Alaska Department of Environmental Conservation

Amendments to:

State Air Quality Control Plan

Vol. III: Appendix III.D.7.8

{Appendix to Volume II. Analysis of Problems, Control Actions; Section III. Area-wide Pollutant Control Program; D. Particulate Matter; 7. Fairbanks North Star Borough PM2.5 Control Plan, Serious Requirements}

Adopted

November 5, 2024

Michael J. Dunleavy, Governor

Emma Pokon, Commissioner

Note: This document is the Appendix to the Modeling Chapter. This document provides the adopted language of the 2024 Amendment to the Serious SIP for inclusion in this section of the State Air Quality Control Plan to address the disapproval of the Serious SIP and the 2020 Amendments. The public notice draft of the 2024 Proposed Amendment can be found and referenced at the following internet site: https://dec.alaska.gov/air/anpms/communities/fbks-pm2-5-2024-proposed-amendment-serious-sip/

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

Appendix III.D.7.08

Contents

1. Technical Modeling Report
2. Notes on US EPA WRF modeling for Fairbanks, AK (Dec 2019-Feb 2020)
3. Alaska Technical Meeting - September 2023 presentation on Modeling the wintertime meteorology for the 2022 ALPACA campaign & 2019-2020 AK Winter

The following documents are included as part of the Appendix, however due to their electronic nature, they may be found posted separately at: http://dec.alaska.gov/air/anpms/communities/fbks-pm2-5-2024-proposed-amendment-serious-sip/

- i. SMAT_091523 Workbook
- ii. Primary Secondary SO_4 Workbook

The files below, which are part of the Appendix, are not supported for posting. However, they are available upon request.

- i. EmissCtrl_git-fix-20192020
- ii. EmisaCtrl_git-fix-20192020_zeropoint
- iii. EmissCtrl_git-fix-20192020_zeroSO2points
- iv. EmissCtrl_git-fix-20192020_zerospaceheat

Alaska Department of Environmental Conservation (DEC)

Division of Air Quality

Technical Analysis Modeling Report for phase 1, 2 and 3

(Last Update February 10, 2023)

EXECUTIVE SUMMARY

The current modeling platform that DEC submitted on December 13, 2019, for the Serious Area State Implementation Plan (SIP) and 2020 Amendment is outdated. First, the Community Multiscale Air Quality model (CMAQ) used an outdated version of the model. Second, all the preprocessing models (WRF, SMOKE and MCIP – described below) that are required to format the emissions and meteorology that are used to drive the model are also outdated. The December 13, 2019, submissions were based on 2008 winter conditions and may no longer be representative of Fairbanks winter conditions. Third, the highest violating monitor for the Fairbanks nonattainment area is at Hurst Road in North Pole, there was no speciation monitoring data available for North Pole and there was no model performance analysis performed. The North Pole area remains the focus for control analysis, model attainment, and poor sulfate model performance. The past controls have centered on woodstoves and mainly organic carbon reduction. The USEPA has outlined these technical deficiencies in its July 19, 2019, and October 29th, 2020, and January 2023 Federal Register Notice comments on the Fairbanks PM2.5 State Implementation Plan (SIP). The deficiencies included that the CMAQ model does not represent secondary sulfate and no model performance evaluation was submitted for the SO2 analysis. The following technical report summarizes those deficiencies and potential next steps in future modeling, outlines the major components of a future SIP amendment and weight of evidence work by the ALPACA (Alaska Layered Pollution and Chemical Analysis) campaign supporting wintertime sulfate chemistry at high latitudes and sulfate model performance.

The technical modeling report contains:

- New versions available at the time for the meteorological model (WRF), the air quality model (CMAQ) and the pre-processor models (SMOKE, MOVES, MCIP)
- New model results for the latest available at the time CMAQ version
- New speciation data in North Pole for year 2019-2021
- New Model Performance Evaluation
- New 5-year design value and Speciated Model Attainment Test (SMAT) calculations needed for a future complete SIP amendment and precursor analysis.
- Updated Weight of Evidence addressing secondary sulfate chemistry in the model and local studies addressing wintertime pollution in the Fairbanks area

CMAQ version 5.3.2 with updated chemistry

The CMAQ air quality model is used as a tool to assess air quality control measures. The old version of the model was 4.7.1 and is no longer supported by USEPA. The air quality control model uses local emissions and meteorology to replicate wintertime conditions in Fairbanks which is when the highest concentrations of PM2.5 occur.

The CMAQ version 5.3.2 has an updated chemistry module (aero5 to aero7), the updates include changes to how the organic carbon portion of PM2.5 is calculated in the model to depict the atmospheric chemistry more accurately. All details of the updates to chemistry are below in section 2.X

The results of updating the CMAQ model and all the preprocessor models is that DEC is now operating with the latest model available from USEPA and the most updated chemistry (available at the time) to address technical limitation of the model and be able to produce a model performance evaluation that includes both Fairbanks and North Pole.

Updated SMOKE version from 2.7 to 4.7

The CMAQ model requires local emissions for all the sectors in the Fairbanks area including point sources, space heating, on road vehicles, aircraft and nonroad vehicles. The preprocessor model SMOKE (Sparse Matrix Operating Kernel Emissions) version 4.7 includes enhanced layer processing for space heating and plume mechanics for the point sources.

In updating the modeling workflow to the latest version of SMOKE (4.7), two sectors of the emissions inventory were also updated to specifically reflect activity and ambient temperature conditions within a new 74-day winter 2019-2020 modeling episode:

1. Point Sources – Day and hour-specific fuel use and activity data for the 74-day episode were collected by facility and emission unit and were used to revise the point source inventory to reflect actual activity and emissions during this new 74-day episode.

2. Space Heating Sources – Space heating emissions, which are ambient temperature dependent, were also adjusted to reflect ambient temperatures that occurred during the new 74-day episode.

The new emissions were key to improving core deficiencies in the model and new hourly data was included for point source sector and other improvements to the emissions for winter 2019-2020 (December 1st, 2019, to February 12th, 2020). These updated emissions and concurrent meteorology allowed for a model evaluation for North Pole.

Updated WRF 3.1 to WRF 4.2

The Weather Research and Forecast (WRF) model is the meteorological data that drives the model. The last meteorological model data was from 2008. The meteorological model is important to update so the that current wintertime Fairbanks conditions are represented, and updated model performance evaluation can be completed. The model performance evaluations use the same day meteorology and monitoring data to compare model outputs daily. Updating the WRF model allowed DEC to complete a Model Performance Evaluation (MPE) for North Pole. Having concurrent meteorological and monitor data addresses a major deficiency in the SIP modeling.

The updated WRF modeling completed a deficiency as commented in the USEPA comments as a technical limitation of the model not having model performance for a precursor analysis. The new meteorological model included 74 days and observations in North Pole for evaluating meteorological model performance. Both WRF simulations had a warm temperature bias that was generally between the +/= 0.5 and +/- 2.0-degree goals, with NCore performing better than North Pole and A Street.

Updated Model Performance Evaluation (MPE)

The last MPE was completed using 2008 concurrent meteorological and speciation monitored data for the State Office Building location. The new updated MPE included model performance for all PM2.5 species at the NCore, A Street and Hurst Rd monitor locations. The update to the model performance evaluation to include North Pole (Hurst Rd) and 25 days of speciation monitoring data addresses technical deficiency in the SIP modeling.

The MPE was completed for each monitor, reviewed and all three monitors[1] for all three months from December 1st – February 12th, 2020, were averaged together. Both the individual monitor model performance and all three monitors together are compared to the performance criteria goals set by the USEPA. The performance criteria mean that "most" or two thirds of the CMAQ models performed at this level. The MPE identified that 13 of 24 measured species criteria or 54% of the metrics are met, the details are found Table 2.7.2. [2]

Updated SMAT calculations.

The Speciate Model Attainment Test (SMAT) is a process that uses a modeling design value for PM2.5, future year modeling for PM2.5 and shows modeled attainment for PM2.5 at all monitor locations in the model. DEC has updated the 5-year modeling design value to 2017-2021 in collaboration with EPA and an updated base year of 2020. The updated SMAT calculations allow the new updated CMAQ model results to be using for regulatory modeling and finalize the updated modeling deign value with a new attainment date. In this technical report the SMAT spreadsheet has been updated using the base year 2020 and an SO2 precursor test run to test the relative response factors and start analyzing the sulfur controls, the last major deficiency in the CMAQ modeling, sulfate performance.

The results of updating to a new 5-year modeling design value to reflect current monitoring results in the Fairbanks and North Pole areas are that the PM2.5 concentrations have decreased at all three monitors. The percentage of organic carbon in the PM2.5 (majority is from wood burning) has decreased and the sulfate has increased.

Updated Weight of Evidence

The section on weight of evidence is one of the most compelling sections of the technical modeling report, since the preliminary results have come out of the ALPACA campaign from the winter 2022 in Fairbanks. There were many scientific studies that are in preliminary stages looking at sulfur chemistry, point source plumes and modeling performance of meteorological data. Two of the most important studies for addressing deficiencies in the CMAQ model are from the USEPA RARE grant study group that have found improved meteorological model performance and updated chemistry to the model

[1] https://www.epa.gov/sites/default/files/2020-10/documents/o3-pm-rh-modeling_guidance-2018.pdf page 72

enhancing secondary sulfate. The CMAQ model needs to accurately represent the Fairbanks winter atmosphere and cold temperature inversions; it is historically difficult to replicate strong inversions with very low wind speeds. The updates to the WRF model performance will help the model performance of PM2.5 along with updated emissions and sulfate chemistry. The sulfate chemistry in the model has been very poor, this is well documented and why the EPA RARE focus is sulfur chemistry. Sulfur chemistry is important in Fairbanks to better understand the relationships between SO_2 in the atmosphere and the sulfate fraction of PM2.5.

The latest sensitivity tests using the meteorological WRF model by USEPA for the winter 2022, show improved temperature bias, and the model is improving at capturing temperatures close to 40 below during inversions. The latest sensitivity test for the secondary sulfate production in the air quality model (CMAQ) have shown improved secondary sulfate production, which is the major deficiency that has only slightly improved with the updated model version available to the public and DEC in this technical modeling report.

Future steps for the SIP amendment modeling are to address the remaining modeling deficiency of production of secondary sulfate by using the ALPACA air quality modeling updates to the sulfur chemistry and the meteorological updates to the WRF. Together these latest updates will represent the most up to date air quality model for wintertime conditions found in Fairbanks that create high PM2.5 days. The ALPACA campaign results represent the work of scientists from USEPA and around the world collaborating with the community, stakeholders, and DEC to further understand winter conditions that lead to exceedances in Fairbanks.

This Technical Analysis Report describes updates to the Fairbanks fine particulate matter (PM2.5 Nonattainment Area State Implementation Plan (SIP) modelling platform for phase 1, and phase 2 and 3 development protocols.

0 Review of Moderate, Serious and 5% Plan Modeling

0.1 Moderate and Serious Area SIP modeling summary

The Fairbanks SIP modeling was completed using the photochemical air quality model version CMAQ[3] 4.7.1, emissions processing version SMOKE 2.7, and meteorological processed WRF (Weather Research and Forecast model) data using version MCIP 3. The rationale behind using this model and all of the details for use in the Fairbanks PM2.5 nonattainment area can be found in the Moderate and Serious Area State Implementation Plans (SIPs).[4,3]

[3] https://dec.alaska.gov/air/anpms/communities/fbks-pm2-5-moderate-sip/

[4] Fairbanks PM2.5 Moderate SIP (Alaska.gov)

The meteorology was selected as two 2-week episodes in 2008 that represent Fairbanks wintertime conditions that cause exceedances (Jan 23- Feb 10 and Nov 2 to 22nd). The details of the meteorology selection can be found in the moderate area SIP.[1,5]

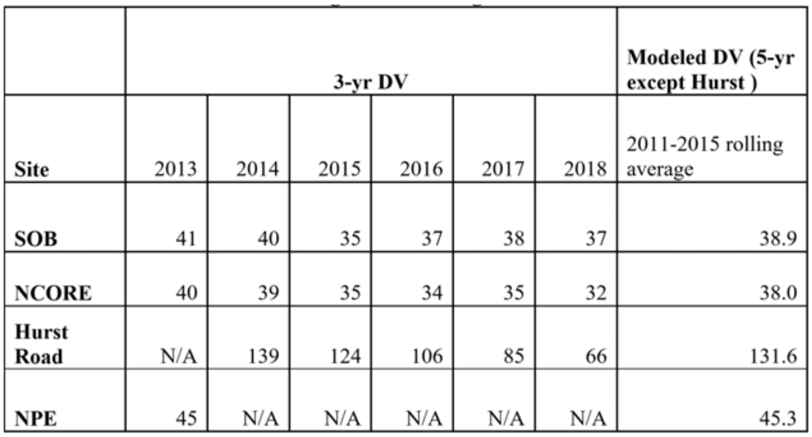
Moderate Area Review

The 35 days selected to model include Federal Reference Method (FRM) data at the Fairbanks State Office Building (SOB) monitor site, 12 days were used for model performance evaluation from 2008. In 2008, there was no FRM monitored data in North Pole, which is now the violating monitor. The base year for Moderate Area SIP was 2009 with a 5-year Design Value of 44.7 ug/m3 at the State Office Building monitor and a future design value (FDV) of 39.6 ug/m3 in 2015 and 33.5 ug/m3 in 2019. [1]

Serious Area Review

The Serious SIP used the same 2008 meteorology and a 2013 base year with 5-year modeling design values from 2011-2015. The modeling design values were used for North Pole (Hurst Rd monitor), State Office Building monitor, NCORE monitor and North Pole Elementary (NPE) monitor. The modeling design value is calculated using monitored data averaged from 3 design values (3 3-year averages of the 98th percentile) from the monitor (Hurst Rd used 2 3-yr averages due to availability). These modeling design values are in Table 0.1.1. [6] The future design values were based on CMAQ model output and using the SANDWICH method. The SANDWICH method is used compare speciation monitor filter data to FRM filter data. Then the non-linear species of PM2.5 from future years of air quality model runs are added together for total PM2.5 future design value. Details of the SANDWICH method recommended by EPA and all the modeling calculations are contained in the Moderate and Serious area SIPS. [1,3]

Table 0.1.1 Five Year Design Value (µg/m³) for 2011-2015 [a]



	3-yr DV						Modeled DV (5-yr except Hurst)
Site	2013	2014	2015	2016	2017	2018	2011-2015 rolling average
SOB	41	40	35	37	38	37	38.9
NCORE	40	39	35	34	35	32	38.0
Hurst Road	N/A	139	124	106	85	66	131.6
NPE	45	N/A	N/A	N/A	N/A	N/A	45.3

[7]

a. The modeling design value is monitored data averaged from 3 3-yr design values from the monitor or a 2 3-yr design value based on available data for Hurst.

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[5] Research Regarding FNSB Particulate Matter (alaska.gov) ***Fairbanks, North Star Borough AK $PM_{2.5}$ Nonattainment Area WRF-ARW, Gaudet et al., Pennsylvania State University, January 2012.***

[6] Fairbanks PM2.5 Serious SIP (Alaska.gov)

The Future Design Value for the year 2019 was calculated from a 2013 base year and the summary for all four monitored sites is in Table 0.1.2.

Table 0.1.2 2013 Base Year and Future Design Values for the 2019 control run and 2029 expeditious attainment year from the Serious Area SIP

	Hurst Road Future Design Value (μg/m^3)	NPE Future Design Value (μg/m^3)	NCORE Future Design Value (μg/m^3)	SOB Future Design Value (μg/m^3)
2013 Base Year	131.63	45.3	37.96	38.93
2019 Control	104.16	36.42	28.87	29.57
2029 Expeditious Attainment	33.87	17.12	18.86	19.41

The model run for 2019 was not able to show attainment, due to higher than the 24-hour standard for PM2.5 concentrations and the change in violating monitor to the Hurst Road monitor in North Pole, which is still in the Fairbanks nonattainment area. Additional attainment modeling was performed for the year 2029 and a FDV was estimated for 2023 based on emissions and did not show attainment[8]

5% Plan – 2020 amendment

The 2020 amendment to the Serious SIP modeling included new 4-year design values from the years 2016 to 2019, and a base year of 2019. The guidance recommends a 5-year design value, but due to the dramatic decrease in PM2.5 concentrations and through collaboration with EPA, a 4–-year design value was determined to be more representative of current concentrations. The changes in the Hurst Rd design value that decreased to 64.7 ug/m3 as well as the end of 2019 has prompted a new baseline run of 2019 and a new attainment year modeling that is more expeditious than 2029 and was submitted to EPA Region 10 (R10) in December of 2020.

Table 0.1.3 Design Value Summary 2013-2019 of monitored data

	1 yr 98% tile FRM concentrations							**3-yr Design Value**							**Modeled DV (5-yr except Hurst)[a]**	**Modeled 4 yr DV [a]**
Site	2013	2014	2015	2016	2017	2018	2019	2013	2014	2015	2016	2017	2018	2019	2011-2015 rolling average	2016-2019
SOB	36.3	34.5	35.3	39.7	38.0	27	27.7	41	40	35	37	38	35	31	38.9	32.9
NCORE	36.2	31.6	36.7	30.3	34.4	25.3	27.7	40	39	35	33	34	30	29	38.0	29.6
Hurst Road	121.6	138.3	111.6	66.8	75.5	52.8	65	NA	139	124	106	85	65	64	131.6	64.7
A St							34.1							N/A		

[a] the modeling design value is monitored data averaged from 3 3-yr design values from the monitor or 2 3-yr design values due to availability.

The modeling platform used in the Moderate Area and Serious Area SIPs were the same (2008 meteorology, projected emission to 2019, 2024 and 2029). The only site with monitored data for modeling performance analysis was the State Office Building monitor. There was no monitoring in North

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[8] https://dec.alaska.gov/air/anpms/communities/fbks-pm2-5-serious-sip/ Table 7.8.14.4

Pole until 2009, therefore there was no model performance evaluation available for the Hurst Road monitor.

Model Performance Summary

The only model performance results were from the initial set up of the CMAQ modeling and used the speciation data from the State Office Building. This monitor sampled on a 1 in 3-day schedule and 10 days were used to verify the model performance in year 2008. The overall PM2.5 performed well, but the elemental carbon (EC) and organic carbon (OC) were overestimated, and sulfate (SO4) and ammonium (NH4) performed poorly.

Table 0.1.4 Modeled versed Observed speciation from the Moderate Area SIP

Species	Observed ($\mu g/m^3$)	Modeled ($\mu g/m^3$)
$PM_{2.5}$	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
SOA	N/A	0.01

0.2 Summary of need for an updated modeling platform

There are several reasons why an updated modeling platform may be beneficial. The current modeling platform is outdated. The new versions of the meteorological model (WRF) are available, the air quality model (CMAQ) and the pre-processor models (SMOKE, MOVES, MCIP), the new models have improved processing capabilities for emissions, advanced meteorological options, and new chemistry. The last meteorological episodes modeled are based on 2008 winter conditions and may no longer be representative of Fairbanks winter conditions. There were only two two-week episodes for meteorology with only 12 days of speciation data for model performance. There was no model performance completed in North Pole; the violating monitor for Fairbanks nonattainment area is at Hurst Road in North Pole. The North Pole area remains the focus for control analysis, model attainment, and poor sulfate performance. The past controls have centered on woodstoves and mainly organic carbon reduction. As the PM2.5 attainment moves closer and sulfate controls need to be further assessed, the model does not perform well for sulfate, and it is difficult to quantitatively assess the benefit of sulfate controls.

Table 0.2.1 Comparison of the technical components of the current CMAQ 4.7.1 versus the new CMAQ system 5.3.2

CMAQ 4.7.1	CMAQ 5.3.2
Aero 5 aerosol chemistry	Aero7 aerosol chemistry
MCIP 3 (from WRF 3.1)	MCIP 5 (from WRF 3.1)
SMOKE 2.7	SMOKE 4.7
Model Performance in Fairbanks	Model performance in Fairbanks and North Pole
Speciation collected at State Office Building	Speciation collected at Hurst Rd and NCORE
2008 WRF 3.1 meteorology – 22 days	2019/2020 WRF 4.2 meteorology – 74 days

Updating the modeling platform required not only North Pole FRM and speciation data that was not available before, but new meteorology and WRF model runs, a CMAQ model version update, and preprocessor model version updates (SMOKE, SMOKE-MOVES and MCIP). In the next few paragraphs and Table 0.2.2 below, each model update and the timelines are summarized:

Table 0.2.2 Phases 1, 2, and 3 of the modeling platform technical updates and estimated timeline

Phase 1 Development of the CMAQ 5.3.1 system using existing emissions and meteorology.

Section	Component	Estimated Timeline	Notes
1.1	MCIP5 (using original 2008 WRF meteorology)	completed 7/20/20	EPA ORD as part of the FY20 RARE grant
1.2	CMAQ 5.3.1 compile	completed 8/20/20	Compiled on the DEC Linux server using MPI and the benchmark simulation
1.3	CMAQ 5.3.2 compile and comparison (5.3.2 released in October of 2020 and contained significant updates to woodstoves)	completed 11/21	DEC/Contractor
1.4	Upgrade to SMOKE 4.7 using Serious SIP 2019 EI	completed January 2021	Contractor
1.5	CMAQ 5.3.2- 2019 EI and 2008 WRF (MCIP5)	completed 7/2021	DEC – Initial comparison modeling run on the original 2008 met and emissions
	EPA review of phase one report, concurrent with DEC review	**8/2021Complete and phase 1 modeling report is online**	**EPA/DEC**

Phase 2 Development of the CMAQ 5.3.2 system with new emissions and meteorology

Section	Component	Estimated Timeline	Notes
2.1	WRF Meteorology simulations for new episode winter 2019/2020	complete	Contractor
2.2	MCIP5- 2019-2020	complete	Contractor
2.3	North Pole Speciation data analysis and SANDWICH calculations	complete	DEC
2.4	Inventory Step A Emission Inventory Revisions (2019/2020): -Day/Hour-specific point sources - Episodic temperature dependence for other sectors	complete	Contractor
2.5	Inventory Step B Emission Inventory Revisions (All Applicable Years):	2023	Contractor / DEC

	- Updated space heating survey - Integration of MOVES3		
2.6	SMOKE 4.7 2019/2020 New episode	Complete	Contractor
2.7	Current configuration of CMAQ 5.3.2 model performance evaluation (MPE)	MPE complete	DEC/Contractor
2.8	EPA review of CMAQ 5.3.2 model performance	1-2 months	EPA

Phase 3 Modeling for Regulatory Purposes

Section	Component	Estimated Timeline	Notes
3.1	5-year modeling design value 2017-2021 summary	After EPA approves model performance 2022 -2023	DEC/EPA
3.2	CMAQ 5.3.2 model run with base year 2020 emissions and meteorology.	Complete	DEC/Contractor – fully updated QA/QC and model performance version of CMAQ 5.3.2
3.2.1	Emission Plots for base year 2020	Complete	Consultant/DEC
3.2.2	Concentration Plots for base year 2020	Complete	Consultant/DEC
3.3	Preliminary SO2 Stationary source zero out model test run (used for testing the current CMAQ configuration)	Complete	DEC
3.4	SMAT (Precursor SANDWICH calculations are in section 2.3)	Complete	DEC
3.5	Weight of Evidence on updates to the modeling program 3.5.1- Re-Run of WRF by USEPA ORD 3.5.2- Re-Run of base year 2020, SO2 precursor with CMAQ 5.4+chemistry (May be moved to Model Performance section pending results)	WOE of preliminary ALPACA work-ongoing Ongoing – CMAQ 5.3.3 + chemistry (science version) Feb/March 2023	DEC
3.5.3	CMAQ future year attainment model runs with final approved configuration and updated control strategies implemented into emissions inventory	May 2023 -After EPA approves model performance and final configuration of CMAQ	DEC
3.6	Other ALPACA work -preliminary work that pertains to wintertime chemistry in Fairbanks and insight into sulfate that may improve regulatory modeling and /or weight of evidence	Ongoing	ALPACA /DEC

1 Phase 1

The initial phase of the modeling update is to run CMAQ 5.3.2 with existing 2008 WRF meteorology and 2019 Serious SIP emissions inventory. The purpose of this phase is to directly compare CMAQ model version differences with existing inputs. This will allow time for getting a new CMAQ system up and running and understanding a direct comparison of new speciation and chemistry with no other changes. The following four sections describe the steps to running CMAQ 5.3.2 versus CMAQ 4.7.1 with no other changes to the model input.

1.1 MCIP

MCIP is the meteorology preprocessor for the WRF meteorology to input into the CMAQ model. The original 2008 meteorology translation from WRF output to CMAQ input was completed using MCIP 3 for CMAQ 4.7.1. MCIP 3 is not compatible with CMAQ 5.3.2. For the first phase of the modeling update, a direct comparison from the old 2019 Serious SIP run using CMAQ 4.7.1 to the new CMAQ 5.3.2 is needed. The first step in the modeling platform development is to run the same meteorology and emissions through CMAQ 5.3.2. The original 2008 meteorology was reprocessed with MCIP 5 by EPA ORD as part of a FY20 EPA Regional Applied Research Effort (RARE) project that included a focus on improving $PM_{2.5}$ modeling in Fairbanks. The MCIP 5 data is in 12 min resolution and the emissions are in hourly averages.

1.2 Technical specifications for CMAQ 5.3.2

The new version of CMAQ 5.3.2 was compiled using PGI 19.10, updated netCDF-C and netCDF-fortran libraries. The operating environment is Centos7, and the multiple processing capacities use OpenMPI 3.1.3. The virtual Linux system runs with 16 processors and is run by DEC. Ramboll is the contractor for the model performance of CMAQ 5.3.2 and the WRF episode. They have built a similar CMAQ 5.3.2 version compiled with PGI to run as a parallel system.

1.3 Parallel Machine Comparison

DEC and Contractor compiled parallel systems using PGI as the compiler and the CMAQ version 5.3.2, the latest release at the time the comparison was conducted. The run scripts were set equal, and the second day was run until completion for a machine comparison on January 24, 2008. The plots below show the difference between the two machines by daily average for PM2.5 and each major species (NH4, SO4, NOx, VOC, EC, OC). In addition, the individual plots for each machine are shown for entire domain comparison. In conclusion, the two Linux systems that were set up using the same complier and inputs, produce the same results to three significant figures. This level of accuracy between the two systems gives confidence we run the CMAQ model version 5.3.3 on either system to double our capacity for multiple model runs, when needed.

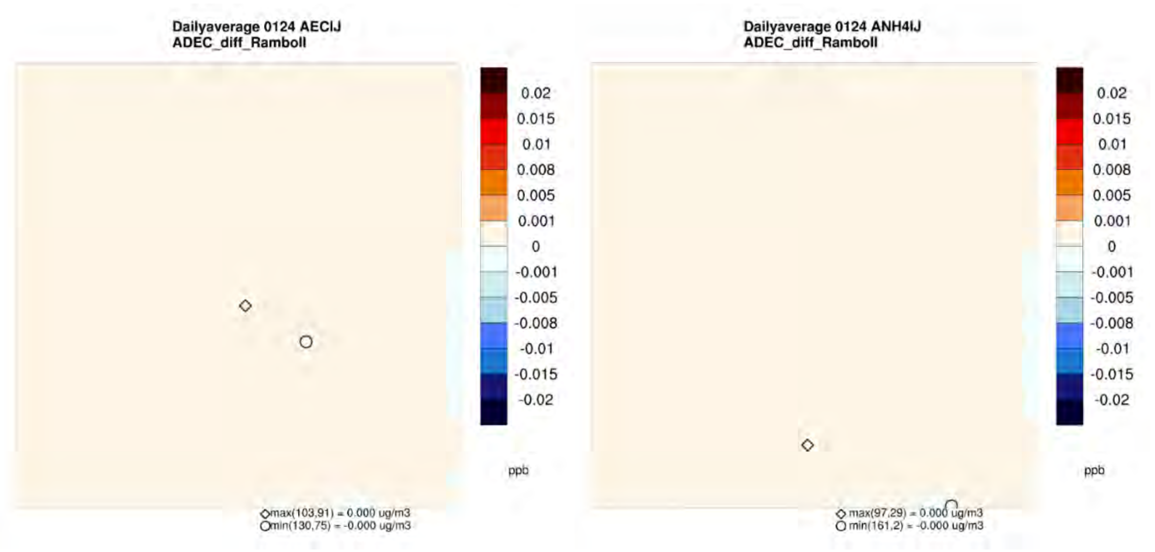

Figure 1.3.1 Elemental Carbon (AECIJ) on the left and Ammonium (ANH4IJ) on the right difference in µg/m^3 between the DEC and Ramboll CMAQ version 5.3.2 modeling systems

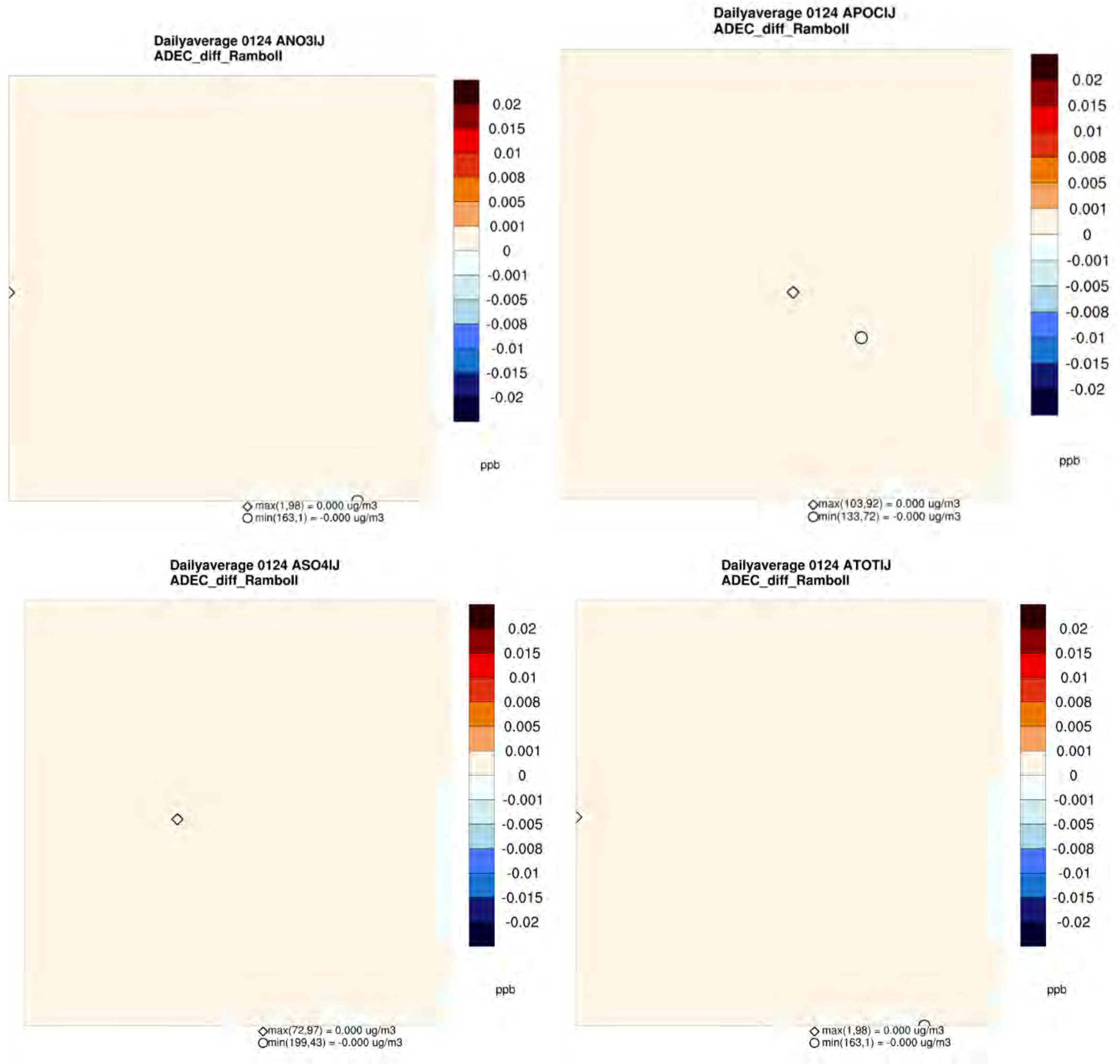

Figure 1.3.2 Nitrate (ANO3IJ) (top left), Organic Carbon (APOCIJ) (top right), Sulfate (ASO4IJ) (bottom left), total PM2.5 (ATOTIJ) (bottom right) difference in µg/m^3 between the DEC and Ramboll CMAQ version 5.3.2 modeling systems

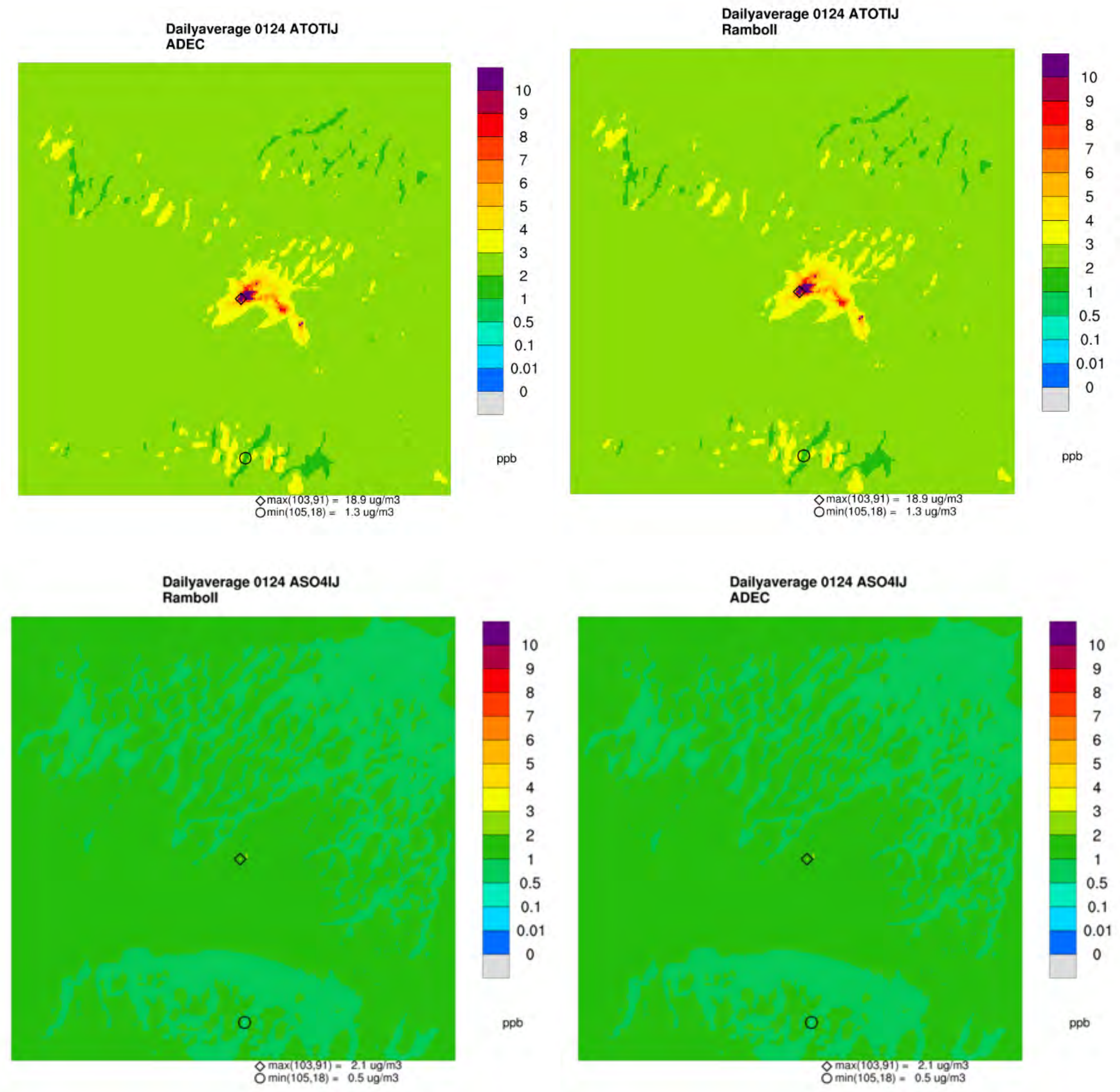

Figure 1.3.3 Total PM2.5 (ATOTIJ) and sulfate (ASO4IJ) for Ramboll (left) and DEC (right) in µg/m^3 for the DEC and Ramboll CMAQ version 5.3.2 modeling systems

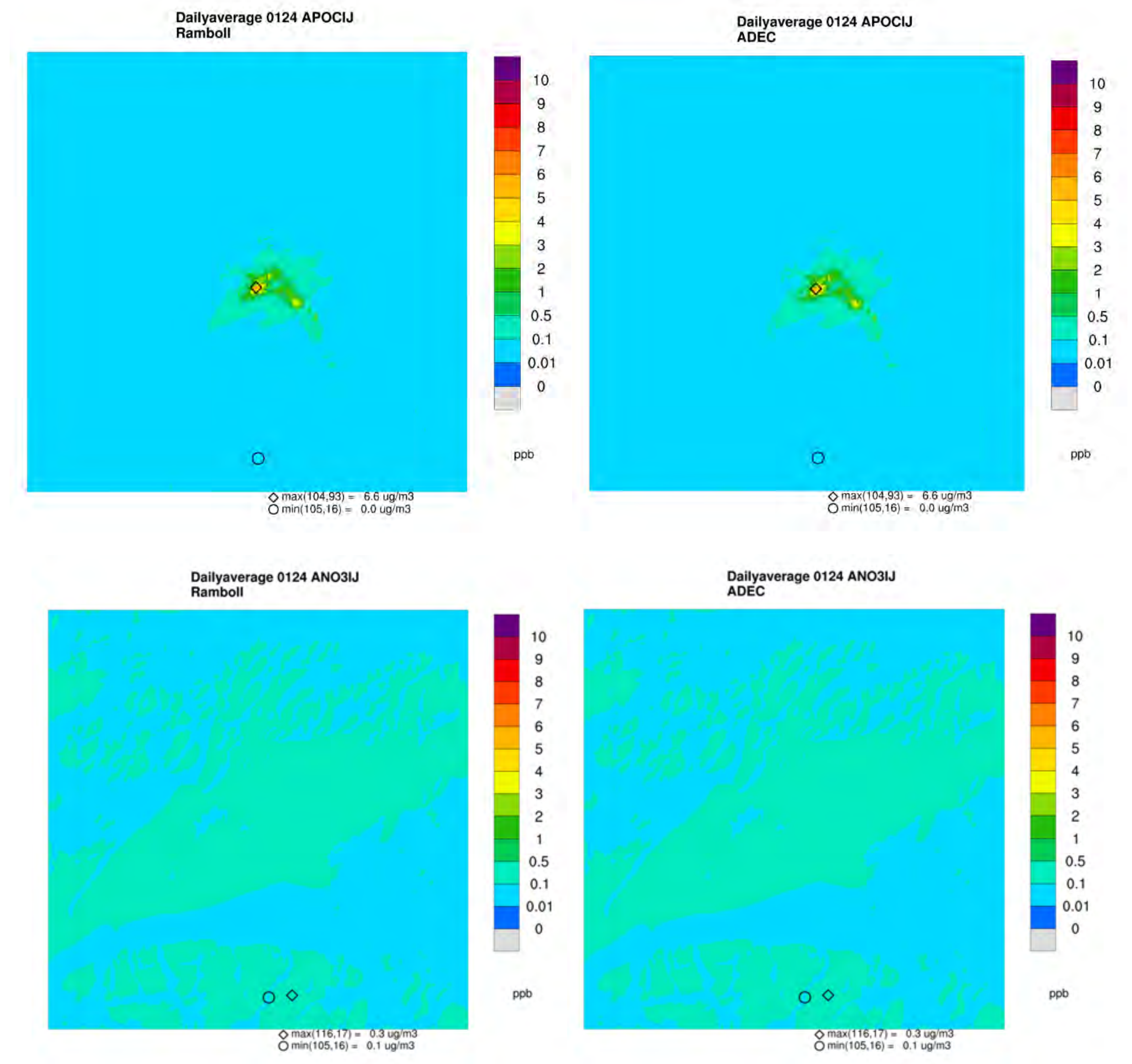

Figure 1.3.4 Primary Organic Carbon and nitrate for Ramboll (left) and DEC (right) in µg/m^3 for the DEC and Ramboll CMAQ version 5.3.2 modeling systems

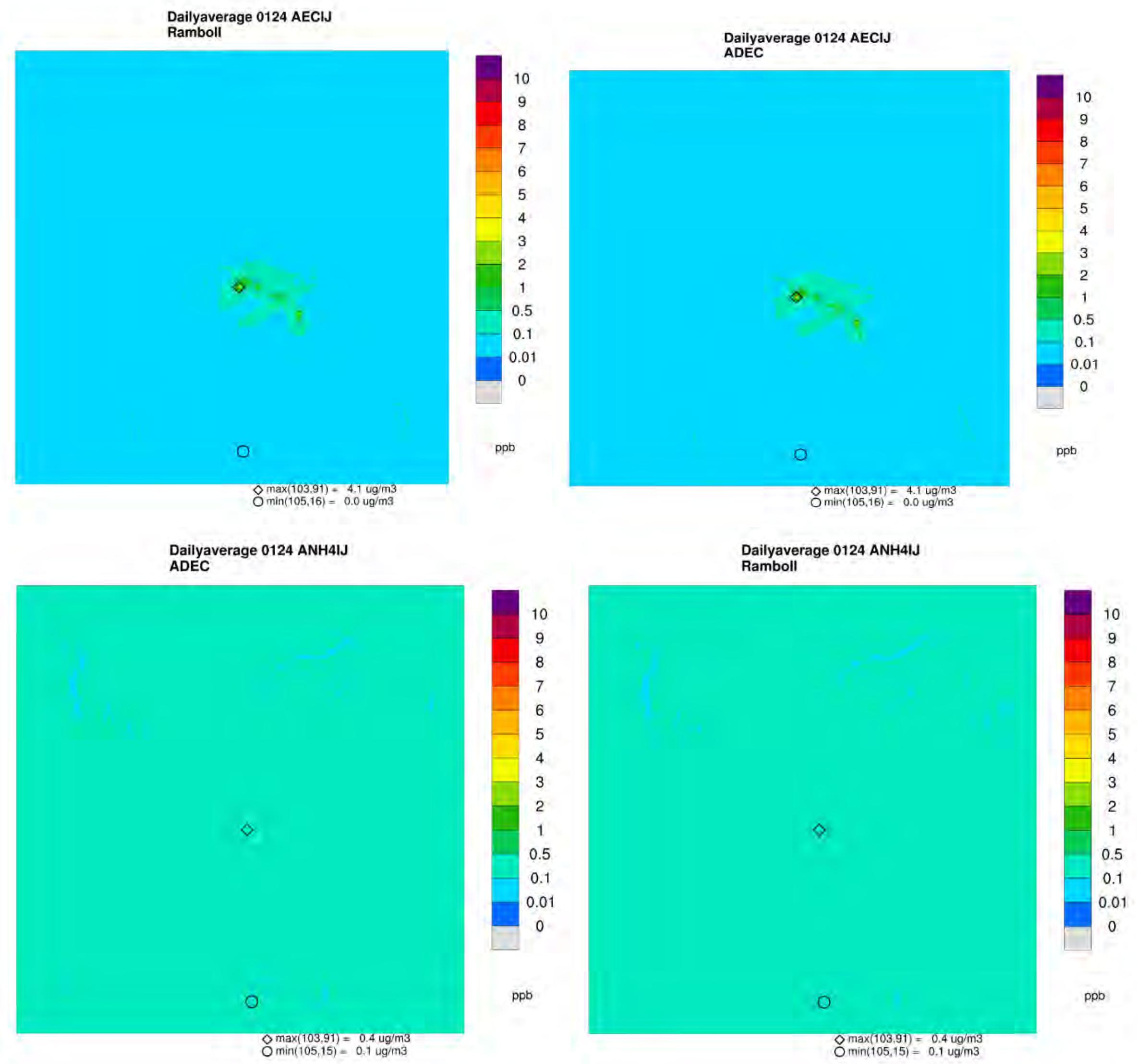

Figure 1.3.5 Elemental Carbon and Ammonium for Ramboll (left) and DEC (right) in µg/m^3 for the DEC and Ramboll CMAQ version 5.3.2 modeling systems

1.4 **SMOKE** – 2019 EI processed through SMOKE

Updated the preprocessor model from SMOKE 2.75b to latest available at the start of the modeling platform upgrade SMOKE 4.7 (an updated version for CMAQ 5.3.2). The SMOKE preprocessor model has updated speciation profiles and more emission profile categories. The same 2019 Serious SIP emissions inventory needs to be run through SMOKE 4.7 to input into CMAQ 5.3.2. The DEC Linux server does not have a compiled current version of SMOKE. The tasks for DEC's contractor to run SMOKE is as follows:

- Run the 2019 emissions through SMOKE 4.7
- Set up and compile SMOKE 4.7 on the DEC Linux server for future use (Revisit after phase 2 CMAQ v5.3.2model performance)

Table 1.4.1 provides a comparison of SMOKE 2.7 and SMOKE 4.7 emissions by source sector for the same input inventory (2019 Baseline from the Fairbanks 2020 Amendments Plan) for the Grid 3 modeling domain, averaged over the 35-day historical 2008 modeling episodes.

Table 1.4.1 Comparison of SMOKE 2.7 and SMOKE 4.7 Emissions (2019 Baseline, Grid 3 Domain)

2019 Baseline Grid 3 Domain Emissions (2008 Episode Average, tons/day)					
Source Sector	**$PM_{2.5}$**	**NOx**	**SO_2**	**VOC**	**NH_3**
SMOKE 2.7 Emissions [a]					
Point	0.59	10.36	5.87	0.03	0.07
Area, Space Heating	2.21	2.61	4.16	9.55	0.14
Area, Other	0.24	0.38	0.03	2.25	0.05
On-Road Mobile	0.27	2.30	0.01	4.90	0.05
Non-Road Mobile	0.36	1.75	7.78	5.26	0.00
SMOKE 2.7 TOTALS	**3.67**	**17.40**	**17.85**	**22.00**	**0.33**
SMOKE 4.7 Emissions					
Point	0.54	9.62	5.44	0.03	0.07
Area, Space Heating	2.08	2.46	3.92	9.00	0.14
Area, Other	0.23	0.36	0.03	2.13	0.04
On-Road Mobile	0.26	2.14	0.01	4.63	0.05
Non-Road Mobile	0.35	1.85	7.20	5.33	0.00
SMOKE 4.7 TOTALS	**3.46**	**16.43**	**16.60**	**21.12**	**0.30**
% Difference (4.7 vs. 2.7)	**-6%**	**-6%**	**-7%**	**-4%**	**-9%**

[a] From Table 7.6.7 of the Fairbanks 2020 Amendments Plan

As shown at the bottom of Table 1.4.1, relative differences in the two SMOKE-processed inventories are within 9% or less for all pollutants. The major difference between SMOKE 2.7 and SMOKE 4.7 is that the point sources for space heating and airport emission are integrated into SMOKE 4.7 without having to change the code. To have a point source for all the home heating sector in SMOKE version 2.7, the code was changed, and the point source information was added. The layer allocation in SMOKE 2.7 was adjusted outside of the SMOKE model both horizontally and vertically. The aircraft emissions were processed by the AEDT (Version2c) aircraft model. For each of the three airfields in the modeling domain (Fairbanks International, Fort Wainwright and Eielson AFB), emissions were horizontally allocated to grid cells encompassing each airfield's runway extent (plus an additional buffer for climb out and descent) and taxiing and terminal areas. AEDT was used to vertically allocate emissions based on input layers that matched those defined for the modeling domain. In SMOKE 4.7, the aircraft emissions are treated as area sources and space heating emissions are treated as point sources. For both these sectors 2D gridded emissions are generated from SMOKE and are vertically allocated in model layers 1-4 using a Layer Allocation SMOKE program to generate gridded 3D emission inputs. All other point sources are processed as inline in SMOKE 4.7.

The major difference in the way emissions are handled between the two versions of SMOKE may account for the large difference in SO2 at the max cell grid (seen Figure 1.5.9 in the CMAQ output in grid cell 51,49 , the Fairbanks International Airport) and below in Figure 1.4.1 in the aircraft emissions sector grid cell plot. The three purple grid cells in Figure 2.3-1 correspond to the Fairbanks, FT WW and Eielson Airforce base.

The gridded emissions plots for SMOKE 4.7 are below for PM2.5, PM other, sulfate and SO2 for all sectors together in Figures 2.3-2 the gridded emission plots for 2019 for SMOKE 2.7 are in lbs/day for all sector emissions together for PM2.5, then points, non-road, road and space heating for PM2.5 in the 2020 amendment.[9] Both sets of plots for total PM2.5 emissions have similar high values in the Fairbanks airport area, Peger Rd and North Pole grid cells and the same magnitude the max cell area of 360 lbs/day (0.18 tons/day) and the 100-500 lb/day values of the grid cells in SMOKE version 4.7.1 (refer to page III.D.7.6-103 of the 2020 amendment referenced above).

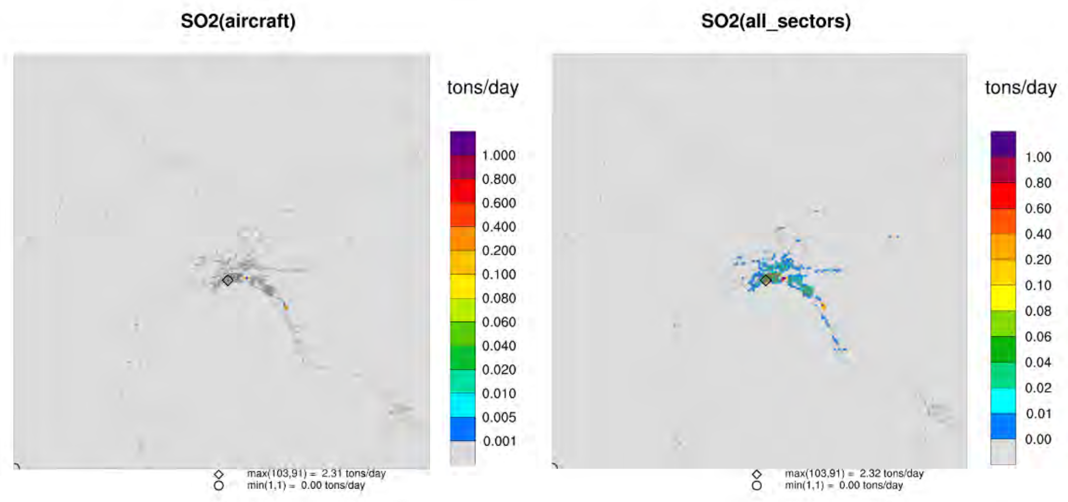

Figure 1.4.1 SO2 emissions plots for all sectors (right) and aircraft sector (left) in tons/day of the lowest four layers in SMOKE 4.7

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[9] Emission Inventory (Alaska.gov)

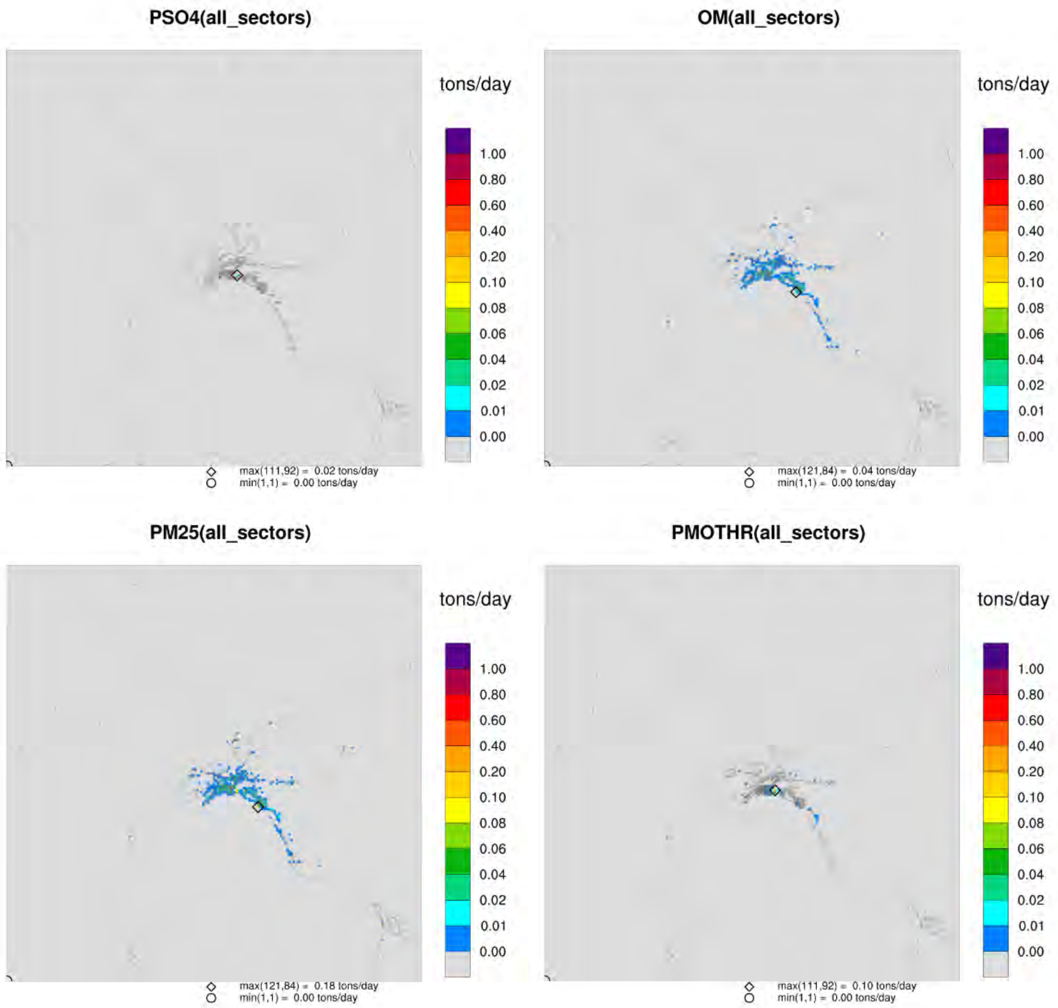

Figure 1.4.2 All sectors' emissions plots for SMOKE version 4.7 with 2019 inventory for PM2.5 (bottom left), PMOTHR (bottom right), Sulfate (PSO4, top left) and Organic Matter (OM, top right)

1.5 Phase 1- Model runs comparison with CMAQ 4.7.1 to CMAQ 5.3.2

The comparison of new CMAQ model version 5.3.2 to the older version of the CMAQ model version 4.7.1 was completed using the 2019 emissions inventory for the last Fairbanks PM2.5 SIP, the 2020 amendment. The DEC Linux system was updated for CMAQ version 5.3.2 and was run on 16 processors with the current 2019 emission inventory and 2008 meteorological episodes. There is no model performance analysis or North Pole speciation data for 2008, since DEC was using the new model version based on the 2008 meteorology and projected emissions inventory of 2019, but DEC can compare model version differences for PM2.5, ammonium, sulfate, nitrate, organic matter (primary and secondary organic carbon), PMother, SO_2, NOx and ozone. Plotting all the PM species and precursors will give an initial comparison of the updated model version differences.

