASOLINE EXHAUST - WINTER, NON-SMOKER
27	SPECIATE 3904, GASOLINE EXHAUST - WINTER, SMOKER PROFILE 1
28	SPECIATE 3908, GASOLINE EXHAUST - WINTER, SMOKER PROFILE 2
29	SPECIATE 3878, DIESEL EXHAUST PROFILE 1
30	SPECIATE 3879, DIESEL EXHAUST PROFILE 2
31	SPECIATE 3880, DIESEL EXHAUST PROFILE 3
32	SPECIATE 3912, DIESEL EXHAUST PROFILE 4
33	SPECIATE 3913, DIESEL EXHAUST PROFILE 5
34	SPECIATE 3914, DIESEL EXHAUST PROFILE 6
35	SPECIATE 92035, HDDV EXHAUST – SIMPLIFIED
36	SPECIATE 92042, LDDV EXHAUST – SIMPLIFIED
37	SPECIATE 92049, NON-CATALYST GASOLINE EXHAUST – SIMPLIFIED
38	SPECIATE 92050, ONROAD GASOLINE EXHAUST – SIMPLIFIED
39	DIESEL TRAIN (SENT FROM MISSOULA)
40	DIESEL TRUCK (SENT FROM MISSOULA)
41	SPECIATE 340022.5, TIRE WEAR PROFILE 1
42	SPECIATE 340032.5, TIRE WEAR PROFILE 2
43	SPECIATE 340082.5, TIRE WEAR PROFILE 3
44	SPECIATE 3156, TIRE WEAR PROFILE 4

45	SPECIATE 92087, TIRE DUST – SIMPLIFIED
46	SPECIATE 340042.5, BRAKE LINING – ASBESTOS
47	SPECIATE 3157, BRAKE WEAR
48	SPECIATE 92009, BRAKE LINING DUST – SIMPLIFIED
49	SPECIATE 160002.5, MEAT COOKING – CHARBROILING
50	SPECIATE 160012.5, MEAT COOKING – FRYING
51	SPECIATE 4383, COOKING
52	SPECIATE 91005, COOKING - CHARBROILING COMPOSITE
53	SPECIATE 92015, CHARBROILING – SIMPLIFIED
54	SPECIATE 421042.5 RESIDENTIAL WOOD SMOKE FROM MEDFORD, OR
55	SPECIATE 421052.5 RESIDENTIAL WOOD SMOKE FROM POCATELLO, ID
56	RESIDENTIAL WOOD COMBUSTION (SUPPLIED BY MISSOULA)
57	SPECIATE 423182.5, RESIDENTIAL WOOD COMBUSTION
58	SPECIATE 423032.5, RESIDENTIAL WOOD COMBUSTION, COMPOSITE
59	SPECIATE 423302.5, COMPOSITE OF RESIDENTIAL WOODBURNING SOURCES
60	SPECIATE 421022.5, WOOD STOVES - AVERAGE ALL FUELS
61	SPECIATE 421012.5, WOOD STOVES - PINE FUELS
62	SPECIATE 3235, RESIDENTIAL WOOD BURNING PROFILE 1
63	SPECIATE 3236, RESIDENTIAL WOOD BURNING PROFILE 2
64	SPECIATE 3238, RESIDENTIAL WOOD BURNING PROFILE 3
65	SPECIATE 3239, RESIDENTIAL WOOD BURNING PROFILE 4
66	SPECIATE 3240, RESIDENTIAL WOOD BURNING PROFILE 5
67	SPECIATE 3769, RESIDENTIAL WOOD BURNING PROFILE 6
68	SPECIATE 3770, RESIDENTIAL WOOD BURNING PROFILE 7
69	SPECIATE 423192.5, RESIDENTIAL WOOD COMBUSTION COMPOSITE
70	SPECIATE 423312.5, RESIDENTIAL WOODSTOVE COMPOSITE
71	SPECIATE 91031, RESIDENTIAL WOOD COMBUSTION: HARDSOFT – COMPOSITE
72	SPECIATE 91032, RESIDENTIAL WOOD COMBUSTION: HARDSOFTN/A – COMPOSITE
73	SPECIATE 91033, RESIDENTIAL WOOD COMBUSTION: SOFT – COMPOSITE
74	SPECIATE 92067, RESIDENTIAL WOOD COMBUSTION: HARD – SIMPLIFIED
75	SPECIATE 92068, RESIDENTIAL WOOD COMBUSTION: HARDSOFT – SIMPLIFIED
76	SPECIATE 92069, RESIDENTIAL WOOD COMBUSTION: HARDSOFT N/A – SIMPLIFIED
77	SPECIATE 92071, RESIDENTIAL WOOD COMBUSTION: SYNTHETIC – SIMPLIFIED
78	SPECIATE 92090, WILDFIRES – SIMPLIFIED
79	SPECIATE 92006, ASPHALT ROOFING – SIMPLIFIED
80	SPECIATE 92025, DISTILLATE OIL COMBUSTION – SIMPLIFIED
81	SPECIATE 92048, NATURAL GAS COMBUSTION – SIMPLIFIED
82	SPECIATE 92052, OVERALL AVERAGE / DEFAULT (WASTE DISPOSAL, MISC) – SIMPLIFIED
83	SPECIATE 92060, PROCESS GAS COMBUSTION – SIMPLIFIED
84	SPECIATE 92063, RESIDENTIAL NATURAL GAS COMBUSTION – SIMPLIFIED
85	SPECIATE 92072, RESIDUAL OIL COMBUSTION – SIMPLIFIED
86	SPECIATE 92075, SEA SALT – SIMPLIFIED
87	SPECIATE 92079, SINTERING FURNACE-SIMPLIFIED (ZINC PROD, FLUE DUST HANDLING)
88	SPECIATE 92082, SOLID WASTE COMBUSTION – SIMPLIFIED
89	SPECIATE 92084, SUBBITUMINOUS COMBUSTION – SIMPLIFIED
90	SPECIATE 92085, SURFACE COATING – SIMPLIFIED
91	SPECIATE 92086, TIRE BURNING – SIMPLIFIED

5.2. CMB Modeling Using Fairbanks-Specific ("OMNI") Profiles

One limitation of using the EPA SPECIATE source profiles for CMB modeling (as described above) is that the profiles are not representative of Fairbanks-specific home heating fuel types. In other words, the

profiles were not developed using Fairbanks specific fuels or generated under Fairbanks-specific operating and meteorological conditions. To address this concern, emission testing was conducted by OMNI Environmental Services (Portland, OR) for a variety of home heating fuels and home heating devices commonly used in Fairbanks. These emissions results were provided to the University of Montana for development of Fairbanks-specific source profiles, with these profiles then used in CMB source apportionment modeling.

Prior to emissions testing, the FNSB provided OMNI with Fairbanks specific fuel types to be used in a variety of home heating devices. The goal of the OMNI testing was to generate emission profiles for the following types of heating appliances and fuel types: pellet stoves, EPA wood stoves (birch, spruce), conventional wood stoves (birch, spruce), EPA hydroponic heaters (birch, spruce), non qualified outdoor hydroponic heaters (spruce, birch, wet stoker coal), oil burners (No. 1 fuel oil, No. 2 fuel oil), waste oil burning, coal stoves (dry stoker coal, wet stoker coal, wet lump coal, dry lump coal), and coal hydroponic heaters (wet stoker coal and coal-typical moisture).

During each of the 41 trials, emission samples were collected on Teflon and quartz filter samples, respectively. From the Teflon filter, $PM_{2.5}$ mass, ions (potassium, sodium, ammonium, nitrate, and sulfate), and elements (33 in total) were quantified. From the quartz filter, levels of Organic Carbon and Elemental Carbon were measured. The Research Triangle Institute (RTI, Research Triangle Park, NC) conducted all of the analyses, and reported results in µg of analyte/filter. Following the completion of OMNI emissions testing, results from the trials were sent to FNSB, ADEC, and Sierra Research for a comprehensive review of methodology (sampling and analytical) and completeness. From the 41 emissions trials that were conducted by OMNI, University of Montana was instructed to focus on only eight of the trials. University of Montana then took the raw emissions data from these eight source types and transformed them into source profiles that were used in the CMB model.

The Fairbanks-specific source profiles that were developed from the OMNI emissions testing are presented in **Table 2.** In developing the profiles, the raw data from OMNI had to be put into a format recognized by the CMB model. First, the raw mass, elemental, OC/EC, and ion data (in µg/filter) measured by the Teflon and quartz filters were corrected for volume ($dsft^3$). This volume was the amount of air collected (for each filter) during each emissions testing trial. For the Teflon filters, the collected volumes varied from 1.12 up to 22.63 $dsft^3$, while for the quartz filter volumes ranged from 1.74 to 21.27 $dsft^3$. These values (µg/ $dsft^3$) were then normalized to the overall mass (units in µg/ $dsft^3$) to give the mass fraction of each species. For uncertainty, a default value of 0.0001 was utilized, with a value of "-99" utilized for missing species.

Table 2: OMNI Source Profiles ("OMNI Profiles") Used in the Fairbanks CMB.

Profile	Description
100	OMNI Profile, EPA Wood Stove, Birch, Low
101	OMNI Profile, EPA OWHH, Birch, Low
102	OMNI Profile, Conventional Wood Stove, Birch, Low
103	OMNI Profile, Oil Burner, No. 2 Fuel Oil
104	OMNI Profile, Coal Stove, Wet Stoker Coal, Low
105	OMNI Profile, Coal HH, Wet Stoker Coal, Single
106	OMNI Profile, WasteOil Brnr, Waste Oil, Single
107	OMNI Profile, EPA Wood Stove, spruce, low
108	OMNI Profile, Coal Stove Dry Lump Coal, low

The eight source profiles developed from the OMNI emissions testing are presented in **Appendix A**.

5.3. CMB Modeling Program QA/QC

A comprehensive QA/QC plan was applied throughout the CMB modeling program to ensure accurate results, including the use of the CMB validation protocol (Watson et al., 2004). The QA/QC protocol:

1) determines model applicability;
2) selects a variety of profiles to represent identified contributors;
3) evaluates model outputs and performance measures;
4) identifies and evaluates deviations from model assumptions;
5) identifies and corrects model input deficiencies;
6) verifies consistency and stability of source contribution estimates; and
7) evaluates CMB results with respect to other data analysis and source assessment methods.

For each model run, evaluations of several different combinations of source profiles were used, with the number of chemical species always exceeding the number of source types. As described in **Table 3**, statistical parameters used to evaluate the validity of source contribution estimates included TSTAT, R^2, Chi^2, DF, and R/U ratios. The results of these fitting parameters (for each modeling run) have to be within the EPA target ranges for the modeling results to be considered valid. It should also be noted that concentrations of species found on field/trip blanks were not subtracted (or blank-corrected) from the ambient sample concentrations before the modeling was conducted.

Table 3: Statistical Criteria for the CMB Model.

Output / Statistic	Abbreviation	EPA Target	Explanation
Std. Error	STD ERR	⩽SCE	The standard error of the SCE.
T-statistic	TSTAT	> 2.0	The ratio of the value of the SCE to the uncertainty in the SCE. A T-STAT greater than 2 means that the SCE has a relative uncertainty of less than 50%.
R-square	R-SQUARE (R^2)	0.8 to 1.0	A measure of the variance of the ambient concentration explained by the calculated concentration.
Chi-square	CHI-SQUARE (Chi^2)	0.0 to 4.0	A term that compares the difference between the calculated and measured ambient concentrations to the uncertainty of the difference. A perfect fit has a chi-square of 0.0, and a chi-square less than 2 usually indicates a good fit.
Percent Mass Explained	% MASS	100% ± 20%	The ratio of the total calculated to measured mass.
Degrees of Freedom	DF	> 5	The difference between the number of fitting species and the number of fitting sources.
Ratio of Calculated to Measured	RATIO C/M	0.5 to 2.0	The ratio of the calculated to measured concentration of an ambient species. Ideally, this value should be 1.0.
Ratio of Residual to Uncertainty	RATIO R/U	–2.0 to 2.0	The ratio of the residual (calculated minus measured) to the uncertainty of the residual (square root of the sum of squares of the uncertainties).

6.0. $PM_{2.5}$ Sampling Results

In presenting the final $PM_{2.5}$ results (in units of microgram of analyte per cubic meter volume of air collected, $\mu g/m^3$), there were several sample days throughout the program that were excluded from the overall average calculations due to sampler malfunctions or collection errors. Sample days where a

good statistical fit was not achieved using the CMB model were also excluded from the average calculations. A complete listing of these sample days along with a description of why the data points were excluded are presented in **Appendix B**.

6.1. $PM_{2.5}$ Mass Results

Table 4 presents the average $PM_{2.5}$ mass that was measured from Teflon filters collected at each of the sites throughout the program. Overall, wintertime $PM_{2.5}$ average concentrations ranged from 8.2 $\mu g/m^3$ (RAMS, winter 2008/2009) up to 46.9 $\mu g/m^3$ (NPF3, winter 2012/2013), with many of the sites having frequent exceedances of the 24-hour NAAQS on the scheduled sample days. Results from the summer 2012 show that $PM_{2.5}$ mass averages were very low, averaging less than 6.0 $\mu g/m^3$ at both the State Building and NCORE sites. Note that in **Table 4** there are two $PM_{2.5}$ masses listed for the winter 2008/2009 State Building and RAMS sites. The first $PM_{2.5}$ mass values are the average $PM_{2.5}$ concentrations originally presented in the Final Report submitted to ADEC (dated July 23, 2012). For consistency with the CMB modeling results presented in this report, updated CMB modeling was conducted on the 2008/2009 datasets using OMNI profiles in addition to automobile and diesel source profiles (note that auto / diesel exhaust were not identified in the initial OMNI modeling). The second $PM_{2.5}$ mass values presented for 2008/2009 (State Building and RAMS) are the average $PM_{2.5}$ concentrations for those sample days in which updated CMB modeling was conducted. Please note that when using the OMNI profiles, there were times when a statistical fit could not be obtained for a specific sampling day, thus explaining the smaller "n" and therefore different average $PM_{2.5}$ mass (compared to the EPA modeling runs) for specific winters/sites. For the remainder of the winters (2009/2010 through 2012/2013), a single asterisk "*" indicates the average concentrations for the days in which modeling was conducted using only the EPA profiles, while "**" indicates the average $PM_{2.5}$ concentrations for those days in which only OMNI profiles were used for modeling. No asterisk indicates that the number of modeling runs was identical between the EPA and OMNI modeling activities (therefore $PM_{2.5}$ averages were the same).

6.2. $PM_{2.5}$ Chemical Speciation Results

Tables 5 through **11** present the average concentrations (in $\mu g/m^3$) of elements, ions, and OC/EC, respectively, measured throughout the sampling programs at each of the sites/years. The minimum detection limits (MDL) in $\mu g/m^3$ for each compound are also presented, with the bolded values (within the tables) indicating analyte concentrations measured at or above the MDL. All MDLs were provided by RTI. Also please note that **Table 6** contains the revised average speciated data for the winter 2008/2009 where CMB modeling was updated using the OMNI profiles (along with the automobile and diesel exhaust profiles). For the remainder of the speciated data results in **Tables 7-11**, a single asterisk "*" indicates the average speciated data concentrations for the days in which modeling was conducted using only the EPA profiles, while "**" indicates the average concentrations for those days in which only OMNI profiles were used for modeling. No asterisk indicates that the number of modeling runs was identical between the EPA and OMNI modeling activities (therefore speciated analyte averages were the same).

Out of the 36 elements quantified, only about 13 were consistently measured at or above their reported MDLs. Sulfur typically had the highest concentration of the measured elements (especially at the State Building and Peger Road sites), followed by chlorine and potassium. Regarding the ions that were measured, sulfate had the highest concentration at each of the sites, followed by ammonium and nitrate. Total Carbon (TC) measurements were always heavily influenced by the OC fractions at each of the sites. Results from the field and trip blanks for the species listed in **Tables 5-11** were minimal throughout the sampling/analytical program, therefore data were not blank corrected prior to using in the CMB model.

Table 4: Average $PM_{2.5}$ Mass Concentrations ($\mu g/m^3$).

Winter, Site	$PM_{2.5}$ mass	Sampling Dates	n
2005/2006, State Building	18.9	11/3/05 – 3/30/06	36
2006/2007, State Building	19.9	11/1/06 – 3/31/07	39
2007/2008, State Building	18.7	11/2/07 – 3/31/08	40
Winter 2008/2009			
State Building	25.3, 24.4	11/8/08 – 4/7/09	47, 46
North Pole	18.9	1/25/09 – 4/7/09	21
RAMS	8.2, 8.3	1/25/09 – 4/7/09	23, 22
Peger Road	16.8	1/25/09 – 4/7/09	26
Winter 2009/2010			
State Building	28.8*, 24.5**	11/3/09 – 3/15/10	40*, 31**
North Pole	33.7	11/3/09 – 3/15/10	35
RAMS	36.7	11/15/09 – 3/15/10	29
Peger Road	29.0*, 29.5**	11/3/09 – 3/15/10	38*, 37**
Winter 2010/2011			
State Building	20.2	11/1/10 – 2/8/11	15
North Pole	26.8	1/9/11 – 2/5/11	10
Peger Road	28.6	1/9/11 – 2/5/11	10
Winter 2011/2012			
State Building	20.0*, 19.5**	11/2/11 – 3/31/12	38*, 36**
North Pole	24.2*, 23.0**	11/2/11 – 3/25/12	35*, 34**
RAMS	22.1*, 22.7**	12/20/11 – 2/27/12	16*, 15**
NCORE	19.5*, 19.3**	11/2/11 – 3/31/12	44*, 42**
NPF3	18.3	3/1/12 – 3/31/12	7
Summer 2012			
State Building	5.7	6/2/12-8/31/12	20
NCORE	5.1	6/14/12-8/31/12	17
Winter 2012/2013			
State Building	21.8	11/2/12 – 3/29/13	29
NPE	28.1*, 27.8**	11/2/12 – 3/29/13	41*, 40**
NCORE	25.5*, 25.1**	11/2/12 – 3/29/13	38*, 39**
NPF3	46.9	11/2/13 – 3/29/13	42

Note: The minimum detection limit (MDL) for the State Building site was 0.740 $\mu g/m^3$, and ~0.745 $\mu g/m^3$ for all of the other sites. *EPA profiles used. ** OMNI profiles used.

Table 5: Average $PM_{2.5}$ Elemental, Ion, and OC/EC Concentrations ($\mu g/m^3$) – State Building, Winters of 2005/2006, 2006/2007, and 2007/2008.

	State Building 11/3/05 – 3/30/06 n= 36	State Building 11/1/06 – 3/31/07 n=39	State Building 11/2/07 – 3/31/08 n=40	MDL
Magnesium	0.009	0.008	0.006	0.011
Aluminum	**0.020**	**0.031**	0.009	0.013
Silicon	**0.063**	**0.042**	**0.048**	0.011
Phosphorus	0.000	0.002	0.001	0.010
Sulfur	**1.339**	**1.249**	**1.153**	0.007
Chlorine	**0.017**	**0.068**	**0.073**	0.005
Potassium	**0.083**	**0.081**	**0.102**	0.004
Calcium	**0.056**	**0.029**	**0.029**	0.005
Titanium	**0.005**	0.000	0.001	0.004
Vanadium	0.001	0.001	0.000	0.003
Chromium	**0.002**	**0.012**	**0.002**	0.002
Manganese	**0.002**	**0.002**	0.001	0.002
Iron	**0.069**	**0.084**	**0.052**	0.001
Nickel	**0.001**	**0.004**	**0.001**	0.001
Copper	**0.004**	**0.006**	**0.004**	0.001
Zinc	**0.043**	**0.040**	**0.039**	0.003
Gallium	0.001	0.000	0.000	0.002
Arsenic	**0.001**	**0.001**	**0.001**	0.001
Selenium	0.001	0.000	0.000	0.002
Bromine	**0.005**	**0.004**	**0.003**	0.002
Rubidium	0.001	0.000	0.000	0.002
Strontium	**0.006**	**0.006**	**0.002**	0.002
Yttrium	0.001	0.000	0.000	0.003
Zirconium	0.001	0.001	0.000	0.004
Molybdenum	0.000	0.000	0.000	0.006
Silver	0.003	0.002	0.001	0.013
Cadmium	0.003	0.001	0.001	0.017
Indium	0.003	0.001	0.000	0.018
Tin	0.005	0.003	0.002	0.025
Antimony	0.004	0.001	0.001	0.038
Barium	**0.016**	0.002	0.002	0.010
Lanthanum	0.006	0.000	0.000	0.008
Mercury	0.002	0.001	0.000	0.007
Lead	**0.007**	**0.004**	**0.004**	0.004
Sodium	**0.045**	**0.041**	0.028	0.037
Cobalt	0.000	0.000	0.000	0.001
Sulfate	**3.816**	**3.479**	**3.215**	0.010
Nitrate	**1.102**	**1.054**	**0.954**	0.007
Ammonium	**1.648**	**1.573**	**1.446**	0.017
Potassium	**0.072**	**0.064**	**0.095**	0.014
Sodium (ion)	**0.066**	**0.072**	**0.076**	0.027
Total Carbon	**10.4**	**10.9**	**11.1**	0.24
Organic Carbon	**8.7**	**9.3**	**9.2**	0.24
Elemental Carbon	**1.7**	**1.6**	**1.8**	0.24

Note: MDL–minimum detection limit. Bolded values indicate concentrations measured at or above the MDL.

Table 6: Average $PM_{2.5}$ Elemental, Ion, and OC/EC Concentrations (µg/m^3) – Winter 2008/2009.

	State Building 11/8/08 – 4/7/09 n= 47*, 46**	North Pole 1/25/09 – 4/7/09 n=21	RAMS 1/25/09 – 4/7/09 n=23*, 22**	Peger Road 1/25/09 – 4/7/09 n=26	MDL
Magnesium	0.011	**0.012**	**0.016, 0.014**	**0.018**	0.013, 0.011
Aluminum	**0.021**	0.005	0.011	**0.016**	0.014, 0.013
Silicon	**0.049, 0.048**	**0.024**	**0.031, 0.032**	**0.062**	0.011
Phosphorus	0.005	0.001	0.000	**0.010**	0.012, 0.010
Sulfur	**1.730, 1.558**	**0.637**	**0.367, 0.369**	**0.968**	0.008, 0.007
Chlorine	**0.125, 0.123**	**0.103**	**0.100, 0.076**	**0.151**	0.007, 0.005
Potassium	**0.136, 0.131**	**0.113**	**0.041, 0.042**	**0.069**	0.006, 0.004
Calcium	**0.047, 0.046**	**0.014**	**0.015**	**0.045**	0.006, 0.005
Titanium	0.001	0.000	0.000	0.001	0.005, 0.004
Vanadium	0.000	0.000	0.000	0.000	0.003
Chromium	**0.003**	**0.004**	0.000	0.000	0.002
Manganese	0.001	0.001	0.000	0.001	0.002
Iron	**0.058, 0.054**	**0.027**	**0.017**	**0.053**	0.002, 0.001
Nickel	**0.001**	**0.001**	0.000	0.000	0.001
Copper	**0.004**	**0.001**	**0.001**	**0.004**	0.002, 0.001
Zinc	**0.065, 0.062**	**0.015**	**0.008**	**0.058**	0.003, 0.004
Gallium	0.000	0.000	0.000	0.000	0.002
Arsenic	0.000	0.000	**0.001**	0.001	0.001, 0.002
Selenium	0.000	0.000	0.000	0.000	0.002
Bromine	**0.005**	**0.003**	**0.005**	**0.007**	0.002
Rubidium	0.000	0.000	0.000	0.000	0.002
Strontium	**0.004**	0.001	0.001	**0.002**	0.002
Yttrium	0.000	0.000	0.000	0.000	0.003
Zirconium	0.000	0.000	0.000	0.000	0.004, 0.005
Molybdenum	0.000	0.000	0.000	0.000	0.006, 0.009
Silver	0.001	0.002	0.001	0.002	0.013, 0.015
Cadmium	0.002	0.000	0.000	0.000	0.017, 0.019
Indium	0.001	0.002	0.002	0.003	0.018, 0.022
Tin	0.005	0.002	0.002	0.003	0.025, 0.032
Antimony	0.001	0.002	0.002, 0.001	0.001	0.038, 0.042
Barium	0.001	0.000	0.000	0.000	0.015, 0.010
Lanthanum	0.000	0.001	0.000	0.000	0.014, 0.008
Mercury	0.001	0.001	0.001	0.001	0.007, 0.009
Lead	0.003	0.002	0.003	**0.005**	0.004, 0.005
Sodium	**0.113, 0.111**	**0.107**	**0.108, 0.092**	**0.141**	0.037, 0.040
Cobalt	0.000	0.000	0.000	**0.001**	0.001
Sulfate	**4.585, 4.194**	**1.739**	**1.052, 1.056**	**2.541**	0.010
Nitrate	**1.282, 1.268**	**0.709**	**0.615, 0.623**	**1.127**	0.007
Ammonium	**2.160, 1.974**	**0.683**	**0.430, 0.439**	**1.235**	0.018, 0.017
Potassium	**0.137, 0.134**	**0.135**	**0.058, 0.057**	**0.096**	0.015, 0.014
Sodium (ion)	**0.126, 0.126**	**0.155**	**0.148, 0.132**	**0.162**	0.027, 0.030
Total Carbon	**14.5, 13.7**	**12.6**	**5.1, 5.2**	**10.0**	0.24
Organic Carbon	**12.9, 12.2**	**11.7**	**4.7, 4.8**	**8.7**	0.24
Elemental Carbon	**1.6, 1.5**	**0.9**	**0.5**	**1.3**	0.24

Note: MDL–minimum detection limit. MDLs include those from both the State building, and other three sites. Bolded values indicate concentrations measured at or above the MDL. *Average concentrations originally presented in the Final Report submitted to ADEC (dated July 23, 2012). **Average concentrations for those sample days in which updated CMB modeling (with OMNI profiles as well as auto/diesel profiles) was conducted.

Table 7: Average $PM_{2.5}$ Elemental, Ion, and OC/EC Concentrations (µg/m^3) – Winter 2009/2010.

	State Building 11/3/09–3/15/10 n=40*, 31**	North Pole 11/3/09–3/15/10 n=35	RAMS 11/15/09–3/15/10 n=29	Peger Road 11/3/09–3/15/10 n=38*, 37**	MDL
Magnesium	0.009	0.004	0.003	0.007, 0.008	0.013, 0.011
Aluminum	**0.020, 0.014**	0.004	0.008	0.007	0.014, 0.013
Silicon	**0.054, 0.050**	**0.031**	**0.057**	**0.073, 0.074**	0.011
Phosphorus	0.008, 0.004	0.000	0.000	**0.025, 0.026**	0.012, 0.010
Sulfur	**1.760, 1.404**	**0.915**	**1.388**	**1.618, 1.654**	0.008, 0.007
Chlorine	**0.151, 0.116**	**0.151**	**0.154**	**0.290, 0.297**	0.007, 0.005
Potassium	**0.130, 0.114**	**0.202**	**0.185**	**0.132, 0.134**	0.006, 0.004
Calcium	**0.042, 0.039**	**0.014**	**0.028**	**0.058, 0.059**	0.006, 0.005
Titanium	0.001, 0.002	0.001	0.002	0.003	0.005, 0.004
Vanadium	0.000	0.000	0.000	0.000	0.003
Chromium	**0.002**	0.000	**0.004**	0.001	0.002
Manganese	**0.002**	0.001	**0.006**	**0.004**	0.002
Iron	**0.061, 0.055**	**0.024**	**0.080**	**0.109, 0.111**	0.002, 0.001
Nickel	**0.001**	0.000	**0.004**	0.000	0.001
Copper	**0.006, 0.004**	**0.006**	**0.004**	**0.008**	0.002, 0.001
Zinc	**0.072, 0.061**	**0.031**	**0.045**	**0.121, 0.123**	0.003, 0.004
Gallium	0.000	0.000	0.000	0.000	0.002
Arsenic	**0.001,** 0.000	0.000	**0.001**	**0.001**	0.001, 0.002
Selenium	0.000	0.000	0.000	0.000	0.002
Bromine	**0.004, 0.003**	**0.004**	**0.011**	**0.011**	0.002
Rubidium	0.001	0.000	0.000	0.000	0.002
Strontium	**0.002**	0.000	0.001	0.001	0.002
Yttrium	0.000	0.000	0.000	0.000	0.003
Zirconium	0.001	0.000	0.000	0.000	0.004, 0.005
Molybdenum	0.000	0.000	0.000	0.000	0.006, 0.009
Silver	0.002	0.002	0.001	0.002	0.013, 0.015
Cadmium	0.003	0.001	0.001	0.003	0.017, 0.019
Indium	0.003	0.001	0.003	0.001	0.018, 0.022
Tin	0.004, 0.003	0.004	0.004	0.001	0.025, 0.032
Antimony	0.007, 0.008	0.008	0.008	0.006, 0.005	0.038, 0.042
Barium	0.005	0.000	0.000	0.000	0.015, 0.010
Lanthanum	0.000	0.000	0.000	0.000	0.014, 0.008
Mercury	0.000	0.000	0.000	0.000	0.007, 0.009
Lead	**0.005**, 0.004	**0.004**	**0.014**	**0.017**	0.004, 0.005
Sodium	**0.084, 0.077**	**0.076**	**0.086**	**0.140, 0.142**	0.037, 0.040
Cobalt	0.000	0.000	0.000	0.000	0.001
Sulfate	**4.633, 3.911**	**2.452**	**3.890**	**4.173, 4.256**	0.010
Nitrate	**1.505, 1.417**	**0.888**	**1.029**	**1.706, 1.725**	0.007
Ammonium	**2.433, 1.894**	**1.232**	**1.822**	**2.420, 2.460**	0.018, 0.017
Potassium	**0.141, 0.129**	**0.184**	**0.170**	**0.123, 0.125**	0.015, 0.014
Sodium (ion)	**0.080, 0.079**	**0.117**	**0.135**	**0.134, 0.131**	0.027, 0.030
Total Carbon	**13.2, 11.4**	**22.3**	**24.1**	**16.2, 16.5**	0.24
Organic Carbon	**11.5, 10.0**	**19.8**	**21.5**	**13.4, 13.7**	0.24
Elemental Carbon	**1.7, 1.4**	**2.5**	**2.6**	**2.8**	0.24

Note: MDL–minimum detection limit. MDLs include those from both the State building, and other three sites. Bolded values indicate concentrations measured at or above the MDL. *EPA runs only. **OMNI runs only.

Table 8: Average $PM_{2.5}$ Elemental, Ion, and OC/EC Concentrations (µg/m^3) – Winter 2010/2011.

Analyte	State Building 11/1/10–2/8/11 n=15	North Pole 1/9/11–2/5/11 n=10	Peger Road 1/9/11–2/5/11 n=10	MDL
Magnesium	0.001	0.000	0.000	0.013, 0.011
Aluminum	0.008	**0.015**	**0.033**	0.014, 0.013
Silicon	**0.027**	0.009	**0.032**	0.011
Phosphorus	0.002	0.000	**0.014**	0.012, 0.010
Sulfur	**1.188**	**0.757**	**1.608**	0.008, 0.007
Chlorine	**0.089**	**0.112**	**0.280**	0.007, 0.005
Potassium	**0.089**	**0.184**	**0.142**	0.006, 0.004
Calcium	**0.027**	**0.016**	**0.046**	0.006, 0.005
Titanium	0.001	0.000	0.001	0.005, 0.004
Vanadium	0.000	0.000	0.000	0.003
Chromium	**0.002**	0.000	0.000	0.002
Manganese	0.001	0.000	**0.004**	0.002
Iron	**0.040**	**0.019**	**0.076**	0.002, 0.001
Nickel	**0.001**	0.000	0.000	0.001
Copper	**0.002**	**0.002**	**0.007**	0.002, 0.001
Zinc	**0.051**	**0.029**	**0.107**	0.003, 0.004
Gallium	0.000	0.000	0.000	0.002
Arsenic	0.000	**0.001**	**0.001**	0.001, 0.002
Selenium	0.000	0.000	0.000	0.002
Bromine	**0.004**	**0.002**	**0.010**	0.002
Rubidium	0.000	0.000	0.000	0.002
Strontium	0.001	0.000	**0.007**	0.002
Yttrium	0.000	0.000	0.000	0.003
Zirconium	0.000	0.001	0.001	0.004, 0.005
Molybdenum	0.000	0.000	0.000	0.006, 0.009
Silver	0.001	0.000	0.000	0.013, 0.015
Cadmium	0.001	0.003	0.004	0.017, 0.019
Indium	0.002	0.005	0.001	0.018, 0.022
Tin	0.001	0.000	0.000	0.025, 0.032
Antimony	0.006	0.012	0.002	0.038, 0.042
Barium	0.000	0.000	0.000	0.015, 0.010
Lanthanum	0.000	0.000	0.000	0.014, 0.008
Mercury	0.000	0.000	0.000	0.007, 0.009
Lead	0.003	0.001	**0.014**	0.004, 0.005
Sodium	**0.044**	0.003	**0.060**	0.037, 0.040
Cobalt	0.000	0.000	**0.001**	0.001
Sulfate	**3.352**	**2.393**	**5.047**	0.010
Nitrate	**1.158**	**0.755**	**1.790**	0.007
Ammonium	**1.565**	**0.885**	**2.396**	0.018, 0.017
Potassium	**0.084**	**0.165**	**0.147**	0.015, 0.014
Sodium (ion)	**0.030**	**0.062**	**0.081**	0.027, 0.030
Total Carbon	**8.5**	**16.7**	**15.3**	0.24
Organic Carbon	**7.5**	**14.6**	**12.6**	0.24
Elemental Carbon	**1.0**	**2.1**	**2.7**	0.24

Note: MDL–minimum detection limit. MDLs include those from both the state building, and other two sites. Bolded values indicate concentrations measured at or above the MDL.

Table 9: Average $PM_{2.5}$ Elemental, Ion, and OC/EC Concentrations (µg/m^3) – Winter 2011/2012.

	State Building 11/2/11 – 3/31/12 n=38*, 36**	North Pole 11/2/11 – 3/25/12 n=35*, 34**	RAMS 12/20/11 – 2/27/12 n=16*, 15**	NCORE 11/2/11 – 3/31/12 n=44*, 42**	NPF3 3/1/12 – 3/31/12 n=7	MDL
Magnesium	**0.011**, 0.009	**0.019, 0.017**	**0.015, 0.016**	**0.017, 0.018**	**0.023**	0.011
Aluminum	0.009, 0.008	0.001	0.009	0.007, 0.008	0.010	0.013
Silicon	**0.042, 0.043**	**0.017**	**0.037, 0.036**	**0.033, 0.032**	**0.031**	0.011
Phosphorus	0.000	0.000	0.000	0.000	0.000	0.010
Sulfur	**1.203, 1.153**	**0.655, 0.627**	**0.971, 0.998**	**1.049**	**0.584**	0.007
Chlorine	**0.080**	**0.150, 0.145**	**0.113, 0.118**	**0.112**	**0.164**	0.005
Potassium	**0.114, 0.111**	**0.264, 0.258**	**0.200, 0.209**	**0.132**	**0.164**	0.004
Calcium	**0.028, 0.027**	**0.017, 0.016**	**0.032, 0.033**	**0.026**	**0.014**	0.005
Titanium	0.003	0.001, 0.000	0.001	0.001	0.000	0.004
Vanadium	0.000	0.000	0.000	0.000	0.000	0.003
Chromium	**0.002**, 0.001	0.001	0.001	0.001	0.000	0.002
Manganese	0.001	0.001	**0.002, 0.003**	**0.002, 0.001**	0.001	0.002
Iron	**0.042, 0.041**	**0.020**	**0.062, 0.064**	**0.039, 0.037**	**0.015**	0.001
Nickel	0.000	0.000	**0.001**	0.000	0.000	0.001
Copper	**0.003**	**0.004**	**0.006**	**0.004**	**0.001**	0.001
Zinc	**0.041**	**0.023, 0.022**	**0.039, 0.041**	**0.037, 0.036**	**0.012**	0.003
Gallium	0.000	0.000	0.000	0.000	0.000	0.002
Arsenic	0.000	0.000	0.000	**0.001**	0.000	0.001
Selenium	0.000	0.000	0.000	0.000	0.000	0.002
Bromine	**0.005**	**0.004, 0.003**	**0.003**	**0.005**	**0.008**	0.002
Rubidium	0.000	0.000	0.000	0.000	0.000	0.002
Strontium	**0.003**	**0.002**	**0.006**	**0.003**	0.000	0.002
Yttrium	0.000	0.000	0.000	0.000	0.000	0.003
Zirconium	0.001	0.001	0.002	0.001	0.000	0.004
Molybdenum	0.000	0.000	0.000	0.000	0.000	0.006
Silver	0.001	0.000	0.000	0.000	0.002	0.013
Cadmium	0.003	0.001	0.000	0.001	0.000	0.017
Indium	0.002	0.002	0.001	0.002	0.001	0.018
Tin	0.004	0.001, 0.002	0.005	0.002	0.000	0.025
Antimony	0.007, 0.006	0.008	0.005	0.008, 0.009	0.005	0.038
Barium	0.000	0.004	**0.023, 0.022**	**0.010**	0.000	0.010
Lanthanum	0.000	0.000	0.000	0.000	0.000	0.008
Mercury	0.000	0.000	0.000	0.000	0.000	0.007
Lead	0.001, 0.002	0.001	0.002	0.002	0.000	0.004
Sodium	**0.097, 0.092**	**0.098, 0.095**	**0.076, 0.078**	**0.107, 0.109**	**0.148**	0.037
Cobalt	0.000	0.000	**0.001**	**0.001**	0.000	0.001
Sulfate	**3.283, 3.135**	**1.817, 1.733**	**2.883, 2.764**	**2.900, 2.901**	**1.576**	0.010
Nitrate	**0.924, 0.915**	**0.502, 0.493**	**0.949, 0.936**	**0.827, 0.815**	**0.462**	0.007
Ammonium	**1.228, 1.176**	**0.491, 0.462**	**0.969, 0.923**	**0.991, 0.992**	**0.432**	0.017
Potassium	**0.095, 0.093**	**0.237, 0.231**	**0.157, 0.159**	**0.105**	**0.114**	0.014
Sodium (ion)	**0.104, 0.101**	**0.101, 0.098**	**0.071, 0.072**	**0.094, 0.095**	**0.143**	0.027
Total Carbon	**8.5, 8.6**	**13.7, 13.4**	**12.4, 12.2**	**10.6, 10.9**	**12.5**	0.24
Organic Carbon	**7.3, 7.4**	**12.5, 12.3**	**10.6, 10.4**	**9.0, 9.2**	**11.3**	0.24
Elemental Carbon	**1.2, 1.3**	**1.2, 1.1**	**1.8**	**1.6**	**1.2**	0.24

Note: MDL–minimum detection limit. Bolded values indicate concentrations measured at or above the MDL.
*EPA runs only. **OMNI runs only.

Table 10: Average $PM_{2.5}$ Elemental, Ion, and OC/EC Concentrations ($\mu g/m^3$) – Summer 2012.

	State Building 6/2/12 – 8/31/12 n=20	NCORE 6/14/12 – 8/31/12 n=17	MDL
Magnesium	0.001	0.000	0.011
Aluminum	**0.021**	**0.021**	0.013
Silicon	**0.080**	**0.098**	0.011
Phosphorus	0.000	0.000	0.010
Sulfur	**0.143**	**0.146**	0.007
Chlorine	**0.005**	0.002	0.005
Potassium	**0.025**	**0.023**	0.004
Calcium	**0.018**	**0.020**	0.005
Titanium	0.003	0.002	0.004
Vanadium	0.000	0.000	0.003
Chromium	**0.002**	0.000	0.002
Manganese	0.001	0.001	0.002
Iron	**0.040**	**0.042**	0.001
Nickel	0.000	0.000	0.001
Copper	**0.001**	**0.001**	0.001
Zinc	0.002	**0.003**	0.003
Gallium	0.000	0.000	0.002
Arsenic	0.000	0.000	0.001
Selenium	0.000	0.000	0.002
Bromine	0.001	0.001	0.002
Rubidium	0.000	0.000	0.002
Strontium	0.001	0.000	0.002
Yttrium	0.000	0.000	0.003
Zirconium	0.000	0.001	0.004
Molybdenum	0.000	0.000	0.006
Silver	0.001	0.000	0.013
Cadmium	0.002	0.000	0.017
Indium	0.002	0.000	0.018
Tin	0.005	0.001	0.025
Antimony	0.012	0.011	0.038
Barium	0.000	0.000	0.010
Lanthanum	0.000	0.000	0.008
Mercury	0.000	0.000	0.007
Lead	0.000	0.000	0.004
Sodium	0.007	0.011	0.037
Cobalt	0.000	0.000	0.001
Sulfate	**0.358**	**0.311**	0.010
Nitrate	**0.181**	**0.207**	0.007
Ammonium	**0.051**	**0.025**	0.017
Potassium	**0.010**	**0.020**	0.014
Sodium (ion)	**0.017**	**0.059**	0.027
Total Carbon	**2.0**	**4.6**	0.24
Organic Carbon	**1.8**	**4.2**	0.24
Elemental Carbon	**0.22**	**0.4**	0.24

Note: MDL–minimum detection limit. Bolded values indicate concentrations measured at or above the MDL.

Table 11: Average $PM_{2.5}$ Elemental Concentrations ($\mu g/m^3$) – Winter 2012/2013.

	State Building 11/2/12 – 3/29/13 n=29	NPE 11/2/12 – 3/29/13 n=41*, 40**	NCORE 11/2/12 – 3/29/13 n=38*, 39**	NPF3 11/2/13 – 3/29/13 n=42	MDL
Magnesium	0.007	0.010	0.006	0.010	0.011
Aluminum	0.008	0.003	0.008	0.001	0.013
Silicon	**0.043**	**0.021**	**0.045, 0.044**	**0.029**	0.011
Phosphorus	0.005	0.001	0.008	0.001	0.010
Sulfur	**1.370**	**0.891, 0.892**	**1.602, 1.573**	**1.239**	0.007
Chlorine	**0.078**	**0.096, 0.097**	**0.081, 0.080**	**0.131**	0.005
Potassium	**0.154**	**0.310, 0.309**	**0.192, 0.189**	**0.438**	0.004
Calcium	**0.036**	**0.018**	**0.038**	**0.014**	0.005
Titanium	0.001	0.000	0.001	0.001	0.004
Vanadium	0.000	0.000	0.000	0.000	0.003
Chromium	**0.002**	**0.002**	**0.003**	0.001	0.002
Manganese	0.001	0.001	0.001	0.001	0.002
Iron	**0.051**	**0.031, 0.030**	**0.054, 0.053**	**0.028**	0.001
Nickel	**0.001**	0.000	**0.001,** 0.000	0.000	0.001
Copper	**0.003**	**0.002**	**0.003**	**0.002**	0.001
Zinc	**0.053**	**0.030**	**0.055**	**0.037**	0.003
Gallium	0.000	0.000	0.000	0.000	0.002
Arsenic	0.000	0.000	0.000	**0.001**	0.001
Selenium	0.000	0.000	0.000	0.000	0.002
Bromine	**0.004**	**0.004**	**0.004**	**0.003**	0.002
Rubidium	0.000	0.000	0.000	0.001	0.002
Strontium	**0.003**	0.001	**0.003**	**0.002**	0.002
Yttrium	0.000	0.000	0.000	0.000	0.003
Zirconium	0.001	0.001	0.000	0.001	0.004
Molybdenum	0.000	0.000	0.000	0.000	0.006
Silver	0.000	0.001	0.001	0.001	0.013
Cadmium	0.001	0.001	0.000	0.000	0.017
Indium	0.001	0.003	0.003, 0.002	0.003	0.018
Tin	0.003	0.003	0.002	0.003	0.025
Antimony	0.007	0.001	0.001	0.002	0.038
Barium	0.002	0.001	0.004	0.001	0.010
Lanthanum	0.000	0.000	0.000	0.000	0.008
Mercury	0.000	0.000	0.000	0.000	0.007
Lead	0.002	0.001	0.002	0.002	0.004
Sodium	**0.068**	**0.064, 0.066**	**0.062**	**0.066**	0.037
Cobalt	0.000	0.000	0.000	0.000	0.001
Sulfate	**3.496**	**2.476, 2.287**	**3.970, 4.088**	**3.004**	0.010
Nitrate	**1.074**	**0.686, 0.655**	**1.250**	**0.805**	0.007
Ammonium	**1.409**	**0.878, 0.783**	**1.636, 1.672**	**1.099**	0.017
Potassium	**0.118**	**0.288**	**0.177, 0.180**	**0.374**	0.014
Sodium (ion)	**0.047**	**0.181, 0.184**	**0.157, 0.155**	**0.130**	0.027
Total Carbon	**9.2**	**18.6, 18.3**	**14.3, 14.5**	**33.3**	0.24
Organic Carbon	**7.5**	**16.3, 16.0**	**12.1, 12.3**	**29.8**	0.24
Elemental Carbon	**1.6**	**2.4, 2.3**	**2.2, 2.2**	**3.6**	0.24

Note: MDL–minimum detection limit. Bolded values indicate concentrations measured at or above the MDL.
*EPA runs only. **OMNI runs only.

7.0. Chemical Mass Balance Results

Tables 12 and 13 present the $PM_{2.5}$ sources identified by the CMB model for each of the sites when using the EPA source profiles, including source contribution estimates (± standard errors) and % of total $PM_{2.5}$. **Tables 14 and 15** present the CMB results when using the OMNI profiles. In addition, **Figures 1-6** present the sources identified (over time) for each of the sites using the EPA source profiles, while **Figures 7-12** present the source trends for each of the sites using the OMNI profiles. Finally, CMB results are summarized as pie charts in **Figures 13-64** for both EPA and OMNI profiles for each winter/site, followed by a table comparing the results generated when using both the EPA and OMNI source profiles (**Tables 16-40**).

When using the EPA profiles, five source profile types were identified by the CMB model as contributors to the ambient $PM_{2.5}$ throughout the winter months. Wood smoke (likely residential wood combustion) was the major source of $PM_{2.5}$ identified, contributing between ~60% to over 80% of the measured $PM_{2.5}$ at the monitoring sites. The other sources of $PM_{2.5}$ identified by the CMB model were secondary sulfate (~7-21%), ammonium nitrate (3-11%), diesel exhaust (not detected-11%), and automobiles (not detected-7%). Approximately 1-2% of the $PM_{2.5}$ was unexplained by the CMB model.

When utilizing the OMNI profiles in the CMB, the results are somewhat different. In addition to the five profiles identified using the EPA profiles, the OMNI source profile representing No. 2 fuel oil was also identified in nearly every CMB run. Wood smoke was still identified as the largest source of wintertime $PM_{2.5}$ at the North Pole, RAMS, NCORE, NPF3, and NPE sites. However, at the State Building and Peger Road sites, No. 2 fuel oil combustion was found to be the largest source, contributing from 30-50% of the ambient wintertime $PM_{2.5}$.

It should be noted that the results of CMB modeling using OMNI profiles for the winter of 2008/2009 were originally presented to ADEC in a previous report (July 23, 2012). In carrying out the updated modeling using the OMNI profiles in other years (in addition to the winter of 2008/2009), it was discovered that automobiles and diesel exhaust contributed a small amount to ambient $PM_{2.5}$ when using the OMNI profiles. To be consistent with results from the other winters, the 2008/2009 data sets were re-analyzed for the State Building, RAMS, North Pole, and Peger Road sites, with these results presented in **Table 14**. Results for the North Pole and RAMS sites remained unchanged to the previous modeling. However, for the State Building and Peger Road sites, automobiles and diesel exhaust which were not detected in the initial CMB modeling were now detected at low contributions (autos: 0.3-1.7%; diesel: 0.1-0.5%). Using this new profile combination also lowered the wood smoke contribution from 56.0% to 36.1% at the State Building, while No. 2 fuel oil contributions increased from 14.2% to 47.4%. At the Peger Road site, wood smoke was revised to 42.0% while No. 2 fuel oil was elevated from 27.2% to 38.7%. These new findings as well as those from the other winters illustrate that No. 2 fuel oil combustion is a significant source of ambient $PM_{2.5}$ (when using the OMNI profiles) – especially at the State Building and Peger Road sites.

For the first time, CMB source apportionment modeling was conducted during the summer months in Fairbanks. Overall, ambient $PM_{2.5}$ concentrations were very low at both sites during the summer of 2012 (5.7 $\mu g/m^3$ at the State Building, and 5.1 $\mu g/m^3$ at the NCORE site). Contributions of sulfate, ammonium nitrate, and street sand/road dust were very similar between the State Building and NCORE sites. More vehicle emissions were detected at the NCORE site compared to the State Building site when using both EPA and OMNI profiles. As expected, No. 2 fuel oil was not detected at either site. However, wood smoke was still determined to be the largest source at both sites (56-74%), likely due to residential outdoor biomass waste burning and influences from regional wildland fire events.

Table 12: Source Contribution Estimates ± Standard Errors (µg/m^3) – EPA profiles.
Note that percentages in parentheses are percent contributions to overall ambient $PM_{2.5}$ mass.

	Sulfate	Ammonium Nitrate	Diesel	Autos	Wood Smoke	Unexplained	$PM_{2.5}$ Mass	n	Sampling Dates
State Building 2005/2006	4.0±0.5 (21.0 %)	1.8 ±0.5 (9.6 %)	1.3±0.4 (7.1 %)	0.4±0.2 (2.3 %)	11.3±1.7 (59.8 %)	0.1 (0.3 %)	18.9	36	11/3/05-3/30/06
State Building 2006/2007	3.7±0.5 (18.7 %)	1.7 ±0.5 (8.4 %)	1.5±0.5 (7.6 %)	1.1±0.4 (5.8 %)	11.5±2.0 (57.9 %)	0.3 (1.6 %)	19.9	39	11/1/06-3/31/07
State Building 2007/2008	3.4±0.4 (18.2 %)	1.5±0.5 (8.1 %)	1.7±0.5 (9.0 %)	1.2±0.4 (6.2 %)	10.9±1.6 (58.5 %)	0.02 (0.1 %)	18.7	40	11/2/07-3/31/08
2008/2009	**Sulfate**	**Ammonium Nitrate**	**Diesel**	**Autos**	**Wood Smoke**	**Unexplained**	**$PM_{2.5}$ Mass**	**n**	**Sampling Dates**
State Building	5.1±0.6 (20.0 %)	2.1 ±0.7 (8.1 %)	0.3±0.1 (1.1 %)	1.7±0.7 (6.8 %)	16.0±2.3 (63.1 %)	0.2 (0.8 %)	25.3	47	11/8/08-4/7/09
North Pole	1.9±0.2 (9.8 %)	1.0±0.2 (5.1 %)	0.2±0.05 (0.8 %)	0.7±0.3 (3.7 %)	15.0±2.0 (79.8 %)	0.2 (0.8 %)	18.9	21	1/25/09-4/7/09
RAMS	1.1±0.1 (13.0 %)	0.9±0.1 (10.5 %)	ND	ND	6.3±0.8 (76.0 %)	0.04 (0.5 %)	8.2	23	1/25/09-4/7/09
Peger Road	2.8±0.3 (16.7 %)	1.5±0.4 (8.9 %)	1.2±0.5 (7.3 %)	0.7±0.2 (3.9 %)	10.6±1.6 (62.7 %)	0.1 (0.5 %)	16.8	26	1/25/09-4/7/09
2009/2010	**Sulfate**	**Ammonium Nitrate**	**Diesel**	**Autos**	**Wood Smoke**	**Unexplained**	**$PM_{2.5}$ Mass**	**n**	**Sampling Dates**
State Building	5.2±0.6 (18.1 %)	2.5±0.7 (8.9 %)	0.6±0.3 (2.2 %)	0.7±0.3 (2.5 %)	19.5±1.9 (67.8 %)	0.2 (0.6 %)	28.8	40	11/3/09-3/15/10
North Pole	2.6±0.3 (7.8 %)	1.2±0.3 (3.6 %)	0.8±0.2 (2.5 %)	1.3±0.4 (3.8 %)	27.1±3.7 (81.2 %)	0.3 (1.0 %)	33.7	35	11/3/09-3/15/10
RAMS	4.0±0.5 (10.9 %)	0.9±0.2 (2.5 %)	2.5±0.6 (6.8 %)	2.3±0.7 (6.2 %)	26.9±4.1 (73.5 %)	0.04 (0.1 %)	36.7	29	11/15/09-3/15/10
Peger Road	4.8±0.5 (16.5 %)	2.1±0.6 (7.4 %)	2.8±0.7 (9.6 %)	0.4±0.1 (1.3 %)	18.6±3.0 (64.4 %)	0.3 (0.9 %)	29.0	38	11/3/09-3/15/10
2010/2011	**Sulfate**	**Ammonium Nitrate**	**Diesel**	**Autos**	**Wood Smoke**	**Unexplained**	**$PM_{2.5}$ Mass**	**n**	**Sampling Dates**
State Building	3.5±0.4	1.7±0.5	ND	0.4±0.1	14.6±1.1	0.004	20.2	15	11/1/10-

	(17.3 %)	(8.4 %)		(1.9 %)	(72.4 %)	(0.02 %)			2/8/11
North Pole	2.1±0.3 (8.0 %)	0.9±0.2 (3.5 %)	0.9±0.3 (3.4 %)	1.4±0.5 (5.1 %)	21.3±3.2 (79.4 %)	0.2 (0.6 %)	26.8	10	1/9/11-2/5/11
Peger Road	4.8±0.5 (16.6 %)	2.0±0.5 (7.1 %)	0.8±0.2 (2.9 %)	0.7±0.3 (2.5 %)	20.2±3.9 (70.6 %)	0.1 (0.3 %)	28.6	10	1/9/11-2/5/11
2011/2012	**Sulfate**	**Ammonium Nitrate**	**Diesel**	**Autos**	**Wood Smoke**	**Unexplained**	**$PM_{2.5}$ Mass**	**n**	**Sampling Dates**
State Building	3.5±0.4 (17.8 %)	1.5±0.5 (7.5 %)	0.2±0.04 (1.2 %)	0.4±0.1 (2.1 %)	14.0±1.4 (70.4 %)	0.2 (1.0 %)	20.0	38	11/2/11-3/31/12
North Pole	1.8±0.2 (7.8 %)	0.7±0.2 (3.1 %)	0.1±0.04 (0.6 %)	0.3±0.1 (1.2 %)	20.4±2.3 (85.5 %)	0.4 (1.9 %)	24.2	35	11/2/11-3/25/12
RAMS	2.9±0.3 (13.2 %)	1.4±0.4 (6.4 %)	1.2±0.3 (5.7 %)	0.9±0.4 (4.0 %)	14.9±1.8 (69.0 %)	0.4 (1.8 %)	22.1	16	12/20/11-2/27/12
NCORE	3.0±0.3 (15.8 %)	1.3±0.4 (6.8 %)	1.4±0.5 (7.5 %)	0.8±0.3 (4.2 %)	12.4±1.6 (64.4 %)	0.2 (1.3 %)	19.5	44	11/2/11-3/31/12
NPF3	1.7±0.2 (9.2 %)	0.7±0.2 (3.8 %)	0.9±0.4 (4.9 %)	0.8±0.4 (4.2 %)	14.2±2.0 (77.0 %)	0.2 (1.0 %)	18.3	7	3/1/12-3/31/12
2012/2013	**Sulfate**	**Ammonium Nitrate**	**Diesel**	**Autos**	**Wood Smoke**	**Unexplained**	**$PM_{2.5}$ Mass**	**n**	**Sampling Dates**
State Building	3.9±0.5 (17.9 %)	1.7±0.5 (8.0 %)	1.2±0.4 (5.5 %)	0.1±0.04 (0.5 %)	14.7±1.5 (67.7 %)	0.1 (0.6 %)	21.8	29	11/2/12-3/29/13
NPE	2.5±0.3 (9.0 %)	1.1±0.3 (3.8 %)	3.0±0.6 (10.9 %)	0.7±0.2 (2.6 %)	20.3±2.5 (72.8 %)	0.2 (0.8 %)	28.1	41	11/2/12-3/29/13
NCORE	4.7±0.5 (18.4 %)	2.0±0.6 (7.9 %)	2.4±0.7 (9.6 %)	1.1±0.5 (4.4 %)	15.1±2.0 (59.3 %)	0.1 (0.3 %)	25.5	38	11/2/12-3/29/13
NPF3	3.4±0.4 (7.4 %)	1.3±0.4 (2.8 %)	4.5±0.9 (9.8 %)	0.6±0.2 (1.4 %)	35.9±4.2 (77.6 %)	0.5 (1.0 %)	46.9	42	11/2/12-3/29/13

ND: not detected by the CMB model. Sampling was not conducted at the RAMS site during the winter of 2010/2011.

Table 13: Source Contribution Estimates ± Standard Errors (µg/m^3) – Summer 2012 EPA Profiles.

Summer 2012	**Sulfate**	**Ammonium Nitrate**	**Diesel**	**Autos**	**Street Sand**	**Wood Smoke**	**Unexplained**	**$PM_{2.5}$ Mass**	**n**	**Sampling Dates**
State Building	0.4±0.1 (7.1 %)	0.2±0.1 (3.9 %)	0.01±0.003 (0.1 %)	0.2±0.1 (3.9 %)	0.3±0.1 (4.4 %)	4.2±0.2 (73.7 %)	0.4 (6.9 %)	5.7	20	6/2/12-8/31/12
NCORE	0.4±0.1 (6.8 %)	0.2±0.1 (3.8 %)	0.3±0.1 (4.9 %)	1.0±0.2 (17.2%)	0.3±0.1 (4.6 %)	3.3±0.4 (56.0 %)	0.4 (6.7 %)	5.1	17	6/14/12-8/31/12

Figure 1: State Building Source Contribution Estimates (µg/m^3) – EPA profiles.

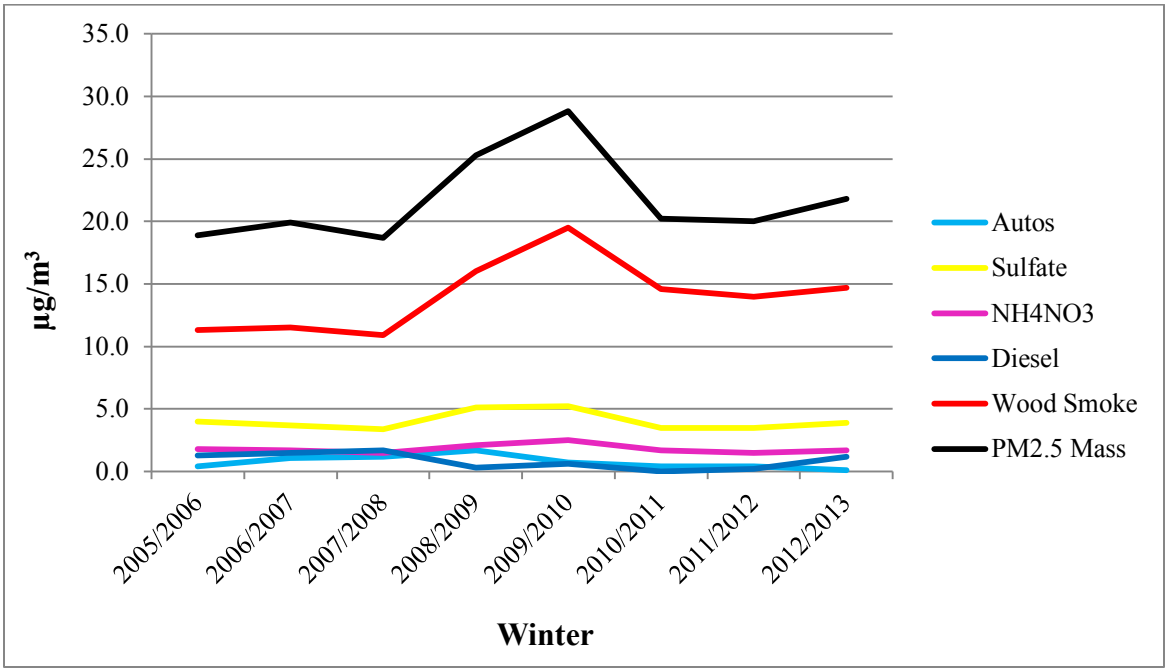

Figure 2: North Pole Source Contribution Estimates (µg/m^3) – EPA profiles.

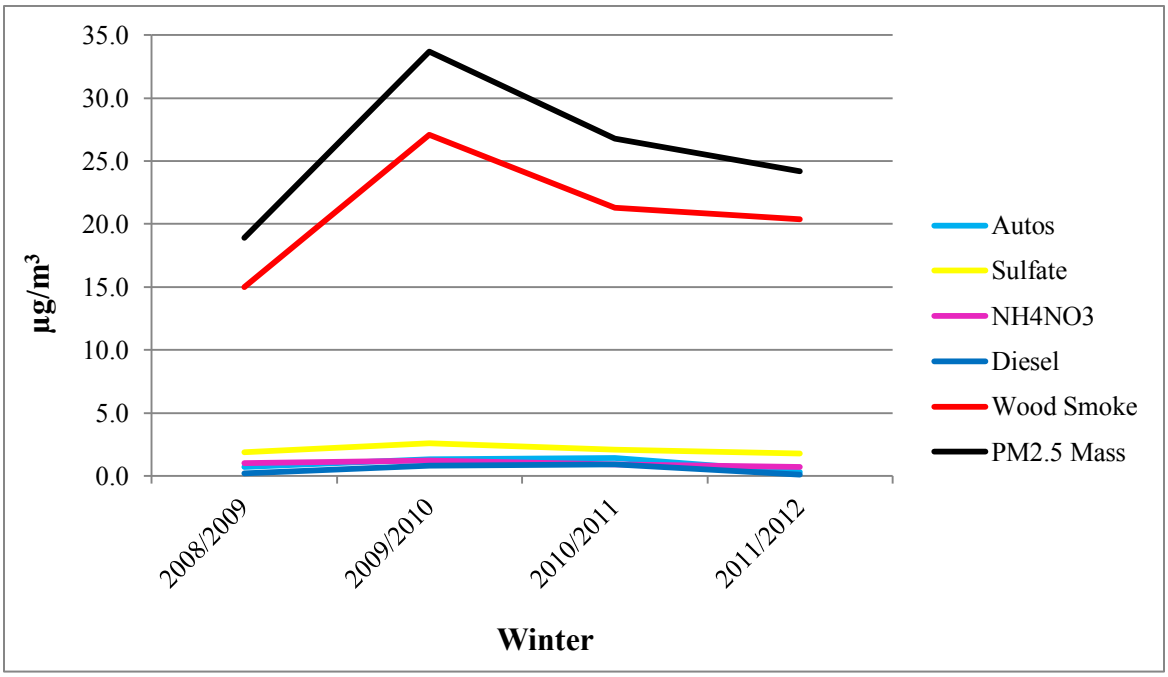

Figure 3: RAMS Source Contribution Estimates (µg/m^3) – EPA profiles.

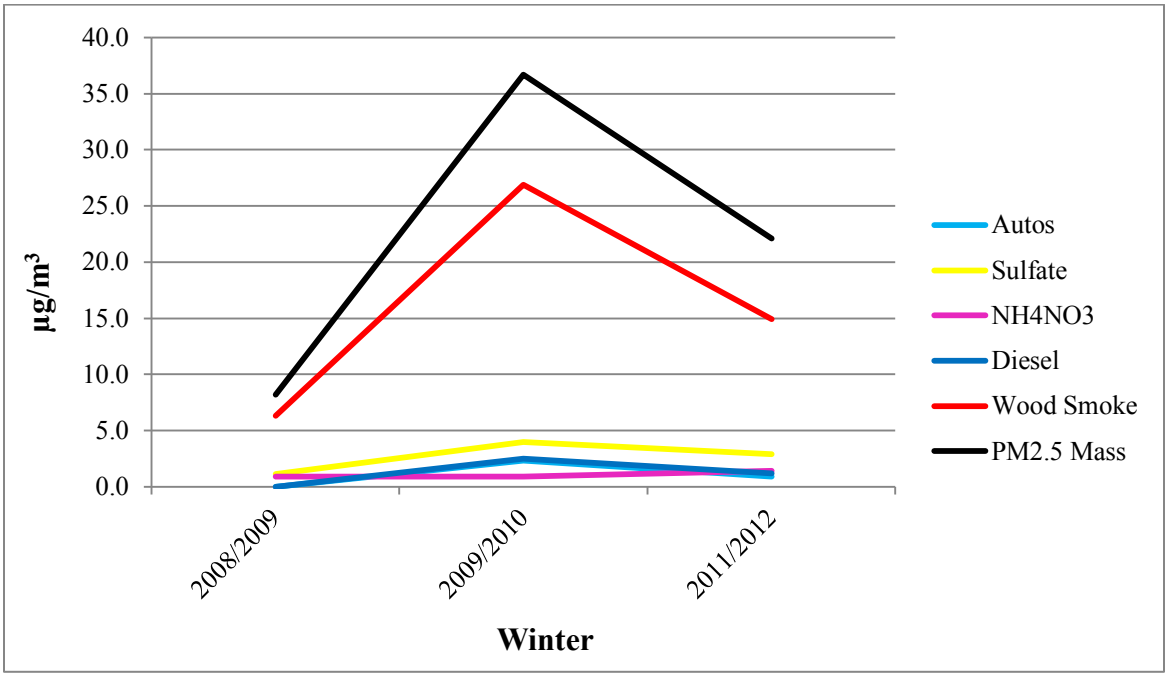

Figure 4: Peger Road Source Contribution Estimates (µg/m^3) – EPA profiles.

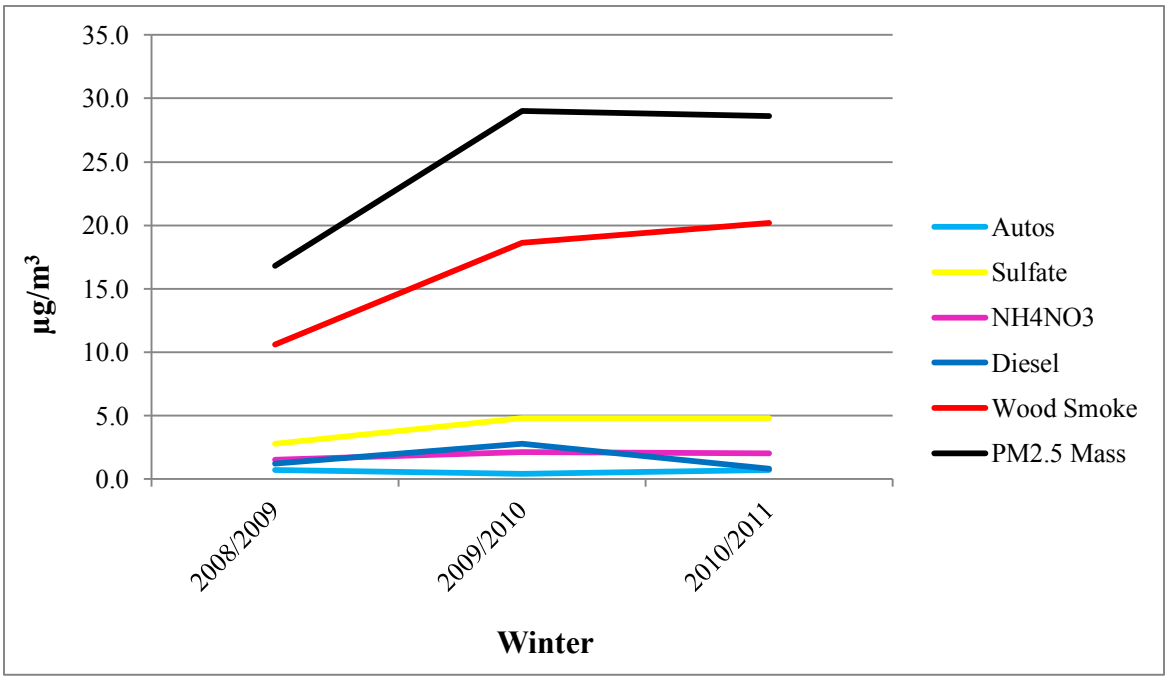

Figure 5: NCORE Source Contribution Estimates (µg/m^3) – EPA profiles.

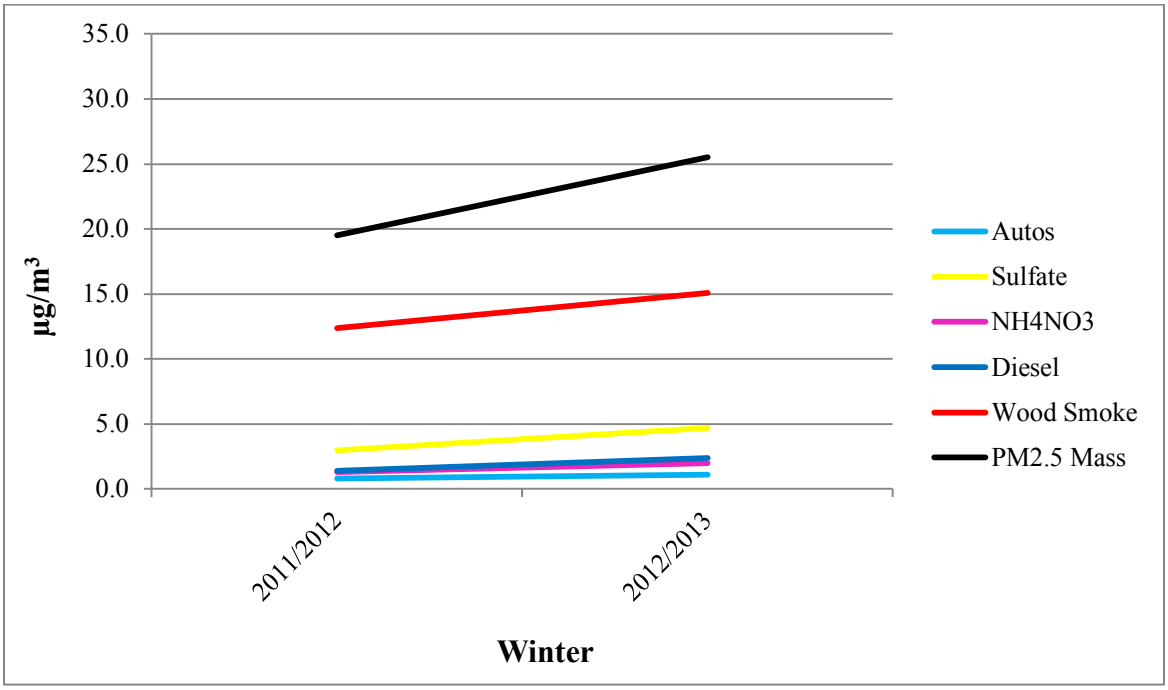

Figure 6: NPF3 Source Contribution Estimates (µg/m^3) – EPA profiles.

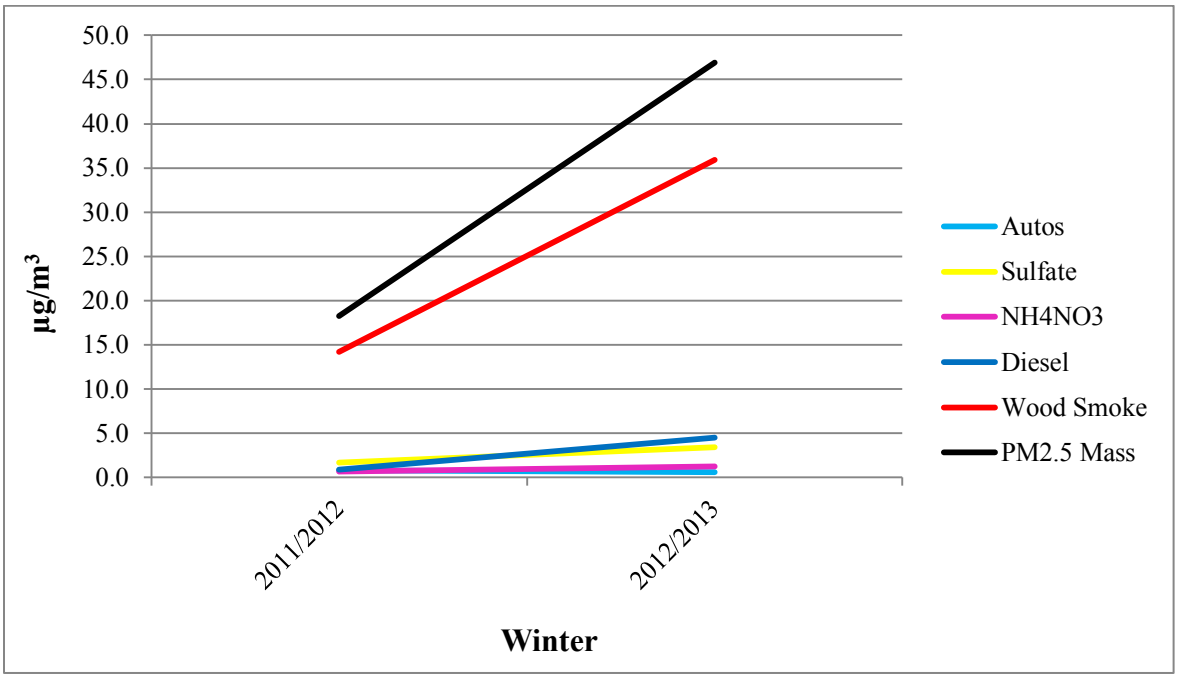

Table 14: Source Contribution Estimates ± Standard Errors (µg/m^3) – OMNI Profiles.
Note that percentages in parentheses are percent contributions to overall ambient $PM_{2.5}$ mass.

	Sulfate	Ammonium Nitrate	Diesel	Autos	Wood Smoke	No. 2 Fuel Oil	Unexplained	$PM_{2.5}$ Mass	n	Sampling Dates
State Building 2005/2006	2.4±0.5 (12.8 %)	1.3 ±0.3 (6.7 %)	0.4±0.2 (2.3 %)	Not Detected	5.9±1.6 (31.7 %)	8.4±1.6 (44.7 %)	0.4 (1.9 %)	18.9	36	11/3/05-3/30/06
State Building 2006/2007	2.0±0.4 (10.1 %)	1.1 ±0.3 (5.7 %)	0.2±0.1 (0.9 %)	0.3±0.1 (1.5 %)	7.3±1.9 (36.6 %)	9.0±1.7 (45.0 %)	0.03 (0.1 %)	19.9	39	11/1/06-3/31/07
State Building 2007/2008	1.9±0.4 (10.0 %)	1.0 ±0.3 (5.5 %)	1.0±0.4 (5.5 %)	0.3±0.1 (1.6 %)	5.9±1.5 (31.9 %)	8.4±1.5 (45.4 %)	0.01 (0.1 %)	18.7	40	11/2/07-3/31/08
2008/2009	**Sulfate**	**Ammonium Nitrate**	**Diesel**	**Autos**	**Wood Smoke**	**No. 2 Fuel Oil**	**Unexplained**	**$PM_{2.5}$ Mass**	**n**	**Sampling Dates**
*State Building	4.4±0.6 (17.9 %)	1.9 ±0.6 (7.9 %)	Not Detected	Not Detected	13.8±1.7 (56.0 %)	3.5±0.7 (14.2 %)	1.0 (4.0 %)	25.3	47	11/8/08-4/7/09
**State Building	2.5±0.5 (10.4 %)	1.2 ±0.3 (5.2 %)	0.04 ±0.02 (0.1 %)	0.06 ±0.03 (0.3 %)	8.7±1.9 (36.1 %)	11.4±1.8 (47.4 %)	0.1 (0.5 %)	24.4	46	11/8/08-4/7/09
North Pole	1.4±0.2 (7.6 %)	0.9 ±0.2 (4.7 %)	Not Detected	Not Detected	13.6±1.2 (73.4 %)	2.1±0.5 (11.1 %)	0.6 (3.3 %)	18.9	21	1/25/09-4/7/09
RAMS	0.8±0.1 (9.2 %)	0.8 ±0.1 (9.2 %)	Not Detected	Not Detected	5.4±0.8 (63.9 %)	1.4±0.4 (16.8 %)	0.1 (0.9 %)	8.3	22	1/25/09-4/7/09
*Peger Road	2.0±0.3 (11.7 %)	1.4 ±0.3 (8.4 %)	Not Detected	Not Detected	8.6±1.2 (51.0 %)	4.6±0.9 (27.2 %)	0.3 (1.6 %)	16.8	26	1/25/09-4/7/09
**Peger Road	1.6±0.3 (9.6 %)	1.2 ±0.2 (7.3 %)	0.1±0.04 (0.5 %)	0.3±0.1 (1.7 %)	7.1±1.4 (42.0 %)	6.6±1.3 (38.7 %)	0.04 (0.3 %)	16.8	26	1/25/09-4/7/09
2009/2010	**Sulfate**	**Ammonium Nitrate**	**Diesel**	**Autos**	**Wood Smoke**	**No. 2 Fuel Oil**	**Unexplained**	**$PM_{2.5}$ Mass**	**n**	**Sampling Dates**
State Building	2.2±0.5 (9.3 %)	1.6 ±0.3 (6.5 %)	0.4±0.1 (1.8 %)	0.4±0.1 (1.4 %)	8.7±2.0 (36.0 %)	10.0±1.8 (41.1 %)	1.0 (3.9 %)	24.5	31	11/3/09-3/15/10
North Pole	1.1±0.2 (3.2 %)	0.9 ±0.2 (2.6 %)	1.5±0.4 (4.3 %)	1.0±0.4 (2.9 %)	22.4±2.1 (65.1 %)	7.3±0.9 (21.3 %)	0.2 (0.6 %)	33.7	35	11/3/09-3/15/10
RAMS	1.8±0.4 (4.9 %)	0.9 ±0.2 (2.5 %)	0.8±0.3 (2.3 %)	0.9±0.4 (2.5 %)	21.0±2.2 (57.2 %)	11.2±1.4 (30.5 %)	0.1 (0.1 %)	36.7	29	11/15/09-3/15/10
Peger Road	2.3±0.5 (7.8 %)	1.9 ±0.4 (6.4 %)	1.7±0.5 (5.7 %)	0.4±0.2 (1.4 %)	9.2±2.5 (31.2 %)	13.7±2.1 (46.3 %)	0.3 (1.2 %)	29.5	37	11/3/09-3/15/10

2010/2011	**Sulfate**	**Ammonium Nitrate**	**Diesel**	**Autos**	**Wood Smoke**	**No. 2 Fuel Oil**	**Unexplained**	**$PM_{2.5}$ Mass**	**n**	**Sampling Dates**
State Building	2.0±0.4 (9.8 %)	1.3 ±0.3 (6.6 %)	0.2±0.04 (0.9 %)	0.2±0.1 (1.1 %)	6.5±1.7 (32.7 %)	8.3±1.5 (41.5 %)	1.5 (7.5 %)	20.2	15	11/1/10-2/8/11
North Pole	1.0±0.2 (3.9 %)	0.7 ±0.1 (2.7 %)	0.9±0.3 (3.3 %)	1.9±0.5 (7.1 %)	16.6±1.9 (62.5 %)	5.3±0.8 (20.0 %)	0.2 (0.6 %)	26.8	10	1/9/11-2/5/11
Peger Road	2.1±0.5 (7.3 %)	2.0 ±0.4 (6.7 %)	1.0±0.3 (3.3 %)	0.6±0.2 (2.2 %)	9.5±2.6 (32.7 %)	13.5±2.1 (46.4 %)	0.4 (1.3 %)	28.6	10	1/9/11-2/5/11
2011/2012	**Sulfate**	**Ammonium Nitrate**	**Diesel**	**Autos**	**Wood Smoke**	**No. 2 Fuel Oil**	**Unexplained**	**$PM_{2.5}$ Mass**	**n**	**Sampling Dates**
State Building	2.2±0.4 (11.0 %)	1.0 ±0.3 (5.1 %)	0.5±0.1 (2.3 %)	0.8±0.2 (4.3 %)	7.6±1.6 (38.5 %)	6.4±1.5 (32.2 %)	1.3 (6.6 %)	19.5	36	11/2/11-3/31/12
North Pole	1.2±0.2 (5.3 %)	0.5 ±0.1 (2.1 %)	None Detected	0.6±0.2 (2.4 %)	17.3±1.6 (75.4 %)	2.4±0.7 (10.3 %)	1.0 (4.5 %)	23.0	34	11/2/11-3/25/12
RAMS	1.9±0.4 (8.4 %)	1.0 ±0.3 (4.7 %)	0.3±0.1 (1.3 %)	0.9±0.4 (4.0 %)	11.5±1.9 (51.4 %)	4.9±1.5 (21.8 %)	1.9 (8.5 %)	22.7	15	12/20/11-2/27/12
NCORE	2.0±0.4 (10.5 %)	0.9 ±0.3 (4.6 %)	0.2±0.1 (1.1 %)	0.4±0.2 (2.1 %)	10.1±1.7 (53.0 %)	5.4±1.4 (28.2 %)	0.1 (0.5 %)	19.3	42	11/2/11-3/31/12
NPF3	1.2±0.2 (6.4 %)	0.5 ±0.2 (2.7 %)	None Detected	None Detected	14.1±1.3 (76.6 %)	2.2±0.7 (12.1 %)	0.4 (2.2 %)	18.3	7	3/1/12-3/31/12
2012/2013	**Sulfate**	**Ammonium Nitrate**	**Diesel**	**Autos**	**Wood Smoke**	**No. 2 Fuel Oil**	**Unexplained**	**$PM_{2.5}$ Mass**	**n**	**Sampling Dates**
State Building	2.9±0.5 (13.3 %)	1.3 ±0.4 (6.1 %)	0.2±0.1 (0.9 %)	0.4±0.2 (2.0 %)	8.7±1.8 (40.1 %)	6.0±1.5 (27.6 %)	2.1 (9.9 %)	21.8	29	11/2/12-3/29/13
NPE	1.5±0.3 (5.4 %)	0.6 ±0.1 (2.0 %)	0.8±0.2 (2.8 %)	0.8±0.2 (2.9 %)	18.8±1.8 (66.6 %)	4.9±1.1 (17.1 %)	0.9 (3.1 %)	27.8	40	11/2/12-3/29/13
NCORE	3.0±0.5 (12.1 %)	1.3 ±0.3 (5.2 %)	0.4±0.1 (1.5 %)	0.7±0.2 (2.6 %)	11.0±2.0 (44.2 %)	8.5±1.8 (34.1 %)	0.1 (0.2 %)	25.1	39	11/2/12-3/29/13
NPF3	2.2±0.4 (4.8 %)	0.6 ±0.1 (1.3 %)	0.4±0.1 (1.0 %)	0.1±0.03 (0.2 %)	34.7±2.3 (75.2 %)	6.4±1.3 (13.8 %)	1.8 (3.8 %)	46.9	42	11/2/12-3/29/13

ND: not detected by the CMB model. Sampling was not conducted at the RAMS site during the winter of 2010/2011. *CMB results originally presented in the Final Report submitted to ADEC (dated July 23, 2012). **Updated CMB modeling was conducted.

Table 15: Source Contribution Estimates ± Standard Errors (µg/m^3) – Summer 2012 OMNI Profiles.

Summer 2012	Sulfate	Ammonium Nitrate	Diesel	Autos	Street Sand	Wood Smoke	Unexplained	$PM_{2.5}$ Mass	n	Sampling Dates
State Building	0.4±0.05 (6.5 %)	0.2±0.05 (3.9 %)	0.02±0.01 (0.4 %)	0.3±0.1 (4.5 %)	0.3±0.1 (4.6 %)	3.6±0.1 (64.3 %)	0.9 (15.8 %)	5.7	20	6/2/12-8/31/12
NCORE	0.4±0.05 (6.0 %)	0.2±0.05 (3.8 %)	0.2±0.03 (2.7 %)	0.3±0.1 (5.7 %)	0.2±0.1 (3.7 %)	4.2±0.4 (70.5 %)	0.5 (7.7 %)	5.1	17	6/14/12-8/31/12

Figure 7: State Building Source Contribution Estimates (µg/m^3) – OMNI profiles.

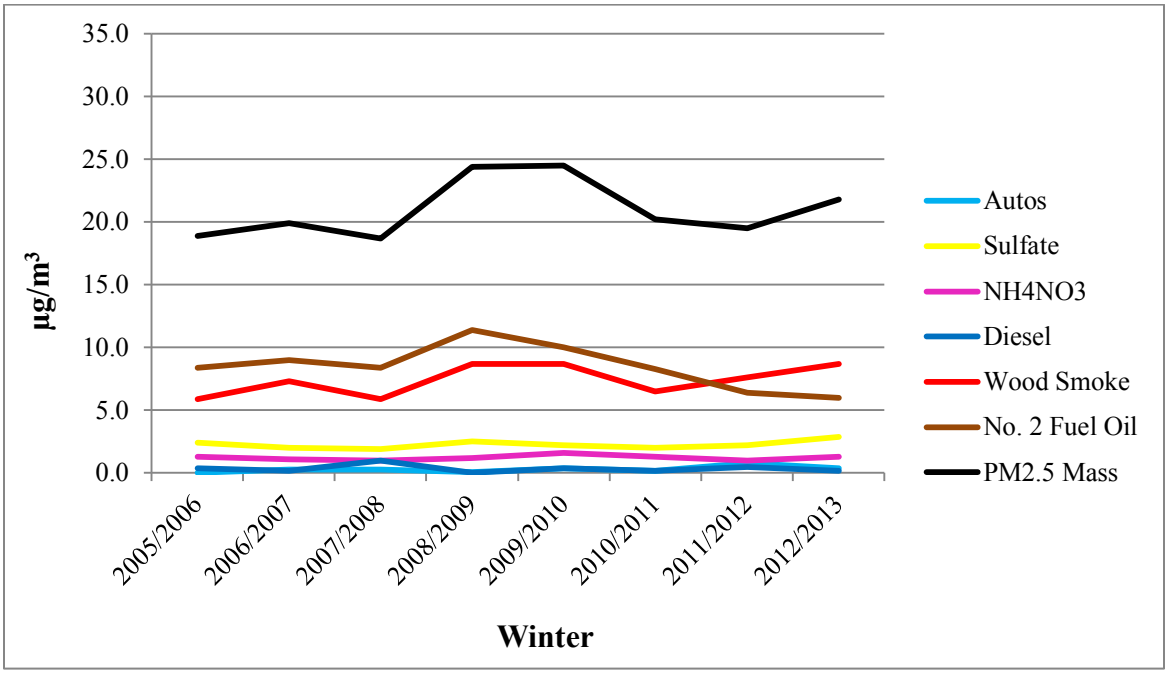

Figure 8: North Pole Source Contribution Estimates (µg/m^3) – OMNI profiles.

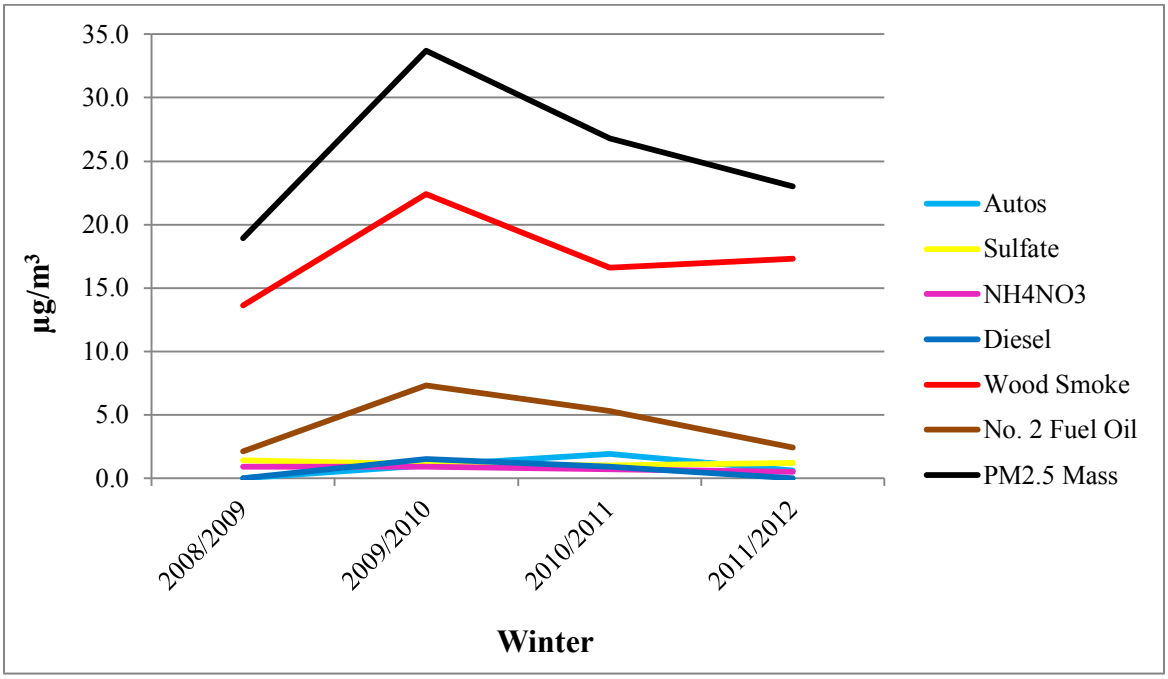

Figure 9: RAMS Source Contribution Estimates (µg/m^3) – OMNI profiles.

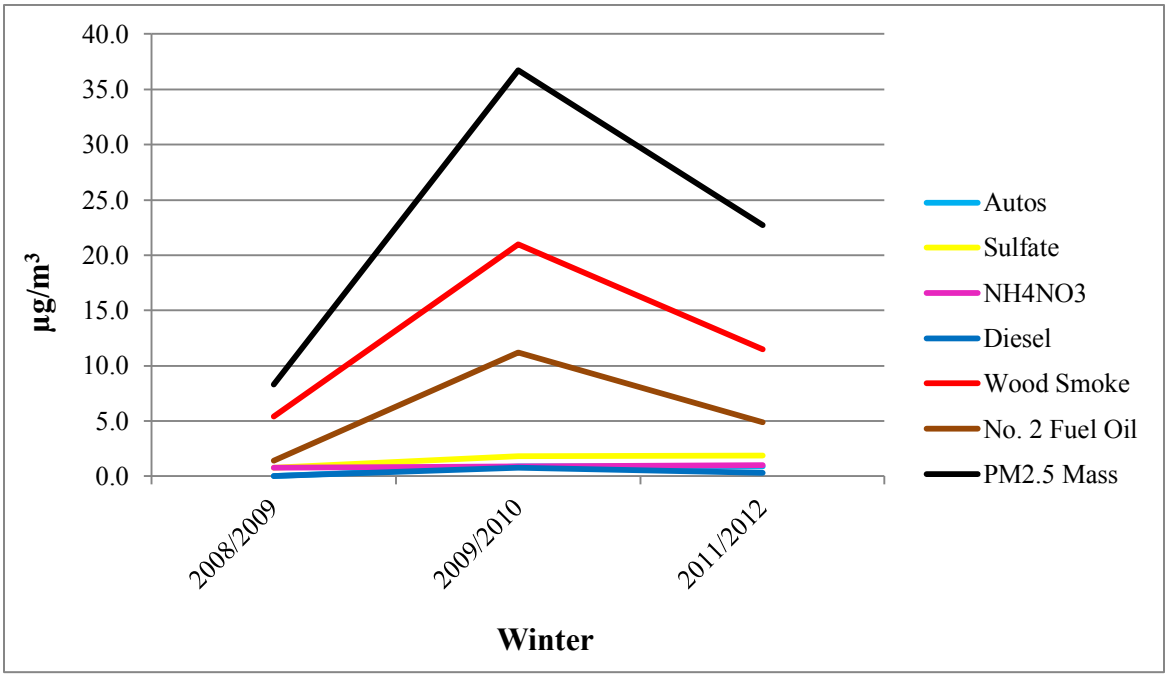

Figure 10: Peger Road Source Contribution Estimates (µg/m^3) – OMNI profiles.

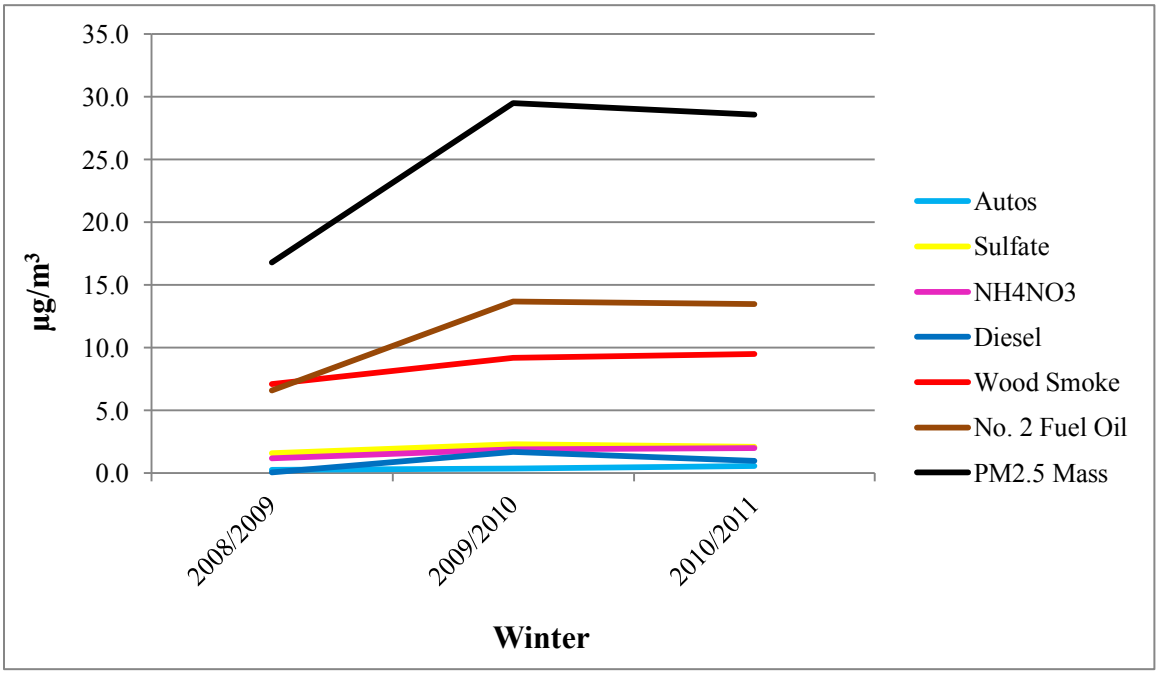

Figure 11: NCORE Source Contribution Estimates (µg/m^3) – OMNI profiles.

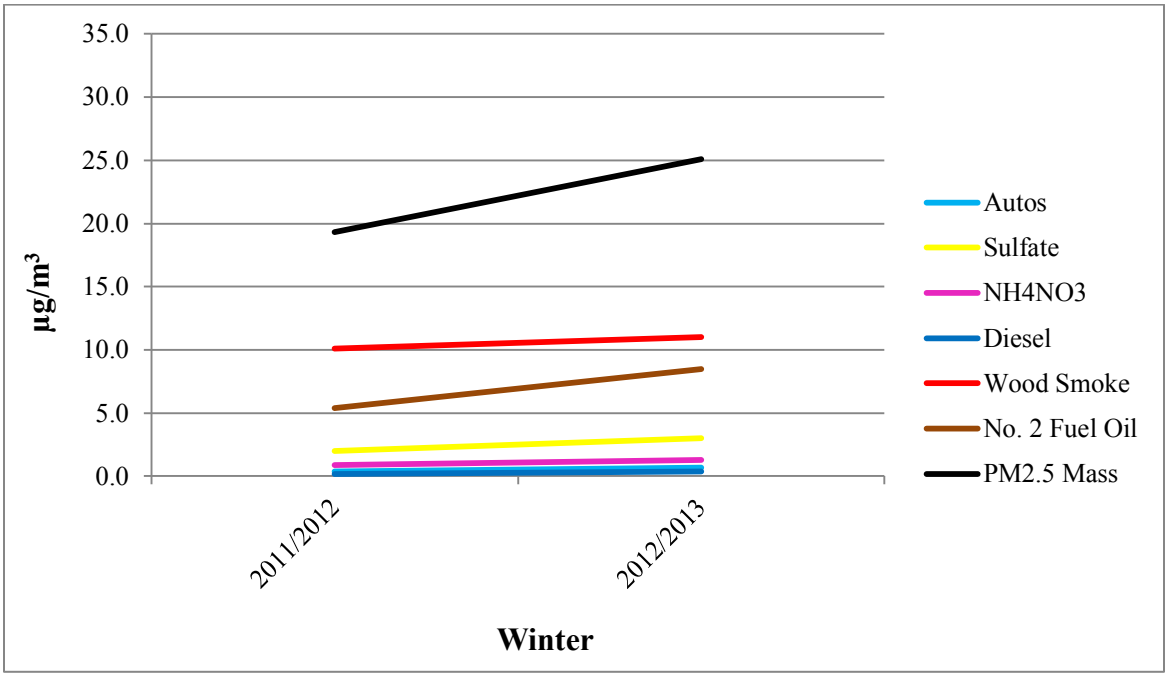

Figure 12: NPF3 Source Contribution Estimates (µg/m^3) – OMNI profiles.

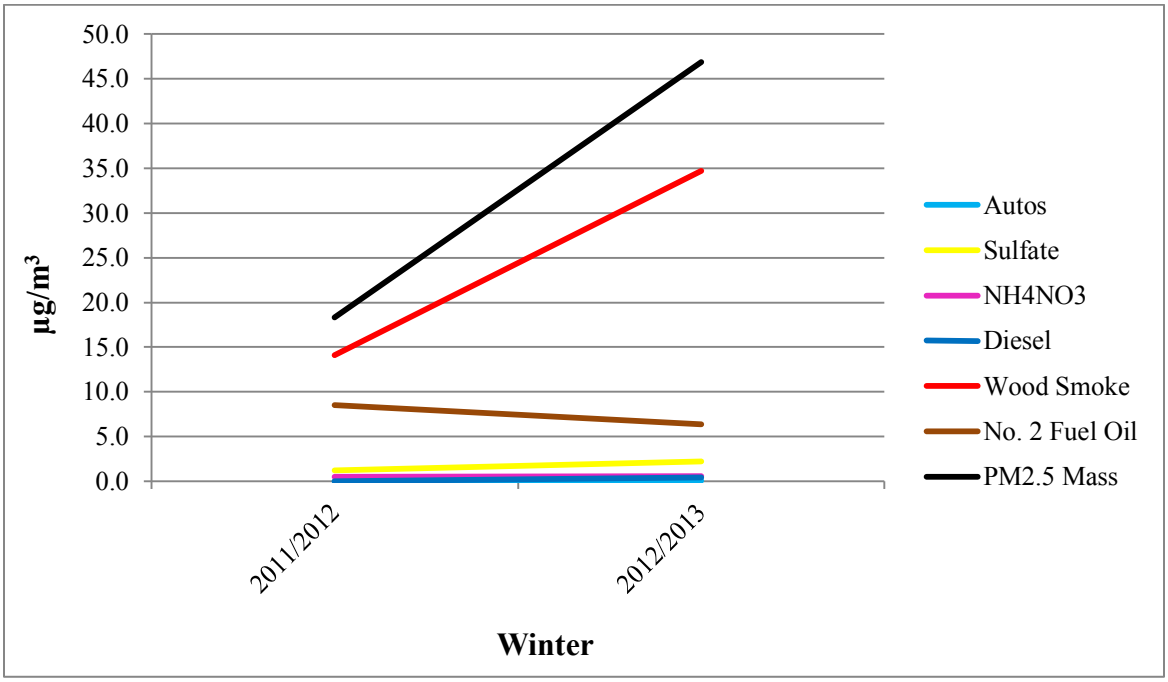

Figure 13: Winter 2005/2006, State Building.
CMB Results with EPA Source Profiles, November 3, 2005 – March 30, 2006.

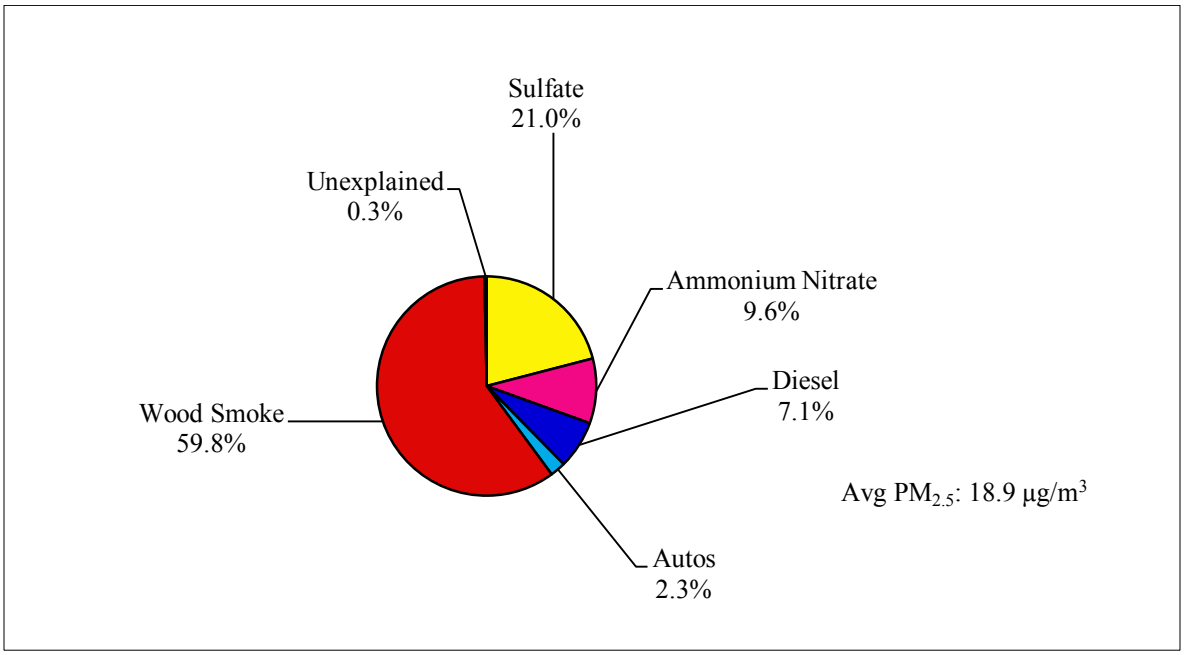

Figure 14: Winter 2005/2006, State Building.
CMB Results with OMNI Source Profiles, November 3, 2005 – March 30, 2006.

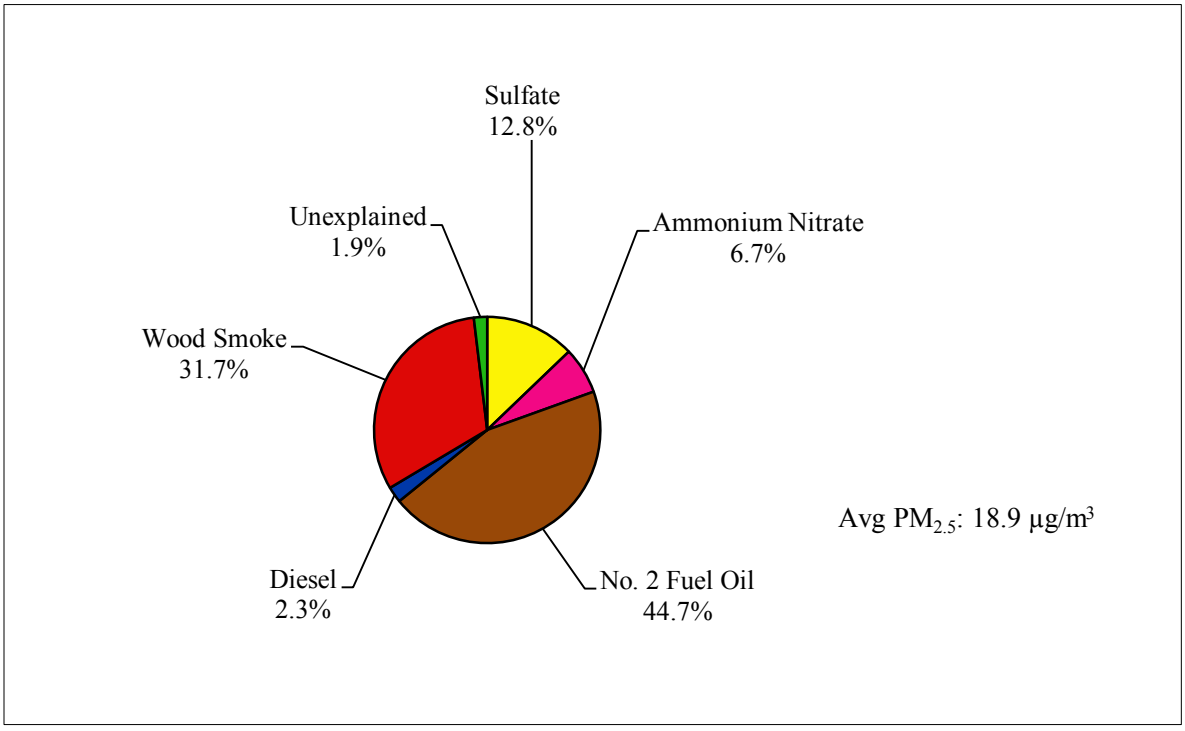

Table 16: Comparison of CMB Results - EPA and OMNI Source Profiles. State Building, Winter 2005/2006.

Season:	Winter 2005/2006 (EPA)	Winter 2005/2006 (OMNI)
Dates:	11/3/05-3/30/06	11/3/05-3/30/06
n:	36	36
$PM_{2.5}$ Mass ($\mu g/m^3$):	18.9	18.9
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	4.0 (21.0 %)	2.4 (12.8 %)
Ammonium Nitrate:	1.8 (9.6 %)	1.3 (6.7%)
Diesel:	1.3 (7.1 %)	0.4 (2.3%)
Automobiles:	0.4 (2.3 %)	Not Identified
Wood Smoke:	11.3 (59.8 %)	5.9 (31.7 %)
No. 2 Fuel Oil:	Not Identified	8.4 (44.7 %)
Unexplained:	0.1 (0.3 %)	0.4 (1.9 %)

Figure 15: Winter 2006/2007, State Building.
CMB Results with EPA Source Profiles, November 1, 2006 – March 31, 2007.

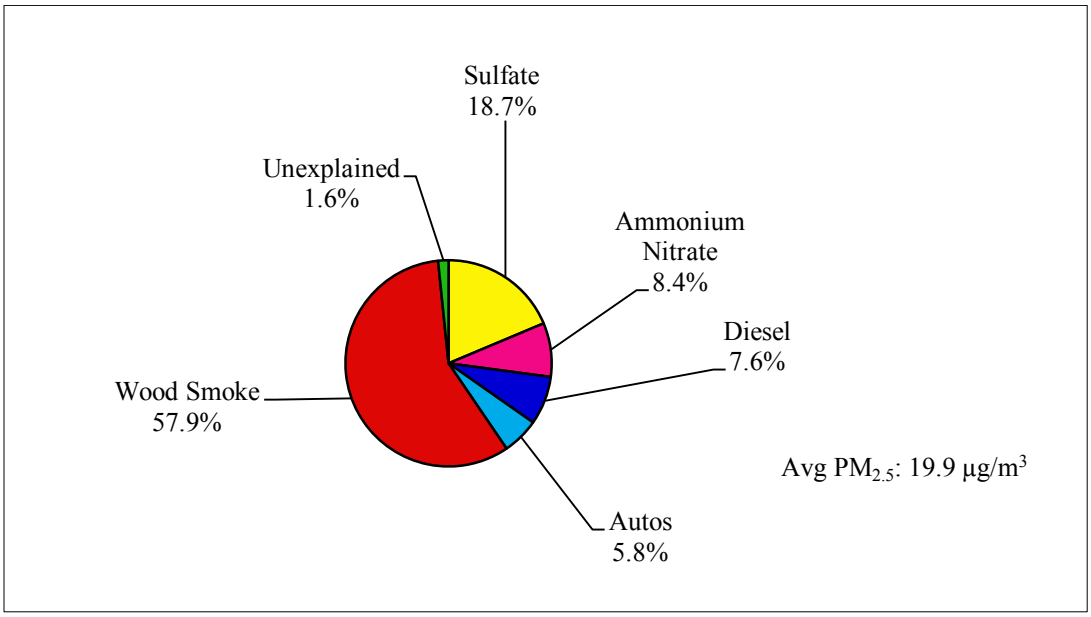

Figure 16: Winter 2006/2007, State Building.
CMB Results with OMNI Source Profiles, November 1, 2006 – March 31, 2007.

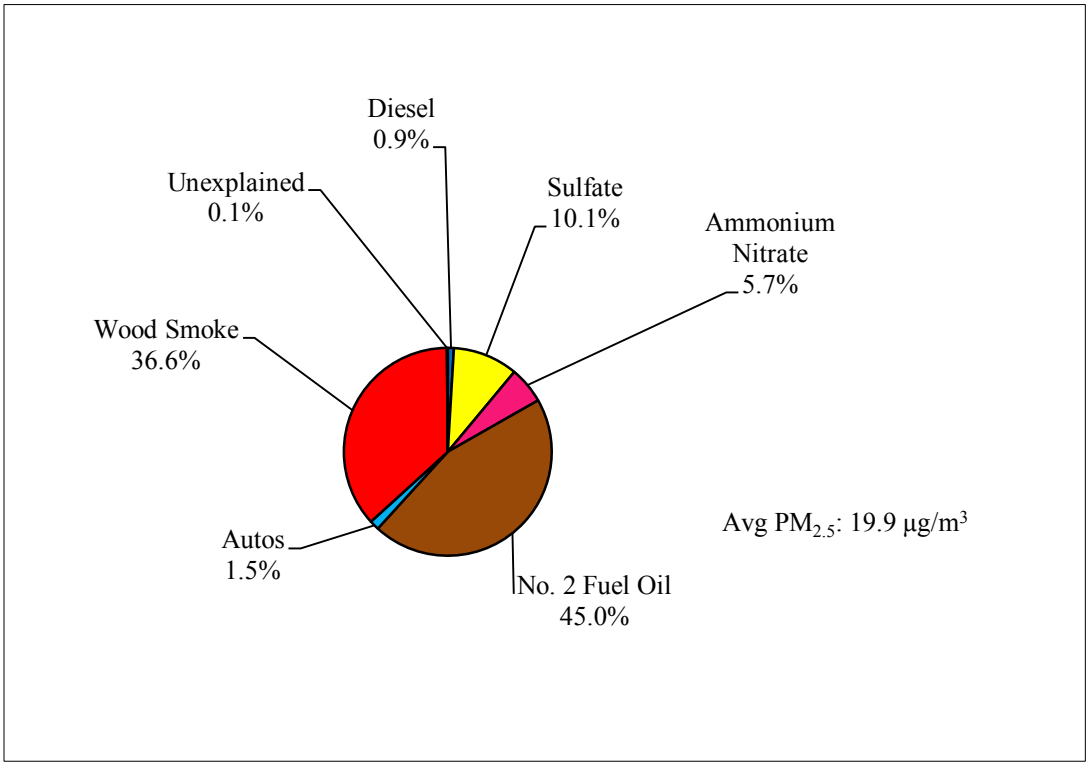

Table 17: Comparison of CMB Results - EPA and OMNI Source Profiles. State Building, Winter 2006/2007.

Season:	Winter 2006/2007 (EPA)	Winter 2006/2007 (OMNI)
Dates:	11/1/06-3/31/07	11/1/06-3/31/07
n:	39	39
$PM_{2.5}$ Mass ($\mu g/m^3$):	19.9	19.9
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	3.7 (18.7 %)	2.0 (10.1 %)
Ammonium Nitrate:	1.7 (8.4 %)	1.1 (5.7 %)
Diesel:	1.5 (7.6 %)	0.2 (0.9 %)
Automobiles:	1.1 (5.8 %)	0.3 (1.5 %)
Wood Smoke:	11.5 (57.9 %)	7.3 (36.6 %)
No. 2 Fuel Oil:	Not Identified	9.0 (45.0 %)
Unexplained:	0.3 (1.6 %)	0.03 (0.1 %)

Figure 17: Winter 2007/2008, State Building.
CMB Results with EPA Source Profiles, November 2, 2007 – March 31, 2008.

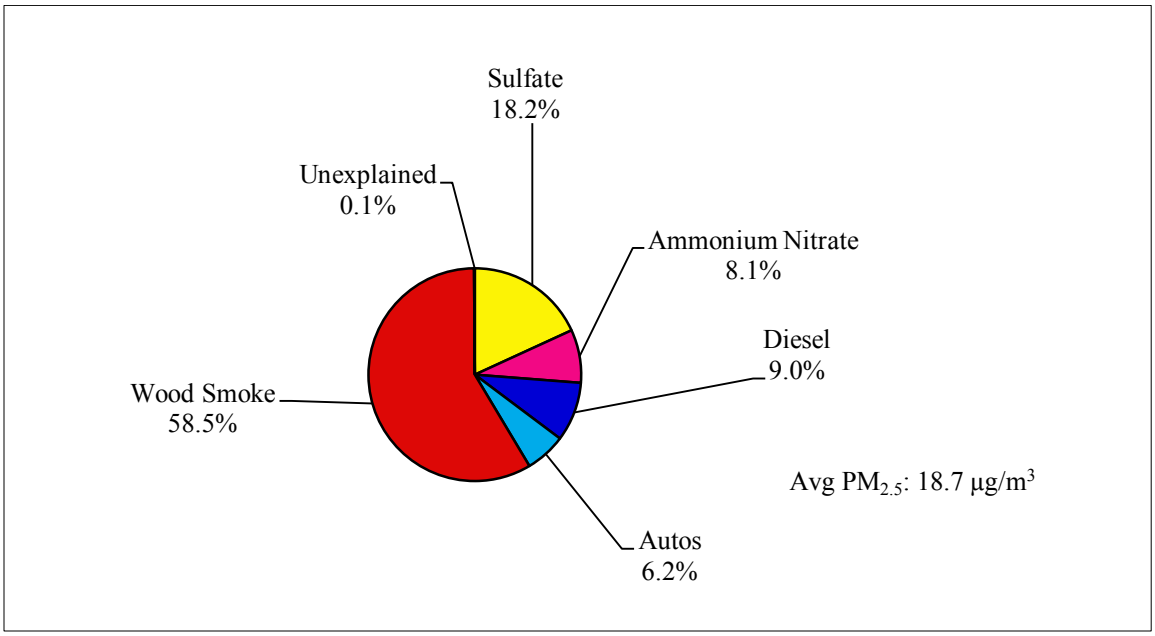

Figure 18: Winter 2007/2008, State Building.
CMB Results with OMNI Source Profiles, November 2, 2007 – March 31, 2008.

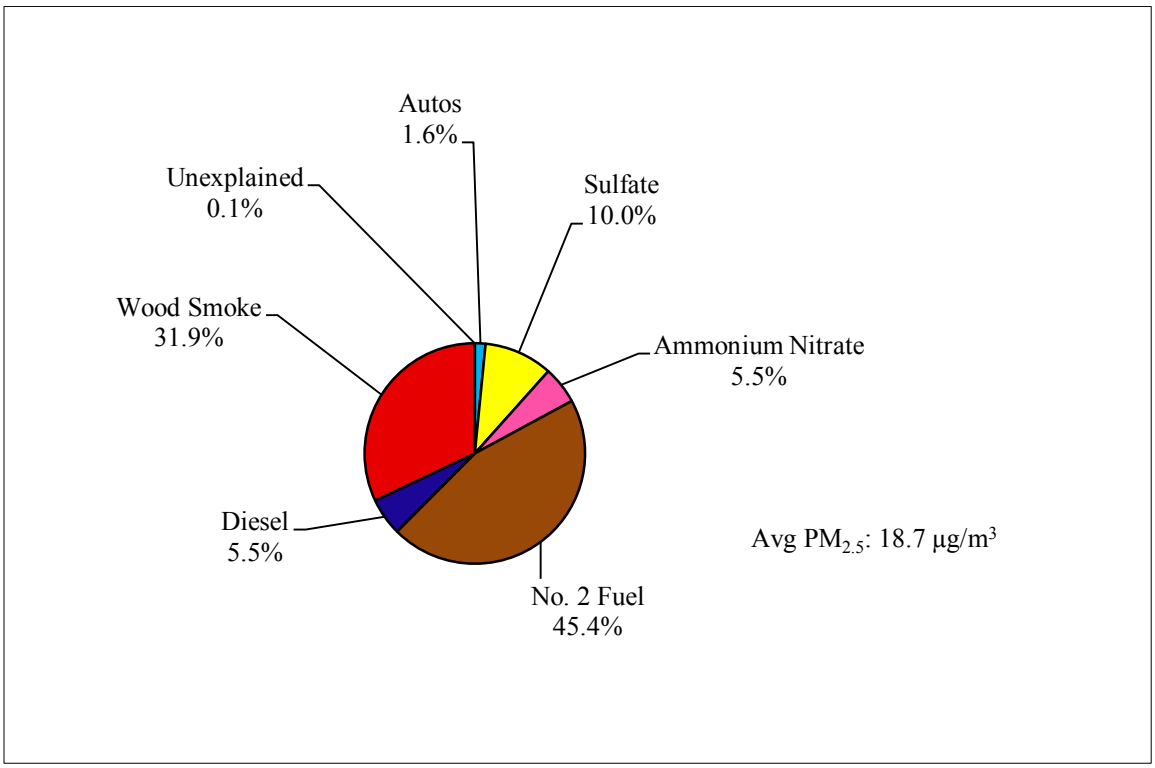

Table 18: Comparison of CMB Results - EPA and OMNI Source Profiles. State Building, Winter 2007/2008.

Season:	Winter 2007/2008 (EPA)	Winter 2007/2008 (OMNI)
Dates:	11/2/07-3/31/08	11/2/07-3/31/08
n:	40	40
$PM_{2.5}$ Mass ($\mu g/m^3$):	18.7	18.7
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	3.4 (18.2 %)	1.9 (10.0 %)
Ammonium Nitrate:	1.5 (8.1 %)	1.0 (5.5 %)
Diesel:	1.7 (9.0 %)	1.0 (5.5 %)
Automobiles:	1.2 (6.2 %)	0.3 (1.6%)
Wood Smoke:	10.9 (58.5 %)	5.9 (31.9 %)
No. 2 Fuel Oil:	Not Identified	8.4 (45.4 %)
Unexplained:	0.02 (0.1 %)	0.01 (0.1 %)

Figure 19: Winter 2008/2009, State Building.
CMB Results with EPA Source Profiles, November 8, 2008 – April 7, 2009.

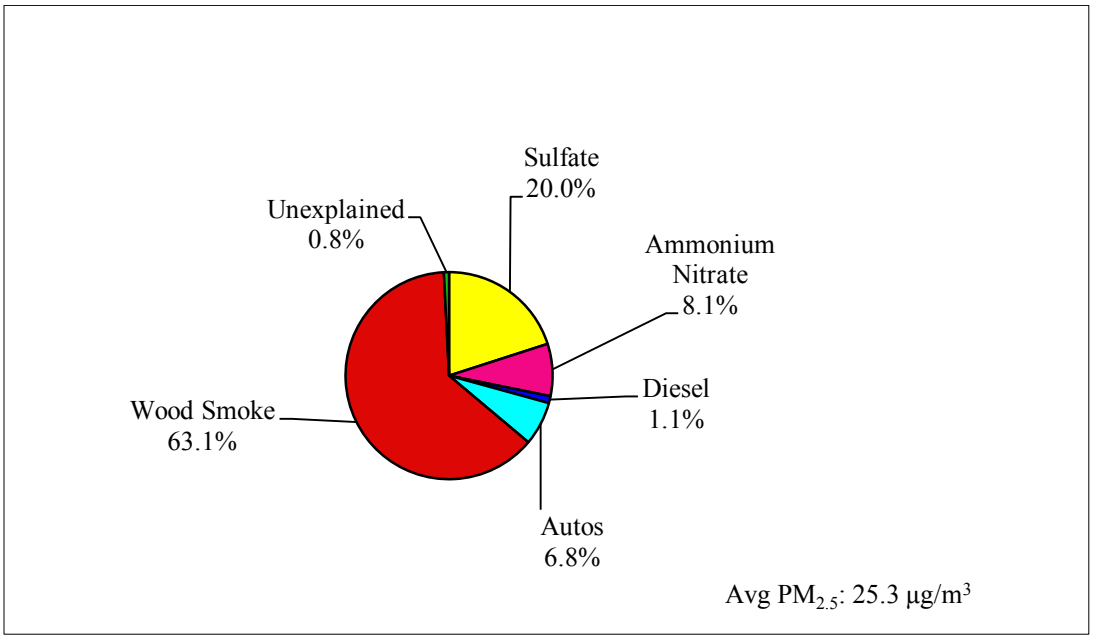

Figure 20: Winter 2008/2009, State Building.
CMB Results with OMNI Source Profiles, November 8, 2008 – April 7, 2009.
(Submitted originally to ADEC in July 23, 2012 final report).

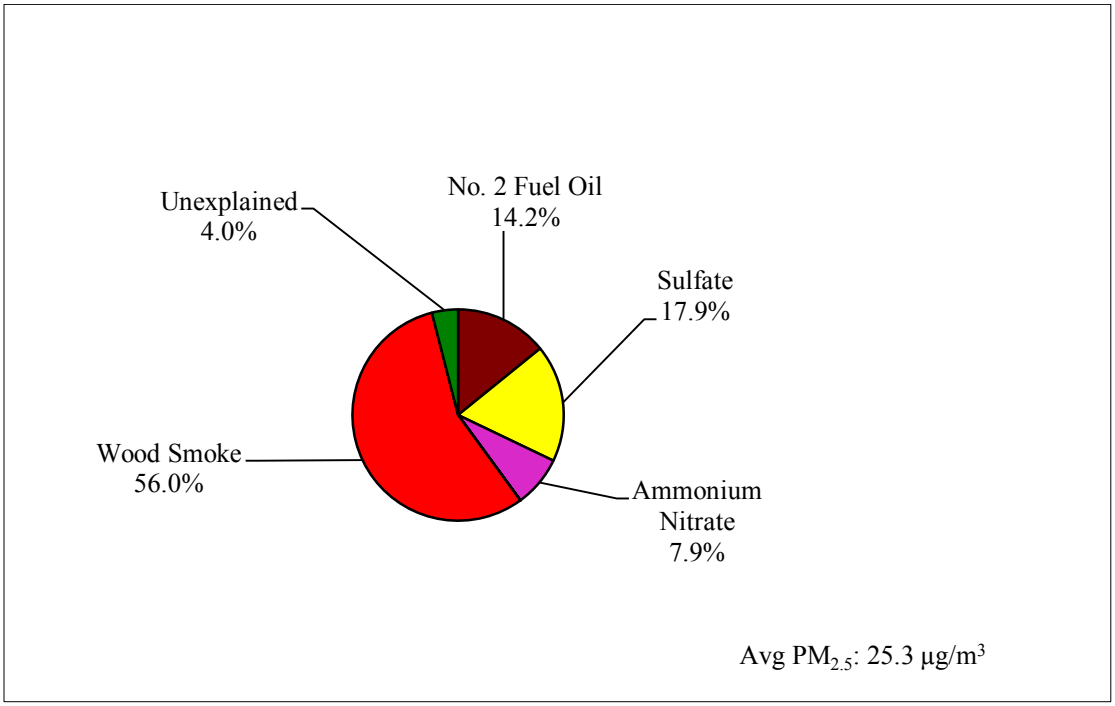

Figure 21: Winter 2008/2009, State Building.
CMB Results with OMNI Source Profiles, November 8, 2008 – April 7, 2009.
(Updated CMB modeling using OMNI profiles and auto / diesel profiles).

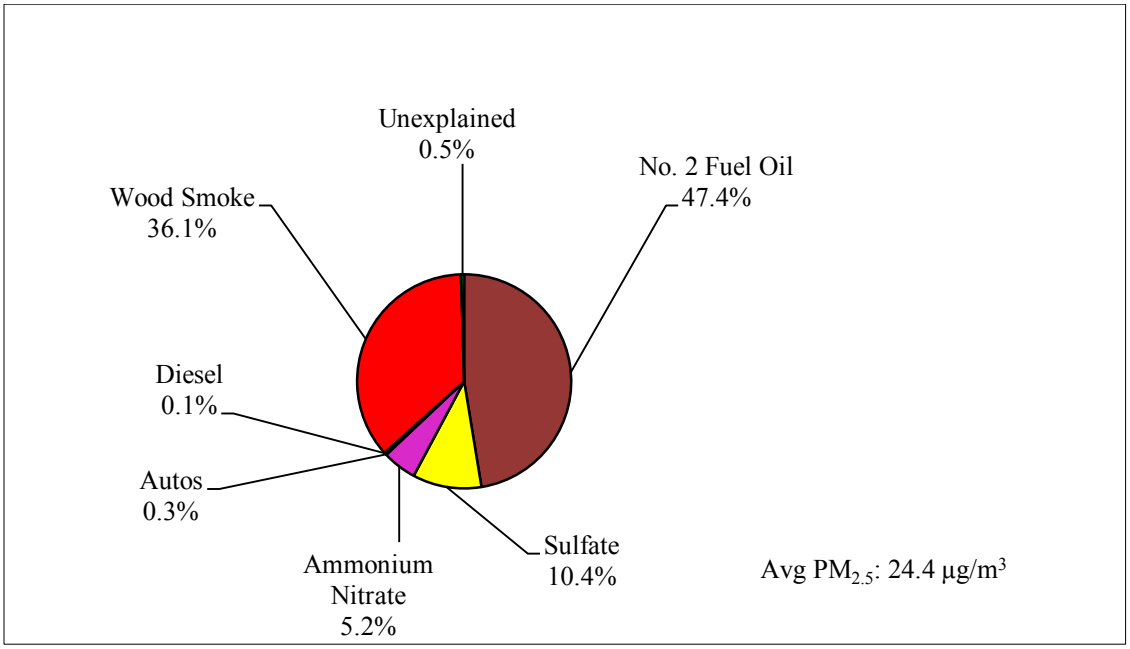

Table 19: Comparison of CMB Results - EPA and OMNI Source Profiles.
State Building, Winter 2008/2009.

Season:	Winter 2008/2009 (EPA)	Winter 2008/2009 (OMNI)*	Winter 2008/2009 (OMNI)**
Dates:	11/8/08-4/7/09	11/8/08-4/7/09	11/8/08-4/7/09
n:	47	47	46
$PM_{2.5}$ Mass (µg/m^3):	25.3	25.3	24.4
CMB Source Estimates (µg/m^3 and %)			
Sulfate:	5.1 (20.0 %)	4.4 (17.9 %)	2.5 (10.4 %)
Ammonium Nitrate:	2.1 (8.1 %)	1.9 (7.9%)	1.2 (5.2%)
Diesel:	0.3 (1.1 %)	Not Identified	0.04 (0.1 %)
Automobiles:	1.7 (6.8 %)	Not Identified	0.06 (0.3 %)
Wood Smoke:	16.0 (63.1 %)	13.8 (56.0 %)	8.7 (36.1 %)
No. 2 Fuel Oil:	Not Identified	3.5 (14.2 %)	11.4 (47.4 %)
Unexplained:	0.2 (0.8 %)	1.0 (4.0 %)	0.1 (0.5 %)

***Original OMNI CMB modeling (July 23, 2012 report). **Updated OMNI CMB modeling with autos and diesel profiles.**

Figure 22: Winter 2008/2009, North Pole.
CMB Results with EPA Source Profiles, January 25, 2009 – April 7, 2009.

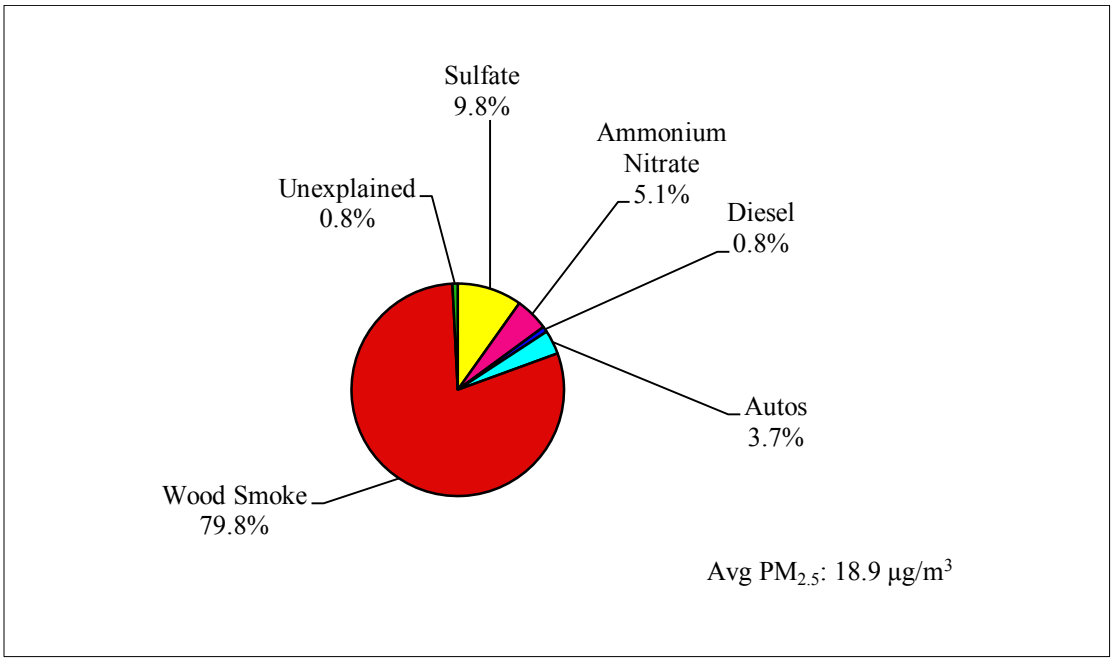

Figure 23: Winter 2008/2009, North Pole.
CMB Results with OMNI Source Profiles, January 25, 2009 – April 7, 2009.

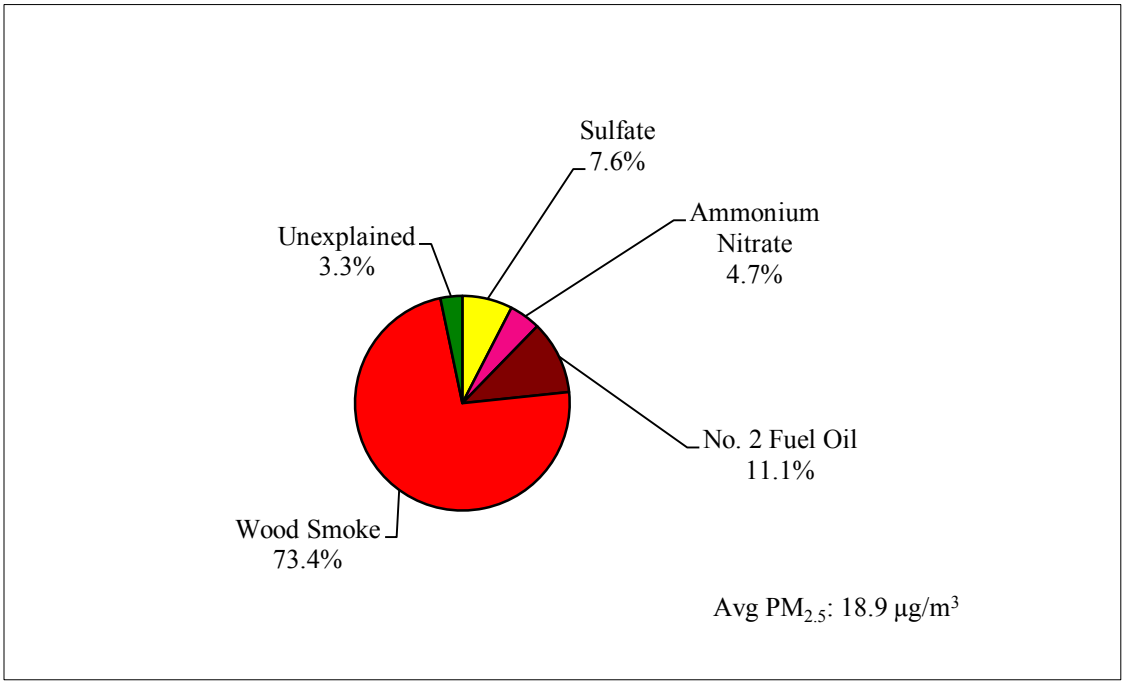

Table 20: Comparison of CMB Results - EPA and OMNI Source Profiles. North Pole, Winter 2008/2009.

Season:	Winter 2008/2009 (EPA)	Winter 2008/2009 (OMNI)
Dates:	1/25/09-4/7/09	1/25/09-4/7/09
n:	21	21
$PM_{2.5}$ Mass ($\mu g/m^3$):	18.9	18.9
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	1.9 (9.8 %)	1.4 (7.6 %)
Ammonium Nitrate:	1.0 (5.1 %)	0.9 (4.7 %)
Diesel:	0.2 (0.8 %)	Not Identified
Automobiles:	0.7 (3.7 %)	Not Identified
Wood Smoke:	15.0 (79.8 %)	13.6 (73.4 %)
No. 2 Fuel Oil:	Not Identified	2.1 (11.1 %)
Unexplained:	0.2 (0.8 %)	0.6 (3.3 %)

Figure 24: Winter 2008/2009, RAMS.
CMB Results with EPA Source Profiles, January 25, 2009 – April 7, 2009.

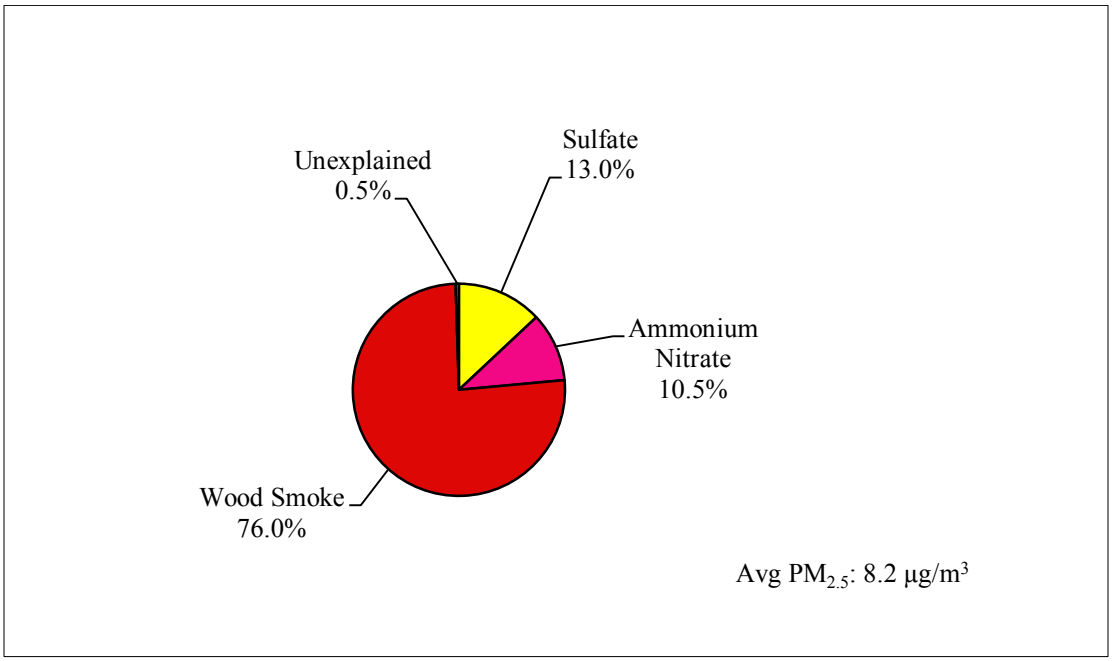

Figure 25: Winter 2008/2009, RAMS.
CMB Results with OMNI Source Profiles, January 25, 2009 – April 7, 2009.

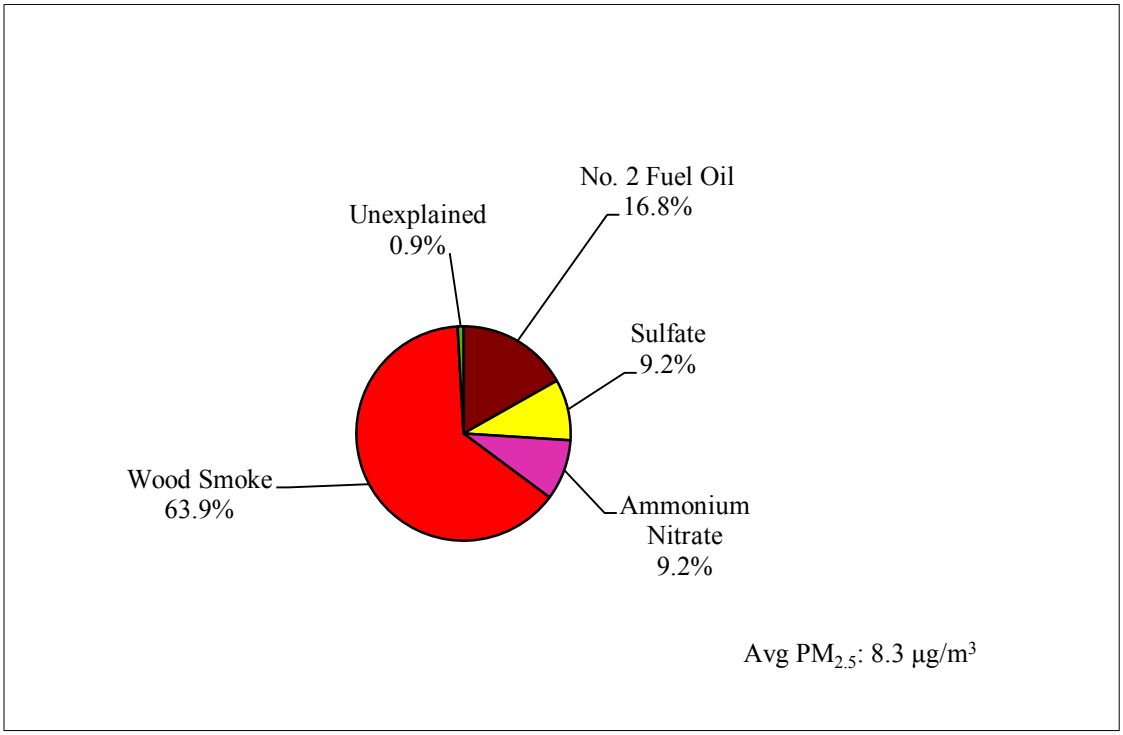

Table 21: Comparison of CMB Results - EPA and OMNI Source Profiles. RAMS, Winter 2008/2009.

Season:	Winter 2008/2009 (EPA)	Winter 2008/2009 (OMNI)
Dates:	1/25/09-4/7/09	1/25/09-4/7/09
n:	23	22
$PM_{2.5}$ Mass ($\mu g/m^3$):	8.2	8.3
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	1.1 (13.0 %)	0.8 (9.2 %)
Ammonium Nitrate:	0.9 (10.5 %)	0.8 (9.2 %)
Diesel:	Not Identified	Not Identified
Automobiles:	Not Identified	Not Identified
Wood Smoke:	6.3 (76.0 %)	5.4 (63.9 %)
No. 2 Fuel Oil:	Not Identified	1.4 (16.8 %)
Unexplained:	0.04 (0.5 %)	0.1 (0.9%)

Figure 26: Winter 2008/2009, Peger Road.
CMB Results with EPA Source Profiles, January 25, 2009 – April 7, 2009.

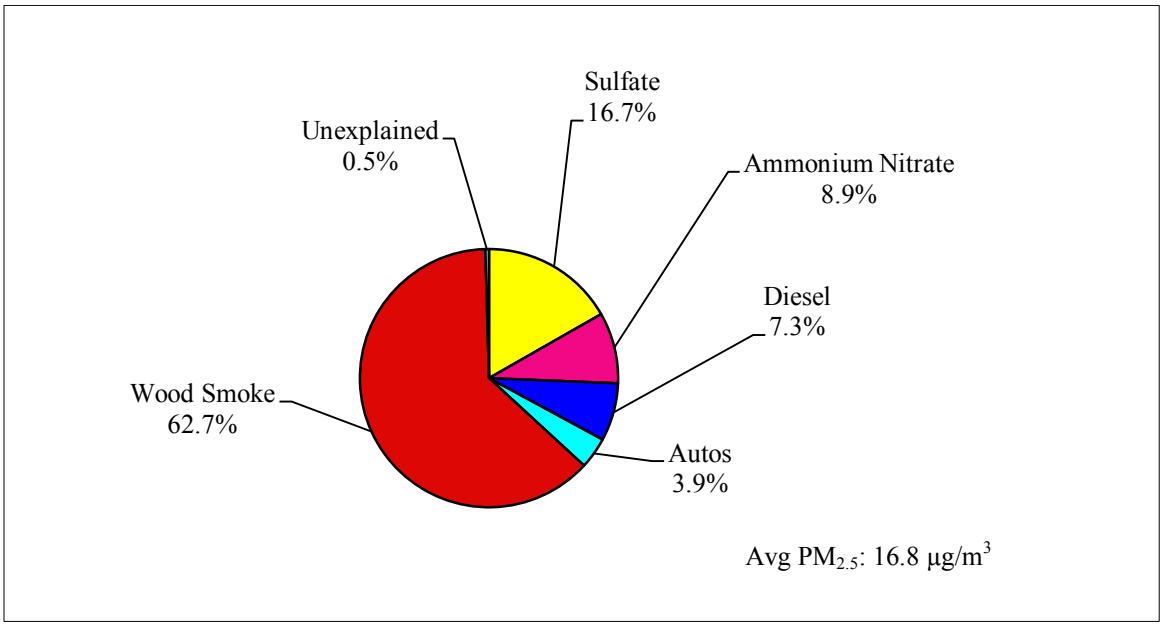

Figure 27: Winter 2008/2009, Peger Road.
CMB Results with OMNI Source Profiles, January 25, 2009 – April 7, 2009.
(Submitted originally to ADEC in July 23, 2012 final report).

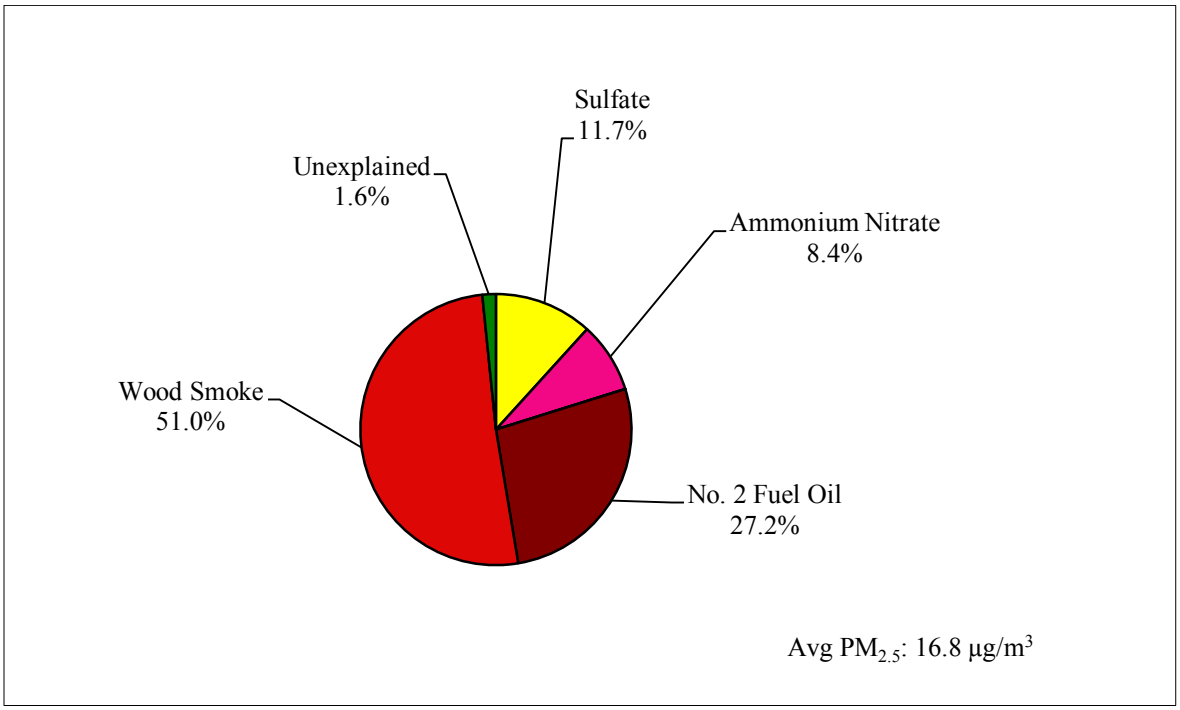

Figure 28: Winter 2008/2009, Peger Road.
CMB Results with OMNI Source Profiles, January 25, 2009 – April 7, 2009.
(Updated CMB modeling using OMNI profiles and auto / diesel profiles).

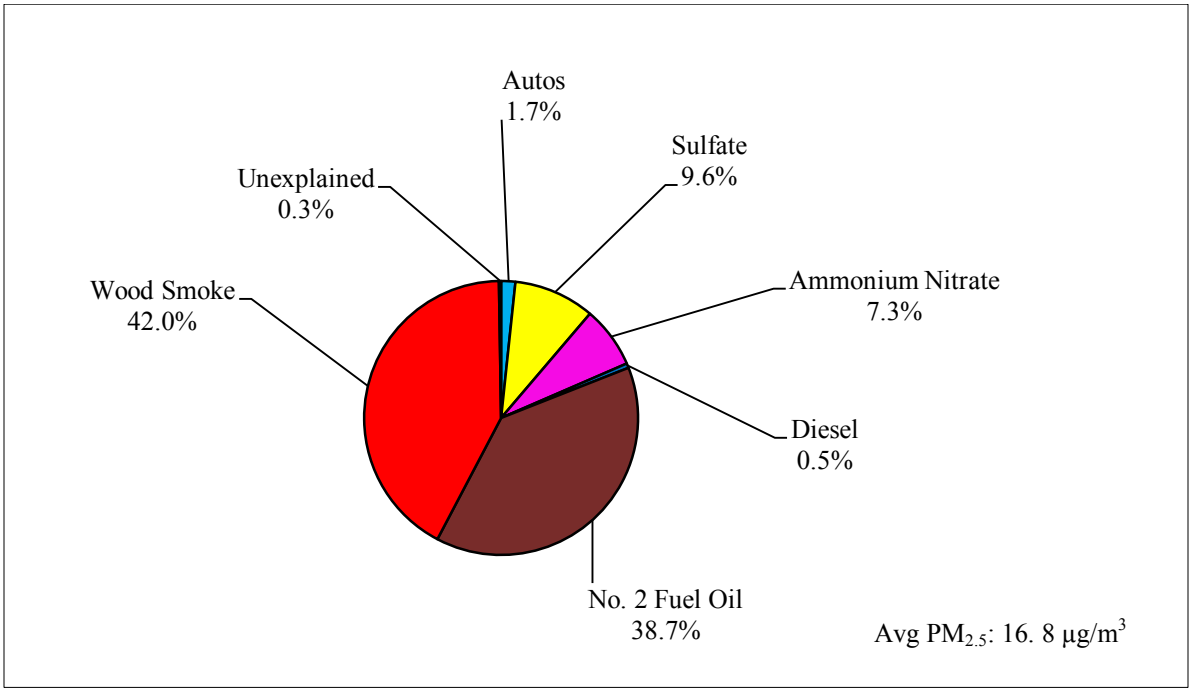

Table 22: Comparison of CMB Results - EPA and OMNI Source Profiles.
Peger Road, Winter 2008/2009.