The grid cell plots below (Figure 1.5.1 - Figure 1.5.11), a raw model output of the grid cell at the Hurst road monitor and the NCORE monitor, were extracted for the version 4.7.1 and version 5.3.2 ORG_EMC, BM and particle in the Table 1.5.1.

The following are the definitions for ORG_EMC, BM and Particle that are used in Table 1.5.1 and all of the species plots, both episode average meteorological episodes January 23 -February 10th, 2008, and November 2-November 22, 2008. There are four model runs completed:

1) V471: The first is the original CMAQ 4.7.1 version with the identical 2019 emissions inventory processed through SMOKE 2.7
2) ORG_EMC: The second is CMAQ version 5.3.2 utilizing the original emission control file provide with the CMAQ code download, this version ORG_EMC, is the standard CMAQ version 5.3.2. The emission control file is a new addition to CMAQ 5.3.2 where you can change or eliminate certain emission sources on the SMOKE post processed emissions.
3) BM: The third is the CMAQ version 5.3.2 emission control file and changing the semi volatile organic carbon fractions to represent a biomass dominated emissions, such as Fairbanks and wood stove emissions.[10] The example emission control file in Appendix A.
4) Particle: The fourth is the CMAQ version 5.3.2 emission control file and is the non-volatile version of CMAQ, changing the organic carbon to be all in the particle form. This version was to directly compare to the mechanisms available in the CMAQ version 4.7.1, but not for use in a regulatory SIP model run since the chemistry is outdated.

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[10] acp-16-4081-2016.pdf (Copernicus.org)

The new version of CMAQ 5.3.2 has additional chemistry mechanisms in AERO7 that change how the individual species are calculated for organic carbon. The following describes the main differences in the results between versions, for a complete list of changes in the CMAQ version 5.3.2, see the EPA website. [11]

Discussion on the PM2.5 differences from CMAQ version 4.7.1 to 5.3.2

The CMAQ version 5.3.2 compared to version 4.7.1 included a large update to the organic aerosol with the addition of semi volatile primary organic aerosol (POA). [12] The other addition in 2012, changed the multiplier for OM/OC, but DEC did not change the raw model output or code and the formulas used are below. The 4.7.1 calculation is using a value of 1.167 and woodburning was found to be closer to 1.8 (https://pubs.acs.org/doi/abs/10.1021/es202361w). The version 5.3.2 includes this value as OM is described in the next paragraph with gas to particle conversion.

The update to the biomass burning and combustion are semi volatile instead of all in the particle phase and a sensitivity test was completed called BM (biomass burning profile).[13] This OA (organic aerosol) update allows CMAQ to properly partition emissions between the gas and particle phase. This update recognizes that secondary organic aerosol (SOA) can dominate over POA in most seasons. To look at all of the OC (organic carbon) produced, the CMAQ variable AOMIJ (Aerosol Organic Matter primary and secondary, the "I" Aitken mode and "J" accumulation mode) is plotted in Figure 1.5.4. The change in actual formulas in CMAQ for organic matter are listed below. The CMAQ 5.3.2 plots in Figure 1.5.4, represent the max cell for the AOMIJ at 26.6 ug/m3 for ORG_EMC, 27.8 ug/m3 for BM and 31.2 ug/m3 for particle. This increase is attributed to the organic carbon species, updated mechanisms, and partitioning of the organic aerosol. The POM (primary organic matter) in Figure 1.5.5, shows for 25.8 ug/m3 compared to 26.6 ug/m3 the secondary organic matter accounts for 0.7 additional ug/m3. The OM is the largest PM2.5 component in Fairbanks and there are regulatory controls on the OM as part of wood stove emissions. In Figure 1.5.4 for the OM there is a large increase, 10 ug/m3, and there is a shift in the max grid cell from downtown to North Pole. The emissions for North Pole are dominated by OM, which accounts for 80% of the ambient particulate organic matter in that area compared to downtown Fairbanks at 54%. There is a possibility that shift will more accurately represent the organic carbon in North Pole with further investigation into the OM in Phase 2 of the modeling update when model performance using the speciation from the Hurst Rd site will be available.

The Organic Matter formulas for versions 4.7.1 and 5.3.2 are:

AOMIJ Primary Organic Matter for version 4.7.1

- APOM IJ=1.167*AORGPAJ+1.167*AORGPAI
- AOM IJ = AORGCJ+AOLGAJ+AOLGBJ+1.167*AORGPAJ+1.167*AORGPAI

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[11] Access CMAQ Source Code | US EPA
[12] https://urldefense.com/v3/__https://acp.copernicus.org/articles/17/11107/2017/__;!!J2_8gdp6gZQ!4-sjXKetFcVpUCGihTZztkfJFhOJyGsdBT2aV22BJMy1ktpK1Xxsj7B_3UpB6y7wMpuk$
[13] https://urldefense.com/v3/__https://science.sciencemag.org/content/315/5816/1259__;!!J2_8gdp6gZQ!4-sjXKetFcVpUCGihTZztkfJFhOJyGsdBT2aV22BJMy1ktpK1Xxsj7B_3UpB6wG_BTEU$

AOMIJ Organic Matter for version 5.3.2 (primary and secondary)

- AOMIJ = APOMIJ+ ASOMIJ
- AOMIJ =ALVPO1I + ASVPO1I + ASVPO2I + APOCI +APNCOMI + ALVPO1J + ASVPO1J + ASVPO2J + APOCJ + ASVPO3J + AIVPO1J + APNCOMJ + ALVOO1I + ALVOO2I + ASVOO1I + ASVOO2I + AISO1J + AISO2J + AISO3J + AMT1J + AMT2J + AMT3J + AMT4J + AMT5J + AMT6J + AMTNO3J + AMTHYDJ + AGLYJ + ASQTJ + AORGCJ + AOLGBJ + AOLGAJ + ALVOO1J + ALVOO2J + ASVOO1J + ASVOO2J +ASVOO3J + APCSOJ + AAVB1J + AAVB2J + AAVB3J + AAVB4J

After the OM, the PM other species (Figure 1.5.7) are the most significant change from CMAQ version 4.7.1 to version 5.3.2. The OM accounts for half of the increase in PM2.5 and PMother (equation and details below) accounts for the other half. The largest components of PM2.5 in Fairbanks are organic matter and sulfate as observed by the speciation monitoring. [14]

The sulfate increased in all three scenarios by 1 ug/m3 (Figure 1.5.6). The increase in sulfate is partly contributed to by the increase in background sulfate, this increase is from a change in the initial conditions and boundary conditions that were used in this version of CMAQ 5.3.2 testing by updating the ICON and BCON files of CMAQ by the USEPA.[15] The original IC/BC conditions were based on monitored values from IMPROVE monitors in Denali winter from October to February in 2008-2009 and that discussion is in the Moderate Area SIP Modeling Appendix. Those files are not supported in the new CMAQ version 5.3.2. The version 5.3.2 used profiles based on ICON/BCON files generated from four ASCII files of vertically resolved concentration profiles distributed with CMAQ to represent annual average concentrations at a grid cell over the Pacific derived from a simulation with the hemispheric CMAQv5.3beta2 for the year 2016. These conditions are representative of a remote marine environment. These are not a realistic interpretation of the conditions along the domain boundaries. The IC/BC were tested with day and hour specific data generated from the CMAQ hemispheric run for 2008, the hemispheric model run is a grid size of 108 km and then re-gridded down to 1.33 km. These files were generated from the available EQUATES data set.[16] The difference plots are in Figure 1.5.11. Overall for total PM2.5 (ATOTIJ) the day and hour specific data is lower by 1.6 ug/m3 in the max cell difference which is located near the domain boundary. Phase 2 is designed with new IC/BC, this will be completed with a nested down hemispheric CMAQ model run.[17] Without model performance there no way to attribute the additional sulfate, but in the next phase with new speciation data concurrent with meteorology and emissions during the meteorological episode DEC will evaluate the sulfate performance.

In CMAQ version 4.7.1, the NCORE and Hurst Rd monitor grid cell values for total PM2.5 are calculated by the following formula from the standard EPA model code:

AECIJ+ANO3IJ+ASO4IJ+ANH4IJ+AOMIJ+PM25_OTH

In CMAQ version 5.3.2 the NCORE and Hurst Rd monitor grid cell values for total PM2.5 are calculated by the following formula: ATOTIi+ATOTJ

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[14] Fairbanks PM2.5 Serious SIP

[15] https://drive.google.com/drive/folders/1oLgDp-jVzVv4Ec3ewzCU29Jv036fGZMy

[16] Data Download: Step 2 | US EPA

[17] https://github.com/USEPA/CMAQ/blob/main/DOCS/Users_Guide/Tutorials/CMAQ_UG_tutorial_HCMAQ_IC_BC.md

Then **ATOTIJ** are broken down further for version 5.3.2:

- ATOTI, ug m-3 , ASO4I+ANO3I+ANH4I+ANAI+ACLI \
  +AECI+AOMI+AOTHRI

- ATOTJ, ug m-3 , ASO4J+ANO3J+ANH4J+ANAJ+ACLJ \
  +AECJ+AOMJ+AOTHRJ+AFEJ+ASIJ \
  +ATIJ+ACAJ+AMGJ+AMNJ+AALJ+AKJ

The other species category that represented the largest difference was PMother (PMOTH), in Figure 1.5.7 the PMOTH max cell in version 4.7.1 was 5.8 ug/m3. In the updated CMAQ version 5.3.2, the PMOTH is 10.8 ug/m3. The formula for the PM Other for both versions are:

PM25_OTH for version 4.7.1: A25J+A25I+ANAJ+ANAI+ACLJ+ACL

PM25_OTH for version 5.3.2: AOTHRI+AOTHRJ+ANAI+ACLI+ANAJ+ACLJ

The CMAQ model version changed the parametrization of the aerosols that has led to an increase in PMother.[18] The emissions from PMFINE were assigned to A25J (non-volatile) and in version 5.3.2, PMFINE is speciated into compounds that can partition between gas and particle phase (NH4, H2O and Cl). These three species are now emitted from anthropogenic sources. The initial and boundary conditions of the model were changed from the version 4.7.1 to 5.3.2 and that led to an increase of 0.6 ug/m3 in background concentrations. The initial and boundary conditions will likely change again as the hemispheric CMAQ model that is used to generate the IC/BC conditions will be updated.

The precursors for NOx, Ozone and SO2 are in Figure 1.5.9, 12 and 13. The SO2 is higher than the max grid cells for the Version 5.3.2, this increase is not represented by the total SO2 emissions (Table 1.4.1). The difference may be meteorology or how layer 1 is defined in version 5.3.2 and the inline point source integrated into SMOKE 4.7. The SO2 in ppbv at the NCORE grid cell is 6ppbv for version v471 and 15.33 ppbv in version 5.3.2. The max cell differences are even higher as seen in Figure 1.5.9. These differences in SO2, are likely from the SMOKE processing changes in layer allocation as mentioned above in section 1.4 and can be seen in the gridded sector plots for the SO2 emissions in section 1.4.

Table 1.5.1 Monitor grid cell averages for both episodes for 2019 for PM2.5 in µg/m^3

Monitor Species (Model variable)	4-year modeling DV (2016-2019)	FRM 98%-tile	Version 4.7.1	Version 5.3.2 ORG_EMC	Version 5.3.2 BM	Particle	New icbc V532 ORG_EMC
NCORE PM2.5 (ATOTIJ)	29.6	29	22.4	19.7	20.5	22.3	19.0

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[18] https://www.airqualitymodeling.org/index.php/CMAQv5.0_PMother_speciation

Sulfate (ASO4IJ)	NA	NA	2.2	2.55	2.54	2.55	1.93
Organic Matter (AOMIJ)	NA	NA	11.15	8.62	9.42	11.17	8.9
Hurst Road PM2.5 (ATOTIJ)	64.7	64	15.9	29.8	30.9	33.6	29.1
Sulfate (ASO4IJ)	NA	NA	1.1	2.16	2.15	2.16	1.5
Organic Matter (AOMIJ)	NA	NA	11.3	21.03	22.13	24.84	21.44

Table 1.5.1 lists the species PM2.5, sulfate, and organic matter for the grid cell at the monitor for Hurst Rd and NCORE. The sulfate increases by 1 ug/m3 at the grid cell and the organic matter has a large shift at the Hurst Rd monitor with the addition of 10 ug/m3.

The only changes made to meteorology were from MCIP3 to MCIP5 both using WRF 3.1, it is unclear if the meteorology played a role in the new version 5.3.2, but EPA RARE grant researchers have presented that their preliminary results of only switching from WRF 3.1 to WRF 4.1.1 showed a 20% increase in Organic Matter.[19] There may be reason to believe that the MCIP change might have added an increase in OM and SO2 at the surface. The SMOKE emissions comparison is listed in section 1.4 of this report and after comparing the SMOKE processed outputs the emissions are the same, so the SO2 increase is not from the emissions.

The modeling design value in the review section 0.1 (Table 0.1.2) was calculated in the 2020 SIP amendment[20] using average winter speciation from years 2016 to 2019. This is the base year of 2019 and the relative response factor used to calculate a future design value is 1 for modeling and then divided by the future years (2023, 2024, 2026). A direct comparison of the modeling design value through SMAT is not possible in Phase 1, without looking at future year emissions inventory for the old 2008 meteorological episodes, as was done for the 2020 amendment. There is no other added insight into the DV calculated for the SIP until Phase 2 when the increase in organic matter and sulfate can be evaluated against model performance. This evaluation will take place in Phase 2 of the modeling platform update.

All the species' plots for version 5.3.2 have been compared to version 4.7.1 and differences are expected with a large update for version 5.3.2. The results of phase 1 all look reasonable and the working modeling platform with CMAQ version 5.3.2 is suitable to use with the current inventories, however, the same challenges still exist in that DEC is using the 2008 WRF without concurrent emissions and meteorology. Phase 2 of this modeling project address these challenges with model performance for all

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[19] Email with Havala Pye and Kathleen Fahey from EPA ORD on the Fairbanks sulfate investigation on the RARE grant

[20] https://dec.alaska.gov/air/anpms/communities/fbks-pm2-5-serious-sip/

species using new monitored speciation in North Pole. A full list of all species definitions that were used in the post processing, are in Appendix A. The species definitions were downloaded from the EPA CMAQ website and no changes were made to v5.3.2 (ORG_EMC plots). The comparison of the two versions included averaging both episodes together, the same as the moderate and serious area SIPs to represent the winter high PM2.5 exceedance days. Episodes 1 and 2 have different meteorology and emissions and the individual episodes for all species and precursors are listed in Appendix A for completeness.

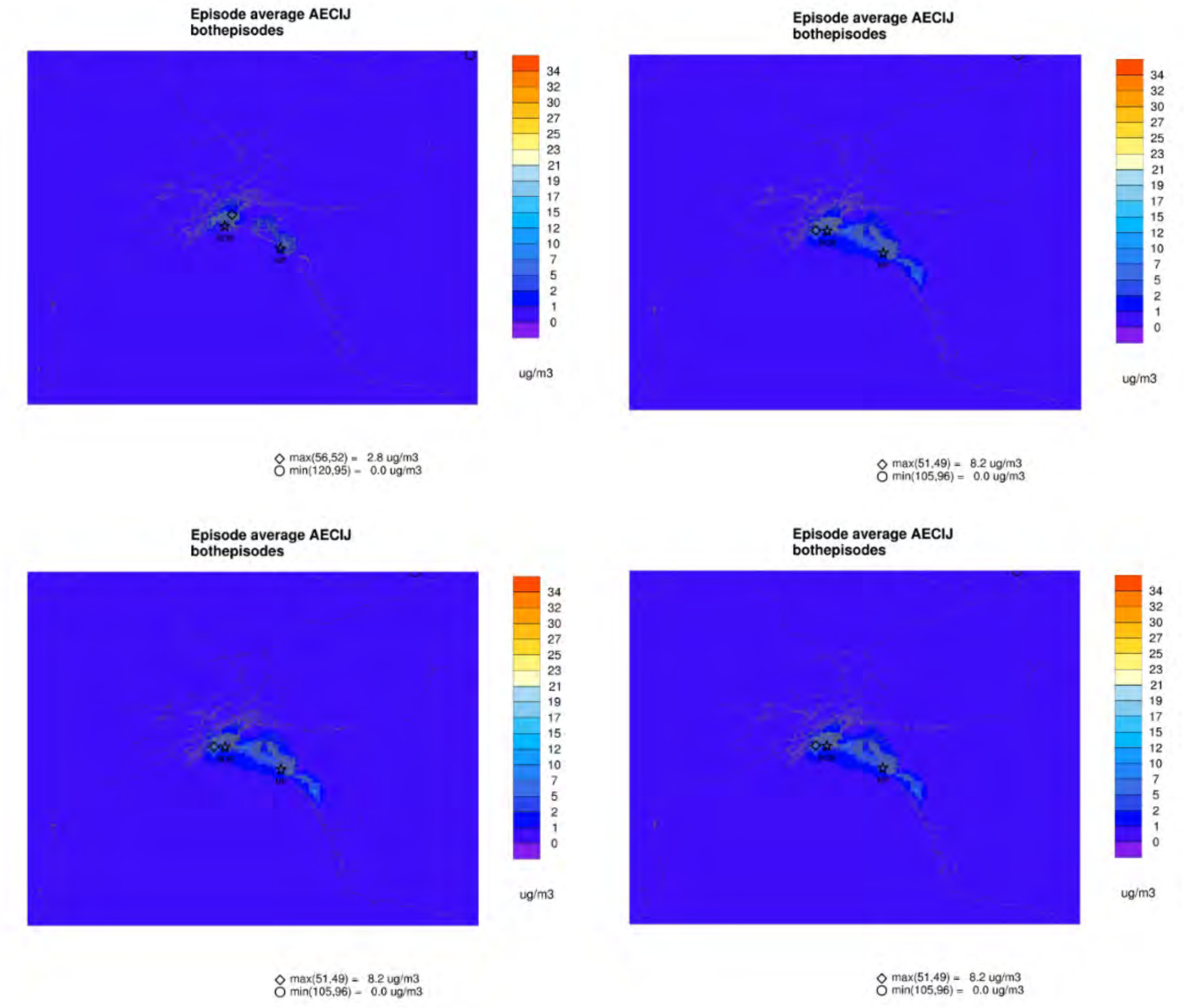


Figure 1.5.1 Elemental Carbon(AECIJ) in µg/m^3 both episode average concentration in the domain area at 1.33 km grid cell for 2019 base year emissions inventory using CMAQ version 4.7.1 (top left), CMAQ version 5.3.2 ORG_EMC (top right), BM (bottom left) and particle (bottom right)

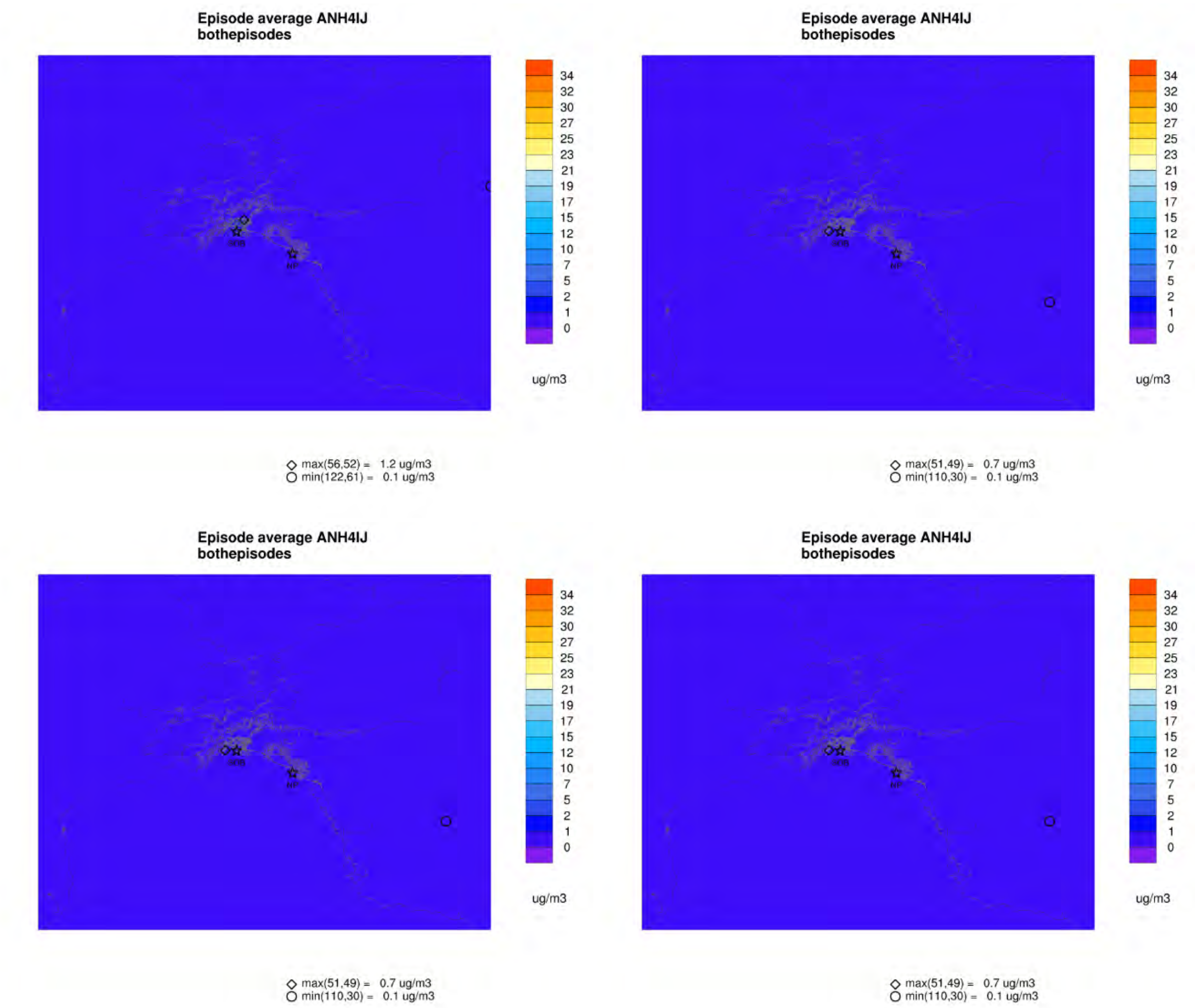


Figure 1.5.2 Ammonium (ANH4IJ) in µg/m^3 both episode average concentration in the domain area at 1.33 km grid cell for 2019 base year emissions inventory using CMAQ version 4.7.1 (top left), CMAQ version 5.3.2 ORG_EMC (top right), BM (bottom left) and particle (bottom right)

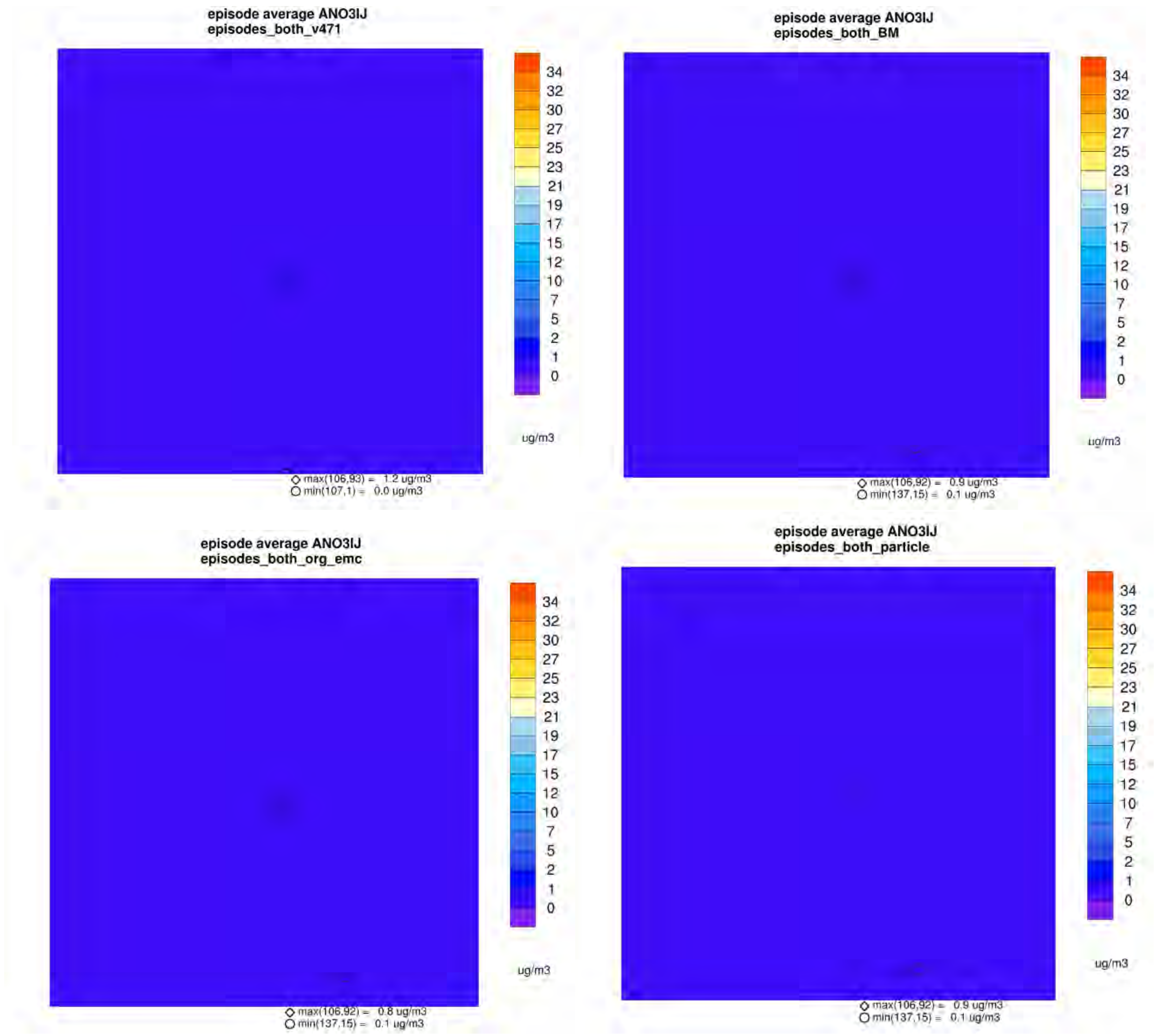


Figure 1.5.3 Nitrate (ANO3IJ) in ug/m3 both episode average concentration in the domain area at 1.33 km grid cell for 2019 base year emissions inventory using CMAQ version 4.7.1 (top left), CMAQ version 5.3.2 ORG_EMC (top right), BM (bottom left) and particle (bottom right)

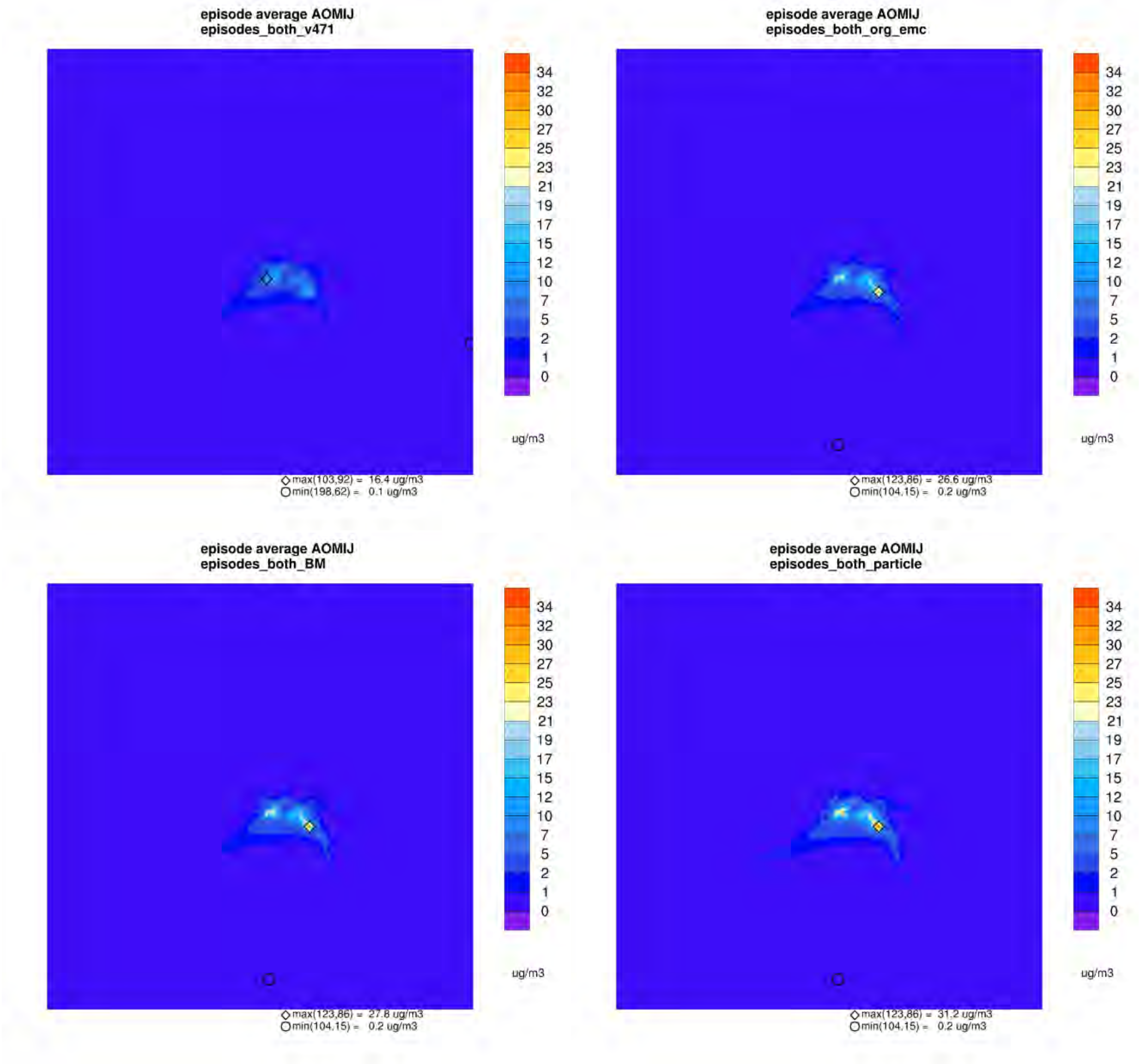


Figure 1.5.4 Organic Matter (AOMIJ) in ug/m3 both episode average concentration in the domain area at 1.33 km grid cell for 2019 base year emissions inventory using CMAQ version 4.7.1 (top left), CMAQ version 5.3.2 ORG_EMC (top right), BM (bottom left) and particle (bottom right)

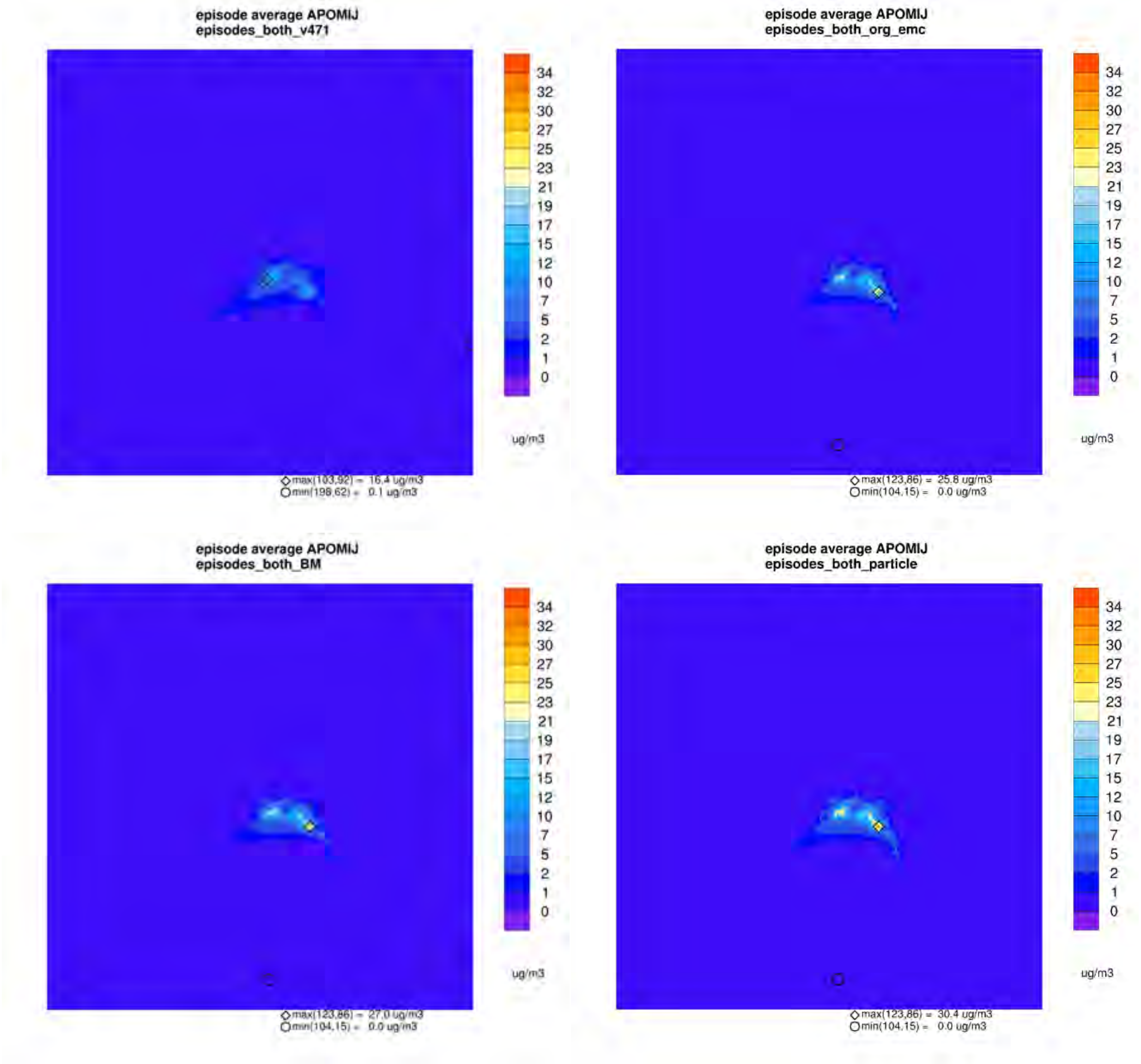


Figure 1.5.5 Particulate Organic Matter (APOMIJ) in µg/m^3 both episode average concentration in the domain area at 1.33 km grid cell for 2019 base year emissions inventory using CMAQ version 4.7.1 (top left), CMAQ version 5.3.2 ORG_EMC (top right), BM (bottom left) and particle (bottom right)

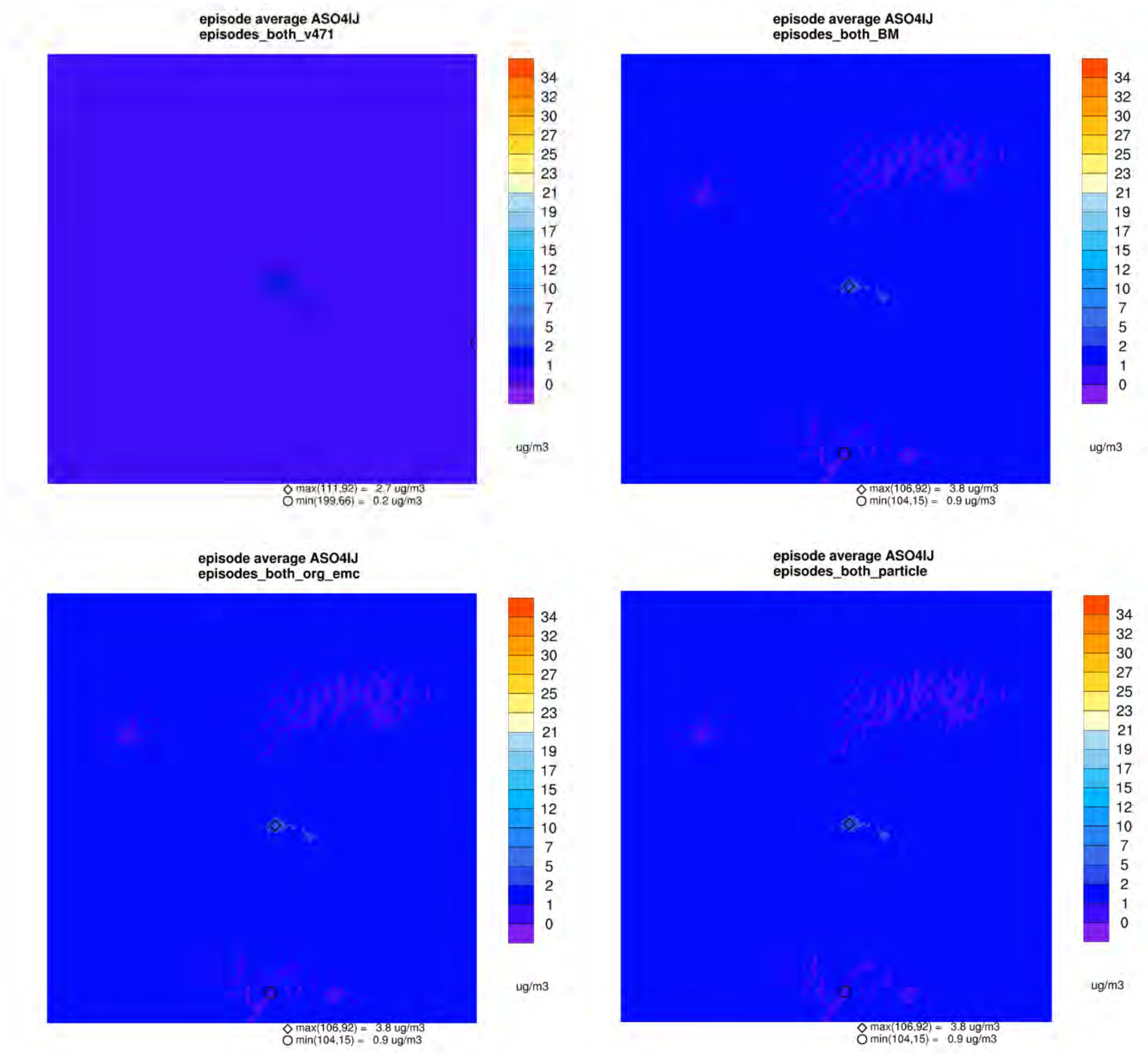
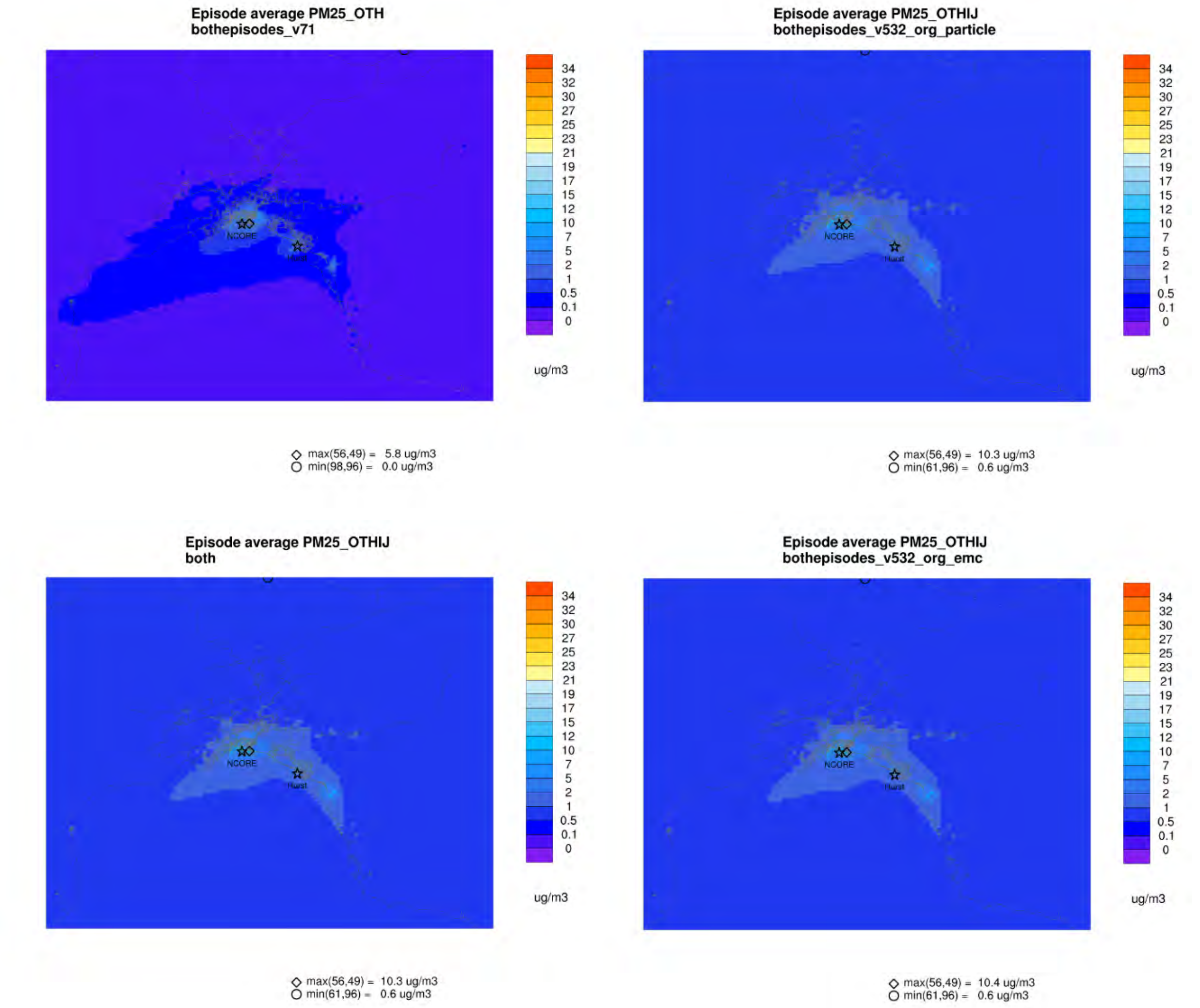


Figure 1.5.6 Sulfate (ASO4) in $\mu g/m^3$ both episode average concentration in the domain area at 1.33 km grid cell for 2019 base year emissions inventory using CMAQ version 4.7.1 (top left), CMAQ version 5.3.2 ORG_EMC (top right), BM (bottom left) and particle (bottom right)


Episode average PM25_OTH
bothepisodes_v71

Episode average PM25_OTHIJ
bothepisodes_v532_org_particle

Episode average PM25_OTHIJ
both

Episode average PM25_OTHIJ
bothepisodes_v532_org_emc

Figure 1.5.7 PM other (PMOTHIJ) in µg/m^3 both episode average concentration in the domain area at 1.33 km grid cell for 2019 base year emissions inventory using CMAQ version 4.7.1 (top left), CMAQ version 5.3.2 ORG_EMC (top right), BM (bottom left) and particle (bottom right)

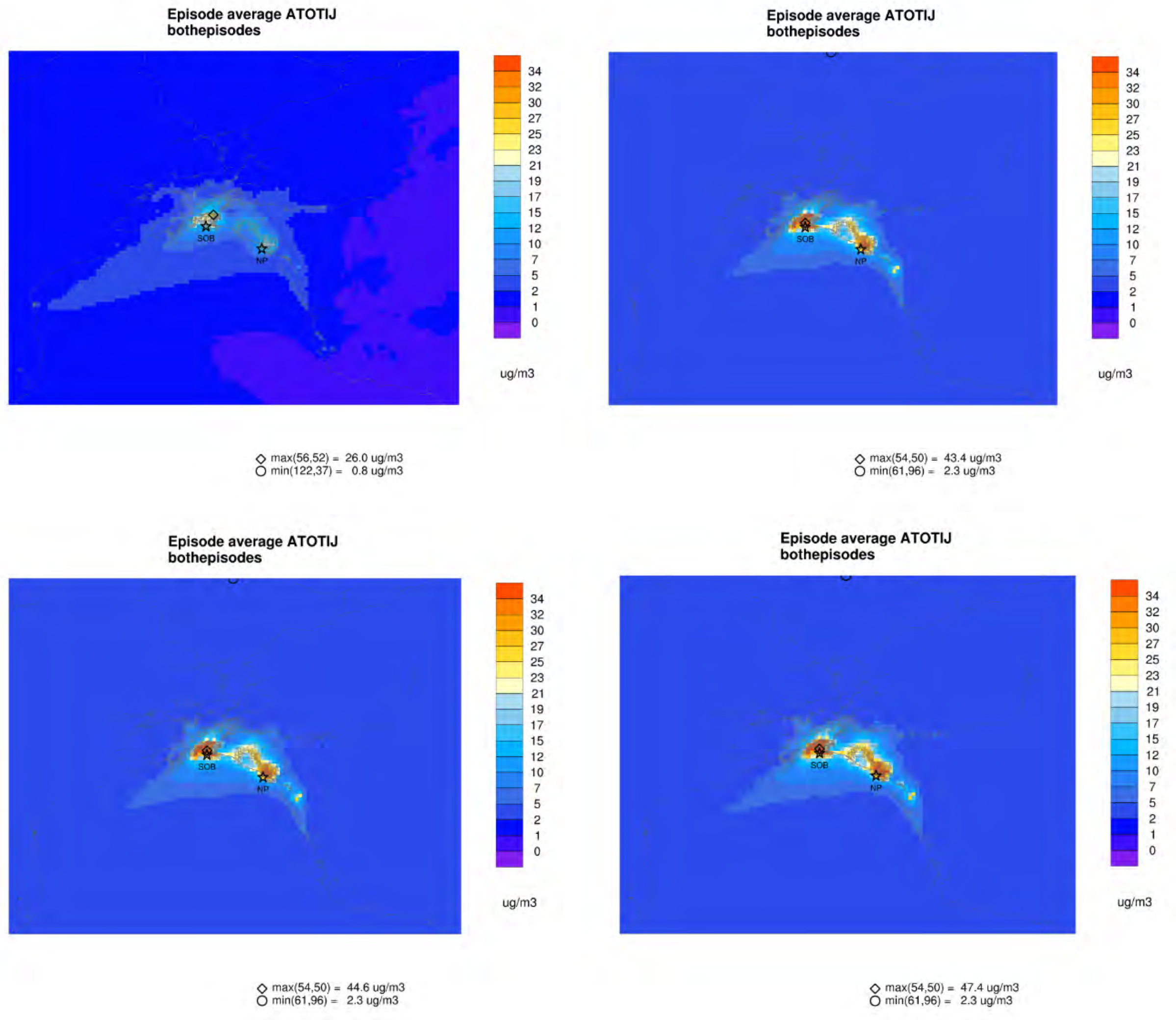


Figure 1.5.8 PM2.5 (ATOTIJ) in µg/m^3 both episode average concentration in the domain area at 1.33 km grid cell for 2019 base year emissions inventory using CMAQ version 4.7.1 (top left), CMAQ version 5.3.2 ORG_EMC (top right), BM (bottom left) and particle (bottom right)

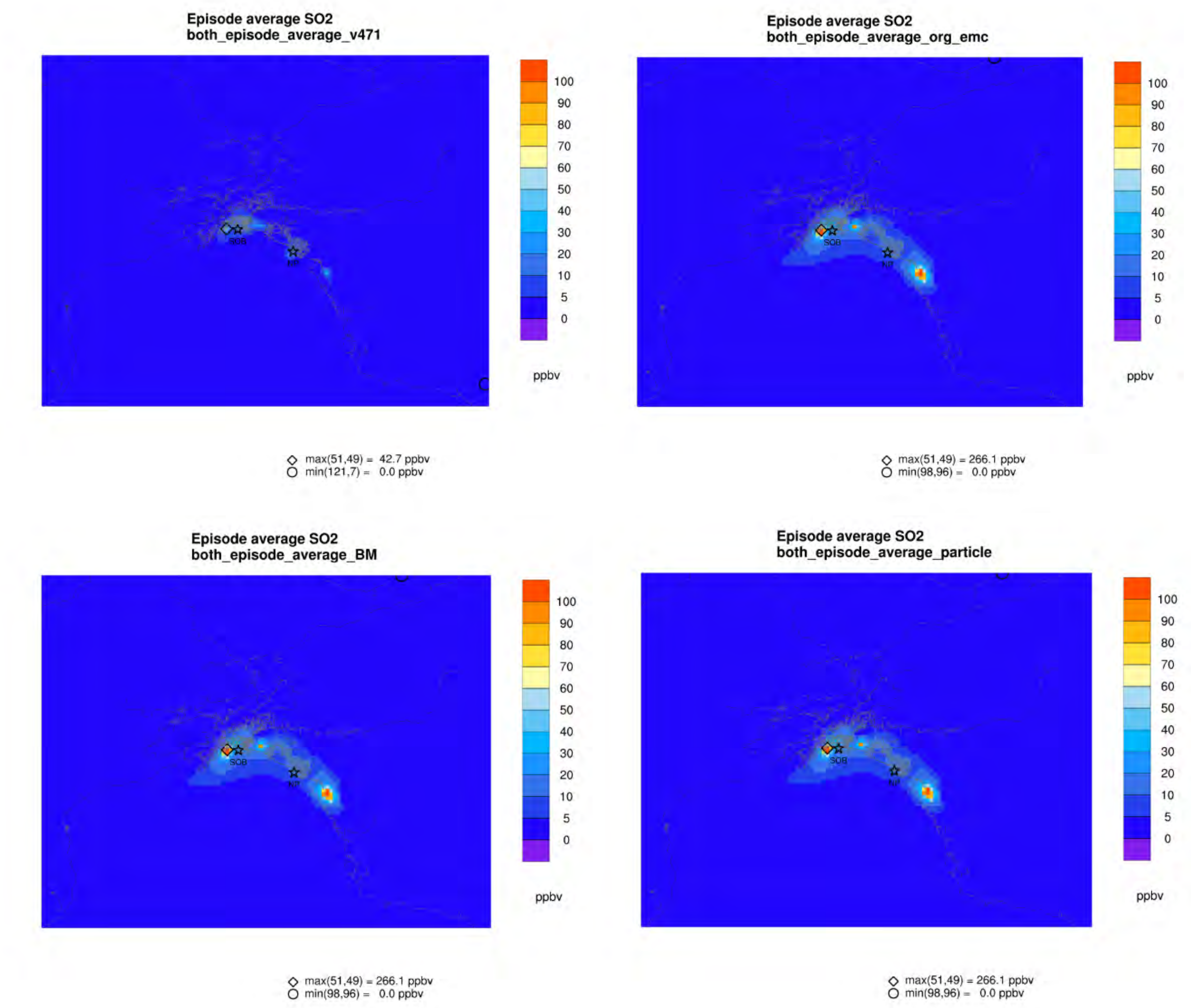


Figure 1.5.9 SO2 in ppbv both episode average concentration in the domain area at 1.33 km grid cell for 2019 base year emissions inventory using CMAQ version 4.7.1 (top left), CMAQ version 5.3.2 ORG_EMC (top right), BM (bottom left) and particle (bottom right)