Season:	**Winter 2008/2009 (EPA)**	**Winter 2008/2009 (OMNI)***	**Winter 2008/2009 (OMNI)****
Dates:	1/25/09-4/7/09	1/25/09-4/7/09	1/25/09-4/7/09
n:	26	26	26
$PM_{2.5}$ Mass (µg/m^3):	16.8	16.8	16.8
CMB Source Estimates (µg/m^3 and %)			
Sulfate:	2.8 (16.7 %)	2.0 (11.7 %)	1.6 (9.6 %)
Ammonium Nitrate:	1.5 (8.9 %)	1.4 (8.4 %)	1.2 (7.3 %)
Diesel:	1.2 (7.3 %)	Not Identified	0.1 (0.5 %)
Automobiles:	0.7 (3.9 %)	Not Identified	0.3 (1.7 %)
Wood Smoke:	10.6 (62.7 %)	8.6 (51.0 %)	7.1 (42.0 %)
No. 2 Fuel Oil:	Not Identified	4.6 (27.2 %)	6.6 (38.7 %)
Unexplained:	0.1 (0.5 %)	0.3 (1.6 %)	0.04 (0.3 %)

***Original OMNI CMB modeling (July 23, 2012 report). **Updated OMNI CMB modeling with autos and diesel profiles.**

Figure 29: Winter 2009/2010, State Building.
CMB Results with EPA Source Profiles, November 3, 2009–March 15, 2010.

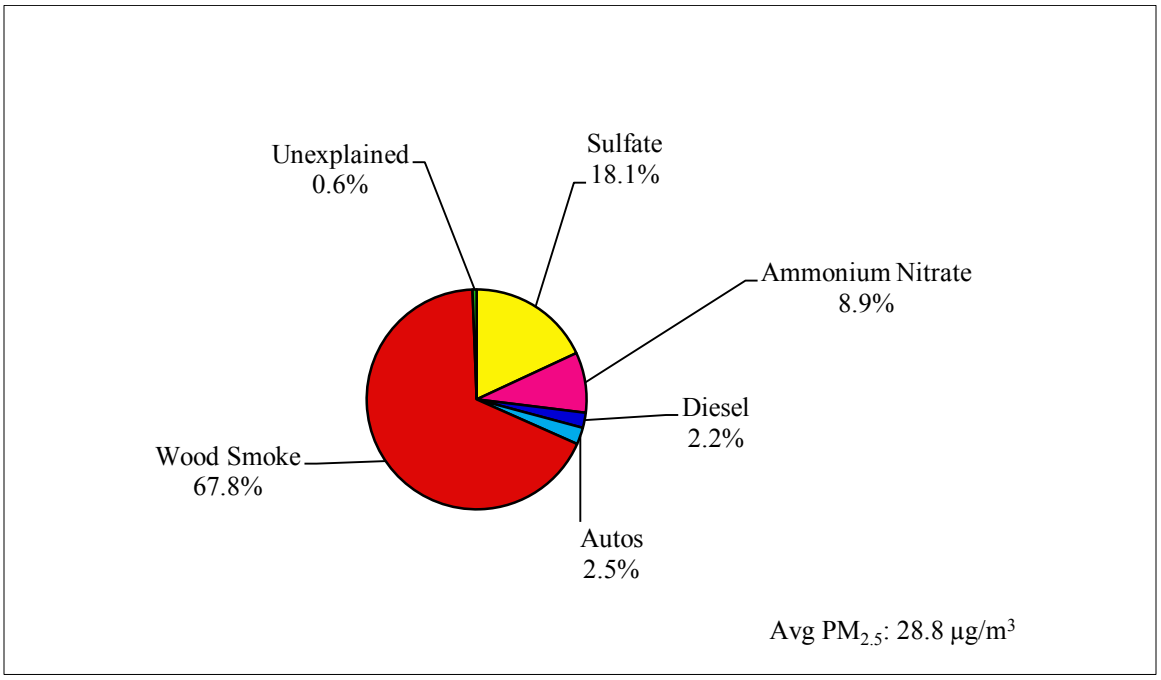

Figure 30: Winter 2009/2010, State Building.
CMB Results with OMNI Source Profiles, November 3, 2009–March 15, 2010.

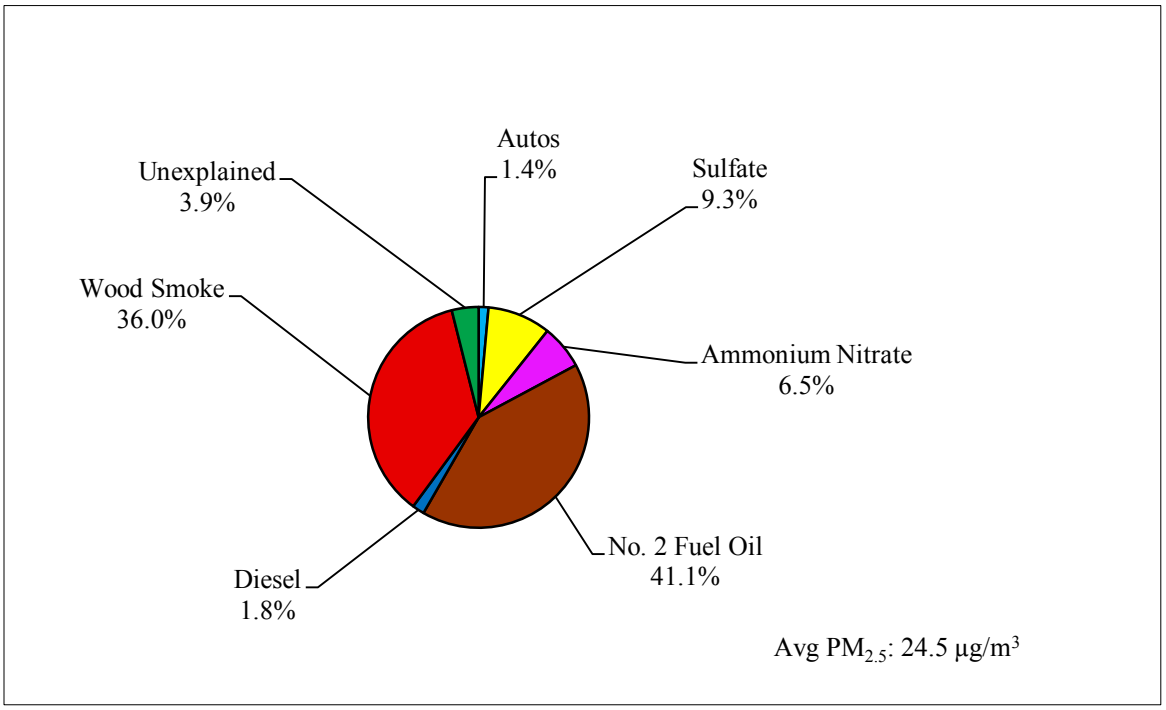

Table 23: Comparison of CMB Results - EPA and OMNI Source Profiles. State Building, Winter 2009/2010.

Season:	Winter 2009/2010 (EPA)	Winter 2009/2010 (OMNI)
Dates:	11/3/09-3/15/10	11/3/09-3/15/10
n:	40	31
$PM_{2.5}$ Mass ($\mu g/m^3$):	28.8	24.5
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	5.2 (18.1 %)	2.2 (9.3 %)
Ammonium Nitrate:	2.5 (8.9 %)	1.6 (6.5 %)
Diesel:	0.6 (2.2 %)	0.4 (1.8 %)
Automobiles:	0.7 (2.5 %)	0.4 (1.4 %)
Wood Smoke:	19.5 (67.8 %)	8.7 (36.0 %)
No. 2 Fuel Oil:	Not Identified	10.0 (41.1 %)
Unexplained:	0.2 (0.6 %)	1.0 (3.9 %)

Figure 31: Winter 2009/2010, North Pole.
CMB Results with EPA Source Profiles, November 3, 2009 – March 15, 2010.

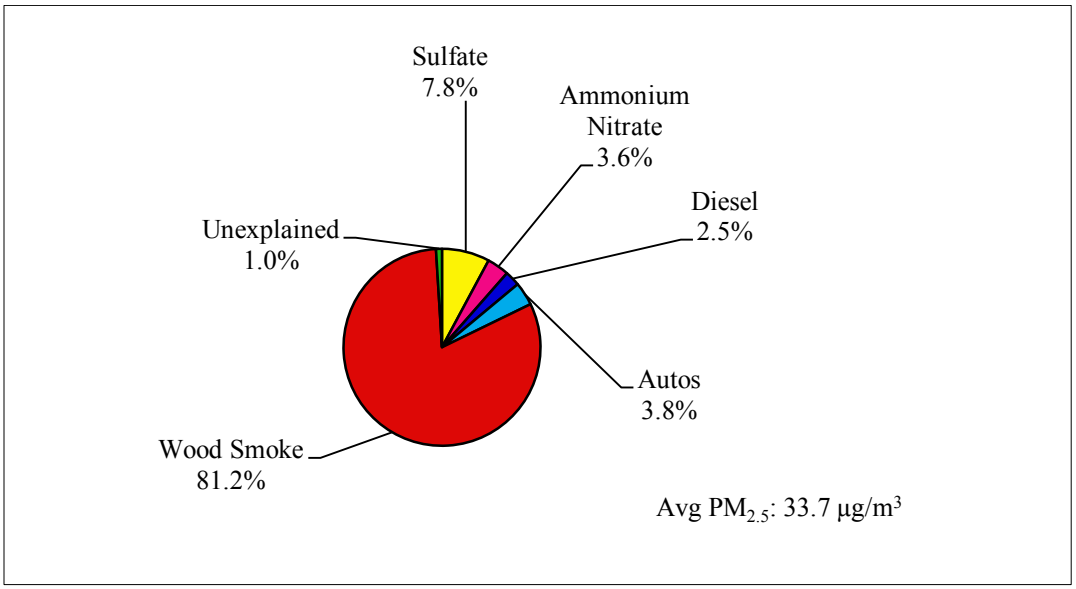

Figure 32: Winter 2009/2010, North Pole.
CMB Results with OMNI Source Profiles, November 3, 2009–March 15, 2010.

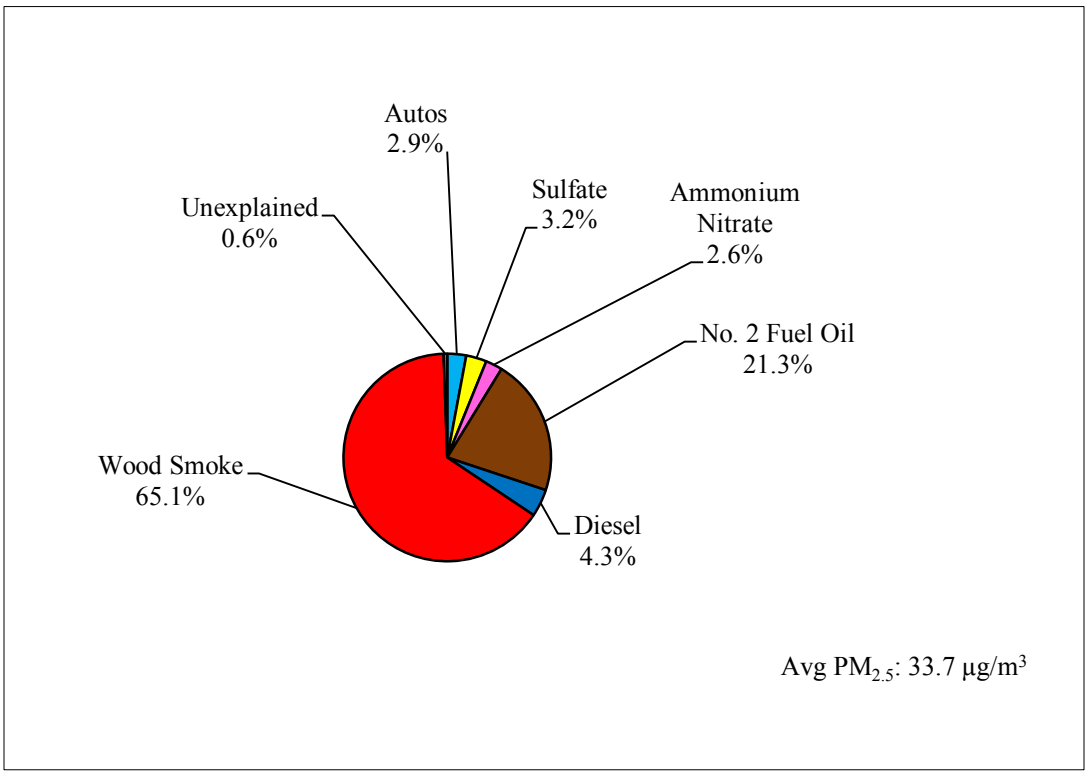

Table 24: Comparison of CMB Results - EPA and OMNI Source Profiles. North Pole, Winter 2009/2010.

Season:	Winter 2009/2010 (EPA)	Winter 2009/2010 (OMNI)
Dates:	11/3/09-3/15/10	11/3/09-3/15/10
n:	35	35
$PM_{2.5}$ Mass ($\mu g/m^3$):	33.7	33.7
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	2.6 (7.8 %)	1.1 (3.2 %)
Ammonium Nitrate:	1.2 (3.6 %)	0.9 (2.6 %)
Diesel:	0.8 (2.5 %)	1.5 (4.3 %)
Automobiles:	1.3 (3.8 %)	1.0 (2.9 %)
Wood Smoke:	27.1 (81.2 %)	22.4 (65.1 %)
No. 2 Fuel Oil:	Not Identified	7.3 (21.3 %)
Unexplained:	0.3 (1.0 %)	0.2 (0.6 %)

Figure 33: Winter 2009/2010, RAMS.
CMB Results with EPA Source Profiles, November 15, 2009 – March 15, 2010.

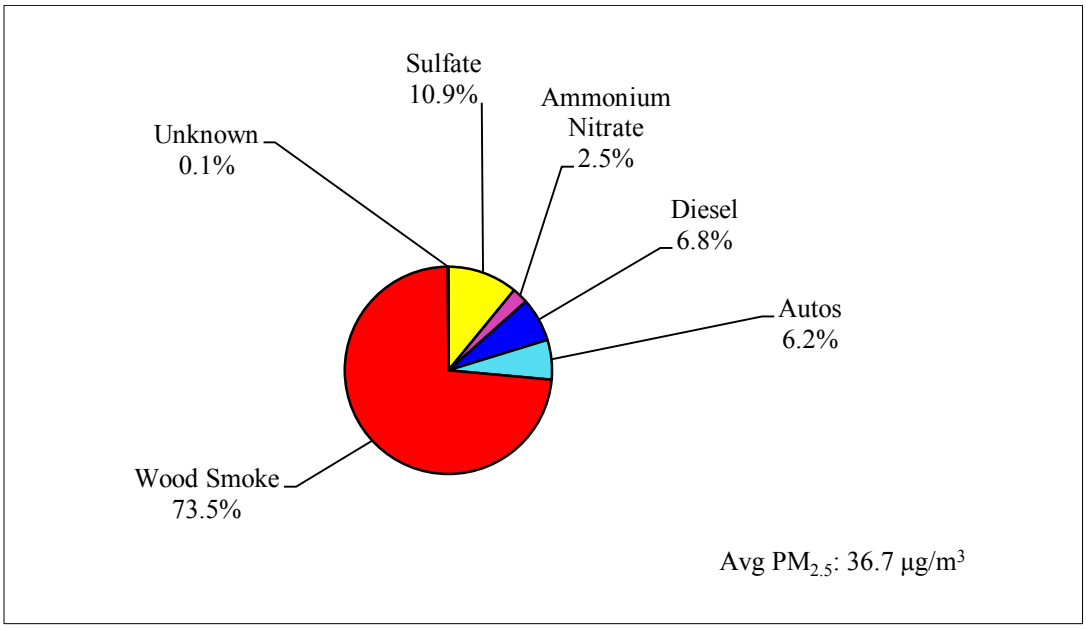

Figure 34: Winter 2009/2010, RAMS.
CMB Results with OMNI Source Profiles, November 15, 2009 – March 15, 2010.

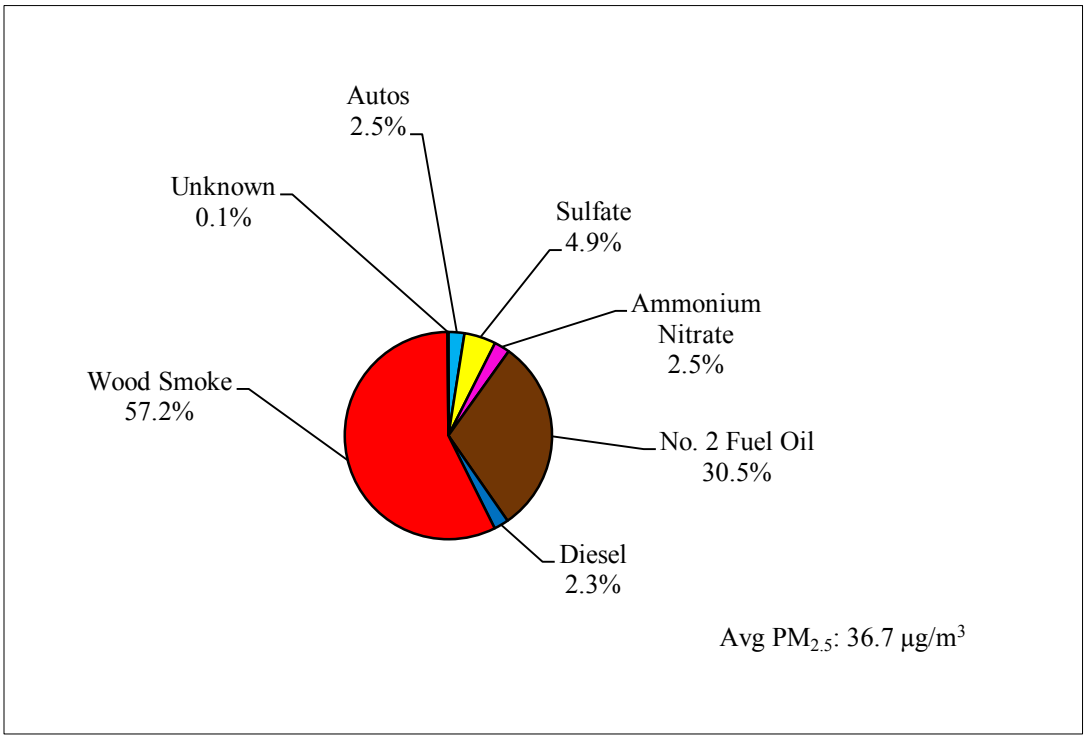

Table 25: Comparison of CMB Results - EPA and OMNI Source Profiles. RAMS, Winter 2009/2010.

Season:	Winter 2009/2010 (EPA)	Winter 2009/2010 (OMNI)
Dates:	11/15/09-3/15/10	11/15/09-3/15/10
n:	29	29
$PM_{2.5}$ Mass ($\mu g/m^3$):	36.7	36.7
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	4.0 (10.9 %)	1.8 (4.9 %)
Ammonium Nitrate:	0.9 (2.5 %)	0.9 (2.5 %)
Diesel:	2.5 (6.8 %)	0.8 (2.3 %)
Automobiles:	2.3 (6.2 %)	0.9 (2.5 %)
Wood Smoke:	26.9 (73.5 %)	21.0 (57.2 %)
No. 2 Fuel Oil:	Not Identified	11.2 (30.5 %)
Unexplained:	0.04 (0.1 %)	0.1 (0.1 %)

Figure 35: Winter 2009/2010, Peger Road.
CMB Results with EPA Source Profiles, November 3, 2009 – March 15, 2010.

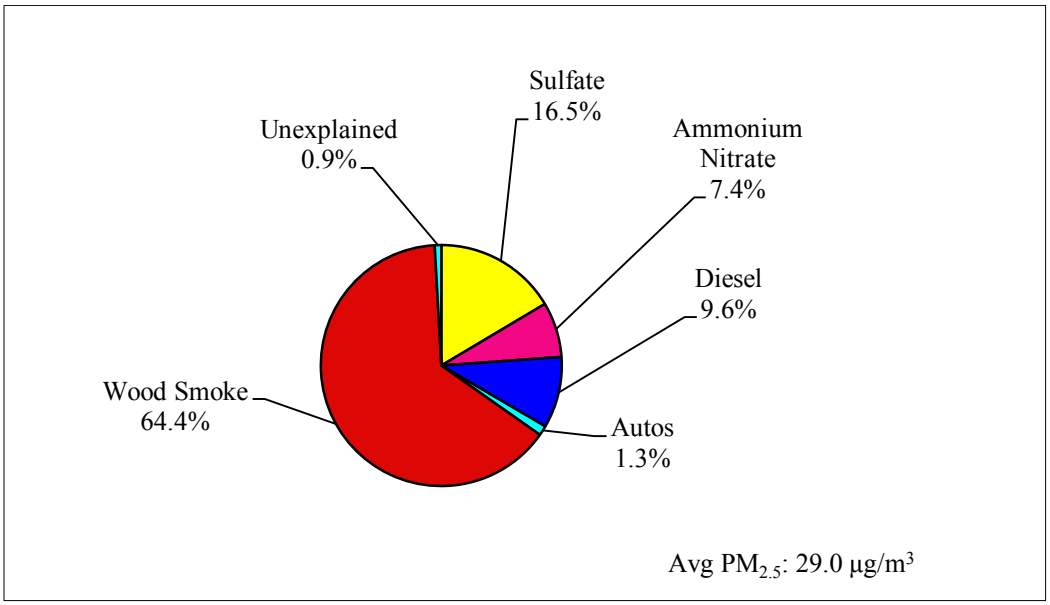

Figure 36: Winter 2009/2010, Peger Road.
CMB Results with OMNI Source Profiles, November 3, 2009 – March 15, 2010.

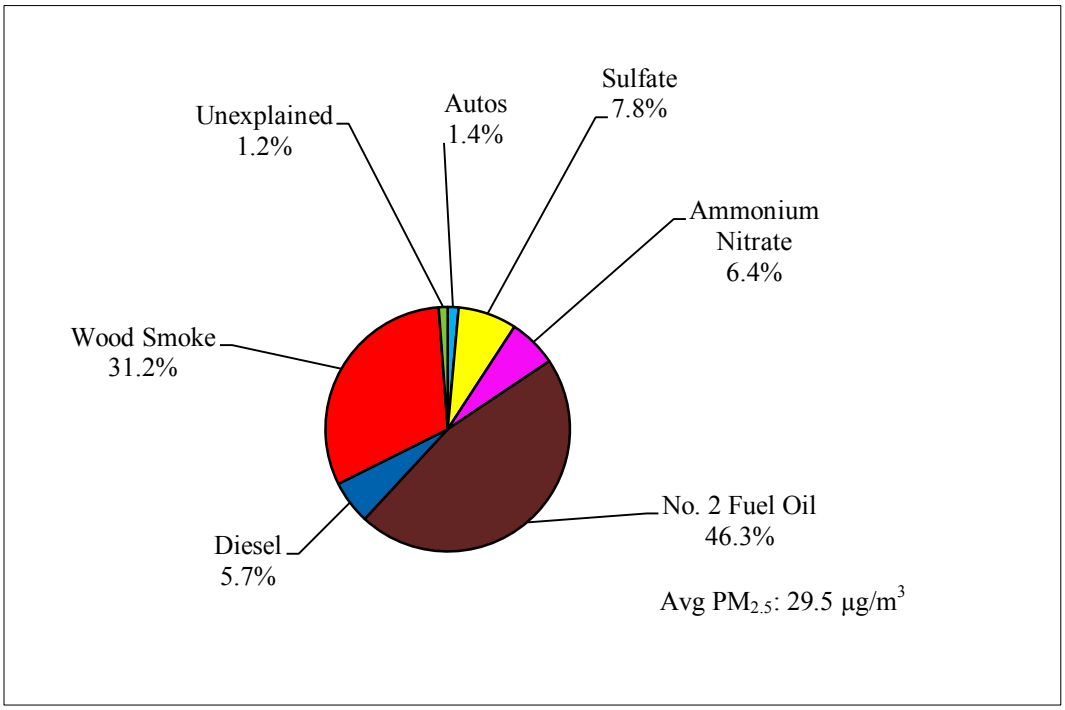

Table 26: Comparison of CMB Results - EPA and OMNI Source Profiles. Peger Road, Winter 2009/2010.

Season:	Winter 2009/2010 (EPA)	Winter 2009/2010 (OMNI)
Dates:	11/3/09-3/15/10	11/3/09-3/15/10
n:	38	37
$PM_{2.5}$ Mass ($\mu g/m^3$):	29.0	29.5
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	4.8 (16.5 %)	2.3 (7.8 %)
Ammonium Nitrate:	2.1 (7.4 %)	1.9 (6.4 %)
Diesel:	2.8 (9.6 %)	1.7 (5.7 %)
Automobiles:	0.4 (1.3 %)	0.4 (1.4 %)
Wood Smoke:	18.6 (64.4 %)	9.2 (31.2 %)
No. 2 Fuel Oil:	Not Identified	13.7 (46.3 %)
Unexplained:	0.3 (0.9 %)	0.3 (1.2 %)

Figure 37: Winter 2010/2011, State Building.
CMB Results with EPA Source Profiles, November 1, 2010 – February 8, 2011.

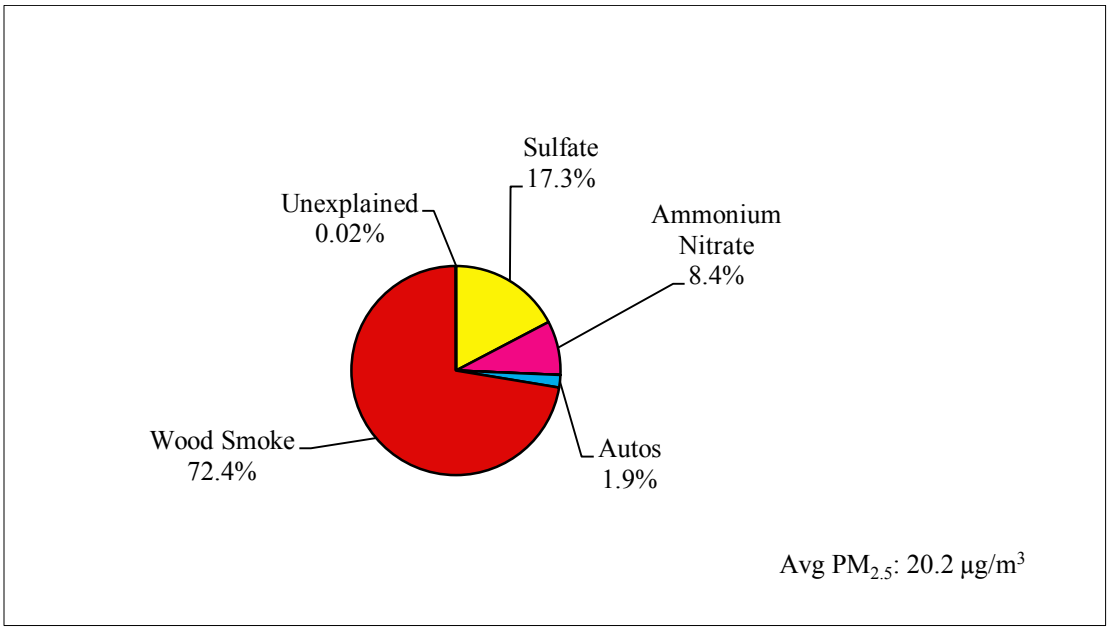

Figure 38: Winter 2010/2011, State Building.
CMB Results with OMNI Source Profiles, November 1, 2010 – February 8, 2011.

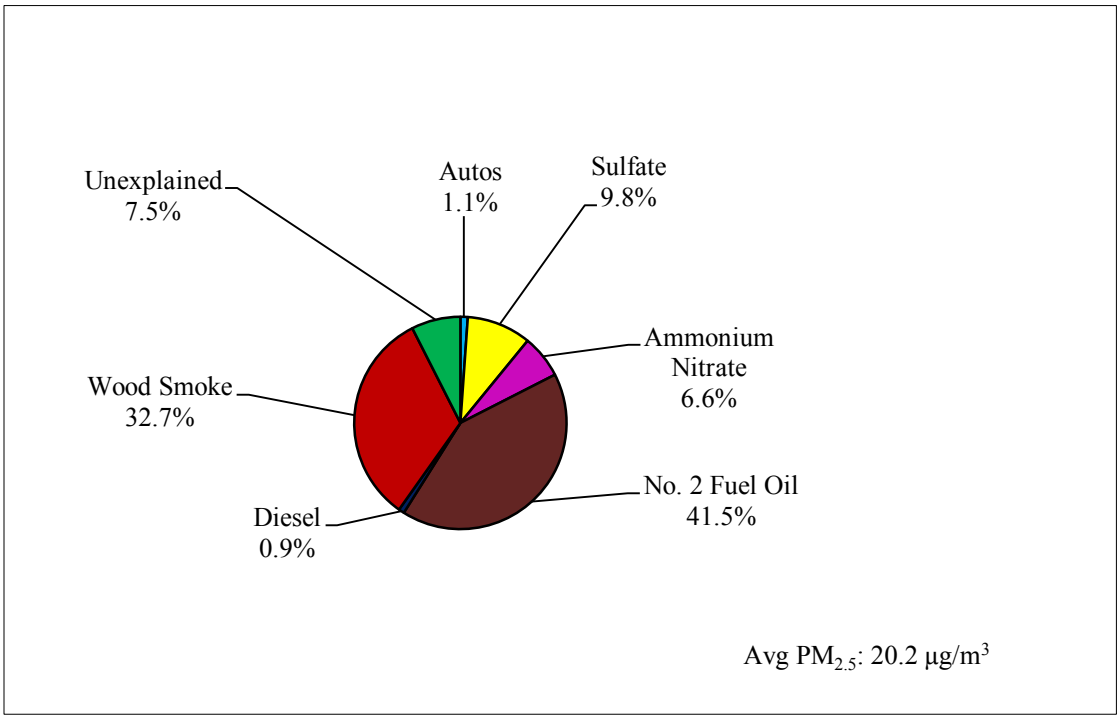

Table 27: Comparison of CMB Results - EPA and OMNI Source Profiles. State Building, Winter 2010/2011.

Season:	Winter 2010/2011 (EPA)	Winter 2010/2011 (OMNI)
Dates:	11/1/10-2/8/11	11/1/10-2/8/11
n:	15	15
$PM_{2.5}$ Mass ($\mu g/m^3$)	20.2	20.2
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	3.5 (17.3 %)	2.0 (9.8 %)
Ammonium Nitrate:	1.7 (8.4 %)	1.3 (6.6 %)
Diesel:	Not Identified	0.2 (0.9 %)
Automobiles:	0.4 (1.9 %)	0.2 (1.1 %)
Wood Smoke:	14.6 (72.4 %)	6.5 (32.7 %)
No. 2 Fuel Oil:	Not Identified	8.3 (41.5 %)
Unexplained:	0.004 (0.02 %)	1.5 (7.5 %)

Figure 39: Winter 2010/2011, North Pole.
CMB Results with EPA Source Profiles, January 9, 2011 – February 5, 2011.

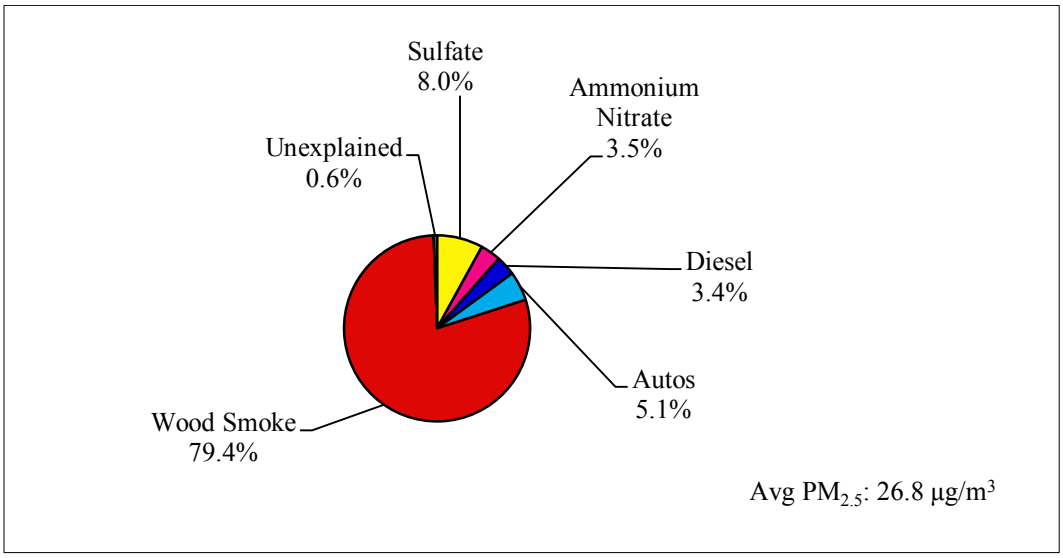

Figure 40: Winter 2010/2011, North Pole.
CMB Results with OMNI Source Profiles, January 9, 2011 – February 5, 2011.

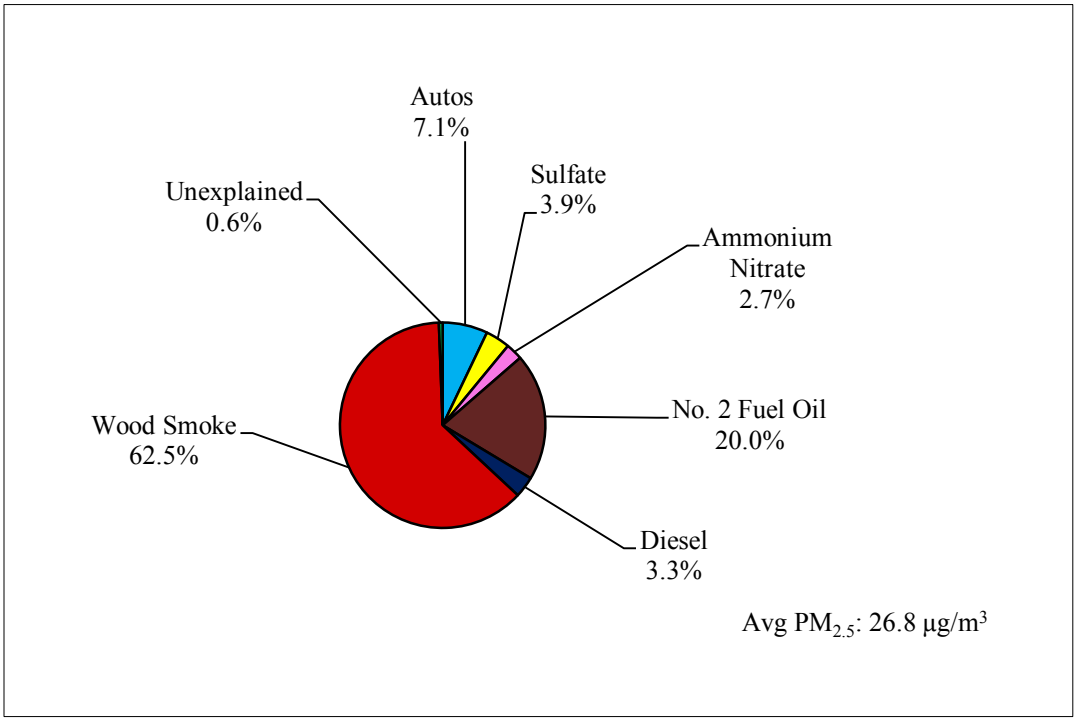

Table 28: Comparison of CMB Results - EPA and OMNI Source Profiles. North Pole, Winter 2010/2011.

Season:	Winter 2010/2011 (EPA)	Winter 2010/2011 (OMNI)
Dates:	1/9/11-2/5/11	1/9/11-2/5/11
n:	10	10
$PM_{2.5}$ Mass (µg/m^3):	26.8	26.8
CMB Source Estimates (µg/m^3 and %)		
Sulfate:	2.1 (8.0 %)	1.0 (3.9 %)
Ammonium Nitrate:	0.9 (3.5 %)	0.7 (2.7 %)
Diesel:	0.9 (3.4 %)	0.9 (3.3 %)
Automobiles:	1.4 (5.1 %)	1.9 (7.1 %)
Wood Smoke:	21.3 (79.4 %)	16.6 (62.5 %)
No. 2 Fuel Oil:	Not Identified	5.3 (20.0 %)
Unexplained:	0.2 (0.6 %)	0.2 (0.6 %)

Figure 41: Winter 2010/2011, Peger Road.
CMB Results with EPA Source Profiles, January 9, 2011 – February 5, 2011.

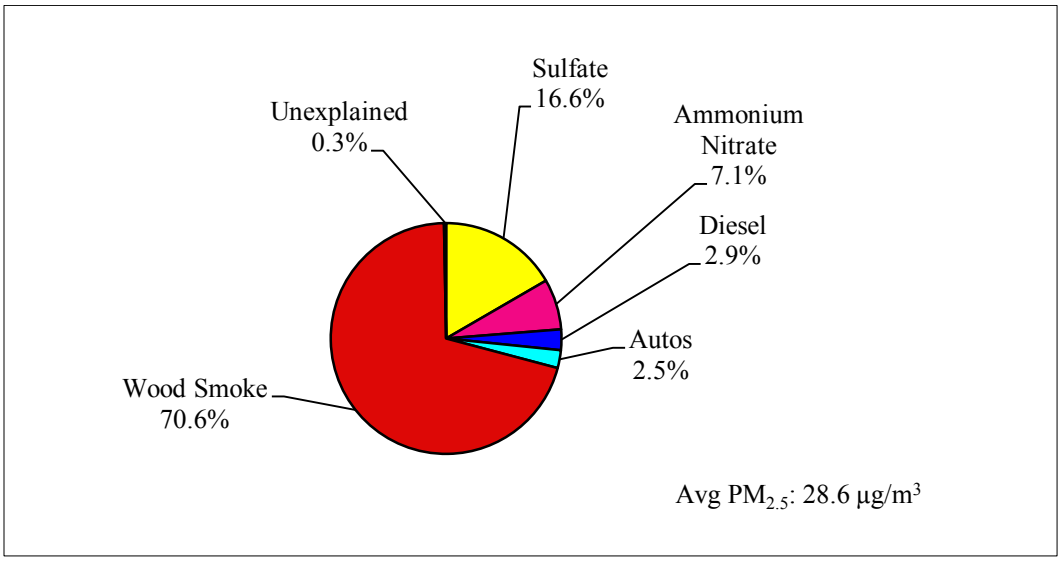

Figure 42: Winter 2010/2011, Peger Road.
CMB Results with OMNI Source Profiles, January 9, 2011 – February 5, 2011.

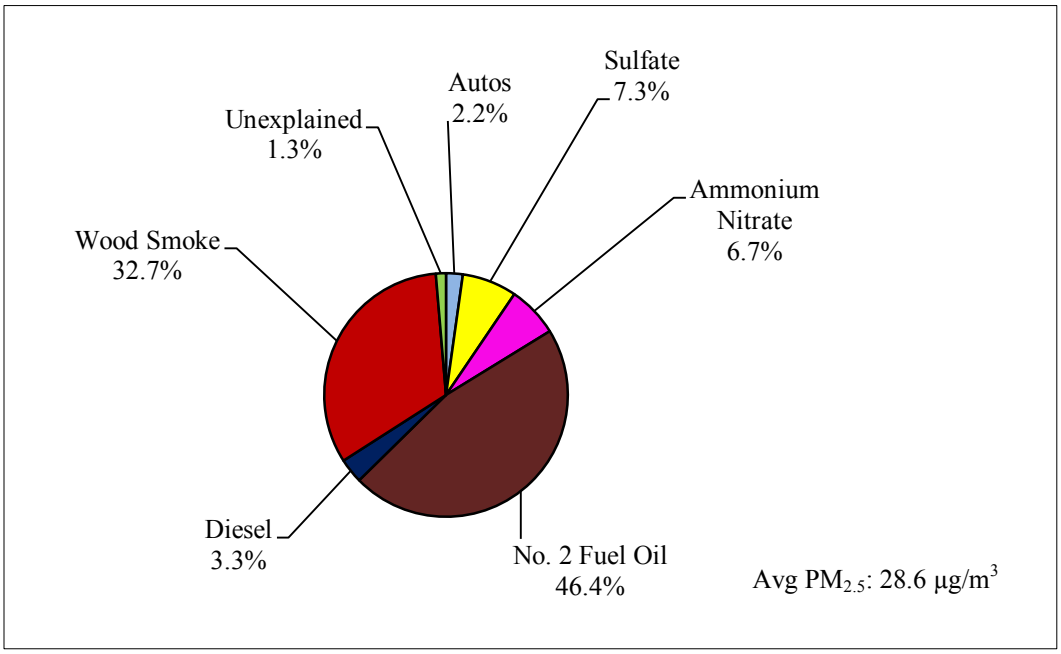

Table 29: Comparison of CMB Results - EPA and OMNI Source Profiles. Peger Road, Winter 2010/2011.

Season:	Winter 2010/2011 (EPA)	Winter 2010/2011 (OMNI)
Dates:	1/9/11-2/5/11	1/9/11-2/5/11
n:	10	10
$PM_{2.5}$ Mass ($\mu g/m^3$):	28.6	28.6
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	4.8 (16.6 %)	2.1 (7.3 %)
Ammonium Nitrate:	2.0 (7.1 %)	2.0 (6.7 %)
Diesel:	0.8 (2.9 %)	1.0 (3.3 %)
Automobiles:	0.7 (2.5 %)	0.6 (2.2 %)
Wood Smoke:	20.2 (70.6 %)	9.5 (32.7 %)
No. 2 Fuel Oil:	Not Identified	13.5 (46.4 %)
Unexplained:	0.1 (0.3 %)	0.4 (1.3 %)

Figure 43: Winter 2011/2012, State Building.
CMB Results with EPA Source Profiles, November 2, 2011 – March 31, 2012.

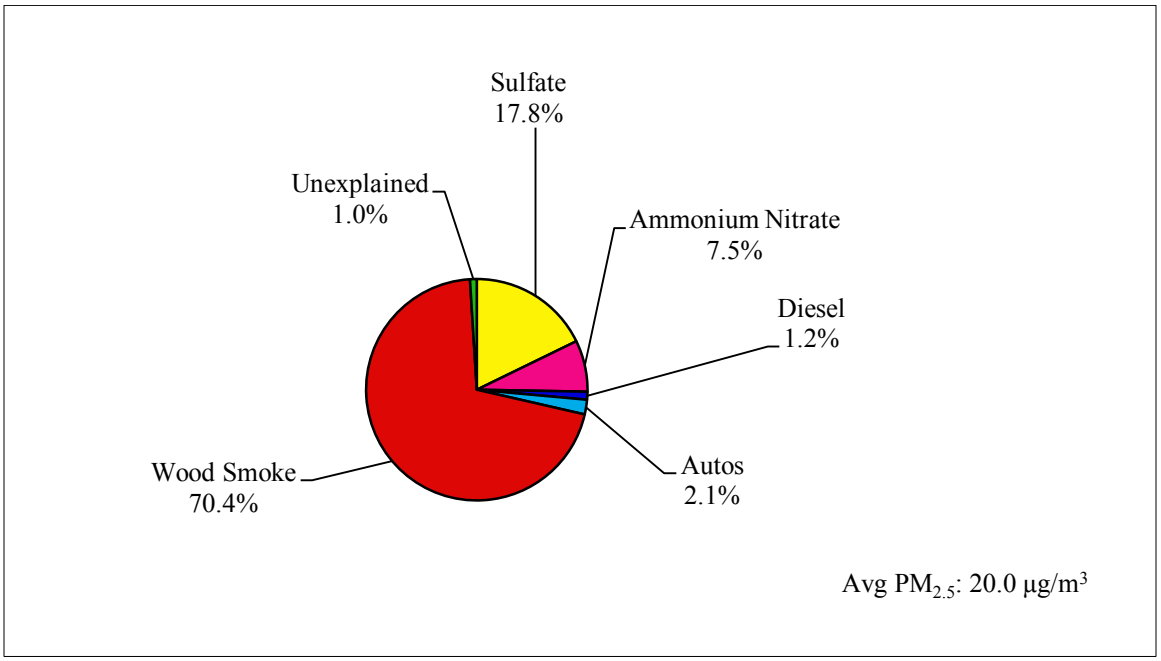

Figure 44: Winter 2011/2012, State Building.
CMB Results with OMNI Source Profiles, November 2, 2011 – March 31, 2012.

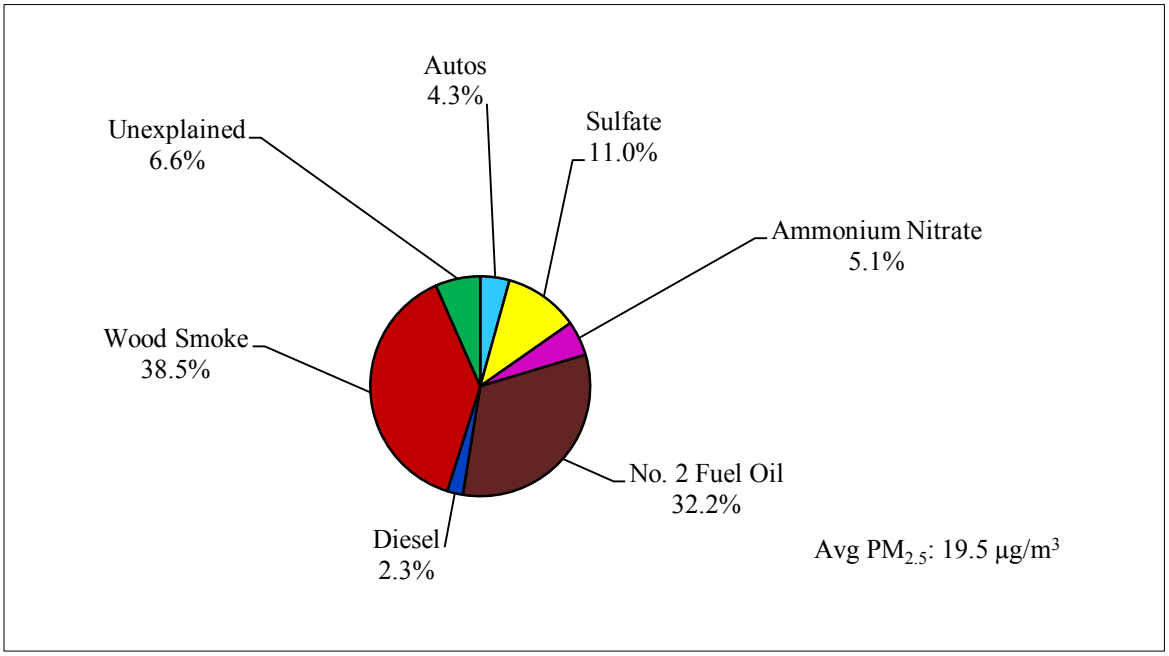

Table 30: Comparison of CMB Results - EPA and OMNI Source Profiles. State Building, Winter 2011/2012.

Season:	Winter 2011/2012 (EPA)	Winter 2011/2012 (OMNI)
Dates:	11/2/11-3/31/12	11/2/11-3/31/12
n:	38	36
$PM_{2.5}$ Mass ($\mu g/m^3$):	20.0	19.5
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	3.5 (17.8 %)	2.2 (11.0 %)
Ammonium Nitrate:	1.5 (7.5 %)	1.0 (5.1 %)
Diesel:	0.2 (1.2 %)	0.5 (2.3 %)
Automobiles:	0.4 (2.1 %)	0.8 (4.3 %)
Wood Smoke:	14.0 (70.4 %)	7.6 (38.5 %)
No. 2 Fuel Oil:	Not Identified	6.4 (32.2 %)
Unexplained:	0.2 (1.0 %)	1.3 (6.6 %)

Figure 45: Winter 2011/2012, North Pole.
CMB Results with EPA Source Profiles, November 2, 2011 – March 25, 2012.

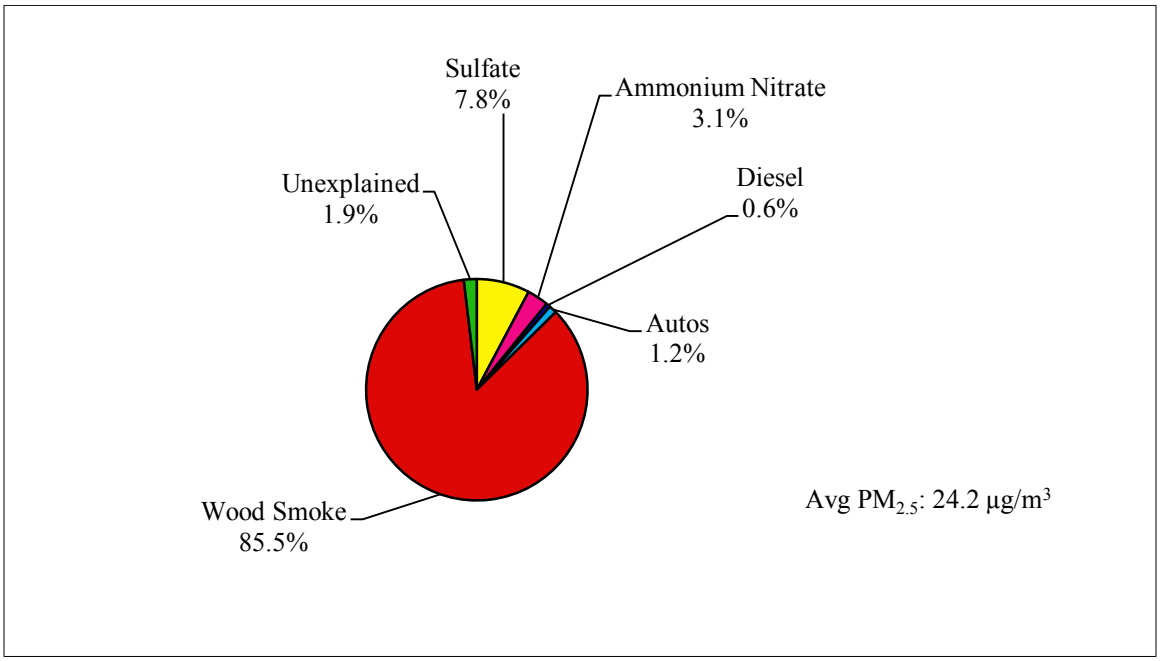

Figure 46: Winter 2011/2012, North Pole.
CMB Results with OMNI Source Profiles, November 2, 2011 – March 25, 2012.

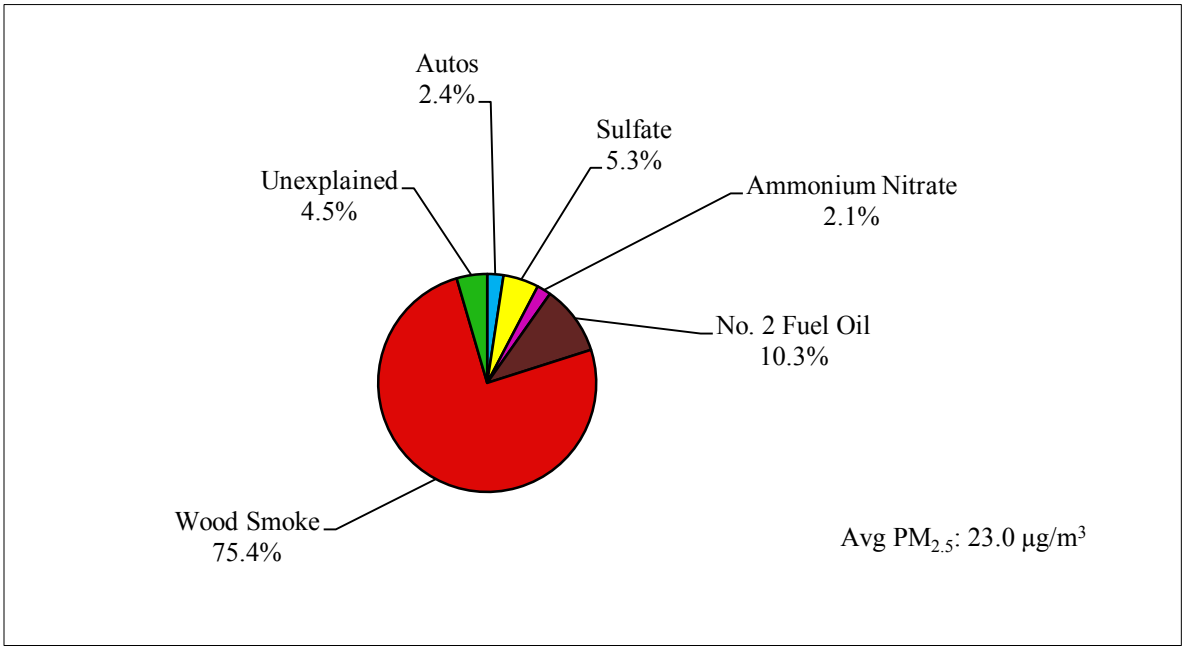

Table 31: Comparison of CMB Results - EPA and OMNI Source Profiles. North Pole, Winter 2011/2012.

Season:	Winter 2011/2012 (EPA)	Winter 2011/2012 (OMNI)
Dates:	11/2/11-3/25/12	11/2/11-3/25/12
n:	36	35
$PM_{2.5}$ Mass ($\mu g/m^3$):	24.2	23.0
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	1.8 (7.8 %)	1.2 (5.3 %)
Ammonium Nitrate:	0.7 (3.1 %)	0.5 (2.1 %)
Diesel:	0.1 (0.6 %)	Not Identified
Automobiles:	0.3 (1.2 %)	0.6 (2.4 %)
Wood Smoke:	20.4 (85.5 %)	17.3 (75.4 %)
No. 2 Fuel Oil:	Not Identified	2.4 (10.3 %)
Unexplained:	0.4 (1.9 %)	1.0 (4.5 %)

Figure 47: Winter 2011/2012, RAMS.
CMB Results with EPA Source Profiles, December 20, 2011 – February 27, 2012.

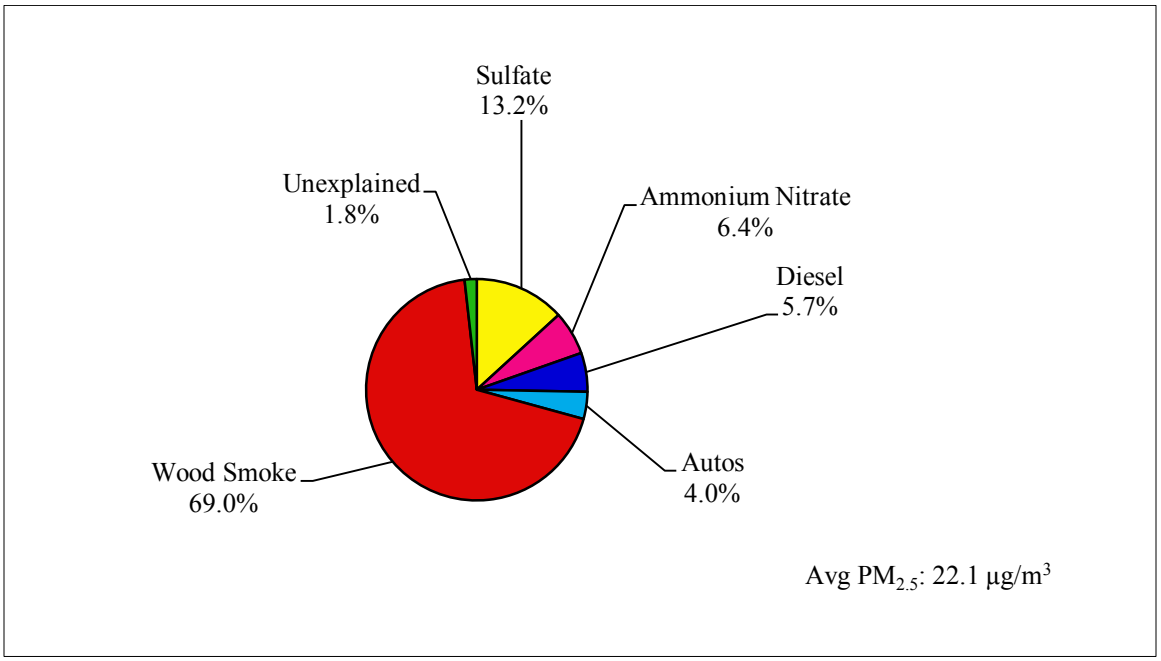

Figure 48: Winter 2011/2012, RAMS.
CMB Results with OMNI Source Profiles, December 20, 2011 – February 27, 2012.

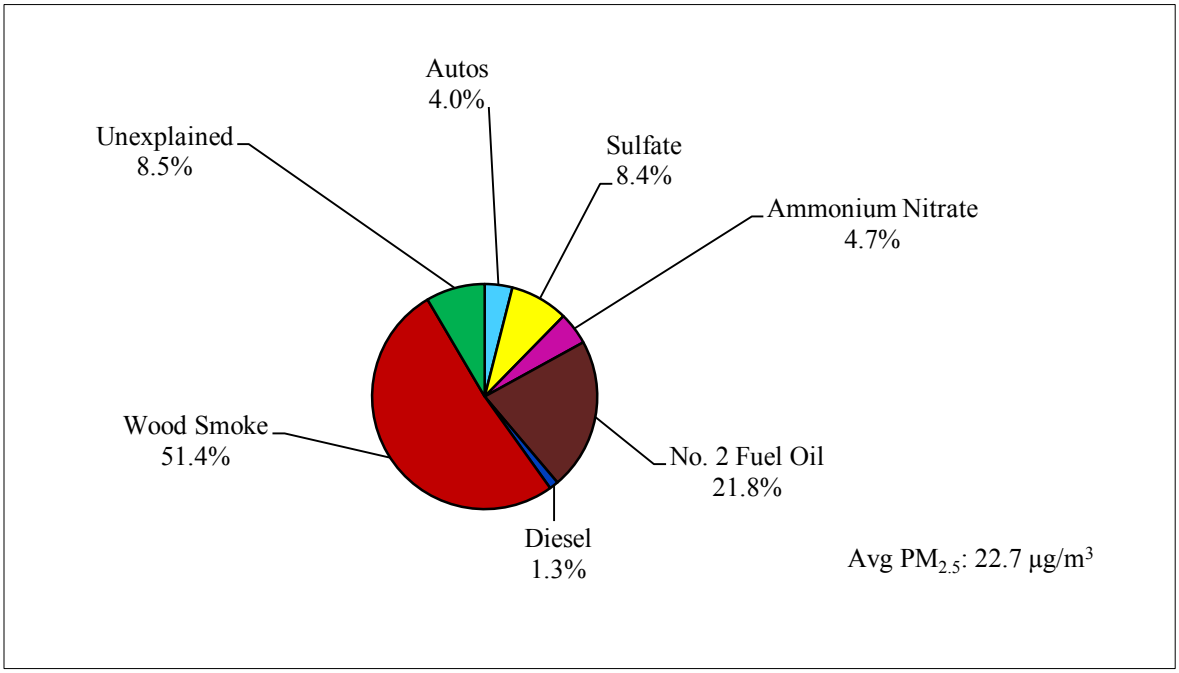

Table 32: Comparison of CMB Results - EPA and OMNI Source Profiles. RAMS, Winter 2011/2012.

Season:	Winter 2011/2012 (EPA)	Winter 2011/2012 (OMNI)
Dates:	12/20/11-2/27/12	12/20/11-2/27/12
n:	16	15
$PM_{2.5}$ Mass (µg/m^3):	22.1	22.7
CMB Source Estimates (µg/m^3 and %)		
Sulfate:	2.9 (13.2 %)	1.9 (8.4 %)
Ammonium Nitrate:	1.4 (6.4 %)	1.0 (4.7 %)
Diesel:	1.2 (5.7 %)	0.3 (1.3 %)
Automobiles:	0.9 (4.0 %)	0.9 (4.0 %)
Wood Smoke:	14.9 (69.0 %)	11.5 (51.4 %)
No. 2 Fuel Oil:	Not Identified	4.9 (21.8 %)
Unexplained:	0.4 (1.8 %)	1.9 (8.5 %)

Figure 49: Winter 2011/2012, NCORE.
CMB Results with EPA Source Profiles, November 2, 2011 – March 31, 2012.

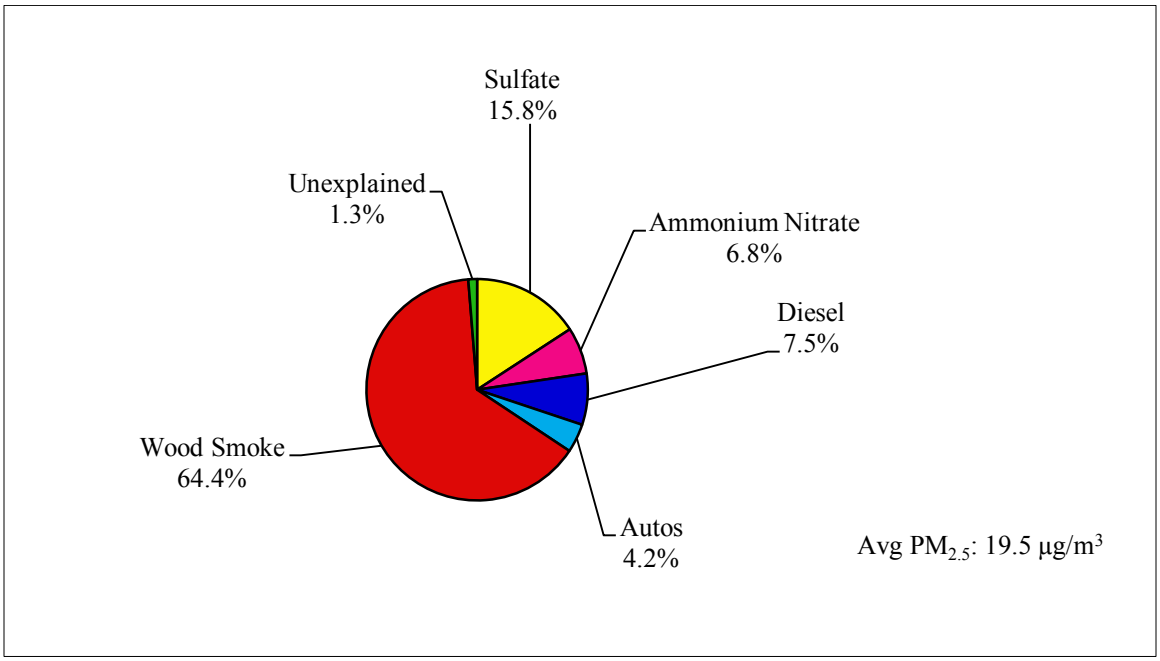

Figure 50: Winter 2011/2012, NCORE.
CMB Results with OMNI Source Profiles, November 2, 2011 – March 31, 2012.

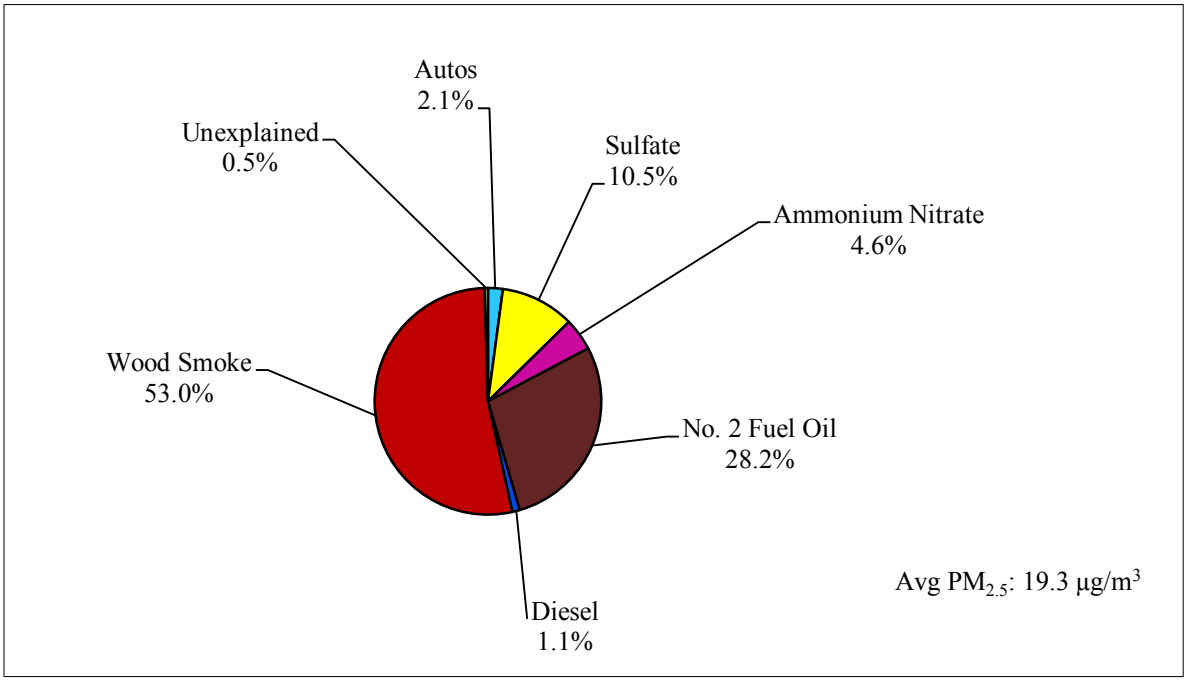

Table 33: Comparison of CMB Results - EPA and OMNI Source Profiles. NCORE, Winter 2011/2012.

Season:	Winter 2011/2012 (EPA)	Winter 2011/2012 (OMNI)
Dates:	11/2/11-3/31/12	11/2/11-3/31/12
n:	44	42
$PM_{2.5}$ Mass ($\mu g/m^3$):	19.5	19.3
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	3.0 (15.8 %)	2.0 (10.5 %)
Ammonium Nitrate:	1.3 (6.8 %)	0.9 (4.6 %)
Diesel:	1.4 (7.5 %)	0.2 (1.1 %)
Automobiles:	0.8 (4.2 %)	0.4 (2.1 %)
Wood Smoke:	12.4 (64.4 %)	10.1 (53.0 %)
No. 2 Fuel Oil:	Not Identified	5.4 (28.2 %)
Unexplained:	0.2 (1.3 %)	0.1 (0.5 %)

Figure 51: Winter 2011/2012, NPF3.
CMB Results with EPA Source Profiles, March 1, 2011 – March 31, 2012.

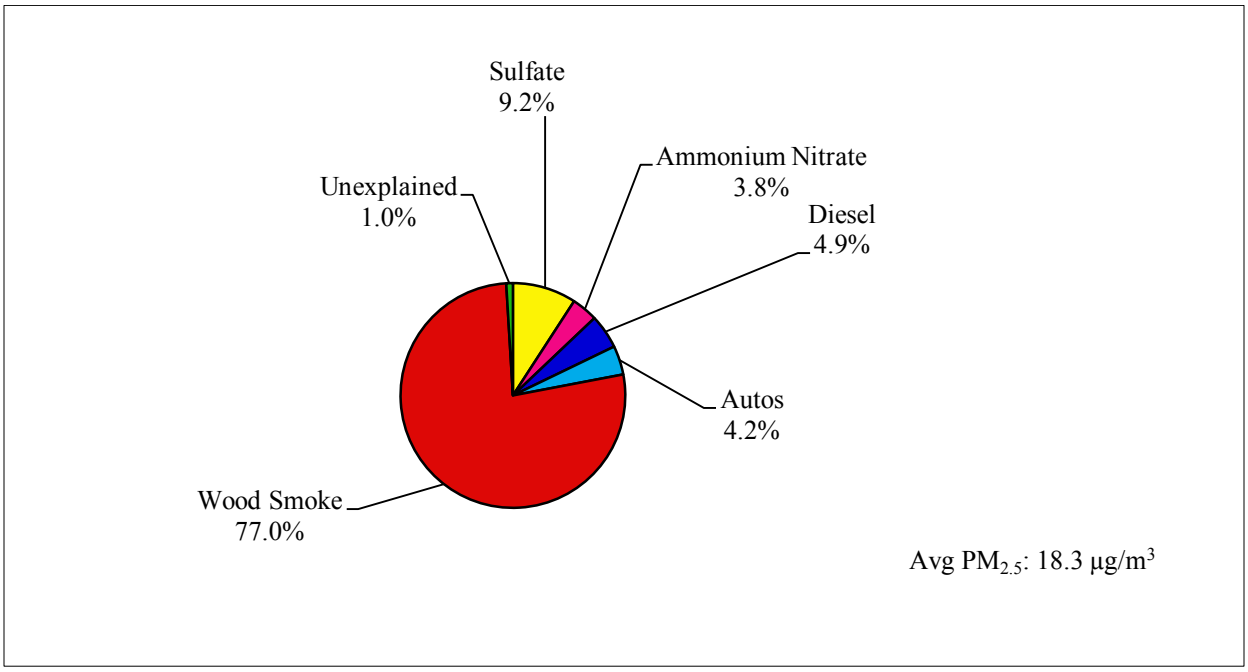

Figure 52: Winter 2011/2012, NPF3.
CMB Results with OMNI Source Profiles, March 1, 2011 – March 31, 2012.

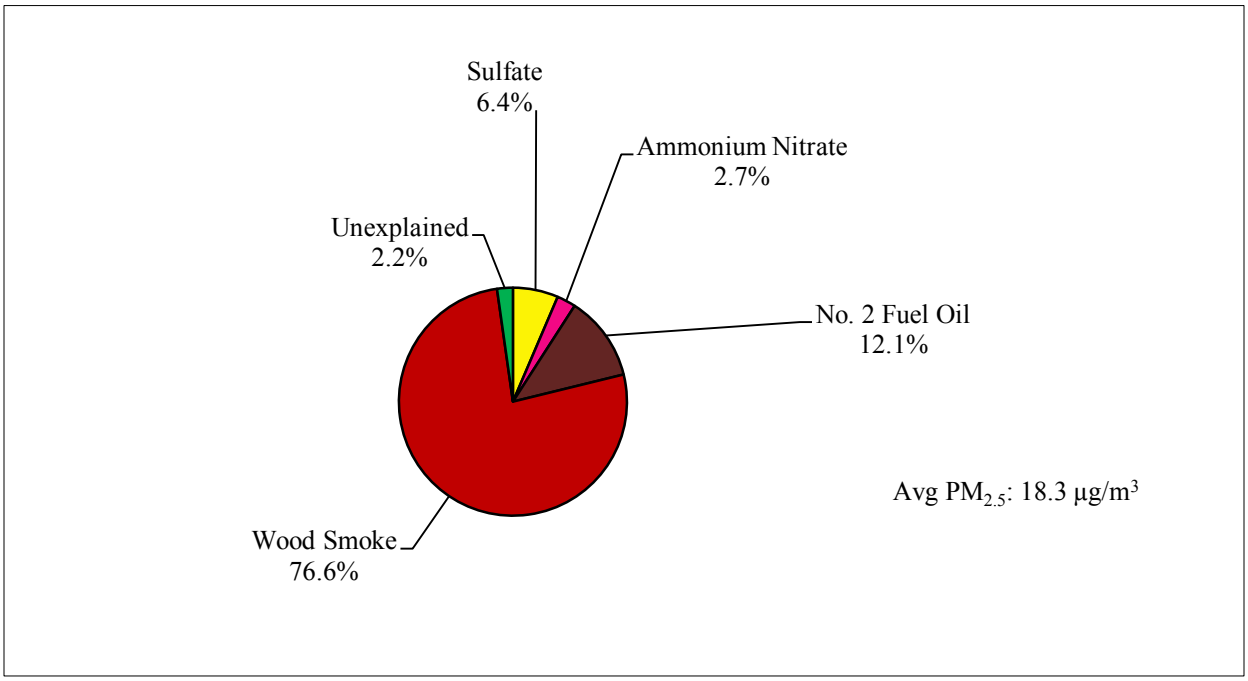

Table 34: Comparison of CMB Results - EPA and OMNI Source Profiles. NPF3, Winter 2011/2012.

Season:	Winter 2011/2012 (EPA)	Winter 2011/2012 (OMNI)
Dates:	3/1/12-3/31/12	3/1/12-3/31/12
n:	7	7
$PM_{2.5}$ Mass (µg/m^3):	18.3	18.3
CMB Source Estimates (µg/m^3 and %)		
Sulfate:	1.7 (9.2 %)	1.2 (6.4 %)
Ammonium Nitrate:	0.7 (3.8 %)	0.5 (2.7 %)
Diesel:	0.9 (4.9 %)	Not Identified
Automobiles:	0.8 (4.2 %)	Not Identified
Wood Smoke:	14.2 (77.0 %)	14.1 (76.6 %)
No. 2 Fuel Oil:	Not Identified	2.2 (12.1 %)
Unexplained:	0.2 (1.0 %)	0.4 (2.2 %)

Figure 53: Summer 2012, State Building.
CMB Results with EPA Source Profiles, June 2, 2012 – August 31, 2012.

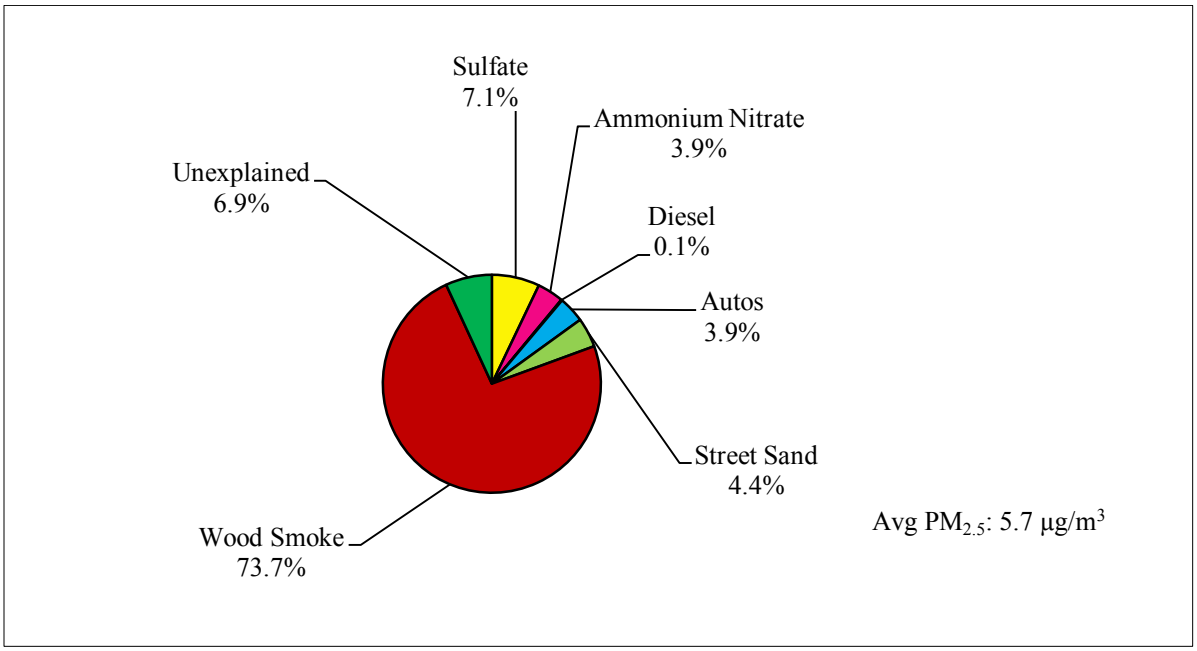

Figure 54: Summer 2012, State Building.
CMB Results with OMNI Source Profiles, June 2, 2012 – August 31, 2012.

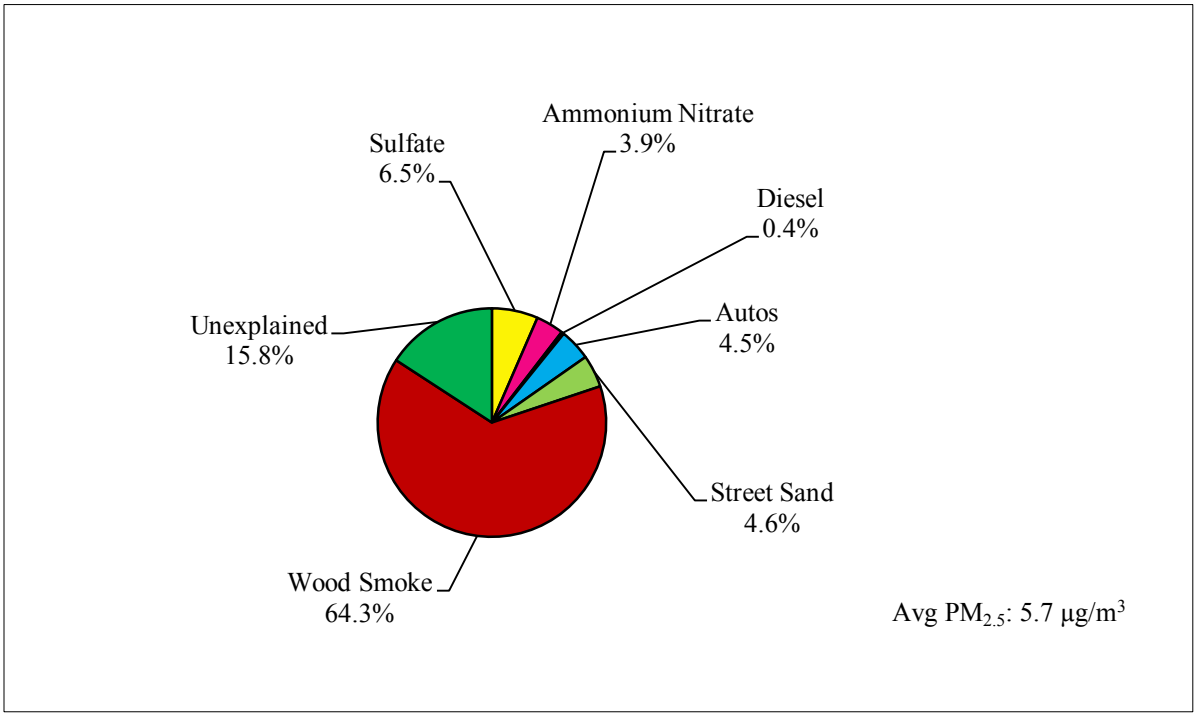

Table 35: Comparison of CMB Results - EPA and OMNI Source Profiles. State Building, Summer 2012.

Season:	Summer 2012 (EPA)	Summer 2012 (OMNI)
Dates:	6/2/12-8/31/12	6/2/12-8/31/12
n:	20	20
$PM_{2.5}$ Mass ($\mu g/m^3$):	5.7	5.7
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	0.4 (7.1 %)	0.4 (6.5 %)
Ammonium Nitrate:	0.2 (3.9 %)	0.2 (3.9 %)
Diesel:	0.01 (0.1 %)	0.02 (0.4 %)
Automobiles:	0.2 (3.9 %)	0.3 (4.5 %)
Wood Smoke:	4.2 (73.7 %)	3.6 (64.3 %)
No. 2 Fuel Oil:	Not Identified	Not Identified
Street Sand:	0.3 (4.4 %)	0.3 (4.6 %)
Unexplained:	0.3 (6.9 %)	0.9 (15.8 %)

Figure 55: Summer 2012, NCORE.
CMB Results with EPA Source Profiles, June 14, 2012 – August 31, 2012.

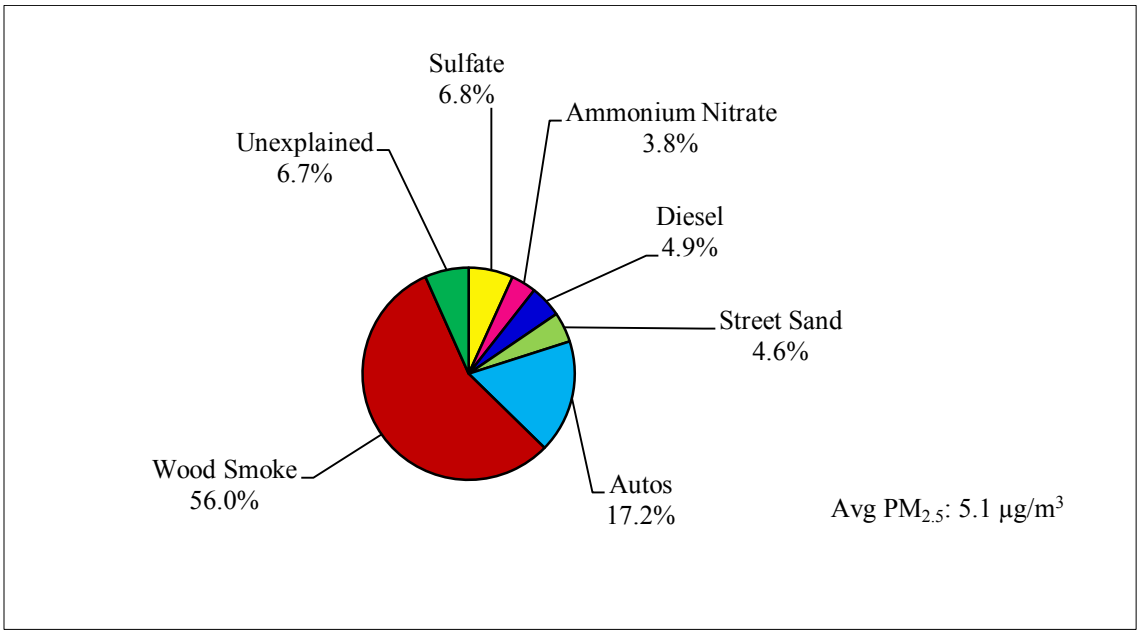

Figure 56: Summer 2012, NCORE.
CMB Results with OMNI Source Profiles, June 14, 2012 – August 31, 2012.

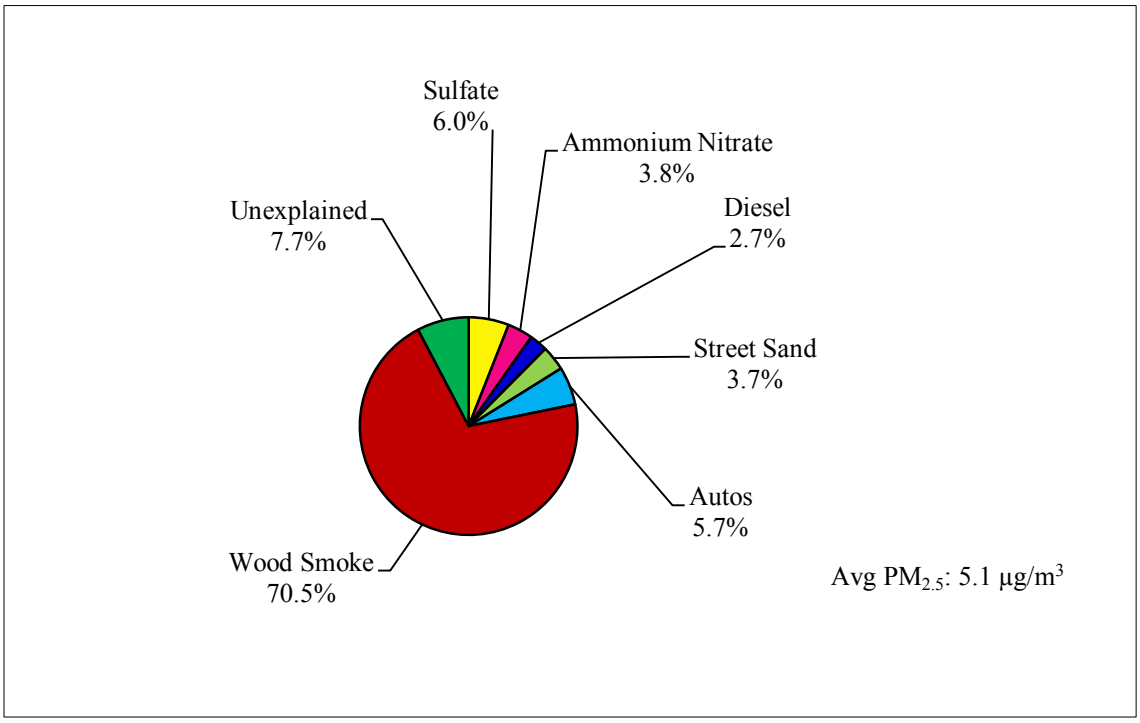

Table 36: Comparison of CMB Results - EPA and OMNI Source Profiles. NCORE, Summer 2012.

Season:	Summer 2012 (EPA)	Summer 2012 (OMNI)
Dates:	6/14/12-8/31/12	6/14/12-8/31/12
n:	17	17
$PM_{2.5}$ Mass ($\mu g/m^3$):	5.1	5.1
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	0.4 (6.8 %)	0.4 (6.0 %)
Ammonium Nitrate:	0.2 (3.8 %)	0.2 (3.8 %)
Diesel:	0.3 (4.9 %)	0.2 (2.7 %)
Automobiles:	1.0 (17.2 %)	0.3 (5.7 %)
Wood Smoke:	3.3 (56.0 %)	4.2 (70.5 %)
No. 2 Fuel Oil:	Not Identified	Not Identified
Street Sand:	0.3 (4.6 %)	0.2 (3.7 %)
Unexplained:	0.4 (6.7 %)	0.5 (7.7 %)

Figure 57: Winter 2012/2013, State Building.
CMB Results with EPA Source Profiles, November 2, 2012 – March 29, 2013.

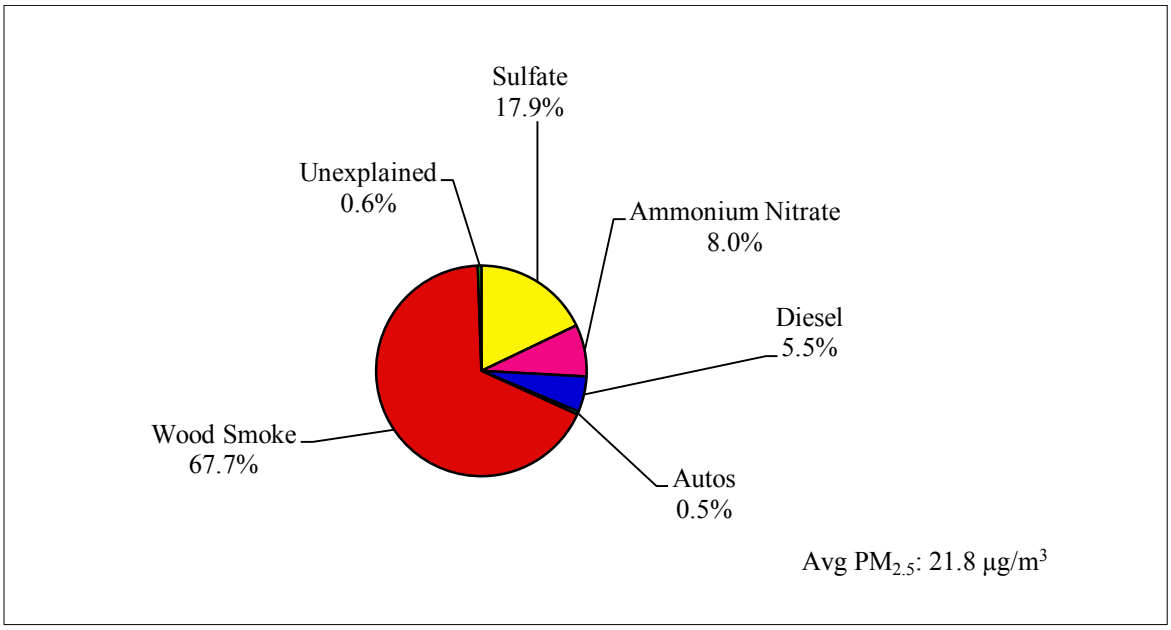

Figure 58: Winter 2012/2013, State Building.
CMB Results with OMNI Source Profiles, November 2, 2012 – March 29, 2013.

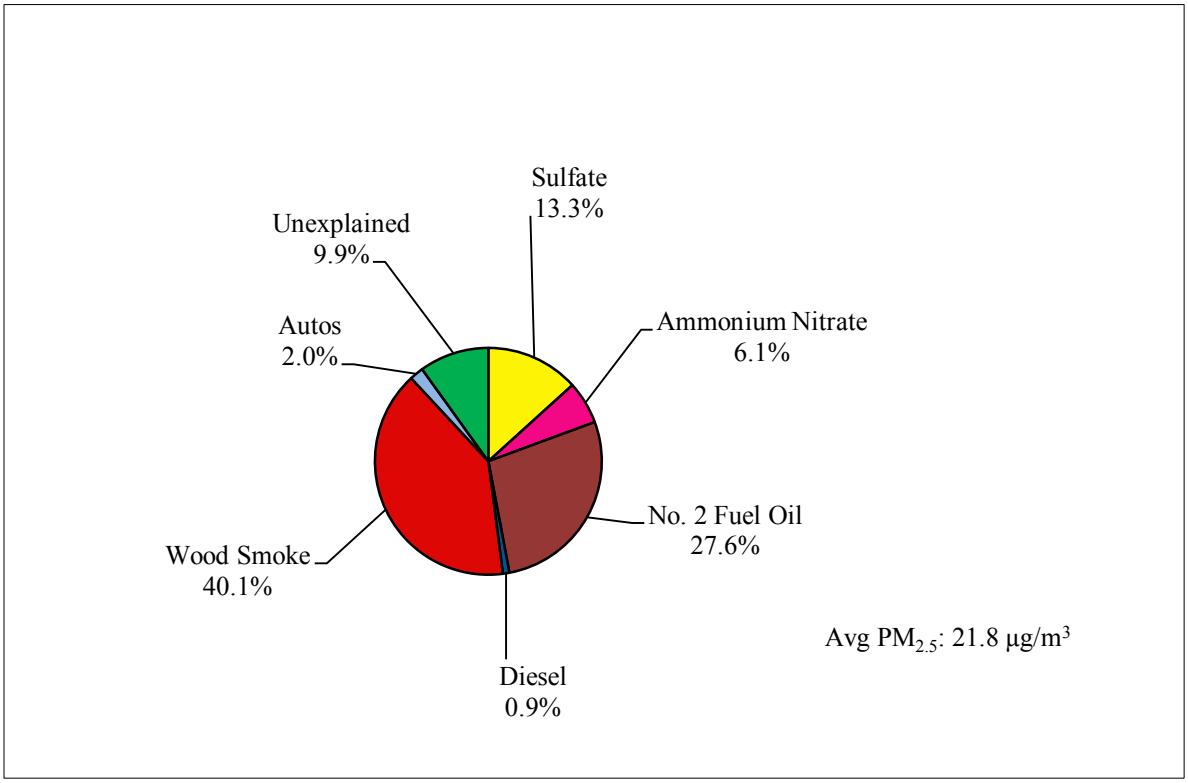

Table 37: Comparison of CMB Results - EPA and OMNI Source Profiles. State Building, Winter 2012/2013.

Season:	Winter 2012/2013 (EPA)	Winter 2012/2013 (OMNI)
Dates:	11/2/12-3/29/13	11/2/12-3/29/13
n:	29	29
$PM_{2.5}$ Mass ($\mu g/m^3$):	21.8	21.8
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	3.9 (17.9 %)	2.9 (13.3 %)
Ammonium Nitrate:	1.7 (8.0 %)	1.3 (6.1 %)
Diesel:	1.2 (5.5 %)	0.2 (0.9 %)
Automobiles:	0.1 (0.5 %)	0.4 (2.0 %)
Wood Smoke:	14.7 (67.7 %)	8.7 (40.1 %)
No. 2 Fuel Oil:	Not Identified	6.0 (27.6 %)
Unexplained:	0.1 (0.6 %)	2.1 (9.9 %)

Figure 59: Winter 2012/2013, NPE.
CMB Results with EPA Source Profiles, November 2, 2012 – March 29, 2013.

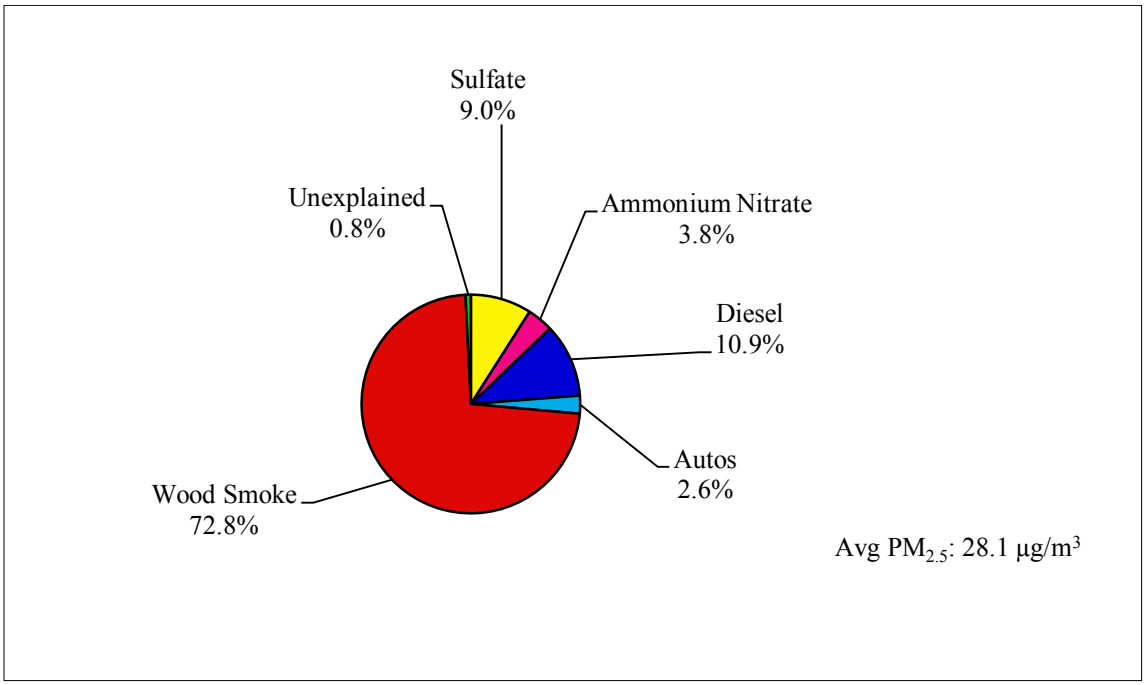

Figure 60: Winter 2012/2013, NPE.
CMB Results with OMNI Source Profiles, November 2, 2012 – March 29, 2013.

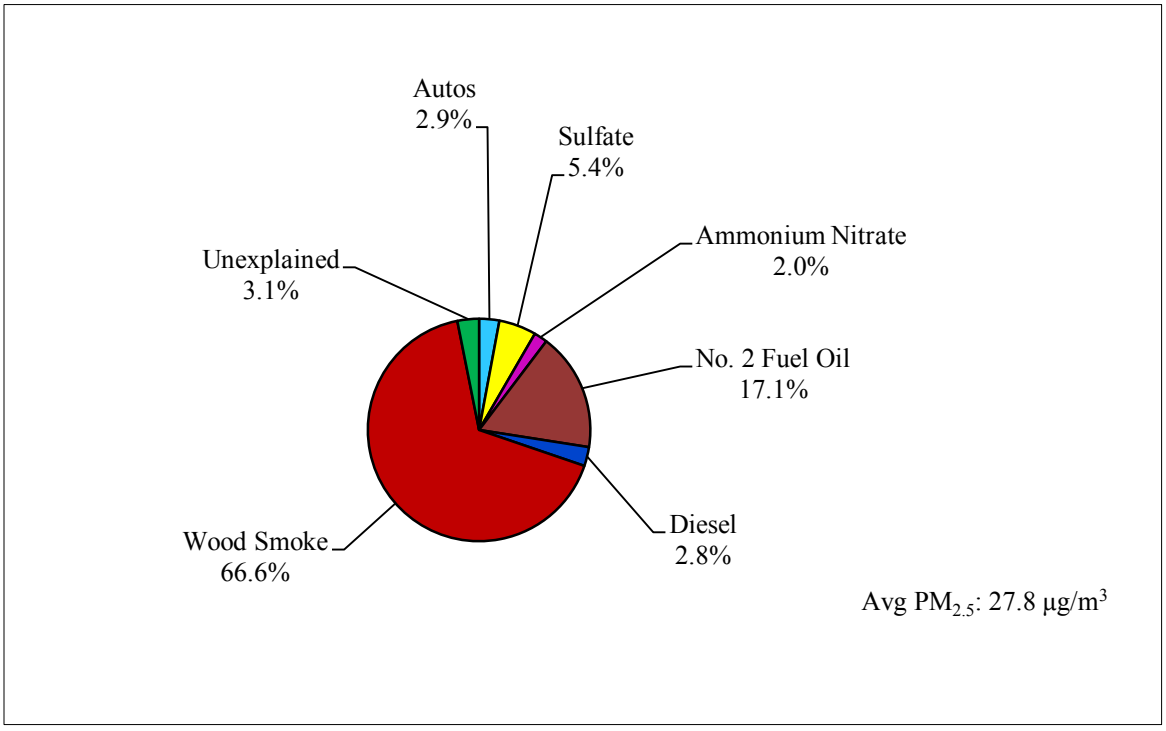

Table 38: Comparison of CMB Results - EPA and OMNI Source Profiles. NPE, Winter 2012/2013.

Season:	Winter 2012/2013 (EPA)	Winter 2012/2013 (OMNI)
Dates:	11/2/12-3/29/13	11/2/12-3/29/13
n:	41	40
$PM_{2.5}$ Mass (µg/m^3):	28.1	27.8
CMB Source Estimates (µg/m^3 and %)		
Sulfate:	2.5 (9.0 %)	1.5 (5.4 %)
Ammonium Nitrate:	1.1 (3.8 %)	0.6 (2.0 %)
Diesel:	3.0 (10.9 %)	0.8 (2.8 %)
Automobiles:	0.7 (2.6 %)	0.8 (2.9 %)
Wood Smoke:	20.3 (72.8 %)	18.8 (66.6 %)
No. 2 Fuel Oil:	Not Identified	4.9 (17.1 %)
Unexplained:	0.2 (0.8 %)	0.9 (3.1 %)

Figure 61: Winter 2012/2013, NCORE.
CMB Results with EPA Source Profiles, November 2, 2012 – March 29, 2013.

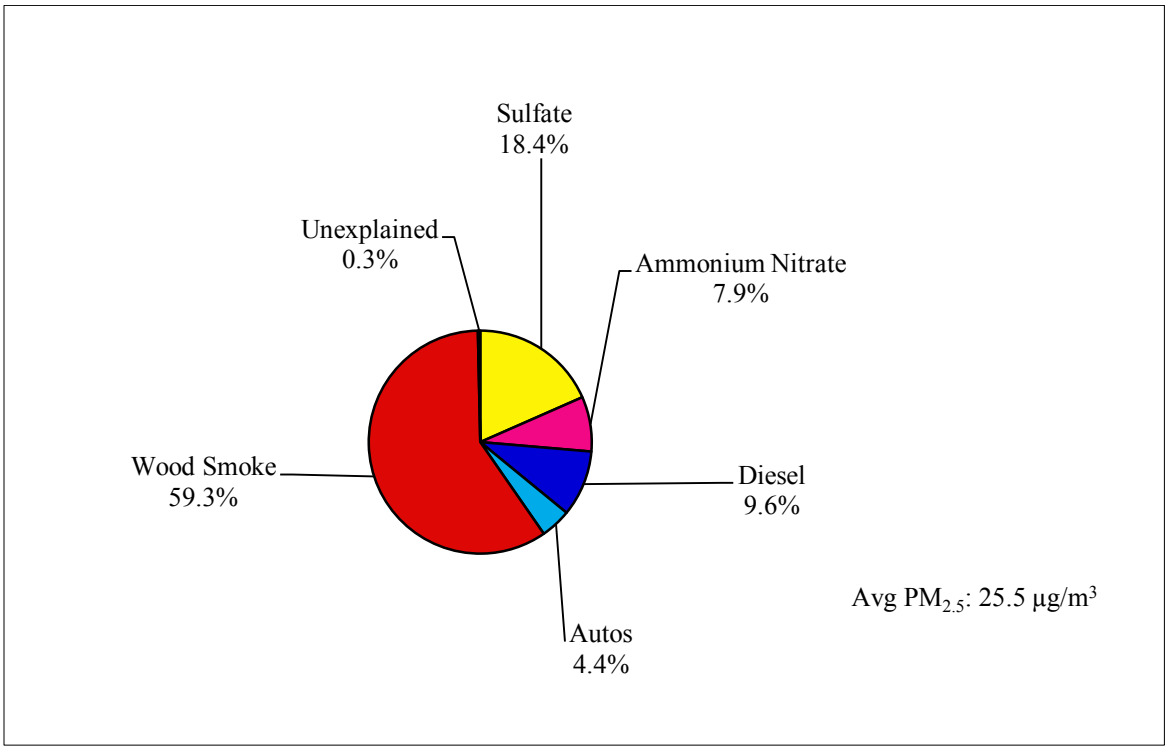

Figure 62: Winter 2012/2013, NCORE.
CMB Results with OMNI Source Profiles, November 2, 2012 – March 29, 2013.

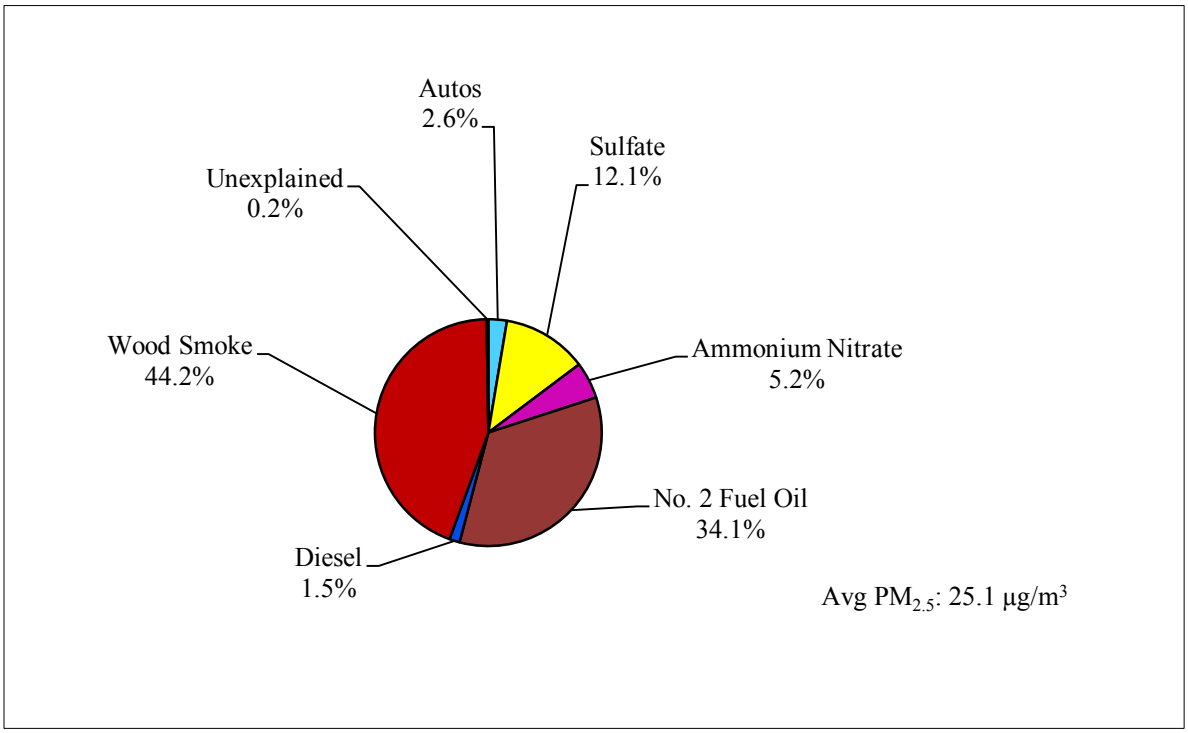

Table 39: Comparison of CMB Results - EPA and OMNI Source Profiles. NCORE, Winter 2012/2013.

Season:	Winter 2012/2013 (EPA)	Winter 2012/2013 (OMNI)
Dates:	11/2/12-3/29/13	11/2/12-3/29/13
n:	38	39
$PM_{2.5}$ Mass (µg/m^3):	25.5	25.1
CMB Source Estimates (µg/m^3 and %)		
Sulfate:	4.7 (18.4 %)	3.0 (12.1 %)
Ammonium Nitrate:	2.0 (7.9 %)	1.3 (5.2 %)
Diesel:	2.4 (9.6 %)	0.4 (1.5 %)
Automobiles:	1.1 (4.4 %)	0.7 (2.6 %)
Wood Smoke:	15.1 (59.3 %)	11.0 (44.2 %)
No. 2 Fuel Oil:	Not Identified	8.5 (34.1 %)
Unexplained:	0.1 (0.3 %)	0.1 (0.2 %)

Figure 63: Winter 2012/2013, NPF3.
CMB Results with EPA Source Profiles, November 2, 2012 – March 29, 2013.

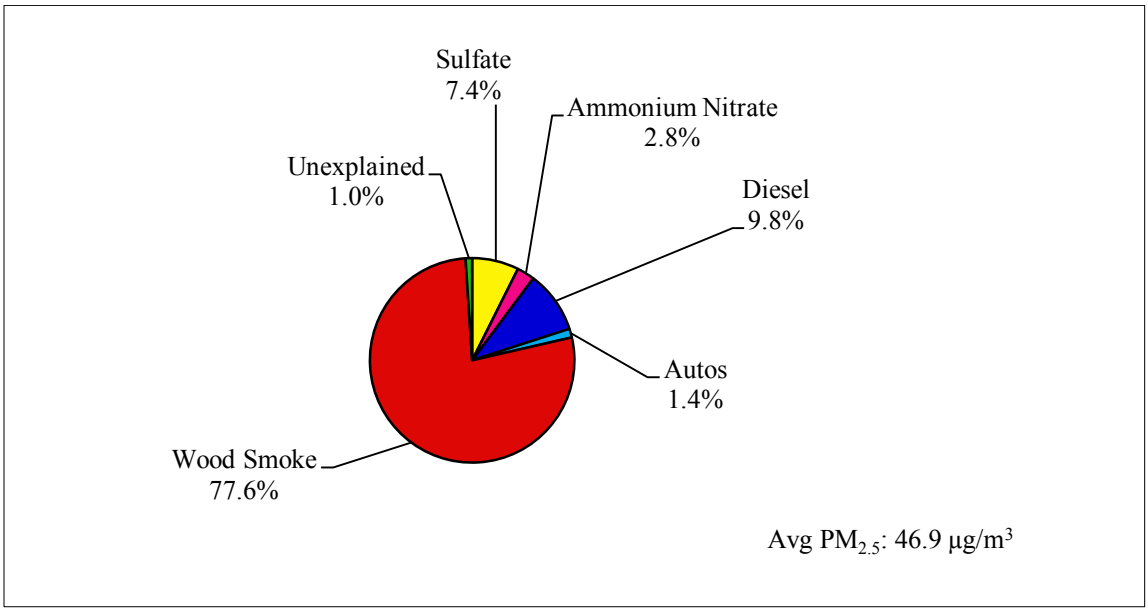

Figure 64: Winter 2012/2013, NPF3.
CMB Results with OMNI Source Profiles, November 2, 2012 – March 29, 2013.

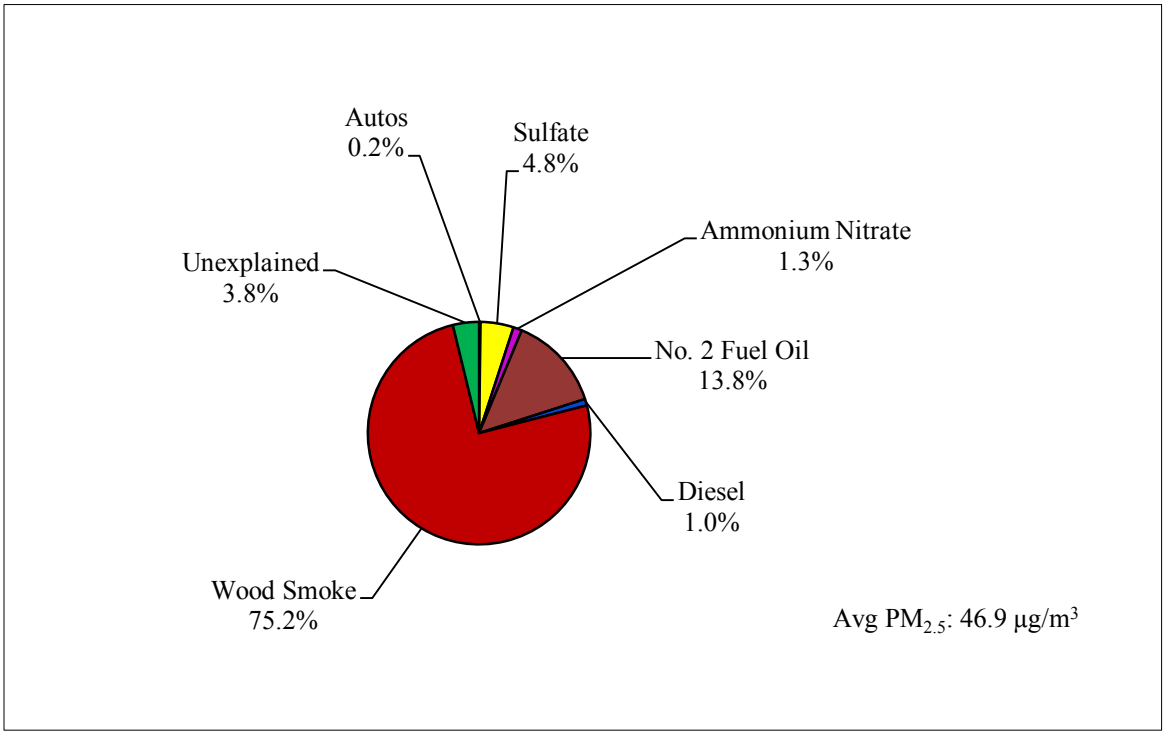

Table 40: Comparison of CMB Results - EPA and OMNI Source Profiles. NPF3, Winter 2012/2013.

Season:	Winter 2012/2013 (EPA)	Winter 2012/2013 (OMNI)
Dates:	11/2/12-3/29/13	11/2/12-3/29/13
n:	42	42
$PM_{2.5}$ Mass (µg/m^3):	46.9	46.9
CMB Source Estimates (µg/m^3 and %)		
Sulfate:	3.4 (7.4 %)	2.2 (4.8 %)
Ammonium Nitrate:	1.3 (2.8 %)	0.6 (1.3 %)
Diesel:	4.5 (9.8 %)	0.4 (1.0 %)
Automobiles:	0.6 (1.4 %)	0.1 (0.2 %)
Wood Smoke:	35.9 (77.6 %)	34.7 (75.2 %)
No. 2 Fuel Oil:	Not Identified	6.4 (13.8 %)
Unexplained:	0.5 (1.0 %)	1.8 (3.8 %)

8.0. Discussion - CMB Modeling

The Tables in **Appendix C** present the $PM_{2.5}$ sources identified by the CMB model (including source contribution estimates and standard errors) for each sample day throughout the program using both EPA and OMNI profiles. The standard error is a single standard deviation. When a standard error value is multiplied by two or three times, the result may be taken as a measure of the upper and lower limit of an individual source"s contribution. There is about a 66% probability that the true source contribution is within one standard error and about a 95% probability that the true contribution is within two standard errors of the source contribution estimate. Below is a more complete discussion of the individual source types identified by the CMB modeling.

8.1. Wood Smoke

The wood smoke source identified by the CMB model during the winter months should be viewed as a general source predominantly composed of wood stove emissions. In addition to residential wood stoves, other biomass combustion emission sources could have contributed to the wood smoke results in Fairbanks, including smoke from outdoor boilers, residential open burning of biomass waste, and small industrial sources. A source profile (Profile 56 in **Table 1**) developed in Missoula, Montana in the late 1980s served as a good statistically fitting wood smoke profile when using the non-OMNI profiles for each of the winters/sites when conducting the Fairbanks CMB analyses. It should also be noted that many other residential wood combustion source profiles from the EPA SPECIATE database gave good statistical fits throughout the computer modeling process for each of the sites, including the following wood smoke profiles listed in **Table 1**: 61, 62, 65, and 66. When compared to profiles of other sources, these wood smoke profiles typically had higher levels of elemental potassium, potassium ion, and OC. Generally, both elemental potassium and the potassium ion gave good fits when modeling, with the elemental form usually providing the better statistical fit.

When focusing on the OMNI profiles in the CMB model, FBK107 (EPA Wood Stove, spruce, low) gave the best statistical fit. However, other OMNI profiles for wood smoke combustion were statistically significant as well, and were used in the CMB modeling: FBK101 (EPA OWHH, Birch, Low), FBK102 (Conventional Wood Stove, Birch, Low), and FBK100 (EPA Wood Stove, Birch, Low). Given that all of these wood smoke profiles (both EPA and OMNI) provided strong statistical fits (i.e. gave the best results), this supports that wood smoke (likely from residential wood combustion) is a major source of $PM_{2.5}$ in the Fairbanks airshed throughout the winter months. It should also be noted that wood smoke was determined to be the largest source of $PM_{2.5}$ at both the State Building and NCORE sites (56-72%) during the summer of 2012, likely due to residential outdoor biomass waste burning and influences from regional wildland forest fire events.

8.2. Secondary Pollutants

"Pure secondary" aerosols such as ammonium nitrate and sulfate are actually formed through gas-to-particle transformations in the atmosphere, and are represented by their chemical form in the model. As noted earlier, one assumption of the CMB model is that compositions of source emissions are constant over the period of ambient and source sampling, and that chemical species do not react with each other. CMB is well suited for apportioning sources of primary aerosols (those emitted directly as particles). However, it is difficult to attribute secondary aerosols formed through gas-to-particle transformation in the atmosphere to specific sources. Using the secondary sulfate and the ammonium nitrate profiles allows us to account for the secondary aerosol contributions to $PM_{2.5}$ mass.

Sulfate is a large source contributor to ambient $PM_{2.5}$, representative of particles directly emitted during combustion and secondary particles formed in the atmosphere. Sulfate is a function of the sulfur content of the fuels burned in the Fairbanks community. Recent regulations have all but eliminated sulfur from

gasoline and diesel fuel in Alaska. Therefore, the fuels contributing sulfur (and sulfate) to the Fairbanks airshed likely include distillate fuel oil used in space heating and coal combustion. Ammonium nitrate (NH_4NO_3) is a secondary pollutant that was also identified frequently by the CMB model at each of the sites. Identified source contributions were very similar when using the EPA and OMNI profiles, with slightly less sulfate and ammonium nitrate identified when using the OMNI profiles. It should be noted that even though ammonium sulfate was not detected by the CMB model as a $PM_{2.5}$ source (secondary) when both sulfate and ammonium nitrate were used as fitting species, it is likely a significant contributor to the measured $PM_{2.5}$ levels. When using the secondary sulfate source profile in the model, sulfur was used as the fitting species in each model run to apportion sulfate contributions.

Ammonia (NH_3) and oxides of nitrogen (NOx) are the precursors for ammonium nitrate particles, with just under half all NOx emissions in the United States estimated to come from the transportation sector (Seinfeld and Pandis, 1998; Dreher and Harley, 1998). $PM_{2.5}$ has been found to correlate with gaseous emissions of NOx from vehicles, with heavy duty vehicles contributing significantly greater amounts of NOx and particulate matter on a per vehicle basis than light duty vehicles (Gillies et al., 2001). Between 40 and 45% of all NOx emissions in the United States are estimated to come from transportation, with about half of this coming from light-duty gasoline trucks and cars and approximately one-quarter from heavy-duty gasoline and diesel vehicles (Seinfeld and Pandis, 1998; Dreher and Harley, 1998). Other sources of NOx in Fairbanks might include industry, natural gas furnaces, and residential wood combustion. In other parts of the lower 48, ammonia emissions to the atmosphere can arise from many sources including the decay of livestock waste, use of chemical fertilizers, emissions from sewage waste treatment plants, and biological processes in soils (Fraser and Cass, 1998). In Fairbanks, combustion processes such as motor vehicles likely are a significant source of ammonia.

8.3. Mobile Sources

Profiles for this source group typically had higher levels of EC when compared to the wood smoke profiles. When using the EPA profiles, the CMB model determined that vehicles were a measurable source of $PM_{2.5}$ at each of the sites throughout the winter months. Automobile exhaust (gasoline-powered) contributions to $PM_{2.5}$ were detected at the sites up to 7%. Diesel exhaust was also measured at each of the sites, contributing up to 11%. When using the OMNI wood smoke and fuel oil profiles in the CMB model, mobile sources were identified as being smaller contributors to the ambient $PM_{2.5}$. For the majority of the CMB runs using OMNI profiles, both automobiles and diesel exhaust were found to typically contribute less than 6% to the overall ambient $PM_{2.5}$.

8.4. Other Sources

When conducting CMB modeling using the EPA source profiles, there were other sources identified by the CMB model as contributors to the ambient $PM_{2.5}$. However, these sources were not identified as statistically significant contributors (i.e. evaluated based on CMB model statistical criteria). These sources include the following: street sand, distillate oil combustion, natural gas combustion, residual oil combustion, and sub bituminous coal combustion. Street sand was detected by the CMB model from filters collected during the early spring, but never in concentrations that were considered statistically significant (TSTAT >2). In addition, the source profile for natural gas combustion was identified on several occasions, but never in amounts that were statistically significant.

Regarding the combustion sources such as distillate oil, residual oil, and sub bituminous coal, primary $PM_{2.5}$ emissions were not identified as being statistically significant from these individual sources. To investigate this further, the CMB model was run with both the EPA SPECIATE distillate oil and coal profile in the model, and in the absence of the secondary sulfate profile (using both the sulfur and sulfate fitting species). In both instances, the model provided very poor statistical fits. Using the secondary

sulfate profile (as a potential surrogate for these sources) provided excellent statistical fits on nearly every sample run.

When using the OMNI profiles in the CMB modeling, the No. 2 fuel oil profile (FBK103) was consistently identified as a source of $PM_{2.5}$ at each of the sites during all winters. The other OMNI profiles for coal, including FBK104 (Coal Stove, Wet Stoker Coal, Low), FBK105 (Coal HH, Wet Stoker Coal, Single), and 108 (Coal Stove Dry Lump Coal, low) were not identified in the CMB model. Similarly, the OMNI profile for waste oil (FBK106, WasteOil Brnr, Waste Oil, Single) was not identified by the CMB model to be a source of $PM_{2.5}$ at any of the other sites (for each year).

9.0. Quality Assurance / Quality Control Results

9.1. Sampling Program QA/QC

For the Fairbanks sampling program, Alaska DEC and FNSB personnel maintained and audited the $PM_{2.5}$ samplers at each of the sites. There were several days throughout the program where samples were not collected (and therefore CMB analyses were not conducted) due to sampler malfunctions. These sample days are identified in **Appendix B**. In addition, CMB source apportionment was not conducted on additional sample days during the winter months due to low $PM_{2.5}$ mass. If the measured $PM_{2.5}$ concentration is less than 7 $\mu g/m^3$, the percent mass may be outside of the acceptable ranges because the uncertainty in the mass measurement is approximately 1 to 2 $\mu g/m^3$. These days are also identified in **Appendix B**. These low mass days were primarily excluded for the winter days when the ambient $PM_{2.5}$ concentrations were much higher. During the summer 2012 sample days, CMB modeling runs were conducted on all days (regardless of ambient $PM_{2.5}$ mass concentrations) in an effort to identify the sources during these low-mass days.

9.2. Analytical Program QA/QC

RTI (speciation analyses) and Desert Research Institute were responsible for QA/QC activities within their respective laboratories. To monitor for artifact contamination in the field and in the laboratory, Teflon, nylon, and quartz filter field blanks were collected throughout the sampling programs. The results of the $PM_{2.5}$ speciation field blank analyses show that the Teflon and quartz filters collected throughout the program did not measure significant artifacts for mass, elements, or Total Carbon. Several ions measured from the nylon filter blanks had levels above the MDLs, including sulfate, nitrate, ammonium, and sodium. Care was taken when utilizing these ions as fitting species to avoid inaccurate source apportionment to the fine PM.

9.3. CMB Program QA/QC

EPA‟s validation protocol (Watson et al., 2004) was followed throughout this CMB modeling program to ensure accurate results. For each model run, several different combinations of source profiles were evaluated, and the number of chemical species always exceeded the number of source types. The source contribution estimates and the statistics and diagnostic information were reviewed for each model run to determine the validity of the initial model results. The analysis was repeated by eliminating source profiles that gave negative source contribution estimates or standard errors that exceeded the source contribution estimates. When conducting the CMB model runs, only sources with TSTATs >2 were reported. If a TSTAT was <2, then the source was not considered a significant contributor for that sample day.

The majority of the CMB fitting parameters used to evaluate the validity of source contribution estimates were well within EPA target ranges. **Tables 41** (CMB with EPA profiles) **and 42** (CMB with OMNI profiles) present the program average key „goodness-of-fit‟ statistics commonly evaluated for CMB models, the results for the Fairbanks CMB runs, and the EPA target ranges for each parameter.

The values for R^2, Chi^2, DF, and % mass explained for each CMB model run were generally well within the EPA target ranges. For the most part, the R/U ratios were all less than 2, and source collinearity (similarities between identified sources) was not a problem throughout this modeling application.

Table 41: Average Goodness-Of-Fit Parameter - EPA Profiles.

	R^2	Chi^2	Degrees of Freedom	% Mass Explained	TSTAT
EPA Target	**0.8 - 1.00**	**0.00 – 4.0**	**> 5**	**80 – 120%**	**>2**
State Building, 2005/2006	0.94	0.35	27	99.7	>2
State Building, 2006/2007	0.95	0.27	26	98.4	>2
State Building, 2007/2008	0.96	0.21	32	100.1	>2
2008/2009	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
State Building	0.95	0.25	28	99.3	>2
North Pole	0.98	0.11	37	99.2	>2
RAMS	0.96	0.19	37	100.5	>2
Peger Road	0.98	0.09	36	99.5	>2
2009/2010	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
State Building	0.96	0.34	37	99.4	>2
North Pole	0.97	0.17	36	99.0	>2
RAMS	0.98	0.07	36	99.9	>2
Peger Road	0.98	0.13	36	99.2	>2
2010/2011	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
State Building	0.98	0.19	38	100.0	>2
North Pole	0.97	0.15	35	99.4	>2
Peger Road	0.98	0.10	36	99.7	>2
2011/2012	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
State Building	0.96	0.25	37	99.0	>2
North Pole	0.97	0.18	38	98.1	>2
RAMS	0.98	0.13	37	98.3	>2
NCORE	0.97	0.18	37	98.8	>2
NPF3	0.98	0.10	36	101.0	>2
Summer 2012	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
State Building	0.98	0.39	38	93.1	>2
NCORE	0.89	0.56	38	107.7	>2

2012/2013	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
State Building	0.96	0.27	38	99.4	>2
NPE	0.97	0.17	35	99.2	>2
NCORE	0.96	0.22	36	99.7	>2
NPF3	0.97	0.21	35	99.0	>2

Note: ND: not detected by the CMB model. Sampling was not conducted at the RAMS site during the winter of 2010/2011.

Table 42: Average Goodness-Of-Fit Parameters - OMNI Profiles.

	R^2	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
EPA Target	**0.8 - 1.00**	**0.00 – 4.0**	**> 5**	**80 – 120%**	**>2**
State Building, 2005/2006	0.98	0.17	22	98.1	>2
State Building, 2006/2007	0.99	0.15	19	100.1	>2
State Building, 2007/2008	0.99	0.13	25	100.1	>2
2008/2009	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
*State Building	0.96	0.40	19	96.1	>2
**State Building	0.99	0.18	20	99.5	>2
North Pole	0.97	0.36	29	96.8	>2
RAMS	0.97	0.27	28	100.9	>2
*Peger Road	0.98	0.19	28	98.4	>2
**Peger Road	0.99	0.12	28	99.7	>2
2009/2010	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
State Building	1.0	0.13	28	96.1	>2
North Pole	0.97	0.67	27	100.6	>2
RAMS	0.98	0.49	28	100.1	>2
Peger Road	0.99	0.15	28	98.9	>2
2010/2011	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
State Building	1.0	0.10	29	92.6	>2
North Pole	0.97	0.65	28	99.4	>2
Peger Road	0.99	0.21	28	101.4	>2
2011/2012	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
State Building	1.0	0.16	27	93.3	>2
North Pole	0.97	0.37	29	95.5	>2
RAMS	0.98	0.17	29	91.6	>2

NCORE	0.99	0.13	29	99.5	>2
NPF3	0.98	0.24	29	97.8	>2
Summer 2012	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
State Building	1.0	0.38	30	84.4	>2
NCORE	0.90	0.62	35	108.3	>2
2012/2013	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
State Building	1.0	0.11	29	90.2	>2
NPE	0.98	0.35	27	96.8	>2
NCORE	0.99	0.10	27	100.2	>2
NPF3	0.98	0.39	27	96.3	>2

Note: ND: not detected by the CMB model. Sampling was not conducted at the RAMS site during the winter of 2010/2011. *Averages originally presented in the Final Report submitted to ADEC (dated July 23, 2012). **Averages for those sample days in which updated CMB modeling (with OMNI profiles as well as auto/diesel profiles) was conducted.

It is believed that all of the $PM_{2.5}$ emission sources (or at least the source types) were identified during this CMB modeling program. Missing source types are identified by a low percent mass explained (<80%) and/or a RATIO R/U <<-2.0 for chemical species which are in the missing source. In addition, a "high negative" residual for one or more species and a large Chi^2 can be indicative of missing sources. The good agreement between the calculated source contributions and the measured ambient concentrations indicate that all of the major source types are included in the calculations, and that ambient and source profile measurements are reasonably accurate. CMB is intended to complement rather than replace other data analysis and modeling methods. For this project, the sensitivity of the CMB model's results to the errors in the source profiles were evaluated by using different chemical abundances of a source type and by changing the fitting species used in the source type. The results of the sensitivity tests for each run showed that the CMB calculations carried out in this study were acceptable. Although there were a few cases where the fitting parameters were outside the EPA target range, none of these cases were considered invalid, and all of the fits were quite strong. Therefore, the source contribution estimates identified in this project can be considered valid.

10.0. References

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Appendix A. OMNI Source Profiles

	FBK100	FBK101	FBK102	FBK103	FBK104	FBK105	FBK106	FBK107	FBK108
	OMNI_5_WS	OMNI_9_OW	OMNI_15_W	OMNI_17_O	OMNI_23_C	OMNI_29_C	OMNI_18_W	OMNI_6_WS	OMNI_38_C
	FINE	FINE	FINE	FINE	FINE	FINE	FINE	FINE	FINE
Magnesium	0.000128902	0.000179751	6.69E-05	0	0	0.003971831	0.002287551	0	0
aluminum	8.06E-05	0	0	0.003478261	6.87E-05	0.007352113	0.000792668	0.0002849	0.000276817
silicon	0	0	0	0.001014493	0	0.01343662	0.000284456	0	0.000138408
phosphorus	0	0	0	0	0	0.00056338	0.083318258	0	0
sulfur	0.004114804	0.005342382	0.006735058	0.060289855	0.002835052	0.131014085	0.022316115	0.002393162	0.004273356
chlorine	0.002239678	0.003898264	0.002305977	0.00115942	0.000790378	0.000676056	0.213184956	0.002336182	0.00032872
potassium	0.018032226	0.026834189	0.021868867	0.001449275	0.000137457	0.03828169	0.044103785	0.008091168	0.000207612
calcium	0.00023565	0.000577158	7.14E-05	0.002753623	0.000120275	0.030732394	0.021598429	0.001168091	0.000155709
titanium	0	1.22E-06	0	0	3.44E-05	0.000450704	0	0	0
vanadium	8.06E-06	0	0	0	1.72E-05	0.000140845	0	0	0
chromium	2.62E-05	1.10E-05	0	0	0	0.000591549	0	2.85E-05	1.73E-05
manganese	3.42E-05	2.57E-05	2.68E-05	0	0	0.000507042	0	5.70E-05	0
iron	0.00012286	3.79E-05	1.78E-06	0.001449275	0.000171821	0.022	0.005232088	8.55E-05	8.65E-05
nickel	1.01E-05	1.22E-06	4.46E-06	0.000144928	1.72E-05	0.000422535	0	0.00017094	0
copper	1.61E-05	1.71E-05	0	0.000144928	0	0.003267606	0	0	0
zinc	0.003689829	0.003307655	0.003407672	2.90E-05	0.000120275	0.006704225	0.160667698	0.000826211	0.000155709
gallium	-99	-99	-99	-99	-99	-99	-99	-99	-99
germanium	-99	-99	-99	-99	-99	-99	-99	-99	-99
arsenic	0	0	4.46E-06	0	1.72E-05	0.000647887	0	0	0
selenium	0	0	0	0	0	0.000112676	0	0	0
bromine	1.81E-05	1.96E-05	2.23E-05	0	0	0.000309859	0.000217805	2.85E-05	3.46E-05
rubidium	3.02E-05	2.93E-05	2.23E-05	0	0	0.000253521	0	0	0
strontium	6.04E-06	6.11E-06	0	0	0	0.000309859	0	2.85E-05	0
yttrium	-99	-99	-99	-99	-99	-99	-99	-99	-99
zirconium	0	2.45E-06	0	0	8.59E-05	0.000422535	0	0	0
molybdenum	-99	-99	-99	-99	-99	-99	-99	-99	-99
palladium	-99	-99	-99	-99	-99	-99	-99	-99	-99

silver	-99	-99	-99	-99	-99	-99	-99	-99	-99
cadmium	0	0	0	0	0.000120275	0	0	0	0
indium	4.63E-05	0	0	0.002173913	0.000137457	0	0	0	0
tin	1.61E-05	0	0	0	0	0	0	0	0
antimony	0	0	0	0	0	0.000535211	0	0	0
barium	2.42E-05	9.78E-06	0	0	0	0.001183099	0	2.85E-05	0
lanthanum	-99	-99	-99	-99	-99	-99	-99	-99	-99
mercury	-99	-99	-99	-99	-99	-99	-99	-99	-99
lead	0.000002	0.000013	0.000009	0	0.000017	0.005352	0.001751	0.000028	0.000104
TC	-99	-99	-99	-99	-99	-99	-99	-99	-99
OC	2.115074382	0.481054286	0.687010777	0.518922229	0.649153878	0.08233928	0.009590277	0.777831363	0.666746667
EC	0.190318936	0.043286298	0.158647144	0.079583588	0.045820433	0.018000626	0.002592587	0.100578934	0.02072309
Sulfate	0.007468278	0.009576914	0.006347012	0.422985507	0.005257732	0.39943662	0.054980957	0.004928775	0.007958478
Nitrate	0.000968781	0.001228907	0.000677966	0.017057971	0.006185567	0.005380282	0.066209236	0.004245014	0.001608997
Ammonium	0.000104733	0.000132062	0	0.149318841	0.00128866	0.026225352	0	0.00017094	0.001799308
Chloride	-99	-99	-99	-99	-99	-99	-99	-99	-99
Potassium	0.015750252	0.022772071	0.016271186	0	0	0.036591549	0.040194001	0.007407407	0.000363322
Fluoride	-99	-99	-99	-99	-99	-99	-99	-99	-99
Sodium	0.000219537	0.000242113	0.000133809	0.003942029	0.000395189	0.041971831	0.06715782	0.000598291	0.000276817
Calcium	-99	-99	-99	-99	-99	-99	-99	-99	-99
Magnesium	-99	-99	-99	-99	-99	-99	-99	-99	-99
Sodium	0.0018429	0.001823184	0.00206512	0	0	0.046957746	0	0	0
Cobalt	6.04E-06	4.89E-06	4.46E-06	0	1.72E-05	0.000140845	0	1.14E-05	0

Appendix B. Days On Which CMB Modeling Was Not Conducted.

State Building Winter 2005/2006	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	State Building Winter 2006/2007	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	State Building Winter 2007/2008	Low $PM_{2.5}$ Mass ($\mu g/m^3$)
11/9/05	*	11/1/06	5.7**	11/14/07	*
11/18/05	4.3**	11/13/06	*	12/2/07	5.4**
11/24/05	*	11/16/06	*	12/14/07	4.0**
12/3/05	*	12/16/06	*	12/20/07	*
12/13/05	*	12/19/06	*	2/24/08	*
12/27/05	*	12/25/06	*	3/1/08	5.2**
1/2/05	*	1/9/07	*	3/7/08	5.8**
1/5/06	*	1/18/07	*	3/10/08	*
1/11/06	*	2/2/07	*	3/16/08	*
1/17/06	*	2/20/07	*	3/25/08	5.7**
2/4/06	*	3/1/07	*	3/31/08	5.7**
2/13/06	5.9**	3/7/07	*		
2/19/06	4.4**				
3/24/06	4.8**				

*No, incomplete, or invalid CMB data set.
**Mass was too small to conduct a CMB analysis.

State Building Winter 2008/2009	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	North Pole Winter 2008/2009	Low $PM_{2.5}$ Mass ($\mu g/m^3$)
12/8/08	*	2/18/09	*
1/16/09	2.3**	3/5/09	4.7**
2/6/09	*	3/17/09	3.8**
3/5/09	5.7**	3/20/09	4.6**
3/20/09	*	3/23/09	4.5**
3/26/09	*	3/26/09	3.0**

*No, incomplete, or invalid CMB data set.
**Mass was too small to conduct a CMB analysis.
Note that 12/29/08 did not give a good fit for OMNI rerun for State Building site.

RAMS Winter 2008/2009	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	Peger Road Winter 2008/2009	Low $PM_{2.5}$ Mass ($\mu g/m^3$)
3/17/09	4.4**	2/6/09	*
3/20/09	*		
3/23/09	4.7**		
3/26/09	3.8**		

*No, incomplete, or invalid CMB data set.
**Mass was too small to conduct a CMB analysis.
Note that 2/21/09 had a low mass (6.2 $\mu g/m^3$) and poor fit for OMNI RAMS CMB.

State Building Winter 2009/2010 EPA Runs	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	State Building Winter 2009/2010 OMNI Runs	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	North Pole Winter 2009/2010	Low $PM_{2.5}$ Mass ($\mu g/m^3$)
11/9/09	*	11/9/09	*	11/19/09	*
11/12/09	4.0**	11/12/09	4.0**	1/14/10	4.5**
11/18/09	4.9**	11/18/09	4.9**	1/29/10	3.3**
12/3/09	*	12/3/09	*	2/1/10	*
12/6/09	0.4**	12/6/09	0.4**	2/19/10	*
12/15/09	4.1**	12/9/09	*	2/25/10	3.8**
12/18/09	3.6**	12/12/09	*	3/6/10	*
2/25/10	3.1**	12/15/09	4.1**	3/9/10	4.1**
3/6/10	3.8**	12/18/09	3.6**		
3/9/10	3.4**	12/30/2009	*		
		1/2/2010	*		
		1/5/2010	*		
		1/20/10	*		
		1/26/10	*		
		2/4/10	*		
		2/25/10	3.1**		
		3/6/10	3.8**		
		3/9/10	3.4**		
		3/12/10	*		

*No, incomplete, or invalid CMB data set.
**Mass was too small to conduct a CMB analysis.

RAMS Winter 2009/2010	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	Peger Road Winter 2009/2010	Low $PM_{2.5}$ Mass ($\mu g/m^3$)
11/17/09	*	11/18/09	*
11/18/09	*	11/19/09	*
11/19/09	*	2/25/10	*
1/26/10	*	3/9/10	3.6**
1/29/10	*		

*No, incomplete, or invalid CMB data set.
**Mass was too small to conduct a CMB analysis.
Note that 2/22/10 gave a poor fit for OMNI Peger Road CMB.

State Building Winter 2010/2011	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	North Pole Winter 2010/2011
11/4/10	3.3**	None.
11/25/10	*	
12/16/10	*	
12/19/10	*	
12/22/10	*	
12/25/10	*	
12/28/10	*	
12/31/10	*	
1/3/11	*	
1/6/11	*	
1/9/11	*	
1/12/11	*	
1/15/11	*	
1/18/11	*	
1/21/11	*	
1/24/11	*	
1/27/11	*	
1/30/11	*	
2/2/11	*	

*No, incomplete, or invalid CMB data set.
**Mass was too small to conduct a CMB analysis.

Peger Road Winter 2010/2011
None.

State Building Winter 2011/2012	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	North Pole Winter 2011/2012	Low $PM_{2.5}$ Mass ($\mu g/m^3$)
11/5/11	*	11/2/11	***
11/20/11	*	12/5/11	2.5**
12/5/11	*	12/23/11	5.6**
12/11/11	*	1/22/12	***
12/23/11	6.3**	1/25/12	***
1/1/12	*	2/3/12	***
1/22/12	*	2/9/12	***
2/3/12	6.5**	2/12/12	***
2/24/12	5.0**	2/24/12	3.5**
2/27/12	4.3**	2/27/12	2.1**
3/4/12	*	3/1/12	5.1**
3/7/12	*	3/7/12	4.1**
3/31/12	5.4**	3/13/12	4.3**
		3/16/12	5.5**

*No, incomplete, or invalid CMB data set.
**Mass was too small to conduct a CMB analysis.
***Could not get a good statistical fit for CMB analysis.
Note that 1/28/12 and 1/31/12 (State Building) provided poor statistical fits for the OMNI CMB.
Note that 1/28/12 and 1/31/12 (State Building) provided poor statistical fits for the OMNI CMB, while the 1/28/12 date also provided a poor fit for the 1/28/12 North Pole CMB run.

RAMS Winter 2011/2012	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	NCORE Winter 2011/2012	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	NPF3 Winter 2011/2012	Low $PM_{2.5}$ Mass ($\mu g/m^3$)
1/13/12	***	12/5/11	5.1**	3/1/12	4.5**
1/19/12	3.1**	12/23/11	5.6**	3/13/12	5.1**
1/22/12	0.8**	1/22/12	3.3**	3/28/12	5.2**
1/25/12	0.7**	2/24/12	5.7**	3/31/12	4.8**
1/28/12	2.8**	2/27/12	3.6**		
2/3/12	5.6**	3/25/12	***		
2/24/12	5.9**	3/31/12	5.6**		
2/27/12	3.5**				

*No, incomplete, or invalid CMB data set.
**Mass was too small to conduct a CMB analysis.
***Could not get a good statistical fit for CMB analysis.
Note that 1/16/12 (RAMS) and 2/6/12 and 2/9/12 (NCORE) provided poor statistical fits for the OMNI CMB.

State Building Summer 2012	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	NCORE Sumer 2012	Low $PM_{2.5}$ Mass ($\mu g/m^3$)
6/2/12	***	6/26/12	***
7/2/12	***	7/5/12	***
7/8/12	***	7/8/12	***
7/14/12	***	7/11/12	***
7/17/12	*	7/14/12	***
7/23/12	***	7/17/12	***
8/4/12	***	7/23/12	***
8/16/12	***	8/25/12	*
8/22/12	***	8/28/12	***
8/28/12	***	8/31/12	***
8/31/12	***		

*No, incomplete, or invalid CMB data set.
**Mass was too small to conduct a CMB analysis.
***Could not get a good statistical fit for CMB analysis.

State Building Winter 2012/2013	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	NPE Winter 2012/2013	Low $PM_{2.5}$ Mass ($\mu g/m^3$)
11/17/12	3.3**	11/23/12	5.3**
11/29/12	*	12/11/12	5.5**
12/5/12	***	1/19/13	5.8**
12/11/12	5.8**	1/22/13	4.4**
12/17/12	***	2/21/13	3.4**
12/20/12	***	3/5/13	*
12/23/12	***	3/14/13	2.6**
12/26/12	***	3/20/13	1.0**
1/10/13	***	3/23/13	4.6**
1/13/13	***		
1/16/13	*		
1/25/13	***		
1/31/13	***		
2/9/13	*		
2/15/13	***		
2/21/13	3.8**		
3/5/13	*		
3/14/13	*		
3/20/13	*		
3/23/13	*		
3/26/13	4.8**		

*No, incomplete, or invalid CMB data set.
**Mass was too small to conduct a CMB analysis.
***Could not get a good statistical fit for CMB analysis.
Note that 12/26/12 (NPE) provided poor statistical fits for the OMNI CMB.

NCORE Winter 2012/2013	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	NPF3 Winter 2012/2013	Low $PM_{2.5}$ Mass ($\mu g/m^3$)
11/2/12	*	11/2/12	*
11/5/12	*	12/5/12	*
11/17/12	3.7**	12/8/12	*
11/26/12	*	1/22/13	4.2**
12/11/12	5.8**	2/15/13	*
1/7/13	*	2/18/13	*
1/31/13	***	2/21/13	4.0**
2/15/13	3.8**	3/14/13	3.2**
2/21/13	*		
3/14/13	3.5**		
3/23/13	5.0**		
3/26/13	5.0**		

*No, incomplete, or invalid CMB data set.
**Mass was too small to conduct a CMB analysis.
***Could not get a good statistical fit for CMB analysis.

Appendix C. CMB Results for Each Sample Day.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors ($\mu g/m^3$) – EPA Profiles. State Building – Winter 2005/2006.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/3/05	17.8	3.9	0.4	1.6	0.5	0.0	0.0	0.0	0.0	13.2	1.4
11/6/05	12.8	2.2	0.2	1.7	0.3	0.0	0.0	0.0	0.0	8.9	1.1
11/9/05	*	*	*	*	*	*	*	*	*	*	*
11/12/05	20.8	3.8	0.6	1.3	0.5	6.6	2.5	0.0	0.0	7.7	2.2
11/15/05	30.5	6.4	1.0	2.6	0.8	0.0	0.0	5.0	1.9	15.4	2.5
11/18/05	4.3**	**	**	**	**	**	**	**	**	**	**
11/21/05	9.1	1.9	0.2	1.3	0.3	0.0	0.0	0.0	0.0	6.3	0.8
11/24/05	*	*	*	*	*	*	*	*	*	*	*
11/27/05	26.4	4.8	0.8	2.1	0.7	0.0	0.0	3.2	1.2	14.5	2.2
11/30/05	21.7	3.7	0.6	4.6	0.7	0.0	0.0	2.4	1.0	9.9	1.6
12/3/05	*	*	*	*	*	*	*	*	*	*	*
12/6/05	17.1	2.9	0.3	2.0	0.6	0.0	0.0	3.4	1.0	9.2	1.5
12/9/05	16.1	2.7	0.3	0.0	0.0	0.0	0.0	4.4	1.0	8.4	1.5
12/13/05	*	*	*	*	*	*	*	*	*	*	*
12/15/05	25.1	5.0	0.6	1.9	0.9	0.0	0.0	4.9	1.4	12.9	2.1
12/18/05	25.8	5.2	0.8	2.2	0.8	0.0	0.0	3.6	1.3	13.8	2.2
12/21/05	25.9	4.8	0.5	1.6	0.6	0.0	0.0	6.4	1.6	12.7	2.1
12/24/05	24.4	4.2	0.5	2.2	0.5	0.0	0.0	4.4	1.4	13.2	2.0
12/27/05	*	*	*	*	*	*	*	*	*	*	*
12/30/05	34.2	7.3	0.8	3.0	0.9	0.0	0.0	0.0	0.0	25.2	3.0
1/2/06	*	*	*	*	*	*	*	*	*	*	*
1/5/06	*	*	*	*	*	*	*	*	*	*	*
1/8/06	31.4	6.1	0.7	2.7	0.8	0.0	0.0	0.0	0.0	23.8	2.2
1/11/06	*	*	*	*	*	*	*	*	*	*	*
1/14/06	18.2	3.3	0.4	1.6	0.4	0.0	0.0	0.0	0.0	12.7	1.5
1/17/06	*	*	*	*	*	*	*	*	*	*	*
1/20/06	31.1	6.5	1.0	2.3	0.8	0.0	0.0	0.0	0.0	23.9	3.1
1/23/06	26.5	5.7	0.9	1.7	0.7	9.0	4.0	0.0	0.0	12.0	2.2
1/26/06	42	12.1	1.3	2.9	1.5	0.0	0.0	0.0	0.0	27.1	3.3
1/29/06	30.7	7.5	0.8	3.6	1.0	0.0	0.0	0.0	0.0	20.0	2.4
2/1/06	7.0	1.3	0.1	1.1	0.2	0.0	0.0	0.0	0.0	5.6	0.9
2/4/06	*	*	*	*	*	*	*	*	*	*	*
2/7/06	15.3	2.9	0.5	2.0	0.6	0.0	0.0	3.3	0.9	7.1	1.3
2/10/06	7.4	1.3	0.1	0.5	0.2	0.0	0.0	0.0	0.0	5.8	0.7
2/13/06	5.9**	**	**	**	**	**	**	**	**	**	**
2/16/06	12.9	2.2	0.3	1.6	0.4	0.0	0.0	2.0	0.7	7.5	1.2
2/19/06	4.4**	**	**	**	**	**	**	**	**	**	**
2/22/06	7.1	1.6	0.2	0.6	0.2	0.0	0.0	0.0	0.0	4.4	0.7
2/25/06	15.1	3.9	0.4	1.6	0.5	0.0	0.0	0.0	0.0	9.9	2.8
2/28/06	20.1	3.4	0.4	1.4	0.4	0.0	0.0	0.0	0.0	14.2	1.7
3/3/06	23.2	5.0	0.6	3.9	0.7	0.0	0.0	5.3	1.6	8.9	1.7

3/6/06	15.1	3.6	0.4	1.7	0.5	0.0	0.0	0.0	0.0	9.6	1.2
3/9/06	7.9	2.6	0.3	0.7	0.3	0.0	0.0	0.0	0.0	4.2	0.8
3/12/06	9.4	2.8	0.3	0.7	0.4	0.0	0.0	0.0	0.0	5.5	0.9
3/15/06	8.5	2.7	0.4	1.0	0.3	0.0	0.0	0.0	0.0	4.7	0.7
3/18/06	11.3	2.5	0.4	1.1	0.3	0.0	0.0	0.0	0.0	7.0	1.0
3/21/06	9.4	2.2	0.4	1.3	0.3	0.0	0.0	0.0	0.0	5.8	0.9
3/24/06	4.8**	**	**	**	**	**	**	**	**	**	**
3/27/06	10.6	2.1	0.3	1.4	0.3	0.0	0.0	0.0	0.0	7.1	1.9
3/30/06	13.7	2.8	0.3	1.6	0.4	0.0	0.0	0.0	0.0	9.6	2.6
Average	**18.9**	**4.0**	**0.5**	**1.8**	**0.5**	**0.4**	**0.2**	**1.3**	**0.4**	**11.3**	**1.7**

Notes: *No or incomplete CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
State Building – Winter 2005/2006.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/3/05	17.8	3.9	0.4	1.5	0.5	0.0	0.0	0.0	0.0	13.8	1.3
11/6/05	12.8	1.2	0.2	1.3	0.2	5.2	1.0	0.0	0.0	5.0	1.1
11/9/05	*	*	*	*	*	*	*	*	*	*	*
11/12/05	20.8	2.2	0.6	0.9	0.3	8.5	1.7	0.0	0.0	7.6	1.7
11/15/05	30.5	3.3	1.0	1.5	0.5	16.6	2.6	0.0	0.0	7.7	2.3
11/18/05	4.3**	**	**	**	**	**	**	**	**	**	**
11/21/05	9.1	1.8	0.2	1.2	0.2	0.0	0.0	0.0	0.0	6.5	0.7
11/24/05	*	*	*	*	*	*	*	*	*	*	*
11/27/05	26.4	2.4	0.7	1.2	0.3	12.9	2.0	0.0	0.0	8.8	1.9
11/30/05	21.7	2.1	0.6	3.9	0.5	8.7	2.0	0.0	0.0	6.4	1.7
12/3/05	*	*	*	*	*	*	*	*	*	*	*
12/6/05	17.1	1.9	0.4	1.5	0.4	5.3	1.9	1.5	0.8	6.8	1.7
12/9/05	16.1	1.5	0.4	0.0	0.0	6.6	2.2	2.9	1.0	5.1	1.9
12/13/05	*	*	*	*	*	*	*	*	*	*	*
12/15/05	25.1	2.8	0.6	1.1	0.4	10.9	2.2	2.5	1.0	7.7	2.1
12/18/05	25.8	2.8	0.8	1.3	0.4	13.3	2.2	0.0	0.0	8.0	2.1
12/21/05	25.9	2.8	0.5	0.8	0.4	11.0	2.2	3.5	1.5	7.1	2.2
12/24/05	24.4	2.4	0.5	1.5	0.4	9.5	1.9	0.0	0.0	10.0	1.8
12/27/05	*	*	*	*	*	*	*	*	*	*	*
12/30/05	34.2	4.3	0.8	2.0	0.6	15.5	3.4	2.7	1.2	5.7	2.8
1/2/06	*	*	*	*	*	*	*	*	*	*	*
1/5/06	*	*	*	*	*	*	*	*	*	*	*
1/8/06	31.4	3.3	0.6	1.6	0.5	15.2	2.7	0.0	0.0	6.8	2.3
1/11/06	*	*	*	*	*	*	*	*	*	*	*
1/14/06	18.2	1.8	0.4	1.0	0.3	8.1	1.5	0.0	0.0	6.6	1.5
1/17/06	*	*	*	*	*	*	*	*	*	*	*
1/20/06	31.1	3.0	1.0	1.1	0.4	18.6	2.5	0.0	0.0	9.1	2.4
1/23/06	26.5	2.4	0.8	1.3	0.4	17.9	2.2	0.0	0.0	3.4	2.0
1/26/06	42	7.9	1.4	1.2	1.1	22.9	5.9	0.0	0.0	9.1	4.5
1/29/06	30.7	4.4	0.8	2.5	0.6	16.6	3.4	0.0	0.0	7.5	2.9
2/1/06	7.0	0.8	0.2	0.9	0.1	2.7	0.6	0.0	0.0	3.9	0.8
2/4/06	*	*	*	*	*	*	*	*	*	*	*
2/7/06	15.3	1.9	0.6	1.5	0.4	6.0	2.2	2.3	0.8	4.0	1.8
2/10/06	7.4	0.8	0.2	0.3	0.1	2.7	0.6	0.0	0.0	4.2	0.8
2/13/06	5.9**	**	**	**	**	**	**	**	**	**	**
2/16/06	12.9	1.5	0.3	1.3	0.2	4.5	1.2	0.0	0.0	6.2	1.2
2/19/06	4.4**	**	**	**	**	**	**	**	**	**	**
2/22/06	7.1	1.0	0.2	0.4	0.1	3.0	0.8	0.0	0.0	2.1	0.8
2/25/06	15.1	2.3	0.4	1.0	0.3	8.4	1.8	0.0	0.0	2.6	1.6
2/28/06	20.1	3.3	0.4	1.4	0.4	0.0	0.0	0.0	0.0	13.8	1.5
3/3/06	23.2	2.9	0.6	3.0	0.5	11.7	2.4	0.0	0.0	5.0	2.1
3/6/06	15.1	3.5	0.4	1.7	0.5	0.0	0.0	0.0	0.0	10.4	1.3
3/9/06	7.9	1.6	0.2	0.4	0.2	5.6	0.7	0.0	0.0	0.0	0.0
3/12/06	9.4	1.6	0.3	0.3	0.2	7.0	0.7	0.0	0.0	0.0	0.0

3/15/06	8.5	1.4	0.4	0.5	0.2	7.1	0.7	0.0	0.0	0.0	0.0
3/18/06	11.3	1.0	0.3	0.5	0.1	8.3	0.7	0.0	0.0	0.0	0.0
3/21/06	9.4	2.2	0.4	1.3	0.3	0.0	0.0	0.0	0.0	6.3	1.0
3/24/06	4.8**	**	**	**	**	**	**	**	**	**	**
3/27/06	10.6	1.3	0.3	1.1	0.2	4.0	1.0	0.0	0.0	3.3	1.0
3/30/06	13.7	1.5	0.3	1.1	0.2	7.1	1.2	0.0	0.0	3.1	1.2
Average	**18.9**	**2.4**	**0.5**	**1.3**	**0.3**	**8.4**	**1.6**	**0.4**	**0.2**	**5.9**	**1.6**

Notes: *No or incomplete CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles. State Building – Winter 2006/2007.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/1/06	5.7**	**	**	**	**	**	**	**	**	**	**
11/4/06	27.9	4.5	0.6	2.3	0.6	0.0	0.0	0.0	0.0	22.4	2.6
11/7/06	13.5	1.8	0.2	1.2	0.2	3.6	1.7	0.0	0.0	6.1	1.5
11/10/06	21.3	3.1	0.4	1.6	0.4	0.0	0.0	3.3	1.2	12.1	1.9
11/13/06	*	*	*	*	*	*	*	*	*	*	*
11/16/06	*	*	*	*	*	*	*	*	*	*	*
11/19/06	25.8	6.2	0.8	1.9	0.8	0.0	0.0	0.0	0.0	16.1	2.0
11/22/06	12.7	1.8	0.2	1.5	0.3	0.0	0.0	1.4	0.6	8.5	1.3
11/25/06	32.1	6.2	0.8	2.0	0.8	0.0	0.0	0.0	0.0	23.0	5.9
11/28/06	25.7	5.2	0.6	2.2	0.8	0.0	0.0	3.5	1.3	13.5	2.1
12/1/06	8.0	1.7	0.2	0.9	0.2	0.0	0.0	0.0	0.0	5.8	0.8
12/4/06	15.5	2.3	0.3	2.5	0.5	0.0	0.0	2.5	0.8	8.3	1.4
12/7/06	35.1	3.9	0.5	1.7	0.5	15.2	3.4	0.0	0.0	10.2	2.0
12/10/06	16.3	2.7	0.3	1.3	0.5	0.0	0.0	2.8	0.9	9.5	1.5
12/13/06	15.1	2.6	0.3	1.3	0.3	4.8	2.0	0.0	0.0	5.4	1.7
12/16/06	*	*	*	*	*	*	*	*	*	*	*
12/19/06	*	*	*	*	*	*	*	*	*	*	*
12/22/06	26.0	6.9	0.9	2.1	1.0	0.0	0.0	3.4	1.6	13.4	2.2
12/25/06	*	*	*	*	*	*	*	*	*	*	*
12/28/06	23.8	3.8	0.5	1.5	0.7	0.0	0.0	3.6	1.1	13.5	2.0
12/31/06	16.9	4.1	0.5	1.4	0.6	0.0	0.0	2.0	0.9	10.7	1.7
1/3/07	11.0	2.1	0.3	1.3	0.3	0.0	0.0	0.0	0.0	7.1	1.0
1/6/07	19.8	3.5	0.4	1.2	0.5	5.8	2.8	0.0	0.0	10.0	1.8
1/9/07	*	*	*	*	*	*	*	*	*	*	*
1/12/07	30.4	5.3	0.7	3.1	0.7	0.0	0.0	5.2	1.7	15.7	2.4
1/15/07	16.3	2.2	0.3	0.9	0.3	0.0	0.0	0.0	0.0	13.1	2.8
1/18/07	*	*	*	*	*	*	*	*	*	*	*
1/21/07	23.8	4.4	0.5	2.2	0.6	0.0	0.0	3.7	1.5	12.1	1.9
1/24/07	17.4	3.7	0.5	1.8	0.5	0.0	0.0	2.8	1.3	8.5	1.5
1/27/07	31.6	5.9	0.7	2.8	0.8	6.9	3.4	0.0	0.0	14.5	3.3
1/30/07	25.0	3.9	0.5	2.0	0.5	0.0	0.0	7.7	1.5	10.2	1.8
2/2/07	*	*	*	*	*	*	*	*	*	*	*
2/5/07	34.6	5.3	0.7	3.3	0.7	8.4	3.8	0.0	0.0	18.3	2.9
2/8/07	14.8	3.0	0.4	0.8	0.4	0.0	0.0	0.0	0.0	11.1	1.3
2/11/07	14.6	2.0	0.2	1.1	0.3	0.0	0.0	0.0	0.0	10.2	1.4
2/14/07	18.0	3.3	0.4	1.7	0.6	0.0	0.0	3.4	1.0	10.0	1.5
2/17/07	21.5	4.1	0.5	1.6	0.5	0.0	0.0	2.1	1.0	13.7	2.0
2/20/07	*	*	*	*	*	*	*	*	*	*	*
2/23/07	38.7	8.4	1.0	3.2	1.1	0.0	0.0	0.0	0.0	27.0	5.9
2/26/07	15.1	3.3	0.4	1.1	0.4	0.0	0.0	0.0	0.0	10.5	2.9
3/1/07	*	*	*	*	*	*	*	*	*	*	*
3/4/07	18.8	4.1	0.5	2.0	0.6	0.0	0.0	0.0	0.0	12.8	1.5
3/7/07	*	*	*	*	*	*	*	*	*	*	*
3/10/07	10.6	2.4	0.3	0.7	0.3	0.0	0.0	0.0	0.0	7.8	1.1
3/13/07	14.6	3.7	0.4	1.0	0.5	0.0	0.0	0.0	0.0	9.5	2.6

3/16/07	13.7	3.0	0.4	0.9	0.4	0.0	0.0	0.0	0.0	10.3	2.7
3/19/07	14.3	2.9	0.4	1.5	0.5	0.0	0.0	2.9	0.9	7.2	1.3
3/22/07	7.2	1.3	0.2	0.4	0.2	0.0	0.0	0.0	0.0	5.4	0.9
3/25/07	15.8	3.4	0.4	1.5	0.4	0.0	0.0	2.7	1.2	7.4	1.3
3/28/07	18.2	3.6	0.4	2.3	0.5	0.0	0.0	3.4	1.3	8.0	1.4
3/31/07	14.0	2.6	0.3	1.6	0.3	0.0	0.0	2.4	1.0	7.6	1.3
Average	**19.9**	**3.7**	**0.5**	**1.7**	**0.5**	**1.1**	**0.4**	**1.5**	**0.5**	**11.5**	**2.0**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
State Building – Winter 2006/2007.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/1/06	5.7**	**	**	**	**	**	**	**	**	**	**	**	**
11/4/06	27.9	2.5	0.5	1.6	0.4	**0.0**	**0.0**	10.0	1.9	**0.0**	**0.0**	14.3	3.0
11/7/06	13.5	0.9	0.2	0.9	0.1	**0.0**	**0.0**	4.5	0.7	**0.0**	**0.0**	8.0	1.4
11/10/06	21.3	1.9	0.4	1.1	0.3	**0.0**	**0.0**	6.7	1.5	**0.0**	**0.0**	9.8	1.6
11/13/06	*	*	*	*	*	*	*	*	*	*	*	*	*
11/16/06	*	*	*	*	*	*	*	*	*	*	*	*	*
11/19/06	25.8	3.3	0.7	0.9	0.5	**0.0**	**0.0**	15.1	2.6	**0.0**	**0.0**	7.3	3.5
11/22/06	12.7	1.0	0.2	1.4	0.2	**0.0**	**0.0**	4.3	0.9	**0.0**	**0.0**	6.8	1.1
11/25/06	32.1	3.1	0.7	0.9	0.4	**0.0**	**0.0**	16.3	2.5	**0.0**	**0.0**	14.1	3.7
11/28/06	25.7	3.1	0.6	1.4	0.4	**0.0**	**0.0**	11.4	2.4	**0.0**	**0.0**	9.2	2.1
12/1/06	8.0	1.0	0.2	0.6	0.1	**0.0**	**0.0**	3.5	0.8	**0.0**	**0.0**	3.8	0.9
12/4/06	15.5	1.2	0.3	2.1	0.2	**0.0**	**0.0**	5.8	1.2	1.5	0.7	5.7	1.3
12/7/06	35.1	2.2	0.5	1.1	0.3	11.6	3.0	8.8	1.7	**0.0**	**0.0**	8.6	3.0
12/10/06	16.3	1.5	0.3	0.8	0.2	**0.0**	**0.0**	6.1	1.2	**0.0**	**0.0**	7.9	1.3
12/13/06	15.1	1.4	0.3	1.0	0.2	**0.0**	**0.0**	6.5	1.1	**0.0**	**0.0**	7.0	1.7
12/16/06	*	*	*	*	*	*	*	*	*	*	*	*	*
12/19/06	*	*	*	*	*	*	*	*	*	*	*	*	*
12/22/06	26.0	3.9	0.8	0.9	0.5	**0.0**	**0.0**	16.8	3.0	**0.0**	**0.0**	5.0	2.5
12/25/06	*	*	*	*	*	*	*	*	*	*	*	*	*
12/28/06	23.8	2.1	0.4	0.9	0.3	**0.0**	**0.0**	9.0	1.7	**0.0**	**0.0**	10.5	1.7
12/31/06	16.9	2.7	0.5	0.8	0.4	**0.0**	**0.0**	7.9	2.0	**0.0**	**0.0**	7.2	1.8
1/3/07	11.0	1.3	0.3	1.0	0.2	**0.0**	**0.0**	4.2	1.0	**0.0**	**0.0**	4.0	1.1
1/6/07	19.8	1.8	0.4	1.0	0.3	**0.0**	**0.0**	9.1	1.4	**0.0**	**0.0**	9.3	2.3
1/9/07	*	*	*	*	*	*	*	*	*	*	*	*	*
1/12/07	30.4	3.0	0.6	2.2	0.5	**0.0**	**0.0**	12.1	2.4	**0.0**	**0.0**	11.7	2.2
1/15/07	16.3	1.1	0.2	0.7	0.2	**0.0**	**0.0**	5.9	0.9	**0.0**	**0.0**	9.1	1.6
1/18/07	*	*	*	*	*	*	*	*	*	*	*	*	*
1/21/07	23.8	2.4	0.5	1.4	0.3	**0.0**	**0.0**	10.7	1.9	**0.0**	**0.0**	8.1	1.8
1/24/07	17.4	2.1	0.4	1.3	0.3	**0.0**	**0.0**	8.3	1.7	**0.0**	**0.0**	5.1	1.6
1/27/07	31.6	3.2	0.7	1.9	0.5	**0.0**	**0.0**	14.9	2.7	**0.0**	**0.0**	9.6	2.4
1/30/07	25.0	2.0	0.6	1.3	0.6	**0.0**	**0.0**	9.3	2.6	3.6	1.1	10.0	3.1
2/2/07	*	*	*	*	*	*	*	*	*	*	*	*	*
2/5/07	34.6	2.2	0.6	2.8	0.4	**0.0**	**0.0**	16.5	2.1	**0.0**	**0.0**	15.2	3.3
2/8/07	14.8	1.5	0.4	0.6	0.2	**0.0**	**0.0**	7.6	1.2	**0.0**	**0.0**	5.2	1.3
2/11/07	14.6	1.0	0.2	0.7	0.1	**0.0**	**0.0**	5.7	0.9	**0.0**	**0.0**	6.1	1.1
2/14/07	18.0	1.9	0.5	1.1	0.4	**0.0**	**0.0**	7.6	2.3	2.3	0.8	5.1	1.9
2/17/07	21.5	2.6	0.5	0.9	0.4	**0.0**	**0.0**	9.6	2.0	**0.0**	**0.0**	8.4	1.9
2/20/07	*	*	*	*	*	*	*	*	*	*	*	*	*
2/23/07	38.7	4.6	0.9	1.8	0.6	**0.0**	**0.0**	20.9	3.4	**0.0**	**0.0**	11.5	4.4
2/26/07	15.1	1.7	0.4	0.9	0.2	**0.0**	**0.0**	8.5	1.4	**0.0**	**0.0**	4.1	1.9
3/1/07	*	*	*	*	*	*	*	*	*	*	*	*	*
3/4/07	18.8	2.5	0.5	1.8	0.4	**0.0**	**0.0**	8.7	2.0	**0.0**	**0.0**	6.1	1.7
3/7/07	*	*	*	*	*	*	*	*	*	*	*	*	*

3/10/07	10.6	1.5	0.3	0.3	0.2	**0.0**	**0.0**	4.9	1.1	**0.0**	**0.0**	3.5	1.6
3/13/07	14.6	1.8	0.4	0.8	0.2	**0.0**	**0.0**	10.5	0.9	**0.0**	**0.0**	**0.0**	**0.0**
3/16/07	13.7	1.7	0.4	0.8	0.2	**0.0**	**0.0**	6.9	1.4	**0.0**	**0.0**	4.0	1.3
3/19/07	14.3	1.6	0.3	0.9	0.2	**0.0**	**0.0**	7.4	1.3	**0.0**	**0.0**	4.4	1.2
3/22/07	7.2	0.7	0.2	0.3	0.1	**0.0**	**0.0**	2.8	0.6	**0.0**	**0.0**	2.9	1.0
3/25/07	15.8	1.9	0.4	0.9	0.3	**0.0**	**0.0**	8.0	1.5	**0.0**	**0.0**	5.8	2.1
3/28/07	18.2	1.6	0.4	1.6	0.3	**0.0**	**0.0**	10.4	1.5	**0.0**	**0.0**	4.9	2.1
3/31/07	14.0	1.4	0.3	1.1	0.2	**0.0**	**0.0**	6.5	1.2	**0.0**	**0.0**	5.0	1.2
Average	**19.9**	**2.0**	**0.4**	**1.1**	**0.3**	**0.3**	**0.1**	**9.0**	**1.7**	**0.2**	**0.1**	**7.3**	**1.9**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
State Building – Winter 2007/2008.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/07	11.0	1.5	0.2	0.8	0.2	0.0	0.0	0.0	0.0	9.4	1.0
11/5/07	23.5	3.2	0.4	1.3	0.4	0.0	0.0	0.0	0.0	19.4	1.8
11/8/07	13.1	1.9	0.2	0.6	0.3	0.0	0.0	4.4	1.0	6.0	1.1
11/11/07	23.8	3.8	0.5	2.2	0.5	0.0	0.0	5.5	1.4	11.7	1.9
11/14/07	*	*	*	*	*	*	*	*	*	*	*
11/17/07	9.1	0.7	0.2	1.5	0.3	1.7	0.8	0.0	0.0	5.2	1.1
11/20/07	18.4	2.4	0.3	0.6	0.3	0.0	0.0	3.8	0.9	11.8	1.7
11/23/07	11.7	1.3	0.2	0.6	0.2	0.0	0.0	2.3	0.7	7.4	1.1
11/26/07	12.7	1.8	0.2	0.6	0.2	0.0	0.0	3.9	1.0	6.0	1.1
11/29/07	29.3	5.0	0.6	2.0	0.6	11.6	3.1	0.0	0.0	9.7	2.8
12/2/07	5.4**	**	**	**	**	**	**	**	**	**	**
12/5/07	24.2	3.1	0.4	1.3	0.4	9.7	2.8	0.0	0.0	10.1	1.8
12/8/07	17.7	2.9	0.4	1.7	0.6	0.0	0.0	3.3	1.0	9.3	1.5
12/11/07	11.8	1.7	0.2	1.0	0.4	0.0	0.0	2.2	0.7	6.8	1.1
12/14/07	4.0**	**	**	**	**	**	**	**	**	**	**
12/17/07	25.6	4.5	0.6	1.8	0.7	0.0	0.0	2.9	1.2	16.5	2.4
12/20/07	*	*	*	*	*	*	*	*	*	*	*
12/23/07	32.5	6.3	0.8	2.4	1.2	0.0	0.0	6.7	1.6	18.0	2.8
12/26/07	13.0	3.0	0.4	1.5	0.4	0.0	0.0	1.5	0.7	7.0	1.2
12/29/07	16.4	2.7	0.3	1.8	0.6	0.0	0.0	4.1	0.9	7.9	1.4
1/1/08	24.4	5.0	0.6	1.3	0.7	7.3	3.6	0.0	0.0	10.2	1.9
1/4/08	10.2	1.4	0.2	1.3	0.3	0.0	0.0	1.2	0.6	6.9	1.1
1/7/08	20.8	4.2	0.5	1.7	0.7	0.0	0.0	3.4	1.1	11.2	1.7
1/10/08	7.3	1.5	0.2	0.6	0.2	0.0	0.0	0.0	0.0	5.2	0.7
1/13/08	8.4	1.4	0.2	0.5	0.2	0.0	0.0	0.0	0.0	6.3	0.8
1/16/08	25.1	3.9	0.5	1.9	0.5	7.5	3.1	0.0	0.0	12.4	2.1
1/19/08	26.4	4.4	0.5	2.6	0.6	0.0	0.0	5.6	1.5	13.2	2.1
1/22/08	7.8	1.4	0.2	0.5	0.3	0.0	0.0	1.6	0.6	4.6	0.8
1/25/08	18.2	4.4	0.5	1.5	0.7	0.0	0.0	2.8	1.1	9.5	1.6
1/28/08	24.4	4.3	0.5	1.4	0.5	8.3	2.7	0.0	0.0	8.5	2.4
1/31/08	26.2	4.6	0.6	2.6	0.6	0.0	0.0	0.0	0.0	19.0	1.8
2/3/08	24.2	4.6	0.6	2.1	0.6	0.0	0.0	0.0	0.0	16.5	1.9
2/6/08	68.0	17.1	2.1	5.0	2.2	0.0	0.0	0.0	0.0	48.3	6.0
2/9/08	43.7	11.1	1.4	3.5	1.4	0.0	0.0	0.0	0.0	27.4	3.7
2/12/08	9.5	2.1	0.3	0.8	0.3	0.0	0.0	0.0	0.0	7.3	1.1
2/15/08	8.7	1.8	0.2	0.6	0.2	0.0	0.0	0.0	0.0	6.1	0.9
2/18/08	14.9	2.0	0.3	1.2	0.5	0.0	0.0	3.6	0.9	8.3	1.4
2/21/08	7.5	1.1	0.1	0.8	0.2	0.0	0.0	0.0	0.0	6.2	0.8
2/24/08	*	*	*	*	*	*	*	*	*	*	*
2/27/08	17.2	3.1	0.4	1.2	0.5	0.0	0.0	2.2	0.8	11.3	1.7
3/1/08	5.2**	**	**	**	**	**	**	**	**	**	**
3/4/08	24.7	3.1	0.4	2.7	0.4	0.0	0.0	6.3	1.3	12.4	1.9
3/7/08	5.8**	**	**	**	**	**	**	**	**	**	**
3/10/08	*	*	*	*	*	*	*	*	*	*	*

3/13/08	11.0	2.1	0.3	2.0	0.3	0.0	0.0	0.0	0.0	7.1	0.9
3/16/08	*	*	*	*	*	*	*	*	*	*	*
3/19/08	6.6	1.3	0.2	0.6	0.2	0.0	0.0	0.0	0.0	4.5	0.7
3/22/08	10.1	2.3	0.3	1.0	0.3	0.0	0.0	0.0	0.0	6.4	0.9
3/25/08	5.7**	**	**	**	**	**	**	**	**	**	**
3/28/08	8.5	1.4	0.2	1.2	0.2	0.0	0.0	0.0	0.0	6.0	0.8
3/31/08	5.7**	**	**	**	**	**	**	**	**	**	**
Average	**18.7**	**3.4**	**0.4**	**1.5**	**0.5**	**1.2**	**0.4**	**1.7**	**0.5**	**10.9**	**1.6**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
State Building – Winter 2007/2008.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/07	11.0	0.8	0.2	0.8	0.1	0.0	0.0	3.2	0.7	0.0	0.0	7.8	1.0
11/5/07	23.5	1.2	0.4	1.1	0.3	0.0	0.0	9.8	1.8	2.1	1.0	10.6	2.3
11/8/07	13.1	1.0	0.2	0.5	0.1	0.0	0.0	4.5	0.8	2.4	1.2	4.3	1.3
11/11/07	23.8	2.2	0.5	1.6	0.3	0.0	0.0	8.9	1.8	2.9	1.3	7.4	1.9
11/14/07	*	*	*	*	*	*	*	*	*	*	*	*	*
11/17/07	9.1	0.4	0.1	1.3	0.1	0.0	0.0	2.2	0.4	1.1	0.5	4.5	0.9
11/20/07	18.4	1.3	0.3	0.4	0.2	0.0	0.0	6.7	1.1	2.0	0.8	8.3	1.4
11/23/07	11.7	0.9	0.2	0.5	0.1	5.2	2.2	3.2	0.7	0.0	0.0	1.8	0.4
11/26/07	12.7	0.9	0.2	0.5	0.1	0.0	0.0	4.6	0.8	2.6	1.0	3.7	1.1
11/29/07	29.3	2.6	0.6	1.3	0.4	0.0	0.0	12.9	2.2	3.1	1.4	7.7	2.3
12/2/07	5.4**	**	**	**	**	**	**	**	**	**	**	**	**
12/5/07	24.2	1.6	0.4	1.0	0.2	0.0	0.0	7.9	1.3	2.6	1.1	10.0	2.4
12/8/07	17.7	1.8	0.4	1.2	0.3	6.3	2.6	6.7	1.4	0.0	0.0	1.8	0.6
12/11/07	11.8	1.0	0.2	0.7	0.1	0.0	0.0	3.5	0.8	0.0	0.0	6.4	1.0
12/14/07	4.0**	**	**	**	**	**	**	**	**	**	**	**	**
12/17/07	25.6	2.2	0.5	0.9	0.3	0.0	0.0	11.9	1.8	0.0	0.0	10.3	1.9
12/20/07	*	*	*	*	*	*	*	*	*	*	*	*	*
12/23/07	32.5	3.2	0.8	1.1	0.4	0.0	0.0	18.2	2.7	7.0	1.7	2.7	1.0
12/26/07	13.0	1.9	0.4	1.0	0.3	0.0	0.0	6.3	1.5	0.0	0.0	4.1	1.3
12/29/07	16.4	1.5	0.4	1.3	0.4	0.0	0.0	6.7	2.1	2.4	0.9	5.3	2.1
1/1/08	24.4	3.8	0.7	1.2	0.5	0.0	0.0	5.6	2.6	0.0	0.0	14.9	3.3
1/4/08	10.2	0.8	0.2	1.0	0.1	0.0	0.0	3.0	0.7	0.0	0.0	6.0	0.9
1/7/08	20.8	2.4	0.6	0.9	0.4	0.0	0.0	10.3	2.3	1.9	0.9	5.3	2.0
1/10/08	7.3	0.9	0.2	0.5	0.1	0.0	0.0	3.6	0.7	0.0	0.0	2.9	0.8
1/13/08	8.4	0.9	0.2	0.5	0.1	0.0	0.0	3.1	0.7	0.0	0.0	4.6	0.9
1/16/08	25.1	1.9	0.4	1.6	0.3	0.0	0.0	10.4	1.6	0.0	0.0	12.4	2.5
1/19/08	26.4	2.1	0.5	1.8	0.3	0.0	0.0	11.5	1.9	0.0	0.0	9.9	1.9
1/22/08	7.8	1.0	0.2	0.3	0.1	0.0	0.0	2.6	0.7	0.0	0.0	3.8	0.8
1/25/08	18.2	2.6	0.6	0.7	0.4	0.0	0.0	10.3	2.1	0.0	0.0	4.7	1.7
1/28/08	24.4	2.2	0.5	0.8	0.4	0.0	0.0	11.2	2.0	1.7	0.8	8.5	2.8
1/31/08	26.2	2.3	0.5	2.4	0.4	0.0	0.0	12.3	2.0	0.0	0.0	7.3	2.7
2/3/08	24.2	2.5	0.6	1.3	0.4	0.0	0.0	11.3	2.1	0.0	0.0	8.2	2.0
2/6/08	68.0	8.5	1.6	1.9	1.1	0.0	0.0	48.1	3.5	0.0	0.0	0.0	0.0
2/9/08	43.7	6.3	1.3	1.5	0.9	0.0	0.0	27.1	5.0	0.0	0.0	9.1	4.0
2/12/08	9.5	1.1	0.3	0.4	0.2	0.0	0.0	5.0	0.9	1.3	0.6	1.3	0.4
2/15/08	8.7	1.0	0.2	0.3	0.1	0.0	0.0	4.0	0.8	0.0	0.0	3.0	0.9
2/18/08	14.9	1.1	0.3	0.8	0.3	0.0	0.0	5.2	1.6	1.9	0.7	5.8	1.6
2/21/08	7.5	0.7	0.2	0.6	0.1	0.0	0.0	2.2	0.6	2.2	0.9	1.3	0.3
2/24/08	*	*	*	*	*	*	*	*	*	*	*	*	*
2/27/08	17.2	1.8	0.4	1.0	0.3	0.0	0.0	7.6	1.4	0.0	0.0	8.2	1.5
3/1/08	5.2**	**	**	**	**	**	**	**	**	**	**	**	**
3/4/08	24.7	1.7	0.4	2.1	0.3	0.0	0.0	7.8	1.5	3.6	1.3	8.8	1.8
3/7/08	5.8**	**	**	**	**	**	**	**	**	**	**	**	**
3/10/08	*	*	*	*	*	*	*	*	*	*	*	*	*

3/13/08	11.0	1.3	0.3	1.7	0.2	0.0	0.0	3.9	1.1	0.0	0.0	4.9	1.1
3/16/08	*	*	*	*	*	*	*	*	*	*	*	*	*
3/19/08	6.6	0.8	0.2	0.3	0.1	0.0	0.0	3.0	0.6	0.0	0.0	2.5	0.7
3/22/08	10.1	1.3	0.3	0.6	0.2	0.0	0.0	5.3	1.0	0.0	0.0	2.3	1.0
3/25/08	5.7**	**	**	**	**	**	**	**	**	**	**	**	**
3/28/08	8.5	0.8	0.2	1.0	0.1	0.0	0.0	2.9	0.7	0.0	0.0	3.6	0.8
3/31/08	5.7**	**	**	**	**	**	**	**	**	**	**	**	**
Average	**18.7**	**1.9**	**0.4**	**1.0**	**0.3**	**0.3**	**0.1**	**8.4**	**1.5**	**1.0**	**0.4**	**5.9**	**1.5**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
State Building – Winter 2008/2009.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/8/08	40.0	4.7	0.6	2.8	0.6	0.0	0.0	2.3	1.1	27.0	3.6
11/11/08	31.9	3.6	0.4	2.0	0.5	10.7	3.2	0.0	0.0	17.2	2.6
11/14/08	52.1	8.8	1.1	4.5	1.1	14.6	5.9	0.0	0.0	26.2	4.2
11/17/08	20.7	2.7	0.3	2.0	0.4	0.0	0.0	0.0	0.0	15.4	2.0
11/20/08	16.8	3.0	0.4	1.2	0.5	2.7	1.3	0.0	0.0	11.7	2.0
11/23/08	23.4	3.6	0.4	2.1	0.6	0.0	0.0	2.8	1.0	14.6	2.2
11/26/08	22.0	3.0	0.5	1.5	0.6	4.0	1.5	0.0	0.0	13.5	2.3
11/29/08	16.4	2.3	0.3	1.6	0.3	0.0	0.0	0.0	0.0	12.0	1.6
12/2/08	47.0	10.5	1.3	3.2	1.3	0.0	0.0	0.0	0.0	28.1	3.8
12/5/08	31.0	4.1	0.5	2.2	0.5	11.1	3.4	0.0	0.0	15.5	2.5
12/8/08	*	*	*	*	*	*	*	*	*	*	*
12/11/08	18.9	2.9	0.4	1.5	0.5	2.6	1.3	0.0	0.0	12.5	2.1
12/14/08	39.0	7.0	0.9	3.0	0.9	0.0	0.0	0.0	0.0	24.2	3.1
12/17/08	34.9	7.3	0.9	2.3	0.9	0.0	0.0	3.1	1.5	21.4	3.0
12/20/08	26.1	4.3	0.5	2.6	0.6	0.0	0.0	0.0	0.0	18.0	2.4
12/23/08	47.5	5.5	0.7	2.8	0.7	0.0	0.0	0.0	0.0	38.5	3.3
12/26/08	15.9	2.6	0.4	1.1	0.6	3.6	1.4	0.0	0.0	9.0	1.8
12/29/08	66.0	28.8	3.5	2.4	3.7	0.0	0.0	0.0	0.0	55.2	6.5
1/1/09	28.2	5.2	0.6	2.2	0.7	0.0	0.0	0.0	0.0	18.2	2.4
1/4/09	37.3	6.8	0.8	1.9	0.8	10.2	4.7	0.0	0.0	20.1	3.2
1/7/09	63.7	17.6	2.2	4.0	2.2	0.0	0.0	0.0	0.0	35.2	5.0
1/10/09	56.7	16.1	2.0	3.7	2.0	0.0	0.0	0.0	0.0	33.5	4.7
1/13/09	31.4	5.9	0.8	3.3	1.0	5.4	2.3	0.0	0.0	17.6	3.1
1/16/09	2.3**	**	**	**	**	**	**	**	**	**	**
1/19/09	8.2	1.7	0.2	1.4	0.2	0.0	0.0	0.0	0.0	3.9	0.7
1/22/09	6.4	1.4	0.2	0.5	0.2	0.0	0.0	0.0	0.0	5.1	0.8
1/25/09	26.7	4.3	0.5	3.7	0.6	0.0	0.0	0.0	0.0	18.2	2.4
1/28/09	31.5	8.3	1.0	2.5	1.0	0.0	0.0	0.0	0.0	20.1	2.8
1/31/09	13.4	3.0	0.4	1.3	0.4	0.0	0.0	0.0	0.0	9.1	1.3
2/3/09	18.7	4.4	0.5	1.7	0.6	0.0	0.0	0.0	0.0	13.4	1.8
2/5/09	43.1	7.2	0.8	4.6	0.9	0.0	0.0	0.0	0.0	26.9	3.2
2/6/09	*	*	*	*	*	*	*	*	*	*	*
2/7/09	32.6	6.2	0.7	3.4	0.8	0.0	0.0	0.0	0.0	22.7	2.8
2/9/09	12.3	2.0	0.2	1.3	0.3	0.0	0.0	0.0	0.0	8.5	1.2
2/12/09	18.6	2.7	0.3	2.4	0.4	0.0	0.0	1.5	0.8	12.5	1.8
2/15/09	29.6	5.3	0.7	3.4	0.7	7.6	3.8	0.0	0.0	14.6	2.4
2/18/09	23.3	4.8	0.6	1.7	0.6	0.0	0.0	0.0	0.0	16.5	4.3
2/21/09	15.6	3.0	0.4	1.2	0.4	0.0	0.0	0.0	0.0	11.7	1.6
2/24/09	19.6	3.2	0.4	2.3	0.5	4.5	2.2	0.0	0.0	9.1	2.1
2/27/09	6.9	1.6	0.2	0.6	0.2	0.0	0.0	0.0	0.0	4.7	1.4
3/2/09	15.7	2.9	0.4	1.3	0.4	4.5	2.0	0.0	0.0	6.7	1.8
3/5/09	5.7**	**	**	**	**	**	**	**	**	**	**
3/8/09	10.2	2.5	0.3	0.7	0.3	0.0	0.0	0.0	0.0	6.5	0.9
3/11/09	16.1	2.1	0.3	2.4	0.4	0.0	0.0	1.8	0.7	9.8	1.4

3/14/09	14.9	3.1	0.4	1.0	0.4	0.0	0.0	0.0	0.0	10.2	1.3
3/17/09	10.0	2.6	0.3	0.8	0.3	0.0	0.0	0.0	0.0	6.4	1.0
3/20/09	*	*	*	*	*	*	*	*	*	*	*
3/23/09	9.6	2.3	0.3	1.0	0.3	0.0	0.0	0.0	0.0	6.0	0.9
3/26/09	*	*	*	*	*	*	*	*	*	*	*
3/29/09	10.0	2.1	0.3	1.0	0.3	0.0	0.0	1.5	0.7	5.4	0.9
4/1/09	9.6	1.8	0.2	1.1	0.3	0.0	0.0	0.0	0.0	6.6	1.0
4/4/09	7.8	1.6	0.2	0.6	0.2	0.0	0.0	0.0	0.0	5.7	0.9
4/7/09	10.4	2.3	0.3	1.3	0.3	0.0	0.0	0.0	0.0	6.8	0.9
Average	**25.3**	**5.1**	**0.6**	**2.1**	**0.7**	**1.7**	**0.7**	**0.3**	**0.1**	**16.0**	**2.3**

Notes: *No or incomplete CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
State Building – Winter 2008/2009.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/8/08	40.0	2.8	0.6	1.8	0.4	11.9	2.3	19.0	2.6
11/11/08	31.9	1.7	0.4	1.3	0.3	8.9	1.4	22.2	2.8
11/14/08	52.1	8.7	1.1	4.4	1.1	0.0	0.0	31.4	2.6
11/17/08	20.7	1.6	0.4	1.5	0.3	5.9	1.3	11.1	1.5
11/20/08	16.8	3.2	0.4	1.1	0.4	0.0	0.0	13.9	1.2
11/23/08	23.4	2.1	0.5	1.5	0.3	8.2	1.7	11.2	1.8
11/26/08	22.0	1.9	0.4	0.9	0.3	7.8	1.5	11.7	1.7
11/29/08	16.4	1.4	0.3	1.2	0.2	4.8	1.1	8.5	1.3
12/2/08	47.0	10.5	1.3	3.1	1.3	0.0	0.0	28.3	2.6
12/5/08	31.0	2.3	0.5	1.5	0.3	9.7	1.9	13.2	1.9
12/8/08	*	*	*	*	*	*	*	*	*
12/11/08	18.9	3.1	0.4	1.5	0.4	0.0	0.0	14.6	1.3
12/14/08	39.0	7.0	0.9	2.8	0.9	0.0	0.0	24.3	2.1
12/17/08	34.9	7.5	0.9	2.2	0.9	0.0	0.0	23.2	2.1
12/20/08	26.1	2.6	0.5	1.9	0.4	9.6	2.1	11.0	2.0
12/23/08	47.5	5.2	0.6	2.7	0.7	0.0	0.0	30.8	2.6
12/26/08	15.9	2.9	0.4	1.1	0.4	0.0	0.0	11.9	1.1
12/29/08	66.0	28.6	3.5	5.8	3.6	0.0	0.0	21.7	2.1
1/1/09	28.2	3.6	0.7	1.4	0.5	9.0	2.7	12.1	2.4
1/4/09	37.3	4.0	0.8	0.7	0.5	15.0	3.1	13.5	2.8
1/7/09	63.7	17.5	2.1	3.8	2.2	0.0	0.0	36.0	3.5
1/10/09	56.7	16.0	2.0	3.5	2.0	0.0	0.0	34.0	3.3
1/13/09	31.4	6.4	0.8	3.2	0.8	0.0	0.0	22.0	1.9
1/16/09	2.3**	**	**	**	**	**	**	**	**
1/19/09	8.2	1.2	0.2	1.2	0.2	2.5	1.0	2.6	0.9
1/22/09	6.4	1.4	0.2	0.4	0.2	0.0	0.0	5.2	0.6
1/25/09	26.7	2.4	0.5	2.9	0.4	10.7	2.2	10.3	2.1
1/28/09	31.5	8.2	1.0	2.4	1.0	0.0	0.0	20.5	1.9
1/31/09	13.4	3.0	0.4	1.2	0.4	0.0	0.0	9.2	1.0
2/3/09	18.7	4.3	0.5	1.6	0.6	0.0	0.0	13.5	1.3
2/5/09	43.1	7.1	0.8	4.5	0.9	0.0	0.0	26.9	1.9
2/6/09	*	*	*	*	*	*	*	*	*
2/7/09	32.6	3.6	0.7	2.3	0.5	14.3	2.8	13.1	2.4
2/9/09	12.3	1.3	0.3	1.1	0.2	4.1	1.0	5.8	1.1
2/12/09	18.6	2.8	0.3	2.7	0.4	0.0	0.0	13.3	1.2
2/15/09	29.6	4.9	0.6	4.1	0.7	0.0	0.0	18.1	1.6
2/18/09	23.3	4.7	0.6	2.2	0.6	0.0	0.0	13.9	1.3
2/21/09	15.6	2.9	0.4	1.6	0.4	0.0	0.0	11.6	1.1
2/24/09	19.6	1.8	0.4	2.2	0.3	7.9	1.6	7.0	1.5
2/27/09	6.9	1.0	0.2	0.5	0.1	2.9	0.8	2.0	0.8
3/2/09	15.7	1.6	0.3	1.3	0.3	6.6	1.3	5.9	1.3
3/5/09	5.7**	**	**	**	**	**	**	**	**
3/8/09	10.2	2.4	0.3	0.9	0.3	0.0	0.0	6.3	0.8
3/11/09	16.1	1.3	0.3	2.3	0.3	4.1	1.2	8.5	1.3

3/14/09	14.9	1.6	0.4	0.8	0.2	7.9	1.3	4.3	1.3
3/17/09	10.0	2.6	0.3	1.1	0.3	0.0	0.0	6.6	0.8
3/20/09	*	*	*	*	*	*	*	*	*
3/23/09	9.6	2.3	0.3	1.2	0.3	0.0	0.0	6.2	0.7
3/26/09	*	*	*	*	*	*	*	*	*
3/29/09	10.0	2.1	0.3	1.2	0.3	0.0	0.0	6.7	0.8
4/1/09	9.6	1.1	0.2	1.1	0.2	3.7	0.9	3.4	1.3
4/4/09	7.8	0.9	0.2	0.5	0.1	3.9	0.7	1.4	0.7
4/7/09	10.4	1.4	0.3	1.2	0.2	5.0	1.1	2.8	1.0
Average	**25.3**	**4.4**	**0.6**	**1.9**	**0.6**	**3.5**	**0.7**	**13.8**	**1.7**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – Revised OMNI Profiles (with auto / diesel). State Building – Winter 2008/2009.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/8/08	40.0	2.8	0.6	1.8	0.4	11.9	2.3	**0.0**	**0.0**	**0.0**	**0.0**	19.0	2.6
11/11/08	31.9	1.7	0.4	1.3	0.3	8.9	1.8	**0.0**	**0.0**	1.6	0.8	19.6	3.1
11/14/08	52.1	3.2	0.9	2.5	0.5	29.7	3.2	**0.0**	**0.0**	**0.0**	**0.0**	18.1	4.9
11/17/08	20.7	1.6	0.4	1.5	0.3	5.9	1.3	**0.0**	**0.0**	**0.0**	**0.0**	11.1	1.5
11/20/08	16.8	1.8	0.4	0.6	0.3	7.8	1.4	**0.0**	**0.0**	**0.0**	**0.0**	8.7	1.5
11/23/08	23.4	2.1	0.5	1.5	0.3	8.2	1.7	**0.0**	**0.0**	**0.0**	**0.0**	11.2	1.8
11/26/08	22.0	1.9	0.4	0.9	0.3	7.8	1.5	**0.0**	**0.0**	**0.0**	**0.0**	11.7	1.7
11/29/08	16.4	1.4	0.3	1.2	0.2	4.8	1.1	**0.0**	**0.0**	**0.0**	**0.0**	8.5	1.3
12/2/08	47.0	5.4	1.2	**0.0**	**0.0**	28.5	4.1	**0.0**	**0.0**	**0.0**	**0.0**	8.3	3.6
12/5/08	31.0	1.6	0.5	1.4	0.5	11.3	2.4	2.9	1.4	**0.0**	**0.0**	13.8	3.4
12/8/08	*	*	*	*	*	*	*	*	*	*	*	*	*
12/11/08	18.9	1.5	0.3	0.9	0.2	8.6	1.3	**0.0**	**0.0**	**0.0**	**0.0**	8.3	1.5
12/14/08	39.0	3.0	0.7	1.5	0.4	21.4	2.7	**0.0**	**0.0**	**0.0**	**0.0**	15.4	4.1
12/17/08	34.9	3.8	0.8	**0.0**	**0.0**	21.0	2.9	**0.0**	**0.0**	**0.0**	**0.0**	9.0	2.7
12/20/08	26.1	2.6	0.5	1.9	0.4	9.6	2.1	0.0	0.0	0.0	0.0	11.0	2.0
12/23/08	47.5	5.2	0.6	2.7	0.7	0.0	0.0	0.0	0.0	0.0	0.0	30.8	2.6
12/26/08	15.9	1.7	0.4	0.6	0.2	7.0	1.4	**0.0**	**0.0**	**0.0**	**0.0**	7.3	1.4
12/29/08	*	*	*	*	*	*	*	*	*	*	*	*	*
1/1/09	28.2	3.6	0.7	1.4	0.5	9.0	2.7	0.0	0.0	0.0	0.0	12.1	2.4
1/4/09	37.3	3.4	0.7	**0.0**	**0.0**	17.4	2.4	**0.0**	**0.0**	**0.0**	**0.0**	19.1	4.0
1/7/09	63.7	8.6	1.7	**0.0**	**0.0**	50.5	3.6	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
1/10/09	56.7	7.8	1.5	**0.0**	**0.0**	46.9	3.3	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
1/13/09	31.4	3.8	0.8	2.2	0.6	14.6	3.0	**0.0**	0.0	**0.0**	**0.0**	12.4	2.7
1/16/09	2.3**	**	**	**	**	**	**	**	**	**	**	**	**
1/19/09	8.2	1.2	0.2	1.2	0.2	2.5	1.0	**0.0**	**0.0**	**0.0**	**0.0**	2.6	0.9
1/22/09	6.4	0.9	0.2	0.3	0.1	2.6	0.7	**0.0**	**0.0**	**0.0**	**0.0**	3.4	0.8
1/25/09	26.7	2.4	0.5	2.9	0.4	10.7	2.2	0.0	0.0	0.0	0.0	10.3	2.1
1/28/09	31.5	4.2	0.9	**0.0**	**0.0**	22.3	3.0	**0.0**	**0.0**	**0.0**	**0.0**	8.8	4.3
1/31/09	13.4	1.8	0.4	0.8	0.3	6.5	1.4	**0.0**	**0.0**	**0.0**	**0.0**	4.8	1.3
2/3/09	18.7	2.9	0.6	1.1	0.4	8.4	2.2	**0.0**	**0.0**	**0.0**	**0.0**	7.8	1.9
2/5/09	43.1	3.7	0.7	3.1	0.6	19.3	3.0	**0.0**	**0.0**	**0.0**	**0.0**	13.5	2.6
2/6/09	*	*	*	*	*	*	*	*	*	*	*	*	*
2/7/09	32.6	3.6	0.7	2.3	0.5	14.3	2.8	**0.0**	**0.0**	**0.0**	**0.0**	13.1	2.4
2/9/09	12.3	1.3	0.3	1.1	0.2	4.1	1.0	**0.0**	**0.0**	**0.0**	**0.0**	5.8	1.1
2/12/09	18.6	1.7	0.4	2.2	0.3	5.9	1.4	**0.0**	**0.0**	**0.0**	**0.0**	9.1	1.5
2/15/09	29.6	2.9	0.7	3.1	0.5	12.8	2.6	**0.0**	**0.0**	**0.0**	**0.0**	8.6	2.2
2/18/09	23.3	2.9	0.6	1.5	0.4	10.0	2.3	**0.0**	**0.0**	**0.0**	**0.0**	7.2	2.0
2/21/09	15.6	1.3	0.3	1.0	0.2	9.5	1.3	**0.0**	**0.0**	**0.0**	**0.0**	5.0	1.3
2/24/09	19.6	1.8	0.4	2.2	0.3	7.9	1.6	**0.0**	**0.0**	**0.0**	**0.0**	7.0	1.5
2/27/09	6.9	1.0	0.2	0.5	0.1	2.9	0.8	**0.0**	**0.0**	**0.0**	**0.0**	2.0	0.8
3/2/09	15.7	1.6	0.3	1.3	0.3	6.6	1.3	**0.0**	**0.0**	**0.0**	**0.0**	5.9	1.3
3/5/09	5.7**	**	**	**	**	**	**	**	**	**	**	**	**
3/8/09	10.2	1.5	0.3	0.5	0.2	5.7	1.1	**0.0**	**0.0**	**0.0**	**0.0**	3.3	1.6
3/11/09	16.1	1.3	0.3	2.3	0.3	4.1	1.2	**0.0**	**0.0**	**0.0**	**0.0**	8.5	1.3

3/14/09	14.9	1.6	0.4	0.8	0.2	7.9	1.3	**0.0**	**0.0**	**0.0**	**0.0**	4.3	1.3
3/17/09	10.0	1.1	0.3	0.6	0.2	8.4	0.7	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
3/20/09	*	*	*	*	*	*	*	*	*	*	*	*	*
3/23/09	9.6	1.4	0.3	0.9	0.2	5.0	1.1	**0.0**	**0.0**	**0.0**	**0.0**	2.9	1.0
3/26/09	*	*	*	*	*	*	*	*	*	*	*	*	*
3/29/09	10.0	1.4	0.3	0.8	0.2	4.6	1.1	**0.0**	**0.0**	**0.0**	**0.0**	3.0	1.0
4/1/09	9.6	1.1	0.2	1.1	0.2	3.7	0.9	**0.0**	**0.0**	**0.0**	**0.0**	3.4	1.3
4/4/09	7.8	0.8	0.2	0.5	0.1	4.0	0.7	**0.0**	**0.0**	**0.0**	**0.0**	2.1	1.1
4/7/09	10.4	1.4	0.3	1.2	0.2	5.0	1.1	**0.0**	**0.0**	**0.0**	**0.0**	2.8	1.0
Average	**25.3**	**2.5**	**0.5**	**1.2**	**0.3**	**11.4**	**1.8**	**0.06**	**0.03**	**0.04**	**0.02**	**8.7**	**1.9**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
North Pole – Winter 2008/2009.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
1/25/09	39.8	2.6	0.3	1.7	0.3	0.0	0.0	0.0	0.0	29.9	3.3
1/28/09	13.8	2.0	0.2	0.9	0.2	0.0	0.0	0.0	0.0	10.7	1.4
1/31/09	9.7	1.3	0.1	0.5	0.2	0.0	0.0	0.0	0.0	7.4	0.9
2/3/09	15.0	1.7	0.2	0.8	0.2	0.0	0.0	0.0	0.0	14.0	1.7
2/5/09	32.1	2.9	0.3	2.4	0.6	3.4	1.0	0.0	0.0	23.8	3.0
2/6/09	26.0	1.9	0.2	1.4	0.3	0.0	0.0	5.0	2.3	18.3	2.4
2/7/09	61.7	5.4	0.6	2.7	0.7	0.0	0.0	0.0	0.0	53.5	5.8
2/9/09	6.0	1.0	0.1	0.7	0.1	0.0	0.0	0.0	0.0	5.3	0.7
2/12/09	32.0	2.1	0.2	1.3	0.3	0.0	0.0	4.8	2.4	24.5	3.1
2/15/09	34.3	2.3	0.3	1.5	0.3	0.0	0.0	0.0	0.0	28.4	3.2
2/18/09	*	*	*	*	*	*	*	*	*	*	*
2/21/09	10.3	1.3	0.1	0.5	0.2	0.0	0.0	0.0	0.0	8.1	1.1
2/24/09	26.1	1.9	0.2	1.1	0.3	0.0	0.0	4.6	2.2	18.3	2.4
2/27/09	6.7	1.4	0.2	0.7	0.2	0.0	0.0	0.0	0.0	4.4	0.7
3/2/09	10.4	1.3	0.1	0.7	0.2	0.0	0.0	0.0	0.0	7.7	1.0
3/5/09	**4.7****	**	**	**	**	**	**	**	**	**	**
3/8/09	6.1	1.1	0.1	0.4	0.1	0.0	0.0	0.0	0.0	4.6	0.7
3/11/09	12.5	1.0	0.1	0.8	0.1	0.0	0.0	0.0	0.0	11.3	2.4
3/14/09	14.1	2.0	0.2	0.6	0.3	0.0	0.0	0.0	0.0	12.1	1.5
3/17/09	**3.8****	**	**	**	**	**	**	**	**	**	**
3/20/09	**4.6****	**	**	**	**	**	**	**	**	**	**
3/23/09	**4.5****	**	**	**	**	**	**	**	**	**	**
3/26/09	**3.0****	**	**	**	**	**	**	**	**	**	**
3/29/09	11.8	1.8	0.2	0.7	0.2	0.0	0.0	0.0	0.0	9.8	2.1
4/1/09	10.6	1.3	0.1	0.5	0.2	0.0	0.0	0.0	0.0	8.2	1.7
4/4/09	7.5	1.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	5.6	1.3
4/7/09	11.4	1.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	9.2	1.2
Average	**18.9**	**1.9**	**0.2**	**1.0**	**0.2**	**0.2**	**0.0**	**0.7**	**0.3**	**15.0**	**2.0**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
North Pole – Winter 2008/2009.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
1/25/09	39.8	1.2	0.2	1.2	0.2	6.3	0.9	30.0	2.4
1/28/09	13.8	1.4	0.2	0.7	0.2	3.1	1.0	8.5	1.1
1/31/09	9.7	0.8	0.1	0.4	0.1	2.2	0.6	5.6	0.8
2/3/09	15.0	1.6	0.2	0.9	0.2	0.0	0.0	13.6	1.0
2/5/09	32.1	1.7	0.3	1.8	0.3	6.5	1.4	21.7	1.8
2/6/09	26.0	0.8	0.2	1.2	0.1	4.9	0.7	20.1	1.8
2/7/09	61.7	5.3	0.6	2.5	0.7	0.0	0.0	48.4	2.7
2/9/09	6.0	1.0	0.1	0.8	0.1	0.0	0.0	5.7	0.6
2/12/09	32.0	1.3	0.2	0.9	0.2	4.0	1.0	22.2	1.6
2/15/09	34.3	1.5	0.3	1.3	0.2	4.6	1.1	22.6	1.7
2/18/09	*	*	*	*	*	*	*	*	*
2/21/09	10.3	1.0	0.2	0.5	0.1	1.6	0.7	7.0	0.9
2/24/09	26.1	1.1	0.2	0.9	0.2	3.7	0.9	16.9	1.4
2/27/09	6.7	1.3	0.1	0.8	0.2	0.0	0.0	4.3	0.6
3/2/09	10.4	1.0	0.2	0.6	0.1	1.7	0.7	6.5	0.8
3/5/09	4.7**	**	**	**	**	**	**	**	**
3/8/09	6.1	1.0	0.1	0.4	0.1	0.0	0.0	4.4	0.6
3/11/09	12.5	0.7	0.1	0.7	0.1	1.4	0.6	8.3	0.9
3/14/09	14.1	1.9	0.2	0.7	0.2	0.0	0.0	12.0	0.9
3/17/09	3.8**	**	**	**	**	**	**	**	**
3/20/09	4.6**	**	**	**	**	**	**	**	**
3/23/09	4.5**	**	**	**	**	**	**	**	**
3/26/09	3.0**	**	**	**	**	**	**	**	**
3/29/09	11.8	1.2	0.2	0.6	0.2	3.2	0.9	5.7	0.9
4/1/09	10.6	1.2	0.1	0.6	0.2	0.0	0.0	8.0	0.9
4/4/09	7.5	1.2	0.1	0.4	0.2	0.0	0.0	5.8	0.8
4/7/09	11.4	1.5	0.2	0.5	0.2	0.0	0.0	9.1	0.8
Average	**18.9**	**1.4**	**0.2**	**0.9**	**0.2**	**2.1**	**0.5**	**13.6**	**1.2**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles. RAMS – Winter 2008/2009.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Wood Smoke	Wood Smoke STD ERR
1/25/09	12.5	1.4	0.2	1.5	0.2	8.8	1.2
1/28/09	7.8	0.9	0.1	0.6	0.1	6.3	0.9
1/31/09	7.2	0.9	0.1	0.6	0.1	6.1	0.9
2/3/09	10.5	1.4	0.2	1.1	0.2	8.4	1.1
2/5/09	8.8	0.7	0.1	0.8	0.1	7.4	0.8
2/6/09	8.5	0.6	0.1	0.9	0.1	7.1	1.0
2/7/09	11.3	1.1	0.1	1.3	0.2	8.8	0.9
2/9/09	5.3	0.7	0.1	0.9	0.1	4.2	0.6
2/12/09	11.8	1.5	0.2	1.6	0.2	8.8	0.9
2/15/09	9.6	0.9	0.1	1.3	0.1	7.4	1.0
2/18/09	6.5	0.7	0.1	0.8	0.1	5.0	0.7
2/21/09	6.2	1.0	0.1	0.6	0.1	4.7	0.7
2/24/09	10.7	1.1	0.1	1.5	0.2	7.6	1.0
2/27/09	6.3	1.0	0.1	0.6	0.1	4.7	0.7
3/2/09	7.4	1.2	0.1	0.7	0.2	5.4	0.7
3/5/09	6.0	1.0	0.1	0.8	0.1	4.4	0.6
3/8/09	6.0	0.9	0.1	0.5	0.1	4.2	0.7
3/11/09	6.3	0.8	0.1	0.8	0.1	5.1	1.2
3/14/09	6.3	1.1	0.1	0.8	0.1	4.4	0.6
3/17/09	4.4**	**	**	**	**	**	**
3/20/09	*	*	*	*	*	*	*
3/23/09	4.7**	**	**	**	**	**	**
3/26/09	3.8**	**	**	**	**	**	**
3/29/09	7.7	1.4	0.2	0.4	0.2	5.6	0.7
4/1/09	9.3	1.7	0.2	1.1	0.2	6.8	1.0
4/4/09	8.3	1.3	0.2	0.4	0.2	6.3	0.8
4/7/09	9.2	1.6	0.2	0.6	0.2	7.6	0.9
Average	**8.2**	**1.1**	**0.1**	**0.9**	**0.1**	**6.3**	**0.8**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles. RAMS – Winter 2008/2009.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
1/25/09	12.5	0.9	0.2	1.2	0.2	2.5	0.7	7.2	0.9
1/28/09	7.8	0.5	0.1	0.4	0.1	1.7	0.4	5.1	0.7
1/31/09	7.2	0.8	0.1	0.6	0.1	0.0	0.0	6.2	0.6
2/3/09	10.5	0.8	0.1	0.8	0.1	3.3	0.6	6.1	0.9
2/5/09	8.8	0.4	0.1	0.7	0.1	1.0	0.3	6.8	0.7
2/6/09	8.5	0.6	0.1	0.9	0.1	0.0	0.0	7.1	0.7
2/7/09	11.3	0.6	0.1	1.1	0.1	2.0	0.5	8.2	0.9
2/9/09	5.3	0.6	0.1	0.9	0.1	0.0	0.0	4.4	0.5
2/12/09	11.8	1.4	0.2	1.5	0.2	0.0	0.0	9.9	0.8
2/15/09	9.6	0.7	0.1	1.2	0.1	1.2	0.6	6.6	0.8
2/18/09	6.5	0.6	0.1	0.8	0.1	0.0	0.0	5.9	0.8
2/21/09	6.2**	**	**	**	**	**	**	**	**
2/24/09	10.7	0.8	0.2	1.3	0.1	1.6	0.7	6.6	0.8
2/27/09	6.3	1.0	0.1	0.6	0.1	0.0	0.0	5.1	0.8
3/2/09	7.4	0.4	0.1	0.6	0.1	4.2	0.4	2.2	0.6
3/5/09	6.0	0.7	0.1	0.7	0.1	1.2	0.5	2.7	0.7
3/8/09	6.0	0.7	0.1	0.4	0.1	1.2	0.5	3.5	0.6
3/11/09	6.3	0.8	0.1	0.8	0.1	0.0	0.0	3.9	0.5
3/14/09	6.3	1.1	0.1	0.8	0.1	0.0	0.0	4.9	0.6
3/17/09	4.4**	**	**	**	**	**	**	**	**
3/20/09	*	*	*	*	*	*	*	*	*
3/23/09	4.7**	**	**	**	**	**	**	**	**
3/26/09	3.8**	**	**	**	**	**	**	**	**
3/29/09	7.7	0.9	0.2	0.3	0.1	2.4	0.6	4.4	0.8
4/1/09	9.3	1.2	0.2	0.9	0.2	2.5	0.9	4.9	1.3
4/4/09	8.3	0.8	0.1	0.2	0.1	2.9	0.6	3.6	1.0
4/7/09	9.2	0.9	0.2	0.3	0.1	3.7	0.7	4.1	1.1
Average	**8.3**	**0.8**	**0.1**	**0.8**	**0.1**	**1.4**	**0.4**	**5.4**	**0.8**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
Peger Road – Winter 2008/2009.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
1/25/09	28.6	4.1	0.5	3.5	0.5	0.0	0.0	3.8	1.4	16.5	2.2
1/28/09	31.3	7.7	0.9	2.5	1.0	0.0	0.0	0.0	0.0	20.6	2.6
1/31/09	13.5	2.4	0.3	0.9	0.3	0.0	0.0	0.0	0.0	10.0	2.7
2/3/09	17.8	3.2	0.4	1.1	0.4	0.0	0.0	0.0	0.0	13.2	1.7
2/5/09	48.0	7.6	0.8	3.8	1.0	17.3	5.2	0.0	0.0	23.9	3.5
2/6/09	*	*	*	*	*	*	*	*	*	*	*
2/7/09	32.7	4.8	0.6	2.5	0.6	0.0	0.0	3.1	1.1	22.4	2.8
2/9/09	9.2	1.2	0.1	1.1	0.2	0.0	0.0	1.4	0.6	6.2	1.0
2/12/09	22.8	3.0	0.3	2.2	0.5	0.0	0.0	2.7	0.8	14.9	2.0
2/15/09	32.1	4.7	0.5	4.2	0.8	0.0	0.0	3.5	1.2	19.6	2.6
2/18/09	17.5	3.3	0.4	1.6	0.5	0.0	0.0	1.7	0.8	11.1	1.6
2/21/09	14.6	2.6	0.3	1.0	0.3	0.0	0.0	2.1	1.0	8.3	1.3
2/24/09	20.1	2.9	0.3	2.5	0.5	0.0	0.0	1.8	0.7	13.1	1.8
2/27/09	8.0	1.7	0.2	0.8	0.2	0.0	0.0	0.0	0.0	5.3	0.8
3/2/09	17.5	3.5	0.4	1.5	0.5	0.0	0.0	2.1	0.8	10.9	1.6
3/5/09	5.7	1.0	0.1	0.7	0.2	0.0	0.0	1.0	0.5	2.6	0.6
3/8/09	8.0	1.9	0.2	0.6	0.2	0.0	0.0	0.0	0.0	5.2	1.5
3/11/09	16.6	2.0	0.2	2.2	0.3	0.0	0.0	4.1	1.0	8.2	1.3
3/14/09	11.9	2.6	0.3	0.8	0.4	0.0	0.0	1.6	0.8	6.8	1.1
3/17/09	10.2	2.0	0.2	0.6	0.3	0.0	0.0	0.0	0.0	7.2	0.9
3/20/09	7.4	1.4	0.2	0.5	0.2	0.0	0.0	0.0	0.0	5.0	0.7
3/23/09	11.5	2.2	0.3	0.7	0.3	0.0	0.0	1.7	0.7	6.9	1.0
3/26/09	6.7	0.9	0.1	0.3	0.1	0.0	0.0	0.0	0.0	5.5	0.8
3/29/09	10.9	1.8	0.2	0.9	0.2	0.0	0.0	1.4	0.6	6.8	1.0
4/1/09	13.0	1.9	0.2	1.1	0.3	0.0	0.0	0.0	0.0	9.8	1.2
4/4/09	7.9	1.2	0.1	0.4	0.2	0.0	0.0	0.0	0.0	6.8	1.6
4/7/09	13.3	2.2	0.2	1.3	0.3	0.0	0.0	0.0	0.0	9.4	2.5
Average	**16.8**	**2.8**	**0.3**	**1.5**	**0.4**	**0.7**	**0.2**	**1.2**	**0.5**	**10.6**	**1.6**

Notes: *No, incomplete, or invalid CMB data set.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles. Peger Road – Winter 2008/2009.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
1/25/09	28.6	2.2	0.4	2.7	0.4	9.9	1.8	12.2	1.7
1/28/09	31.3	7.7	0.9	2.3	1.0	0.0	0.0	21.0	1.6
1/31/09	13.5	1.3	0.2	0.7	0.2	5.8	1.0	5.0	1.1
2/3/09	17.8	3.1	0.4	1.4	0.4	0.0	0.0	13.3	1.0
2/5/09	48.0	3.7	0.7	3.3	0.6	19.9	3.0	17.3	2.7
2/6/09	*	*	*	*	*	*	*	*	*
2/7/09	32.7	2.4	0.5	2.2	0.4	13.9	1.9	14.2	1.9
2/9/09	9.2	0.9	0.2	1.0	0.1	1.9	0.7	6.1	0.8
2/12/09	22.8	1.7	0.3	2.0	0.3	7.3	1.4	12.5	1.5
2/15/09	32.1	2.3	0.5	3.8	0.4	12.2	2.0	13.9	1.9
2/18/09	17.5	3.3	0.4	1.9	0.4	0.0	0.0	12.6	1.0
2/21/09	14.6	1.6	0.3	0.8	0.2	5.3	1.2	6.4	1.2
2/24/09	20.1	2.8	0.3	2.7	0.4	0.0	0.0	14.7	1.1
2/27/09	8.0	1.2	0.2	0.7	0.2	2.8	0.9	3.1	0.9
3/2/09	17.5	3.5	0.4	1.8	0.5	0.0	0.0	12.7	1.0
3/5/09	5.7	0.7	0.1	0.6	0.1	1.5	0.6	2.6	0.7
3/8/09	8.0	1.2	0.2	0.5	0.2	3.5	0.9	2.0	0.9
3/11/09	16.6	1.2	0.2	2.1	0.2	3.7	1.0	8.9	1.1
3/14/09	11.9	1.6	0.3	0.7	0.2	5.7	1.2	4.2	1.1
3/17/09	10.2	1.1	0.2	0.5	0.2	4.1	0.9	4.0	0.9
3/20/09	7.4	0.8	0.1	0.5	0.1	2.8	0.6	2.8	0.7
3/23/09	11.5	1.4	0.3	0.6	0.2	5.3	1.0	4.2	1.0
3/26/09	6.7	0.6	0.1	0.3	0.1	1.6	0.4	4.0	0.9
3/29/09	10.9	1.7	0.2	1.1	0.2	0.0	0.0	8.1	0.8
4/1/09	13.0	1.2	0.2	1.1	0.2	3.4	0.9	7.3	1.4
4/4/09	7.9	0.7	0.1	0.3	0.1	2.7	0.5	4.7	1.0
4/7/09	13.3	1.2	0.2	1.2	0.2	5.0	1.0	4.7	1.0
Average	**16.8**	**2.0**	**0.3**	**1.4**	**0.3**	**4.6**	**0.9**	**8.6**	**1.2**

Notes: *No, incomplete, or invalid CMB data set.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – Revised OMNI Profiles (with auto / diesel). Peger Road – Winter 2008/2009.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
1/25/09	28.6	2.2	0.4	2.7	0.4	0.0	0.0	0.0	0.0	9.9	1.8	12.2	1.7
1/28/09	31.3	3.9	0.7	0.0	0.0	0.0	0.0	0.0	0.0	21.3	2.8	6.7	2.4
1/31/09	13.5	1.3	0.2	0.7	0.2	0.0	0.0	0.0	0.0	5.8	1.0	5.0	1.1
2/3/09	17.8	1.9	0.4	0.9	0.3	0.0	0.0	0.0	0.0	7.2	1.4	8.4	1.4
2/5/09	48.0	3.8	0.7	3.1	0.6	7.4	3.1	0.0	0.0	19.9	3.0	17.8	5.3
2/6/09	*	*	*	*	*	*	*	*	*	*	*	*	*
2/7/09	32.7	2.4	0.5	2.2	0.4	0.0	0.0	0.0	0.0	13.9	1.9	14.2	1.9
2/9/09	9.2	0.9	0.2	1.0	0.1	0.0	0.0	0.0	0.0	1.9	0.7	6.1	0.8
2/12/09	22.8	1.7	0.3	2.0	0.3	0.0	0.0	0.0	0.0	7.3	1.4	12.5	1.5
2/15/09	32.1	2.3	0.5	3.8	0.4	0.0	0.0	0.0	0.0	12.2	2.0	13.9	1.9
2/18/09	17.5	2.1	0.4	1.4	0.3	0.0	0.0	0.0	0.0	6.3	1.6	8.4	1.4
2/21/09	14.6	1.6	0.3	0.8	0.2	0.0	0.0	0.0	0.0	5.3	1.2	6.4	1.2
2/24/09	20.1	1.8	0.3	2.3	0.3	0.0	0.0	0.0	0.0	6.1	1.4	10.6	1.4
2/27/09	8.0	1.2	0.2	0.7	0.2	0.0	0.0	0.0	0.0	2.8	0.9	3.1	0.9
3/2/09	17.5	2.2	0.4	1.2	0.3	0.0	0.0	0.0	0.0	7.3	1.7	7.8	1.5
3/5/09	5.7	0.7	0.1	0.6	0.1	0.0	0.0	0.0	0.0	1.5	0.6	2.6	0.7
3/8/09	8.0	1.2	0.2	0.5	0.2	0.0	0.0	0.0	0.0	3.5	0.9	2.0	0.9
3/11/09	16.6	1.3	0.3	2.1	0.2	0.0	0.0	2.4	1.0	3.6	1.1	6.8	1.2
3/14/09	11.9	1.6	0.3	0.7	0.2	0.0	0.0	0.0	0.0	5.7	1.2	4.2	1.1
3/17/09	10.2	1.1	0.2	0.5	0.2	0.0	0.0	0.0	0.0	4.1	0.9	4.0	0.9
3/20/09	7.4	0.8	0.1	0.5	0.1	0.0	0.0	0.0	0.0	2.8	0.6	2.8	0.7
3/23/09	11.5	1.4	0.3	0.6	0.2	0.0	0.0	0.0	0.0	5.3	1.0	4.2	1.0
3/26/09	6.7	0.6	0.1	0.3	0.1	0.0	0.0	0.0	0.0	1.6	0.4	4.0	0.9
3/29/09	10.9	1.1	0.2	0.8	0.2	0.0	0.0	0.0	0.0	4.0	0.8	5.1	0.9
4/1/09	13.0	1.2	0.2	1.1	0.2	0.0	0.0	0.0	0.0	3.4	0.9	7.3	1.4
4/4/09	7.9	0.7	0.1	0.3	0.1	0.0	0.0	0.0	0.0	2.7	0.5	4.7	1.0
4/7/09	13.3	1.2	0.2	1.2	0.2	0.0	0.0	0.0	0.0	5.0	1.0	4.7	1.0
Average	**16.8**	**1.6**	**0.3**	**1.2**	**0.2**	**0.3**	**0.1**	**0.1**	**0.04**	**6.6**	**1.3**	**7.1**	**1.4**

Notes: *No, incomplete, or invalid CMB data set.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
State Building – Winter 2009/2010.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/3/09	13.8	2.1	0.3	1.1	0.3	3.5	1.3	0.0	0.0	6.4	0.8
11/6/09	5.2	0.8	0.1	0.3	0.1	0.0	0.0	0.0	0.0	4.1	0.2
11/9/09	*	*	*	*	*	*	*	*	*	*	*
11/12/09	4.0**	**	**	**	**	**	**	**	**	**	**
11/15/09	15.7	2.2	0.3	1.4	0.3	0.0	0.0	0.0	0.0	13.0	1.0
11/17/09	21.8	3.3	0.4	2.0	0.4	0.0	0.0	6.1	1.3	9.8	1.5
11/18/09	4.9**	**	**	**	**	**	**	**	**	**	**
11/19/09	10.5	1.5	0.2	1.2	0.2	0.0	0.0	0.0	0.0	7.7	0.8
11/21/09	24.9	3.9	0.5	1.6	0.5	0.0	0.0	0.0	0.0	19.0	1.5
11/24/09	34.2	6.2	0.8	2.7	0.8	0.0	0.0	3.6	1.7	21.1	1.6
11/27/09	20.9	3.1	0.4	1.1	0.4	4.5	1.8	0.0	0.0	12.2	1.8
11/30/09	14	2.7	0.3	1.3	0.3	3.3	1.6	0.0	0.0	6.3	0.9
12/3/09	*	*	*	*	*	*	*	*	*	*	*
12/6/09	0.4**	**	**	**	**	**	**	**	**	**	**
12/9/09	49	9.5	1.2	3.9	1.2	0.0	0.0	9.4	4.5	27.0	5.2
12/10/09	54.4	8.8	1.0	2.2	1.1	0.0	0.0	0.0	0.0	43.9	8.9
12/11/09	43.7	7.4	0.8	4.8	1.0	0.0	0.0	0.0	0.0	29.5	3.5
12/12/09	38.1	6.9	0.8	1.9	0.9	0.0	0.0	0.0	0.0	29.8	2.5
12/13/09	44.4	7.2	0.8	3.8	0.9	12.6	4.0	0.0	0.0	19.1	3.8
12/15/09	4.1**	**	**	**	**	**	**	**	**	**	**
12/18/09	3.6**	**	**	**	**	**	**	**	**	**	**
12/21/09	40.2	6.8	0.8	2.7	0.9	0.0	0.0	0.0	0.0	30.9	2.5
12/24/09	29.8	4.8	0.6	2.3	0.6	0.0	0.0	0.0	0.0	22.5	0.9
12/27/09	24.1	4.5	0.6	1.5	0.6	0.0	0.0	0.0	0.0	19.5	1.6
12/30/09	42.2	8.1	1.0	2.7	1.0	0.0	0.0	0.0	0.0	33.2	2.8
1/2/10	48.6	11.2	1.4	3.4	1.4	0.0	0.0	0.0	0.0	28.3	3.1
1/5/10	52.3	8.8	1.1	3.7	1.1	0.0	0.0	0.0	0.0	42.8	3.5
1/8/10	46.2	9.5	1.2	3.5	1.2	0.0	0.0	0.0	0.0	28.6	1.8
1/11/10	38.5	8.6	1.1	2.4	1.1	0.0	0.0	0.0	0.0	27.3	1.6
1/14/10	11.8	2.4	0.3	1.0	0.3	0.0	0.0	0.0	0.0	8.5	0.7
1/17/10	15.8	2.7	0.3	1.3	0.4	0.0	0.0	0.0	0.0	12.0	1.0
1/20/10	41.0	6.8	0.8	3.1	0.9	0.0	0.0	0.0	0.0	29.1	2.1
1/23/10	30.7	5.5	0.7	2.6	0.7	0.0	0.0	0.0	0.0	23.2	1.0
1/26/10	80.2	18.9	2.3	8.0	2.4	0.0	0.0	0.0	0.0	53.6	3.6
1/29/10	26.4	5.5	0.7	2.2	0.7	0.0	0.0	0.0	0.0	18.4	1.0
2/1/10	24.1	4.0	0.5	5.0	0.6	0.0	0.0	0.0	0.0	15.2	3.0
2/4/10	32.4	7.9	1.0	3.6	1.0	0.0	0.0	0.0	0.0	20.4	1.5
2/7/10	14.6	2.8	0.3	1.7	0.4	0.0	0.0	0.0	0.0	9.7	0.5
2/10/10	22.1	3.2	0.4	3.1	0.5	0.0	0.0	0.0	0.0	15.7	0.6
2/13/10	30.6	4.9	0.6	3.9	0.7	0.0	0.0	0.0	0.0	23.5	1.9
2/16/10	26.3	4.1	0.5	4.0	0.6	0.0	0.0	4.6	2.1	13.8	2.4
2/19/10	22.8	2.6	0.3	3.8	0.4	4.5	1.5	0.0	0.0	12.0	1.5
2/22/10	12.2	2.2	0.3	1.5	0.3	0.0	0.0	0.0	0.0	8.8	0.8
2/25/10	3.1**	**	**	**	**	**	**	**	**	**	**

2/28/10	10.1	1.2	0.1	2.0	0.2	0.0	0.0	0.0	0.0	7.2	0.4
3/3/10	21.3	2.8	0.3	1.8	0.4	0.0	0.0	1.8	0.8	13.9	0.8
3/6/10	3.8**	**	**	**	**	**	**	**	**	**	**
3/9/10	3.4**	**	**	**	**	**	**	**	**	**	**
3/12/10	9.1	1.3	0.2	0.7	0.2	0.0	0.0	0.0	0.0	6.7	0.4
3/15/10	6.9	1.1	0.1	1.1	0.2	0.0	0.0	0.0	0.0	4.8	1.2
Average	**28.8**	**5.2**	**0.6**	**2.5**	**0.7**	**0.7**	**0.3**	**0.6**	**0.3**	**19.5**	**1.9**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
State Building – Winter 2009/2010.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/3/09	13.8	1.1	0.2	0.7	0.2	**0.0**	**0.0**	**0.0**	**0.0**	5.3	0.8	6.5	0.9
11/6/09	5.2	0.5	0.1	0.2	0.1	**0.0**	**0.0**	0.4	0.1	1.7	0.4	2.2	0.4
11/9/09	*	*	*	*	*	*	*	*	*	*	*	*	*
11/12/09	4.0**	**	**	**	**	**	**	**	**	**	**	**	**
11/15/09	15.7	1.2	0.2	1.1	0.2	**0.0**	**0.0**	**0.0**	**0.0**	4.5	0.9	10.5	1.0
11/17/09	21.8	1.1	0.5	1.3	0.6	4.2	1.4	**0.0**	**0.0**	9.4	2.7	5.9	2.9
11/18/09	4.9**	**	**	**	**	**	**	**	**	**	**	**	**
11/19/09	10.5	0.8	0.2	1.0	0.1	**0.0**	**0.0**	**0.0**	**0.0**	3.2	0.7	6.3	0.9
11/21/09	24.9	1.8	0.4	1.0	0.3	**0.0**	**0.0**	**0.0**	**0.0**	10.5	1.5	10.8	1.7
11/24/09	34.2	3.3	0.7	1.7	0.5	**0.0**	**0.0**	2.7	0.9	15.9	2.7	6.7	2.9
11/27/09	20.9	1.8	0.4	0.8	0.2	**0.0**	**0.0**	2.0	0.5	7.0	1.4	9.1	1.5
11/30/09	14	1.6	0.3	0.9	0.2	**0.0**	**0.0**	**0.0**	**0.0**	5.8	1.2	5.9	1.3
12/3/09	*	*	*	*	*	*	*	*	*	*	*	*	*
12/6/09	0.4**	**	**	**	**	**	**	**	**	**	**	**	**
12/9/09	*	*	*	*	*	*	*	*	*	*	*	*	*
12/10/09	54.4	5.5	0.9	**0.0**	**0.0**	**0.0**	**0.0**	5.6	2.0	17.4	3.7	26.0	5.1
12/11/09	43.7	2.3	0.6	2.8	0.4	**0.0**	**0.0**	**0.0**	**0.0**	28.4	2.4	8.8	2.4
12/12/09	*	*	*	*	*	*	*	*	*	*	*	*	*
12/13/09	44.4	2.8	0.6	2.4	0.4	**0.0**	**0.0**	**0.0**	**0.0**	23.2	2.4	13.3	2.3
12/15/09	4.1**	**	**	**	**	**	**	**	**	**	**	**	**
12/18/09	3.6**	**	**	**	**	**	**	**	**	**	**	**	**
12/21/09	40.2	3.6	0.8	1.6	0.5	**0.0**	**0.0**	**0.0**	**0.0**	16.1	2.8	18.1	3.1
12/24/09	29.8	2.6	0.5	1.5	0.4	**0.0**	**0.0**	**0.0**	**0.0**	12.1	2.0	11.7	2.2
12/27/09	24.1	2.6	0.5	0.9	0.4	**0.0**	**0.0**	**0.0**	**0.0**	9.8	1.9	12.1	2.2
12/30/09	*	*	*	*	*	*	*	*	*	*	*	*	*
1/2/10	*	*	*	*	*	*	*	*	*	*	*	*	*
1/5/10	*	*	*	*	*	*	*	*	*	*	*	*	*
1/8/10	46.2	6.4	1.2	2.4	0.9	**0.0**	**0.0**	**0.0**	**0.0**	16.8	4.3	13.7	4.7
1/11/10	38.5	5.0	1.0	1.0	0.7	**0.0**	**0.0**	**0.0**	**0.0**	20.4	3.8	7.9	4.2
1/14/10	11.8	1.6	0.3	0.7	0.2	**0.0**	**0.0**	**0.0**	**0.0**	4.8	1.2	2.7	1.3
1/17/10	15.8	1.7	0.3	1.0	0.2	**0.0**	**0.0**	**0.0**	**0.0**	4.9	1.3	8.6	1.4
1/20/10	*	*	*	*	*	*	*	*	*	*	*	*	*
1/23/10	30.7	3.1	0.6	1.7	0.4	**0.0**	**0.0**	**0.0**	**0.0**	12.9	2.4	11.6	2.7
1/26/10	*	*	*	*	*	*	*	*	*	*	*	*	*
1/29/10	26.4	3.2	0.6	1.4	0.4	**0.0**	**0.0**	**0.0**	**0.0**	13.2	2.4	5.9	2.7
2/1/10	24.1	2.1	0.5	4.2	0.5	**0.0**	**0.0**	**0.0**	**0.0**	9.9	2.0	8.5	2.2
2/4/10	*	*	*	*	*	*	*	*	*	*	*	*	*
2/7/10	14.6	1.7	0.3	1.2	0.3	**0.0**	**0.0**	**0.0**	**0.0**	6.2	1.3	3.9	1.5
2/10/10	22.1	1.5	0.4	2.5	0.3	**0.0**	**0.0**	**0.0**	**0.0**	9.2	1.4	7.2	1.5
2/13/10	30.6	2.6	0.6	3.1	0.5	**0.0**	**0.0**	**0.0**	**0.0**	11.7	2.2	14.5	2.4
2/16/10	26.3	2.5	0.5	3.3	0.4	**0.0**	**0.0**	**0.0**	**0.0**	9.2	2.1	4.8	2.3
2/19/10	22.8	1.1	0.3	3.3	0.3	**0.0**	**0.0**	1.9	0.3	7.5	1.3	8.5	1.4
2/22/10	12.2	1.3	0.3	1.1	0.2	**0.0**	**0.0**	0.8	0.4	4.6	1.0	4.3	1.1
2/25/10	3.1**	**	**	**	**	**	**	**	**	**	**	**	**

2/28/10	10.1	0.9	0.2	1.8	0.2	**0.0**	**0.0**	**0.0**	**0.0**	1.7	0.7	4.8	0.8
3/3/10	21.3	1.6	0.3	1.3	0.2	6.7	1.0	**0.0**	**0.0**	6.6	1.3	6.1	1.4
3/6/10	3.8**	**	**	**	**	**	**	**	**	**	**	**	**
3/9/10	3.4**	**	**	**	**	**	**	**	**	**	**	**	**
3/12/10	*	*	*	*	*	*	*	*	*	*	*	*	*
3/15/10	6.9	1.0	0.1	1.1	0.2	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	4.3	0.1
Average	**28.8**	**2.2**	**0.5**	**1.6**	**0.3**	**0.4**	**0.1**	**0.4**	**0.1**	**10.0**	**1.8**	**8.7**	**2.0**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
North Pole – Winter 2009/2010.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/3/09	6.1	0.4	0.0	0.1	0.1	0.0	0.0	0.0	0.0	5.7	0.7
11/9/09	12.9	0.8	0.1	0.5	0.1	0.0	0.0	0.0	0.0	11.0	1.0
11/15/09	16.7	0.9	0.1	0.8	0.1	0.0	0.0	0.0	0.0	13.1	1.3
11/17/09	13.3	1.3	0.1	1.3	0.2	0.0	0.0	0.0	0.0	10.9	1.1
11/18/09	6.5	0.9	0.1	0.9	0.1	0.0	0.0	0.0	0.0	4.6	0.6
11/19/09	*	*	*	*	*	*	*	*	*	*	*
11/21/09	18.5	1.9	0.2	1.0	0.2	0.0	0.0	0.0	0.0	15.0	1.3
11/27/09	27.8	1.4	0.2	0.8	0.2	0.0	0.0	0.0	0.0	25.4	5.0
12/3/09	15.3	1.1	0.1	0.6	0.1	0.0	0.0	0.0	0.0	12.1	1.2
12/9/09	83.5	5.1	0.7	1.3	0.7	0.0	0.0	0.0	0.0	81.0	15.7
12/10/09	80.5	5.9	0.7	1.4	0.8	0.0	0.0	0.0	0.0	73.3	14.3
12/11/09	58.4	4.5	0.5	1.7	0.6	0.0	0.0	0.0	0.0	48.8	5.3
12/12/09	37.9	2.7	0.3	1.8	0.4	0.0	0.0	0.0	0.0	32.6	3.6
12/13/09	54.8	4.2	0.5	1.7	0.6	0.0	0.0	0.0	0.0	46.2	5.0
12/15/09	6.2	0.5	0.1	0.5	0.1	0.0	0.0	0.0	0.0	6.0	0.7
12/21/09	45.0	4.0	0.4	1.8	0.5	0.0	0.0	0.0	0.0	36.1	2.9
12/24/09	25.2	1.5	0.2	0.9	0.2	0.0	0.0	0.0	0.0	20.0	1.7
12/27/09	17.0	1.5	0.2	0.5	0.2	0.0	0.0	0.0	0.0	13.1	1.3
12/30/09	115.4	9.9	1.1	3.1	1.2	0.0	0.0	14.0	3.2	79.0	9.6
1/2/10	53.1	5.0	0.6	1.3	0.6	0.0	0.0	0.0	0.0	44.9	5.0
1/8/10	36.6	2.9	0.3	2.2	0.4	0.0	0.0	0.0	0.0	33.2	5.8
1/11/10	17.6	1.8	0.2	0.5	0.2	5.5	2.1	0.0	0.0	10.6	1.6
1/14/10	4.5**	**	**	**	**	**	**	**	**	**	**
1/17/10	20.0	1.7	0.2	0.9	0.2	4.2	2.1	0.0	0.0	14.0	1.9
1/20/10	53.5	4.3	0.5	1.4	0.6	14.8	3.7	0.0	0.0	32.7	4.2
1/23/10	42.0	2.8	0.3	1.4	0.4	0.0	0.0	0.0	0.0	35.9	6.0
1/26/10	90.9	7.3	0.8	2.4	1.0	0.0	0.0	0.0	0.0	79.1	6.7
1/29/10	3.3**	**	**	**	**	**	**	**	**	**	**
2/1/10	*	*	*	*	*	*	*	*	*	*	*
2/4/10	31.4	3.0	0.3	1.2	0.4	0.0	0.0	7.0	1.3	18.8	2.5
2/7/10	10.3	1.3	0.1	1.1	0.2	0.0	0.0	0.0	0.0	8.2	0.9
2/10/10	32.9	2.8	0.3	1.4	0.4	0.0	0.0	8.0	1.4	18.8	2.5
2/13/10	54.6	3.3	0.4	2.0	0.4	0.0	0.0	0.0	0.0	53.6	10.4
2/16/10	39.6	2.3	0.3	1.7	0.3	12.7	2.8	0.0	0.0	25.0	3.3
2/19/10	*	*	*	*	*	*	*	*	*	*	*
2/22/10	7.0	0.8	0.1	0.8	0.1	0.0	0.0	0.0	0.0	7.0	0.8
2/25/10	3.8**	**	**	**	**	**	**	**	**	**	**
2/28/10	8.2	0.9	0.1	1.2	0.1	0.0	0.0	0.0	0.0	5.7	0.7
3/3/10	28.2	1.5	0.2	0.9	0.2	7.7	2.3	0.0	0.0	16.8	2.3
3/6/10	*	*	*	*	*	*	*	*	*	*	*
3/9/10	4.1**	**	**	**	**	**	**	**	**	**	**
3/12/10	5.6	0.8	0.1	0.5	0.1	0.0	0.0	0.0	0.0	4.3	0.6
3/15/10	7.5	0.9	0.1	0.6	0.1	0.0	0.0	0.0	0.0	6.3	1.4
Average	**33.7**	**2.6**	**0.3**	**1.2**	**0.3**	**1.3**	**0.4**	**0.8**	**0.2**	**27.1**	**3.7**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
North Pole – Winter 2009/2010.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/3/09	6.1	0.2	0.0	0.1	0.0	0.0	0.0	2.0	0.8	0.8	0.1	2.8	0.6
11/9/09	12.9	0.5	0.1	0.4	0.1	0.0	0.0	0.0	0.0	1.7	0.3	8.2	1.0
11/15/09	16.7	0.4	0.1	0.6	0.1	0.0	0.0	0.0	0.0	2.1	0.4	11.2	0.9
11/17/09	13.3	0.6	0.1	1.2	0.1	0.0	0.0	0.0	0.0	3.1	0.5	9.8	1.0
11/18/09	6.5	0.6	0.1	0.7	0.1	0.0	0.0	0.0	0.0	1.6	0.5	3.7	0.6
11/19/09	*	*	*	*	*	*	*	*	*	*	*	*	*
11/21/09	18.5	0.8	0.2	0.6	0.1	0.0	0.0	0.0	0.0	4.8	0.6	13.0	1.1
11/27/09	27.8	0.6	0.1	0.6	0.1	0.0	0.0	1.7	0.7	1.7	0.5	27.2	2.1
12/3/09	15.3	0.3	0.1	0.5	0.1	0.0	0.0	2.8	0.8	3.5	0.3	7.3	1.0
12/9/09	83.5	1.7	0.4	0.8	0.3	0.0	0.0	11.9	1.7	16.4	1.5	48.5	4.4
12/10/09	80.5	2.4	0.5	1.0	0.3	0.0	0.0	0.0	0.0	15.5	1.9	62.7	4.8
12/11/09	58.4	1.8	0.4	0.8	0.3	0.0	0.0	0.0	0.0	11.9	1.4	47.2	3.7
12/12/09	37.9	1.5	0.3	1.2	0.2	0.0	0.0	0.0	0.0	6.6	1.2	24.1	1.9
12/13/09	54.8	1.7	0.4	1.3	0.2	0.0	0.0	4.9	1.3	11.5	1.4	39.7	3.6
12/15/09	6.2	0.1	0.0	0.5	0.0	0.0	0.0	1.8	0.6	1.9	0.2	2.2	0.5
12/21/09	45.0	2.3	0.4	1.1	0.3	9.8	3.8	0.0	0.0	8.8	1.7	24.4	2.7
12/24/09	25.2	0.5	0.1	0.7	0.1	0.0	0.0	0.0	0.0	5.6	0.5	15.6	1.2
12/27/09	17.0	0.5	0.1	0.4	0.1	0.0	0.0	0.0	0.0	4.0	0.4	13.5	1.3
12/30/09	115.4	4.0	0.8	1.1	0.5	0.0	0.0	6.2	2.2	26.6	3.1	91.0	7.7
1/2/10	53.1	2.0	0.4	0.9	0.3	0.0	0.0	0.0	0.0	13.7	1.6	43.2	3.7
1/8/10	36.6	1.2	0.3	1.8	0.2	0.0	0.0	4.4	1.1	9.9	1.1	21.5	2.5
1/11/10	17.6	0.8	0.2	0.4	0.1	0.0	0.0	0.0	0.0	4.6	0.6	13.2	1.4
1/14/10	4.5**	**	**	**	**	**	**	**	**	**	**	**	**
1/17/10	20.0	1.0	0.2	0.8	0.1	0.0	0.0	0.0	0.0	3.9	0.8	12.7	1.2
1/20/10	53.5	1.4	0.4	1.0	0.3	0.0	0.0	1.9	0.8	13.4	1.8	35.4	3.3
1/23/10	42.0	1.4	0.3	1.1	0.2	0.0	0.0	9.1	1.4	8.6	1.1	24.1	2.8
1/26/10	90.9	2.6	0.6	2.1	0.4	0.0	0.0	0.0	0.0	22.0	2.2	59.2	5.0
1/29/10	3.3**	**	**	**	**	**	**	**	**	**	**	**	**
2/1/10	*	*	*	*	*	*	*	*	*	*	*	*	*
2/4/10	31.4	1.7	0.3	1.0	0.2	7.2	3.1	0.0	0.0	7.3	1.3	15.7	2.1
2/7/10	10.3	0.2	0.1	1.0	0.1	0.0	0.0	0.0	0.0	5.6	0.4	4.1	0.6
2/10/10	32.9	1.3	0.3	1.2	0.2	9.6	3.1	0.0	0.0	8.1	1.1	15.0	2.0
2/13/10	54.6	1.4	0.3	1.6	0.2	8.8	3.8	0.0	0.0	10.4	1.3	29.5	2.9
2/16/10	39.6	1.0	0.2	1.4	0.2	0.0	0.0	4.7	1.1	5.6	0.9	26.5	2.5
2/19/10	*	*	*	*	*	*	*	*	*	*	*	*	*
2/22/10	7.0	0.0	0.0	0.7	0.1	0.0	0.0	0.0	0.0	4.3	0.2	1.7	0.1
2/25/10	3.8**	**	**	**	**	**	**	**	**	**	**	**	**
2/28/10	8.2	0.5	0.1	1.2	0.1	0.0	0.0	0.0	0.0	1.8	0.4	4.7	0.7
3/3/10	28.2	0.5	0.1	0.7	0.1	0.0	0.0	0.0	0.0	5.6	0.5	15.8	1.2
3/6/10	*	*	*	*	*	*	*	*	*	*	*	*	*
3/9/10	4.1**	**	**	**	**	**	**	**	**	**	**	**	**
3/12/10	5.6	0.5	0.1	0.5	0.1	0.0	0.0	0.0	0.0	1.4	0.4	3.5	0.6
3/15/10	7.5	0.4	0.1	0.5	0.1	0.0	0.0	0.0	0.0	2.5	0.3	4.6	0.9
Average	**33.7**	**1.1**	**0.2**	**0.9**	**0.2**	**1.0**	**0.4**	**1.5**	**0.4**	**7.3**	**0.9**	**22.4**	**2.1**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
RAMS – Winter 2009/2010.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/15/09	34.6	3.0	0.3	1.3	0.4	6.2	2.8	0.0	0.0	24.7	3.2
11/17/09	*	*	*	*	*	*	*	*	*	*	*
11/18/09	*	*	*	*	*	*	*	*	*	*	*
11/19/09	*	*	*	*	*	*	*	*	*	*	*
11/21/09	50.2	4.6	0.5	0.0	0.0	11.3	3.8	0.0	0.0	34.9	4.5
11/27/09	33.7	2.4	0.3	0.8	0.3	0.0	0.0	0.0	0.0	30.1	6.0
12/3/09	22.5	2.3	0.3	0.0	0.0	5.8	2.4	0.0	0.0	14.8	2.1
12/9/09	55.4	6.4	0.7	0.0	0.0	0.0	0.0	8.3	2.1	36.0	4.5
12/10/09	72.2	7.4	0.8	0.0	0.0	0.0	0.0	4.9	2.3	56.8	6.9
12/11/09	57.6	6.2	0.7	0.0	0.0	0.0	0.0	0.0	0.0	53.2	10.5
12/12/09	59.3	7.0	0.8	2.1	0.9	0.0	0.0	0.0	0.0	49.9	5.6
12/13/09	68.7	6.7	0.8	0.0	0.0	24.1	5.2	0.0	0.0	42.0	5.5
12/21/09	52.0	5.1	0.6	0.0	0.0	0.0	0.0	7.6	1.8	35.9	4.5
12/24/09	32.2	3.0	0.3	0.9	0.4	0.0	0.0	5.1	1.3	21.6	2.8
12/27/09	6.6	0.5	0.1	0.3	0.1	0.0	0.0	2.4	0.8	3.4	0.7
12/30/09	68.8	8.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	60.9	12.1
1/2/10	64.9	8.6	1.0	0.0	0.0	18.3	5.9	0.0	0.0	41.7	5.5
1/8/10	39.0	3.9	0.5	1.1	0.5	0.0	0.0	7.7	1.2	25.2	3.1
1/11/10	52.5	8.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	45.2	9.1
1/14/10	12.5	1.4	0.2	0.8	0.2	0.0	0.0	1.2	0.6	9.2	1.2
1/17/10	24.4	1.9	0.2	0.9	0.3	0.0	0.0	2.2	0.7	20.2	2.5
1/20/10	56.7	5.5	0.7	2.1	0.7	0.0	0.0	0.0	0.0	51.2	10.1
1/23/10	55.4	5.9	0.7	1.8	0.8	0.0	0.0	11.1	2.1	33.6	4.3
1/26/10	*	*	*	*	*	*	*	*	*	*	*
1/29/10	*	*	*	*	*	*	*	*	*	*	*
2/19/10	35.9	4.5	0.5	4.9	0.7	0.0	0.0	8.1	1.6	16.6	2.3
2/22/10	21.4	2.9	0.3	2.0	0.4	0.0	0.0	2.7	0.8	13.6	1.8
2/25/10	7.2	0.8	0.1	0.3	0.1	0.0	0.0	0.0	0.0	5.8	1.1
2/28/10	17.1	1.5	0.2	2.3	0.3	0.0	0.0	0.0	0.0	13.1	2.5
3/3/10	28.4	3.6	0.4	2.1	0.5	0.0	0.0	4.8	1.3	17.2	2.3
3/6/10	5.2	0.7	0.1	0.4	0.1	0.0	0.0	0.0	0.0	4.8	0.6
3/9/10	5.3	0.6	0.1	0.4	0.1	0.0	0.0	0.0	0.0	4.1	0.6
3/12/10	12.0	1.5	0.2	0.7	0.2	0.0	0.0	3.9	0.9	5.6	1.0
3/15/10	12.0	1.2	0.1	1.3	0.2	0.0	0.0	2.3	0.6	7.9	1.1
Average	**36.7**	**4.0**	**0.5**	**0.9**	**0.2**	**2.3**	**0.7**	**2.5**	**0.6**	**26.9**	**4.1**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
RAMS – Winter 2009/2010.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/15/09	34.6	1.6	0.3	1.1	0.2	0.0	0.0	0.0	0.0	7.7	1.3	20.6	1.8
11/17/09	*	*	*	*	*	*	*	*	*	*	*	*	*
11/18/09	*	*	*	*	*	*	*	*	*	*	*	*	*
11/19/09	*	*	*	*	*	*	*	*	*	*	*	*	*
11/21/09	50.2	1.5	0.4	0.6	0.2	0.0	0.0	0.0	0.0	14.9	1.3	35.9	2.8
11/27/09	33.7	0.7	0.2	0.6	0.1	7.8	2.1	0.0	0.0	8.8	0.7	15.4	2.0
12/3/09	22.5	1.3	0.2	0.4	0.2	0.0	0.0	0.0	0.0	5.5	1.0	13.0	1.3
12/9/09	55.4	3.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	17.0	2.3	29.9	2.7
12/10/09	72.2	3.8	0.7	0.0	0.0	0.0	0.0	0.0	0.0	19.8	2.7	41.5	3.5
12/11/09	57.6	2.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	18.5	1.8	42.0	3.5
12/12/09	59.3	3.8	0.7	1.6	0.5	0.0	0.0	0.0	0.0	17.9	2.9	32.8	3.2
12/13/09	68.7	2.2	0.5	1.0	0.3	0.0	0.0	4.4	1.1	20.4	1.8	41.8	3.7
12/21/09	52.0	1.7	0.4	0.5	0.2	0.0	0.0	3.0	0.9	15.2	1.4	34.5	3.1
12/24/09	32.2	1.0	0.2	0.6	0.1	0.0	0.0	3.6	1.0	10.2	0.9	18.5	2.1
12/27/09	6.6	0.1	0.0	0.3	0.0	0.0	0.0	1.6	0.8	2.2	0.2	2.4	0.6
12/30/09	68.8	3.8	0.7	0.0	0.0	0.0	0.0	0.0	0.0	23.3	2.5	49.9	4.3
1/2/10	64.9	2.6	1.2	0.9	0.4	9.3	4.8	0.0	0.0	23.1	2.2	28.2	5.3
1/8/10	39.0	2.3	0.5	0.8	0.3	0.0	0.0	5.7	1.6	12.3	1.8	17.7	2.3
1/11/10	52.5	4.5	0.8	0.0	0.0	0.0	0.0	0.0	0.0	20.1	3.2	21.7	3.0
1/14/10	12.5	0.9	0.2	0.7	0.1	0.0	0.0	0.0	0.0	3.3	0.7	7.7	0.9
1/17/10	24.4	1.1	0.2	0.7	0.2	0.0	0.0	0.0	0.0	5.2	0.9	17.6	1.4
1/20/10	56.7	2.2	0.5	1.7	0.3	0.0	0.0	0.0	0.0	16.1	1.8	42.1	3.8
1/23/10	55.4	3.1	0.6	1.4	0.4	9.4	4.3	0.0	0.0	14.8	2.4	27.2	3.3
1/26/10	*	*	*	*	*	*	*	*	*	*	*	*	*
1/29/10	*	*	*	*	*	*	*	*	*	*	*	*	*
2/19/10	35.9	2.2	0.5	4.6	0.5	0.0	0.0	0.0	0.0	11.4	2.0	15.4	2.0
2/22/10	21.4	1.1	0.3	1.7	0.2	0.0	0.0	0.0	0.0	10.3	1.1	8.6	1.2
2/25/10	7.2	0.3	0.1	0.3	0.1	0.0	0.0	1.4	0.7	2.3	0.3	1.9	0.8
2/28/10	17.1	0.8	0.2	2.2	0.2	0.0	0.0	3.3	0.9	3.8	0.8	7.1	1.5
3/3/10	28.4	1.9	0.4	1.8	0.3	0.0	0.0	0.0	0.0	9.2	1.6	14.2	1.6
3/6/10	5.2	0.3	0.1	0.4	0.1	0.0	0.0	0.0	0.0	1.5	0.3	3.9	0.6
3/9/10	5.3	0.3	0.1	0.3	0.0	0.0	0.0	1.4	0.7	1.7	0.2	2.0	0.7
3/12/10	12.0	0.7	0.1	0.6	0.1	0.0	0.0	0.0	0.0	3.5	0.6	8.0	1.2
3/15/10	12.0	0.7	0.2	1.2	0.1	0.0	0.0	0.0	0.0	3.5	0.6	6.8	0.8
Average	**36.7**	**1.8**	**0.4**	**0.9**	**0.2**	**0.9**	**0.4**	**0.8**	**0.3**	**11.2**	**1.4**	**21.0**	**2.2**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
Peger Road – Winter 2009/2010.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/3/09	13.7	1.7	0.2	1.0	0.4	0.0	0.0	2.4	0.8	8.2	1.2
11/9/09	12.0	1.5	0.2	1.0	0.2	0.0	0.0	2.3	0.9	6.1	1.0
11/15/09	16.2	1.7	0.2	1.2	0.2	0.0	0.0	2.2	0.9	10.4	1.5
11/17/09	13.7	1.7	0.2	1.2	0.4	0.0	0.0	2.0	0.7	8.9	1.2
11/18/09	*	*	*	*	*	*	*	*	*	*	*
11/19/09	*	*	*	*	*	*	*	*	*	*	*
11/21/09	19.1	3.6	0.4	1.1	0.5	0.0	0.0	1.8	0.8	13.0	1.8
11/27/09	16.5	2.7	0.3	1.4	0.4	0.0	0.0	0.0	0.0	15.7	1.4
12/3/09	12.9	1.5	0.2	1.0	0.3	0.0	0.0	2.2	0.6	8.1	1.2
12/9/09	66.6	12.4	1.4	0.0	0.0	0.0	0.0	0.0	0.0	56.3	5.6
12/10/09	64.0	12.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	54.0	5.4
12/11/09	58.8	10.3	1.2	2.7	1.3	0.0	0.0	4.4	2.1	38.4	4.7
12/12/09	36.8	6.3	0.7	2.6	0.8	0.0	0.0	0.0	0.0	29.0	6.0
12/13/09	40.7	6.6	0.7	2.6	0.9	0.0	0.0	0.0	0.0	30.8	7.7
12/21/09	41.7	6.5	0.7	2.1	0.9	0.0	0.0	9.2	2.1	22.1	3.1
12/24/09	28.6	4.8	0.5	2.2	0.6	11.2	3.0	0.0	0.0	10.8	2.6
12/27/09	17.8	2.8	0.3	1.3	0.4	0.0	0.0	5.7	1.2	7.1	1.2
12/30/09	49.9	9.6	1.1	0.0	0.0	0.0	0.0	0.0	0.0	41.9	3.0
1/2/10	45.6	9.5	1.1	3.7	1.2	0.0	0.0	0.0	0.0	29.9	3.7
1/8/10	39.7	7.7	0.9	2.7	1.0	0.0	0.0	0.0	0.0	28.2	7.3
1/11/10	47.1	12.1	1.3	3.1	1.5	0.0	0.0	0.0	0.0	30.3	7.8
1/14/10	9.2	1.0	0.1	0.6	0.1	3.4	1.4	0.0	0.0	3.7	1.2
1/17/10	17.6	2.3	0.3	1.4	0.3	0.0	0.0	3.5	1.0	10.0	1.5
1/20/10	29.6	5.2	0.6	2.6	0.7	0.0	0.0	7.8	1.7	12.7	2.0
1/23/10	32.2	5.0	0.6	2.3	0.7	0.0	0.0	0.0	0.0	24.4	6.2
1/26/10	64.1	11.0	1.2	4.0	1.5	0.0	0.0	0.0	0.0	49.7	4.9
1/29/10	33.9	5.7	0.6	2.2	0.8	0.0	0.0	12.6	2.0	11.5	2.0
2/1/10	23.5	3.5	0.4	3.5	0.5	0.0	0.0	0.0	0.0	16.5	4.6
2/4/10	33.9	7.4	0.8	3.1	1.0	0.0	0.0	0.0	0.0	23.3	6.1
2/7/10	11.1	1.6	0.2	1.2	0.2	0.0	0.0	1.7	0.6	6.5	1.0
2/10/10	33.5	3.8	0.4	4.2	0.6	0.0	0.0	8.5	1.5	15.5	2.2
2/13/10	32.6	4.9	0.5	5.7	1.1	0.0	0.0	6.4	1.7	15.4	2.2
2/16/10	35.9	4.6	0.5	6.2	1.2	0.0	0.0	7.8	1.9	16.8	2.3
2/19/10	33.2	2.9	0.3	6.5	0.5	0.0	0.0	9.4	1.4	14.1	2.0
2/22/10	8.9	0.8	0.1	1.3	0.3	0.0	0.0	2.2	0.7	4.7	0.8
2/25/10	*	*	*	*	*	*	*	*	*	*	*
2/28/10	9.4	0.8	0.1	1.7	0.1	0.0	0.0	0.0	0.0	7.2	1.5
3/3/10	25.8	3.1	0.3	2.1	0.4	0.0	0.0	10.7	1.5	9.4	1.6
3/6/10	6.5	0.6	0.1	0.4	0.1	0.0	0.0	0.0	0.0	5.6	0.8
3/9/10	3.6**	**	**	**	**	**	**	**	**	**	**
3/12/10	7.8	1.0	0.1	0.8	0.1	0.0	0.0	2.5	0.8	3.5	0.7
3/15/10	10.8	0.9	0.1	1.1	0.1	0.0	0.0	0.0	0.0	8.9	1.9
Average	**29.0**	**4.8**	**0.5**	**2.1**	**0.6**	**0.4**	**0.1**	**2.8**	**0.7**	**18.6**	**3.0**

Notes: **Incomplete filter collection, so no model run conducted.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
Peger Road – Winter 2009/2010.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/3/09	13.7	0.8	0.2	0.7	0.1	0.0	0.0	0.0	0.0	4.4	0.6	7.3	0.9
11/9/09	12.0	0.6	0.3	0.8	0.3	1.9	0.8	0.0	0.0	3.9	1.3	4.9	1.5
11/15/09	16.2	0.9	0.2	1.0	0.1	0.0	0.0	0.0	0.0	4.1	0.8	9.0	1.0
11/17/09	13.7	1.0	0.2	1.1	0.2	0.0	0.0	0.0	0.0	4.2	0.8	7.4	1.0
11/18/09	*	*	*	*	*	*	*	*	*	*	*	*	*
11/19/09	*	*	*	*	*	*	*	*	*	*	*	*	*
11/21/09	19.1	1.9	0.4	0.8	0.3	0.0	0.0	0.0	0.0	9.6	1.5	8.1	1.4
11/27/09	16.5	1.0	0.4	1.2	0.4	0.0	0.0	3.0	0.8	8.8	2.3	2.7	0.7
12/3/09	12.9	0.7	0.1	0.7	0.1	0.0	0.0	0.0	0.0	4.0	0.6	7.6	0.9
12/9/09	66.6	6.0	1.1	2.1	0.8	0.0	0.0	0.0	0.0	33.8	4.5	27.5	6.2
12/10/09	64.0	5.9	1.1	2.1	0.8	0.0	0.0	0.0	0.0	32.0	4.4	27.0	6.1
12/11/09	58.8	5.2	1.0	2.0	0.7	0.0	0.0	0.0	0.0	30.4	4.1	19.9	3.6
12/12/09	36.8	3.4	0.7	2.2	0.5	0.0	0.0	0.0	0.0	16.1	2.7	11.8	2.4
12/13/09	40.7	3.0	0.6	2.1	0.4	6.2	2.7	0.0	0.0	19.0	2.4	12.2	4.5
12/21/09	41.7	3.4	0.7	1.6	0.5	0.0	0.0	4.3	1.7	17.5	2.6	13.4	2.6
12/24/09	28.6	1.9	0.4	2.1	0.3	0.0	0.0	0.0	0.0	15.1	1.7	9.6	1.7
12/27/09	17.8	1.2	0.2	0.8	0.2	0.0	0.0	3.1	0.7	6.8	1.0	6.9	1.6
12/30/09	49.9	4.2	0.8	1.8	0.6	0.0	0.0	5.6	1.3	27.6	3.3	11.4	4.5
1/2/10	45.6	5.2	1.0	1.9	0.7	0.0	0.0	0.0	0.0	24.0	4.0	13.0	3.3
1/8/10	39.7	3.4	0.7	2.3	0.5	0.0	0.0	3.2	1.1	22.0	2.7	7.4	3.6
1/11/10	47.1	6.2	1.1	0.9	0.8	0.0	0.0	0.0	0.0	32.2	4.6	5.3	5.7
1/14/10	9.2	0.5	0.1	0.5	0.1	0.0	0.0	0.0	0.0	2.3	0.4	6.4	1.0
1/17/10	17.6	1.1	0.2	0.9	0.2	0.0	0.0	0.0	0.0	6.2	0.9	8.4	1.1
1/20/10	29.6	2.5	0.6	1.6	0.6	0.0	0.0	3.4	1.0	13.8	3.0	8.5	3.6
1/23/10	32.2	1.9	0.6	2.0	0.5	3.2	1.4	0.0	0.0	14.9	2.7	10.8	3.5
1/26/10	64.1	5.1	1.0	3.5	0.7	0.0	0.0	4.9	2.0	31.9	4.1	16.2	5.5
1/29/10	33.9	1.9	0.4	1.8	0.3	0.0	0.0	6.8	1.0	17.9	1.7	5.6	2.6
2/1/10	23.5	1.5	0.3	3.2	0.3	0.0	0.0	0.0	0.0	11.0	1.4	4.2	1.9
2/4/10	33.9	4.0	0.7	2.7	0.6	0.0	0.0	0.0	0.0	18.6	3.1	5.0	2.6
2/7/10	11.1	0.9	0.2	1.1	0.2	0.0	0.0	0.0	0.0	4.2	0.8	5.0	0.9
2/10/10	33.5	1.7	0.4	3.9	0.4	0.0	0.0	5.1	1.4	11.5	1.7	9.9	1.9
2/13/10	32.6	2.2	0.7	4.5	0.7	0.0	0.0	4.3	1.2	15.1	3.7	6.6	2.8
2/16/10	35.9	2.0	0.7	5.2	0.8	0.0	0.0	4.5	1.4	14.0	3.7	10.2	3.2
2/19/10	33.2	1.0	0.3	5.5	0.4	0.0	0.0	4.7	1.5	9.6	1.5	10.9	2.0
2/22/10	*	*	*	*	*	*	*	*	*	*	*	*	*
2/25/10	*	*	*	*	*	*	*	*	*	*	*	*	*
2/28/10	9.4	0.6	0.1	1.4	0.1	2.6	1.2	0.0	0.0	1.9	0.5	3.1	1.5
3/3/10	25.8	0.7	0.2	1.9	0.2	0.0	0.0	6.3	0.9	9.9	0.9	8.1	1.6
3/6/10	6.5	0.3	0.1	0.3	0.0	1.8	0.8	0.0	0.0	2.0	0.2	1.7	0.8
3/9/10	3.6**	**	**	**	**	**	**	**	**	**	**	**	**
3/12/10	7.8	0.5	0.2	0.7	0.2	0.0	0.0	1.3	0.5	2.5	0.9	3.1	1.2
3/15/10	10.8	0.5	0.1	1.0	0.1	0.0	0.0	2.2	0.8	2.6	0.4	4.2	1.0
Average	**29.0**	**2.3**	**0.5**	**1.9**	**0.4**	**0.4**	**0.2**	**1.7**	**0.5**	**13.7**	**2.1**	**9.2**	**2.5**

Notes: **Incomplete filter collection, so no model run conducted.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
State Building – Winter 2010/2011.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/1/10	14.5	2.0	0.2	0.9	0.3	0.0	0.0	0.0	0.0	11.5	0.4
11/4/10	3.3**	**	**	**	**	**	**	**	**	**	**
11/7/10	9.6	1.9	0.2	1.2	0.3	0.0	0.0	0.0	0.0	6.5	1.0
11/10/10	8.6	1.2	0.1	0.8	0.2	0.0	0.0	0.0	0.0	6.5	0.2
11/13/10	8.1	1.0	0.1	0.7	0.1	0.0	0.0	0.0	0.0	6.5	0.2
11/16/10	22.0	3.1	0.4	1.4	0.4	0.0	0.0	0.0	0.0	18.2	1.1
11/19/10	17.6	2.4	0.3	1.5	0.3	0.0	0.0	0.0	0.0	13.9	0.5
11/22/10	11.5	2.0	0.2	0.8	0.3	5.9	1.2	0.0	0.0	2.9	0.5
11/25/10	*	*	*	*	*	*	*	*	*	*	*
11/28/10	14.4	2.4	0.3	1.2	0.3	0.0	0.0	0.0	0.0	10.4	0.5
12/1/10	43.1	8.9	1.1	3.1	1.1	0.0	0.0	0.0	0.0	31.0	1.7
12/4/10	7.0	1.3	0.2	0.7	0.2	0.0	0.0	0.0	0.0	5.0	0.7
12/7/10	36.5	7.6	0.9	1.9	1.0	0.0	0.0	0.0	0.0	26.6	3.9
12/10/10	26.1	4.5	0.6	2.2	0.6	0.0	0.0	0.0	0.0	19.1	2.8
12/13/10	15.2	2.4	0.3	1.3	0.3	0.0	0.0	0.0	0.0	11.4	1.6
12/16/10	*	*	*	*	*	*	*	*	*	*	*
12/19/10	*	*	*	*	*	*	*	*	*	*	*
12/22/10	*	*	*	*	*	*	*	*	*	*	*
12/25/10	*	*	*	*	*	*	*	*	*	*	*
12/28/10	*	*	*	*	*	*	*	*	*	*	*
12/31/10	*	*	*	*	*	*	*	*	*	*	*
1/3/11	*	*	*	*	*	*	*	*	*	*	*
1/6/11	*	*	*	*	*	*	*	*	*	*	*
1/9/11	*	*	*	*	*	*	*	*	*	*	*
1/12/11	*	*	*	*	*	*	*	*	*	*	*
1/15/11	*	*	*	*	*	*	*	*	*	*	*
1/18/11	*	*	*	*	*	*	*	*	*	*	*
1/21/11	*	*	*	*	*	*	*	*	*	*	*
1/24/11	*	*	*	*	*	*	*	*	*	*	*
1/27/11	*	*	*	*	*	*	*	*	*	*	*
1/30/11	*	*	*	*	*	*	*	*	*	*	*
2/2/11	*	*	*	*	*	*	*	*	*	*	*
2/5/11	34.9	6.8	0.8	4.4	0.9	0.0	0.0	0.0	0.0	23.3	1.3
2/8/11	33.5	5.0	0.6	3.1	0.7	0.0	0.0	0.0	0.0	26.3	1.0
Average	**20.2**	**3.5**	**0.4**	**1.7**	**0.5**	**0.4**	**0.1**	**0.0**	**0.0**	**14.6**	**1.1**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
State Building – Winter 2010/2011.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/1/10	14.5	1.0	0.2	0.5	0.1	0.0	0.0	1.0	0.2	4.5	0.8	7.0	0.9
11/4/10	3.3**	**	**	**	**	**	**	**	**	**	**	**	**
11/7/10	9.6	1.2	0.2	1.0	0.2	0.0	0.0	0.0	0.0	3.2	0.9	3.3	1.0
11/10/10	8.6	0.7	0.1	0.6	0.1	0.0	0.0	0.0	0.0	2.7	0.5	4.1	0.6
11/13/10	8.1	0.7	0.1	0.6	0.1	0.8	0.4	0.0	0.0	1.6	0.5	4.5	0.6
11/16/10	22.0	1.8	0.4	1.3	0.3	2.6	1.2	0.0	0.0	7.2	1.5	7.6	1.6
11/19/10	17.6	1.4	0.3	1.3	0.2	0.0	0.0	0.0	0.0	5.6	1.1	9.2	1.2
11/22/10	11.5	1.8	0.2	0.8	0.2	0.0	0.0	1.5	0.3	0.0	0.0	6.8	0.4
11/25/10	*	*	*	*	*	*	*	*	*	*	*	*	*
11/28/10	14.4	1.4	0.3	0.9	0.2	0.0	0.0	0.0	0.0	5.1	1.1	5.9	1.2
12/1/10	43.1	5.0	1.0	1.7	0.7	0.0	0.0	0.0	0.0	21.4	3.9	10.7	4.3
12/4/10	7.0	0.9	0.2	0.5	0.1	0.0	0.0	0.0	0.0	2.1	0.6	2.7	0.7
12/7/10	36.5	3.8	0.8	1.6	0.5	0.0	0.0	0.0	0.0	20.9	3.1	4.5	3.4
12/10/10	26.1	2.6	0.5	2.1	0.4	0.0	0.0	0.0	0.0	10.2	2.0	8.6	2.2
12/13/10	15.2	1.4	0.3	0.9	0.2	0.0	0.0	0.0	0.0	5.5	1.0	5.7	1.2
12/16/10	*	*	*	*	*	*	*	*	*	*	*	*	*
12/19/10	*	*	*	*	*	*	*	*	*	*	*	*	*
12/22/10	*	*	*	*	*	*	*	*	*	*	*	*	*
12/25/10	*	*	*	*	*	*	*	*	*	*	*	*	*
12/28/10	*	*	*	*	*	*	*	*	*	*	*	*	*
12/31/10	*	*	*	*	*	*	*	*	*	*	*	*	*
1/3/11	*	*	*	*	*	*	*	*	*	*	*	*	*
1/6/11	*	*	*	*	*	*	*	*	*	*	*	*	*
1/9/11	*	*	*	*	*	*	*	*	*	*	*	*	*
1/12/11	*	*	*	*	*	*	*	*	*	*	*	*	*
1/15/11	*	*	*	*	*	*	*	*	*	*	*	*	*
1/18/11	*	*	*	*	*	*	*	*	*	*	*	*	*
1/21/11	*	*	*	*	*	*	*	*	*	*	*	*	*
1/24/11	*	*	*	*	*	*	*	*	*	*	*	*	*
1/27/11	*	*	*	*	*	*	*	*	*	*	*	*	*
1/30/11	*	*	*	*	*	*	*	*	*	*	*	*	*
2/2/11	*	*	*	*	*	*	*	*	*	*	*	*	*
2/5/11	34.9	3.2	0.7	3.0	0.5	0.0	0.0	0.0	0.0	20.4	2.8	3.3	3.1
2/8/11	33.5	2.5	0.6	2.9	0.4	0.0	0.0	0.0	0.0	13.6	2.1	14.0	2.4
Average	**20.2**	**2.0**	**0.4**	**1.3**	**0.3**	**0.2**	**0.1**	**0.2**	**0.04**	**8.3**	**1.5**	**6.5**	**1.7**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
North Pole – Winter 2010/2011.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
1/9/11	23.4	1.3	0.1	1.3	0.2	0.0	0.0	0.0	0.0	20.8	1.5
1/12/11	11.7	1.0	0.1	0.5	0.1	0.0	0.0	2.2	0.6	8.1	1.1
1/15/11	33.8	2.6	0.3	0.8	0.3	9.8	2.7	0.0	0.0	21.9	2.9
1/18/11	26.8	2.3	0.3	1.1	0.3	0.0	0.0	3.0	1.1	18.7	2.4
1/21/11	40.8	5.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	37.0	7.4
1/24/11	6.5	0.8	0.1	0.4	0.1	0.0	0.0	0.0	0.0	5.5	0.8
1/27/11	14.0	1.1	0.1	0.7	0.1	3.8	1.9	0.0	0.0	7.8	1.2
1/30/11	58.5	3.3	0.4	1.6	0.4	0.0	0.0	0.0	0.0	54.3	10.6
2/2/11	23.3	2.0	0.2	1.5	0.3	0.0	0.0	0.0	0.0	19.4	1.4
2/5/11	28.8	2.2	0.2	1.5	0.3	0.0	0.0	4.0	1.1	19.7	2.5
Average	**26.8**	**2.1**	**0.3**	**0.9**	**0.2**	**1.4**	**0.5**	**0.9**	**0.3**	**21.3**	**3.2**

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
North Pole – Winter 2010/2011.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
1/9/11	23.4	0.7	0.1	1.1	0.1	5.3	1.9	0.0	0.0	2.9	0.6	13.0	1.6
1/12/11	11.7	0.7	0.1	0.3	0.1	0.0	0.0	0.0	0.0	1.8	0.5	8.5	0.8
1/15/11	33.8	0.8	0.2	0.6	0.1	0.0	0.0	1.8	0.7	7.3	0.7	22.8	2.1
1/18/11	26.8	0.8	0.2	0.6	0.2	0.0	0.0	1.2	0.6	6.9	1.1	17.8	1.9
1/21/11	40.8	2.6	0.5	0.0	0.0	0.0	0.0	0.0	0.0	13.4	1.9	19.6	2.1
1/24/11	6.5	0.4	0.1	0.4	0.1	0.0	0.0	0.0	0.0	1.6	0.3	4.6	0.6
1/27/11	14.0	0.6	0.1	0.5	0.1	0.0	0.0	0.0	0.0	2.1	0.5	11.4	1.1
1/30/11	58.5	1.4	0.3	1.1	0.2	13.5	2.6	0.0	0.0	8.8	1.2	35.1	4.9
2/2/11	23.3	1.4	0.2	1.3	0.2	0.0	0.0	3.8	1.0	2.5	1.1	14.0	1.9
2/5/11	28.8	0.8	0.2	1.1	0.1	0.0	0.0	1.9	0.7	5.9	0.7	19.0	1.8
Average	**26.8**	**1.0**	**0.2**	**0.7**	**0.1**	**1.9**	**0.5**	**0.9**	**0.3**	**5.3**	**0.8**	**16.6**	**1.9**

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
Peger Road – Winter 2010/2011.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
1/9/11	22.7	3.0	0.3	2.6	0.4	0.0	0.0	0.0	0.0	17.2	4.4
1/12/11	48.4	10.8	1.2	0.0	0.0	0.0	0.0	0.0	0.0	37.3	4.0
1/15/11	24.6	3.8	0.4	1.1	0.5	7.2	3.0	0.0	0.0	12.9	2.0
1/18/11	44.9	9.1	1.0	2.7	1.2	0.0	0.0	0.0	0.0	34.7	7.2
1/21/11	23.3	4.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0	18.2	4.6
1/24/11	12.4	1.7	0.2	1.1	0.3	0.0	0.0	1.5	0.6	8.2	1.2
1/27/11	14.6	2.0	0.2	1.6	0.5	0.0	0.0	3.0	0.7	8.3	1.3
1/30/11	35.4	4.9	0.5	2.8	0.7	0.0	0.0	0.0	0.0	26.5	6.6
2/2/11	25.1	2.6	0.3	4.3	0.4	0.0	0.0	3.8	1.1	13.4	1.8
2/5/11	34.0	5.6	0.6	4.0	0.8	0.0	0.0	0.0	0.0	25.0	6.3
Average	**28.6**	**4.8**	**0.5**	**2.0**	**0.5**	**0.7**	**0.3**	**0.8**	**0.2**	**20.2**	**3.9**

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
Peger Road – Winter 2010/2011.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
1/9/11	22.7	1.1	0.5	2.5	0.6	4.1	1.4	0.0	0.0	7.5	2.6	7.4	2.8
1/12/11	48.4	5.1	1.0	1.8	0.7	0.0	0.0	3.2	1.3	29.4	4.0	7.5	5.0
1/15/11	24.6	1.6	0.3	0.8	0.2	0.0	0.0	0.0	0.0	11.8	1.3	11.7	2.1
1/18/11	44.9	4.2	0.8	2.1	0.6	0.0	0.0	0.0	0.0	26.9	3.2	11.0	4.3
1/21/11	23.3	2.0	0.4	0.8	0.3	0.0	0.0	0.0	0.0	11.4	1.6	11.0	2.3
1/24/11	12.4	1.0	0.2	0.8	0.1	0.0	0.0	0.0	0.0	3.7	0.8	7.0	0.9
1/27/11	14.6	1.1	0.2	1.2	0.2	0.0	0.0	0.0	0.0	5.1	0.9	7.4	1.0
1/30/11	35.4	2.0	0.5	2.5	0.5	0.0	0.0	2.5	0.9	14.6	2.4	13.7	3.2
2/2/11	25.1	0.7	0.4	3.5	0.4	2.4	1.0	0.0	0.0	8.5	1.8	11.7	2.0
2/5/11	34.0	2.2	0.5	3.7	0.4	0.0	0.0	3.9	0.9	16.3	2.0	6.8	2.8
Average	**28.6**	**2.1**	**0.5**	**2.0**	**0.4**	**0.6**	**0.2**	**1.0**	**0.3**	**13.5**	**2.1**	**9.5**	**2.6**

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
State Building – Winter 2011/2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/11	11.0	2.2	0.3	0.8	0.3	0.0	0.0	0.0	0.0	8.2	0.7
11/5/11	*	*	*	*	*	*	*	*	*	*	*
11/8/11	10.3	1.6	0.2	0.5	0.2	0.0	0.0	0.0	0.0	8.4	1.2
11/11/11	8.9	1.1	0.1	0.5	0.1	0.0	0.0	0.0	0.0	7.2	0.2
11/14/11	24.6	3.6	0.4	1.2	0.5	0.0	0.0	0.0	0.0	19.8	1.6
11/17/11	32.8	6.2	0.8	2.1	0.8	0.0	0.0	0.0	0.0	23.4	5.7
11/20/11	*	*	*	*	*	*	*	*	*	*	*
11/23/11	14.8	2.1	0.3	0.9	0.3	0.0	0.0	0.0	0.0	11.5	0.7
11/26/11	24.7	4.4	0.5	1.6	0.6	0.0	0.0	0.0	0.0	18.3	1.5
11/29/11	27.2	4.6	0.6	1.5	0.6	0.0	0.0	0.0	0.0	20.2	1.7
12/2/11	14.7	1.9	0.2	1.0	0.2	0.0	0.0	0.0	0.0	11.5	2.1
12/5/11	*	*	*	*	*	*	*	*	*	*	*
12/8/11	27.2	4.4	0.5	1.9	0.6	0.0	0.0	0.0	0.0	21.1	1.7
12/11/11	*	*	*	*	*	*	*	*	*	*	*
12/14/11	24.7	4.0	0.5	1.6	0.5	8.2	2.3	0.0	0.0	9.9	1.3
12/17/11	37.3	5.9	0.7	1.5	0.7	0.0	0.0	0.0	0.0	31.6	5.8
12/20/11	13.8	1.5	0.2	0.8	0.2	0.0	0.0	0.0	0.0	12.1	0.4
12/23/11	6.3**	**	**	**	**	**	**	**	**	**	**
12/26/11	23.1	4.0	0.5	1.6	0.5	8.0	2.4	0.0	0.0	10.9	1.4
12/29/11	31.8	5.7	0.7	1.6	0.7	0.0	0.0	0.0	0.0	25.5	2.1
1/1/12	*	*	*	*	*	*	*	*	*	*	*
1/4/12	14.3	2.0	0.2	1.0	0.3	0.0	0.0	0.0	0.0	11.2	0.9
1/7/12	15.6	3.2	0.4	1.1	0.4	0.0	0.0	0.0	0.0	11.0	1.0
1/10/12	24.4	4.0	0.5	1.2	0.5	0.0	0.0	0.0	0.0	18.0	2.6
1/13/12	23.2	4.8	0.6	1.2	0.6	0.0	0.0	0.0	0.0	17.9	0.9
1/16/12	29.1	6.1	0.8	2.4	0.8	0.0	0.0	8.8	1.6	12.1	1.6
1/19/12	40.5	8.1	1.0	4.0	1.0	0.0	0.0	0.0	0.0	27.3	1.5
1/22/12	*	*	*	*	*	*	*	*	*	*	*
1/25/12	9.8	1.8	0.2	0.8	0.2	0.0	0.0	0.0	0.0	6.9	0.5
1/28/12	36.8	7.6	0.9	2.2	1.0	0.0	0.0	0.0	0.0	18.3	2.0
1/31/12	18.7	4.9	0.6	1.8	0.6	0.0	0.0	0.0	0.0	11.4	1.2
2/3/12	6.5**	**	**	**	**	**	**	**	**	**	**
2/6/12	24.8	3.9	0.5	2.1	0.5	0.0	0.0	0.0	0.0	18.4	1.2
2/9/12	18.1	2.3	0.3	1.2	0.3	0.0	0.0	0.0	0.0	13.8	0.8
2/12/12	18.3	2.1	0.3	1.9	0.3	0.0	0.0	0.0	0.0	14.8	0.8
2/15/12	27.0	4.5	0.6	2.2	0.6	0.0	0.0	0.0	0.0	20.2	2.9
2/18/12	25.6	3.9	0.5	3.2	0.5	0.0	0.0	0.0	0.0	17.5	1.2
2/21/12	13.7	2.9	0.4	1.7	0.4	0.0	0.0	0.0	0.0	9.8	0.9
2/24/12	5.0**	**	**	**	**	**	**	**	**	**	**
2/27/12	4.3**	**	**	**	**	**	**	**	**	**	**
3/1/12	9.0	2.2	0.3	0.8	0.3	0.0	0.0	0.0	0.0	5.8	0.4
3/4/12	*	*	*	*	*	*	*	*	*	*	*
3/7/12	*	*	*	*	*	*	*	*	*	*	*
3/10/12	9.5	2.2	0.3	1.3	0.3	0.0	0.0	0.0	0.0	5.9	0.4
3/13/12	13.9	2.7	0.3	1.4	0.4	0.0	0.0	0.0	0.0	9.7	0.8

3/16/12	16.3	3.4	0.4	1.3	0.4	0.0	0.0	0.0	0.0	11.5	0.9
3/19/12	10.6	2.6	0.3	1.2	0.3	0.0	0.0	0.0	0.0	6.9	1.1
3/22/12	13.3	3.0	0.4	1.4	0.4	0.0	0.0	0.0	0.0	9.2	0.8
3/25/12	11.0	1.7	0.2	1.2	0.2	0.0	0.0	0.0	0.0	7.9	0.5
3/28/12	8.6	1.4	0.2	1.0	0.2	0.0	0.0	0.0	0.0	6.3	0.4
3/31/12	5.4**	**	**	**	**	**	**	**	**	**	**
Average	**20.0**	**3.5**	**0.4**	**1.5**	**0.5**	**0.4**	**0.1**	**0.2**	**0.04**	**14.0**	**1.4**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
State Building – Winter 2011/2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/11	11.0	1.6	0.3	0.6	0.2	0.0	0.0	0.0	0.0	2.4	1.1	6.8	1.3
11/5/11	*	*	*	*	*	*	*	*	*	*	*	*	*
11/8/11	10.3	1.1	0.2	0.3	0.2	0.0	0.0	0.0	0.0	2.2	0.8	6.1	0.9
11/11/11	8.9	0.8	0.1	0.4	0.1	0.0	0.0	0.0	0.0	1.4	0.5	6.3	0.6
11/14/11	24.6	2.3	0.4	0.9	0.3	0.0	0.0	0.0	0.0	5.9	1.7	16.4	1.9
11/17/11	32.8	3.8	0.8	1.2	0.5	0.0	0.0	0.0	0.0	12.9	3.0	12.4	2.0
11/20/11	*	*	*	*	*	*	*	*	*	*	*	*	*
11/23/11	14.8	1.4	0.3	0.6	0.2	0.0	0.0	0.0	0.0	3.7	1.0	6.4	1.2
11/26/11	24.7	2.7	0.5	1.1	0.4	0.0	0.0	0.0	0.0	8.2	2.0	12.5	2.2
11/29/11	27.2	2.8	0.5	0.9	0.4	0.0	0.0	0.0	0.0	8.8	2.1	13.5	2.3
12/2/11	14.7	1.4	0.3	0.9	0.2	0.0	0.0	1.0	0.3	2.2	1.1	8.5	1.2
12/5/11	*	*	*	*	*	*	*	*	*	*	*	*	*
12/8/11	27.2	2.5	0.5	1.2	0.4	0.0	0.0	0.0	0.0	9.8	1.9	13.2	2.1
12/11/11	*	*	*	*	*	*	*	*	*	*	*	*	*
12/14/11	24.7	2.5	0.5	1.1	0.3	4.2	1.6	0.0	0.0	7.5	1.9	10.3	2.1
12/17/11	37.3	3.7	0.7	0.0	0.0	7.9	2.4	0.0	0.0	13.6	2.6	12.2	2.9
12/20/11	13.8	1.4	0.2	0.8	0.2	3.1	0.9	0.0	0.0	0.0	0.0	8.2	0.5
12/23/11	6.3**	**	**	**	**	**	**	**	**	**	**	**	**
12/26/11	23.1	2.2	0.5	1.0	0.4	1.7	0.8	0.0	0.0	8.3	2.1	11.2	2.2
12/29/11	31.8	3.8	0.7	1.1	0.5	0.0	0.0	0.0	0.0	9.0	2.6	20.0	2.9
1/1/12	*	*	*	*	*	*	*	*	*	*	*	*	*
1/4/12	14.3	1.4	0.3	0.8	0.2	0.0	0.0	0.0	0.0	2.9	1.0	9.6	1.1
1/7/12	15.6	2.1	0.4	0.7	0.3	0.0	0.0	0.0	0.0	5.6	1.5	6.4	1.6
1/10/12	24.4	2.7	0.5	0.8	0.4	0.0	0.0	0.0	0.0	6.7	1.9	11.3	2.1
1/13/12	23.2	3.0	0.6	0.6	0.4	0.0	0.0	0.0	0.0	10.1	2.2	8.7	2.4
1/16/12	29.1	3.7	0.8	1.4	0.5	0.0	0.0	5.9	1.0	13.6	2.9	4.8	2.0
1/19/12	40.5	5.2	1.0	2.9	0.7	0.0	0.0	0.0	0.0	15.4	3.6	13.4	4.0
1/22/12	*	*	*	*	*	*	*	*	*	*	*	*	*
1/25/12	9.8	1.2	0.2	0.6	0.2	0.0	0.0	0.8	0.2	2.9	0.9	2.0	1.0
1/28/12	*	*	*	*	*	*	*	*	*	*	*	*	*
1/31/12	*	*	*	*	*	*	*	*	*	*	*	*	*
2/3/12	6.5**	**	**	**	**	**	**	**	**	**	**	**	**
2/6/12	24.8	2.2	0.5	1.6	0.3	0.0	0.0	4.9	0.4	7.7	1.7	4.7	1.9
2/9/12	18.1	1.6	0.3	0.9	0.2	5.4	1.1	0.0	0.0	4.2	1.2	5.2	1.4
2/12/12	18.3	1.4	0.3	1.6	0.2	4.5	0.9	0.0	0.0	4.2	1.1	6.6	1.2
2/15/12	27.0	2.4	0.5	1.5	0.4	0.0	0.0	3.0	0.5	10.4	1.9	6.7	2.1
2/18/12	25.6	2.6	0.5	2.6	0.4	0.0	0.0	0.0	0.0	7.7	2.0	7.7	2.2
2/21/12	13.7	1.9	0.4	1.3	0.3	0.0	0.0	0.9	0.4	5.2	1.6	4.3	1.7
2/24/12	5.0**	**	**	**	**	**	**	**	**	**	**	**	**
2/27/12	4.3**	**	**	**	**	**	**	**	**	**	**	**	**
3/1/12	9.0	1.2	0.2	0.4	0.2	0.0	0.0	0.0	0.0	5.8	0.2	0.0	0.0
3/4/12*	*	*	*	*	*	*	*	*	*	*	*	*	*
3/7/12*	*	*	*	*	*	*	*	*	*	*	*	*	*
3/10/12	9.5	1.6	0.3	1.1	0.2	0.0	0.0	0.0	0.0	2.7	1.2	3.5	1.3

3/13/12	13.9	1.8	0.3	1.0	0.3	0.0	0.0	0.0	0.0	5.6	1.3	2.7	1.4
3/16/12	16.3	2.1	0.3	0.7	0.3	3.8	1.3	0.0	0.0	7.8	0.7	0.0	0.0
3/19/12	10.6	1.7	0.3	0.9	0.2	0.0	0.0	0.0	0.0	4.5	1.3	2.2	1.4
3/22/12	13.3	2.0	0.4	1.0	0.3	0.0	0.0	0.0	0.0	5.6	1.5	2.4	1.6
3/25/12	11.0	1.3	0.2	1.0	0.2	0.0	0.0	0.0	0.0	2.1	1.0	4.8	1.1
3/28/12	8.6	1.0	0.2	0.8	0.2	0.0	0.0	0.0	0.0	2.3	0.8	3.1	0.9
3/31/12	5.4**	**	**	**	**	**	**	**	**	**	**	**	**
Average	**20.0**	**2.2**	**0.4**	**1.0**	**0.3**	**0.8**	**0.2**	**0.5**	**0.1**	**6.4**	**1.5**	**7.6**	**1.6**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
North Pole – Winter 2011/2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/11	***	***	***	***	***	***	***	***	***	***	***
11/5/11	8.8	0.5	0.1	0.2	0.1	0.0	0.0	0.0	0.0	7.7	1.3
11/8/11	9.2	0.6	0.1	0.3	0.1	0.0	0.0	0.0	0.0	7.7	0.9
11/11/11	12.3	0.5	0.1	0.3	0.1	0.0	0.0	0.0	0.0	12.4	1.2
11/14/11	30.5	1.4	0.2	0.6	0.2	0.0	0.0	0.0	0.0	27.5	4.1
11/17/11	23.2	1.8	0.2	0.7	0.2	0.0	0.0	0.0	0.0	21.7	2.5
11/20/11	82.6	7.7	0.9	2.0	1.0	0.0	0.0	0.0	0.0	63.9	7.1
11/23/11	12.6	0.6	0.1	0.4	0.1	0.0	0.0	0.0	0.0	10.4	1.0
11/26/11	22.4	1.5	0.2	0.7	0.2	0.0	0.0	0.0	0.0	19.2	2.2
11/29/11	30.4	2.6	0.3	0.9	0.3	0.0	0.0	0.0	0.0	28.5	5.7
12/2/11	10.5	0.9	0.1	0.4	0.1	0.0	0.0	0.0	0.0	8.6	1.1
12/5/11	2.5**	**	**	**	**	**	**	**	**	**	**
12/8/11	42.0	2.8	0.3	1.0	0.4	0.0	0.0	0.0	0.0	38.1	3.3
12/11/11	7.9	0.4	0.0	0.1	0.1	0.0	0.0	0.0	0.0	7.0	1.3
12/14/11	16.1	1.1	0.1	0.4	0.1	0.0	0.0	0.0	0.0	14.6	3.0
12/17/11	36.4	2.8	0.3	0.8	0.3	0.0	0.0	0.0	0.0	32.2	2.1
12/20/11	12.5	0.8	0.1	0.3	0.1	0.0	0.0	0.0	0.0	11.6	1.3
12/23/11	5.6**	**	**	**	**	**	**	**	**	**	**
12/26/11	38.3	1.9	0.2	1.0	0.2	0.0	0.0	0.0	0.0	33.3	2.3
12/29/11	34.1	2.6	0.3	1.0	0.3	0.0	0.0	0.0	0.0	31.8	2.9
1/1/12	33.5	2.8	0.4	0.8	0.4	0.0	0.0	0.0	0.0	31.5	2.3
1/4/12	11.6	0.9	0.1	0.7	0.1	0.0	0.0	0.0	0.0	9.5	1.0
1/7/12	10.0	0.9	0.1	0.4	0.1	0.0	0.0	0.0	0.0	8.2	0.9
1/10/12	16.5	1.3	0.2	0.5	0.2	0.0	0.0	0.0	0.0	14.7	3.0
1/13/12	17.8	2.1	0.2	0.6	0.3	4.5	2.2	0.0	0.0	11.2	1.7
1/16/12	43.0	2.6	0.3	1.2	0.4	0.0	0.0	0.0	0.0	39.8	5.9
1/19/12	39.5	3.0	0.3	1.8	0.4	0.0	0.0	5.2	1.3	28.2	3.5
1/22/12	***	***	***	***	***	***	***	***	***	***	***
1/25/12	***	***	***	***	***	***	***	***	***	***	***
1/28/12	64.9	4.7	0.5	1.5	0.6	0.0	0.0	0.0	0.0	48.5	3.1
1/31/12	14.5	2.1	0.2	1.0	0.3	0.0	0.0	0.0	0.0	12.3	1.2
2/3/12	***	***	***	***	***	***	***	***	***	***	***
2/6/12	42.8	3.0	0.3	1.6	0.4	0.0	0.0	0.0	0.0	32.9	2.3
2/9/12	***	***	***	***	***	***	***	***	***	***	***
2/12/12	***	***	***	***	***	***	***	***	***	***	***
2/15/12	9.0	0.7	0.1	0.3	0.1	0.0	0.0	0.0	0.0	8.3	1.1
2/18/12	29.2	2.1	0.2	1.1	0.3	0.0	0.0	0.0	0.0	25.4	3.8
2/21/12	13.2	0.6	0.1	0.3	0.1	0.0	0.0	0.0	0.0	12.5	2.0
2/24/12	3.5**	**	**	**	**	**	**	**	**	**	**
2/27/12	2.1**	**	**	**	**	**	**	**	**	**	**
3/1/12	5.1**	**	**	**	**	**	**	**	**	**	**
3/4/12	26.0	2.1	0.2	0.8	0.3	5.2	2.3	0.0	0.0	18.8	2.5
3/7/12	4.1**	**	**	**	**	**	**	**	**	**	**
3/10/12	11.1	1.4	0.2	0.6	0.2	0.0	0.0	0.0	0.0	8.6	1.1

3/13/12	4.3**	**	**	**	**	**	**	**	**	**	**
3/16/12	5.5**	**	**	**	**	**	**	**	**	**	**
3/19/12	18.3	1.9	0.2	0.8	0.2	0.0	0.0	0.0	0.0	14.7	1.8
3/22/12	8.3	1.4	0.2	0.5	0.2	0.0	0.0	0.0	0.0	6.8	0.9
3/25/12	6.5	0.8	0.1	0.4	0.1	0.0	0.0	0.0	0.0	4.9	0.7
Average	**24.2**	**1.8**	**0.2**	**0.7**	**0.2**	**0.3**	**0.1**	**0.1**	**0.04**	**20.4**	**2.3**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn‟t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
North Pole – Winter 2011/2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/11	***	***	***	***	***	***	***	***	***	***	***
11/5/11	8.8	0.4	0.1	0.2	0.1	2.2	0.9	0.0	0.0	4.4	1.1
11/8/11	9.2	0.4	0.1	0.2	0.1	0.0	0.0	0.6	0.3	8.1	0.9
11/11/11	12.3	0.4	0.1	0.2	0.1	0.0	0.0	0.0	0.0	10.5	1.0
11/14/11	30.5	0.7	0.1	0.5	0.1	0.0	0.0	2.0	0.5	26.3	1.9
11/17/11	23.2	1.4	0.2	0.4	0.2	0.0	0.0	2.4	1.0	18.0	1.5
11/20/11	82.6	3.9	0.7	0.0	0.0	0.0	0.0	16.0	2.7	69.5	5.8
11/23/11	12.6	0.4	0.1	0.3	0.1	0.0	0.0	0.8	0.3	7.8	0.9
11/26/11	22.4	1.1	0.2	0.5	0.2	0.0	0.0	2.3	0.8	16.6	1.3
11/29/11	30.4	1.9	0.3	0.5	0.3	0.0	0.0	4.0	1.4	19.6	1.7
12/2/11	10.5	0.9	0.1	0.4	0.1	0.0	0.0	0.0	0.0	8.6	0.7
12/5/11	2.5**	**	**	**	**	**	**	**	**	**	**
12/8/11	42.0	1.5	0.3	0.8	0.2	0.0	0.0	4.5	1.1	36.6	2.7
12/11/11	7.9	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	7.2	0.9
12/14/11	16.1	0.7	0.1	0.3	0.1	0.0	0.0	1.4	0.5	14.0	1.3
12/17/11	36.4	1.8	0.3	0.5	0.2	0.0	0.0	4.0	1.3	28.9	2.5
12/20/11	12.5	0.7	0.1	0.3	0.1	2.7	1.2	0.0	0.0	8.8	1.6
12/23/11	5.6**	**	**	**	**	**	**	**	**	**	**
12/26/11	38.3	1.1	0.2	0.8	0.2	0.0	0.0	2.5	0.9	24.7	2.1
12/29/11	34.1	1.2	0.2	0.6	0.2	3.7	1.7	5.7	0.9	22.8	2.9
1/1/12	33.5	4.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	25.4	1.9
1/4/12	11.6	0.7	0.1	0.7	0.1	0.0	0.0	0.0	0.0	10.6	0.9
1/7/12	10.0	0.5	0.1	0.3	0.1	0.0	0.0	1.1	0.4	8.1	0.8
1/10/12	16.5	1.1	0.1	0.4	0.1	0.0	0.0	0.0	0.0	17.8	1.3
1/13/12	17.8	1.5	0.3	0.0	0.0	0.0	0.0	3.5	1.0	10.5	1.2
1/16/12	43.0	1.4	0.3	0.9	0.2	0.0	0.0	4.1	1.0	37.0	2.7
1/19/12	39.5	2.0	0.4	1.3	0.3	0.0	0.0	5.2	1.5	27.6	2.0
1/22/12	***	***	***	***	***	***	***	***	***	***	***
1/25/12	***	***	***	***	***	***	***	***	***	***	***
1/28/12	***	***	***	***	***	***	***	***	***	***	***
1/31/12	14.5	1.5	0.3	0.8	0.2	0.0	0.0	3.2	1.1	11.1	1.2
2/3/12	***	***	***	***	***	***	***	***	***	***	***
2/6/12	42.8	2.1	0.4	1.3	0.3	10.2	2.8	3.7	1.5	17.0	2.5
2/9/12	***	***	***	***	***	***	***	***	***	***	***
2/12/12	***	***	***	***	***	***	***	***	***	***	***
2/15/12	9.0	0.5	0.1	0.3	0.1	0.0	0.0	0.0	0.0	8.3	0.7
2/18/12	29.2	1.4	0.2	1.0	0.2	0.0	0.0	2.4	1.0	22.2	1.9
2/21/12	13.2	0.4	0.1	0.3	0.1	0.0	0.0	0.0	0.0	12.6	1.1
2/24/12	3.5**	**	**	**	**	**	**	**	**	**	**
2/27/12	2.1**	**	**	**	**	**	**	**	**	**	**
3/1/12	5.1**	**	**	**	**	**	**	**	**	**	**
3/4/12	26.0	1.6	0.3	0.5	0.2	0.0	0.0	2.9	1.1	18.2	1.5
3/7/12	4.1**	**	**	**	**	**	**	**	**	**	**
3/10/12	11.1	0.9	0.2	0.5	0.1	0.0	0.0	2.0	0.7	7.4	0.9
3/13/12	4.3**	**	**	**	**	**	**	**	**	**	**