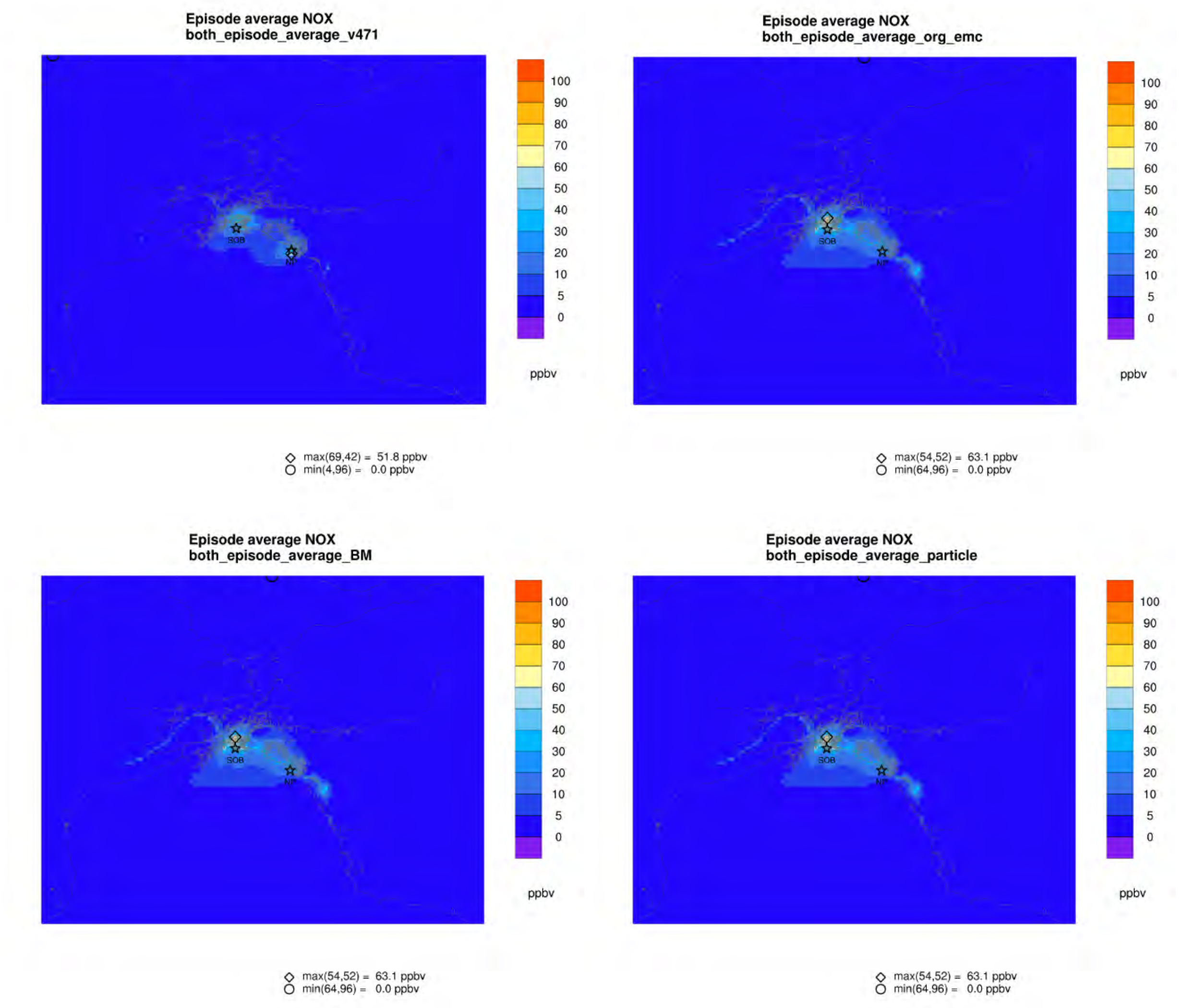


Figure 1.5.10 NOx in ppbv both episode average concentration in the domain area at 1.33 km grid cell for 2019 base year emissions inventory using CMAQ version 4.7.1 (top left), CMAQ version 5.3.2 ORG_EMC (top right), BM (bottom left) and particle (bottom right)

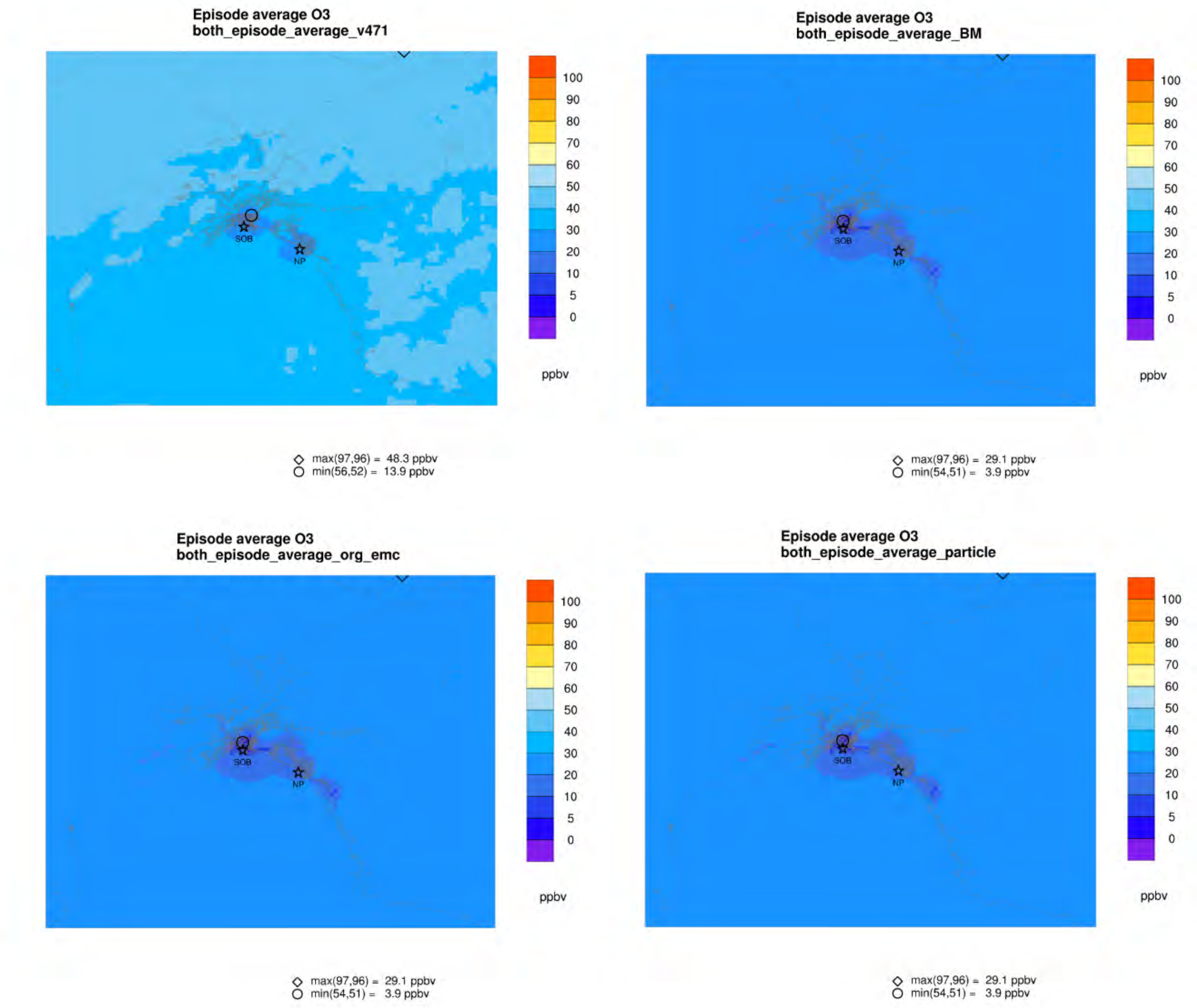


Figure 1.5.11 O3 in ppbv both episode average concentration in the domain area at 1.33 km grid cell for 2019 base year emissions inventory using CMAQ version 4.7.1 (top left), CMAQ version 5.3.2 ORG_EMC (top right), BM (bottom left) and particle (bottom right)

2 Phase 2

The modeling platform update is complete, and CMAQ 5.3.2 is up and running using a new 74-day episode of WRF (weather research and forecast) meteorological model inputs for a newer meteorological episode from winter 2019/2020 that represents both Fairbanks and North Pole wintertime conditions that create PM2.5 exceedances. Figure 2.1.1 shows the meteorological episode and the corresponding PM2.5 monitor data that is available during the same time, the final meteorological episode is December 1, 2019, to February 12th, 2020. The new episode is 74 days compared to the two- two-week episodes used in the Moderate and Serious SIPs. It is important to select an episode that includes inversions that happen in both warmer temperatures and colder temperatures. The colder temperatures represent the PM2.5 nonattainment days and the warmer temperatures have lower PM2.5 and this helps with the spin up phase of the model so it can properly build emissions and check that the model is working accurately at low PM2.5 levels. Figure 2.1.1 shows the monitored data from three monitors: the Hurst Rd monitor in North Pole, A street and NCORE in Fairbanks. The monitored PM2.5 is plotted with the local Fairbanks Airport temperature and wind speed at the same time. The high PM2.5 days coincide with the colder temperatures and low wind speeds. These are the conditions that combined with local emissions create high PM2.5 in the Fairbanks area and that are captured within the 74 days. Phase 2 uses these 74 days of data (monitored and meteorology) with the model to customize the modeling for the communities' conditions.

Phase 2 includes new emissions and meteorological inputs developed for the model and this contracted work is complete and described in the section below for meteorology (2.1) and emissions (2.4). The model performance required an entire winter of FRM and speciation data to be collected for North Pole (2.3) and compared to daily concurrent model outputs. All the tasks involved in the development of new meteorological and emissions inputs into the CMAQ model are outlined in this section.

2.1 WRF Meteorology

The winter 2019-2020 is the focus for choosing the new WRF (weather research and forecast model) episodes that represent Fairbanks's wintertime conditions that cause PM2.5 exceedances.

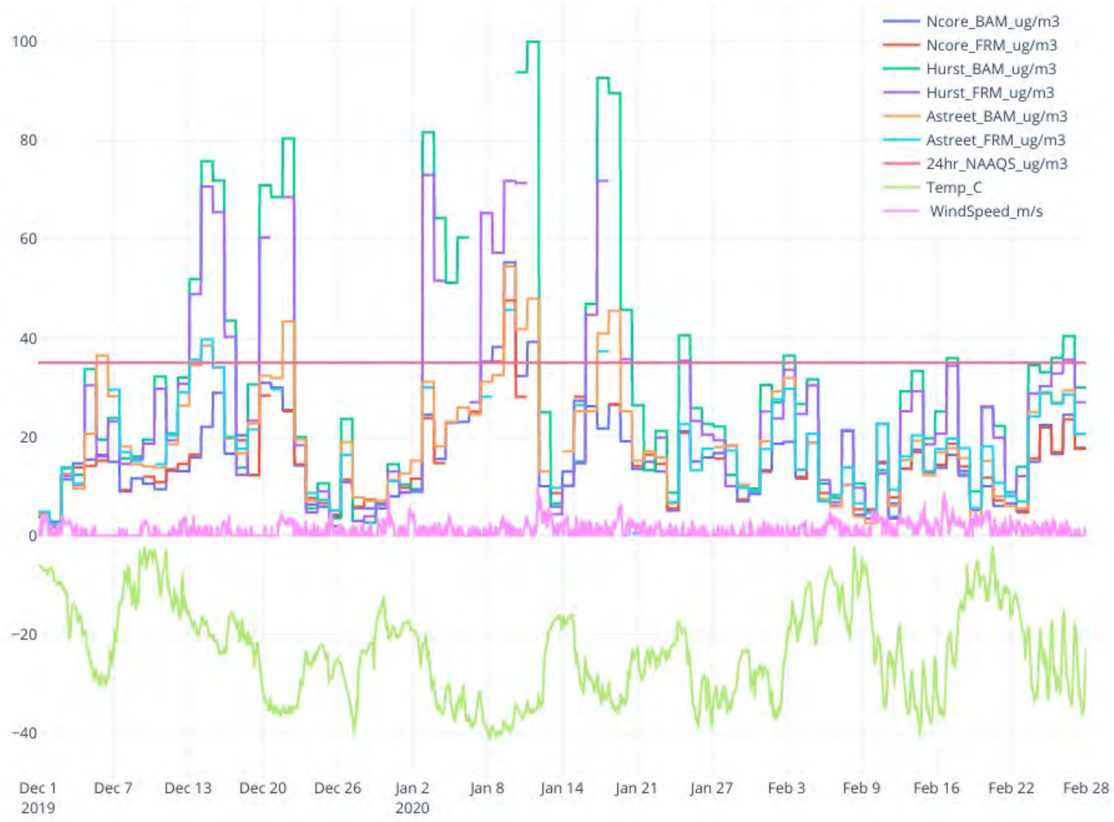


Figure 2.1.1 WRF episode for Fairbanks winter 2019-2020, 74 days from December 1st to 2019, to February 12th, 2020.

The selection criteria were set by EPA Region 10 in accordance with the PM2.5 modeling guidance. The following list summarizes the criteria that must be met based on Fairbanks winter conditions and past meteorological episode analysis.

- Days with 24-hour concentrations near the 2019-2021 current design value (i.e., 67 ug/m3 at Hurst Rd).[21]
- Sufficient days with total PM2.5 and PM2.5 speciation measurements at regulatory monitors to facilitate model performance evaluation.
- Meteorological conditions representative of inversion conditions typically associated with high pollution episodes.
- Time periods of elevated concentrations and sufficient days before and after these time periods to show the transitions from low --> high --> low pollutant concentrations

Past meteorological studies on long term weather patterns in the Crawford (2019) study, show severe inversion conditions in recent years have included temperatures decreasing to approximately -25 to -35 degrees C. Using the median temperatures (-8 to -12 degrees C) presented in the Crawford (2019) study as pollution episode guides for temperatures during non-severe pollution episodes was also suggested as a relevant criterion for the Fairbanks wintertime episode.

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[21] FNSB Summary PM2.5 (Alaska.gov)

The episode selection is from 12/1/2019 to 2/12/2020 (Figure 2.1.2). There are 10 days > 50 ug/m3 (all the highest PM2.5 days at Hurst Road) and this satisfies the criteria of having design value episode days at 67 ug/m3. The wintertime episode includes all days at 40 below for the winter 2019/2020 and strong inversions. There are a few missing FRM days at 40 below, but the one long episode will ensure that there are plenty of FRM days for model performance. The quantity and quality of the sonic anemometer data at Hurst Road during this time is being evaluated by DEC. There are missing data, but with a long episode DEC will capture enough additional met data. The NCORE sonic anemometer is available at 10 and 3 meters for the Fairbanks area to help with the model performance. The Hurst Road sonic anemometers are at 3, 10 and 23 meters. The sonic anemometers track wind speed, and wind direction. There are separate temperatures probes at 3,10 and 23 meters.

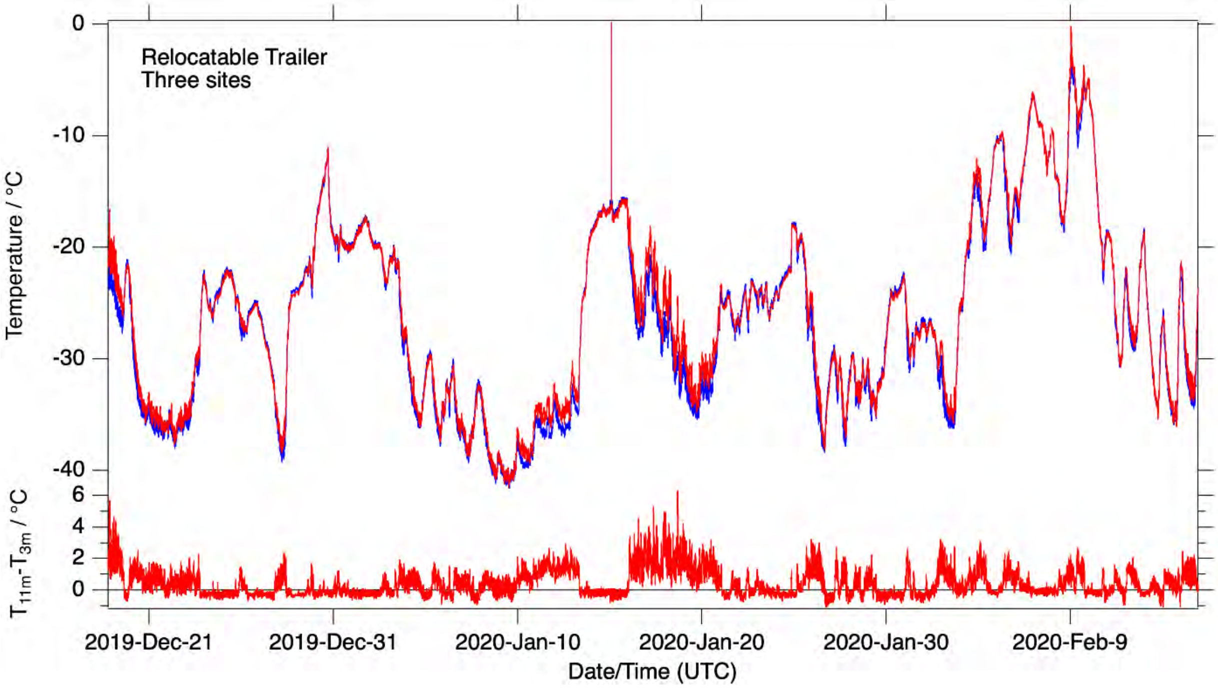

Figure 2.1.2 Temperature gradients of three temperature sites at 11 and 3 meters in the FT WW area

The University of Alaska Fairbanks Bill Simpson research group conducted a concurrent study of temperature gradients in the Fairbanks area and the results are shown in Figure 2.1.2. Figure 2.1.2 depicts periods with large temperature gradients and strong inversions, specifically from Jan 15-20th. During that time the temperature at 3 meters is 6 degrees colder than the temperature at 11 meters, indicating an inversion at these low elevations. These strong inversions are typical in Fairbanks winter and lead to a stable boundary layer and increasing PM2.5. The same dates for example, Jan 15-20th coincides with Hurst Rd PM2.5 concentrations that are near 70 ug/m3, see Figure 2.1.1. There are also periods of neutral stability, or no temperature difference shown from the 12-15th of Jan. This shows that the wintertime episode contains high PM2.5 days at different inversion strengths and periods of neutral stability where the PM2.5 is low.

The WRF meteorology simulations were performed by DEC's contractor, there were multiple sensitivity test and model performance completed.[22] The model performance included comparison to local meteorological stations, including NCORE and Hurst Rd as well the data presented in Figure 2.1.2 from the mobile trailers. The final Table 2.1.1 compares the final two WRF runs that were run to completion for model performance. The final two WRF sensitivity tests were subjected to a model performance evaluation by comparing the WRF estimates with the observed hourly surface wind speed (m/s), wind direction (degrees), temperature (K) and water vapor mixing ratio (g/kg). In addition to using different PBL (Planetary Boundary Layer) schemes (MYJ vs. MYNN2.5) and vertical layer structure (39 vs. 37 levels), the MYNN2.5_37lev also included observation nudging to the DS-3505 surface monitoring network, whereas MYJ_39lev did not include any observation nudging and then was re-run to include obs nudging. Ultimately, the CMAQ version 5.3.2 was run with the MYJ_39Lev_allobs configuration as shown in Table 2.1.1.

Table 2.1.1 WRF configurations for the final two WRF sensitivity tests that were able to simulate the December 1, 2019, to February 12, 2020, modeling period to completion.

Input/Scheme	MYJ_39lev_allobs	MYNN2.5_37lev_allobs
IC/BC and Snow Cover	ERA5	ERA5
SST	FNMOC	FNMOC
Longwave Radiation	Fast RRTMG	Fast RRTMG
Shortwave Radiation	Fast RRTMG	Fast RRTMG
Microphysics	Morrison	Morrison
Cumulus Parameterization	Kain-Fritsch 12 km	Kain-Fritsch 12 km
PBL	MYJ	MYNN2.5
LSM	Noah	Noah
Surface Layer	Noah	Noah
Levels	39	37
Obs Nudging (DS3505 + ADEC)	Yes	Yes

The final modeling report contains monthly comparisons of model performance and time series. Both WRF simulations had a warm temperature bias that was generally between the +/- 0.5 and +/- 2.0-degree goals, with NCore performing better than North Pole and A-Street. See Table 2.1.2 for the monthly summary of metrics for model performance as well as the old 2008 WRF simulations for comparison. As recommended in the WRF report, the kz min sensitivity tests were performed on the CMAQ model run and did not have an impact on the model performance, due to severe overpredictions of PM2.5 on high days at the NCore monitor.

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[22] FAIRBANKS NORTH STAR BOROUGH WRF METEOROLOGICAL MODELING OF WINTER 2019-2020 TO SUPPORT PM2.5 SIP MODELING

Table 2.1.2 Monthly and 2-month average bias and error statistics for wind speed, wind direction and temperature for the final two WRF configurations in this study and the previous WRF simulations from the RARE (Gaudet and Stauffer, 2010) and ADEC TWIND2X30 (Gaudet and Stauffer, 2012) studies.

	MYJ_39lev_allobs		MYNN2.5_37lev_allobs		RARE	TWIND2X30
Site	Dec	Jan	Dec	Jan	Jan-Feb	Jan-Feb
Wind Speed Bias (m/s)						
PAFA	0.67	1.14	1.20	1.43	0.87	0.86
PAFB	0.50	0.64	0.82	0.86	0.32	0.25
PAEI	0.25	0.41	0.60	0.75	0.69	0.69
Wind Speed RMSE (m/s)						
PAFA	1.38	1.48	1.67	1.75	1.58	1.51
PAFB	1.30	1.40	1.35	1.56	1.32	1.21
PAEI	1.11	0.95	1.27	1.22	1.17	1.18
Wind Direction Bias (degrees)						
PAFA	-7.6	6.1	-2.9	-9.0	0.3	-5.6
PAFB	6.8	-14.0	-0.4	-22.7	18.9	3.4
PAEI	-18.3	-10.8	-4.9	-7.4	-19.4	-10.3
Wind Direction RMSE/Error (degrees)						
PAFA	41.1	55.0	43.7	59.7	43.6	21.6
PAFB	50.7	28.8	44.5	56.7	66.4	40.3
PAEI	65.4	64.9	56.1	64.9	55.7	26
Temperature Bias (°C)						
PAFA	4.38	4.68	3.23	3.63	-0.03	-0.12
PAFB	2.61	2.90	1.88	2.14	0.23	0.51
PAEI	1.77	2.39	1.37	1.05	-0.07	-0.23
Temperature RMSE (°C)						
PAFA	4.39	5.06	3.86	4.21	2.20	2.22
PAFB	3.12	3.36	2.72	2.84	1.33	0.51
PAEI	3.01	3.27	3.13	2.53	1.81	2.05

2.2 MCIP

MCIP 5 was completed after the WRF meteorological episode was completed for Fairbanks winter 2019-2020. MCIP 5 will input into the CMAQ 5.3.2 model. This task was completed by DEC's contractor along with the new WRF meteorology.

Upgraded modeling Grid Definition:

MCIP5 has rounding errors and rounded the X/Y origin which created a 166-meter offset. The following steps were taken and a script modifying the grid was used to change the MCIP headers (#5). The header script was created by a DEC consultant and shared with EPA RARE grant team for their modeling. They also used the grid modification for their 2022 ALPACA (see weight of evidence section below) work until the source code can be changed.

- The WRF grid is 201x201 and has X orig, Y orig (-132000, -120000)
- To extract the 199x199 MCIP/CMAQ grid we give a offset of "1" (typically we go with minimum of 5 offset in MCIP but here our WRF grid is not that big)
- So if we do the math with 1 offset, MCIP files (and GRID) should have Xorig = -132000-(-1333.330) = -130666.671875; Yorig= -120000-(-1333.33)=-118666.671875
- However, the MCIP is rounding off and giving -130500, -118500.
- The MCIP source code cannot be fixed at this time. EPA is working on this code. The MCIP source code does not have any impact in the MCIP variables but for emission processing it matters. A header script was made to change the header of the MCIP files. The header script was shared with USEPA RARE grant scientists as well for their modeling work.

The final corrected X and Y origin for the WRF/SMOKE/CMAQ grids: `-130666.672 -118666.672`

2.3 North Pole Speciation data analysis and SANDWICH calculations

The current North Pole speciation for the Serious SIP was based on available years of data from 2012-2015 for the 2011 to 2015 modeling design value (Figure 2.3.1). The only other speciation data available in North Pole was one quarter in 2009. A SASS and an URG speciation monitors were placed at the Hurst Road location in October of 2019 and the data through the winter 2021 was used for the modeling design value calculation. Data collection is ongoing. The updated 5-year modeling design value (DV) for the Speciated Modeling Attainment Test (SMAT) uses the FRM-derived data below. The term FRM-derived is used because the SANDWICH is applied to the speciation data to compare filter mass from the FRM monitor to the mass from the SASS-Speciation monitor as per the EPA guidance.[23] , [24]There are now three monitoring sites with 5-year modeling design values Hurst Road, NCore and A Street. The A Street 5-year DV is based on FRM data for the years available as specified below in Table 2.3.2 and the SMAT calculations are based on FRM data for the A Street monitor and speciation data for NCORE and the averaging % are all top 25 % of wintertime days for years 2017-2021. The SANDWICH method is applied first, this method takes the SASS-speciation filters and makes them mass balance and equal the FRM filters. Then the FRM filter total PM2.5 can be distributed into species percentages for modeling.

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[23] https://www.tandfonline.com/doi/pdf/10.1080/10473289.2006.10464517

[24] https://www.epa.gov/sites/default/files/2020-10/documents/o3-pm-rh-modeling_guidance-2018.pdf

The complete description of the SANDWICH and SMAT calculations can be found the modeling chapter of the Moderate and Serious Area SIPs, the summary tables of new data are below.[25]

Table 2.3.1 Read codes for table below (check online moderate/serious SIP for these definitions)

Species	Definition for Species on filters [a]
PM2.5	Total particulate Matter size 2.5 microns and below
SO4	Sulfate
NO3	Nitrate
NH4	Ammonium
OC	Organic Carbon
EC	Elemental Carbon
PBW	Particle Bound Water
OPP	Other particle particles, including Silica, Calcium, Iron and Titanium
Blank	Blank weight of the filter

Note [a] Definition for species as output from the CMAQ model are different and already account for particle bound water and volatilization.

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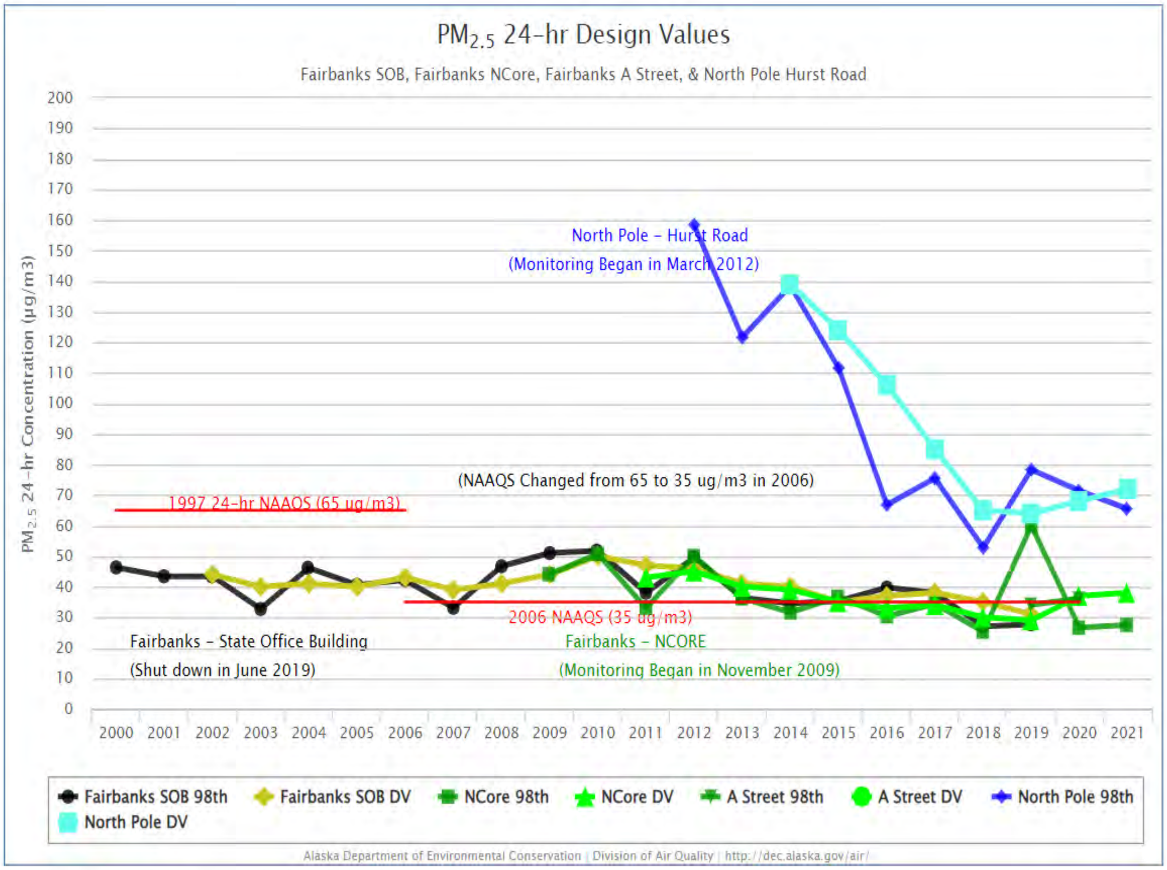
[25] Fairbanks PM2.5 serious SIP (Alaska.gov)



Note: The vertical axis of this chart extends to **200 µg/m^3**.

Figure 2.3.1 Fairbanks PM2.5 24-hr Design Values from 2000-2021[26]

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[26] FNSB Summary PM2.5 (Alaska.gov)

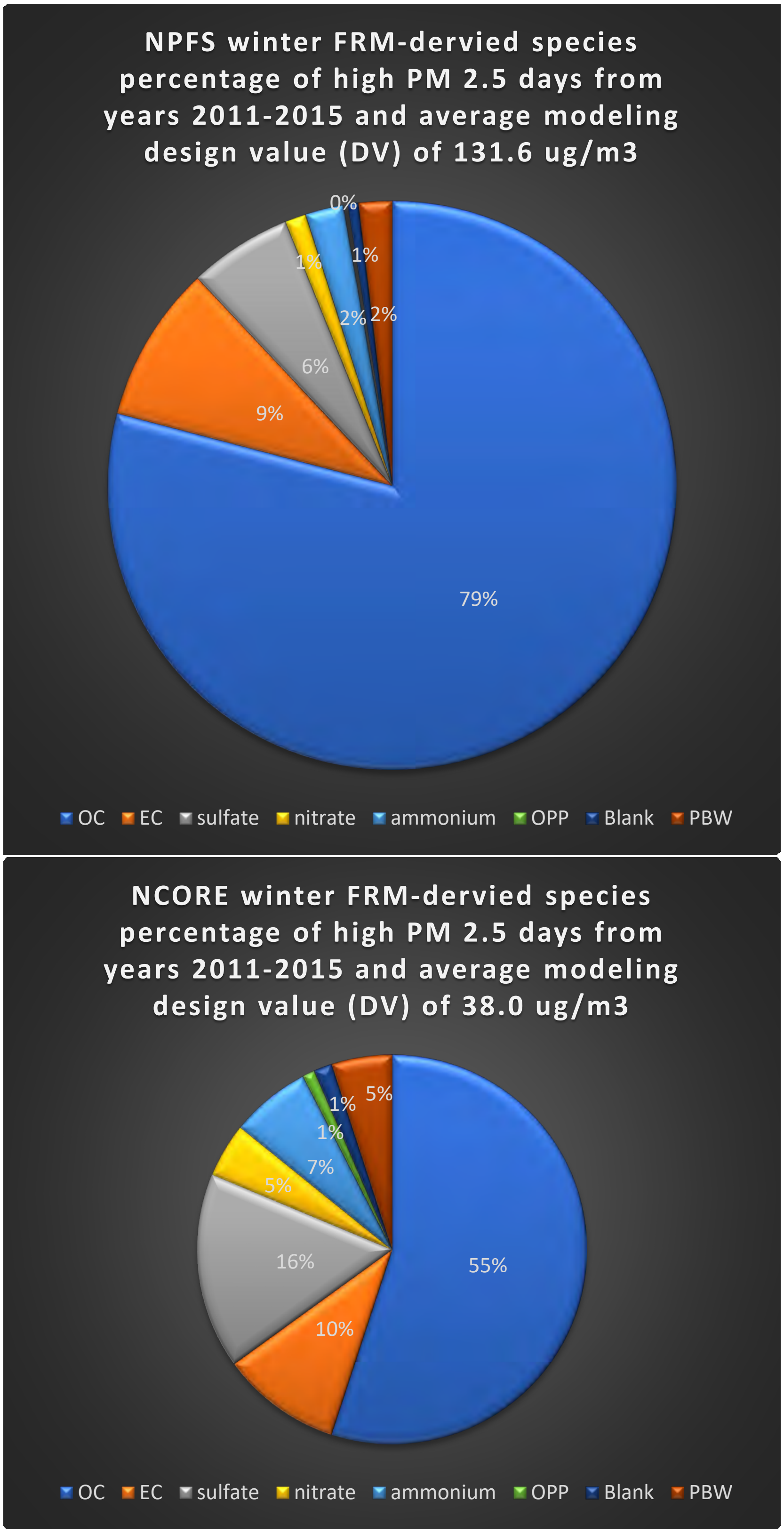

Figure 2.3.2 Serious Area SIP Hurst Rd and NCore winter FRM-derived species percentage of high PM2.5 days from the years 2011 to 2015

Table 2.3.2 Updated 5-year Deign Value 2017-2021 for NCore, Hurst, and A Street monitors with FRM-derived species percentages.

NCORE		**Top 25% winter speciation Data: NCORE 2017-2021**								
		OC	EC	sulfate	nitrate	ammonium	OPP	Blank	PBW	Total Check
µg/m3		13.00	2.42	5.69	1.33	2.01	0.36	0.50	1.64	26.95
% (includes blank)		48%	9%	21%	5%	7%	1%	2%	6%	100%
5-yr DV (2017-2021)	27.5	13.28	2.47	5.81	1.36	2.05	0.37	0.50	1.68	27.5

Hurst		**Top 25% winter speciation Data: Hurst 2019-2021**								
		OC	EC	sulfate	nitrate	ammonium	OPP	Blank	PBW	Total Check
µg/m3		26.64	5.05	3.44	0.71	1.08	0.22	0.50	1.07	38.71
% (includes blank)		69%	13%	9%	2%	3%	1%	1%	3%	100%
5-yr DV[a] (2017-2021)	64.9	44.93	8.51	5.81	1.20	1.82	0.37	0.50	1.80	64.9

Note [a] The 5 year speciation data is based on the speciation available, and may not have been all 5 years.

A Street		**Top 25% winter Speciation Data: A Street 2017-2021 *(NCORE speciation and A street FRM data)**								
		OC	EC	sulfate	nitrate	ammonium	OPP	Blank	PBW	Total Check
µg/m3		13.00	2.42	5.69	1.33	2.01	0.36	0.50	1.64	26.95
% (includes blank)		48%	9%	21%	5%	7%	1%	2%	6%	100%
5-yr DV (2017-2021)	34.8	16.84	3.13	7.37	1.72	2.60	0.47	0.50	2.13	34.77

The SMAT calculations above will be used in the future for the regulatory SIP model runs in Phase 3 and future year attainment model runs that plan on being submitted after the final CMAQ configuration is confirmed. The basis of SMAT is the RRF (relative response factor) that divides the future by the base for a Future Design Value (FDV). The RRF for each species in is added together and multiplied by the 5-year speciation winter high days from above to calculate a final FDV. In SMAT, every day of the year for 5 years is considered and the highest or 98%-tile day for each species is chosen. Excluded are exceptional events days; please see the appendix or attached spreadsheet for the complete set of calculations. The SMAT calculations use the SANDWICH method first in Table 2.3.2 to establish the speciation data for all the FRM data for 5 years for all three monitors. The 5-year design value average is the start of the regulatory modeling and based on 5 years of nonattainment with a base year inventory. The base year is 2020 and emissions inventory is based on 2020. The Base year and emissions inventory is tied directly to Phase 3, the regulatory monitoring. The detail of the completed model runs and using the SMAT calculations based on the working SMATDV tables in Section 2.3 are further explained in the Phase 3 regulatory monitoring section. Establishing new meteorology and emissions in the CMAQ 5.3.2 require the use of an emissions inventory, the next step is the Model Performance Evaluation (MPE) using the new emissions inventory of the winter 2019-2020 and all available speciation for MPE. The base year

2020 rational and all other SMAT calculations using applied controls are found in the Phase 3 section of the modeling report.

The top 25% of winter high PM2.5 day for the three monitor locations Hurst Rd, NCore and A Street are above in the Figure 2.3.1. The Organic Carbon portion of PM2.5 at Hurst Road decreased from 80% in 2011-2015 to 69% in 2017-2021 with a 5-year DV of 64.9 ug/m3. Organic carbon also decreases at NCore from 55% to 48%, while sulfate increased from 16 to 21%. This change in OC is possibly attributed to the wood stove change out and stage 1 and 2 alert curtailment programs. This analysis is ongoing as the ALPACA campaign has a group of scientists looking into these changes.[27]

2.4 Inventory Step A Emission Inventory Revisions (2019/2020)

The emissions inventories (EIs) supporting the new modeling platform will be updated in two phases dictated by likely data/model availability and lead-time requirements. As noted earlier in Table 0.2.2, the Step A emissions inventory was completed in January of 2022. Both Emission inventory phases will include emission estimates for the following pollutants: PM2.5, PM10, SO2 (SOx), NOx, VOC, and NH3 over the selected modeling domains.

The Step A emission inventory was prepared for the 74-day winter episode December 1st 2019 to February 12th, 2020. The Step A 2019 Emissions inventory utilized data sources and methods from the Initial Serious SIP Plan with the following key revisions:

- Use of New Episode Days – New 74 modeling episode days from December 1st, 2019, to January 12, 2020, were selected from the winter 2019/2020 monitoring period were selected and used to update source emissions that are day-specific or temperature dependent. As described separately below, the 2019 EI revisions triggered by use of the new episodes will be handled separately by source sector.

- Incorporation of 2019/2020 Episodic Data for Point Sources – The point sources provided hour and day specific emissions for all emissions units from December 1st, 2019 to February 12, 2020 in site specific excel spreadsheets that were sent by DEC and details are below. Eielson AFB (just outside the nonattainment area)was included in this episodic data solicitation since it is anticipated that Eielson's actual day-specific stationary source emissions may change associated with the F-35 squadron deployment phasing in. The data provided by the point source facilities was reviewed/validated and re-formatted for episodic input to SMOKE using the "PTHOUR" input structure. Where only fuel usage data are provided, facility/emission unit/fuel-specific emission factors from the Initial 5% Plan will be used to calculate episodic emissions.

2020 BASE YEAR EPISODIC POINT SOURCE DATA

To support development of the 2020 Baseline episodic emissions inventory for the new Fairbanks modeling platform, DEC developed data-entry spreadsheet templates for each of the point source facilities in the Fairbanks PM2.5 nonattainment area. These templates were designed to collect hourly fuel use data by emission unit for the 74-day Winter 2019-2020 modeling episode. Data request letters (along with the spreadsheet templates) were sent to the following facilities in December 2020:

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[27] https://fairair.community.uaf.edu/

- GVEA Zehnder Power Plant (Facility ID 109),
- GVEA North Pole Power Plant (Facility ID 110),
- Fort Wainwright (Facility ID 236),
- Aurora Energy Chena Power Plant (Facility ID 315),
- University of Alaska-Fairbanks Campus Power Plant (Facility ID 316), and
- Doyon Utilities Privatized Fort Wainwright Units (Facility ID 1121).

In addition to hourly fuel use for the 74-day episode (12/1/2019 through 2/12/2020), the spreadsheet templates also requested the following elements:

- Emission Factors – Factors for all criteria pollutants, emission factor sources (e.g., AP42, source tests, CEMS, etc.) and units (i.e., by fuel or energy unit).

- Emission Unit (EU) Information – Unit ID and description, SCC code, design capacity, control type and efficiency (where applicable), material processed, seasonal and annual throughput, weekly/daily/hourly operating schedule, fuel characteristics (e.g., sulfur content, energy content, etc.) and release point correspondence.

- Release Point (RP) Information – Point ID and description, stack/vent location latitude and longitude coordinates (and datum), and stack parameters (stack height, exit velocity and temperature, flowrate, etc.).

The data received from each facility were then reviewed for completeness, assembled into a master spreadsheet, and processed into SMOKE4.7-ready input files. This assembly, processing and formatting consisted of the following steps:

1. Master Spreadsheet Import – The hourly fuel use, emission factors, EU and RP data from each facility spreadsheet were loaded into a large “master” spreadsheet for subsequent processing. Due to the fact that some of the facilities slightly altered the data entry template layouts or provided separate information and notes, the data from each facility template were manually copied into the master spreadsheets and edited to reflect a consistent data layout/structure. Separate tabs containing compiled lookup tables of emission factors (indexed by Facility ID and EU ID), emission units and release points (with mapping to appropriate emission units) were also assembled from the data from each facility.

2. Data Completeness and Emissions Processing – In several isolated cases, hourly fuel use data were provided for certain emission units, but emission factors were not provided. Where these data were not provided in separate notes or “ReadMe” information provided by selected facilities, emission factors were assigned by SCC code from AP42. Hourly emissions were then calculated for all facility/emission units operated during the episode and loaded into a separate “PHOUR” tab within the master spreadsheet. The fields in this tab were laid out to match those in the EMS95-Wider Format described in Table 8.25 of the SMOKE 4.7 manual[28] as required for inputting hourly point source emissions via the PTHOUR SMOKE input file.

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[28] “SMOKE v4.7 User’s Manual,” Institute for the Environment – University of North Carolina Chapel Hill, October 2019.

3. Data Validation – A series of validation checks were then performed to review, and where necessary, correct selected elements of the facility-submitted data. These checks included:
    - Release Point coordinate datum conversions (all to WGS84) and visual checks using Google Earth imagery,
    - Rough cross checks against daily episodic emissions for applicable facilities/emission units from the 2019 Point Source modeling inventory from the Serious SIP and notation of where/why difference were observed (e.g., new source test, etc.), and
    - Consistency comparisons to 2020 annual emissions (on average daily basis) for each facility from data assembled into DEC's AirTools Point Source Emission Inventory web portal.[29]
4. Data Export & Formatting – A spreadsheet macro was written and executed to generate CSV versions of the PTHOUR hourly emission and companion ORL file required by SMOKE. A SAS program was then written and run to convert the CSV files into SMOKE-ready ASCII input text files fitting the field width/position requirements for the point source ORL and PTHOUR input files to SMOKE.

This summarizes the key processes used to generate and validate the episodic emissions data for the 2020 Baseline Point Source emissions inventory.

Revision of Episodic Emissions for Other Source Sectors

Based on timing requirements, no new activity data will be collected for the other source sectors (Area/Nonpoint and Mobile). However, emissions for source sectors that are temperature and/or calendar day-dependent will be re-calculated based on these data from the 2019/2020 episode(s). At a minimum, this will include space heating area sources and mobile sources. The Fairbanks Home Heating Energy Model (HHEM) will be re-run to reflect temperatures and days of week from the new episode days and used to adjust space heating emissions. For mobile sources, MOVES2014b and the corresponding version of SMOKE-MOVES will be re-run to reflect the dates and ambient temperatures of the new episode(s). (Although EPA may release a new version of MOVES (MOVES202x) before early 2021, the development of the corresponding SMOKE-MOVES tool may lag the release of MOVES202x. Therefore, Phase 2 emissions were developed using the current MOVES2014b model and SMOKE-MOVES tool.)

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[29] Point Source Emission Inventory (Alaska.gov)

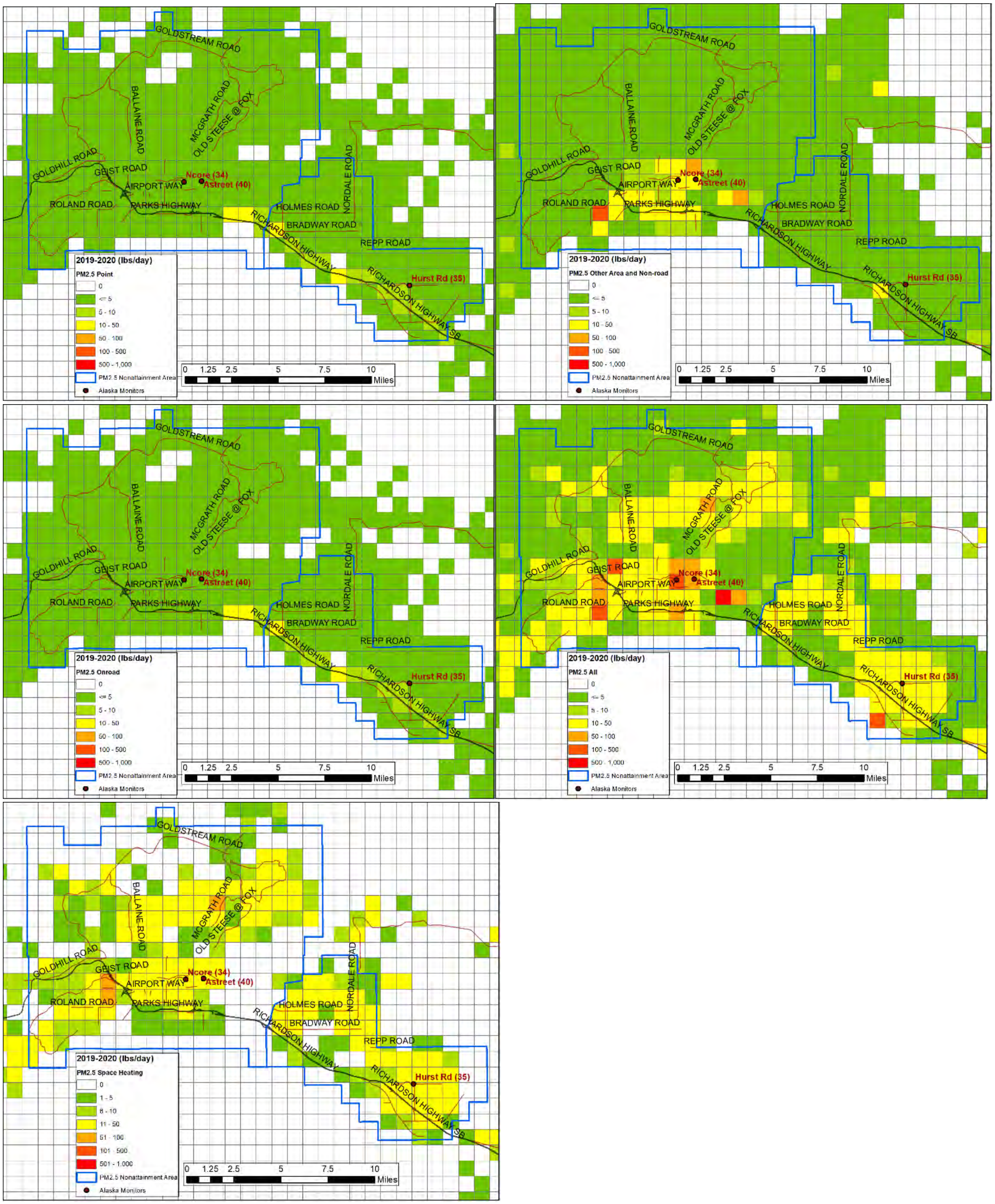

Figure 2.4.1 74-day episode (December 1, 2019 to February 12th, 2020) emission plots of all layers in lbs/day in each grid cell in the Fairbanks Nonattainment Area for PM2.5 for PM2.5 points (top left), PM2.5 other area (top right), PM2.5 onroad (middle left), PM2.5 all (middle right) and PM2.5 space heating (bottom left)

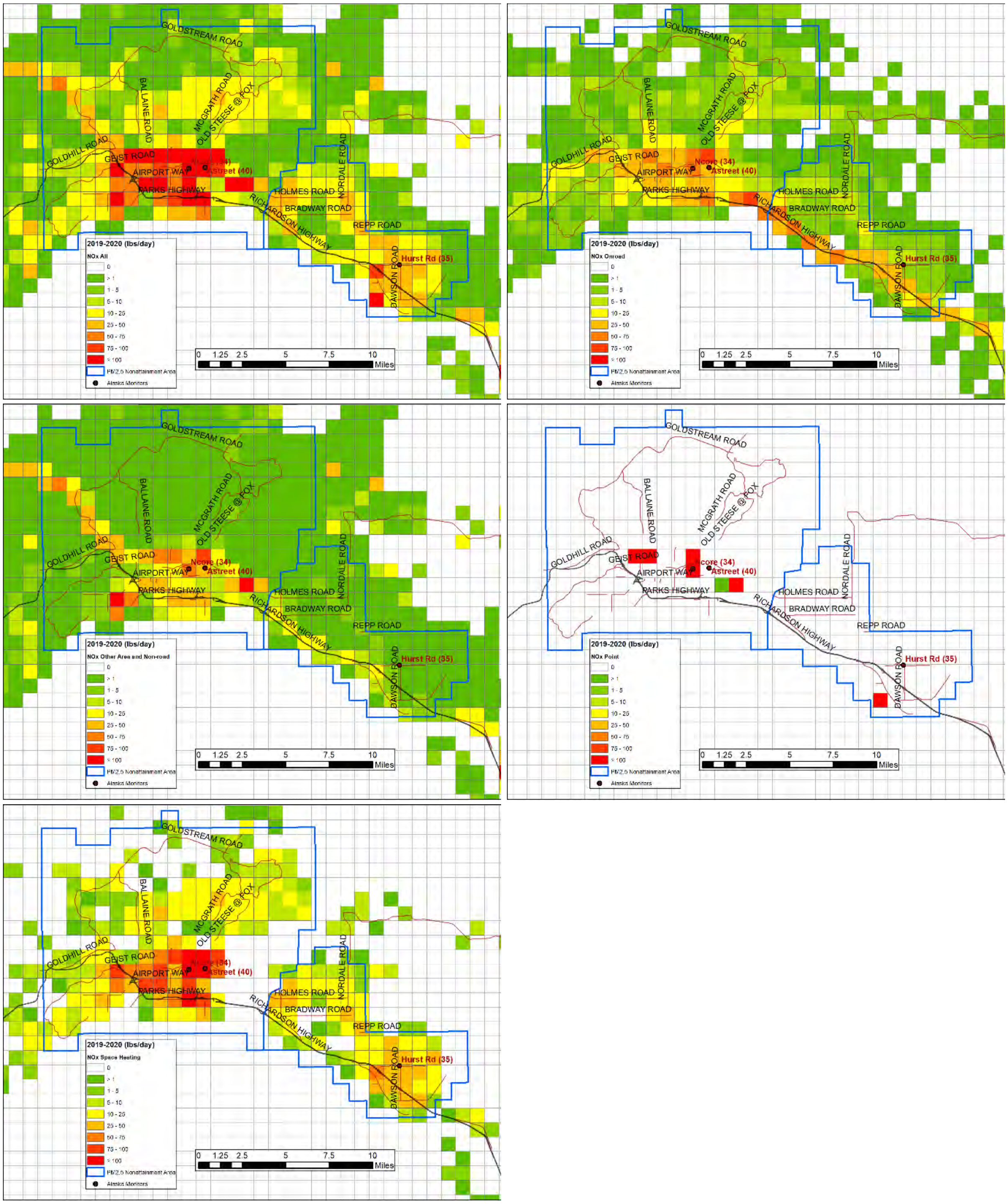

Figure 2.4.2 74-day episode (December 1, 2019 to February 12th, 2020) emission plots of all layers in lbs/day in each grid cell in the Fairbanks Non-Attainment Area for NOx for NOx all (top left), NOx onroad (top right), NOx other area (middle left), NOx points (middle right), and NOx space heating (bottom left)

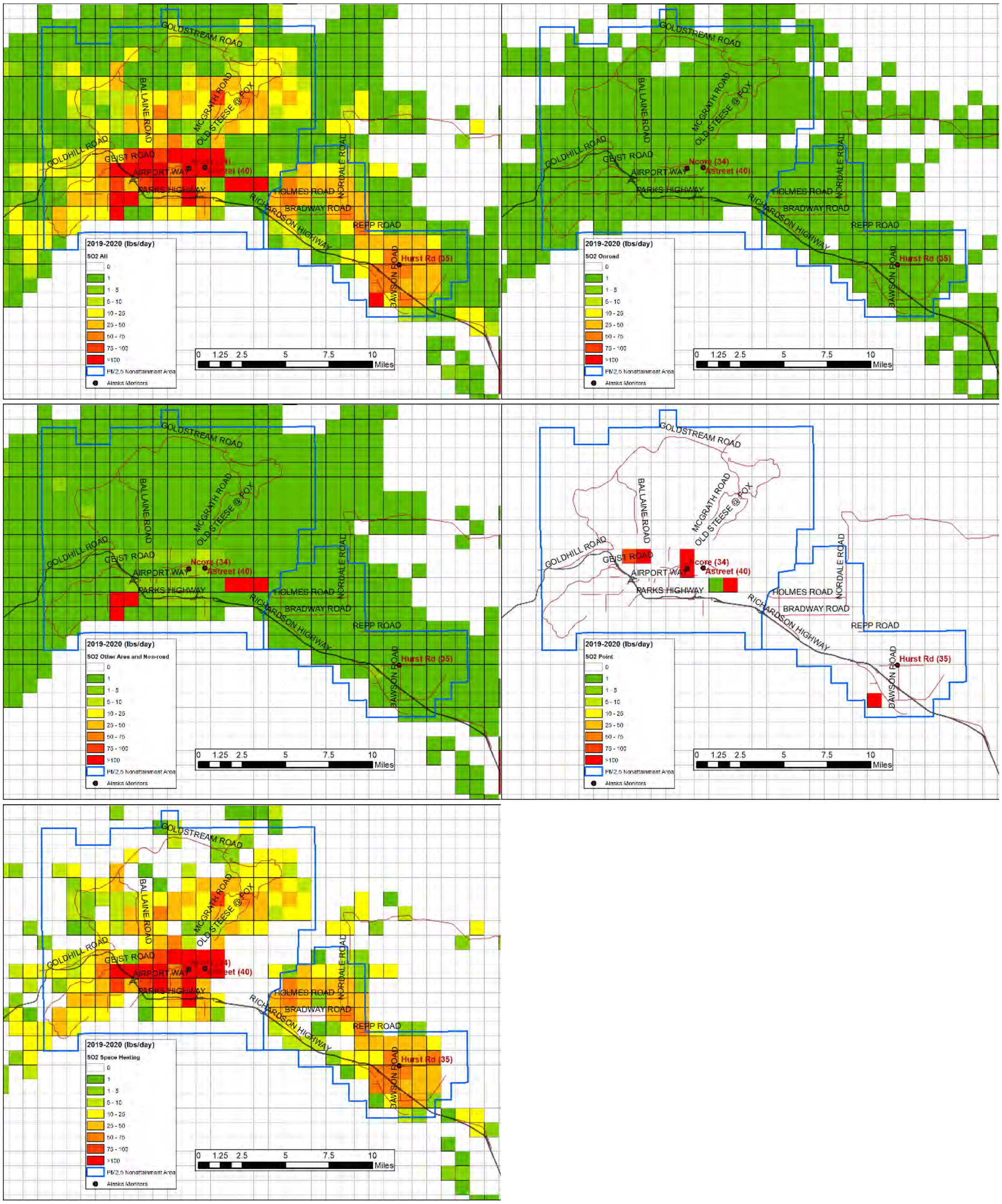

Figure 2.4.3 74-day episode (December 1, 2019 to February 12th, 2020)emission plots of all layers in lbs/day in each grid cell in the Fairbanks Non-Attainment Area for SO2 with SO_2 all (top left), SO_2 onroad (top right), SO_2 other area (middle left), SO_2 points (middle right), and SO_2 space heating (bottom left)

2.5 Step B Emission Inventory Revisions (All Applicable Years)

Emission inventory revisions expected to require new data collection with lead time and other scheduling requirements or related to new source models (e.g., MOVES) will be completed under Step B of the EI development. Step B will also include development of EIs for both 2019/2020 and applicable future years (to be determined) to support updated attainment analysis modeling. As noted in Table 0.2.2, the Step B EI work is expected to be completed in 2023.

At this time, the Step B EI revisions will include (at a minimum):

- Space Heating Survey – The Initial 5% SIP utilizes space heating device and fuel use activity data within the Fairbanks Home Heating Energy Model (HHEM) based on household survey data collected in Fairbanks from 2011-2015. This is coupled with wood-oil cross-price elasticity estimated from similar data that accounts for year-to-year shifts in wood vs. heating oil usage as oil prices change. It is envisioned that additional local space heating survey work will be conducted after the Step A EI is completed to provide more current space heating device and fuel usage patterns beyond 2021 and verify/update the wood and oil price elasticities from the earlier 2011-2015 survey data (as well as elasticity-based fuel usage projections). The results of the new survey will be used to update the space heating activity estimates by device and fuel type (and resulting emissions) within the EI.

- MOVES3 – EPA released a new version of MOVES in January 2021 called MOVES3. The latest update to MOVES3 (MOVES3.1) was released in December 2022. Updates to MOVES3 since its original January 2021 release have included correction of an error in the sulfur correction for Tier 4 nonroad diesel engines that underestimated particulate (PM) emissions from these engines and changes to Inspection and Maintenance (I/M) Program benefits (the latter revision is not applicable to Fairbanks). The release of MOVES3 and its updates came after most of the development of the Phase 1 modeling and may involve workflow changes related to the SMOKE/MOVES tool for use in gridding emissions within SMOKE Thus revisions to mobile source-based emissions (onroad and nonroad) using the newer MOVES3 model will be deferred until Step B of the EI revisions. This will give sufficient time to test and compare MOVES outputs to those from MOVES2014b version for wintertime emissions in Fairbanks from both on-road and non-road mobile sources to ensure emission changes are consistent with the underlying improvements to the MOVES model.

Finally, DEC will also be evaluating potential use of revised solid fuel burning device emission factors from current/on-going testing research that is expected to be published under the Step B EI timeframe. Expected issues to be addressed under this evaluation include completeness/representativeness of testing data and test methods, mechanisms to weight the test results to Fairbanks-specific usage patterns and mapping the tested devices/technologies to the population of installed devices and/or those incentivized through state/local control programs.

2.6 SMOKE Step A 2019-2020 Emissions Inventory

The new 74-day episode emission were prepared for the new winter 2019/2020 episode, it was run through SMOKE 4.7 for CMAQ 5.3.2. This task was completed by our contractor on a parallel Linux system that was compared in Phase I of this modeling update above. The differences between Phase I and Phase 2 emissions are in Table 2.6.1. The differences are represented red as increased and green as decreased in the 3rd table. The overall PM2.5 primary (no chemical transformation) emissions have decreased and precursor gases NOx, SO2, VOC and ammonia have slightly increased.

Table 2.6.1 Phase 1 and Phase 2 emissions totals, Phase 1 base year 2019 using 2008 WRF meteorology and Phase 2 December 1st, 2019, to February 12th, 2020 (same exact dates for meteorology, for MPE)

Phase 1 emission totals	**PM2.5**	**NOx**	**SO2**	**VOC**	**NH3**
Point	0.54	9.62	5.44	0.03	0.07
Area, Space Heating	2.08	2.46	3.92	9	0.14
Area, Other	0.23	0.36	0.03	2.13	0.04
On-Road Mobile	0.26	2.14	0.01	4.63	0.05
Non-Road Mobile	0.35	1.85	7.2	5.33	0
SMOKE 4.7 TOTALS	3.46	16.43	16.6	21.12	0.3

Phase 2 emission totals	**PM2.5**	**NOx**	**SO2**	**VOC**	**NH3**
Point	0.66	13.63	6.60	0.04	0.09
Area, Space heating	1.88	2.44	3.85	8.87	0.15
Area, Other	0.24	0.38	0.03	2.25	0.05
On-road Mobile	0.23	2.39	0.02	4.38	0.06
Non-road Mobile	0.19	1.35	0.02	5.35	0.00
Aircraft	0.18	0.63	7.95	0.30	0.00
SMOKE 4.8 TOTALS	3.39	20.83	18.47	21.19	0.35

Difference (Phase 2 - Phase 1)	**PM2.5**	**NOx**	**SO2**	**VOC**	**NH3**
Point	0.12	4.01	1.16	0.01	0.02
Area, Space heating	-0.20	-0.02	-0.07	-0.13	0.01
Area, Other	0.01	0.02	0.00	0.12	0.01
On-road Mobile	-0.03	0.25	0.01	-0.25	0.01
Non-road Mobile	0.02	0.13	0.78	0.32	0.00
Aircraft [a]					
SMOKE TOTAL	-0.07	4.40	1.87	0.07	0.05

[a] Please note that non-mobile included aircraft in the old 2008 episode and not split out, so the purely aircraft difference is not recorded.

2.7 CMAQ Model Performance Evaluation for CMAQ version 5.3.2

DEC has new 74-day episode emissions processed for December 1st, 2019, to February 12th,2020, and new MCIP5 meteorological inputs for the CMAQ 5.3.2. The CMAQ 5.3.2 model runs were completed for the following scenarios listed in Table 2.7.1. Then a current Model Performance Evaluation was completed on the chosen scenario number 5 in the Table 2.7.1 for (CMAQ v5.3.2 with the update grid and biomass profile). The model performance evaluation includes soccer plots and time series and compared using the metrics found in Table 2.7.3. The model performance was completed by the DEC contractor using the Atmospheric Model Evaluation tool (AMET[30,31]). The model performance will continue to be evaluated as the ALPACA modeling science version and other updates are received (see Weight of Evidence section 3.5.1)

AMET is a suite of software designed to facilitate the analysis and evaluation of model predictions against observations. AMET matches model output from grid cells with observations from monitoring sites operating within one or more networks. AMET also maps individual modeled species to corresponding compounds reported in the observation database. Model and observation data pairings are then used to analyze the model's performance using a variety of statistical and graphical techniques.

Emery et al.[32] developed a set of performance goals and criteria based on the variability in past US photochemical modeling exercises. These model performance goals and criteria were chosen, because they provide a framework to use for a model performance evaluation based a meta-analysis of many model performance studies. "Goals" indicate statistical values that about a third of the top performance applications have met and should be viewed as the best a model can be expected to achieve. "Criteria" indicate statistical values that about two thirds of past applications have met and should be viewed as what models should be able to achieve. Statistical results outside the criteria indicate that the model performs poorly. We compared the model performance statistics for normalized mean bias (NMB), normalized mean error (NME) , Fractional Bias (FB) and Fractional Error (FE) against the goals and criteria proposed by Emery et al. (2016), as listed in Table 2.7.3.

The full MPE was performed for PM2.5 and all species and precursor gases (PM2.5, OC, EC, SO4, NO3, NH4, TC (Total Carbon), Other, NOx and SOx). The full MPE model run was completed using all sectors of emissions: space heating, points, on-road, non-road, aircraft.

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[30] https://www.cmascenter.org/amet/

[31] https://www.epa.gov/cmaq/atmospheric-model-evaluation-tool

[32] Performance Goals and Criteria Values Source: Christopher Emery, Zhen Liu, Armistead G. Russell, M. Talat Odman, Greg Yarwood & Naresh Kumar (2017) Recommendations on statistics and benchmarks to assess photochemical model performance, Journal of the Air & Waste Management Association, 67:5, 582-598, DOI: 10.1080/10962247.2016.1265027

Table 2.7.1 scenarios ran for optimal Model Performance Evaluation

Scenario	Changes made	Final
1-CMAQ v 5.3.2 default	None	Full run MPE starting point
2-CMAQ v 5.3.2 kz min 0.1	Kz min changed from default value	Over predict NCore-stopped run
3-CMAQ v 5.3.2 kz min 0.01	Kz min changed from default value	Over predict NCore-stopped run
4-CMAQ v 5.3.2 biomass	Emissions control file [1]	Modeling grid was off due to MCIP rounding error
5-CMAQ v5.3.2 new grid biomass	MCIP modeling grid changed Biomass emissions control file	Full run MPE
6-CMAQ v5.3.2 new grid Default	MCIP modeling grid changed	Full run MPE

Note [1]: the exact changes to the emission control file are in the Appendix.

The CMAQ model sensitivity tests in Phase 1 showed that the original emission control file, which bases the temperature dependent partitioning organic aerosol volatility on a diesel engine and the biomasses based on wood burning specific profiles are very similar. The difference results in a 1.5 ug/m3 increase with biomass on average. These results were presented to the USEPA ORD RARE grant group on 9/14/21 and the question of which emissions control file profile to use was raised. Both represent volatility based on temperature and at cold temperatures this volatility is low. EPA stated that both would be representative of wood burning due to the cold temperatures. The decision was made to start with the original emission control file that will speed up the modeling and if the model performance is acceptable then the additional runs using the biomass profile will not be run. The species included in MPE are OC, EC, SO4, NH4, NO3, Other and precursor gases, SO2, NOx, NH3 and VOCs. The model performance was conducted on NCORE and Hurst RD for species and A Street for the total PM2.5 model performance.

Table 2.7.2 Current MPE model run including grid update and biomass emission control file for all three monitors NCORE and Hurst for TOT PM2.5 and species and A Street for TOT PM2.5 GridMod Biogenic final model run, green cells meet performance criteria

Species	No. of Obs/Model Pairs	Average Observed	Average Modeled	Normalized Mean Bias	Normalized Mean Error	Fractional Bias	Fractional Error
PM25_TOT	415	21.481	18.532	-13.7	60.8	-6.01	63
SO4	44	2.8325	1.4974	-47.1	52.9	-49.2	60.8
NO3	44	0.87341	0.6016	-31.1	62.2	-59.5	83.6
EC	40	2.6602	1.4514	-45.4	60.7	-39.3	66.8
OC	40	9.5506	8.1858	-14.3	76	7.94	80.1
OTHR	34	5.5099	2.4535	-55.5	65.1	-79.2	95.3
NH4	44	1.0509	0.3573	-66	73.2	-71.7	91.6

The PM2.5 and criteria goals are < 50%, from the Table 2.7.2, the SO2 and PM2.5 goals for NME are within 10% to the performance criteria. All criteria goals met are highlighted green and Other (OTHR) are not evaluated in the metrics chart. The sulfate averaged for both monitors and all speciation days are just outside of the performance criteria of 17% for NMB. For NMB, the PM2.5 is lower than the performance goal of <30%, for the performance criteria. The sulfate performance in Figure 2.7.8 for the month of February at all three monitors is in the performance criteria for both NMB and NME. The sulfate month of December for all three monitors is also in the performance criteria for NME.

The current Model Performance Evaluation can potentially be improved with the new CMAQ 5.3.3+ chemistry version (referred to as the science version) that USEPA Office of Research and Development released for initial testing to DEC on 2/1/23. The results of the ALAPCA RARE grant sulfate study for 2022 CMAQ modeling for plot for showing improved sulfate chemistry are below in section 5.3.2.

Table 2.7.3 Performance Criteria and Goal Metrics table

Statistical Measure	Mathematical Expression	Performance Goals	Performance Criteria
Normalized Mean Bias (%), NMB	$\frac{\sum_{i=1}^{N}(P_i - O_i)}{\sum_{i=1}^{N} O_i}$	MDA8 O_3 <±5% $PM_{2.5}$, SO_4,NH_4 <±10% NO_3 <±15% OC <±15% EC <±20%	MDA8 O_3 <±15% $PM_{2.5}$, SO_4,NH_4 <±30% NO_3 <±65% OC <±50% EC <±40%
Normalized Mean Error (%), NME	$\frac{\sum_{i=1}^{N}\lvert P_i - O_i\rvert}{\sum_{i=1}^{N} O_i}$	MDA8 O_3 <15% $PM_{2.5}$, SO_4,NH_4 <35% NO_3 <65% OC <45% EC <50%	MDA8 O_3 <25% $PM_{2.5}$, SO_4,NH_4 <50% NO_3 <115% OC <65% EC <75%
Fractionalized Bias (%), FB	$\frac{2}{N}\sum_{i=1}^{N}\left(\frac{P_i - O_i}{P_i + O_i}\right)$	24-hr total and speciated $PM_{2.5}$ <±30%	24-hr total and speciated $PM_{2.5}$ <±60%
Fractional Error (%), FE	$\frac{2}{N}\sum_{i=1}^{N}\left\lvert\frac{P_i - O_i}{P_i + O_i}\right\rvert$	24-hr total and speciated $PM_{2.5}$ <50%	24-hr total and speciated $PM_{2.5}$ <75%

- "Goals" indicate statistical values that approximately a third of the top performing past PGM applications have met and should be viewed as the best a model can be expected to achieve.
- "Criteria" indicates statistics values that approximately two thirds of past PGM applications have met and should be viewed as what most of the models have achieved.[33]

The Table 2.7.3 represents the goals and criteria for the model run. The soccer plots will show the goal and criteria lines below in Figure 2.7.1 to Figure 2.7.9.

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[33] Performance Goals and Criteria Values Source: Christopher Emery, Zhen Liu, Armistead G. Russell, M. Talat Odman, Greg Yarwood & Naresh Kumar (2017) Recommendations on statistics and benchmarks to assess photochemical model performance, Journal of the Air & Waste Management Association, 67:5, 582-598, DOI: 10.1080/10962247.2016.1265027

Table 2.7.4 Sites involved in MPE

Site ID	Site Name	Lat	Lon
020900034	NCORE	64.845	-147.727
020900035	Hurst Road	64.762	-147.31
020900040	A street	64.845	-147.693

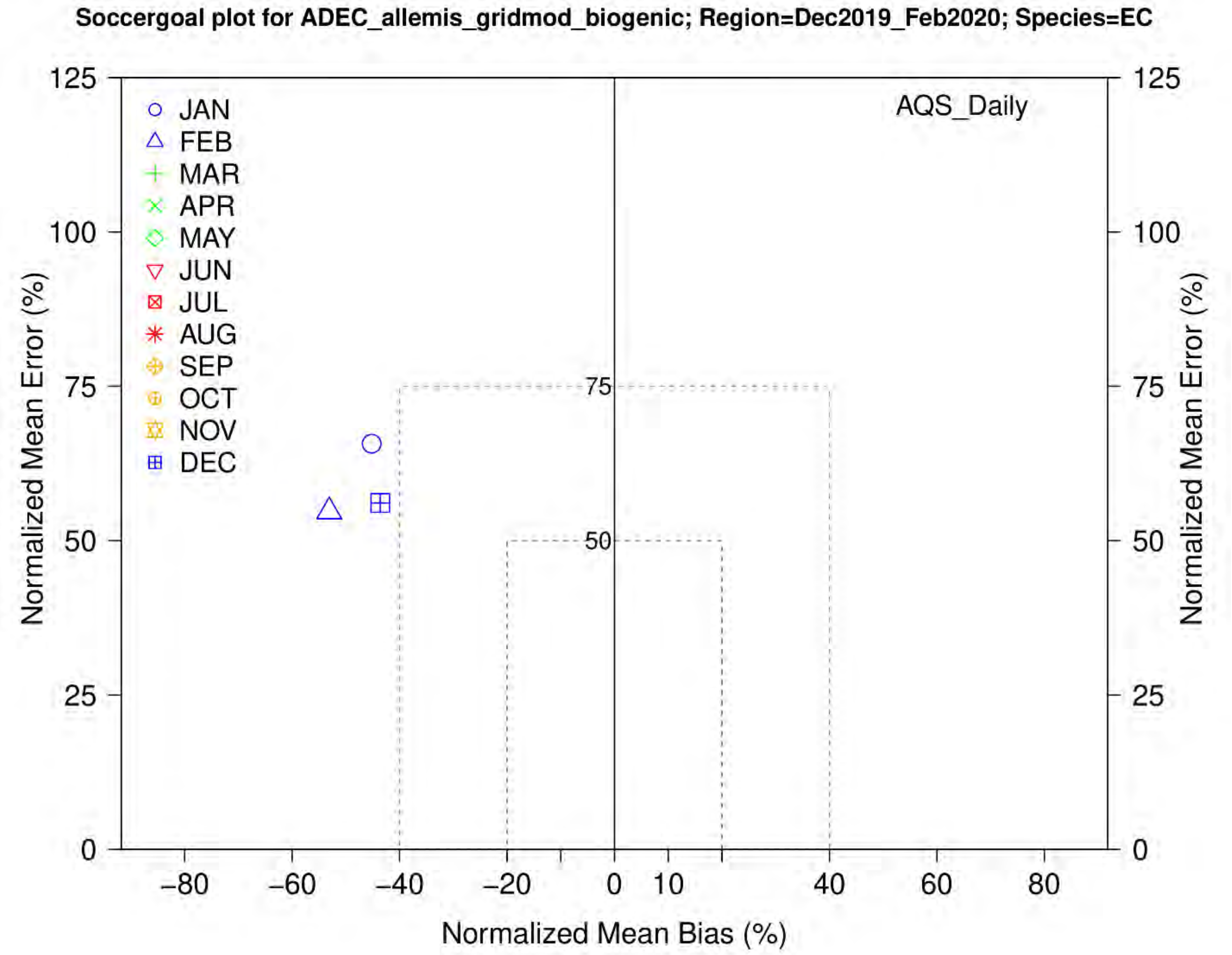


Figure 2.7.1 Soccergoal plot for EC Species

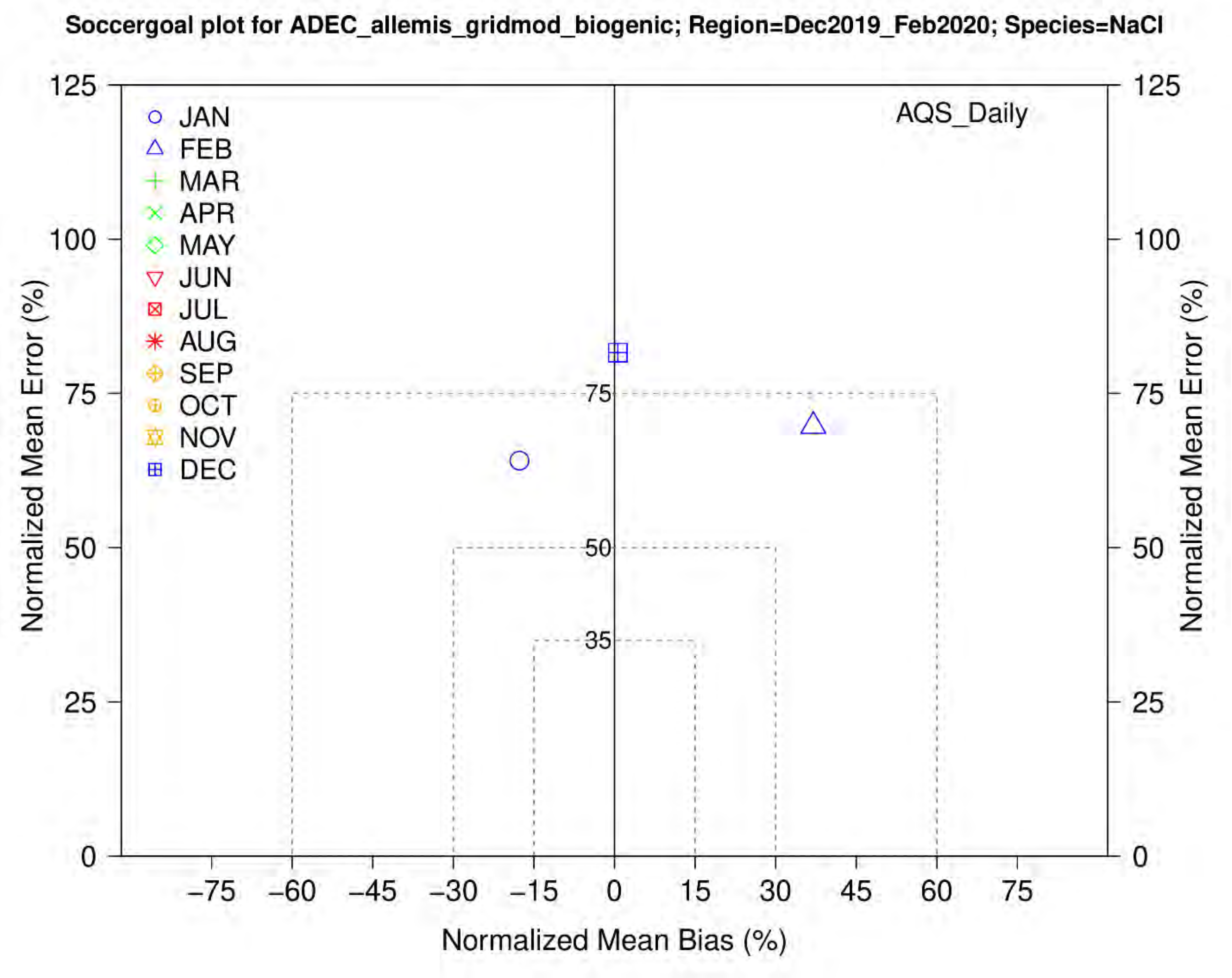


Figure 2.7.2 Soccergoal plot for NaCl Species

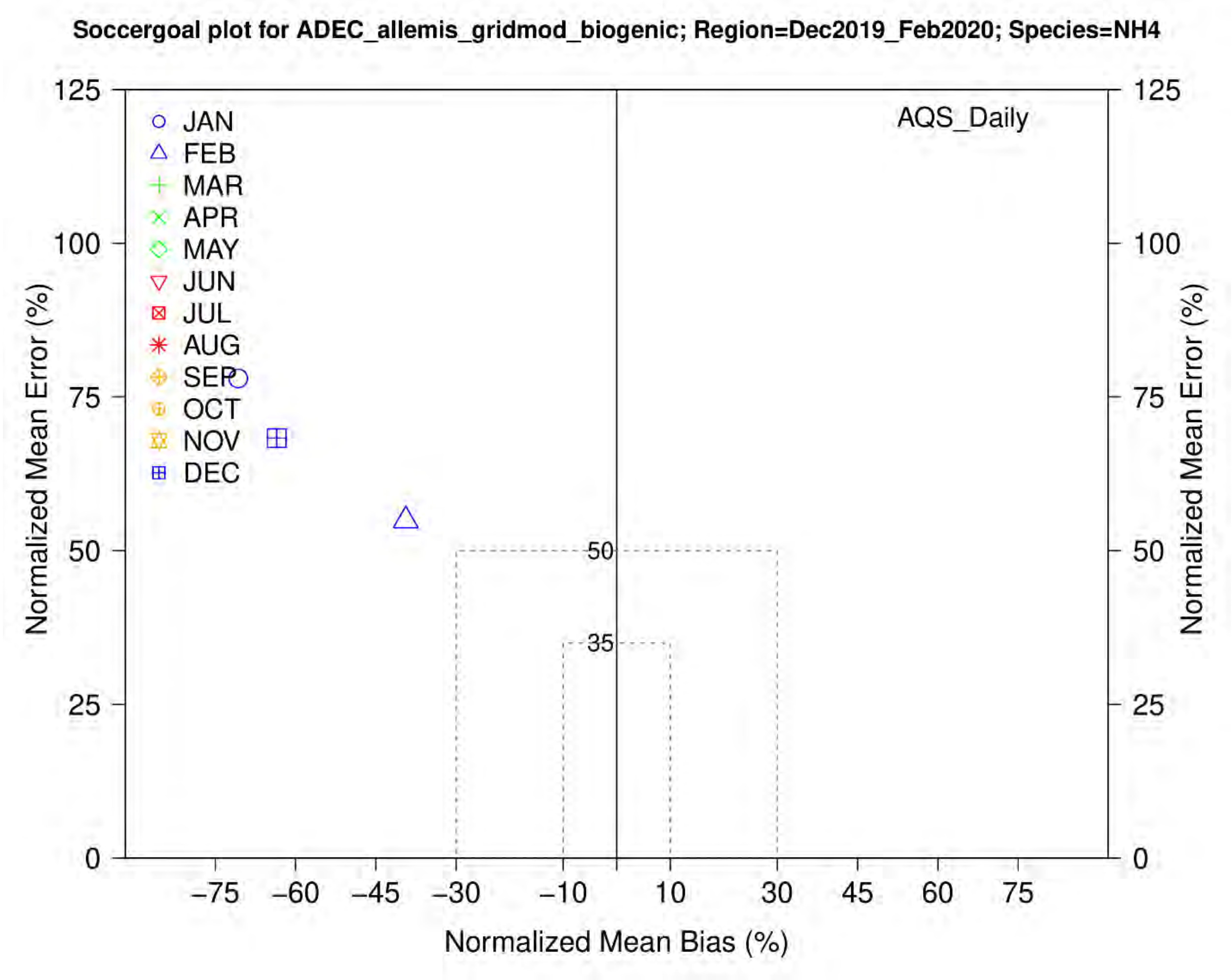


Figure 2.7.3 Soccergoal plot for NH4 Species

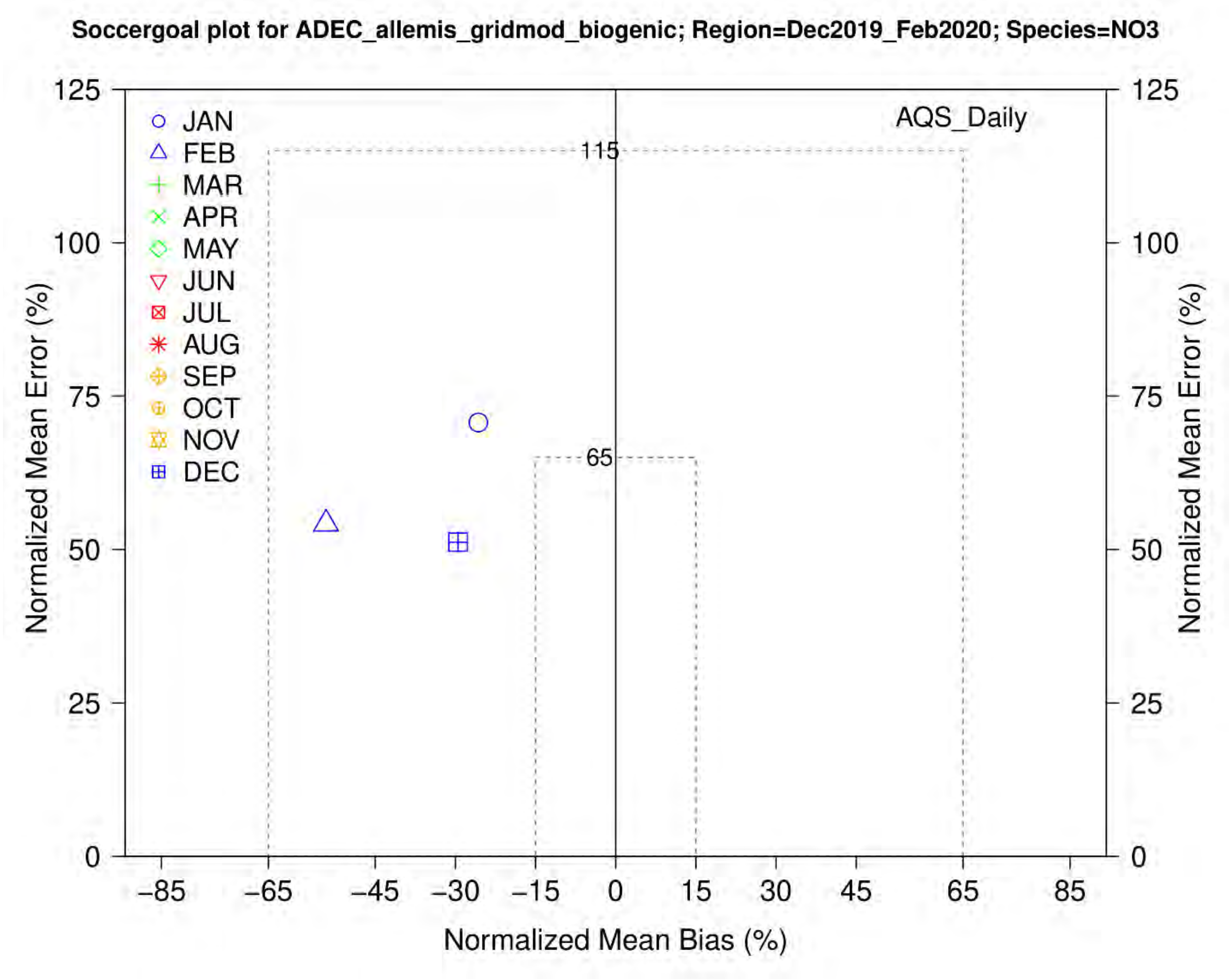


Figure 2.7.4 Soccergoal plot for NO3 Species

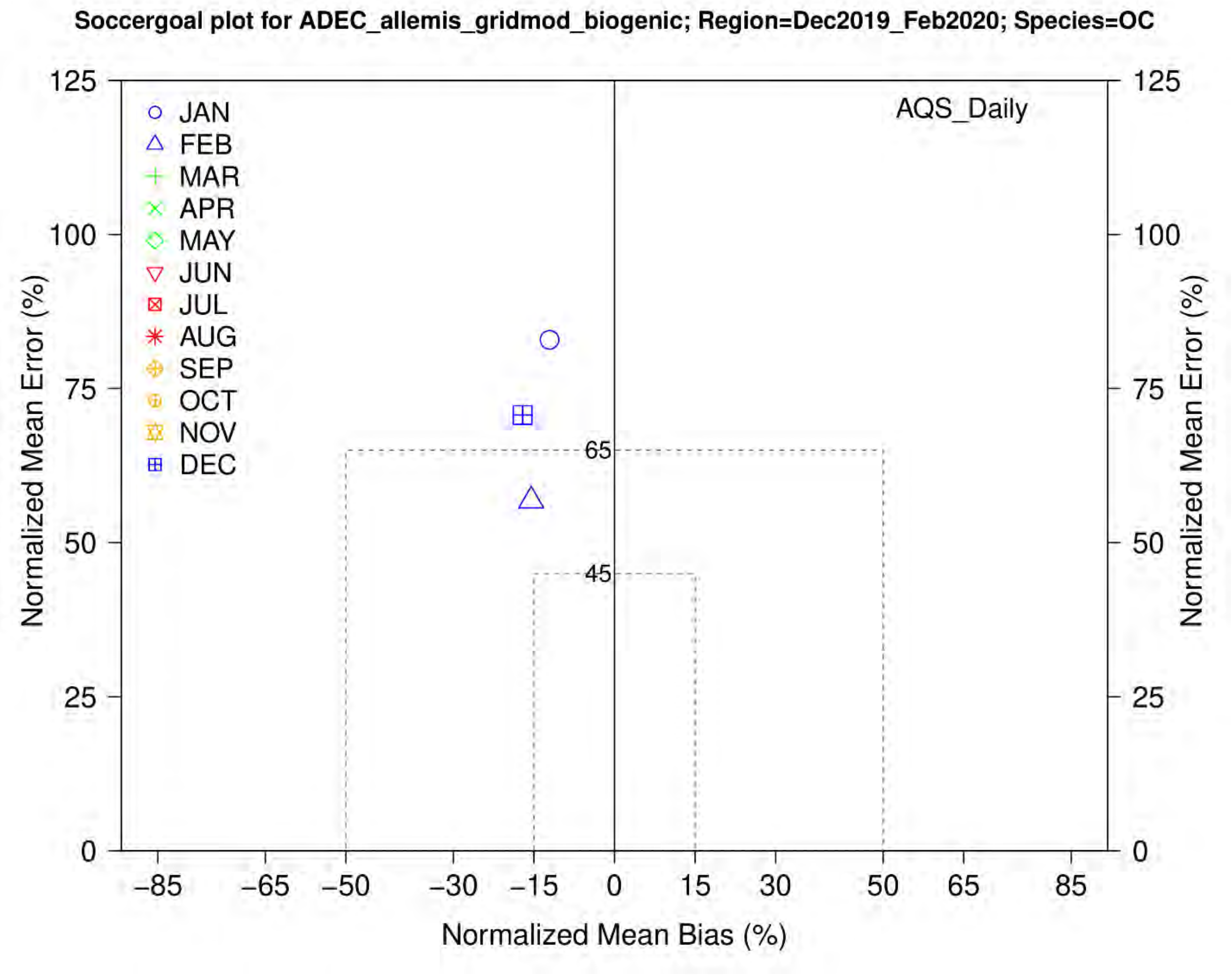


Figure 2.7.5 Soccergoal plot for OC Species

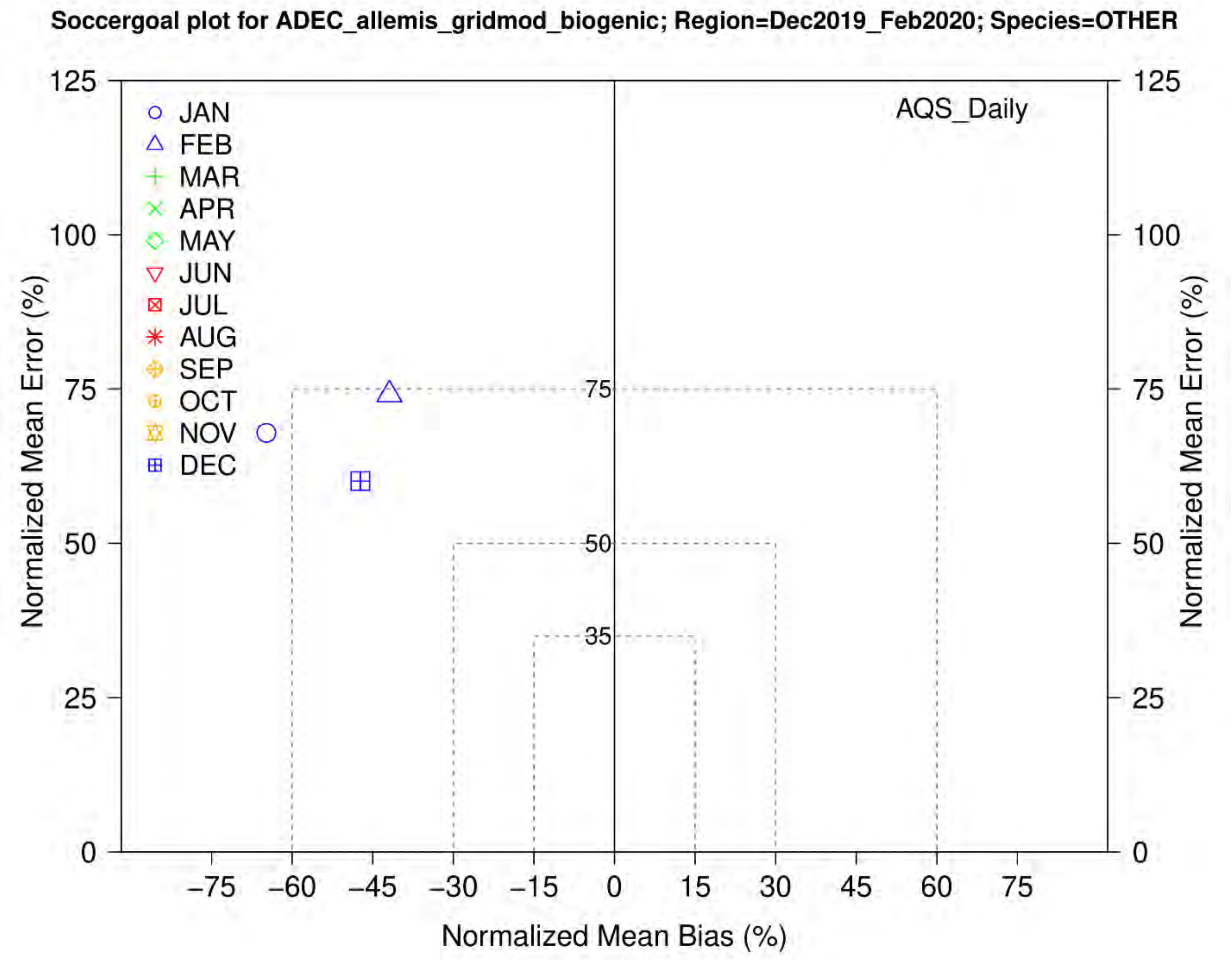


Figure 2.7.6 Soccergoal plot for OTHER Species

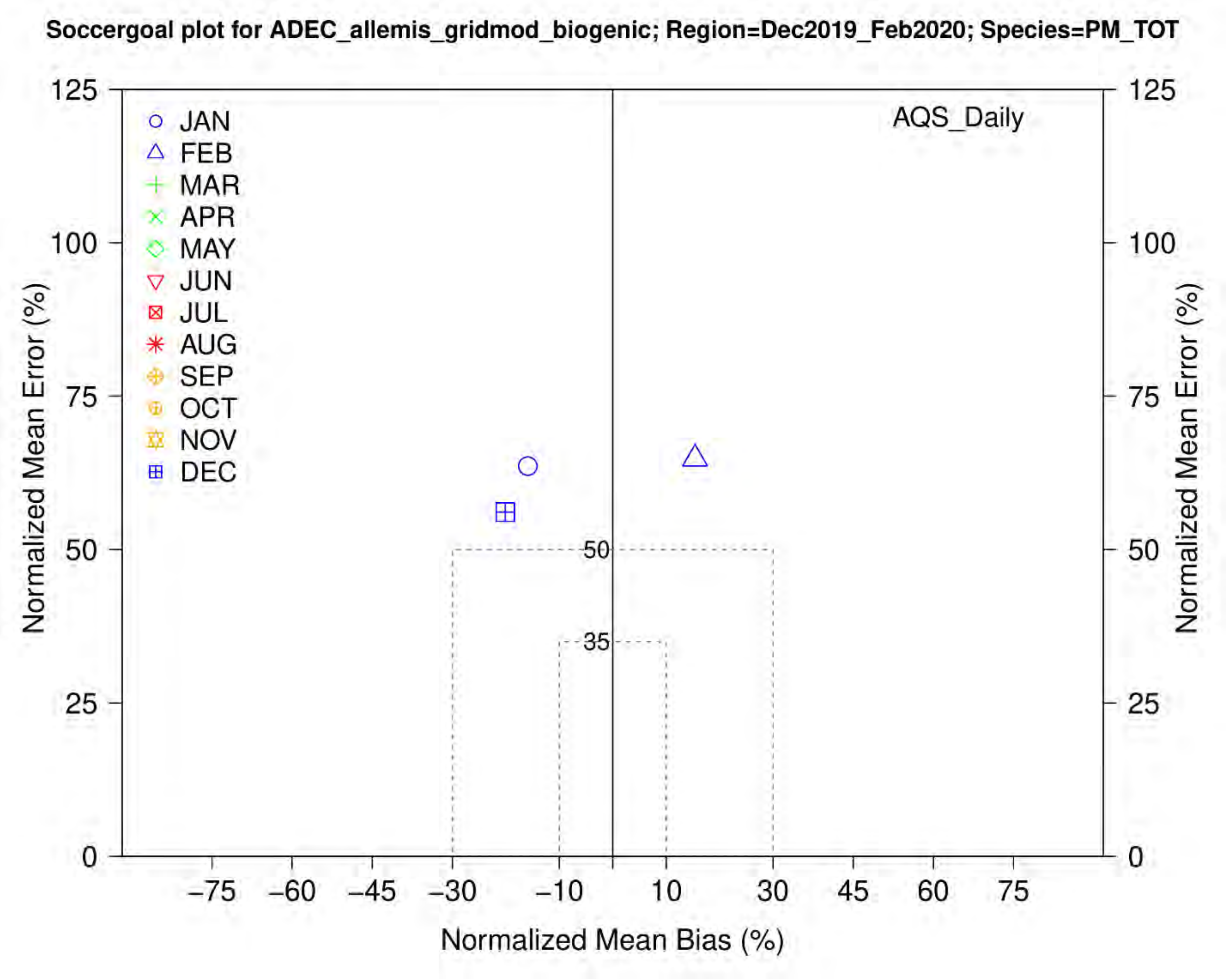


Figure 2.7.7 Soccergoal plot for PM_TOT Species

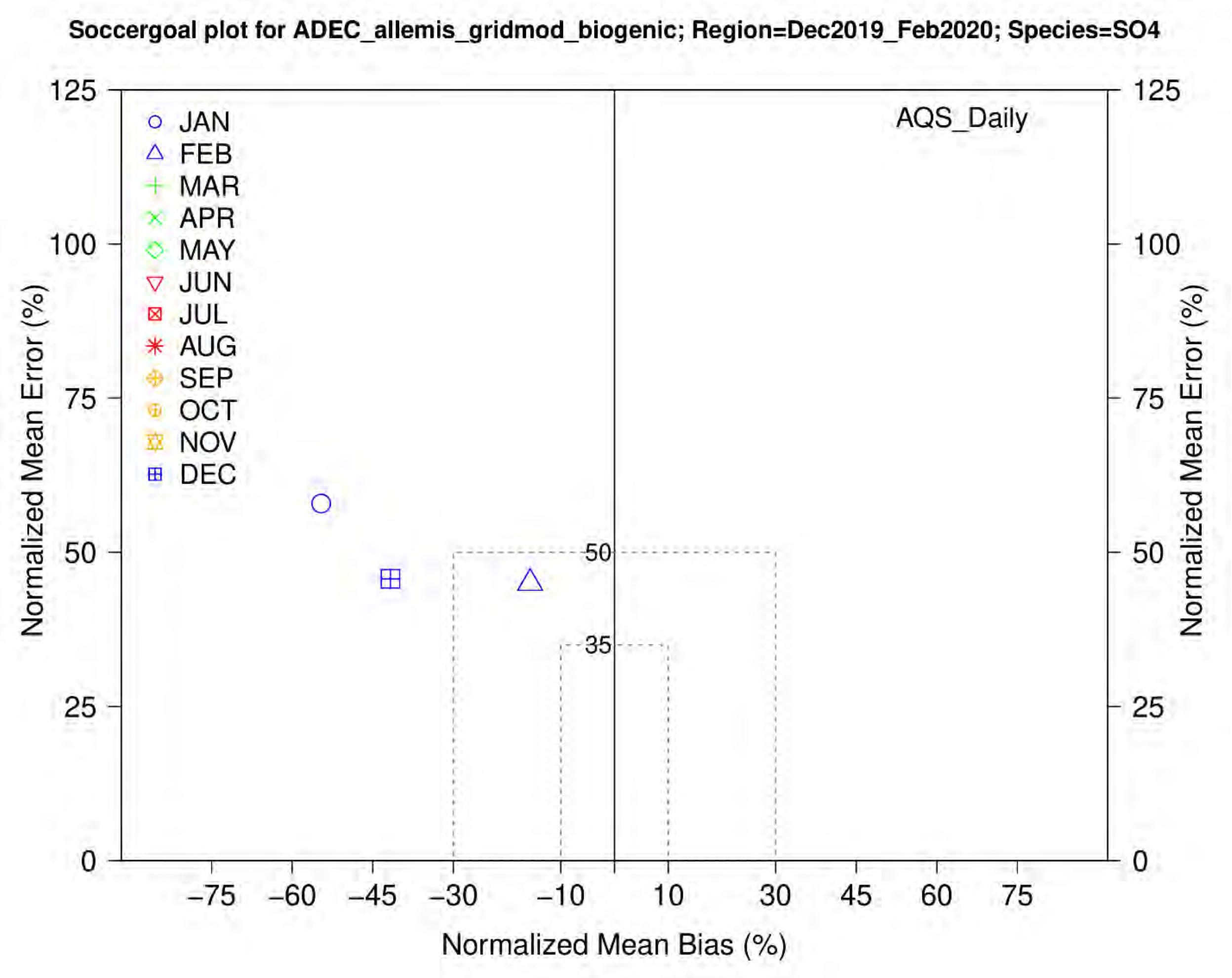


Figure 2.7.8 Soccergoal plot for SO4 Species

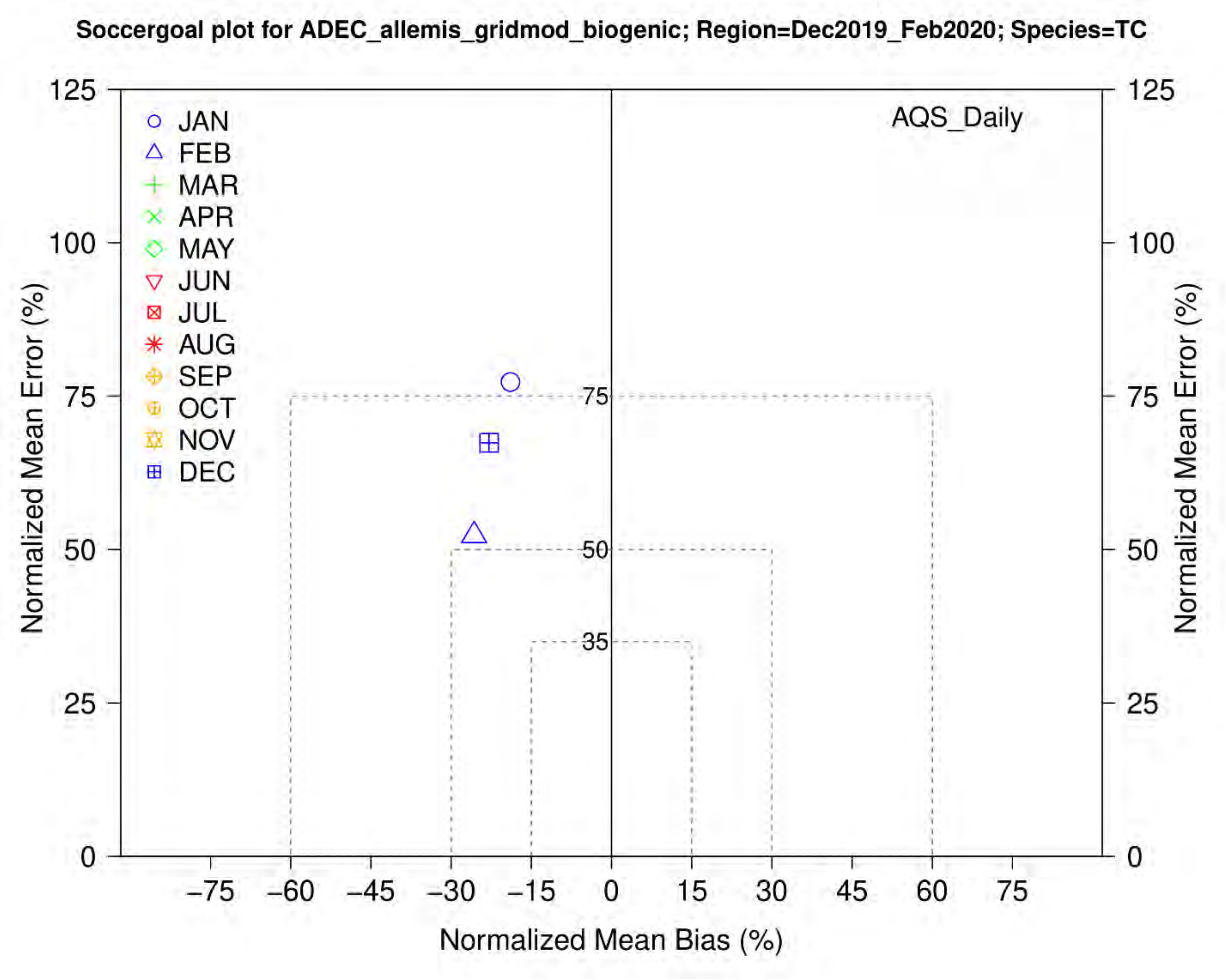


Figure 2.7.9 Soccergoal plot for TC Species

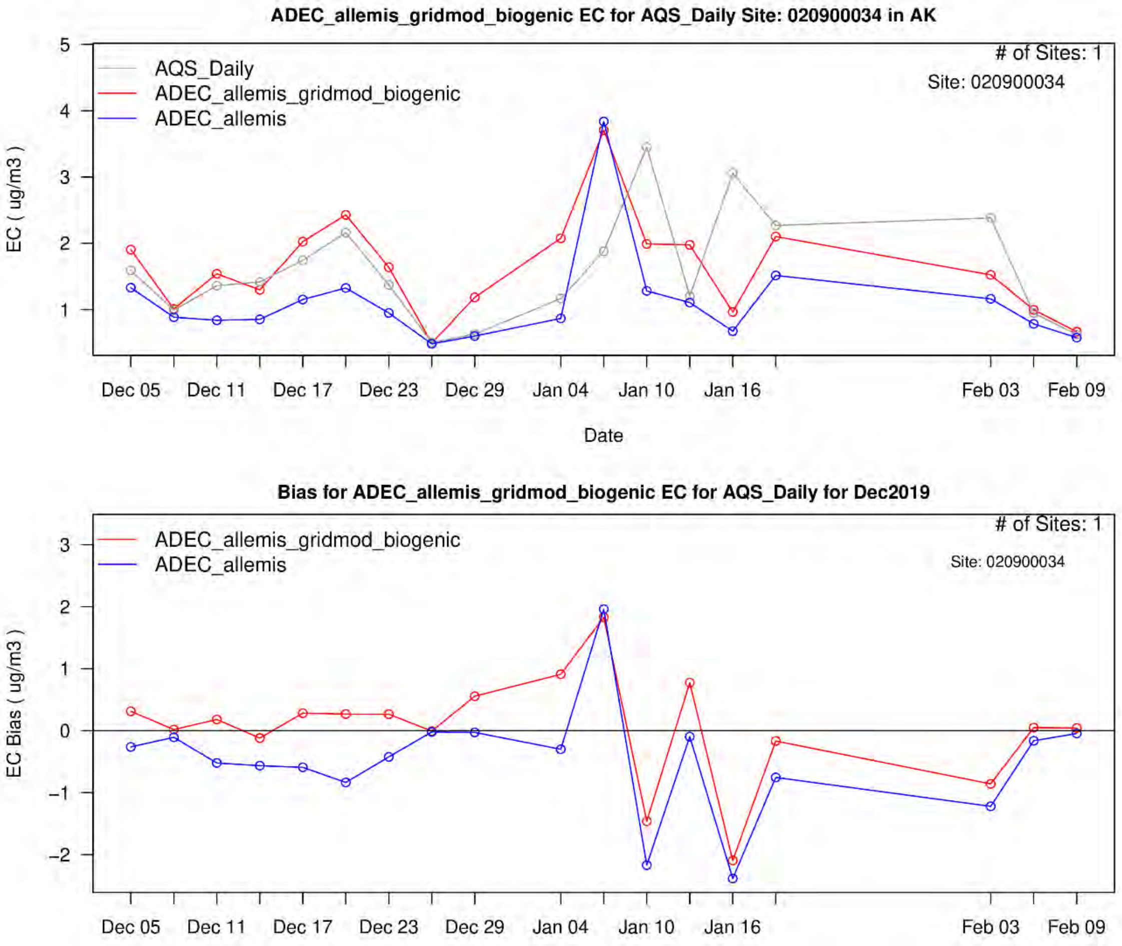


Figure 2.7.10 Timeseries of site 34 (NCORE) for the observed EC (Speciation filter), modeled EC for default all emissions model run (ADEC_allemis) and final MPE model run (ADEC_allemis_gridmod_biogenic)