3/16/12	5.5**	**	**	**	**	**	**	**	**	**	**
3/19/12	18.3	1.3	0.2	0.5	0.2	0.0	0.0	3.5	0.9	12.0	1.2
3/22/12	8.3	0.8	0.1	0.4	0.1	0.0	0.0	2.5	0.6	5.0	1.1
3/25/12	6.5	0.8	0.1	0.4	0.1	0.0	0.0	0.0	0.0	4.7	0.6
Average	**23.0**	**1.2**	**0.2**	**0.5**	**0.1**	**0.6**	**0.2**	**2.4**	**0.7**	**17.3**	**1.6**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
RAMS – Winter 2011/2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
12/20/11	21.8	1.5	0.2	0.9	0.2	0.0	0.0	0.0	0.0	15.6	1.4
12/23/11	13.7	1.0	0.1	0.4	0.1	0.0	0.0	0.0	0.0	8.8	1.1
12/26/11	45.0	4.0	0.4	1.6	0.5	0.0	0.0	0.0	0.0	29.4	2.3
12/29/11	24.6	3.9	0.4	1.4	0.5	0.0	0.0	0.0	0.0	18.9	2.3
1/1/12	21.3	3.5	0.4	1.4	0.4	6.7	2.8	0.0	0.0	11.1	1.8
1/4/12	15.1	2.0	0.2	1.0	0.3	0.0	0.0	1.9	0.9	9.9	1.4
1/7/12	23.4	2.7	0.3	1.0	0.3	0.0	0.0	0.0	0.0	18.1	1.7
1/10/12	16.2	2.8	0.3	0.8	0.4	0.0	0.0	0.0	0.0	15.6	1.4
1/13/12	***	***	***	***	***	***	***	***	***	***	***
1/16/12	13.5	1.7	0.2	1.5	0.2	0.0	0.0	0.0	0.0	16.1	1.4
1/19/12	3.1**	**	**	**	**	**	**	**	**	**	**
1/22/12	0.8**	**	**	**	**	**	**	**	**	**	**
1/25/12	0.7**	**	**	**	**	**	**	**	**	**	**
1/28/12	2.8**	**	**	**	**	**	**	**	**	**	**
1/31/12	23.5	3.6	0.4	1.2	0.5	0.0	0.0	0.0	0.0	19.8	1.7
2/3/12	5.6**	**	**	**	**	**	**	**	**	**	**
2/6/12	24.8	4.1	0.5	1.9	0.5	0.0	0.0	0.0	0.0	18.0	4.6
2/9/12	19.4	2.3	0.3	1.2	0.3	0.0	0.0	4.3	1.1	11.0	1.6
2/12/12	18.1	2.1	0.2	1.7	0.3	0.0	0.0	3.7	1.0	9.3	1.4
2/15/12	30.8	4.4	0.5	2.1	0.6	0.0	0.0	6.9	1.5	14.5	2.1
2/18/12	25.9	3.8	0.4	2.9	0.5	7.0	3.0	0.0	0.0	13.3	2.0
2/21/12	17.0	2.4	0.3	1.2	0.3	0.0	0.0	2.9	1.0	9.6	1.4
2/24/12	5.9**	**	**	**	**	**	**	**	**	**	**
2/27/12	3.5*	**	**	**	**	**	**	**	**	**	**
Average	**22.1**	**2.9**	**0.3**	**1.4**	**0.4**	**0.9**	**0.4**	**1.2**	**0.3**	**14.9**	**1.8**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
RAMS – Winter 2011/2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
12/20/11	21.8	1.3	0.2	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	12.1	1.1
12/23/11	13.7	0.9	0.1	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	6.8	0.8
12/26/11	45.0	2.3	0.4	0.9	0.3	0.0	0.0	0.0	0.0	8.5	1.7	14.3	2.4
12/29/11	24.6	2.5	0.5	0.8	0.3	0.0	0.0	0.0	0.0	7.7	1.9	13.3	1.8
1/1/12	21.3	2.5	0.4	1.1	0.3	0.0	0.0	0.0	0.0	4.3	1.8	11.5	1.7
1/4/12	15.1	1.3	0.2	0.8	0.2	0.0	0.0	0.0	0.0	3.5	1.0	8.9	1.1
1/7/12	23.4	1.7	0.3	0.6	0.2	0.0	0.0	0.0	0.0	5.5	1.2	11.8	1.9
1/10/12	16.2	1.8	0.3	0.7	0.2	0.0	0.0	4.4	1.2	5.7	1.3	3.5	0.6
1/13/12	***	***	***	***	***	***	***	***	***	***	***	***	***
1/16/12	***	***	***	***	***	***	***	***	***	***	***	***	***
1/19/12	3.1**	**	**	**	**	**	**	**	**	**	**	**	**
1/22/12	0.8**	**	**	**	**	**	**	**	**	**	**	**	**
1/25/12	0.7**	**	**	**	**	**	**	**	**	**	**	**	**
1/28/12	2.8**	**	**	**	**	**	**	**	**	**	**	**	**
1/31/12	23.5	2.3	0.4	1.0	0.3	0.0	0.0	0.0	0.0	6.9	1.7	17.0	1.8
2/3/12	5.6**	**	**	**	**	**	**	**	**	**	**	**	**
2/6/12	24.8	2.8	0.5	1.4	0.4	5.2	2.4	0.0	0.0	6.2	2.1	10.4	3.6
2/9/12	19.4	1.6	0.3	1.0	0.2	0.0	0.0	0.0	0.0	2.8	1.2	12.6	1.3
2/12/12	18.1	0.9	0.4	1.4	0.4	3.0	1.1	0.0	0.0	4.4	2.0	9.3	2.3
2/15/12	30.8	2.3	0.7	1.5	0.8	5.2	1.8	0.0	0.0	7.8	3.8	14.9	4.4
2/18/12	25.9	2.3	0.4	2.3	0.4	0.0	0.0	0.0	0.0	7.2	1.6	16.9	2.4
2/21/12	17.0	1.7	0.3	1.0	0.2	0.0	0.0	0.0	0.0	3.1	1.2	10.0	1.2
2/24/12	5.9**	**	**	**	**	**	**	**	**	**	**	**	**
2/27/12	3.5**	**	**	**	**	**	**	**	**	**	**	**	**
Average	**22.1**	**1.9**	**0.4**	**1.0**	**0.3**	**0.9**	**0.4**	**0.3**	**0.1**	**4.9**	**1.5**	**11.5**	**1.9**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles. NCORE – Winter 2011/2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/11	12.8	2.2	0.2	0.8	0.3	0.0	0.0	0.0	0.0	9.5	1.0
11/5/11	7.5	1.0	0.1	0.4	0.1	0.0	0.0	0.0	0.0	6.4	1.5
11/8/11	12.7	1.6	0.2	0.6	0.2	0.0	0.0	0.0	0.0	10.3	1.0
11/11/11	14.0	1.2	0.1	0.6	0.2	0.0	0.0	0.0	0.0	13.6	1.3
11/14/11	17.8	2.7	0.3	1.1	0.3	0.0	0.0	3.2	1.1	11.0	1.6
11/17/11	38.1	5.2	0.6	1.9	0.7	0.0	0.0	0.0	0.0	30.8	2.2
11/20/11	30.4	5.8	0.6	1.7	0.7	0.0	0.0	4.0	1.8	18.4	2.5
11/23/11	12.6	2.3	0.3	0.9	0.3	0.0	0.0	0.0	0.0	9.7	1.0
11/26/11	31.9	3.7	0.4	1.5	0.5	0.0	0.0	0.0	0.0	25.6	1.8
11/29/11	22.3	3.9	0.4	1.4	0.5	0.0	0.0	1.8	0.9	15.4	2.0
12/2/11	12.8	1.7	0.2	0.9	0.2	0.0	0.0	1.5	0.6	8.9	1.2
12/5/11	5.1**	**	**	**	**	**	**	**	**	**	**
12/8/11	27.4	3.6	0.4	1.5	0.5	9.9	3.0	0.0	0.0	12.6	1.9
12/11/11	9.0	1.2	0.1	0.5	0.3	0.0	0.0	1.8	0.6	5.8	0.9
12/14/11	28.3	4.1	0.5	1.6	0.5	9.7	3.2	0.0	0.0	12.9	2.0
12/17/11	29.7	5.4	0.6	1.4	0.7	0.0	0.0	6.5	1.7	15.9	2.3
12/20/11	10.8	1.5	0.2	0.9	0.2	0.0	0.0	2.0	0.9	6.2	1.0
12/23/11	5.6**	**	**	**	**	**	**	**	**	**	**
12/26/11	24.9	4.0	0.4	1.6	0.5	9.5	3.1	0.0	0.0	12.0	1.9
12/29/11	23.6	4.1	0.5	1.5	0.6	0.0	0.0	1.9	0.9	16.4	2.2
1/1/12	28.0	3.3	0.4	1.4	0.4	0.0	0.0	0.0	0.0	23.5	2.1
1/4/12	33.6	0.8	0.2	1.1	0.1	0.0	0.0	0.0	0.0	24.0	1.8
1/7/12	14.6	2.8	0.3	1.0	0.4	0.0	0.0	0.0	0.0	11.0	1.1
1/10/12	19.6	3.8	0.4	1.1	0.5	0.0	0.0	0.0	0.0	15.3	1.4
1/13/12	19.0	4.3	0.5	1.1	0.5	0.0	0.0	0.0	0.0	13.2	1.5
1/16/12	26.4	4.9	0.6	2.0	0.6	0.0	0.0	4.9	1.6	14.4	2.1
1/19/12	38.0	6.5	0.7	3.6	0.8	0.0	0.0	6.7	2.0	19.2	2.7
1/22/12	3.3**	**	**	**	**	**	**	**	**	**	**
1/25/12	9.0	1.6	0.2	0.6	0.2	0.0	0.0	0.0	0.0	7.1	1.6
1/28/12	28.1	5.7	0.6	1.5	0.7	0.0	0.0	0.0	0.0	20.2	3.3
1/31/12	20.1	3.8	0.4	1.7	0.7	0.0	0.0	3.5	1.1	11.1	1.6
2/3/12	6.7	1.1	0.1	0.5	0.1	0.0	0.0	0.0	0.0	5.0	1.2
2/6/12	24.7	3.9	0.4	2.0	0.5	0.0	0.0	0.0	0.0	9.0	1.5
2/9/12	24.0	2.4	0.3	1.3	0.3	0.0	0.0	0.0	0.0	14.4	1.4
2/12/12	17.0	2.2	0.3	1.7	0.5	0.0	0.0	2.8	0.8	10.9	1.6
2/15/12	30.7	4.5	0.5	2.2	0.6	0.0	0.0	9.4	1.6	12.7	2.0
2/18/12	26.9	3.9	0.4	3.0	0.5	6.5	3.0	0.0	0.0	13.3	2.0
2/21/12	16.2	2.4	0.3	1.3	0.3	0.0	0.0	1.9	0.7	10.8	1.4
2/24/12	5.7**	**	**	**	**	**	**	**	**	**	**
2/27/12	3.6**	**	**	**	**	**	**	**	**	**	**
3/1/12	13.9	2.5	0.3	0.9	0.3	0.0	0.0	1.9	0.7	8.5	1.2
3/4/12	13.1	2.4	0.3	0.9	0.3	0.0	0.0	2.2	0.7	7.1	1.1
3/7/12	6.4	1.0	0.1	0.8	0.1	0.0	0.0	1.3	0.6	3.3	0.6
3/10/12	9.8	2.0	0.2	1.0	0.3	0.0	0.0	0.0	0.0	6.8	0.9

3/13/12	15.8	3.0	0.3	1.3	0.4	0.0	0.0	0.0	0.0	13.1	1.7
3/16/12	17.1	3.2	0.4	1.3	0.4	0.0	0.0	3.9	1.2	8.2	1.3
3/19/12	12.1	2.4	0.3	1.2	0.3	0.0	0.0	0.0	0.0	8.2	1.0
3/22/12	13.3	2.8	0.3	1.3	0.4	0.0	0.0	2.3	1.0	6.5	1.1
3/25/12	***	***	***	***	***	***	***	***	***	***	***
3/28/12	9.2	1.5	0.2	1.2	0.2	0.0	0.0	0.0	0.0	8.0	1.1
3/31/12	5.6**	**	**	**	**	**	**	**	**	**	**
Average	**19.5**	**3.0**	**0.3**	**1.3**	**0.4**	**0.8**	**0.3**	**1.4**	**0.5**	**12.4**	**1.6**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn˝t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
NCORE – Winter 2011/2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/11	12.8	1.5	0.3	0.6	0.2	0.0	0.0	0.0	0.0	3.0	1.1	7.6	1.5
11/5/11	7.5	0.9	0.1	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	6.9	0.8
11/8/11	12.7	1.1	0.2	0.4	0.1	0.0	0.0	0.0	0.0	2.4	0.8	8.3	1.3
11/11/11	14.0	1.1	0.1	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	11.1	1.1
11/14/11	17.8	1.8	0.3	0.7	0.2	0.0	0.0	0.0	0.0	4.5	1.3	10.4	1.3
11/17/11	38.1	2.9	0.5	1.1	0.4	0.0	0.0	0.0	0.0	11.9	2.1	21.0	3.2
11/20/11	30.4	3.1	0.6	0.8	0.4	0.0	0.0	0.0	0.0	13.8	2.4	11.7	2.1
11/23/11	12.6	1.6	0.3	0.6	0.2	0.0	0.0	0.0	0.0	3.8	1.2	7.6	1.1
11/26/11	31.9	2.1	0.4	0.9	0.3	0.0	0.0	0.0	0.0	8.0	1.5	18.9	2.3
11/29/11	22.3	2.7	0.5	0.8	0.4	0.0	0.0	0.0	0.0	7.5	2.0	11.4	1.8
12/2/11	12.8	1.7	0.2	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	10.3	0.9
12/5/11	5.1**	**	**	**	**	**	**	**	**	**	**	**	**
12/8/11	27.4	2.3	0.4	1.0	0.3	5.3	2.2	0.0	0.0	6.1	1.7	12.9	3.4
12/11/11	9.0	1.1	0.1	0.5	0.1	0.0	0.0	1.3	0.6	0.0	0.0	6.2	0.7
12/14/11	28.3	2.7	0.5	1.0	0.4	4.8	2.4	0.0	0.0	6.8	2.0	13.4	3.7
12/17/11	29.7	3.5	0.6	0.0	0.0	6.8	3.3	0.0	0.0	10.5	2.4	7.9	3.1
12/20/11	10.8	1.4	0.2	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	7.9	0.7
12/23/11	5.6**	**	**	**	**	**	**	**	**	**	**	**	**
12/26/11	24.9	2.2	0.4	0.9	0.3	0.0	0.0	0.0	0.0	9.2	1.6	14.5	2.4
12/29/11	23.6	2.3	0.4	0.9	0.3	0.0	0.0	0.0	0.0	9.2	1.7	11.8	1.7
1/1/12	28.0	2.6	0.4	1.1	0.4	0.0	0.0	0.0	0.0	3.9	1.8	19.5	2.6
1/4/12	33.6	1.2	0.2	0.8	0.2	0.0	0.0	0.0	0.0	3.3	0.9	15.3	1.8
1/7/12	14.6	1.8	0.3	0.6	0.2	0.0	0.0	0.0	0.0	5.5	1.4	7.9	1.3
1/10/12	19.6	2.4	0.4	0.7	0.3	0.0	0.0	2.5	0.9	6.2	1.8	9.9	1.6
1/13/12	19.0	2.6	0.4	0.0	0.0	0.0	0.0	0.0	0.0	8.7	1.8	6.5	1.6
1/16/12	26.4	3.0	0.5	1.3	0.4	0.0	0.0	0.0	0.0	9.7	2.2	11.7	2.0
1/19/12	38.0	3.7	0.7	2.6	0.5	0.0	0.0	0.0	0.0	14.7	2.8	14.4	2.5
1/22/12	3.3**	**	**	**	**	**	**	**	**	**	**	**	**
1/25/12	9.0	1.2	0.2	0.5	0.2	0.0	0.0	0.0	0.0	1.9	0.9	6.1	1.3
1/28/12	28.1	3.6	0.6	0.8	0.5	0.0	0.0	0.0	0.0	11.0	2.6	8.4	3.2
1/31/12	20.1	2.4	0.4	1.1	0.3	0.0	0.0	0.0	0.0	7.4	1.8	9.4	1.6
2/3/12	6.7	1.0	0.1	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	5.3	0.8
2/6/12	***	***	***	***	***	***	***	***	***	***	***	***	***
2/9/12	***	***	***	***	***	***	***	***	***	***	***	***	***
2/12/12	17.0	1.6	0.3	1.5	0.2	0.0	0.0	0.0	0.0	2.6	1.2	12.4	1.3
2/15/12	30.7	2.8	0.7	1.6	0.7	0.0	0.0	4.8	1.1	7.7	3.8	14.8	4.3
2/18/12	26.9	2.4	0.4	2.4	0.4	0.0	0.0	0.0	0.0	7.0	1.8	17.5	2.6
2/21/12	16.2	1.7	0.3	1.1	0.2	0.0	0.0	0.0	0.0	3.5	1.3	10.0	1.3
2/24/12	5.7**	**	**	**	**	**	**	**	**	**	**	**	**
2/27/12	3.6**	**	**	**	**	**	**	**	**	**	**	**	**
3/1/12	13.9	1.6	0.3	0.5	0.2	0.0	0.0	0.0	0.0	5.2	1.2	6.5	1.2
3/4/12	13.1	1.8	0.3	0.7	0.3	0.0	0.0	0.0	0.0	3.5	1.3	6.5	1.2
3/7/12	6.4	1.1	0.1	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	4.3	0.6
3/10/12	9.8	1.4	0.2	0.8	0.2	0.0	0.0	0.0	0.0	3.2	1.0	4.3	1.0

3/13/12	15.8	2.0	0.4	0.9	0.3	0.0	0.0	0.0	0.0	5.8	1.5	9.5	1.5
3/16/12	17.1	2.0	0.4	0.8	0.3	0.0	0.0	0.0	0.0	6.0	1.5	7.3	1.4
3/19/12	12.1	1.5	0.3	0.9	0.2	0.0	0.0	0.0	0.0	4.4	1.1	4.8	1.1
3/22/12	13.3	1.7	0.3	0.9	0.2	0.0	0.0	0.0	0.0	5.4	1.3	4.6	1.2
3/25/12	***	***	***	***	***	***	***	***	***	***	***	***	***
3/28/12	9.2	1.1	0.2	1.0	0.2	0.0	0.0	0.0	0.0	2.1	0.9	6.5	0.9
3/31/12	5.6**	**	**	**	**	**	**	**	**	**	**	**	**
Average	**19.3**	**2.0**	**0.4**	**0.9**	**0.3**	**0.4**	**0.2**	**0.2**	**0.1**	**5.4**	**1.4**	**10.1**	**1.7**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn˝t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles. NPF3 – Winter 2011/2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
3/1/12	4.5**	**	**	**	**	**	**	**	**	**	**
3/4/12	37.4	2.7	0.3	1.1	0.3	0.0	0.0	3.3	1.2	29.7	3.7
3/7/12	6.1	0.7	0.1	0.3	0.1	0.0	0.0	1.8	0.7	3.5	0.7
3/10/12	20.5	1.9	0.2	0.8	0.2	0.0	0.0	0.0	0.0	16.9	2.0
3/13/12	5.1**	**	**	**	**	**	**	**	**	**	**
3/16/12	7.5	1.1	0.1	0.5	0.1	0.0	0.0	0.0	0.0	5.9	0.9
3/19/12	27.8	2.5	0.3	0.9	0.3	5.4	2.5	0.0	0.0	18.3	2.4
3/22/12	15.2	1.9	0.2	0.7	0.3	0.0	0.0	1.3	0.6	12.5	1.7
3/25/12	13.6	1.1	0.1	0.6	0.1	0.0	0.0	0.0	0.0	12.7	2.6
3/28/12	5.2**	**	**	**	**	**	**	**	**	**	**
3/31/12	4.8**	**	**	**	**	**	**	**	**	**	**
Average	**18.3**	**1.7**	**0.2**	**0.7**	**0.2**	**0.8**	**0.4**	**0.9**	**0.4**	**14.2**	**2.0**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles. NPF3 – Winter 2011/2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
3/1/12	4.5**	**	**	**	**	**	**	**	**
3/4/12	37.4	2.0	0.3	0.6	0.3	3.9	1.4	27.8	2.0
3/7/12	6.1	0.6	0.1	0.3	0.1	0.0	0.0	4.8	0.6
3/10/12	20.5	1.5	0.3	0.5	0.2	2.2	1.1	14.8	1.3
3/13/12	5.1**	**	**	**	**	**	**	**	**
3/16/12	7.5	0.8	0.1	0.4	0.1	1.5	0.6	4.9	1.0
3/19/12	27.8	1.4	0.2	0.6	0.2	4.3	1.0	25.4	2.2
3/22/12	15.2	1.1	0.2	0.5	0.2	3.5	0.8	11.0	1.1
3/25/12	13.6	1.1	0.1	0.6	0.1	0.0	0.0	10.0	0.8
3/28/12	5.2**	**	**	**	**	**	**	**	**
3/31/12	4.8**	**	**	**	**	**	**	**	**
Average	**18.3**	**1.2**	**0.2**	**0.5**	**0.2**	**2.2**	**0.7**	**14.1**	**1.3**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
State Building – Summer 2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Street Sand	Street Sand STD ERR	Wood Smoke	Wood Smoke STD ERR
6/2/12	***	***	***	***	***	***	***	***	***	***	***	***	***
6/5/12	4.8	0.5	0.1	0.4	0.1	1.5	0.3	0.0	0.0	0.5	0.2	1.6	0.2
6/8/12	6.0	0.5	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	5.4	0.3
6/11/12	5.9	0.5	0.1	0.3	0.1	0.0	0.0	0.0	0.0	0.6	0.2	4.5	0.1
6/14/12	4.6	0.4	0.0	0.2	0.0	0.5	0.2	0.0	0.0	0.0	0.0	2.5	0.2
6/17/12	3.8	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.1	2.8	0.1
6/20/12	8.6	0.4	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.9	0.2	6.0	0.1
6/23/12	6.4	0.4	0.1	0.3	0.1	0.0	0.0	0.0	0.0	0.6	0.2	5.1	0.3
6/26/12	3.2	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	0.1
6/29/12	3.7	0.4	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.1
7/2/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/5/12	4.3	0.3	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.1
7/8/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/11/12	3.7	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	0.1
7/14/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/17/12	*	*	*	*	*	*	*	*	*	*	*	*	*
7/20/12	3.6	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.2
7/23/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/26/12	8.1	0.8	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	5.3	0.2
7/29/12	3.9	0.4	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.2
8/1/12	3.6	0.2	0.0	0.1	0.0	0.7	0.1	0.0	0.0	1.1	0.1	1.4	0.2
8/4/12	***	***	***	***	***	***	***	***	***	***	***	***	***
8/7/12	4.2	0.4	0.0	0.2	0.0	1.3	0.2	0.0	0.0	0.0	0.0	2.3	0.2
8/10/12	4.6	0.3	0.0	0.2	0.0	0.5	0.2	0.0	0.0	0.3	0.1	3.7	0.3
8/13/12	7.7	0.6	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.7	0.3	5.9	0.1
8/16/12	***	***	***	***	***	***	***	***	***	***	***	***	***
8/19/12	20.2	0.5	0.1	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	18.6	0.1
8/22/12	***	***	***	***	***	***	***	***	***	***	***	***	***
8/25/12	3.2	0.3	0.0	0.2	0.0	0.0	0.0	0.2	0.1	0.0	0.0	2.6	0.1
8/28/12	***	***	***	***	***	***	***	***	***	***	***	***	***
8/31/12	***	***	***	***	***	***	***	***	***	***	***	***	***
Average	**5.7**	**0.4**	**0.1**	**0.2**	**0.1**	**0.2**	**0.1**	**0.1**	**0.003**	**0.3**	**0.1**	**4.2**	**0.2**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
State Building – Summer 2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Street Sand	Street Sand STD ERR	Wood Smoke	Wood Smoke STD ERR
6/2/12	***	***	***	***	***	***	***	***	***	***	***	***	***
6/5/12	4.8	0.4	0.1	0.4	0.1	0.0	0.0	0.3	0.1	0.5	0.2	3.2	0.1
6/8/12	6.0	0.4	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.1
6/11/12	5.9	0.4	0.1	0.3	0.1	0.0	0.0	0.0	0.0	0.6	0.2	3.6	0.1
6/14/12	4.6	0.3	0.0	0.2	0.0	0.7	0.2	0.0	0.0	0.0	0.0	1.9	0.1
6/17/12	3.8	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.1	2.2	0.0
6/20/12	8.6	0.4	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.9	0.2	4.8	0.1
6/23/12	6.4	0.4	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.6	0.2	4.7	0.1
6/26/12	3.2	0.2	0.0	0.1	0.0	0.4	0.1	0.0	0.0	0.0	0.0	2.2	0.1
6/29/12	3.7	0.3	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	0.1
7/2/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/5/12	4.3	0.3	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.1
7/8/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/11/12	3.7	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.1
7/14/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/17/12	*	*	*	*	*	*	*	*	*	*	*	*	*
7/20/12	3.6	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.1
7/23/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/26/12	8.1	0.7	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.2
7/29/12	3.9	0.4	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.1
8/1/12	3.6	0.2	0.0	0.1	0.0	0.0	0.0	0.2	0.0	1.2	0.2	2.0	0.1
8/4/12	***	***	***	***	***	***	***	***	***	***	***	***	***
8/7/12	4.2	0.4	0.0	0.1	0.0	1.5	0.2	0.0	0.0	0.0	0.0	1.8	0.1
8/10/12	4.6	0.3	0.0	0.2	0.0	0.8	0.2	0.0	0.0	0.3	0.1	3.1	0.1
8/13/12	7.7	0.5	0.1	0.2	0.1	0.9	0.3	0.0	0.0	0.7	0.2	4.3	0.2
8/16/12	***	***	***	***	***	***	***	***	***	***	***	***	***
8/19/12	20.2	0.4	0.1	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	15.0	0.1
8/22/12	***	***	***	***	***	***	***	***	***	***	***	***	***
8/25/12	3.2	0.2	0.0	0.2	0.0	0.8	0.2	0.0	0.0	0.0	0.0	1.9	0.1
8/28/12	***	***	***	***	***	***	***	***	***	***	***	***	***
8/31/12	***	***	***	***	***	***	***	***	***	***	***	***	***
Average	**5.7**	**0.4**	**0.05**	**0.2**	**0.05**	**0.3**	**0.1**	**0.02**	**0.01**	**0.3**	**0.1**	**3.6**	**0.1**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
NCORE – Summer 2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Street Sand	Street Sand STD ERR	Wood Smoke	Wood Smoke STD ERR
6/14/12	2.9	0.2	0.0	0.1	0.3	0.0	0.0	2.2	0.5	0.2	0.1	0.0	0.0
6/17/12	4.3	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.4	0.1	3.7	0.4
6/20/12	5.9	0.5	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.4	0.1	5.1	0.5
6/23/12	6.6	0.3	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.8	0.1	5.9	1.0
6/26/12	***	***	***	***	***	***	***	***	***	***	***	***	***
6/29/12	3.1	0.3	0.0	0.0	0.0	0.0	0.0	2.8	0.5	0.0	0.0	0.0	0.0
7/2/12	4.3	0.3	0.0	0.3	0.1	4.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0
7/5/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/8/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/11/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/14/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/17/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/20/12	3.4	0.6	0.1	0.3	0.1	2.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0
7/23/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/26/12	5.9	0.8	0.1	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	5.2	0.5
7/29/12	4.2	0.4	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	4.5	0.6
8/1/12	4.0	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	1.3	0.2	3.4	0.4
8/4/12	3.2	0.3	0.1	0.2	0.0	3.4	0.6	0.0	0.0	0.0	0.0	0.0	0.0
8/7/12	4.5	0.4	0.0	0.2	0.1	3.8	0.6	0.0	0.0	0.0	0.0	0.0	0.0
8/10/12	4.3	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.1	4.2	0.6
8/13/12	6.5	0.5	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.4	0.1	5.1	0.5
8/16/12	4.2	0.5	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	3.9	0.6
8/19/12	15.6	0.5	0.1	0.7	0.1	0.0	0.0	0.0	0.0	0.3	0.1	15.3	1.8
8/22/12	4.3	0.2	0.1	0.2	0.0	3.5	0.7	0.0	0.0	0.6	0.1	0.0	0.0
8/25/12	*	*	*	*	*	*	*	*	*	*	*	*	*
8/28/12	***	***	***	***	***	***	***	***	***	***	***	***	***
8/31/12	***	***	***	***	***	***	***	***	***	***	***	***	***
Average	**5.1**	**0.4**	**0.1**	**0.2**	**0.1**	**1.0**	**0.2**	**0.3**	**0.1**	**0.3**	**0.1**	**3.3**	**0.4**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
NCORE – Summer 2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Street Sand	Street Sand STD ERR	Wood Smoke	Wood Smoke STD ERR
6/14/12	2.9	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	2.8	0.4
6/17/12	4.3	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.1	4.2	0.4
6/20/12	5.9	0.4	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.4	0.1	5.7	0.5
6/23/12	6.6	0.3	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.8	0.1	6.6	0.7
6/26/12	***	***	***	***	***	***	***	***	***	***	***	***	***
6/29/12	3.1	0.3	0.0	0.0	0.0	0.0	0.0	2.8	0.5	0.0	0.0	0.0	0.0
7/2/12	4.3	0.3	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	0.4
7/5/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/8/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/11/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/14/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/17/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/20/12	3.4	0.6	0.1	0.3	0.1	2.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0
7/23/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/26/12	5.9	0.8	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	5.9	0.4
7/29/12	4.2	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	0.6
8/1/12	4.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.7	0.1	3.2	0.3
8/4/12	3.2	0.3	0.1	0.2	0.0	3.4	0.6	0.0	0.0	0.0	0.0	0.0	0.0
8/7/12	4.5	0.4	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	3.6	0.5
8/10/12	4.3	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.1	3.9	0.5
8/13/12	6.5	0.4	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.5	0.2	5.6	0.4
8/16/12	4.2	0.5	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.5
8/19/12	15.6	0.5	0.1	0.6	0.1	0.0	0.0	0.0	0.0	0.4	0.1	14.3	1.0
8/22/12	4.3	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.1	3.5	0.5
8/25/12	*	*	*	*	*	*	*	*	*	*	*	*	*
8/28/12	***	***	***	***	***	***	***	***	***	***	***	***	***
8/31/12	***	***	***	***	***	***	***	***	***	***	***	***	***
Average	**5.1**	**0.4**	**0.05**	**0.2**	**0.05**	**0.3**	**0.1**	**0.2**	**0.03**	**0.2**	**0.1**	**4.2**	**0.4**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
State Building – Winter 2012/2013.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/12	14.9	2.2	0.3	1.0	0.3	0.0	0.0	0.0	0.0	10.8	0.4
11/5/12	19.7	3.6	0.4	1.7	0.5	0.0	0.0	0.0	0.0	14.6	1.2
11/8/12	34.9	6.3	0.8	2.6	0.8	0.0	0.0	0.0	0.0	26.1	1.2
11/11/12	13.8	1.9	0.2	0.8	0.2	0.0	0.0	0.0	0.0	10.5	0.7
11/14/12	22.2	3.4	0.4	1.6	0.4	0.0	0.0	0.0	0.0	16.7	0.6
11/17/12	3.3**	**	**	**	**	**	**	**	**	**	**
11/20/12	27.4	5.7	0.7	1.9	0.7	0.0	0.0	0.0	0.0	19.9	1.8
11/23/12	19.3	3.7	0.5	1.4	0.5	0.0	0.0	1.6	0.7	12.8	0.8
11/26/12	52.0	10.6	1.3	3.4	1.3	0.0	0.0	12.0	4.8	24.5	6.0
11/29/12	*	*	*	*	*	*	*	*	*	*	*
12/2/12	31.0	5.1	0.6	2.3	0.7	0.0	0.0	0.0	0.0	24.0	4.7
12/5/12	***	***	***	***	***	***	***	***	***	***	***
12/8/12	22.6	4.7	0.6	1.2	0.6	0.0	0.0	0.0	0.0	17.7	3.5
12/11/12	5.8**	**	**	**	**	**	**	**	**	**	**
12/14/12	10.6	1.9	0.2	0.8	0.2	0.0	0.0	1.7	0.5	7.1	0.8
12/17/12	***	***	***	***	***	***	***	***	***	***	***
12/20/12	***	***	***	***	***	***	***	***	***	***	***
12/23/12	***	***	***	***	***	***	***	***	***	***	***
12/26/12	***	***	***	***	***	***	***	***	***	***	***
12/29/12	26.9	4.1	0.5	2.3	0.5	0.0	0.0	5.4	0.8	14.6	1.2
1/1/13	7.0	0.9	0.1	0.8	0.1	0.0	0.0	0.0	0.0	5.4	1.0
1/4/13	24.4	3.3	0.4	1.4	0.4	0.0	0.0	5.9	0.6	13.4	0.7
1/7/13	29.1	5.4	0.7	1.7	0.7	0.0	0.0	2.7	1.0	20.0	1.1
1/10/13	***	***	***	***	***	***	***	***	***	***	***
1/13/13	***	***	***	***	***	***	***	***	***	***	***
1/16/13	*	*	*	*	*	*	*	*	*	*	*
1/19/13	21.5	4.7	0.6	1.7	0.6	0.0	0.0	0.0	0.0	14.3	2.2
1/22/13	22.2	4.3	0.5	1.6	0.6	0.0	0.0	0.0	0.0	15.9	2.3
1/25/13	***	***	***	***	***	***	***	***	***	***	***
1/28/13	41.4	9.1	1.1	2.7	1.1	0.0	0.0	0.0	0.0	28.3	2.3
1/31/13	***	***	***	***	***	***	***	***	***	***	***
2/3/13	23.1	3.6	0.5	1.9	0.5	0.0	0.0	0.0	0.0	17.8	1.0
2/6/13	18.0	3.3	0.4	2.4	0.4	0.0	0.0	0.0	0.0	13.0	0.9
2/9/13	*	*	*	*	*	*	*	*	*	*	*
2/12/13	27.0	4.7	0.6	2.5	0.6	0.0	0.0	3.9	1.7	14.4	2.6
2/15/13	***	***	***	***	***	***	***	***	***	***	***
2/18/13	17.8	4.0	0.5	1.8	0.5	0.0	0.0	0.0	0.0	12.2	0.8
2/21/13	3.8**	**	**	**	**	**	**	**	**	**	**
2/24/13	16.1	2.2	0.3	1.3	0.3	0.0	0.0	0.0	0.0	13.1	0.6
2/27/13	18.2	2.8	0.4	1.5	0.4	0.0	0.0	1.2	0.5	11.9	0.6
3/2/13	17.1	2.6	0.3	2.0	0.4	0.0	0.0	0.0	0.0	11.7	1.7
3/5/13	*	*	*	*	*	*	*	*	*	*	*
3/8/13	14.6	1.9	0.2	1.3	0.3	0.0	0.0	0.0	0.0	11.4	0.7
3/11/13	16.6	3.2	0.4	1.9	0.4	0.0	0.0	0.0	0.0	11.2	2.2

3/14/13	*	*	*	*	*	*	*	*	*	*	*
3/17/13	10.7	2.1	0.3	1.2	0.3	3.0	1.2	0.0	0.0	4.3	0.6
3/20/13	*	*	*	*	*	*	*	*	*	*	*
3/23/13	*	*	*	*	*	*	*	*	*	*	*
3/26/13	4.8**	**	**	**	**	**	**	**	**	**	**
3/29/13	12.2	1.4	0.2	1.3	0.2	0.0	0.0	0.0	0.0	9.5	0.4
Average	**21.8**	**3.9**	**0.5**	**1.7**	**0.5**	**0.1**	**0.04**	**1.2**	**0.4**	**14.7**	**1.5**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
State Building – Winter 2012/2013.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/12	14.9	1.6	0.3	0.8	0.2	0.0	0.0	0.8	0.3	2.8	1.1	8.4	1.3
11/5/12	19.7	2.2	0.4	1.2	0.3	0.0	0.0	0.0	0.0	7.1	1.6	8.8	1.8
11/8/12	34.9	3.7	0.7	1.7	0.5	0.0	0.0	0.0	0.0	13.9	2.8	13.3	3.1
11/11/12	13.8	1.4	0.3	0.6	0.2	0.0	0.0	0.0	0.0	2.7	1.0	6.7	1.1
11/14/12	22.2	2.1	0.4	1.2	0.3	0.0	0.0	0.0	0.0	6.9	1.5	10.7	1.7
11/17/12	3.3**	**	**	**	**	**	**	**	**	**	**	**	**
11/20/12	27.4	3.3	0.7	1.0	0.5	0.0	0.0	0.0	0.0	12.8	2.5	8.8	2.8
11/23/12	19.3	2.4	0.5	0.9	0.3	0.0	0.0	1.3	0.5	7.1	1.8	6.5	2.0
11/26/12	52.0	10.2	1.3	3.5	1.3	0.0	0.0	0.0	0.0	0.0	0.0	32.0	2.1
11/29/12	*	*	*	*	*	*	*	*	*	*	*	*	*
12/2/12	31.0	2.8	0.6	1.4	0.4	0.0	0.0	0.0	0.0	11.8	2.2	17.7	2.4
12/5/12	***	***	***	***	***	***	***	***	***	***	***	***	***
12/8/12	22.6	2.8	0.6	0.5	0.4	0.0	0.0	0.0	0.0	9.9	2.1	7.4	1.6
12/11/12	5.8**	**	**	**	**	**	**	**	**	**	**	**	**
12/14/12	10.6	1.3	0.2	0.6	0.2	2.3	1.1	0.0	0.0	2.7	1.0	3.6	0.9
12/17/12	***	***	***	***	***	***	***	***	***	***	***	***	***
12/20/12	***	***	***	***	***	***	***	***	***	***	***	***	***
12/23/12	***	***	***	***	***	***	***	***	***	***	***	***	***
12/26/12	***	***	***	***	***	***	***	***	***	***	***	***	***
12/29/12	26.9	3.1	0.6	1.7	0.4	0.0	0.0	0.0	0.0	8.2	2.3	5.3	2.6
1/1/13	7.0	0.9	0.1	0.7	0.1	1.8	0.6	0.0	0.0	0.0	0.0	3.9	0.3
1/4/13	24.4	2.6	0.5	1.0	0.4	0.0	0.0	0.0	0.0	6.5	1.8	10.3	2.0
1/7/13	29.1	3.3	0.7	0.9	0.4	0.0	0.0	2.3	0.6	12.0	2.5	9.1	2.7
1/10/13	***	***	***	***	***	***	***	***	***	***	***	***	***
1/13/13	***	***	***	***	***	***	***	***	***	***	***	***	***
1/16/13	*	*	*	*	*	*	*	*	*	*	*	*	*
1/19/13	21.5	3.0	0.6	1.1	0.4	0.0	0.0	0.0	0.0	9.1	2.2	4.7	2.5
1/22/13	22.2	2.8	0.5	1.1	0.4	0.0	0.0	0.0	0.0	8.1	2.0	7.3	2.3
1/25/13	***	***	***	***	***	***	***	***	***	***	***	***	***
1/28/13	41.4	8.9	1.1	2.6	1.1	0.0	0.0	0.0	0.0	0.0	0.0	22.8	1.8
1/31/13	***	***	***	***	***	***	***	***	***	***	***	***	***
2/3/13	23.1	3.2	0.6	1.4	0.4	0.0	0.0	0.0	0.0	7.4	2.3	6.0	2.6
2/6/13	18.0	3.7	0.5	2.3	0.5	0.0	0.0	1.4	0.7	0.0	0.0	9.4	0.9
2/9/13	*	*	*	*	*	*	*	*	*	*	*	*	*
2/12/13	27.0	3.5	0.7	2.0	0.5	0.0	0.0	0.0	0.0	8.4	2.6	6.7	2.9
2/15/13	***	***	***	***	***	***	***	***	***	***	***	***	***
2/18/13	17.8	2.6	0.5	1.3	0.4	0.0	0.0	0.0	0.0	7.9	1.9	4.8	2.1
2/21/13	3.8**	**	**	**	**	**	**	**	**	**	**	**	**
2/24/13	16.1	2.0	0.4	1.0	0.3	0.0	0.0	0.0	0.0	4.2	1.5	5.8	1.6
2/27/13	18.2	2.1	0.4	1.3	0.3	3.9	1.4	0.0	0.0	4.0	1.6	7.5	1.7
3/2/13	17.1	1.9	0.4	1.8	0.3	2.6	1.3	0.0	0.0	3.3	1.5	6.8	1.6
3/5/13	*	*	*	*	*	*	*	*	*	*	*	*	*
3/8/13	14.6	1.3	0.3	1.1	0.2	0.0	0.0	0.0	0.0	3.0	1.0	6.7	1.1
3/11/13	16.6	2.2	0.4	1.5	0.3	0.0	0.0	0.0	0.0	5.7	1.6	4.4	1.8

3/14/13	*	*	*	*	*	*	*	*	*	*	*	*	*
3/17/13	10.7	1.2	0.2	0.9	0.2	0.0	0.0	0.0	0.0	4.5	1.0	3.7	1.1
3/20/13	*	*	*	*	*	*	*	*	*	*	*	*	*
3/23/13	*	*	*	*	*	*	*	*	*	*	*	*	*
3/26/13	4.8**	**	**	**	**	**	**	**	**	**	**	**	**
3/29/13	12.2	1.2	0.2	1.0	0.2	1.9	0.8	0.0	0.0	3.4	1.0	2.8	1.0
Average	**21.8**	**2.9**	**0.5**	**1.3**	**0.4**	**0.4**	**0.2**	**0.2**	**0.1**	**6.0**	**1.5**	**8.7**	**1.8**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
NPE – Winter 2012/2013.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/12	30.0	2.6	0.3	0.8	0.3	0.0	0.0	7.2	1.0	16.8	2.2
11/5/12	23.9	1.6	0.2	0.9	0.2	8.2	1.7	0.0	0.0	15.1	2.0
11/8/12	51.2	3.2	0.4	1.0	0.4	0.0	0.0	4.0	1.0	45.1	2.8
11/11/12	17.4	1.4	0.2	0.6	0.2	5.9	1.4	0.0	0.0	10.5	1.4
11/14/12	14.9	0.9	0.1	0.5	0.1	0.0	0.0	0.0	0.0	13.5	2.0
11/17/12	7.3	0.5	0.1	0.2	0.1	0.0	0.0	0.0	0.0	5.1	0.6
11/20/12	21.8	3.0	0.3	0.8	0.4	0.0	0.0	4.9	1.0	12.3	1.6
11/23/12	5.3**	**	**	**	**	**	**	**	**	**	**
11/26/12	75.2	6.3	0.7	1.8	0.8	0.0	0.0	12.4	2.1	46.9	5.7
11/29/12	68.1	6.2	0.7	1.9	0.8	0.0	0.0	11.6	2.0	44.3	5.4
12/2/12	51.7	4.0	0.4	1.2	0.5	0.0	0.0	10.7	1.5	30.1	3.7
12/5/12	32.7	2.8	0.3	1.7	0.4	0.0	0.0	9.0	1.2	20.6	2.6
12/8/12	56.8	6.9	0.8	1.8	0.9	0.0	0.0	6.9	1.5	37.4	4.5
12/11/12	5.5**	**	**	**	**	**	**	**	**	**	**
12/14/12	7.0	0.6	0.1	0.5	0.1	0.0	0.0	0.7	0.3	5.5	0.7
12/17/12	37.3	3.5	0.4	1.0	0.4	0.0	0.0	6.1	0.9	29.0	3.4
12/20/12	47.3	4.2	0.5	1.1	0.5	0.0	0.0	5.9	1.1	35.9	4.2
12/23/12	62.4	5.8	0.7	1.8	0.7	0.0	0.0	7.3	1.4	46.7	5.5
12/26/12	40.2	2.0	0.2	2.5	0.3	0.0	0.0	5.3	0.8	31.8	3.7
12/29/12	31.5	2.6	0.3	1.0	0.3	0.0	0.0	6.0	1.0	21.4	2.7
1/1/13	10.0	0.8	0.1	0.4	0.1	0.0	0.0	0.0	0.0	9.4	1.0
1/4/13	47.7	3.1	0.3	1.2	0.4	0.0	0.0	8.3	1.2	28.9	3.5
1/7/13	38.3	3.4	0.4	1.3	0.4	0.0	0.0	4.3	1.1	25.9	3.2
1/10/13	17.8	1.9	0.2	0.9	0.2	5.3	1.6	0.0	0.0	10.1	1.4
1/13/13	14.9	1.1	0.1	0.6	0.1	4.6	1.2	0.0	0.0	8.2	1.1
1/16/13	19.8	2.0	0.2	1.0	0.3	0.0	0.0	0.0	0.0	17.7	3.6
1/19/13	5.8**	**	**	**	**	**	**	**	**	**	**
1/22/13	4.4**	**	**	**	**	**	**	**	**	**	**
1/25/13	26.8	4.2	0.5	1.4	0.5	0.0	0.0	2.7	0.9	18.8	2.3
1/28/13	39.9	4.8	0.5	1.5	0.6	0.0	0.0	6.1	1.5	26.6	3.3
1/31/13	22.3	2.0	0.2	1.0	0.3	0.0	0.0	0.0	0.0	19.8	1.8
2/3/13	11.0	1.3	0.1	1.3	0.2	0.0	0.0	0.0	0.0	8.7	1.1
2/6/13	15.2	2.3	0.3	1.4	0.3	0.0	0.0	0.0	0.0	11.4	2.9
2/9/13	23.6	1.9	0.2	0.7	0.2	0.0	0.0	0.0	0.0	22.6	1.8
2/12/13	41.6	2.9	0.3	1.8	0.4	6.1	2.8	0.0	0.0	31.0	3.9
2/15/13	11.1	0.8	0.1	0.6	0.1	0.0	0.0	0.0	0.0	6.5	1.0
2/18/13	16.0	2.0	0.2	0.9	0.3	0.0	0.0	0.0	0.0	13.4	1.6
2/21/13	3.4**	**	**	**	**	**	**	**	**	**	**
2/24/13	13.9	1.6	0.2	0.7	0.2	0.0	0.0	0.0	0.0	11.2	1.0
2/27/13	20.3	1.4	0.2	1.0	0.2	0.0	0.0	2.0	0.9	15.7	2.0
3/2/13	23.6	1.8	0.2	1.5	0.2	0.0	0.0	1.1	0.5	25.6	3.0
3/5/13	*	*	*	*	*	*	*	*	*	*	*
3/8/13	12.4	0.9	0.1	0.7	0.2	0.0	0.0	1.2	0.4	9.8	1.2

3/11/13	14.4	1.6	0.2	1.0	0.2	0.0	0.0	0.0	0.0	13.0	1.6
3/14/13	2.6**	**	**	**	**	**	**	**	**	**	**
3/17/13	15.5	1.3	0.1	0.8	0.2	0.0	0.0	1.0	0.4	13.0	1.6
3/20/13	1.0**	**	**	**	**	**	**	**	**	**	**
3/23/13	4.6**	**	**	**	**	**	**	**	**	**	**
3/26/13	6.2	0.8	0.1	0.3	0.1	0.0	0.0	0.0	0.0	4.4	0.9
3/29/13	11.8	1.0	0.1	0.7	0.1	0.0	0.0	0.0	0.0	10.8	1.4
Average	**28.1**	**2.5**	**0.3**	**1.1**	**0.3**	**0.7**	**0.2**	**3.0**	**0.6**	**20.3**	**2.5**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn˝t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
NPE – Winter 2012/2013.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/12	30.0	0.9	0.4	0.0	0.0	3.4	0.7	0.0	0.0	7.9	2.0	19.1	2.2
11/5/12	23.9	0.6	0.1	0.6	0.1	0.0	0.0	1.7	0.4	3.0	0.5	19.2	1.5
11/8/12	51.2	1.9	0.4	0.5	0.3	0.0	0.0	7.9	1.2	6.9	1.4	35.0	3.1
11/11/12	17.4	0.7	0.2	0.4	0.2	0.0	0.0	1.0	0.4	2.9	0.9	14.3	1.4
11/14/12	14.9	0.5	0.1	0.4	0.1	0.0	0.0	0.0	0.0	1.5	0.4	10.9	0.9
11/17/12	7.3	0.3	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.7	0.3	3.1	0.5
11/20/12	21.8	2.0	0.3	0.0	0.0	5.3	2.2	0.0	0.0	5.5	1.4	9.8	1.5
11/23/12	5.3**	**	**	**	**	**	**	**	**	**	**	**	**
11/26/12	75.2	2.3	0.7	0.0	0.0	0.0	0.0	4.7	1.1	17.8	3.3	55.4	5.1
11/29/12	68.1	1.6	0.7	0.0	0.0	0.0	0.0	5.2	1.1	22.5	3.4	43.1	4.3
12/2/12	51.7	2.0	0.4	0.0	0.0	13.4	2.4	0.0	0.0	8.9	1.4	34.0	4.7
12/5/12	32.7	1.8	0.3	1.2	0.3	0.0	0.0	4.7	1.1	5.3	1.4	19.7	1.9
12/8/12	56.8	4.5	0.8	0.0	0.0	0.0	0.0	0.0	0.0	15.9	3.1	31.2	3.0
12/11/12	5.5**	**	**	**	**	**	**	**	**	**	**	**	**
12/14/12	7.0	0.6	0.1	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	6.1	0.4
12/17/12	37.3	2.3	0.5	0.0	0.0	0.0	0.0	1.7	0.8	8.4	2.0	25.2	2.4
12/20/12	47.3	2.8	0.5	0.0	0.0	0.0	0.0	0.0	0.0	10.0	1.9	33.0	2.3
12/23/12	62.4	3.6	0.7	0.0	0.0	0.0	0.0	0.0	0.0	14.7	2.5	41.4	3.0
12/26/12	40.2	**	**	**	**	**	**	**	**	**	**	**	**
12/29/12	31.5	1.8	0.3	0.9	0.3	0.0	0.0	0.0	0.0	3.5	1.4	23.4	1.6
1/1/13	10.0	0.7	0.1	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	9.5	0.8
1/4/13	47.7	1.3	0.3	0.8	0.2	0.0	0.0	4.2	0.7	5.4	1.0	37.2	2.5
1/7/13	38.3	2.3	0.4	0.7	0.3	0.0	0.0	0.0	0.0	5.8	1.7	24.2	1.8
1/10/13	17.8	1.0	0.2	0.6	0.2	1.4	0.7	0.0	0.0	3.4	1.2	12.9	1.7
1/13/13	14.9	0.8	0.1	0.6	0.2	1.6	0.6	0.0	0.0	0.0	0.0	12.9	1.2
1/16/13	19.8	1.4	0.2	0.8	0.2	0.0	0.0	0.0	0.0	2.7	1.0	11.8	1.2
1/19/13	5.8**	**	**	**	**	**	**	**	**	**	**	**	**
1/22/13	4.4**	**	**	**	**	**	**	**	**	**	**	**	**
1/25/13	26.8	2.7	0.5	0.7	0.4	0.0	0.0	0.0	0.0	8.6	2.0	14.3	1.8
1/28/13	39.9	2.4	0.5	0.7	0.3	0.0	0.0	0.0	0.0	11.8	1.8	21.2	1.9
1/31/13	22.3	1.2	0.2	0.8	0.2	2.9	1.2	0.0	0.0	3.1	0.9	15.3	2.1
2/3/13	11.0	1.3	0.1	1.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	8.7	0.7
2/6/13	15.2	1.4	0.3	1.2	0.2	0.0	0.0	0.0	0.0	4.1	1.1	7.1	1.1
2/9/13	23.6	1.7	0.2	0.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	18.1	1.4
2/12/13	41.6	2.0	0.4	1.3	0.3	0.0	0.0	0.0	0.0	4.7	1.5	28.0	2.1
2/15/13	11.1	0.8	0.1	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	5.2	0.7
2/18/13	16.0	1.5	0.3	0.6	0.2	0.0	0.0	0.0	0.0	3.0	1.1	11.1	1.2
2/21/13	3.4**	**	**	**	**	**	**	**	**	**	**	**	**
2/24/13	13.9	1.1	0.2	0.3	0.2	5.2	1.5	0.0	0.0	2.8	0.8	4.0	1.4
2/27/13	20.3	1.3	0.2	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	16.7	1.1
3/2/13	23.6	1.8	0.2	1.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	23.9	1.3
3/5/13	*	*	*	*	*	*	*	*	*	*	*	*	*
3/8/13	12.4	0.9	0.1	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	10.9	0.7
3/11/13	14.4	1.4	0.2	1.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	12.5	1.0

3/14/13	2.6**	**	**	**	**	**	**	**	**	**	**	**	**
3/17/13	15.5	1.0	0.2	0.6	0.1	0.0	0.0	0.0	0.0	2.0	0.7	11.8	0.9
3/20/13	1.0**	**	**	**	**	**	**	**	**	**	**	**	**
3/23/13	4.6**	**	**	**	**	**	**	**	**	**	**	**	**
3/26/13	6.2	0.7	0.1	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.7
3/29/13	11.8	0.6	0.1	0.6	0.1	0.0	0.0	0.0	0.0	1.3	0.5	9.4	0.9
Average	**27.8**	**1.5**	**0.3**	**0.6**	**0.1**	**0.8**	**0.2**	**0.8**	**0.2**	**4.9**	**1.1**	**18.8**	**1.8**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
NCORE – Winter 2012/2013.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/12	*	*	*	*	*	*	*	*	*	*	*
11/5/12	*	*	*	*	*	*	*	*	*	*	*
11/8/12	29.9	5.9	0.7	2.4	0.8	0.0	0.0	0.0	0.0	22.3	1.9
11/11/12	16.3	1.8	0.2	0.8	0.2	0.0	0.0	0.0	0.0	13.7	0.9
11/14/12	23.0	3.2	0.4	1.7	0.4	0.0	0.0	2.9	0.7	15.8	1.9
11/17/12	3.7**	**	**	**	**	**	**	**	**	**	**
11/20/12	27.2	5.1	0.6	2.2	0.6	0.0	0.0	5.0	1.1	15.4	2.0
11/23/12	29.2	4.7	0.5	1.6	0.6	0.0	0.0	0.0	0.0	23.2	5.8
11/26/12	*	*	*	*	*	*	*	*	*	*	*
11/29/12	57.4	11.2	1.3	1.0	1.4	0.0	0.0	0.0	0.0	45.4	3.2
12/2/12	35.5	6.4	0.7	2.6	0.8	0.0	0.0	8.6	1.8	15.5	2.2
12/5/12	32.2	6.5	0.7	2.9	0.8	0.0	0.0	3.7	1.8	17.0	2.4
12/8/12	25.1	4.5	0.5	1.5	0.6	0.0	0.0	3.4	1.0	13.8	1.8
12/11/12	5.8**	**	**	**	**	**	**	**	**	**	**
12/14/12	11.4	1.9	0.2	0.9	0.4	0.0	0.0	2.9	0.6	7.2	1.0
12/17/12	49.2	10.9	1.2	3.1	1.4	0.0	0.0	5.8	2.1	34.6	4.3
12/20/12	46.4	12.2	1.4	2.9	1.5	12.4	7.4	0.0	0.0	21.1	3.6
12/23/12	41.2	9.8	1.1	2.8	1.2	13.4	6.0	0.0	0.0	16.9	3.0
12/26/12	27.8	5.9	0.7	1.9	0.7	0.0	0.0	4.9	1.6	14.8	2.1
12/29/12	28.2	4.4	0.5	2.3	0.6	0.0	0.0	5.1	1.3	14.8	2.0
1/1/13	7.9	1.0	0.1	0.7	0.1	0.0	0.0	0.0	0.0	6.7	0.6
1/4/13	23.4	3.4	0.4	1.6	0.4	0.0	0.0	5.1	1.1	13.0	1.8
1/7/13	*	*	*	*	*	*	*	*	*	*	*
1/10/13	21.6	3.3	0.4	2.5	0.4	0.0	0.0	3.6	0.8	12.8	1.6
1/13/13	14.9	2.2	0.3	1.1	0.3	0.0	0.0	2.0	0.7	10.0	1.4
1/16/13	26.7	4.9	0.5	2.9	0.6	0.0	0.0	4.9	1.4	13.9	1.9
1/19/13	22.4	4.6	0.5	2.0	0.6	0.0	0.0	0.0	0.0	16.1	2.0
1/22/13	27.9	4.8	0.5	2.1	0.7	0.0	0.0	3.5	1.0	17.7	2.3
1/25/13	28.6	6.3	0.7	2.4	0.8	8.0	3.9	0.0	0.0	13.3	2.1
1/28/13	40.3	8.7	1.0	2.2	1.1	0.0	0.0	0.0	0.0	27.0	2.8
1/31/13	***	***	***	***	***	***	***	***	***	***	***
2/3/13	22.5	3.7	0.4	1.3	0.5	0.0	0.0	0.0	0.0	14.8	1.4
2/6/13	19.6	3.6	0.4	2.5	0.5	0.0	0.0	4.2	1.3	8.2	1.4
2/9/13	21.4	3.3	0.4	1.7	0.4	0.0	0.0	4.6	1.0	9.6	1.4
2/12/13	25.5	5.1	0.6	2.8	0.7	0.0	0.0	5.2	1.5	12.7	1.8
2/15/13	3.8**	**	**	**	**	**	**	**	**	**	**
2/18/13	18.4	4.1	0.5	1.9	0.5	0.0	0.0	0.0	0.0	12.2	3.1
2/21/13	*	*	*	*	*	*	*	*	*	*	*
2/24/13	15.5	2.5	0.3	1.4	0.3	0.0	0.0	0.0	0.0	12.3	1.5
2/27/13	21.4	3.4	0.4	1.9	0.4	0.0	0.0	3.6	0.9	12.9	1.7
3/2/13	24.4	2.8	0.3	2.5	0.4	9.1	2.1	0.0	0.0	9.6	1.4
3/5/13	35.4	4.9	0.6	5.2	0.7	0.0	0.0	5.7	1.6	17.8	2.5
3/8/13	17.4	2.1	0.2	1.7	0.3	0.0	0.0	4.4	0.8	7.9	1.1
3/11/13	17.5	3.1	0.3	1.9	0.4	0.0	0.0	3.3	0.9	8.8	1.3

3/14/13	3.5**	**	**	**	**	**	**	**	**	**	**
3/17/13	13.0	2.2	0.2	1.4	0.3	0.0	0.0	0.0	0.0	9.0	1.2
3/20/13	11.4	2.0	0.2	1.3	0.3	0.0	0.0	0.0	0.0	8.1	1.1
3/23/13	5.0**	**	**	**	**	**	**	**	**	**	**
3/26/13	5.0**	**	**	**	**	**	**	**	**	**	**
3/29/13	10.8	1.8	0.2	1.4	0.2	0.0	0.0	0.0	0.0	8.0	1.1
Average	**25.5**	**4.7**	**0.5**	**2.0**	**0.6**	**1.1**	**0.5**	**2.4**	**0.7**	**15.1**	**2.0**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
NCORE – Winter 2012/2013.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/12	*	*	*	*	*	*	*	*	*	*	*	*	*
11/5/12	*	*	*	*	*	*	*	*	*	*	*	*	*
11/8/12	29.9	3.2	0.6	2.1	0.5	5.6	2.8	0.0	0.0	14.8	2.6	4.5	0.9
11/11/12	16.3	1.0	0.2	0.6	0.1	0.0	0.0	0.0	0.0	3.4	0.8	10.9	1.2
11/14/12	23.0	2.2	0.4	1.2	0.3	0.0	0.0	0.0	0.0	6.6	1.7	13.1	1.5
11/17/12	3.7**	**	**	**	**	**	**	**	**	**	**	**	**
11/20/12	27.2	3.1	0.7	1.2	0.5	0.0	0.0	2.4	0.8	12.9	2.9	7.5	2.3
11/23/12	29.2	2.3	0.5	0.0	0.0	2.2	0.7	0.0	0.0	12.3	2.2	12.4	2.8
11/26/12	*	*	*	*	*	*	*	*	*	*	*	*	*
11/29/12	57.4	10.6	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	49.8	3.5
12/2/12	35.5	3.6	0.8	1.6	0.7	0.0	0.0	3.7	1.0	13.7	3.7	13.7	4.3
12/5/12	32.2	3.5	0.7	1.7	0.5	0.0	0.0	0.0	0.0	16.2	2.6	8.5	2.2
12/8/12	25.1	2.8	0.5	0.8	0.4	0.0	0.0	0.0	0.0	10.2	2.1	9.6	1.8
12/11/12	5.8**	**	**	**	**	**	**	**	**	**	**	**	**
12/14/12	11.4	1.4	0.3	0.6	0.2	0.0	0.0	3.5	0.7	3.1	1.0	2.1	0.4
12/17/12	49.2	6.2	1.1	0.0	0.0	0.0	0.0	0.0	0.0	28.7	4.3	18.7	3.6
12/20/12	46.4	6.9	1.2	0.0	0.0	0.0	0.0	0.0	0.0	28.6	4.6	10.3	5.7
12/23/12	41.2	5.3	1.0	1.1	0.7	0.0	0.0	0.0	0.0	24.7	3.9	8.2	4.8
12/26/12	27.8	3.5	0.6	1.0	0.5	0.0	0.0	0.0	0.0	12.6	2.6	10.0	2.1
12/29/12	28.2	2.6	0.5	1.7	0.4	0.0	0.0	0.0	0.0	8.6	1.9	13.2	1.7
1/1/13	7.9	0.9	0.1	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	8.0	0.6
1/4/13	23.4	2.1	0.4	1.0	0.3	4.6	2.0	0.0	0.0	7.3	1.6	7.9	2.1
1/7/13	*	*	*	*	*	*	*	*	*	*	*	*	*
1/10/13	21.6	2.2	0.5	1.9	0.4	0.0	0.0	1.5	0.6	7.7	2.0	8.4	1.7
1/13/13	14.9	2.2	0.2	1.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	11.6	0.9
1/16/13	26.7	2.8	0.5	2.2	0.4	0.0	0.0	0.0	0.0	10.5	2.1	10.6	1.8
1/19/13	22.4	2.7	0.5	1.2	0.4	0.0	0.0	0.0	0.0	10.5	2.0	9.1	1.8
1/22/13	27.9	2.8	0.5	1.2	0.4	0.0	0.0	0.0	0.0	11.5	2.1	13.3	1.8
1/25/13	28.6	3.5	0.6	1.4	0.5	0.0	0.0	0.0	0.0	14.9	2.6	9.9	3.2
1/28/13	40.3	8.4	0.9	2.1	1.1	0.0	0.0	0.0	0.0	0.0	0.0	21.7	2.2
1/31/13	***	1.4	0.2	1.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	9.2	0.5
2/3/13	22.5	3.5	0.4	1.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0	12.1	1.1
2/6/13	19.6	2.2	0.4	2.0	0.4	0.0	0.0	1.8	0.7	7.2	2.1	7.1	2.6
2/9/13	21.4	2.3	0.4	1.2	0.3	6.3	1.8	0.0	0.0	5.2	1.6	7.1	2.8
2/12/13	25.5	3.3	0.6	2.1	0.5	0.0	0.0	0.0	0.0	9.3	2.4	10.5	2.0
2/15/13	3.8**	**	**	**	**	**	**	**	**	**	**	**	**
2/18/13	18.4	2.4	0.4	1.3	0.3	0.0	0.0	0.0	0.0	8.9	1.8	6.4	2.2
2/21/13	*	*	*	*	*	*	*	*	*	*	*	*	*
2/24/13	15.5	1.5	0.3	1.0	0.2	0.0	0.0	0.0	0.0	5.8	1.2	8.6	1.2
2/27/13	21.4	2.4	0.4	1.4	0.3	0.0	0.0	0.0	0.0	6.8	1.8	10.3	1.6
3/2/13	24.4	1.9	0.4	2.2	0.4	0.0	0.0	1.5	0.6	3.7	1.8	15.1	2.3
3/5/13	35.4	2.6	0.5	4.3	0.5	0.0	0.0	0.0	0.0	12.0	2.2	14.1	2.0
3/8/13	17.4	2.1	0.2	1.6	0.3	6.8	2.1	0.0	0.0	0.0	0.0	8.3	1.0
3/11/13	17.5	2.2	0.4	1.6	0.3	0.0	0.0	0.0	0.0	4.1	1.6	8.8	1.3

3/14/13	3.5**	**	**	**	**	**	**	**	**	**	**	**	**
3/17/13	13.0	1.5	0.3	1.1	0.2	0.0	0.0	0.0	0.0	3.5	1.1	7.2	1.1
3/20/13	11.4	1.4	0.3	1.0	0.2	0.0	0.0	0.0	0.0	3.1	1.1	6.1	1.0
3/23/13	5.0**	**	**	**	**	**	**	**	**	**	**	**	**
3/26/13	5.0**	**	**	**	**	**	**	**	**	**	**	**	**
3/29/13	10.8	1.2	0.2	1.1	0.2	0.0	0.0	0.0	0.0	3.1	0.9	6.1	1.0
Average	**25.1**	**3.0**	**0.5**	**1.3**	**0.3**	**0.7**	**0.2**	**0.4**	**0.1**	**8.5**	**1.8**	**11.0**	**2.0**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
NPF3 – Winter 2012/2013.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/12	*	*	*	*	*	*	*	*	*	*	*
11/5/12	34.9	2.5	0.3	1.1	0.3	0.0	0.0	5.5	1.0	23.1	2.8
11/8/12	106.4	7.5	0.8	1.9	0.9	0.0	0.0	17.3	2.6	69.1	8.3
11/11/12	31.5	2.3	0.3	0.8	0.3	0.0	0.0	4.8	0.9	21.1	2.6
11/14/12	25.5	1.9	0.2	1.0	0.2	0.0	0.0	2.0	0.7	19.5	2.4
11/17/12	7.3	0.8	0.1	0.2	0.1	0.0	0.0	0.0	0.0	6.1	0.5
11/20/12	44.0	3.3	0.4	0.9	0.4	0.0	0.0	3.6	1.5	38.9	2.9
11/23/12	8.5	0.8	0.1	0.3	0.1	0.0	0.0	0.7	0.3	7.0	0.9
11/26/12	138.1	9.3	1.0	2.4	1.2	0.0	0.0	22.0	3.3	98.1	11.7
11/29/12	154.6	11.2	1.3	3.0	1.4	0.0	0.0	25.2	3.8	108.4	13.0
12/2/12	124.7	7.2	0.8	2.1	0.9	0.0	0.0	14.2	2.0	91.8	10.6
12/5/12	*	*	*	*	*	*	*	*	*	*	*
12/8/12	*	*	*	*	*	*	*	*	*	*	*
12/11/12	6.4	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.6
12/14/12	9.8	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	8.4	0.7
12/17/12	83.6	6.0	0.7	1.6	0.8	0.0	0.0	7.0	1.5	62.6	7.2
12/20/12	111.4	8.7	1.0	2.0	1.1	0.0	0.0	13.6	2.2	98.5	11.4
12/23/12	98.2	8.0	0.9	2.3	1.0	0.0	0.0	12.2	2.0	76.0	8.8
12/26/12	106.5	6.5	0.8	2.4	0.8	0.0	0.0	9.1	1.7	85.3	9.8
12/29/12	55.9	3.4	0.4	0.6	0.4	0.0	0.0	6.9	1.0	42.5	4.9
1/1/13	24.4	1.4	0.2	0.9	0.2	0.0	0.0	0.0	0.0	22.3	2.6
1/4/13	84.3	6.6	0.7	2.1	0.8	0.0	0.0	12.2	2.2	55.2	6.7
1/7/13	95.6	6.6	0.7	2.0	0.8	0.0	0.0	8.6	2.4	73.8	8.8
1/10/13	23.9	2.0	0.2	1.0	0.3	0.0	0.0	0.0	0.0	21.2	2.4
1/13/13	23.6	1.2	0.1	0.7	0.2	0.0	0.0	2.8	0.7	18.6	2.3
1/16/13	36.8	2.9	0.4	1.4	0.4	0.0	0.0	0.0	0.0	33.3	6.5
1/19/13	10.3	1.1	0.1	0.7	0.2	0.0	0.0	0.7	0.3	8.3	1.1
1/22/13	4.2**	**	**	**	**	**	**	**	**	**	**
1/25/13	58.1	5.7	0.7	2.2	0.7	0.0	0.0	4.2	1.3	45.5	5.3
1/28/13	66.2	5.9	0.7	1.6	0.7	0.0	0.0	4.4	1.5	57.1	6.7
1/31/13	36.1	2.8	0.3	1.6	0.4	0.0	0.0	3.6	1.2	26.6	3.3
2/3/13	24.0	1.5	0.2	1.5	0.2	0.0	0.0	0.0	0.0	21.1	2.4
2/6/13	26.0	3.1	0.3	1.9	0.4	0.0	0.0	2.8	1.0	16.9	2.1
2/9/13	30.1	1.7	0.2	0.9	0.2	6.1	1.7	0.0	0.0	21.3	2.7
2/12/13	26.6	2.5	0.3	1.4	0.3	7.0	2.5	0.0	0.0	17.5	2.4
2/15/13	*	*	*	*	*	*	*	*	*	*	*
2/18/13	*	*	*	*	*	*	*	*	*	*	*
2/21/13	4.0**	**	**	**	**	**	**	**	**	**	**
2/24/13	24.6	2.1	0.2	1.0	0.3	4.7	1.8	0.0	0.0	17.4	2.2
2/27/13	37.6	3.0	0.3	1.5	0.4	4.7	2.3	0.0	0.0	28.2	3.5
3/2/13	32.2	1.8	0.2	1.3	0.2	0.0	0.0	0.0	0.0	28.3	2.1
3/5/13	32.2	1.8	0.2	1.3	0.2	0.0	0.0	2.9	1.0	25.1	3.1
3/8/13	25.7	1.4	0.2	1.3	0.2	0.0	0.0	1.1	0.5	22.7	2.6
3/11/13	31.4	2.5	0.3	1.5	0.3	4.5	2.0	0.0	0.0	23.0	2.9

3/14/13	3.2**	**	**	**	**	**	**	**	**	**	**
3/17/13	25.3	1.7	0.2	1.1	0.3	0.0	0.0	1.5	0.5	21.2	2.5
3/20/13	9.8	1.0	0.1	0.8	0.1	0.0	0.0	0.0	0.0	8.0	0.9
3/23/13	6.6	0.8	0.1	0.5	0.1	0.0	0.0	0.0	0.0	5.8	0.7
3/26/13	6.3	0.7	0.1	0.4	0.1	0.0	0.0	0.0	0.0	5.4	0.7
3/29/13	23.5	1.2	0.1	1.2	0.2	0.0	0.0	1.6	0.5	19.9	2.3
Average	**46.9**	**3.4**	**0.4**	**1.3**	**0.4**	**0.6**	**0.2**	**4.5**	**0.9**	**35.9**	**4.2**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
NPF3 – Winter 2012/2013.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/12	*	*	*	*	*	*	*	*	*	*	*	*	*
11/5/12	34.9	1.7	0.3	0.7	0.2	0.0	0.0	0.0	0.0	3.6	1.3	24.5	1.6
11/8/12	106.4	2.5	0.6	0.0	0.0	0.0	0.0	8.0	1.3	18.7	1.8	80.0	5.7
11/11/12	31.5	1.7	0.3	0.5	0.2	0.0	0.0	0.0	0.0	3.2	1.2	22.2	1.5
11/14/12	25.5	1.5	0.3	0.7	0.2	0.0	0.0	0.0	0.0	2.3	1.1	18.1	1.3
11/17/12	7.3	0.5	0.1	0.2	0.1	0.0	0.0	0.0	0.0	1.1	0.4	5.3	0.7
11/20/12	44.0	1.3	0.3	0.5	0.2	0.0	0.0	5.6	0.8	6.8	1.0	30.7	2.4
11/23/12	8.5	0.6	0.1	0.2	0.1	0.0	0.0	0.0	0.0	1.0	0.4	6.9	0.6
11/26/12	138.1	5.3	1.0	0.0	0.0	0.0	0.0	0.0	0.0	20.2	3.7	100.1	5.5
11/29/12	154.6	5.9	1.1	0.0	0.0	0.0	0.0	0.0	0.0	27.6	4.1	108.2	6.1
12/2/12	124.7	4.7	0.9	0.0	0.0	0.0	0.0	0.0	0.0	18.6	3.3	88.5	4.9
12/5/12	*	*	*	*	*	*	*	*	*	*	*	*	*
12/8/12	*	*	*	*	*	*	*	*	*	*	*	*	*
12/11/12	6.4	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.8	0.5
12/14/12	9.8	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.7	0.6
12/17/12	83.6	4.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	13.6	2.8	55.2	3.6
12/20/12	111.4	5.8	1.0	0.0	0.0	0.0	0.0	0.0	0.0	20.8	4.0	91.5	5.4
12/23/12	98.2	5.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	20.8	3.5	70.0	4.5
12/26/12	106.5	4.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	16.3	2.9	75.2	4.4
12/29/12	55.9	3.8	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	46.8	2.3
1/1/13	24.4	1.4	0.2	0.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	20.9	1.3
1/4/13	84.3	2.7	0.6	1.1	0.4	0.0	0.0	4.8	1.1	14.0	2.1	71.4	5.1
1/7/13	95.6	4.1	0.7	0.0	0.0	0.0	0.0	0.0	0.0	13.0	2.8	65.1	4.1
1/10/13	23.9	1.5	0.3	0.7	0.2	0.0	0.0	0.0	0.0	2.6	1.1	18.2	1.5
1/13/13	23.6	1.2	0.1	0.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	19.9	1.1
1/16/13	36.8	1.6	0.3	1.0	0.2	0.0	0.0	0.0	0.0	5.2	1.2	34.4	2.5
1/19/13	10.3	0.7	0.1	0.6	0.1	0.0	0.0	0.0	0.0	1.4	0.5	7.5	0.7
1/22/13	4.2**	**	**	**	**	**	**	**	**	**	**	**	**
1/25/13	58.1	3.7	0.7	1.1	0.5	0.0	0.0	0.0	0.0	12.5	2.8	37.4	3.0
1/28/13	66.2	3.8	0.7	0.0	0.0	0.0	0.0	0.0	0.0	12.9	2.6	47.4	3.5
1/31/13	36.1	1.8	0.3	1.1	0.3	0.0	0.0	0.0	0.0	4.9	1.4	24.8	1.9
2/3/13	24.0	1.4	0.2	1.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	19.6	1.3
2/6/13	26.0	2.1	0.4	1.4	0.3	0.0	0.0	0.0	0.0	5.6	1.6	14.6	1.5
2/9/13	30.1	0.9	0.2	0.6	0.1	4.1	1.1	0.0	0.0	2.6	0.7	22.4	2.2
2/12/13	26.6	1.8	0.3	1.1	0.3	0.0	0.0	0.0	0.0	3.7	1.3	17.4	1.5
2/15/13	*	*	*	*	*	*	*	*	*	*	*	*	*
2/18/13	*	*	*	*	*	*	*	*	*	*	*	*	*
2/21/13	4.0**	**	**	**	**	**	**	**	**	**	**	**	**
2/24/13	24.6	1.6	0.3	0.7	0.2	0.0	0.0	0.0	0.0	2.8	1.1	16.5	1.3
2/27/13	37.6	2.2	0.4	1.1	0.3	0.0	0.0	0.0	0.0	4.0	1.6	24.6	1.8
3/2/13	32.2	1.3	0.2	1.1	0.2	0.0	0.0	0.0	0.0	2.1	0.9	26.6	1.9
3/5/13	32.2	1.8	0.2	1.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	25.9	1.5
3/8/13	25.7	1.4	0.2	1.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	21.1	1.2
3/11/13	31.4	2.4	0.3	1.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	23.4	1.3

3/14/13	3.2**	**	**	**	**	**	**	**	**	**	**	**	**
3/17/13	25.3	1.2	0.2	0.8	0.2	0.0	0.0	0.0	0.0	2.8	0.9	19.5	1.3
3/20/13	9.8	0.6	0.1	0.7	0.1	0.0	0.0	0.0	0.0	1.0	0.5	8.4	0.8
3/23/13	6.6	0.5	0.1	0.4	0.1	0.0	0.0	0.0	0.0	0.8	0.4	5.9	0.7
3/26/13	6.3	0.4	0.1	0.3	0.1	0.0	0.0	0.0	0.0	0.8	0.3	5.2	0.6
3/29/13	23.5	1.2	0.1	1.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	19.7	1.1
Average	**46.9**	**2.2**	**0.4**	**0.6**	**0.1**	**0.1**	**0.03**	**0.4**	**0.1**	**6.4**	**1.3**	**34.7**	**2.3**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

Final Report

To

Environmental Protection Agency (EPA)

Purchase order EP08D000663

Reporting Period: 1 September 2008 – 31 January 2010

'Stable Boundary Layers Representation in Meteorological Models in Extremely Cold Wintertime Conditions'

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12 May 2010

EXECUTIVE SUMMARY

This final report describes work performed by Penn State for the EPA-funded Purchase Order EP08D000663 titled 'Stable Boundary Layers Representation in Meteorological Models in Extremely Cold Wintertime Conditions'. The purpose of the project was to develop, adapt, and test a methodology for stable boundary layer representation (initial onset, space/time evolution, dissipation) in three-dimensional numerical models, with a specific focus on the dark, extremely cold environments such as those in the winter in the Fairbanks, AK region. A particular concern is the frequent occurrence of very high fine particular matter (PM2.5) concentrations within the stable boundary layers that form in these conditions.

Ten tasks were defined in the Statement of Work (SOW) for this project. A summary of these tasks and a brief overview of the work completed can be found in the Appendix to this report. Two twenty-day episodes were selected from the 2007-2008 winter season to study periods of extremely cold temperatures and high PM2.5 concentrations and to evaluate model performance: one in near total darkness (14 Dec 2007 – 03 Jan 2008), and the other in partial sunlight (23 Jan 2008 – 12 Feb 2008). One baseline physics configuration and three physics sensitivity experiments were performed for each episode. The physics sensitivity experiments were used to assess the impact of different planetary boundary layer (PBL) parameterizations, land surface models, and atmospheric radiation schemes on the simulations. Each simulation used three nested grids: Grid 1 (12-km horizontal grid spacing) and Grid 2 (4-km) utilized the multiscale multigrid data assimilation strategy of Stauffer and Seaman (1994) in order to ensure the model and observations remain close over the extended duration of the simulations, and Grid 3 (1.3-km) did not use any direct data assimilation, and so was best-suited for quantifying the physics sensitivity. Grid 3, which is centered over the Fairbanks region, also possesses sufficient horizontal resolution to be used by the EPA as meteorological input to chemical and air transport and dispersion models. From the different physics packages one was to be recommended to the EPA for further mesoscale modeling of the region.

The major findings and impacts of this project are as follows:

- The use of the three-grid configuration with a multiscale, multigrid four-dimensional data assimilation (FDDA) strategy on the outer two grids and no direct FDDA on Grid 3 consistently produced qualitatively plausible atmospheric fields throughout the variety of meteorological conditions found in the episodes, despite the relatively sparse data density. Quantitatively, the multiscale, multigrid FDDA strategy led to improved root-mean-square-error (RMSE) scores for both wind and temperature on all grids. The FDDA on the outer domains had the desired effect of improving the simulations of Grid 3 without FDDA and used for physics sensitivity tests, by providing improved lateral boundary conditions.

- The best RMSE scores for the combination of both surface and sounding data required modification of the default FDDA procedure. These modifications included applying surface wind observational data to the third model vertical level instead of the lowest model level because wind observations are normally taken at a height of 10 m which is the height of the third level in the high vertical resolution configuration used here. The influence of surface observations was also restricted to approximately the lowest 100 m, instead of the top of the PBL, because the model-predicted PBL height in these simulations, based on the turbulent kinetic energy profile, was often found to be 1 km or higher. This correction applied the surface innovation (observation minus model value) in these predominantly stable boundary layers over a much shallower layer and produced improved statistical results in the lower troposphere.

- All model physics combinations tended to have a positive temperature bias on Grid 3, especially during the most extremely cold periods. All of the physics sensitivity tests tended to reduce the warm bias in comparison with the selected baseline physics package.

- Switching from the RRTM longwave / Dudhia shortwave radiation package to the RRTMG longwave and shortwave radiation package led to significantly reduced warm biases and better RMSE statistics. RRTMG was then used in all future physics sensitivity tests. The reduced warm bias seemed to be due to the longwave component, both because of direct examination of surface fluxes in the partial sunlight case, and due to the fact that the difference was more pronounced in the near total darkness episode.

- The simulation with the Rapid Update Cycle (RUC) land surface model, the Mellor-Yamada-Janjić (MYJ) PBL model, and the RRTMG radiation package was the coldest of the four physics suites tested, and had the lowest positive temperature bias and best statistics during those periods when the temperature was coldest. It was thus selected as the physics configuration of choice, since the coldest temperature conditions are those with the potential for the highest PM2.5 concentrations. However, there were periods in each episode, generally when the temperature was steadily decreasing in advance of an extremely cold period, during which the models had a cold bias. During these periods the RUC/MYJ/RRTMG configuration would usually be even colder and thus have worse magnitude temperature biases and RMSE scores. Thus, while this configuration was recommended, we also strongly recommended that the final fine-scale atmospheric data (i.e., from Grid 3) to be provided to EPA should come from an additional simulation in which FDDA is performed directly on Grid 3, in order to reduce some of this error.

- Wind component and wind speed statistics generally showed much less variability among the model physics sensitivity experiments than that seen for temperature. The MYJ/RUC/RRTMG (MRR) configuration usually produced slightly better wind statistics than the other configurations.

- Use of obs nudging for temperature and humidity (and not surface wind) on Grid 3 produced large improvements in the mass fields as expected, and also improvements in the wind fields

above the surface. Results were very encouraging and suggested that a smaller (larger) time window should be used for the surface (above-surface) data assimilation. This capability present in the Penn State MM5 FDDA system has been added to the new-release version of WRF.

- In addition to this final report, deliverables to the EPA will include the full three-dimensional output at relatively fine temporal resolution (every 1 hour for Grid 1; every 12 minutes for Grids 2 and 3) for the final Grid 3 nudging simulation as well as all the baseline and physics sensitivity simulations. Model namelists, initialization files, and modifications to the model source code will also be provided.

- The development and refinement of WRF FDDA capabilities and supporting software, including the surface analysis nudging, observation nudging and the OBSGRID objective analysis and obs-nudging pre-processing code, occurred concurrently with this project. This separate development effort led by PI Dave Stauffer and funded by the Defense Threat Reduction Agency (DTRA) allowed us rapid access to the most recent and robust versions of the WRF FDDA code, and this greatly benefited this project.

- The results of the default FDDA procedures not performing well in this high vertical resolution modeling study of stable boundary layer environments motivated an additional FDDA code development effort to make the vertical influence functions of surface observations within the FDDA be a function of stability regime type, as well as to provide the user with greater flexibility in specifying the vertical influence functions. These modifications were not finalized in time to be used for this project but are scheduled to appear in the next official release of the WRF model.

- An extended abstract and oral presentation were made at the 13th Conference on Mesoscale Processes (Gaudet et al. 2009), and a manuscript based on the project is in preparation.

- Since the first draft of the final report, the Grid 3 FDDA design and simulations have been completed for both twenty-day episodes. The results showed that the use of obs nudging for temperature and humidity (but not surface wind) on Grid 3 produced large improvements in the mass fields (as expected), and also improvements in the wind fields above the surface. Results were very encouraging and suggested that a smaller (larger) time window should be used for the surface (above-surface) data assimilation. This capability present in the Penn State MM5 FDDA system has been added to the new-release version of WRF.

1. INTRODUCTION

Fine particulate matter (PM2.5, referring to particles with aerodynamic diameters equal or less than 2.5 microns) has been implicated in a variety of health problems, including respiratory disease. With the recent decrease in the allowable 24-hour PM2.5 concentration to 35 micrograms per cubic meter, there is now an even greater need to be able to determine the sources primarily responsible for exceedance events when they occur, as well as to predict the potential impact of source emission changes. Modeling the behavior of fine particulate matter typically involves coupling between an inventory of emissions sources, chemical and air transport and dispersion models, and synoptic and mesoscale atmospheric models. (Synoptic atmospheric models are designed to represent features with characteristic horizontal scales greater than about 2000 km; mesoscale atmospheric models represent features with scales of approximately 2 – 2000 km.) The purpose of the meteorological models is to use physical predictive equations and assimilation of available meteorological data to capture the evolution of the local atmospheric state over sufficiently long periods for use by the other models.

During the winter season the part of interior Alaska consisting of Fairbanks and the surrounding Fairbanks North Star Borough often have extremely cold temperatures due to the strong longwave radiative cooling, the absence of moderating marine influences, and the generally weak winds. Although this region often has a clean, relatively pristine atmosphere, the periods of coldest temperatures are often accompanied by some of the strongest low-level temperature inversions that have been observed, with temperature increases up to 20°C as one ascends from the surface (Benson 1970). The inversions cap stable boundary layers (SBLs) that can be as shallow as tens of meters in clear nocturnal conditions (Sereze et al. 1992; Vickers and Mahrt 2004). Emissions from vehicular traffic, power plants, and home heating (mostly diesel and wood fuels) remain trapped within the SBL, leading to high concentrations of particulates and other pollutants. In the extremely cold conditions of interior Alaska an additional problem that arises is ice fog that can be triggered by combustion-generated water vapor at temperatures below approximately -25°C (Benson 1970; Girard and Blanchet 2001). The dispersal of pollutants is further hindered by the fact that winds and turbulence are quite weak in these conditions. The winds and turbulence that do exist in the SBL are strongly modulated by drainage flows, gravity waves, and other less understood phenomena (Hanna 1983; Mahrt 2009). Thus predicting the behavior of SBLs becomes a complex problem involving synoptic weather patterns, topography, turbulence, surface energy budgets, and precipitation.

The tool used for the meteorological modeling component of this project is the Weather Research and Forecasting (WRF) model (Skamarock et al. 2008), more specifically, the Advanced Research WRF dynamic core (WRF-ARW, henceforth simply called WRF). WRF contains separate modules to compute different physical processes such as surface energy budgets and soil interactions, turbulence, cloud microphysics, and atmospheric radiation. Since turbulent eddies in the SBL are typically much smaller than mesoscale model horizontal grid spacing (e.g., ten meters vs. a thousand or more meters), they cannot be modeled directly (e.g., Wyngaard 2004), but typically their effect is parameterized by a Planetary Boundary Layer (PBL) scheme that predicts turbulent kinetic energy (TKE). Within WRF the user has many options for selecting the different schemes for each type of physical process. There is

also a WRF Preprocessing System (WPS) that generates the initial and boundary conditions used by WRF, based on topographic datasets, land use information, and larger-scale atmospheric and oceanic models. New software associated with objective analysis and data assimilation will be discussed later.

The goal of this project was to select and perform two twenty-day simulations down to 1-km horizontal grid spacing for two episodes from the 2007-2008 winter season characterized by high PM2.5 exceedance events in the Fairbanks region. One episode was to be characterized by near total darkness, while the second was to contain partial sunlight. From a set of modeling experiments including a baseline physics configuration and a series of physics sensitivity tests, modified as appropriate to be suitable to the unique Alaskan atmospheric conditions, a best performing physics suite was to be selected and delivered to the EPA, along with source code and the model output. The project had two main components: (1) creating the best possible representation of the atmosphere through the use of a mesoscale model with continuous data assimilation, and (2) determining the best set of physics parameterizations by performing a series of sensitivity tests without the direct effects of data assimilation. Both components are included in a multiscale, multigrid data assimilation procedure, which will be described in more detail below.

2. METHODOLOGY AND BASELINE EXPERIMENTAL DESIGN

2.1 Grid Configuration

The simulations presented in this report involve three one-way nested horizontal grids with horizontal grid spacing of 12 km, 4 km and 1.3 km, respectively (Table 1 and Fig. 1). Grid 1 covers the entirety of Alaska and extends from Siberia to the northwestern continental United States. Grid 2 closely coincides with the extent of the Alaskan landmass south of the Brooks range; it includes the Anchorage region and the Gulf of Alaska in the south. Grid 3, centered around Fairbanks and extending south to the Alaska Range and north past the White Mountains and other uplands just north of Fairbanks, includes all of the proposed non-attainment area within the Fairbanks North Star Borough (Fig. 2). It can be seen in the figure that Fairbanks is located next to a semicircle of low mountains that are generally a few hundred meters above the city; this tends to restrict airflow near the city and further reduce the dispersion of pollutants in stable conditions.

Grid	Dimensions	Horizontal Grid Spacing
1	401 x 301	12 km
2	202 x 202	4 km
3	202 x 202	1.3 km

Table 1: Specifications of model grids.

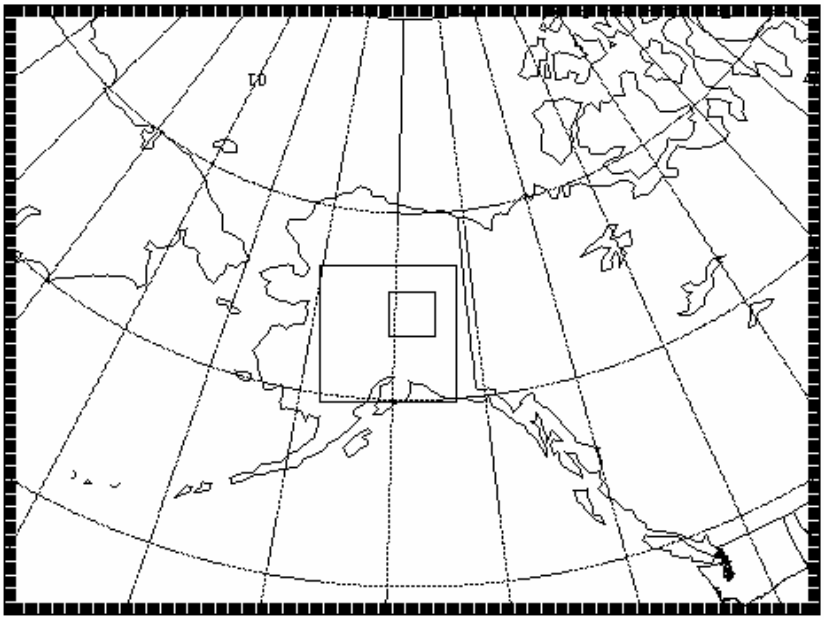


Fig. 1: Nested grid configuration of WRF, showing the 12-km Grid 1, the 4-km Grid 2, and the 1.3-km Grid 3 described in the text.

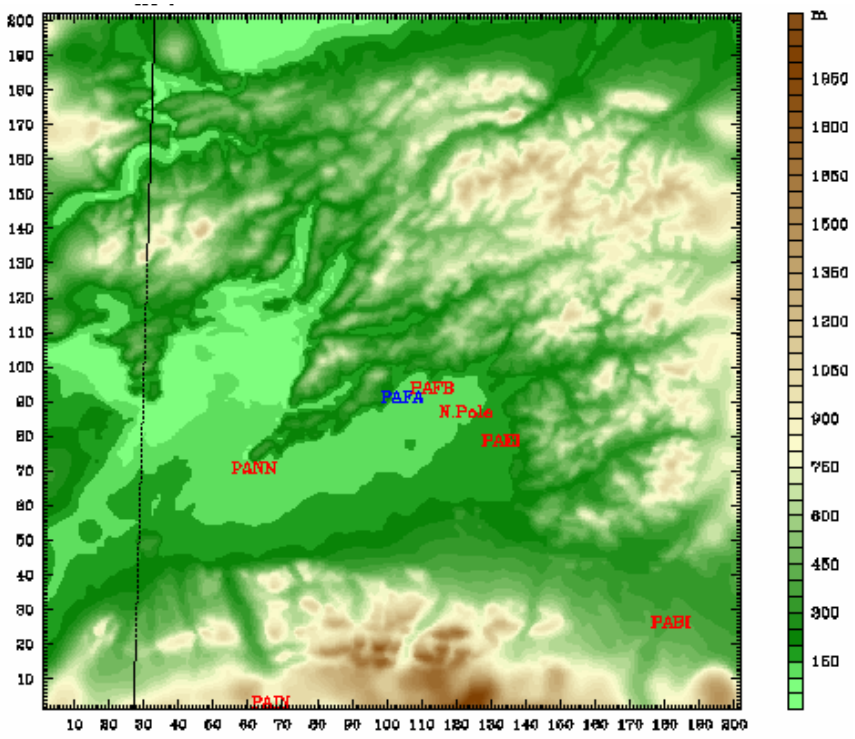


Fig. 2: Elevation on Grid 3 used in study. The location of the Fairbanks sounding is labeled in blue; other local METAR stations are shown in red.

The vertical grid spacing needed to be fine enough to resolve the structure of SBLs that can be only tens of meters deep, but not so fine that numerical instabilities arise in regions of steep topography (in particular the Alaska Range). After a series of initial tests a vertical grid configuration with 38 half layers (39 full levels) was defined, with a minimum vertical grid spacing of 4 m near the surface (see Fig. 3). Numerical stability was achieved through the use of time steps of 24 s, 8 s, and 4 s on the 12-km, 4-km and 1.3-km grids, respectively. These parameters are comparable to those used over central PA in the Seaman et al. (2008) SBL study. but with 4-m rather than 2-m vertical resolution near the surface, and slightly shorter timesteps.

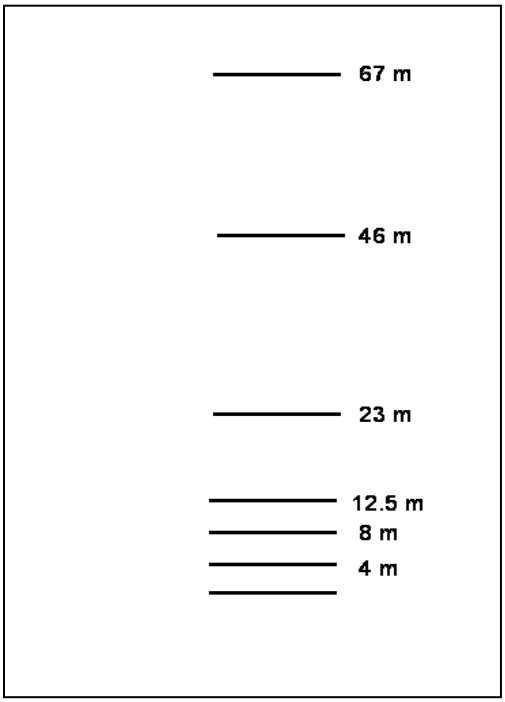


Fig. 3: Lowest few vertical full levels (i.e., locations where vertical velocity is calculated) in WRF model configuration, roughly to scale.

Two twenty-day episodes from the 2007-2008 winter season were selected for study. One episode was from 14 Dec 2007 to 03 Jan 2008, a time of year when there is little solar radiation in the Fairbanks area (approximately three hours of daylight per day near the solstice). During this episode the temperature rapidly decreased to near -40°C by 21 Dec, accompanied by rapid increases in PM2.5 concentrations, and then temperatures generally increased and PM2.5 decreased for the remainder of the episode (Fig. 4). The second episode was from 23 Jan 2008 to 14 Feb 2008, when solar insolation was more significant (between five and eight hours of sunlight per day), and provides an example of 'partial

sunlight' conditions. During this episode temperatures were initially relatively warm (near 0°C), decreased briefly to near -35°C by 27 Jan, rebounded slightly, and then decreased during the most extensive period of sub -35°C weather of the season. Consistent with the prolonged period of cold temperatures were recurring violations of the PM2.5 standard in the Fairbanks area.

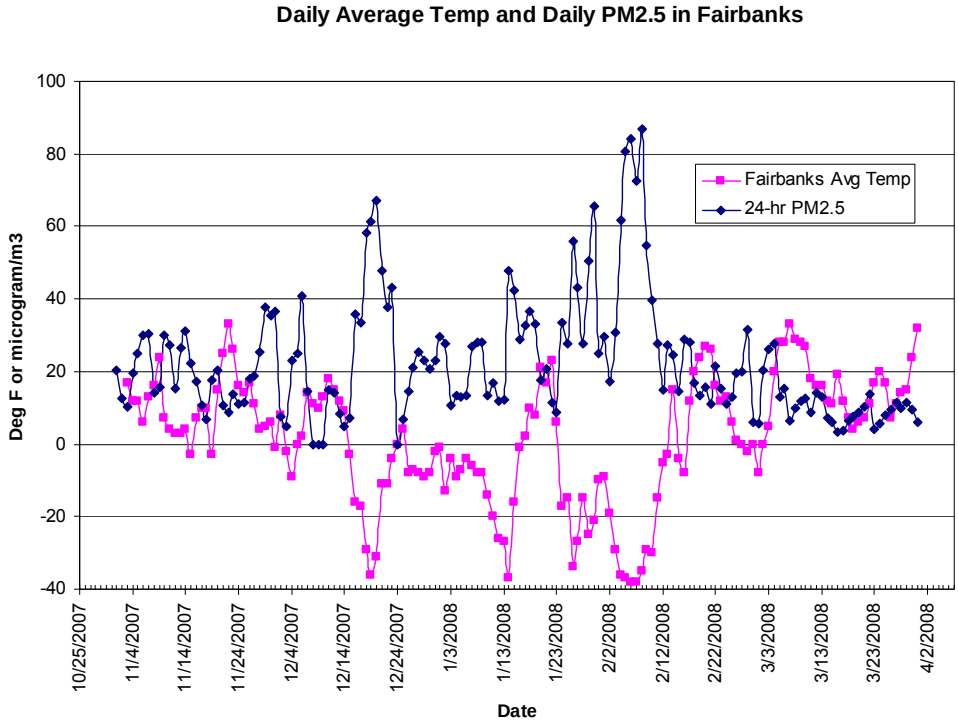


Fig. 4: Observations of daily average temperature and 24-hr PM2.5 concentrations taken in Fairbanks during 2007-2008 winter season. Courtesy Robert Dulla, Sierra Research, Inc.

In the initial period of a regional model simulation there is generally a period of several hours when the atmospheric state, whose initial conditions are usually provided by a global or coarser regional model, is still dynamically adjusting to the finer scale resolution and topography of the regional model. Therefore the model output from this initial 'spin-up' period is not completely reliable as an indicator of the true atmospheric state. However, if a regional model simulation is allowed to progress for too long without re-initialization (normally several days), it tends to drift away from the actual observed atmospheric state. Therefore, our method of obtaining realistic regional atmospheric analyses over an entire twenty-day episode was to divide each episode into four overlapping simulation segments. Each segment is around five days long with a twelve-hour overlap between each segment to avoid spin-up effects. (Specifically, the near total darkness episode was divided into successive segments of 6 days, 5.5 days,

5.5 days, and 4.5 days; the partial sunlight episode was divided into successive segments of 5 days, 5.5 days, 5.5 days, and 5.5 days).

Initial conditions and most of the Grid 1 lateral boundary conditions were obtained from the half-degree Global Forecast System (GFS) zero-hour analyses that were obtained from the NOAA National Operational Model Archive and Distribution System (NOMADS) website maintained by the National Climatic Data Center. The exceptions were some analysis times during the near total darkness episode when the half-degree GFS product was unavailable; in these instances the one-degree GFS analysis was used. All simulation segments for the near total darkness episode were selected such that all initial conditions could be obtained from half-degree global analyses.

The simulations were performed on one of two Linux clusters: one local cluster with 128 available processor cores, and the other cluster with 512 processor cores maintained by the Research Computing and Cyberinfrastructure High Performance Computing Group (RCC HPCG) at Penn State. Each 5.5 day simulation segment took 1-2 days to complete. The full 3D model output from each simulation was saved at a frequency of one hour for the 12-km Grid 1, and at a frequency of 12 minutes for the 4-km Grid 2 and 1.3-km Grid 3. For our configuration as shown in Table 1, the file size at each model output time is 500 MB for Grid 1 and 170 MB for each of Grids 2 and 3 (although this size can be approximately halved through file compression).

2.2 Four-Dimensional Data Assimilation (FDDA)

Even with the overlapping simulation segment strategy, it is difficult to ensure that the interior of a regional model simulation remains close to observations for simulations of more than a day or so. Therefore, dynamic analyses of historical cases are often performed, in which a Four-Dimensional Data Assimilation (FDDA) strategy is applied throughout the model integration. Relaxation terms based on the differences between actual observations and the corresponding model fields at the observation sites (also known as the 'innovations') are added to the model's predictive equations. In this way the model error is constrained based on available observations while the model still provides dynamic consistency and finer mesoscale structure not present in the observations. The version of FDDA used in these simulations is the multiscale, multigrid nudging FDDA strategy developed by Stauffer and Seaman (1994) for the MM5 mesoscale model. Nudging is also known as Newtonian relaxation, where the nudging relaxation terms are proportional to the innovation divided by a characteristic e-folding time inversely proportional to a nudging coefficient G. Nudging does not perform a direct insertion of observational information at a single point in space and time, but rather it applies the correction or innovation gradually in time and space based on the model terrain influences and prescribed / assumed weighting functions. For example, when a well-mixed PBL is present, one would generally want the influence of surface observations to be extended throughout the PBL, because in these conditions there is high correlation between errors in atmospheric fields at the surface and those anywhere within the PBL.

The multiscale multigrid FDDA method uses a combination of two forms of nudging: analysis nudging and observation ('obs') nudging. Analysis nudging is performed in model grid space where an objective

analysis of observations (e.g., with a modified Cressman scheme (Benjamin and Seaman 1985)) is performed using the interpolated global analyses (e.g., from the GFS) as a background field. The resultant 'enhanced analysis' can then be used as the basis for analysis nudging. Analysis nudging is generally applied on coarser model domains where synoptic data can be used to produce a reasonable gridded analysis. Obs nudging is more attractive for finer-scale domains and asynoptic data. It is particularly effective where observational data density is sparse and corrections are applied only in the neighborhood of the observations, allowing the model to still add value in regions without any data by propagating observation information into the data-sparse regions and creating mesoscale structure not in the observations. In this case the nudging is performed in observation space, and the model field is interpolated to the observation site to compute the innovation that is then analyzed back to the model grid over some three-dimensional neighborhood in space, and over some time window. Quality control (QC) of observations is critically important for the success of both analysis nudging and observation nudging.

In the multiscale multigrid FDDA method applied in this study, 3D-analysis nudging, as well as surface analysis nudging using higher temporal frequency surface data within the PBL (e.g., Stauffer et al. 1991), are performed on the outermost 12-km domain. Obs nudging is applied on at least the 12-km and 4-km domains. (Obs nudging is not applied on the finest 1.3-km model nest for the physics sensitivity studies described further below.) The finer domains thus have the benefit of improved lateral boundary conditions from the coarsest 12-km domain using both types of nudging, as well as the obs nudging performed directly on the 4-km nested domain.

This project was one of the first applications of the multiscale FDDA strategy of Stauffer and Seaman (1994) in WRF. It is important to note that many of the WRF FDDA capabilities were not available and still under development via a contract from the Defense Threat Reduction Agency (DTRA) to Penn State at the time that this project was proposed. In fact, the WRF 3D / surface analysis nudging and obs nudging capabilities were still being developed during this contract period. The WRF end-to-end FDDA system is shown in Fig. 5 and described in more detail in Deng et al. (2009). This contract was able to take advantage of the fact that the WRF FDDA developers at Penn State were also working on this contract.

The new OBSGRID module in the WRF end-to-end FDDA system produces gridded objective analyses and observation files similar to those produced by Rawins / Little_r in the MM5 system. These files can be used for 3D/surface analysis nudging and obs nudging within WRF. OBSGRID takes as input raw WMO observations (both surface and upper air) and the output of WPS, which consists of atmospheric initial and boundary gridded data (e.g., GFS output) horizontally interpolated to the model grid to be used in WRF. The outputs of OBSGRID relevant to this study include 1) pressure-level and surface objective analyses of the WMO observations (passing internal QC checks) using the WPS GFS output as background fields; the resultant analyses are then vertically interpolated to the WRF terrain-following "sigma" layers to be used for 3D analysis nudging; 2) surface analysis nudging files that can be directly used by WRF; 3) observation nudging files usable by WRF, and 4) files of the WMO observations including those passing the QC tests for use in the statistical verification software.

As mentioned above, for the physics sensitivity part of this study, 3D analysis nudging, surface analysis nudging, and obs nudging are performed on the 12-km Grid 1; obs nudging is performed on the 4-km Grid 2; and no nudging is performed on the 1.3 km Grid 3. Thus Grid 3 has no direct FDDA tendencies and can be used to determine physics sensitivities, while still benefitting from improved lateral boundary conditions derived from the coarser grids that do have FDDA.

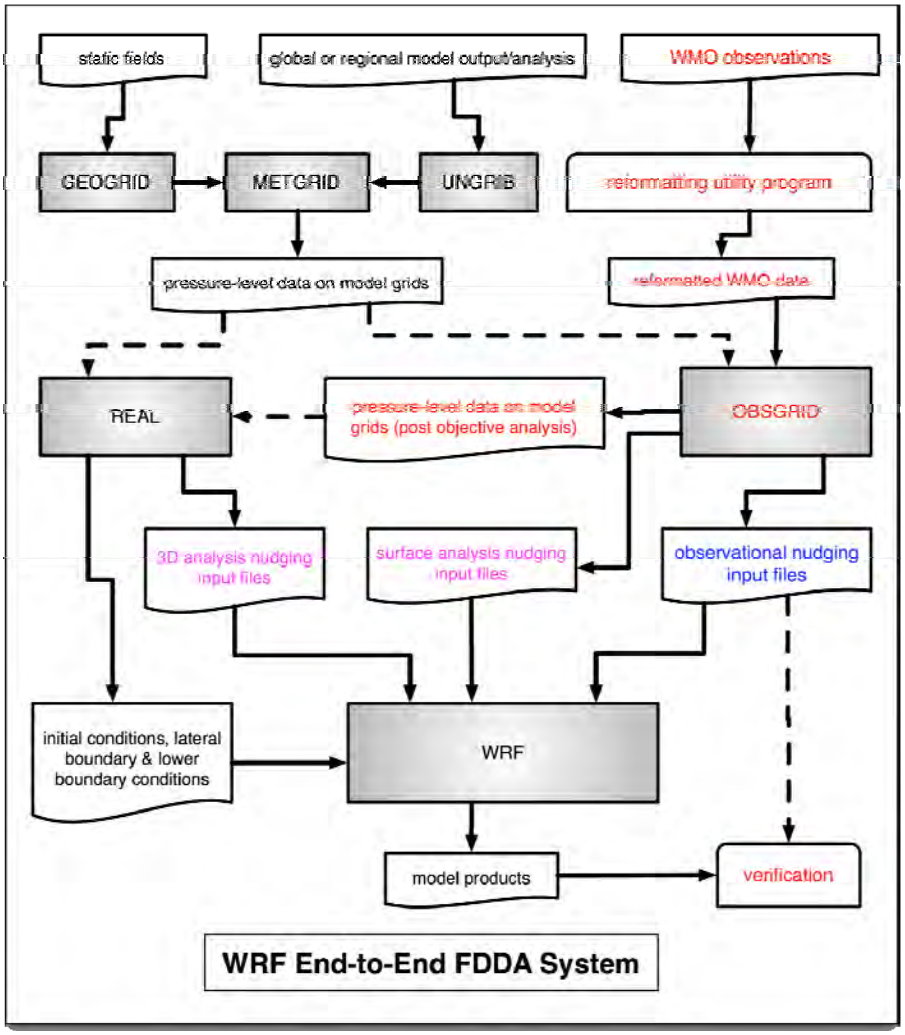


Fig. 5: Diagram of the WRF End-to-End FDDA system used for this study (from Deng et al. 2009). Items in magenta apply to analysis nudging; items in blue apply to obs nudging; items in red apply to both.

For the generation of the final dynamic analysis, obs nudging was performed on Grid 3, but with a reduced horizontal radius of influence (from 100 to 75 km), a reduced vertical pressure difference within the terrain-modified radius of influence function used for surface obs nudging (from 75 hPa to 37.5 hPa),

and obs nudging of surface data was performed on mass fields only (i.e., not winds). The values of FDDA-related WRF namelist parameters for these simulations can be found in Table 2.

	3D/Sfc Analysis Nudging			OBS Nudging		
Parameter	Grid 1 12-km	Grid 2 4-km	Grid 3 1.3-km	Grid 1 12-km	Grid 2 4-km	Grid 3 1.3-km
G (1/sec)	$3*10^{-4}$	**Not Used**	**Not Used**	$4*10^{-4}$	$4*10^{-4}$	$(4*10^{-4})$
Wind field	Yes	**Not Used**	**Not Used**	Yes	Yes	No
Mass field	Yes	**Not Used**	**Not Used**	Yes	Yes	(Yes)
RINXY (km)	N/A	N/A	N/A	100	100	(75)
TWINDO (hours)	N/A	N/A	N/A	2	2	(2 – but see Section 5)
Time Frequency of Data (hours)	6 / 3 (Sfc)	**Not Used**	**Not Used**	1	1	(1)

Table 2: List of WRF FDDA namelist parameter values used in this study. Analysis nudging parameters apply to both surface and 3D versions unless otherwise specified. Values in parentheses for Grid 3 do not apply to the physics sensitivity studies, which have no FDDA on Grid 3, but do apply to the final dynamic analysis performed in this study.

2.3 Baseline Physics Suite

Two of the most important controls on the evolution of SBLs in mesoscale models are the PBL scheme and the Land Surface Model (LSM). The former is critical for determining the effects of vertical mixing both within and outside of the PBL, and thus helps regulate how rapidly pollutants can disperse. The LSM helps to determine the details of the surface energy balance and thus the thermal tendency and stability of air near the surface. In addition to these, other physical processes that are important in these conditions are the atmospheric radiation scheme (because of the impact on the thermal cooling and temperature structure of the lower atmosphere) and the microphysics scheme (because of the interactions between radiation, latent heat, and quantities of water vapor and condensate, as well as the value of predicting such features as ice fog).

The baseline physics suite used for these simulations was originally derived from that of Seaman et al. (2008) for central Pennsylvania, but with some modifications. To determine the longwave component of radiation, the RRTM scheme of Mlawer et al. (1997) was used, whereas the Dudhia (1989) scheme was used to determine the shortwave component. The PBL scheme used was a version of the Level 2.5 Mellor Yamada scheme as modified by Janjić (2002); henceforth this will be referred to as the Mellor-Yamada-Janjić (MYJ) scheme. A Level 2.5 scheme explicitly predicts the evolution of turbulent kinetic energy (TKE) at each grid point, and uses the predicted TKE to compute the magnitude and vertical extent of mixing. The MYJ scheme used is that available in version 3.1 of WRF; however, based on subsequent work from the central Pennsylvania study, the threshold of minimum TKE within the MYJ scheme was reduced to 0.01 $m^2 s^{-2}$, due to the extremely weak winds and turbulence expected in these stable conditions.

The LSM for the baseline was originally the 5-layer thermal diffusion model used in Seaman et al. (2008). However, we performed a series of preliminary tests with the Alaska grid configuration using the Noah LSM, originating from NCEP, Oregon State University and AFWA (Chen and Dudhia 2001). This was done because the Noah LSM includes a number of features that are potentially important in the central Alaska environment, including time-dependent snow cover, time-dependent snow density, and snow-dependent emissivities and ground conduction. Some properties of the Noah LSM that had just been incorporated into standard WRF (e.g., a more rigorous treatment of latent heat release in the presence of ice) were based on the 'Polar-WRF' and 'Polar-MM5' versions of Noah used for high latitude simulations (Bromwich et al. 2001; Hines and Bromwich 2008). A number of other features of the polar-modified Noah were not in the standard WRF at the time, but not directly relevant to central Alaska (e.g., modification of sea ice properties). Preliminary tests in the relatively mild conditions immediately prior to the partial sunlight episode revealed that the use of the Noah LSM initialized directly from the soil levels of the half-degree GFS resulted in smaller surface temperature biases. Thus, based on our preliminary favorable results, we used the version of Noah in WRF v3.1 as the LSM for the baseline simulation.

The microphysics model selected for the baseline was the Morrison et al. (2005) scheme, also new to WRF v3.1. This scheme was developed specifically for high-latitude cold temperature microphysics, and includes the prediction of two moments (mixing ratio and number concentration) for rain, snow, graupel, and cloud ice, in addition to single moment prediction of cloud water. We thus felt it was worth using this scheme in the baseline even though file sizes and computational costs were significantly increased (by 50% in time) from the simple ice scheme used previously.

3. Initial Baseline Testing and FDDA Modifications

Initial testing of the baseline WRF configuration for the two episodes began in January 2009. The purpose of the 'pre-baseline' testing was to confirm that the proposed WRF grid configuration would remain numerically stable and physically realistic for simulation segments of several days, to determine the resource and timing requirements of the simulations, and to confirm that the WRF FDDA features were working as expected. Furthermore, a number of key WRF system features to be used in this study

were still under development at the beginning of 2009; in particular, surface analysis nudging, OBSGRID, and the official WRF v3.1 release itself, which included the QNSE PBL scheme and a modified version of the Noah LSM. Thus all of these new features had to be tested and evaluated when they became available.

At the beginning many of these tests were performed on the first segment of the partial sunlight episode (23 – 28 Jan 2008). Not only was this a convenient place to begin, but it began as a time of relatively warm temperatures in central Alaska, allowing the model configurations to be evaluated in relatively mild conditions before being used in the extreme cold conditions of the high exceedance episodes. Nonetheless, a brief period of colder temperatures occurred toward the end of the 23-28 Jan 2008 period, so some evaluation of model performance in different temperature regimes could be determined.

A preliminary assessment of the skill of the FDDA components of the WRF end-to-end system for the baseline simulation of the 23-28 Jan 2008 period, made in April 2009, is shown in Table 3 for the 12-km (Grid 1) and 4-km (Grid 2) domains. Raw WMO observations from both surface METAR and rawinsonde stations were given QC codes within OBSGRID, and only those observations of sufficient quality to be used in the objective analysis were retained for verification. The table compares a simulation without FDDA, a simulation using only analysis nudging on Grid 1; a simulation using only obs nudging on Grids 1 and 2; and a simulation combining the analysis nudging and obs nudging features, corresponding to the proposed multiscale multigrid FDDA procedure. Furthermore, since the surface analysis nudging feature of WRF had only just become available from Penn State, two versions of each simulation including analysis nudging were performed: one with and one without surface analysis nudging.

The table confirms that, for virtually every grid, observation station type, and variable, the best root-mean-square error (RMSE) scores occur for multiscale multigrid FDDA, and the worse RMSE scores occur for the simulation without any FDDA. However, a more careful analysis of the table revealed a few puzzling results. While surface analysis nudging led to expected improvements in temperature on Grid 1 (vs. analysis nudging without surface analysis nudging) when verified against surface METAR stations, the RMSE scores of METAR winds and relative humidity actually became slightly worse. Furthermore, when the verification was performed against rawinsondes on Grid 1, surface analysis nudging made temperature RMSEs considerably worse, and wind RMSEs far worse, than the corresponding runs without surface analysis nudging.

For Grid 2 verified against rawinsonde data, we see the expected result that a simulation with only obs nudging improves the RMSE scores more than either version of the analysis nudging only simulation. (Since analysis nudging is always applied to Grid 1 only, the analysis-nudging-only simulations have only indirect FDDA improvements on Grid 2, through the lateral boundary conditions from Grid 1; the obs nudging simulations do have direct FDDA on Grid 2.) However, when surface METARs are used for Grid 2 verification, we have the puzzling result that obs nudging only is outperformed by analysis nudging only (except for temperature).

Verification Domain	Verification Field and Station Type	Simulation FDDA Method (O – Obs Nudging; 3DA – 3D Analysis Nudging; SA – Surface Analysis Nudging; No – No Nudging)			
Grid 1 (12 km)		Grid 1: No Grid 2: No	Grid 1: O Grid 2: O	Grid 1: 3DA / 3DA + SA Grid 2: No / No	Grid 1: 3DA + O / 3DA + SA + O Grid 2: O / O
	Surface U-Component	3.2	2.6	2.3 / 2.4	**2.1** / 2.2
	Surface V-Component	3.2	2.7	2.1 / 2.3	**2.0** / 2.1
	Surface Temperature	5.6	2.9	2.9 / 2.4	2.5 / **2.1**
	Surface Rel. Humidity	21.0	18.7	17.7 / 18.2	**17.0** / 17.5
	Sounding U-Component	4.6	2.2	1.5 / 3.3	**1.1** / 2.0
	Sounding V-Component	4.2	2.3	1.5 / 2.9	**1.1** / 1.9
	Sounding Temperature	3.5	1.4	1.4 / 2.0	**1.0** / 1.3
	Sounding Rel. Humidity	21.2	10.2	11.2 / 16.0	**8.3** / 10.5
Grid 2 (4 km)	Surface U-Component	3.8	3.3	**2.2** / 2.3	2.5 / 2.7
	Surface V-Component	**2.5**	3.1	2.7 / 2.8	2.9 / **2.5**
	Surface Temperature	5.0	2.5	3.1 / 3.0	1.9 / **1.8**
	Surface Rel. Humidity	23.8	22.0	20.7 / 20.7	19.6 / **19.3**
	Sounding U-Component	4.5	2.2	2.6 / 2.8	**1.7** / 1.8
	Sounding V-Component	4.5	3.2	3.4 / 3.8	**2.8** / 3.4
	Sounding Temperature	3.1	1.3	2.2 / 2.2	**0.9** / 1.4
	Sounding Rel. Humidity	27.0	14.1	21.7 / 24.5	**12.5** / 13.1

Table 3: Root-mean-square error (RMSE) values of u-component wind (m s^{-1}), v-component wind (m s^{-1}), temperature (°C) and relative humidity (%) as verified within Grids 1 and 2 during test FDDA simulation of 23-28 Jan 2008 for various FDDA combinations. Verification was performed against METAR stations for the surface and rawinsonde stations for the sounding data. The best value for each row is in bold.

Investigations into the cause of these puzzling results led to the realization that a number of the components of the WRF end-to-end FDDA system probably needed to be modified to adapt the system to the special conditions of the Alaska configuration. First, in most mesoscale model simulations it can be assumed that surface wind observations, normally made at a height of 10 m above ground level (AGL), and surface temperature and moisture observations, normally made at 2 m AGL, are located within the lowest model layer. In fact, normally the problem is that the midpoint of the lowest model layer (or first half-layer height above the surface) is often tens of meters in height and still well above the height of the surface observations. A proper interpolation of model values to the height of the surface observations usually requires using similarity theory or some similar procedure. For the Alaska configuration, however, a 10-m wind would actually be located within the *third* model layer from the surface, while 2-m temperature essentially corresponds to the height of the lowest model half layer (midway between the surface and the lowest model full level). There are at least two consequences of this. The first is that, for the default procedure of verifying surface wind observations with model output from the lowest model half layer, observed 10-m winds are actually being compared to modeled 2-m winds whereas they should be verified against the modeled 10-m winds of the third model half layer. The second consequence is that the surface wind innovations used in the WRF FDDA code are by default based on the difference between 10-m observed winds and 2-m modeled winds in this case, which is wrong and may introduce erroneous biases into the FDDA simulation.

An additional issue was revealed by examining fields of PBL height produced by the PBL turbulence parameterization in various test simulations. Though, as expected, PBL heights are very low over many large areas within the model domains, especially during the colder periods, some patches of unexpectedly high PBL height values can be seen at times (Fig. 6). PBL heights of 1500 m or greater are more typical of convective boundary layers than of the nocturnal SBL conditions found in interior Alaska. Model soundings taken in the proximity of these patches (Fig. 7) confirm that the atmosphere is certainly rather stable and not well mixed in potential temperature (although some layers above show potential temperatures close to a saturated adiabat). The high PBL height zones appear to be associated with regions of elevated shear-generated TKE and cloudiness, since it is the TKE profile in the MYJ scheme that determines the PBL height. The issue is that the default WRF surface analysis and obs nudging schemes spread the influence of surface innovations throughout the depth of the PBL, but in these stable conditions this may overestimate the vertical error correlation length scale for surface innovations. This helped explain why the use of surface analysis nudging on Grid 1 made the rawinsonde-verified statistics worse.

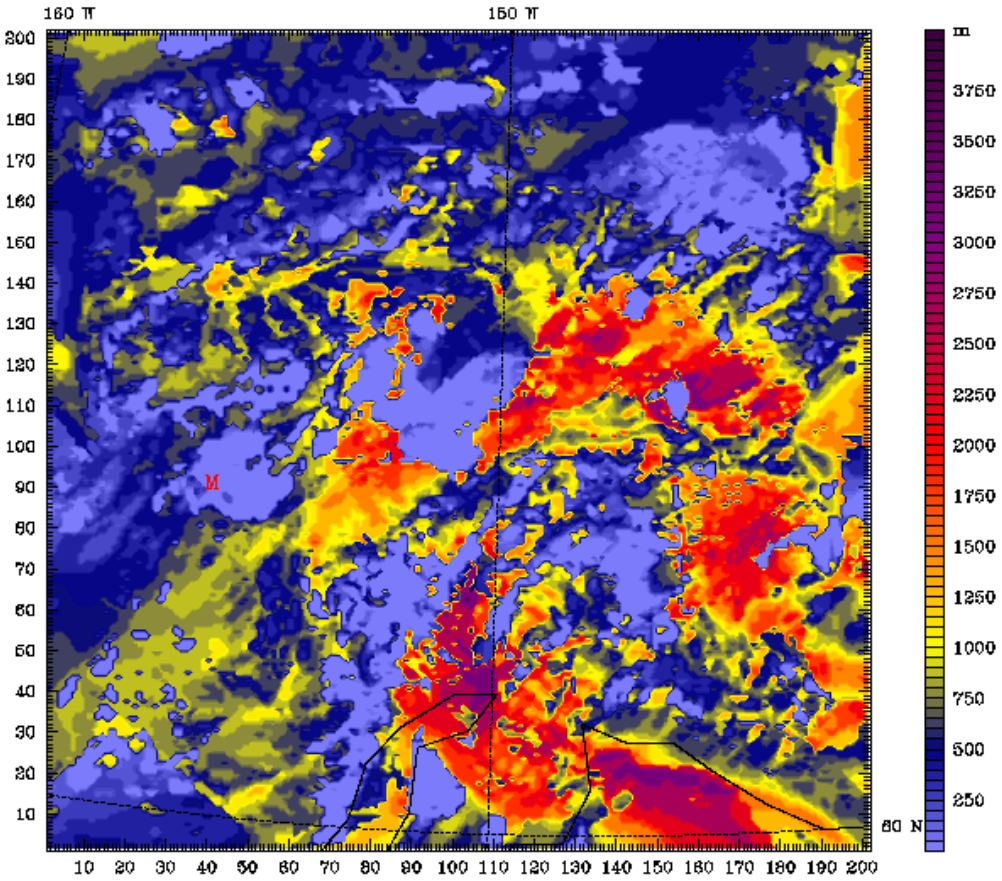


Fig. 6: WRF-predicted PBL height at 1200 UTC 25 Jan 2008 (60-hour simulation time) within the 4-km Grid 2. Simulation does not include FDDA.

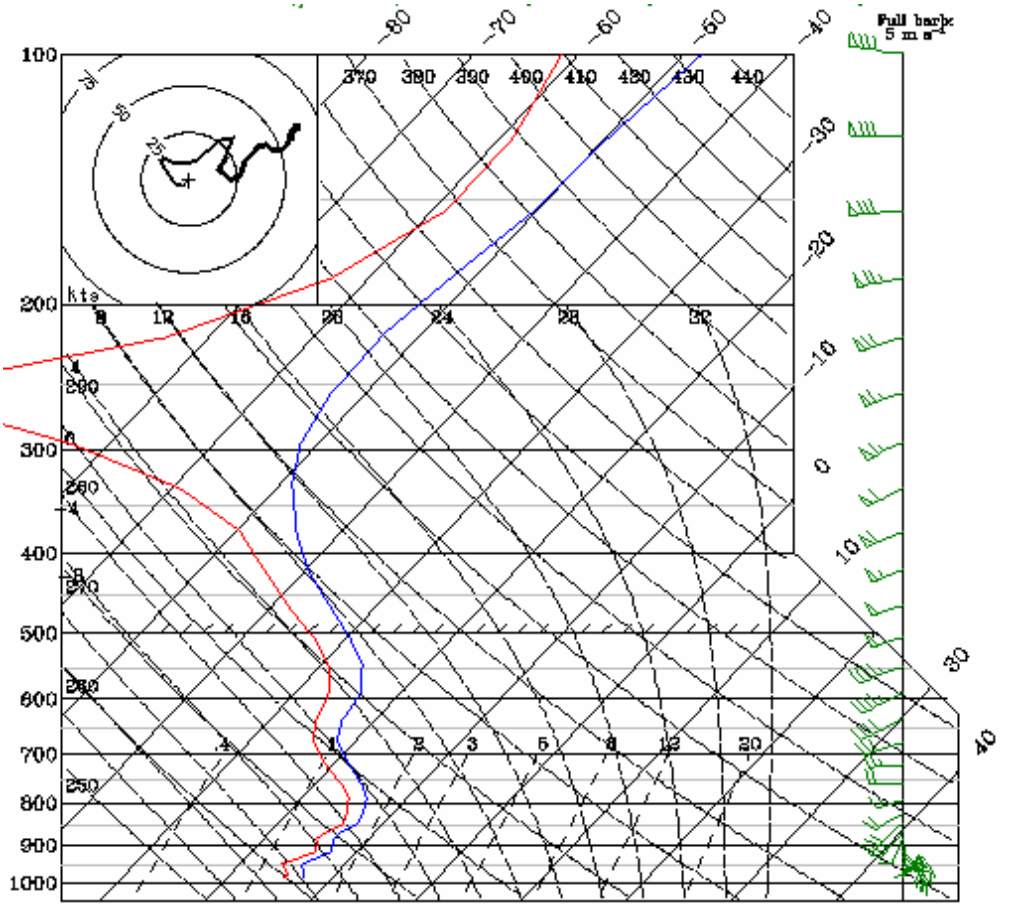


Fig. 7: WRF-predicted model sounding at Fairbanks for same time and simulation as Fig. 6.

Based on a series of similar tests, the following modifications were made to the WRF FDDA schemes for use in the baseline Alaska simulations. 1) The verification software was rewritten so that surface wind observations are verified against the third model half-layer from the ground, while surface moisture and temperature observations are verified against the lowest model half-layer. 2) A portion of the verification software that uses an assumed lapse rate to adjust model temperatures based on the difference between modeled and actual elevation was disabled, because this can lead to large errors in very stable conditions. 3) The surface analysis nudging and obs nudging codes were modified so that surface innovations for wind are computed and applied directly at the third model level. 4) Because surface wind observations directly relate to the third model layer and surface temperature and moisture observations directly relate to the lowest model layer, the similarity-based adjustments normally performed on model output for surface innovation computation was also disabled. 5) Hardwired vertical weighting functions for surface innovations were implemented into the surface analysis nudging and obs nudging codes, replacing the default functions that extend surface corrections to the model-predicted PBL height. Trial and error established that the functions shown in Fig. 8 for surface obs

nudging and analysis nudging extend the surface innovations in the vertical enough to improve surface statistics but without degrading rawinsonde-verified RMSE scores; furthermore, the vertical extent of

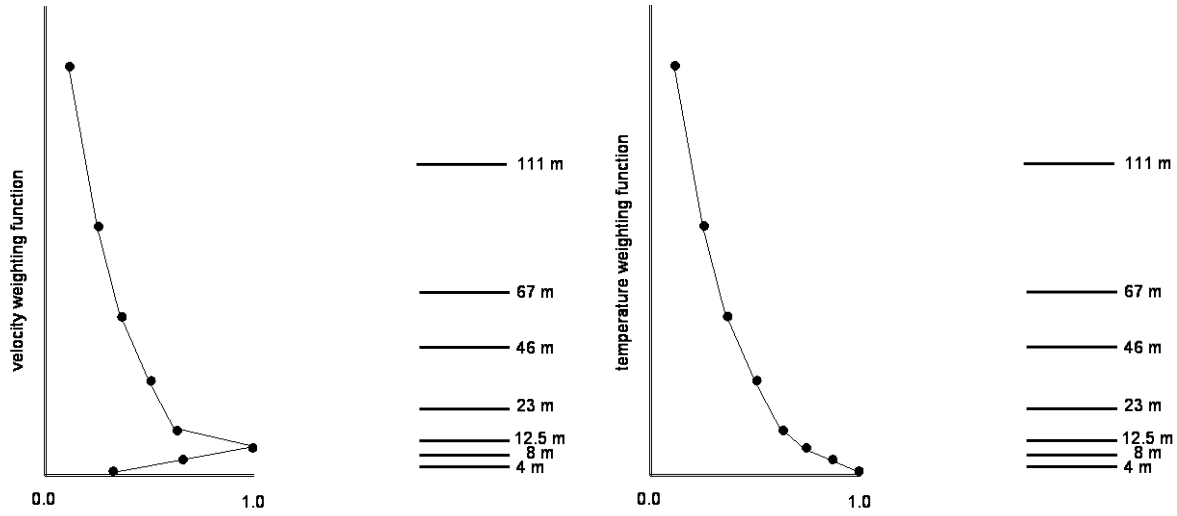


Fig. 8: Vertical weighting functions at model half-layers for wind components (left) and temperature and moisture (right), as used by modified surface analysis nudging and obs nudging FDDA procedures for Alaska simulations. Heights of model full layers are shown to the right, roughly to scale.

these functions (about 150 m) is a reasonable order of magnitude estimate for the maximum depth of nocturnal radiatively-driven SBLs.

Results from this phase of the project were presented at an oral presentation at the 13th AMS Conference on Mesoscale Processes in Salt Lake City, UT, from 17-20 Aug 2009. (Gaudet et al. 2009).

4. PHYSICS SENSITIVITY EXPERIMENTS

4.1 Experimental Design

Three modifications of the baseline physical parameterizations were evaluated in the physics sensitivity component of this project. The first involved modifying the atmospheric radiation schemes so that both the longwave and shortwave components used the new RRTMG radiation package, which uses the RRTM methodology but in a more efficient form adaptable to global climate models. This particular radiation package first became available in WRF v3.1. Though the RRTM and RRTMG longwave radiation schemes should produce very similar clear-sky fluxes, when mult-layered condensate is present the RRTMG makes use of the Monte Carlo Independent Column Approximation (McICA) to take into account 3D scattering effects.

The second involved changing the PBL parameterization from MYJ to the Quasi-Normal Scale Elimination (QNSE) scheme (Sukoriansky et al. 2005; Galperin et al. 2007). The theory behind the scheme is quite

advanced, but it is specifically designed for stable conditions, and allows both turbulent mixing and gravity wave motions to be represented in a unified framework. Dr. Boris Galperin was invited to Penn State University to give a seminar on the theory of the QNSE scheme in October 2008 before it was officially made public in WRF v3.1. The implementation of the QNSE scheme in WRF is actually similar to that of the MYJ, but with the values of vertical mixing parameters derived from the theory as a function of Richardson number (i.e., essentially the ratio of atmospheric stability to the square of the wind shear).

The third modification involved changing the LSM model from Noah to the Rapid Update Cycle (RUC) LSM. Among the features of the RUC LSM that suggest its use for this study is the presence of a snow model that potentially can have multiple layers depending on the snow depth (Smirnova et al. 2000). Other users have reported favorable results from using the RUC LSM in simulations of the Arctic (Mölders and Kramm 2010). The RUC LSM can also be initialized using soil information from the half-degree GFS after minor modification of the WRF source code. By default WRF can use either 6 or 9 soil levels, but we chose 6 because it is closer to the 4 levels of Noah and because it is the typical number of soil levels used in the RUC (e.g, Hines and Bromwich 2008).

4.2 Model Initialization and Setup

The objective analyses used for model initialization and analysis nudging were performed using the multi-quadric method within the OBSGRID software designed for WRF. The background analysis files were derived from the half-degree GFS and topographic and land use dataset through the WPS. The background fields also served as the basis for performing QC on the WMO rawinsonde and surface METAR data used for verification and obs nudging, through 'buddy-check' (excluding obs too different from their neighbors) and 'err-max' (excluding obs too different from the background) procedures. A consequence of the current QC methodology is that all observations were located at the surface or at the standard pressure levels of the GFS model.

For the baseline and sensitivity experiments the model setup was the same except for the choice of physics options. Both the near total darkness and the partial sunlight episodes were simulated in their entirety using the four overlapping simulation segments referred to above. The FDDA procedure (using the modified vertical weighting functions) was defined to use surface and 3D analysis nudging on the 12-km Grid 1, obs nudging on both the 12-km Grid 1 and the 4-km Grid 2, and no FDDA on the 1.3-km Grid 3. Physics sensitivities on Grid 3 would thus be given greater weight than sensitivities on the other grids (which would not be expected to be as large due to the influence of FDDA). (However, we left open the possibility of performing a final dynamic-analysis simulation with obs nudging also performed on Grid 3 once a best-choice physics suite was selected; this final simulation would then have our best available model analysis of the atmospheric state during the episodes, and would be appropriate for use in atmospheric chemistry or transport and dispersion models. These results have been added to the report in Section 5 below.)

For each sensitivity experiment verification was performed using model output every 3 hours (excluding the initial time). For the periods of overlapping simulation segments, the model output from the segment at the larger forecast time was used, so all of the verification model output was at least 12 hours after a model initialization (except of course for the first 12 hours of an episode). All three grids were verified against only those stations located within the boundaries of Grid 3, to ensure that statistical differences between grids are not due to the different set of stations available on each domain. As previously discussed, verification of surface METAR data is performed directly with the third model level from the surface for winds, and the lowest model level for temperature and moisture.

The first physics sensitivity test involved changing the radiation to the RRTMG scheme for both longwave and shortwave components. We all agreed that if this produced favorable results we could simply retain the RRTMG radiation scheme rather than the Dudhia shortwave / RRTM longwave radiation suite of the baseline simulation in future sensitivity experiments. An initial three-day test (23-26 Jan) was performed without FDDA on any grid so as to maximize physics sensitivity. It was indeed found that the surface METAR temperature RMSE scores were consistently improved by the use of RRTMG (Fig. 9), although winds and relative humidity were little affected (not shown). The improvement seemed to be related to reduced downward longwave fluxes beneath patches of ice condensate. Thus, the decision was made that all future physics sensitivity tests, this time with FDDA on Grids 1 and 2 as described above, would make use of the RRTMG scheme.

The combinations of physics parameterizations used in the physics sensitivity tests are summarized in Table 4. To facilitate the comparison of different physics sensitivity experiments, the baseline simulation, with the combination of MYJ PBL scheme, Noah LSM, and Dudhia shortwave / RRTM longwave radiation, will henceforth be denoted as experiment MND. Another experiment, with MYJ PBL / Noah LSM / RRTMG radiation, will be noted as MNR, and another with QNSE PBL / Noah LSM / RRTMG radiation will be denoted as QNR. Finally, the experiment with MYJ PBL / RUC LSM / RRTMG radiation will be denoted as MRR.

Experiment Name	Planetary Boundary Layer (PBL)	Land Surface Model (LSM)	Radiation
MND (Baseline)	Mellor-Yamada-Janjić (MYJ)	Noah	Dudhia Shortwave / RRTM Longwave
MNR	Mellor-Yamada-Janjić (MYJ)	Noah	RRTMG Shortwave / RRTMG Longwave
QNR	Quasi-Normal Scale Elimination (QNSE)	Noah	RRTMG Shortwave / RRTMG Longwave
MRR	Mellor-Yamada-Janjić (MYJ)	Rapid Update Cycle (RUC)	RRTMG Shortwave / RRTMG Longwave

Table 4: Names and physical parameterizations used for physics sensitivity studies.

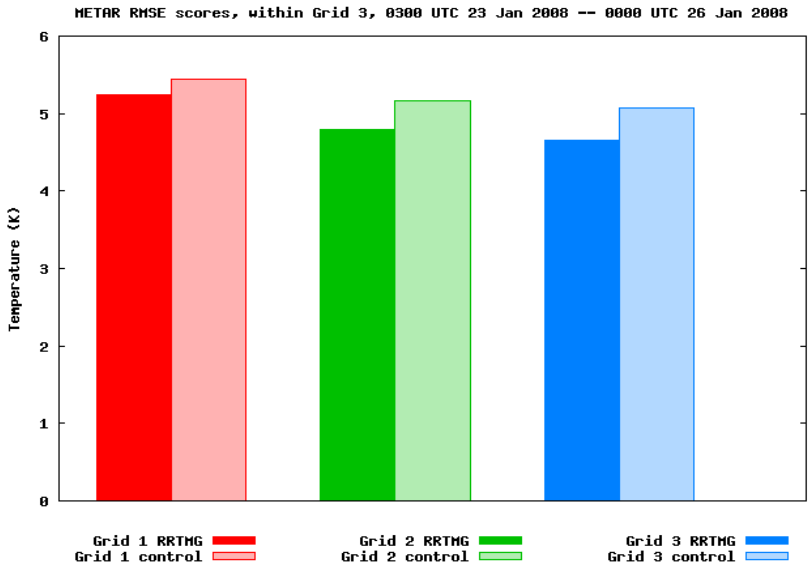


Fig. 9: Surface METAR RMSE scores for temperature compiled for those stations located within Grid 3 for simulations from 00 UTC 23 Jan 2008 – 00 UTC 26 Jan 2008. Verification statistics are computed every three hours during the period. 'Control' denotes baseline physics configuration; 'RRTMG' denotes baseline physics configuration but with the RRTMG longwave and shortwave radiation schemes. All simulations shown were performed without FDDA.

4.3 Results of Physics Sensitivity Experiments

Figures 10 and 11 present the temperature RMSE and bias scores, respectively, for Grid 3 surface METAR stations for both the partial sunlight and near total darkness episodes. First, it can be seen that the RMSE score increases from Grid 1 to Grid 2 to Grid 3, which can be explained by the fact that less FDDA forcing is being applied from Grid 1 (both analysis and obs nudging) to Grid 2 (obs nudging) to Grid 3 (no nudging). These RMSE scores are large compared to typically reported surface meteorological values (e.g., Seaman and Michelson 2000), but of course the large temperature range through the period (about 40°C for both episodes) and extreme conditions make these challenging forecasts for a numerical model. Second, we see the previously discussed result that switching the radiation to RRTMG (compare MND and MNR) leads to improved temperature RMSE scores and lower positive temperature biases; the improvement is most noticeable on the no-FDDA Grid 3. The fact that the RMSE improvement through the use of the RRTMG is greater for the near total darkness episode than for the

partial sunlight episode was not unexpected, because previous examination of the partial sunlight episode revealed that the reduced positive temperature bias with RRTMG was due to the longwave component while the shortwave component of RRTMG partially counteracted this effect (not shown).

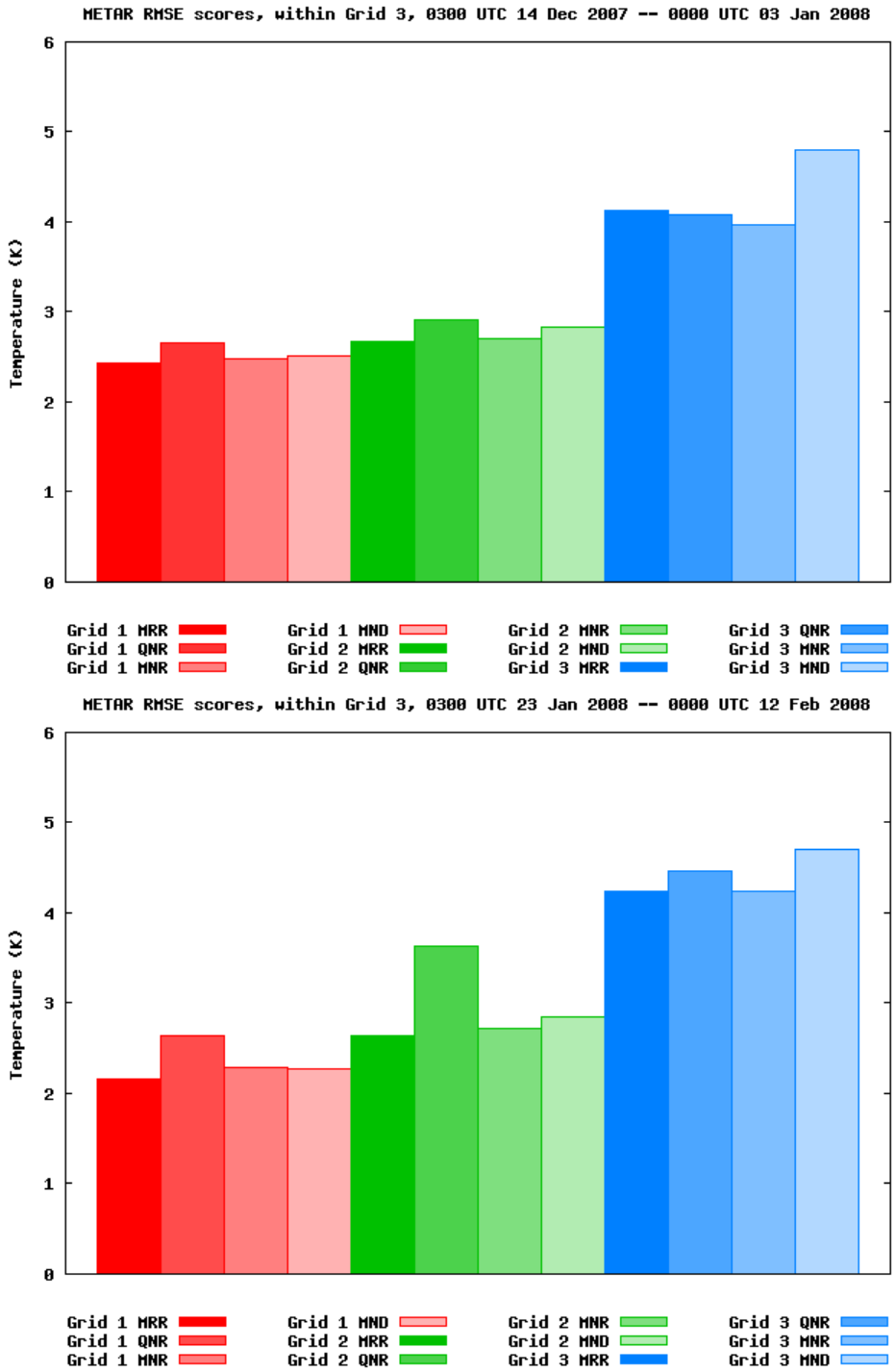


Fig. 10: Surface METAR RMSE scores for temperature for entire near total darkness episode (top) and partial sunlight episode (bottom). Labels for degree of shading refer to experiment names in Table 3. Verification statistics were computed every 3 hours during each episode as described in text.

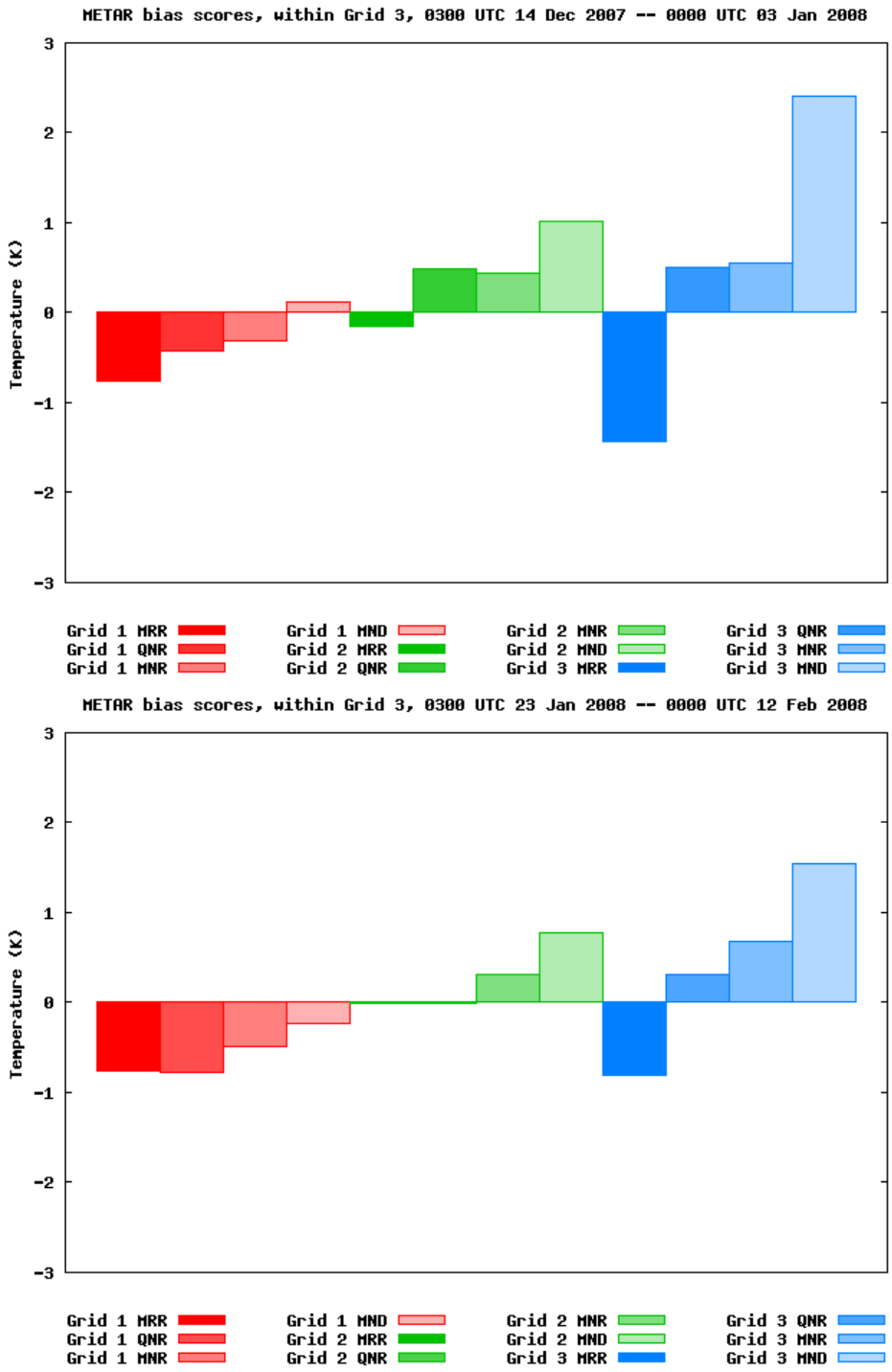


Fig. 11: Same as Fig. 10, but for surface METAR bias scores for temperature.