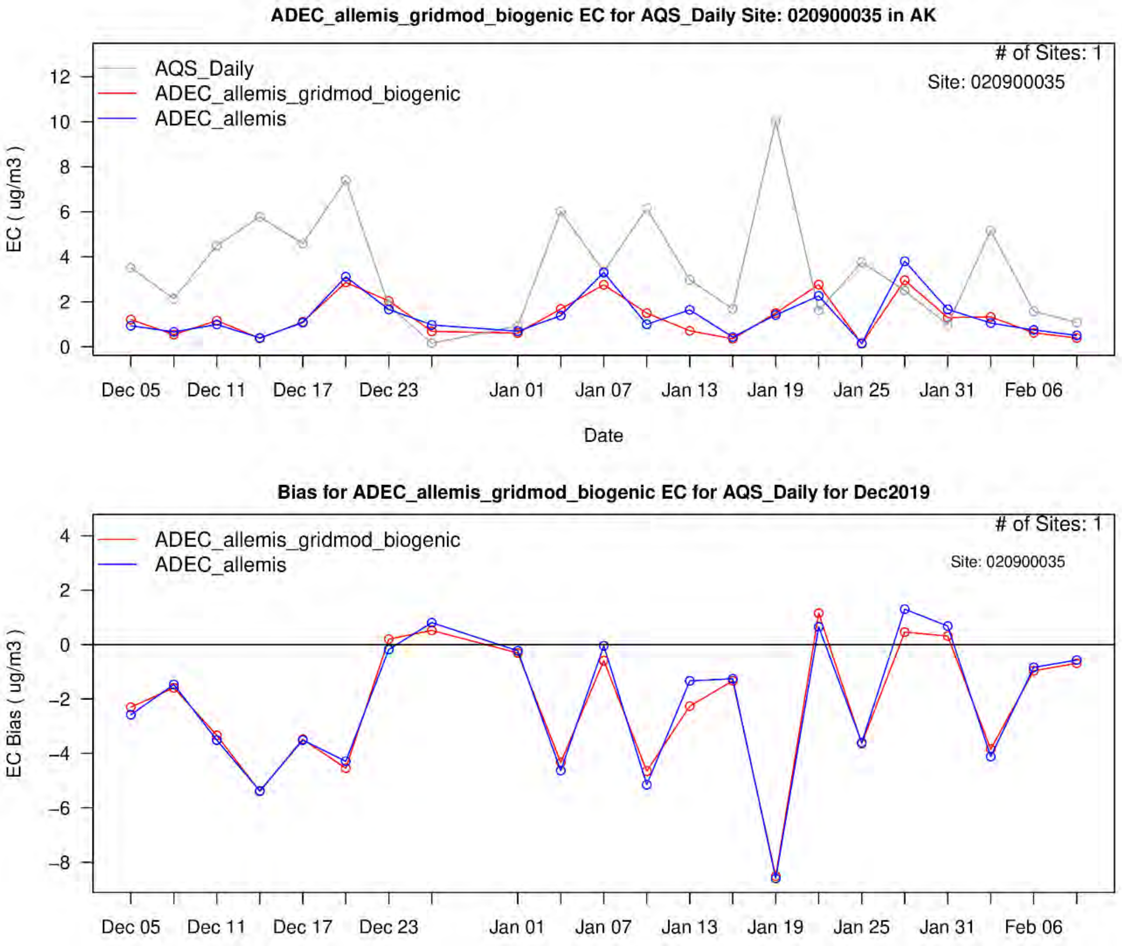


Figure 2.7.11 Timeseries of site 35 (Hurst) for the observed EC (Speciation filter), modeled EC for default all emissions model run (ADEC_allemis) and final MPE model run (ADEC_allemis_gridmod_biogenic)

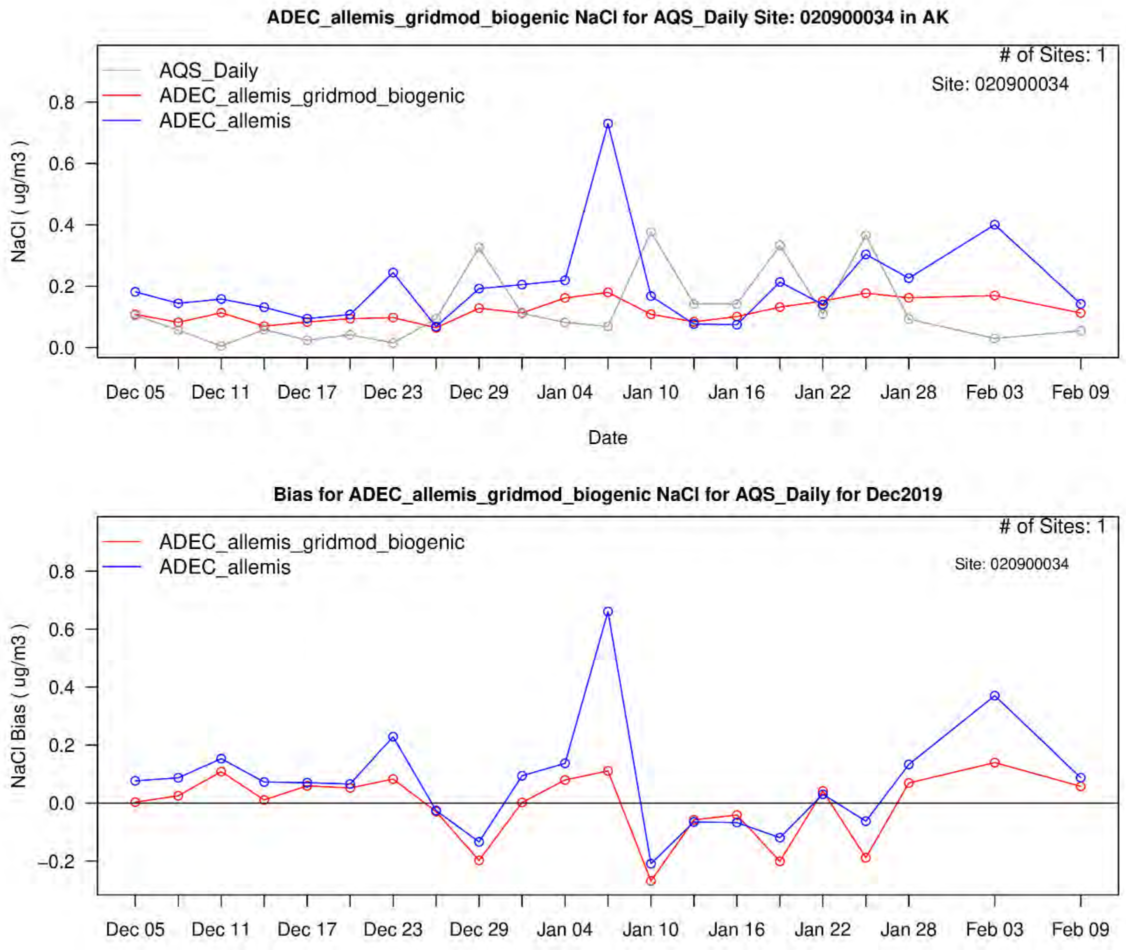


Figure 2.7.12 Timeseries of site 34 (NCORE) for the observed NaCl (Speciation filter), modeled NaCl for default all emissions model run (ADEC_allemis) and final MPE model run (ADEC_allemis_gridmod_biogenic)

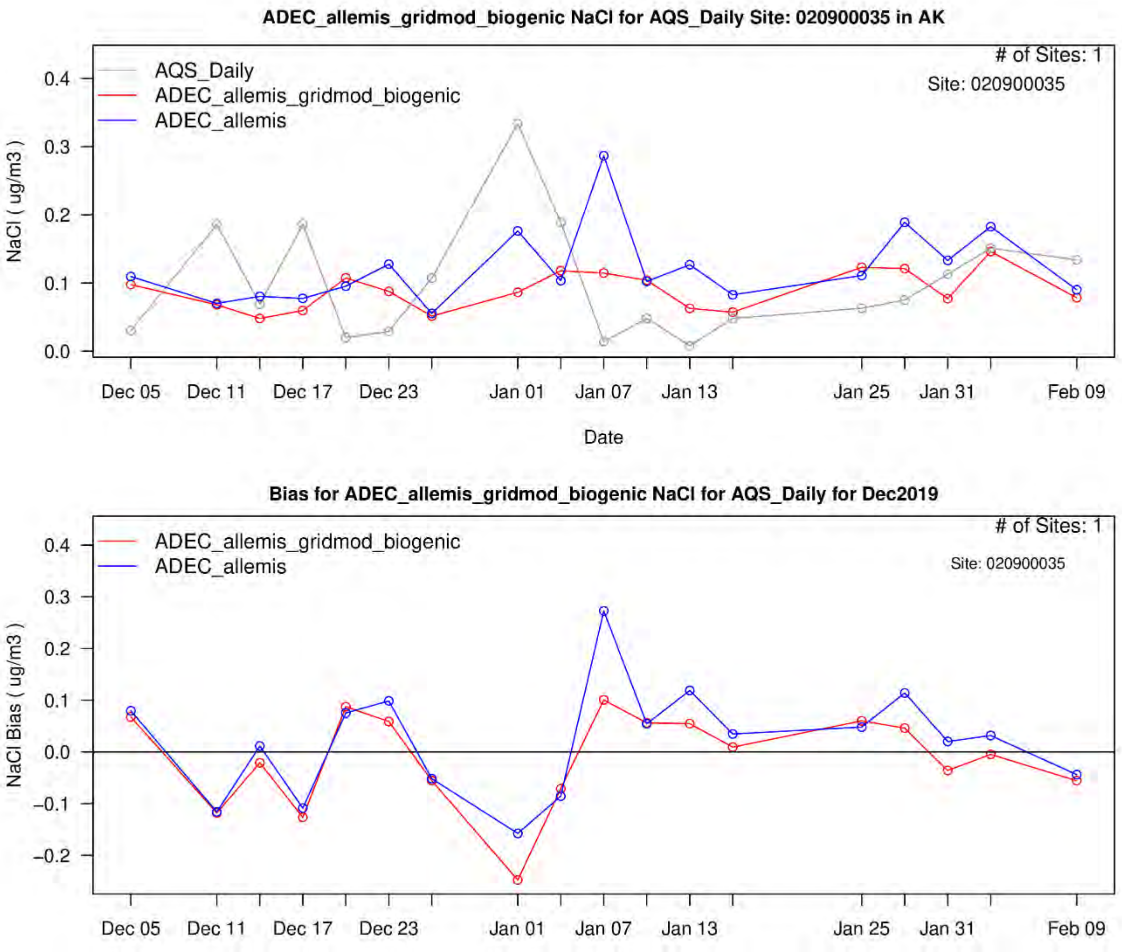


Figure 2.7.13 Timeseries of site 35 (Hurst) for the observed NaCl (Speciation filter), modeled NaCl for default all emissions model run (ADEC_allemis) and final MPE model run (ADEC_allemis_gridmod_biogenic)

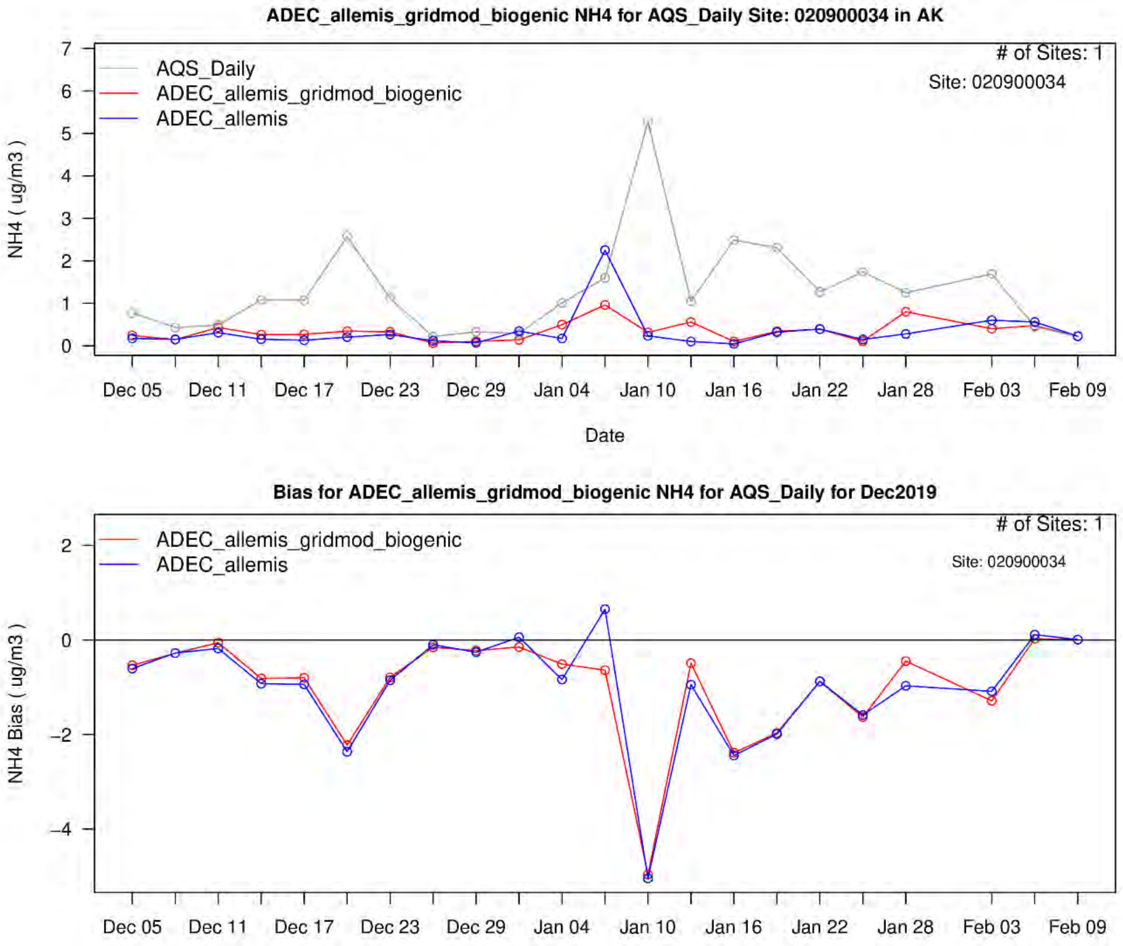


Figure 2.7.14 Timeseries of site 34 (NCORE) for the observed NH4 (Speciation filter), modeled NH4 for default all emissions model run (ADEC_allemis) and final MPE model run (ADEC_allemis_gridmod_biogenic)

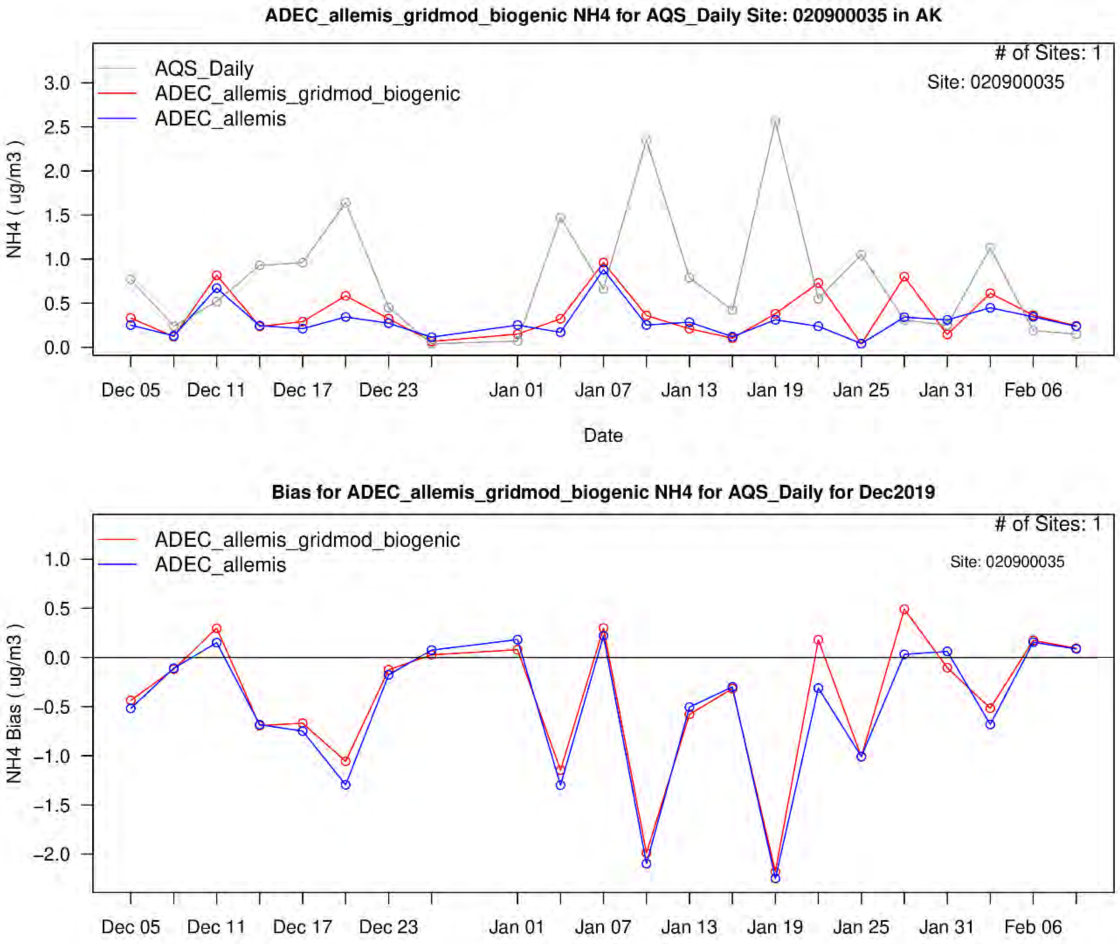


Figure 2.7.15 Timeseries of site 35 (Hurst) for the observed NH4 (Speciation filter), modeled NH4 for default all emissions model run (ADEC_allemis) and final MPE model run (ADEC_allemis_gridmod_biogenic)

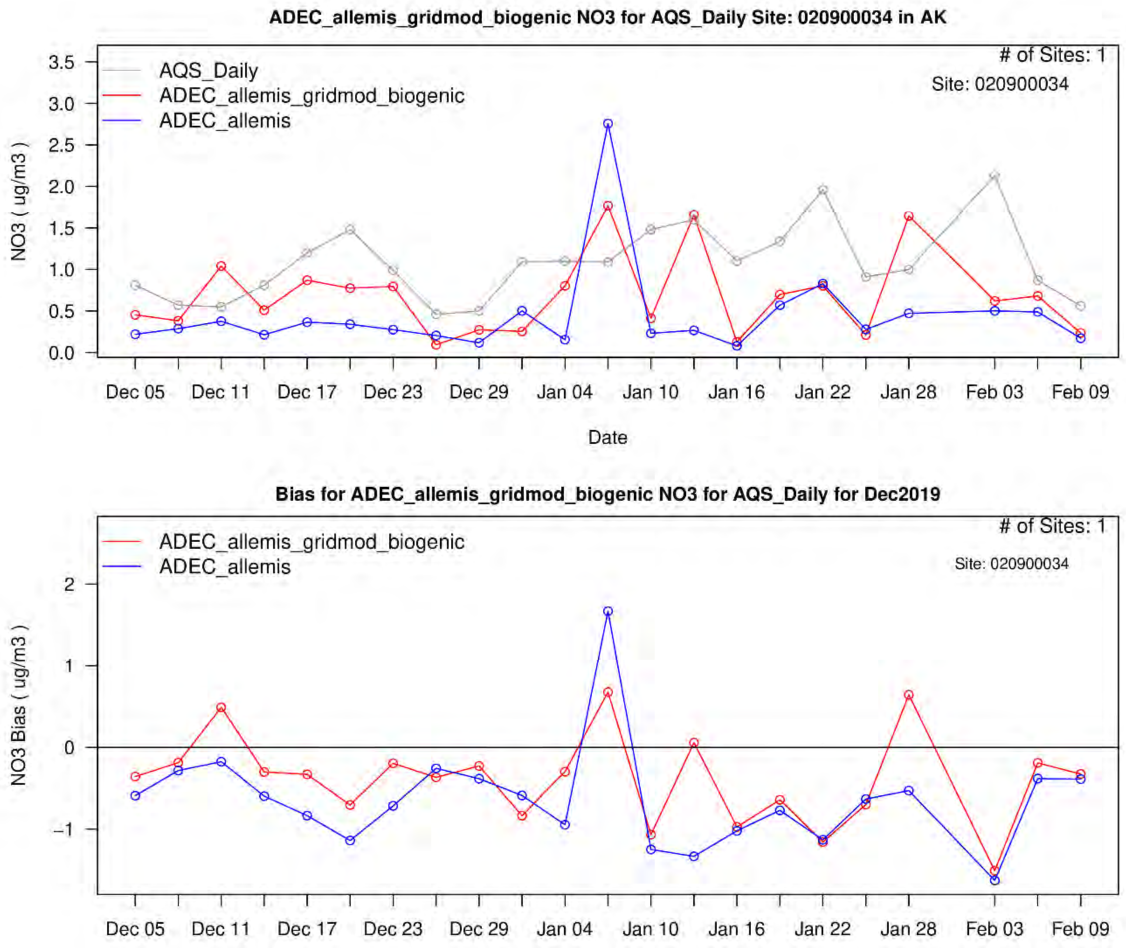
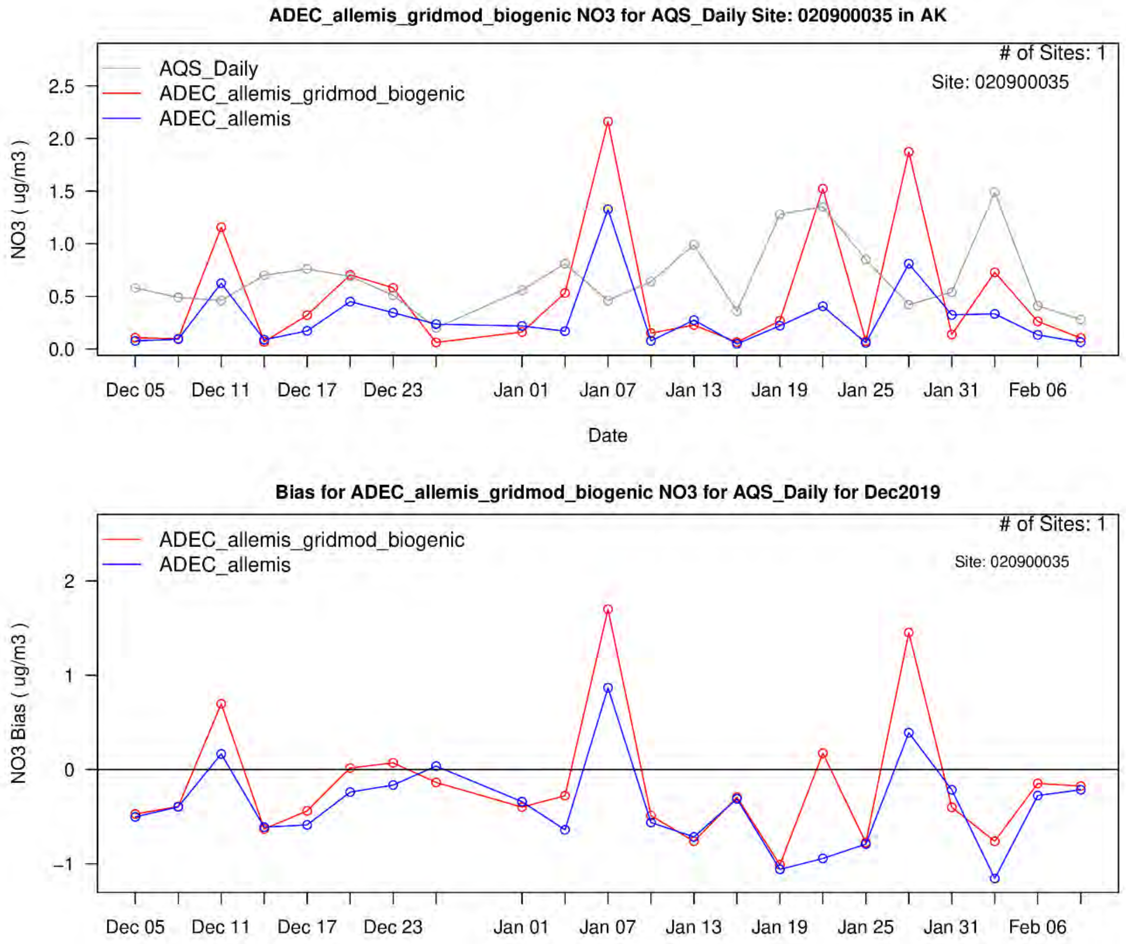


Figure 2.7.16 Timeseries of site 34 (NCORE) for the observed NO3 (Speciation filter), modeled NO3 for default all emissions model run (ADEC_allemis) and final MPE model run (ADEC_allemis_gridmod_biogenic)


ADEC_allemis_gridmod_biogenic NO3 for AQS_Daily Site: 020900035 in AK

Bias for ADEC_allemis_gridmod_biogenic NO3 for AQS_Daily for Dec2019

Figure 2.7.17 Timeseries of site 35 (Hurst) for the observed NO3 (Speciation filter), modeled NO3 for default all emissions model run (ADEC_allemis) and final MPE model run (ADEC_allemis_gridmod_biogenic)

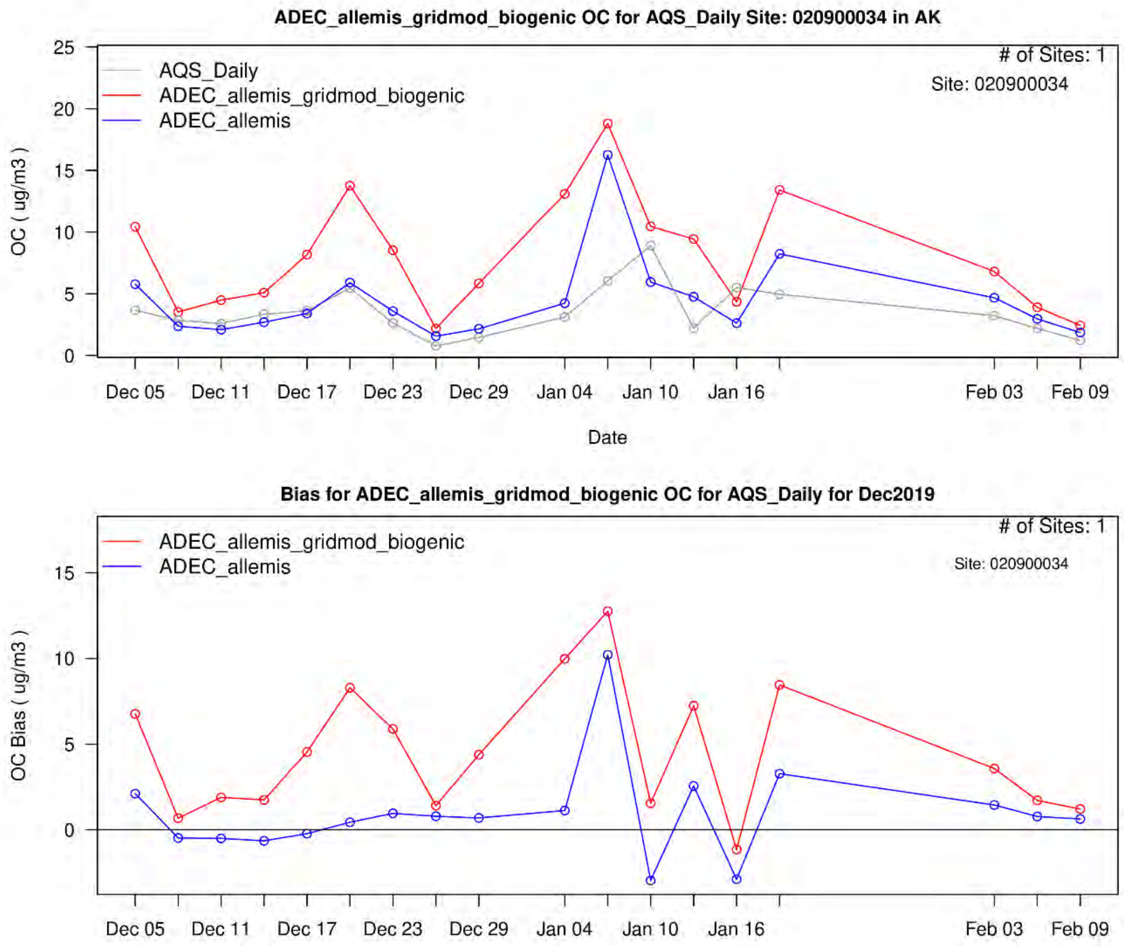


Figure 2.7.18 Timeseries of site 34 (NCORE) for the observed OC (Speciation filter), modeled OC for default all emissions model run (ADEC_allemis) and final MPE model run (ADEC_allemis_gridmod_biogenic)

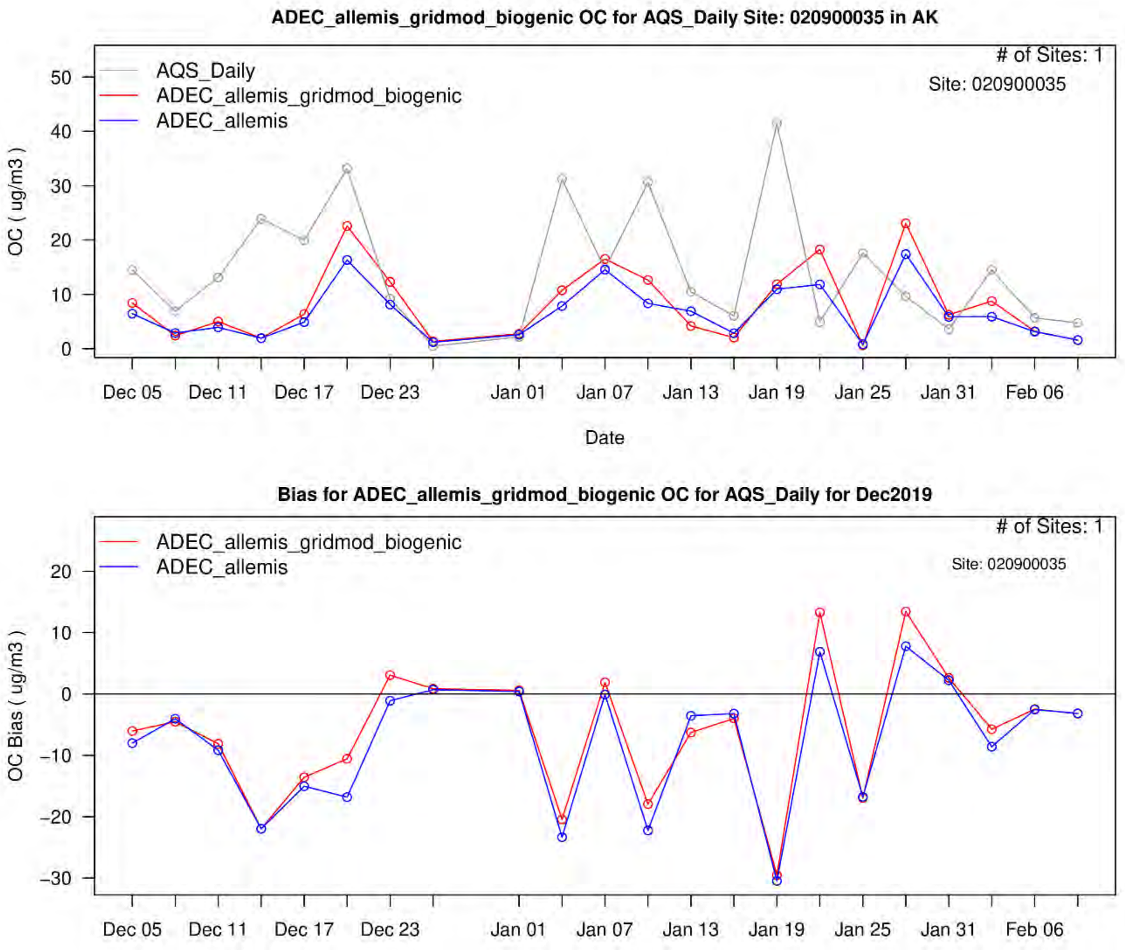


Figure 2.7.19 Timeseries of site 35 (Hurst) for the observed OC (Speciation filter), modeled OC for default all emissions model run (ADEC_allemis) and final MPE model run (ADEC_allemis_gridmod_biogenic)

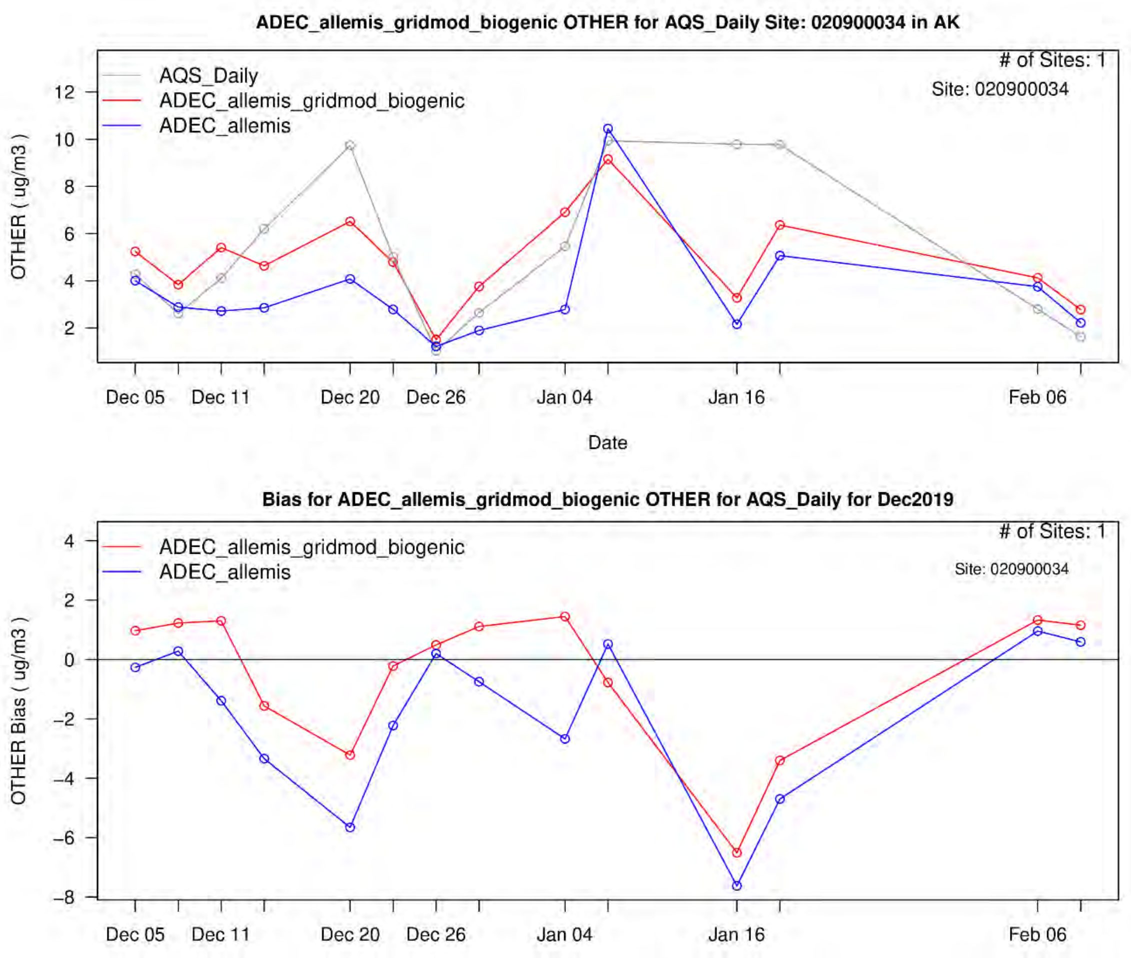


Figure 2.7.20 Timeseries of site 34 (NCORE) for the observed OTHER (Speciation filter), modeled OTHER for default all emissions model run (ADEC_allemis) and final MPE model run (ADEC_allemis_gridmod_biogenic)

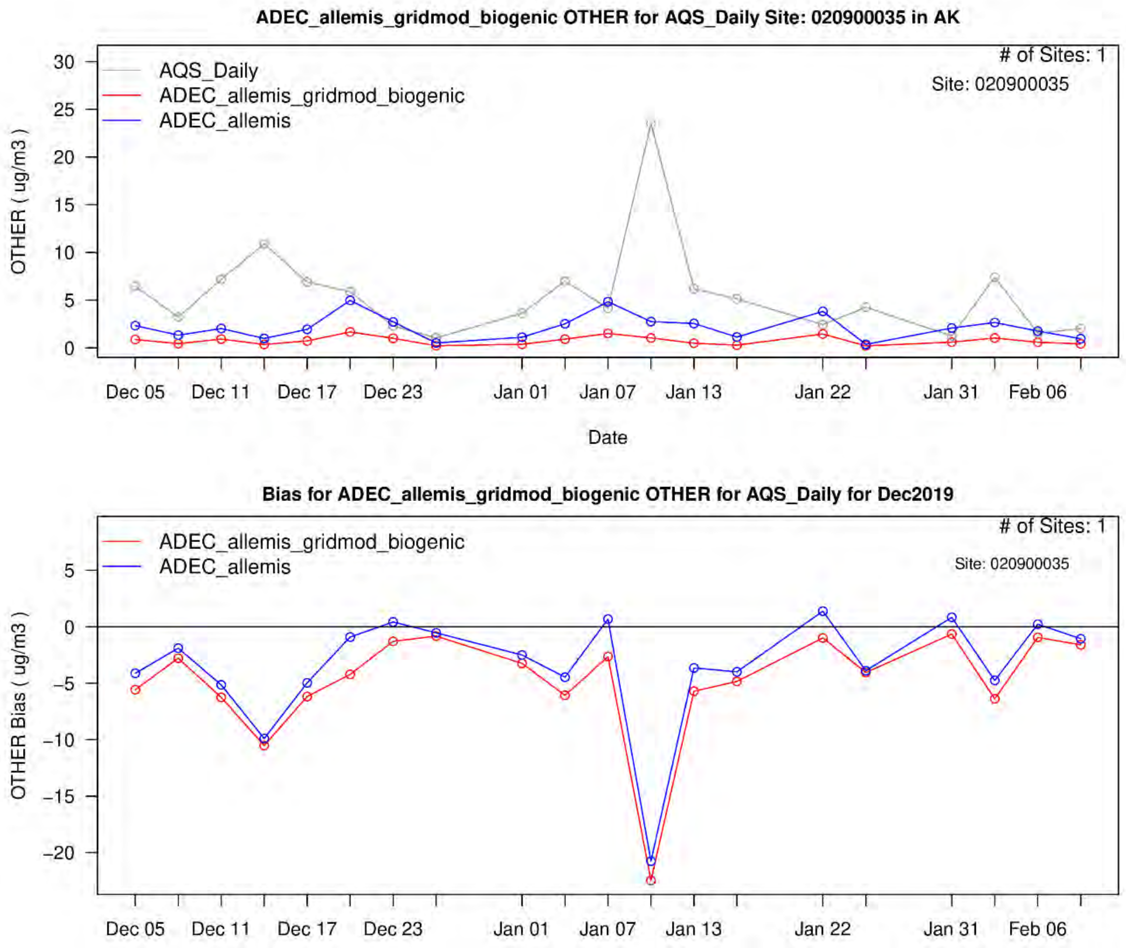


Figure 2.7.21 Timeseries of site 35 (Hurst) for the observed OTHER (Speciation filter), modeled OTHER for default all emissions model run (ADEC_allemis) and final MPE model run (ADEC_allemis_gridmod_biogenic)

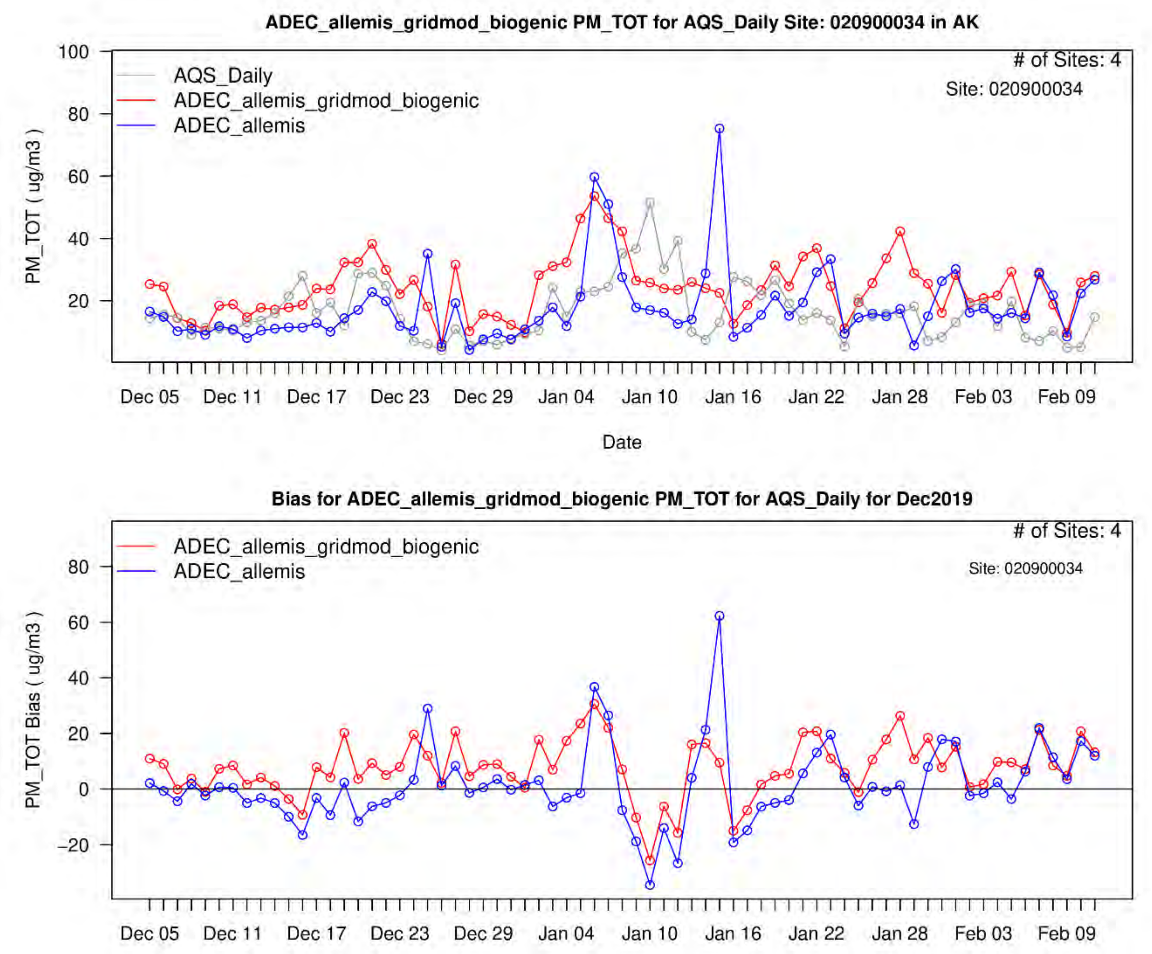


Figure 2.7.22 Timeseries of site 34 (NCORE) for the observed PMTOT (Speciation filter), modeled PMTOT for default all emissions model run (ADEC_allemis) and final MPE model run (ADEC_allemis_gridmod_biogenic)

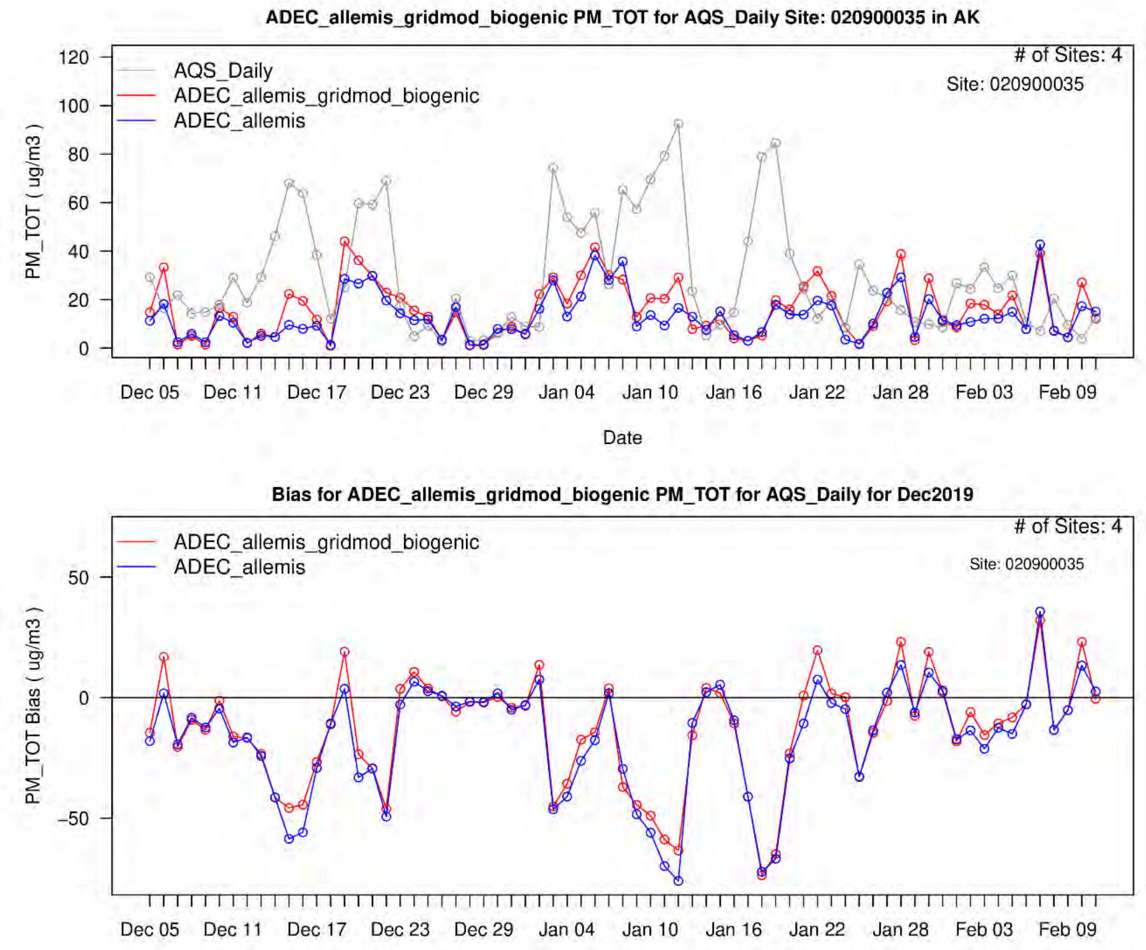


Figure 2.7.23 Timeseries of site 35 (Hurst) for the observed PMTOT (Speciation filter), modeled PMTOT for default all emissions model run (ADEC_allemis) and final MPE model run (ADEC_allemis_gridmod_biogenic)

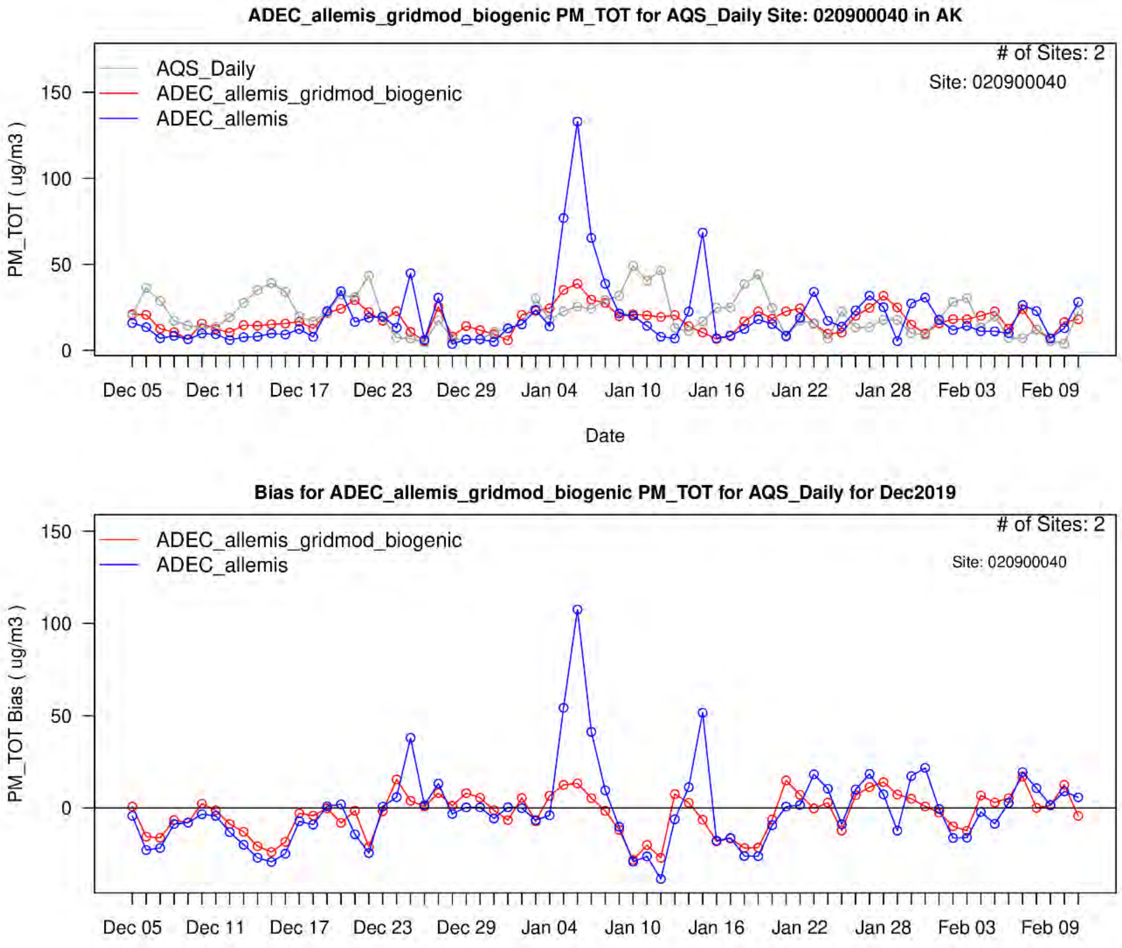
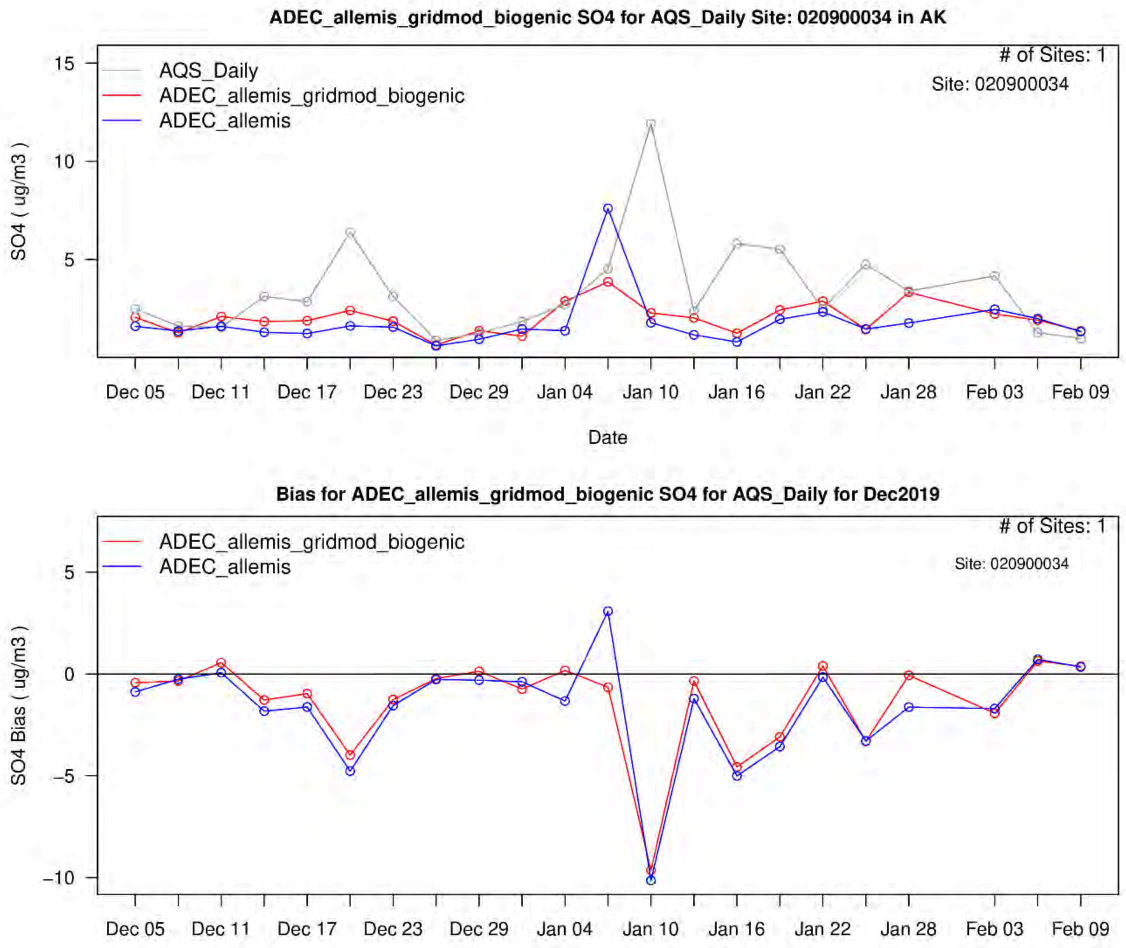


Figure 2.7.24 Timeseries of site 40 (AStreet) for the observed PMTOT (Speciation filter), modeled PMTOT for default all emissions model run (ADEC_allemis) and final MPE model run (ADEC_allemis_gridmod_biogenic)



ADEC_allemis_gridmod_biogenic SO4 for AQS_Daily Site: 020900034 in AK

Bias for ADEC_allemis_gridmod_biogenic SO4 for AQS_Daily for Dec2019

Figure 2.7.25 Timeseries of site 34 (NCORE) for the observed SO4 (Speciation filter), modeled SO4 for default all emissions model run (ADEC_allemis) and final MPE model run (ADEC_allemis_gridmod_biogenic)

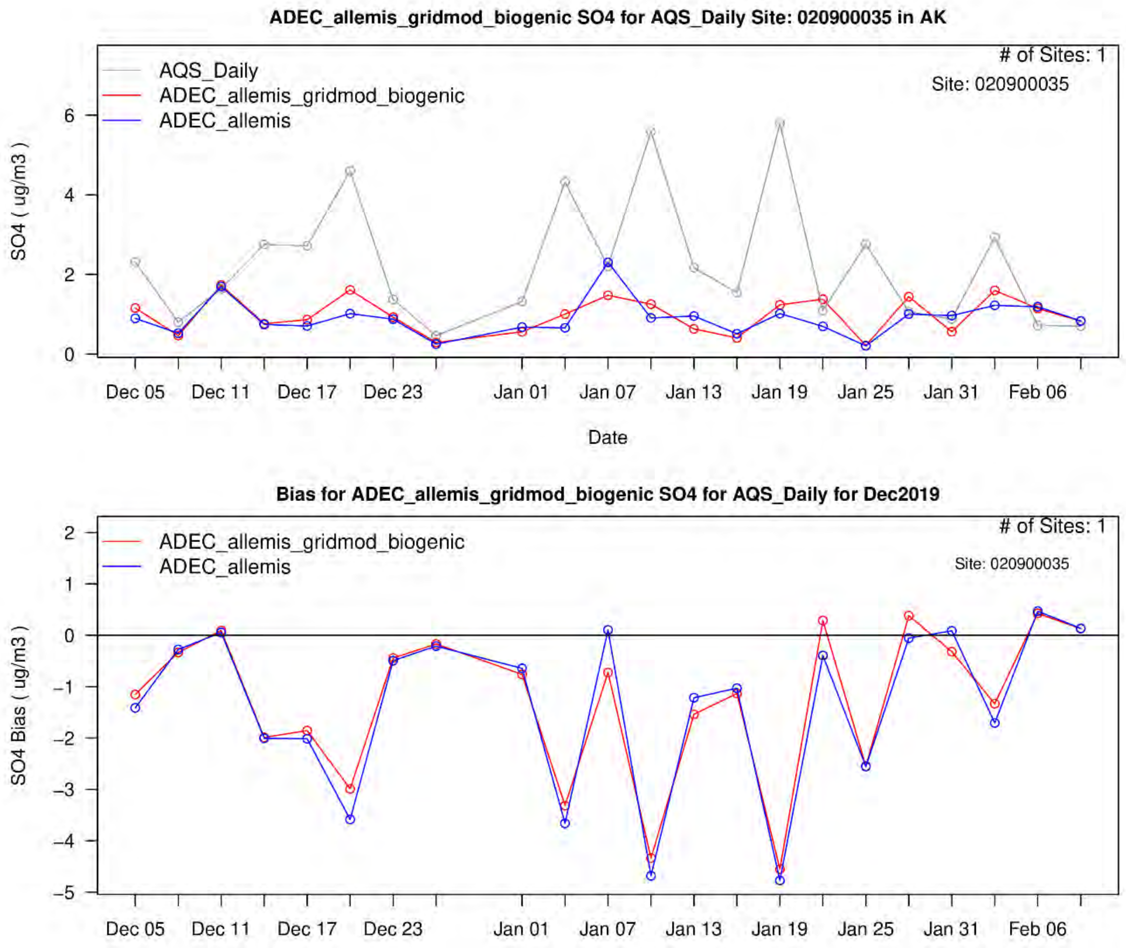


Figure 2.7.26 Timeseries of site 35 (Hurst) for the observed SO4 (Speciation filter), modeled SO4 for default all emissions model run (ADEC_allemis) and final MPE model run (ADEC_allemis_gridmod_biogenic)

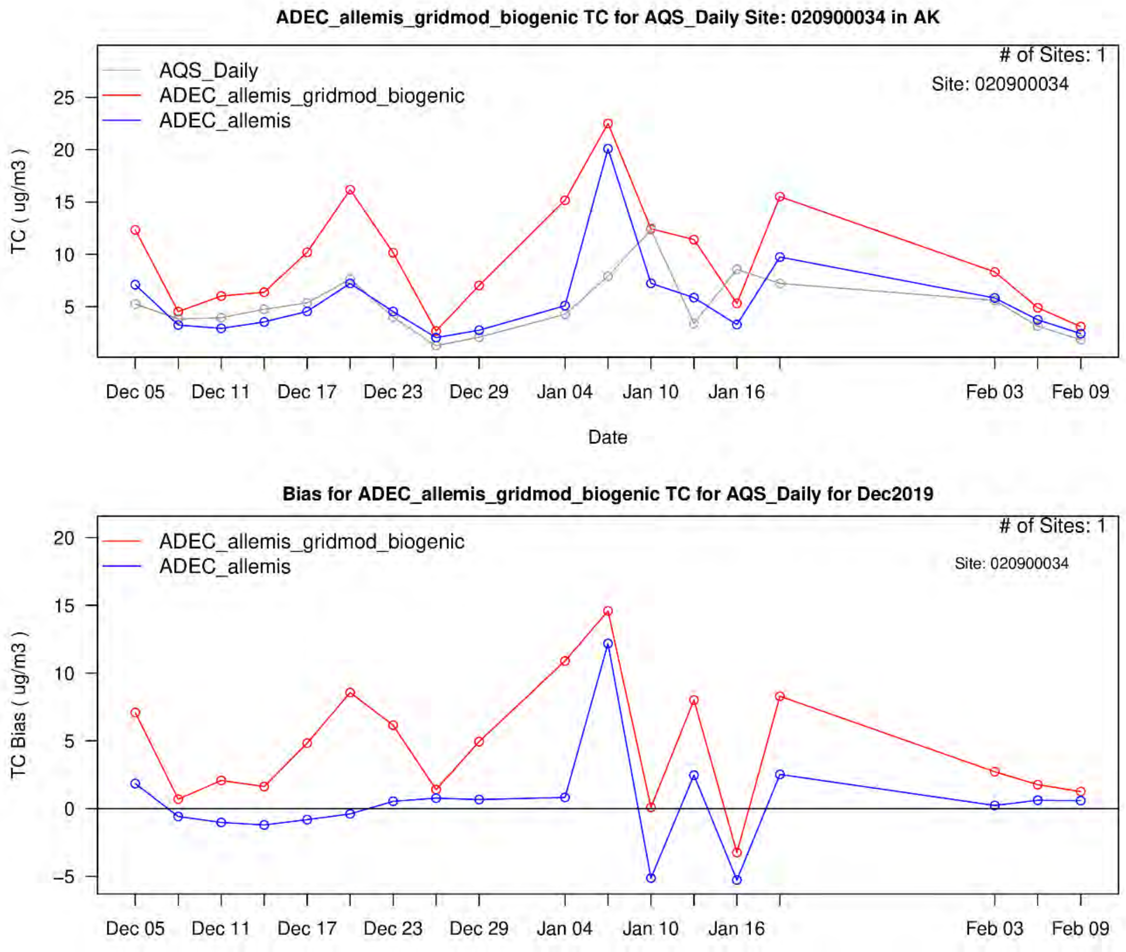


Figure 2.7.27 Timeseries of site 34 (NCORE) for the observed TC (Speciation filter), modeled TC for default all emissions model run (ADEC_allemis) and final MPE model run (ADEC_allemis_gridmod_biogenic)

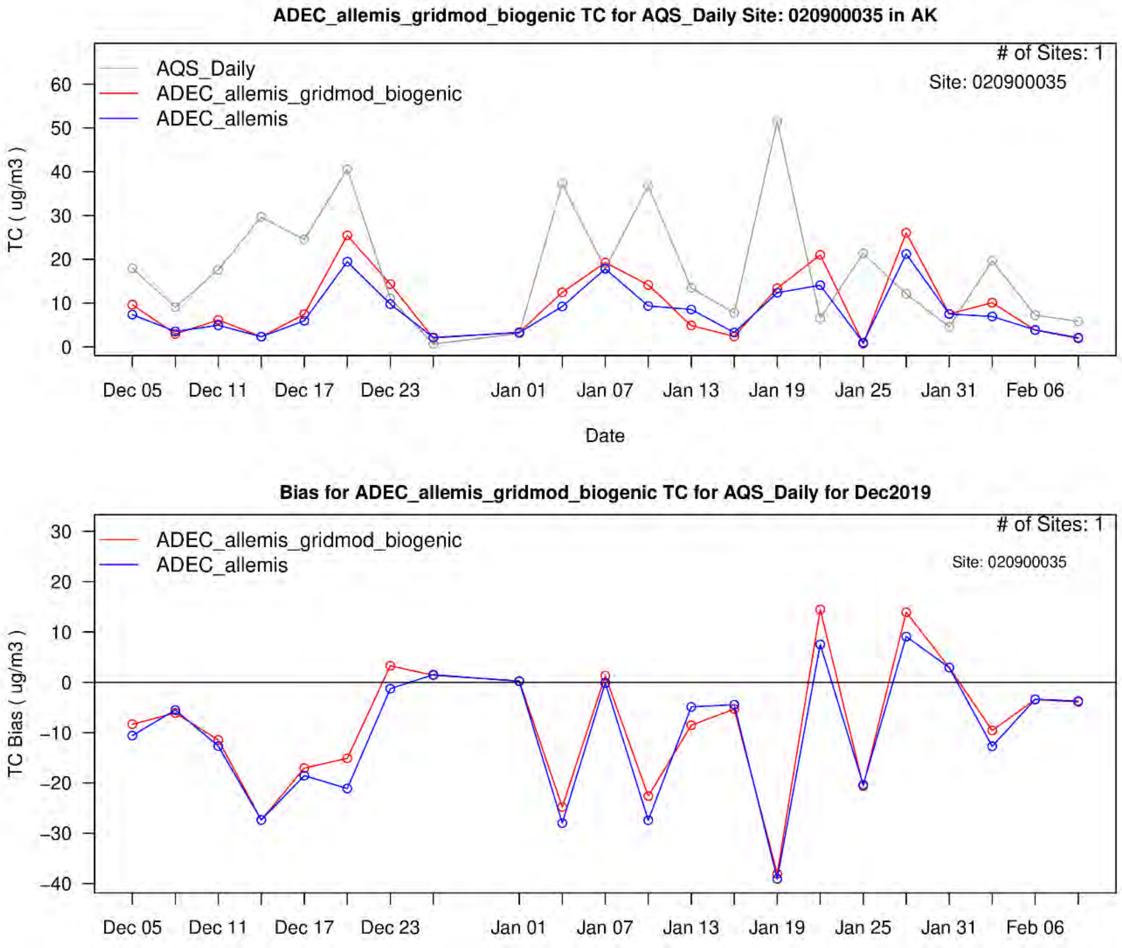


Figure 2.7.28 Timeseries of site 35 (Hurst) for the observed TC (Speciation filter), modeled TC for default all emissions model run (ADEC_allemis) and final MPE model run (ADEC_allemis_gridmod_biogenic)

2.8 Modeling performance discussion and approval

The Model Performance Evaluation (MPE) and resulting metrics, including soccer plots for all the species and total PM2.5 soccer plots and time series presented, the summary overall metrics for discussion above, these initial and final MPE plots were discussed informally with EPA Region 10 and EPA RARE grant /ALPACA modeling group the final MPE will and following information will be with collaboration between DEC, FNSB, EPA and stakeholders on the final modeling platform. The specific operational model performance evaluation (MPE) is outlined in the section 3.1 of the Ozone and PM2.5 modeling guidance.[34] The technical modeling report for Phase 1 and II will be shared in draft for EPA R10 to review the MPE. Phase 3 regulatory modeling is concurrently being completed to analyze the 5-year Design Value and the SMAT (speciated modeled attainment test) calculations. Once a final model configuration is agreed upon, areport will be written up and sent to EPA for review and approval of the new modeling platform.

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[34] o3-pm-rh-modeling_guidance-2018.pdf (epa.gov)

3 Phase 3 PM2.5 Model for regulatory purposes

Phase 3 of the modeling platform update is using the new model (completed from Phase 2) for regulatory work including SIP updates and precursor demonstrations. There are mandatory steps that must be completed before a model may be used for regulatory purposes. These mandatory steps have been documented previously in the Moderate and Serious SIPs. Briefly, these steps include development of a new 5-yr modeling design value with concurrence from EPA, selection of a new base year and the development of a new emissions inventory.

When conducting regulatory modeling there are several additional steps to those identified above. For example, the raw model outputs from the updated CMAQ model are run through speciated model attainment testing (SMAT) to identify a baseline design value and a future design value. Future modeling runs and different scenarios are identified and run through the model based on things like current regulations and control programs in place and input from stakeholder groups, community members, FNSB, DEC and EPA. Then future year model runs are conducted to assess controls and precursors. It can take multiple model runs to assess possible efficacy of various control measures (typically 2-5 runs). Phase 3 including step B of the emissions inventory of the modeling update, has not started, except to identify elements that need to be updated and that have significant lead time (e.g., home heating survey).

The precursor model run that was completed for future SIP (State Implementation Plan) modeling using the base year 2020 emissions was a point source zero out run for SO2. This model run was completed as a preliminary SO2 precursor model run and once this technical modeling report has been reviewed, DEC will continue modeling using a final configuration of CMAQ and all required modeling to satisfy a SIP amendment with completely updated CMAQ modeling for base year, attainment year, all precursors and other control runs that are needed.

3.1 5-year modeling DV summary

The speciation analysis section 2.3 has the complete Table 2.3.1 for the top 25% of wintertime days for the 5-year design value. A summary of the 5-year design values for all three monitors are presented in Table 3.1.1.

Table 3.1.1 Base Year Design Value for modeling runs between each monitoring site

Monitor	2017 98%-tile	2018 98%-tile	2019	2020	2021	**5-yr PM2.5 Modeling Design Value (2017-2021)**
Ncore	32.9	26.2	27.7	26.6	27.5	**27.7**
A Street	NA	NA	34.10	36.1	NA	**34.8**
Hurst	75.5	52.8	65.0	71.4	65.5	**64.9**

These modeling design values are the start of the base year modeling, and all future attainment and precursor model runs start with these current 5-year modeling designs values in Table 3.1.1 for each monitored grid cell in the model. The RRFs represent the relative response of each component of PM2.5 (OC, EC, NH3, SO4, and NO3) from the chosen base year to resulting ratio of the concentrations from any future model run or precursor modeling run divided by the base year modeling. The resulting factor is 1 with the base year (Base year RRF/Base year). An RRF below the ratio of 1:1 (Base year RRF/future year RRF) shows that the future year had a decrease in that component from either an emission decrease, change in the chemistry or from a control. An RRF above 1:1 is from an increase in emissions, a change in the chemistry or results from a decrease in another component or species of PM2.5.

For this modeling report, the preliminary RRFs for a SO2 precursor test modeling RRF results are in Table 3.4.2. The RRF is then multiplied by each species and added together to get the total future year design value from a control model run or a precursor model run. The future year design value should be below 35.4 ug/m3 of total PM2.5 to show modeled attainment. Modeled attainment or modeled insignificance (< 1.5 ug/m3) is the final step in the SMAT process after completed updated MPE and a final model configuration are agreed upon.

3.2 Base year 2020 – Emissions for 2020 and Modeled Concentrations from 2020

The base modeling year must be one of the 5-year design value years 2017-2021. *See* (section 3.1). That guidance [35]recommends using the average of the three design value periods centered on the year of the base year emissions. Since 2020 is the base year for planning, design values for 2017-2019, 2018-2020, and 2019-2021 were used to calculate the design value for use in attainment modeling at this time. For the final SIP amendment modeling over the next year, there is possibility that 2022 data will be added for a design value that is the most relevant of current conditions.

The emissions for the base year 2020 modeling are below in section 3.5.1 and represent the emissions in all sectors for PM2.5, NOx, SO2, VOC and NH3 in lbs/day. The emissions plots show each 1.33 km grid cell in the nonattainment area (black line). Gridded emissions plots for 2020 show all layers combined in the model and not only the surface as in concentrations plots. The emissions are input into their perspective layers (ie – point sources at the stack height and space heating at the stack height) and then the photochemical CMAQ model transforms the emissions into final concentrations of organic carbon (OC), elemental carbon (EC), sulfate (SO4), nitrate (NO3), and ammonium (NH4).

Then the following modeled concentrations (section 3.5.2) show total PM2.5 and the individual components: OC, EC, SO4 and NH4 in a gridded output of the nonattainment area for 2020 at the surface or monitor (breathing) level. The following are direct outputs from the CMAQ model. These outputs are then used for the SMAT calculations that anchor the outputs in the monitored 5-year design values discussed above (section 3.1). The 2020 base year concentrations are the starting point for the SIP modeling process (3.5.2). The darker red the grid cell color, the higher the concentrations of PM2.5. These grid cells inform the control strategy process to understand the higher concentration grid cells. Estimates can be made for the reduction and then apply those reduction in pollutants to future modeling years. Note in the Figures for the 2020 gridded outputs below, the scale is not the same across species and the units are µg/m3 for concentrations as labeled and ppb (parts per million) for the SO2 plots (Figure 3.2.10). The 2020 base year modeling is the first step and no RRF (relative response factor) is calculated, and the values are 1 for PM2.5 and all components. The relative response factor changes in PM2.5 and its components are referenced to the base year and is calculated for baseline and all future model runs, including the SO2 precursor model run, the only other model run completed at this time.

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[35] appw_17.pdf (epa.gov)

The RRFs represent the relative response of each component of PM2.5 (OC, EC, NH3, SO4, and NO3) from 2020 to resulting concentrations from SO2 precursor modeling run (3.4). An RRF below the ratio of 1 (2020 RRF/SO2 precursor RRF) shows that SO2 precursor had a decrease in that component from either an emission decrease, change in the chemistry or from a control (zero SO2 emissions for the point sources). An RRF above 1 is from an increase in emissions, a change in the chemistry or results from a decrease in another component or species of PM2.5. The SO2 precursor modeling results are in the next section.

3.2.1 Emission Plots for base year 2020

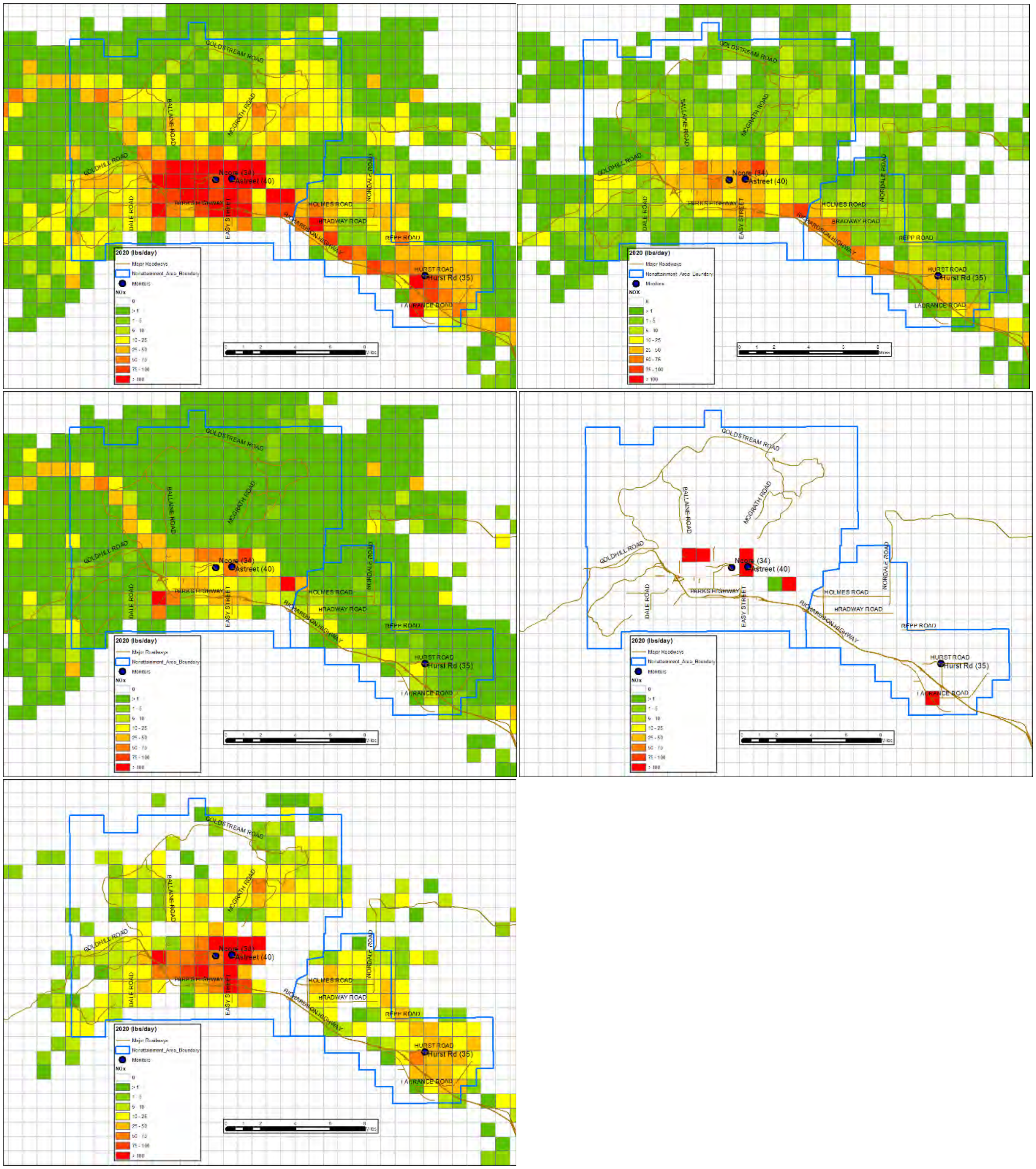

Figure 3.2.1 NOx emission maps in lbs/day. NOx all sector (top left), Onroad (top right), Other (middle left), Point (middle right), Spaceheat (bottom left)

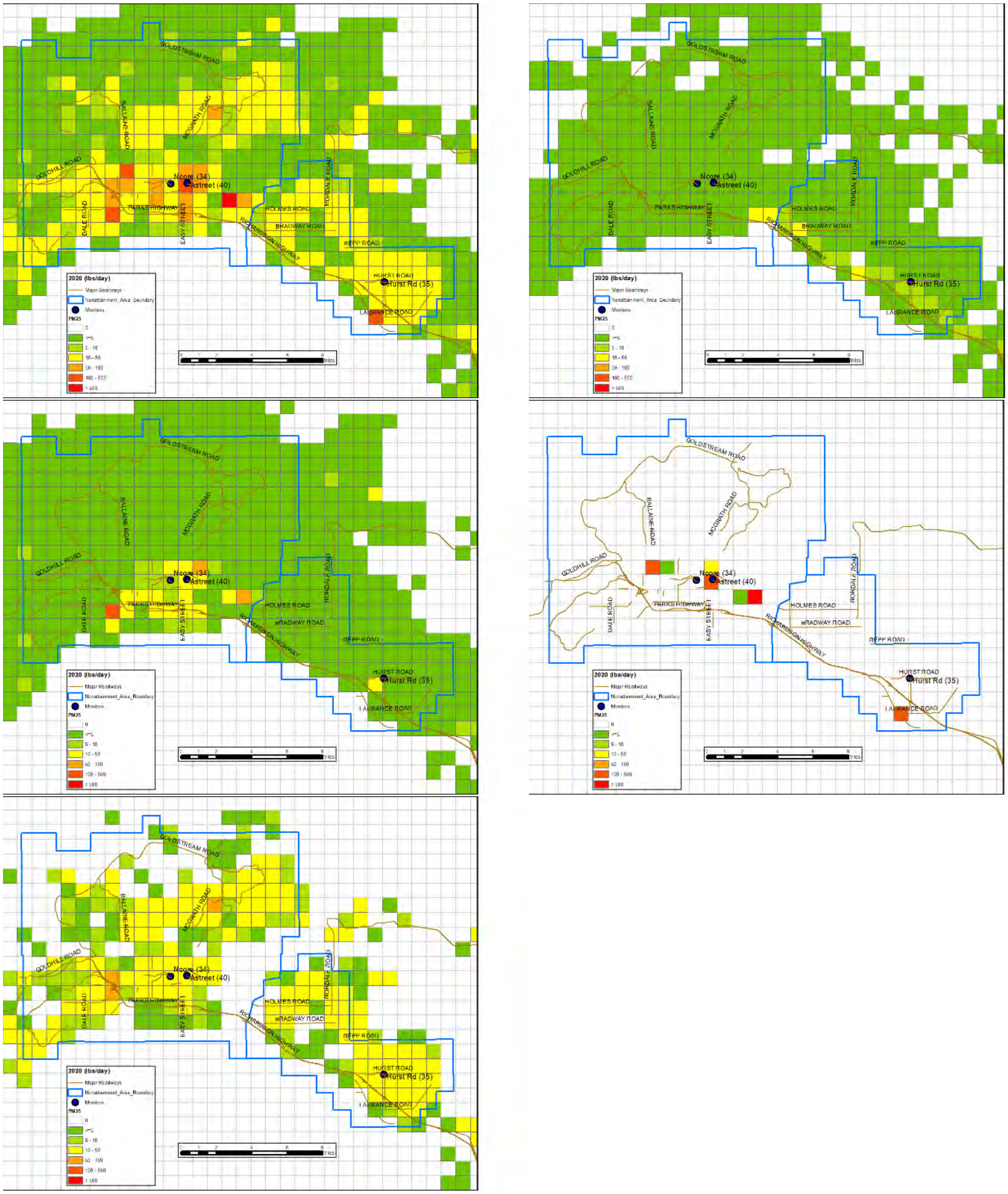

Figure 3.2.2 PM2.5 emission gridded maps in lbs/day. PM2.5 all sector (top left), Onroad (top right), Other (middle left), Point (middle right), Spaceheat (bottom left)

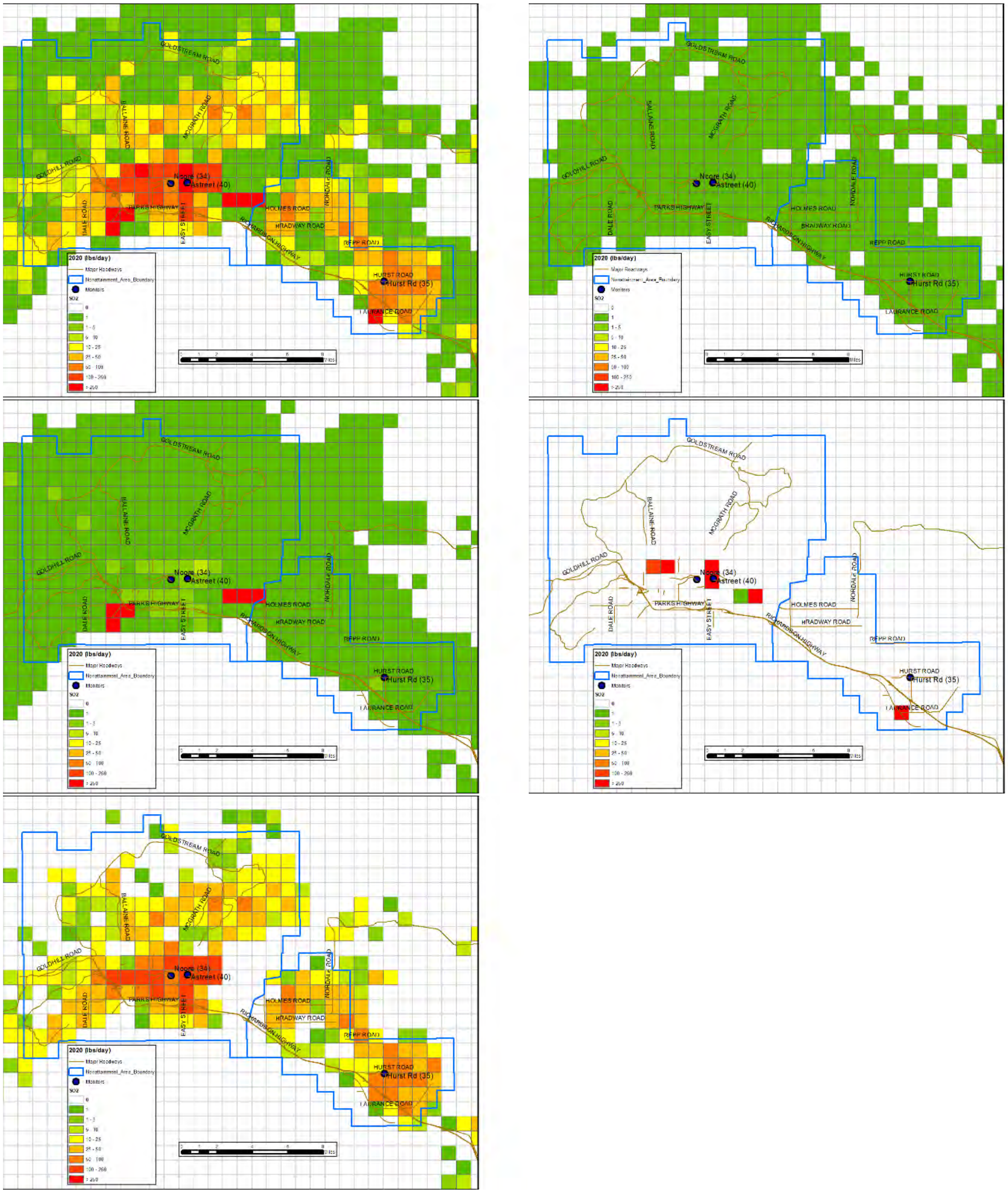

Figure 3.2.3 SO2 emission gridded maps in ppbv for the base year 2020. SO2 all sector (top left), Onroad (top right), Other (middle left), Point (middle right), Spaceheat (bottom left)

3.2.2 Concentration plots for base year 2020

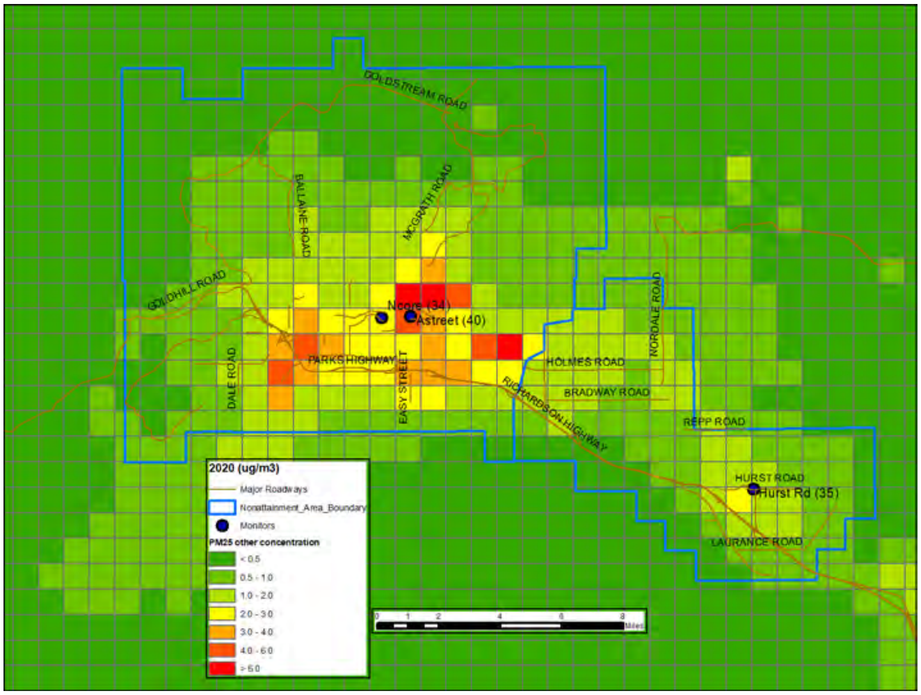

Figure 3.2.4 PM2.5 Other concentration plot in µg/m^3 at the surface for the Fairbanks NAA for the base year 2020

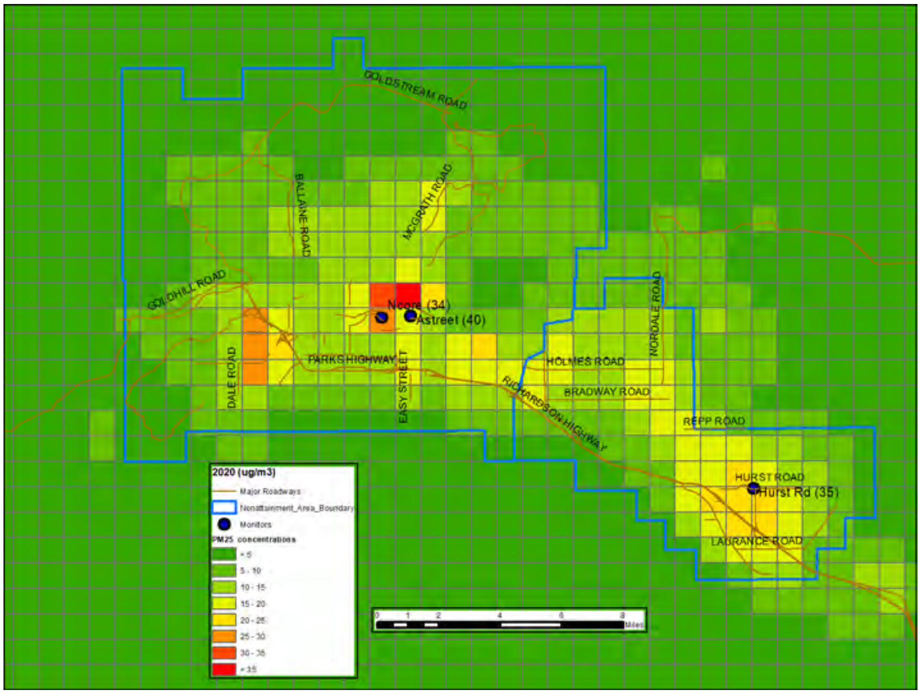

Figure 3.2.5 PM2.5 concentration plot in µg/m^3 at the surface for the Fairbanks NAA for the base year 2020

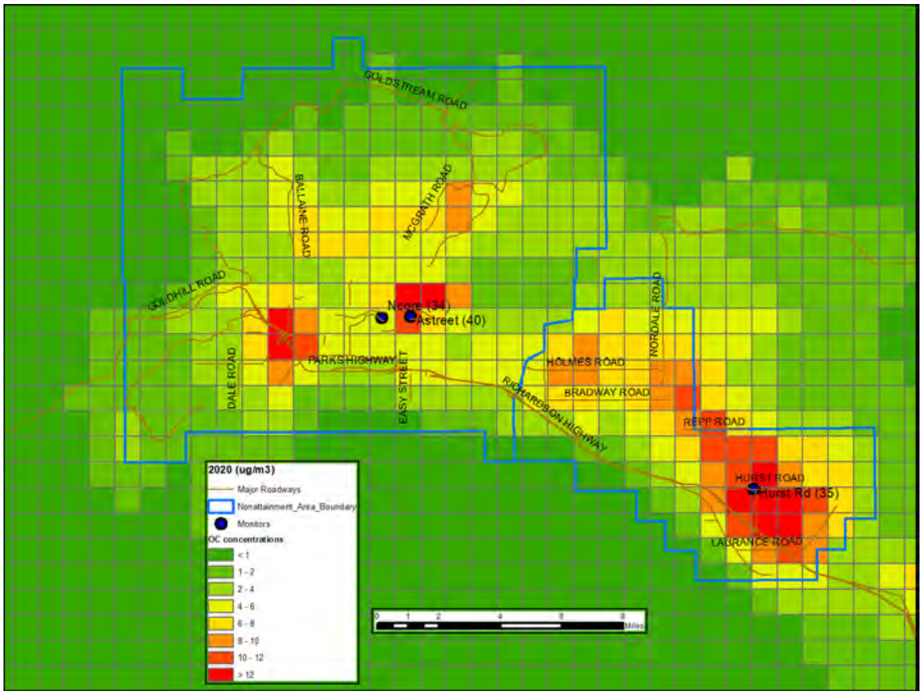

Figure 3.2.6 Organic Carbon (OC) concentration plot in µg/m^3 at the surface for the Fairbanks NAA for the base year 2020

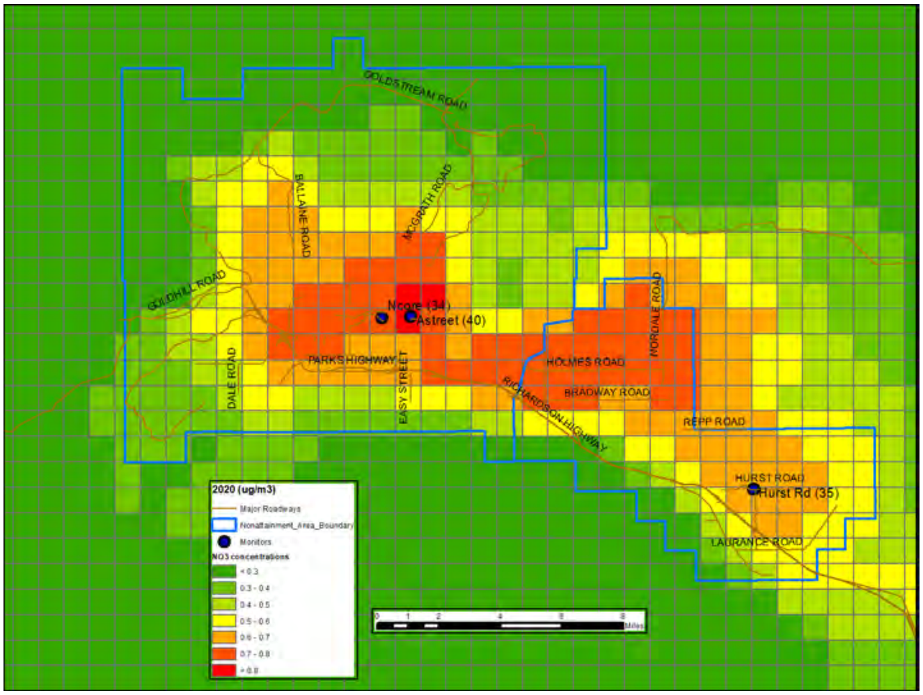

Figure 3.2.7 Nitrate (NO3) concentration plot in µg/m^3 at the surface for the Fairbanks NAA for the base year 2020

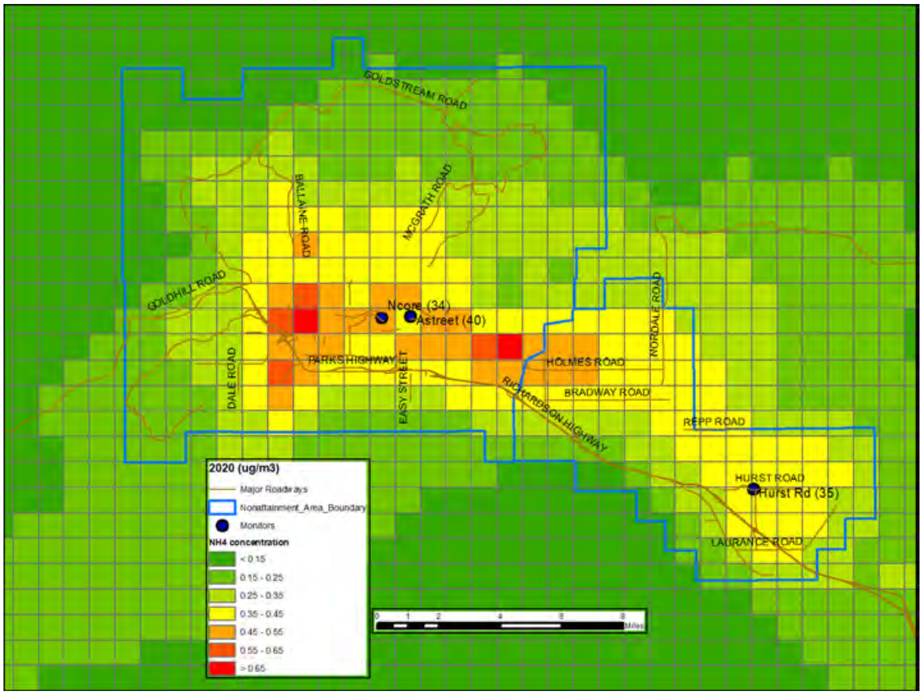

Figure 3.2.8 Ammonia (NH4) concentration plot in µg/m³ at the surface for the Fairbanks NAA for the base year 2020

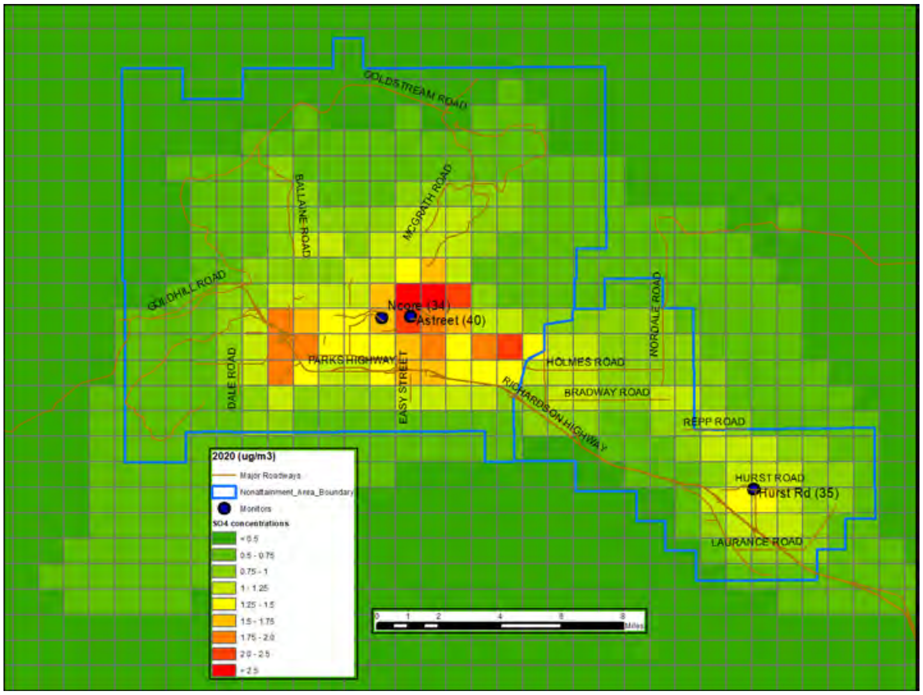

Figure 3.2.9 Sulfate (SO4) concentration plot in µg/m³ at the surface for the Fairbanks NAA for the base year 2020

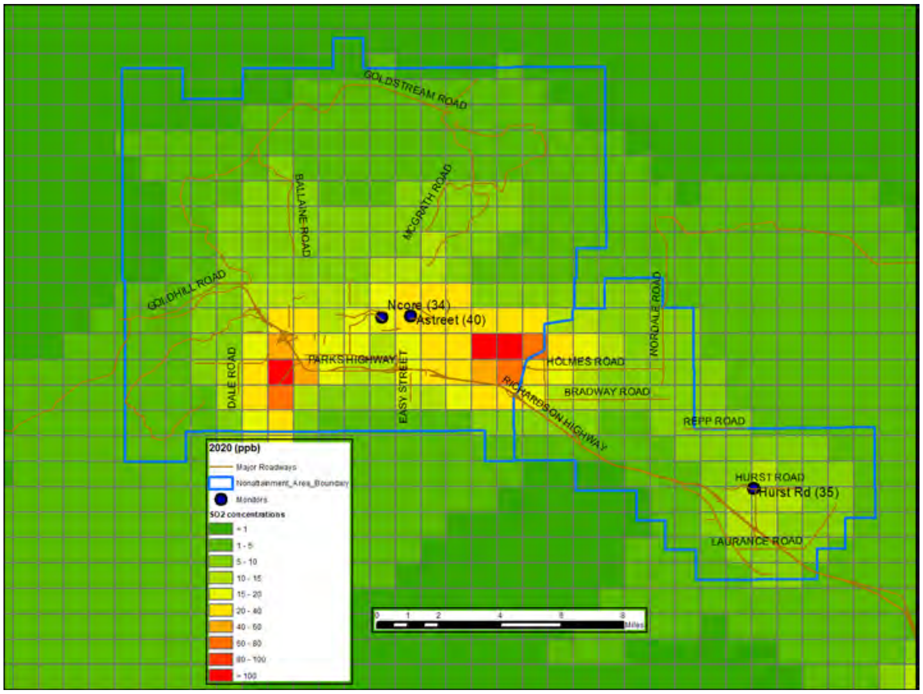

Figure 3.2.10 Sulfur dioxide (SO2) concentration plot in ppb at the surface for the Fairbanks NAA for the base year 2020

3.3 Preliminary SO2 stationary source (point sources) precursor test run using the current available modeling platform. Acknowledging that another modeling platform update is likely with updated sulfate performance, this preliminary run will not necessarily be representative of the final precursor analysis but is meant to be indicative of the process for a precursor analysis.

Testing the current CMAQ configuration and the SO2 test model run was a zero out run for the point sources using a precursor model run process per the EPA guidance on precursors.[36] All of the point source SO2 emissions are set to zero to see the difference in sulfate on all the speciation days.

When DEC submits a SIP amendment in the future, DEC will apply the same tiered approach to the precursor demonstration for both NOx and VOCs in the Fairbanks North Star Borough 24-hour PM2.5 Nonattainment Area in the Serious Area SIP.[37] DEC is using the same approach for the SO2 precursor model run with the final updated modeling platform configuration in the future.