Switching from the MYJ to the QNSE PBL scheme (compare MNR to QNR) further reduced and improved the magnitude of positive METAR temperature bias (for Grid 3 and the Grid 2 partial sunlight episode). However, the temperature RMSE scores for QNR are consistently greater than those for MNR; so this improved bias is not reflected in more skillful forecasts. The results of the QNSE PBL scheme are encouraging and should be analyzed in greater depth in a future project. We decided that the sensitivity test introducing the RUC LSM should use the MYJ scheme due to our greater experience with MYJ in WRF.

The effect of switching from Noah to RUC (compare MNR to MRR) produces the coldest surface temperatures of any of the experiments. While this leads to the best magnitude METAR temperature biases for Grid 2, the MRR Grid 3 temperature bias is considerably more negative, especially for the near total darkness episode. The MRR temperature RMSE scores for the METARs are the best, or tied for the best, of the four physics experiments for Grid 2 and the Grid 3 partial sunlight episode, but slightly worse than MNR and QNR for the Grid 3 near total darkness episode.

In terms of surface METAR wind speed RMSE and bias errors (Figs. 12 and 13) we see that there is less variability among the different physics schemes. For virtually all variables, grids, and episodes, however, the scores for experiment MNR are slightly better than the others. The wind speed RMSE scores tend to be slightly worse on Grid 3 without FDDA than on Grid 2 with obs nudging, but better than those on Grid 1 that uses analysis nudging but with a much coarser horizontal resolution.

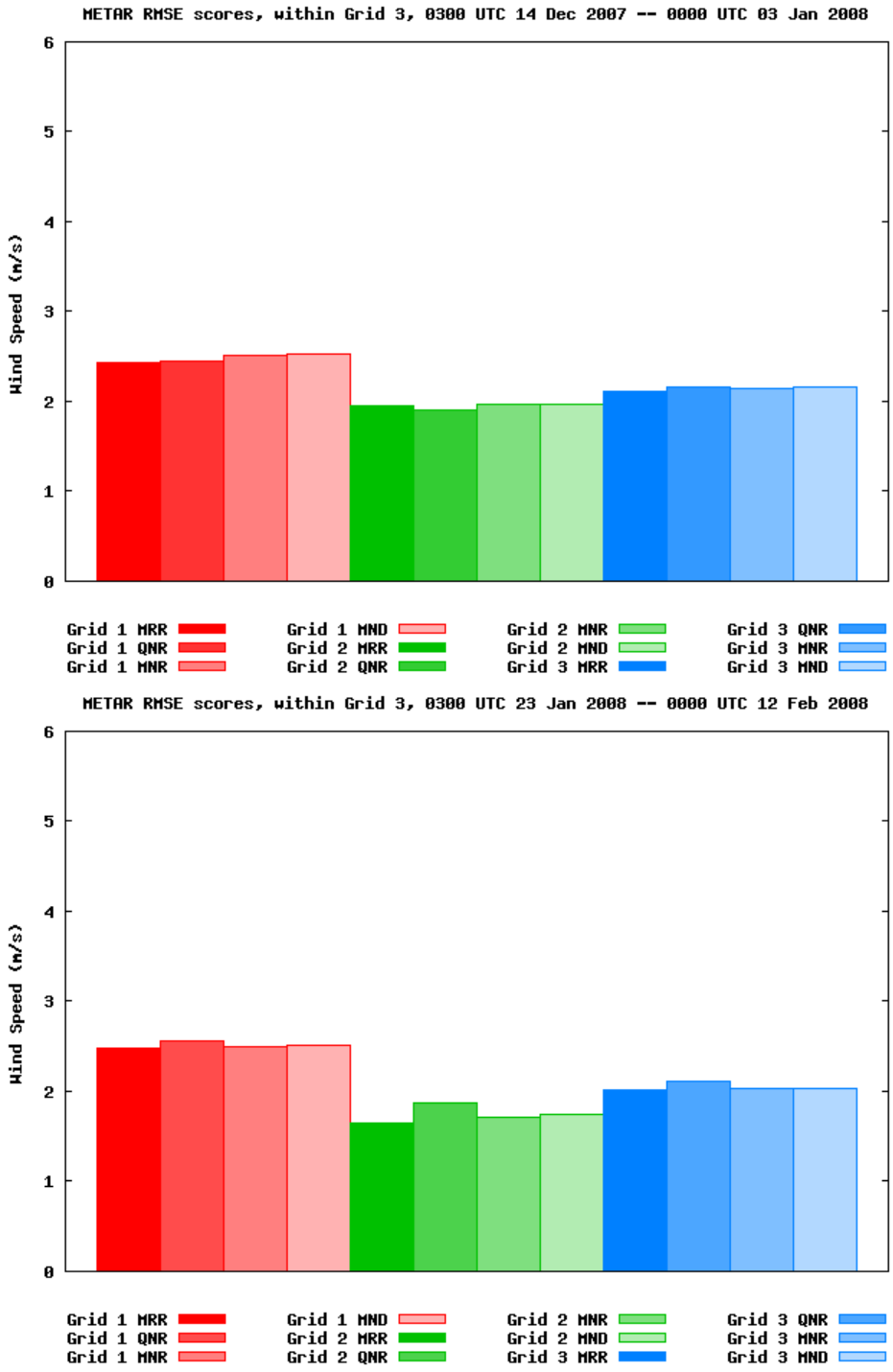


Fig. 12: Same as Fig. 10, but for surface METAR RMSE scores for wind speed.

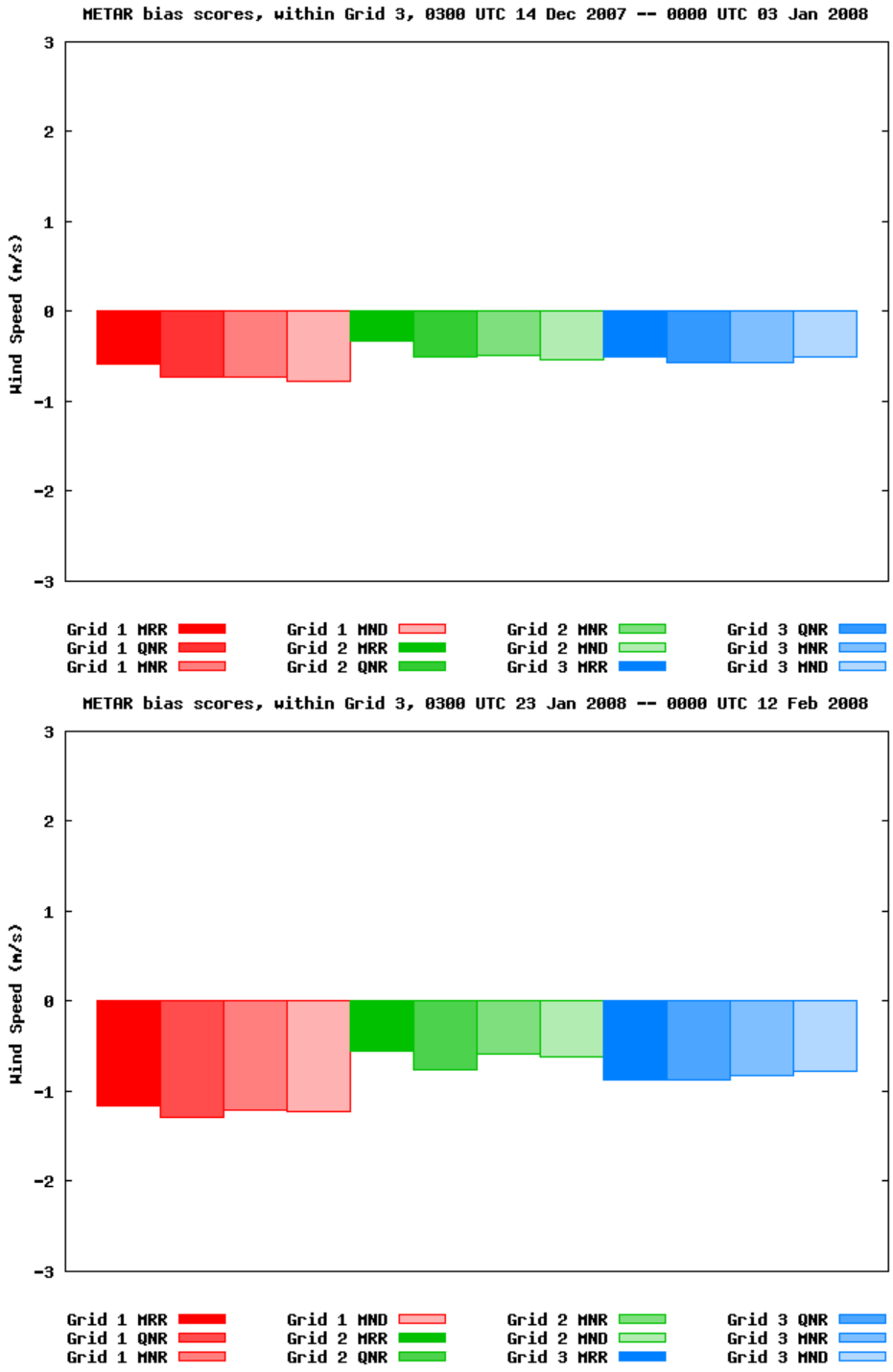


Fig. 13: Same as Fig. 10, but for surface METAR bias scores for wind speed.

In order to learn more about the nature of these biases, statistics for each episode can be compiled for each of the four 5-day (or 5.5-day or 6-day) simulation segments. One instructive comparison is between 14-20 Dec 2007 and 20-25 Dec 2007 (Fig. 14). The temperature difference between different physics configurations remains quite consistent between the two periods, but in the 14-20 Dec period the model temperature bias tends to be more negative than for the 20-25 Dec period. It can be shown that the large negative temperature biases of MRR are predominantly from the 14-20 Dec period. It should be noted that the highest exceedances / lowest temperatures for the near total darkness episode occur around 21 Dec. In general, Grid 3 tends to magnify the temperature biases of Grid 2, except for the MRR model for 20-25 Dec, where the Grid 3 temperature bias is reduced to almost zero.

A time series of the averaged observed, MNR, and MRR temperatures at the locations of the Grid 3 METARs is shown in Fig. 15. Note that the strongest MRR negative temperature biases in each episode tend to occur during times when the temperature is decreasing toward the coldest temperatures near 21 Dec in the near total darkness episode and about 05-09 Feb 2008 for the partial sunlight episode. At these times the MNR temperature bias also tends to be negative, but not by as much. However, immediately after the coldest temperatures are reached, the model biases become positive, and then the MRR configuration is preferred because temperature biases are smaller in magnitude. In particular, during the cold 5-9 Feb period MRR lacks the strong positive spikes in temperature bias that occur in the MNR simulation during the afternoons.

Verifying model features above the surface was made difficult by the scarcity of such observations in the region; the only rawinsonde sounding stations within Grid 2 are at Anchorage, McGrath, and Fairbanks, and of these only Fairbanks is located within Grid 3. No other reliable set of above-surface observations within Grid 3 was available for the episodes. A time-averaged composite of the vertical temperature structure of the Fairbanks sounding, compared to that from the different model physics configurations, is shown in Fig. 16. Since the quality-controlled observations used in the verification are located at the background GFS pressure levels, which have 25 hPa spacing near the ground, this is the effective maximum vertical resolution of the figure. The figure shows the zone from 700 hPa down to 975 hPa, which is the lowest pressure bin located entirely above the surface at Fairbanks. Note that the chosen variations in physics packages have virtually no effect above approximately 850 hPa, and all the modeled temperature profiles are extremely close to the observed profile, presumably due to the impact of Grid 2 obs nudging along the boundaries of Grid 3. From about 850 hPa to 925 hPa, the models begin to diverge from the observations for the near total darkness episode; the MND configuration is about one degree C too warm, but the models with the RRTMG radiation package reduce the positive temperature bias by about a factor of two. For the partial sunlight episode all models track the observations closely down to about 900 hPa. Below 950 hPa the MRR configuration becomes the coldest of the models, and the closest to the observed profile, especially for the near total darkness episode. At these lowest levels the RRTMG sensitivity remains much greater for the near total darkness episode than for the partial sunlight episode. The MNR and QNR configurations are always virtually indistinguishable, suggesting that choice of PBL scheme has little impact on the vertical temperature structure at 975 hPa and higher elevations.

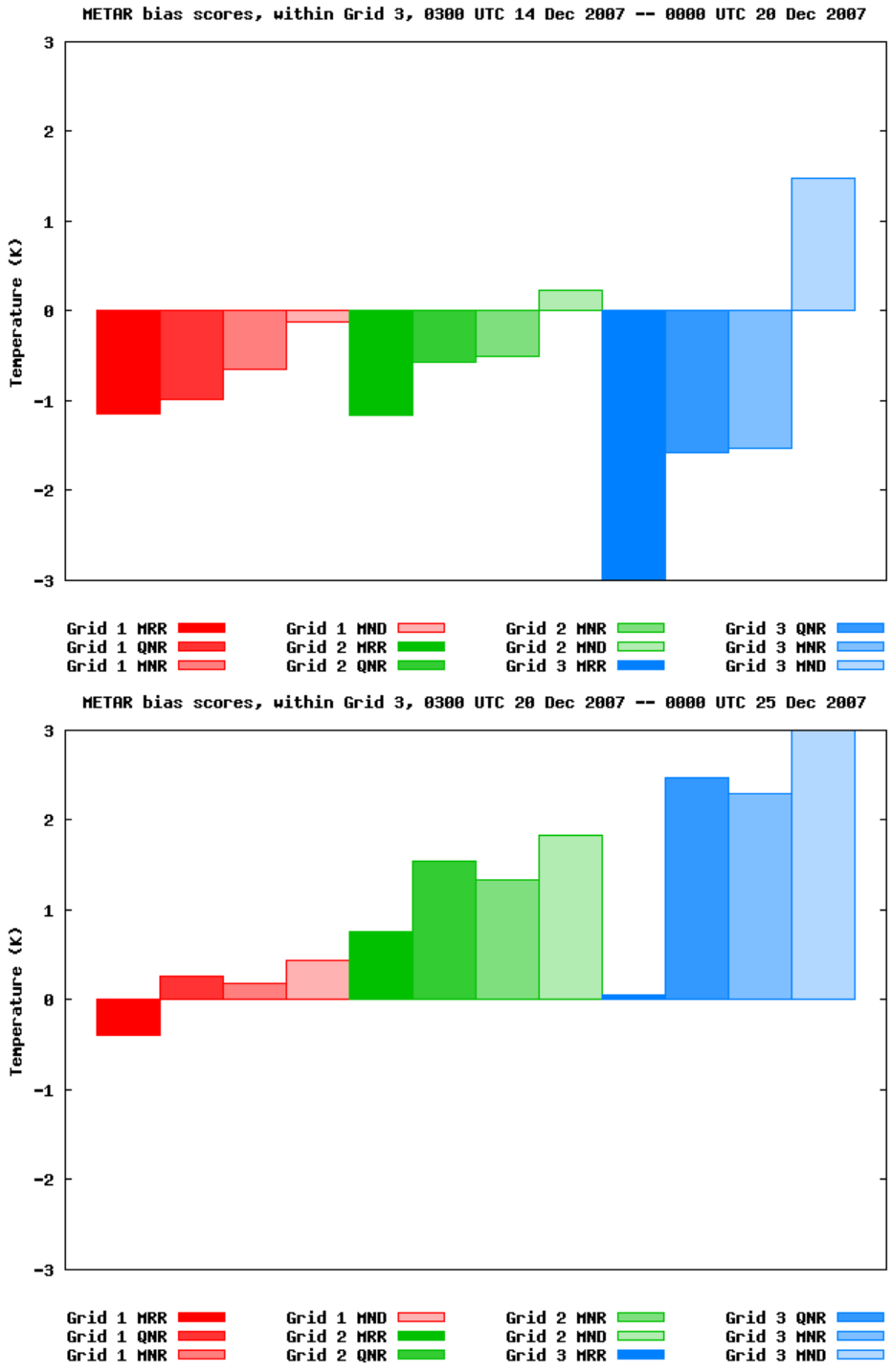


Fig. 14: Surface METAR bias scores for temperature during the near total darkness episode within the 14-20 Dec period (top) and 20-25 Dec period (bottom). Otherwise, same as Fig. 11.

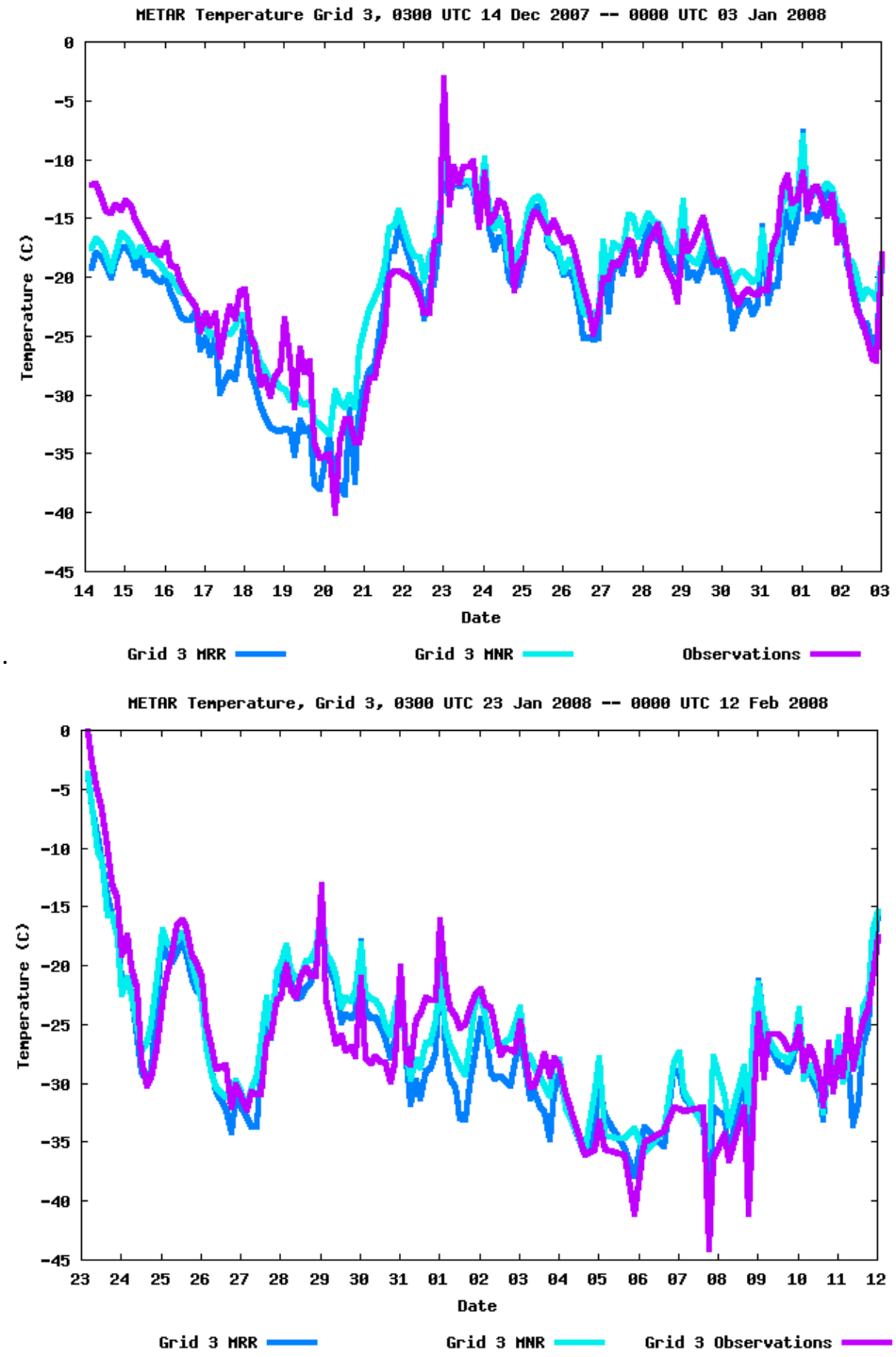


Fig. 15: Time series of temperature for near total darkness episode (top) and partial sunlight episode (bottom), averaged over the sites of all the surface METAR stations within Grid 3. Dark blue indicates value within Grid 3 from experiment MRR; light blue indicates value within Grid 3 from experiment MNR; purple indicates observed METAR value.

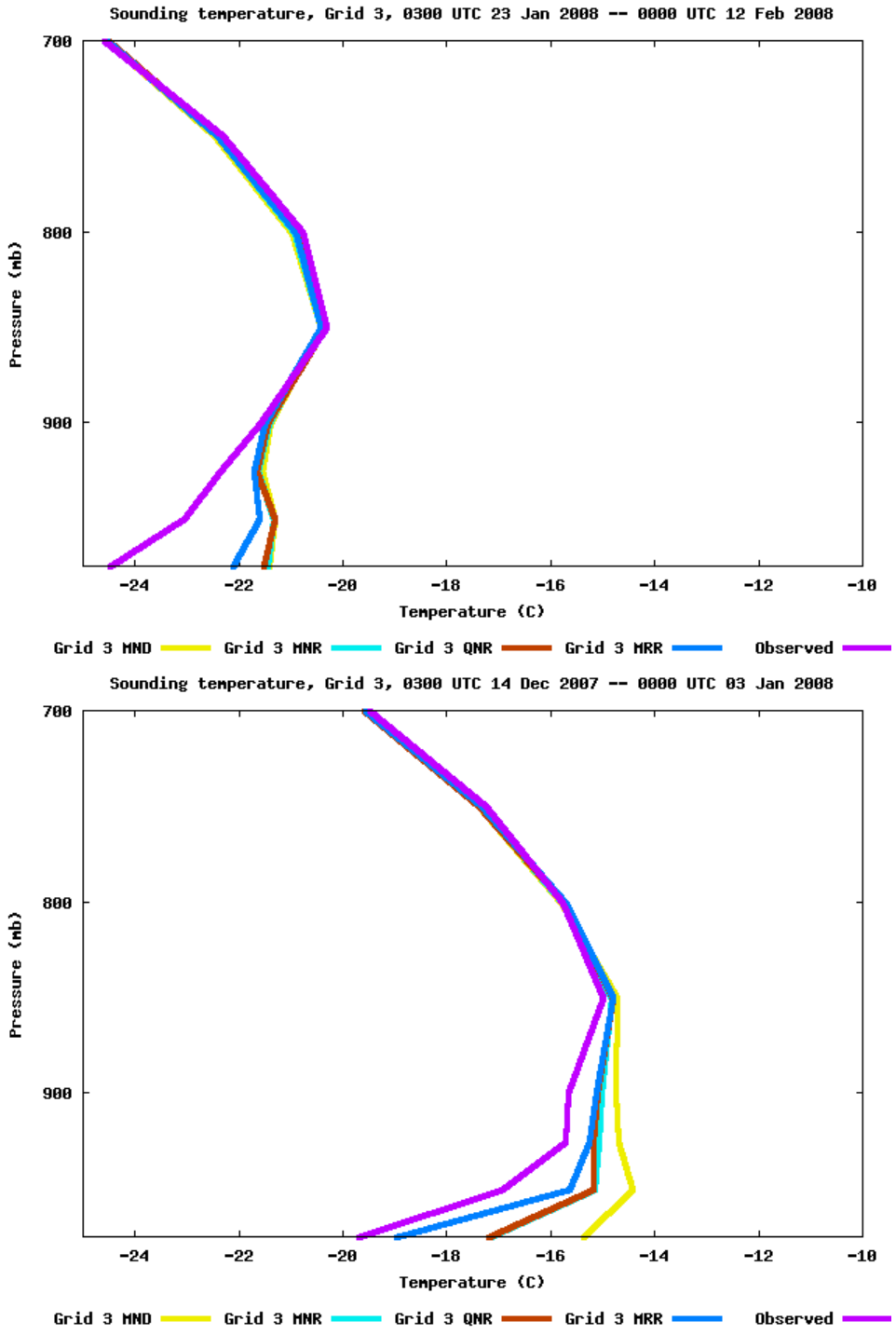


Fig. 16: Time-averaged vertical profile of Fairbanks sounding (PAFA) temperatures for near total darkness episode (top) and partial sunlight episode (bottom). Dark blue indicates value from experiment MRR; brown indicates value from experiment QNR; light blue indicates value from experiment MNR; yellow indicates value from experiment MND; purple indicates observed sounding value.

In order to learn more about the behavior of the different models, we examined the time series of the reported surface-level temperature of the raw Fairbanks sounding in comparison to the lowest-level model values at that location. When we compare the time series for the period surrounding the coldest temperatures of each episode (Fig. 17), an obvious diurnal trend appears in the partial sunlight episode observations during the coldest period from about Day 12 to Day 19 (4 – 11 Feb 2008). Little diurnal trend appears in the observations earlier in the episode; by contrast, the models all have a significant diurnal trend in surface temperature throughout the partial sunlight episode. The model diurnal amplitude during the 4-11 Feb 2008 period for the experiments other than MRR is approximately consistent with the observed amplitude, but the temperature values are consistently about 7°C too warm during this period. The MRR diurnal amplitude is somewhat larger than the others, such that it is similar to the other models for the warmer 0000 UTC times, but is much closer to the observations for the colder 1200 UTC times. For the period of rapidly falling temperatures immediately prior to 4-11 Feb the MRR experiment remains colder than the other models at the 1200 UTC times. In this case, the model 0000 UTC soundings are close to the observations, so the presence of a diurnal tendency in the model but not the observations during this time causes the 1200 UTC model soundings to be too cold, and the MRR sounding to be very cold.

During the near total darkness episode there is little diurnal variation in either the model or the observations. However, we again see the feature that when the temperatures are rapidly decreasing below -30°C, the MRR configuration has a substantial cold bias; once the coldest temperatures are achieved, however, the MRR configuration is better able to capture the low temperatures than the other models.

Finally, in order to gain as much insight as possible into the model-predicted PBL structure near the surface during the coldest episodes, we performed an alternate verification procedure using the raw Fairbanks sounding for the last ten days of the partial sunlight episode (2 – 12 Feb 2008). Instead of interpolating the model sounding to 25 hPa increments of the observed sounding, we interpolated the raw sounding to each WRF model level using some basic assumptions. (The WRF model levels are specified in terms of $(p - p_T)/(p_s - p_T)$ where p_T is the specified model top pressure, p_s is the surface pressure, and all pressures are the dry hydrostatic components; here we converted each WRF level to a pressure in the Fairbanks sounding using the observed surface pressure and the assumption that the actual pressure is approximately the dry hydrostatic pressure; the temperature at the resultant pressure was found by log-pressure interpolation. Finally, the physical height for each WRF level in the base state over ocean was used to determine the abscissa coordinate in Fig. 18.) This procedure gives us increased vertical resolution near the surface, where the model levels are much closer than 25 hPa (i.e., roughly 250 m in physical distance) apart. A plot of the temperature structure (Fig. 18) shows the same general trends as in the 25-hPa plot of Fig. 16. The two simulations using the Noah scheme (QNR and MNR) are similar, while the simulation using the RUC LSM (MRR) is consistently colder in the lowest 500 m. However, all simulations have a warm bias in the lowest 700 m. Though in the lowest 100 m the models have average vertical temperature gradients as large as, or even larger than, those in the observations, the vertical temperature gradients comprising the inversions in the observations extend to a much

greater altitude, consistent with the significantly greater temperature differences between the surface and the 1-km level found in the observations.

In summary, it appears that during periods of near total darkness and the cold, dry, calm conditions characteristic of high fine particulate concentrations, all models possess a low-level warm bias, but the bias is minimized and the statistics are generally the best in the MRR (MYJ PBL / RUC LSM / RRTMG radiation) experiment. The reason for the improved statistics in MRR for the extremely cold episodes is not precisely known at present, but it is probably related to some combination of its potentially multi-level snow model (which can serve to reduce the heat flux from the ground to the atmosphere) and the presence of a ground surface 'skin' layer in the RUC LSM (which has no thermal inertia itself and could decrease the time needed for the ground and the adjacent atmosphere to respond to a negative heat budget). A few caveats are in order, however. During the period of decreasing temperatures immediately preceding temperatures below approximately -35°C, the MRR configuration is still colder than the other models, but for these periods MRR tends to exacerbate an already cold model bias instead of improve a warm model bias. Since the observations for these falling temperature periods tend to show fairly continuous frozen precipitation (in contrast to the coldest temperature periods which tend to have ice fog and no precipitation), it is possible that all the model configurations have difficulties with modeling the microphysics/radiation interaction. For example, if the radiation scheme is not taking into account the presence of ice crystals when they exist in the actual atmosphere, the absence of their radiative heating effect on the surface during these extremely cold conditions could be significant. Another caveat is that when partial sunlight is present, MRR tends to warm more rapidly than the other models, and all models tend to have substantial warm biases in these conditions.

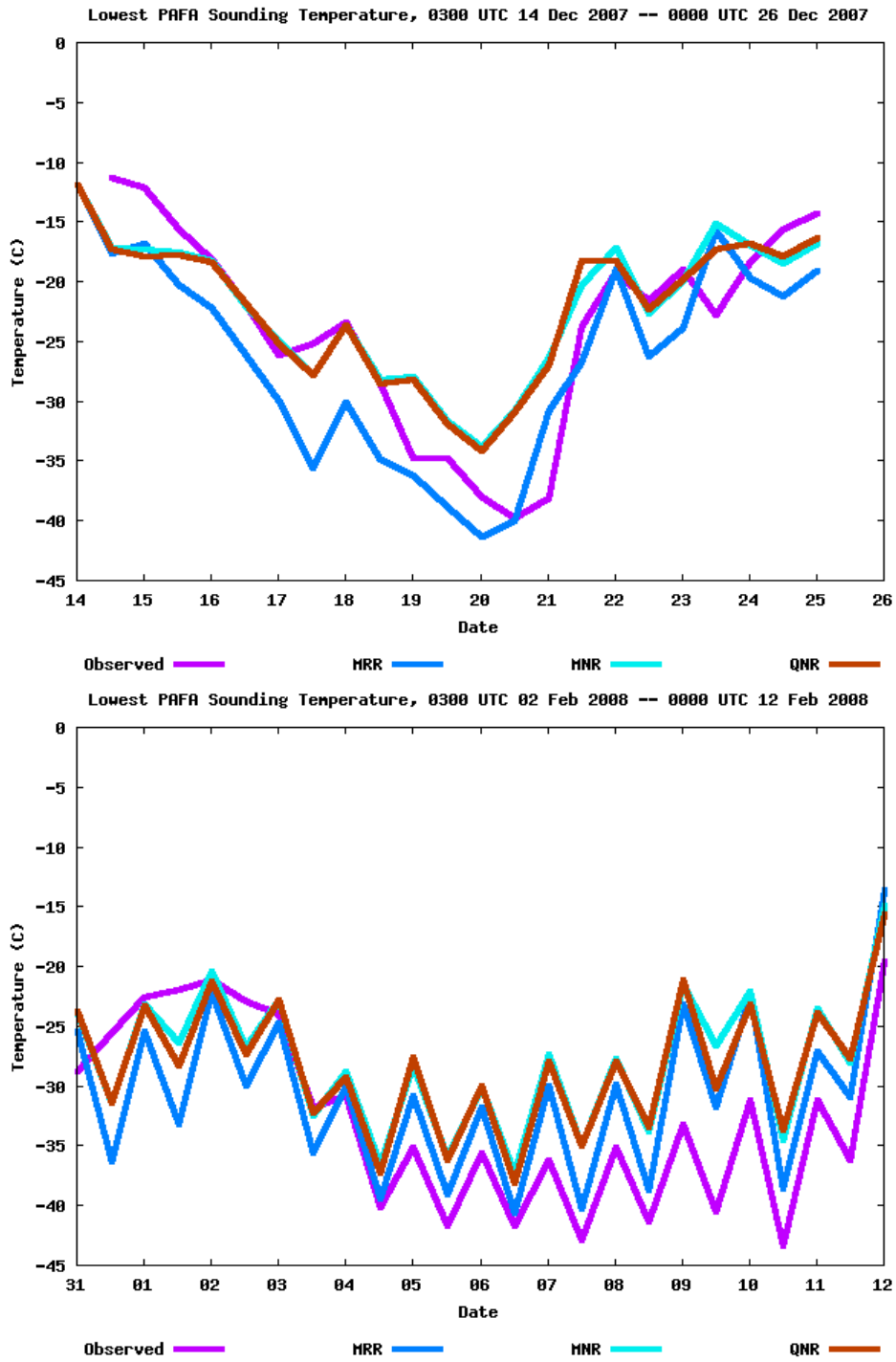


Fig. 17: Time series of raw Fairbanks surface-level reported sounding temperatures (PAFA) for 14-26 Dec 2007 period of near total darkness episode (top), and 02-12 Feb 2008 period of partial sunlight episode (bottom). Colors are same as in Fig. 16.

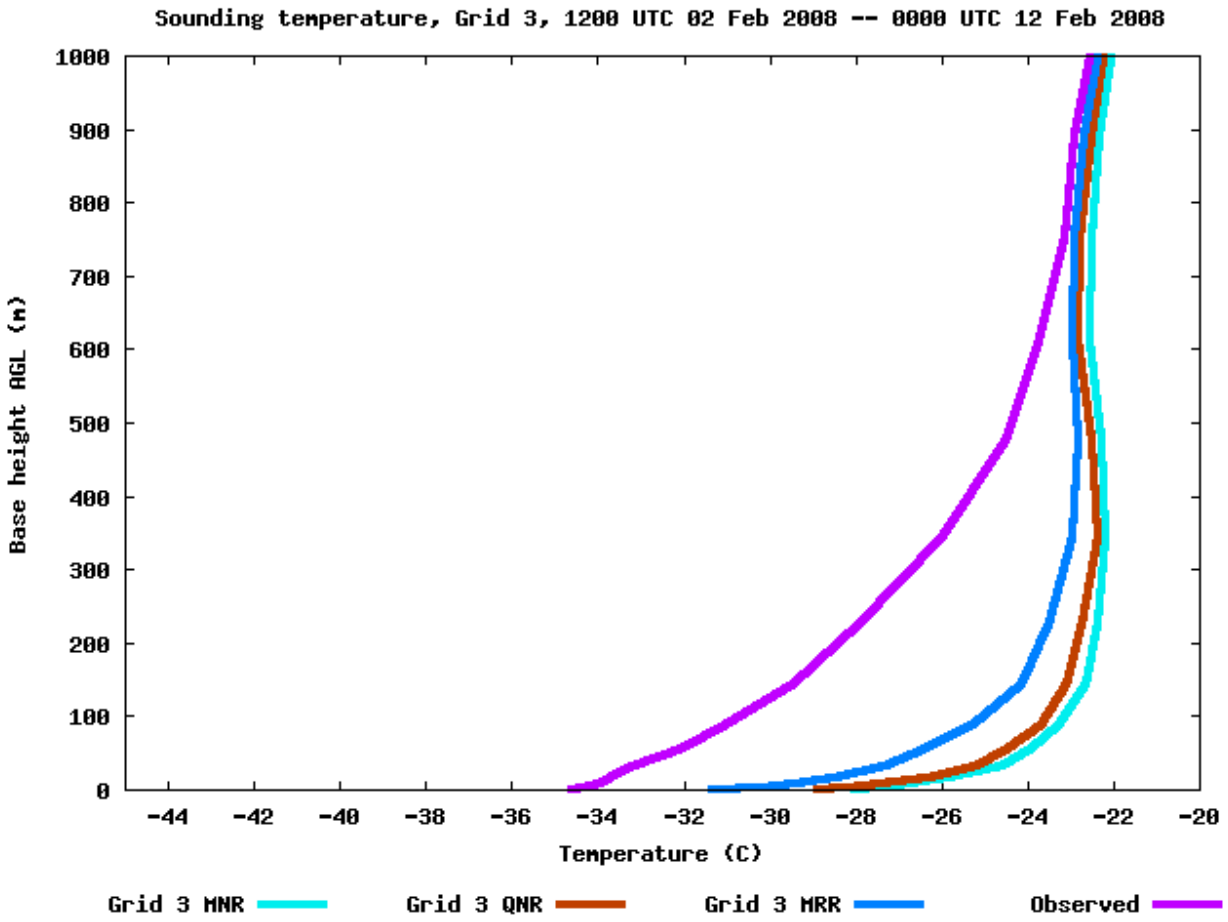


Fig. 18: Time-averaged vertical profile of Fairbanks sounding (PAFA) temperatures for 02-12 Feb 2008 period during partial sunlight episode, where observations are interpolated to WRF vertical levels as described in text. Dark blue indicates value from experiment MRR; brown indicates value from experiment QNR; light blue indicates value from experiment MNR; purple indicates observed sounding value.

5. SELECTION OF PREFERRED PHYSICS CONFIGURATION AND FINAL DYNAMIC-ANALYSIS SIMULATION

Based on the results of the physics sensitivity test, we concluded that the physics suite contained in experiment MRR (MYJ PBL, RUC LSM, and RRTMG radiation) was the best one to be used to simulate the two episodes. The high exceedance events that are of importance occur during the coldest temperature periods when the RUC LSM appeared to perform the best. However, the tendency of the MRR suite to produce significant negative temperature biases during the falling temperature periods must be noted.

We thus concluded that we should perform an additional dynamic-analysis simulation with the MRR physics package but with Grid 3 obs nudging in order to reduce the noted temperature biases and generate the best atmospheric analysis. Because the MRR Grid 2 statistics, in the presence of obs

nudging, were almost always quite good, we were optimistic that any systematic biases present in the MRR simulation on Grid 3 would be greatly alleviated through obs nudging. As noted above, however, we did not nudge the wind fields from surface data on Grid 3, whose influence is below ~150 m (see Fig. 8), because of concerns that the local topographic drainage flows generated by the model in the topography around Fairbanks may be smoothed out by the FDDA procedure. However, we did retain nudging of wind fields on Grid 3 for observations above the surface (i.e., from the Fairbanks sounding).

The initial specifications of the parameters used for the Grid 3 obs nudging simulation are listed within the parentheses of Table 2. They closely correspond to values on the other grids. However, the value of RINXY (a horizontal radius of influence) was decreased on Grid 3 from a value of 100 km to 75 km. This value was determined by performing a temporal correlation of the Grid 3 temperature innovations within the MRR no-FDDA simulation at the location of the METAR stations, and estimating the characteristic horizontal distance at which the Grid 3 METAR observational-based surface innovations were correlated for (see Fig. 19). The surface pressure difference parameter used in the horizontal weighting function in complex terrain (henceforth Δp_d) was also reduced from 75 hPa to 37.5 hPa based on the results of the correlation analysis (e.g., note the relationship between correlation value and the elevation difference labels in Fig. 19). This parameter controls how far the influence of a surface observation may spread along topography as the surface pressure varies from that at the obs site; our results suggested that some station pairs close in horizontal distance but with different vertical elevations were much less correlated than similar stations with little terrain difference.

An additional complication derives from the fact that the WRF method of reducing the weight of surface observations based on Δp_d is different from the MM5 method defined in Stauffer and Seaman (1994). In default WRF, if there is a difference between the model surface pressure at the location of a surface observation, p_b, and the model surface pressure at a grid point in question, p, the weight of the surface observation is reduced by a factor w given by:

$$w = \max\left[0.0,\ 1.0 - \frac{|p - p_b|}{\Delta p_d}\right]\left[\frac{r_0^2 - r^2}{r_0^2 + r^2}\right], \tag{1}$$

where r is the horizontal distance between the grid point and the observation, and r_0 is the surface radius of influence parameter (RINXY in Table 2). In MM5, on the other hand, the surface pressure difference is used to artificially increase the horizontal radius of influence parameter, according to:

$$w = \frac{r_0^2 - \left[r + r_0 \frac{|p - p_b|}{\Delta p_d} \right]^2}{r_0^2 + \left[r + r_0 \frac{|p - p_b|}{\Delta p_d} \right]^2}. \quad (2)$$

Though the two functions are often similar, the WRF function tends to be more horizontally isotropic and less sensitive to terrain features, as well as generally nonzero over greater horizontal differences. (The WRF method will give nonzero weights to surface observations unless either $|p\text{-}p_b|$ exceeds Δp_d or r exceeds r_0, whereas the MM5 method can give a zero weight even if neither criterion is met because the terrain difference increases the effective distance from observation to grid point.) In the final Grid 3 FDDA simulations used here, the MM5 method for surface pressure difference weighting was used.

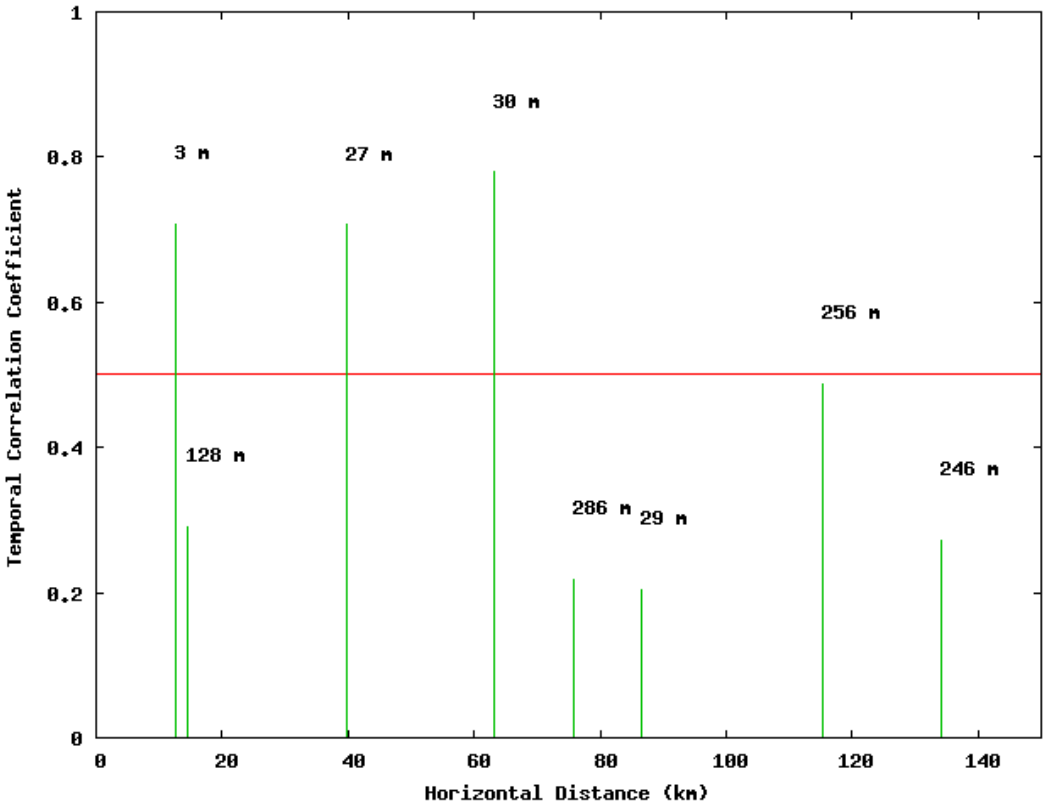


Fig. 19: Temporal correlation coefficients vs. horizontal separation distance between various pairs of surface METAR stations located within Grid 3 (green). Red line indicates a temporal correlation coefficient of 0.5. Numerical labels indicate elevation distance between stations in meters.

The value of TWINDO (Table 2), the obs nudging time window half-period defining the temporal influence of an innovation (Stauffer and Seaman 1994), should also be considered. Ideally this parameter would be a function of height and decrease in value towards the surface, to take into account the shorter temporal correlation time scales for surface data reflecting surface processes. Although this capability will be present in WRF version 3.2, in the version 3.1 that we used for this study, it is simply a constant (though it may vary with grid). Our experience suggests that the value chosen, 2.0 hours, is generally best for the assimilation of sounding data, but may be somewhat too large for the surface (Schroeder et al. 2006). For the final version of the Grid 3 FDDA simulations, we manually encoded the Penn State MM5 method used in WRF version 3.2 so that the effective value of TWINDO was 2.0 hours above the surface, but 1.0 hours at the surface.

Finally, two additional modifications were made to the default WRF version 3.1 FDDA procedure. In the default procedure the surface level observation of a sounding is treated differently than a surface observation. Specifically, a surface observation is assumed to be applicable to the lowest model level at the horizontal location of the observation, whereas all sounding observations including one at the surface level are assumed to be applicable at the vertical model location with the same pressure as the pressure of the observation. So a sounding surface level observation will not necessarily be placed at the lowest model level if the model surface pressure is not the same as the observed surface pressure. Also, the surface pressure difference is used to reduce the weight of a surface observation at remote horizontal grid points , but not the weight of a surface-level sounding observation. This inconsistent treatment becomes more of an issue in station-poor regions such as that of the Grid 3 used in this study, where the relative influence of the Fairbanks sounding to all Grid 3 METAR stations may be quite significant. In the final Grid 3 FDDA simulations, the code was modified to remove the surface-level observation from the rest of the sounding and treat it as a separate surface observation. Furthermore, to reflect the Penn State MM5 method, the Δp_d weighting function was applied to soundings as a unit, in addition to surface observations.

Figures 20-22 show the vertical profiles of RMSEs verified against the Fairbanks sounding for a series of trial simulations of the first six days of the near total darkness episode (14-20 Dec. 2007) using the MRR physics suite but different variations of the Grid 3 obs nudging procedure. First, the benefit of Grid 3 obs nudging is immediately apparent, and Fig. 21 shows in particular that the simulations with retained Grid 3 wind obs nudging above the near-surface layer have substantially reduced wind speed RMSE scores in comparison with the two simulations that don't. This helps justify our proposed procedure of retaining Grid 3 wind obs nudging above the near-surface layer but turning it off within the near-surface layer to allow the model to generate its own topographic flows. Second, for the non-wind fields shown in Fig. 20 and Fig. 22 we see that the TWINDO = 2.0 hours statistics tend to be somewhat better than the TWINDO = 0.45 hours statistics, in agreement with our past experience. The proposed Grid 3 obs nudging procedure, including, among other modifications, using TWINDO = 2.0 hours above the surface but TWINDO = 1.0 hours at the surface, produces results quite similar to the TWINDO = 2.0 hours simulation.

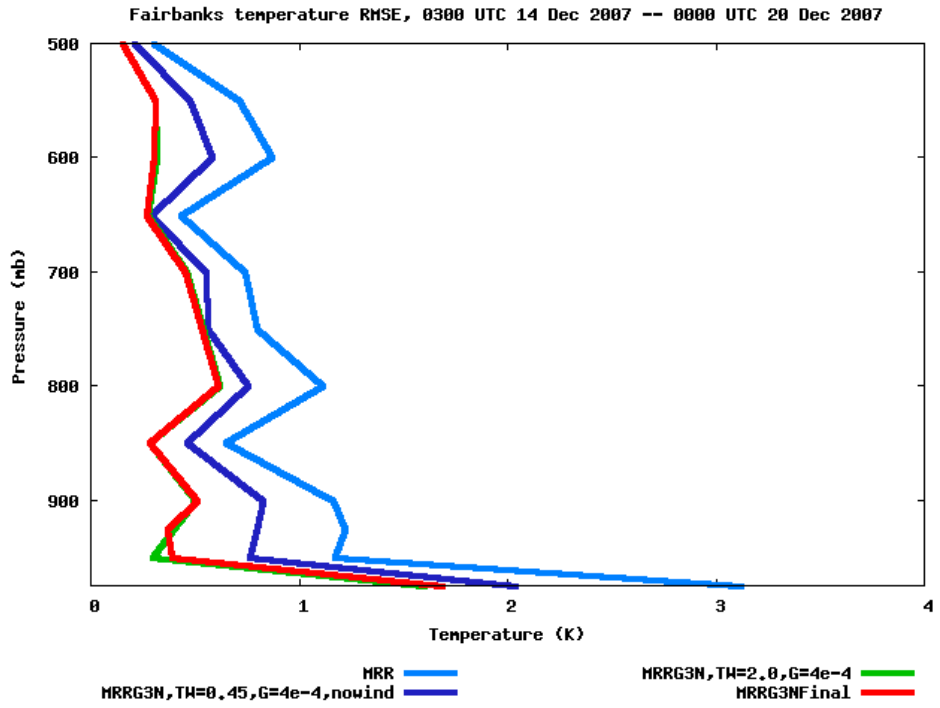


Fig. 20: Time-averaged vertical profile of Fairbanks sounding (PAFA) temperature RMSE scores for 14-20 Dec 2007 period of near total darkness episode. Blue indicates the value from experiment MRR; violet indicates the value from MRR experiment using default Grid 3 obs nudging with TWINDO = 0.45 hours and no wind nudging; green indicates the value from MRR experiment using default Grid 3 obs nudging with TWINDO = 2.0 hours and nudging of wind above the near-surface layer only; red indicates the value from MRR experiment using the final version of Grid 3 obs nudging with the modifications as described in the text.

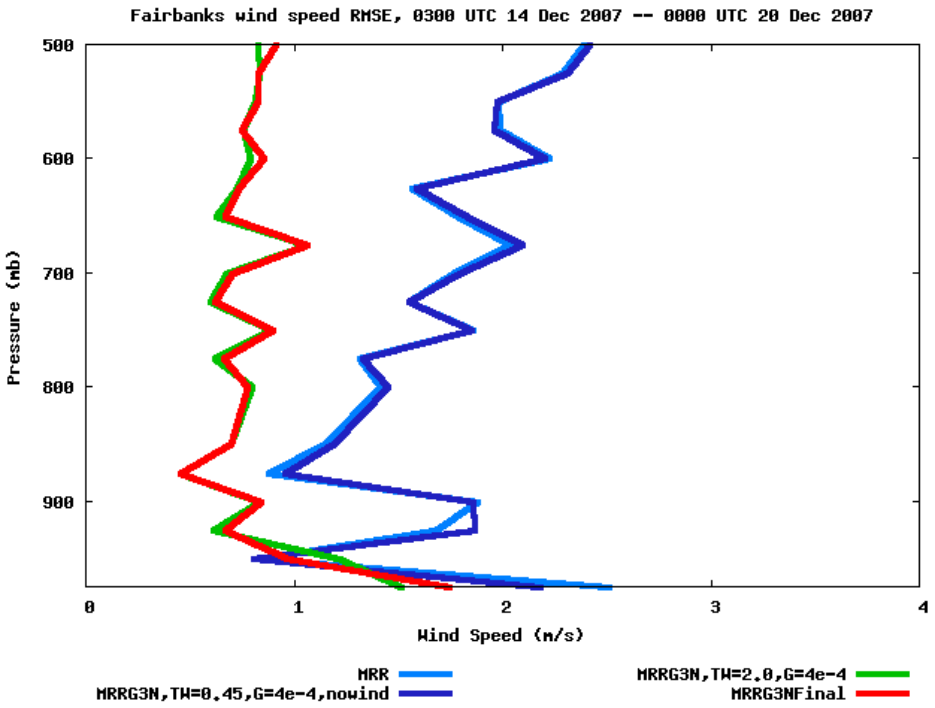


Fig. 21: Same as Fig.20, but for wind speed RMSEs.

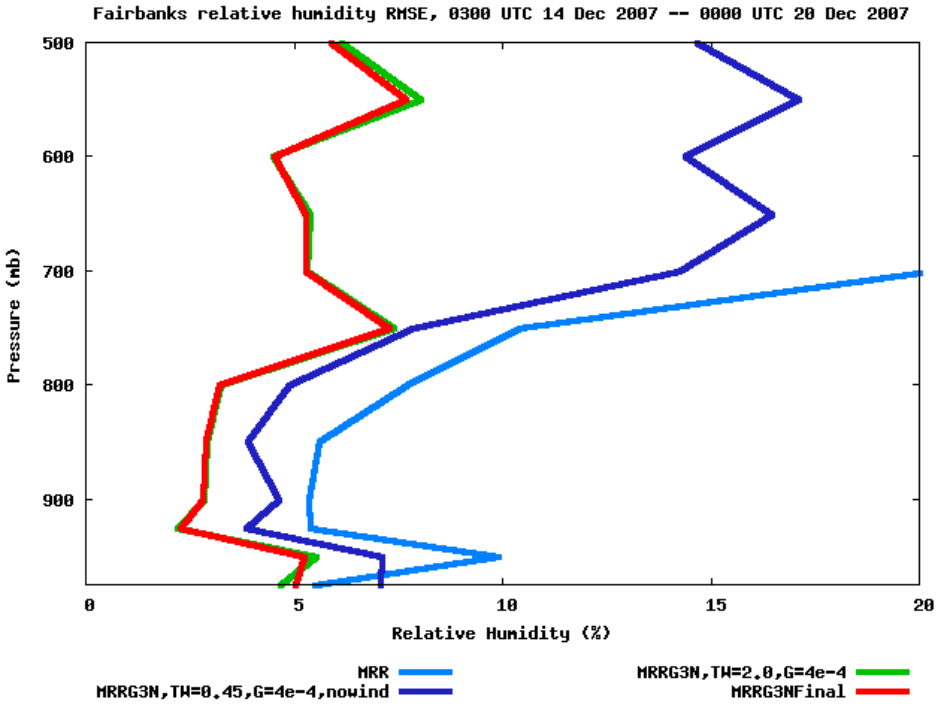


Fig. 22: Same as Fig. 20, but for relative humidity RMSEs.

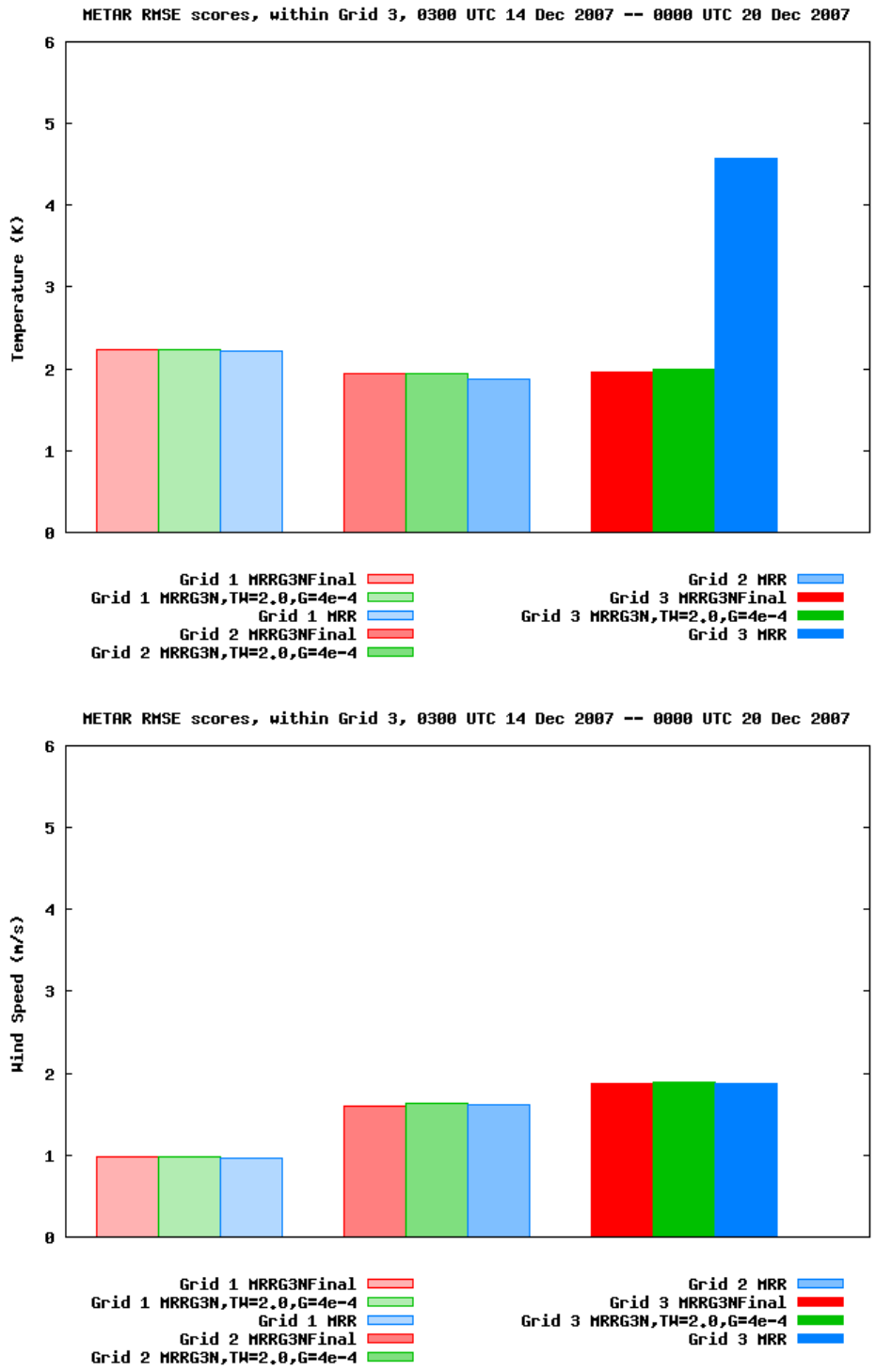


Fig. 23: Surface METAR RMSE scores for during 14-20 Dec 2007 period of near total darkness for temperature (top) and wind speed (bottom). Blue indicates value from experiment MRR; green indicates value from experiment MRR using default Grid 3 obs nudging with TWINDO = 2.0 hours and nudging of wind above the near-surface layer only (i.e., MRRG3N,TW=2.0,G=4e-4); red indicates the value from MRR experiment using the final version of Grid 3 obs nudging with the modifications as described in the text (i.e., MRRG3NFinal).

Fig. 23 shows RMSE statistics for the sample period for the surface METAR stations within Grid 3. The lightest, medium, and darkest shades in the histogram plot correspond to the dark blue, brown, and yellow curves in the vertical profile plots. In all cases the improvement of the MRR temperature RMSE scores from the Grid 3 obs nudging is quite dramatic, and shows the utility of our dynamic analysis approach. The fact that some of our modified obs nudging procedures carried over to all grids caused the Grid 1 and Grid 2 results to change from those of the MRR experiment, but the magnitudes of the changes are small. Wind speed statistics for the surface METARs show little sensitivity to the presence of either Grid 3 obs nudging of temperature and humidity, or Grid 3 obs nudging of winds above the near-surface layer. The proposed Grid 3 obs nudging procedure produces only slight differences from those of the more standardized Grid 3 obs nudging procedure shown, but to the extent there are differences they are generally slight improvements.

In summary, the use of our proposed modified Grid 3 obs nudging procedure, at least for this six-day test period, produces the desired effect of greatly improving the surface temperature statistics without significantly degrading the other statistics, and is also consistent with our past experience as to the preferred specification of obs nudging parameters. Therefore, we proceded to perform the final dynamic-analysis simulations in their entirety using the proposed Grid 3 obs nudging procedure.

Figures 24-26 show the overall statistics for the final dynamic-analysis Grid 3 obs nudging simulation for the entire near-total darkness episode in comparison to those of the non-Grid 3 obs nudging simulation MRR. The final temperature biases in comparison to the surface METARs are below 0.5°C in magnitude, with RMSE errors 2-3°C. The temperature RMSE errors decrease below 1°C above 900 hPa. Wind speed biases are under 1 m s^{-1} at the surface, while RMSE errors are on the order of 2 m s^{-1} throughout the lower troposphere. Qualitatively, the statistics for the final partial sunlight episode (Figs. 27-29) show very similar tendencies.

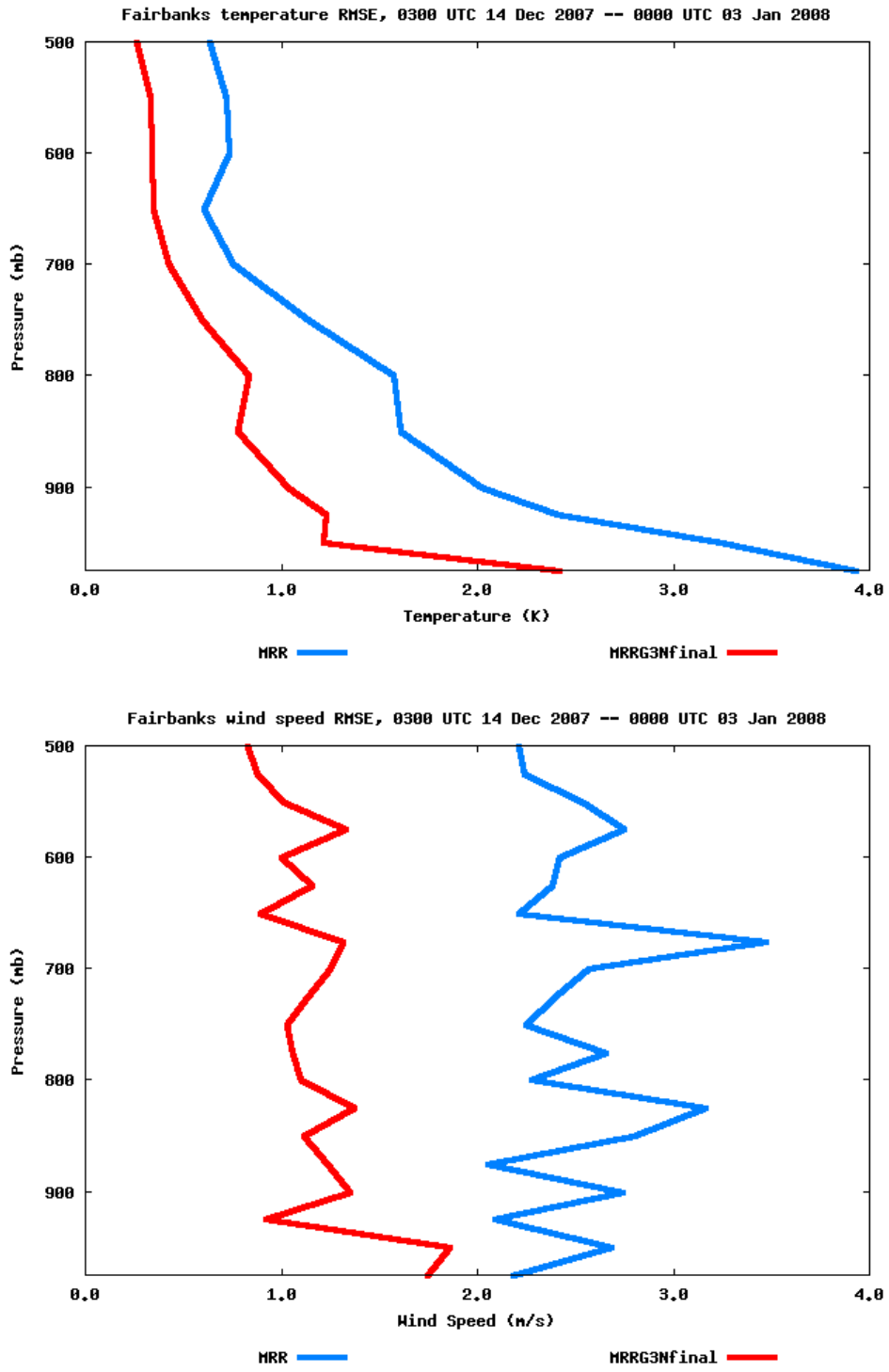


Fig. 24: Time-averaged vertical profile of Fairbanks sounding (PAFA) on Grid 3 for temperature (top) and wind speed (bottom) for 14 Dec 2007—03 Jan 2008 near total darkness episode. Blue indicates value from experiment MRR; red indicates value from final dynamic-analysis MRR simulation using Grid 3 obs nudging.

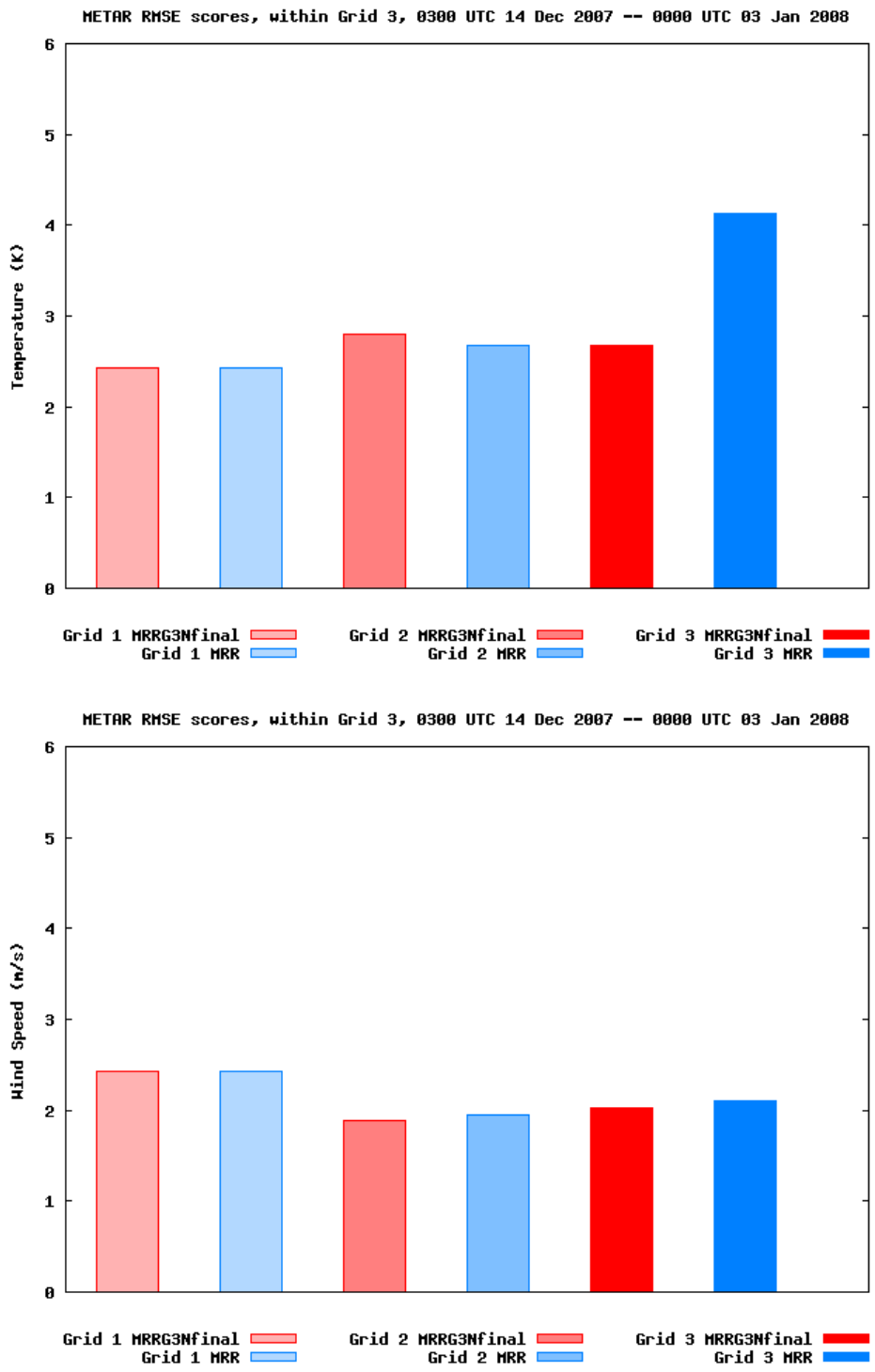


Fig. 25: Surface METAR RMSE scores during 14 Dec 2007—03 Jan 2008 near total darkness episode for temperature (top) and wind speed (bottom). Blue indicates value from experiment MRR; red indicates value from final dynamic-analysis MRR simulation using Grid 3 obs nudging.

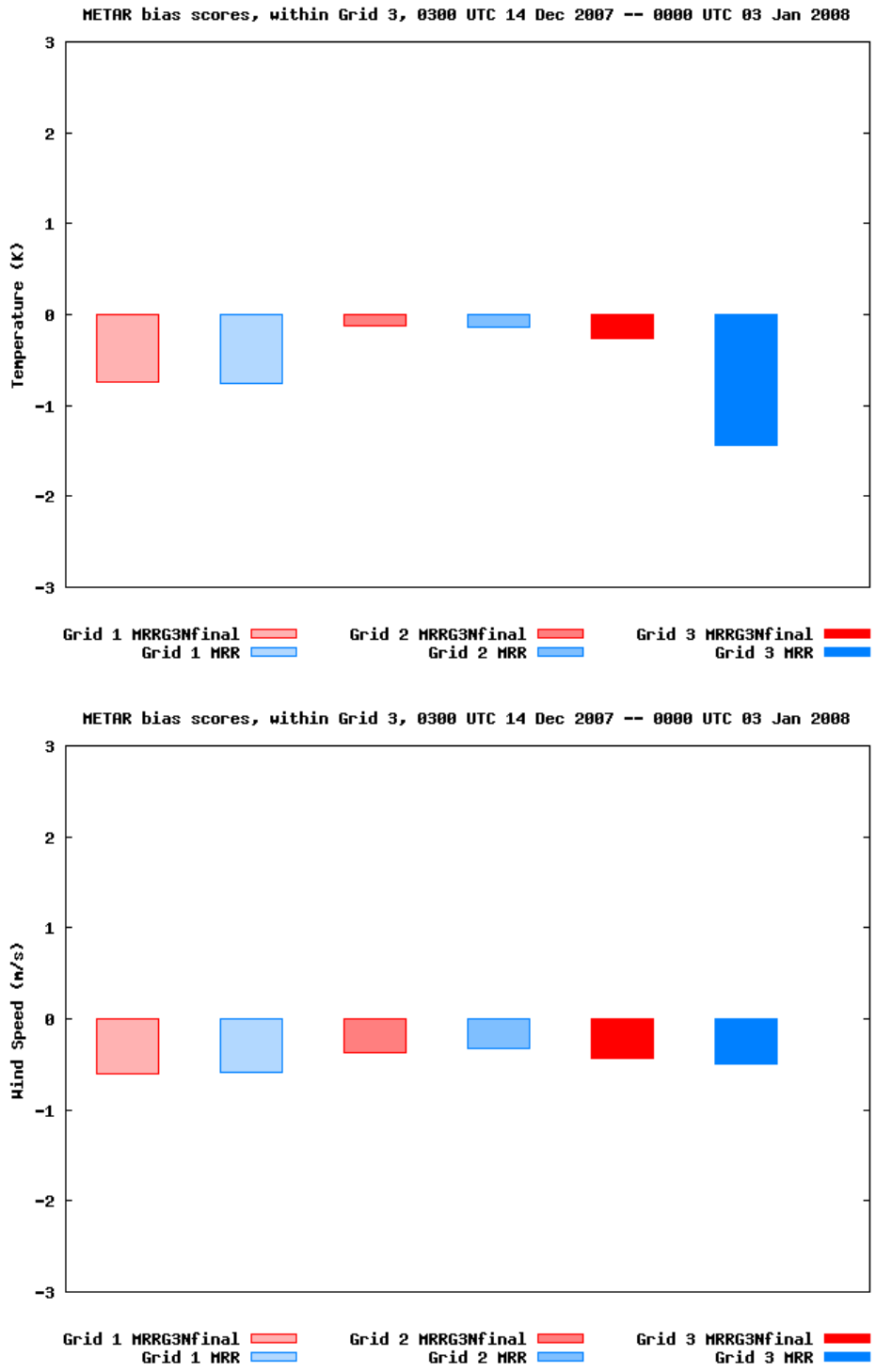


Fig. 26: Same as Fig. 25, but for bias errors.

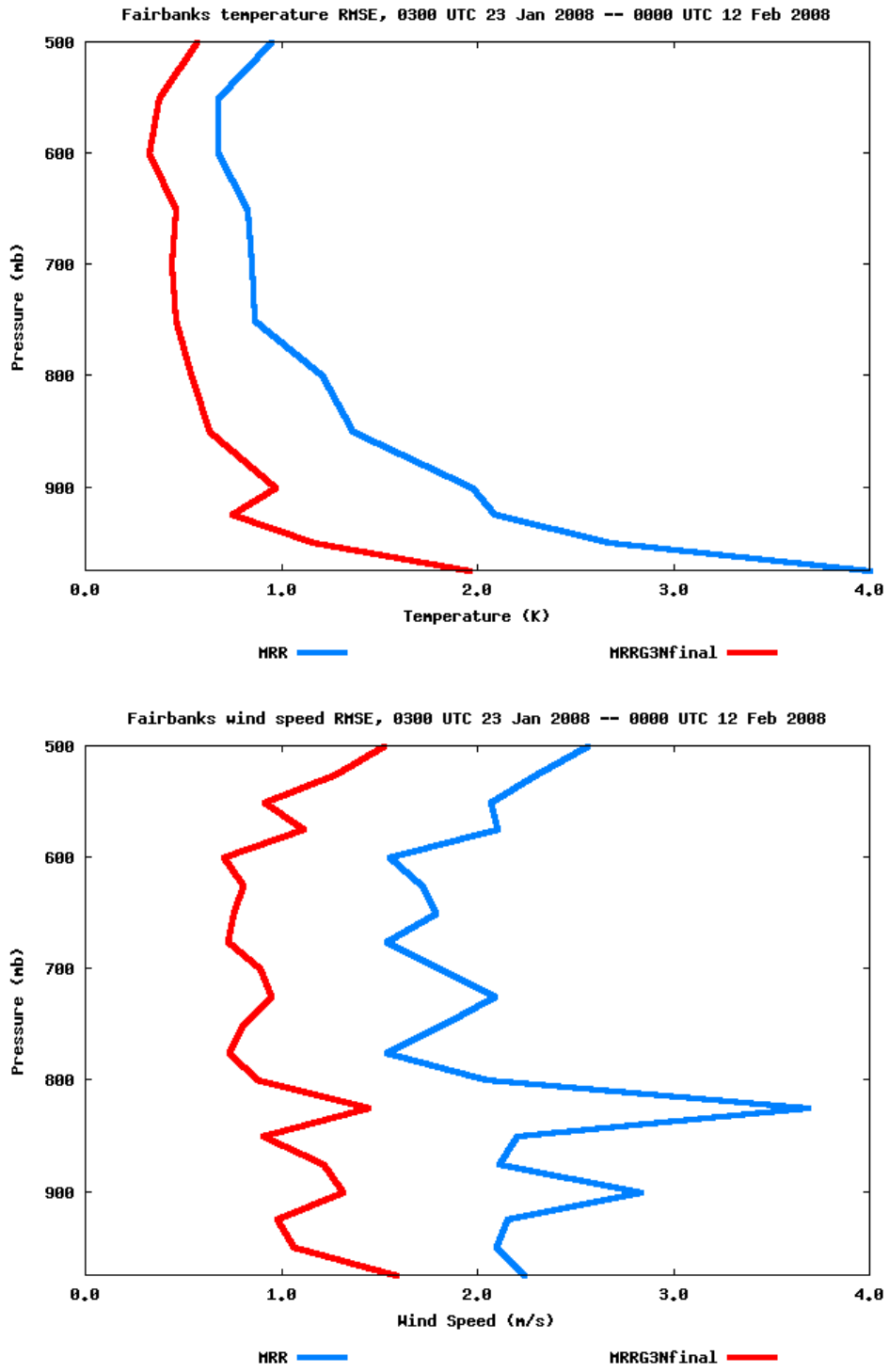


Fig. 27: Time-averaged vertical profile of Fairbanks sounding (PAFA) on Grid 3 for temperature (top) and wind speed (bottom) for 23 Jan 2008—12 Feb 2008 partial sunlight episode. Blue indicates value from experiment MRR; red indicates value from final dynamic-analysis MRR simulation using Grid 3 obs nudging.

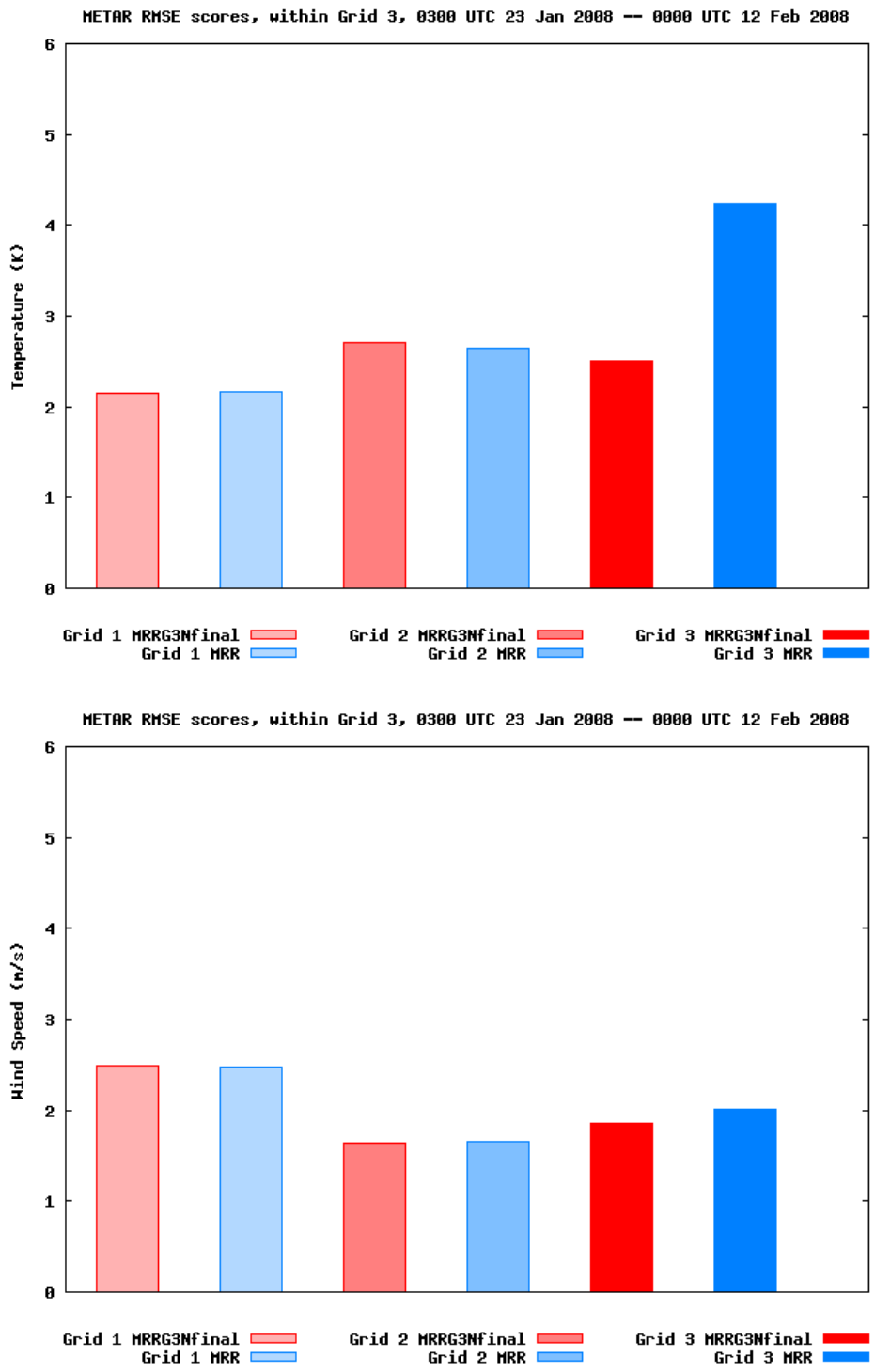
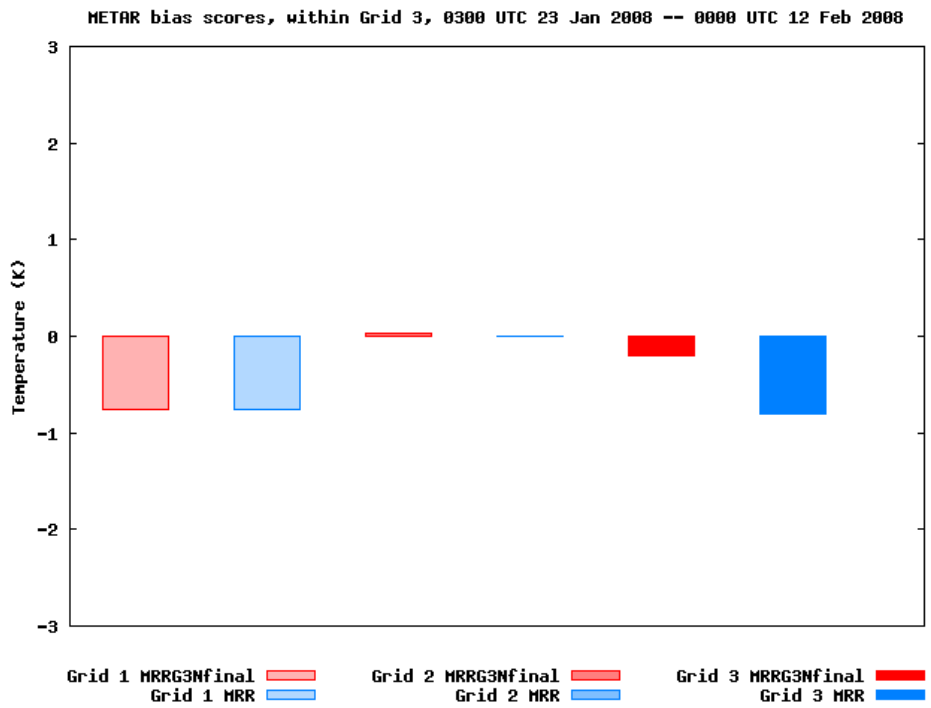


Fig. 28: Surface METAR RMSE scores during 23 Jan 2008—12 Feb 2008 partial sunlight episode for temperature (top) and wind speed (bottom). Blue indicates value from experiment MRR; red indicates value from final dynamic-analysis MRR simulation using Grid 3 obs nudging.



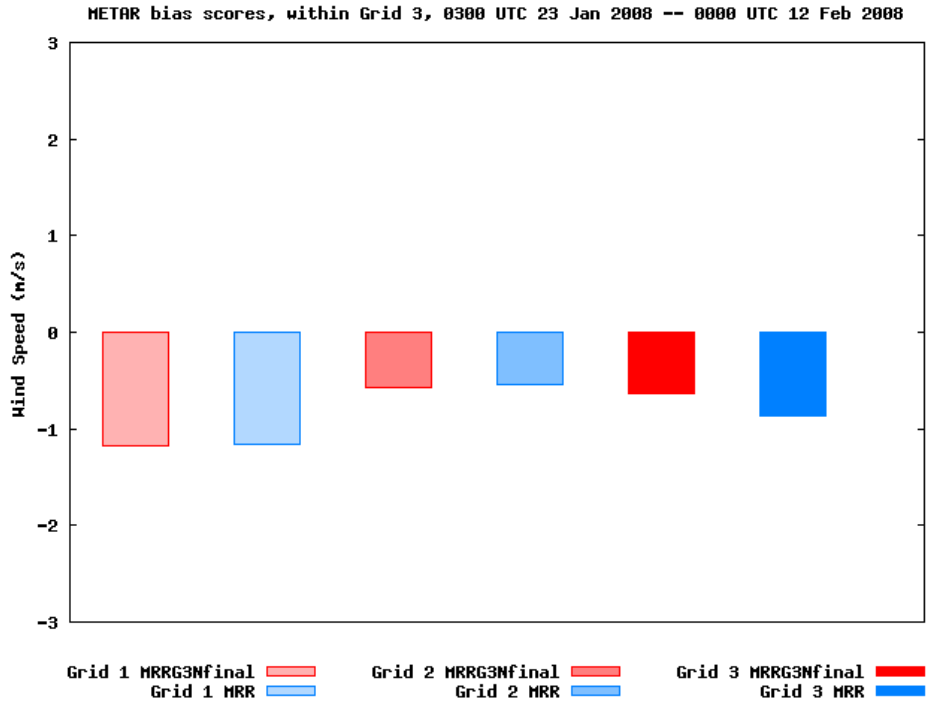


Fig. 29: Same as Fig. 28, but for bias errors.

6. CONCLUSIONS

6.1 Summary

The purpose of the project was to develop, adapt, and test a methodology for stable boundary layer representation (initial onset, space/time evolution, dissipation) in three-dimensional numerical models, with a specific focus on the dark, extremely cold environments such as those in the winter in the Fairbanks, AK region. A particular concern is the frequent occurrence of very high fine particular matter (PM2.5) concentrations within the stable boundary layers that form in these conditions.

Ten tasks were defined in the Statement of Work (SOW) for this project. A summary of these tasks and a brief overview of the work completed can be found in the Appendix to this report. Two twenty-day episodes were selected from the 2007-2008 winter season to study periods of extremely cold temperatures and high PM2.5 concentrations and to evaluate model performance: one in near total darkness (14 Dec 2007 – 03 Jan 2008), and the other in partial sunlight (23 Jan 2008 – 12 Feb 2008). One baseline physics configuration and three physics sensitivity experiments were performed for each episode. The physics sensitivity experiments were used to assess the impact of different planetary boundary layer (PBL) parameterizations, land surface models, and atmospheric radiation schemes on the simulations. Each simulation used three nested grids: Grid 1 (12-km horizontal grid spacing) and Grid 2 (4-km) utilized the multiscale multigrid data assimilation strategy of Stauffer and Seaman (1994) in order to ensure the model and observations remained close over the extended duration of the simulations. Grid 3 (1.3-km), centered over the Fairbanks region, did not use any direct data assimilation, and so was best-suited for quantifying the physics sensitivity; it also possesses sufficient horizontal resolution to be used by the EPA as meteorological input to chemical and air transport and dispersion models. From the different physics packages one was to be recommended to the EPA for further mesoscale modeling of the region.

The use of the three-grid configuration with a multiscale, multigrid four-dimensional data assimilation (FDDA) strategy on the outer two grids and no direct FDDA on Grid 3 consistently produced qualitatively plausible atmospheric fields throughout the variety of meteorological conditions found in the episodes, despite the relatively sparse data density. Quantitatively, the multiscale, multigrid FDDA strategy led to improved root-mean-square-error (RMSE) scores for both wind and temperature on all grids. The FDDA on the outer domains had the desired effect of improving the simulations of Grid 3 without FDDA and used for physics sensitivity tests, by providing improved lateral boundary conditions.

The best RMSE scores for the combination of both surface and sounding data required modification of the default FDDA procedure. These modifications included applying surface wind observational data to the third model vertical level instead of the lowest model level, because wind observations are normally taken at a height of 10 m which is the height of the third level in the high vertical resolution configuration used here. The influence of surface observations was also restricted to approximately the lowest 100 m, instead of to the top of the PBL, because the model-predicted PBL height in these simulations, based on the turbulent kinetic energy profile, was often found to be 1 km or higher. This

correction applied the surface innovation (observation minus model value) in these predominantly stable boundary layers over a much shallower layer than in the default FDDA procedure and produced improved statistical results in the lower troposphere.

All model physics combinations tended to have a positive temperature bias on Grid 3, especially during the most extremely cold periods. All of the physics sensitivity tests tended to reduce the warm bias in comparison with the selected baseline physics package. Switching from the RRTM longwave / Dudhia shortwave radiation package to the RRTMG longwave and shortwave radiation package led to significantly reduced warm biases and better RMSE statistics. RRTMG was then used in all future physics sensitivity tests. The reduced warm bias seemed to be due to the longwave component, both because of direct examination of surface fluxes in the partial sunlight case, and due to the fact that the difference was more pronounced in the near total darkness episode.

Though none of the four physics suites tested in the study was unambiguously superior to all of the others in terms of RMSE statistics, the simulation with the Rapid Update Cycle (RUC) land surface model, the Mellor-Yamada-Janjić (MYJ) PBL model, and the RRTMG radiation package was selected as the one to be recommended to EPA for modeling extremely cold SBLs and as the basis for producing the final atmospheric analysis. For both the near-total-darkness and partial sunlight episodes, the MYJ/RUC/RRTMG (henceforth MRR) physics suite had the lowest surface wind speed RMSE scores. For the partial sunlight episode the MRR configuration was one of two physics suites with the lowest surface temperature RMSE scores, and was among the lowest for the near-total-darkness episode. Of all the physics suites, the MRR package had the lowest warm bias during the most extremely cold periods, both when compared to the surface METAR stations and the Fairbanks sounding. The reason is not known for sure but is probably due to some combination of the effects of its snow model and top-level 'skin' layer. Since the extremely cold conditions are those with the potential for the highest PM2.5 concentrations, we took this as an additional reason to recommend the MRR physics suite for use by EPA.

However, there were periods in each episode, generally when the temperature was steadily decreasing in advance of an extremely cold period, during which all the physics configurations would tend to have a cold bias. During these periods the MRR configuration would still have colder temperatures than the other physics suites, and thus have worse magnitude temperature biases and RMSE scores. The relatively poorer performance of the MRR suite during a such a period accounts for the relatively poorer surface temperature statistics of the MRR suite compared to the MNR suite for the entire near-total-darkness episode. The reason for this behavior is not definitely known, but it is thought to be related to the interaction of radiation with the ice condensate that tends to occur during these periods. Also, the temperature biases of the MRR physics suite during the extremely cold period near the end of the partial sunlight episode were not quite as improved during daylight hours as during nighttime hours as compared to the other physics suites. Therefore, while overall we recommended the MRR configuration to EPA for these episodes, we also strongly recommended that the final fine-scale atmospheric data analysis (i.e., from Grid 3) to be provided to EPA should come from an additional simulation in which FDDA is performed directly on Grid 3, in order to reduce some of this error.

Use of obs nudging for temperature and humidity (and not surface wind) on Grid 3 produced large improvements in the mass fields as expected, and also improvements in the wind fields above the surface. Results were very encouraging and suggested that a smaller (larger) time window should be used for the surface (above-surface) data assimilation. This capability present in the Penn State MM5 FDDA system has been added to the new-release version of WRF.

In addition to this final report, deliverables to the EPA will include the full three-dimensional output at relatively fine temporal resolution (every 1 hour for Grid 1; every 12 minutes for Grids 2 and 3) for the final Grid 3 nudging simulation as well as all the baseline and physics sensitivity simulations. Model namelists, initialization files, and modifications to the model source code will also be provided.

The development and refinement of WRF FDDA capabilities and supporting software, including the surface analysis nudging, observation nudging and the OBSGRID objective analysis and obs-nudging pre-processing code, occurred concurrently with this project. This separate development effort led by PI Dave Stauffer and funded by the Defense Threat Reduction Agency (DTRA) allowed us rapid access to the most recent and robust versions of the WRF FDDA code, which greatly benefited this project.

The results of the default FDDA procedures not performing well here in this high vertical resolution modeling study of stable boundary layer environments motivated an additional FDDA code development effort to make the vertical influence functions of surface observations within the FDDA be a function of stability regime type, as well as to provide the user with greater flexibility in specifying the vertical influence functions. These modifications were not finalized in time to be used for this project but are scheduled to appear in the next official release of the WRF model.

An extended abstract and oral presentation were made at the 13th Conference on Mesoscale Processes (Gaudet et al. 2009), and a manuscript based on the project is in preparation.

6.2 Limitations of the Study and Recommendations for Future Work

Sensitivity to the microphysics parameterization was not performed here, but may be important to investigate further. In particular, results from this study suggested that both the occurrence of large negative RUC temperature biases and large differences between the RRTM and RRTMG longwave radiation schemes tended to occur when low-level ice condensate was present. Therefore, the microphysics / radiation interaction should probably be investigated further.

A fourth grid with 0.44-km horizontal grid spacing centered over Fairbanks was set up and initialized with topography, but it was not used in the sensitivity experiments here. Although this is finer horizontal resolution than the resolution requested by EPA, some of Penn State's past studies of SBLs (Stauffer et al. 2009) have suggested that the weak wind flows in these conditions may be sensitive to topographic features on these smaller scales, and it might be important to know if finer resolution is also required to resolve the topographic flows of the Fairbanks region.

The latest version of the WRF FDDA code has been designed to have more flexibility in how the temporal and spatial weighting functions are specified. Future simulations that use these new WRF FDDA options that were not yet available for this study should produce a further reduction of model error.

The availability of more meteorological observations from the immediate Fairbanks North Star Borough region, and in particular observations immediately above the surface, would allow one to make a more rigorous assessment of the accuracy of the different physics schemes (in particular, the PBL parameterizations).

More testing and analysis of the model physical parameterizations should be performed to determine the cause of the strong model biases often observed in the simulations, such as the generally persistent warm bias, and the cold RUC land surface model bias during falling temperature conditions.

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APPENDIX – SUMMARY OF TASKS

Ten tasks were included in the Statement of Work (SOW) for this project. An overview of the tasks and a summary of the work completed on each of these tasks are provided below:

- Task 1 – Participate in kick-off teleconference in accordance with the SOW.

This took place on 11 Sep 2008. The EPA was provided with the specifications of the nested grid configuration that we proposed in the SOW, and we received in turn particular information about the period and region of study from the EPA.

- Task 2 – Prepare workplan and QA/QC plan in accordance with the SOW.

This was submitted to the EPA during Nov. 2008, along with an updated timetable of deliverables provided during the next monthly teleconference. Included was a description of our proposed simulation plan, choice of baseline physics and grid configuration, and method of simulation.

- Task 3 – Participate in monthly project teleconferences.

We held hour-long teleconferences with the project manager and other scientists at Research Triangle Park and EPA Region 10 (which includes Alaska in its jurisdiction) near the beginning of every month between the kick-off meeting and Jan. 2010. These teleconferences were indispensible for coordinating the needs of EPA with our capabilities and adapting to unforeseen developments as they arose.

- Task 4 – Prepare brief monthly progress reports.

These reports provided to the EPA at the end of every month from Oct. 2008 – Dec. 2009, contained in total most of the information and task completion history found in this report.

- Task 5 – Set up meteorological model and conduct initial baseline testing.

After some minor modifications were made to the proposed model grid configuration to maximize the utility of available data, the final specifications of Grids 1, 2, and 3 were confirmed with the EPA in Feb. 2009; more precise coordination of these grids with a parallel emissions modeling project were completed in May 2009. The data assimilation procedures required for the multiscale multigrid procedure to be used for the project were still being developed for the WRF meteorological model, led by PI Dave Stauffer also working on this contract, which helped expedite the testing and validation of these procedures. Furthermore, the testing results had to be confirmed with the version 3.1 of WRF used for most of this study, released in Apr 2009. By Jun 2009 we determined that the model components were ready to begin physics sensitivity testing.

- Task 6 – Develop and/or adapt one or more stable boundary layer and land-surface models in accordance with the SOW.

For the choice of stable boundary model in the WRF baseline physics package, we used the Mellor-Yamada-Janjić (MYJ) parameterization that we had used for our previous studies of the stable boundary layer in Alaska, with a few modifications. For the land surface model, however, we decided that we should make use of the Noah model available in version 3.1 of WRF, since it included a number of adaptations to snow-covered terrain that would be critical in this study. Using the particular Noah adaptations in version 3.1 of WRF was one reason for using that model when it became available. After we confirmed that using the Noah land surface model initialized with Global Forecast System (GFS) model data produced reasonable results, we discovered that the default WRF data assimilation procedure needed to be modified to interact properly with the stable boundary layers generated by the high-resolution model. By Jul 2009 we had decided on the baseline physics package to be used for the main simulations.

- Task 7 – Conduct up to five sensitivity tests for the selected modeling periods and evaluate results in accordance with the SOW.

Two twenty-day episodes from the 2007-2008 winter season, both with periods of extremely cold temperatures and high PM2.5 concentrations, were selected for evaluation of model performance: one in near total darkness (14 Dec 2007 – 03 Jan 2008), and the other in partial sunlight (23 Jan 2008 – 12 Feb 2008). In addition to the baseline physics configuration that included the MYJ planetary boundary layer (PBL) scheme, the Noah land surface model, and the RRTM longwave / Dudhia shortwave radiation package, three other physics sensitivity tests were performed for the entirety of each twenty-day episode, which involved using the RRTMG radiation package (longwave and shortwave), the Quasi-Normal Scale Elimination (QNSE) PBL scheme, and the Rapid Update Cycle (RUC) land surface model. After some discussion, the specific combinations used, in addition to the baseline, were MYJ / Noah / RRTMG, QNSE/ Noah / RRTMG, and MYJ / RUC / RRTMG. After statistical comparison with available observations, there was no clearly superior model physics combination; however, the MYJ / RUC / RRTMG option seemed to do the best job at reproducing the extremely cold temperatures characteristic of the high exceedance episodes. However, all model configurations tended to have substantial warm surface temperature biases in these conditions on the innermost 1.3-km Grid 3 when no data assimilation was performed on it. (Data assimilation was performed on the outer Grids 1 and 2 for the physics sensitivity experiments to improve the lateral boundary conditions on Grid 3.) In Jan 2009 it was decided that the MYJ / RUC / RRTMG combination was to be recommended, but that final dynamic analyses using this physics package along with Grid 3 data assimilation should be performed for each episode in order to reduce the atmospheric model errors and biases before they are used in air transport and chemistry models.

- Task 8 – Participate in 1.5-day meeting with Project Officer and scientific staff at EPA/RTP in accordance with the SOW.

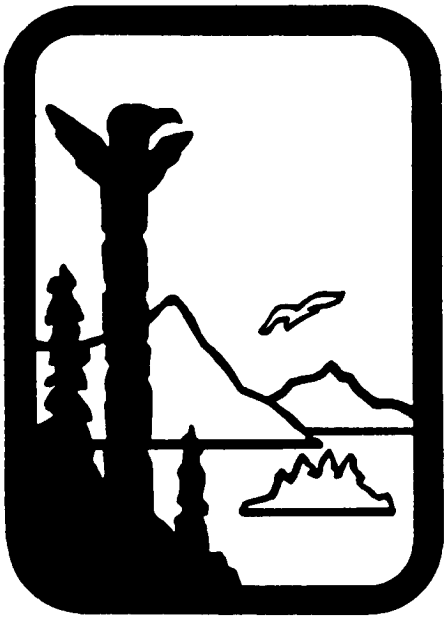
This meeting occurred 19-20 Nov 2009 at Research Triangle Park (RTP), NC, between one of the co-PI's (Brian Gaudet) and the Project Officer and other scientific staff at RTP. During this meeting scientific discussion of the results occurred, and a preliminary agreement that the MYJ/RUC/RRTMG combination was the most promising was reached. The main results of the project to date were presented, and plans for bringing the project to completion were made.

- Task 9 – Prepare final report and electronic data and computer code files in accordance with the SOW.

- Task 10 – Revise draft final report and data files.

This report serves to help complete Tasks 9 and 10. A pair of 2-Terabyte external hard drives were obtained from EPA for use for transferring the data, whose cumulative size is approximately 600 Gigabytes per episode simulation. The files to be transferred consist of a full three-dimensional set of model output files, generated every hour for the 12-km Grid 1, and every 12 minutes for the 4-km Grid 2 and 1.3-km Grid 3. The output for each episode from the final dynamic initialization (i.e., with data assimilation on Grid 3) using the best choice physics package will be transferred first; later, the output from the baseline and physics sensitivity studies without Grid 3 data assimilation will be transferred to EPA. In addition, the namelist specifications for each simulation, the WRF version 3.1 code as modified for the project, and the initial, boundary condition, and four-dimensional data assimilation (FDDA) files required for each WRF simulation will be included.

Alaska Department of Environmental Conservation



Amendments to:
State Air Quality Control Plan

Vol. III: Appendix III.D.5.9

{Appendix to Volume II. Analysis of Problems, Control Actions; Section III. Area-wide Pollutant Control Program; D. Particulate Matter; 5. Fairbanks North Star Borough PM2.5 Control Plan}

Adopted

December 24, 2014

Bill Walker
Governor

Larry Hartig
Commissioner

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By: John Davies
Kathryn Dodge
Introduced: 12/11/2014
Amended: 12/11/2014
Adopted: 12/11/2014
Immediate Reconsideration
Failed: 12/11/2014
Adopted: 12/11/2014

FAIRBANKS NORTH STAR BOROUGH

RESOLUTION NO. 2014 – 45

A RESOLUTION URGING THE DEPARTMENT OF ENVIRONMENTAL CONSERVATION TO TIMELY FILE THE STATE IMPLEMENTATION PLAN (SIP) AS REQUIRED BY THE ENVIRONMENTAL PROTECTION AGENCY AND TO CONTINUE TO DEVELOP AND SUBMIT A STRONGER SIP THAT WILL MEET CLEAN AIR GOALS SOONER

WHEREAS, a large portion of the Fairbanks North Star Borough (FNSB) has been declared a non-attainment area by the Environmental Protection Agency (EPA); and

WHEREAS, the EPA declaration requires the State submit a State Implementation Plan (SIP) for implementing measures that are intended to clean up the air by December 31, 2015; and

WHEREAS, early in 2014, the Department of Environmental Conservation (DEC) has circulated draft regulations that might be incorporated into the SIP; these regulations received much public comment and DEC has had months to create the plan based on those comments; and

WHEREAS, the revised plan has only been available for the Assembly to review for 22 days and the comment period runs until December 19, 2014, so DEC may make modifications based on this last round of public comment; and

WHEREAS, the SIP calls for measures that will eventually “achieve attainment” (clean up the air under the official monitoring guidelines) but likely not until 2019 or beyond; and

WHEREAS, the Assembly is concerned that the pace of cleaning our air is too slow given the seriousness of the health hazard posed by the PM2.5 in our airshed; and

WHEREAS, the Assembly is concerned that the mechanisms proposed for resolving the nuisance posed by some nearby outdoor wood-fired boilers is too cumbersome and potentially expensive to be effective; and

WHEREAS, it is understood that this SIP can be amended in the future.

NOW, THEREFORE, BE IT RESOLVED, that it is in the interest of the citizens of the Borough for the Department of Environmental Conservation to timely file the SIP as required by Environmental Protection Agency.

NOW, THEREFORE, BE IT FURTHER RESOLVED, the Assembly calls on the Governor, the Congressional Delegation, the Interior Delegation, and the State Departments of Environmental Conservation, Health and Social Services, and Transportation to work together to find additional solutions and resources to help the citizens of the Borough significantly reduce the pollution generated by wood combustion and other sources of PM2.5 and to restore our air to a healthy condition.

PASSED AND APPROVED THIS 11th DAY OF DECEMBER, 2014.

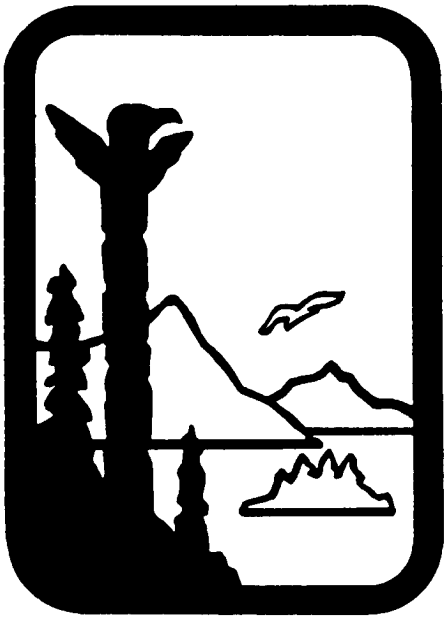
Karl Kassel
Presiding Officer

ATTEST:

Nanci Ashford-Bingham, MMC
Borough Clerk

Ayes: Lawrence, Roberts, Golub, Hutchison, Quist, Dodge, Davies, Kassel
Noes: None
Excused: Sattley

Alaska Department of Environmental Conservation



Amendments to:
State Air Quality Control Plan

Vol. III: Appendix III.D.5.10

{Appendix to Volume II. Analysis of Problems, Control Actions; Section III. Area-wide Pollutant Control Program; D. Particulate Matter; 5. Fairbanks North Star Borough PM2.5 Control Plan}

Adopted

December 24, 2014

Bill Walker
Governor

Larry Hartig
Commissioner

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Appendix III.D.5.10

Preliminary Summary of Fairbanks Firewood & Pellet Log Emission Measurements.

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sierra research

Preliminary Summary of Fairbanks Firewood & Pellet Log Emission Measurements

prepared for:

Alaska Department of Environmental Conservation

September 28, 2014

prepared by:

Sierra Research
1801 J Street
Sacramento, California 95811
(916) 444-6666

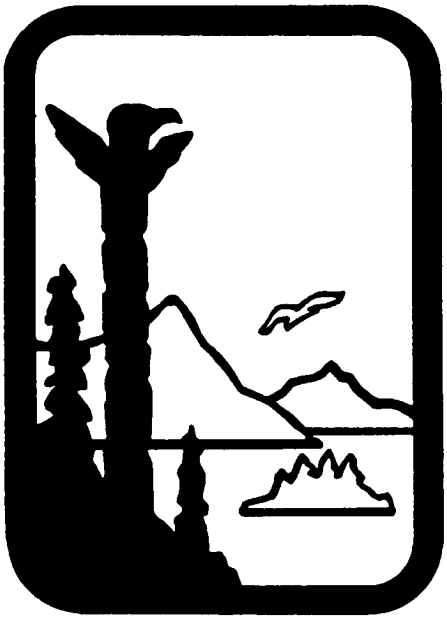
and

Dirigo Laboratories
Clackamas, OR

Preliminary Summary of Fairbanks Firewood & Pellet Log Emission Measurements

- The Borough and State commissioned Dirigo Laboratories to measure PM emission benefits of burning locally produced pellet logs in Fairbanks.
- Fairbanks commissioned tests of (1) dry Fairbanks birch cordwood (20% moisture content), (2) pellet logs (7.5% moisture content), and (3) a 50/50 mix of cordwood and pellet logs in both a U.S. EPA certified stove and an uncertified stove.
- Dirigo followed EPA test procedures and measured PM emissions at both low-medium and high burn rates. Test results at low-medium burn rates (typical in Fairbanks and used to quantify emissions in the SIP inventory) showed the following:
    - Reductions in PM emissions for both the pellet logs and the mix relative to dry cordwood, ranged from 18% - 54%; and
    - 50/50 mix reductions were roughly twice those found for pellet logs, ranging from 40% - 54%.
- DEC commissioned tests of (1) wet Fairbanks birch cordwood (~40% moisture content) and (2) a 50/50 mix of wet cordwood and pellet logs. Test results at low-medium burn rates showed the 50/50 mix produced the following:
    - 64% reduction in PM emissions for both uncertified and certified stoves relative to wet cordwood.
- Because the tests showed variability in the low burn emission rates, additional tests are needed to confirm the results and assess benefits relative to spruce and other sources of cord wood (wet and dry) burned in Fairbanks.
- While the test results are based on limited samples, they indicate substantial emission reduction potential when the pellet logs are burned in combination with cord wood (wet or dry).
- The test results cannot be generalized to other “energy logs” because they are sensitive to the wood composition and moisture content of the product.
- A preliminary estimate of emission reductions that could be achieved through pellet log use was developed based on existing annual production capacity of 3,000 tons that could be expanded to 15,000 tons by 2019.
- A program targeting pellet log/cordwood mix use on unhealthy days (defined as days forecasted above 35 ug/m^3), which averaged 24 days/winter 2010 – 2013 at the State Office Building, was considered based on current and forecasted pellet log production capacity.
- Assuming a 60% compliance rate with such a targeted program by 2019, a 50/50 mix program would produce an additional 21.8% reduction in space heating PM emissions using 3,700 tons per/year, which is well below potential production capacity in 2019.

Alaska Department of Environmental Conservation



Amendments to:
State Air Quality Control Plan

Vol. III: Appendix III.D.5.11

{Appendix to Volume II. Analysis of Problems, Control Actions; Section III. Area-wide Pollutant Control Program; D. Particulate Matter; 5. Fairbanks North Star Borough PM2.5 Control Plan}

No Appendix- Placeholder

December 24, 2014

Bill Walker
Governor

Larry Hartig
Commissioner

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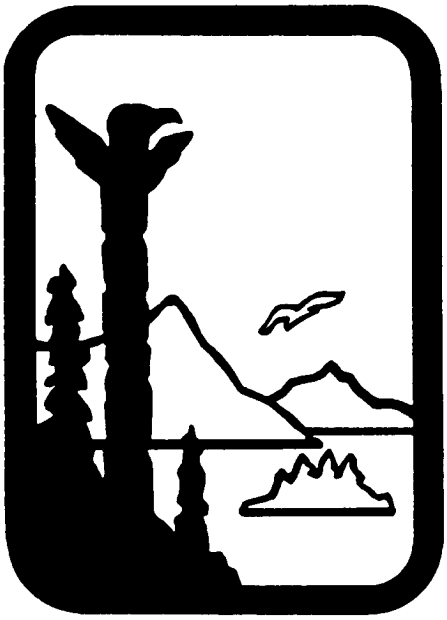
Alaska Department of Environmental Conservation



Amendments to:
State Air Quality Control Plan

Vol. III: Appendix III.D.5.12

{Appendix to Volume II. Analysis of Problems, Control Actions; Section III. Area-wide Pollutant Control Program; D. Particulate Matter; 5. Fairbanks North Star Borough PM2.5 Control Plan}

Adopted

September 7, 2016

Bill Walker
Governor

Larry Hartig
Commissioner

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Appendix III.D.5.12

FNSB Air Quality Ordinances.

ADEC & FNSB MOU January 2010.

MOA for the Selection & Funding of Projects Funded by CMAQ within the FNSB PM2.5 Nonattainment Area.

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Title 8
HEALTH AND SAFETY

Chapters:

Chapter 8.01
EMERGENCY MEDICAL SERVICE

Sections:

8.01.010 Creation of powers.

There is established a nonareawide service within the borough designated “Fairbanks North Star Borough Emergency Medical and Facilities Service” within the area outside of the cities of Fairbanks and North Pole, as shown on the corresponding map in the clerk’s office. The Fairbanks North Star Borough Emergency Medical Service area shall have emergency medical services and facilities, including ambulance powers. (Ord. 83-154 § 2, 1983)

8.01.020 Emergency medical service – Intent.

The borough shall exercise the power to provide emergency medical service as approved by the electorate to promote efficiency and performance of emergency medical services throughout the borough. (Ord. 83-154 § 2, 1983)

8.01.030 Emergency medical services (EMS) boards.

A. EMS Advisory Board. There is created an emergency medical services board, which shall consist of members appointed by the mayor with assembly concurrence. The composition of the board shall be as follows:

1. Three citizens-at-large;

2. Three service unit representatives (nominations to be elected by all EMS service units collectively);

3. One medical board representative;

4. One Fairbanks Memorial Hospital representative;

5. One regional EMS planning agency representative;

6. One Fairbanks North Star Borough EMS coordinator (ex officio, nonvoting);

7. One Fairbanks North Star Borough assembly member (ex officio, nonvoting).

The EMS advisory board shall contain no more than nine voting members.

B. Medical Board. There is created a medical board which shall consist of members appointed by the mayor with assembly concurrence. The composition of the medical board shall be as follows:

1. Seven physicians, to include at least one emergency room physician and one physician-at-large (non-EMS related);

2. One ambulance service unit representative (to be selected by provider groups);

3. One nonambulance EMS service unit representative (to be selected by provider groups);

4. One Fairbanks North Star Borough EMS coordinator (ex officio, nonvoting).

The medical board shall contain no more than nine voting members. (Ord. 87-034 § 2, 1987; Ord. 83-154 § 2, 1983)

8.01.040 Board compensation.

Repealed by Ord. 87-034. (Ord. 83-154 § 2, 1983)

8.01.050 Functions and duties.

A. The EMS advisory board shall act as an emergency medical service advisory board for the area outside of the cities of Fairbanks and North Pole to the mayor, including making studies, holding public hearings, and making recommendations to the mayor in conjunction with medical board recommendations, on areas which may include, but are not limited to, the following:

1. Levels of EMS service;

2. Capital improvement projects;

3. The annual operational budget of service units;

4. Emergency medical service policies and procedures;

5. Emergency medical services training units;

6. Appropriate equipment for service units;

7. Service unit personnel qualifications;

8. Service unit backup equipment;

9. New emergency medical service unit areas and locations;

10. Fees to be charged for ambulance service;

11. Mutual aid and support agreements with ambulance services of other jurisdictions and with private ambulance services;

12. The EMS policy manual;

13. *Repealed by Ord. 87-034;*

14. The proposed annual budget for emergency medical services within the Fairbanks North Star Borough;

15. Capital improvement needs for each service unit;

16. Ordinances and actions to be taken by the mayor;

17. Consultations with other advisory bodies, such as the planning commission, medical board, and any other medical, health, or public safety organizations.

Each service unit shall coordinate directly with the EMS advisory board in regard to its budget and all other matters for which the board is responsible.

B. The medical board shall perform the following functions and duties:

1. Create and supervise standing orders;

2. Establish medical communication protocols;

3. Establish medical criteria for new and current levels of service, to include:

a. Desirable response times;

b. Personnel qualifications and levels of training;

c. Medical equipment needs for designated levels of service;

d. Response area boundaries, medical facilities, and changes to existing service areas;

4. Approve all medical equipment and training requests that require borough funding. (Ord. 87-034 § 2, 1987; Ord. 83-154 § 2, 1983)

8.01.060 Organization.

All matters of administration shall be the responsibility of the emergency medical services (EMS) coordinator. (Ord. 87-034 § 2, 1987; Ord. 83-154 § 2, 1983)

8.01.070 Definitions.

As used herein, “service unit” means a geographically defined area to which a certain emergency medical service group is assigned. (Ord. 87-034 § 2, 1987; Ord. 83-154 § 2, 1983)

Chapter 8.02
HEALTH AND SOCIAL SERVICES

Sections:

8.02.010 Definitions.

“Health and social services” means programs that are essential to the maintenance of life or focus primarily on prevention such as health screening, preventive services and referral. (Ord. 93-039 § 3, 1993)

Chapter 8.03
EMERGENCY COMMUNICATION SERVICES

Sections:

8.03.010 Enhanced 911 emergency reporting system.

A. Pursuant to AS 29.35, any *local exchange telephone company* providing service within the *borough* shall cooperate in the establishment of an enhanced 911 emergency reporting system.

B. The area served by the *enhanced 911 system* shall be the entire Fairbanks North Star Borough, excluding Eielson Air Force Base. (Ord. 2014-29 § 3, 2014; Ord. 2013-64 § 3, 2013; Ord. 93-057 § 2, 1993)

8.03.020 Definitions.

In this chapter and Chapter 3.60 FNSBC, the following definitions apply:

"*911 PSAP selective router demarcation point*" is the physical point at which the public network of a telecommunications company ends and the private network of the *borough*'s 911 system begins.

"*911 service area*" or "*enhanced 911 service area*" means the area within the *borough* that has been designated to receive enhanced 911 service; the area designated to receive an *enhanced 911 system* is not a "service area" under Article X, Section 5 of the Alaska Constitution.

"*Borough*" means the Fairbanks North Star Borough.

"*Enhanced 911 equipment*" means any equipment dedicated to the operation of, or use in, the establishment, operation or maintenance of an *enhanced 911 system*, including customer premises equipment, automatic number identification or automatic location identification controllers and display units, printers, recorders, software and other essential communication equipment.

"*Enhanced 911 system*" or "*system*" means a telephone system consisting of network, database and *enhanced 911 equipment* that uses the single three-digit number, 911, for

reporting a medical, fire, police, or other emergency situation, and which enables the users of a public telephone system to reach a *public safety answering point* and includes the personnel required to acquire, install, operate and maintain the system.

"*Local exchange access line*" means a telephone line that connects a *local exchange service* customer to the *local exchange telephone company* switching office and has the capability of reaching local public safety agencies, but does not include a line used by a carrier to provide interexchange services.

"*Local exchange service*" means the transmission of two-way interactive switched voice communications furnished by a *local exchange telephone company* within the Fairbanks North Star Borough, including access to *enhanced 911 systems*.

"*Local exchange telephone company*" means a telephone utility certified by the Alaska Public Utilities Commission to provide *local exchange service* in the Fairbanks North Star Borough.

"*Public safety answering point*" means a 24-hour local communications facility that receives 911 service calls and directly dispatches emergency response services or that relays calls to the appropriate public or private safety agency. (Ord. 2013-64 § 4, 2013; Ord. 2010-59 § 3, 2011; Ord. 93-057 § 2, 1993)

8.03.030 Enhanced emergency reporting systems.

A. The *borough* may purchase, lease or contract for any *enhanced 911 equipment* or services required to establish or maintain an *enhanced 911 system* at *public safety answering points* from a *local exchange telephone company* or other qualified vendor of an *enhanced 911 system*.

B. If the *enhanced 911 system* is to be provided for an area that is included in more than one telephone company service area, the *borough* may enter into such agreements as are necessary to establish and operate the *system*.

C. The *borough* hereby designates both 911 Cushman Street and 800 William C Leary Lane in Fairbanks as the two *911 PSAP selective router demarcation points* solely for the purposes of 911 call delivery by telecommunications carriers. (Ord. 2013-64 § 5, 2013; Ord. 93-057 § 2, 1993)

8.03.040 Enhanced 911 advisory committee.

Repealed by Ord. 2014-13. (Ord. 2010-59 § 4, 2011; Ord. 94-010 § 2, 1993)

Chapter 8.04
AIR POLLUTION

(Repealed by Ord. 2013-07)

Chapter 8.05
CARBON MONOXIDE EMERGENCY EPISODE PREVENTION PLAN

Sections:

8.05.010 Purpose.

The Fairbanks area emergency episode prevention plan is designed to prevent carbon monoxide concentrations within the borough from reaching levels which endanger the public health. Primary responsibility for implementation of this plan rests with the borough's air quality division of the department of transportation. (Amended during 1993 republication; Ord. 85-065 § 2, 1985)

8.05.020 Episode criteria.

A. During the winter months of November through February the borough shall review daily carbon monoxide data. When the CO concentration reaches the onset level for an episode and is expected to remain at that level for 12 hours, an alert will be declared.

B. The following definitions are adopted:

"Alert" means when the FNSB air quality division determines, using available data, that a violation of the nine parts per million for an eight-hour average will likely occur.

"Episode" means when conditions reach alert status.

"Forecast" means a description of the current dispersion conditions described as good, fair or poor and including the expected CO concentrations expressed in parts per million for an eight-hour average.

"Maintenance area" means:

1. The Fairbanks/Fort Wainwright subarea, including Township 1 South, Range 1 West, Sections 2 through 23, the portion of Section 1 west of the Fort Wainwright military reservation boundary, and the portions of Section 24 north of the Old Richardson Highway and west of the military reservation boundary;

2. Township 1 South, Range 2 West, Sections 13 and 24, the portion of Section 12 southwest of Chena Pump Road, and the portions of Sections 14 and 23 southeast of the Chena River;

3. Township 1 South, Range 1 East, Sections 7, 8 and 18, and the portions of Section 19 north of the Richardson Highway; and

4. The North Pole subarea, including Township 2 South, Range 2 East, and the portions of Section 9 and 10 southwest of the Richardson Highway.

C. Carbon Monoxide Control Measures. FNSB air quality division will notify local media to ensure the declared alert is broadcast. Information within the notification will contain the CO forecast and procedures to reduce sources of CO, e.g., use of public transportation, use of engine preheating, elimination of unnecessary use of motor vehicles. (Ord. 2013-07 § 3, 2013; Ord. 2004-61 § 2, 2004; Ord. 2003-71 § 2, 2003; amended during 1993 republication; Ord. 91-044 § 2, 1991; Ord. 85-065 § 2, 1985)

Chapter 8.06
OXYGENATED FUEL

Sections:

8.06.010 Purpose.

The purpose of this chapter is the protection of health and safety of the residents of the Fairbanks North Star Borough from problems caused by the use of oxygenated fuel.

It establishes a zero tolerance local ambient air quality standard as provided for by 42 USC 7545(M)(3). (Ord. 94-018 § 2, 1994)

8.06.020 Definitions.

“Borough” means the Fairbanks North Star Borough.

“Mandate” includes, but is not limited to, cases where sanctions of any kind are proposed for failure to adopt an oxygenated fuel program.

“Oxygenated fuel” means a fuel that:

1. Contains an average of 2.7 percent oxygen by weight for the control period; and

2. Contains at least 2.0 percent oxygen by weight. (Ord. 94-018 § 2, 1994)

8.06.030 Unlawful acts.

A. No public official or government entity may cause or enforce mandatory sales and use of oxygenated fuel within the borough.

B. This chapter shall remain in effect until such time that the federal, state and borough governments certify, in conjunction with independent peer-reviewed scholarly confirmation, that the oxygenated fuel to be used in the Fairbanks North Star Borough is not harmful to the health and safety of borough residents and their environment. (Ord. 94-018 § 2, 1994)

8.06.040 Penalty for violations.

A. Nothing in this chapter shall prohibit the Fairbanks North Star Borough from taking civil action for violations of any provisions of this chapter.

B. Nothing in this chapter shall prohibit individuals from taking civil action for violations of their rights or for the compromising of their health and safety. (Ord. 94-018 § 2, 1994)

Chapter 8.07
CURFEW FOR MINORS

Sections:

8.07.010 Definitions.

In this chapter:

“Curfew hours” means:

1. September through May:

   a. 11:00 p.m. on any Sunday, Monday, Tuesday, Wednesday, or Thursday until 5:00 a.m. of the following day; and

   b. 1:00 a.m. on any Saturday and Sunday until 5:00 a.m. of the same day.

2. June through August: 1:00 a.m. on any day until 5:00 a.m. of the same day.

“Emergency” means an unforeseen combination of circumstances or the resulting state that calls for immediate action. The term includes, but is not limited to, a fire, natural disaster, automobile accident, or any situation requiring immediate action to prevent physical injury or loss of life.

“Establishment” means any privately owned place of business operated for a profit to which the public is invited, including but not limited to any place of amusement or entertainment.

“Guardian” means:

1. A person who, under court order, is the guardian of the minor; or

2. Public or private agency with whom a minor has been placed by a court.

“Knowingly” means, with respect to conduct or to a circumstance described by a provision of law defining an offense, that a person is aware that his or her conduct is of that nature or that the circumstance exists; when knowledge of the existence of a particular fact is an element of an offense, that knowledge is established if a person is aware of a substantial probability of its existence, unless the person actually believes it does not exist.

"Minor" means any person under the age of 18 years.

"Operator" means any individual, firm, association, partnership, or corporation operating, managing, or conducting any establishment. The term includes the members or partners of an association or partnership and the officers of a corporation.

"Parent" means a person who is:

1. A natural parent, adoptive parent, or stepparent of another person; or

2. At least 18 years of age and authorized by a parent or guardian to have the care and custody of a minor.

"Physical injury" means a physical pain or an impairment of physical condition.

"Public place" means any place to which the public or a substantial group of the public has access, and includes but is not limited to streets, highways, sidewalks, bridges, alleys, plazas, parks, driveways, parking lots, and the common areas of schools, hospitals, apartment houses, office buildings, transport facilities, and shops.

"Remain" means to:

1. Linger or stay; or

2. Fail to leave the premises when requested to do so by a police officer or the owner, operator, or other person in control of the premises. (Ord. 98-043 § 2, 1998)

8.07.020 Offenses.

A. A minor commits an offense if he or she remains in any public place or on the premises of any establishment within the Fairbanks North Star Borough during curfew hours.

B. A parent or guardian of a minor commits an offense if he or she knowingly permits, or by insufficient control allows, the minor to remain in any public place or on the premises of any establishment within the Fairbanks North Star Borough during curfew hours in violation of this chapter. Indifference as to the activities or whereabouts of the minor shall be prima facie evidence of insufficient control.

C. The owner, operator, or any employee of an establishment commits an offense if he or she knowingly allows a minor to remain upon the premises of the establishment during curfew hours. (Ord. 98-043 § 2, 1998)

8.07.030 Exceptions.

A. It is an exception to prosecution under FNSBC 8.07.020(A) and (B) if the minor was:

1. Accompanied by his or her parent or guardian;

2. On an errand at the written direction of his or her parent or guardian, without any detour or stop (written direction must be signed, timed, and dated by the parent or guardian and must indicate the specific errand);

3. Involved in an emergency;

4. Engaged in an employment activity, or going to or returning from an employment activity, without detour or stop;

5. On the public right-of-way immediately abutting the minor's residence or immediately abutting the residence of a next door neighbor, if the neighbor did not complain to the police department about the minor's presence;

6. Attending, or going to or returning home from, without any detour or stop, an official school, religious, or other recreational activity supervised by adults and sponsored by the Fairbanks North Star Borough, Fairbanks North Star Borough School District, a civic organization, or another similar entity that takes responsibility for the minor;

7. Exercising First Amendment rights protected by the United States Constitution, such as the free exercise of religion, freedom of speech, and the right of assembly; or

8. Married or had disabilities of minority removed in accordance with AS 9.55.

B. It is an exception to prosecution under FNSBC 8.07.020(C) that the owner, operator, or employee of an establishment promptly notified the police department that a minor was present on the premises of the establishment during curfew hours and refused to leave. (Ord. 98-043 § 2, 1998)

8.07.040 Penalties.

Repealed by Ord. 2013-26. (Ord. 2012-66 § 4, 2013; Ord. 98-043 § 2, 1998)

Chapter 8.08
FIREWORKS[1]

Sections:

8.08.010 Defined.

"*Fireworks*" means and includes any combustible or explosive composition, or any substance or combination of substances, or article prepared for the purpose of producing a visible or an audible effect by combustion, explosion, deflagration or detonation, and shall include toy pistols, toy cannons, toy canes or toy guns in which explosives are used, the type of nonmanned balloons which require fire underneath to propel the same, firecrackers, torpedoes, skyrockets, Roman candles, daygo bombs, or other devices of like construction and any devices containing any explosive or flammable compound, or any tablets or other devices containing any explosive substance, except that the term "*fireworks*" shall not include auto flares, ammunition, paper caps, containing not in excess of an average of 0.25 of a grain of explosive content per cap manufactured in accordance with the Interstate Commerce Commission regulations for packing and shipping as provided therein, and toy pistols, toy canes, toy guns, or other devices for use of such caps, and sale and use of which shall be permitted at all times. (Ord. 72-27, 1972; Ord. 72-5, 1972; Ord. 69-1, 1969; prior code § 32.05.010)

8.08.020 Sale prohibited.

The sale of *fireworks* is prohibited. (Ord. 72-27, 1972; Ord. 72-5, 1972; Ord. 69-1, 1969; prior code § 32.05.020)

8.08.030 Use restricted.

Except as provided in FNSBC 8.08.040 and 8.08.050, no person shall, except on real property owned by him, under his control or with permission granted by the owner, use or explode *fireworks*. The mayor may, in times of extreme fire danger, prohibit all use or explosion of *fireworks* in the Fairbanks North Star Borough within the areas outside the cities of Fairbanks and North Pole. (Ord. 2014-16 § 2, 2014; Ord. 72-27, 1972; Ord. 72-5, 1972; Ord. 69-1, 1969; prior code § 32.05.030)

8.08.040 Displays – Permit required.

A. *Fireworks* may be used for public displays by municipalities, fair associations, amusement parks and other organizations or groups of individuals, under the following conditions:

1. A permit is obtained from the borough mayor or his authorized representative after approval of the local fire authorities;

2. In determining whether to issue or deny a permit for the use of *fireworks* at a public display, the borough mayor or his designee shall consider the following:

a. The location of the proposed display and the surrounding property;

b. The type of *fireworks* and the length of the proposed display;

c. The danger of the proposed display to persons and property; and

d. The experience and the competency in handling *fireworks* of the person in charge of the proposed display;

3. A bond is filed with the borough, in the amount of at least $1,000 to ensure payment of all damages to persons or property caused by the display. The bond requirement will not be operative if the holder of the permit has in effect an insurance policy which accomplished the same purpose as the bond.

B. No permit is transferable.

C. Any *fireworks* that remain unfired after the display is concluded shall be immediately disposed of in a way safe for the particular type of *fireworks* remaining. (Ord. 72-27, 1972; Ord. 72-5, 1972; Ord. 69-1, 1969; prior code § 32.05.040)

8.08.050 Authorized sale and use.

Nothing in this chapter shall be construed to prohibit any resident wholesaler, dealer or jobber to sell at wholesale such *fireworks* as are not herein prohibited; or the sale of any kind of *fireworks* provided the same are to be shipped directly out of the borough, in accordance with the Interstate Commerce Commission regulations covering the transportation of explosives and other dangerous articles by motor, rail, and water; or the use of *fireworks* by railroads or other transportation agencies for signal purposes or illumination, or the sale or use of blank cartridges for a show or theater, or for signal or ceremonial purposes in athletics or sports, or for use by military organizations. This chapter does not pertain to those explosives or devices

used in construction, logging or mining and would not prohibit the use of these explosives or devices in such activities. (Ord. 72-27, 1972; Ord. 72-5, 1972; Ord. 69-1, 1969; prior code § 32.05.050)

8.08.060 Penalty for violations.

Every person, firm, corporation, club, association or organization violating any of the provisions of this chapter is guilty of a violation punishable by a $1,000 fine. (Ord. 2013-65 § 17, 2013; Ord. 72-27, 1972; Ord. 72-5, 1972; Ord. 69-1, 1969; prior code § 32.05.060)

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[1] For statutory provisions authorizing municipalities to regulate the offering for sale, exposure for sale, sale, use or explosion of fireworks, see AS 29.35.

Chapter 8.10
SOLID WASTE COLLECTION DISTRICT

Sections:

8.10.010 Solid waste collection district.

A. There is hereby established the Fairbanks North Star Borough solid waste collection district. The district is not a service area. The district shall consist of the area lying within the boundaries of the city of North Pole and the area outside all the cities in the borough.

B. The assembly may levy taxes, charges, or assessments in the district to finance the collection of solid waste in the district. (Recodified during 2004 republication; Ord. 91-008 § 3, 1991. Formerly 1.02.160.)

Chapter 8.12
GARBAGE AND SOLID WASTE[1]

Sections:

8.12.011 Chapter purpose.

The declared purpose of this chapter is the protection of the public health, safety and welfare of the people of the Fairbanks North Star Borough. The chapter and any regulations promulgated pursuant thereto are intended to:

A. Control dumping and disposal of solid waste at such place and in such manner that it will not be a detriment to the health, safety and welfare of the citizens of the borough;

B. Provide facilities for the proper disposal of solid waste at minimum cost;

C. Reduce litter and littering;

D. Promote resource recovery, recycling and reuse of solid waste;

E. Preserve and enhance the beauty and quality of our environment;

F. Promote responsible agricultural practices and encourage economic activity.

No section of this chapter should be interpreted as prohibiting residents from reusing articles from the waste stream discarded at a borough transfer site. (Ord. 2009-39 § 2, 2009; Ord. 84-29 § 2, 1984)

8.12.021 Definitions.

In this chapter unless the context requires otherwise:

“Avoided costs” means the savings realized by the solid waste collection district or solid waste disposal funds of the borough if recyclables are diverted from the landfill or separated from the waste stream prior to being deposited in the landfill or a transfer station. Avoided costs shall not include hauling costs avoided by the city of Fairbanks. Avoided hauling costs of the borough shall include avoided costs of hauling recyclables from outside the city of Fairbanks, tipping fees avoided by the taxpayers of the solid waste collection district, and calculated savings to the solid waste operation that result from a lower amount of refuse being handled at the landfill including avoided closure and post-closure costs. To determine avoided hauling costs and tipping fees, an approved recycler must have a method of weighing the recycled goods approved as accurate and verifiable by the Fairbanks North Star Borough. To determine avoided landfill costs, the methodology used will be the methodology used by the MacTech study, or other comparable study as selected at the sole discretion of the mayor, to calculate landfill costs, adjusted for the projected reduction in tonnage.

“Biomass” means a given quantity of organic material.

“Bulky wastes” are large items of refuse including but not limited to appliances, vehicles, furniture, large auto parts, tires, trees and branches, stumps and flotage.

“Commingled recyclables” means a mixture of several recyclable materials into one container.

“Curbside collection” means programs where recyclable materials are collected at the curb from special containers, to be brought to various processing facilities.

“Director” means the public works director, or his/her designee.

“Diversion rate” means a measure of the amount of recyclables diverted for recycling compared with the total amount that was previously landfilled.

“Documentation” means written proof that a quantity of recyclables has been recycled and will not be landfilled.

“Drop-off center” means a method of collecting recyclable or compostable materials in which individuals take materials to collection sites and deposit them into designated containers.

“Garbage” means any putrescible solid and semisolid animal or vegetable wastes resulting from the production, handling, preparation, cooking, serving or consumption of food or food materials.

“Hazardous waste” means a waste or combination of wastes that because of quantity, concentration or physical, chemical or infectious, pathological or radiological characteristics might cause, or significantly contribute to:

1. An increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness; or

2. A substantial present or potential hazard to human health or to the environment if improperly managed, treated, stored, transported or disposed of or otherwise managed.

“Industrial solid waste” means any waste substance or a combination thereof resulting from the operation of or from any process of industry, manufacturing, trade or business, or from the development of any agricultural or natural resources.

“Inert solid wastes” means wastes including but not limited to wood, glass, crockery, brick, plastics, rubber or other materials which have minimum potential for environmental degradation and leachate production.

“Infectious waste” means certain laboratory, surgical and hospital waste; surgical specimens including pathological specimens, tissues, blood elements, excreta and secretions obtained from patients; disposable materials that have been in contact with persons who have a suspected or diagnosed communicable disease; a substance that might harbor or transmit pathogenic organisms; disposable materials from outpatient areas, emergency rooms and rooms of patients with a suspected or diagnosed communicable disease that requires isolation; and certain equipment, including instruments, syringes and needles.

“Junk” means used materials which will not be further utilized unless collected and processed for reuse or recycling.

“Litter” means any discarded, used or unconsumed substance or waste material which has not been deposited in a suitable litter receptacle.

“Manual separation” means the separation of recyclable or compostable materials from waste by hand sorting.

“Materials recovery” means extraction of materials from the waste stream for reuse or recycling, including source separation, front-end recovery, in-plant recycling, post-combustion recovery, leaf composting, etc.

“Mechanical separation” means the separation of waste into various components using mechanical means, such as cyclones, trommels and screens.

“Putrescible waste” means material that can decompose and cause obnoxious odors.

“Recyclable metals” means copper, brass, bronze, aluminum, lead, zinc, and ferrous metals, but does not include steel cans and those metals that are bonded or fused to other materials and cannot be readily separated.

“Recyclables” means materials that have useful physical or chemical properties after serving their original purpose and that can, therefore, be reused or remanufactured into additional products, including refuse derived fuel (RDF).

“Recycling” means the process by which a material that would otherwise be placed in the landfill is collected, reprocessed, or remanufactured, and then reused, or used for energy.

“Refuse” means any putrescible or nonputrescible solid waste, except human excreta.

“Resource recovery” means the processing of solid wastes in such a way as to produce materials or energy which may be used in manufacturing, agriculture, or other processes.

“Rubbish” means any solid waste except ashes and putrescible waste.

“Secured” means tied down or otherwise not subject to release.

“Sewage sludge” means the organic sludge generated by municipal or other wastewater collection and treatment activities, and may include primary, secondary and digested sludges, grit and screenings.

“Sludge” means any solid, semisolid or liquid waste which contains at least five percent solids by weight generated at a municipal, commercial or industrial wastewater treatment plant, septic tank, water supply treatment plant or air pollution control facility; “sludge” includes any similar material accumulated in and removed from a storage tank or surface impoundment containing oil, industrial liquid waste, acid, chemicals or other similar substances.

“Solid waste” means drilling wastes, garbage, refuse, sludge and other discarded material, including solid, liquid, semi-solid or contained gaseous material resulting from industrial, commercial and agricultural operations, and from community activities. For the purposes of this chapter “solid waste” does not include:

1. Spoil and overburden from road construction, land clearing or mining operations;

2. Mining waste regulated by the Federal Surface Mining Control and Reclamation Act of 1977, as amended, and by the Alaska Surface Mining Control and Reclamation Act of

1982 (AS 27.21);

3. Domestic sewage and other wastes that are discharged into the pass through a sewer system to a publicly owned treatment works;

4. Industrial or mining wastes that are being collected, stored or treated in:

a. A wastewater treatment plant before discharge or removal, or

b. An industrial processing facility for continual reuse;

5. Industrial discharges that are point sources subject to permits under Section 402 of the Federal Water Pollution Control Act, as amended;

6. Source, special nuclear, or byproduct material as defined by the Nuclear Waste Policy of 1982, as amended January 7, 1983, at Public Law 97-425.

“Source separation” means the segregation of specific materials at the point of generation for separate collection. Recyclables are source separated at residences as part of a recycling program.

“Special solid waste” means hazardous wastes, infectious wastes, radioactive wastes, industrial wastes or sludges and sewage residues. (Ord. 2012-49 § 2, 2012; Ord. 2009-39 § 3, 2009; Ord. 2003-43 § 2, 2003; Ord. 94-045 §§ 2, 3, 1994; amended during 1993 republication; Ord. 89-038 § 2, 1989; Ord. 84-29 § 2, 1984)

8.12.031 Solid waste disposal facilities.

A. The borough may require any person dumping solid waste at the following areas to dump where specified, and may reject or impound any waste which is judged to be unacceptable. Impoundment implies that the waste and its container, but not the vehicle used to transport the waste, may be impounded. The following facilities are designated for the disposal of all types of solid waste, with the exception of special solid waste:

1. South Cushman baler and landfill;

2. Other borough-owned or borough-operated landfills.

B. Collection and transfer sites provided as part of the borough’s solid waste collection district are designated solely for the disposal of residential solid waste by residents of the borough residing outside the city of Fairbanks.

C. The following facilities are for the disposal of solid waste as approved by the owners of

such facilities. Only persons with the prior approval of the owners may dump solid waste at these facilities:

1. Military landfills;

2. Other containers which will be dumped at the South Cushman baler and landfill, including private dumpsters located at apartment complexes, mobile home parks and other locations. For the purposes of this paragraph, in the case of leased private dumpsters, the lessee shall be considered the owner;

3. Other locations, as approved and permitted by the state, subject to the conditions of such permits.

D. Any administrative decisions of the director or the solid waste superintendent pursuant to this chapter may be appealed to the pollution control commission. In all actions under the provisions of this chapter, the name of the complainant will be a matter of public information. (Ord. 94-056 § 2, 1994; amended during 1993 republication; Ord. 89-038 § 3, 1989; Ord. 84-29 § 2, 1984)

8.12.033 Recycling of materials.

A. The borough shall ensure that, at all borough-owned or operated landfills and primary collection and transfer sites, separate locations or containers are provided to receive and hold recyclable materials. These may include but are not limited to:

1. Glass;

2. Aluminum cans;

3. Corrugated cardboard, flattened;

4. Computer paper;

5. Office paper;

6. Scrap metal:

a. Aluminum,

b. Copper,

c. Iron,

d. Brass,

e. Stainless steel;

7. Car radiators;

8. Plastic;

9. Biomass material;

10. Other materials selected by the borough.

B. The borough may provide for this separation by either:

1. Ensuring that borough-provided locations or containers are available; or

2. Contracting with a private firm to furnish and service such locations or containers.

C. If the borough provides for the deposit of such materials directly, periodically the borough shall sell to recycling firms the materials collected in these locations or containers.

D. Deposit of materials other than the appropriate, designated materials in any of the thus-established locations or containers, or the removal of any such materials, except by prior written permission of the borough, is prohibited.

E. The borough shall waive in whole or in part the tipping fee to persons, businesses and entities which separate recyclable materials into lots designated by the borough which may include aluminum, glass, plastic, cardboard, mixed paper, newspaper, electronics or wood products in loads delivered to the landfill. A waiver may be granted for other materials, if recommended by the commission and approved by the mayor with notification to the assembly. The waiver shall be no greater than 100 percent of the tipping fee. Nonseparated loads of recyclables shall not receive a waiver. The mayor is authorized to establish a rate schedule for such waivers.

F. It is the policy of the Fairbanks North Star Borough to encourage reduction, reuse and recycling of solid wastes generated in the borough. These efforts may include payment of a portion of actual avoided costs of hauling and land filling to approved recyclers/reusers not to exceed $175,000. Subject to appropriation, avoided costs, less a 25 percent reduction, may be paid to approved recyclers when documentation is provided to show that materials separated as recyclables have been removed from the waste stream by recycling within the current fiscal year. Twenty-five percent of avoided costs may be paid to a fund established to maintain the efforts of the commission.

G. The borough may implement a program of designated burial of source separated recyclable materials that are not removed from the waste stream. (Ord. 2009-39 §§ 4, 5, 2009; Ord. 94-045 § 4, 1994; amended by voter approval 10/5/93; Ord. 91-035 § 2, 1991; Ord. 89-060 § 2, 1990)

8.12.034 Recycling commission.

Recodified as Chapter 2.110 FNSBC by Ord. 2011-30. (Ord. 2009-39 § 7, 2009; Ord. 94-045 § 5, 1994)

8.12.035 Approved recyclers.

A. The recycling commission shall recommend to the administration those recyclers authorized to remove recyclables for the purpose of reuse or remanufacture who will be eligible to receive payment for tonnage of materials that will not be placed in the landfill. The commission shall evaluate proposals from recyclers. The evaluation criteria will include the following:

1. Valid Alaska business license and city license if applicable;

2. Proof of financial resources in proportion to the business purpose;

3. Authorized site approval documentation by DEC and FNSB, if necessary;

4. Submission and approval of a business plan to show:

    a. Type(s) of materials to be recycled or shipped;

    b. Location of approved material sites including appropriate site zoning;

    c. Estimated number of tons to be recycled each month;

    d. Program start date for waste generated after specified date; and

    e. Consistency with the borough's overall recycling plan.

5. The overall impact on the goal of recycling and reduction of solid wastes generated in the borough.

B. Notwithstanding FNSBC 16.30.010 through 16.30.080, the mayor or his designee may enter into a contract with any or all recyclers recommended by the recycling commission and who demonstrate an ability to make a significant positive impact on the borough's recycling plan goals sufficient to justify the cost of the contract. No funds shall be paid pursuant to

FNSBC 8.12.033(F) to a recycler until a contract has been agreed to and signed by the borough and recycler. The contract shall not exceed a term of 10 years. The contract must include a provision authorizing termination at will by the mayor. (Ord. 2009-39 § 8, 2009; Ord. 94-045 § 6, 1994)

8.12.036 Recycling promotion special revenue fund.

Repealed by Ord. 2009-39. (Ord. 94-045 § 7, 1994)

8.12.041 General prohibition.

A. No person shall dispose of solid wastes, special solid wastes or sludge in any place except those listed in FNSBC 8.12.031.

B. No person shall dump, throw, drop or deposit any special solid waste in the Fairbanks North Star Borough except approved haulers at approved facilities.

C. No person shall allow the accumulation of garbage, solid waste, animal feces, etc., on property where he resides or which he owns or controls to impose a threat to public health. Nothing in this section shall be construed to restrict normal agricultural practices in the rural and agricultural or general use zones.

D. No person shall discard any litter into or on any water or land within the borough, except that nothing in this section shall be construed to affect the authorized collection and discarding of such litter in or on areas or receptacles provided for such purpose.

E. No person shall dump solid waste in the borough's public dumpsters collected from any location other than individual residences located in the borough outside the city of Fairbanks.

F. No solid waste shall be dropped, deposited, discarded or otherwise disposed at a public dumpster unless it remains within the public dumpster. Any disposal outside the container is a violation of subsection (D) of this section.

G. No person shall dump at the borough's public dumpsters bulky wastes, dead animals, infectious wastes, demolition debris or special solid wastes. (Ord. 2013-07 § 4, 2013; Ord. 94-056 § 3, 1994; Ord. 89-038 § 4, 1989; Ord. 84-29 § 2, 1984)

8.12.046 Landfill tipping fees.

A. Except as otherwise provided in this chapter, any person disposing of solid waste at the borough landfill shall pay a tipping fee established in accordance with FNSBC 3.50.010.

B. The borough mayor may permit a commercial hauler regulated by the state of Alaska to

dispose of residential solid waste collected solely from individual residences located in the solid waste collection district and delivered directly to the borough landfill without direct payment of a tipping fee. Such tipping fees shall be paid to the landfill by the solid waste collection district. (Ord. 2001-34 § 2, 2001)

8.12.051 Use of borough waste facilities.

A. Any person wishing to dispose of solid waste generated or collected from a location outside of the borough shall be charged a fee that reflects the actual costs of providing such services, including but not limited to current operational costs, probable operational and monitoring costs for the life of the landfill, and landfill closure and replacement costs.

B. Disposal of solid waste generated or collected from a location outside of the borough shall not be permitted unless the solid waste meets the conditions of the borough's ADEC solid waste permit.

C. Disposal of more than 25 tons of solid waste per month from a source outside of the borough shall not be permitted unless the mayor determines that:

1. The solid waste can be safely and efficiently disposed of at the borough landfill;

2. The solid waste will not significantly impact the capacity of the borough landfill; and

3. There will be no harm to the borough or the borough landfill.

D. Disposal of solid waste from a source outside the borough for longer than 60 days shall also require concurrence of the borough assembly. (Ord. 97-036 § 2 1997; Ord. 84-29 § 2, 1984)

8.12.055 Waiver of tipping fees.

A. The borough will waive the tipping fee to residents of the borough who bring minor loads of nonhazardous solid waste to the landfill. For the purpose of this subsection, loads of nonhazardous waste brought to the landfill from a residence in a passenger vehicle, a pick-up truck, or a trailer with two wheels and a single axle will be considered minor loads if the vehicle is not registered in the name of a company or business or used for commercial purposes.

B. Any Internal Revenue Code Section 501(c)(3) or 501(d) nonprofit organization which accepts clothing, furniture or other items of personal property, on a year-round basis, and sells those items of personal property to raise funds for the organization's services, or distributes those items of personal property to persons in need, shall be exempt from paying tipping fees on that personal property which is in such disrepair that it cannot be resold and must be

transported to and disposed of in the landfill.