The tiered analysis can be broken down into five stages each with a decreasing level of confidence in the demonstration. The various precursor demonstration available are the following:

Concentration Based Analysis
o Ambient data
o Air Quality Modeling (zero-out emissions from a precursor gas for NOX, VOC and SO2)
Sensitivity Based Analysis (only if needed)

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[36] PM2.5 precursor demonstration guidance (epa.gov)
[37] Fairbanks PM2.5 Serious SIP (Alaska.gov)

o 70% Reduction
o 50% Reduction
o 30% Reduction

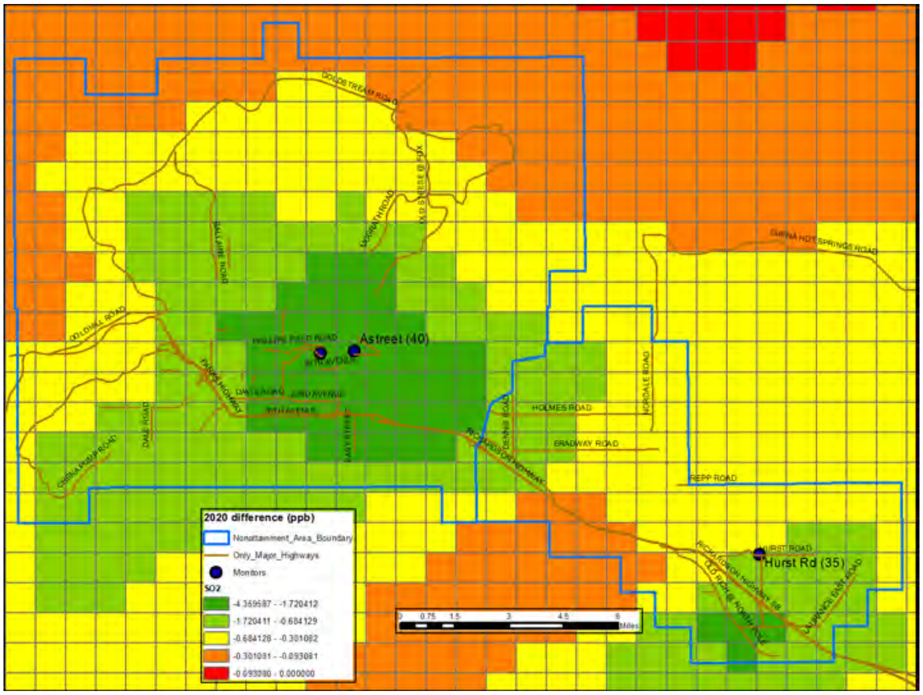

Figure 3.3.1 SO2 point source zero out run – 2020 base case difference plot for SO2 in ppb

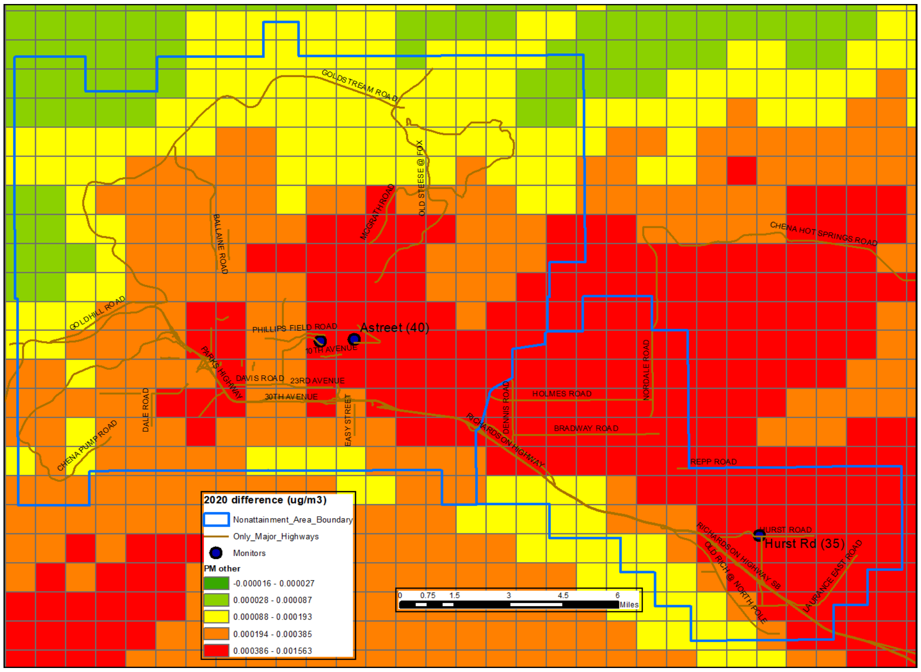

Figure 3.3.2 SO2 point source zero out run – 2020 base case difference plot for PM Other in ppb

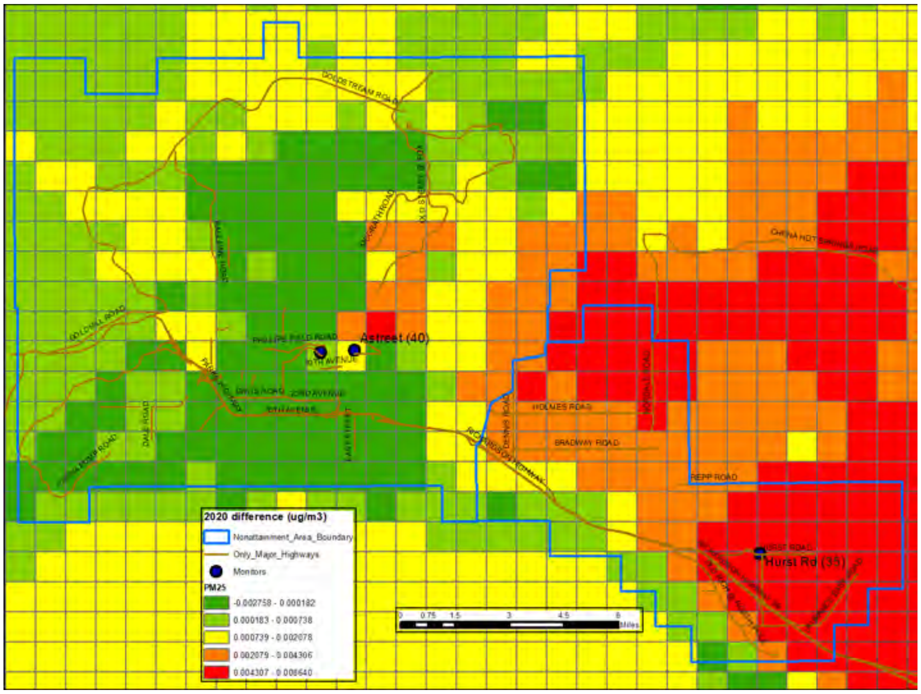

Figure 3.3.3 SO2 point source zero out run – 2020 base case difference plot for PM2.5 in µg/m^3

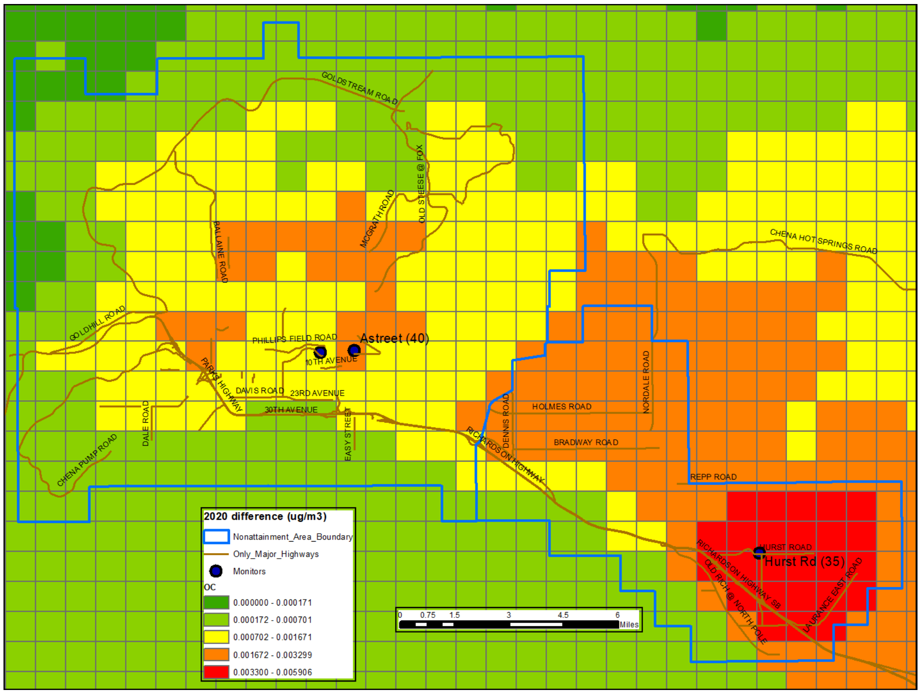

Figure 3.3.4 SO2 point source zero out run – 2020 base case difference plot for OC in µg/m^3

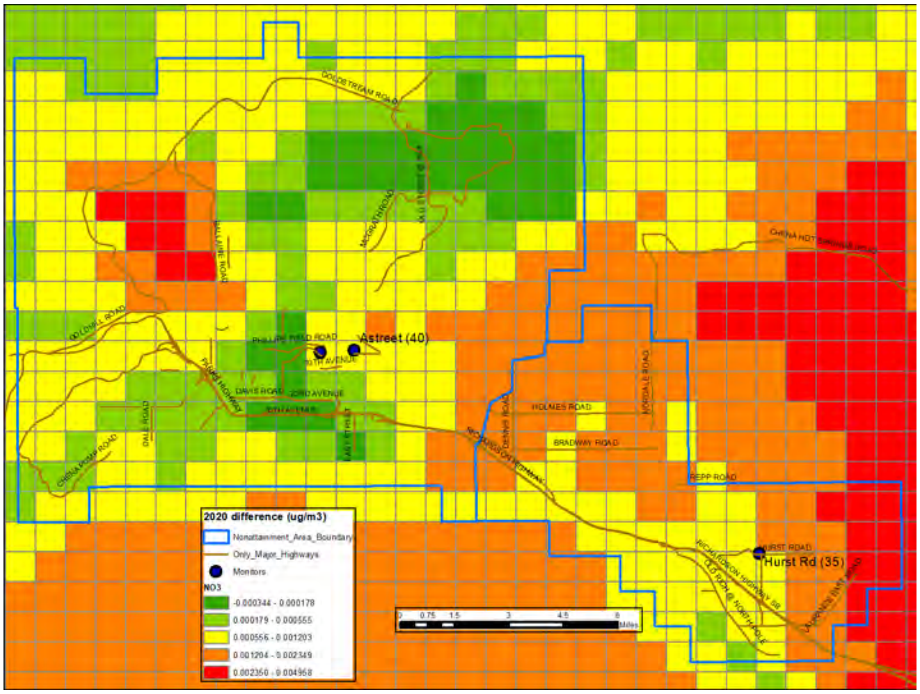

Figure 3.3.5 SO2 point source zero out run – 2020 base case difference plot for NO3 in μg/m^3

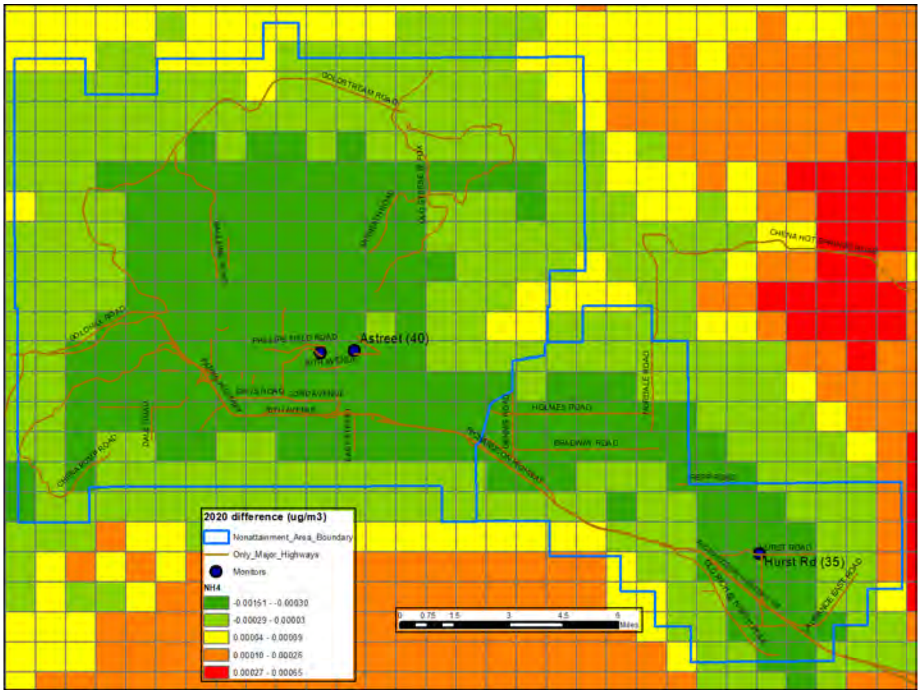

Figure 3.3.6 SO2 point source zero out run – 2020 base case difference plot for NH4 in μg/m^3

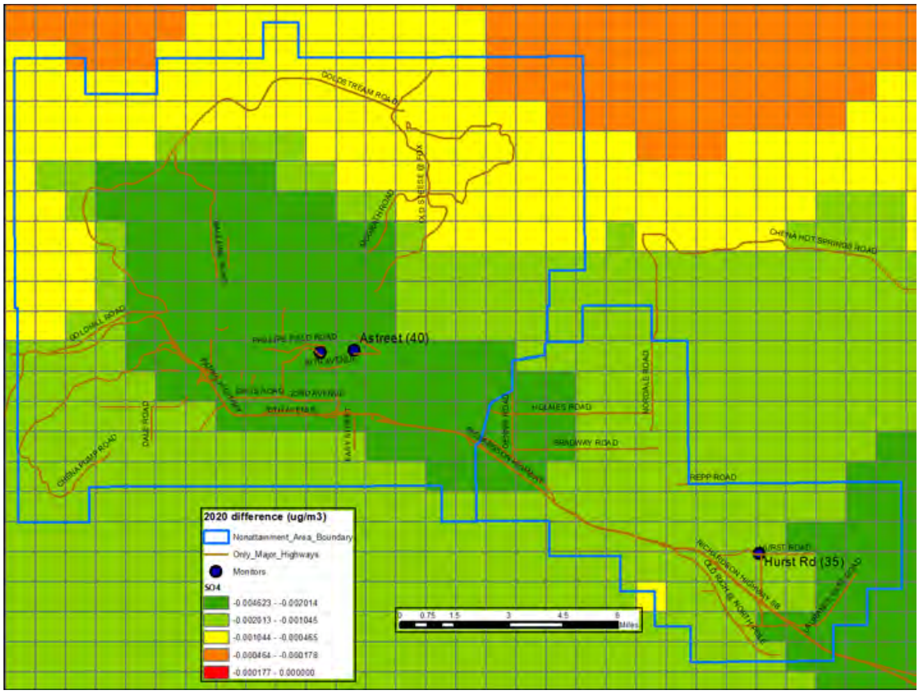

Figure 3.3.7 SO2 point source zero out run – 2020 base case difference plot for SO4 in µg/m^3

Table 3.3.1 SO2 Precursor model test run results for Episode average and max daily value for absolute concentration and Design Value

	Episode Average (ug/m3)			Max Daily Value (ug/m3)		
CMAQ Sensitivity 100%	A Street	NCORE	Hurst	A Street	NCORE	Hurst
CMAQ - Absolute						
SOx	0.00017	0.00169	0.00791	-0.04065	-0.05280	-0.01904
CMAQ - Design Value						
SOx	-0.00633	0.02196	-0.00289			

Table 3.3.2 SO2 precursor test run maximum cell on a max day for PM2.5 (ATOTIJ), Sulfate (ASO4IJ), Nitrate (ANO3IJ) and SO2

SO2_minus_Base_dailyavg Min indices			
ATOTIJ (ug/m3)			
	-0.1789627		
	1-Jan	DAY	
	96	ROW	
	108	COL	
ASO4IJ			
	-0.1323823		
	1-Jan	DAY	
	96	ROW	
	108	COL	
ANO3IJ			
	-0.0124117		
	8-Jan	DAY	
	98	ROW	
	131	COL	
SO2 (ppbv)			
	-19.181366		
	6-Jan	DAY	
	92	ROW	Y
	110	COL	X

Max cell, max day is 0.17 ug/m3 for the design value total PM2.5 and then using MPE for PM2.5 (ATOTIJ) and 0.13 ug/m3 for sulfate (ASO4IJ), there is a negative average episode NMB (normal mean bias) for all monitors at -50% (Table 2.7.2). The Maximum sulfate from point source accounting for the biases in the model is 0.13 + 50% = 0.26 ug/m3, with the current modeling platform and model performance evaluation as presented in this report.

The science version of CMAQ 5.3.3. +chemistry has enhanced secondary sulfate chemistry which can be used for improved sulfate model performance. In addition, DEC is working with USEPA ALPACA modelers to corroborate results of contribution of each sector with their 2022 CMAQ 5.4 and CMAQ 5.3.3+chemistry modeling results and sulfur tracking, where they will be looking at individual sectors for SO2 to sulfate conversion.

3.4 SMAT (Speciated Model Attainment Test)

Using the 5-year design value tables with wintertime top 25% speciation values from all three monitor cells the raw model outputs are put into a 5-year design value concentration.

SMAT takes the RRF by species as raw model output and puts that into a design value by multiplying the resulting RRF (SO2 test run/base) by each species for the FRM value for all days for 5 years and choosing the future or precursor model run 98%-tile per year and final DV is calculated using the 5-year design value (Table 3.4.3).

The complete SMAT calculations for an attainment model run will be completed in the upcoming year when inventory step B (section 2.7) is completed, and updates to the attainment year inventory can be used for an attainment model run.

Table 3.4.1 SMAT summary tables for all three monitored grid cells in the model for base year 2020 and SO2 precursor model test run

A Street Values	**5year** Design Value PM2.5 ug/m3	Hurst Values	**5year** Design Value PM2.5 ug/m3	NCore Values	**5year** Design Value PM2.5 ug/m3
AStreet_2020_base	34.767	**Hurst_2020_base**	64.933	**NCore_2020_base**	27.678
Atreet_SO2_precursor	34.760	**Hurst_SO2_precursor**	64.955	**NCore_SO2_precursor**	27.675

Table 3.4.1 RRF values from each monitor site for the SO2 precursor model run and final 5 year future design value (FDV) of PM2.5 in ug/m3 resulting from the SO2 precursor zero out model test run

RRFs	PM25	OC	EC	SO4	NO3	NH4	OTH	SO2	FDV
A Street	1.00001	1.00018	1.00022	0.99868	1.00089	0.99847	1.00018	0.87758	34.760
NCORE	1.00006	1.00019	1.00025	0.99887	1.00117	0.99838	1.00018	0.88231	27.675
Hurst	1.00046	1.00053	1.00072	0.99806	1.00290	0.99930	1.00063	0.92751	64.955

Table 3.4.2 A Street, NCORE and Hurst Modeling Design Values for the Base Year and the SO2 precursor test run.

	A street		NCore		Hurst	
Year	Base Year DV	SO2 Precursor DV	Base Year DV	SO2 Precursor DV	Base Year DV	SO2 Precursor DV
2017	NA	NA	32.900	32.897	75.500	75.526
2018	NA	NA	26.200	26.197	52.800	52.818
2019	34.10	34.09	27.700	27.697	65.000	65.022
2020	36.10	36.09	26.600	26.597	71.400	71.424
2021	NA	NA	27.500	27.497	65.500	65.522
Rolling Average	**34.767**	**34.760**	**27.678**	**27.675**	**64.933**	**64.955**

3.5 Weight of Evidence on updates to the modeling platform

The modeling platform has at least four significant updates: (1) CMAQ model version; (2) SMOKE model version; (3) emissions inventory for all sectors; and (4) new meteorological WRF episode. In addition, new information for the North Pole area, (Hurst Road speciation monitor) was collected for three winters of the 5-year modeling design values. A Model Performance Evaluation was completed on

PM2.5 at all three monitor locations (A Street, NCore and Hurst) and on all species at NCore and Hurst for the entire 74 day modeling episode.

There are still several major improvements to be made to the CMAQ Modeling Platform on current projects in progress by USEPA and the ALPACA study and they are outlined in the following sections. The model testing and updates below may be adopted into the final configuration for CMAQ regulatory runs. After a full analysis, if these updates warrant a permanent change due to improved performance, the weight of evidence model runs will be moved to the final CMAQ configuration and be in the model performance section above.

3.5.1 Sulfate Model Performance

The EPA RARE group focused on the poor modeling performance for sulfate by performing several model runs using additional chemistry. Sensitivity tests were run on the formation of sulfate and the end results were additional heterogeneous and aerosol sulfate chemistry being added to the model. The preliminary results showed 20% higher secondary sulfate formation from heavy metal catalysts reactions. These studies lead to the “science” version of CMAQ that is yet to be released. The importance of hydroxymethanesulfonate (HMS) in Fairbanks wintertime chemistry is a major finding of the ALPACA campaign work in measurement studies (below) and the chemistry has been added to the new CMAQ science version that has yet to be released.

The following bullets are a summary of updates to HMS in the model from EPA Office of Research and Development, Kathleen Fahey:

- Hydroxymethanesulfonate (HMS) is an adduct formed from the aqueous reaction of HCHO (and only the unhydrated form really participates in this reaction which is ~1% of the total dissolved HCHO in cloud water) and HSO_3^- or SO_3^{2-}. These reactions are reversible, so it can revert back to HCHO and HSO_3^- or SO_3^{2-}. It is a S(IV) species (similar to SO_2*H_2O, HSO_3^-, and SO_3^{2-}). And it’s not a newly discovered compound, this species in fog water back in the 80s when researchers were trying to understand why there was higher S(IV) in fog water compared to what they would expect based on the observed $SO_{2(g)}$ concentration and Henry’s Law.
- The HMS reactions are highly influenced by pH (e.g., the rate coefficient of HCHO + SO_3^{2-} (i.e., the $SO_{2(aq)}$ species dominant at high pH) is many times larger than HCHO + HSO_3). High pH also promotes faster HMS loss back to SO_2 and HCHO, so it is thought that moderate pH will be most conducive to higher HMS concentrations. HMS can also be lost to a reaction with hydroxyl (OH) – though that’s probably not a major loss pathway for HMS in Fairbanks in the winter (unless OH formation is significant in aerosol water or something).
- These new pathways were added to the Sulfur Tracking Method (STM), so we can see what pathways are contributing what to SO_4^{2-} concentrations. Also IC/BC, gas-phase production, and primary emissions of SO_4^{2-} are tracked, so you can tell how much of the modeled SO_4^{2-} is primary vs. secondary.

The inclusion of heterogeneous sulfur chemistry enhances wintertime sulfur aerosol in AK and the northern hemisphere. USEPA Office of Research and Development (ORD) presented the early findings in a poster presented at CMAS modeling conference [38]. Since then, they have included the heterogeneous and aerosol chemistry pathways in the CMAQ science version.

The EPA RARE grant group has started preliminary model runs modeling CMAQ version science addition (CMAQ 5.3.3 +chemistry) for the 2022 ALPACA winter field season for 6 weeks of 2022.

The 2022 ALPACA period has been modeled with the emission files that are ready to go so far. Figure 3.5.1 shows the sulfate concentrations for NCORE and Hurst Rd speciation data.

The bars = observations, blue line = CMAQv5.4 (no additional heterogeneous sulfur chemistry), and the red line = CMAQv5.3.3+ with (one of the few configurations) of the heterogeneous chemistry (still running).

The Figure 3.5.1 shows significant increase in sulfate using the chemistry addition and trends with the sulfate production. These results are preliminary but can greatly increase the sulfate model performance.

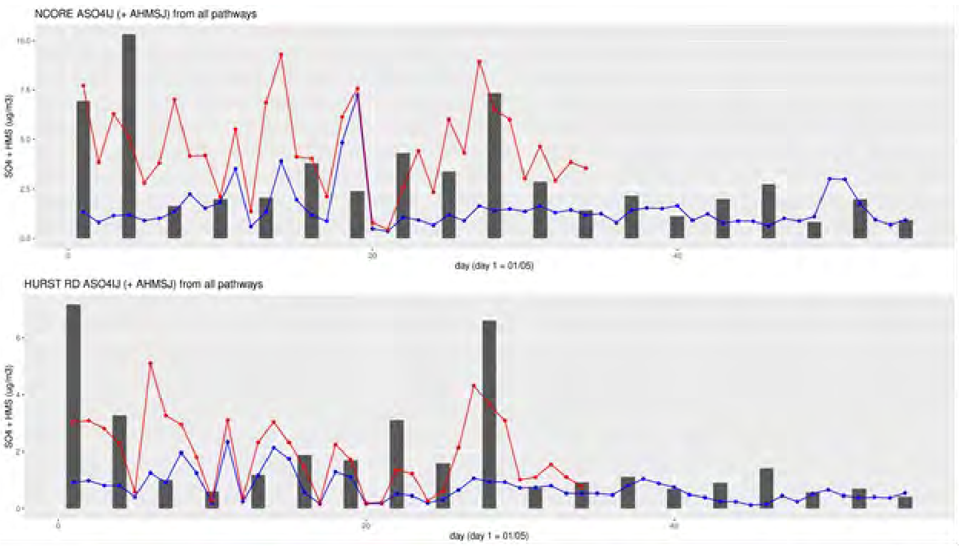

Figure 3.5.1- Sulfate concentrations during the 2022 Alpaca 6-week winter episode for the NCore and Hurst Rd grid monitor grid cell in the CMAQ model, with (red line) and without (blue line) sulfate chemistry. Note at the time of these preliminary results the red line CMAQ +chemistry had not completed.

The focus the CMAQ APLACA modeling being completed by the USEPA -ORD RARE group is sulfur tracking of the SO2 precursor gas to conversion to sulfate to attribute this to sectors in the model from space heating and point sources. DEC is including this completed 2022 modeling from EPA for the ALPACA campaign as Weight of Evidence.

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[38] Predicted impacts of heterogeneous chemical pathways on particulate sulfur over the N. Hemisphere and Fairbanks, Alaska (poster in Appendix)

DEC has recently started the base year 2020 for the 74-day episode using the CMAQ science version 5.3.3+ and results will be added to next version of this technical modeling report.

3.5.2 WRF model performance

The USEPA-ORD RARE group of scientists participated in the ALAPACA campaign in Fairbanks and are in the process of conducting WRF modeling for the winter of 2022. The motivation behind this grant work is the provide and effective modeling tool to characterize Fairbanks PM2.5 for use in the SIP planning efforts to reduce high PM concentrations. The WRF meteorological model runs by USEPA-ORD RARE group and the winter 2019-2020 episode for ADEC modeling, in the initial runs, had similar performance for stable boundary layer conditions that are common in Fairbanks in winter (**Table 3.5.1**).

The USEPA-ORD RARE group (Rob Gilliam) presented a poster at the CMAS conference[39] on their 2022 WRF modeling results so far. "The final modeling platform will incorporate the latest scientific understanding to provide an improved modeling tool for the state of Alaska to use in its air pollution program in Fairbanks." Currently the modeling is still in progress, but DEC is very interested is using their improved modeling for our regulatory SIP modeling.

The presentation details the meteorological modeling component of ALPACA, a principal input to the Community Multiscale Air Quality (CMAQ) model that is being used to characterize the atmospheric chemistry and transport of pollutants in and around Fairbanks.[40] The abstract: "We employ the Weather Research and Forecasting (WRF) model to simulate meteorology at a grid scale of 1.33 km. More specifically, we will cover the WRF configuration including physics and data assimilation for this complex subarctic, mid-winter, problem as well as an evaluation that focuses on several extreme cold periods where observed PM2.5 was well above the NAAQS. Results of the preliminary evaluation indicate that WRF can simulate near-surface meteorology and vertical temperature and moisture gradients around Fairbanks with high confidence considering the complex meteorology of the area. This is accomplished with four-dimensional data assimilation using global model analyses, observational nudging of standard surface observation networks, mesonet and above-surface rawinsonde soundings in combination with the selection of land-surface and boundary layer physics options." The Figure 3.5.1 shows the modeling sensitivity results in the time series for the six-week APLACA 2022 winter episode at 3 meters.

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[39] https://cmascenter.org/conference/2022/agenda.cfm

[40] **Modeling the wintertime meteorology for the 2022 Alaskan Layered Pollution and Chemical Analysis (ALPACA) campaign**. Robert Gilliam, Kathleen Fahey, George Pouliot, Havala Pye, Nicole Briggs, Deanne Huff and Sara Farrell

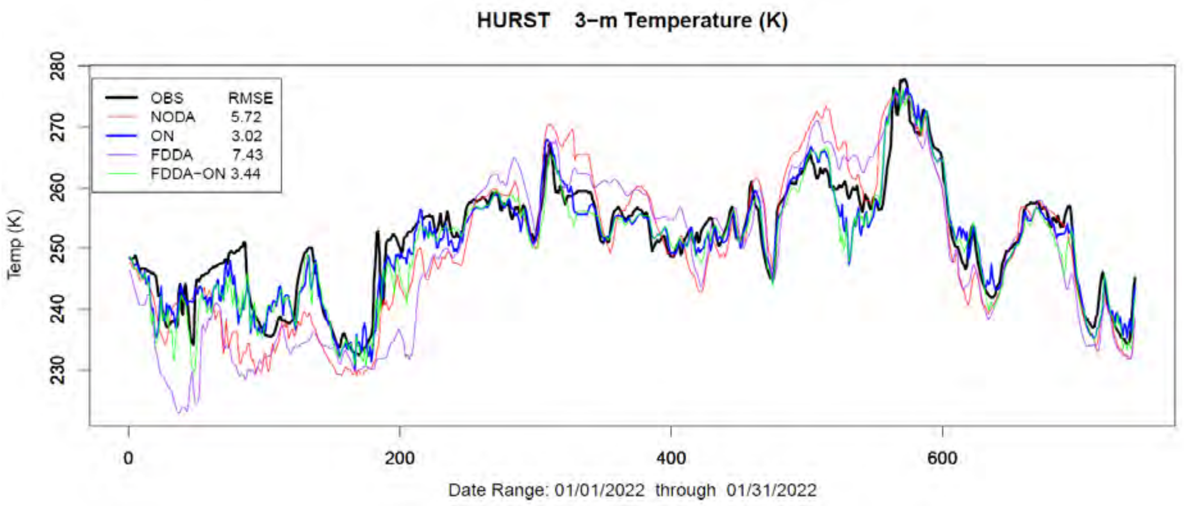

Figure 3.5.1 Temperature comparison of different WRF sensitivity run completed by USEPA for 2022 modeling episode for ALPACA

A preliminary comparison of the current final configuration for WRF from USEPA-ORD is not for the cold periods only, but for comparing to the DEC -WRF episode monthly values. The statistics in Table 3.5.1 are similar for both years ran with the metrological model WRF.

Table 3.5.1 Preliminary RMSE (root mean square error) comparison of the DEC 74-episode to USEPA 2022 ALPACA WRF meteorology statistics.

JAN	DEC 2020	US EPA 2022
A St	1.39	1.98
NCORE	1.32	1.87
Hurst	2.39	3.02

Feb	DEC 2020	US EPA 2022
A St	2.15	2.00
NCORE	2.00	1.54
Hurst	2.66	2.35

Since Table 3.5.1, USEPA was able to run more WRF sensitivities[41] and has come up with series of physics options that have made significant improvement on the temperature and wind speed biases and error. The meteorological input to CMAQ is tied the overall model performance, with temperature and wind speed controlling the vertical and horizontal distribution of emissions. USEPA is now in the planning stages of re-running the DEC 2019-2020 meteorological episode and this is a large advancement and improvement if the error and biases are greatly improved for the DEC modeling platform.

With both the meteorological and CMAQ chemistry being updated greatly effecting the outcome of the DEC modeling performance, DEC plans to turn in SIP amendments that includes updated modeling using

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[41] WRF Modeling in Support of FY2020 Fairbanks RARE Project by Rob Gilliam (presentation in Appendix)

the CMAQ science version, updated MPE using the science version, and new base year 2020, attainment year, UMAA (unmonitored area analysis) modeling, and precursor demonstrations for SO2, NOx and VOC.

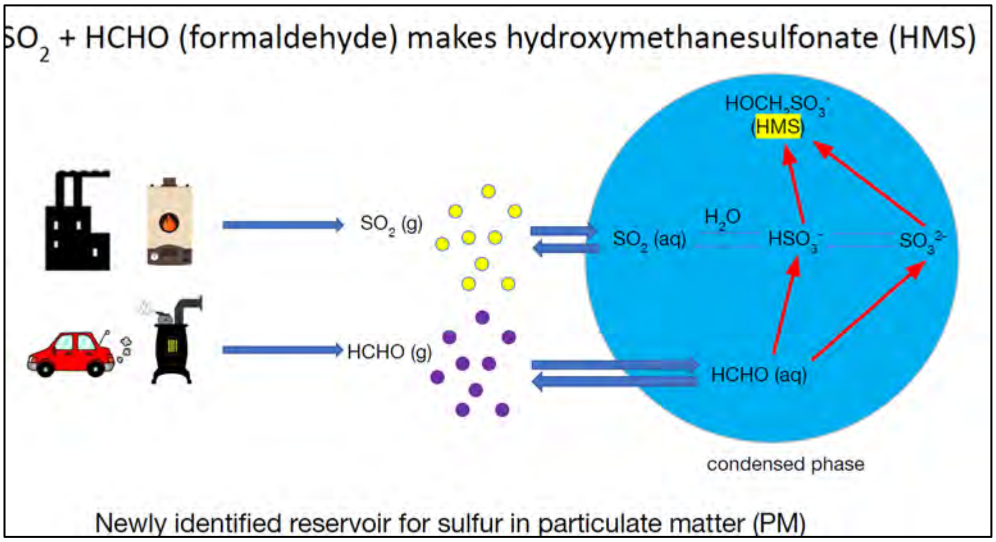
3.5.3 NEXT STEPS: CMAQ future year attainment model runs

DEC is planning on re-running the base year 2020 and the WRF episode for 2019-2020 winter with the CMAQ science version. Then after the re-run and new model performance evaluation using CMAQ 5.3.3 +-science, a new emissions inventory with Step B outlined in the summary will be added and an attainment model run along with all other SIP amendment requirements will be added to the modeling chapter.

3.6 Other ALPACA work

The Alaskan Layered Pollution and Chemical Analysis (ALPACA) 2022 air quality study took place in Fairbanks for 6 weeks in the winter of 2022. The preliminary results are mentioned in relation to the CMAQ model above in this report (section 3.5 and modeling performance 2.4). There are many reports and presentations highlighting the work of this campaign. It was designed to bring scientists together to Fairbanks, Alaska to study wintertime cold climate chemistry. [42]

Dr. Bill Simpson from University of Alaska, Fairbanks is one of the leaders of the ALPACA campaign and recently gave presentation to the Air Pollution Control Committee in Fairbanks, Alaska on the preliminary work from the results of the ALPACA campaign. [43]



SO_2 + HCHO (formaldehyde) makes hydroxymethanesulfonate (HMS)

Newly identified reservoir for sulfur in particulate matter (PM)

Figure 3.6.1 HMS pathway and sources slide from Results from the Alaskan Layered Pollution And Chemical Analysis (ALPACA) 2022 air quality study

In addition to investigating HMS, Bill Simpson's group looked at historical SO2 measurements, see **Figure 3.6.2**. The historical look at SO2 measurements show a drop in SO2. This may be attributed to the fuel

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[42] https://fairair.community.uaf.edu/

[43] https://www.fnsb.gov/414/Air-Pollution-Control-Commission

switch from fuel #2 to #1, but as the scientists are still working on looking further into this trend, this conclusion is preliminary.

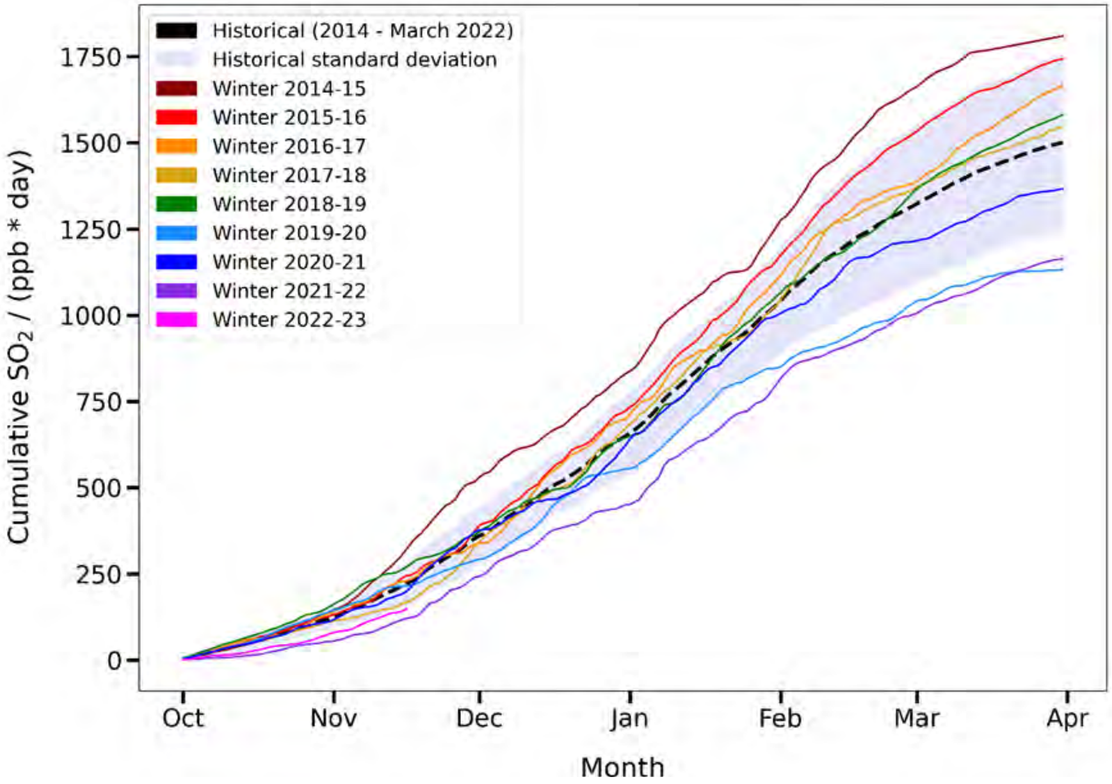

Figure 3.6.2 Cumulative SO2 measurements from Fairbanks, Alaska

There is also a group focused on identifying local sources of air pollution by using the local power plant plumes emissions and tracking the vertical structure with the FLEXPART-WRF model and observations. These results are being presenting at the American Geophysical Union conference in December of 2022.[44] These preliminary results provide insight into the amount of power plant emissions that reach to the surface in the Fairbanks and North Pole areas. The ALPACA group worked locally with the power plants in Fairbanks and obtained hourly 2022 emissions for the ALPACA campaign timeframe to use with their model.

{end of report. Beginning of Appendix.}

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[44] Identifying sources of local air pollution in Fairbanks, using FLEXPART-WRF simulations and observations from ALPACA 2022 https://agu2022fallmeeting-agu.ipostersessions.com/default.aspx?s=BF-59-85-22-75-5A-8A-94-8C-FA-2D-7A-20-BF-61-2D&guestview=true

Appendix A.

1. Emission Control File –BM (Biomass burning profile)

```
'EVERYWHERE', 'ALL'       ,'POC'    ,'APOC'      ,'FINE',0.   ,'MASS','a',
   'EVERYWHERE', 'ALL'       ,'PNCOM'  ,'APNCOM'    ,'FINE',0.   ,'MASS','a',
  ! --> Semivolatile POA
  ! modified by DMH (9/1/22) biomass burning from
(https://acp.copernicus.org/articles/16/4081/2016/acp-16-2081-2016.pdf)
   'EVERYWHERE', 'ALL'       ,'POC'    ,'VLVPO1'    ,'GAS' ,0.   ,'MASS','a',
   'EVERYWHERE', 'ALL'       ,'PNCOM'  ,'VLVPO1'    ,'GAS' ,0.   ,'MASS','a',
   'EVERYWHERE', 'ALL'       ,'POC'    ,'VSVPO1'    ,'GAS' ,0.0  ,'MASS','a',
   'EVERYWHERE', 'ALL'       ,'PNCOM'  ,'VSVPO1'    ,'GAS' ,0.0  ,'MASS','a',
   'EVERYWHERE', 'ALL'       ,'POC'    ,'VSVPO2'    ,'GAS' ,0.0  ,'MASS','a',
   'EVERYWHERE', 'ALL'       ,'PNCOM'  ,'VSVPO2'    ,'GAS' ,0.0  ,'MASS','a',
   'EVERYWHERE', 'ALL'       ,'POC'    ,'VSVPO3'    ,'GAS' ,0.2  ,'MASS','a',
   'EVERYWHERE', 'ALL'       ,'PNCOM'  ,'VSVPO3'    ,'GAS' ,0.2  ,'MASS','a',
   'EVERYWHERE', 'ALL'       ,'POC'    ,'VIVPO1'    ,'GAS' ,0.4  ,'MASS','a',
   'EVERYWHERE', 'ALL'       ,'PNCOM'  ,'VIVPO1'    ,'GAS' ,0.4  ,'MASS','a',
   'EVERYWHERE', 'ALL'       ,'POC'    ,'ALVPO1'    ,'FINE',0.20 ,'MASS','a',
   'EVERYWHERE', 'ALL'       ,'PNCOM'  ,'ALVPO1'    ,'FINE',0.20 ,'MASS','a',
   'EVERYWHERE', 'ALL'       ,'POC'    ,'ASVPO1'    ,'FINE',0.1  ,'MASS','a',
   'EVERYWHERE', 'ALL'       ,'PNCOM'  ,'ASVPO1'    ,'FINE',0.1  ,'MASS','a',
   'EVERYWHERE', 'ALL'       ,'POC'    ,'ASVPO2'    ,'FINE',0.1  ,'MASS','a',
   'EVERYWHERE', 'ALL'       ,'PNCOM'  ,'ASVPO2'    ,'FINE',0.1  ,'MASS','a',
   'EVERYWHERE', 'ALL'       ,'POC'    ,'ASVPO3'    ,'FINE',0.   ,'MASS','a',
   'EVERYWHERE', 'ALL'       ,'PNCOM'  ,'ASVPO3'    ,'FINE',0.   ,'MASS','a',
   'EVERYWHERE', 'ALL'       ,'POC'    ,'AIVPO1'    ,'FINE',0.   ,'MASS','a',
   'EVERYWHERE', 'ALL'       ,'PNCOM'  ,'AIVPO1'    ,'FINE',0.   ,'MASS','a',
```

SO2 Emission Control file:

```
! Sensitivity -- zero out point source SO2
  'EVERYWHERE', 'POINT'        ,'SO2'    ,'SO2'        ,'GAS'  ,0.0  ,'UNIT','o',
```

```
setenv N_EMIS_PT 1           #> Number of elevated source groups

  # Time-Independent Stack Parameters for Inline Point Sources

  setenv STK_GRPS_001
$IN_PTpath/point/CMAQ_GRID3/stack_groups.point.CMAQ_GRID3.${YYYY}.ncf

  # Emission Rates for Inline Point Sources

  setenv STK_EMIS_001
$IN_PTpath/point/CMAQ_GRID3/inlnts_l.point.${YYYYMMDD}.1.CMAQ_GRID3.${YYYY}.ncf

  # Label Each Emissions Stream

  setenv STK_EMIS_LAB_001 POINT
```

2. SPECIES Definition File for CMAQ version 5.3.2

```
!#start   YYYYJJJ  010000
!#end     YYYYJJJ  000000
!#layer       1

/
! This Species Definition File is for Use with the COMBINE tool built for
! post-processing CMAQ output. It is compatible with CMAQv5.2.
! Date: May 12, 2017

! Output variables that begin with 'PM' represent those in which a size cut was
! applied based on modeled aerosol mode parameters.  For example, PM25_NA is all
! sodium that falls below 2.5 um diameter. These 'PM' variables are used for
! comparisons at IMPROVE and CSN sites.

! Output variables that begin with 'PMAMS' represent the mass that would have
! been detected  by an Aerosol Mass Spectrometer.

! Output variables beginning with 'A' (aside from AIR_DENS) represent a
! combination of aerosol species in which no size cut was applied.  For example,
! ASO4IJ is the sum of i-mode and j-mode sulfate.  These 'A' variables are used
! for comparisons at CASTNet sites.

! Output variables beginning with 'PMC' refer to the coarse fraction of total PM,
! computed by summing all modes and subtracting the PM2.5 fraction.  These 'PMC'
! variables are used for comparisons at SEARCH sites.

! This Species Definition File is just for use with the uncoupled, offline CMAQ,
! model. If you are processing WRF-CMAQ results, a different Species Definition
! file is required.

/ File [1]: CMAQ conc/aconc file


/new species    ,units     ,expression

!-------------------------------------------!
!--------------- Particles -----------------!
!-------------------------------------------!
!! Crustal Elements
AFEJ            ,ug m-3    ,AFEJ[1]
AALJ            ,ug m-3    ,AALJ[1]
```

```
ASIJ          ,ug m-3     ,ASIJ[1]
ATIJ          ,ug m-3     ,ATIJ[1]
ACAJ          ,ug m-3     ,ACAJ[1]
AMGJ          ,ug m-3     ,AMGJ[1]
AKJ           ,ug m-3     ,AKJ[1]
AMNJ          ,ug m-3     ,AMNJ[1]
ASOILJ        ,ug m-3     ,2.20*AALJ[1]+2.49*ASIJ[1]+1.63*ACAJ[1]+2.42*AFEJ[1]+1.94*ATIJ[1]

!! Non-Crustal Inorganic Particle Species
AHPLUSIJ      ,umol m-3   ,(AH3OPI[1]+AH3OPJ[1])*1.0/19.0
ANAK          ,ug m-3     ,0.8373*ASEACAT[1]+0.0626*ASOIL[1]+0.0023*ACORS[1]
AMGK          ,ug m-3     ,0.0997*ASEACAT[1]+0.0170*ASOIL[1]+0.0032*ACORS[1]
AKK           ,ug m-3     ,0.0310*ASEACAT[1]+0.0242*ASOIL[1]+0.0176*ACORS[1]
ACAK          ,ug m-3     ,0.0320*ASEACAT[1]+0.0838*ASOIL[1]+0.0562*ACORS[1]
ACLIJ         ,ug m-3     ,ACLI[1]+ACLJ[1]
AECIJ         ,ug m-3     ,AECI[1]+AECJ[1]
ANAIJ         ,ug m-3     ,ANAJ[1]+ANAI[1]
ANO3IJ        ,ug m-3     ,ANO3I[1]+ANO3J[1]
ANO3K         ,ug m-3     ,ANO3K[1]
ANH4IJ        ,ug m-3     ,ANH4I[1]+ANH4J[1]
ANH4K         ,ug m-3     ,ANH4K[1]
ASO4IJ        ,ug m-3     ,ASO4I[1]+ASO4J[1]
ASO4K         ,ug m-3     ,ASO4K[1]

!! Organic Particle Species
APOCI         ,ugC m-3    ,ALVPO1I[1]/1.39 + ASVPO1I[1]/1.32 + ASVPO2I[1]/1.26 \
                           +APOCI[1]
APOCJ         ,ugC m-3    ,ALVPO1J[1]/1.39 + ASVPO1J[1]/1.32 + ASVPO2J[1]/1.26 \
                           +ASVPO3J[1]/1.21 + AIVPO1J[1]/1.17  + APOCJ[1]
APOCIJ        ,ugC m-3    ,APOCI[0] + APOCJ[0]

APOMI         ,ug m-3     ,ALVPO1I[1] + ASVPO1I[1] + ASVPO2I[1] + APOCI[1]     \
                           +APNCOMI[1]
APOMJ         ,ug m-3     ,ALVPO1J[1] + ASVPO1J[1] + ASVPO2J[1] + APOCJ[1]     \
                           +ASVPO3J[1] + AIVPO1J[1]  + APNCOMJ[1]
APOMIJ        ,ug m-3     ,APOMI[0] + APOMJ[0]

ASOCI         ,ugC m-3    ,ALVOO1I[1]/2.27 + ALVOO2I[1]/2.06  \
                           +ASVOO1I[1]/1.88 + ASVOO2I[1]/1.73
ASOCJ         ,ugC m-3    ,AISO1J[1]/2.20  + AISO2J[1]/2.23  + AISO3J[1]/2.80 \
                           +AMT1J[1]/1.67   + AMT2J[1]/1.67   + AMT3J[1]/1.72  \
                           +AMT4J[1]/1.53   + AMT5J[1]/1.57   + AMT6J[1]/1.40  \
                           + AMTNO3J[1]/1.90 + AMTHYDJ[1]/1.54              \
                           +AGLYJ[1]/2.13   + ASQTJ[1]/1.52                 \
```

```
                     +AORGCJ[1]/2.00  + AOLGBJ[1]/2.10  + AOLGAJ[1]/2.50 \
                     +ALVOO1J[1]/2.27 + ALVOO2J[1]/2.06 + ASVOO1J[1]/1.88\
                     +ASVOO2J[1]/1.73 + ASVOO3J[1]/1.60 + APCSOJ[1] /2.00 \
                     +AAVB1J[1]/2.70  + AAVB2J[1]/2.35  + AAVB3J[1]/2.17  \
                     +AAVB4J[1]/1.99
ASOCIJ        ,ugC m-3    ,ASOCI[0] + ASOCJ[0]

ASOMI         ,ug m-3     ,ALVOO1I[1] + ALVOO2I[1] + ASVOO1I[1] + ASVOO2I[1]
ASOMJ         ,ug m-3     ,+AISO1J[1]+ AISO2J[1]  + AISO3J[1]            \
                     +AMT1J[1]   + AMT2J[1]   + AMT3J[1]   + AMT4J[1]  \
                     +AMT5J[1]   + AMT6J[1]   + AMTNO3J[1]\
                     +AMTHYDJ[1] + AGLYJ[1]   + ASQTJ[1]             \
                     +AORGCJ[1]  + AOLGBJ[1]  + AOLGAJ[1]            \
                     +ALVOO1J[1] + ALVOO2J[1] + ASVOO1J[1] + ASVOO2J[1]\
                     +ASVOO3J[1] + APCSOJ[1]  + AAVB1J[1] + AAVB2J[1]\
                     +AAVB3J[1] + AAVB4J[1]
ASOMIJ        ,ug m-3     ,ASOMI[0] + ASOMJ[0]

AOCI          ,ugC m-3    ,APOCI[0]  + ASOCI[0]
AOCJ          ,ugC m-3    ,APOCJ[0]  + ASOCJ[0]
AOCIJ         ,ugC m-3    ,APOCIJ[0] + ASOCIJ[0]

AOMI          ,ug m-3     ,APOMI[0]  + ASOMI[0]
AOMJ          ,ug m-3     ,APOMJ[0]  + ASOMJ[0]
AOMIJ         ,ug m-3     ,APOMIJ[0] + ASOMIJ[0]

!!! Anthropogenic-VOC Derived Organic Aerosol
AORGAJ        ,ug m-3     ,AAVB1J[1]+AAVB2J[1]+AAVB3J[1]+AAVB4J[1]+AOLGAJ[1] \

!!! Biogenic-VOC Derived Organic Aerosol
AORGBJ        ,ug m-3     ,AISO1J[1] + AISO2J[1] + AISO3J[1]           \
                     +AMT1J[1]  + AMT2J[1]  + AMT3J[1] + AMT4J[1]  \
                     +AMT5J[1]  + AMT6J[1]                       \
                     +AMTNO3J[1]+ AMTHYDJ[1] + AGLYJ[1]           \
                     +ASQTJ[1]  + AOLGBJ[1]

!!! Cloud-Processed  SOA
AORGCJ        ,ug m-3     ,AORGCJ[1]

!!! OM/OC ratios
AOMOCRAT_TOT    ,ug ug-1    ,AOMIJ[0]/AOCIJ[0]

!! Total PM Aggregates
ATOTI         ,ug m-3     ,ASO4I[1]+ANO3I[1]+ANH4I[1]+ANAI[1]+ACLI[1] \
```

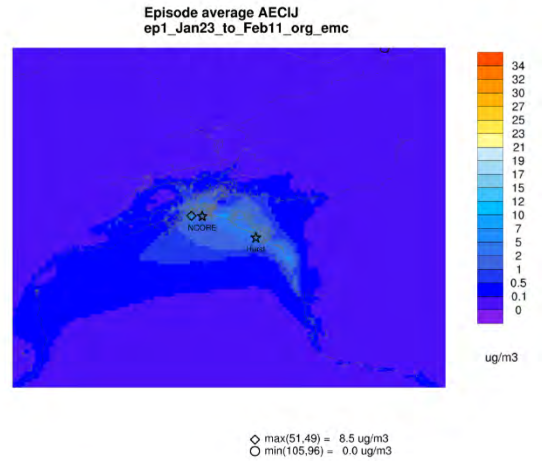
```
                        +AECI[1]+AOMI[0]+AOTHRI[1]
ATOTJ          ,ug m-3     ,ASO4J[1]+ANO3J[1]+ANH4J[1]+ANAJ[1]+ACLJ[1] \
                        +AECJ[1]+AOMJ[0]+AOTHRJ[1]+AFEJ[1]+ASIJ[1]  \
                        +ATIJ[1]+ACAJ[1]+AMGJ[1]+AMNJ[1]+AALJ[1]+AKJ[1]
ATOTK          ,ug m-3     ,ASOIL[1]+ACORS[1]+ASEACAT[1]+ACLK[1]+ASO4K[1] \
                        +ANO3K[1]+ANH4K[1]
ATOTIJ         ,ug m-3     ,ATOTI[0]+ATOTJ[0]
ATOTIJK        ,ug m-3     ,ATOTIJ[0]+ATOTK[0]

PM25_OTHIJ     ,ug m-3    ,AOTHRI[1]+AOTHRJ[1]+ANAI[1]+ACLI[1]+ANAJ[1]+ACLJ[1]

!!! gas species
CO             ,ppbV      ,1000.0*CO[1]
O3             ,ppbV      ,1000.0*O3[1]
SO2            ,ppbV      ,1000.0*SO2[1]
NOX            ,ppbV      ,1000.0*(NO[1] + NO2[1])
```

3. Species Def file for CMAQ 4.7.1

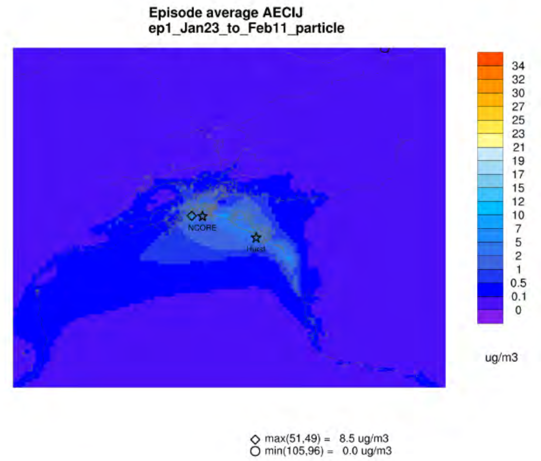
```
/new species    ,units     ,expression
AECIJ          ,ug m-3     ,AECI[1]+AECJ[1]
ANAIJ          ,ug m-3     ,ANAJ[1]+ANAI[1]
ANO3IJ         ,ug m-3     ,ANO3I[1]+ANO3J[1]
ANH4IJ         ,ug m-3     ,ANH4I[1]+ANH4J[1]
ASO4IJ         ,ug m-3     ,ASO4I[1]+ASO4J[1]
APOMIJ         ,ug m-3     ,1.167*AORGPAJ[1]+1.167*AORGPAI[1]
AOMIJ          ,ug m-3
,AORGCJ[1]+AOLGAJ[1]+AOLGBJ[1]+1.167*AORGPAJ[1]+1.167*AORGPAI[1]
CO             ,ppbV      ,1000.0*CO[1]
O3             ,ppbV      ,1000.0*O3[1]
SO2            ,ppbV      ,1000.0*SO2[1]
NOX            ,ppbV      ,1000.0*(NO[1] + NO2[1])
PM25_OTH       ,ug/m3   ,A25J[1]+A25I[1]+ANAJ[1]+ANAI[1]+ACLJ[1]+ACLI[1]
ATOTIJ         ,ug/m3   ,AECIJ[0]+ANO3IJ[0]+ASO4IJ[0]+ANH4IJ[0]+AOMIJ[0]+PM25_OTH[0]
```

4. **Figures for the CMAQ version comparison with 2019 EI and 2008 WRF for episode 1 and episode 2**

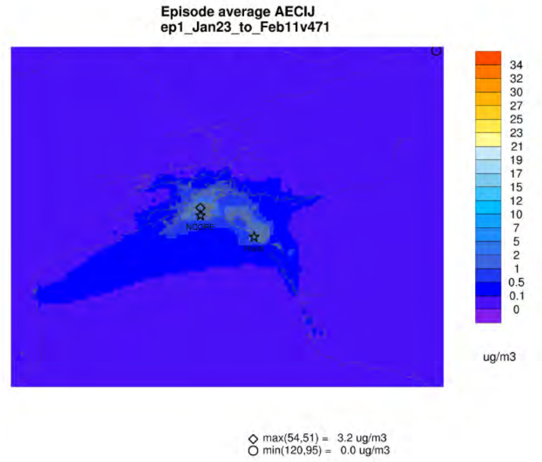
PM2.5, OM (organic matter, primary and secondary), POM (primary organic matter), POC (primary organic carbon), PMOTH, AN4, NO3, SO4, NOx, SO2 and O3 are following for CMAQ v471, v532_org_emc, v532_BM and v532_particle