C. The borough mayor may waive tipping fees for materials to the landfill for borough recycling or hazardous waste disposal programs and for community cleanup activities. The mayor may waive tipping fees for debris from private residences in the borough damaged by fire if there is no reimbursement for such waived fees from any other source. The mayor, when there is a direct and primary benefit to the public, may waive tipping fees for materials removed from deteriorated property, as defined in FNSBC 3.11.070, during the course of rehabilitation, repair, construction, reconstruction, renovation, demolition, removal or replacement of any structure on such property.[2]

D. All other loads will be considered commercial and will be charged the usual tipping fee on the entire load. (Ord. 2005-26 § 4, 2005; Ord. 99-006 § 2, 1999; Ord. 94-085 § 2, 1994; Ord. 94-074 §§ 2, 3, 1994; Ord. 93-002 § 3, 1993; Ord. 91-056 § 2, 1991)

8.12.061 Collection and transportation of solid waste.

A. The owner or occupant of any premises, business establishment, industrial establishment, or refuse collection service shall be responsible for the collection and transportation of all solid waste accumulated at a premises, business establishment or industrial establishment to an approved solid waste disposal facility in accordance with this chapter.

B. Garbage and similar putrescible wastes, or refuse containing such materials, shall be collected and transported in containers which are covered and leakproof.

C. Vehicles or containers used for the collection and transportation of any solid waste shall be loaded and moved in such a manner that the contents will not fall, leak or spill therefrom. Where spillage does occur, it is the responsibility of the collector or transporter to pick up the material, return it to the vehicle or container, and properly clean the area. Any person collecting or transporting solid waste who permits the waste to fall, leak or spill from the vehicle or who fails to clean up waste which has fallen, leaked or spilled from his vehicle shall be subject to a civil penalty not to exceed $1,000 in addition to the cost of cleanup incurred by the borough or other public agency.

D. Any person who arrives at any borough-operated solid waste disposal facility, including the South Cushman balefill/landfill and any borough solid waste transfer station, with a vehicle or container which is not covered or with a load which is not secured is in violation of this section. (Ord. 2003-43 § 3, 2003; Ord. 84-29 § 2, 1984)

8.12.071 Penalty for violations.

This chapter does not affect the private right of any person to bring an action for damages or other relief because of injury caused by garbage or solid waste. (Ord. 2013-26 § 7, 2013; Ord. 2003-43 §§ 4, 5, 6, 2003; Ord. 89-038 § 5, 1989; Ord. 84-29 § 2, 1984)

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[1] For statutory provisions authorizing municipalities to regulate garbage and solid waste collection and disposal, see AS 29.35.

[2] Code reviser's note: Ordinance 2005-26, amending subsection (C) of this section, may be repealed by voters through referendum.

Chapter 8.14
ABANDONED VEHICLES

Sections:

8.14.010 Definitions.

“Abandoned vehicle” means a vehicle that is:

1. Registered or titled as required under AS 28.10 that has been left unattended, standing, parked upon or within 10 feet of the traveled portion of a highway or vehicular way or area in excess of 48 hours;

2. Registered or titled as required under AS 28.10 that reasonably appears to have been left standing or parked on private property in excess of 24 hours or upon other public property for more than 30 days, without the consent of the owner or person in charge of the property;

3. A wrecked or junked vehicle that reasonably appears to have been left unattended, standing, parked upon or within 10 feet of the traveled portion of a highway or vehicular way or area in excess of 24 hours; or

4. A wrecked or junk vehicle that reasonably appears to have been left standing or parked on private property or other public property in excess of 24 hours and without the consent of the owner or person in charge of the property.

“Director” means the director of community planning, or his designee.

“Junk vehicle” means a vehicle that:

1. Is not currently registered, except for a vehicle used exclusively for competitive racing;

2. Is stripped, wrecked, or otherwise inoperable due to mechanical failure;

3. Has not been repaired because of mechanical difficulties or because the cost of

repairs required to make it operable exceeds the fair market value of the vehicle; or

4. Is in a condition that exhibits more than one of the following: broken glass, missing wheels or tires, missing body panels or parts, or missing drive train parts.

"Wrecked vehicle" means a vehicle that is disabled and cannot be used as a vehicle without substantial repair or reconstruction.

These definitions are for the purpose of this chapter only and shall not be used as definitions for language used in other chapters. (Ord. 2001-71 § 2, 2001; Ord. 86-017 § 42, 1986; Ord. 82-41 § 2, 1982)

8.14.015 Unlawful acts.

A. A person may not abandon a vehicle upon a highway or vehicular way or area.

B. A person may not abandon a vehicle upon public property or upon private property without the consent of the owner or person in lawful possession or control of the property. (Ord. 2001-71 § 8, 2001)

8.14.020 Removal of abandoned vehicles.

A. An abandoned vehicle may be impounded by the director or his designee in accord with this chapter.

B. Notwithstanding subsection (A) of this section, no vehicle may be removed from private property without the written request or consent of the property owner or occupant. (Ord. 2001-71 § 3, 2001; Ord. 82-41 § 2, 1982)

8.14.030 Notice of impoundment.

A. Within 30 days of impoundment, notice shall be given to the registered owner of record (and lienholder of record, if any) of the abandoned vehicle. When the persons involved are known, adequate notice shall be by either certified mail or personal service. The giving of notice by mail is considered complete upon the return of the receipt or upon return of the notice as undeliverable, refused or unclaimed. If such persons are not known or cannot be located the vehicle shall be impounded and notice shall be by publication in the manner prescribed in the rules of court for service of process by publication. The director shall attempt to ascertain ownership from the Department of Public Safety.

B. Notice under this section shall contain:

1. The description of the vehicle;

2. The date, time, grounds and place of removal;

3. An itemized statement of amounts due the borough for towing and storage and stating that such fees must be paid prior to redemption of the vehicle;

4. A statement that the vehicle will be disposed of 15 days from the date notice was mailed or published unless the vehicle is redeemed and costs paid; and

5. A statement that the owner of the vehicle may, at any time within the 15-day period, request a hearing before the director concerning whether the vehicle was left for the period specified in FNSBC 8.14.010 or concerning the amount due. (Ord. 2001-71 § 4, 2001; Ord. 82-41 § 2, 1982)

8.14.040 Disposition – Destruction.

If the director determines that an abandoned vehicle impounded pursuant to this chapter has been scrapped, dismantled or destroyed beyond repair, or if he determines that because of the age and condition of the vehicle it is no longer of significant value, he may dispose of it by crushing or other means of destruction upon the expiration of the 15-day period required by FNSBC 8.14.030.

The borough may also dispose of junk vehicles at the written request of the registered owner of the vehicle or person in lawful possession or control of the vehicle. This written request shall be on a form prescribed by the borough. (Ord. 2001-71 § 5, 2001; Ord. 82-41 § 2, 1982)

8.14.050 Disposition – Sale.

A. The director may sell abandoned vehicles impounded in accord with this chapter at a public auction.

B. The public auction shall be preceded by at least 20 days' notice of public auction posted in a newspaper of general circulation in the borough.

C. The notice of public auction shall state the description of the vehicle, date, time and place of auction, the name of the owner if known and a statement that, subject to the provisions of subsection (E) of this section, the vehicle shall be sold to the highest spot cash bidder.

D. The owner of the vehicle, upon presenting satisfactory proof of ownership, may redeem an abandoned vehicle prior to the time of sale after paying the borough towing and storage costs and a pro rata share of the cost of the notice and other costs of impoundment and sale.

E. A certificate of sale shall be issued for all vehicles sold at the auction. The certificate shall

stipulate that the vehicle must be titled with the Department of Public Safety before the vehicle is released to the purchaser. Upon a showing that certificate of title has been obtained the vehicle will be released to the purchaser. If no such showing has been made within a 20-day period the purchase price will be returned and the vehicle may be disposed of pursuant to this section. (Ord. 2001-71 § 6, 2001; Ord. 82-41 § 2, 1982)

8.14.060 Waiver of claims for damages.

A. An owner of an abandoned vehicle, by the act of abandonment, waives any claims he may have for damage to or loss of his vehicle which may result from actions taken pursuant to this chapter. Such damage or loss includes but is not limited to accidental damage or destruction occasioned by removal transport and storage, and acts of third parties.

B. Should a vehicle purchased at auction pursuant to FNSBC 8.14.050 be damaged or destroyed prior to release, the purchaser's remedy is limited to a return of the purchase price. (Ord. 2001-71 § 7, 2001; Ord. 82-41 § 2, 1983)

Chapter 8.16
JUNKYARDS

(Repealed by Ord. 2005-29)

Chapter 8.18
VEHICLE INSPECTION AND MAINTENANCE PROGRAM

(Repealed by Ord. 2009-36)

Chapter 8.20
VEHICLE PLUG-IN PROGRAM

Sections:

8.20.010 Vehicle plug-in program.

A. Parking Lot Owner Responsibilities. Between November 1st of each year and March 31st of the subsequent year, each employer or business with a total of 275 or more parking spaces with outlets within the borough maintenance area shall supply electricity to outlets located in its parking lots for use by motorists in plugging in vehicles equipped with engine heaters. Electricity shall be supplied on days when temperatures fall below 21 degrees Fahrenheit, as measured by the National Weather Service at the Fairbanks International Airport.

1. Power Cycling. Power to parking lots may be cycled on and off every other hour during days when temperatures fall below the 21 degrees Fahrenheit threshold to conserve electricity use.

2. Record Keeping. Each employer or business subject to subsection (A) of this section shall maintain a logbook that documents the days on which power is supplied to electrical outlets located in its parking lots. Notations of special circumstances that prevent the supply of electricity to outlets shall be included. The logbooks shall be maintained for a five-year period and be available for inspection upon borough request.

3. New Parking Lots.

a. Employers and businesses subject to subsection (A) of this section shall provide outlets for any new parking spaces intended for use by a motorist for longer than two hours.

b. Notwithstanding subsection (A) of this section, an employer or business shall provide outlets for new parking spaces when such spaces increase its number of spaces intended for use by a motorist for longer than two hours to 275 or more. The employer or business shall supply electricity to such outlets on days when temperatures fall below 21 degrees Fahrenheit, as measured by the National Weather Service at the Fairbanks International Airport in accordance with this chapter.

4. Maintenance of Outlets. Each employer or business subject to subsection (A) of this section shall maintain the electrical outlets in operable condition. No employer or

business subject to subsection (A) of this section shall decrease the number of parking spaces with outlets without prior approval of the I/M program administrator.

B. Implementing Policies and Procedures. Within six months of the effective date of the ordinance codified in this chapter, the borough shall develop administrative policies and procedures for implementing and enforcing this program.

C. Penalties for Violation.

1. The borough may institute a civil action against an employer or business that violates a provision of this chapter. In addition to injunctive and compensatory relief, the borough may obtain a civil penalty not to exceed $1,000 for each violation. The borough may bring an action to enjoin a violation or to recover a civil penalty notwithstanding the availability of any other remedy.

2. Each day that a violation of this chapter continues constitutes a separate violation.

D. Definitions.

“Employer” or “business” means all private and public sector entities, including state, local and federal agencies, departments, offices, boards, commissions, corporations and political subdivisions or other organizational units, including the University of Alaska and school district. The total number of parking spaces includes all agencies, divisions, subsidiaries and locations of the employer or business within the borough maintenance area.

“Maintenance area” means the area located within the borough that is set out and described by federal law (40 CFR 81.302) but excluding the city of North Pole. (Ord. 2004-61 § 3, 2004; Ord. 2001-17 § 3, 2001)

Chapter 8.21
PM2.5 AIR QUALITY CONTROL PROGRAM

Sections:

8.21.010 Definitions.

In this chapter, the following definitions apply:

"*Air quality alert*" means an advisory, *alert* or *episode* concerning air quality whether issued by the Fairbanks North Star Borough or the state of Alaska.

"*Alert*" means a notice issued by the FNSB air quality division when the *division* determines, using available data, that a violation of the 35 micrograms per cubic meter will likely occur.

"*Appliance*" means a device or apparatus that is manufactured and designed to utilize energy and which does not require a stationary source air quality permit from the state of Alaska under 18 AAC 50.

"*Cook stove*" means a wood burning *appliance* that is designed primarily for cooking food and that has the following characteristics:

1. An oven, with a volume of 0.028 cubic meters (one cubic foot) or greater, and an oven rack;

2. A device for measuring oven temperatures;

3. A flame path that is routed around the oven;

4. A shaker grate;

5. An ash pan;

6. An ash clean-out door below the oven; and

7. The absence of a fan or heat channels to dissipate heat from the device.

"*Division*" means the Fairbanks North Star Borough air quality division.

"*Episode*" means when conditions reach *alert* status.

"*Fireplace*" means an assembly consisting of a hearth and open fire chamber of noncombustible factory-built or masonry materials and provided with a chimney, for use with solid fuels, which cannot be operated with an air to fuel ratio of less than 35 to one.

"*Fireplace insert*" means a *solid fuel burning appliance* similar in function and performance to a freestanding wood burning stove, which is made from cast iron or steel designed to be installed in an existing masonry or prefabricated *fireplace*.

"*Forecast*" means a description of the current dispersion conditions described as good, fair, or poor and including the expected $PM_{2.5}$ concentrations expressed in micrograms per cubic meter.

"*Heating appliances*" means, but is not limited to: oil furnaces, gas furnaces, wood stoves, coal stoves, wood-fired *hydronic heaters*, wood-fired furnaces, coal-fired *hydronic heaters*, coal-fired furnaces, *masonry heaters*, *pellet stoves*, *cook stoves*, and *fireplaces.*

"*Hydronic*" means having to do with a system moving heat from one location to another by means of the circulation of a heat transfer liquid through piping or tubing.

"*Hydronic heater*" means a fuel burning *appliance* designed to (1) burn wood or other solid fuels and (2) heat building space and/or domestic hot water via the distribution, typically through pipes, of a fluid heated in the *appliance*.

"*Masonry heater*" means a wood burning *appliance* that complies with the guidelines of ASTM E1602-08, Standard Guide for Construction of *Masonry Heaters*, and:

1. Is designed and intended for operation only in a closed combustion chamber configuration; and

2. Has enough thermal storage capacity to maintain no less than 50.0 percent of the maximum masonry-mass temperature for at least four hours after the maximum masonry-mass temperature has been reached; and

3. The *masonry heater* design and installation has been confirmed and documented by a qualified person or entity approved by the borough.

"*Nonattainment area*" is the area depicted on the map attached to the ordinance codified in this chapter and is further defined as follows:

Township Range Delineated Boundary for the Fairbanks *Nonattainment Area*

MTRS F001N001 – All Sections, MTRS F001N001E – Sections 2-11, 14-23, 26-34, MTRS F001N002 – Sections 1-5, 8-17, 20-29, 32-36, MTRS F001S001E – Sections 1, 3-30, 32-36, MTRS F001S001W – Sections 1-30, MTRS F001S002E – Sections 6-8, 17-20, 29-36, MTRS F001S002W – Sections 1-5, 8-17, 20-29, 32-33, MTRS F001S003E – Sections 31-32, MTRS F002N001E – Sections 31-35, MTRS F002N001 – Sections 28, 31-36, MTRS F002N002 – Sections 32-33, 36, MTRS F002S001E – Sections 1-2, MTRS F002S002E – Sections 1-17, 21-24, MTRS F002S003E – Sections 5-8, 18.

"*Particulate matter*" or "*PM*" means total particulate matter including PM_{10} and $PM_{2.5}$ (condensable and noncondensable fraction) and is a complex airborne mixture of extremely small particles and liquid droplets that are made up of a number of components, including acids, organic chemicals, metals, soil, or dust.

"*Pellet fuel burning appliance*" or "*pellet stove*" means a closed combustion, vented pellet burning *appliance* with automatic components creating an active air flow system, sold with the hopper and auger combination as integral parts, and designed, warranted, safety listed, and advertised by the manufacturer specifically to be fueled by pellets of sawdust, wood products and other biomass materials while prohibiting the use of cordwood.

"*$PM_{2.5}$*" means *particulate matter* comprised of particles that have diameters of two and one-half microns or less.

"*Sale*" means the transfer of ownership or control.

"*Solid fuel burning appliance*" means any *appliance*, unless specifically excluded from this definition, designed to produce heat by burning nongaseous and nonliquid fuels. This definition includes, but is not limited to:

1. Wood stoves;

2. Coal stoves;

3. Wood-fired *hydronic heaters*;

4. Wood-fired furnaces;

5. Coal-fired *hydronic heaters*;

6. Coal-fired furnaces; and

7. *Fireplace inserts*.

The following *appliances* are specifically excluded from this definition:

1. *Masonry heaters*;

2. *Pellet fuel burning appliances*;

3. *Cook stoves*; and

4. *Fireplaces*. (Ord. 2013-35 § 3, 2013; Ord. 2013-06 § 2, 2013; Ord. 2011-32 § 2, 2011; Ord. 2011-12 § 2, 2011; Ord. 2011-03 § 2, 2011; amended by citizen initiative 10/28/10; Ord. 2010-28 § 2, 2010)

8.21.020 Borough listed appliances.

An *appliance* shall be listed by the borough if:

A. The *appliance* is certified by the U.S. Environmental Protection Agency as meeting the federal emissions limit standard appropriate for that *appliance* or in the case of *hydronic heaters* is at least phase II qualified. For purposes of this section, “certified” means that the solid fuel *appliance* meets emission performance standards when tested by an accredited independent laboratory and labeled according to procedures specified by the EPA in 40 CFR 60 Subpart AAA; or

B. The *appliance* is tested by an accredited independent laboratory, or other qualified person or entity approved by the borough, establishing that it meets the EPA emissions limit standard appropriate for that *appliance* or an emissions limit standard equivalent to that of a listed *appliance* in a similar category. (Ord. 2012-61 § 2, 2012)

8.21.025 Prohibited acts.

The borough shall not, in any way, regulate, prohibit, curtail, nor issue fines or fees associated with the *sale*, distribution, or operation of *heating appliances* or any type of combustible fuel. (Ord. 2013-06 § 3, 2013)

8.21.030 Voluntary replacement and repair program.

Repealed by Ord. 2014-10. (Ord. 2012-61 § 3, 2012; Ord. 2011-32 §§ 3 – 9, 2011; Ord. 2010-37 §§ 2 – 5, 2010; Ord. 2010-28 § 2, 2010)

8.21.035 Enhanced voluntary removal, replacement and repair program.

The Fairbanks North Star Borough shall, to the extent funds are available and appropriated by the assembly, offer an enhanced removal, replacement and repair program to help offset the costs of removing, replacing or repairing a *solid fuel burning appliance* (SFBA) or *fireplace*. This program shall be subject to the following eligibility requirements, conditions, and criteria:

A. General Requirements.

1. Application. An application approved by the *division* and signed by all property owner(s) must be submitted along with any documentation required by the *division*. Applicants must fully comply with the *division*'s inspection process which shall verify the existence of a qualifying SFBA or *fireplace*.

2. Priority Ranking. Applications may be prioritized and may be limited by the *division* in its discretion based on geographical location, the overall air quality benefit and the type of SFBA or *fireplace* being removed, replaced or repaired.

3. Eligibility[1]. The program is limited to properties within the borough's $PM_{2.5}$ *nonattainment area* boundary in which a qualifying SFBA or *fireplace* is installed. If an application is approved for the program, the applicant will be given up to 90 days to meet all of the requirements. Applicants must have no delinquent property tax or penalty or interest owing at the time of application and at completion of the program requirements.

4. Additional Requirements. In addition to the general requirements set forth in this section, applicants must also meet the following requirements:

a. Fully comply with the inspection process required by the *division* that shall ensure that the existence of the qualifying *appliance* to be removed, replaced or repaired is properly documented.

b. Removal of *appliance*.

c. Delivery of *appliance* to an authorized decommission station.

d. Certificate of destruction delivered to the *division*, if applicable.

e. Final installation of a qualified *appliance* visually verified.

f. All aspects of this section may be performed by borough-approved personnel or a borough-approved vendor.

5. Payments. Applicants will be eligible for reimbursements or, at the option of the applicant, payment may be made directly to a borough-approved vendor. Reimbursements and payments shall be available as follows:

a. Replacement of an outdoor *hydronic heater*: With either an EPA certified SFBA with an emission rate less than or equal to 2.5 grams/hour, an EPA Phase II qualified pellet burning *hydronic heater* with an emission rate equal to or less than 0.2 pounds/million BTUs, or an *appliance* designed to use pellets, home heating oil (excluding waste oil), natural gas, propane, hot water district heat, electricity or a *masonry heater* (including parts, labor and any costs associated with upgrading the chimney to the extent required by the manufacturer of the appliance for proper installation).

Appliance + Fuel Payment
Up to $10,000 for purchase and installation of the *appliance* plus fuel payment, if applicable.

b. Replacement of a non-EPA certified SFBA, *fireplace*, or an EPA certified SFBA that has an emission rate greater than 2.5 grams/hour: With either an EPA certified SFBA with an emission rate equal to or less than 2.5 grams/hour and an emission rate 50 percent or less than the replaced heater, or an *appliance* designed to use pellets, home heating oil (excluding waste oil), natural gas, propane, hot water district heat, electricity or a *masonry heater* (including parts, labor and any costs associated with upgrading the chimney to the extent required by the manufacturer of the appliance for proper installation).

Appliance + Fuel Payment
Up to $4,000 for purchase and installation of the *appliance* plus fuel payment, if applicable.

c. Removal of a SFBA (limited to a one-time participation in this program per

property).

Cash Payment
$2,000 – if removing outdoor *hydronic heater*
$1,000 – if removing other SFBAs

d. Fuel Payment. If a *pellet fuel burning appliance* or a *pellet stove* is purchased and installed under this program, the applicant is eligible to receive an additional $300.00 payment for the purchase of pellets manufactured in the Fairbanks North Star Borough. If a wood burning *appliance* is purchased and installed under this program, the applicant is eligible to receive an additional $300.00 payment for borough-approved pressed wood energy logs manufactured in the Fairbanks North Star Borough.

e. Repair Program.

i. The repair program will pay for the:

(A) Replacement of a wood stove's catalytic converter that has exceeded its life span through the one-time payment of up to $750.00.

(B) Replacement of any emissions-reducing component of an EPA-certified wood stove up to the maximum amount of $750.00.

ii. In addition to the general requirements set forth in this section, applicants must fully comply with any inspection process required by the *division*, which may be performed by a borough-approved vendor. (Ord. 2014-10 § 3, 2014)

8.21.040 Forecasting exceedances and voluntary restrictions in the nonattainment area during an alert.

A. During the winter months of October through March, the borough shall issue a daily *PM forecast* at 4:30 p.m. Monday through Friday. When the *PM* concentration reaches the onset level for an *episode* and is expected to remain at that level for 12 hours, an *alert* will be declared. Once an *alert* is declared, *PM* control measures set forth in this section shall be implemented and continued until the *alert* is cancelled.

B. Voluntary Restrictions in the *Nonattainment Area* During an *Alert*.

1. Residents shall be requested to voluntarily stop operation of *solid fuel burning*

appliances, *pellet stoves*, and *masonry heaters* in the *nonattainment area*.

2. The *division* will notify local media to ensure the declared *alert* is broadcast. Information within the notification will contain the *PM forecast* and procedures to reduce sources of *PM*. (Ord. 2010-28 § 2, 2010)

8.21.045 Voluntary burn cessation program.

The Fairbanks North Star Borough will, to the extent funds are available and appropriated by the assembly, establish a program to encourage, incentivize, and facilitate the voluntary cessation of the use of wood burning *appliances* (i.e., wood stoves, wood-fired *hydronic heaters*, wood-fired furnaces, *fireplaces*, *fireplace inserts*, *masonry heaters* or *pellet fuel burning appliances*) in the *nonattainment area* during *air quality alerts*. It is recognized that it will be difficult or impossible for some households to participate in this program (e.g., those that heat solely with wood or for which wood is a necessary supplement during periods of cold weather). Therefore, this program is intended for households that are able to use space heating alternatives with significantly lower $PM_{2.5}$ emissions, including those fueled by gas, oil, electricity, propane or district heat, but not wood or *pellet stoves* or other wood burning *appliances*. This program will at a minimum consist of the following components:

A. The borough may contract with an agency that will provide services to promote the program. This agency must have the standing, experience, and capability to carry out a campaign to advertise, reach out, and attract a large number of participants in the *nonattainment area* who are willing to cease the use of a wood burning *appliance* during *air quality alerts*.

B. Incentives will be provided to households that participate in the program. These incentives may include the provision of (1) a sign-up bonus such as cash, a voucher, or goods and services useful to a household that heats with wood; (2) a thank-you letter, window or yard sign; or, (3) other form of public acknowledgment. The cost of this incentive to the borough shall not exceed $25.00 per household. These incentives may be provided or augmented by private contributions.

C. Facilitation of this program by the borough will include, but not be limited to, the provision of notice of *air quality alerts* to individual households by methods such as electronic mail messages, text messages, automated phone calls, notices to radio and television stations, and information posted on electronic reader or display boards located throughout the borough in locations best suited to notify residents of *air quality alerts*.

D. Private contributions, including goods and/or services, will be sought for all appropriate

elements of the program. In general this will focus on the provision of materials, equipment, and certain one-time services, but not to fund borough staff positions. (Ord. 2014-11 § 2, 2014)

8.21.050 Voluntary emissions standard and educational program.

Repealed by Ord. 2012-09. (Ord. 2011-03 § 9, 2011)

8.21.060 Enhanced SFBA change out program.

Repealed by Ord. 2014-10. (Ord. 2013-35 § 2, 2013)

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[1] Code reviser's note: Section 4 of Ordinance 2014-10 provides: "This ordinance shall be effective at 5:00 p.m. of the first Borough business day following its adoption except that the amendment expanding the program outside the borough's $PM_{2.5}$ nonattainment area by deleting the geographically limiting eligibility language in FNSB 8.21.035 (3) is effective January 1, 2015."

By:	John Davies
	Kathryn Dodge
	Janice Golub
Introduced:	01/15/2015
Advanced:	01/15/2015
Substituted:	02/12/2015
Amended:	02/12/2015
Amended:	02/26/2015
Amended:	02/27/2015
Adopted:	02/27/2015
Immediate Reconsideration Failed:	02/27/2015
Adopted:	02/27/2015

FAIRBANKS NORTH STAR BOROUGH

ORDINANCE NO 2015 - 01

AN ORDINANCE AMENDING CHAPTER 8.21 OF THE FNSB CODE OF ORDINANCES REGARDING THE PM2.5 AIR QUALITY CONTROL PROGRAM, AMENDING 2.48.120 REGARDING THE AIR POLLUTION CONTROL COMMISSION'S DUTIES, AND AMENDING 1.04.050 REGARDING THE FINE SCHEDULE TO ADD VIOLATIONS OF THE PM2.5 AIR QUALITY CONTROL PROGRAM

WHEREAS, EPA, on December 22, 2008, declared part of the Fairbanks North Star Borough a non-attainment area for fine particulate pollution ($PM_{2.5}$); and

WHEREAS, in the winter, $PM_{2.5}$ concentrations in the non-attainment area routinely exceed the allowable limit, thereby violating the federal health-based standards; and

WHEREAS, an excessive level of $PM_{2.5}$ impacts the health and well-being of borough residents; and

WHEREAS, air quality issues could impact large scale economic development, including military expansion; and

WHEREAS, studies have identified wood burning as a significant contributor of $PM_{2.5}$, particularly wood with high moisture content; and

WHEREAS, the combined effort of an educational program concerning the importance of burning only dry wood and an increase in the availability of dry wood could significantly reduce Borough $PM_{2.5}$ levels; and

WHEREAS, $PM_{2.5}$ emissions from solid fuel burning appliances can be significantly reduced through the selection and proper use of modern, EPA rated models designed to meet more stringent emissions standards and by operating in accordance with “best practices”, including selection of appropriate fuel sources; and

WHEREAS, voluntary, incentive-based programs coupled with comprehensive education programs have been employed in other communities to help reduce $PM_{2.5}$ emissions; and

WHEREAS, voluntary measures may enable the Borough to model attainment, however, it is likely that they would take more than five years to reach this goal and they would not address local neighborhood problems arising from one or two significant polluters, neither of which is acceptable; and

WHEREAS, the State of Alaska, through a Memorandum of Agreement with the Borough, has authorized the Fairbanks North Star Borough to establish and administer an area-wide local $PM_{2.5}$ air quality control program that will operate in lieu of and consistent with the State’s air quality program; and

WHEREAS the State of Alaska Department of Environmental Conservation has issued draft regulations intended to be part of the State Implementation Plan (SIP) as required by the EPA; those regulations provide some new restrictions on the sale of solid fuel burning appliances and firewood, and authorize the borough to take on additional regulatory responsibility related to the SIP; and

WHEREAS, at the recent “Town Hall” on the $PM_{2.5}$ problem, more than 50 citizens provided testimony indicating that our air quality was not acceptable and that they expected the Assembly to act to put into place programs that will improve the air quality in the borough.

WHEREAS, it is the intent of the Fairbanks North Star Borough Assembly to respond to calls for regulations that will help improve the air quality within the borough by adopting a program that balances the need for clean air with the needs for economically heating our buildings; and

WHEREAS, in adopting this clean air program, it is the intent of the Assembly that it be enforced by concentrating on the most significant sources of PM2.5 pollution first, both for attainment within the Non-Attainment area and for significant local sources of pollution that affect adjacent and nearby properties; and

WHEREAS, in enforcing this clean air program, it is the intent of the Assembly that the focus be on assisting violators to come into compliance through the use of warning, education, and assistance provided through programs such as the enhanced solid fuel burning device change-out program.

NOW, THEREFORE, BE IT ORDAINED by the Assembly of the Fairbanks North Star Borough:

Section 1. This ordinance is of a general and permanent nature and shall be codified.

Section 2. The following definitions in FNSBC 8.21.010 Definitions are amended or added as follows:

"Advisory" means a notice issued by the FNSB Air Quality division when the division determines, using available data, that a PM2.5 concentration of 25 ug/m³ has, or will likely occur.

"Air Quality Control Zone" means the area of the Borough currently contained in the EPA designated non-attainment area, which uses the non-attainment area southern, western and eastern boundaries as modified by their respective intersection with the following northern boundary described as; beginning at the intersection of Isberg Road with Chena Ridge Road on the western boundary of the EPA designated non-attainment area, then following Chena Ridge Road back to Chena Pump Road and continuing north on the Parks Highway to Sheep Creek Road, then Sheep Creek Road to Miller Hill Road, then north on Miller Hill Road, then east on Yankovich, then north from Yankovich Road along the east boundary of the Large Animal Research Station to a point just north of its intersection with Nottingham drive and follows the ridge crest across Nottingham Estates to approximately the point where Swallow Drive intersects Dalton Trail to north on Dalton Trail to the crest of the Farmer's Loop Ridge, then follow the geographic crest of Farmer's Loop Ridge to its intersection with the New Steese Highway, then south east on Bennet Road, and along Steel Creek Road to the intersection of Chena Hot Springs Road, and Chena Hot Springs Road to the eastern boundary of the EPA designated non-attainment area.

"*Alert*" means a notice issued by the FNSB air quality division when the *division* determines, using available data, that a $PM_{2.5}$ violation of the 35 [MICROGRAMS PER CUBIC METER] ug/m^3 has, or will likely occur.

"Clean wood" means natural wood that has not been painted, varnished, or coated with a similar material, has not been treated with preservatives, and does not contain resins or glues as in plywood or other composite wood products.

"Construction and demolition debris" means a conglomeration of materials from construction, repair, remodeling or demolition of buildings and structures containing any prohibited fuels.

"*Episode*" means when conditions reach or are predicted to reach advisory or alert status.

"*Forecast*" means a description of the current dispersion conditions described as good, fair, or poor and including the expected $PM_{2.5}$ concentrations expressed in micrograms per cubic meter.

"Opacity" means the reduction in transmitted light through a column of smoke as measured by an observer certified in using EPA Reference Method 9 as defined by federal law.

Section 3. Section 8.21.020 **Borough listed appliances** shall be amended as follows:

A[N] *solid fuel burning appliance* shall be listed by the borough if:

A. The *solid fuel burning appliance* is certified by the U.S. Environmental Protection Agency as meeting the federal emissions [LIMIT STANDARD APPROPRIATE FOR THAT *APPLIANCE* OR IN THE CASE OF *HYDRONIC HEATERS* IS AT LEAST PHASE II QUALIFIED*]* rate of 2.5 grams of $PM_{2.5}$ per hour or less or for hydronic heaters, meets Phase II qualifications and has an annual average emission level rating equal to or less than 2.5 grams of PM2.5 per hour. For purposes of this section, "certified" means that the *solid fuel burning appliance* meets emission performance standards when tested by an accredited independent laboratory and labeled according to procedures specified by the EPA in 40 CFR 60 Subpart AAA; or

B. The *solid fuel burning appliance* is tested, including by use of a handheld or other portable device, by an accredited independent laboratory, or other qualified person or entity approved by the borough, establishing that it meets an [THE EPA] emissions [LIMIT STANDARD APPROPRIATE FOR THAT *APPLIANCE* OR AN EMISSIONS LIMIT STANDARD EQUIVALENT TO THAT OF A LISTED *APPLIANCE* IN A SIMILAR CATEGORY] rate of 2.5 grams of $PM_{2.5}$ per hour or less or for hydronic heaters the appliance has an annual average emission level rating equal to or less than 2.5 grams of PM2.5 per hour.

Section 4. Section 8.21.025 **Prohibited acts** shall be amended as follows:

[THE BOROUGH SHALL NOT, IN ANY WAY, REGULATE, PROHIBIT, CURTAIL, NOR ISSUE FINES OR FEES ASSOCIATED WITH THE *SALE*, DISTRIBUTION, OR OPERATION OF *HEATING APPLIANCES* OR ANY TYPE OF COMBUSTIBLE FUEL.]

A. Installation of certain solid fuel burning appliances in the non-attainment area. Within the non-attainment area no person shall install or allow the installation of a solid fuel burning appliance unless it is listed by the Borough as qualifying under this chapter and the installation complies with all other requirements imposed in this chapter. It is a separate violation to fail to remove a solid fuel burning appliance installed in violation of this chapter.

B. All persons owning and selling their property within the Air Quality Control Zone with an unlisted installed solid fuel burning appliance that will not be removed before sale must, if the solid fuel burning appliance was not listed by the Borough as qualifying

at the time of installation, provide a written disclosure to the buyer and to the Division prior to closing.

C. Visible Emissions Standard in the Air Quality Control Zone.

1. Standard. No person shall cause, permit, or allow the emission from a solid fuel burning appliance in the Air Quality Control Zone to create opacity greater than 20 percent for a period or periods aggregating more than 10 minutes in any hour except during the first 30 minutes after the initial firing of a cold unit when the opacity limit shall be less than 50 percent.

2. Procedures and Enforcement. When ambient weather and light conditions permit, methods and procedures specified by the EPA in 40 CFR 60 Appendix A reference method 9 (Visual determination of the Opacity of Emissions From Stationary Sources), or an alternative technology that replaces method 9, when the technology is available and the choice is feasible, upon request of the person being investigated, shall be used to determine compliance with this section. Smoke visible from a chimney, flue or exhaust duct in excess of the opacity standard for a period in excess of 30 minutes shall constitute prima facie evidence of unlawful operation of an applicable solid fuel burning appliance.

D. $PM_{2.5}$ Emissions Crossing Property Lines. No person shall cause or permit emissions from a solid fuel burning appliance to impact the resident(s) of a neighboring property through the creation of an emissions plume that:

1. crosses a property line

2. is observable using EPA method 22 (40 CFR 60 Appendix A), and

3. is 25ug/m^3 greater than the surrounding immediate vicinity background $PM_{2.5}$ level using methods defined by the Borough Division of Air Quality. For purposes of this subsection, the surrounding "immediate vicinity" means land within an area measured 1,200 feet in all directions from the boundaries of the emitting property.

E. Borough-Wide Installation Requirements for Hydronic Heaters.

1. Setback. Unless permitted by a variance, installing an approved pellet fuel burning appliance, or replacing an existing hydronic heater with a listed appliance, no person shall install or allow the installation of a hydronic heater located less than**:**

a. 330 feet from the closest property line, or

b. 660 feet from a school, clinic, hospital, or senior housing unit.

2. Any hydronic heater installed in violation of this section shall be immediately remedied or made inoperable and removed as soon as practicable; however, in no case shall the time of removal be longer than 180 days after notice from the Division of a violation.

F. Prohibited Fuels.

No person shall burn in the Borough any fuel, except coal in an appliance designed to use coal, which is not listed in the manufacturer's owner's manual as an acceptable fuel for that device or any of the following items in a solid fuel burning appliance:

1. Any wood that does not meet the definition of clean wood or has more than 20% moisture content,

2. Garbage,
3. Tires,
4. Materials containing plastic or rubber,
5. Waste petroleum products,
6. Paints and paint thinners,
7. Chemicals,
8. Glossy or colored papers,
9. Construction and demolition debris,
10. Plywood,
11. Particleboard,
12. Saltwater driftwood,
13. Manure,
14. Animal carcasses,
15. Asphalt products,
16. Flooring products.

G. Sales or Leasing of Solid Fuel Burning Appliances.

1. No person shall sell or lease a solid fuel burning appliance or barrel stove kit in the borough that does not meet the emissions limits established in 8.21.020 A. unless the buyer signs an affidavit, on a form prescribed by the Borough, that the appliance will not be installed or used in the Air Quality Control Zone. This section does not apply to appliances or stoves that transfer pursuant to a sale of property.

2. No person shall commercially sell or offer for sale or lease a solid fuel burning appliance in the borough unless the commercial seller or dealer provides the prospective buyer or lessee, prior to any sales or lease agreement, with a written notice, prepared or approved by the Division, that includes, but is not limited to, the following:

a. The fuel restrictions imposed in this chapter;

b. Proper installation, property location, operation, and maintenance of the appliance;

c. An advisory statement noting that operation of solid fuel burning appliances may not be appropriate in some areas due to terrain, meteorological conditions, or other relevant conditions that render the operation of the appliance a public nuisance or health hazard even though it is otherwise legally installed and operated, and

3. The written notice required in this section shall be signed and dated by the prospective buyer or lessee prior to purchase or lease to indicate receipt of the notification requirements of this section.

4. The commercial dealer or seller shall mail or otherwise provide a copy of the notice, any required affidavit, to the Division within thirty days of the sale. All commercial dealers or sellers shall also include with the notice documentation showing whether the appliance sold or leased meets the Borough's emissions standard.

H. Nuisance. No person within the Fairbanks North Star Borough shall cause or allow emissions of a solid fuel or waste oil burning appliance that are injurious to human life or to property or that unreasonably interfere with the comfortable enjoyment of life or

property. No person within the Fairbanks North Star Borough shall operate a solid fuel or waste oil burning appliance in a manner so as to create a public or private nuisance. A violation of a provision of this chapter is hereby declared to be a nuisance.

I. Other laws. Nothing in this section precludes other local jurisdictions from having more restrictive codes.

J. Penalties. Upon first conviction of an offense in this chapter, the penalty(ies)/fines(s) set forth in FNSBC Title 1 regarding violations of the PM2.5 air quality control program may be satisfied by completion within 60 days of a borough approved class covering PM2.5 health concerns, non-attainment, importance of dry wood and proper operation of solid fuel burning appliances. The borough may on its own initiative file notice of satisfaction of attendance requirements with the court, or the defendant may file a certificate of completion with the court within the applicable time frame.

Section 5. Section 8.21.040, **Forecasting exceedances and voluntary restrictions in the non-attainment area during an alert,** shall be amended as follows:

8.21.040 Forecasting exceedances and [VOLUNTARY] restrictions in the Air Quality Control Zone [NON-ATTAINMENT AREA] during an alert

A. During the winter months of October through March, the Borough shall issue a daily *$PM_{2.5}$ forecast* [at] by 4:30 p.m. [MONDAY THROUGH FRIDAY]. When the $PM_{2.5}$ concentration reaches the onset level for an episode and is expected to remain at that level for 12 hours or more, an alert or advisory will be declared. An alert or advisory may apply to the Air Quality Control Zone as a whole, or to one or more sub-areas designated by the division. Once an alert or advisory is declared, $PM_{2.5}$ control measures set forth in this section shall be implemented and continued until the alert or advisory is cancelled. There are three levels of episodes: Stage 1, 2 and 3. The obligations imposed in this sub-section do not require, absent specific funding for that purpose, any actions to be taken outside of the borough's normal business days and hours of operation.

B. The Division will notify local media to ensure the declared alert or advisory is broadcast. The Division shall also use social media and methods of direct communication such as text messages as feasible. Information within the notification will contain the $PM_{2.5}$ forecast, Stage level for areas, and actions required to reduce sources of $PM_{2.5}$. The obligations imposed in this sub-section do not require, absent specific funding for that purpose, any actions to be taken outside of the borough's normal business days and hours of operation.

[B]C. Stage 1: Voluntary Restrictions in the Air Quality Control Zone [NON-ATTAINMENT AREA] During an [ALERT] Advisory.

1. A Stage 1 air advisory is implemented when concentrations exceed or are forecasted to exceed 25ug/m^3.

[1]2. Residents shall be requested to voluntarily stop operation of solid fuel [BURNING APPLIANCES], pellet [STOVES], and waste oil burning appliance**s**, [AND] as well as masonry heaters and all outdoor burning that includes recreational fires such

as bonfires, campfires and the use of fire pits, non-permitted incinerators and burn barrels in the Air Quality Control Zone [NON-ATTAINMENT AREA].

[2. THE DIVISION WILL NOTIFY LOCAL MEDIA TO ENSURE THE DECLARED ALERT IS BROADCAST. INFORMATION WITHIN THE NOTIFICATION WILL CONTAIN THE PM FORECAST AND PROCEDURES TO REDUCE SOURCES OF PM.]

D. Stage 2: Required Restrictions in the Air Quality Control Zone During an Alert

1. A Stage 2 air alert is implemented when concentrations exceed or are forecasted to exceed 35ug/m^3.

2. Burning is permitted in all borough listed appliances. No fuel source may be added to the combustions chamber or firebox of any non-listed solid fuel burning appliance or waste oil burning appliance. Residents should rely instead on their home's alternate, cleaner source of heat (such as a gas or fuel oil fired furnace or boiler or electric baseboard heaters) until the Stage 2 air alert is cancelled.

3. If a building owner or other person with a property or managerial interest in the building has an approved "No Other Adequate Source of Heat" designation, the building owner is exempted from complying with the Stage 2 air alert restrictions for that building.

4. Outdoor burning is prohibited including non-permitted incinerators and burn barrels. This does not include recreational fires such as bonfires, campfires or ceremonial fires and the use of fire pits.

5. These restrictions shall not apply during a power failure.

E. Stage 3: Required Restrictions in the Air Quality Control Zone During an Alert.

1. A Stage 3 air alert is implemented when concentrations exceed or are forecasted to exceed 55ug/m3.

2. No fuel source may be added to the combustions chamber or firebox of any solid fuel burning appliances, masonry heaters, pellet fuel burning appliances, cook stoves, fireplaces, or waste oil burning appliances. No waste oil may be added to a waste oil burning appliance. Residents should rely instead on their home's alternate, cleaner source of heat (such as a furnace, boiler or electric baseboard heaters) the Stage 3 air alert is cancelled.

3. If a building owner or other person with a property or managerial interest in the building has an approved "No Other Adequate Source of Heat" designation the building owner is exempted from complying with the Stage 3 air alert restrictions for that building.

4. Outdoor burning is prohibited including non-permitted incinerators and burn barrels. This does not include recreational fires such as bonfires, campfires or ceremonial fires and the use of fire pits.

5. These restrictions shall not apply during a power failure or to listed appliances, masonry heaters or pellet fuel burning appliances when the temperature is below -15 as recorded at the Fairbanks International Airport.

Section 6. FNSB 2.48.120 **Powers and duties** of the Air Pollution Control Commission are amended as follows:

F. The commission may [SHALL] develop or review comprehensive plans for the prevention, abatement, and control of air pollution in the borough. Such plans may include recommendations on subjects including, but not limited to, transportation control measures, zoning, taxation, research, and public relations.

H. After a public hearing, the commission shall determine whether a person may receive a variance from the installation requirements of FNSB 8.21.020 E allowing them to install a hydronic heater. In determining whether to grant the variance, the commission shall consider the proposed location of the appliance, impact on surrounding neighborhood, emission levels of the appliance, terrain, meteorological conditions, and other relevant conditions that may render the operation of the appliance at that location a nuisance or a health hazard.

Section 7. A new section, Section 8.21.043, **No other adequate source of heat determination**, shall be added as follows:

A. A building-owner or other person with a property or managerial interest in the building may obtain a "No Other Adequate Source of Heat" determination from the Division if:

1. The building-owner(s) or other person with a property or managerial interest in the building applies with the Division on a form developed by the Division.

2. The building-owner(s) or other person with a property or managerial interest in the building files an affidavit with the application that the subject structure must be heated and the structure has no adequate heating source without using a solid fuel or waste oil burning appliance or that economic hardships require the applicant's use of a solid fuel or waste oil burning appliance or complying with a restriction would result in damage to property including damage to the appliance itself and its heating system components.

B. There shall be no fee for applying for or obtaining a determination.

C. It shall be a violation to submit a false affidavit for a "no other adequate source of heat" determination.

D. If the "no other adequate source of heat" appliance does not meet the standards set in this chapter, the Division shall provide the applicant with information concerning the borough's voluntary removal, replacement and repair program.

E. Applications denied by the division may be appealed to the Air Pollution Control Commission.

Section 8**.** FNSB 1.04.050 **Fine schedule** is amended to add the following:

Code Section	Offense	Penalty/Fine	Mandatory Warning Required
8.21.025(A)	Installation of an unlisted appliance	$500.00	No

8.21.025(A)	Failure to remove an unlisted appliance	$500.00	Yes
8.21.025(B)	Failure to disclose an unlisted appliance before sale	$500.00	No
8.21.025(C)	Violation of visible emissions standard 1st offense	$100.00	Yes
8.21.025(C)	Violation of visible emissions standard 2nd offense	$500.00	No
8.21.025(D)	Emissions crossing property lines 1st offense	$500.00	Yes
8.21.025(D)	Emissions crossing property lines 2nd offense	$1000.00	No
8.21.025(E)	Illegal installation of hydronic heaters	$500.00	No
8.21.025(E)	Failure to remove hydronic heaters	$500.00	No
8.21.025(F)	Use of prohibited fuels--1st offense	$100.00	Yes
8.21.025(F)	Use of prohibited fuels--2nd offense	$500.00	No
8.21.025(G)	Violation of commercial sale requirements	$500.00	No
8.21.040(D)	Violation of a stage 2 air alert restriction	$500.00	Yes
8.21.040(D)	Violation of a stage 3 air alert restriction	$1000.00	Yes
8.21.043	Filing a false affidavit	$500.00	No

Section 9. Effective Date. Except for FNSBC 8.21.025 G (Commercial Sales) which shall be effective 30 days after adoption, and FNSBC 8.21.025 B (sale of property) which shall be effective on May 1st, 2015, and FNSBC 8.21.025(F)(1) (requirement wood be 20% moisture content) which shall be effective on October 1, 2015. This ordinance shall be effective at 5:00 pm on the first Borough business day

following its adoption and shall have only prospective application, meaning no provision shall apply to any act, including installation or purchase of a solid fuel appliance completed prior to the effective date.

PASSED AND APPROVED THIS 27TH DAY OF FEBRUARY, 2015.

Karl Kassel
Presiding Officer

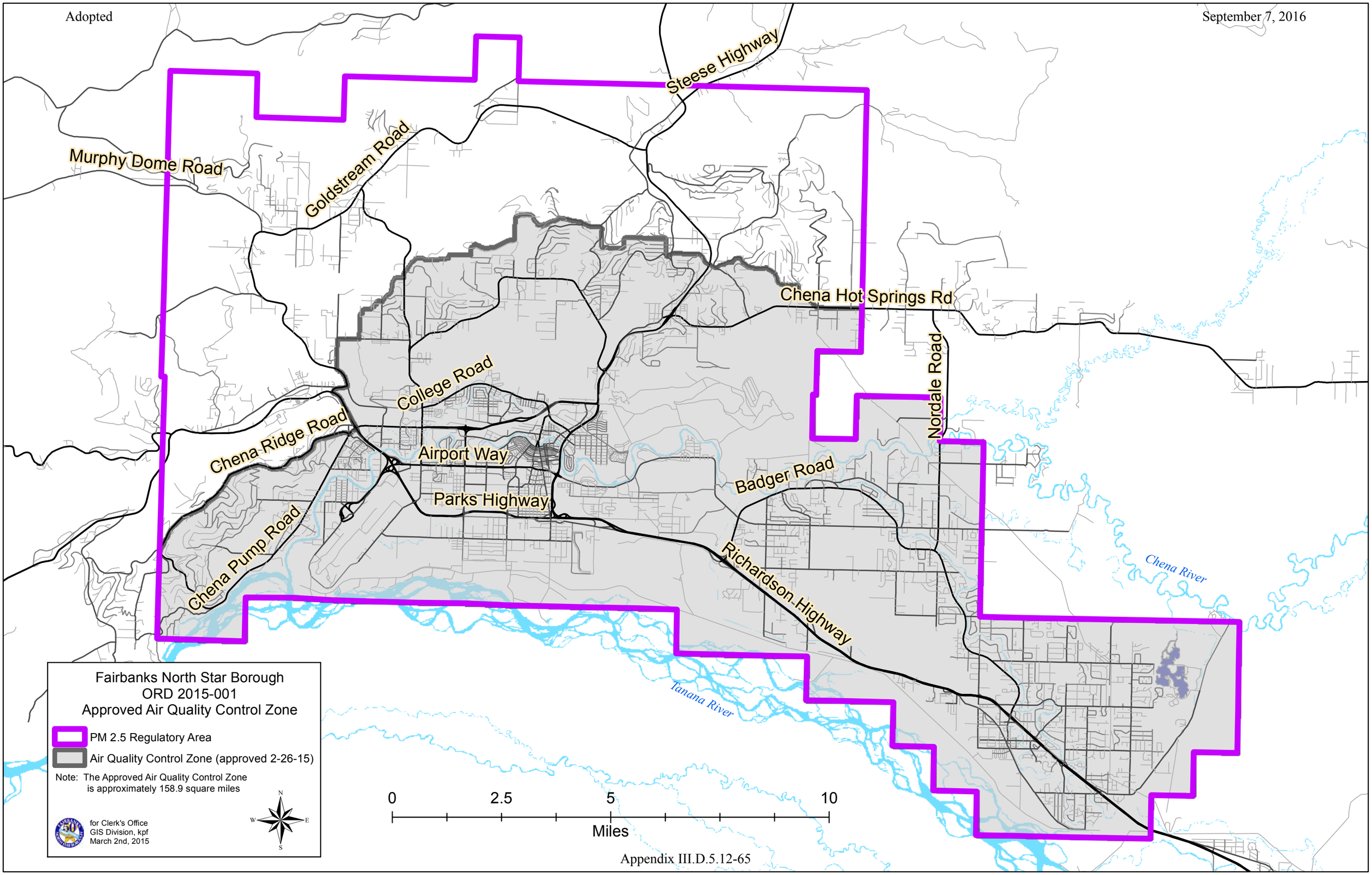
ATTEST:

Nanci Ashford-Bingham, MMC
Borough Clerk

Ayes: Golub, Hutchison, Lawrence, Dodge, Quist, Davies, Kassel
Noes: Sattley, Roberts

Adopted

September 7, 2016



By: Lance Roberts
Introduced: 04/09/2015
Advanced: 04/09/2015
Amended: 04/23/2015
Adopted: 04/23/2015

FAIRBANKS NORTH STAR BOROUGH

ORDINANCE NO. 2015 - 18

AN ORDINANCE AMENDING FNSBC 8.21.035 REGARDING THE ENHANCED VOLUNTARY REMOVAL, REPLACEMENT AND REPAIR PROGRAM, REMOVING THE ADDITIONAL FUEL PAYMENT FROM THE PROGRAM AND AMENDING FNSBC 8.21.045 REGARDING THE VOLUNTARY BURN CESSATION PROGRAM

WHEREAS, the Borough Assembly recently amended FNSBC 8.21.020 regarding borough listed solid fuel burning appliances so that the use of that defined term can now be substituted for the current lengthier description of an acceptable solid fuel burning appliance replacement for the enhanced voluntary removal, replacement and repair program ;and

WHEREAS, in order to maximize the limited funds available for the enhanced voluntary removal, replacement and repair program, it is necessary to remove the additional payment for the purchase of fuel; and

WHEREAS, the recently amended voluntary, removal, replacement and repair program largely replaces the separate voluntary burn cessation program and any funds intended to be spent on the cessation program could be more efficiently spent on the removal, replacement and repair program.

NOW, THEREFORE, BE IT ORDAINED by the Assembly of the Fairbanks North Star Borough:

Section 1. This ordinance is of a general and permanent nature and shall be codified.

Section 2. FNSBC 8.21.035, **Enhanced voluntary removal, replacement and repair program**, is hereby amended as follows:
The Fairbanks North Star Borough shall, to the extent funds are available and appropriated by the assembly, offer an enhanced removal, replacement and repair program to help offset the costs of removing, replacing or repairing a *solid fuel burning appliance* (SFBA) or *fireplace*. This program shall be subject to the following eligibility requirements, conditions, and criteria:

CODE *AMENDMENTS* ARE SHOWN IN LEGISLATIVE FORMAT
Text to be *added* is underlined
Text to be *deleted* is [BRACKETED AND CAPITALIZED]

A. General Requirements.

1. Application. An application approved by the *division* and signed by all property owner(s) must be submitted along with any documentation required by the *division*. Applicants must fully comply with the *division*'s inspection process which shall verify the existence of a qualifying SFBA or *fireplace*.

2. Priority Ranking. Applications may be prioritized and may be limited by the *division* in its discretion based on geographical location, the overall air quality benefit and the type of SFBA or *fireplace* being removed, replaced or repaired.

3. Eligibility. The program is limited to properties within the borough boundary in which a qualifying SFBA or fireplace is installed. If an application is approved for the program, the applicant will be given up to 90 days to meet all of the requirements. Applicants must have no delinquent property tax or penalty or interest owing at the time of application and at completion of the program requirements.

4. Additional Requirements. In addition to the general requirements set forth in this section, applicants must also meet the following requirements:

a. Fully comply with the inspection process required by the *division* that shall ensure that the existence of the qualifying *appliance* to be removed, replaced or repaired is properly documented.

b. Removal of *appliance*.

c. Delivery of *appliance* to an authorized decommission station.

d. Certificate of destruction delivered to the *division*, if applicable.

e. Final installation of a qualified *appliance* visually verified.

f. All aspects of this section may be performed by borough-approved personnel or a borough-approved vendor.

5. Payments. Applicants will be eligible for reimbursements or, at the option of the applicant, payment may be made directly to a borough-approved vendor. Reimbursements and payments shall be available as follows:

a. Replacement of an outdoor *hydronic heater*: With either a <u>borough listed solid fuel burning appliance</u> [N EPA CERTIFIED SFBA WITH AN EMISSION RATE LESS THAN OR EQUAL TO 2.5 GRAMS/HOUR, AN EPA PHASE II QUALIFIED PELLET BURNING *HYDRONIC HEATER* WITH AN EMISSION RATE EQUAL TO OR LESS THAN 0.2 POUNDS/MILLION BTUS], or an *appliance* designed to use pellets, home heating oil (excluding waste oil), natural gas, propane, hot water district heat, electricity or a *masonry heater* (including parts, labor and any costs associated with upgrading the chimney to the extent required by the manufacturer of the appliance for proper installation).

Appliance + Fuel Payment
Up to $10,000 for purchase and installation of the *appliance* plus fuel payment, if applicable.

b. Replacement of a non-borough listed [EPA certified] SFBA, or *fireplace[*, OR AN EPA CERTIFIED SFBA THAT HAS AN EMISSION RATE GREATER THAN 2.5 GRAMS/HOUR]: With either a borough listed solid fuel burning appliance [N EPA CERTIFIED SFBA WITH AN EMISSION RATE EQUAL TO OR LESS THAN 2.5 GRAMS/HOUR AND] that has an emission rate 50 percent or less than the replaced heater, or an *appliance* designed to use pellets, home heating oil (excluding waste oil), natural gas, propane, hot water district heat, electricity or a *masonry heater* (including parts, labor and any costs associated with upgrading the chimney to the extent required by the manufacturer of the appliance for proper installation). Multiple non-borough-listed *solid fuel burning appliances* or fireplaces, or combinations thereof, may be replaced with a single heating device that meets the requirements above, except for those that are fired by solid fuels. Payment will be based on the number of devices removed, up to a maximum of three, and may not exceed the replacement cost.

Appliance + Fuel Payment
Up to $4,000 per device for purchase and installation of the *appliance* plus fuel payment, if applicable.

c. Removal of a SFBA (limited to a one-time participation in this program per property).

Cash Payment
$2,000 – if removing outdoor *hydronic heater* $1,000 – if removing other SFBAs

d. Fuel Payment. [IF A *PELLET FUEL BURNING APPLIANCE* OR A *PELLET STOVE* IS PURCHASED AND INSTALLED UNDER THIS PROGRAM, THE APPLICANT IS ELIGIBLE TO RECEIVE AN ADDITIONAL $300.00 PAYMENT FOR THE PURCHASE OF PELLETS MANUFACTURED IN THE FAIRBANKS NORTH STAR BOROUGH.] If a wood burning *appliance* is purchased and installed under this program, the applicant is eligible to receive an additional $300.00 payment for borough-approved pressed wood energy logs manufactured in the Fairbanks North Star Borough.

e. Repair Program.

i. The repair program will pay for the:

(A) Replacement of a wood stove's catalytic converter that has exceeded its life span through the one-time payment of up to $750.00.

(B) Replacement of any emissions-reducing component of an EPA-certified wood stove up to the maximum amount of $750.00.

ii. In addition to the general requirements set forth in this section, applicants must fully comply with any inspection process required by the *division*, which may be performed by a borough-approved vendor.

Section 3. FNSBC 8.21.045, **Voluntary burn cessation program**, is hereby amended:

8.21.045 Voluntary burn cessation program.

The Fairbanks North Star Borough will, to the extent funds are available and appropriated by the assembly, establish a program to encourage, incentivize, and facilitate the voluntary cessation of the use of wood burning *appliances* (i.e., wood stoves, wood-fired *hydronic heaters*, wood-fired furnaces, *fireplaces*, *fireplace inserts*, *masonry heaters* or *pellet fuel burning appliances*) in the [*NONATTAINMENT AREA]* *air quality control zone* during *air quality alerts*. It is recognized that it will be difficult or impossible for some households to participate in this program (e.g., those that heat solely with wood or for which wood is a necessary supplement during periods of cold weather). Therefore, this program is intended for households that are able to use space heating alternatives with significantly lower $pm_{2.5}$ emissions, including those fueled by gas, oil, electricity, propane or district heat, but not wood or *pellet stoves* or other wood burning *appliances*. This program will at a minimum consist of the following components:

A. The borough may contract with an agency that will provide services to promote the program. This agency must have the standing, experience, and capability to carry out a campaign to advertise, reach out, and attract a large number of participants in the *nonattainment area* who are willing to cease the use of a wood burning *appliance* during *air quality alerts*.

B. [INCENTIVES WILL BE PROVIDED TO HOUSEHOLDS THAT PARTICIPATE IN THE PROGRAM. THESE INCENTIVES MAY INCLUDE THE PROVISION OF (1) A SIGN-UP BONUS SUCH AS CASH, A VOUCHER, OR GOODS AND SERVICES USEFUL TO A HOUSEHOLD THAT HEATS WITH WOOD; (2) A THANK-YOU LETTER, WINDOW OR YARD SIGN; OR, (3) OTHER FORM OF PUBLIC ACKNOWLEDGMENT. THE COST OF THIS INCENTIVE TO THE BOROUGH SHALL NOT EXCEED $25.00 PER HOUSEHOLD. THESE INCENTIVES MAY BE PROVIDED OR AUGMENTED BY PRIVATE CONTRIBUTIONS.

C.] Facilitation of this program by the borough will include, but not be limited to, the provision of notice of *air quality alerts* to individual households by methods such as electronic mail messages, text messages, automated phone calls, notices to radio and television stations, and information posted on electronic reader or display boards located throughout the borough in locations best suited to notify residents of *air quality alerts*.

[D]C. Private contributions, including goods and/or services, will be sought for all appropriate elements of the program. In general this will focus on the provision of materials, equipment, and certain one-time services, but not to fund borough staff positions.

Section 4. Effective Date. This ordinance shall be effective at 5:00 p.m. of the first Borough business day following its adoption.

PASSED AND APPROVED THIS 23RD DAY OF APRIL, 2015.

Karl Kassel
Presiding Officer

ATTEST:

Nanci Ashford-Bingham, MMC
Borough Clerk

Ayes: Golub, Sattley, Hutchison, Roberts, Lawrence, Dodge, Quist, Davies, Kassel
Noes: None

By:	Kathryn Dodge
	John Davies
Introduced:	04/23/2015
Advanced:	04/23/2015
Substituted:	06/25/2015
Amended:	06/25/2015
Adopted:	06/25/2015

FAIRBANKS NORTH STAR BOROUGH

ORDINANCE NO. 2015 – 29

AN ORDINANCE AMENDING FNSBC 8.21.025.B TO PERMIT FILING OF PROPERTY SALE WRITTEN DISCLOSURES WITH THE AIR QUALITY DIVISION AFTER THE RECORDING OF THE SALE AND AMENDING FNSBC 8.21.040 CONCERNING USE OF APPLIANCES THAT WERE BOROUGH LISTED AT THE TIME OF INSTALLATION DURING A STAGE 2 & 3 AIR ALERT

WHEREAS, As part of the recently adopted $PM_{2.5}$ Air Quality Control Program, borough code requires certain property sellers to provide written disclosures to the buyer and to the borough's Air Quality Division, prior to closing; and

WHEREAS, Although disclosure prior to closing serves to fully inform the buyer prior to purchase, disclosure to the borough can wait until after closing; and

WHEREAS, Because property transactions sometimes fail to close for a variety of reasons, waiting until after closing to provide a copy of the disclosures to the borough will potentially avoid an unnecessary step and ensure that the Borough receives accurate information.

NOW, THEREFORE, BE IT ORDAINED by the Assembly of the Fairbanks North Star Borough:

Section 1. Classification. This ordinance is of a general and permanent nature and shall be codified.

Section 2. Section 8.21.025.B, **Prohibited acts**, is amended as follows:

CODE *AMENDMENTS* ARE SHOWN IN LEGISLATIVE FORMAT
Text to be *added* is underlined
Text to be *deleted* is [BRACKETED AND CAPITALIZED]

B. All persons owning and selling their property within the Air Quality Control Zone with an [UNLISTED SOLID FUEL BURNING APPLIANCE] <u>installed non EPA certified solid fuel burning appliance, or for hydronic heaters non EPA Phase II qualifications,</u> that will not be removed before sale must[, IF THE SOLID FUEL BURNING APPLIANCE WAS NOT LISTED BY THE BOROUGH AS QUALIFYING AT THE TIME OF INSTALLATION,] provide a written disclosure to the buyer [AND TO THE DIVISION] prior to closing, <u>and a copy to the division no later than 10 days after the recording of the sale.</u>

Section 3. FNSBC 8.21.040, **Forecasting exceedances and restrictions in the air quality control zone during an alert**, is amended as follows:

A. During the winter months of October through March, the borough shall issue a daily $PM_{2.5}$ *forecast* by 4:30 p.m. When the $PM_{2.5}$ concentration reaches the onset level for an *episode* and is expected to remain at that level for 12 hours or more, an *alert* or *advisory* will be declared. An *alert* or *advisory* may apply to the *air quality control zone* as a whole, or to one or more sub-areas designated by the *division*. Once an *alert* or *advisory* is declared, $PM_{2.5}$ control measures set forth in this section shall be implemented and continued until the *alert* or *advisory* is cancelled. There are three levels of *episodes*: Stage 1, 2 and 3. The obligations imposed in this subsection do not require, absent specific funding for that purpose, any actions to be taken outside of the borough's normal business days and hours of operation.

B. The *division* will notify local media to ensure the declared *alert* or *advisory* is broadcast. The *division* shall also use social media and methods of direct communication such as text messages as feasible. Information within the notification will contain the $PM_{2.5}$ *forecast*, stage level for areas, and actions required to reduce sources of $PM_{2.5}$. The obligations imposed in this subsection do not require, absent specific funding for that purpose, any actions to be taken outside of the borough's normal business days and hours of operation.

C. Stage 1: Voluntary Restrictions in the *Air Quality Control Zone* During an *Advisory*.

1. A Stage 1 air *advisory* is implemented when concentrations exceed or are forecasted to exceed 25 $\mu g/m^3$.

2. Residents shall be requested to voluntarily stop operation of solid fuel, pellet, and waste oil burning *appliances*, as well as *masonry heaters* and all outdoor burning that includes recreational fires such as bonfires, campfires and the use of fire pits, nonpermitted incinerators and burn barrels in the *air quality control zone*.

D. Stage 2: Required Restrictions in the *Air Quality Control Zone* During an *Alert*.

1. A Stage 2 air *alert* is implemented when concentrations exceed or are forecasted to exceed 35 $\mu g/m^3$.

2. Burning is permitted in all [BOROUGH LISTED *APPLIANCES*] EPA certified solid fuel burning appliances, and EPA Phase II Qualified hydronic heaters with an annual average emission rating of 2.5 grams or less, masonry heaters, pellet fuel burning appliances, cook stoves, and fireplaces. No fuel source may be added to the combustions chamber or firebox of any [NONLISTED] *solid fuel burning appliance* or waste oil burning *appliance* not listed above. Residents should rely instead on their home's alternate, cleaner source of heat (such as a gas or fuel oil fired furnace or boiler or electric baseboard heaters) until the Stage 2 air *alert* is cancelled.

3. If a building owner or other person with a property or managerial interest in the building has an approved "no other adequate source of heat" designation, the building owner is exempted from complying with the Stage 2 air *alert* restrictions for that building.

4. Outdoor burning is prohibited including nonpermitted incinerators and burn barrels. This does not include recreational fires such as bonfires, campfires or ceremonial fires and the use of fire pits.

5. These restrictions shall not apply during a power failure.

E. Stage 3: Required Restrictions in the *Air Quality Control Zone* During an *Alert*.

1. A Stage 3 air *alert* is implemented when concentrations exceed or are forecasted to exceed 55 $\mu g/m^3$.

2. No fuel source may be added to the combustions chamber or firebox of any *solid fuel burning appliances*, *masonry heaters*, *pellet fuel burning appliances*, *cook stoves*, *fireplaces*, or waste oil burning *appliances*. No waste oil may be added to a waste oil burning *appliance*. Residents should rely instead on their home's alternate, cleaner source of heat (such as a furnace, boiler or electric baseboard heaters) until the Stage 3 air *alert* is cancelled.

3. If a building owner or other person with a property or managerial interest in the building has an approved "no other adequate source of heat" designation the building owner is exempted from complying with the Stage 3 air *alert* restrictions for that building.

4. Outdoor burning is prohibited including nonpermitted incinerators and burn barrels. This does not include recreational fires such as bonfires, campfires or ceremonial fires and the use of fire pits.

5. These restrictions shall not apply during a power failure or to [LISTED *APPLIANCES*] EPA certified solid fuel burning appliances, EPA Phase II Qualified hydronic heaters with an annual average emission rating of 2.5 grams or less, *masonry heaters* or *pellet fuel burning appliances* when the temperature is below -15 Fahrenheit as recorded at the Fairbanks International Airport.

Section 4. This ordinance is effective at 5:00 p.m. on the first Borough business day following its adoption except that Section 2 shall apply retroactively with an effective date of May 1st, 2015.

PASSED AND APPROVED THIS 25TH DAY OF JUNE, 2015.

Karl Kassel
Presiding Officer

ATTEST:

Nanci Ashford-Bingham, MMC
Borough Clerk

Ayes: Quist, Sattley, Hutchison, Lawrence, Dodge, Davies, Kassel
Noes: Roberts
Excused: Golub

CODE *AMENDMENTS* ARE SHOWN IN LEGISLATIVE FORMAT
Text to be *added* is underlined
Text to be *deleted* is [BRACKETED AND CAPITALIZED]

By: Karl W. Kassel, Mayor
Introduced: 12/10/2015
Advanced: 12/10/2015
Amended: 01/14/2016
Adopted: 01/14/2016

FAIRBANKS NORTH STAR BOROUGH

ORDINANCE NO. 2015-73

AN ORDINANCE AMENDING CHAPTER 8.21 OF THE FAIRBANKS NORTH STAR BOROUGH CODE OF ORDINANCES REGARDING THE PM2.5 AIR QUALITY CONTROL PROGRAM

WHEREAS, FNSB code of ordinances requires realty disclosures for all residences sold where an unlisted solid fuel burning device is installed, a requirement that to date has only produced two disclosures with zero solid fuel burning device change outs; and

WHEREAS, FNSB code of ordinances limits air quality complaint response to emissions from solid fuel burning appliances only; and

WHEREAS, In adopting a clean air program that is enforced by concentrating on the most significant sources of PM2.5 pollution, both for attainment within the Non-Attainment area and for significant local sources of pollution that affect nearby properties, the complaint response program would be better suited to all types of high particulate emitting sources; and

WHEREAS, On February 27th, 2015 the assembly adopted ordinance 2015-01 which created an Air Quality Control Zone, an area designated to refocus the FNSB woodsmoke mitigation efforts ; and

WHEREAS, The current code of ordinances dictates that the Enhanced Voluntary Removal, Replacement, and Repair Program be made available to all residences within the FNSB, an area larger than the non-attainment boundary and the Air Quality Control Zone; and

WHEREAS, The FNSB has made $500,000 of general fund balance money available for the woodstove change out program and the greatest air quality improvement can be achieved by applying it within designated hot spot areas; and

WHEREAS, The FNSB assembly and the State of Alaska has adopted a 20% moisture content requirement for cordwood as part of ordinance 2015-01; and

WHEREAS, Dirigo Laboratories conducted a series of tests detailing the benefits and limitations of mixing Superior Pellet Fuels energy logs with local cordwood, the largest benefits to stove emissions reductions were with wet wood which is now illegal within the borough; and

WHEREAS, The price of heating fuel has dropped to a 8 year low making it a more economical and cleaner to heat with oil instead of energy logs; and

WHEREAS, FNSB code allows a one-time cash payment for the removal of a solid fuel burning appliance, a benefit which could see larger participation with a higher incentive.

NOW, THEREFORE, BE IT ORDAINED by the Assembly of the Fairbanks North Star Borough:

Section 1. Classification. This ordinance is of a general and permanent nature and shall be codified.

Section 2. FNSB 8.21.020, **Borough listed appliances**, is amended as follows:

A solid fuel burning appliance shall be listed by the borough if:

A. The solid fuel burning appliance is certified by the U.S. Environmental Protection Agency as meeting the federal emissions rate of 2.5 grams of PM2.5 per hour or less or for hydronic heaters, meets Phase II qualifications and has [AN ANNUAL AVERAGE EMISSION LEVEL RATING EQUAL TO OR LESS THAN 2.5 GRAMS OF PM2.5 PER HOUR] an emission rating of 0.10 pounds per million BTU or less. For purposes of this section, "certified" means that the solid fuel burning appliance meets emission performance standards when tested by an accredited independent laboratory and labeled according to procedures specified by the EPA in 40 CFR 60 Subpart AAA; or

B. The solid fuel burning appliance is tested, including by use of a handheld or other portable device, by an accredited independent laboratory, or other qualified person or entity approved by the borough, establishing that it meets an emissions rate of 2.5 grams of PM2.5 per hour or less or for hydronic heaters the appliance has [AN ANNUAL AVERAGE EMISSION LEVEL RATING EQUAL TO OR LESS THAN 2.5 GRAMS OF PM2.5 PER HOUR] an emission rating of 0.10 pounds per million BTU or less.

Section 3. FNSB 8.21.025 C. 1. regarding the visible emissions standard is amended as follows:

1. Standard. No person shall cause, permit, or allow [THE] particulate emissions [FROM A SOLID FUEL BURNING APPLIANCE] from a non-mobile source in the air quality control zone to create opacity greater than 20 percent for a period or periods aggregating more than 10 minutes in any hour except during the first 30

minutes after the initial firing [OF A COLD UNIT] when the opacity limit shall be less than 50 percent.

Section 4. FNSB 8.21.025 D. is amended as follows:

D. PM2.5 Emissions Crossing Property Lines. No person shall cause or permit particulate emissions [FROM A SOLID FUEL BURNING APPLIANCE] from a non-mobile source to impact the resident(s) of a neighboring property through the creation of an emissions plume that:

1. Crosses a property line;
2. Is observable using EPA Method 22 (40 CFR 60 Appendix A); and
3. Is 25 µg/m3 greater than the surrounding immediate vicinity background PM2.5 level using methods defined by the borough division of air quality. For purposes of this subsection, the surrounding "immediate vicinity" means land within an area measured 1,200 feet in all directions from the boundaries of the emitting property.

Section 5. FNSB 8.21.025 H. is amended as follows:

H. Nuisance. No person within the Fairbanks North Star Borough shall cause or allow particulate emissions [OF A SOLID FUEL OR WASTE OIL BURNING APPLIANCE] from a non-mobile source that are injurious to human life or to property or that unreasonably interfere with the comfortable enjoyment of life or property. No person within the Fairbanks North Star Borough shall operate a solid fuel or waste oil burning appliance in a manner so as to create a public or private nuisance. A violation of a provision of this chapter is hereby declared to be a nuisance.

Section 6. FNSB 8.21.035 A. 1. Regarding applications for the enhanced voluntary removal, replacement and repair program is amended as follows:

1. Application. An application approved by the *division* and signed by all property owner(s) must be submitted along with any documentation required by the *division*. Applications for either the removal of a solid fuel burning appliance or replacement with an appliance designed to use natural gas, propane or home heating oil shall include a signed recordable document restricting future installations of solid fuel burning appliances and requiring appropriate notice to purchasers in the seller's disclosure statement. Applicants must fully comply with the *division*'s inspection process which shall verify the existence of a qualifying SFBA or *fireplace*.

Section 7. FNSB 8.21.035 A. 3., regarding eligibility for the enhanced voluntary removal, replacement and repair program is amended as follows:

3. Eligibility. The program is limited to properties within the [BOROUGH] air quality control zone boundary in which a qualifying SFBA or fireplace is installed. If an application is approved for the program, the applicant will be given up to 90 days to meet all of the requirements. Applicants must have no delinquent property tax or penalty or interest owing at the time of application and at completion of the program requirements.

Section 8. FNSB 8.21.035 A. 5., regarding payments for the enhanced voluntary removal, replacement and repair program is amended as follows:

5. Payments. Applicants will be eligible for reimbursements or, at the option of the applicant, payment may be made directly to a borough-approved vendor. Reimbursements and payments shall be available as follows:

a. Replacement of an [OUTDOOR] *hydronic heater*:

i. With either an [BOROUGH LISTED *SOLID FUEL BURNING APPLIANCE*, OR AN *APPLIANCE* DESIGNED TO USE PELLETS] EPA certified wood or pellet stove with an emission rate less than or equal to 2.0 grams of PM2.5 per hour, or an EPA phase II certified pellet burning hydronic heater with an emission rate equal to or less than 0.1 pounds per million BTU, up to $10,000 for purchase and installation of the appliance.

ii. With an appliance designed to use home heating oil (excluding waste oil) or a *masonry heater* (including parts, labor and any costs associated with upgrading the chimney to the extent required by the manufacturer of the *appliance* for proper installation), up to $12,000 for purchase and installation of the appliance.

iii. With an appliance designed to use natural gas, propane, hot water district heat, or electricity up to $14,000 for purchase and installation of the appliance. [OR A *MASONRY HEATER* (INCLUDING PARTS, LABOR AND ANY COSTS ASSOCIATED WITH UPGRADING THE CHIMNEY TO THE EXTENT REQUIRED BY THE MANUFACTURER OF THE *APPLIANCE* FOR PROPER INSTALLATION).

APPLIANCE + FUEL PAYMENT
UP TO $10,000 FOR PURCHASE AND INSTALLATION OF THE *APPLIANCE* PLUS FUEL PAYMENT, IF APPLICABLE

]

b. Replacement of a non-borough-listed SFBA or *fireplace*:

i. With either an [BOROUGH LISTED *SOLID FUEL BURNING APPLIANCE*] EPA certified wood stove, or fireplace insert that has an emission rate less than or equal to 2.0 grams of PM2.5 per hour, or in the case of an EPA certified wood stove, PM2.5 emissions must be reduced by 50 percent and emit 2.0 grams of PM2.5 per hour or less [THAN THE REPLACED HEATER], up to $4,000 for purchase and installation of the *appliance*.

ii. With[or]an *appliance* designed to use pellets, - up to $5,000 for purchase and installation of the appliance.

iii. With an *appliance* designed to use home heating oil (excluding waste oil), hot water district heat, electricity, or a *masonry heater* (including parts, labor and any costs associated with upgrading the chimney to the extent required by the manufacturer of the *appliance* for proper installation) up to $6,000 for the purchase and installation of the appliance.

iv. With an *appliance* designed to use natural gas[,] or propane up to $10,000 per purchase and installation of the appliance. [, HOT WATER DISTRICT HEAT, ELECTRICITY OR A *MASONRY HEATER* (INCLUDING PARTS, LABOR AND ANY COSTS ASSOCIATED WITH UPGRADING THE CHIMNEY TO THE EXTENT REQUIRED BY THE MANUFACTURER OF THE *APPLIANCE* FOR PROPER INSTALLATION).] Multiple non-borough-listed *solid fuel burning appliances* or *fireplaces*, or combinations thereof, may be replaced with a single heating device that meets the requirements above, except for those that are fired by solid fuels. Payment will be based on the number of devices removed, up to a maximum of three, and may not exceed the replacement cost.

[APPLIANCE + FUEL PAYMENT
UP TO $4,000 PER DEVICE FOR PURCHASE AND INSTALLATION OF THE *APPLIANCE* PLUS FUEL PAYMENT, IF APPLICABLE.]

c. Removal of a SFBA (limited to a one-time participation in this program per property).

Cash Payment
$5,000 [$2,000] – if removing [OUTDOOR] *hydronic heater* $2,000 [$1,000]– if removing other SFBAs

[D. FUEL PAYMENT. IF A WOOD BURNING APPLIANCE IS PURCHASED AND INSTALLED UNDER THIS PROGRAM, THE APPLICANT IS ELIGIBLE TO RECEIVE AN ADDITIONAL $300.00 PAYMENT FOR BOROUGH APPROVED PRESSED WOOD ENERGY LOGS MANUFACTURED IN THE FAIRBANKS NORTH STAR BOROUGH.]

Section 9. Effective Date. This ordinance is effective at 5:00 p.m. on the first Borough business day following its adoption.

PASSED AND APPROVED THIS 14TH DAY OF JANUARY, 2016.

John Davies
Presiding Officer

ATTEST:

Nanci Ashford-Bingham, MMC
Borough Clerk

Ayes: Cooper, Golub, Lawrence, Dodge, Quist, Davies
Noes: Roberts
Excused: Sattley, Hutchison

CODE *AMENDMENTS* ARE SHOWN IN LEGISLATIVE FORMAT
Text to be *added* is underlined
Text to be *deleted* is [BRACKETED AND CAPITALIZED]

By: Karl W. Kassel, Mayor
Kathryn Dodge
John Davies
Introduced: 07/28/2016
Advanced: 07/28/2016
Adopted: 08/11/2016

FAIRBANKS NORTH STAR BOROUGH

ORDINANCE NO. 2016-20-1A

AN ORDINANCE AMENDING THE FY 2016-17 BUDGET BY APPROPRIATING $290,400 FROM THE GENERAL FUND FUND BALANCE TO THE TRANSIT ENTERPRISE PROJECTS FUND TO DESIGN AND OPERATE AN AIR QUALITY MONITORING NETWORK

WHEREAS, In 2009 the Environmental Protection Agency (EPA) designated Fairbanks a “PM2.5 Non-Attainment” area; and

WHEREAS, The Fairbanks North Star Borough (FNSB) returned regulatory air quality monitoring responsibilities to the State of Alaska in FY 2017; and

WHEREAS, The FNSB has designed a community based Air Quality Monitoring Plan that will enhance real-time decision making and provide actionable inputs for improved air quality; and

WHEREAS, The FNSB Air Quality Division will integrate several different monitor types to identify, in real-time, high PM2.5 emissions sources, resulting in targeted and increased community engagement actions; and

WHEREAS, The last comprehensive Air Quality speciation study was conducted by the FNSB in 2013; and

WHEREAS, This funding will be used for, but not limited to, the purchase of a variety of monitor types, a maintenance and deployment contract, equipment hosting contracts, equipment operating supplies, and a speciation study; and

WHEREAS, This Community-Based Air Quality Monitoring Program is estimated to last three years and funding in subsequent fiscal years for operating the program (FY18 and FY19) are intended to be included in the Mayor’s recommended budgets for those years.

NOW, THEREFORE, BE IT ORDAINED by the Assembly of the Fairbanks North Star Borough:

Section 1. Classification. This ordinance is not of a general and permanent nature and shall not be codified.

Section 2. General Fund Appropriation. The FY 2016-17 budget is hereby amended by appropriating $290,400 to the General Fund budgetary guideline entitled "Contribution to Transit Enterprise Projects Fund" and by increasing Contribution from Fund Balance by a like amount.

Section 3. Transit Enterprise Projects Fund Appropriation. The FY 2016-17 budget is hereby amended by appropriating $290,400 to the Transit Enterprise Projects Fund budgetary guideline entitled "Community-Based Air Quality Monitoring Program" and increasing Contribution from General Fund by a like amount.

Section 4. Lapse of Funds. Upon completion or abandonment of the project, any unexpended, unencumbered funds will lapse to the General Fund fund balance.

Section 5. Effective Date. This ordinance is effective at 5:00 p.m. on the first Borough business day following its adoption.

PASSED AND APPROVED THIS 11TH DAY OF AUGUST, 2016.

John Davies
Presiding Officer

ATTEST:

Nanci Ashford-Bingham, MMC
Borough Clerk

Yeses: Cooper, Sattley, Hutchison, Westlind, Lawrence, Quist, Davies
Noes: Roberts
Other: Dodge (Excused)

By:	Van Lawrence
	Matthew Cooper
Introduced:	03/24/2016
Advanced:	03/24/2016
Substituted:	05/04/2016
Amended:	05/04/2016
Adopted:	05/04/2016

FAIRBANKS NORTH STAR BOROUGH

ORDINANCE NO. 2016-21

AN ORDINANCE AMENDING FNSB 8.21.025 TO REQUIRE THE REMOVAL OF CERTAIN UNLISTED HYDRONIC HEATERS IN THE AIR QUALITY CONTROL ZONE, AMENDING THE FY 2015-16 BUDGET BY APPROPRIATING $500,000 FROM THE GENERAL FUND FUND BALANCE TO THE TRANSIT ENTERPRISE PROJECTS FUND TO PAY FOR THE REMOVAL OF THE UNLISTED HYDRONIC HEATERS AND SUSPEND ALL OTHER PAYMENTS FROM THE VOLUNTARY REMOVAL AND REPLACEMENT PROGRAM UNTIL MAY 1, 2017

WHEREAS, Hydronic heaters that do not have an emissions rating of 0.10 pounds per million BTU or less cannot, under existing code, be legally installed in the borough's nonattainment area; and

WHEREAS, Certain hydronic heaters significantly contribute to the borough's air quality problem; and

WHEREAS, The Borough has offered in past years and continues to offer a removal program that pays homeowners to remove or replace these hydronic heaters; and

WHEREAS, The Borough needs to increase funding of the removal program and temporarily preclude other program spending in order to ensure funds are available to pay owners who are required to remove these unlisted hydronic heaters; and

WHEREAS, The imminent reclassification by the EPA of the Fairbanks North Star Borough from a Moderate to a Serious non-attainment area will result in the imposition of control measures, including expensive technology upgrades for power plants and other stationary sources, which will lead to insignificant improvement to air quality but will significantly increase utility rates; and

WHEREAS, The Borough's continued failure to significantly reduce PM2.5 pollution will further result in offset sanctions which will strangle economic development in the non-attainment area and highway sanctions eliminating federal funding of road projects within the non-attainment area; and

WHEREAS, These sanctions will be lifted if and when air quality violations cease.

NOW, THEREFORE, BE IT ORDAINED by the Assembly of the Fairbanks North Star Borough:

Section 1. Sections 2, 3 and 4 are of a general and permanent nature and shall be codified. Sections 5, 6 and 7 shall not be codified.

Section 2. FNSBC 8.21.025 B. is hereby amended as follows:

B. No person who has been convicted of or pled no contest to two or more violations of this chapter involving visible emissions or emissions crossing property lines shall, in the *air quality control zone, operate, use or keep installed a hydronic heater unless the hydronic heater is*:

1. Borough listed or was listed at the time of installation,

2. A closed combustion system with automatic components that feed solid fuel, including wood pellets, into a firebox where the combustion is enhanced by an active airflow system, or

3. Connected to a thermal mass system that is certified by the contractor or installer as sufficient to allow the hydronic heater to burn at maximum capacity minimizing on/off cycling. The division may require an owner to provide documentation supporting the certification.

This prohibition shall be effective 90 days after the 2nd conviction or entry or a no contest plea.

All persons owning and selling their property within the *air quality control zone* with an installed non-EPA-certified *solid fuel burning appliance*[, OR FOR *HYDRONIC HEATERS* NON-EPA PHASE II QUALIFICATIONS,]that will not be removed before sale must provide a written disclosure to the buyer prior to closing, and a copy to the *division* no later than 10 days after the recording of the sale.

Section 3. FNSBC 1.04.050, fine schedule, is amended to add the following:

Code Section	***Offense***	Penalty/Fine	Mandatory Warning Required
8.21.025(B)	Failure to remove, using or operating a prohibited hydronic heater. 1st offense.	$500	Yes, with removal as soon as practicable.
8.21.025(B)	Failure to remove, using or operating a prohibited hydronic heater. 2nd offense.	$1,000	No.

Section 4. General Fund Appropriation. The FY 2015-16 budget is hereby amended by appropriating $500,000 to the General Fund budgetary guideline entitled "Contribution to Transit Enterprise Projects Fund" and by increasing Contribution from Fund Balance by a like amount.

Section 5. Transit Enterprise Projects Fund Appropriation. The FY 2015-16 budget is hereby amended by appropriating $500,000 to the Transit Enterprise Projects Fund budgetary guideline entitled "Enhanced Voluntary Removal, Replacement, and Repair Program" and by increasing Contribution from General Fund by a like amount.

Section 6. Limited Use of Funds. All unencumbered funds remaining in the removal, replacement and repair program on the effective date of this ordinance may be spent only on payments to applicants within the air quality zone who are (1) removing or replacing an unlisted hydronic heater or (2) removing or replacing a woodstove that has been the subject of more than one substantiated neighborhood complaint and meeting additional criteria established by the Mayor. This restriction shall continue until May 1, 2017 or until the assembly appropriates additional funds to pay for the other removal, replacement or repairs authorized under the program, whichever occurs first.

Section 7. Lapse of Funds for the "Enhance Voluntary Removal, Replacement, and Repair Program". Upon completion or abandonment of the program, any unexpended and unencumbered funds will lapse to the General Fund fund balance.

Section 8. Effective Date. Sections 2, 3 and 4 of this ordinance shall be effective on October 1, 2016. The remaining sections shall be effective at 5:00 pm. on the first Borough business day following its adoption.

PASSED AND APPROVED THIS 4TH DAY OF MAY, 2016.

John Davies
Presiding Officer

ATTEST:

Nanci Ashford-Bingham, MMC
Borough Clerk

Ayes: Sattley, Hutchison, Cooper, Westlind, Lawrence, Dodge, Quist, Davies
Noes: Roberts

By: John Davies
Introduced: 04/14/2016
Advanced: 04/14/2016
Adopted: 04/28/2016

FAIRBANKS NORTH STAR BOROUGH

ORDINANCE NO. 2016-30

AN ORDINANCE AMENDING THE FAIRBANKS NORTH STAR BOROUGH CODE OF ORDINANCES TO ADOPT THE PROPOSED RENUMBERING AND REORGANIZATION

WHEREAS, Codification is a process of organizing and arranging all legislation of a permanent and general nature into Code and a recodification is any new replacement of the original Code; and

WHEREAS, The Fairbanks North Star Borough Code of Ordinances was first codified in 1975 and has since undergone two recodifications, the most recent in 2004; and

WHEREAS, It is necessary to routinely update a Code to ensure maximum usability, flexibility, amendibility and economy resulting in a Code that is easy to access, easy to understand, has room to grow and is simple and inexpensive to maintain; and

WHEREAS, The proposed recodification is a product of an extensive legal review by Code Publishing, Co. and the FNSB Legal Department to eliminate expired provisions, outdated references to state law, and conflicts with other code provisions or laws; and

WHEREAS, Following recodification, the Fairbanks North Star Borough Code of Ordinances will present an updated, orderly and logical composition of all permanent Borough legislation.

NOW, THEREFORE, BE IT ORDAINED by the Assembly of the Fairbanks North Star Borough:

Section 1. This ordinance is not of a general and permanent nature and shall not be codified.

Section 2. The Clerk is authorized to approve the attached Fairbanks North Star Borough Code proposed renumbering and reorganization plan prepared by Code Publishing Company and to take all other action necessary to implement the plan.

Section 3. The attached proposed renumbering and reorganization is adopted.

Section 4. Effective Date. Section 2 of this ordinance shall be effective at 5:00 p.m. of the first Borough business day following its adoption. Section 3 of the ordinance is effective July 15th, 2016.

PASSED AND APPROVED THIS 28TH DAY OF APRIL, 2016.

John Davies
Presiding Officer

ATTEST:

Nanci Ashford-Bingham, MMC
Borough Clerk

Ayes: Sattley, Hutchison, Cooper, Westlind, Roberts, Lawrence, Dodge, Quist, Davies
Noes: None

Fairbanks North Star Borough Code
Proposed Renumbering
Prepared by Code Publishing Company

2004 Code	New Code	New Name
	TITLE 1	GENERAL PROVISIONS
1.03.010 – 1.03.040, 1.03.110 – 1.03.160	1.04	Code Adoption – General Provisions
1.01	1.08	Borough Incorporation
1.02, 8.01.010, 8.01.020, 8.02.010	1.12	Borough Powers
2.60	1.16	Public Records and Privacy
1.04	1.20	Penalty Provisions
	TITLE 2	ADMINISTRATION AND PERSONNEL
2.04	2.04	Borough Mayor
2.16	2.08	Borough Administration Departments
2.19	2.12	Borough Attorney
2.28, 9.04	2.16	Emergency Management
2.05 (except 2.05.050)	2.20	Risk Management
2.32.042, 2.32.052	2.24	Library Director
2.36.070 – 2.36.100	2.28	Parks and Recreation
2.24	2.32	Personnel System
	TITLE 3	ASSEMBLY
2.08, 2.09.010(A) – (D) and (H), 2.09.020, 2.09.200	3.04	Borough Assembly
2.09.070, 2.20	3.08	Borough Clerk
1.03.050 – 1.03.100	3.12	Ordinances
2.09.030, 2.09.050, 2.09.060, 2.09.080, 2.09.090	3.16	Meetings
2.09.035	3.20	Agendas
2.09.010(E) – (G) and (I), 2.09.040, 3.01.200(C), 14.02.040(A)	3.24	Committees
	TITLE 4	BOARDS AND COMMISSIONS
2.21 (except 2.21.190)	4.04	General Provisions
2.63	4.08	Agricultural Commission
2.48	4.12	Air Pollution Control Commission
2.38, 6.14.020, 6.14.030	4.16	Animal Control Commission
2.10.040 – 2.10.110	4.20	Assembly Board of Ethics

Fairbanks North Star Borough Code
Proposed Renumbering
Prepared by Code Publishing Company

2004 Code	New Code	New Name
18.52.030, last three sentences of 18.56.025(C)	4.24	Board of Adjustment
3.24.002	4.28	Board of Equalization
2.37	4.32	Chena Riverfront Commission
2.100	4.36	Early Childhood Development Commission
2.75	4.40	Economic Development Commission
8.01.030, 8.01.050 – 8.01.070	4.44	Emergency Medical Services (EMS) Boards
2.67	4.48	Health and Social Services Commission
2.64	4.52	Historic Preservation Commission
3.04.130	4.56	Investment Advisory Committee
2.65	4.60	John A. Carlson Community Center Advisory Board
2.80	4.64	Land Management Advisory Commission
2.105	4.68	Landscape Review Board
2.32.012, 2.32.022	4.72	Library Commission
2.36.010 – 2.36.060	4.76	Parks and Recreation Commission
2.40, 18.52.020	4.80	Planning Commission
2.39	4.84	Platting Board
2.56	4.88	Public Transportation Advisory Commission
2.110	4.92	Recycling Commission
2.95	4.96	Road Service Revolving Loan Fund Board
2.70	4.100	Senior Citizens Advisory Commission
2.22	4.104	Salaries and Emoluments Commission
2.45	4.108	Sister City Commission
2.62	4.112	Trails Advisory Commission
2.90	4.116	Youth Commission
	TITLE 5	ELECTIONS
2.12.010 – 2.12.120, 2.12.780, 14.01.071	5.04	General Provisions
2.12.130 – 2.12.170	5.08	Voter Qualifications
2.12.180 – 2.12.270	5.12	Candidate Qualifications
2.12.280 – 2.12.315	5.16	Ballots

Fairbanks North Star Borough Code
Proposed Renumbering
Prepared by Code Publishing Company

2004 Code	New Code	New Name
2.12.320 – 2.12.455	5.20	Operation of Polls
2.12.460 – 2.12.510	5.24	Ballot Counting Procedures
2.12.520 – 2.12.620	5.28	Absentee Voting
2.12.630 – 2.12.680	5.32	Canvass Board and Certification of Election Results
2.12.690 – 2.12.730	5.36	Election Recount
2.12.740	5.40	Appeal or Judicial Review
	TITLE 6	CODE OF ETHICS
	Division 1.	Assembly Code of Ethics
2.10.330	6.04	Definitions
2.10.010 – 2.10.030	6.08	Purpose and Applicability
2.10.120	6.12	Violations
2.10.130	6.16	Gifts and Required Disclosure
2.10.150 – 2.10.300	6.20	Procedures
2.10.310, 2.10.320	6.24	Penalties and Remedies
	Division 2.	Code of Ethics for Boards and Commissions, Mayor and Borough Employees
2.21.190	6.28	Code of Ethics for Boards and Commissions
2.25	6.32	Code of Ethics for Mayor and Borough Employees
	TITLE 7	FINANCE
3.01 (except 3.01.200(C))	7.04	Fiscal Management
3.02	7.08	Grant Management
3.03	7.12	Budget Management
3.04 (except 3.04.130, 3.04.140)	7.16	Investment of Borough Funds
	TITLE 8	REVENUE AND TAXATION
	Division 1.	Property Taxes
3.08, 3.11.070, 3.12	8.04	General Provisions
3.10	8.08	Exemptions and Deferrals
3.11.010 – 3.11.060, 3.11.080	8.12	Criteria for Real Property Exemptions and Deferrals

Fairbanks North Star Borough Code
Proposed Renumbering
Prepared by Code Publishing Company

2004 Code	New Code	New Name
3.24.001, 3.28	8.16	Appeal – Remedies Available to Property Taxpayers Seeking Relief From Taxes Assessed or Paid
3.32	8.20	Delinquency and Foreclosure
3.36	8.24	Redemption, Sale and Repurchase
3.40	8.28	Statute of Limitations
	Division 2.	Other Assessments, Taxes and Fees
3.05	8.32	Special Assessment Procedures
3.46	8.36	Oil and Gas Property Tax
3.55	8.40	Borough Debt and Bonds
3.57	8.44	Tobacco Distribution Excise Tax
3.58	8.48	Hotel-Motel Room Tax
3.59	8.52	Alcoholic Beverage Tax
8.10	8.56	Solid Waste Collection District
3.50	8.60	User Fees
	TITLE 9	PUBLIC PEACE, MORALS AND WELFARE
9.12	9.04	Offenses Against Public Property
9.16	9.08	Liquor Licenses
9.17	9.12	Marijuana Regulation
9.20	9.16	Compulsory Attendance
8.07	9.20	Curfew for Minors
	TITLE 10	TRAFFIC AND VEHICLES
	Division 1.	Abandoned Vehicles – Vehicle Impoundment
8.14	10.04	Abandoned Vehicles
10.01	10.08	Vehicle Impoundment
	Division 2.	Permanent Motor Vehicle and Noncommercial Trailer Registration
10.02	10.12	Permanent Motor Vehicle and Noncommercial Trailer Registration
	TITLE 11	NATURAL GAS UTILITY
11.01.010, 11.01.030	11.04	Establishment of Utility and Management
	TITLE 12	STREETS AND SIDEWALKS
12.01	12.04	Protection of Public Roads and Areas

Fairbanks North Star Borough Code
Proposed Renumbering
Prepared by Code Publishing Company

2004 Code	New Code	New Name
12.02	12.08	Traffic Regulations
12.03	12.12	Street and Road Maintenance
14.03	12.16	Excavation and Construction on Public Roads Within Road Service Areas
	TITLE 13	STORM WATER DISCHARGE
21.20	13.04	Definitions
21.10	13.08	General Provisions
21.30	13.12	Illicit Discharge Detection and Elimination
21.40	13.16	Construction Site Storm Water Runoff Control
21.50	13.20	Post-Construction Storm Water Management
	TITLE 14	SERVICE AREAS AND COMMISSIONS
	Division 1.	General Provisions
14.01.011 – 14.01.061, 14.01.091 – 14.01.181 (except last sentence of 14.01.151(C))	14.04	General Provisions
14.01.081, 14.01.160, 17.60.200	14.08	Annexation and Boundaries
	Division 2.	Service Area District Councils
14.02.010, 14.02.020, 14.02.030, 14.02.040(B), 14.02.050	14.12	Service Area District Councils
	Division 3.	Service Area Creation, Powers and Commissions
14.08 (except 14.08.030, 14.08.110, 14.08.150, 14.08.155, 14.08.180, 14.08.230, 14.08.270, 14.08.275, 14.08.290, 14.08.300, 14.08.900)	14.16	Road Construction, Maintenance, and Improvement
14.08.110, 14.08.150, 14.08.155, 14.08.180, 14.08.290, 14.08.300, 14.08.900	14.20	Fire Protection

Fairbanks North Star Borough Code
Proposed Renumbering
Prepared by Code Publishing Company

2004 Code	New Code	New Name
14.08.030, 14.08.230, 14.08.270, 14.08.275	14.24	Utilities – Parks and Recreation
	TITLE 15	BUILDINGS AND CONSTRUCTION
15.04	15.04	Floodplain Management Regulations
	TITLE 16	PUBLIC PROCUREMENT AND SURPLUS
2.05.050, 3.04.140, 11.01.020, 16.21	16.04	Procurement Generally
16.25	16.08	Office of the Chief Procurement Officer
14.01.151(C) last sentence, 16.30	16.12	Source Selection and Contract Formation
16.35	16.16	Specifications
16.40	16.20	Construction Contract Management and Contract Administration
16.45	16.24	Bonds and Bid Security
16.50	16.28	Contract Clauses and Their Administration
16.55	16.32	Professional Services
16.60	16.36	Debarment or Suspension
16.65	16.40	Appeals and Remedies
16.70	16.44	Ethics in Public Contracting
	TITLE 17	SUBDIVISIONS
	Division 1.	General Provisions
17.20	17.04	Definitions
17.10	17.08	General Provisions
	Division 2.	Subdivision Applications and Approval Processes
17.30.010 – 17.30.030	17.12	Major Plats
17.30.040 – 17.30.060	17.16	Quick Plats
17.30.070 – 17.30.100	17.20	Waiver of a Plat
17.30.110, 17.30.120	17.24	Amendments
17.30.130 – 17.30.160	17.28	Right-of-Way Acquisition Plats
	Division 3.	Other Related Applications and Approval Processes
17.40.010 – 17.40.040	17.32	Vacations
17.40.050 – 17.40.080	17.36	Street Naming of Public Roads

Fairbanks North Star Borough Code
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2004 Code	New Code	New Name
17.40.090 – 17.40.120	17.40	Street Naming of Private Roads
17.50	17.44	Assurances for Completion
	Division 4.	Subdivision Requirements
17.60.010	17.48	Preliminary Plats
17.60.020 – 17.60.055	17.52	Final Plats
17.60.060 – 17.60.180	17.56	Design and Public Improvement Requirements
17.60.190, 17.60.210, 17.60.220, 17.60.230	17.60	Other Miscellaneous Requirements
	Division 5.	Variances – Appeals
17.70	17.64	Variances
17.80	17.68	Appeals
	TITLE 18	ZONING
18.06	18.04	Definitions
18.02	18.08	Comprehensive Plan
18.04	18.12	General Provisions
18.08	18.16	Zoning District Designations
18.10	18.20	OR Outdoor Recreational District
18.11	18.24	OSB Open Space Buffer District
18.14	18.28	RA-40, RA-20, RA-10 and RA-5 Rural and Agricultural Districts
18.16	18.32	RF-4 and RF-2 Rural Farmstead Districts
18.18	18.36	RE-4 and RE-2 Rural Estate Districts
18.20	18.40	RR Rural Residential District
18.22	18.44	SF-20, SF-10 and SF-5 Single-Family Residential Districts
18.24	18.48	TF Two-Family Residential District
18.26	18.52	MF Multiple-Family Residential District
18.28	18.56	MFO Multiple-Family Residential/ Professional Office District
18.32	18.60	LC Light Commercial District
18.34	18.64	GC General Commercial District
18.36	18.68	CBD Central Business District
18.38	18.72	LI Light Industrial District
18.40	18.76	HI Heavy Industrial District

Fairbanks North Star Borough Code
Proposed Renumbering
Prepared by Code Publishing Company

2004 Code	New Code	New Name
18.42	18.80	ML Mineral Lands District
18.44	18.84	GU-1 General Use District
18.45	18.88	GU-5 General Use District
18.48	18.92	Overlay Designations
18.50	18.96	Supplementary Regulations
18.52.010	18.100	Department of Community Planning
18.54	18.104	Amendments, Changes and Procedures
18.56 (except last three sentences of 18.56.025(C))	18.108	Nonconforming (Grandfathered) Uses and Lots
18.58	18.112	Enforcement and Penalties
Title 18 Appendix A	18.116	Geometric Standards
	TITLE 19	MOBILE HOMES
19.20	19.04	Definitions
3.16	19.08	Mobile Home Registration
19.10	19.12	Mobile Home Parks
3.44	19.16	Mobile Home Sales
	TITLE 20	LAND ACQUISITION, MANAGEMENT AND SALE
25.25.030	20.04	Definitions
25.25.010	20.08	Purpose
25.05	20.12	Land Acquisition
25.10	20.16	Land Management
25.15	20.20	Land Sale
25.20	20.24	Determining Which Borough Lands May Be Sold or Retained
	TITLE 21	HEALTH AND SAFETY
3.60, 8.03	21.04	Emergency Communication Services
8.05	21.08	Carbon Monoxide Emergency Episode Prevention Plan
8.06	21.12	Oxygenated Fuel
8.08	21.16	Fireworks
8.12	21.20	Garbage and Solid Waste
8.20	21.24	Vehicle Plug-In Program
8.21	21.28	$PM_{2.5}$ Air Quality Control Program

Fairbanks North Star Borough Code
Proposed Renumbering
Prepared by Code Publishing Company

2004 Code	New Code	New Name
	TITLE 22	ANIMALS
6.04.010	22.04	Definitions
6.04.020	22.08	Animal Control Management
6.06	22.12	Fees and Deposits
6.12	22.16	Impoundment
6.14.010	22.20	Animal Bite Incidents
6.16	22.24	Rabies Control
6.24	22.28	Unlawful Acts
6.04.030, 6.28	22.32	Enforcement – Penalties

Approved by borough: Nanci Ashford-Bingham (Name) 4-29-16 (Date)
Borough Clerk (Position)

By: Karl Kassel, Mayor
Introduced: 06/23/2016
Advanced: 06/23/2016
Amended: 07/28/2016
Adopted: 07/28/2016

FAIRBANKS NORTH STAR BOROUGH

ORDINANCE NO. 2016-37

AN ORDINANCE AMENDING TITLE 21 REGARDING NO OTHER ADEQUATE SOURCE OF HEAT DETERMINATIONS

WHEREAS, Borough code exempts qualifying buildings with no other adequate source of heat from compliance with certain air quality regulations; and

WHEREAS, Granting these exemptions only to buildings constructed prior to December 31, 2016 will encourage property owners to include an alternative source of heat in new construction for use during times of exceedances; and

WHEREAS, Because borough codes imposing restrictions on the use of solid fuel and other appliances during air alerts apply only to the air quality zone, only owners within the air quality zone need to apply for a “no other adequate source of heat” determination.

NOW, THEREFORE, BE IT ORDAINED by the Assembly of the Fairbanks North Star Borough:

Section 1. This ordinance is of a general and permanent nature and shall be codified.

Section 2. FNSBC 21.28.060 **No other adequate source of heat determination** is amended to read as follows:

A. A building owner or other person with a property or managerial interest in [THE] a building located within the air quality control zone may obtain a “no other adequate source of heat” determination from the division if:

1. The building owner(s) or other person with a property or managerial interest in the building applies with the division on a form developed by the division[.];

2. The building owner(s) or other person with a property or managerial interest in the building files an affidavit with the application that the subject structure must be heated and the structure has no adequate heating source without using a solid fuel or waste oil burning appliance or that economic hardships require the applicant’s use of a solid fuel or waste oil burning appliance or complying with a restriction would

result in damage to property including damage to the appliance itself and its heating system components[.]; and

3. The building was constructed on or before December 31, 2016.

B. There shall be no fee for applying for or obtaining a determination.

C. It shall be a violation to submit a false affidavit for a "no other adequate source of heat" determination.

D. If the "no other adequate source of heat" appliance does not meet the standards set in this chapter, the division shall provide the applicant with information concerning the borough's voluntary removal, replacement and repair program.

E. Applications denied by the division may be appealed to the air pollution control commission.

Section 3. Effective Date. This ordinance shall be effective at 5:00 p.m. of the first Borough business day following its adoption.

PASSED AND APPROVED THIS 28TH DAY OF JULY, 2016.

John Davies
Presiding Officer

ATTEST:

Nanci Ashford-Bingham, MMC
Borough Clerk

Yeses: Cooper, Sattley, Hutchison, Westlind, Lawrence, Dodge, Davies
Noes: Roberts
Other: Quist (Excused)

MEMORANDUM OF UNDERSTANDING
BETWEEN
ALASKA DEPARTMENT OF ENVIRONMENTAL CONSERVATION
AND
FAIRBANKS NORTH STAR BOROUGH
FOR
AIR POLLUTION CONTROL

I. Purpose

The purpose of this memorandum of understanding is to clarify the joint responsibilities for air pollution control and monitoring within the Fairbanks North Star Borough with respect to $PM_{2.5}$ and for the maintaining and monitoring of carbon monoxide within the Fairbanks North Star Borough. The Alaska Department of Environmental Conservation (DEC) and the Fairbanks North Star Borough (Borough) have joint responsibility for air pollution control in the Fairbanks North Star Borough. The parties to this Memorandum of Understanding recognize that clear lines of responsibility must be established and maintained to maximize the efficient utilization of available resources and to provide the greatest protection to the public's health and safety. It is with this recognition that these two parties hereby enter into this agreement.

II. Major Stationary Sources

DEC will retain responsibility for permitting, inspection, surveillance, and enforcement of all currently permitted facilities under DEC authority, and for any new sources that require DEC permit approval under AS 46.14.

DEC will:

notify the Borough upon receipt of any permit applications or renewals for State Air Quality Permits for stationary sources located within the Borough, to allow sufficient time for Borough comment on such permitting activities;

respond to Borough requests during the Department permit review, for additional information from a permit applicant pursuant to 18 AAC 50 or the State Implementation Plan for Air Quality Control; and

provide information in a reasonable time period to the Borough in response to requests for information on permitted facilities.

The Borough will:

register with DEC's online system for public notice announcements when it becomes available; and

notify DEC when it desires information on a permitted facility, permit application or renewal.

III. Open Burning

DEC will be responsible for issuing approvals for open burning of materials from land clearing operations of 40 acres or greater, and for the open burning of petroleum-based materials or other materials in a way that gives off black smoke.

DEC will:

provide the Borough with copies of all open burning approvals issued by DEC for sites within the Borough; and

notify applicants to contact the Borough regarding the Borough Codes pertaining to open burning.

The Borough will:

provide DEC and the Division of Forestry with copies of a handout, designed for distribution to burn permit applicants, which outlines the Borough open burning regulations;

advise DEC and the Division of Forestry of any changes to the Borough's open burning regulations and permit procedures; and

conduct an advertising campaign designed to educate the public regarding any significant changes in the Borough's open burning regulations and permit procedures.

IV. Area Source Control Programs

The Borough and DEC recognize that many small stationary pollution emission sources have the potential to collectively impact air quality. These small sources are categorized as area sources by EPA and DEC and may be regulated by local, state, or federal rules, but are not typically permitted by the DEC Air Permit program. They include, but are not limited to, the following types of sources: solid fuel-fired heating devices, commercial and residential space heating, small sources that fall below permitting thresholds, and fugitive dust sources.

The Borough will:

take the lead in developing and implementing local control programs to address pollution from area sources and will notify and consult with DEC regarding local control programs being considered for implementation to

insure coordination with any existing state programs or regulations .

DEC will:

notify and consult with the Borough regarding any proposed state area source programs or regulations that could impact a local control program or activities within the Borough; and

provide technical assistance related to state and federal requirements that could impact development and implementation of a local control program.

The Borough and DEC will:

look for opportunities to share data related to area sources that can further technical efforts in assessing air quality impacts;

jointly determine whether, and when, the two agencies will need to coordinate on implementation of an area source program;

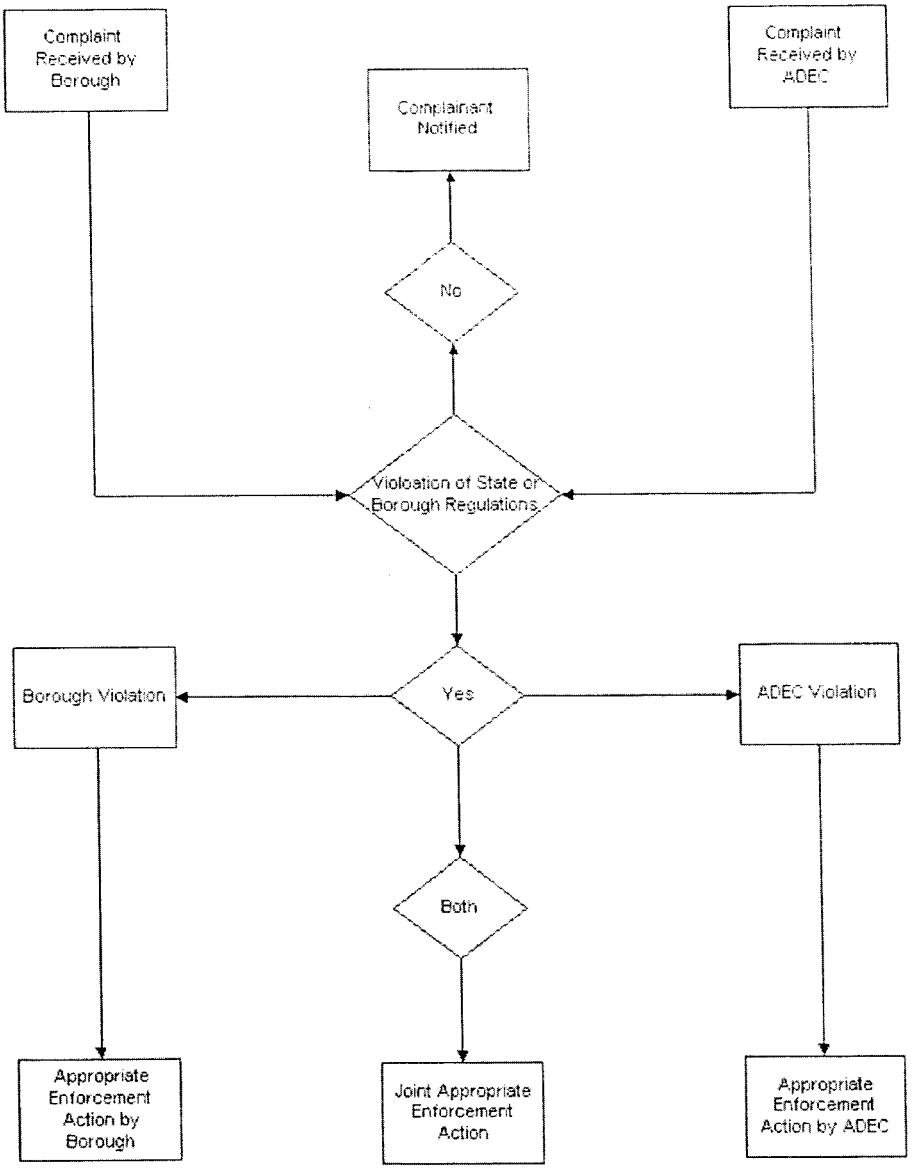
jointly determine the roles and responsibilities for each agency in implementing any coordinated area source program;

upon agreement by both agencies as to the roles, responsibilities, funding, and any other essential details of a coordinated area source program, work cooperatively to implement the program; and

amend this agreement, as soon as practical, to incorporate the relevant details related to an approved area source program so that clear lines of responsibility are delineated.

V. Complaint Response

DEC and the Borough will continue to respond jointly to public complaints regarding air pollution within the Borough. The flow chart delineates the course of action to be used in assessing the need for appropriate enforcement actions.



As indicated above, both DEC and the Borough will be responsible for assessing whether or not an air quality complaint received by their respective agency is a violation of either Borough or State regulations. This will necessitate close communication between the agencies regarding each other's regulations. Once it is determined whether or not either, or both, State or Borough regulations are being, or have been violated, the appropriate agency will take the lead role in enforcement action.

Complaints received by DEC related to permitted stationary sources will be handled by DEC. If the Borough is interested in any complaints regarding permitted facilities, the Borough will contact DEC and DEC will provide the information.

VI. Ambient Air Monitoring/Air Quality Forecasting

The Borough will maintain and operate the network of carbon monoxide (CO) and fine particulate ($PM_{2.5}$) ambient air monitors to identify and describe existing air quality conditions within the Borough. The Borough will review monitoring needs with DEC and EPA in consideration of resources available for the purpose of assigning monitoring priorities. The Borough will continue to provide recorded daily ambient air quality forecasts during the period of October 1 through March 31 each winter. DEC will provide technical support and quality assurance related to the ambient air monitoring network.

Close communication and cooperation between the agencies is necessary to share information on ambient air conditions to determine the need for issuing an air quality advisory, or declaring an air episode due to anthropogenic or natural events.

DEC will:

continue to provide technical assistance to the Borough in the areas of ambient air monitoring science, instrument operation, and quality assurance;

send to the Borough copies of correspondence and applicable materials associated with air quality monitoring work performed by DEC within the Borough and air monitoring information received from EPA or other sources which may be of interest to the Borough;

notify the Borough as to reporting requirements, due dates, etc.;

review and approve in writing monitoring site locations as required;

provide, or facilitate in-state, technical assistance and training as time and funding allows;

perform quarterly audit tests on the Borough's air quality monitoring network;

assist Borough staff with field monitoring during periods of Borough staffing problems as time and funding allows;

provide filter weighing operations for the analysis of particulate filters;

loan air monitoring equipment, shelters and supplies for use in FNSB seasonal monitoring studies, based on availability;

replace air monitoring equipment (e.g. CO, PM, meteorological monitors,

data loggers) in future years, based on state amortization priorities and available funding;

work cooperatively with the Borough to select the State's NCORE site, to be located in Fairbanks;

provide assistance for major repairs to air monitoring equipment to insure minimum down time for instrumentation during catastrophic failures; and

conduct an annual monitoring network assessment and develop recommendations for any changes which may be necessary in coordination with the Borough and EPA.

The Borough will:

operate and maintain the CO and $PM_{2.5}$ ambient air and meteorological monitoring network as required in accordance with state and federal regulations, guidelines, and the yearly DEC/EPA and Borough Air Programs work plan;

operate and maintain the PM2.5 speciation monitor in accordance with state and federal regulations, guidelines, and the yearly DEC/EPA and Borough Air Programs work plan;

conduct special air monitoring studies of criteria pollutants to identify/better define air quality problem areas, as funding and staff allow;

maintain instruments and equipment in good working order subject to available funding. In the event that funding is reduced DEC/FNSB will discuss and mutually agree before deferring maintenance;

submit to DEC in writing for approval any desired/required changes in the monitoring network;

maintain trained staff capable of operating and maintaining monitoring equipment and coordinate training needs with DEC to identify potential local and in-state training opportunities;

participate in the State's air quality data quality assurance program, and submit required data to DEC and/or EPA;

submit annual/quarterly air quality monitoring data to DEC within 30 days after the end of a quarter, to include but not be limited to CO and $PM_{2.5}$;

work cooperatively with DEC to select the State's NCORE site, to be located in Fairbanks;

continue to implement, as needed, the Borough's emergency episode

prevention and response plan for CO;

provide a recorded daily CO forecast during periods of poor air quality, when CO concentrations are of concern. The daily CO forecast will also be provided on the Borough web page and phone system for media and the general public; and

provide a recorded weekly $PM_{2.5}$ forecast to address potential impacts during the summer wildfire season and the winter $PM_{2.5}$ season. A daily forecast will be provided during periods of poor air quality. The $PM_{2.5}$ forecast will also be provided on the Borough web page and phone system for media and the general public. As part of that forecast, provide a description of the air dispersion (poor, fair, or good) forecast for each day, with weekend and holiday projections made the previous Friday.

VII. Air Quality Planning

The Borough will continue its efforts to maintain the national ambient air quality standard for carbon monoxide and work towards meeting attainment for fine particulate matter ($PM_{2.5}$). This will include the study and possible implementation of reasonable, cost-effective strategies designed to reduce ambient air pollutant concentrations which will allow the Borough to maintain the carbon monoxide standard and attain the $PM_{2.5}$ standard.

DEC will:

provide technical and administrative assistance to the Borough;

- in the area of maintenance of the national ambient air quality standard for carbon monoxide; and
- In the area of development of the attainment plan for $PM_{2.5}$

work with the Borough to develop additional programs that will;

- aid the Borough in maintaining the health based standard for carbon monoxide in the Fairbanks area, subject to available funding;
- aid the Borough in attaining the health based standard for $PM_{2.5}$ in the Fairbanks area, subject to available funding; and
- assist the Borough in its dealings with EPA, particularly in the development of additional strategies to reduce ambient air pollutant levels in the Fairbanks area.

The Borough will:

continue its efforts to maintain the national ambient air quality standard for carbon monoxide;

update the CO maintenance plan per the Clean Air Act requirements or as

needed to address local objectives;

continue its efforts to attain the national ambient air quality standard for $PM_{2.5}$.;

implement $PM_{2.5}$ strategies to attain the standard that are shown to be reasonable and cost effective;

assist DEC to study $PM_{2.5}$ concentrations at cold temperatures, and the resultant impact of $PM_{2.5}$ on the prospects for attaining and maintaining the $PM_{2.5}$ standard in Fairbanks, including potential use of new and innovative programs;

develop emission inventories as needed to support or implement $PM_{2.5}$ SIPs; and

take the lead in collaboratively developing with DEC a $PM_{2.5}$ attainment plan to bring Fairbanks into attainment with the national ambient air quality standard.

VIII. Mobile Source Control Programs

The Borough and DEC recognize that air pollution emissions from motor vehicles and other mobile sources have the potential to collectively impact air quality. Mobile sources are typically regulated by federal and state rules, but local programs can be beneficial in reducing emissions.

The Borough will:

take the lead in developing and implementing local control programs to address pollution from mobile sources and will notify and consult with DEC regarding local control programs being considered for implementation to insure coordination with any existing state programs or regulations;

DEC will:

maintain state regulations that allow a vehicle inspection & maintenance program to remain as a CO contingency measure in the Fairbanks CO maintenance plan as required by EPA;

notify and consult with the Borough regarding any proposed state mobile source programs or regulations that could impact a local control program or activities within the Borough; and

provide technical assistance related to state and federal requirements that could impact development and implementation of a local control program.

The Borough and DEC will:

look for opportunities to share data related to mobile sources that can further technical efforts in assessing air quality impacts;

jointly determine whether, and when, the two agencies will need to coordinate on implementation of an mobile source program;

jointly determine the roles and responsibilities for each agency in implementing any coordinated mobile source program;

upon agreement by both agencies as to the roles, responsibilities, funding, and any other essential details of a coordinated mobile source program, work cooperatively to implement the program; and

amend this agreement, as soon as practical, to incorporate the relevant details related to any approved mobile source program so that clear lines of responsibility are delineated.

IX. Dynamometer Testing System and Congestion Mitigation & Air Quality Projects

The Borough will:

use the test van, dynamometer, analytical equipment and support equipment for vehicle and cold weather testing projects as needed;

share data collected from all studies utilizing the dynamometer testing system;

with adequate notice, provide DEC access to the dynamometer testing system for special projects; and

provide DEC the opportunity to reclaim the dynamometer testing system.

DEC will:

notify the Borough 90-days prior to the department's need to use the dynamometer testing facility for special projects; and

share data collected from all studies utilizing the dynamometer testing system.

DEC and the Borough will:

coordinate requests for CMAQ projects; and

jointly determine roles and responsibilities for implementing CMAQ projects

at the time that the projects are submitted to the metropolitan planning organization or Department of Transportation for funding.

X. Notice/Project Contacts

For purposes of this agreement each agency will identify a project manager who will have overall responsibility for management of the agreement. The project managers may designate and identify in writing to the other agency, other staff with responsibility for implementing specific activities under the agreement.

For purposes of this agreement DEC's project manager is,

Alice Edwards, Acting Director, Division of Air Quality

For purposes of this agreement, the Borough's project manager is,

Glenn Miller, Director, Department of Transportation

All project work plans and approvals shall be submitted through the project managers designated in this section.

Parties agree to notify each other in writing of changes in project manager or activity managers within 10 days of change.

XI. Budgetary

DEC and the Borough shall negotiate annually funding agreements for the coming year. These annual funding agreements will be negotiated between the DEC Air Quality Director and the FNSB Director of Transportation. Future year appropriations shall be discussed and operational costs agreed upon no later than January 31st of each year to assist with annual budget development. The annual funding agreements shall be documented in writing and make specific reference to this Memorandum of Understanding.

DEC shall:

provide each year that the conditions of this Memorandum of Understanding are met, a total of $54,000 per year for the work described in the approved annual work plan and up to $18,500 per year for operation and maintenance of the PM2.5 speciation sampler (to be negotiated annually); and

make, upon receipt of a request for reimbursement which shows at least 50 percent of the local match funds have been expended, an initial payment of $40,000. The balance will be provided upon completion of the work identified in the approved annual work plan, for each fiscal year, and the

submission of a final Financial Status Report which identifies the total program expenditures.

The Borough shall:

adhere to applicable sections of 40 CFR 30, 31, 32, 33, and 35, Subpart A. The principal "parts" of 40 CFR, Chapter 1, Subchapter B, and Part 32 "Debarment and Suspension Under EPA Assistance Programs"; Part 31 "Uniform Administrative Requirements for Grants and Cooperative Agreements to State and Local Governments"; and Part 32 "Debarment and Suspension Under EPA Assistance Programs";

comply with the requirements of the Single Audit Act (OMB Circular A128);

file a preliminary financial status report on or before August 20 each-year;

file a final financial status report on or before September 20 each year;

inventory and track all equipment purchased. Disposal shall be in accordance with current federal requirements. Purchase of equipment exceeding $3,000 for a complete unit must be approved by DEC in advance of purchase;

when issuing statements, press releases, requests for proposals, bid solicitations, and other documents describing projects or programs funded in whole or in part with grant money, clearly state (a) the percentage of the total cost of the program or project which will be funded with grant money, and b) the dollar amount of grant funds for the project or program;

make a good-faith effort to maintain a drug-free work place by publishing a statement notifying employees that manufacturing, distributing, dispensing, possessing, or using a controlled substance in the work place is prohibited;

when issuing contracts, ensure all contractors and subcontractors have a valid Alaska business license;

provide for DEC representation on committees reviewing RFPs and contract awards using DEC pass through or DEC grant and Borough funds;

submit copies of signed subcontracts and purchase orders between FNSB and minority/women construction and supply firms on a quarterly bases;

ensure that no portion of this award may be used for lobbying or propaganda purposes as prohibited by 18 U.S.C. Section 1913 or Section 607(a) of Public Law 96-74;

ensure that the cost principles of OMB Circular A-87 are applicable to this award. When indirect costs are included within the assistance budget, the

recipient must be in compliance with A-87 and EPA regulations regarding allowable project costs. Actual indirect costs charged to this agreement may not exceed the final approved rates as negotiated annually between the State and the appropriate cognizant federal agency;

in accordance with the Clean Air Act, Section 105 b(3) and EPA regulations, provide matching funds to support the programs which are at least equal to the local matching funds spent in the prior year; and

spend local matching funds on at least a pro rata share with the understanding that local funds spent for the year must equal or exceed the amount spent in the previous year. Should the amount of local funds not equal or exceed the previous year's grant expenditures, the grant may be revoked. Unexpended grant funds shall revert to DEC to be reprogrammed (if prior to June 30 of each year) or returned to EPA according to federal law.

XII. It is mutually agreed:

1. that the Borough and DEC shall employ and maintain staff to carry out the activities necessary to administer the air quality programs outlined in this agreement;

2. that payments under this agreement require funds from future appropriations and are subject to future appropriations by the Borough Assembly and the state legislature;

3. that nothing in this agreement shall be construed as obligating DEC or the Borough to the expenditure of funds, or for the future payment of funds, in excess of that authorized by this agreement.

4. that the Borough may provide funding to DEC for performing special projects negotiated under this agreement.

5. that future year awards will be authorized only upon receipt of federal funds and upon an approved annual work plan, which must include lawfully appropriate detailed budget information, project period, and signature blocks for both parties.

6. that an interim financial status report will be filed on or before March 31 each year. The purpose is to determine if all grant funds will be expended by the end of the fiscal year (June 30). If grant funds will not be fully expended, DEC may restrict the amount of grant funds and reprogram the unexpended funds in accordance with EPA regulations.

7. that specific full-time equivalents listed for each task in the annual work plan are both parties' best estimate and only approximate; and

8. that amendments to this agreement may be proposed by either party and shall become effective upon approval of both parties.

XIII. Execution/Modification and Duration of Agreement

This amendment will be in effect upon signature by both parties until amended or revoked. The agreement may be terminated upon 90 days' written notice by either party. FNSB shall return all unexpended funds to DEC. In addition, all notes, data collected, equipment and any draft reports shall be submitted to DEC within 30 days of termination of this agreement by either party.

Alaska Department of
Environmental Conservation

By: _____
Larry Hartig
Commissioner

Date: 1/26/10

By: _____
Joanna McDowell
DEC Finance Officer

Date: 1/22/10

Fairbanks North Star Borough

By: _____
Luke Hopkins
Mayor

Date: 1/20/10

Reviewed by Legal Department
Date: 1/20/10
By: _____

FINAL

MEMORANDUM OF AGREEMENT FOR THE SELECTION AND FUNDING OF PROJECTS FUNDED BY CMAQ WITHIN THE FAIRBANKS NONATTAINMENT AREA FOR PM 2.5

Among the Alaska Department of Transportation and Public Facilities (ADOT&PF), the Fairbanks Metropolitan Area Transportation System (FMATS), the Fairbanks North Star Borough (FNSB) and the Alaska Department of Environmental Conservation (ADEC)

I. PURPOSE

A. This Memorandum of Agreement (MOA) is a written agreement among the Fairbanks area MPO (FMATS), state agencies (ADEC, ADOT&PF), and the designated air quality planning agency (Fairbanks North Star Borough, FNSB) describing their respective roles and responsibilities including project selection and CMAQ fund management necessary for air quality related transportation planning.

II. BACKGROUND

A. The U.S. Environmental Protection Agency (EPA) has designated the following townships and ranges of the Fairbanks North Star Borough as a non-attainment area for PM 2.5: -MTRS F001N001 – All sections; -MTRS F001N001E – Sections 2 – 11, 14 – 23, 26 – 34; -MTRS F001N002 – Sections 1 – 5, 8 – 17, 20 – 29, 32 – 36; -MTRS F001S001E – Sections 1, 3 – 30, 32 – 36; -MTRS F001S001W – Sections 1 – 30; -MTRS F001S002E – Sections 6 – 8, 17 – 20, 29 – 36; -MTRS F001S002W – Sections 1 – 5, 8 – 17, 20 – 29, 32 - 33; -MTRS F001S003E-Sections 31 - 32; -MTRS F002N001E- Sections 31 – 35; -MTRS F002N001-Sections 28, 31 – 36; -MTRS F002N002-Sections 32 - 33, 36; -MTRS F002S001E - Sections 1 - 2; -MTRS F002S002E - Sections 1 - 17, 21 – 24; -MTRS F002S003E - Sections 5 - 8, 18. A map of the non-attainment area is attached as Appendix A.

B. This PM 2.5 nonattainment designation became effective on December 14, 2009.

C. The above non-attainment area is larger than the FMATS Metropolitan Planning Area (MPA) illustrated in Appendix A as the MPO boundary.

D. 23 CFR 450.314(b) states that if the metropolitan planning area does not include the entire nonattainment or maintenance area, there shall be an agreement among the state department of transportation, state air quality agency, affected local agencies and the metropolitan planning organizations describing the process for cooperative planning and analysis of all projects outside the metropolitan planning area but within the nonattainment or maintenance area.

E. Further, 23 CFR 450.314(c) states that in the nonattainment area or maintenance areas, if the MPO is not the designated agency for air quality planning under section 174 of the Clean Air Act (42 USC 7504), there shall be a written agreement between the MPO and the designated air quality planning agency describing their respective roles and responsibilities for air quality related transportation planning.

III. AGENCY ROLES & RESPONSIBILITIES

A. ADEC

1. ADEC and the FNSB have joint responsibility for air pollution control in the FNSB.

2. ADEC will provide technical assistance in the development of the Fairbanks PM2.5 nonattainment area CMAQ transportation project listing.

3. ADEC will participate and be a member on the Fairbanks CMAQ Project Evaluation Board.

B. ADOT&PF Northern Region (NR)

1. NR will provide technical assistance in the development of the Fairbanks CMAQ transportation project listing.

2. NR will prepare and submit the PDAs to fund the selected projects, administer project funds to the appropriate implementing agency, and will assist in the development of the environmental documentation, design, right-of-way, utility and construction of selected projects as required.

3. NR will participate and be a member on the Fairbanks CMAQ Project Evaluation Board.

4. NR will issue an annual thirty-day Call for Nominations prior to January 31.

C. ADOT&PF Division of Program Development (HQ)

1. HQ will make Federal CMAQ funding available for eligible air quality projects in Fairbanks.

2. HQ will provide CMAQ funding for the purposes of travel demand modeling and conformity determination for the updates of the plans and programs and to include projects outside of the MPA in the nonattainment area. No local match is currently required. Should local match be required in the future, agreements will be developed through interagency consultation.

3. HQ will participate and be a member on the Fairbanks CMAQ Project Evaluation Board.

4. HQ will (subject to available CMAQ funding) include in the STIP all projects agreed to by the Fairbanks CMAQ Project Evaluation Board and submitted by the FNSB.

D. FMATS

1. FMATS will work with local agencies in developing and submitting projects to the Fairbanks CMAQ Project Evaluation Board.

2. FMATS will include all projects approved by the Fairbanks CMAQ Project Evaluation Board and submitted by the FNSB in the informational section of the TIP.

3. FMATS will participate and be a member on the Fairbanks CMAQ Project Evaluation Board.

E. FNSB

1. FNSB and the ADEC have joint responsibility for air pollution control in the FNSB.

2. FNSB is the lead air quality agency for the Fairbanks area and will determine the priorities for the CMAQ funding provided to the PM2.5 nonattainment area.

3. FNSB will provide to the NR a list of PM 2.5 CMAQ transportation projects for the PM2.5 nonattainment area for inclusion in the STIP.

4. FNSB will participate and be a member on the Fairbanks CMAQ Project Evaluation Board.

IV. CMAQ PROJECT EVALUATION BOARD

A. Board membership

1. The Fairbanks CMAQ Project Evaluation Board (hereinafter Board) will have 7 members representing the following entities: ADEC, FMATS, City of Fairbanks, City of North Pole, FNSB, ADOT&PF (NR) and ADOT&PF (HQ). The Board may select a chair to facilitate evaluation discussions.

B. Project Evaluation Criteria

1. The Board will develop criteria to use in evaluating projects submitted to the Board.

2. The developed criteria will take into account eligible uses of CMAQ funding and consider the projects efficacy in addressing PM2.5 attainment.

3. Evaluation criteria will be provided to agencies for use in developing CMAQ project proposals for submittal to the Board.

C. Project Submission

1. Any member of the Board may submit a project for evaluation and possible inclusion in the STIP.

2. Board Members will notify their respective agencies of the time window for the Call for Nominations.

D. Project Evaluation

1. The Board will use the developed evaluation criteria to score the projects.

2. Projects evaluated will be ranked by their total score.

3. Based upon the project ranking and scheduling, projects will be submitted to the FNSB mayor for approval and then to NR for inclusion in the STIP subject to CMAQ funding available to the Fairbanks PM2.5 nonattainment area.

4. In compiling the proposed list for inclusion in the STIP, if the next ranked project is too costly to be included due to fiscal constraint, the next project below it may be included instead.

5. The Board will meet as necessary to allow FNSB to submit its slate of proposed projects in time for inclusion in a draft STIP or draft STIP amendment. It is anticipated that the Board will meet at a minimum once per year, preferably no later than March 31, to solicit, rank, and recommend projects.

E. Conflict Resolution Process

1. Conflicts regarding the submission of a project listing to NR, including the inclusion or absence of a project, will be resolved according to the following process:

a) The conflict resolution process is initiated in writing, via email, from any signatory who has a conflict or grievance to all other signatories in the MOA who are affected by the conflict or grievance.

b) Within fifteen (15) working days after receipt of such notice, each affected party, along with its director or designee, will meet and determine reasonable measures to resolve the conflict.

c) If the conflict has not been resolved at the expiration of sixty (60) days after receipt of the initial notice, the conflict shall be referred to the Office of the Governor for final resolution.

2. All parties understand and agree that the timeline above, while ambitious, may not suffice in getting the matter resolved in time for inclusion in the draft STIP or draft STIP amendment.

V. AGREEMENT TERMS

A. This agreement shall be effective upon signature of all parties and binding until amended or revoked. The anticipated duration of the agreement is tied to the PM 2.5 non-attainment designation and is required until the area has achieved attainment status and maintained such status for a period of at least twenty years. The undersigned agencies may revise or replace this MOA via unanimous written agreement. The agreement may be terminated by a signing agency upon 90 days' written notice to all the signatory parties.

B. An interagency consultation process shall be used for revision of the MOA as necessary.

VI. SIGNATORIES

The undersigned hereby agree to comply with the provisions and terms of this MOA as described above.

Steve Titus

Steve Titus, P.E., Chair, FMATS — Date 9/15/10

Larry Hartig

Larry Hartig, Commissioner, ADEC — Date 10/4/10

Luke Hopkins

Mayor Luke Hopkins, Fairbanks North Star Borough — Date 9/15/10

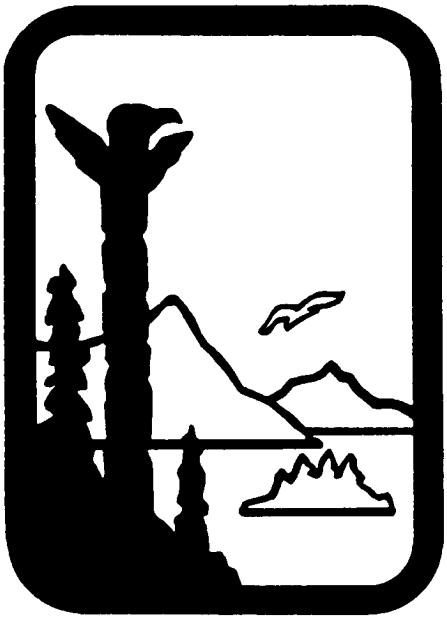
Leo von Scheben, P.E., L.S., M.B.A., Commissioner, ADOT&PF — Date 9/29/10

Reviewed by Legal Department
Date: 9/15/10
By:

Abbreviations Guide

ADOT & PF – Alaska Department of Transportation and Public Facilities
ADEC – Alaska Department of Environmental Conservation
CMAQ – Congestion Mitigation/Air Quality Program
EPA – United States Environmental Protection Agency
FHWA – Federal Highway Administration
FMATS – Fairbanks Metropolitan Area Transportation System
FNSB – Fairbanks North Star Borough
FTA – Federal Transit Administration
HQ - Alaska Department of Transportation and Public Facilities, Headquarters
PDA – Project Development Authorization
PM2.5 – Fine Particulate Matter Less Than 2.5 Micrometers
MOA – Memorandum of Agreement
MPA – Metropolitan Planning Area
MPO – Metropolitan Planning Organization
MTP – Metropolitan Transportation Plan
NR - Alaska Department of Transportation and Public Facilities, Northern Region
RLRTP – Regional Long Range Transportation Plan
SIP – State Implementation Plan
STIP – Statewide Transportation Improvement Program
TIP – Transportation Improvement Program
USDOT – United States Department of Transportation

Alaska Department of Environmental Conservation



Amendments to:
State Air Quality Control Plan

Vol. III: Appendix III.D.5.13

{Appendix to Volume II. Analysis of Problems, Control Actions; Section III. Area-wide Pollutant Control Program; D. Particulate Matter; 5. Fairbanks North Star Borough PM2.5 Control Plan}

Adopted

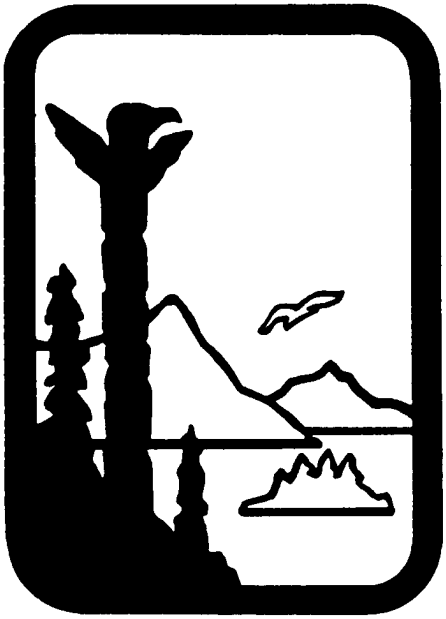
December 24, 2014

Bill Walker
Governor

Larry Hartig
Commissioner

(This page serves as a placeholder for two-sided copying)

ALASKA DEPARTMENT OF ENVIRONMENTAL CONSERVATION



18 AAC 50 AIR QUALITY CONTROL

Response to Comments on September 19, 2013 Proposed Regulations:

Open Burning,

Wood-Fired Heating Device Visible Emission Standards,

Solid Fuel-Fired Heating Device Fuels,

Wood-Fired Heating Device Standards,

&

Fine Particulate Matter (PM 2.5) Air Episodes and Advisories

November 14, 2014

INDEX

Introduction

This document provides the Alaska Department of Environmental Conservation's (**DEC**) response to public comments received concerning its September 19, 2013 draft regulations pertaining to Wood-Fired Heating Device Emission Standards, Fuel Standards for Solid Fuel-Fired Heating Devices and fine particulate matter (**PM2.5**) Air Quality Index values for the Fairbanks North Star Borough (**FNSB**) non-attainment area as proposed in Title 18, Chapter 50 of the Alaska Administrative Code (**18 AAC 50**). The details describing the proposed regulation changes are presented in DEC's public notice dated September 19, 2013 and its three supplemental public notices dated: September 24, 2013; November 13, 2013 and December 13, 2013. DEC received comments in the form of emails; electronic comments submitted via DEC's webpage; hand written comments received at DEC's Open Houses; as well as oral and written testimony received at DEC's public hearings. For each section, this document summarizes the public comments received, summarizes and responds to some comments raised that were outside of the regulatory proposal, describes the regulatory options considered upon consideration of the comments, and provides the Department's response to comments and decisions with respect to the regulatory proposal.

Open Burning- 18 AAC 50.065(f)

The proposed amendment to this regulation restricts wintertime outdoor open burning in PM 2.5 non-attainment area between November 1 and March 31. At this time only the Fairbanks North Star Borough (FNSB) is designated as a PM2.5 nonattainment area. The proposed amendment to 18 AAC 50.065(f) is as follows:

> (f) **Wood Smoke Control and PM 2.5 Non-Attainment Areas**. Open burning is prohibited between November 1 and March 31 in **all** [A] wood smoke control **areas** [AREA] identified in 18 AAC 50.025(b) **and in all PM 2.5 non-attainment areas identified in 18 AAC 50.015(b)(3)**.

Summary of Comments: Comments on this section of the proposed regulation revisions expressed varying levels of support and concern for winter time open burning restrictions as a means of reducing emissions to help the FNSB Borough Nonattainment Area become compliant with the 2006 24-Hour PM 2.5 National Ambient Air Quality Standard (NAAQS). Some commenters felt that restricting open burning during the proposed period would positively impact air quality without affecting the ability of individuals to heat homes or businesses. Other commenters felt that open burning provided important benefits to individuals and questioned the extent and significance of open burning impacts to ambient air quality. Comments questioned the necessity of a blanket restriction, instead favoring an approach that restricts open burning on days with impaired air quality. Commenters noted that regulations already exist that use this approach by prohibiting open burning on days with declared air quality advisories. Comments addressed the impacts of open burning to air quality and human health, the need for open burning, the impacts of wintertime restrictions, the proposed beginning and end dates for seasonal restriction, and alternatives to the proposed restrictions.

- **Impacts of Open Burning in Winter**

Commenters noted impacts associated with open burning on ambient air quality and human health. These impacts included the release of visible plumes of harmful emissions from open burning practices, contributions of these emissions to poor air quality during inversions, and effects of human exposure to emissions. Comments cited increased medical costs due to aggravation of existing respiratory conditions, emergency room visits, and increased medication usage. Commenters noted that inversions can be prevalent during the proposed time period and that these impacts can be exacerbated by inversions which limit the dispersion of emissions. Commenters described open burning restriction in PM 2.5 nonattainment areas during the season of the highest ambient pollution concentrations as an appropriate, common sense measure.

- **Reasons for Open Burning During Winter**

Commenters expressed varying views of the importance and necessity of the opportunities for open burning during wintertime. Comments noted that open burning fulfilled a variety of needs and that wintertime burning opportunities were needed because of restrictions in other parts of the year by other agencies in response to wildfire

dangers. Other comments noted that regulating open burning will improve air quality in the interior of Alaska while having no impact on people's ability to heat their homes or businesses. The regulation will reduce particulates produced for no other purpose than to burn materials.

Debris Burning

Commenters reported that open burning is a valuable method for disposing of debris. Commenters noted the use of burn barrels to dispose of refuse. Commenters also noted pile burning to dispose of debris such as slash created during wildfire suppression, landscaping, land clearing, fuel cutting, and firescaping. Commenters suggested frequently burning debris in smaller fires of pile sizes of 10' by 10' or smaller with 50' spacing in a manner that produces a hot and short lived fire with little visible emissions can produce fewer emissions than a larger, and longer lasting, fire that smolders.

Commenters noted that controlled burning of slash piles was preferable over leaving them in place to decompose due to the increased risk of decaying piles catching fire during a wildfire. Commenters noted that open burning during winter months with snow cover and cool temperatures is less likely to start a wildfire than during warmer months with conditions that are more conducive to wildfires and that agencies often restrict open burning because of this risk. Commenters argue that the proposed regulation would limit the opportunities to safely dispose of slash piles through open burning during winter and shift open burning to parts of the year with increased wildfire risks. Commenters noted that periods outside of the proposed restriction allow safe burning such as cool fall months including September and October or spring months beginning in April.

Other commenters felt that there were viable alternatives for outdoor burning and noted that the existence and accessibility of refuse stations provides year round disposal options and that disposing of refuse and slash wastes in a landfill is less polluting than disposing of the wastes into the airshed through combustion. Commenters also suggested creating biomass waste collection bins to accommodate slash refuse. Other commenters felt that refuse stations are not always a convenient or practicable alternative to open burning due to labor and transportation requirements that may be unattractive or unavailable to individuals. Commenters questioned the need for outdoor burning during periods of diminished air quality in the winter and mentioned occasions when they had witnessed outdoor open burning during periods of diminished air quality.

Recreational

Comments expressed concern about the applicability of the law to outdoor fires used for warmth, ceremonial, or recreational purposes. There was varying support for restricting open burning from burn barrels, bonfires, campfires, and warming fires. Commenters suggested exceptions to the proposed restrictions for these types of open burning during periods of good air quality. Commenters also suggested

that exemptions be provided similar to those that had previously been included in the Borough's historical open burning program. Comments weighed the significance of traditional customs and events such as burn barrels at outdoor events, fireworks, and celebratory bonfires against their impacts to air quality. Some commenters argued that the magnitude of emissions from recreational fires was not great enough to justify restrictions. Other commenters held that some celebratory fires were significant sources of air pollution such as the annual UAF fall Starvation Gulch bonfire and other bonfire events and suggested those activities be regulated or that all nonessential open burning be restricted.

Commenters were also concerned about the types of fires that would be regulated and feared that the regulation would affect campfires, fireworks, cooking fires, barbeque grills, cigarette smoking, and other small fires. Commenters requested a clarification of the term "open burning" because of the perceived ambiguity in the term which could be used to broadly regulate activities that do not significantly contribute to air quality episodes.

- **Existing Regulations**

Commenters questioned the necessity of the proposed amendment and referenced existing regulations that govern open burning year round. Commenters felt that a blanket restriction would unnecessarily burden individuals that conduct open burning and instead suggested the restrictions only occur during days of poor air quality. Commenters referenced 18 AAC 50.065 (a) that specifies limitations on open burning meant to mitigate potential impacts and 18 AAC 50.065(e) that prohibits open burning on days in which an air quality advisory has been declared. Comments suggested these regulations would prevent open burning impacts on days that matter most. Commenters felt that, because of the existing regulations, the proposed amendment was unnecessary and burdensome.

- **Time Period**

Comments addressing the beginning and end dates of the wintertime season in the proposed amendment expressed varying support for either the proposed dates or for alternative dates suggested by commenters. Some commenters felt that open burning was unnecessary and should be restricted year round. Some comments addressing the proposed dates expressed concern that the period would leave little opportunity for open burning and would unnecessarily inconvenience individuals. Other commenters felt that the proposed dates would adequately protect air quality and human health while also leaving sufficient time to safely conduct open burning during times immediately preceding and following the proposed dates.

Comments also expressed a desire that the beginning and end dates be determined using an analysis of historical air quality advisories to ensure the restriction will have a significant impact on air quality without unnecessarily restricting open burning in periods with little historical air quality impairment. They noted that if exceedances of the 24-hour PM 2.5 NAAQS are common outside of the proposed range, the dates of the open burning prohibition should be extended to reflect the historic data. Comments cited open

burning impacts such as smoke, poor air quality, air quality alerts and advisories, and alleged open burning related exceedances of the PM 2.5 NAAQS during October as reason to change the start of the restriction to dates such as September 1st, October 1st, or October 15th. Other commenters felt that opportunities to burn during September and October were important due to a decreased risk of wildfires and limited chances to burn during the summer. Comments also proposed extending the time period to include April.

- **Enforcement of Proposed Amendment**

Commenters questioned the means by which the proposed regulation would be enforced. Commenters pointed out that the FNSB had removed regulations governing outdoor open burning during the winter in response to a local proposition restricting the Borough's ability to regulate home heating. Commenters also pointed out that DEC lacks the authority to issue citations to enforce the regulation. Commenters wanted to know what consequences would be associated with violating the regulation and what agency would enforce the regulation.

- **Alternatives**

Comments proposed different methods of mitigating impacts from open burning during the proposed time period. Several options were presented including restrictions based on ambient air quality similar to prohibition of woodstove operation, defining allowable open burning conditions, and a permitting system to regulate open burning.

Air Quality Dependent Restrictions

Comments expressed a desire to restrict open burning only on days when open burning would have the effect of causing ambient air quality to exceed or increase beyond the NAAQS or the thresholds used to limit wood burning devices used for home or business heating. Commenters further suggested that outdoor open burning bans should be avoided unless warranted by already diminished air quality. Essentially, restricting open burning only on days with air quality alerts or episodes. Comments questioned the need for new regulations, pointing to regulations that currently prohibit open burning on days that an air quality advisory has been declared. Some commenters question whether much open burning is occurring, whether it is a major contributor to the problem, and whether the ban might be an inconvenience to people unnecessarily.

Allowable Open Burning Conditions

Commenters suggested reducing emissions from open burning by prescribing methods that would allow for more efficient burning with fewer emissions. Commenters suggested that burn piles be no more than 10' x 10' and spaced no less than 50' apart in order to allow for fast, non-smoldering fires. Comments also suggested allowing only certain types of fuels to be burned. They suggested prohibiting open burning of putrescible wastes, garbage, animal carcasses, feces, diapers, treated lumber, plastics, carpet, styrene foam, and other materials that produce harmful or toxic compounds when burned.

Permitting Open Burning

Commenters suggested regulating open burning with a permit process for planned burns or burning of burn piles. Suggestions for implementation included administration by the FNSB Air Quality (AQ) Program or a program coordinated between FNSB AQ and the Alaska Department of Environmental Conservation (ADEC) with permits available online, at the Borough building, Borough Air Quality office, and fire departments. Commenters supported substantial fines for violations of permits or failure to obtain permits.

Commenters suggested that permits regulate and consider some or all of the following:

- Appropriate weather conditions or air quality
- Time of year for burning
- Amount and substance to be burned
- How and when a pile can be burned.
- Maximum size of piles (10x10 foot)
- Public notice/notification ahead of time
- Call-in requirements before burning

Comments Outside the Regulatory Proposal: Comments and questions were received that were outside the specific regulatory proposal. Specifically, these comments suggest mechanisms for permitting of open burns, regulation of the size or timing of open burns, public education about regulations, and enforcement of regulations. Those comments and questions are summarized below.

1) Permitting Open Burning

Comments proposed a permitting system as an alternative to a blanket restriction suggesting that such a program would more closely regulate open burning and provide adequate protections to public health while allowing for individuals to conduct open burning in a safe manner.

Response: Current state regulations require department approvals for large scale controlled burns and firefighter training. Those regulations can be found in 18 AAC 50.065 (g)-(i). The department also has general open burning regulations for smaller open burns, like backyard burning, but not specific permitting requirements.

With respect to open burning in the PM 2.5 non-attainment area, DEC is not moving forward to adopt the draft regulatory proposal as written at this time. After careful consideration, the department plans to re-propose revisions to 18 AAC 50.065(f) for public comment. DEC appreciates that a permit system is another means of controlling emissions from small scale burns, but the Division of Air Quality is not currently staffed at a level to implement an effective permit program for these activities occurring at individual households (ie. backyard burning). To avoid the need for additional state growth in this area, the department is considering, as part of a re-proposal, inclusion of provisions for local air quality programs to have open burn permit programs in lieu of the

department's proposed seasonal restriction. This would allow for a local air quality program to provide more flexible and tailored open burning requirements for a specific non-attainment area rather than just having a blanket wintertime restriction.

2) Need for enforcement and consequences of violations

Commenters pointed to a lack of information about consequences of violation. Commenters want to know how this regulation will be enforced, and if it will be enforced. Commenters ask who will enforce it because borough enforcement capability has been removed. Commenters ask whether violations will be illegal, and what punishments will be imposed.

Response: In addressing any violations of state air quality regulations, the Department of Environmental Conservation Division of Air Quality will use the compliance and enforcement tools for which it is allowed under state statute. The Division has not been given the authority in statute by the legislature to issue administrative penalties for violations of Alaska environmental laws. This means the Division cannot issue "tickets" and must use other tools like written notices of violation, compliance agreements, or in rare cases civil court actions. In most cases, the department finds compliance can be achieved through assisting businesses and individuals in understanding the regulatory requirements and how they can comply.

3) Need for outreach

Commenters pointed out needs for considerable public outreach to attain compliance with open burning restrictions.

Response: The Department agrees that public outreach is important and intends to conduct education and outreach to assist citizens in understanding open burning requirements and how to comply.

4) Summer and winter smoke impacts, health effects, and regulatory approach

Commenters questioned the difference between summertime health effects due to wildfire and winter PM 2.5 related health effects. Commenters also questioned the different regulatory approaches to the two: why summer wildfire smoke and associated health effects are not regulated, but less severe winter air pollution needs to be regulated.

Response: Regardless of the time of year, elevated levels of PM 2.5 from smoke can be a concern for public health. There are differences in how smoke from wildfires and smoke from wood-fired heating devices are addressed under the Clean Air Act. The federal "exceptional events" rule governs which air monitoring data can be waived in determining compliance with the National Ambient Air Quality Standards. In general terms, the federal rules allow exemptions for violations of the standards that are clearly caused by events that are singular/unusual or not controllable. This prevents extensive planning and mitigation from being required for one time unusual events or events that

are beyond our control. Even emissions from naturally occurring wildfires are not automatically exempted from the EPA air quality requirements; they may be 'waived' by the EPA, only if all the EPA criteria established in the exceptional event rule is met. Following is a link to the latest DEC Air Quality Exceptional Events Request to EPA for 2010: http://dec.alaska.gov/air/am/exceptional_events.htm.

One of the main differences between summer wildfire events and wintertime pollution episodes during inversions is that it is human-caused pollution sources that result in violations of the ambient air quality standards in the winter. Human sources of pollution can be controlled and mitigated in a variety of ways to reduce air pollution. Many areas of the country experience air pollution episodes as a result of winter inversion conditions and they all, like Fairbanks, are required to lower their emissions to reduce air pollution to meet the air quality health standards.

5) Are wood emissions really worse than oil-fired heater emissions?

Commenters questioned whether wood smoke is really worse than emissions of oil-fired boilers. They note historic use of both coal and wood in Fairbanks. Commenters ask why oil boilers are not being regulated; some oil boilers are putting out black smoke.

Response: In looking at PM2.5 emissions, on average wood is 500 times more polluting than fuel oil (from local and national wood device heat testing and EPA AP-42 research studies on wood devices). Even though a higher percentage of homes use fuel oil, the burning of wood as either a primary or supplemental heat source has a greater contribution to the area's PM 2.5 than fuel oil. Measurement studies in the Fairbanks area have shown that more than 50% of the PM 2.5 measured on the filters at the monitor sites is from wood burning, with an even higher percentage contribution from wood burning at some monitor locations.

6) Ultimate Goals of DEC

Some commenters stated the expectation that ADEC will regulate the size of your campfire, hotdog and marshmallow fire, pig roast and that ADEC wants to regulate how you cook your food.

Response: After careful consideration, the department plans to re-propose revisions to 18 AAC 50.065(f) for public comment. To address these concerns, DEC plans in the new proposal to better define open burning terms providing additional clarification on what constitutes open burning and how campfires fit in.

Fiscal Concerns: Those comments specifically noting fiscal impacts are summarized here.

Commenters expressed that open burning regulations affect direct costs for resident's health care and affect indirect costs related to wildfire suppression, land maintenance, residential firescaping, and nonattainment. Comments focused on the length of the seasonal prohibition noting impacts for the proposed season or a longer season.

Commenters suggested that the Department's proposed open burning season, which allows open burning in October and April, will contribute to failure to meet attainment, which may ultimately result in economic sanctions. Commenters that desired a longer open burning prohibition noted there would be reduced health effects due to open burning and it may reduce state costs for fire suppression during the prohibition period. Commenters noted that allowing open burning in October and April will result in higher health care costs for individuals affected by the smoke during those months. Health costs due to open burning cited by commenters included purchase of indoor and outdoor air monitors, advanced air filtration systems (HEPA and gaseous) for homes and cars, added electrical costs, respirator masks and filters for gases and particulates, doctor visits, emergency room visits, asthma medications, and asthma and cardiac medical costs. Fiscal impacts cited by commenters related to a lengthier open burning ban period also included reduced state costs for fire suppression since October is an increasingly hot, dry month. Open burning in those conditions could potentially lead to an increase in late season wildfire.

Other commenters noted that prohibiting open burning during the winter could increase fiscal costs of wildfires and firefighting if slash piles and wood waste are left in place, adding to ground level fuels that can ignite during summer wildfire season. Seasonal residential yard cleanup activities also result in piles of ground level fuels that would need to be removed to protect residences against fire. Fiscal impacts of banning public open burning could include costs of loading and transporting slash piles to dumps or public biomass waste bins, as well as the costs of expanding or creating, and maintaining public wood waste sites. These costs would affect businesses, residents, and governmental agencies. Commenters also expressed impacts related to longer bans (including additional months) which could reduce residential firescaping activities, ultimately leading to increased wildfire and economic losses due to wildfires.

Commenters suggested that a cost analysis for these regulations is needed.

Regulatory Options: Based on the comments received the department considered the following regulatory options.

1) Do not implement the proposed regulation (keep current regulation)
2) Implement regulation as proposed
3) Implement proposed regulation with amendments
    a) Clarify definition of open burning (e.g. camp fires exempt, etc.)
4) Expand regulation
    a) Expand time period for the seasonal restriction: October-March 31 or October-April or expand to include September as well.
    b) Establish open burn permit program
        i) Within nonattainment area
        ii) During all or portion of the winter
        iii) Allow small pile burning, etc. during periods of good dispersion.

Department Decision: After careful consideration 18 AAC 50.065(f) will be re-proposed for public comment in conjunction with proposed revisions and additions to definitions in 18 AAC 50.990 related to open burning.

Prohibition of Wood-Fired Heating Device Operation- 18 AAC 50.075(b)

DEC proposed to amend this regulation to give the Department the flexibility to prohibit operation of wood-fired heating devices in areas where an air quality episode has been declared under 18 AAC 50.245. The proposed amendment was as follows:

> (b) **The department may prohibit operation of** [A PERSON MAY NOT OPERATE A] wood-fired heating **devices** [DEVICE] in an area for which the department has declared an air quality episode under 18 AAC 50.245.

Summary of Comments: Comments on this section of the proposed regulation revisions expressed varying levels of support for a regulatory pathway that included prohibition as a mitigating measure in cases of impaired air quality. Commenters opposed to prohibition felt that prohibiting the use of wood-fired heating devices during wintertime air quality episodes would interfere with lifestyle choices and would create an undue burden on individuals trying to heat interior spaces. Comments expressed fear that prohibiting sources of heat would negatively impact an individual's ability to provide heat to survive and prevent property damage in conditions of extreme cold. These comments suggested that prohibition should either not be implemented at all, that it should affect only highly polluting individuals, or should affect only specific classes of wood-fired heating devices. Comments supporting prohibition of wood-fired heating device use during air quality episodes argued that reducing or eliminating the emissions caused by wood-fired heating devices would help the nonattainment area to attain the National Ambient Air Quality Standards and protect public health by preventing worsening of air quality during episodes. Comments suggested providing exemptions to individuals in a variety of circumstances. Comments that supported prohibition of wood-fired heating devices during air episodes felt that the existing regulation prohibiting the use of wood-fried heating devices during air episodes was appropriate and would protect human health. Additional details related to comments on various aspects of the proposed regulation follow.

- **Include All Solid-Fuel Heating Devices**

Comments argued that limiting the scope of the prohibition to wood-fired devices would not lead to attainment of NAAQS and could have unintended consequences. Commenters listed a variety of solid-fuel heating devices that emit PM 2.5 that would not be affected by the proposed regulation. Commenters recommended that the wording "*wood-fired heating devices*" be changed in the final regulation to "*all solid-fuel heating devices.*" to include pellet fuel devices, coal-fired heating devices, outdoor wood and coal hydronic heaters or boilers, open burning, waste oil burners, incinerators, wigwams and commercial size (non-permitted) solid-fuel heating devices. Comments argued that although studies have not found these devices to be significant contributors to PM 2.5 levels, the devices are readily available and the proposed regulation could drive a transition to these devices with unintended consequences. Comments noted localized air quality impacts of devices such as coal-fired heaters and expressed concern that the proposed regulations are currently and could further incentivize the purchase and use of coal-fired devices in order to circumvent curtailment actions. Commenters expressed fear that a shift away from solid fuel consumption to diesel fuel oil usage in the non-attainment area could increase SO_x emissions, lead to air episodes due to SOx, and

possibly lead to an expensive requirement to use ULSD in heating devices. Some commenters suggested outright banning of certain classes of devices, such as wood-fired and coal fired outdoor hydronic heaters, from the non-attainment area altogether.

- **Provide Exemptions**

Commenters noted burdens of the proposed regulations on individuals who operate wood-fired heating devices and suggested those may be undue in certain circumstances. Comments noted that wood-fired heating devices are used as the primary heating device for a variety of reasons including lifestyle, economic factors, and necessity. The expense of alternative energy sources such as natural gas, fuel oil, and electricity was proposed to be a major contributing factor to the increasing use of wood-fired heating devices. Comments noted that the financial burden of using those more expensive energy sources would be too great on individuals that meet certain income thresholds. Commenters described being on a fixed income and were concerned that the proposed regulations would result in higher home heating costs if they had to heat with oil instead. Other citizens suggested that the FNSB or the State either subsidize their fuel costs or provide the option of heating with natural gas at a lower cost.

Commenters recommended that the final rule include exemptions for the following:

1) if the resident had a financial hardship; Comments suggested defining income limits for an exemption based on the federal poverty level income requirements.
2) if the wood-fired fired heating device was the resident's or commercial building's sole source of heat; Comments proposed defining "sole-source" of heat based on a lack of alternative devices or an inability to operate other devices due to a lack of electrical service and exempting these individuals due to the impact a prohibition would have on safety.
3) if the resident or commercial building was using an EPA certified wood/pellet stove or EPA voluntary Phase 2 approved pellet hydronic heater. Comments also expressed concern that cleaner burning devices such as EPA certified devices and masonry heaters would be affected by prohibition despite lower contributions to PM 2.5 levels. Comments suggested prohibiting these devices in the same manner as other devices would offer little reward to individuals that have replaced older devices with cleaner burning devices and lessen the incentive to replace older appliances with clean burning devices.
4) unforeseen emergency events; Commenters also expressed concern that exemptions should be made in cases of unforeseen emergency events such as power outages or device failure emergencies that would impact the ability to operate non-wood-fired heating devices.
5) extreme cold temperatures; Commenters expressed concern that wood-fired heating devices are needed to supplement other heating devices during periods of extreme cold and proposed that exemptions to any prohibitions be made during extremely cold periods.

Other commenters felt that no exemptions should be made or that individual exemptions should be permitted with the requirement that individuals take advantage of a device change-out program within a specified time frame.

- **Adding Discretion**

Comments addressing the inclusion of the phrase "the department may prohibit" expressed concern over discretion and the lack of detail about how that discretion would be used. Commenters wanted to know how the prohibition would be triggered, suggesting that the proposed wording is vague, and should be rewritten to define exactly when DEC would prohibit operation of wood-fired heating devices. Commenters expressed concern over the lack of specific curtailment action pathway and presented a variety of options for curtailment actions (see below). Commenters that indicated a lack of approval for the proposed amendment felt that no discretion should be given to the Department and that prohibition should be mandatory in the event of a declared air episode. Other comments expressed concern that without prescribed details, the Department could use discretion improperly in response to political or economic concerns. Comments also noted that since DEC proposed to add discretion to the existing approved regulation adopted and approved in the 1998 SIP, DEC must address the Clean Air Act Section110 (l) requirements – an anti-backsliding provision.

- **Suggested Curtailment Strategies**

Commenters expressed concern over the lack of specific curtailment action pathway and presented a variety of options for curtailment actions. Commenters desired a clarification of potential curtailment actions including criteria, authority, implementation, and enforcement. Commenters suggested specific approaches to curtailment actions. Some comments suggested mandatory prohibitions while others suggested a multi-stage approach used in other areas, like Sacramento, CA or Washington state, that selectively prohibits certain classes of devices at certain pollution thresholds. The comments proposed curtailing the largest sources of PM 2.5 by first prohibiting operation of higher polluting devices that aren't EPA certified while allowing the operation of EPA certified devices. Commenters suggested this would provide an incentive to change out older devices and install newer EPA certified devices. Other commenters expressed concern that prohibiting by device class would unfairly affect device users that burn in a manner consistent with public education recommendations and instead proposed curtailments prescribing maximum emission opacity noting that device emissions are highly dependent on the manner in which they are operated. Commenters also noted a need for enforcement of prohibitions and felt the enforcement actions available to DEC and the FNSB were ineffective or too lengthy which could in effect make curtailment actions voluntary and ineffective.

- **Establish a Clear Regulatory Path**

Commenters stated that the proposed language in 18 AAC 50.075(b) was confusing when compared to the language proposed in 18 AAC 50.245 that would add local programs to

agencies that can prescribe curtailment actions. The commenters suggested that the regulations should be made clearer as to who will issue the curtailment, how the curtailment will be announced and enforced. Commenters wanted further clarification, written into the regulations, concerning who is responsible for announcing and enforcing the air quality episode. Some commenters wanted to see a strong local enforcement presence while other commenters wanted the State to take more of the responsibility, still other commenters wanted no new regulations or their enforcement at all.

Comments Outside the Regulatory Proposal: Comments and questions were received that were outside the regulatory proposal. Those comments and questions are summarized below.

Commenters wanted clarification on 18 AAC 50.075(b), stating that flexibility in the prohibition described is important, but how are such determinations to be made and enforced? Commenters suggested that without measures for enforcement, DEC's regulatory proposals will not have much of an effect. Commenters suggested that the flexibility of the language "may prohibit" opens up the potential for little or no enforcement, questioning how the proposed regulation will be enforced. Commenters wanted to know what agency will be responsible for enforcement when an air quality episode has been determined. Commenters opposed this amendment based on DEC's track record, because it took DEC 4.5 years to address the smoke at Wood River elementary school. Commenters suggested that the local DEC and/or police/state troopers be given the authority to write citations with financial penalties.

Commenters also expressed concerns that DEC may regulate heating oil and that DEC should not require the use of ultra-low sufur diesel (ULSD) for home heating.

1) Enforcement Authority

   DEC is responsible for enforcing these state regulations. In addressing any violations of state air quality regulations, the Department of Environmental Conservation Division of Air Quality will use the compliance and enforcement tools for which it is allowed under state statute. The Division has not been given the authority in statute by the legislature to issue administrative penalties for violations of Alaska environmental laws. This means the Division cannot write "tickets" and must use other tools like written notices of violation, compliance agreements, or in rare cases civil court actions. In most cases, the department finds compliance can be achieved through assisting businesses and individuals in understanding the regulatory requirements and how they can comply.

2) ULSD requirements should not be used for home heating

   Concern for fuel switching and the potential to increase sulfur emissions was expressed. DEC's proposed regulations did not suggest any fuel switching for home heating oil nor any mandate for use USLD.

Fiscal concerns: Those comments specifically noting fiscal impacts are summarized here.

Comments stated that the financial burden of using those more expensive energy sources would be too great on individuals that meet certain income thresholds. Commenters also described being on a fixed income and were concerned that the proposed curtailment regulations would impose restrictions on heating with wood or coal which could result in higher home heating costs if they had to heat with oil or electricity. Other comments suggested that more effort be put forth into providing a natural gas line to residents living in the FNSB while other citizens suggested that the FNSB or State either subsidize their fuel costs or provide the option of heating with natural gas at a lower cost. Additional suggestions to improve costs include continuing the wood-stove change-out program by a non-governmental agency and opening more state land so dry wood is more accessible. Commenters indicated concern that curtailment during extreme cold weather could lead to frozen pipes and property damage that would be costly to repair. Commenters also expressed concern regarding costs to upgrade non-compliant devices, especially items that were not covered by any change out programs such as chimneys, stove pipes, etc.

Regulatory Options: Based on the comments received the department considered the following regulatory options.

1) Do not implement the proposed regulation (keep current regulation)
2) Implement the regulations as proposed
3) Implement proposed regulation with amendments
    a. Include language clarifying discretion,
        i. Clarifying who will call curtailment and how announced/enforced
            1. In regulation, 18 AAC 50.075(b)
            2. In episode plan within SIP
        ii. Ensure Clean Air Act anti-backsliding provisions are met
        iii. Remove discretion
    b. Provide for exemptions and their timing
        i. Sole-source of heat
        ii. Financial hardship
        iii. Temperature
        iv. Clean burning devices
        v. Timing
            1. Unforeseen emergencies
            2. Two-stage trigger
4) Expand Regulation
    a. Include all solid-fueled heating devices
    b. Include units burn trash or waste oil
    c. Ban certain types of devices

Department Decision: After careful consideration, 18 AAC 50.075(b) will not be amended as proposed. The current language will remain in effect. This addresses concerns raised about the Clean Air Act anti-backsliding provisions and the addition of discretion in applying the existing regulation.

To address the other concerns and suggestions associated with exemptions, timing, and other issues, DEC intends to issue a new regulatory proposal that will include a separate subsection addressing the use of solid fuel-fired heaters during PM 2.5 air episodes. That new proposal will be subject to additional public review and comment.

Solid Fuel Heating Device Fuel Requirements- 18 AAC 50.076

DEC proposed to amend 18 AAC 50 by adding a new section (18 AAC 50.076) to clarify the types of solid fuels that can be burned in heating devices operating within the FNSB PM 2.5 non-attainment area.

> **18 AAC 50.076. Solid fuel-fired heating device fuel requirements**. (a) A person operating a solid fuel-fired heating device in areas identified in 18 AAC 50.015(b)(3) may only use the following fuels:
>
> (1) For wood burning devices:
>
> (A) clean wood;
>
> (B) wood pellets made from clean wood;
>
> (C) manufacturer recommended starter fuels including home heating oil, propane, natural gas or wood-based material for dual-fired hydronic heaters; and
>
> (D) biomass fuels approved by the manufacturer.
>
> (2) For coal burning devices:
>
> (A) coal; and
>
> (B) coal pellets.

Summary of Comments: Comments on the proposed regulations limiting the types of fuels that can be used in solid fuel-fired heating devices expressed a variety of levels of support for the proposed regulations. Some commenters articulated a desire for limitations on the types of allowable fuels for solid fuel-fired heating devices and felt that the public health and environmental impacts of certain types of fuels outweighed any economic benefits to individuals and warranted the proposed regulations. Commenters also proposed changes to the types of allowable fuels such as specifying allowable wood moisture content, adding locally manufactured fuels, and specifying allowable types of coal. Other commenters felt that the regulation should not be implemented because it may be duplicative of current regulations, would be counter to a local ballot proposition, could prevent the use of fuels derived from recycled materials, could prevent development of technologies to burn potentially prohibited fuels without impacting air quality, would place an undue constraint on individuals who are financially unable to heat using the specified fuels, or would be unenforceable. Comments addressed the types of fuels used by individuals; the impacts of those fuels, wood fuels, manufactured biomass fuels, coal, and coal pellets; the advantages and disadvantages of implementing the proposed regulation; and proposed altering the list.

- **Regulating Fuels**

Comments expressed a range of support for the proposed regulation that restricts the types of fuels that may be used in a solid fuel fired heating device. Some commenters expressed a desire that individuals cease burning highly polluting improper fuels in their heating devices due to the adverse impacts toxic emissions may have on the health of others and ambient air quality. They felt that the proposed regulation was needed to limit individuals to burning only the fuels that devices were designed to burn and prohibit the incorrect use of fuels and other burnable materials in ways that disproportionately degrade air quality and emit hazardous air pollutants. Commenters recognized that

burning highly polluting fuels provided economic savings to individuals but some countered that any savings realized by those individuals caused the public to incur disproportionately high costs. Other commenters felt that the proposed regulation would place a burden upon individuals that could not afford to heat using fuels specified in the proposed regulation. They felt that the state should not infringe on the ability of any individual to heat interior spaces using any means necessary and that the proposed regulation would be counter to citizen's wishes as expressed in local ballot propositions that removed the FNSB's ability to regulate fuel types. Other commenters noted that the consequences of using fuel for which a device was not designed can go beyond impacting air quality. They stated that device warranties may be voided by the use of incorrect fuels and mentioned increased risks of explosions, chimney fires, and structural fires. Commenters felt that these potential outcomes could pose safety and liability concerns, increase public emergency response costs, and unnecessarily place firefighters and other first responders at risk.

- **Currently Used Fuels**

Commenters mentioned a variety of fuels that they believe are or could be used in solid fuel-fired heating devices. Commenters noted the widespread use of the fuels included in the proposed regulation including wood, wood pellets, biomass fuels, coal, and coal pellets. Comments also alleged the use of a variety of highly polluting fuels not mentioned in the proposed regulation such as stained or painted wood, chemically treated lumber, wood treated with creosote, chromated copper arsenate, or pentachlorophenol, manufactured boards, tires, rubber, plastics, paint, solvents, styrene, foam, carpeting, trash, garbage, used or waste oil, diapers, animal carcasses, sewage, animal feces, lawn clippings, and supported prohibiting the use of these highly polluting fuels in solid fuel heating devices. Commenters also alleged that some individuals may burn any combustible materials regardless of potential impacts. Commenters reported being affected by emissions from neighbor's solid-fuel heating devices burning improper fuels including green and un-split wood. Commenters asserted that although most individuals using solid fuel-fired heating devices likely do so in a manner that minimizes emissions, air quality is negatively affected by individuals fueling solid fuel-fired devices using improper fuels.

- **Wood**

Current Use

Commenters described current wood burning practices in the nonattainment area. Commenters note that the use of wood is popular because it is more economical than using fuel oil or electricity to heat especially when harvested by the individual. Commenters also note that wood is an important supplemental heating fuel during periods of extreme cold, is a traditional lifestyle method of heating, is a renewable resource, and may be a building's sole source of heat. Comments noted that many individuals harvest their own wood fuels from private or state lands and process that wood themselves. Commenters cited study findings that 58% of Fairbanks residents supply all of their own wood and 22% supply at least

some of their own wood but that only 40% of wood burned is adequately cured. Commenters describe wood smoke as the source of 60-80 percent of winter PM 2.5. Some commenters suggested that burning wet wood contributes significantly to PM 2.5 levels and should be prohibited. Commenters described processing wood for fuel use and following the "Split, Stack, Store and Save" educational campaign. Some commenters indicated support for the educational program, adhere to its wood seasoning recommendations, and would like the program to continue or expand to reach younger audiences. Commenters also noted that individuals continue to burn wood that has not been split, has not been seasoned, or has become wet due to wet storage conditions. Commenters also said that individuals obtain processed wood fuel through commercial distributors and the moisture content of that wood is not regulated or typically advertised. Commenters also note the availability and use of treated lumber and manufactured boards that contain harmful chemicals and produce harmful emissions.

Availability

Commenters described the availability of wood fuel. Individuals described cutting, processing, and seasoning wood fuel harvested from private and public lands open to wood cutting. Commenters suggested that additional state lands be opened to fuel cutting to increase the availability of dry wood. Commenters also propose that opening additional lands to the harvest of fuels would reduce wildfire fuel and allow for harvest and efficient combustion of wood that may otherwise burn inefficiently and produce pollutants in a wildfire. Commenters note the availability of commercially harvested firewood and cordwood. Commenters note that wood can be delivered to an individual's home and is a source of wood that requires little advanced planning or effort to obtain and burn. Comments also note that commercially sold wood is not subject to any moisture requirements and businesses may be providing wet or unseasoned wood to consumers. Comments also noted the availability of treated wood that contains binders or preservatives such as chromated copper arsenate, creosote, and pentachlorophenol that give off toxic emissions when burned. Commenters reported the availability of chemically treated or preserved wood debris at landfill transfer sites that individuals sometimes scavenge to burn.

Moisture Content

Commenters had various suggestions related to wood moisture content and offered ideas for moisture content requirements. Those comments that proposed restricting wood moisture levels to 20 or 25 percent wet weight or less, suggested adding such a requirement to either this proposed amendment or to the definition of "clean wood" in 18 AAC 50.990 (135). Commenters noted that burning un-split, unseasoned, green, or wet wood decreases efficiency, causes unsafe creosote buildup in chimneys, and creates excessive smoke and toxic particle pollution. Commenters noted that EPA certified woodstove emissions were highly

dependent on the manner in which they are operated and that the 2.5 gram per hour rating a woodstove receives is based on the burning of dry crib wood. Commenters said that a 2.5 gram per hour woodstove would burn dirty with the use of wet wood regardless of its emissions rating. Commenters felt that implementing emission limits for new woodstoves without requiring their correct operation by using dry and seasoned wood would do little to achieve meaningful woodstove emissions reductions.

Commenters suggested that seasoning and maintaining dry wood was easily done with advanced preparation and suggested continuing educational campaigns to educate the public about wood cutting, splitting, and seasoning to help individuals understand the benefits of burning properly seasoned wood. Other commenters felt that the supply of dry wood accessible to residents of the nonattainment area was insufficient and such a requirement could cause financial impacts to individuals who had not seasoned wood or could not commercially obtain dry wood. Commenters argued that that state should facilitate compliance with any regulations that require the use of dry, seasoned wood by increasing the availability of dry, seasoned wood to the public. To increase the public's access to dry wood commenters proposed opening additional state lands to fuel cutting to allow for access to dead standing fuel. Commenters also suggested a warehouse wood exchange program should be created, similar to the woodstove exchange program, to allow individuals to trade freshly cut wood for dry, seasoned wood.

- **Wood Pellets**

Commenters noted the availability and use of wood pellet fuels and supported their inclusion in the proposed amendment. Commenters said that pellet burning devices were economical, convenient, efficient, and clean burning. Commenters noted the availability of locally manufactured wood pellets and felt that pellets were an easier fuel source to obtain, handle, and store than cordwood.

- **Coal**

Commenters expressed varying levels of support for the regulations regarding coal in the proposed amendment. Commenters noted that coal is used as a fuel in certain heating devices and expressed differing opinions about the reasonableness of its use in the nonattainment area. Commenters pointed out that coal is currently used both in very rural areas and in urban areas including downtown Fairbanks and North Pole by individuals, businesses, and organizations. Some commenters felt that coal is a locally extracted resource that is more economical than fuel oil and should remain allowable in the proposed regulation. Other commenters felt that the impacts of coal emissions to air quality and human health were disproportionate to any fuel savings realized by coal burning individuals. Commenters described coal as being a dirty fuel and cited evidence that coal fueled appliances emit up to thousands of times more emissions than oil burning devices. Commenters reported decreased air quality from local coal burning appliances and related negative impressions of air quality gained through travel to other regions in

the country that predominantly use coal. Comments noted that as written, the regulation does not specify the types of coal that can be used. Comments cited manufacturer requirements for the use of anthracite or bituminous coal in appliances and characterized the local coal as consisting mainly of sub-bituminous coal and lignite. Commenters felt that requiring the use of anthracitic or manufacturer specified coal types would ensure safe and efficient operation of coal burning devices when compared to an increased risk of structural fire and increased emissions produced by burning lower grade sub-bituminous coal and lignite. Other commenters felt that coal use should be outright prohibited from either urban areas or the entire nonattainment area due to the high and disproportionate emissions of a coal-fired heating device when compared to other heating devices.

- **Geographic Area of Applicability**

Comments addressed the regional applicability of the proposed regulation. Comments proposed the area to which the proposed regulation apply encompass a greater area than the nonattainment area such as the entire Fairbanks North Star Borough or the entire State of Alaska. Comments mentioned instances of nuisance or hazardous smoke from solid fuel heating devices outside of the nonattainment area. Commenters argued that extending these regulations to other parts of the state would protect ambient air quality and human health throughout the state.

- **Current Regulations**

Commenters that addressed the need for the proposed state regulation either felt that current state regulations were sufficient or felt that the current regulation was insufficient and the proposed regulation would be more easily interpreted by the public. Commenters noted 18 AAC 50.110 that currently stipulates that "no person may permit any emission which is injurious to human health or welfare, animal or plant life, or property, or which would unreasonably interfere with the enjoyment of life or property. (Eff. 5/26/72, Register 42)". Commenters felt that this regulation prohibits the emissions produced by the combustion of materials restricted by the proposed regulation and that the proposed regulation was unnecessary. Other commenters felt that the current regulation was vague and did not help individuals to understand how to comply with the regulation. Those commenters argued that the proposed regulation would help individuals to comply by specifying allowable fuels instead of prohibiting actions based on subjective interpretations of impacts of which individuals may or may not be aware.

Commenters also addressed current FNSB regulations and recent ballot initiatives concerning solid fuel heating. Commenters either felt that the proposed state regulation was needed because ballot initiatives had removed the FNSB's ability to regulate fuel types or that the proposed regulation could violate the will of voters to not have fuels regulated. Commenters that said the FNSB had insufficient protections argued that state regulations would help to protect public health and felt that public health issues should be decided by public health officials and not popular vote.

- **Enforcement**

Comments that addressed the enforceability of the proposed regulation questioned how the rules would be enforced. Some commenters suggested penalties while other commenters argued that authorities would be unable to determine what kinds of fuels were being burned in woodstoves without searching homes, properties, or sampling plumes and commenters vehemently opposed this possibility. Comments proposed that prima fascia evidence consisting of opacity readings, air sampling and monitoring, and citizen complaints could be used to determine compliance with the law. Commenters also addressed the possibility of placing restrictions on commercial sellers of fuels to ensure that the fuel sold in the nonattainment area met the characteristics described in the adopted regulations. Commenters noted that the availability of data to consumers was sparse concerning the moisture content of purchased cordwood. Commenters suggested that regulating the sale of fuels would help to ensure compliance with any possible regulation concerning wood moisture content. Comments expressed a desire for wood moisture content disclosure requirements on sellers to help consumers avoid purchasing inefficient and polluting unseasoned or wet wood. Commenters also proposed a restriction on sellers that allowed only the sale of wood that had been tested and labeled with a moisture content of 20% or less by weight and mentioned regulations in other states that make it illegal to advertise, sell, or supply wood that has a moisture content of greater than 20%. Commenters argued that these requirements on sellers would decrease the use of wet wood by allowing consumers to make informed choices or by preventing the sale of wet wood entirely. Commenters indicated that some wood sellers already work to provide only seasoned and dry wood while others felt that the industry's capacity to provide seasoned and dry wood could not sustain the community's demand for cordwood. Commenters also noted that consumers may season the wood they obtain from sellers themselves before burning and that adding a requirement for sellers to season wood could increase the cost of cordwood to consumers. However comments also suggested requiring the sale of dry wood directly before and during the heating season to prevent the burning of wet wood while also giving consumers the chance to season commercially purchased wood during the summer.

- **Proposed Changes**

Commenters proposed changes to the proposed regulations such as altering the required characteristics of allowable fuels, adding allowable fuels to the list, or explicitly prohibiting the use of certain fuels.

Altering Required Characteristics:

The comments that suggested altering the required characteristics of allowable fuels specifically mentioned wood and coal. Commenters proposed that wood be clean, split, have a moisture content of 20% by weight or less, and seasoned. Commenters felt that by burning clean, dry, and seasoned wood, individuals would be able to heat more efficiently, require less fuel, and cause fewer emissions when compared to burning dirty, wet, unseasoned wood. Commenters

suggested that these requirements could either be incorporated into this section or into definition 135. Other comments proposed adding language that would ensure the use of dry, seasoned wood by requiring that wood be seasoned for various lengths of time such as 6 months to a year.

Commenters that addressed coal characteristics sought to either implicitly allow or prohibit the use of regionally mined coal. Commenters that felt local coal should be an allowable fuel argued that it is a local resource that financially supports local industry and is less expensive to purchase than imported coal. Other commenters that felt local coal should not be allowed arguing that it predominantly consists of low grade sub-bituminous coal and lignite that contains moisture, burns less efficiently and produces more PM 2.5 emissions. Commenters noted that many coal-fueled devices specify the use of higher grade coal such as anthracite and that the use of local coal represented a risk to the individual operator and general public due to the possibility of explosions, the possibility of fires, and greater emissions.

Including Other Fuels as Allowable:

Commenters expressed a desire for the inclusion of other allowable fuels to the proposed regulation. Comments noted the development of new solid fuels in the nonattainment area and felt that the regulations could prevent the use of these forms of fuel such as pellets or logs made from recycled materials or biomass. Commenters expressed a desire that these locally manufactured fuels be added to the list to allow for sustainable local economic activity and to lessen fuel costs to individual consumers when compared to other fuel sources.

Prohibition of Fuels:

Commenters proposed alterations to the regulation that would explicitly prohibit certain fuels. Comments proposed adding language that would prohibit burning materials that are not specified by a device manufacturer; generate noxious, poisonous, or injurious fumes; or are contained in lists developed by NESCAUM or other states. Commenters noted that lists such as those developed by NESCAUM and other states could be adopted by reference.

Comments Outside the Regulatory Proposal: Comments and questions were received that were outside the specific regulatory proposal. Those comments and questions are summarized in more detail below. Commenters felt that the regulation should prohibit certain fuels instead of listing allowable fuels. Commenters also suggested mechanisms that would ensure availability of dry wood to individuals by either opening additional state lands to fuel harvest or placing regulatory restrictions on wood sellers. Commenters also expressed confusion and concern about how the proposed regulation would be enforced.

1) Reasons for Listing Allowable Fuels Instead of Prohibited Fuels

As noted above, commenters expressed belief that listing what is a prohibited fuel would better serve the community and didn't understand why just allowable fuels were listed. Response: The department recognizes the value of having a list of prohibited fuels included in the regulation to provide greater clarity to the public with respect to fuels that should and shouldn't be burned in solid fuel-fired heaters. In response to the concern that the proposed regulations do not have a list of prohibited fuels, DEC plans to re-propose a revised version of 18 AAC 50.076 for further public review and comment. The department plans to include a list of prohibited fuels along with the list of appropriate fuels in the new proposal.

2) Wood Exchange Program

Commenters support a wood exchange program by which wet firewood could be exchanged for dry wood. Commenters consider this warranted, as a stove exchange program already exists. Commenters note that regulations forbidding burning of wet wood would force adoption of wood exchange or other programs.

Response: A wood exchange program may be a viable option to promote additional dry wood supply in the community. There are a number of ways a wood exchange could be established, ranging from a private enterprise to a cooperative/non-profit operation to a government program. In considering such a program, there would be a number of practical, logistical, and operational challenges to address along with funding to initiate and operate the program. Exchanging wood means that wood is handled multiple times, which may be a practical deterrent to participation by some in the community. It is our understanding that the Fairbanks North Star Borough has explored this idea to some extent but has not opted to move forward with such a program to date. The Department will make the Borough aware of the comments of support that were received for this type of program.

3) Regulations on Wood Sellers

Commenters also addressed the possibility of placing restrictions on commercial sellers of fuels to ensure that the fuel sold in the nonattainment area met the characteristics described in the adopted regulations. Commenters noted that the availability of data to consumers was sparse concerning the moisture content of purchased cordwood. Commenters suggested that regulating the sale of fuels would help to ensure compliance with any possible regulation concerning wood moisture content. Comments expressed a desire for wood moisture content disclosure requirements on sellers to help consumers avoid purchasing inefficient and polluting unseasoned or wet wood. Commenters also proposed a restriction on sellers that allowed only the sale of wood that had been tested and labeled with a moisture content of 20% or less by weight and mentioned regulations in other states that make it illegal to advertise, sell, or supply wood that has a moisture content of greater than 20%. Commenters argued that these requirements on sellers would decrease the use of wet wood by allowing consumers to make informed choices or

by preventing the sale of wet wood entirely. Commenters indicated that some wood sellers already work to provide only seasoned and dry wood while others felt that the industry's capacity to provide seasoned and dry wood could not sustain the community's demand for cordwood. Commenters also noted that consumers may season the wood they obtain from sellers themselves before burning and that adding a requirement for sellers to season wood could increase the cost of cordwood to consumers. However comments also suggested requiring the sale of dry wood directly before and during the heating season to prevent the burning of wet wood while also giving consumers the chance to season commercially purchased wet wood during the summer.

Response: In response to concerns that the proposed regulations do not address commercial wood sellers, DEC plans to re-propose a revised version of 18 AAC 50.076 with a new section addressing some aspects of commercial wood sales. The new proposal will be subject to additional public review and comment. DEC also plans to initiate a voluntary program late in 2014 that would encourage commercial wood sellers to provide information on wood moisture content to their consumers when wood is sold. DEC also plans to establish a voluntary certification program for dry wood vendors. Wood sellers that agree to the moisture content disclosure and/or certified dry wood program requirements will be listed on the DEC Internet web site to assist consumer confidence in understanding the moisture content of the wood they purchase and in locating sources of dry wood.

4) Enforcement Concerns

As noted above commenters had enforcement concerns and questions.

Response: DEC is responsible for enforcing and final regulations. In addressing any violations of state air quality regulations, the Department of Environmental Conservation Division of Air Quality will use the compliance and enforcement tools for which it is allowed under state statute. The Division has not been given the authority in statute by the legislature to issue administrative penalties for violations of Alaska environmental laws. This means the Division cannot write "tickets" and must use other tools like written notices of violation, compliance agreements, or in rare cases civil court actions. In most cases, the Department finds compliance can be achieved through assisting businesses and individuals in understanding the regulatory requirements and how they can comply.

Fiscal Concerns: Those comments specifically noting fiscal impacts are summarized here.

Commenters addressed the fiscal impacts to individuals heating spaces using fuels not allowable under the proposed regulation or in final regulations that may incorporate suggestions found in the comments. Commenters felt that individuals may need to burn any combustible material to heat spaces and that limiting those individuals to burning certain fuels would cause financial strain or hardship. Other commenters said that wood could be harvested and seasoned inexpensively or that the cost savings to individuals or businesses should be compared to costs incurred by the public. Commenters also felt that any regulation that explicitly or implicitly

prohibits the use of Healy coal would force coal burners to use more expensive coal types that are not locally extracted or would lead to expensive replacement of coal burning devices with devices that burn other fuels.

Commenters also addressed potential savings to individuals that heat with cleaner burning fuels such as seasoned and dry wood. Commenters noted increased heating efficiency and decreased maintenance costs associated with burning clean, split, dry, and seasoned wood.

Commenters addressed the costs associated with health issues caused by breathing pollution in part caused by burning of solid fuels that release harmful emissions. Commenters indicated having purchased and incurred expenses operating home and car filtration systems including particle counters, HEPA filters, masks and gaseous pollutant filters. Commenters reported incurring significant medical expenses from emergency room visits, specialist appointments, medications, treatments, and surgeries. Commenters also reported lost work, recreation, and schooling. Commenters were also concerned about decreased property values due to impaired ambient air quality.

Commenters that addressed financial impacts of increased risk of fires and explosions to building owners and occupants and to public services felt that the proposed regulation would lead to decreased cost and risk. Commenters noted the increased likelihood of chimney fires from creosote accumulation, house fires, and explosions resulting from the use of improper fuels in solid fuel heating devices. Commenters noted that firefighters and first responders must use financial resources to respond to these emergencies and that building owners and occupants are financially impacted by such emergencies. Commenters argued that encouraging the use of proper fuels in devices by implementing the proposed regulation would decrease the incidence of fires and lower risks and costs associated with responding to them.

Regulatory Options: Based on the comments received, the department considered the following regulatory options:

1) Do not implement the proposed regulation (keep current regulation)
2) Implement the regulations as proposed
3) Implement the proposed regulation with amendments
    a. Include language:
        i. Requiring the use of split and seasoned wood that meets moisture criteria
        ii. Specifying lengths of time wood must dry
        iii. Requiring the use of anthracitic or bituminous coal and coal pellets
        iv. Allowing the use of fuels made of recycled or biomass materials
        v. Requiring use of manufacturer or warranty specified fuels
    b. Specifically prohibit fuels
        i. List prohibited fuels
        ii. Prohibit coal
        iii. Prohibit fuels that release noxious, poisonous, or injurious emissions
        iv. Incorporate NESCAUM or other lists by reference

4) Expand Regulation
    a. Regulate wood moisture content through controls on suppliers and retailers
    b. Make regulation apply statewide
    c. Ban certain types of devices

Department Decision: DEC appreciates the many and varied comments received on this proposed regulation. After careful consideration, DEC is not planning to move forward with the proposed regulations as written. Instead, the department plans to make additional revisions to the draft requirements in 18 AAC 50.076, which will be re-proposed for additional public review and comment.

Wood-Fired Heating Device Emission Standards- 18 AAC 50.077

DEC proposed to amend 18 AAC 50 by adding a new section (**18 AAC 50.077**) to establish particulate matter emission limits for new wood-fired heating devices, including outdoor hydronic heaters and woodstoves, being manufactured, sold or installed within the FNSB PM 2.5 non-attainment area.

18 AAC 50.077. Wood-fired heating device standards.

(a) **Applicability**. These regulations apply to

(1) air quality and special protection areas identified in 18 AAC 50.015(b)(3);

(2) any manufacturer, supplier, distributor or person intending to sell, lease, distribute, market, or convey a new wood-fired heating device for use in areas listed in (a)(1) of this section; and

(3) any person who owns or operates a wood-fired heating device in areas listed in (a)(1) of this section.

(b) **Prohibitions**. Except as provided in (4) of this subsection, no person subject to (a) of this section may supply, distribute, lease, sell, convey, or install

(1) a new hydronic heater unless the model has been

(A) tested by an EPA-accredited lab to meet the particulate matter emission limit of 2.5 grams per hour using the EPA hydronic heater test procedure, "Test Method 28 WHH for Measurement of Particulate Emissions and Heating Efficiency of Wood-Fired Hydronic Heating Appliances", approved by EPA as of October 12, 2011 and adopted by reference; or

(B) listed on EPA's Phase II White Tag Model list, provided the unit meets the emission standard in (A) of this subsection and its rated size is under 300,000 BTU as of {*the effective date of regulation*};

(2) a new woodstove unless the model has been

(A) tested by an EPA-accredited lab to meet the particulate matter emission limit of 2.5 grams per hour using the applicable EPA Test "Method 28" and appropriate emission concentration measurement procedures "5G" or "5H" found in Appendix A to Part 60, revised as of December 23, 1971 and adopted by reference; or

(B) listed on EPA's certified woodstove list, provided the unit meets the emission standard in (A) of this subsection and its rated size is under 300,000 BTU, as of six months after the {*effective date of regulation*}.

(3) a new wood-fired heating device greater than 300,000 BTU unless the model has been

(A) tested by an EPA-accredited lab to meet the particulate matter emission limit of 2.5 grams per hour using ASTM test procedures E2515-11, approved as of November 1, 2011, and E2618-09, approved as of February 15, 2009, and adopted by reference.

(4) the prohibitions in subsection (b) do not apply to:

(A) the supply, distribution, lease, sale, conveyance or installation of a new wood-fired device by a person subject to (a) of this section where that person has confirmed in writing with the buyer or user of the device that they intend the device will be installed and used in an area other than one of the areas described in (a) (1) of this section.

(B) the sale, lease or conveyance of a wood-fired heating device where the device is being sold, leased or conveyed as part of a single or multifamily residence and the device was installed in that residence prior to {*effective date of regulation*}.

Summary of Comments:

- **Grandfathering**

Commenters addressed the applicability of the proposed regulation to only devices sold and installed after the adoption of any regulations. Commenters argued that this would in effect grandfather older devices that would be noncompliant under new regulations and could have varying impacts. Commenters that felt that, by grandfathering older devices, any regulations would fail to have an appreciable impact on current air quality were countered by commenters that felt that not grandfathering older devices would have a significant negative impact on the local economy.

Comments expressed concern that the proposed regulations would not significantly improve air quality in the nonattainment area because they would grandfather devices that currently contribute significant emissions and could last for many years. Commenters felt that allowing currently operated highly polluting devices to continue to operate would not improve air quality. They said that allowing the worst polluters to continue polluting by grandfathering their devices was preposterous. However, commenters noted that 18 AAC 50.110 – Air Pollution Prohibited (Eff. 5/26/72, Register 42) would still govern the operation of any grandfathered device. Comments noted that solid-fuel heating devices can last for decades before needing to be replaced and that the proposed regulation would not be able to reduce pollution from such devices until many years into the future. Commenters argued that this would do nothing to resolve air quality issues in hotspot areas and would slow the change-out of older devices for efficient and clean new devices. In addition, commenters said that many potentially non-compliant devices were being installed in response to the proposed regulations. Commenters desired regulations that would require replacement of highly polluting devices either immediately or over a period of time.

Commenters expressed concern that not grandfathering heating devices would require individuals and businesses to purchase and install new heating devices at significant expense. Commenters suggested that these economic impacts could include lack of disposable income to spend at area businesses and undue financial costs to individuals unable to afford compliant heating devices. Other comments countered that individuals could take advantage of programs such as the borough change-out program to reduce any associated costs. Comments indicated, however, that individuals may be unwilling to participate in the government-run program or be unable to afford any upfront or other costs not covered by the FNSB change-out program. Comments suggested modifications to the FNSB change-out program to alleviate these and other challenges such as transferring the program to a non-government entity, eliminating required upfront costs, funding the entire cost of purchase and installation of a heating device, funding

inspection and modifications to flues and chimneys, and prioritizing low-income individuals and highly polluting devices.

- **Geographic Area of Applicability**

Commenters that addressed the geographic area in which the proposed regulations would cover had a variety of opinions about the areas of the state this regulation should apply to. Commenters that argued that the regulations should apply to areas outside of the nonattainment area raised a variety of points. Some commenters argued that the air quality protections offered by these regulations could benefit air quality in other areas of the state or areas outside of the nonattainment area such as adjacent neighborhoods. Other commenters worried about the implications of only regulating device sales in the nonattainment area. Commenters argued that placing limitations on the supply, distribution, or sale of heating devices only in the nonattainment area would enable individuals to bypass the regulations and purchase appliances in other areas accessible by road. Commenters felt that individuals would travel to retailers on the road system that were not affected by the proposed regulation to skirt the proposed regulation and obtain an uncertified device. Commenters worried that this would put retailers in the nonattainment area at a competitive disadvantage and reduce the effectiveness of the proposed regulation. Other comments suggested that allowing retailers in the nonattainment area to sell noncompliant devices if the customer verifies in writing that they intend to install the device outside of the nonattainment area would allow for customers to easily subvert the regulation by providing a false verification. Comments suggested that customers should be required to provide a notarized verification specifying the physical address the appliance would be installed.

- **Coal-Fired Devices**

Commenters noted the proposed regulations do not place restrictions on the supply, distribution, lease, sale, conveyance, or installation of coal-fired heating appliances. Commenters indicated that coal-fired heating devices were currently used in the nonattainment area and had disproportionately negative impacts on air quality. They cited a study that found fuel oil to be 137 times cleaner burning than a coal stove and 2,328 times cleaner burning than a non-qualified coal-fired hydronic heater. Commenters also note that coal combustion emits more and different pollutants than wood combustion including potentially harmful metals. Commenters felt that a lack of regulations regarding coal-fired device supply, distribution, sale, lease, conveyance, or installation would incentivize consumers to switch to heating residences and buildings using coal-fired instead of wood-fire heating devices. Commenters noted that while studies have shown that coal currently contributes only a small fraction of the total PM 2.5 emissions, inadvertently increasing the usage of coal-fired heating devices could cause that contribution to grow to a significant enough percentage of overall emissions that it could require a time-consuming and controversial regulatory package proposal process for coal-fired devices similar to the current proposal for wood-fired heating devices. They suggested regulating coal-fired devices now would avoid the possibility of a similar effort in the future.

Commenters requested that emissions standards apply to coal-fired heating devices and that such emission standards should exist due to the inclusion of coal as an approved fuel type in the proposed regulations package. Commenters noted that no EPA emissions testing methods or standards currently exist for coal-fired heating devices. Comments suggested that Alaska create such testing methods and standards. Commenters noted that DEC had indicated that developing emission standards for coal-fired heating devices would require significant research, testing, time, and resources; regardless, commenters desired some form of emissions standards for coal-fired heating devices. Commenters suggested emissions standards based on opacity readings, such as emitting no visible emissions or allowing visible emissions for only 6 minutes of any 60 minute period, as an alternative to developing emissions standards through research and testing.

Other comments suggested that the fuel savings to individuals heating their homes or businesses using coal-fired heating devices were significantly outweighed by health and other costs incurred by the public as a result of the emissions of those devices. For this reason, commenters suggested coal-fired heating devices be banned altogether in the nonattainment area or in any populated area. They suggested prohibiting the installation of new coal-fired heating devices and either an immediate prohibition of their use or a phase out of coal-fired device use over a several year period.

- **Hydronic Heaters**

Commenters addressed hydronic heaters. Commenters indicated that there are an estimated 150 Outdoor Hydronic Heaters in the nonattainment area and expressed varying opinions about the reasonableness of their use in the nonattainment area, the reasonableness of the proposed regulation, and offered alternatives to the proposed regulation.

Some commenters felt that the use of outdoor hydronic heaters was an economical alternative to heating by more expensive means such as fuel oil or electricity. Commenters also noted that hydronic heaters provide greater benefits and safety to users when compared to woodstoves. Commenters said that hydronic heaters provide individuals with hot water and provide heat for an entire building whereas a woodstove may provide heat for only a single room. Commenters also said that outdoor hydronic heaters provided increased safety to individuals due to decreased risk of indoor CO poisoning, indoor smoke, and chimney or structural fires. Some commenters said that outdoor hydronic heaters, while economical, were inconvenient due to maintenance and fueling requirements. Commenters said that some outdoor hydronic heaters were operated only for economic reasons and users may switch to more convenient heating oil if it were less expensive.

Other commenters felt the use of hydronic heaters in the nonattainment area was unreasonable due to their impacts to ambient air quality and public health. Commenters suggested prohibiting the use of hydronic heaters either in the nonattainment area, the entire Fairbanks North Star Borough, or any populated area. While some commenters reported operating hydronic heaters in populated areas without complaints from neighbors, other commenters reported individual financial and health impacts from the

emissions of their neighbor's hydronic heaters and noted that hydronic heater emissions may have highly localized impacts that are not measured by air monitors. Commenters noted the two outdoor hydronic heaters near Woodriver Elementary School that were declared to be a public nuisance and had caused $500,000 in documented expenses over a four year period. Commenters said that these boilers were EPA Phase 2 qualified devices but still had significant negative impacts on neighbors and school students and staff including missed days of school and or work, asthma attacks, discomfort, increased medical costs, and ongoing medical conditions. Commenters argued that the fuel savings to individuals were outweighed by the costs incurred by the individuals and the public. Commenters stated that those costs included absences from school, missed days of work, air filtration systems, increased health care, travel, relocating, and loss of future productivity.

- **Masonry Heaters**

Commenters that addressed masonry heaters and rocket stoves detailed their benefits when compared to other solid-fueled heating devices and argued for modifications to the proposed regulation to allow for their use and installation in the nonattainment area. Commenters said that masonry heaters and rocket stoves are highly efficient and clean burning wood-fired heating devices because of the ability to store and radiate heat stored from short, hot, and efficient fires rather than continuous, smoldering fires often required in other devices. Commenters reported that masonry stoves burned less wood and were clean burning but were a significant financial investment for individuals. Commenters said that, as written, the proposed regulation would not allow the installation of wood-fired masonry heaters. Commenters said that masonry heaters are locally manufactured and cannot be transported to EPA testing facilities to obtain certification and should be exempt from any emission standards. To ensure proper construction, commenters suggested requiring masonry heater installation by only certified heater masons according to ASTM E1602.

- **Device Installation**

Commenters addressed device installation and the effects of certain considerations on the impact of emissions on immediate neighbors and overall emissions. Commenters relayed experiences of working cooperatively with device owners to abate the effects of emissions on neighboring properties by raising the stack height or relocating stacks on the operator's property.

Stack Height

Commenters noted that the elevation at which device exhaust is emitted affects the dispersal of emissions and can help to lessen the impacts of emissions on neighbors. Comments suggested requiring that stack heights reach certain heights relative to the ground or relative to surrounding rooflines to ensure proper dispersion of emissions.

Device Setback

Commenters noted that the position of stacks had an effect on the concentration of emissions reaching neighboring properties by promoting dispersion of emissions before reaching property lines. Commenters suggested requiring outdoor hydronic heating devices to be setback a minimum distance from a property's boundaries. Commenters suggested values such as 100 feet to allow proper dispersion of emissions or to prevent the installation of outdoor hydronic heating devices in urban areas where property lot sizes would likely be too small for an owner to install a device and meet setback requirements.

Sole-Source

Commenters noted that a solid-fuel heating device may be the sole source of heat for a residence or business and that exemptions to any curtailment strategies should be made for individuals providing essential heating or operating a sole-source heating device. Comments noted building codes in Juneau that were implemented to help alleviate PM 10 pollution that prevent construction of new homes where a solid-fuel heating device is the sole source of heat. Commenters suggested similar strategies for the nonattainment area to prevent new homes from being constructed with a solid fuel fired heating device as the sole source of heat.

- **Testing Methods**

Commenters argued that the results obtained from laboratory test methods may not accurately predict the emissions of appliances that operate using cordwood in the nonattainment area. Commenters said that, because of this, either emissions standards should not be implemented or that testing methods should be altered. Commenters noted that the EPA test methods required the use of crib wood which is dry dimensional lumber with spacers for air flow. Commenters pointed out that the species and preparation of cordwood burned in the nonattainment area has different characteristics than crib wood which may result in a device emitting more or less PM 2.5 during real-world operation than a controlled laboratory test predicts. Commenters suggested requiring wood-fired heating devices to be tested using cordwood to better predict real-world performance and to make the emission cap an absolute cap rather than averaging results over 24 hours which can hide emissions spikes. Commenters questioned the reliability of EPA's testing methods and results and cited a study that indicated many EPA hydronic heater tests had questionable results for efficiency or emission rates or were missing data necessary for their determination. These comments suggested strong emission standards using modified testing methods that predict real world emissions and efficiency would inform customers of device efficiency, protect customers from marketing hype, and prevent the installation of inefficient or highly polluting devices. Commenters said that device performance was highly dependent on factors such as the type of fuel used, the use of un-split or unseasoned wood, burn rate, heat requirements of a space compared to the BTU rating of the appliance used, whether a device is allowed to smolder or burn efficiently, the knowledge and skill level of the device operator, air temperature, device maintenance,

and device condition. Commenters also cited a field study testing real-world stove operation that found no statistically relevant difference in emissions between stoves with emissions ratings less than or equal to 2.5 g/hr and stoves rated between 2.5 and 4.5 g/hr.

Commenters desired the inclusion of additional testing methods in the proposed regulation. Commenters suggested that the regulation allow the use of devices tested using method ASTM E2618 – Standard Test Method for Measurement of Particulate Emissions and Heating Efficiency of Solid Fuel-Fired Hydronic Heating Appliances. Commenters also requested the inclusion of test method ASTM E2515 – Standard Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel. Commenters noted the lack of available test methods for determining emissions from coal-fired heating appliances and desired testing of these devices to ensure an emission standard was met.

- **Device Standards**

Hydronic Heaters

Commenters addressed the proposed device standards for hydronic heaters. Commenters felt that the proposed regulation would likely be inconsistent with potential future EPA NSPS for outdoor hydronic heaters. Comments detailed the efforts of manufacturers and the EPA to cooperatively develop the voluntary Phase 1 and Phase 2 Outdoor Hydronic Heater Programs. Commenters indicated that manufacturers have developed many appliances that meet the Phase 2 program limit of 0.32 lb/MMBtu for devices under 350,000 Btu/hour and that these efforts have yielded devices that emit 90% less particulate matter when compared to unqualified models, commenters noted that the white hangtags that indicate qualification are regulated by EPA. Comments suggested that aspects of the Phase 2 program standards should be incorporated into DEC's regulations such as changing the Btu threshold from 300,000 to 350,000 Btu/hour, the emissions standard units from g/hr to lb/MMBtu, and adopting the emission limit of 0.32 lb/MMBtu. Commenters said that a majority of states and EPA use 350,000 Btu/hour as the cutoff when regulating outdoor hydronic heaters and argued that units above 350,000 Btu/hour are generally considered commercial units that would be regulated by individual permits. Commenters also felt that limiting the choices of consumers available through the Phase 2 qualification program by only allowing devices under 300,000 Btu/hour would interfere with an individual's ability to choose a device that ideally suited their needs and may place limitations on manufacturer's ability to design and produce devices that best suit the needs of their customers. Commenters also felt that regulating hydronic heaters on a g/hr basis disregarded the relative utility and efficiency of outdoor hydronic heaters when compared to indoor woodstoves and ignored precedents both within the Phase 2 program and regulations adopted by other states. Some commenters suggested that the limit of 0.32 lb/MMBtu should be adopted instead of the proposed 2.5 g/hr limit, however, other commenters felt that an emissions limit of 2.5 g/hr should apply to all solid-fuel heating devices including hydronic heaters. Commenters also said that other states have requirements that solid-fuel

heating devices such as hydronic heaters must meet both EPA Phase 2 qualification standards and stricter state imposed emissions standards and suggested that Alaska adopt such a requirement.

Woodstoves

Comments addressed emission standards for woodstoves. Commenters felt that emissions standards should be more stringent, less stringent, or that other factors should dictate which woodstoves are allowed in the nonattainment area. Commenters noted that the 2014 proposed EPA NSPS included a two-step implementation scheme where the first step was 4.5 g/hr and the second step, five years later, was 1.3 g/hr. Commenters suggested adopting the 1.3 g/hr value to be consistent with the proposed NSPS and prevent having to amend regulations at a later date to reflect any adopted NSPS. Commenters noted that studies have shown that the emissions of 4.5 g/hr and <2.5 g/hr stoves had no statistically significant difference and recommended that the woodstove emissions standard be raised to 4.5 g/hr. Commenters also noted that device operation dictates emissions and that relying on EPA method test results to set standards may be counterproductive because either the methods were unreliable and should be modified to more accurately predict real-world emissions or that <2.5 g/hr stoves may actually produce more emissions than a 4.5 g/hr stove due to nonattainment area wintertime conditions. Other commenters felt that no emission standards should be adopted. Commenters suggested all woodstoves sold or installed in the nonattainment area should have a catalytic element to reduce device emissions. Commenters also suggested standards based on the presence or absence of a catalytic element such as 2.5 g/hr for catalytic stoves and 4.5 g/hr for non-catalytic stoves. Comments also suggested that instead of creating emissions standards, DEC could adopt an approach used in other states and only allow the sale of EPA certified or qualified devices.

- **Solid Fuel-Fired Heating Device Sales**

Commenters addressed possible impacts of the proposed regulations on local businesses and individuals trying to sell solid fuel-fired heating devices.

Commenters noted that local businesses may be at a competitive disadvantage to businesses outside of the nonattainment area because the proposed regulation would limit the types of stoves that they were able to sell to local customers whereas other retailers on the road system could still offer non-compliant appliances. Comments indicated that individuals had preferences for both devices that would be compliant under the proposed regulation and devices that would not be compliant. Commenters reported that wood-fired heating devices with an EPA emissions rating of 2.5 g/hr or less were desirable due to their efficiency, reduced fuel consumption, and reduced pollution. Commenters noted and reiterated a finding in the peer review that numerous models of woodstoves with emissions less than 2.5 g/hr were available and were comparable in cost. Commenters said that even if a woodstove were more expensive than a less efficient model, a customer would recoup that cost over time as a result of increased fuel efficiency. Other

commenters felt that the peer review did not accurately assess the woodstove market. Commenters said that many customers purchase the least expensive stoves for economic reasons and that 2.5 g/hr woodstoves were only comparable in price to higher end or specialty woodstoves with emissions ratings greater than 2.5 g/hr. Commenters also expressed disappointment that regulations would prevent them from buying stoves they might otherwise have chosen. Commenters felt that these factors created an easily exploited loophole that would lead to individuals travelling to unregulated businesses on the road system to purchase a non-certified woodstove. Commenters suggested that the regulations should apply to all road-accessible retailers in Alaska or should not be implemented at all.

Commenters noted that there have been instances of retailers not abiding by previous borough regulations regarding the sale of woodstoves. These commenters feared that some businesses within the nonattainment area may choose not to follow the regulations and gain an unfair competitive advantage. Commenters suggested that to prevent this scenario, the regulation should either be enforced or should not be implemented at all. Commenters were concerned about potential paperwork that retailers could be required to have their customers sign to complete a sale. Commenters argued that this would put the enforcement burden on businesses who may lose sales to customers that refuse to sign any statements.

Commenters addressed a provision within (b)(2)(B) that stipulates a period of six months after the effective date of the regulation. Commenters viewed this as an opportunity for retailers to sell non-certified inventory and either felt that this was not a long enough period or that no such period should be allowed. Commenters that felt that the period should be longer than six months argued that excess inventory of non-compliant devices likely consisted of specialty woodstoves which were slow moving and would be unlikely to sell out before six months had elapsed, causing retailers to be stuck with those devices and incur financial losses. Other commenters felt that allowing a six month period was unproductive. They argued that allowing the sale of uncertified appliances after the effective date of the regulation would allow non-compliant devices with long effective lifespans to be sold, installed, and operated in the nonattainment area which would not help to reduce emissions. Commenters felt that retailers could have foreseen coming regulations and not risked losses by acquiring excess inventory of non-certified woodstoves. Commenters suggested retailers should either have or not have the opportunity to sell excess inventory and either receive or not receive reimbursement for financial losses incurred as a result of the proposed regulations.

Commenters noted that the proposed regulation would also impact woodstove sales between private parties. Comments suggested that the proposed regulation would wrongly deprive an individual of any financial gains an individual could realize through selling their used non-certified device to another individual after purchasing a new woodstove for their residence.

- **Home Sales**

Commenters that addressed 50.077(b)(4)(b) had varying levels of support for the provision.

Some commenters expressed a desire that the provision be removed from the regulation. These commenters felt that the regulations should not allow residences to be sold without requiring the replacement of non-certified devices and that requiring the replacement of a non-compliant device was a reasonable means of increasing the turnover of existing devices. Commenters noted that the cost of new certified devices was small in comparison to the average price of a residence in the nonattainment area. Commenters argued that these costs could be incorporated into mortgages and enforced by the real estate and mortgage industries similar to requirements that septic systems and other aspects of homes meet building codes before a bank will issue a loan. Commenters noted that replacing older devices with newer and more efficient models upon the sale of a home would speed the replacement of non-certified devices in the nonattainment area, provide fuel savings to new owners, and that homeowners could participate in the woodstove exchange program to help cover the cost of replacement. Commenters felt that, as proposed, the regulation would slow the change-out of older devices that may continue to pollute for decades due to long useful lifespans and that other states have successfully implemented requirements to change-out of non-certified devices upon the sale of a home.

Other commenters expressed support for the exemption or expressed concern that the exemption would only apply to single and multi-family residences. Commenters felt that not exempting woodstoves sold, leased, or conveyed as part of a residence would place a financial burden on individuals and businesses. Commenters noted that the regulation did not mention buildings other than residences such as businesses, garages, outbuildings, and others. They argued that requiring the replacement of a non-compliant device each time such a property is sold or leased would place an undue financial strain on individuals and businesses which would impact the local economy due to the large number of structures in the nonattainment area that use wood-fired heating devices but are not considered single or multi-family residences.

Comments Outside the Regulatory Proposal: Comments and questions were received that were outside the specific regulatory proposal. Those comments and questions are summarized below.

Commenters addressed a variety of air quality topics that are outside of the specific regulatory proposal. Commenters addressed existing EPA approved laboratory test methods that are used to determine the emissions of wood-fired heating devices. These comments suggested that the methods do not accurately predict device performance under real world conditions. Commenters proposed changes such as requiring the use of area-specific cordwood as fuel. Other comments indicated a desire that the regulation encompass coal-fired heating devices. Commenters noted that no EPA standards for coal-fired heating devices exist and suggested that DEC develop

standards or regulate emissions using opacity. Commenters also addressed installation of heating devices and factors that influence device emission dispersion.

1) Using Cord Wood Test Methods

Woodstoves are tested using EPA Reference Method 28 and sampling methods 5G or 5H by an accredited laboratory. EPA test methods for certifying wood heaters use standardized fuel to ensure results are repeatable and can be compared to results obtained by testing other devices. DEC appreciates that there is debate and discussion over the EPA test methods and that consideration is being given to revising them to a cord wood fuel standard in the future. However, those methods are not yet fully developed and vetted by EPA, the industry, and others. DEC proposed its wood heater emission standards so that they could rely on the testing already used in current EPA programs. These methods have been in place for many years and are used by EPA in certifying or approving heating devices. If Alaska mandated a different test method, manufacturers would then need to conduct separate laboratory tests to certify to both EPA and Alaska emission standards. To change fuel requirements in existing EPA methodologies and establish different test methods for Alaska, would require considerable time, expense, and may be less reliable than existing methods. Given the immediate need and efforts to improve heating devices in the nonattainment area, DEC decided to move forward using the test methods currently established and in use within the industry.

For more information on the EPA testing methods, please visit:
http://www.epa.gov/Compliance/monitoring/programs/caa/whlabs.html

2) Developing Emission Standards for Coal-Fired Devices

As part of the air quality planning effort, studies have been conducted to determine the specific sources of the pollution found on the monitor filters from within the non-attainment area. The studies found that the portion of particulate coming from coal burning is small compared to the particulate on the filters from wood burning. This is consistent with surveys of residents' home heating devices which show wood heaters are much more prevalent that coal heaters. Given that the majority of the problem, area wide, is wood smoke, the current proposed regulations are focused there. However, the department is very aware of citizen concerns regarding smoke from coal-fired heaters. Unfortunately, the U.S. EPA has not developed any emission standards for new residential coal-fired indoor stoves or outdoor boilers nor has EPA established any specific test methods or program to certify residential coal heating devices. As a result, DEC does not have an existing federal program or framework to use to make a regulatory decision on an emission standard for coal heaters. For DEC to regulate coal-fired heating devices, significant research is needed to establish standards for these devices. DEC would need to work with a testing laboratory to test and develop a method for certifying coal-fired heating devices and then use that method to test many types of coal-fired devices. This research, testing, and development would take time and resources.

DEC continues to evaluate the need for and the options to address emissions from residential coal-fired heating devices. DEC plans to propose additional revisions to state regulations that would help to address emissions from these devices. Given the time and resource constraints discussed above, that proposal will focus on reducing smoke from coal heaters during operation rather than through a new heater emission standard. The public will have opportunity to review and comment on that new proposal.

3) Device Installation

The proposed regulations, while specifying installation, are not intended to dictate how a device is installed, only whether a device can be installed. Regulating stack height, setbacks, and presence of non-solid-fuel-fired heating devices is outside the proposed regulation. Local building codes may be a more appropriate place to regulate how devices are installed in a community.

Fiscal Concerns: Those comments specifically noting fiscal impacts are summarized here.

Commenters felt that grandfathering currently installed devices would have both negative and positive fiscal impacts on individuals and the public. Commenters noted that the regulation does not affect currently installed devices that can be highly polluting and are currently contributing to the problem. Commenters said that requiring devices to be replaced would have a negative impact on the local economy and to the individuals that must change their devices. Other commenters noted that those individuals could take advantage of the change-out program. Commenters also suggested that allowing devices to be grandfathered would force the public to incur greater health costs.

Commenters indicated that devices that emit less than 2.5 g/hr may cost more than higher polluting stoves in contrast to the findings in the peer-review. Commenters feared that purchasing compliant devices would limit the available selection of devices and raise costs to the consumer. Other commenters suggested that any additional costs of purchasing a <2.5 g/hr device would be recouped over time due to increased device efficiency.

Commenters felt that there could be fiscal impacts on retailers and resellers. Commenters said that retailers may lose business to retailers outside of the nonattainment area or even businesses within the nonattainment area that do not follow any adopted regulations. Comments also said that retailers would likely be stuck with inventory they could not sell under the proposed regulation. Comments were also received that suggested the proposed regulation would wrongly take the resale value of a non-compliant device from private individuals who could have sold their device after purchasing a new device.

Regulatory Options: Based on the comments received the department considered the following regulatory options.

1. Do not implement the proposed regulation
2. Implement the regulations as proposed
3. Implement proposed regulation with amendments
    a. Technical edits
        i. Consider using lb/MMBTU as opposed to just g/hr for Outdoor Hydronic Heaters
        ii. Large unit break point should be 350,000 BTU heat output
        iii. Consider scaling standards for larger units
        iv. Consider stack height and set back provisions for OHH/larger units
        v. Clarify masonry heater provisions
        vi. Remove the term "installation" in 50.077(b)(4)(A) and strengthen to require more than just confirmation in writing that the device will be installed in another area (e.g. address and notarization)
        vii. Consider other test methods for certifying some devices
        viii. Consider using a cordwood test method
    b. Clarify grandfathering exemption to include existing buildings that are not homes
4. Modify regulation
    a. Expand emission standards to cover all wood-fired heating devices, not just those currently in an EPA program (single burn rate stoves, pellet stoves, masonry heaters, forced air heaters, fireplace inserts, etc.)
        i. Align more with EPA proposed NSPS
        ii. Consider moving to the more stringent (out year) levels from the NSPS now
    b. Prohibit installation of coal heaters and outdoor wood hydronic heaters (OWHH) within populated areas
    c. Remove grandfathering provision– upon resell seller required to upgrade to 2.5 g/hr implementation.
    d. Exempt masonry heaters from the regulations
    e. Make emission standards statewide
    f. Include emission standards for coal-fired heaters

Department Decision: The department appreciated the feedback received on the proposed emission standards for wood heating devices. DEC thinks it is important to move forward with regulations specifying the emission standards for new wood stoves, hydronic heaters, and larger heating devices within the nonattainment area. Significant efforts and resources are being expended to upgrade wood heating devices in the nonattainment area through incentive programs. It is critical that the heaters used in this air quality problem area be as clean as possible in order to reduce the impacts of air pollution while maintaining the option for residents to use wood as an affordable source of heat. The department's analysis contained in the peer review indicated that there are affordable heating device options in various sizes that can meet the emission standards.

In response to comments received the department agreed that a number of technical revisions were warranted based on the comments received. Therefore, after careful consideration, 18 AAC 50.077 will be adopted with changes.

- Subsection (a) is being adopted without changes, as proposed.

- Changes to Subsection (b) will include:

  - Increasing the maximum BTU/hr rating from 300,000 to 350,000 in categorizing wood heating devices;

  - Referring to EPA's Phase 2 Hydronic Heater Program as "Phase 2" instead of "Phase II";

  - Adopting hydronic heater emissions standards that are more consistent with the EPA's Voluntary Phase 2 Hydronic Heater Program by expanding beyond a simple 2.5 gram per hour requirement. The adopted provisions would include an annual average emission level of 0.32 pound per million BTU of heat output, a maximum individual test run of 18.0 grams per hour, and a particulate matter annual average emission rate of 2.5 grams per hour;

  - Incorporating ASTM Method E2618, "Standard Test Method for Measurement of Particulate Emissions and Heating Efficiency of Outdoor Solid Fuel-fired Hydronic Heating Appliances," and ASTM Method E2515, "Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel," as methods for demonstrating device compliance with relevant emissions standards;

  - Requiring submission of proof of EPA certification or test results demonstrating compliance with the final state emissions standards limits in (b)(1)-(3) for departmental approval before inclusion on a publicly available list of approved devices;

  - Clarifying "wood-fired device" in (5) as "wood-fired heating device"; and

  - Changing "single or multi-family residence" in (5) to "an existing building or other property."

These changes address a number of issues raised by commenters on this proposal. The program has been better aligned with EPA's programs and industry standards with respect to the size classes of heaters, the requirements for hydronic heaters, and relevant test methods. DEC also clarified the masonry heater requirements within the definition section. These emission standards would not apply to masonry heaters unless they are sized over 350,000 BTU per hour.

DEC did not move ahead, as suggested by some commenters, to adopt EPA's proposed wood heater emission standards at this time. Should EPA finalize those standards in the future, they

would ultimately result in more stringent requirements than the regulations being adopted and the state could revisit its requirements.

DEC also maintained the nonattainment area as the geographic area covered by these requirements. DEC recognizes an immediate need to reduce air pollution in this area that does not exist in all parts of the state. With EPA working to update its emission standards for wood heaters, future federal requirements will likely help in maintaining and improving air quality in other areas of the state. Further, the proposed rules do not prevent a retailer from selling wood heating devices that do not meet these emission standards to residents located outside the nonattainment area. This should address retailer concerns about existing inventory of heating devices that do not meet the proposed emission standards as there is still a market for these units. Also, to address concerns about sales from retailers outside the nonattainment area, DEC plans during implementation of this regulation to contact retailers throughout the state, not just those located within the nonattainment area, to ensure the requirements related to the nonattainment area are known and complied with. In addition, DEC will assist retailers as needed to address concerns with implementation.

With respect to clarifying the exemption grandfathering existing heaters from emission standard requirements, DEC did make changes to the exemption language to expand from “residences” to “existing buildings or property”. This should better capture the universe of devices already existing in the community. However, in response to concerns that grandfathering should not be allowed due to the need to significantly improve air quality in the nonattainment area, DEC is planning to propose revisions to the adopted regulations that would seek to provide additional requirements in the future if the area fails to attain the air quality standards. The new proposal would require the replacement of wood heaters that do not meet emission standards upon the sale of a property inside the nonattainment area. This new proposal will be available for public review and comment.

As discussed previously, DEC did not revise its regulations to alter the testing methods to rely on cordwood or to add specific device installation requirements, such as setbacks or stack heights. DEC thinks that these specific installation requirements would fit better within the structure of any local building codes rather than in an environmental regulation. DEC also did not extend the emission standards to residential coal heaters, but will be proposing other requirements that will help to address smoke for these units during operation.

PM 2.5 Concentrations Triggering an Air Quality Episode (Table 6) - 18 AAC 50.245(a)

DEC proposed to amend 18 AAC 50.245 (a) to establish PM 2.5 concentrations in **Table 6** that will be used to trigger air quality alert, air quality warning, or air quality emergency episodes.

The proposed PM 2.5 concentrations for Table 6 are as follows:

Episode Type	Pollutant	Concentration in µg/m^3
Air Alert	PM 2.5	56 (24-hour average)
Air Warning	PM 2.5	251 (24-hour average)
Air Emergency	PM 2.5	351 (24-hour average)

Summary of Comments: Comments on the proposed changes to 18 AAC 50.245(a) and Table 6 suggested the proposed concentrations were arbitrarily derived, not stringent enough, or too stringent. Others suggested altering the format of Table 6 or adding other pollutant criteria to Table 6.

- **Air Alerts**

Comments focused primarily on the first episode level, the air alert, with varying degrees of support or concern. Commenters felt the value of 56 µg/m^3 was arbitrarily derived and was either too stringent or not attainable, not likely to lead to attainment of the National Ambient Air Quality Standard (NAAQS), or not protective enough of public health. Some comments proposed a higher value or suggested a higher value that could be reduced over time as the situation within the nonattainment area improved. Other commenters suggested the proposed PM 2.5 alert level in Table 6 should be consistent with the 24-hour PM 2.5 NAAQS of 35 µg/m^3 to be protective of public health and to help achieve the NAAQS. Some commenters suggested that DEC's proposed PM 2.5 concentrations are not protective for sensitive individuals such as children and the elderly. Commenters noted that other communities and states use a lower PM 2.5 concentration for curtailment programs, for example: Juneau, AK uses 30 µg/m^3; Washington State uses 25 µg/m^3 and 35 µg/m^3; Sacramento, CA uses 31 µg/m^3 and 35 µg/m^3; and Utah's nonattainment areas use 25 µg/m^3.

Comments noted that the proposed alert level of 56 µg/m^3 would interfere with attainment of the NAAQS because it was above the NAAQS level of 35 µg/m$^{3.}$ They indicated this would not comply with Clean Air Act provisions. These comments proposed values at or below the NAAQS to prevent exceedances by curtailing emissions. Comments also cited scientific studies that show negative health effects impact children, the elderly, and sensitive groups at levels equal to or below the NAAQS. These comments proposed setting the value to 35 µg/m^3 or lower to be more protective of public health. Other comments argued that the value should be lowered because an air alert should serve the purpose of alerting sensitive groups to unhealthy conditions and allowing those individuals to protect their health by minimizing their exposure to polluted air.

- **Air Warnings and Air Emergencies**

  Comments addressing the thresholds for warning and emergency episodes suggested they be lowered to 55 and 150 µg/m^3 respectively or eliminated altogether in favor of a single threshold for air quality episodes and curtailment actions.

- **Other Comments**

  Commenters suggested creating an episode level below the air alert level that would be publicized in the same manner as other episodes but would not involve any curtailment actions to alert the public of the potential for a declaration of an air alert. Comments suggested adding other pollutants to Table 6 or altering existing thresholds within the table. Comments also suggested considering weather and inversion forecasts as criteria when declaring air episodes as is done for air quality advisories.

Comments Outside the Regulatory Proposal: Comments and questions were received that were outside the specific regulatory proposal. Those comments and questions are summarized below.

1) Coarse particulate matter (PM 10) should be added to the statewide curtailment regulations.

   Comments indicated a desire to add PM10 to the statewide air quality episode regulations.

   Response: DEC has already established air quality episode thresholds for a number of criteria air pollutants as required by the Clean Air Act and is not proposing to revise these thresholds at this time. The pollutants already included in state regulations at 18 AAC 50.245(a) are: carbon monoxide (CO), PM 10, and sulfur dioxide (SO2).The thresholds established for these pollutants have been approved by the EPA as part of Alaska's State Implementation Plan.

2) Adding other contaminants or altering existing thresholds

   Commenters suggested adding other air pollutants or changes to existing thresholds in Table 6.

   Response: DEC has already established air quality episode thresholds for other criteria air pollutants as required by the Clean Air Act and is not proposing to revise these thresholds at this time. The pollutants already included in state regulations are: CO, PM 10, and SO2. The thresholds established for these pollutants have been approved by the EPA as part of Alaska's State Implementation Plan. This regulation was meant to add PM 2.5 to this existing table of pollutant episode thresholds. EPA established a NAAQS for PM 2.5 in 1997 and this regulation amendment was proposed to allow the state to meet Clean Air Act requirements for this pollutant.

3) Altering design of Table 6 to remove air warnings and air emergencies.

Comments suggested that Table 6 should be altered to have just one triggering level for air episodes for the pollutants listed.

Response: DEC is not proposing to change existing episode thresholds and levels. The episode thresholds included in Table 6 are a required element of the Clean Air Act and part of the existing EPA-approved State Implementation Plan for Alaska. The framework was established to allow DEC or a local air quality program to implement progressive actions reflecting the severity of unique air pollution events.

4) Explain the NAAQS attainment calculations.

Questions were raised about the calculations used to demonstrate attainment with the NAAQS.

Response: The 24-hour NAAQS for PM 2.5 is 35 $\mu g/m^3$. To comply with this, 24-hour measurements taken every third day within the non-attainment area are statistically analyzed. The 98^{th} percentile values for each year over a period of three consecutive years are averaged and rounded to the nearest whole number. If this result is less than or equal to the NAAQS 24-hour standard of 35 $\mu g/m^3$ then the area is determined to be in attainment. Further information on determining compliance with the NAAQS can be found in the Code of Federal Regulations.

5) How are NAAQS values obtained (every third day, long analysis times) and how is continuous monitoring data used to declare real-time advisories and episodes?

Questions were raised about how the data used to demonstrate attainment with the NAAQS is obtained.

Response: Compliance with NAAQS is determined using 24-hour measurements from federal reference method monitors. In Fairbanks, those monitors operate every third day. Each filter is sent to Juneau for analysis. To monitor PM 2.5 levels in near real time, continuous monitors are employed that take hourly measurements and report the values to the officials responsible for declaring air quality advisories.

Fiscal Concerns: Those comments specifically noting fiscal impacts are summarized here

1) Healthcare costs from health issues exacerbated by PM 2.5.

Commenters cited scientific studies that have indicated negative health effects may occur in some segments of the population at PM 2.5 concentrations below the proposed thresholds for Table 6. Commenters suggested that these negative health impacts would cause individuals in sensitive groups to incur additional health care costs if emissions were not curtailed at thresholds that prevented concentration of PM 2.5 to reach levels equal to or below the NAAQS value of 35 $\mu g/m^3$.

2) Costs of complying with more episodes if thresholds are too low.

   Commenters noted that potential curtailment actions that include prohibition of wood burning heating devices would require individuals to heat spaces using other more expensive energy sources. Comments suggested that low episode thresholds would increase the number of days an individual would incur additional expenses associated with heating spaces without using wood as a primary or supplemental source of heat.

Regulatory Options: Based on the comments received the department considered the following regulatory options.

1) Do not implement the proposed regulation (keep current regulation)
2) Implement the regulations as proposed
3) Implement the proposed regulation with amendments:
   a) Lower initial air alert episode threshold to 45 µg/m^3, 35 µg/m^3 or lower to prevent NAAQS violations
   b) Lower air alert, warning and emergency thresholds to 35 µg/m^3, 56 µg/m^3 and 150 µg/m^3, respectively.
   c) Raise the thresholds to higher levels
   d) Add another level before an air alert is triggered

Department Decision: After careful consideration, only the amendment to the title of 18 AAC 50.245(a) Table 6 will be adopted. The remainder of Table 6 will not be amended as proposed and the current language will remain in effect.

DEC intends to issue a new regulatory proposal to address PM 2.5 episode thresholds. This new proposal will be subject to additional public review and comment.

Authority to Declare Air Episodes and Advisories - 18 AAC 50.245 (a) (b) (c)

The proposed amendment to this regulation would clarify that, in addition to the Department, authorized local air quality control programs may declare air quality episodes and air quality advisories and prescribe and publicize emissions curtailment action in the event that the air pollutant concentrations in Table 6 (18 AAC 50.245 (a)) are exceeded.

18 AAC 50.245 is amended to read:

(a)The department **or a local air quality control program authorized by the department under AS 46.14.400** may declare an air **quality** episode and prescribe and publicize curtailment action if the concentration of an air pollutant in the ambient air has reached, or is likely in the immediate future to reach, any of the concentrations established in Table 6 in this subsection.

(b) The department **or a local air quality control program authorized by the department under AS 46.14.400** will declare an air quality advisory if, in its judgment, air quality or atmospheric dispersion conditions exist that might threaten public health.

(c) If the department **or a local air quality control program authorized by the department under AS 46.14.400** declares an air quality advisory under (b) of this section, the department **or a local air quality control program authorized by the department under AS 46.14.400** will…

Summary of Comments: Commenters expressed varying opinions on the proposed regulatory changes that clarify the role of authorized local air quality programs in declaring air quality episodes and advisories and managing air pollution during events.

With respect to the delegation of authority to local programs, comments voiced a number of opinions including a lack of support for any regulations and lack of support for delegation to local programs. A number of comments focused on the delegation of authority specific to the FNSB. Commenters cited the passage of the Home Heating Proposition #3 (2012) in FNSB as a wish by citizens to not be regulated by anyone and as a perception by the public of the FNSB abusing powers related to the regulation of solid fuel heating devices. Commenters felt these proposed changes ignored the intentions of Proposition #3 by giving authority to the Borough to declare episodes and prescribe curtailment actions or declare air advisories.

Comments also raised a concern that within the regulation there is no specific designation of which entity would be responsible for declaring air episodes or advisories and prescribing curtailment actions. Commenters wanted further clarification written into the regulations concerning who is responsible for announcing and enforcing the air quality episode. Commenters suggested that the proposed amendment does not specify a single authority responsible for air alerts and that without a single, designated authority there is potential for confusion and inaction.

Comments also expressed concern that the regulations may go unimplemented by potentially unwilling local programs affected by local political climates. Therefore, comments suggested no ability for local discretion and instead suggested that the regulation use terms such as *will* instead

of *may declare*. Other comments expressed doubt that the FNSB could effectively prescribe curtailment actions citing failures to attain the NAAQS despite the State's 2010 delegation of authority to the Borough for PM 2.5 air pollution planning and given the language of Proposition #3 that resulted in the removal of local PM 2.5 regulations by removing the Borough's authority and enforcement related to home heating and fuel use.

Commenters also felt the delegation of authority to implement the program would constitute an unfunded mandate that should be funded by the state. Some comments expressed a desire for state regulation or a state partnership with a local program. Other commenters interpreted Proposition #3 as a mandate by the citizens of the FNSB that the state take over the authority previously held by the FNSB. Commenters felt state implementation would be less prone to local political volatility and be more able to ensure NAAQS compliance. Other commenters desired a partnership between local and state programs or even a citizen's advisory panel to ensure transparent and constructive discourse between citizens, local government, and state government.

Commenters supportive of delegating authority to local programs favored local authority in general and felt that local programs would have a greater ability to react quickly and to allow for enforcement actions not available to the state. Comments expressed a desire for a clear description of how a local program would use discretion in declaring an advisory or episode. Other comments suggested that discretion be eliminated and curtailment actions be mandatory. Comments also suggested a comprehensive alert system.

Comments Outside the Regulatory Proposal: Comments and questions were received that were outside the regulatory proposal. Those comments and questions are summarized below.

1) Regulation Enforcement

   Some comments focused on the need for a strong local enforcement presence. Commenters felt that advisories had limited value if local authorities did not have the power to enforce through fines and the threat of legal action. Comments received indicated the belief that the proposed regulations were illegal as they would give the Fairbanks North Star Borough authority that is contrary to or in violation of the enacted local ballot Proposition #3.

   Response: The proposed regulations do not empower the Borough or any other local government to act outside the authority of its duly-authorized local air quality program, which is established by enabling ordinance. In other words, these proposed regulations do not give the Borough new powers unless there is a local ordinance already in place. The proposed regulations are statewide regulations.

   With respect to addressing any violations of the state air quality regulations, the Department of Environmental Conservation Division of Air Quality is responsible and will use the compliance and enforcement tools for which it is allowed under state statute. The Division has not been given the authority in statute by the legislature to issue administrative penalties for violations of Alaska environmental laws. This means the

Division cannot write "tickets" and must use other tools like written notices of violation, compliance agreements, or in rare cases civil court actions. In most cases, the department finds compliance can be achieved through assisting businesses and individuals in understanding the regulatory requirements and how they can comply.

2) Improving State and Local Discourse

Commenters suggested that a partnership between local and state programs or a citizen's advisory panel to ensure transparent and constructive discourse between citizens, local government, and state government was needed.

Response: The Department does enter into partnerships with local governments to address air quality issues in communities. These partnerships are generally outlined through the use of Memorandum of Understanding between the Department and a local government. In the case of the Municipality of Anchorage and the Fairbanks North Star Borough, more formal partnerships have been established under Alaska Statute 46.14.400-410 delegating authorities to the local governments for air pollution activities in lieu of the Department administering all aspects of the air quality program in these areas. The Department has found these local partnerships to be critical in addressing air quality concerns within communities and gaining local input and perspectives on approaches to improve air quality. The Department has not formed a formal citizen's advisory panel to address statewide air quality concerns, however both the Municipality of Anchorage and the Fairbanks North Star Borough have air quality related committees whose members include local citizens representing the public and various stakeholder groups within the community. These committees provide input and recommendations to the local air quality planning process in these communities.

3) Specify which party is responsible for calling episodes and advisories

Comments were received that requested the regulations be more specific as to who is responsible for calling episodes and advisories.

Response: These particular regulation sections apply statewide and to other possible local air quality programs beyond the Fairbanks North Star Borough. Local governments derive their authorities from their citizens. The Department may delegate state authority to the local air quality program. In order for a local air quality program to have the authority to call an episode under these proposed regulations, two things must occur. First, the department and the local program must enter into a Memorandum of Understanding (MOU) that delegates authority to the program and outlines the roles and responsibilities for each agency (DEC and local program) including how advisory and episodes will be addressed. Second, the local governing body, such as an Assembly, must concur with or approve of the MOU and its delegation of authority.

Fiscal Concerns: Those comments specifically noting fiscal impacts are summarized here.

Commenters addressed possible costs to local air quality programs identified under the proposed regulations. Commenters suggested that programs would incur costs implementing the regulations and that those costs would be borne by local tax payers instead of the State. Commenters felt that requiring local programs to implement or enforce the regulations would constitute an unfunded mandate and that the State should either fund those programs or not delegate to local programs.

Regulatory Options: Based on the comments received the department considered the following regulatory options.

1) Do not implement the proposed regulations (keep current regulation)
2) Implement the regulations as proposed
3) Implement proposed regulations with amendments
    a. Rephrase to replace "…*may* declare an air **quality** episode and prescribe and publicize curtailment action…" with "…*will* declare an air **quality** episode and prescribe and publicize curtailment action…"
    b. Rephrase to replace "…*may* declare an air **quality** episode and prescribe and publicize curtailment action…" with "…*will* declare *and publicize* an air **quality** episode and *may* prescribe and publicize curtailment action…"
    c. Specify which party is responsible
    d. Clarify regulation to remove the confusion over whether the regulations provide additional authority to a local government beyond that provided by its citizens

Department Decision: One concern expressed by the public with this regulatory revision was a perception that it granted a power to the local air quality program that was in conflict with the authorities provided by citizens to their local government. Legal review on this point clarified that this perception was not correct and the wording does not provide additional authorities to a local government beyond that provided by its citizens.

DEC's statutory authority to implement regulations and enter into agreements with local programs is contained in AS 46.03.010, AS 46.03.020, AS 46.14.010, AS 46.14.030, and AS 46.14.400. 18 AAC 50.245 is a statewide regulation. The proposed regulations do not empower the Fairbanks North Star Borough to act outside the authority of its duly-authorized air quality program and enabling ordinances. This regulation recognizes that some communities may give their local program more duties and authorities than other communities. Further, this regulation does not change the local air quality Memorandum of Understanding (MOU) between DEC and the Fairbanks North Star Borough. The MOU may only be changed by joint agreement of both parties. The finalization of the proposed regulations provides an opportunity for the Department and the Borough to further clarify their respective roles, responsibilities, and the Borough's delegated authorities related to air quality activities, but only through a separate process to update the MOU.

However, to alleviate this concern overall, the department is clarifying this point in the final adopted regulation. Therefore, DEC is adopting the amendments to 18 AAC 50.245 with changes.

- The amendment to (a) will be adopted with a clarification stating that the regulation does not alter a local government's powers or obligations under a local air quality control program or other applicable laws.

- The amendments to (b) and (c) will be adopted as proposed.

The department is not changing the remainder of paragraph 18 AAC 50.245(a) in response to public comments seeking less discretion on the declaration of air episodes. Because of the many types of situations that could lead to an air pollution event, DEC thinks it is important to maintain flexibility to address and respond to unique situations and circumstances.

Definitions- 18 AAC 50.990

DEC proposed to amend this regulation to clarify the definition of a wood-fired heating device and to add the definitions for "wood heater/wood stove", "clean wood", "hydronic heater", and "solid fuel-fired heating device".

The proposed amendment to 19 AAC 50.990(123) is as follows:

> (123) "wood-fired heating device" means a device designed **or used** for wood combustion so that usable heat is derived for the interior of a building; "wood-fired heating device" includes wood-fired **or pellet-fired** stoves, fireplaces, **wood-fired forced air furnaces,** wood-fired **or pellet-fired** cooking stoves, **hydronic heaters** and combination fuel furnaces or boilers that burn wood; "wood-fired heating device" does not include a device that is primarily a part of an industrial process and incidentally provides usable heat for the interior of a building.

The proposed additions to 18 AAC 50.990 are as follows:

> (135) "clean wood" means wood that has no paint, stains, or other types of coatings, and wood that has not been treated with preservatives including copper chromium arsenate, creosote, or pentachlorophenol.
>
> (136) "hydronic heater" means a fuel burning device, including wood boilers and pellet boilers, designed to
>
> (A) burn wood, biomass or other solid fuels;
> (B) that the manufacturer specifies for installation in structures not normally occupied by humans (e.g., garages); and
> (C) heats building space or water via the distribution, typically through pipes, of a fluid heated in the device, typically water or a water/antifreeze mixture.
>
> (137) "solid fuel-fired heating device" means a device designed or used for wood or coal combustion so that usable heat is derived for the interior of a building; "solid fuel-fired heating device" includes wood-fired heating devices, coal stoves, coal forced air furnaces, coal-fired cooking stoves, coal-fired hydronic heaters and combination fuel furnaces or boilers that burn wood and coal; "solid fuel-fired heating device" does not include a device that is primarily a part of an industrial process and incidentally provides usable heat for the interior of a building
>
> (138) "woodstove" or "wood heater" has the meaning given to "wood heater" in 40 C.F.R. 60.531, revised as of October 17, 2000 and adopted by reference.

Summary of Comments: Comments on this section of the proposed regulation revisions expressed varying levels of support for the proposed definitions amendment and additions. Some commenters expressed support for the proposed revisions saying that they included most devices in common usage today while others proposed alterations to the proposed definitions or adding definitions of additional terminology.

- **(123) "wood-fired heating device"**

Commenters expressed support for this amendment but also proposed several changes. Commenters felt that it was appropriate to add devices not designed for but used for wood combustion, wood-fired forced air furnaces, and hydronic heaters. Other commenters noted that the listed devices may use either cordwood or pellets and argued that pellet fuels were dry and cleaner burning. For this reason, they requested that pellet-fired devices be separated from cordwood burning devices. Commenters also requested that additions be made to the list including masonry heaters and rocket stoves but similarly suggested that they are cleaner burning than other devices and should not be included in any curtailment actions.

- **(135) "clean wood"**

Comments expressed support for defining "clean wood" and for the list of contaminants in the definition but also made several suggestions to strengthen the definition. Commenters noted that additional contaminants can be found in wood in addition to those listed in the proposed definition. They said that often burned plywood and particle board contains glues and binders that produce toxic emissions. Comments suggested adding a requirement that "clean wood" be required to have a moisture content of less than or equal to 20% by weight but other commenters desired a separate definition of dry, seasoned, and split wood for use in defining allowable fuels. Other commenters suggested expanding the definition to define not only clean wood but all clean fuels.

- **(136) "hydronic heater"**

Comments expressed support for defining hydronic heaters but made suggestions to make the definition more representative of the types of hydronic heaters currently used and available on the market. Commenters noted that some hydronic heaters are designed and rated for standalone installation outdoors. Commenters suggested changing (B) to "that the manufacturer specifies for installation **outdoors or** in structures not normally occupied by humans (e.g., garages)" so that it is more inclusive. Other commenters noted that many hydronic heaters use coal as fuel and supported the addition of coal boilers to the definition of hydronic heaters.

- **(137) "solid fuel-fired heating device"**

Commenters expressed support for the proposed definition and desired that other sections in the regulations proposal refer to "solid fuel-fired heating devices" instead of the less inclusive "wood-fired heating device" as a way to ensure that the regulations also applied to coal burning devices.

- **Commenter Proposed Additions**

"Essential Residential Heating"

Commenters proposed defining "essential residential heating" to clarify the term in the event that 18 AAC 50.075(b) provides exemptions to curtailment actions for "essential residential heating" in any finalized regulations. Commenters suggested defining "essential residential heating" as instances when a potentially curtailed device is the sole-source of heat, i.e., the only available heat source for an entire residence not including small portable heaters.

"Curtailment Actions and Flexibility"

Commenters proposed defining the actions the department would take and the flexibility the department would have in the event of a curtailment action described by 18 AAC 50.075(b). Commenters said that without such a definition, the regulation was vague and possibly ineffective. Commenters suggested listing the devices that would be affected and the type of evidence that could prove a violation. Comments listed solid fuel-fired heating devices including coal burning devices, incinerators, and waste oil burners as devices that should be affected by any curtailment action and that smoke or visible emissions should be prima fascia evidence of a violation. Commenters note that other states have defined curtailment actions and strategies.

"Dry Wood"

Commenters suggested incorporating a definition of "dry wood." Commenters proposed that by defining dry wood and using that definition in 18 AAC 50.076, excess emissions caused by the combustion of wet, unsplit, or unseasoned wood could be avoided. Comments suggested defining dry wood as having dried to a moisture content of less than or equal to 20% by weight. Other comments suggested requiring specific amounts of time wood must season before being an allowable fuel or requiring wood to be split and seasoned before being considered an allowable fuel.

"Pellet Fuels"

Commenters proposed adding a definition of pellet fuels that includes pellets manufactured from clean wood and from materials other than clean wood such as recycled paper products, grass, and other biomass.

"Petroleum and Used Oil Products"

Comments proposed defining petroleum and used oil products that are commonly burned in waste oil burners or in other devices to produce heat.

"Open Burning"

Commenters requested clarification on the types of burning that are considered "open-burning" and would be regulated by 18 AAC 50.065(f). Commenters worried that the regulation would affect campfires, cooking fires, fireworks, and other instances where open flame meets the current definition of open burning in 18 AAC 50.990(65) but is not a significant contributor to ambient air quality degradation.

Comments Outside the Regulatory Proposal: Comments and questions were received that were outside the specific regulatory proposal. Those comments and questions are summarized below.

Commenters proposed specific definitions that are outside of this portion of the regulatory proposal. Commenters desired a definition detailing the actions DEC would take in the event an air quality episode warranted a curtailment action and what kind of flexibility would be allowed. Commenters also requested definitions pertaining to petroleum and used oil fuels as well as clarification of what types of burning constitute "open burning".

1) Essential Residential Heating

   Commenters felt this term could be useful in any changes to 18 AAC 50.075(b). As DEC is not moving forward with revisions to that section and the term is not included in the final regulations proposed for adoption, it was not added to the definitions in 18 AAC 990.

2) Curtailment Actions and Flexibility

   The regulation definition section is meant to clarify terms used in the chapter. While curtailment is a term used, it can take different forms for different air pollutants and pollution sources. DEC has decided that curtailment action plans and flexibilities cannot be readily incorporated into a definition term in 18 AAC 50.990. The department thinks that this type of action plan and its detail would need to appear in either 18 AAC 50.075, another section of the state regulation, or in the Alaska Air Quality Control Plan adopted by reference in 18 AAC 50.030; this would require a new regulatory proposal.

3) Dry Wood

   Commenters suggested adding a definition for the term "dry wood" in conjunction with the regulatory proposal for a new section 18 AAC 50.076 dealing with fuels that can be burned in solid fuel-fired heating devices. Since the department plans to make additional revisions to the draft requirements in 18 AAC 50.076 and release a new proposal for additional public review, there is no need to adopt a definition of "dry wood" at this time. Should this or any other definition changes be needed to address

terms referenced in the new proposal for 18 AAC 50.076 they will be included in that subsequent proposal.

4) Pellet Fuels

Commenters proposed adding a definition of pellet fuels that includes pellets manufactured from clean wood and from materials other than clean wood such as recycled paper products, grass, and other biomass. Again, this suggestion would be coupled with a new section 18 AAC 50.076 dealing with fuels that can be burned in solid fuel-fired heating devices. Since the department plans to make additional revisions to the draft requirements in 18 AAC 50.076 and release a new proposal for additional public review, there is no need to adopt a definition of "pellet fuels" at this time. Should this or any other definition changes be needed to address terms referenced in the new proposal for 18 AAC 50.076 they will be included in that subsequent proposal.

5) Petroleum and Used Oil Fuels

These regulation revisions do not propose to regulate non solid fuel-fired heating devices. While comments indicate that these substances may be used as fuel in solid fuel-fired heating devices by some individuals, DEC had proposed that 18 AAC 50.076 would stipulate what types of fuel can be used in solid fuel-fired heating devices rather than what cannot be burned in a solid fuel-fired heater. As the proposed 18 AAC 50.076 did not refer to petroleum and used oil products there was not a need to define them in the chapter.

However, the department plans to make further revisions to the draft requirements in 18 AAC 50.076 and release a new proposal for additional public review. Should any definition changes be needed to address terms referenced in the new proposal, they will be included in the revised proposal.

6) Open Burning

Commenters proposed that open burning definitions be clarified. Open Burning is already defined in 50.990(65) as:

> "Open Burning" means the burning of a material that results in the products of combustion being emitted directly into the ambient air without passing through a stack, flare, vent, or other opening of an emission unit from which an air pollutant could be emitted;

In reviewing the comments received on the open burning requirements at 18 AAC 50.065(f) and after careful consideration, DEC plans to revise and re-propose changes for additional public review including proposed revisions and additions to the definitions in 18 AAC 50.990 related to open burning.

Fiscal Concerns: DEC did not receive any comments specifically addressing fiscal concerns associated with the definitions proposed in this section.

Regulatory Options: Based on the comment received the department considered the following regulatory options.

1) Do not implement the proposed regulations (keep current definitions in regulation)
2) Implement the regulations as proposed
3) Implement proposed regulations with amendments to definitions as needed to address the comments received in other sections of the proposed regulations

Department Decision: Definition of terms rely on their use within the final regulations. Given the comments received on the definitions in conjunction with the action being taken on the other regulation provisions, DEC proposes to move ahead with amendments to 18 AAC 50.990. The final definitions adopted were changed as a result of both the comment process and the finalization of certain aspects of the regulation proposal as described below.

The amendment to definition paragraph (123) "wood-fired heating device" is being adopted with a change to add "masonry heater" to the list of devices. This change reflects DEC's agreement with commenters that masonry heaters were not clearly identified as wood-fired heating devices in the regulation. Because masonry heaters burn wood, it is appropriate to include them specifically in this definition. With respect to additional comments received on this definition, the department responds as follows:

- With respect to comments that suggested the department should split out devices like pellet-fired heaters and masonry heaters from the wood-fired heater definition because they are cleaner burning, DEC decided to keep them in this definition to ensure that general regulatory provisions apply equally to all wood-fired heating devices. The primary operational requirements that relate to all wood-fired heating devices are the visible emission standards found in 18 AAC 50.075. While the department agrees that pellet units generally burn cleanly, DEC thinks that all units should be operated to burn cleanly with low visible emissions.

  These concerns can also be viewed in the context of the wood-fired heating device emission standards being adopted in 18 AAC 50.077. In this case the emission standards apply to specific types of new wood-fired heaters, which have their own definitions, including: woodstoves and, hydronic heaters. New wood-fired heating units over 350,000 BTU/hour do have to meet emission requirements, but these are larger units that are not typically installed in homes and few comments were received on this category of heaters.

- Regarding comments on allowing cleaner burning wood-fired heating devices to operate during any curtailment, DEC plans to propose a new regulatory approach to address the use of wood-fired heating devices during fine particulate matter air quality episodes. That new proposal will be released for public review and comment.

The regulatory proposal also included the addition of several definitions relevant to the new provisions under consideration. DEC's actions in response to comments on these new definitions are detailed below:

- The definition of "clean wood," listed as (135) in the proposal, is not being adopted at this time. This definition was defined to support the proposed revisions to add a new section 18 AAC 50.076. Since the department plans to make additional revisions to the draft requirements in 18 AAC 50.076 and release a new proposal for additional public review, there is no need to adopt a definition of "clean wood" at this time. Should this or any other definition changes be needed to address terms referenced in the new proposal for 18 AAC 50.076 they will be included in that subsequent proposal.

- Because the definition for "clean wood" is not being proposed for adoption, the remaining definition paragraphs that are being adopted will be re-numbered in the final regulations as follows: (135) "hydronic heater", (136) "solid fuel-fired heating device", and (137) "woodstove" or "wood heater".

- Proposed paragraph (136) "hydronic heater" is being adopted with changes. The department agreed with commenters that the definition could be clearer with respect to outdoor installations. However, hydronic heating units may also be indoors. As a result, DEC is broadening the definition to clearly include both indoor and outdoor units that may or may not have heat storage units. The adopted definition also clarifies that forced air furnaces are not considered hydronic heaters. This definition will be re-numbered as (135).

  Commenters also noted that many hydronic heaters use coal as fuel and supported the addition of coal boilers to the definition of hydronic heaters. No change was made to the definition because the proposed hydronic heater definition notes the burning of "other solid fuels," which would include coal. As a practical matter, DEC's regulations may specify whether a provision applies to all solid fuel-fired hydronic heaters or just to those that burn wood products.

- Proposed paragraph (137) "solid fuel-fired heating device" is being adopted as proposed but will be re-numbered as (136). No comments suggesting specific changes were received on this definition.

- Proposed paragraph (138) "woodstove" or "wood heater" is also being adopted as proposed but will be re-numbered as (137). No comments suggesting specific changes were received on this definition.

- A new paragraph (138) “masonry heater” is being added to define masonry heaters based on their function and design or as otherwise described in the International Building Code, ASTM E1602, or UL1482. DEC added this definition in response to concerns raised that masonry heaters were not included in the wood-fired heating device definition in section (123). When the term “masonry heater” was added to (123), DEC decided that it would also warrant its own definition to further ensure clarity for this type of heating device within the regulations.

General Comments

Summary of Comments: Comments received in response to the proposals for changes to regulations governing the nonattainment area for the PM 2.5 NAAQS standards in the Fairbanks North Star Borough (FNSB) represented the views of the public, businesses, and special interest groups. Comments were submitted via oral testimony and in writing. General comments are categorized and summarized as follows:

- **Efficacy of Proposed Regulations**

Commenters identified Clean Air Act State Implementation Plan (SIP) requirements and expressed opinions about the effectiveness of the proposed regulations at bringing the nonattainment area into attainment for the 2006 PM 2.5 24-hour NAAQS. Commenters noted that DEC's SIP must demonstrate a 22% reduction in EPA's designated ambient design value concentration of 44.7 µg/m^3 which would constitute an approximately 9.7 µg /m^3 decrease. Commenters felt that the materials and evidence DEC provided to the public as part of the review process did not demonstrate the potential for the proposed regulations to achieve a 22% reduction and either argued that stronger regulations were needed to protect public health and attain the NAAQS or that certain proposed regulations should not be implemented because they would only provide insignificant improvements. Commenters also noted that the DEC did not release a proposed SIP for examination during the public review process. Commenters felt that this made it impossible to determine the overall role of the proposed regulations in achieving attainment and their possible efficacy.

- **Air Quality/Health**

Commenters reported experiencing impaired air quality as a result of the operation of solid fuel-fired heating devices including wood and coal burning devices. Commenters reported a visible layer of smoke, impaired visibility, smells of smoke, and physical reactions attributed to the smoke including: stinging eyes, coughing, asthma, and other acute or chronic health conditions. Commenters reported sometimes substantial or staggering medical expenses as high as one million dollars that they had accumulated due to treatment of conditions caused by air pollution including prescriptions, doctor and specialist appointments, emergency room visits, surgeries, out of state treatments, treatment of acute conditions such as heart attacks, stroke, and asthma attacks, and treatment of chronic conditions such as emphysema, asthma in children, and atrial fibrillation. Some commenters felt that the proposed regulations were not protective enough of human health and wanted DEC to consider the health costs borne by these individuals and the public as a result of implementing or not implementing the regulations as proposed. Comments identified scientific materials that demonstrate a causal relationship between PM 2.5 and effects on human health. Other commenters questioned the validity of the results of researchers and denied assertions that the burning of solid fuels by individuals heating their homes or businesses had caused the physical reactions experienced by others in the community. A sentiment was expressed that individuals affected by smoke should voluntarily relocate instead of insisting on the imposition of new regulations.

- **Impacts of Pollution on Community**

Comments identified further impacts of air pollution on the community within the nonattainment area. In addition to medical expenses, commenters reported declines in property values, inability to sell property, expenses incurred relocating to cleaner areas within the nonattainment area or outside of the nonattainment area, travel, lost wages due to work absences, absences from school, loss of outdoor recreation opportunities, and installing air filtration units. Commenters also pointed to hypothetical impacts such as loss of tourism revenue and potential loss of jobs as companies or even government agencies either relocate or choose not to operate in the nonattainment area due to health concerns.

- **Use of Airshed**

Comments addressed the use of exterior air during periods of high pollution levels. Commenters noted that pollution events occurred year round and sometimes coincided with conditions that otherwise would limit outdoor activity and exposure to air such as extreme cold. Comments also noted the persistence of wildfire smoke during summer months when outdoor activities would not otherwise be limited by natural conditions. Commenters expressed doubt that the airshed is used during extreme cold weather events while other comments cited multiple uses of the airshed that would benefit from the reduction of PM 2.5. Commenters noted that all indoor air within confined spaces such as households, public buildings, schools, businesses, and automobiles ultimately comes from the outside and that while the presence of pollution could be mitigated through the installation and operation of expensive filtration units, laser particle counters, or masks, this option was unavailable to many affected citizens due to financial constraints. Commenters listed outdoor activities that require individuals to breathe polluted air such as bicycling, walking, running, jogging, skiing, dog mushing, and other recreational activities. It was proposed that PM 2.5 pollution limited access to clean air and outdoor activities that promote positive impacts on physical and mental health during winter months.

- **Sources of PM 2.5**

Comments showed acceptance that the combustion of solid fuels in solid fuel-fired heating devices and through open burning during winter contributed to the formation of PM 2.5 but also identified other contributing sources of PM 2.5. Commenters pointed to major and minor permitted sources, idling vehicles and construction equipment, aircraft, coal fired power plants, refineries, local industries, forest fires, diesel engines, and regional haze as sources of PM 2.5 and argued that the proposed regulations unfairly burdened solid fuel heating device users and open burning practices. Commenters identified coal fired power plants as emitting visible plumes and causing deposition of contamination outside the boundaries of the facilities. Comments suggested curtailing other sources of PM 2.5 and offered mitigation technologies and strategies that could be used to reduce the pollution caused by those other sources. Commenters suggested promotion of renewable, non-biomass, energy sources such as wind, solar, geothermal,

and hydroelectric. Commenters also felt that natural gas would be a clean energy source but may take too long to have an effect or may not be adopted by residents due to upgrade costs or higher fuel cost compared to wood or coal.

- **Causes of Air Quality Episodes**

Commenters noted two scenarios under which PM 2.5 exceedances occurred, wildfires during the summer months and inversions during the winter. It was suggested that efforts would be better spent on the prevention and fighting of wildfires during the summer to reduce the intense wood smoke experienced in the nonattainment area during wildfires; however, other comments pointed out that wildfires do not cause the majority of exceedances. Commenters noted that wildfires were a natural occurrence that could not be regulated. Comments said that the inversions that lead to episodes in the winter are also a natural occurrence that cannot be controlled and that exceedances resulting from inversions either should or should not be addressed through regulation. It was noted that inversions occur during extremely cold temperatures that necessitate the burning of fuels to maintain safe interior environments and prevent property damage such as burst pipes.

- **Monitoring**

Commenters made note of the current monitoring efforts and expressed concerns on the use of the current model of using only several monitors to regulate the entirety of the non-attainment area. Comments suggested the installation of additional monitoring stations or subdividing the nonattainment area to allow regulators to target specific areas for curtailment. Other comments expressed concern with this strategy pointing out that even areas outside of the nonattainment area contributed to the PM 2.5 levels and that exempting certain sources within the nonattainment area during curtailment periods would unfairly penalize the residents of areas where PM pollution from other areas tends to accumulate. Comments expressed concern over the timeliness of changes to curtailment action levels in response to the real time improvement of air quality or conditions and suggested that regulators would update information or curtailment actions during non-business hours. Commenters also desired an explanation of how the monitoring data would be used in calling an air episode.

- **Need for Solid Fuel Heating Devices (SFHDs)**

Commenters expressed need for SFHDs. They noted that exceedances typically occur during extreme cold weather conditions when SFHDs are used to heat spaces to maintain safe, survivable, and habitable environments and to prevent property damage. Commenters addressed the types of heating options available to residents including electric heaters; hydrocarbon based systems such as fuel oil, propane, natural gas, and kerosene fueled devices; and solid fuel burning devices such as biomass, wood, pellets, and coal. Commenters noted that fuel sources that produce significantly less PM 2.5 can be significantly more expensive than their alternatives. Comments suggested that economic factors influences the need for the use of cheaper solid fuels and that the use of wood as a fuel source contributes less to greenhouse gas emissions. Commenters proposed fuel oil subsidies as a solution to the use of solid fuels due to the use of SFHDs

for economic reasons. Other commenters noted that SFHDs were the sole source of heat for their homes or businesses citing a lack of electricity or lack of any other heating device. Commenters expressed concern over the need for electricity to operate devices other than woodstoves and worried about curtailment actions at times when power outages prevented usage of alternative heating devices. Other commenters noted that their woodstoves were needed as supplements to other heat sources during extreme cold weather events or in the event of non SFHD inoperability or failure.

- **Need for Regulations**

Commenters expressed both a desire for and rejected a regulatory approach to the air pollution problem. Those that rejected the need for regulations offered multiple explanations including: a perceived adequacy of current regulations, alleged political and economic motivations behind the regulations, a desire for legislative action on the issue, disapproval of government involvement, a local ballot proposition that voiced a desire to not be regulated, enhanced access to natural gas or improved technology developed by the free market would solve the problem, or preferred a community based approach that emphasized cooperation and education. Other commenters expressed dissatisfaction with current regulations, felt the proposed regulations would not be effective, pointed to a need to curtail PM 2.5 emissions to protect public health in the nonattainment area, desired state regulations due to an impotency of the FNSB caused by the local ballot initiative, maintained that waiting for access to natural gas would not solve the problem quickly enough and that effective technologies already existed, or pointed out that a community and education based approach had already been tried and was not working to a satisfactory extent. Commenters felt that the proposed regulations may fail to establish federally required enforceable control measures or contingency measures.

- **Possible Regulatory Options**

Industry experts offered the results of an informal survey of local chimney sweeps that found that the number of non EPA certified woodstoves in residences approached 50% and surmised that a majority of pollution was caused by non-certified stoves. Citing a low turnover rate of woodstoves due to the long lifespan of wood stoves and the current availability of cleaner burning appliances, commenters offered several options for incentivizing or requiring replacement. Commenters expressed need for an expanded change-out program that is less financially burdensome and less intrusive that would cover the entire cost of a stove installation to incentivize the installation of devices that could provide users with greater economy through increased efficiency. Comments also sought a provision requiring the replacement of non-certified devices upon the sale or transfer of property suggesting the cost of upgrades could be included in a mortgage and could be enforced by the real estate industry. Commenters suggested that upgrades would be more attractive if they could be incentivized through an exception to curtailment under certain conditions that would curtail the use of non-certified appliances. Commenters also suggested citations or imposition of fines for highly polluting appliances to further incentivize replacement or compliance with regulations. Comments questioned the effectiveness of the results of EPA testing labs in predicting the real world performance of devices in the nonattainment area. Comments also

expressed concern that a regulation that expressly required EPA-certified devices could stifle local technological innovation due to a lack of a local EPA-certified testing facility. Comments also stated a need for increased insulation of buildings through building codes applicable to new structures suggesting that increased insulation would decrease the energy needed to heat a space and result in less PM 2.5 emissions. Commenters also felt that regulations could protect the most vulnerable portions of the population by placing more strict restrictions in areas directly surrounding public places and schools.

- **Regional Applicability of Regulations**

Commenters suggested various alternatives for the extent to which regulations applied throughout the state. Some comments sought the imposition of the proposed regulations on the entire state of Alaska, the entire FNSB, the entire nonattainment area, or subdivisions of the nonattainment area. Comments reasoned that expanded impositions would reduce instances of purchasing non-certified appliances outside of the nonattainment area for installation within and reduce or possibly allow enforcement in cases of localized nuisance problems elsewhere in the state.

Fiscal Concerns Summary: Comments listed a variety of ways in which the current conditions have fiscal impacts and ways in which the proposed regulations would have fiscal impacts on individuals and businesses within the non-attainment area

Commenters noted a variety of costs including those associated with the present pollution patterns, costs predicted if the area is not brought into attainment, and costs associated with compliance with the proposed regulations. Commenters said current and past costs associated with the pollution problem in Fairbanks included increased healthcare costs associated with an increase of emergency room visits during exceedances, increased doctor and specialist visits, medication costs, surgery costs, and travel expenses. Commenters reported having missed days of work or school due to health effects associated with pollution or to prevent exposure to pollution. Commenters experienced losses in property values in highly polluted locations impacting an individual's ability to relocate to less polluted areas. Commenters who were able to move and moved due to pollution levels reported costs associated with selling old homes, purchasing new homes, and moving. Other commenters reported costs associated with purchasing and installing and operating home air monitoring and filtration systems. Commenters addressed financial impacts that could possibly continue or arise if pollution control measures are not adopted. Comments suggested continuation of the pollution problem would cause a continuation of currently reported expenses. Comments also suggested that impacts to the FNSB economy could occur due to pollution levels. These impacts included the loss of productivity, loss of employers, loss of residents, and loss of potential tourism. Comments addressed the potential costs associated with complying with the proposed regulations. Commenters stated that the costs of complying with a burn ban by using other fuels or energy sources would be financially unfeasible for residents of the nonattainment area. Commenters listed a variety of financial impacts including the costs of upgrading heating devices, switching to different heating fuels, and purchasing certified devices.

Responses to Comments:

- CAA Requirements for Attainment of NAAQS and Efficacy of Proposed Regulations

The U.S. Environmental Protection Agency has determined that a portion of the Fairbanks North Star Borough is in nonattainment for the health-based National Ambient Air Quality Standard for fine particulate matter. As a result, Alaska is required under the Federal Clean Air Act to develop and implement a State Implementation Plan (SIP) that commits to implement measures that will provide for timely attainment and comprise the SIP.

These proposed regulations are being developed in an effort to reduce PM 2.5 emissions in the Fairbanks nonattainment area. These regulations coupled with other programs and requirements will help to bring the Fairbanks nonattainment area into compliance with the NAAQS. The full suite of measures will be incorporated into Alaska's SIP, which is being released for public review and comment along with the re-proposal of certain aspects of this regulation package and new regulatory proposals.

- Public Health Impacts

One of ADEC's primary objectives is the protection of human health and welfare via the safeguarding of air quality. At the same time, DEC recognizes that citizens of Alaska face extreme winter temperatures and high energy costs. The PM 2.5 and PM 10 NAAQS are health-based standards, and the health effects due to inhalation of particulate matter are well documented. Particles smaller than 2.5 microns in aerodynamic diameter tend to diffuse across the alveoli of the lung. This diffusion allows for systemic distribution of the particles and their contents throughout the body via the circulatory system. In addition to asthma and lung-related irritation, research indicates that exposure to PM 2.5 can cause premature death in individuals with heart and lung diseases and it can increase the risk of nonfatal heart attacks, irregular heartbeat, and decreased lung function. Children, older adults, and those with heart and lung issues are affected more commonly than healthy adults. PM 2.5 monitoring data collected during the 2008-2009, 2009-2010, and 2010-2011 winters in the FNSB suggest that the 24-hour PM 2.5 NAAQS is being exceeded about 25% of the days during the winter months. These regulatory proposals are meant to address the public health impacts from poor air quality within the nonattainment area.

- The Airshed and How it is Used

The Clean Air Act (CAA) regulates ambient air pollution. This includes the outside air that people breathe. While indoor air quality is very important, it is not regulated by the CAA. However, it is important to note that indoor air comes from the outdoor airshed and that outdoor air pollution can enter indoor spaces. People use the outdoor air when they do any outdoor activity including transportation and recreation. People can encounter and breathe polluted air that may affect their health. People are also affected by polluted air entering vehicles or the buildings in which they visit, work, go to school, or live.

The Fairbanks North Star Borough nonattainment area can be considered an airshed, although there are some distinct sub-areas within the nonattainment area boundary. The boundary was determined in 2009 by the Environmental Protection Agency through the designation process. The Borough and State provided information to EPA and made recommendations on a boundary. EPA considered the recommendations but also used additional analytical tools, and other relevant information, to make final decisions on nonattainment area boundaries including: emission data, air quality data, population density and degree of urbanization (including commercial development), traffic and commuting patterns, growth rates and patterns, meteorology (weather/transport patterns), geography/topography (mountain ranges or other air basin boundaries), jurisdictional boundaries (e.g., counties, , metropolitan planning organizations), and the level of control of emission sources. Additional information on the area designation process is available on EPA's web site at:
http://www.epa.gov/airquality/particlepollution/designations/2006standards/index.htm

- Sources of PM 2.5

Studies have consistently shown that space-heating by wood-fired devices is the largest single category of PM 2.5 emissions in the nonattainment area during the period of wintertime PM 2.5 exceedances. The 2008 Baseline Episode average daily emission estimates for the air quality plan indicates that space heating devices are responsible for approximately 2.76 tons of PM 2.5 emissions per day as compared to the nonattainment area total emissions from all sources of 4.93 tons per day. Thus, all space heat represents an estimated 56% of total emissions during winter episodes of high PM 2.5 concentrations and 96% (2.66 tons per day) of those PM 2.5 space heating emissions are attributed to wood burning. Other winter episode sources include power and industrial plants, commercial sources, vehicles, coal burning devices, and non-road equipment.

- Causes of Air Quality Episodes: Wildfires and Winter Emissions

The FNSB experiences PM 2.5 exceedances caused by wildfires and by anthropogenic emissions. Fairbanks is regularly impacted by wildland fire smoke in the summer months. While some wildfires are caused by the actions of humans, others are naturally occurring. The Federal, State, and Local firefighting agencies cannot control or extinguish every wildfire that may impact air quality in the FNSB nonattainment area. EPA allows states to apply for exemptions to exclude the data affected by exceptional events such as wildfires from the calculations used to determine attainment or nonattainment. Alaska applies to EPA for exemptions for exceedances caused by wildfire smoke. These events are considered natural phenomenon that have effects on pollution levels that human activity cannot fully mitigate.

Inversions are periods when air is trapped close to the ground and is often paired with stagnation events that prevent dispersion of atmospheric pollutants. While these events are a natural phenomenon, they do not directly cause the emissions of pollutant as

wildfires do, they simply alter the dispersion of the pollutants and cause them to accumulate. Human actions can mitigate emissions to lower the level of pollutants in the air trapped under an inversion. EPA's definition of 'exceptional event' in 40 CFR 50.1 (j) specifically excludes stagnation of air masses and meteorological inversions. EPA will not exclude any exceedances that cannot be attributed to exceptional events that occurred during an inversion or stagnation event.

Anthropogenic emissions within the nonattainment area have been identified as the cause of wintertime exceedances. These proposed regulations are part of a suite of actions proposed to be taken by local, state, and federal regulators in an effort to reduce emissions and improve air quality within the Fairbanks nonattainment area.

- Air Monitoring Program

The Fairbanks non-attainment area was designated based on the State Office Building (SOB) PM2.5 air monitoring site using the data from 2006- 2008. At the time there only existed one PM2.5 monitoring site in Fairbanks. Only one official site is required by federal rules for a metropolitan area the size of the Fairbanks/North Pole non-attainment area. (40 CFR 50 Appendix D 4.7)

Since 2008 DEC and FNSB have established numerous short term monitoring sites to determine the extent of the PM2.5 impacted areas within the non-attainment area and the various levels of PM2.5 in the community. Monitoring is resource intensive and efforts are made to find sites that generally represent certain parts of the community, whether at a broader neighborhood scale or on a micro-scale.

Compliance with the NAAQS is determined using a testing method that differs from the method that would be used to call air quality episodes. The NAAQS is based on a 24-hour average taken using equipment that passes ambient air through a filter for a period of 24 hours every third day. Each filter is then analyzed for the amount of PM 2.5 and for other characteristics. Using this method to call advisories and episodes would be ineffective and slow. As a result, advisories are called using continuous monitoring technology that measures the amount of PM 2.5 in the air hourly, giving regulators an up to date picture of air quality to use to call advisories. This same technology would be used to call PM 2.5 episodes in the future.

Concerns continue to be raised about the extent of the air monitoring network in the nonattainment area. Community discussions and the programs developed under the SIP may result in changes to the monitoring network in the months and years to come.

- Need for Solid Fuel Heating Devices and Economical Heating Options

Commenters expressed concern about maintaining economical heating options within the nonattainment area and that wood was the most economic choice for heating their homes. DEC recognizes that individuals gather wood for fuel as part of their lifestyles. DEC also understands the shift away from cleaner burning fuel oil and electricity towards wood, biomass, and coal as fuels for heating as costs for fuel oil and electricity have risen. The portion of the regulation package that DEC has finalized does not prevent the use of wood as a heating option within the nonattainment area.

Some commenters proposed a fuel oil subsidy to help address the high costs of heating and reduce dependence on more affordable wood. DEC understands these comments about high heating oil costs in the Interior driving the use of more solid fuels for home heating in the nonattainment area and the desire to lower those costs for the primary base heating fuel, which is fuel oil. There are a number of ways to address the air quality impact of solid fuel use in lieu of and in addition to fuel oil. Given the work and priorities identified by the local community through the air planning process to date, the state is currently focused on a project to enhance the availability of natural gas in the community as well as providing funding to subsidize the replacement of high emitting wood heaters with of cleaner burning stoves.

While switching from solid fuels to a less polluting fuel source such a fuel oil would have an effect on air quality, the department has heard that many homes that have heating oil systems require supplemental wood heat during extreme cold periods. This is why the department has focused on finding economical cleaner burning fuel options and reducing emissions from wood heaters by ensuring the cleanest burning devices are installed and operated correctly. The regulations being adopted would ensure that only clean burning wood heaters are installed when residents upgrade or put in new devices inside the nonattainment area. The department plans to release additional regulation options and the overall air quality plan for the nonattainment area for further public review and comment. A fuel oil subsidy would require additional resources beyond those currently available to DEC and identified to date. As a result, this option would need to be addressed through either the local government process or through the state legislative process.

In discussing sources of PM 2.5 and the need for affordable heating options in the nonattainment area, commenters noted that the enhanced availability of natural gas and other energy alternatives would provide air quality benefits. While promoting these types of activities is not specific to this regulatory action, the State of Alaska is involved in a variety of efforts to provide additional energy sources to the FNSB including a natural gas pipeline, natural gas trucking, hydroelectric power, and the Healy coal-fired power plant. Of particular significance for the nonattainment area is the effort by the State of Alaska in expanding the availability and use of natural gas in the nonattainment area through the implementation of the Interior Energy Project. The Interior Energy Project provides the financial tools needed to bring natural gas to the Fairbanks and North Pole area. The project was established through Senate Bill 23 which passed the Alaska

Legislature unanimously in April 2013. The legislation authorizes the Alaska Industrial Development and Export Authority (AIDEA) to provide the financing package to partner with the private sector to build a liquefied natural gas (LNG) plant on the North Slope and natural gas distribution system in Fairbanks and North Pole. The current projections indicate that the earliest this project will provide additional natural gas into the community is 2016.

- Need for Regulations

Commenters expressed both a general desire for regulations to address air pollution or rejected regulatory approaches. Responses related to these general comments are contained in the sections of this Response to Comments dedicated to the specific sections of the regulatory proposal.

- Possible Regulatory Options

Commenters provided ideas and options to revise the proposed regulations and for potential regulations and programs beyond those proposals identified in this regulatory proposal. Many of the options raised as general comments are included in the sections of this Response to Comment specific to various aspects of the proposal.

In terms of some of the general comments received, DEC's Justification Document and Peer Review demonstrated the economic feasibility of establishing wood-fired heating device regulations. With respect to incentivizing additional upgrades to wood-fired heating devices, the FNSB wood heater change-out program provides such an opportunity to individuals living in the nonattainment area. Individuals who upgrade to more efficient devices will not only help to lessen the air quality problems in the nonattainment area, they will enjoy increased efficiency that will save them time and money by using less fuel to provide heat.

With respect to energy efficiency, there are many ways of reducing PM 2.5 emissions by increasing efficiency. As noted in the comments, one example is increasing the amount of insulation in a building. Increased insulation leads to less heat loss and a reduced need for fuel to heat a space. Newly constructed homes usually incorporate features that reduce heat loss, however energy efficiency improvements can also be made to older homes. Programs exist to help homeowners improve the energy efficiency of their homes such as programs administered by the Alaska Housing Finance Company. While there are many benefits to increasing home energy efficiency to both the individual and community, DEC has not proposed to implement regulations regarding home insulation requirements as there are other non-regulatory programs and building codes where this issue could be addressed.

- Regional Applicability of Regulations

Portions of the proposed regulatory package apply to all of Alaska and others apply only to PM 2.5 nonattainment areas, current and future. The regulations were crafted to give the state flexibility to consider the circumstances and causes of non-attainment in specific areas to best address the root cause and bring the area into attainment. As a result, the department has focused some regulations to the nonattainment area while others are being proposed to take effect statewide. For example, wood heater fuel requirements and emission standards and winter open burning restrictions were proposed for the nonattainment area to assist with addressing the specific air quality problem. Air episode levels and changes to visible emission requirements were already statewide regulations and were proposed for revision statewide.

Comments on Public Review Process

DEC provided an extended 120 day public review opportunity for the public and interested stakeholders to evaluate and comment on the proposed regulations. During this process open houses and public hearings were held. The public was able to provide oral testimony at public hearings or submit written comments in person, through mail, by email, and through DEC's online comment form.

Summary of Comments: Comments on the public review process included general comments about the process, reports of experiences of individuals participating in the process, aspects of the process that could be improved, and suggestions for improving the process. DEC tracked these comments as they were received and adjusted its approach and process, in some cases during the comment period.

- **General Comments**

Commenters made general comments about the public review process including the effectiveness of the process in conveying information and providing opportunities for public comment, the length of time of the public review and comment period, and the responsiveness of DEC during the public review process. Some commenters said that DEC did a reasonable job of conveying information and providing opportunities for public comment but other commenters indicated areas that DEC could have improved. Some commenters felt that the amount of advertising done by DEC was inadequate and that proposed regulations should be printed or made available in other formats than newspaper legal notices and that public hearings should have been better publicized. Comments also addressed the length of the public review process. Some commenters felt that the 120 day length was excessive and served only to delay the implementation of any regulations until after the end of winter. Other commenters felt that the 120 day public review period was necessary to provide adequate time for the public to review, understand, and comment on the proposed regulations. Commenters also felt that it was difficult to get responses from DEC during the process about how comments were being answered and what changes to the proposed regulations were being considered as a result of the comments. Commenters suggested that posting comments online like other states have done and responding to those comments during the comment period would promote a more constructive discourse between the public and DEC. Commenters also felt the public review process could have benefited if the regulations had been more specific about curtailment actions, enforcement, and delegation to local authorities. Commenters suggest that the process could have been more focused if the public were aware of these aspects of the proposed regulations.

- **Electronic Comment Submission**

Commenters used the online Air Quality Electronic Comment Submission form to submit comments on the proposed regulations and noted several characteristics of the process that they found either helpful or not helpful. Commenters felt that the online comment form was a valuable tool for promoting public involvement. Comments were submitted on personal computers and on computers provided for public use during DEC's open

houses. Commenters noted that they were able to conveniently make comments without needing to attend a public hearing which individuals may have found unattractive or impossible due to work, school, or out of state travel. Commenters indicated that they liked being able to comment on each issue individually on the comment form. Commenters expressed confusion about whether comments would be emailed to them after they were submitted and felt that a confirmation email would allow them to retain their comments and confirm that DEC had successfully received their comments. Other commenters noted that if they had not clicked a box indicating the presence of fiscal impacts for each section that DEC's automatically generated email confirmation would say "FALSE" in the fiscal impacts category. Commenters felt that this did not accurately represent their comments and chose to resubmit their comments with the fiscal impact box checked to ensure DEC understood that they felt the regulations would have fiscal impacts.

- **Public Hearings and Open Houses**

Timing and Frequency

Commenters addressed the timing and frequency of public hearings. Commenters felt that public hearings were an important venue for individuals to provide comments. Commenters reported difficulty in attending hearings due to timing. Commenters felt that the public hearing that were scheduled during the day time made it difficult for individuals attending school or work to be present. Comments suggested possible motivations for holding hearings during the daytime including convenience for DEC employees or as an attempt to avoid or limit public comment opportunities. Commenters suggested the addition of evening hearings to better suit the needs of individuals who must attend school or work during the daytime to strengthen the public hearing process. Commenters appreciated DEC's responsiveness and subsequent addition of an evening public hearing. Commenters also expressed disappointment that testimony was limited to three minutes for each private individual testifying at the Fairbanks hearings. Some commenters were unable to finish their testimony in their allotted time. Commenters suggested alleviating this problem by adding additional hearing opportunities.

Facilities

Commenters addressed the facilities used by DEC for the public review process. Commenters felt that the rooms used were too small and resulted in overcrowding, that microphone and speaker systems were not used effectively, and that it was sometimes smoky in the venues which impacted sensitive individual's ability to participate. Commenters suggested that these issues be remedied at future events. Commenters also relayed difficulty locating meeting rooms for public hearings.

Advertising

Commenters addressed the amount and types of advertising done as part of the public review process. Commenters noted that the draft regulations were available online and in newspaper legal sections. Commenters felt that these forms of advertisement were not sufficient. Commenters described adequate advertisement for open houses but felt that, by comparison, public hearings were less advertised. Commenters viewed this as an attempt to avoid public participation through comment. Some commenters said that they were unaware of public hearings until seeing or hearing advertisements by private parties.

Outside Parties Accepting Comments

Comments were received that expressed concerns about an outside party who was soliciting comments from the public on the regulatory proposal which were to be forwarded on to DEC.

Public Hearing Decorum

Commenters addressed participant decorum at the public hearings by describing inappropriate behaviors, speculating on the causes, suggesting corrective measures, and reacting to actions taken by DEC. Commenters mentioned inappropriate participant behaviors at public hearings including booing, making "raspberries", speaking out of turn, interruptions, threatening and intimidating behaviors, disrespectful testimony, open display of firearms, and suggested there was a mob mentality. Commenters speculated that the facilities contributed to the negative decorum demonstrated. Commenters said that the spaces rented for the hearings were too small which resulted in overcrowding and that audience members were unable to hear testimony due to a lack of or proper use of a microphone and speaker system. Commenters felt that these factors helped lead to the lack of decorum observed. Commenters suggested that the observed lack of decorum prevented a respectful environment where individuals can freely voice their opinions and suggested measures to improve decorum at hearings.

Commenters suggested laying out ground rules for behavior and consequences for breaking those rules. Commenters suggested that violations of ground rules be met with consequences such as being warned to comply with rules, being asked to leave, being removed, losing the opportunity to provide oral testimony, or extending the time allotment of the specific individual whose testimony is affected by inappropriate behaviors. Commenters suggested that DEC staff should have called for interruptions to cease during testimony or should use a professional facilitator to run the hearings. Other commenters complimented DEC staff performance during difficult circumstances. Some commenters suggested that DEC Commissioner Larry Hartig attend the hearings to prevent intimidation of DEC staff. Commenters also addressed the presence of a uniformed police officer at one hearing in response to the behaviors at the previous hearing. Some commenters said that the officer's presence was welcome

and helped to ensure proper behavior during the hearing. Other commenters, however, interpreted the officer's presence as an intimidation tactic by DEC to wrongly influence individuals present at the hearing.

Response to Comments:

DEC appreciated receiving comments on the public review process. These comments are helpful because they allowed DEC to actively modify its public review process for these proposed regulations and will help DEC plan future public review processes. Comments on the public process help DEC facilitate more effective public involvement for issues that are important to our communities.

During this public review process DEC responded to several concerns addressed in these comments. DEC responded to concerns about the timing of the first public hearing by adding a second hearing scheduled in the evening. DEC also requested the presence of a local police officer at the second hearing in response to comments about safety/security concerns and the decorum demonstrated at the first hearing.

DEC met and in some areas exceeded the regulatory advertising requirements of the Administrative Procedures Act found in Alaska Statutes Title 44 Chapter 62 and the Alaska Department of Law 20th Edition Drafting Manual for Administrative Regulations. "AS 44.62.190 Notice of Proposed Action" requires agencies to give notice of a proposed action at least 30 days prior to the adoption, amendment, or repeal of a regulation. The agency must publish a notice in a newspaper of general circulation or trade or industry publication, distribute the notice to interested persons, and may publish the notice in an additional form prescribed by the agency. If the agency decides to hold public hearings, the date, time, and location of the hearing must be published as part of the public notice.

DEC published its first public notice on September 20, 2013 in three newspapers for three days each which fulfilled the minimum requirements. DEC also posted the public notice on the State of Alaska online public notice portal and on the Division's public notice webpage. In addition, all those individuals who were signed up with the Division to receive electronic notices received an email notification.

In addition to the public notice, DEC held four open houses and advertised for these open houses to provide additional opportunities to learn about the issues. At each of these open houses, DEC prominently displayed "How to Comment" which listed out both open houses and hearings in addition to providing addresses, websites as well as comment forms. Ultimately, DEC issued 4 more public notices (9/25, 11/14, 12/13, and 1/10/14) to fix a notice issue, announce the availability of the justification document for wood heater emission standards, to announce the addition of an evening public hearing (as requested by commenters), and to clarify the public comment end date.

With respect to process comments about an individual soliciting and gathering public comments to be submitted to the department, DEC notes that it has no control over individuals who wish to collect and provide comments to the department on a regulatory proposal. However, DEC can only consider comments it receives during the public comment period, so the best way to ensure

that comments are received and considered is to submit them directly to the department following the methods provided and announced in the public notice. The primary goal of a public review period is to obtain feedback and comments from the public to allow for full consideration of all aspects of the proposal. In this case, DEC did receive a number of batches of public comments during the comment period that had been collected in the community and those comments were considered and are summarized in this Response to Comments. Overall, the comments received regarding the public comment review process have been very helpful as DEC looks toward making improvements to future public comment processes.

Wood Heater Emission Standard Justification Document and Peer Reviews

Alaska Statute 46.14.010 requires DEC to develop a peer reviewed written finding when it intends to adopt an emission standard more stringent than those set by EPA. The standards proposed in 18 AAC 50.077 for wood-fired heating devices are more stringent than current EPA standards. In November 2013, DEC released "Department Findings: The Need and Basis for More Stringent Wood-fired Heating Device Emission Standards" and contracted with three independent consultants to conduct a peer review of the findings in DEC's justification document. The justification document and the findings of the three peer reviewers were made available for public review as part of the public review process and DEC solicited public comment.

Summary of Comments: Comments received addressing the justification document and peer reviews expressed varying degrees of support for the scope and findings of the analysis.

- **Scope of Analysis**

Commenters mentioned topics that had not been covered in the justification document or peer reviews that they felt should have been considered. Some commenters felt that the peer review should have encompassed all of the proposed regulations and included a peer review of the evidence and causes of the PM 2.5 nonattainment. Other commenters felt that the analysis should have, but did not, fully considered all of the potential financial impacts of the proposed regulation. Commenters said that the analysis focused on the cost to consumers of needing to purchase 2.5 g/hr woodstoves. Commenters felt that the analysis should have considered the fiscal impacts of the proposed standards on public health. Commenters felt that although these costs may be difficult to quantify, they are important to consider when deciding to adopt or not adopt the proposed standards. These commenters suggested that an analysis of the public health costs in comparison to the costs of cleaner burning woodstoves would show that adopting the proposed standards would have a greater financial benefit than not adopting the proposed standards. Commenters also felt that the analysis should have included a peer review by a public or respiratory health expert of the physical health impacts of PM 2.5 on the health of individuals including sensitive groups such as children and other vulnerable populations.

- **Analysis Findings**

Commenters indicated that they agreed with or didn't agree with certain findings of the analysis and peer reviews. Some commenters agreed with the finding in the justification document and the peer review comment by Steve Colt, UAA Institute of Social and Economic Research that the standards that require the purchase of cleaner burning woodstoves were unlikely to increase costs to the public because cleaner burning devices, Btu for Btu, were not more expensive than less clean burning stoves. Commenters said that the finding justified holding new devices to the highest attainable standards under current technology and proposed that the standards be updated periodically. Other commenters took issue with this finding. These commenters said that a majority of stoves sold would not meet the proposed standards and that these stoves were popular

because of their lower costs compared to 2.5 g/hr stoves. Commenters said that the 2.5 g/hr stoves were similarly priced with more expensive woodstoves, purchased for their aesthetic appeal rather than their cost, but were more expensive than the most popular non-certified woodstoves that are purchased because of their lower price.

Commenters also addressed findings in the peer review about the effectiveness of the new standards in helping to attain the 2006 24-hr PM 2.5 NAAQS. Commenters felt that there was a lack of verifiable evidence supporting the proposed standards. Commenters also noted that the emissions reduction resulting from the proposed standards would not bring the nonattainment area into attainment. Commenters suggested that this was because the proposed standard only applies to new devices and that the standards could have a greater effect if they targeted older, currently installed, highly polluting devices.

Commenters desired a more inclusive justification document and peer review that analyzed the impacts and effects of the entire regulatory proposal package and suggested topics they felt should have been included in the review.

Fiscal Concerns: Those comments specifically noting fiscal impacts are summarized here.

Commenters addressed the finding that PM 2.5 stoves were not more expensive than uncertified stoves. Some commenters agreed with the finding or felt that even if a PM 2.5 stove happened to be more expensive upfront, any increased costs would be regained through efficiency and fuel savings. Other commenters felt that the review did not consider the different price ranges within each category and incorrectly compared the least expensive PM 2.5 stoves with more expensive stoves purchased primarily for aesthetic appeal instead of more popular lower cost non-certified stoves.

Commenters noted that the review did not include a more comprehensive analysis of the costs associated with operating non-certified heating devices. Commenters felt that the analysis focused only on the costs to the purchasers of woodstoves while it should have also included the costs associated with increased emissions by non-certified stoves such as healthcare costs.

Response to Comments:

Alaska Statute 46.14.010 requires DEC to develop a peer reviewed written finding when it intends to adopt an emission standard more stringent than those set by EPA. The standards proposed in 18 AAC 50.077 for wood-fired heating devices are more stringent than current EPA standards and DEC therefore focused its analysis on this portion of the regulatory proposal. The statutes in place at the time did not require an additional peer review analysis for the remainder of DEC's regulatory proposals. As a result, DEC did not expend the additional resources to prepare a similar peer reviewed justification for the remainder of the package. In future packages, new state statute provisions will require that additional information, particularly related to the estimated cost to private parties, be provided to the public for each regulation package.

Commenters that asserted that cleaner burning wood heaters were similarly priced with more expensive woodstoves and were more expensive than the most popular non-certified woodstoves being purchased did not provide data to support their claim. DEC's analysis as presented in the peer-reviewed document did not find such a result.

With respect to comments about the effectiveness of new standards in helping to attain the PM2.5 NAAQS, DEC notes that the wood heater emission standards are just one of a number of strategies designed to work together to reduce PM2.5 air pollution in the nonattainment area. It is being adopted to support and backstop the local, voluntary incentive program to change out old, high-emitting wood heaters with cleaner burning units. This regulation, in combination with other programs and control strategies, will improve air quality over time. This is demonstrated in the air quality plan or SIP that is being made available for public review and comment.

ALASKA DEPARTMENT OF ENVIRONMENTAL CONSERVATION

18 AAC 50 AIR QUALITY CONTROL

Response to Comments on November 14, 2014 Proposed Regulations:

Purpose and Applicability of Chapter,

State Air Quality Control Plan,

Open Burning,

Wood-Fired Heating Device Visible Emission Standards,

Solid Fuel-Fired Heating Device Fuels,

Commercial Wood Seller Disclosure Program

Wood-Fired Heating Device Standards,

&

Fine Particulate Matter (PM2.5) Air Episodes and Advisories

December 24, 2014

Contents

Introduction

This document provides the Alaska Department of Environmental Conservation's (DEC) response to public comments received regarding its November 14, 2014 draft regulatiosn pertaining to open burning, the state air quality control plan for the Fairbanks North Star Borough nonattainment area, wood-fired ehating device visible emissions tandards, solid fuel-fired heating device fuels, commercial wood seller disclosure program, and fine particulate matter ($PM_{2.5}$) air episodes and advisories.

The details describing the proposed regulation changes are presented in DEC's public notice dated November 14, 2014. DEC received comments in the form of emails, electronic comments submitted online, hand written comments received at DEC's open houses, oral testimony at DEC's public hearings, letters, and faxes.

For each section of the proposed regulations and for the SIP, this document summarizes the comments received, identifies the regulatory options considered, and provides DEC's response and decisions.

18 AAC 50.065(f) – Open Burning and Related Definitions

The proposed amendment to state regulation 18 AAC 50.065(f) prohibits open burning in a PM-2.5 nonattainment area between November 1st and March 31st but allows for exceptions under a local air quality open burn permit program.

> (f) **Wood Smoke Control and PM-2.5 Non-Attainment Areas**. Open burning is prohibited between November 1 and March 31 in **all** [A] wood smoke control **areas** [AREA] identified in 18 AAC 50.025(b) **and in all PM-2.5 non-attainment areas identified in 18 AAC 50.015(b)(3) except where authorized under a local air quality open burn permit program**.

The proposed amendments and additions to the definitions in 18 AAC 50.990 relevant to open burning are as follows:

> (65) "open burning" means the burning of a material that results in the products of combustion being emitted directly into the ambient air without passing through a stack, flare, vent, or other opening of an emission unit from which an air pollutant could be emitted**; camp fires as defined in 18 AAC 50.990(140), barbeques, candles, tobacco, and celebratory fireworks are not considered open burning.**

and

> (140) "camp fire" means any open fire less than 3 feet in diameter used for cooking, personal warmth, lighting, ceremonial or aesthetic purposes that is hand built and that is not associated with any debris disposal activities.

Summary of Comments: Some commenters supported restricting outdoor open burning between November and March and felt that providing the option for a local permitting program to grant exceptions on days with good air quality and favorable weather patterns for dispersion was a reasonable measure that would allow for debris disposal and other open burning to occur on days where it would not significantly impact air quality. Other commenters felt DEC should be more specific and further define what a local air quality burn permit program is and what responsibilities it would have, as well as the requirements a local program must meet to receive DEC approval. With respect to local program authority, a commenter expressed concern that this would be a roll back of the existing open burning requirement that would result in less stringent requirements. Commenters also suggested exceptions to the outdoor burn prohibition for specific ceremonial or recreational outdoor open burning.

Other commenters felt that the proposed amendment was not protective enough of public health. Some commenters wanted no exemptions to wintertime open burning. They said that the definition of open burning, as proposed, would allow for recreational camp fires and other open burning even on days with the worst air quality. Commenters asked if the annual UAF bonfire would be affected, suggesting it was unreasonable to prohibit the public's ability to burn if the event were allowed to continue without restriction. Commenters wanted to know how the

November 1 and March 31 dates were chosen. One commenter suggest changing the beginning date to October 1. Commenters also said that the dates seemed arbitrary and that restrictions on outdoor burning be extended to any time that concentrations exceeding the level of the health standard occur. They suggested that the regulation be extended to any time the was an air quality episode or conditions with unfavorable wind conditions, last longer, or be in effect all year so that open burning was only permitted during periods of good air quality and dispersion characteristics throughout the year. Another commenter suggested removing the text, "that is hand built" from the proposed definition for "camp fire." A commenter suggested adding outdoor wood and coal boilers to the definition of outdoor burning.

Fiscal Concerns: No fiscal concerns were noted on this section of the regulation.

Regulatory Options: Based on the comments received the department considered the following regulatory options.

1) Do not implement the proposed regulation (keep current regulation and related definition)
2) Implement regulation as proposed
3) Implement proposed regulation with amendments
    a. Clarify the local program option to better identify requirements
    b. Expand time period for the restriction
    c. Change definition of campfire to remove the text regarding "hand built"

Department Decision:

Based on the public input received, the department will be adopting the proposed regulation with amendments. First, the department is adding additional language to clarify that a local open burning program may only be used in $PM_{2.5}$ nonattainment areas if they demonstrate that it will not cause or contribute to violations of the $PM_{2.5}$ ambient air quality standards and the program has been adopted into the State Implementation Plan for the area.

The department has reviewed requests for expanded time periods for the open burn prohibition. DEC will adopt and finalize the regulation with the November to March seasonal prohibition. In response to public comments received on the prior regulatory proposal from 2013-2014, the department considered a longer season for open burning restrictions. In analyzing the data available, DEC found that in the months of October and April conditions have not shown a prevalence for significant air quality deterioration as a result of normal open burning. As a result, DEC did not lengthen the seasonal restriction on open burning to include those two months in its re-proposal of this regulation. Problem open burns during these "shoulder seasons" can typically be addressed through the use of other open burning and air pollution regulations. The department also considered comments from this and previous comment periods about the need for residents to be able to open burn safely during non-summer months (outside the

wildland fire season) to address build-up of biomass fuels that create a wildland fire hazard to properties.

DEC has determined that the data supports prohibiting open burning during the winter months of November-March, but that an extension of that time period into October, April, or other months is not currently needed to address the wintertime $PM_{2.5}$ problem. DEC recognizes that open burn events can create smoke issues in localized areas if individuals fail to follow existing ordinances or regulations. However, expanding the length of the open burning prohibition does not by itself prevent such non-compliance events or the impacts they create. In response to general concerns raised about the need to restrict open burning on poor air quality days, existing state regulation (18 AAC 50.065(e)) already prohibits open burning at any time of the year for days when air quality advisories are in effect in a given area.

The department will also adopt the definition of camp fire as proposed. It is not clear from the comments what the concern is with the inclusion of "hand built." The department, in the definition, wanted to further reduce the potential for confusion or misunderstanding regarding a small scale camp fire, which is typically hand built, from an open burn for debris disposal, where mechanical devices may be used to form a debris pile for burning.

The suggestion that outdoor hydronic heaters (wood or coal) be included in outdoor open burning is contrary to the basic definition of open burning, which is the burning of material that results in combustion products being emitted into the air without passing through a stack, flare, vent, or other opening. Hydronic heaters have stacks from which air pollution is emitted and, like other air pollution emission sources with stacks, are addressed through other sections of the state's regulation.

18 AAC 50.075 – Visible Emissions Standards

The proposed amendment to this regulation requires people using wood-fired and solid-fuel fired heating device to operate their devices to meet opacity requirements during air quality advisories or episodes as established in the SIP.

18 AAC 50.075. Wood-fired and solid fuel-fired heating device visible emission standards.

(a) A person may not operate a wood-fired **or solid fuel-fired** heating device in a manner that causes

(1) black smoke; or

(2) visible emissions that exceed 50 percent opacity for more than **six [15]** minutes in any one hour**, except during the first 20 minutes after initial firing of the unit,** in an area for which an air quality advisory is in effect under 18 AAC 50.245 **or 18 AAC 50.246. Visible emissions are measured following opacity reading procedures as required by Vol. 3., sec. IV-3, Appendix IV-3, of the state air quality control plan, adopted by reference in 18 AAC 50.030.**

18 AAC 50.075 is amended by adding a new subsection to read:

(d) A person may operate a wood-fired or solid fuel-fired heating device in an area for which the department has declared a PM-2.5 air quality episode under 18 AAC 50.246, only if:

(1) visible emissions or opacity from the wood-fired or solid fuel-fired heating device is below the opacity limits identified in the episode announcement for that area as defined in the State Air Quality Control Plan adopted by reference in 18 AAC 50.030 or

(2) the owner or operator of the wood-fired or solid fuel-fired heating device has received a waiver from the department or local air quality program from the opacity limits identified in the episode announcement; which waiver may be granted by the department or local air quality program, either on a temporary or permanent basis, where they have found that meeting the opacity limits would be unreasonably expensive, technically not feasible, or would otherwise create an unreasonable burden on the owner or operator of the device.

Summary of Comments: Commenters expressed concern over the proposed visible emissions standards, their seasonality, and measurement techniques. Commenters suggested a variety of solutions to perceived problems. Comments indicated confusion and requested clarification about whether and how masonry heaters, fireplaces, and pellet stoves are included in the opacity limits, as well as in the adopted emission standards.

Commenters said that some degree of opacity is normal and that some spikes in opacity were due to initial startup and refueling of devices and should be allowed for 15 minutes every four hours but said that opacity could also be the result of burning wet wood or incorrect fuels, damping down fires, or using inefficient devices, such as uncertified wood stoves. Others suggested that opacity limits more than 20% should not be allowed for more than 3 minutes. Commenters said that smoke opacity could not be easily modulated in response to air quality episodes and instead low opacities were the result of operating clean and efficient devices the right way and using the correct fuels. Other comments said that even devices that do meet opacity standards during episodes will continue to add to $PM_{2.5}$ levels and suggested mandatory burn bans with exceptions for essential burners and cases of financial hardship as an alternative to the opacity standards. In addition, commenters indicated that they believe the 20 minute start up provision in the regulation proposal was a roll back of existing regulations, which had a 15 minute provision. With respect to the opacity levels identified for the Fairbanks non-attainment area in the proposed plan, one comment suggested a 30% opacity level if concentrations were less than 15 $\mu g/m^3$and 20% if concentrations were above 15 $\mu g/m^3$.

Some comments expressed the importance of including all solid fuel burning heaters in the requirements, while others went further recommending that all heating devices, including oil and waste oil, be included as well. Commenters felt that the regulation's applicability to all solid fuel-fired heating devices weakens requirements in 18 AAC 50.055 "Industrial Processes and Fuel-Burning Equipment" section (a) that limits opacity to 20% for an industrial process or fuel-burning equipment. They indicated that the new regulation for solid-fuel heaters would be a significant loophole for coal heaters and weaken existing requirements. Commenters also desired coal-specific opacity requirements and suggested standards as low as zero percent.

Commenters said that the proposed waivers to the opacity requirements were not protective of public health, or not specific enough to define hardship. Commenters were concerned that the waivers were too broad and that the number of waivers granted by a state or local agency could be unlimited. This would render the control non-mandatory and ineffective. Commenters said that the current language was vague and suggested that DEC further define financial hardship and sole source heaters. Commenters said that factors affecting opacity were low cost and available to burners faced with hardships, such as participating in the borough change out program to obtain a cleaner burning heating device or obtaining wood early in order to let it season at no cost. Commenters said that either no waivers should be allowed, or that waivers should be temporary and carry requirements to change out the device. Some commenters suggested that waivers should only be granted if the use of the device would not create an unreasonable health and associated financial burden on the public. It was suggested that there be a public process to review and approve any waiver that is issued on a permanent basis.

Commenters felt that the opacity levels in the SIP's local emergency episode plan and the months specified in the regulation were not protective of public health and could prove confusing for operators. Commenters desired year-round opacity limits of values at or below 20% opacity, which they felt would not be burdensome to achieve. Commenters suggested that essential burners be limited to 20% opacity during the commenters' own proposed burn ban measures.

Commenters also suggested that fireplaces should be prohibited from use during alerts or episodes as they are primarily aesthetic and not good sources for heat.

Commenters were concerned with the ability of device operators to be able to gauge the opacity of their own heating devices either because they were unaware of how to measure the opacity of their smoke or because they would not be willing to venture outdoors during cold weather to check their opacity. Commenters suggested educational outreach efforts such as classes for homeowners to understand the relationship between opacity and pollution, the importance of minimizing opacity, how to minimize opacity, and how to gauge the opacity of their smoke.

Commenters expressed doubt over the use of EPA Method 9 for measuring visible emissions. Comments suggested that the implementation of opacity standards using Method 9 would be unwelcomed by the community for a variety of reasons. Some commenters felt that it was wrong and an invasion of privacy to take an opacity reading without the operator's knowledge or consent. Other commenters felt that Method 9 was inadequate due to a perception that it is a subjective method based on the reader's opinion that could not be corroborated. Some commenters wanted a mechanism for contesting the results of an opacity reading. Commenters asked what types of information would be recorded by observers such as factors that may affect the reading like lighting, visibility, and distance.

Commenters suggested that Method 9 was not adequate for determining opacity in certain conditions present in Fairbanks such as through ice fog, dense smoke, or in poor lighting conditions. Commenters also raised issues and suggestions with respect to how water vapor should be dealt with in the Method 9 observations. Commenters said that opacity during extreme cold was not an appropriate estimation of particulate emissions because even clean burning natural gas and oil fired heaters produce emissions with high opacity due to the condensation of water. In addition, commenters wanted studies performed locally that would determine the actual correlation between opacity of smoke that includes condensed water and the amount of particulate emissions in the smoke. This, comments said, would allow DEC to develop meaningful opacity standards based on actual emissions rather than the seemingly arbitrary values contained in the emergency episode plan.

Commenters suggested alternative methods of measuring opacity. Commenters suggested the use of digital cameras to perform visible emission readings and said that properties are already photographed and in the public domain because of satellite mapping and street level road photography. They mentioned private companies that provide the tools and computer analysis necessary to perform EPA Method ALT-082: Alternative Method for Determining Visible Emissions. These companies provide fast third party analysis of a series of photographs taken with a certified camera, by a person knowledgeable about Method 9, and at the same intervals required by Method 9. This, commenters said, would provide more informative and accurate results while minimizing costs associated with training and maintaining certification of multiple employees. Commenters worried about the amount of time DEC employees would be spending conducting opacity readings, the costs, and asked how to report potential violators of the opacity standards to DEC.

Commenters suggested that the opacity requirements proposed allow more emissions during an air quality episode than current regulations. These commenters stated that 18 AAC 50.075(b) currently prohibits use of wood-fired heating devices where the department has declared an air quality episode and by allowing wood-fired heating devices to operate, even with opacity limits, is actually more permissive than current regulations. Instead, they suggest mandatory burn bans for all air episodes with exemptions exclusively for essential burners and circumstances of demonstrated hardship. Commenters have also suggested alternate $PM_{2.5}$ concentration levels for air quality episodes.

Fiscal Concerns: Those comments specifically noting fiscal impacts are summarized here.

Commenters raised concerns about the costs involved with training and paying DEC staff to make opacity readings. Commenters also expressed concern that any potential requirement of stack mounted opacity reading devices would be financially unfeasible for property owners in the area.

Commenters suggested having a third-party company use certified digital photography to determine opacity would be less expensive than having departmental staff visually read opacity.

Regulatory Options: Based on the comments received, the department considered the following regulatory options:

1) Do not implement the proposed regulation
2) Implement the regulation as proposed
3) Implement the proposed regulation with amendments
    a. Limit opacity to no more than 20% for more than 3 minutes or allow opacity to spike for 15 minutes every 4 hours
    b. Establish burn bans during episodes for all but essential burners and financial hardship waivers
    c. Limit start up emissions to 15 minutes instead of 20 minutes
    d. Modify $PM_{2.5}$ concentrations triggering episodes and modifying opacity limits
    e. Establish specific opacity requirements for coal fire devices
    f. Apply opacity requirements to all heating devices
    g. Further define financial hardship and sole source heat for waivers
    h. Make waivers temporary and require appliance change out
    i. Establish a public review process for issuing permanent waivers
    j. Establish an opacity requirement, e.g., 20% for homes with waivers during burn bans
    k. Prohibit fireplace use during episodes
    l. Establish a mechanism for contesting an opacity reading
    m. Allow the use of a camera-based method for opacity reading

Department Decision:

Based on the feedback received on the proposal, the department will make changes when finalizing this regulation.

The department is not revising the final regulation to reduce the 50% opacity requirement in 18 AAC 50.075(a)(2) to a more stringent level, such as 20%. The department believes that while there may be merit in considering such a change to this statewide regulation, it would warrant additional public review. The department will consider advancing another regulatory proposal in the near future.

Concerns have been raised that the expansion of 18 AAC 50.075 to include all solid fuel-fired heaters will result in less stringent control of visible emissions for coal-fired heaters than in current regulation (18 AAC 50.055). While the department has typically viewed 18 AAC 50.055 as requirements for larger, industrial sources, it is not clear that the regulation excludes small, residential-sized coal-fired heaters and boilers. 18 AAC 50.055(a)(1) governs fuel-burning equipment in general (note: the definition of fuel burning equipment excludes wood-fired heating devices) and 18 AAC 50.055(a)(1)(9) addresses visible emission from coal burning boilers. As a result of the concerns raised in comments about decreasing the stringency of state regulations with respect to visible emissions from residential-sized coal-fired heaters, the department will seek further legal review of this issue. Given the December 31, 2014 deadline for submittal of the Fairbanks $PM_{2.5}$ plan to EPA, the department does not have sufficient time to fully complete this review for purposes of this initial regulatory action which is linked to that plan. Therefore, the department will not advance the expansion of this section of the regulations to coal-fired heaters at this time; 18 AAC 50.075 will remain applicable only to wood-fired heating devices. The department continues to think that adding requirements for small, residential-sized coal-fired heaters to 18 AAC 50.075 alongside wood-fired heating devices would allow visible emission requirements for these heaters to be more visible and understandable to owners and operators. DEC will further consider its options and potential regulatory revisions once state legal review of this issue is complete.

Comments also raised concerns about weakening the opacity requirements in 18 AAC 50.075(a)(2) as a result of the change in excursion times allowed. The department believes its proposed revision restricting opacity excursions above 50% to no more than six minutes per hour with a twenty minute start up exclusion, is at least as, or more, stringent than the existing requirement that restricts excursions above 50% opacity to no more than 15 minutes per hour. However, to alleviate the concern that the revisions would weaken this provision, the department is revising the final regulation to provide only fifteen minutes for higher opacity levels during the initial firing of the unit. This change should address concerns related to weakening this provision and ensure that the regulation is at least as stringent as the current requirement.

In response to comments suggesting that cameras be used to determine compliance with the requirements, the department will amend the final regulation to include both the standard EPA Method 9 and a camera-based EPA approved Method 9 alternative for measuring visible emissions to determine compliance with this section. DEC notes that the camera-based Method

9 requires specializes equipment, training, and certification. Simply taking pictures of stacks is not sufficient to measure opacity under this method.

The department will be revising 18 AAC 50.075(d) from the original proposal. The change will clarify that the provisions apply when the department declares an air quality episode as identified under 18 AAC 50.246 or through more stringent episode threshold levels identified in a local air quality episode plan incorporated into the State Air Quality Control Plan (State Implementation Plan or SIP) in 18 AAC 50.030. The department understands that in the Fairbanks $PM_{2.5}$ nonattainment area, like the Juneau PM_{10} nonattainment area, a reduced episode threshold could be useful for implementing many of the programs that are designed to bring the area into attainment for the National Ambient Air Quality Standards. Selected thresholds for actions are generally best identified by the local government with respect to implementing the programs identified in the emergency episode plan in the local SIP. However, in this case, these opacity regulations are to be implemented by DEC. Pending legal approval, DEC will amend the final opacity regulations to reflect the use of adopted local air quality plans for use in triggering episodes and associated requirements. DEC will also amend the emergency episode section (5.11) of the Fairbanks $PM_{2.5}$ SIP to identify a lower threshold of 30 $\mu g/m^3$ for implementing the state's opacity requirements within the nonattainment area and revise and simplify the opacity requirements listed based on the comments discussed above. The approach to local air quality episode thresholds for the FNSB nonattainment area can be amended to add more detail or stringency in the future based on further local input on this issue.

With respect to the waiver provisions proposed by the department, the department plans to revise the waiver requirements to only allow for temporary waivers. Revisions will also be made to add criteria and factors for agency consideration in granting a waiver that take into account potential health impacts and the nonattainment status of the community. It is expected that waivers will not be considered until mitigating measures have been implemented by the owner/operator to comply with the requirements. While the department does not plan to public notice waiver actions, it does plan to provide records of waivers issued on its internet site. Waivers under this section of the regulation will only apply to the requirements of 18 AAC 50.075(d) and do not provide any protection to owners/operators that fail to comply with other regulatory provisions of 18 AAC 50.

The department also provides responses to a number of other issues raised by commenters as follows:

- Applicability of regulations to various solid fuel devices – The final visible emission regulations will apply to all wood-fired heating units as defined in 18 AAC 50.990. This includes fireplaces, wood stoves, pellet-fired heaters, masonry heaters, and hydronic heaters. Based on comments received and as described above, DEC is not including coal-fired or oil-fired heaters in this new section of the regulation at this time as a programmatic and legal review is being conducted regarding the applicability of 18 AAC 50.055.

- Costs for DEC to conduct Method 9 training and readings – There is no additional cost for DEC to train and certify staff to conduct EPA Method 9 visible emission measurements. Staff routinely use Method 9 in their work as inspectors for industrial permits and this program can rely on that training as well. The addition of the camera method provides an alternative approach that could be used by the department in the future, but would rely on procuring additional equipment and specialized training to do so. DEC will continue to explore the viability of instituting a camera-based Method 9 in its programs.

- How to report violations – The Division of Air Quality has an on-line complaint form that individuals can use to file complaints or report violations of state air quality regulations. The form can be accessed at:

  https://dec.alaska.gov/Applications/Air/airtoolsweb/Complaints

  Violations can also be reported by phone to the DEC Air Quality offices in Fairbanks (451-5173), Anchorage (269-7577), or Juneau (465-5100). Air Quality staff will then follow up with an investigation.

- Mechanism for contesting a Method 9 reading – DEC employees are certified in EPA Method 9 to measure opacity. While there may be minor variability, these opacity readings are not considered to be "opinion," rather, this method is used around the country to determine compliance with opacity requirements. DEC does not have the authority to issue tickets/fines. After initially identifying a burner that exceeds opacity limits, DEC would follow up with violators to help them understand the regulations and how they can comply. Should DEC need to proceed to a more formal enforcement action, such as a notice of violation, the owner/operator of the heating unit in question has the opportunity to discuss and provide information to the department with respect to the alleged violation.

- Local studies to develop correlation between smoke opacity and $PM_{2.5}$ emissions – DEC appreciates the desire to have additional local data and correlation. At this time, funding is not available to complete this type of study, but DEC will consider this for a future research effort and watch for funding opportunities.

- Suggestion to establish burn ban – In its last regulatory proposal, the department proposed regulatory revisions that would have included wood heating curtailment on days when the air quality levels had reached "Unhealthy" levels as defined by the Air Quality Index. Based on the numerous comments received and lack of consensus in the community regarding curtailment and various options for curtailment, the department did not advance to finalize those regulatory revisions. Instead, the department drafted the opacity requirements in this proposal to address concerns from many that the focus of compliance and restriction should be placed on poorly burning devices. This proposal

would assist in addressing that desire to clean up or restrict use of heating devices that are burning poorly, while allowing cleaner burning units to continue operation. Given the regulatory proposals currently out for comment, it is not possible for the department to include a “burn ban” in the regulations at this time. This type of action would be subject further public review and comment. The department believes that developing such a program would be best accomplished through the local government. Local government has different tools available to implement programs and can likely be most responsive to local conditions and concerns. DEC recognizes that for a number of years the local Borough has not had the authority to consider or implement such a program. However, it is now possible for local government to consider whether such a program is reasonable, warranted, and could be put in place and added to the emergency episode plan in the local SIP. DEC would encourage additional local consideration and dialogue on this issue.

18 AAC 50.076(a) and (b) – Solid Fuel-Fired Heating Device Fuels

The proposed amendment to this regulation creates a list that identifies approved fuels for wood fired and coal fired devices and creates a list of prohibited fuels for all solid fuel fired heating devices located within a PM2.5 nonattainment area. The proposed amendment also creates a requirement to use dry wood or a mixture of wet wood with compressed wood logs to meet opacity requirements between October 1st and March 31st beginning October 2015.

18 AAC 50.076. Solid fuel-fired heating device fuel requirements.

(a) A person operating a solid fuel-fired heating device in areas identified in 18 AAC 50.015(b)(3) may only use the following fuels:

(1) For wood-fired heating devices:

(A) wood;

(B) wood pellets, manufactured compressed wood logs, bricks, or pucks made from clean wood;

(C) manufacturer recommended starter fuels including home heating oil, propane, natural gas or wood-based material for dual-fuel fired hydronic heaters; and

(D) biomass fuels approved by the manufacturer.

(2) For coal burning devices:

(A) coal; and

(B) coal pellets.

(3) For all solid fuel-fired heating devices:

(A) a fuel that is approved by the manufacturer that is not prohibited by the department in (3)(B);

(B) persons are prohibited from burning or incinerating the following items: wood that has paint, stains, or other types of coating, wood that has been treated with preservatives including copper chromium arsenate, creosote, or pentachlorophenol, asphalt, rubber or tar products including materials contaminated with petroleum, petroleum derivatives, oily wastes or oil cleanup materials; chlorinated or halogenated organic compounds including plastics, polyurethane products, pesticides, herbicides, fungicides; compounds containing cyanide or asbestos; animal carcasses; putrescible garbage.

(b) Effective October 1, 2015, between October 1 and March 31 each year, a person operating a wood-fired heating device in areas identified in 18 AAC 50.015(b)(3) may only use the following fuels:

(1) dry wood;

(2) wood pellets, manufactured compressed wood logs, bricks, or pucks made from clean wood;

(3) a mix of wet wood with manufactured compressed wood logs providing the visible emissions meet the requirements of 18 AAC 50.075;

(4) manufacturer recommended starter fuels including home heating oil, propane, natural gas or wood-based material for dual fuel-fired hydronic heaters;

(5) biomass fuels approved by the manufacturer; and

(6) a fuel that is approved by the manufacturer, other than wet wood or a fuel that is not prohibited by the department under (a)(3).

Summary of Comments: Commenters said that seasoning wood properly takes effort and time and buying seasoned wood is more expensive but burning dry wood results in more efficient fires and less pollution. Commenters reported cutting, splitting, and storing wood for at least one year before burning in order to burn responsibly, efficiently and produce less pollution. Some commenters felt that only dry wood should be sold in the nonattainment area or that birch firewood logs be cut to stove length and split so that they have the chance to season without significant effort by a device owner because truckloads of birch logs are the least expensive firewood but people sometimes fail to season the wood before the burning season begins.

Commenters addressed allowing the use of wet wood with pellet logs. Some commenters indicated that only dry wood should be allowed and that allowing the mix of wet wood with pellet logs would lead the public to an assumption that burning wet wood is an acceptable practice. Comments also noted that burning wet wood can damage some heating devices and creates creosote which can lead to chimney fires. Commenters said that the results of a recent study showing emissions reductions were confusing or misleading. They said that replacing half of the wet wood with compressed wood logs would reduce emissions by half just by not burning the other half of the wet wood. They asked if EPA has certified the results or if the study had been conducted in an EPA accredited lab. Commenters desired access to the results of the study so that the public could ensure the compressed wood logs they would buy would actually reduce emissions as advertised while others expressed concern that the regulation would benefit one local compressed wood log manufacturing business by requiring the use of their product.

Some commenters felt that the use of wet wood in any manner should be prohibited year round and that the list of allowable fuels should just specify dry wood. Some commenters felt that coal and coal pellets should not be on the list of allowable fuels and that no coal burning devices should be allowed in the nonattainment area due to toxins found in the emissions, especially metals, and their localized and visible effects on surrounding properties. Other commenters said that no oil products should be allowable as starter fuels. Commenters also suggested that having a list of both allowable and prohibited fuels would help the public comply.

Commenters felt that the requirement for dry wood or a mix of wet wood and compressed wood logs to meet opacity requirements should not be limited to winter months. Commenters submitted photographs of high opacity smoke coming from an outdoor wood boiler during summer months and piles of un-split and unseasoned firewood presumably used as fuel for the heater.

Commenters would like to see continued education on how to prepare dry wood and when to measure moisture content (frozen wood cannot be tested). Education could help ensure residents understand that wood does not dry during winter months and how to measure moisture content. Education could also address the characteristics of compressed logs that are appropriate to use in wood stoves and mix with wet wood to reduce emissions. Some comments suggested that the regulatory process include a standardized practice for taking wood moisture content readings so that the public understands how enforcement officers will measure wood as part of any complaint driven inspections.

Several commenters suggested outright banning the use of coal and coal stoves. One commenter reported installing a coal boiler and that it burns so cleanly his neighbors are unaware of when it is in use. Another commenter suggested banning the use of #2 fuel oil.

Fiscal Concerns: Those comments specifically noting fiscal impacts are summarized here.

Commenters noted seasoned wood is more expensive, but burns more efficiently. It was noted that some people purchase wood as long logs because it is less expensive, but this requires the user to cut into stove lengths and split for proper drying.

Commenters expressed concern that the use of compressed wood logs with wet wood would benefit one manufacturer because their product would be required.

Regulatory Options: Based on the comments received on 18 AAC 50.076(a)-(b), the department considered the following regulatory options:

1) Do not implement the proposed regulation
2) Implement the regulation as proposed
3) Implement the proposed regulation with amendments
    a. Restrict the use of wet wood seasonally or year-round within the nonattainment area (ie. specify dry wood in the list of allowable fuels or remove wet wood provision)
    b. Require that compressed logs be used with wet wood year-round
    c. Allow only the sale of dry wood within the nonattainment area
    d. Remove coal and coal pellets in the list of allowable fuels
    e. Remove oil products as fire starters

Department Decision:

Based on the feedback received on the proposed fuel requirements for solid-fuel heating devices within the $PM_{2.5}$ nonattainment area, the department is proposing to make changes when finalizing this regulation. Given the local concerns raised about wet wood being permitted to be burned even with the addition of manufactured compressed wood logs, the department has decided to remove the provision that would allow for wet wood to be burned in the winter time if it is mixed with manufactured logs and the burn meets visibility requirements. The department included this provision in the proposal as a practical flexibility to provide individuals an option to burn wet wood with compressed logs in a clean manner should they run out of dry wood during a winter season and be unable to procure additional seasoned wood. However, the department also understands concerns and questions that were raised about the emission testing of the locally manufactured compressed wood logs which was just recently completed. The department agrees that it is appropriate to allow some time for further review of the emission testing results and consideration of how manufactured logs may be best used in the community to address air quality concerns. Removal of this regulatory option will further reinforce the need for residents to store and season adequate quantities of wood to ensure it is dry prior to use in winter months. Manufactured, compressed wood logs will be an allowable fuel and can be mixed with dry wood year round.

The department has decided not to amend the final requirements to restrict the use of wet wood or require the use of energy logs with wet wood during the months of April through September as this timeframe does not generally see air quality episodes like those associated with winter inversions, but rather air pollution events related to wildland fires. This means that during the months of April through September, wet wood could be burned and that compressed wood logs could be mixed with either dry or wet wood to reduce smoke emissions. Should human-caused $PM_{2.5}$ air episodes occur during the summer months, the relevant opacity and open burn requirements would be in effect and the department could revisit these regulations to address that concern.

Requiring that wood sellers only sell dry wood or only provide stove length/split wood to consumers as suggested by commenters could help to promote dry wood use within the nonattainment area, but making this change would go beyond the scope of this regulatory proposal. The final regulations and SIP will require that local citizens and businesses burn dry wood in the winter months, the addition of a requirement that only dry wood or split wood be sold could be considered as enhancement with a goal to increase compliance with dry wood use requirements. DEC is willing to consider these suggestions for a future regulation proposal. However, in the interim, the department encourages the FNSB to consider this option at the local level to gather input from residents and wood sellers on the pros and cons of such requirements.

Commenters continued to raise concerns about the use of coal heaters within the nonattainment area. The proposal to remove coal as an acceptable fuel would place those residents that have coal-fired heaters immediately out of compliance. To come into compliance, those individuals relying on coal-fired heat would need to replace their heating unit. Making this change goes beyond this regulatory proposal and would require additional public comment. The SIP emission

inventory includes emissions from coal-fired heaters and analyses suggest that they are currently a relatively small portion of space heating emissions in the nonattainment area. However, to address coal heating concerns, DEC is finalizing these fuel regulations and has visible emission regulations that impact coal heating as well as wood heating operations. The department encourages the FNSB to consider additional options at the local level that may address concerns raised about coal heaters and their impacts in localized areas. DEC is willing to consider proposing additional options to address coal heaters in a future regulation proposal in conjunction with additional local input on amendments to the SIP.

With respect to the suggestion to remove oil as an approved fire starter in the regulation, the department did not make this revision and will proceed with the proposal as written. The regulations only allows for the use of home heating oil, propane, natural gas, or wood-based material for dual-fuel fired hydronic heaters if those fuels being are recommended by the manufacturer as starter fuels for specific heaters. This does not mean that heating oil can be used indiscriminately in solid fuel-fired heating, but only as a starter fuel when recommended by the manufacturer.

In response to other comments on this section of the proposal, the Department provides the following:

- Both approved and prohibited fuels should be listed in the regulations – the proposed regulations do provide what can be burned in 18 AAC 50.076 (a) as well as a list of prohibited items in 18 AAC 50.076 (a)(3)(B).

- Promoting continued education on how to prepare dry wood and when to measure moisture content – DEC agrees that continuing education is important. DEC and the FNSB have public outreach materials and campaigns to raise awareness and provide information to local residents on how to season wood and test its moisture content.

- Regulatory method for taking wood moisture content readings – DEC is not proposing a standardized method for measuring wood moisture content in this regulation. Checking wood moisture content is relatively straightforward to do with simple devices available at local retailers. DEC believes that focused education can help residents to understand how to check wood moisture levels with a commercially available moisture meter, which is the same way that an inspector would check moisture content. Residents can also use other methods to estimate wood dryness, such as looking for cracked and checkered ends on split wood, using wood that is light weight for its size (is also a sign of dry wood), and noting a hollow sound when pieces are knocked together (another sign of dry wood). DEC approved moisture meters will be identified for the voluntary (and mandatory) wood seller moisture disclosure program and this information will also be made readily available to the public on the DEC web site.

18 AAC 50.076 – Commercial Wood Seller Registration Program

The proposed amendment to this regulation requires commercial wood sellers in a $PM_{2.5}$ "serious" nonattainment area to register under the Commercial Wood Seller Disclosure Program. Under the program, commercial wood sellers are required to measure, document, and provide the moisture content of the wood they sell to customers using a DEC approved moisture meter and DEC supplied forms.

18 AAC 50.076. Solid fuel-fired heating device fuel requirements

(c) Commercial Wood Seller Registration Program:

(1) a commercial wood seller, an individual or business who sells wood for use in space heating, is required to register in the commercial wood seller registration program and is subject to all requirements of this section, except 18 AAC 50.076(c)(7), if they sell or provide wood to entities located in a fine particulate matter non-attainment area classified by the Environmental Protection Agency as "serious" pursuant to 42 U.S.C. 7513 and identified in 18 AAC 50.015(b)(3) where the department has issued a finding that wood smoke is a significant component of the fine particulates leading to an area being designated as "non-attainment";

(A) requirements on wood sellers shall become effective on the sixty-first day after the department publishes a notice identifying the need for and establishment of the program for the serious fine particulate matter area;

(B) that departmental notice shall be published, no less than 60 days before the implementation of a wood seller registration program, in a newspaper of general circulation, posted in the local air pollution control program office, and on the state online public notice system;

(C) wood pellets, manufactured compressed wood logs, bricks, or pucks made from clean wood are exempt from the requirements of the commercial wood seller registration program;

(D) retailers whose principle business is not selling wood for space heating and that sell only wood pellets, manufactured, compressed wood logs, bricks, or pucks made from clean wood or seasoned split wood bundles sized 0.75 cubic feet or less are not considered "commercial wood sellers".

(2) a commercial wood seller subject to this section shall:

(A) prior to selling or providing wood, initially register with the department by submitting a registration application and required documentation to the department in a format provided by the agency;

(B) have available for use a department-approved wood moisture content meter;

(C) have a valid Alaska business license as required under AS 43.70 and 12 AAC 12;

(D) renew registration by submitting a renewal application and required documentation to the department, in a format provided by the agency, 30 days before the expiration date of the existing registration.

(3) upon receipt of a complete registration application and associated documentation, the department may:

(A) issue a unique registration identification number to the wood seller;

(B) identify the time period covered by the registration, not to exceed

three years;

(C) issue a batch of uniquely numbered three-part moisture disclosure forms for use in this program; and

(D) add the registered wood seller to the publically available registration list.

(4) a registered commercial wood seller shall:

(A) upon sale or point of delivery of wood to the consumer,

(i) test the moisture content of the wood in accordance with 18 AAC 50.076 (c)(6);

(ii) fully complete and sign the uniquely numbered moisture content disclosure form;

(iii) obtain the buyer's signature or mark on the form that the buyer is 'unavailable'; and

(iv) provide the buyer with a copy of the signed form.

(B) after sale or delivery of wood to the consumer:

(i) submit to the department the ADEC copy of the fully completed forms no later than the fifteenth day of the month for sales conducted during the preceding month; and

(ii) retain the seller copy of the completed forms for two years after date of sale or delivery.

(C) provide the seller copy of completed forms for inspection at the request of the department;

(D) account for all of the moisture content disclosure forms received from the department. At the time of the monthly submittal under (B)(i), any moisture content disclosure forms not given to a customer due to damage or errors must be submitted, and for any forms lost, the unique number must be reported;

(E) upon loss of registration or non-renewal of registration return to the department any unused moisture content disclosure forms;

(F) failure to comply with the requirements of (4)(A) - (E) may result in any or all of the following actions:

(i) remedial training on program requirements;

(ii) notice of violation;

(iii) removal from publically available registration list until deemed in compliance;

(iv) revocation of registration; or

(v) enforcement under AS 46.03.020, AS 46.03.760, AS 46.03.761, or AS 46.03.790.

(5) the department shall approve commercially-available moisture test meters for use by commercial wood sellers and provide a list of approved devices on the ADEC Division of Air Quality Internet web site and upon request.

(6) the commercial wood seller shall test the moisture content of the wood in the delivered or purchased load, except as provided by 18 AAC 50.076(c)(6)(B) and (C), using a moisture meter approved by the department under (5) as follows:

(A) for split wood, wood rounds, or logs that are cut at the time of, or prior to, sale,

(i) moisture content shall be measured in a minimum of three pieces of wood for each cord of wood purchased;

(ii) the commercial wood seller shall randomly select the wood to be tested from differing locations throughout the entire load; and

(iii) each selected piece of wood shall undergo a fresh cut, be tested in the center of the fresh cut end and the measured moisture content documented on the department-provided form;

(B) for frozen wood, wood cut and sold or delivered at freezing temperatures below 32 degrees Fahrenheit, the commercial wood seller shall note on the moisture content disclosure form that the wood is frozen and assumed to be greater than 20 percent moisture content; and

(C) for wood split prior to freezing, provided the split wood is covered and stacked for ventilation,

(i) the moisture content shall be measured randomly after splitting while stacking and storing;

(ii) the moisture content and the date of the measurements will be recorded and saved; and

(iii) upon actual sale, if the temperature is at or below 32 degrees Fahrenheit the previously recorded moisture content and date will be documented on the department-provided form.

(7) a registered commercial wood seller may be certified as a "Certified Dry Wood Seller" provided:

(A) the department has reviewed the registered commercial wood seller's business practices and determined that the business is capable of consistently providing dry wood or manufactured compressed wood logs;

(B) the registered commercial wood seller commits to consistently providing buyers dry wood or manufactured compressed wood logs; and

(C) the registered commercial wood seller signs an acknowledgement form that failure to provide dry wood or accurately provide moisture content information for wood sold is subject to 18 AAC 50.076(c)(4)(f) and revocation of certification as a "Certified Dry Wood Seller

Summary of Comments: Commenters addressed the proposed future implementation of DEC's wood moisture disclosure program for commercial wood sellers in the nonattainment area. Some commenters felt that the measure was reasonable and would provide customers with knowledge of the moisture content of their purchased wood. Other commenters felt that the program would be a burden on commercial and noncommercial wood sellers. These commenters felt that the administrative time and costs associated with measuring, filling out paperwork, and submitting paperwork would increase wood seller expenses and that those costs would be passed on to customers. Commenters said that some wood sellers advertise their wood as green or unseasoned and that the requirement would not provide useful information to customers of those wood sellers because they already are aware that the wood has a high moisture content. These commenters suggested that the program not be required for businesses selling wood advertised as wet, green, or unseasoned. Commenters said that the responsibility to ensure wood is dry before burning lies with the burner and that they should verify the wood moisture content and season any wet wood on their own. Some commenters suggested that the forms be simplified to the point where a wood seller would mark the wood as dry or wet and ensure the form had instructions for how to season wet wood. Some suggested simplifying the requirement to have wood sellers just disclose to customers whether the wood met the dry or wet wood defined by

regulation. Comments also suggested that a structure should be established to track the purchase of green wood as submitted by the vendor to utilize the information and that more consideration should be given to how to get firewood vendors to register. Concern expressed was that the program may encourage a black market in firewood and poached wood as many commercial businesses will register but local sellers may continue to only sell a little here and there or through internet sites without registering.

Some commenters felt that the moisture disclosure program would allow consumers to verify their wood was dry upon purchase and would allow for spot checks to ensure dry wood was being sold. Other commenters pointed out that the State's Department of Law Consumer Protection Agency gives consumers the ability to seek compensation for falsely advertised dry wood and felt that the moisture disclosure program would be duplicative.

Some commenters expressed concern over the definition of commercial wood sellers. They said that cutting or selling several cords of firewood per year and exchanging it between friends or selling it locally was a cultural aspect of life in Fairbanks and Bush Alaska. Commenters worried that requiring individuals who cut and sell several cords of firewood annually or who sell leftover firewood to participate in the moisture disclosure program would be burdensome to those individuals due to the costs and time required to participate. Those commenters suggested that commercial wood sellers be defined so that persons selling less than 10 cords per year would not be required to participate in the program.

Commenters also questioned the need to wait to implement provisions as a contingency measure and indicated a desire to implement when the regulations are finalized and not wait until a "serious" area classification.

Commenters recommended removing the language, "…where the department has issued a finding that wood smoke is a significant component of the fine particulates leading to an area being designated as 'non-attainment'" from 18 AAC 50.076(c)(1). This commenter noted that the language in 18 AAC 50.015(b)(3) does not include language indicating the wood smoke is a significant component of the particulates leading to the nonattainment designation.

Fiscal Concerns: Those comments specifically noting fiscal impacts are summarized here.

Some commenters felt that the administrative time and costs associated with measuring, filling out paperwork, and submitting paperwork would increase wood seller expenses and that those costs would be passed on to customers.

Some commenters perceived the proposed regulation as requiring wood sellers to season their wood before sale, which would be burdensome due to the labor and space requirements of seasoning large volumes of wood and would negatively affect customers who would need to absorb those costs when they otherwise would have seasoned the wood on their own. Some commenters felt that wood sellers should be required to season all wood before sale in the nonattainment area and that the increased costs should be passed on the consumers.

Commenters worried that requiring individuals who cut and sell several cords of firewood annually or who sell leftover firewood to participate in the moisture disclosure program would be burdensome to those individuals due to the costs and time required to participate.

Regulatory Options: Based on the comments received, the department considered the following regulatory options:

1) Do not implement the proposed regulation
2) Implement the regulation as proposed
3) Implement the proposed regulation with amendments
    a. Exempt wood sellers advertising wet wood from the wood seller program
    b. Simplify forms so that wood is only identified as "wet" or "dry"
    c. Require all sellers to season wood before selling so they are only selling dry wood
    d. Define a commercial wood seller based on the quantity of wood sold, e.g., 10 cords or more per year
    e. Establish the wood seller program immediately, instead of as a contingency measure
    f. Include instructions for seasoning wood on the disclosure forms
    g. Revise the language to eliminate the department finding that "wood smoke is a significant component of the fine particles leading to the area being designated as 'non-attainment.'"

Department Decision: Based on the public comments received, the department will be finalizing the proposed regulations with some changes.

A number of suggestions were raised to simplify or eliminate requirements for wood sellers that market wet or green wood. Completely eliminating the requirements for "wet" wood sellers will not assist in ensuring that residents are informed about the product they are receiving so that they can adequately season the product before use. Enhancing compliance rates for the required use of dry wood during winter months is the goal of this regulatory measure. As a result, the department agrees that some simplification can be added to the regulations with respect to green wood sales, but has also determined that these wood sellers should register and follow program requirements. The department agrees that for wood sellers advertising and selling wet wood, it is acceptable to forgo moisture content testing and simply mark that the wood being sold is wet on the approved form. In considering the removal of specific moisture content testing for green wood sales, the department believes it remains important that any wood that is marketed and sold as "dry" be tested and the moisture content information disclosed to the buyer. The regulations will continue to require moisture content testing for any wood being sold as "dry" wood. Therefore, the department has made revisions in finalizing these regulations and will develop a moisture content disclosure form for the implementation phase of the program that includes a simple check box for denoting either "wet" or "frozen" wood. In addition, the department agrees with comments that the moisture content disclosure form contain information related to

seasoning wood. During implementation, the department will work to help provide additional information through the form and other means to assist wood users in this regard.

A commenter suggested revising the language that triggers the program to eliminate the department finding that "wood smoke is a significant component of the fine particles leading to the area being designated as 'non-attainment.'" The reason the department included this language in the proposal was that it is conceivable that in the future there could be another $PM_{2.5}$ nonattainment area in the state where wood smoke is not a significant contributor to the area's $PM_{2.5}$ problem. The inclusion of this language is simply meant to add flexibility that would prevent implementation of a control requirement that may not be universally relevant or necessary to mitigate $PM_{2.5}$ in all nonattainment areas. Making such a finding should be quick and simple for the department given the rigorous analysis that is typically conducted in identifying source contributions for nonattainment areas. As a result, the department intends to retain this language in the adopted regulation.

Suggestions were made to include a level of firewood sales, such as ten cords, below which a wood seller would not be considered a commercial seller. The proposed regulatory requirement includes having an Alaska business license, which are required for businesses defined by AS 43.70.110(1) as a for-profit or non-profit entity engaging or offering to engage in a trade, a service, a profession, or an activity with the goal of receiving a financial benefit in exchange to the provision of services, or goods, or other property. Given the regulatory goal of improving resident's compliance rate for burning dry wood, the department feels it is critical to ensure that all commercial businesses that sell wood in the nonattainment area are equally required to comply with these requirements. Entities that do not require a business license would not be considered commercial wood sellers under this regulation. As a result, the department is not amending the regulation to incorporate a minimum level of wood sold for inclusion in the program.

Suggestions were also received to institute a requirement that only dry wood be allowed for sale in the nonattainment area. Requiring that wood sellers only sell dry wood or only provide stove length/split wood to consumers as suggested by commenters could help to promote dry wood use within the nonattainment area, but making this change would go beyond the scope of this regulatory proposal. The final regulations and SIP will require that local citizens and businesses burn dry wood in the winter months, the addition of a requirement that only dry wood or split wood be sold could be considered as an enhancement with a goal of increasing compliance with dry wood use requirements. DEC is willing to consider these suggestions for a future regulation proposal. However, in the interim, the department encourages the FNSB to consider this option at the local level to gather input from residents and wood sellers on the pros and cons of such requirements.

With respect to comments suggesting the implementation of these requirements immediately, the department notes that this program was initiated in November as a voluntary measure. This is a completely new program and it will require work on the part of the department and wood sellers to fine tune the operational aspects. Having a limited time to work through program implementation issues will allow the department to consider whether additional modifications to

technical aspects of the regulations are needed prior to all wood sellers in the nonattainment area having to comply with it as a state requirement. The department believes that taking some time to work through practical implementation issues with wood sellers and consumers will ultimately result in a stronger program when the regulations are triggered in 2016. As discussed previously, the final regulations and SIP will require that local citizens and businesses burn dry wood in the winter months, the addition of this program is essentially meant to enhance and assist with increasing compliance with dry wood use requirements.

Comments also suggested that a structure should be established to track the purchase of green wood as submitted by the vendor to utilize the information. The department intends to track and use the moisture content disclosure forms to better understand the wood market in the nonattainment area and as additional data to inform public outreach efforts, emission estimates, and control program benefits for the local air quality plan.

18 AAC 50.077 – Heating Device Standards – House sale

The proposed amendment to this regulation requires wood-fired devices not meeting specific standards be replace at the time of the sale of a property.

18 AAC 50.077 Wood-fired heating device standards.

(b) **Prohibitions**. Except as provided in (5) [AND]**,** (6) **and (7)** of this subsection, no person subject to (a) of this section may supply, distribute, lease, sell, convey, or install in an area identified in 18 AAC 50.015(b)(3)

18 AAC 50.077(b) is amended by adding a new subsection to read:

(7) the prohibitions in subsection (b) do not apply to the following wood-fired devices located in a fine particulate matter non-attainment areas classified by the Environmental Protection Agency as "Serious" pursuant to 42 U.S.C. 7513 and identified in 18 AAC 50.015(b)(3):

(i) a wood stove certified by the Environmental Protection Agency or the department to be compliant with federal and state performance standards applicable to fine particulate emissions from that device and in effect prior to {effective date of regulation} or the date of installation of the device at its present location, whichever is later; or

(ii) a hydronic heater approved or certified by the Environmental Protection Agency or the department to be compliant with federal and state performance standards applicable to fine particulate emissions from that device and in effect prior to {effective date of regulation} or the date of installation of the device at its present location, whichever is later; or

(iii)a wood-fired heating device for which the owner has received a written temporary or permanent waiver from the prohibitions in subsection (b) from the department or a local air quality program. A waiver may be granted if the department or the local air quality program finds that compliance with subsection (b) would be unreasonably expensive or burdensome to the owner or would put their property at an unreasonable risk

Summary of Comments: Commenters addressed the proposed regulation that would require certain high emitting devices to be removed or replaced before a home could be sold in a serious nonattainment area and the exemption provision within the regulation.

Some commenters felt that the regulation was not protective enough of public health. Commenters questioned the need to wait to implement provisions as a contingency measure and

indicated a desire to implement when the regulations are finalized and not wait until a "serious" area classification. Commenters also said that houses may not be sold for many years and that this measure, in the absence of mandatory device change out requirements, would make device change out voluntary and unlikely. They said this regulation would grandfather existing high emitting devices for long periods of time. Some commenters suggested that the regulations require replacement of all uncertified fireplaces, wood stoves, hydronic wood/coal heaters within the nonattainment area within a specified time, such as 12 or 18 months. In making this suggestion, commenters also noted that a date for certain replacement was reasonable if adequate funding is available through the Borough change-out program.

Commenters noted that the regulation exempts EPA certified wood stoves and hydronic heaters that also meet federal and state emissions standards but does not mention pellet stoves. Commenters said that pellet stoves are the cleanest burning class of wood-fired heating devices but would seemingly not be exempt from the requirement to remove or replace the device upon the sale of a home. Commenters requested that pellet stoves be exempt from this requirement.

Commenters were concerned with the ability of device owners to obtain temporary or permanent exemptions from section 18 AAC 50.077(b), saying these waivers were not protective enough of public health. Commenters desired an open and public process with a review period before waivers are granted. Some commenters felt that temporary or permanent waiver provisions for high emitting devices should not be included in the regulation at all. In addition, commenters felt the waiver provisions were complicated and unclear. There were concerns that no documentation would be required to justify waiver requests and that the number of waivers granted by a state or local agency could be unlimited.

Commenters also felt that the requirement of the removal of high emitting devices on the sale of a home would be a burden and would constitute taking by the State because the device could no longer be resold in the nonattainment area and would have no value. Commenters felt that this violated constitutional protections. Other comments said that device owners could participate in the Borough's change out program to recoup all or some of the cost of purchasing or removing certain high emitting devices but commenters said that this program was unattractive because the reimbursement amount was considered taxable by the IRS.

Confusion about the regulations was noted by commenters and they would like to see them re-proposed. They also felt that the regulations could be simplified to one standard for stoves and outdoor hydronic heaters, regardless of the size of the unit. Comments noted a numbering discrepancy between the adopted regulations and the proposed regulation.

With respect to the wood-fired heating device emission standards overall, commenters recommended requiring a stronger statement, including an address and notarized statement, that a non-complying stove will be used outside the non-attainment area. Other comments were received suggesting that the state prohibit the sale of "non-EPA certified" devices statewide, to further public health statewide and to prevent members of the public from purchasing these heaters outside the nonattainment area and then installing them within the area. Comments also

expressed a desire for a similar standard for coal stoves, and recommended a zero opacity limit on them.

Some commenters recommended requiring that all solid fuel heating devices be registered and regularly inspected. Some also recommended limiting the number of devices based on neighborhood density, i.e., areas with more homes could have fewer wood and coal burning devices. Another suggestion was to require a "burn class" for anyone participating in the Borough's wood stove change out program. The class would cover proper handling of firewood, wood stove firing, etc. The participants would have to complete the class before they could receive their reimbursement funds. Commenters also asked to have new homes built with non-polluting heat sources so no new essential burners are created in the non-attainment area.

Fiscal Concerns: Those comments specifically noting fiscal impacts are summarized here.

Commenters felt that removing high emitting devices at the time of the sale of the home would be a financial burden because the device could not be resold within the non-attainment area. Other commenters felt that the Borough's change out program would help those replacing stoves recoup some or all of the costs. Some commenters said this option was unattractive because the amount received is taxable by the IRS. Commenters also suggested making it easier for low income residents to purchase more efficient stoves.

Commenters noted that devices complying with standards are widely available and cost about the same as higher emitting devices.

Regulatory Options: Based on the comments received, the department considered the following regulatory options:

1) Do not implement the proposed regulation
2) Implement the regulation as proposed
3) Implement the proposed regulation with amendments
    a. Making the measure applicable now instead of as a contingency measure
    b. Requiring change outs of all non-EPA certified devices sooner than the sale of the home, e.g., 12 or18 months
    c. Exempting pellet stoves from the requirement
    d. Clarifying and adding detail to requirements for waivers
    e. Requiring a stronger statement from customer purchasing a stove in the non-attainment area for use outside the area to evidence that the stove will be installed outside the non-attainment area
    f. Prohibiting the sale of non-EPA certified stoves statewide
    g. Establishing requirements for coal-fired heating devices

Department Decision:

Based on the comments received, the department plans to revise the waiver requirements to only allow for temporary waivers. Revisions will also be made to add criteria and factors for agency consideration in granting a waiver that take into account potential health impacts and the nonattainment status of the community. While the department does not plan to public notice waiver actions, it does plan to provide records of waivers issued on its internet site. Waivers under this section of the regulation will only apply to the requirements of 18 AAC 50.077 and do not provide any protection to owners/operators that fail to comply with other regulatory provisions of 18 AAC 50.

With respect to comments suggesting the implementation of these requirements immediately, the department notes that the emission standard requirements for new wood heaters are still in final legal review prior to becoming effective. The department believes it is wise to initiate the program for new wood heaters prior to requiring mandatory conversions of existing wood heaters on sale of homes in the nonattainment area. The department feels it is reasonable to allow residents this next year to continue to change out wood heaters and to plan for future home sales before instituting required removals or replacements of old devices. The FNSB change out program has been providing opportunities for property owners to upgrade their devices and would be helpful in assisting residents in meeting this requirement that is anticipated to start in 2016.

Suggestions were made about including pellet stoves in the exceptions from the requirement to change out on sale of home. When finalized, the adopted emission standards will apply to wood stoves, hydronic heaters, and larger (greater than 350,000 BTU/hr) wood heaters. Not all pellet units meet the definition of wood stove or hydronic heater. Some existing pellet stoves are certified by EPA and meet the state emission standards, while others do not. A smaller, residentially-sized pellet unit that does not meet the definition of a wood stove or hydronic heater is not affected by the emission standards and would not need an exception to regulations. As a result, the department is not moving forward with a simple exception for all pellet heating devices in this regulation package. The units that meet the state emission requirements in the regulation would retain their grandfathering and not be required for replacement. If an existing pellet woodstove or hydronic heater is not EPA certified/approved and does not meet the state emission standard, it may need to be removed or replaced upon sale of the home. It is anticipated that EPA will finalize revised new source performance standards for wood heaters in 2015. The department intends to review that final regulation and will determine whether to propose regulatory revisions to state emission standards. Additional clarification with respect to pellet stoves could also be considered at that time.

The suggestions raised in comments about requiring a stronger statement from a customer purchasing a stove in the nonattainment area for use outside the area to evidence that the stove will be installed outside the nonattainment area is a good one. While the adopted emission standards are undergoing legal review prior to final filing and an effective date, DEC is consulting with wood heater retailers on implementation aspects for the wood heater emission standards and welcomes input on this issue. One of the items being worked on to assist wood

heater retailers is a model affidavit that purchasers would sign if they wish to purchase a wood heater for installation outside the nonattainment area that does not meet the state emission standards for the nonattainment area. DEC will also be working with retailers statewide to ensure they are aware of the emission standard requirements for new wood heaters sold for use within the FNSB nonattainment area.

Additional suggestions made by commenters with respect to prohibiting the sale of non-EPA certified stoves statewide or establishing requirements for coal-fired heating devices are not being acted on by the department in this regulation proposal. These types of regulation revisions go beyond the current regulatory proposal and would require additional public review and comment. The department takes note of these suggestions and will give them consideration for future regulatory action.

Some commenters recommended requiring that all solid fuel heating devices be registered and regularly inspected. This suggestion goes beyond the scope of this regulatory program and would require additional work to develop followed by public comment.

Limiting the number of devices based on neighborhood density, i.e., areas with more homes could have fewer wood and coal burning devices, was another suggestion that goes beyond this regulatory proposal. Commenters also asked to have new homes built with non-polluting heat sources so no new essential burners are created in the non-attainment area. These types of requirements are likely best addressed through local zoning or building codes rather than state environmental regulation. DEC encourages the FNSB and local cities to consider the pros and cons of these ideas for potential local action.

Another suggestion was to require a “burn class” for anyone participating in the Borough’s wood stove change out program. The class would cover proper handling of firewood, wood stove firing, etc. The participant would have to complete the class before they could receive their reimbursement funds. The department appreciates this suggestion for enhancing the wood stove change out program and will pass it along to the FNSB for their consideration.

18 AAC 50.246 – PM2.5 Episodes and Advisories

The proposed amendment sets thresholds for the department or local air quality agency to declare an air quality episode and prescribe and publicize actions to be taken.

> **Air quality episodes and advisories for PM-2.5.** (a) The department or a local air quality control program may declare an air quality episode and prescribe and publicize the actions to be taken if the concentration of PM-2.5 in the ambient air has reached, or is likely in the immediate future to reach, any of the concentrations established in Table 6a in this subsection. The actions prescribed for any area that has a local air quality plan included in the State Air Quality Control Plan adopted under 18 AAC 50.030 shall be consistent with the emergency episode provisions included in that plan.
>
> Table 6a – Concentrations Triggering an Air Quality Episode for PM-2.5

Episode Type	Air Pollutant	Concentration in micrograms per cubic meter µg/m^3
Air alert	PM-2.5	35 (24-hour average)
Air warning	PM-2.5	251 (24-hour average)
Air emergency	PM-2.5	351 (24-hour average)

Summary of Comments: Commenters addressed several aspects of the proposal for $PM_{2.5}$ episode levels, including the triggering concentrations for various levels, links to other regulations, and terms within the section.

Commenters suggested that the air warning and air emergency levels proposed for $PM_{2.5}$ were too high and proposed alternative levels for consideration. These commenters felt the levels proposed showed negligence on the part of the state with respect to the public health impacts associated with exposure to high $PM_{2.5}$ concentrations. They suggested a 24-hour level of 15 µg/m^3 to initiate an air alert, with an additional "watch" level starting when concentrations exceed 35 µg/m^3, a "warning" level when concentrations exceed 55 µg/m^3, and an "emergency level when concentrations exceed 150 µg/m^3. These levels correspond, respectively, to the AQI levels deemed, "moderate", "unhealthy for sensitive groups", "unhealthy", and "very unhealthy." Another commenter felt that there were too many terms, numbers, and levels in the various regulations. They suggested that the air quality episodes should be simplified to reflect one level, an air quality emergency, which could replace all levels. They indicated that an air emergency should exist at levels over 35 µg/m^3, but also referenced the Juneau ordinances that set the level at a 24-hour concentration of 30 µg/m^3.

Comments were received that questioned why the new 18 AAC 50.246 was developed as it is similar to 18 AAC 50.245. They noted that the new section eliminates the link to the existing

regulation's curtailment action (18 AAC 50.075b) that is triggered by episodes called under 18 AAC 50.245. The concern was raised that the language only allows the department to announce episodes.

Commenters indicated a desire to define the portion of the regulation that indicates that episodes may be called and actions taken when concentrations have reached or are "likely in the immediate future to reach" a threshold in the table. They felt that "immediate future" limits the agency's ability to promptly respond to meteorological conditions that can be anticipated farther in the future than "immediate."

Some commenters proposed that episode actions include burn bans for all solid fuel-fired devices, for non-certified devices, for outdoor boilers, or in localized "no smoke" zones to be defined around schools, medical facilities, etc. One commenter suggested requiring all business to close on bad air days to discourage people from coming into town.

For at least one commenter, it was unclear if an episode would apply in just the nonattainment area or apply to the whole Borough.

Fiscal Concerns: There were no comments noting fiscal concerns on this topic.

Regulatory Options: Based on the comments received, the department considered the following regulatory options.

1) Do not implement the proposed regulation
2) Implement the regulation as proposed
3) Implement the proposed regulation with amendments
    a. Lower initial air alert episode threshold to a concentration between 15 and 35 $\mu g/m^3$ to prevent NAAQS violations
    b. Lower the air warning and emergency thresholds to 55 and 150 $\mu g/m^3$ respectively
    c. Add another level ("watch") between an alert and a warning.
    d. Simplify to one "emergency" level at a concentration in the range of 30 to 35 $\mu g/m^3$
    e. Add language to better define "immediate future"

Department Decision:

Based on the feedback received on the proposed air quality episode levels, the department will make changes when finalizing this regulation. The department agrees with commenters that reducing the air warning and emergency thresholds to lower concentrations will allow for quicker action to address the significant public health concerns associated with exposures to high concentrations of fine particulate matter during an air quality episode. The department has

decided to lower the air warning level to a 24 hour $PM_{2.5}$ concentration of 55.5 µg/m^3, which is the "Unhealthy" level of the Air Quality Index. The department is lowering the air emergency level to a 24 hour $PM_{2.5}$ concentration of 150.5 µg/m^3, which is the "Very Unhealthy" level of the Air Quality Index. The department believes that having a three level approach to air quality episodes is a useful framework to allow DEC or a local air quality program to implement progressive actions reflecting the severity of unique air pollution events.

Because this is a statewide regulation, the department has decided to keep the air episode threshold for the initial level, i.e., alert, at the concentration where it first exceeds the 24-hour $PM_{2.5}$ National Ambient Air Quality Standard, 35.5 µg/m^3, which corresponds to the "Unhealthy for Sensitive Groups" level of the Air Quality Index. However, the department understands that in the Fairbanks $PM_{2.5}$ nonattainment area, like the Juneau PM_{10} nonattainment area, a reduced episode threshold could be useful for implementing many of the programs that are designed to bring the area into attainment for the National Ambient Air Quality Standards. Like Juneau, a different level for an air episode can be established through the local air quality plan (State Implementation Plan). The selected thresholds for actions would be best identified by the local government with respect to implementing the programs identified in the emergency episode plan in the SIP.

Based on the comments received and the state's proposed opacity requirements during air episodes, the department will take some first steps to reducing the episode threshold for the nonattainment area. Pending legal concurrence, this may be accomplished by revising the final regulations to clarify that lower episode thresholds can be enacted through local SIPs. If this cannot be accomplished in finalizing this regulation, DEC would include a proposal in the future presumably when amendments are proposed for the FNSB $PM_{2.5}$ SIP.

Pending legal approval, DEC will amend the final opacity regulations and the emergency episode section (5.11) of the Fairbanks $PM_{2.5}$ SIP to identify a lower threshold of 30 µg/m^3 for implementing the state's opacity requirements within the nonattainment area. The approach to local air quality episode thresholds can be amended to add more detail or stringency in the future based on further local input on this issue.

The department is not changing the regulation language, "in the immediate future." Typically, air quality forecast are made for the current and one to two upcoming days. The forecast considers current and predicted weather patterns, current pollution concentrations, and includes a database of historical air quality and weather conditions. Because the forecast is based on weather predictions and emissions depend on human behavior, it is difficult to accurately forecast air quality more than a few days out. That said, sometimes weather patterns are quite stable and anticipated to stay that way, and forecasts can accurately be made for slightly longer periods of time. Both DEC and Borough staff review weather and air quality information on a daily or more frequent basis to prepare forecasts for the area. For these reasons, the department is not able to define "immediate future" with a specific number of days.

50.990 – Definitions

The prosed regulations include modifying the definition of open burning and adding definitions for dry wood, camp fire, wet wood, and manufacturer compressed wood logs.

18 AAC 50.990 Definitions

(65) "open burning" means the burning of a material that results in the products of combustion being emitted directly into the ambient air without passing through a stack, flare, vent, or other opening of an emission unit from which an air pollutant could be emitted**; camp fires as defined in 18 AAC 50.990(140), barbeques, candles, tobacco, and celebratory fireworks are not considered open burning.**

18 AAC 50.990 is amended by adding new paragraphs to read:

(139) “dry wood” means wood with a moisture content of 20 percent or less.

(140) "camp fire" means any open fire less than 3 feet in diameter used for cooking, personal warmth, lighting, ceremonial or aesthetic purposes that is hand built and that is not associated with any debris disposal activities.

(141) "wet wood" means wood with moisture content of more than 20 percent.

(142) “manufactured compressed wood logs” means logs that have been made from 100 percent compressed sawdust and/or other organic material with no wax additive.

Summary of Comments: Comments were received on the revision to the “open burning” definition and the definition of “camp fire.” Given the specific ties and implications of these definitions within the context of the regulation proposal, these comments and the department’s consideration and decisions related to these definitions are included in the section on the 18 AAC 50.065(f) open burning regulation proposal.

For the definitions of dry and wet wood, comments indicated that defining dry and wet wood using 20% moisture content was an easy to understand concept that will help sellers, buyers, and users of wood burn cleanly.

A comment was also received on the definition of “manufactured compressed wood logs.” The commenter particularly expressed concern about the “wax additive” portion of the definition and wondered if it was clear enough. They suggested removing “wax” as there are many types of logs that add additives to bind or enhance the log. They also felt that “wood chips” should be added after “compressed sawdust.”

Fiscal Concerns: No specific concerns on fiscal impacts were raised on this section of the regulation proposal.

Regulatory Options: Based on the comments received, the department considered the following regulatory options:

1) Do not implement the proposed regulation
2) Implement the regulation as proposed
3) Implement the proposed regulation with amendments
    a. Change the definition of compressed wood logs to remove “wax” and/or add “wood chips” along with compressed sawdust as an acceptable material for creating manufactured logs.

Department Decision:

The department is proceeding to adopt the wet and dry wood definitions as proposed. With respect to the definition for manufactured compressed wood logs, the department agrees that changes to this definition would provide additional clarity and is adopting a revised definition as follows:

(142) “manufactured compressed wood logs” means logs that have been made from 100 percent compressed sawdust, wood chips, and/or other organic material with no additive.

As described above, decisions made with respect to the regulatory definition of “open burning” and “camp fire” are discussed in the open burning section of this response to comments.

Outdoor Hydronic Heaters

Comments were received on the use, emissions, and effects of outdoor hydronic heaters, both coal and wood, and suggested control measures to reduce emissions from hydronic heaters. Given the public attention devoted to outdoor hydronic heaters in response to the proposed regulations and the State Implementation Plan, this section compiles the general comments received specific to these heating devices.

Summary of Comments:

Use of Outdoor Hydronic Heaters

Some commenters reported reduced heating bills as a result of installing hydronic heaters and that the high cost of heating fuel incentivized installing hydronic heaters. Other commenters said that the use of hydronic heaters, in some cases, seemed financially unwarranted. They said that purchase and installation costs could exceed many thousands of dollars and that some devices could be seen heating presumably high income homes. These factors led some commenters to believe that some hydronic heater owners could afford to and should heat with oil. Commenters felt that the savings the individuals enjoyed were outweighed by the health and other costs associated with high pollution levels incurred by individuals and the public.

Commenters also reported attempting to minimize emissions when operating their devices by keeping their devices in good working order with frequent maintenance and only burning correct fuels such as coal in coal boilers and seasoned wood in wood boilers. Commenters said that some hydronic heaters run for only 4-6 hours per day while woodstoves run for many more hours each day and presumably create fewer emissions compared to wood stoves. Other commenters indicated that hydronic heaters account for only four percent of wood burning devices but produce more than half of the $PM_{2.5}$ from wood combustion in the nonattainment area.

Impacts

Commenters reported impacts of outdoor hydronic heater operation. Some commenters relayed sometimes prolonged or continuing personal experiences and health effects due to a neighbor's hydronic heater, other commenters said that they could observe the smoke from nearby hills and reported seeing smoke from specific hydronic heaters covering large areas of Fairbanks. Commenters said that the impacts to a localized area from hydronic heaters were noticeable and severe, especially in the case of newly installed ones where there had been none previously.

Control Measures

Commenters said that control measures on outdoor hydronic heaters would negatively impact a relatively small number of individuals but would provide many positive benefits for the

community as a whole. Commenters suggested a variety of control measures to reduce or eliminate emissions from solid fuel fired outdoor hydronic heaters. Components of these included prohibiting device sales and installations and requiring replacement, removal, or burning restrictions on either all such devices or subsets of devices such as coal boilers, non-EPA Phase 2 Qualified devices, or boilers located in areas with sensitive populations such as around schools, hospitals, senior centers, and day cares. Commenters suggested that measures involving removal of devices be enforced immediately or by a specified deadline either by device owners or the government. Some suggested banning non-certified units statewide.

Commenters suggested that control measures requiring removal of hydronic heaters would likely need to incentivize compliance using a combination of attractive financial incentives for device owners and financial or legal consequences for not complying with such a requirement. Financial incentives included cash payouts for removal or cash combined with subsidized replacement with cleaner burning devices and subsequent fuel cost subsidies. Commenters mentioned the options available to device owners through the current Borough change out program but said that the program was ineffective at reducing the total number of outdoor hydronic heaters in the nonattainment area.

To demonstrate the potential effects of banning outdoor hydronic heaters, commenters noted the positive impact the removal of two hydronic heaters near Woodriver Elementary School had on local air quality. They also cited apportionment and other studies in the nonattainment area that indicates that over half of the $PM_{2.5}$ from wood burning is produced by a relatively small number of hydronic heaters.

Commenters said that control measures involving burn bans on hydronic heaters would be unfeasible because stopping outdoor hydronic heaters for extended periods of time during cold weather, like during a burn ban, could cause damage to the appliance and water lines due to water freezing in the water-jacket or lines which would make restarting the unit impossible without difficult or expensive repairs. Commenters wanted to know if device operators would be reimbursed for such costs.

Fiscal Concerns: Those comments specifically noting fiscal impacts are summarized here or within the specific regulation sections for 18 AAC 50.075, 18 AAC 50.076, and 18 AAC 50.077.

Comments regarding hydronic heaters included some discussion of fiscal impacts. Some comments discussed the benefit of reduced heating costs associated with their use of hydronic heaters, which they use because of the high costs of heating oil. Other comments noted that the impacts of hydronic heaters can be excessive and this leads to increased health costs and costs for air filtration systems to prevent smoke from impacting air inside homes and other structures. Comments also noted the high purchase and installation costs for hydronic heaters. Some comments suggested removal of hydronic heaters and linked that requirement for removal to providing attractive financial incentives that could help offset the burden of changing these devices out.

Regulatory Options: Current regulatory proposals for 18 AAC 50.075, 18 AAC 50.076, and 18 AAC 50.077 impact the use or installation of hydronic heaters. Regulatory options for these three regulatory proposals were considered by the department in response to public comments. Details are identified and included in those specific sections of this document.

Department Decision:

As noted above, the current regulatory proposals impact the use or installation of hydronic heaters and specific issues noted for those proposals are include in the sections of the response to comment related to visible emissions/opacity, fuels, and emission standards for wood heaters. A number of comments were received that generally discussed the impacts of hydronic heaters and include suggestions for further regulatory actions that go beyond the scope of this regulatory proposal.

The measures recommended in the comments, banning further sales of hydronic heaters in the non-attainment area or a larger area, banning the use of these devices or a subset of the devices during an air quality episode, and requiring change out of hydronic heaters either to a less polluting model or to a different type of device are beyond the scope of the proposed regulations under consideration. The department understands the public's desire to remove the most highly polluting devices from the nonattainment area and will further consider its options and potential regulatory revisions. The department also encourages local government to consider the issues raised including how the Borough's change out program might further incentivize and assist homeowners in replacing high emitting devices.

Other regulations in this package will regulate both outdoor hydronic heating devices and their emissions. Emissions will be limited through opacity requirements tied to air quality episodes established in 18 AAC 50.075 and 18 AAC 50.246, respectively. Based on comments received, these two regulations will be amended to ensure there is no backsliding in opacity requirements and air quality episode thresholds are set at levels to protect air quality. Components of the episode plan are also identified in the SIP document and revisions were made in response to comments. Regulations in 18 AAC 50.76 identify the allowable fuels for the devices and limit the fuels during the winter months, October 1 through March 31, to dry wood or other dry wood products for wood-fired heating devices. Finally, when the non-attainment area is designated as "serious," expected mid-2016, the additional requirement in 18 AAC 50.077 will become effective that requires high emitting devices be removed or replaced upon sale of the property. DEC is willing to consider additional amendments or measures in the future based on local discussion that is anticipated to occur in the next several months.

General Comments on the Regulations and State Implementation Plan

Summary of Comments: Comments received in response to the proposed regulations and proposed State Implementation Plan (SIP) suggested changes to the regulations to improve $PM_{2.5}$ air quality and to the air quality plan for the Fairbanks North Star Borough (FNSB) $PM_{2.5}$. The public, business, local governments, the EPA, and special interest groups all expressed their views. Comments were submitted via oral testimony and in writing. Specific comments have been included within the regulation revision sections of this document. Overarching comments on the regulations and comments on the SIP are categorized here and generally organized by SIP chapters.

In addition to the comments described below, a number of commenters noted inconsistencies, typographical errors, and references in the SIP that they suggested the department correct or clarify. Simple clarifications and corrections are not individually noted, more substantive changes are noted in the sections below. Following the general comments are the specific administrative comments EPA provided with the departments responses noted. Finally, at the end of this section, some specific comments received regarding the RACM and RACT analyses are listed and detailed responses are provided.

Local Air Quality Program Provisions

Summary of Comments: Commenters expressed concern about confusion if multiple authorities are making statements about air quality in the non-attainment area. These commenters requested clear requirements for when a local program is authorized.

Department Response:

The reason for adding the local air pollution control program references to the regulations is to provide clarity that local programs can choose to adopt or take on various requirements in place of the state. With respect to announcing air episodes and advisories, adding the local air pollution control program references assists the department by clarifying that the department can act to enforce state regulations based on episode or advisory announcements made by local programs. This is important because it will allow the department and local air programs the ability to reduce redundancy that currently exists in calling air episodes and advisories. The department and individual local air programs enter into Memorandums of Understanding that further clarify roles and responsibilities with the goal of reducing or eliminating any duplication of effort and allowing efficient use of resources. While the regulations may appear to be creating complexity, the reality is that the MOUs between the agencies will clarify the respective roles of the department and local agencies with respect to air quality management.

Impact of Changing Conditions on Air Quality Planning

Summary of Comments: Commenters expressed concern over several aspects of the proposed SIP and regulations. Commenters noted that several factors of the SIP and several assumptions

that the SIP relied on are now in the process of changing. Commenters noted that the price of oil was dropping and forecasted to stay down which reduces the financial burden of relying on oil for heat instead of burning wood.

Commenters said that the price estimates for delivered natural gas were increasing and the project to bring natural gas to Fairbanks residences was subject to continuing delays and uncertainties. Commenters said that it would be unlikely that customers would switch to natural gas due to the high furnace purchase and installation costs of approximately $10,000 and the rising gas price estimates. Commenters said that the plan's reliance on individuals and businesses switching to natural gas for attainment was unrealistic and would take too long. They also stated that the assumption that 77% of wood burning homes would switch to natural gas was unrealistic. Commenters suggested that plan revisions be made now or in the serious plan to update natural gas projections based on more recent information.

Commenters also noted the results of the recent ballot initiative that have given the Borough the ability to regulate home heating devices once again, although some commenters also expressed concerns with the recent ballot initiative results saying rhetorically that a statewide marijuana initiative passed as well. Commenters said that the SIP was developed while the Borough was unable to regulate home heating and that it should be modified to address the change and that it should be amended often to reflect borough control measures as they are adopted.

Commenters noted that the release of the SIP and proposed regulations occurred after the results of the gubernatorial race, which resulted in the changing of state administrations, were known. The open houses occurred just after the new governor was inaugurated and commenters asked if the proposal had been approved by new governor.

Department Response:

Air quality planning is a complex process that involves understanding local air pollution conditions and projecting changes over time. In the case of the air pollution issues in Fairbanks, there are clearly a number of issues that are evolving as time progresses. In order to complete this plan, significant time was needed to complete the supporting technical work and demonstrations. The FNSB and DEC used the best available information at the time that work was completed. The recent drop in oil prices could not have been predicted several months ago. The natural gas projections were based on the latest publically available economic report from the Interior Energy Project and the LNG project staff were consulted just prior to release of the plan to ensure that the plan was consistent with the available data. With respect to the recent October election results, most of the technical and control measure analyses were completed prior to that vote, which has the potential to change the air quality planning dialogue as time moves on. In order to meet the federal deadline for submission of this plan, it was necessary to move ahead with the plan that had been developed prior to all of these events. To stop and completely re-work the plan to incorporate new assumptions would prevent moving forward to finalize important air quality provisions that can help to bring the area into attainment. That being said, things change and the air quality planning process provides a mechanism for addressing those changes. Air quality plans are living documents that are amended and updated

over time to reflect new initiatives, changes to various control programs, other changing conditions in the community and new federal planning requirements. As the air quality planning effort for the FNSB $PM_{2.5}$ nonattainment area continues, the department is committed to working with the FNSB and the local community as a whole to incorporate additional local measures and update planning assumptions to reflect a variety of changes that have occurred since the development of this initial plan.

Concerns with Federal Authority and the NAAQS

Some commenters felt that the NAAQS, with which the design value is compared when determining attainment or nonattainment, was flawed or even illegal. One commenter understood the Fairbanks standard to be 25 $\mu g/m^3$, and thought it unfair that this area has a stricter standard than the rest of the country. Commenters cited books and senate committee reports that detail the influence of John Beale a former EPA employee, who was convicted and is now imprisoned for theft from the federal government, on the development of the NAAQS and the EPA supposedly resulting in non-peer reviewed scientific papers, fraudulent data, and corruption heavily influencing the development of the $PM_{2.5}$ NAAQS. Commenters suggested that the NAAQS were unconstitutional and constituted federal overreach. They said that the EPA should be disbanded and replaced and that individual states could use the 10^{th} Constitutional Amendment to nullify EPA's requirements and that Article 5 of the U.S. Constitution allows for states to amend the constitution to rebalance state and federal powers.

Department Response:

The department understands that there are many perspectives with respect to federal environmental laws. This plan has been developed as required to meet federal Clean Air Act requirements with respect to bringing the FNSB $PM_{2.5}$ nonattainment area into compliance with the 24-hour $PM_{2.5}$ NAAQS. The 24-hour standard is 35 $\mu g/m^3$, which applies to the entire country, including Fairbanks. The NAAQS was the subject of litigation and has been upheld by the Courts.

Fiscal Concerns

Commenters felt that the fiscal consequences of poor air quality were inadequately addressed. They noted that the area is losing economic activity because of people moving away and suggested that the Department of Defense might use poor air quality as a reason to reduce the military presence in the area.

Department Response: As part of this planning process, the department has provided simple cost benefit analyses and identified costs associated with implementation of state regulations. The department understands that poor air quality leads to health effects that have associated costs. These costs are difficult to estimate, but the department recognizes that they exist and are important considerations alongside the more direct economic costs associated with the

implementation of control measures. DEC also acknowledges that air quality problems result in additional requirements for federal agencies, like the Department of Defense, and that this can be a consideration for these agencies as they consider their actions and projects within nonattainment areas.

Section Specific Comments and Changes

- **Section 5.1 – Executive Summary**

Summary of Comments: Some technical/administrative comments were received on the Executive Summary.

Department Response: The Subpart 4 submittal deadline was clarified as December 31, 2014. Volatile organic compounds (VOCs) were added to the list of pollutants addressed in the SIP. In the impracticability discussion, design values were clarified.

- **Section 5.2 – Background and Rule Overview**

Summary of Comments: Commenters expressed varying opinions regarding the timing for adoption of the plan. Some commenters indicated the need to meet EPA's plan deadline and expressed the desire for the state to adopt the plan as quickly as possible. Commenters also expressed concern with the timing and length of the public and agency review process and requested the plan be held back from submittal to EPA to allow more time for adequate review. Commenters expressed concerns about inaccuracies in the SIP and the lack of time DEC has had to make corrections. Other commenters felt that the plan was inadequate and expressed a desire for the plan to be held until it could be strengthened with additional mandatory measures that would promote emission reductions much more quickly. A number of commenters noted the need to amend the plan quickly to add stronger measures, measures adopted by the Borough, or to initiate work on the "Serious" plan.

A comment was received that requested that DEC update this section to ensure that precursor lists correctly note and include the full set of $PM_{2.5}$ precursor pollutants. Other technical/administrative comments were also received on this section.

Department Response: The background section of the SIP includes discussion of the federal requirements and the deadline for submittal of a moderate area SIP to EPA. The department understands the various perspectives regarding the timing for the adoption of this plan but has determined that it is important to meet the federal deadline of December 31, 2014. As a result, the department has worked to complete this initial plan as quickly as possible. However, DEC considers the air quality plan to be a living document and looks forward to working with the local community and the FNSB to amend the plan in the near future with any additional locally identified measures. DEC will also be working with the FNSB to begin work on the "Serious" plan which will require a full update of technical work that can incorporate new data and issues that have developed since the initial plan analyses.

With respect to the precursor pollutant comment, DEC has made that correction as requested. DEC also made clarifying edits. Elemental carbon's interaction with light was changed to absorption. A statement of EPA's recent designations for the annual $PM_{2.5}$ standard was added. A description of the recent open houses and hearings was added.

- **Section 5.3 – Nonattainment Boundary and Design Day Episode Selection**

Summary of Comments: Comments requested that Moose Creek, which lies just outside of North Pole, be added to the nonattainment area boundary as it is experiencing smoke problems as well.

Department Response: Moose Creek is currently outside the nonattainment boundary. EPA is the agency responsible for finalizing the boundary for the $PM_{2.5}$ nonattainment area. At the time of designation, the concerns related to Moose Creek were not known. DEC cannot unilaterally change the boundary and add Moose Creek within this SIP. While this plan has been focused on addressing air pollution within the nonattainment area, DEC hopes that the measures being implemented to reduce air pollution can have some effect in Moose Creek. DEC is willing to work with, and encourages, the FNSB to consider the air pollution concerns coming from residents in the Moose Creek area and seek solutions for their local pollution issues.

With respect to Section 5.3, in the final SIP DEC clarified the method for calculating a design value and added a definition of design day.

- **Section 5.4 – Ambient Air Quality Trends**

Summary of Comments: A number of technical/administrative comments were received on the Ambient Air Quality Trends section of the plan.

Department Response: The department made a number of technical updates and corrections to this section. Updates were made to ensure consistency in reporting design values for calendar year 2013 by excluding exceptional event days impacted by wildland fire. The design values for other years were reported with the wildland fire exceptional event days excluded. The exceptional event wildland fire days for 2013 have been flagged and submitted to EPA, but EPA has not yet taken action to concur. The change allows for consistent comparison, but notes were included with the design values wherever EPA concurrence on exceptional event flags is pending.

- **Section 5.5 – $PM_{2.5}$ Network and Monitoring Program**

Summary of Comments: Commenters felt that modeling air quality and attainment based on the FRM monitor in downtown Fairbanks did not adequately represent air quality throughout the nonattainment area. They submitted data showing instances when other monitors in the

nonattainment area such as the FEM monitor in North Pole or the mobile RAMS monitor displayed higher concentrations than the FEM monitor in downtown Fairbanks. They noted that the monitor was located 100 feet in the air in downtown Fairbanks, away from residential areas and above the air people predominantly breathe. They said that there were no outdoor hydronic heaters located within one half mile of the monitor which prevented it from collecting data representative of hotspot locations around outdoor hydronic heaters. Commenters also submitted sniffer maps showing non-homogeneous air quality throughout the nonattainment area with hotspots in areas without FRM or FEM monitors. Commenters expressed concern that the Fairbanks North Star Borough would also not meet the annual standard.

Some commenters also expressed concern that the placement of monitors in North Pole and mobile monitors were influenced by diesel particulates from road, rail, and industrial sources and said that the readings were biased high because of these particulate sources. Other commenters said that the North Pole fire station monitor was representative of a large area of North Pole and was not located in a hotspot as identified by the Department in the plan. A number of commenters expressed a concern that North Pole data was not included in the Plan and must be included in any "Serious" plan. One commenter suggested that a monitor be place at the library because that is central location for schools and the elderly.

Comments were also received about the correlation factors applied to data from the continuous $PM_{2.5}$ air monitors in the area. Concerns were raised about the practice of reporting correlated data rather than un-correlated data or both.

Department Response:

Air monitoring data from throughout the nonattainment area is used by DEC and the FNSB for a variety of purposes including characterization of the spatial extent of the air pollution problem and calling air quality advisories. The State Office Building $PM_{2.5}$ air monitoring site is the original violating monitor that established the nonattainment area and, as a result, there is a long term air monitoring data trend that can be used to compare to the National Ambient Air Quality Standard at that location. However, the air quality plan has to reduce air pollution throughout the entire nonattainment area and must demonstrate through monitoring and modeling how the entire area will come into compliance with the $PM_{2.5}$ National Ambient Air Quality Standard. The plan includes an analysis of future predicted concentrations at the long term State Office Building monitoring site, but also includes an analysis of predicted air quality concentrations in all the unmonitored areas within the nonattainment area. The demonstration and the unmonitored area analysis is discussed in the modeling and attainment sections of the plan (5.8 and 5.9). Further, in future plans there will be data from additional air monitoring sites that can be used to calculate design values for North Pole and further inform the technical modeling and monitoring analyses for future air quality plan updates.

DEC made a number of updates to section 5.5. The new North Pole Water stationary site at 2696 Mockler Ave was added to Table 5.5-2 and Figure 5.5-4. While another monitor has recently been installed by the FNSB to the North of North Pole Fire station, this monitor is in the RAMS trailer and is only a short term site; as a result, it was not updated to the tables in the SIP. To

address concerns and recent discussion with individuals in the community and EPA on the North Pole Fire station site, the SIP was revised to show this monitoring site as an "undetermined" spatial scale (microscale or neighborhood). The FNSB continues to monitor at various locations in North Pole to better understand the spatial scale of the North Pole Fire station site and whether it can be used to represent North Pole neighborhoods overall. DEC also received "sniffer" maps from commenters and notes that the "sniffer" data is used to inform the FNSB about hot spots, but it is only 2 second data and does not represent hourly concentrations and such is not used as part of the regulatory network monitoring.

- **Section 5.6 – Emission Inventory Data**

Summary of Comments: Comments were received that requested additional information and explanation of Reasonable Further Progress (RFP) emission inventory for 2017 and RFP plan requirements. It was noted that to meet RFP requirements, NO_x must be addressed in the RFP plan and inventory. Commenters also noted that the 2017 quantitative milestones were presented as an average of the 2015 and 2019 emission controls and felt that the milestones would be stronger if the numbers associated with the average target were more explicitly identified.

Comments on the emission inventory noted that CAA Section 172(c)(3) requires the use of actual emissions, not allowable, emissions in the baseline inventory for 2008. The commenters requested additional clarification and correction of some inconsistencies with respect to this requirement.

Comments included questions and concerns regarding the use of the OMNI test results rather than the AP-42 emission factors. Concerns were that the OMNI tests were conducted under laboratory testing conditions, while AP-42 wood heater emission factors are conducted under field conditions. The commenter felt that outdoor models should be tested in realistic ambient temperatures, reflective of conditions in the Fairbanks area. They further questioned why the makes and models of the tested devices were not identified and made available with the test results to allow for full review, scientific inquiry, and assessment of study validity.

Comments were received regarding the coal emission factors used in the emission inventory. The commenters noted that Usibelli coal is not bituminous and indicated that they believed incorrect factors were used for coal heaters as a result.

Comments were received with respect to the home heating section of the emission inventory and the energy model that was developed for that effort. Concern was expressed about an error in the CCHRC study report that may have resulted in incorrect assumptions being made with respect to the Btu/day from outdoor wood boilers and wood stoves.

Comments were also received regarding the methodology for determining the inventory of coal heaters in the nonattainment area. The commenters had concerns about the phone survey method for identifying the numbers of these devices. Questions were also raised about why the 2012 Home Heating Survey was not included in the emission inventory.

Comments indicated that the appendix for the emission inventory was missing a number of data files that support the inventory estimates and requested that those be provided for additional public review before the SIP is finalized.

Department Response: The department updated the Emission Inventory section and its associated appendices to address the comments discussed above. All RFP comments were addressed and updated in Section 5.6. Interchangeable references to allowable and PTE point source emissions were revised and text was added to explain that allowable and PTE emissions are equivalent when expressed on an average daily basis as used in the inventory. Changes were also made to add explanation that actual point source emissions were used for the 2008 baseline modeling and PTE emissions were used for future year attainment modeling in accordance with CAA 172(c)(3) even though both sets are shown throughout the chapter for completeness. To address comments on Section 5.6 and 5.13, additional text was added as well as a 2017 EI table for $PM_{2.5}$ and NO_x to put the Motor Vehicle Emission Budgets (MVEBs) in context and explain differences in vehicle emissions in the RFP inventory versus the MVEBs.

The changes included updating typos on a misidentified device in the section 5.6 technical appendix. It was confirmed that this did not change the model results. The department reviewed the coal emission factor data and found that they are correct for the local coal, but that the category description had been mislabeled; this was corrected. Similarly, the CCHRC study report was also reviewed with respect to the concern raised and in that case the data was also correct, but a mislabeling had occurred; this was corrected. These labeling errors did not result in any incorrect assumptions being carried forward into the analyses.

In developing estimates of home heating devices, phone survey data was used along with other available data, such as the OMNI testing data. The department and FNSB have used phone survey data such as this in previous plans and the surveys are developed to obtain statistically valid samples. The collection of locally relevant data is important to improving emission estimates and the phone surveys are one set of data that are used to help allow the agencies to understand the number and distribution of these sources throughout the community. The OMNI testing data was also developed to allow for testing of wood heating device emissions using local Fairbanks area wood. The objective of this emission testing was to ensure that the emission factors used were more relevant to local practices because of the differences in emissions that result from burning different types of wood. AP-42 emission factors do not reflect Fairbanks area wood fuels. The agencies have discussed the local data available and the method of estimation for home heating sources with EPA as the SIP has been developed; similar methods have been used and approved in other air quality plans developed for Fairbanks and other communities in Alaska.

DEC also notes that the development of the emission inventory took place over an extended period of time and local data continued to be collected for a variety of purposes (like the 2012 phone survey) over that same time. It was not always possible with the resources and time available to back up and integrate all the new local data collected into an emission inventory that was largely complete. Future inventories will be updated with additional available survey data.

With respect to missing information in the appendices, the department notes that the emission inventory appendices contain supporting studies and detailed documentation related to the emission inventory estimates that are described in SIP section 5.6. The department has corrected errors, made clarifications, and added to the supporting documentation in response to comments. These additions do not change the final emission inventory or negate the technical modeling analyses that show it is not possible for the community to demonstrate attainment by 2015. The department also notes that EPA will review all the information provided in the final plan and may request further clarification or documentation from the state. The EPA process to take action on the plan will provide additional opportunities for public review and input related to the emission inventory and its supporting data and documentation.

- **Section 5.7 – Control Strategies**

Summary of Comments: Commenters felt that the community cannot wait 4-5 years for the air quality to improve, but need measures that are effective immediately to reduce the health consequences while the community waits for natural gas to become widely available. Commenters expressed concerns that voluntary measures are only reasonable if the area demonstrates attainment. They also stated that state and local control measures that shield pollution sources from independent enforcement actions are not "enforceable" as required for plan approval under CAA Section 110(a)(2)(A).

Commenters noted that for the SIP to find it is "impracticable" to attain the air quality standard by the end of 2015, it must demonstrate that all reasonable control measures were implemented and that the area still could not meet attainment by the moderate area date. Some commenters felt that the SIP demonstration of "impracticability" was inadequate because it did not consider all potential control measures and that the reasons some were excluded were improper. They stated that DEC must use all reasonably available control measures and that DEC failed to consider many. Specifically, partial implementation of some measures should have been considered, local opposition to a measures is not a sufficient reason for exclusion as technologically infeasible, and there should have been a more complete assessment of costs particularly those associated with health impacts and the need for air filtration systems.

Commenters also were concerned that the SIP had not been updated to reflect the change in local program authorities that occurred with the defeat of a voter initiative on October 7, 2014. For several years, voter initiatives had established local ordinances restricting the Borough's authority to regulate home heating and fuels. The recent failure of a voter initiative to continue that restriction failed and this should have been reflected in determining what measures were reasonable to implement in the plan. Commenters either felt that the state should have considered measures that were not authorized for Borough implementation in this plan or that the state should immediately update the plan to quickly adopt and incorporate any additional Borough measures that are put in place. Additionally, commenters raised concerns that the voters could, in the future, remove the ability of the Borough to regulate home heating and fuels.

Commenters provided examples of programs from other areas (Juneau, Fairbanks, Washington state, Oregon, Utah, Libby MT, Sacramento CA) that they felt should have been explicitly considered in the RACM assessment. Suggestions for additional controls included: regulate point sources as stringently as law allows; implement BACT now; establish year round rather than seasonal controls; announce and enforce new wood heater emission standards; expand opacity, emission standards, and curtailment to all solid fuel devices and waste oil; restrict idling from vehicles; enlist business and commercial compliance for smoke; authorize overtime for sniffer vehicle on high $PM_{2.5}$ days and inspectors on evenings and weekends; do not allow any permanent waivers and allow temporary waivers only for short times to rectify the situation; and declare a public health emergency to jump start implementation of stringent controls. Commenters also suggested that more public education would be helpful, citing the use of readouts near roadways so people could understand what the pollution levels currently are.

Some comments recommended requiring curtailment of wood stove use instead of this measure being voluntary through the FNSB voluntary cessation program. They would also like to see curtailment take place before the NAAQS standard is exceeded, so that exceedances can be avoided. Commenters suggested that curtailment should be included in the plan with very limited exemptions for sole source or hardship, citing programs in Utah and Libby, MT. Others suggested that the department prepare a "Serious" SIP that includes a mandatory burn ban for all but essential burning when the AQI reaches "Unhealthy" and place restriction on essential burner emissions to not exceed 20% opacity.

Commenters noted that they would like to see the stove change out program and educational efforts continue. With respect to the Fairbanks North Star Borough change out program, comments suggested that the program prioritize funds to homes with solid fuels as a sole source of heat. They also suggested that the change out program be coupled with stringent regulations. Suggestions related to the change out program included adding an approved moisture meter to be given to the qualified applicant upon completion and requiring a mandatory burn class (e.g., 1 hour) on the appropriate handling of wood, firing operations, and other relevant best burning practices. They also suggested starting a program to subsidize fuel oil use in lieu of wood and more home weatherization. Additional educational information on the health effects of $PM_{2.5}$ was requested.

Comments were received suggesting that no credit be taken for the Alaska Resource Agency retrofit program. The assertions were that this program was ultimately not successful in generating any on-going benefits and disputed the estimates of emission reductions achieved.

Commenters suggested that localized zones be established around locations where sensitive populations breathe such as schools, day care facilities, hospitals, and senior housing. Commenters relayed personal experiences or observations about the negative health effects of $PM_{2.5}$ on sensitive populations in their homes, workplaces, neighborhoods, and schools. Commenters proposed several control measures for these zones including burn bans at low $PM_{2.5}$ levels, removal and prohibition of outdoor hydronic heaters and other devices considered to be highly polluting. Commenters suggested that the wood stove change out program focus on these

areas or that monitors be located in these areas to better protect the health of sensitive populations.

Commenters raised concerns over the lack of additional controls for major point sources, specifically the Chena and Fort Wainwright Power Plants, and noted that these facilities may emit up to 20% of the particulate pollution. They also cited dispersion modeling that shows these two facilities potentially violating the 1-hour SO_2 NAAQS. Commenters expressed that SIP controls should include point sources and that coal and waste oil burners should also be controlled. Commenters also raised concerned about the analysis of stationary sources being based on average technical and cost information and suggested that additional confidence would be gained through source specific technology evaluations. Comments also identified areas where additional technical information on the analysis of $PM_{2.5}$ precursors would be useful in further documenting the department's process for determining reasonably available control technologies for point sources.

Commenters expressed concerns about enforceability of measures included in the SIP, that enforcement measures must be sufficient to deter violations, such as the authority to issue tickets or an administrative fining mechanism, which DEC does not have. Commenters listed multiple current public and private voluntary programs aimed at reducing pollution in the nonattainment area such as the Fairbanks North Star Borough's change-out program, voluntary burn ban days, and educational outreach; outreach programs by organizations such as the American Lung Association, Cold Climate Housing Research Center, and Clean Air Fairbanks; and outreach made by individuals to neighbors. Commenters noted that these voluntary programs and educational efforts have been in effect for many years but have not brought the area into attainment and that the air has worsened even with these measures in place.

Commenters felt that the enforcement methods available to DEC make compliance with any regulations essentially voluntary because of the lack of ticketing authority and the infrequency and expense of civil litigation for DEC and private parties. Commenters used the case of the wood boilers impacting Wood River Elementary School to argue that DEC enforcement tools were ineffective, take too long, and do not adequately protect human health. Commenters recommended that the State seek approval from the legislature for statutory authority to use administrative penalties to enforce control programs in the nonattainment area. These commenters felt that the success of control strategies is being hampered by this lack of statutory authority. Commenters suggested that fines imposed be added to property tax obligations.

Department Response: The department appreciates the many comments and suggestions provided on the control measures for the air quality plan. Commenters suggested a number of additional measures that they believed should be considered for implementation within the FNSB $PM_{2.5}$ non-attainment area. The department appreciates all of these suggestions and will continue to work with the FNSB and the local community to further explore and consider options for controlling and mitigating $PM_{2.5}$ pollution to achieve compliance with the ambient air quality standard before 2019.

The Reasonably Available Control Measures (RACM) analysis conducted for this plan reviewed many control options from other areas of the country. In some cases, the Fairbanks situation differs significantly from those of other jurisdictions. For example, the extreme cold temperatures, heating needs, fuel costs, and types of fuel available in the Fairbanks area are strikingly different than in many of the other $PM_{2.5}$ areas. Measures implemented in other states, may not be reasonable to implement in the Fairbanks area. Some of the commenter's suggestions are variations on control measures that were considered but not determined to be feasible at the time this plan was developed. Other suggestions could be considered as part of the public outreach and education programs in the community or may be part of implementation considerations for programs. Additional detailed responses to comments on the RACM analysis are included later in this section. In the end, for progress to be made in reducing air pollution, the community must be willing to accept control strategies and act on them. Control measures that face opposition by roughly half the community cannot be implemented with a reasonable amount of effort and with a reasonable expectation of success. The vote in the latest election to reject the ballot initiative restricting the FNSB's authority to address home heating device emissions and fuels, appears to indicate that there is greater recognition of the need to address air pollution issues locally but the vote was still a close outcome and it is clear that concerns remain for many individuals on both sides of this important issue. Additional detailed comments and responses on RACT and RACM are included near the end of this document.

With respect to the inclusion of the Alaska Resource Agency program in the analysis of emission benefits presented for this plan, the department did not change the plan to remove the small amount of emission benefit identified for this program. This program did occur during the time frame covered by this plan and may have resulted in some short term benefits. The department concedes that the long term benefits of the program are not well known and the department is willing to consider removing the benefits from this program based on new data in future plans. However, removing the credit in this plan will not change the determination that it is impracticable for the area to attain by the 2015 moderate area attainment deadline.

The control of point sources was the subject of a Reasonably Available Control Technology assessment conducted as part of the planning process. The point sources in the nonattainment area are well controlled for direct $PM_{2.5}$ emissions placing focus for potential control on precursor emissions, which account for a much smaller percentage of the overall $PM_{2.5}$ in the area. The coal-fired point sources in the area currently use extremely low sulfur coal for fuel. The costs of add on controls, both exhaust scrubbers and shifting to lower sulfur content fuels, were assessed and determined to be unreasonable given their small impact on ambient $PM_{2.5}$ concentrations. Additional detailed responses to comments on point source control are included later in this section.

With respect to concerns overall about the enforceability of measures and enforcement methods, DEC has clearly laid out in the air quality plan its current authorities and general approaches to compliance activities and enforcement of state regulations. The department appreciates the concerns expressed about the enforcement tools available to DEC, but it is only through passage of statutory changes by the legislature that administrative penalties can be added to DEC's suite

of available compliance and enforcement tools for addressing compliance with air quality regulations. As DEC does not currently have that authority, the agency notes that it does use the compliance and enforcement tools for which it is allowed under state statute. Further, DEC also considers the potential compliance rates for various programs based on available data and its understanding of the effectiveness of its compliance and enforcement programs. The compliance rates assumed for regulatory measures when projecting emission benefits in the SIP are carefully considered to ensure that unrealistic rates of compliance are not factored into any attainment demonstration.

- **Section 5.8 – Modeling**

Summary of Comments: A number of technical/administrative and clarifying comments were received on the modeling section of the plan.

Department Response: Updates to the modeling section 5.8 included clarification on the 2008 baseline modeling year and the use of actual point source emissions to accurately estimate the control benefits. To approximate what the concentrations were in other areas away from the State Office Building, other monitoring data in Fairbanks and North Pole was used to determine control benefits by using an observed ratio of the concentrations, because actual monitoring data in that modeling base year of 2008 was not available. Table 5.8.7 gives sites that were able to have an average winter concentration (data that was collected for at least one entire winter) that was able to be used for the baseline design years of 2006 to 2010.

- **Section 5.9 – Attainment Projects, Demonstration, and RFP**

Summary of Comments: Comments were received about the RACM analysis requesting additional discussion of why more measures could not have been put in place by 2015. This is also discussed in comments listed previously under section 5.7.

Department Response: A statement was added describing the defeat of the recent ballot initiative defeat in Fairbanks that would have extended the prohibition of the borough's ability to enforce air quality regulations, as well as a reference to the unanimous resolution adopted by the Borough Assembly in support of the SIP. The FNSB resolution in its entirety is provided in Appendix 5.9. Additional detailed discussion and response related to RACM comments is included at the end of this section of the response to comments.

- **Section 5.10 – Contingency Plan**

Summary of Comments: Commenters suggested that the SIP contingency measures (wood moisture program and required change out or removal of old stoves upon sale of a property) should be implemented immediately. They did not see a reason these measures should be held as contingency when it is almost certain that FNSB nonattainment area will be designated "serious"

in 2016. Other comments noted that EPA's 1992 General Preamble indicates that contingency measures "should be a portion of the actual emissions reductions by the SIP control strategy to bring about attainment… approximately equal to the emissions reductions necessary to demonstrate RFP for one year."

Commenters also suggested that the contingency plan is inadequate and does not meet the area's needs or legal requirements that measures be enforceable and take effect without further action by the state or EPA. Commenters claimed that regulatory measures identified were not enforceable in practice.

A suggestion was made to adopt a contingency measures similar to the measure used in Libby, Montana which would prohibit all solid fuel heaters other than EPA certified pellet-burning stoves if adequate progress is not made.

Department Response: The department is adopting regulatory contingency measures including the wood seller moisture content disclosure program and changes that would require uncertified devices to be changed out upon sale of a property. Changes were made section 5.11 to reflect changes made to the regulatory proposals and address minor typographical issues. The department is responsible for enforcing state regulations and the enforcement approach is discussed in this response to comments and the SIP.

Responses related to comments and concerns on the regulatory contingency measures and the timing for their implementation is included in the sections of this response to comment devoted to these regulatory proposals. In addition to these regulatory measures, the department and FNSB have a number of programs underway that can provide significant emission reductions in the years beyond 2015, including continued change outs of solid-fuel heaters and the expansion of natural gas infrastructure and associated conversion of space heating to natural gas. These measures have real long term emission reduction potential and deserve consideration and inclusion in out-year projections and discussions of future emission benefits. Because this section of the plan discusses additional actions that will be taken beyond the 2015 attainment date, they were included in the contingency measure section of the plan.

- **Section 5.11 – Emergency Episode Plan**

Summary of Comments: Comments were received on the regulatory thresholds and opacity requirements that have relevance to section 5.11.

Department Response: Responses related to comments and concerns on the opacity requirements and the $PM_{2.5}$ episode thresholds is discussed in the section of this document relevant to those regulations. Within the SIP, the department made revisions to reflect changes to the final adopted regulations. In addition, the department, in response to comments received, has established a lower episode threshold at 30 $\mu g/m^3$ with a requirement for wood heaters to meet a 20% opacity limit when concentrations exceed that threshold. Other changes made to section 5.11 include adding more detail describing the Borough Episode Program. Notices of Violation were added to the discussion of available administration enforcement tools.

- **Section 5.12 – Assurance of Adequacy**

Summary of Comments: No comments were received on this section.

Department Response: Only minor typographical changes were made to this section.

- **Section 5.13 – Conformity and Motor Vehicle Emission Budget**

Summary of Comments: Comments were received that noted the motor vehicle emission budget should be considered together with all other emission sources. A suggestion was provided to include a table showing all of the emission sources in the 2017 RFP emission inventory to provide this context.

Comments also required clarification of how the meteorology inputs to MOVES are consistent with the "Time Aggregation Level" for SIPs from EPA's *Technical Guidance on the Use of MOVES2010 for Emission Inventory Preparation in State Implementation Plans and Transportation Conformity*.

Department Response: Additional text was added as well as a 2017 EI table for $PM_{2.5}$ and NO_x to put the Motor Vehicle Emission Budgets (MVEBs) in context and explain differences in vehicle emissions in the reasonable forward progress (RFP) inventory versus the MVEBs. Clarification was also provide on the meteorology inputs to MOVES. These changes are reflected in the Emission Inventory section as well.

- **Section 5.14 – Acronyms and Abbreviations**

Summary of Comments: No comments were received. This section was added to assist future readers of the plan.

Department Response: A table of acronyms and abbreviations was added to the document to assist the reader.

Additional Detailed Responses Related to Specific SIP Comments

Responses to EPA Administrative Comments

Executive Summary

p. 5.1-4: Include the due date of the moderate area attainment plan of 12/31/2014.

- Corrected

p. 5.1-4: VOCs should be included in list of precursors to be controlled.

- Corrected

p. 5.1-7: 44.7 $\mu g/m^3$ is the baseline design value, not the design value.

- Corrected

p. 5.1-7: The standard is 35 $\mu g/m^3$, not 35.0.

- Corrected

Background and Overview of $PM_{2.5}$ Rule

p. 5.2-2: VOCs are not components of $PM_{2.5}$. The document could say semi-volatile VOCs are components of $PM_{2.5}$. VOCs are $PM_{2.5}$ precursors.

- Corrected

p. 5.2-2: It would be more clear to say that the great majority of particle absorption is from elemental carbon, not particle scattering.

- Corrected to read "particle absorption"

p. 5.2-3: "because they" not "because it".

- Corrected

p. 5.2-4: Clarify which years the SIP is referring to in the 43 $\mu g/m^3$ and 35 $\mu g/m^3$ design value number for Fairbanks and Mendenhall Valley.

- Added SIP years 2006-2008

p. 5.2-6: The statement about EPA not responding to the annual designations is out of date and should be updated for the final SIP. On December 18, 2014, the EPA issued final area designations for the 2012 annual national air quality standard for fine particulate matter ($PM_{2.5}$). In the action, the EPA designated the entire state of Alaska as "unclassifiable/attainment," consistent with the recommendation from the state of Alaska.

- Added "On December 18, 20014, the EPA…." Until the end of the statement above

p. 5.2-6: The list of precursors does not list VOCs.

- Corrected

p. 5.2-6: Subpart 1 still applies in cases when not superceded by Subpart 4. The right way to refer to the court ruling is that Subpart 4 must be implemented in addition to Subpart 1.

- Added "technical requirements in addition to subpart 1"

p. 5.2-6: The Subpart 4 deadline for attainment of the $PM_{2.5}$ air quality standard is 12/31/2015.

- Corrected

p. 5.2-12: It is more appropriate to say that ADEC and EPA worked collaboratively on the SIP to address CAA requirements.

- Corrected

Non-Attainment Boundary and Design Day Episode Selection

p. 5.3-1: "micrometers per cubic meter," not "meter"

- Corrected

p. 5.3-3: In the sentence about the "design value", a design value is for any three year period, as noted in the last sentence of the paragraph, not just for the three year period ending in the base year. Regardless, the baseline design value is based on 2006-2010.

- Corrected

p. 5.3-4: This page says the baseline design value is 42 $\mu g/m^3$, while the previous pages say 41 $\mu g/m^3$ and 40.7 $\mu g/m^3$.

- Clarified the values were from design day averages from each episode and a baseline DV.

Ambient Air Quality and Trends

p. 5.4-1: The short period of daylight, low sun angle, and dry climate are not the only factors in creating the inversion. A key factor is that the persistent freezing temperatures result in predictable snow cover. The strong radiational properties of the snow cover dramatically help inversion formation. The EPA recommends including the influence of snow cover to be scientifically complete.

- Added snow cover helps form inversions.

p. 5.4-1: A temperature inversion is not the result of a stable airmass. They are related conditions but not causing the other. A stable airmass is the result of radiational cooling under calm and usually clear weather conditions, and the radiational cooling is enhanced by snow cover. A

temperature inversion is an extreme form of a stably stratified atmosphere, one in which the temperature increases with height. Please clarify this relationship in the text.

- Added "A stable airmass." The entire sentence and deleted a temperature inversion is a result of a stable airmass.

p. 5.4-1: The sentence describing how inversions plus their associated meteorological conditions create conducive atmospheric conditions is convoluted. It is better to address how calm and clear weather lead to a stably stratified atmosphere. The result is calm air in three dimensions and thus emissions close to the ground do not disperse readily. A temperature inversion is just a strong kind of stable atmosphere.

- Added calm, clear and in the next sentence poor dispersion

p. 5.4-1: It is not appropriate to call it nocturnal radiation inversion when there is daylight. It is simply just a scenario where the daytime heating is not enough to overcome the stably stratified boundary layer.

- Corrected

p. 5.4-1: It is not the inversion that causes pollutants to be so concentrated. It is the low horizontal mixing due to the calm synoptic pattern and the low vertical mixing due to the stable atmosphere. The low temperature contributes to high emission levels.

- Added low horizontal mixing, deleted inversion.

p. 5.4-1: Be consistent in referring to the $PM_{2.5}$ NAAQS. If "average" is in one, then it should be in both, though we advocate for taking it out of both.

- Deleted average in both 24-hr and annual

p. 5.4-2: The text refers to five active permanent sites but the list is not current. North Pole Elementary needs to be clarified as a historical site.

- Updated and North Pole Elementary was clarified as shut down.

p. 5.4-9: Figure 5.4.4. Officially, design values are rounded to the nearest whole integer. 98^{th} percentiles are rounded to the tenth. If you have reason to include the design value to the tenths, such as in calculating one year's worth of attainment, that makes sense. But otherwise please keep the rounding convention in mind and choose appropriately depending on your context.

- Updated Figure with all EE excluded DVs

p. 5.4-10: EPA strongly suggested 2008 as a base year. Any year in the 2006-2010 period could have been used with appropriate justification according to EPA modeling guidance, but there were several important factors pointing to 2008 as the appropriate choice. The EPA recommends that the final SIP state "EPA strongly suggested" instead.

- Added "EPA strongly suggested…"

p. 5.4-10: “measurements and observations”? To make them obviously distinct, it would be better to say “instrument measurements and human observations”.

- Corrected

p. 5.4-12: Revise to say “each NAAQS-comparable monitor” instead of “each monitor.”

- Corrected

p. 5.4-13-14: The discussion of Exceptional Events does not mention which sites EPA concurred on for which days. It is important to clarify which sites the EPA concurred on because as it reads, the implication is that the EPA concurred on 7/13/2010 at North Pole Elementary School, which is not the case. While ADEC has provided these data to the EPA, the EPA has not yet finally concurred on the data. Please be consistent in the table -- either only use EPA concurred values or use values that the state has already qualified as EE and note that EPA concurrence is pending.

- Corrected

$PM_{2.5}$ Network and Monitoring Program

p. 5.5-1. Table 5.5.1 says that NPFS does not have an AQS ID, but the state’s network plan lists it as 02-090-0035.

- Corrected

p. 5.5-1. The SIP should list all Regulatory Monitors that are valid at the time that the SIP is being proposed and finalized – this includes The North Pole Water site and the North Pole site that was just installed north of North Pole Fire Station.

- Added North Pole Water, did not add the new RAMS trailer that was just installed, it is not a stationary monitor.

p. 5.5-2. The SOB is said to be influenced by home heating, vehicle exhaust, and wood smoke, but wood smoke is part of home heating.

- Added “home heating (wood, fuel oil and coal)…”

p. 5.5-2 The NCORE site is listed as SLAMS on this page but was listed as SPM in the previous chapter.

- Changed to SLAM site in previous chapter

p. 5.5-3 Text says the BAM 1020 data is uploaded once a week, but we know they are uploaded every hour to the state’s and borough’s web sites. Please clarify.

- Added “the BAM 1020 is uploaded hourly to the State and Borough websites and uploaded once a week to a computer. “

Emission Inventory

- General responses (including those addressing "Letter" comments:
- Revised interchangeable references to allowable and PTE point source emissions to PTE starting on p. 5.6-6. Added sentences highlighted in bold to explain that allowable and PTE emissions are equivalent when expressed on an averaged daily basis as used in the inventory.
- Also added text on p. 5.6-27 below Table 5.6-7 that explains that actual point source emissions were used for 2008 baseline modeling and PTE emissions were used for future year attainment modeling in accordance with CAA 172 (c) (3) even though both sets are shown throughout the Inventory chapter for completeness.

This chapter should include an EI table for the year 2017, and it needs to include NOx to support the MVEB. Currently, the 2017 RFP MVEB is a number out of context.

- Section 5.6.6 has additional sub-paragraphs of text and a 2017 EI table for PM2.5 and NOx to put the MVEBs in context and explain differences in vehicle emissions in the RFP inventory vs. the MVEBs.

p. 5.6-7: In Section 5.6.1.3. Sources Not Inventoried, final SIP should include more documentation from ADEC on the sources excluded due to the unavailability of data.

- Not sure what additional documentation is available to be provided. I added a sentence explaining what other missing data there were, but I don't know what else to do.

p. 5.6-31: There appears to be a disconnect in the data. The statement indicates that wood burning is the largest source of ammonia, but ammonia is missing from the point source inventory.

- Added a clarifying sentence for NH3 explaining that wood burning is the largest source only when considering sectors for which NH3 data were available.

p. 5.6-46: Use of 2.4% moisture-driven wood use reduction: Is ADEC confident enough in the driving force behind the shift towards owner cut wood enough to have confidence that the trend will extend into 2015 and 2019? Some additional text would be helpful to give better certainty here.

- Added a phrase clarifying the sources of multiple 2013 surveys and added the following sentence at the end of the paragraph: "The State plans to continue performing periodic surveys going forward to confirm the permanence of this shift."

p. 5.6-56: Cumulative $PM_{2.5}$ emission reductions should probably be cumulative primary $PM_{2.5}$ emission reductions.

- Corrected.

p. 5.6-58: The dry wood program assumes the Cut Own category would use dry wood more than now, based on the $50 per cord question. If they are cutting their own, and the trend of drier wood for the Cut Own category is already accounted for, how can the result of a $50 per cord question be used to further increase dry wood for the Cut Own category?

- Sentence was added:" The movement of both the Buy group and the Cut Own group to use greater use of dry wood comes about from additional State education efforts that span both groups. It was assumed that the same relative shift toward greater dry wood use would occur in both groups."

p. 5.6-59: The draft plan assumes data based on the Cardno report, specifically an assumption that natural gas would be delivered at $15-$17 mcf. However, the head of the Interior Gas Utility told the Borough assembly that the new estimated price is $20.50 per mcf. This new estimate needs to be taken into account in future 2019 emission estimates.

- Agreed, under the Serious Area SIP. But no edits were made in response to this comment.

p. 5.6-60: The MVEB needs to be considered together with all other emissions sources ((93.118(e)(4)(iv)), and that applies to all of the pollutants in the MVEB, $PM_{2.5}$ and the precursors.

- The subsection now includes an additional table showing emissions for all sources and text referencing this section of the conformity regs.

p. 5.6-60. The title of Table 5.6.24 says the point source emissions are actual emissions but the first row says they are PTE. The final SIP should clarify which of these is correct.

- Corrected. The first row now reads PTE.

p. 5.6-62. The parenthetical starting "(no later" needs a right parentheses…. Also, the first "the" in the second paragraph sentence, should be replaced with the word "with"). The word "assessment" is misspelled in the first sentence in the third paragraph.

- Corrected.

p. 5.6-67: Align the first sentence in the fifth paragraph (MVEB Calendar Year and Pollutants) with the first sentence in the third paragraph on page 5.6-62. One approach could be to revise this sentence to: "As discussed above, the RFP milestone year for RFP is 2017. Also, add "RFP inventories and" to the sentence that follows it:

- Corrected as suggested.

p. 5.6-67: Could consider revising to be more clear. One approach could be to add a sentence along the following lines: Thus, RFP inventories and MVEBs were established for calendar year 2017. Separate budgets of on-road motor vehicle emissions occurring within the non-attainment area were set for both directly-emitted $PM_{2.5}$ and NOx, the latter based on EPA's interpretation

of applicable precursor requirements under 40 CFR §93.102(b)(1), which applies to criteria pollutants, and §93.102(b)(2)(iv), which applies to precursors of $PM_{2.5}$."

- Corrected as suggested.

p. 5.6-68: The description of "Activity Inputs" is an incomplete sentence.

- Corrected

p. 5.6-68: In the Fleet Characteristics Inputs description, consider adding a reference to the EPA guidance about how to adjust fleet inputs.

- Added a sentence at the end of this paragraph explaining that the inputs were supplied to MOVES using the County Data Manager in accordance with the EPA guidance (and referenced it).

p. 5.6-68: The final SIP should clarify the meteorology inputs to MOVES. The public review draft describes that "the average ambient temperature across all hours of the 35 modeling episode days was -11.8°F" and that both "the average meteorology profile" and "the individual day meteorology" were used to establish the MVEB. It should also confirm that the -11.8°F single temperature value was not used to represent all hours of the day over the modeling period (See section 3.3.1. Time Aggregation Level, in Using MOVES to Prepare Emission Inventories in State Implementation Plans and Transportation Conformity: Technical Guidance for MOVES2010, 2010a and 2010b, available at http://www.epa.gov/otaq/models/moves/documents/420b12028.pdf). Also, please discuss whether the "Hour" option was used for the "Time Aggregation Level" as is required for SIPs and regional emissions analyses.

- Clarified with a revised sentence in the "Meteorology Inputs" paragraph explaining that the temperature profile was not a constant -11.8F, but reflected a diurnal range based on the 35 days of episodic data. Also added a sentence to confirm the use of "Hour" Time Aggregation Level in accordance with the guidance document and cited it as a reference.

Control Strategies

p. 5.7-7: typos in second paragraph

- Corrected

p. 5.7-22: Table 5.7-7 should include RACT control measures.

- Added a row titled "RACT" and checked the quantified emissions box

p. 5.7-22: Table 5.7-7 needs to clarify which year inventory the RACM measures are accounted for - 2015 or 2019.

- Added 2013 to top row of controls and added 2019 to Natural Gas.

Modeling

p. 5.8-2: Lack of weather systems in the winter at the latitude of Fairbanks contributes to reduced horizontal mixing. This is another factor in the build-up of pollution in Fairbanks.

- Added text stating " a lack of weather systems at this latitude limits the amount of horizontal mixing."

p. 5.8-14: CMAQ references need to include Byun and Schere's CMAQ journal article.

- Added reference #14 "Byun, D., Schere, K.L., (2006), Review of the governing equations, computational algorithms, and other components of the models-3 Community Multiscale Air Quality (CMAQ) modeling system. Applied Mechanics Reviews 59, 51-77."

p. 5.8-15: Section 5.8.7.1 needs some proofreading.

- Revised text to change meteorology to meteorological and remove an errant reference.

p. 5.8-33: The attainment model used the average of Q1 and Q4 speciation. The text does not make this clear.

- Modified text on 5.8-33 for clarity. The revised text reads, "The method uses winter quarterly (Q1 and Q4) average FRM-derived species concentrations from the STN (speciation trend network) monitor. "

p. 5.8-33 "the design value concentration" should be "the baseline design value concentration".

- Added "baseline" to text on 5.8-34 (note the page number has shifted during editing).

p. 5.8-33: The 2015 scenario is said to include benefits from the state standards for woodstoves in new homes, but this law will not provide any benefits by December 31st, 2014.

- This was stated in error as the control scenario modeled for 2015 did not include this measure. The text has been removed.

p. 5.8-34: The baseline 2008 inventory should use actual emissions for the point sources.

- The 2008 baseline was modeled with actual emissions for point sources. Additional text was added for clarity that the 2015 scenarios contain either actual or PTE emissions while the 2008 baseline always contains actual point source emissions.

p. 5.8-35: Table 5.8.10 suggests that 2008 point source emissions were Actual, because otherwise the OTH factor would not be 1.8.

- This is correct and additional text added for the previous comment should make this less ambiguous.

p. 5.8-36: In Table 5.8.12, benefits from the state standard in new homes is not quantified even though page 33 says that it is included in the control scenario.

- the text stating that the state new home standard was in place by 2015 has been removed as it was in error. The program was not modeled for 2015 and the table should remain as is.

p. 5.8-36: Final SIP should clarify what the range in 40.1-43.5 represents. Where does 43.5 come from?

- The following sentence was added for clarity, "The low end of the range fixes sulfate RRFs to 1.0 in future years, and the high end calculates sulfate RRFs based on primary sulfate and sulfur dioxide as shown in Appendix III.D.5.8."

p. 5.8-36: The sentence starting "CMB, C-14, and PMF" is confusing.

- This sentence has been revised as follows, "The CMAQ and SMOKE modeling estimates that wood burning's share of the inventory is on the higher end of the winter averages established by CMB, C-14 and PMF analyses , but the results are not outside of their range of estimates. "

p. 5.8-39: "It is unclear how much these concentrations persist as a result of noise in the high resolution (1.33 x 1.33 km) modeling or reflect actual hot spots in the region." The use of the term model 'noise' is confusing. A more accurate phrase would be model 'uncertainty'.

- The term noise has been replaced with "assumptions or uncertainties".

Attainment Demonstration

p. 5.9-3: Final SIP should include more discussion of why other measures could not have been put in place by 2015, either here or in the RACM section of the appendix.

- Following the completion of the RACM document, the vote on Proposition 2 was certified on October 27 with 52% supporting and /48% opposing. This proposition now gives the FNSB authority to enforce air quality regulations. The vote, however, hardly provides a mandate, as there is still considerable opposition to more stringent wood burning controls in the community. Despite the opposition, the Assembly has determined that more stringent controls should be considered but not at the expense of delaying the submission of the SIP as noted in the unanimous resolution adopted on 12/11/14 (Appendix III.D.5.9). A review of more stringent control measure costs and benefits will be conducted after the end of the year (and submission of the SIP) with the goal of accelerating the pace of attainment through amendments to the submitted SIP.

Emergency Episode Plan

p. 5.11-2: Final SIP should clarify what averaging time is used to determine whether ambient data has exceeded 35 $\mu g/m^3$.

- "24-hr rolling average of the 1-hr BAM instrument measurements"

p. 5.11-4: In Table 5.11.1, is this a rolling 24-hour average, or midnight-midnight local time?

- "24-hr rolling average of the 1-hr BAM instrument measurements"

p. 5.11-6: The first full paragraph says that the department may issue a Notice of Violation, but later on the same page and the following page there is no reference to the ability of the state to issue notices of violation.

- Corrected

Conformity and Motor Vehicle Emissions Budget

p. 5.13-1: We suggest adding the year of the NAAQS to the title of the quoted implementation rule, as follows: "Specific guidance on $PM_{2.5}$ conformity requirements is also contained in the Final Fine Particulate Implementation Rule for the 2006 $PM_{2.5}$ NAAQS." The next sentence will need to be modified to refer to "that" implementation rule, so that it is clear (there are a number of implementation rules discussed).

- Edited as suggested.

p. 5.13-2: We suggest adding the definition of control strategy implementation plan revision as located in §93.101: "Control strategy implementation plan revision is the implementation plan which contains specific strategies for controlling the emissions of and reducing ambient levels of pollutants in order to satisfy CAA requirements for demonstrations of reasonable further progress and attainment (including implementation plan revisions submitted to satisfy CAA sections 172(c), 182(b)(1), 182(c)(2)(A), 182(c)(2)(B), 187(a)(7), 187(g), 189(a)(1)(B), 189(b)(1)(A), and 189(d); sections 192(a) and 192(b), for nitrogen dioxide; and any other applicable CAA provision requiring a demonstration of reasonable further progress or attainment)."

- Added under §93.101 as suggested.

p. 5.13-3: The description of "Activity Inputs" is an incomplete sentence.

- Corrected, same as in Section 5.6

p. 5.13-4: Final SIP should clarify the meteorology inputs to MOVES. See comment above for page 5.6-68.

- Corrected, same as in Section 5.6

p. 5.13-4: In the "plug-in adjustments" paragraph, remove the phrase about additional interagency consultation for MOVES2014.

- Done.

p. 5.13-4: The MVEB must be considered together with all other emissions sources and the MVEB must be consistent with and clearly related to the EI and control measures in the implementation plan. A table summarizing the 2017 EI should be included here or include a reference to the new 2017 EI table in the EI section (as recommended in "Emissions Inventory, General comments", above). The final SIP would be stronger if it includes some discussion of Alaska's analysis indicating how on-road sources are not the driving source of non-attainment.

- Addressed by incorporating the new "MVEB Context Within 2017 Inventory" sub-section from Section 5.6.6 into Section 5.13 after the discussion of the MVEBs. This added sub-section includes a new table (5.13-2) that contains emission summaries for all sources and ensuing narrative pointing out that on-road vehicles are not the dominant source of emissions.

p. 5.13-5: The list of 40 CFR 93.118(e)(4) requirements does not include 93.118(e)(4)(iv). It should be added: (iv) The motor vehicle emissions budget(s), when considered together with all other emissions sources, is consistent with applicable requirements for reasonable further progress, attainment, or maintenance (whichever is relevant to the given implementation plan submission);

- Addressed by rewording bulleted item & in the 93.118(e)(4) list.

p. 5.13-6: Specify section 93.123 (instead of just part 93) in paragraph four, sentence three.

- Corrected

Detailed Responses to Comments on Available Control Measures Not Considered for RACM

The department received some specific comments regarding control measures that were determined not to be reasonably available control measures in the SIP. This topic is covered in chapter 7. These comments are addressed separately here given their detailed and somewhat technical nature.

Comment: "The Draft SIP is incomplete and unlawful because there are many available control measures for residential wood combustion that the Department has neglected to consider. Indeed, there is a substantial inventory of measures that have been recommended by EPA or implemented in other communities to reduce emissions caused by residential wood combustion, but do not appear on the list of control measures that ADEC considered for the SIP."

Response: Many of the unconsidered "control measures" suggested by the commenter are not control measures themselves, but examples of elements or strategies to be considered during implementation of control measures. For example, several of the suggested measures are actually elements of a public outreach and education program, at a level of detail not usually provided in SIP documents. These have been added, where appropriate, to the relevant control measures in the SIP.

Some of the suggested control measures are variations on control measures that were considered and rejected as technologically infeasible. The variations do not address the features that made their siblings infeasible; as a result, they are infeasible as well.

Some of the suggested control measures come from regulations and programs in jurisdictions that are very dissimilar from Fairbanks. They have different climates, and none of the affected homeowners face a comparable economic burden in heating their homes. Wood burning appliances in those jurisdictions are principally used for aesthetics, not for heat. Even when used for heat, very few homes in these jurisdictions rely solely, or even principally, on wood for heat. As explained in the analysis, the striking difference in climate and home heating patterns, and the economics of fuel supply means that adoption of a restriction on wood burning by a jurisdiction in a temperate climate is not an indication that the restriction would be reasonable in Fairbanks.

The following specific measures were suggested by the commenter. As required by EPA guidance, measures suggested during the public review process must be addressed in the RACM analysis. The results of that additional analysis are summarized below.

Suggested Measure: Providing voluntary dryness certification programs for dealers and/or making free or inexpensive wood moisture checks available to burners.

Response: This is a not a control measure itself, it is an example of a possible element of the "Dry Wood Programs: Education and Outreach" measure. As suggested by the commenter, a reference to this element has been added to the description of the control measure.

Suggested Measure: Discouraging the resale of used stoves through taxes, fees, or other disincentives.

Response: The suggested control measure has been added to the analysis. As is currently the case with almost all involuntary measures, this measure would face opposition from the local community and would not be practically enforceable. Enforcement of restrictions on the sale of new stoves is enforced by monitoring vendors. In contrast, enforcement of restrictions on the sale of used stoves would require detection and intervention in transactions between individuals. The resources needed to enforce such a measure are out of line with the resulting emission reductions.

This control measure is not technologically feasible.

It should also be noted that the SIP already includes a Solid Fuel Burning Appliance (SFBA) Changeout program as a RACM. FNSB offers reimbursement of 75% of the cost (up to $3,000) of a new certified combustion device. There is also a bounty program for dismantling an old device without replacement. Because this program is voluntary, it has none of the drawbacks (other than high cost per pound of reduction) of the suggested disincentive program.

Suggested Measure: Label requirements for sale of solid fuel or wood to advise purchaser of potential restrictions on burning and how to determine whether any current restrictions exist (e.g., by calling informational phone line or checking website).

Response: This is a not a control measure itself, it is an example of a possible element of the "Dry Wood Programs: Education and Outreach" measure. As suggested by the commenter, a reference to this element has been added to the description of the control measure.

Suggested Measure: Label requirements for sale of wood indicating whether wood meets moisture content requirements. If wood has too high of a moisture content, label should indicate that wood must be dried before burning.

Response: This is a not a control measure itself. It is an example of a possible element of the "Dry Wood Programs: Education and Outreach" measure. As suggested by the commenter, a reference to this element has been added to the description of the control measure.

Suggested Measure: Requiring retrofit or conversion of wood-burning stoves or fireplaces when a residence undergoes a major remodeling.

Response: The suggested control measure has been added to the analysis. As is currently the case with almost all involuntary measures, this measure would face opposition from the local community and would not be practically enforceable. Requiring retrofit at the time of a home sale was previously evaluated and determined to be not technologically feasible. Requiring retrofit when a residence is remodeled would, for similar reasons, not be technologically feasible.

This control measure is not technologically feasible.

Suggested Measure: Restricting number of wood-burning devices allowed in homes under construction (i.e., construction of new homes or remodeling of existing homes).

Response: The suggested control measure has been added to the analysis as a partial implementation of the measure to ban all new installations. As is currently the case with all involuntary measures, this measure would face of opposition from the local community and would not be practically enforceable. This proposal lies somewhere between banning installations in new homes and requiring that an alternative source of heat be included in new homes. Both of those measures were evaluated and determined to be not cost effective. This proposal would not contribute to emission reductions, but could reduce increases from new construction.

This control measure is not technologically feasible.

Suggested Measure: Application of different tiers of control measures based on density of homes in the area.

Response: This is not a control measure at all. It is a strategy to minimize opposition by focusing control requirements on areas where they are most needed or most effective. This strategy will be considered, where appropriate, during the rule development process.

Suggested Measure: Programs to improve operation and maintenance of wood-burning stoves or fireplaces.

Response: This suggested control measure is the same as the Outreach and Education control measure for each of the wood burning appliances, and has already been included in the proposed SIP as RACM.

Suggested Measure: Installation training and certification programs.

Response: As a preliminary matter, the reference[1] cited by the commenter is no longer valid. It has been superseded by subsequent guidance,[2] most recently updated in 2013. The new guidance does not recommend an installation training and certification program as a control measure. This is not because EPA thinks there is no value in using certified installers—to the contrary, EPA recommends that consumers use a certified installers in several outreach

[1] Guidance Document for Residential Wood Combustion Emission Control Measures (September 1989).
[2] Strategies for Reducing Residential Wood Smoke.

documents.[3] It is apparently because the existence of industry certification programs makes agency-sponsored programs unnecessary.

The program suggested by the commenter was described by EPA as follows:

> "An installation training and certification program improves RWC (Residential Wood Combustion) device installation and reduces emissions by improving the knowledge of the retailers, chimney sweeps , and others who are involved in the business of installing wood heaters or constructing fireplaces . This program can be either voluntary or mandatory. A voluntary program offers a course in RWC device installation and fireplace design. Individuals and businesses participating in the program are then able to advertise their certification status. Purchasers of RWC devices can choose certified installers on the assumption that installation by a certified installer results in more efficient, less polluting, and safer operation of the device. In a voluntary program, effectiveness is a function of the degree to which installers and purchasers can be convinced that certification provides benefits to the individual homeowner and to the community."[4]

A mandatory program requires that any individual installing an affected device be certified.

Following EPA's example, recommendation that consumers use certified installers has been added to the outreach program descriptions. Also following EPA's example, an agency sponsored training and certification program is not RACM. The mandatory program is not RACM, for the same reasons that other involuntary programs have been determined to be not RACM.

Suggested Measure: Emission offset program requiring builder or owner of a new home to eliminate an existing wood-burning stove or fireplace before being allowed to install a new one.

Response: The suggested control measure has been added to the analysis as a partial implementation of the measure to ban all new installations. The suggested program is described by EPA as follows:

> "Under an emission offset requirement, the builder or owner of a new dwelling would have to eliminate an existing RWC device before the air quality agency would permit the installation of a new RWC device . This may mean that the homeowner or builder would eliminate an existing device that the owner or builder already owns, but more frequently would require the purchase of an RWC device from another individual . This may mean negotiating with other homeowners for the purchase and disabling of their wood stoves, or for the dismantling of their fireplaces." [5]

[3] For example, "EPA recommends that your wood-burning appliance be professionally installed and maintained by a certified technician to insure its safety and proper performance. The safety of your home and family depends on fully understanding and carrying out the critical manufacturer and building code requirements" http://www.epa.gov/burnwise/maintenance.html accessed 12/21/2014
[4] Guidance Document for Residential Wood Combustion Emission Control Measures (September 1989), p. 3-11.
[5] Guidance Document for Residential Wood Combustion Emission Control Measures (September 1989), p. 4-13.

As is currently the case with all involuntary measures, this measure would face of opposition from the local community and would not be practically enforceable. For this reason, the proposed control measure is not technologically feasible at this time.

Partial implementation not considered

ADEC considered partial implementation of many possible control measures, as demonstrated by its division of some control measures into discrete components for assessment. For example, several partial implementations of the broad category "elimination of uncertified stoves" were evaluated: requiring all new stoves to be certified; requiring replacement of all old uncertified stoves by a specified date, or upon property transfer, or only those in rental property, or voluntary replacement through economic incentives. All of these measures are partial implementation proposals.

Partial implementation could redeem a rejected control measure if the partial implementation eliminates the basis for rejection. If the control measure was rejected because of technological infeasibility, partial implementation must identify the subset of situations where the measure would be feasible. If the control measure was rejected because of cost, partial implementation must identify the subset of situations where cost is not an obstacle.

Commenter suggested that several control measures that were rejected in whole might be feasible if applied in part. Commenter provided as an example of its suggested approach a discussion on the ban of green wood. However, the comment does not make clear what partial implementation was being suggested, nor how partial implementation would avoid the central reason for determining that the control measure is technologically infeasible: the widespread community opposition to local regulation of the use of wood as a home heating fuel.

Similarly, it is not clear what specific limitations commenter was contemplating when suggesting that several control measures could be made feasible if implemented in stages or by employing a more targeted approach. As a result, no further analysis is possible, and the RACM determinations were not revised as result of this comment.

Local opposition used as a reason for rejection

Comment: Thus, the reason implementation of certain control measures is infeasible is because ADEC is more concerned with submitting a plan, which will likely be rejected if based on outdated information and an arbitrary conclusion as to its application, than correcting the plan in the first instance.

Response: The commenter's conclusion is incorrect. The reason that certain control measures were determined to be infeasible is because the community has indicated strong opposition to precisely the type of measure being evaluated. The recent referendum, which failed by a small

margin,[6] taken together with the past referenda, indicates that this opposition is diminishing. There is reason to believe that public opinion is shifting towards acceptance of the value, in terms of improvements in human health, of regulations that restrict or eliminate the use of dirtier devices. However, the small margin of failure of the referendum indicates that there is still a large portion of the community opposed to regulation of any kind. The discussion of the economics of home heating provided in the RACM analysis document explains the passion of opposition to regulation.

It is in recognition of this opposition that ADEC has determined, and continues to determine, that the affected control measures are not feasible, and therefore not RACM. The measures determined to be RACM (specifically outreach and education, and incentives to encourage voluntary replacement of old devices which reduces the number of people with a stake in not controlling them) are expected to improve the community's receptiveness to regulation. Many programs across the country have recognized that the ground must be prepared before controls may be implemented. ADEC has determined that, if controls are attempted before the community as a whole is ready, they will not be effective.

Even though the commenter's overall conclusion is incorrect, it makes a valid point regarding the need to submit the SIP on time. There is a statutory deadline by which the plan must be submitted. The determinations underlying the elements of the plan necessarily reflect the best information available at the time that the plan is drafted.

The October referendum had not occurred at the time that the draft Plan was being finalized; the results of the referendum were not verified until the end of October. The Borough Assembly, which was prevented from regulating home heating activities until the failure of the referendum, has only had two meetings since the results became known. It is still in the process of evaluating the new information and its new authority.

The information upon which the SIP is based is not "outdated." It is in the process of being supplemented, but has not been supplanted. Furthermore, even if the basis for the plan were determined to be outdated (which it is not), a conclusion that relied on that basis would not be "arbitrary," because there is a rational basis for the conclusion.

The Borough Assembly has expressed its commitment[7] to gauge the level of community support (and opposition) to individual control measures, and revisit both the SIP and its own ordinances in order to achieve attainment as expeditiously as possible. Nevertheless, the Borough also recognizes the need to meet statutory deadlines for submittal of its SIP, and has therefore expressed its support for the timely submittal of the SIP. If there were no looming deadline, the plan might be improved by delaying its submittal until the Borough Assembly has taken its next

[6] 51.57% to 48.43%. *Election Summary Report, 2014 Regular Election,* October 30, 2014

[7] "[T]he Assembly calls on the Governor, the Congressional Delegation, the Interior Delegation, and the State Departments of Environmental Conservation, Health and Social Services, and Transportation to work together to find additional solutions and resources to help the citizens of the Borough significantly reduce the pollution generated by wood combustion and other sources of PM2.5 and to restore our air to a healthy condition. *Fairbanks North Star Borough Resolution No. 2014-45*

step. However, the deadline exists, the plan must be submitted using information available now, and improvements will need to be incorporated at a later date.

EPA guidance indicates that the capability of effective implementation and enforcement of the measure are relevant factors in the RACM analysis. A RACM measure is, by definition, one that can be implemented with a reasonable amount of effort and with a reasonable expectation of success. A control measure that faces the opposition of nearly half the affected community does not meet that definition.

Comment: Significantly, public opposition to wood smoke regulations is by no means unique to Fairbanks. EPA has recognized that "there are areas where wood heat is a mainstay of rural heating habits and is perceived as a 'constitutional right.'" However, the solution is not to reject a control measure for that reason, but to adjust how it is implemented. For example, "[t]he issue of the individual's right to burn has implications for how a [public awareness] program should approach its message for that area. Obviously, the [public awareness] program element would be more effective at overcoming entrenched resistance to regulation by adopting a stance that emphasizes the benefits of more efficient and cleaner burning [residential wood combustion] devices rather than threats of sanctions for failure to attain the standard." Likewise, control requirements are more likely to overcome public resistance if ADEC and local authorities adopt complementary non-regulatory programs that will ease the transition to cleaner-burning devices and reduce energy use.

By ruling out control measures based on assumed public opposition without attempting to create approaches that could work in the nonattainment are, ADEC has not satisfied its obligation to justify rejection of those measures.

Response: First, the public opposition is not "assumed." The success of the previous initiatives, and the close vote in the defeat of the most recent initiative, demonstrates that opposition to regulation of wood heating appliances is real. Second, ADEC has incorporated into the SIP precisely the sort of "complementary non-regulatory programs that will ease the transition to cleaner-burning devices and reduce energy use." The outreach and education programs, economic incentives, and voluntary curtailment programs all work to increase public awareness of the health implications of particulate pollution and the contribution that individual behavior makes to it. These are all necessary steps to increasing community acceptance of controls that will require that acceptance to be successful.

The control measures that have been rejected are not RACM for Fairbanks because Fairbanks is not yet ready to embrace them.

<u>Incomplete assessment of costs.</u>

Comment: EPA has noted that "[t]he true economic costs of wood burning may be much higher than most people realize. It is important to provide consumers with a means (1) to calculate the actual costs of wood burning (including the value of homeowner's time for cutting and hauling

wood, ash disposal, etc.) and (2) to compare this with alternative heating costs." ADEC has done neither.

Response: The quoted passage does not refer to methodology for economic analysis of control measures, but to educational materials that should be included in public awareness programs.

Assuming that Fairbanks has, on average, much lower winter temperatures than all of the other cities given as examples, it is likely that residents of Fairbanks require more fuel to heat their homes, whether provided by wood, fuel oil, or electricity, which could account for a large portion of the higher costs in Fairbanks relative to the rest of the country. ADEC's cost comparison should be revised to determine the actual costs of wood burning in Fairbanks, the costs of wood burning elsewhere in the United States, and to provide a comparison of costs that accounts for Fairbanks's winter climate, which is much colder than the other cities used as examples.

The heating cost information in the RACM analysis document was provided to explain that the economics of home heating explain why wood burning in Fairbanks is a more passionate issue than elsewhere in the United States. The additional analysis requested by the commenter would not provide additional insight into the issue, or affect the RACM analysis or determinations.

<u>The Proposed SIP fails to require RACT for Major Stationary Sources</u>

Comment: ADEC's own speciation analysis reveals that SO2 emissions constitute roughly one-fifth of the PM-2.5 problem on poor air quality days during the winter. Nonetheless, ADEC has proposed no control measures for any major stationary source, not even for Aurora Energy's Chena Plant or the Fort Wainwright Power Plant—even though the boilers at these plants "are currently not equipped with SO2 controls" and emit hundreds of tons of SO2 each year.

Response: That is correct. As explained in the RACT analysis document, those facilities currently use extremely low sulfur coal for fuel. The costs of controls—both exhaust scrubbing, and shifting to a fuel with lower sulfur content—were assessed, and were determined to be unreasonable considering their small impact on ambient PM concentrations.

Comment: In light of the dispersion modeling purporting to show SO2 impacts well above federal ambient air quality standards, it is plain that major stationary sources in Fairbanks contribute significantly to the local air pollution problem. The Chena and Fort Wainwright plants, in particular, not only emit huge quantities of SO2 in violation of the 1-hour SO2 NAAQs, but these precursor emissions undoubtedly contribute to the exceedances of the 24-hour PM-2.5 NAAQS as well. ADEC therefore should adopt appropriate control requirements for these and other stationary sources along with the measures currently proposed for homeowners.

Response: Questions about the validity of the dispersion modeling aside, this is a PM2.5 SIP. The procedure for determining RACT for SO_2 as a $PM_{2.5}$ precursor does not take SO_2 impacts

into account. As indicated above, the cost of achieving reductions in ambient $PM_{2.5}$ by reducing SO_2 emissions is too high to allow those controls to be deemed RACT.

Comments on the Public Review Process

DEC provided a public review opportunity for the public and interested stakeholders to evaluate and comment on the proposed regulations and air quality plan. The comment period was first noticed in the newspaper on November 17 and ended December 19, 2014. During this process two open houses were held in Fairbanks and North Pole on December 1st and 2nd. DEC aggregated and posted responses to written questions received from the public prior to December 9th. Public hearings to receive oral testimony were held on December 3rd and 17th in Anchorage, Fairbanks, and Juneau. In Fairbanks, two public hearing opportunities, midday and evening, were provide on each hearing day. The public was able to provide oral testimony at public hearings or submit written comments in person, through mail, by email, and through DEC's online comment form.

Summary of Comments: The department received a number of comments with respect to the public review process.

Some commenters felt that the public review process was adequate and provided ample opportunity for everyone to comment. Commenters appreciated the open house opportunities to learn more about the regulations and plan. Other commenters made specific suggestions on improvements for the on-line comment form and having additional, simple handouts that help to summarize main points and provide definitions.

Some commenters felt the public review process was inadequate. They raised concerns about the timing of the release of the material for public review and the short time available to review the large volume of material provided. They noted that the public review process should have occurred earlier or the Plan updated to reflect recent information and events affecting air quality issues in the community.

A concern was also raised that no peer review justification for this proposal was released for public review as required by state statutes, AS 46.14.010 or AS 46.14.015.

Department Response: DEC appreciated receiving comments on the public review process. These comments are helpful because they allow DEC to better plan for future public review processes. Comments on the public process help DEC facilitate more effective public involvement for issues that are important to our communities. Given the deadline for the federal plan, the department was not able to provide a significantly extended public comment period for this proposal. However, previous public comments allowed for extensive input that was used in developing the proposals that were included in this package of regulations along with the local air quality plan.

DEC met and in some areas exceeded the regulatory advertising requirements of the Administrative Procedures Act found in Alaska Statutes Title 44 Chapter 62 and the Alaska Department of Law 20th Edition Drafting Manual for Administrative Regulations. "AS 44.62.190 Notice of Proposed Action" requires agencies to give notice of a proposed action at least 30 days prior to the adoption, amendment, or repeal of a regulation. The agency must

publish a notice in a newspaper of general circulation or trade or industry publication, distribute the notice to interested persons, and may publish the notice in an additional form prescribed by the agency. If the agency decides to hold public hearings, the date, time, and location of the hearing must be published as part of the public notice. DEC also made provisions to take and timely respond to written questions received as required by state statute.

In addition to meeting these regulatory requirements, DEC held two open houses and advertised for these open houses to provide additional opportunities to learn about the issues. At each of these open houses, DEC prominently displayed “How to Comment” which listed out both open houses and hearings in addition to providing addresses, websites as well as comment forms. DEC also held public hearings to take oral testimony on two days, and in Fairbanks offered both midday and evening hearing opportunities.