Episode average AECIJ
ep1_Jan23_to_Feb11_org_emc

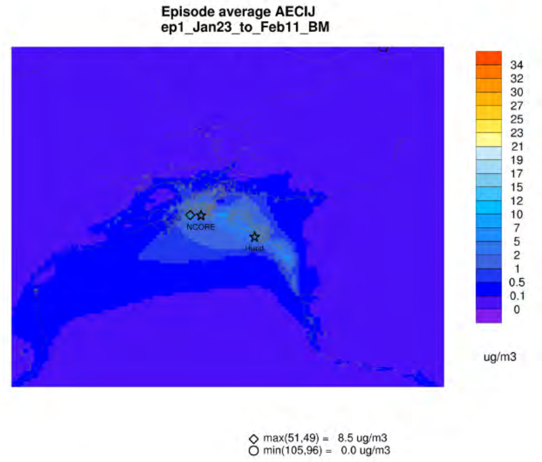
◇ max(51,49) = 8.5 ug/m3
○ min(105,96) = 0.0 ug/m3


Episode average AECIJ
ep1_Jan23_to_Feb11_particle

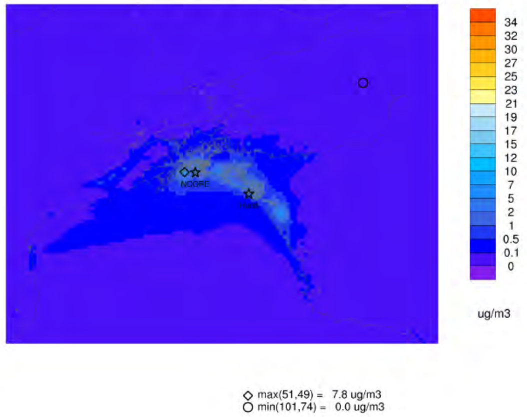
◇ max(51,49) = 8.5 ug/m3
○ min(105,96) = 0.0 ug/m3


Episode average AECIJ
ep1_Jan23_to_Feb11v471

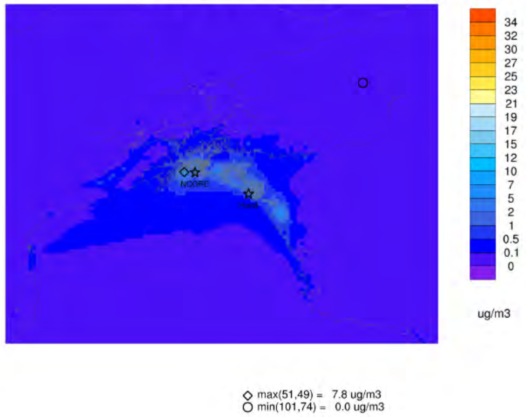
◇ max(54,51) = 3.2 ug/m3
○ min(120,95) = 0.0 ug/m3


Episode average AECIJ
ep1_Jan23_to_Feb11_BM

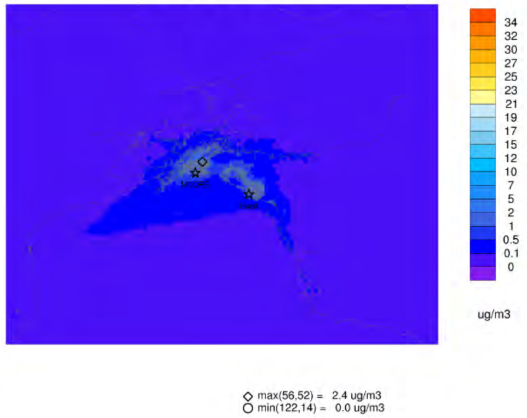
◇ max(51,49) = 8.5 ug/m3
○ min(105,96) = 0.0 ug/m3



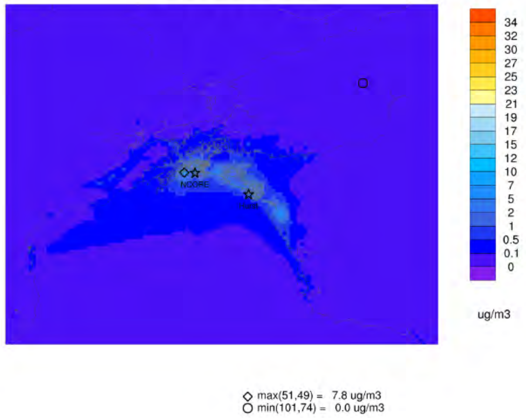
Episode average AECIJ
ep2_Nov2_to_Nov22_org_emc



Episode average AECIJ
ep2_Nov2_to_Nov22_particle

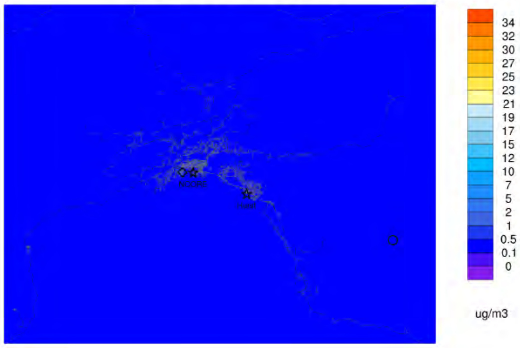


Episode average AECIJ
ep2_Nov2_to_Nov22v471



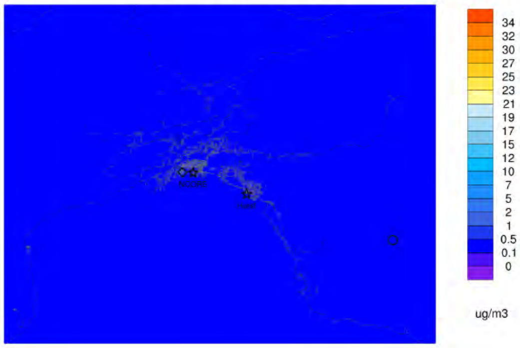
Episode average AECIJ
ep2_Nov2_to_Nov22_BM

Episode average ANH4IJ
ep1_Jan23_to_Feb11_org_emc



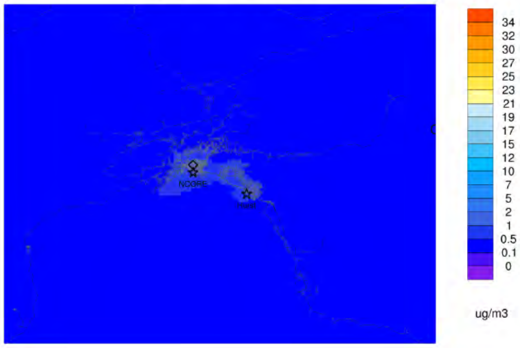
◇ max(51,49) = 0.8 ug/m3
○ min(110,30) = 0.1 ug/m3

Episode average ANH4IJ
ep1_Jan23_to_Feb11_particle



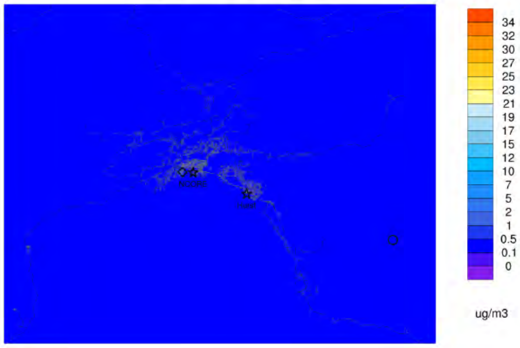
◇ max(51,49) = 0.8 ug/m3
○ min(110,30) = 0.1 ug/m3

Episode average ANH4IJ
ep1_Jan23_to_Feb11v471

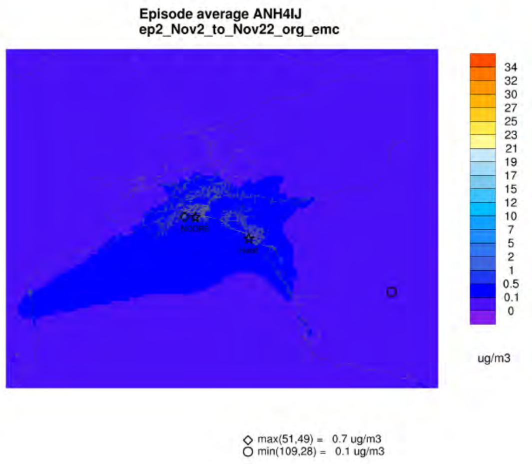


◇ max(54,51) = 1.2 ug/m3
○ min(122,61) = 0.1 ug/m3

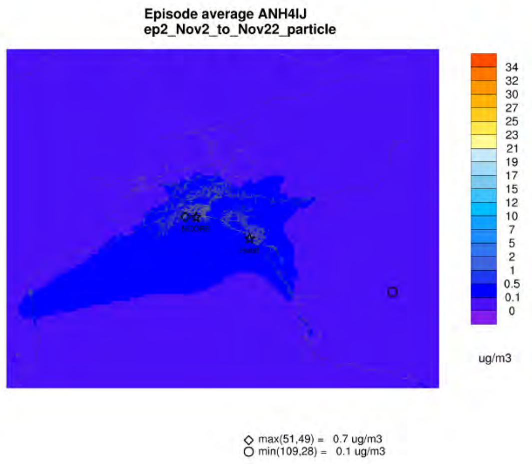
Episode average ANH4IJ
ep1_Jan23_to_Feb11_BM



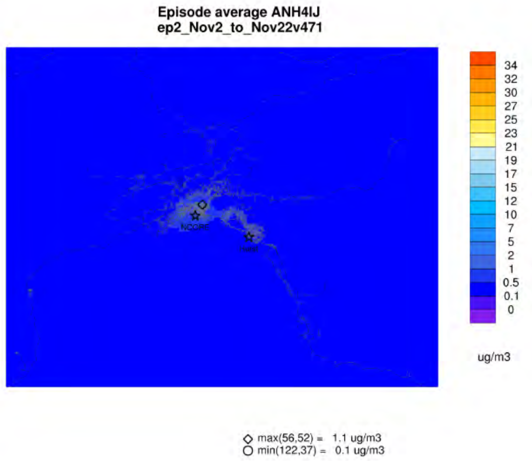
◇ max(51,49) = 0.8 ug/m3
○ min(110,30) = 0.1 ug/m3


Episode average ANH4IJ
ep2_Nov2_to_Nov22_org_emc

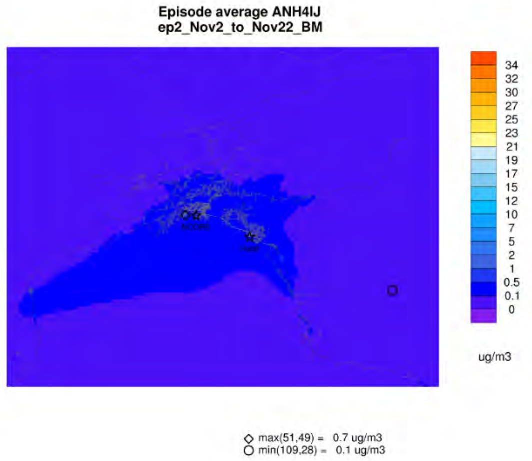
◇ max(51,49) = 0.7 ug/m3
○ min(109,28) = 0.1 ug/m3


Episode average ANH4IJ
ep2_Nov2_to_Nov22_particle

◇ max(51,49) = 0.7 ug/m3
○ min(109,28) = 0.1 ug/m3

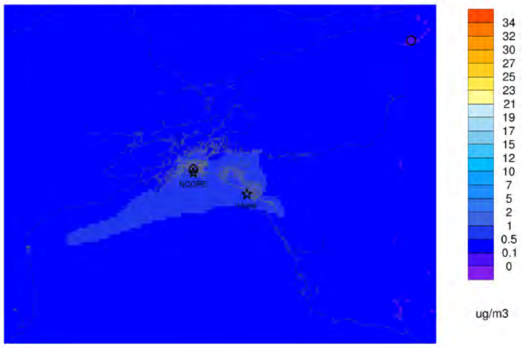

Episode average ANH4IJ
ep2_Nov2_to_Nov22v471

◇ max(56,52) = 1.1 ug/m3
○ min(122,37) = 0.1 ug/m3


Episode average ANH4IJ
ep2_Nov2_to_Nov22_BM

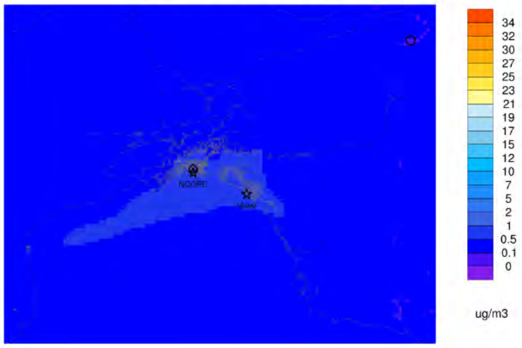
◇ max(51,49) = 0.7 ug/m3
○ min(109,28) = 0.1 ug/m3

Episode average ANO3IJ
ep1_Jan23_to_Feb11_org_emc



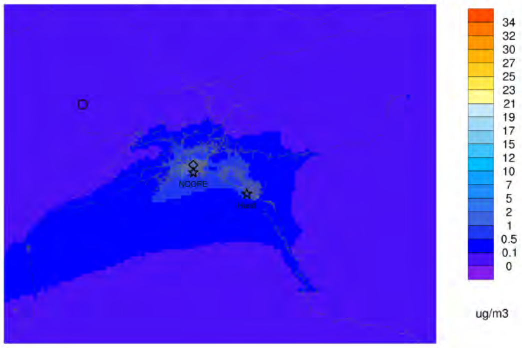
◇ max(54,50) = 0.8 ug/m3
○ min(115,86) = 0.1 ug/m3

Episode average ANO3IJ
ep1_Jan23_to_Feb11_particle



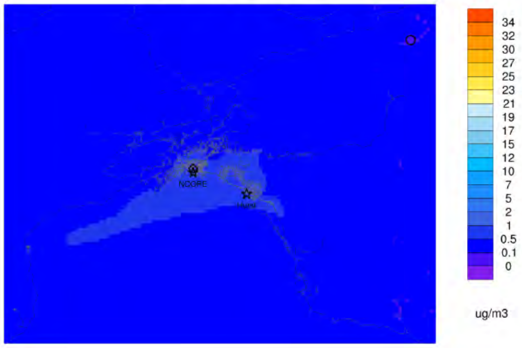
◇ max(54,50) = 0.8 ug/m3
○ min(115,86) = 0.1 ug/m3

Episode average ANO3IJ
ep1_Jan23_to_Feb11v471

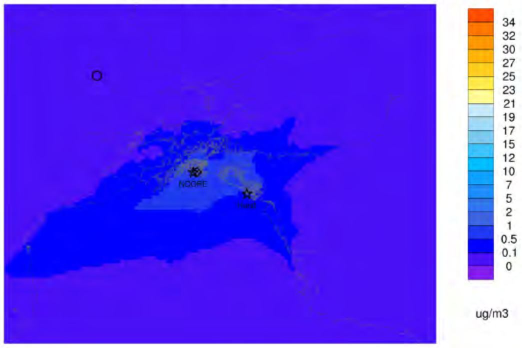


◇ max(54,51) = 1.1 ug/m3
○ min(23,68) = 0.0 ug/m3

Episode average ANO3IJ
ep1_Jan23_to_Feb11_BM

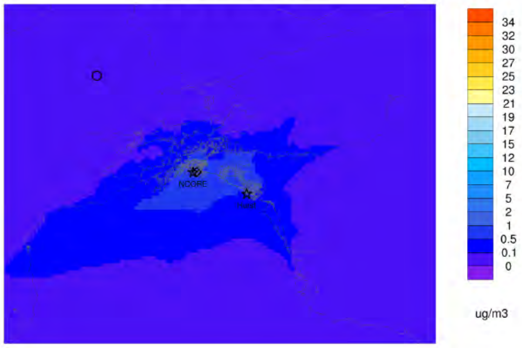


◇ max(54,50) = 0.8 ug/m3
○ min(115,86) = 0.1 ug/m3



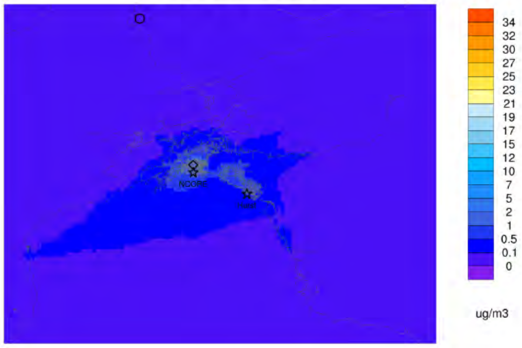
Episode average ANO3IJ
episode2_Nov2_to_Nov22_org_emc

◇ max(55,49) = 0.9 ug/m3
○ min(27,76) = 0.0 ug/m3



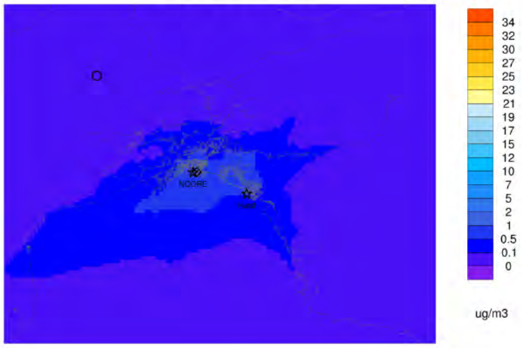
Episode average ANO3IJ
ep2_Nov2_to_Nov22_particle

◇ max(55,49) = 0.9 ug/m3
○ min(27,76) = 0.0 ug/m3



Episode average ANO3IJ
ep2_Nov2_to_Nov22v471

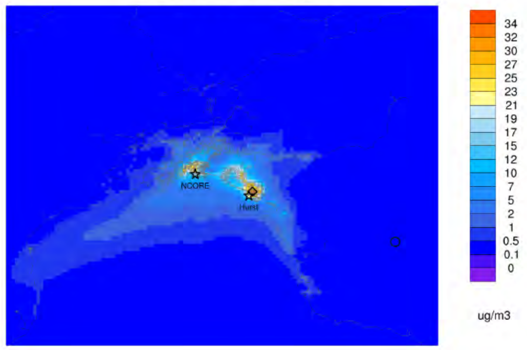
◇ max(54,51) = 1.2 ug/m3
○ min(39,92) = 0.0 ug/m3



Episode average ANO3IJ
ep2_Nov2_to_Nov22_BM

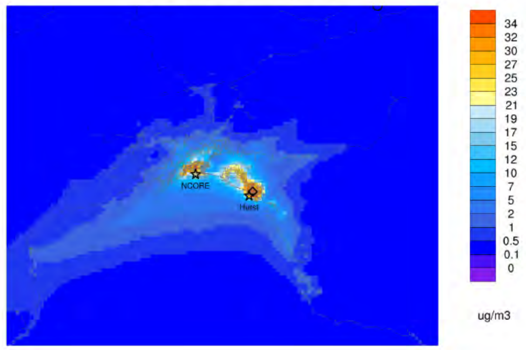
◇ max(55,49) = 0.9 ug/m3
○ min(27,76) = 0.0 ug/m3

Episode average AOMIJ
ep1_Jan23_to_Feb11_org_emc



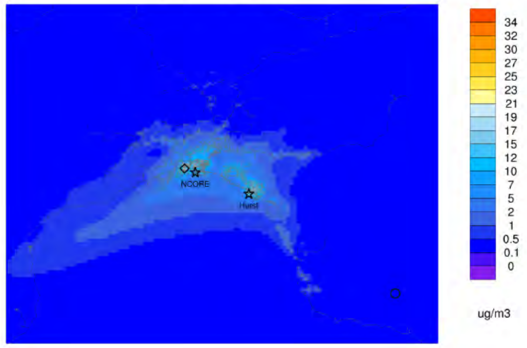
◇ max(70,44) = 32.5 ug/m3
○ min(110,30) = 0.2 ug/m3

Episode average AOMIJ
ep1_Jan23_to_Feb11_particle



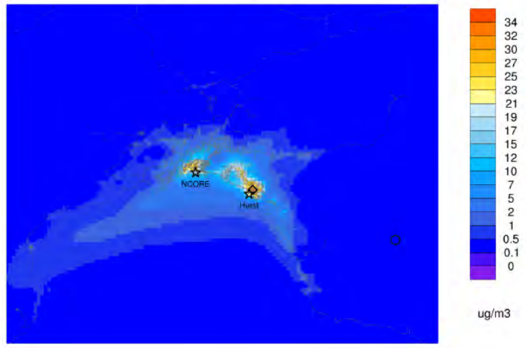
◇ max(70,44) = 40.7 ug/m3
○ min(105,96) = 0.2 ug/m3

Episode average AOMIJ
ep1_Jan23_to_Feb11v471

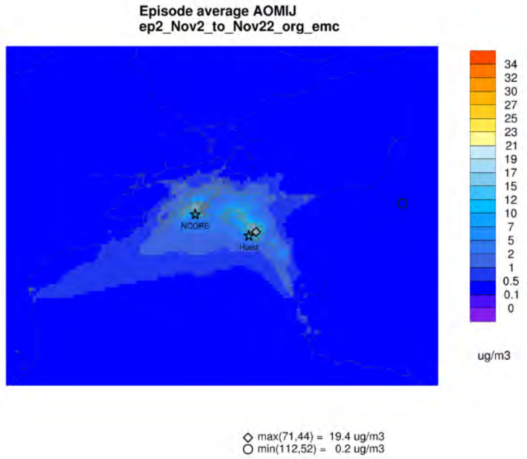


◇ max(51,50) = 18.6 ug/m3
○ min(110,15) = 0.1 ug/m3

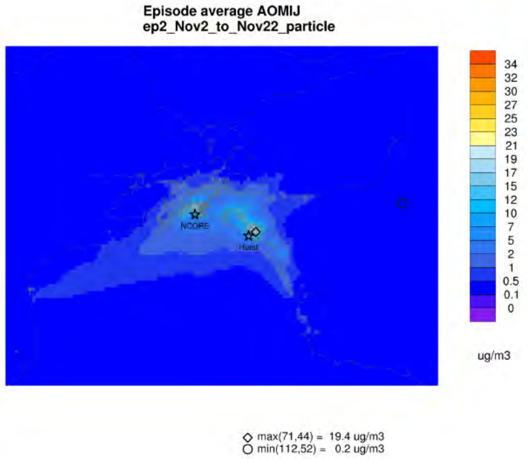
Episode average AOMIJ
ep1_Jan23_to_Feb11_BM



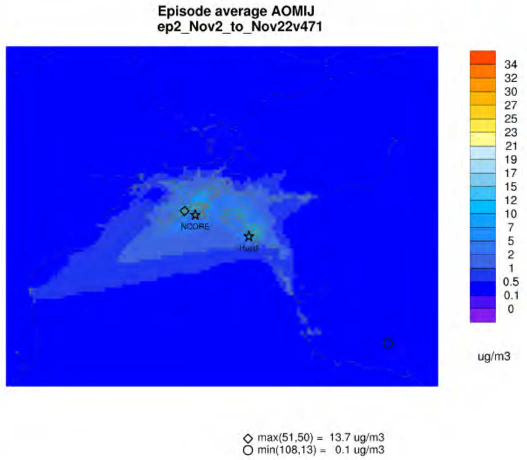
◇ max(70,44) = 33.3 ug/m3
○ min(110,30) = 0.2 ug/m3


Episode average AOMIJ
ep2_Nov2_to_Nov22_org_emc

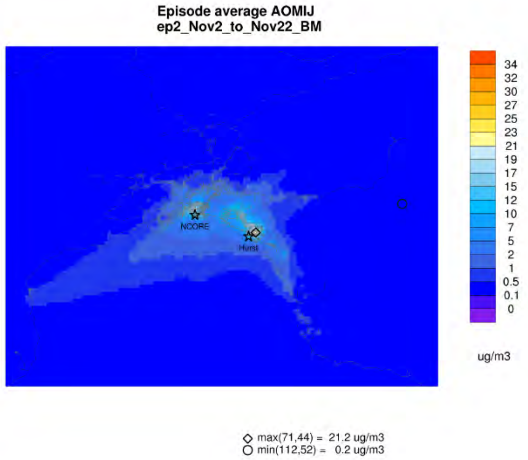
◇ max(71,44) = 19.4 ug/m3
○ min(112,52) = 0.2 ug/m3


Episode average AOMIJ
ep2_Nov2_to_Nov22_particle

◇ max(71,44) = 19.4 ug/m3
○ min(112,52) = 0.2 ug/m3

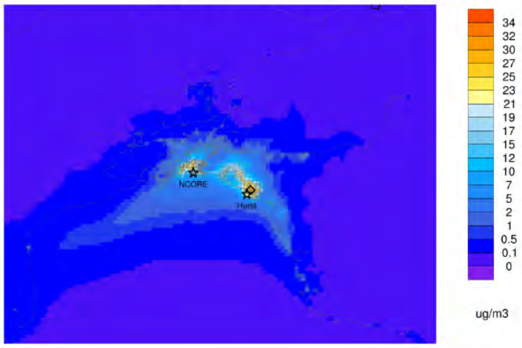

Episode average AOMIJ
ep2_Nov2_to_Nov22v471

◇ max(51,50) = 13.7 ug/m3
○ min(108,13) = 0.1 ug/m3


Episode average AOMIJ
ep2_Nov2_to_Nov22_BM

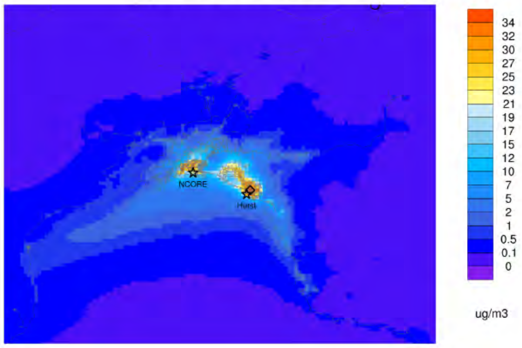
◇ max(71,44) = 21.2 ug/m3
○ min(112,52) = 0.2 ug/m3

Episode average APOMIJ
ep1_Jan23_to_Feb11_org_emc



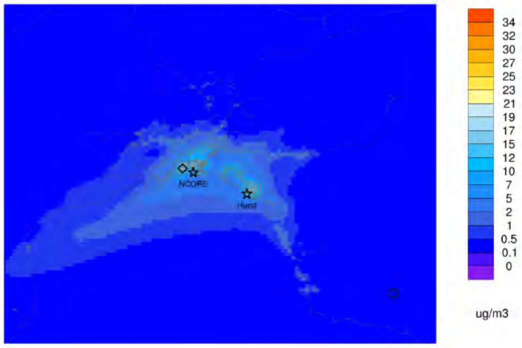
◇ max(70,44) = 31.7 ug/m3
○ min(105,96) = 0.0 ug/m3

Episode average APOMIJ
ep1_Jan23_to_Feb11_particle



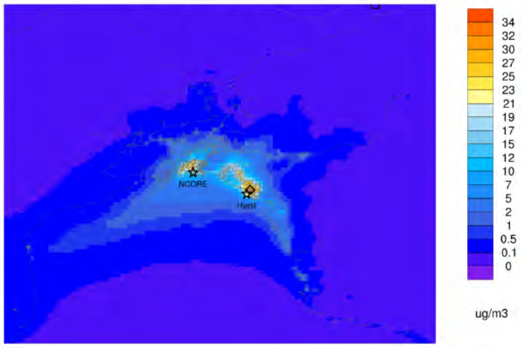
◇ max(70,44) = 39.9 ug/m3
○ min(105,96) = 0.0 ug/m3

Episode average APOMIJ
ep1_Jan23_to_Feb11v471

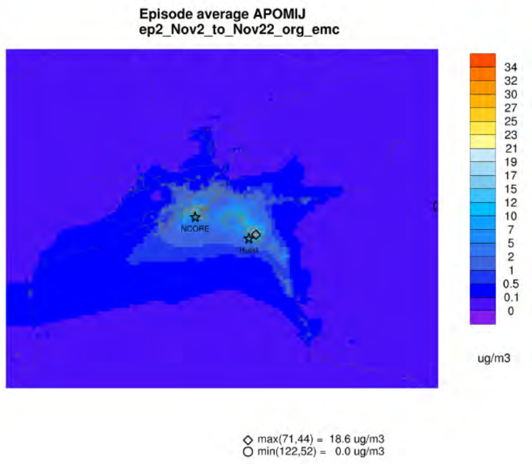


◇ max(51,50) = 18.6 ug/m3
○ min(110,15) = 0.1 ug/m3

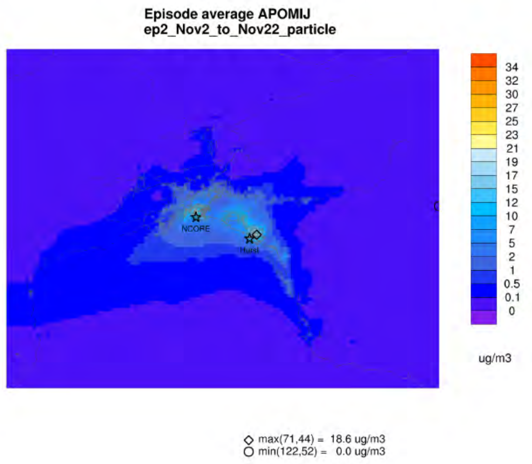
Episode average APOMIJ
ep1_Jan23_to_Feb11_BM



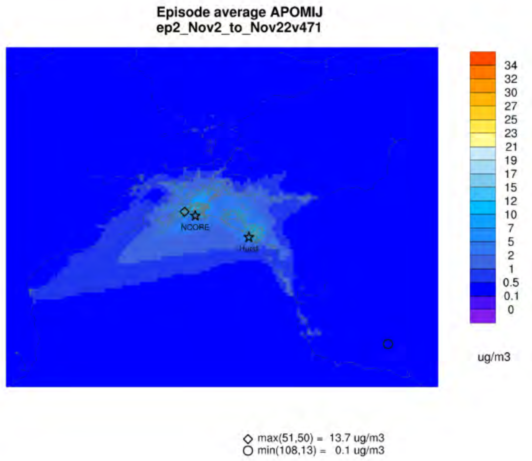
◇ max(70,44) = 32.5 ug/m3
○ min(105,96) = 0.0 ug/m3


Episode average APOMIJ
ep2_Nov2_to_Nov22_org_emc

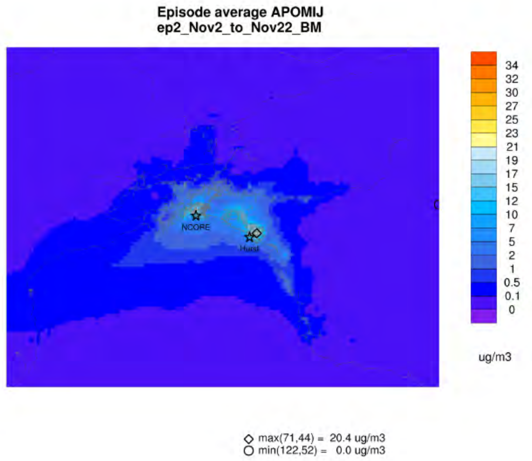
◇ max(71,44) = 18.6 ug/m3
○ min(122,52) = 0.0 ug/m3


Episode average APOMIJ
ep2_Nov2_to_Nov22_particle

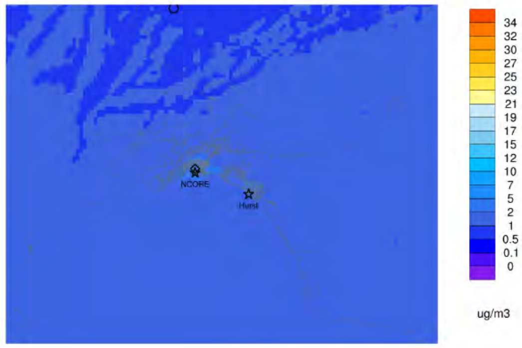
◇ max(71,44) = 18.6 ug/m3
○ min(122,52) = 0.0 ug/m3


Episode average APOMIJ
ep2_Nov2_to_Nov22v471

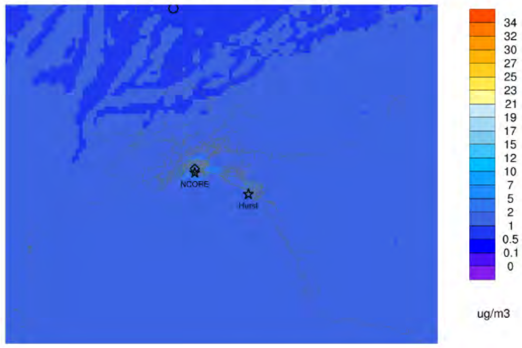
◇ max(51,50) = 13.7 ug/m3
○ min(108,13) = 0.1 ug/m3


Episode average APOMIJ
ep2_Nov2_to_Nov22_BM

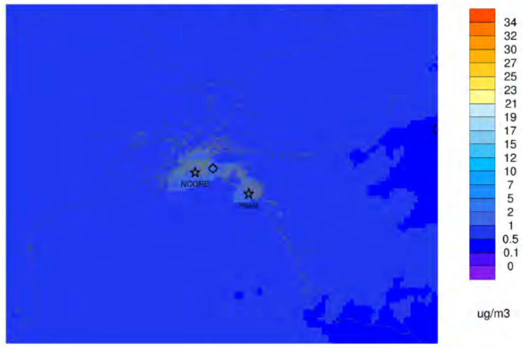
◇ max(71,44) = 20.4 ug/m3
○ min(122,52) = 0.0 ug/m3


Episode average ASO4IJ
ep1_Jan23_to_Feb11_org_emc

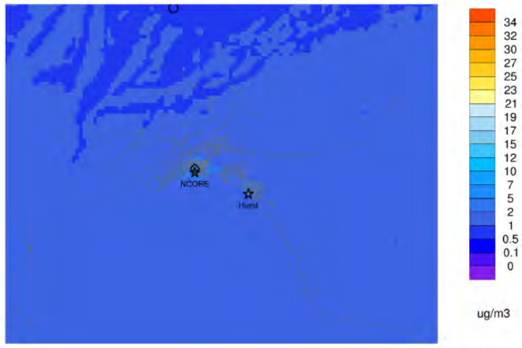
◇ max(54,50) = 3.9 ug/m3
○ min(48,95) = 0.9 ug/m3


Episode average ASO4IJ
ep1_Jan23_to_Feb11_particle

◇ max(54,50) = 3.9 ug/m3
○ min(48,95) = 0.9 ug/m3

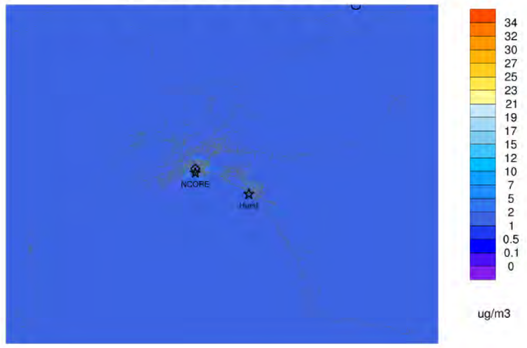

Episode average ASO4IJ
ep1_Jan23_to_Feb11v471

◇ max(59,50) = 2.5 ug/m3
○ min(122,61) = 0.4 ug/m3


Episode average ASO4IJ
ep1_Jan23_to_Feb11_BM

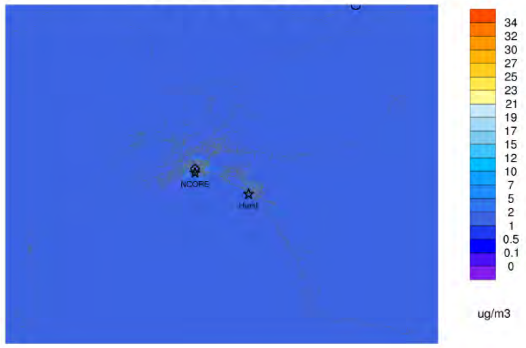
◇ max(54,50) = 3.9 ug/m3
○ min(48,95) = 0.9 ug/m3

Episode average ASO4IJ
episode2_Nov2_to_Nov22_org_emc



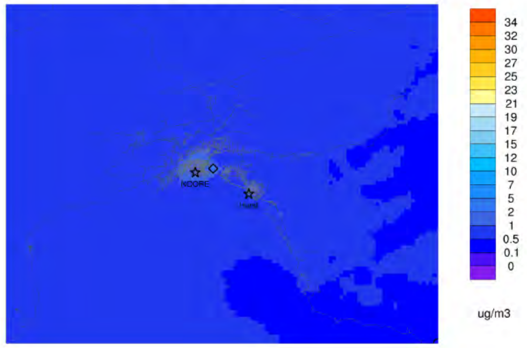
◇ max(54,50) = 3.7 ug/m3
○ min(99,96) = 1.0 ug/m3

Episode average ASO4IJ
ep2_Nov2_to_Nov22_particle



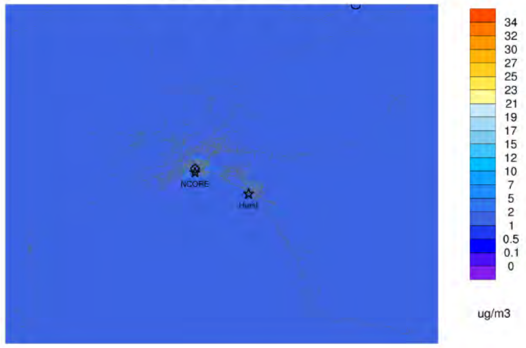
◇ max(54,50) = 3.7 ug/m3
○ min(99,96) = 1.0 ug/m3

Episode average ASO4IJ
ep2_Nov2_to_Nov22v471



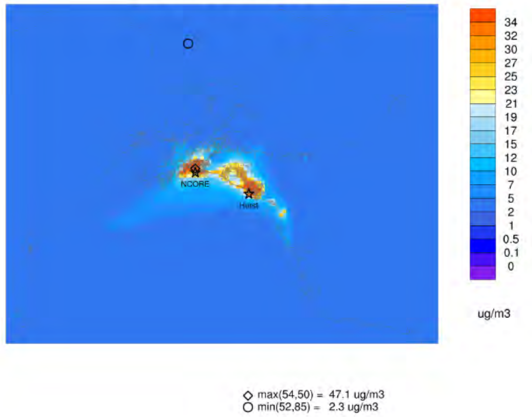
◇ max(59,50) = 2.9 ug/m3
○ min(122,1) = 0.4 ug/m3

Episode average ASO4IJ
ep2_Nov2_to_Nov22_BM

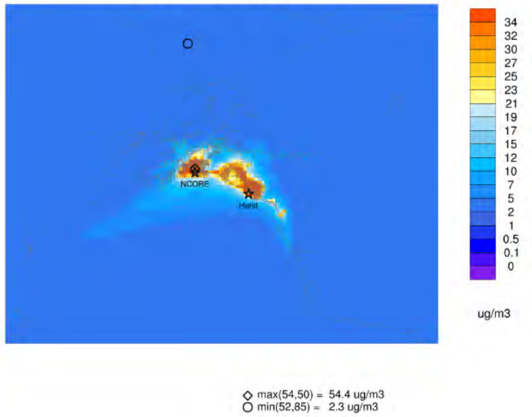


◇ max(54,50) = 3.7 ug/m3
○ min(99,96) = 1.0 ug/m3

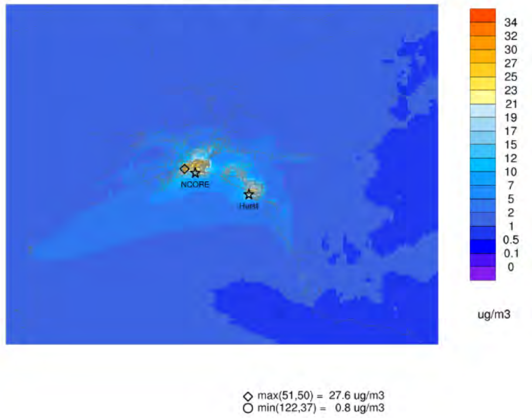
Episode average ATOTIJ
ep1_Jan23_to_Feb11_org_emc



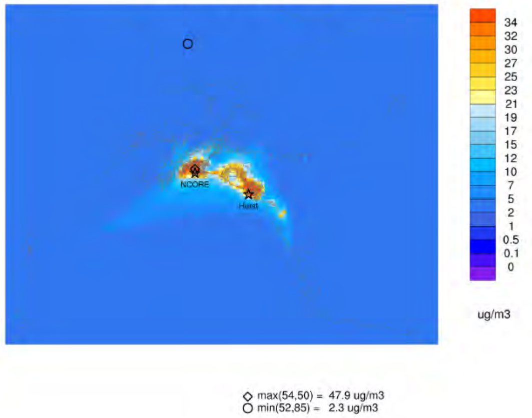
Episode average ATOTIJ
ep1_Jan23_to_Feb11_particle



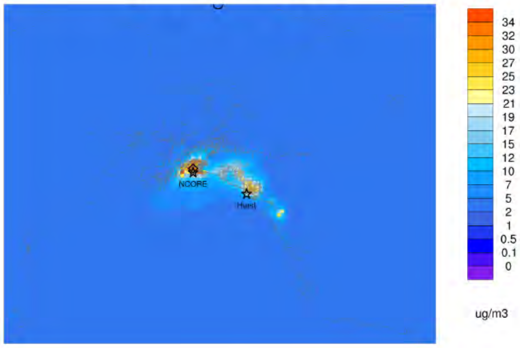
Episode average ATOTIJ
ep1_Jan23_to_Feb11v471



Episode average ATOTIJ
ep1_Jan23_to_Feb11_BM

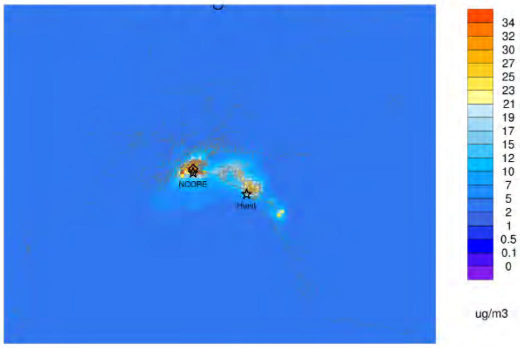


Episode average ATOTIJ
ep2_Nov2_to_Nov22_org_emc



◇ max(54,50) = 38.7 ug/m3
○ min(61,96) = 2.3 ug/m3

Episode average ATOTIJ
ep2_Nov2_to_Nov22_particle

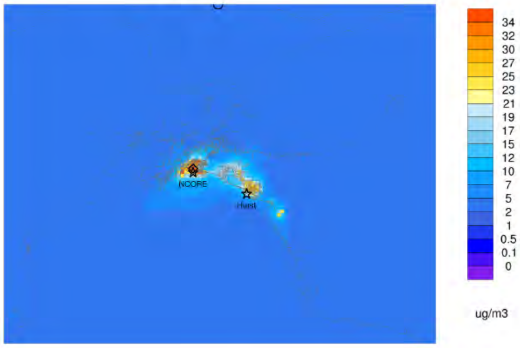


◇ max(54,50) = 38.7 ug/m3
○ min(61,96) = 2.3 ug/m3

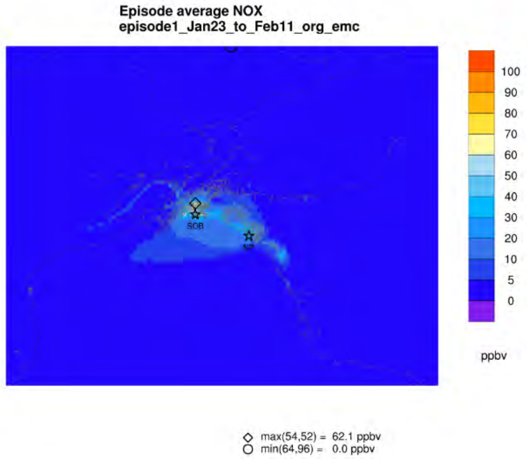
Episode average ATOTIJ
ep2_Nov2_to_Nov22v471

◇ max(56,52) = 24.5 ug/m3
○ min(122,37) = 0.7 ug/m3

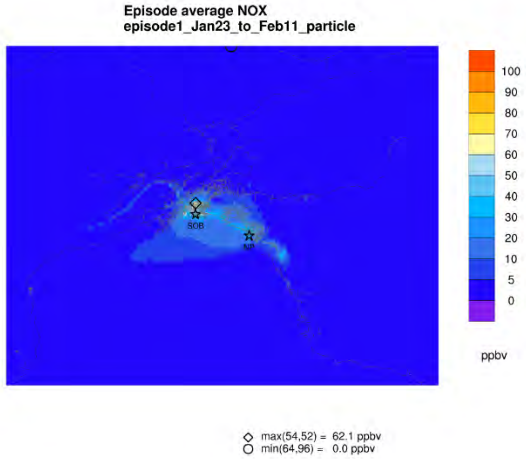
Episode average ATOTIJ
ep2_BM



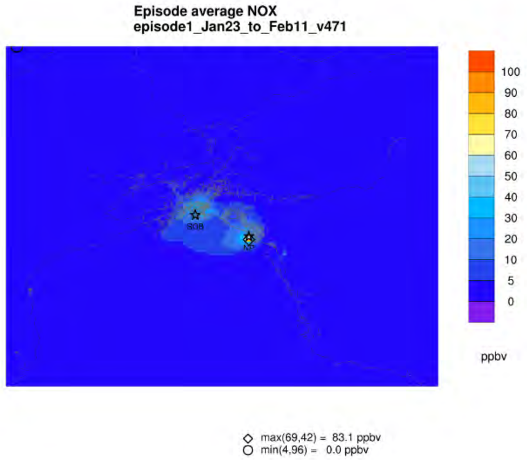
◇ max(54,50) = 40.4 ug/m3
○ min(61,96) = 2.3 ug/m3


Episode average NOX
episode1_Jan23_to_Feb11_org_emc

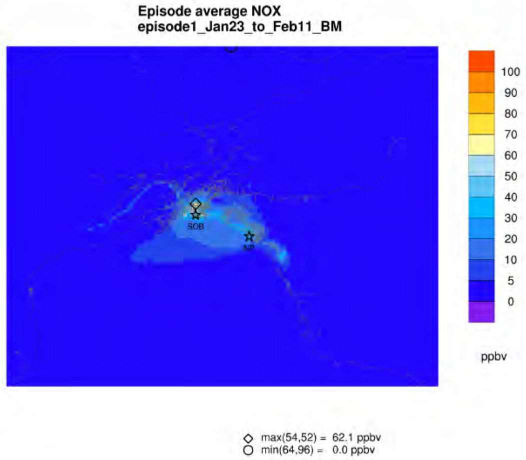
◇ max(54,52) = 62.1 ppbv
○ min(64,96) = 0.0 ppbv


Episode average NOX
episode1_Jan23_to_Feb11_particle

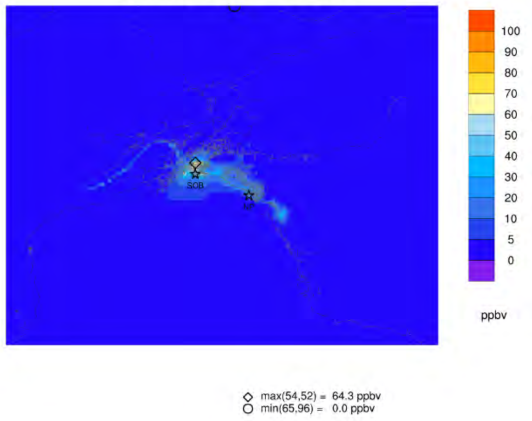
◇ max(54,52) = 62.1 ppbv
○ min(64,96) = 0.0 ppbv


Episode average NOX
episode1_Jan23_to_Feb11_v471

◇ max(69,42) = 83.1 ppbv
○ min(4,96) = 0.0 ppbv

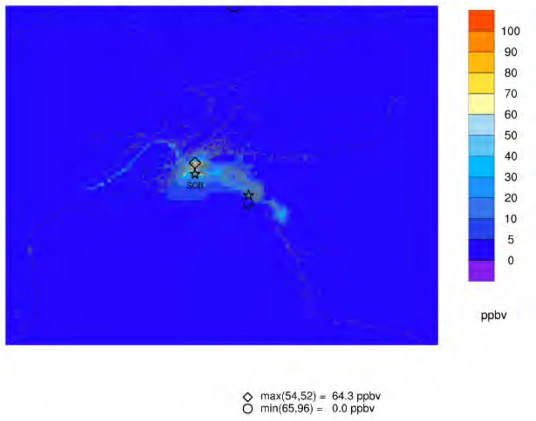

Episode average NOX
episode1_Jan23_to_Feb11_BM

◇ max(54,52) = 62.1 ppbv
○ min(64,96) = 0.0 ppbv



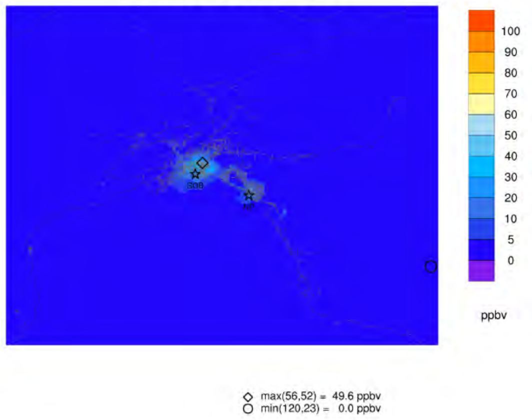
Episode average NOX
episode2_Nov2_to_Nov22_org_emc

◇ max(54,52) = 64.3 ppbv
○ min(65,96) = 0.0 ppbv



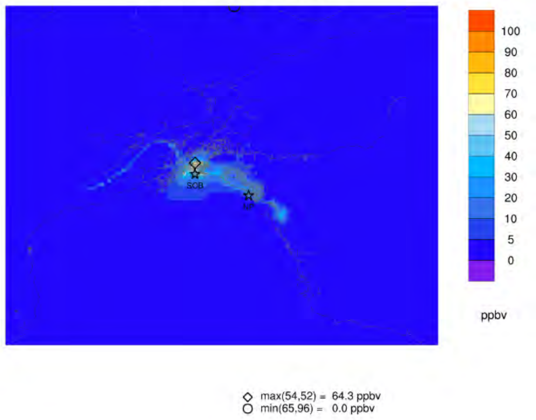
Episode average NOX
episode2_Nov2_to_Nov22_particle

◇ max(54,52) = 64.3 ppbv
○ min(65,96) = 0.0 ppbv



Episode average NOX
episode2_Nov2_to_Nov22_v471

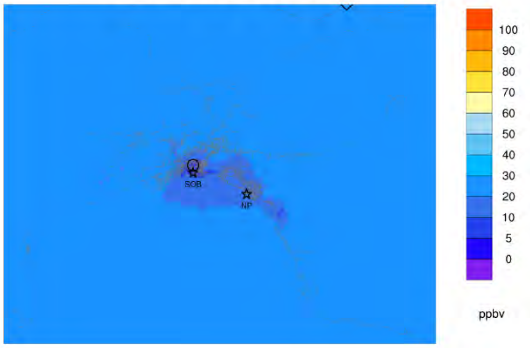
◇ max(56,52) = 49.6 ppbv
○ min(120,23) = 0.0 ppbv



Episode average NOX
episode2_Nov2_to_Nov22_BM

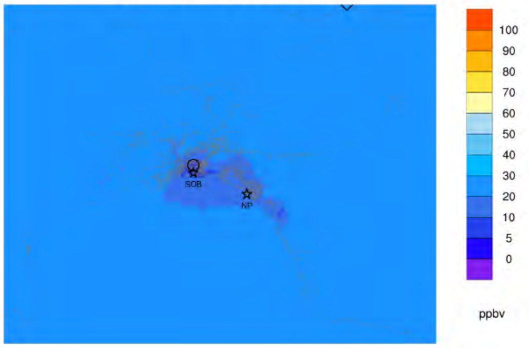
◇ max(54,52) = 64.3 ppbv
○ min(65,96) = 0.0 ppbv

Episode average O3
episode1_Jan23_to_Feb11_org_emc



◇ max(97,96) = 29.2 ppbv
○ min(54,51) = 4.8 ppbv

Episode average O3
episode1_Jan23_to_Feb11_particle

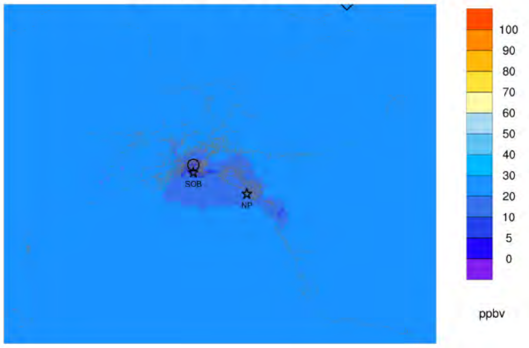


◇ max(97,96) = 29.2 ppbv
○ min(54,51) = 4.8 ppbv

Episode average O3
episode1_Jan23_to_Feb11_v471

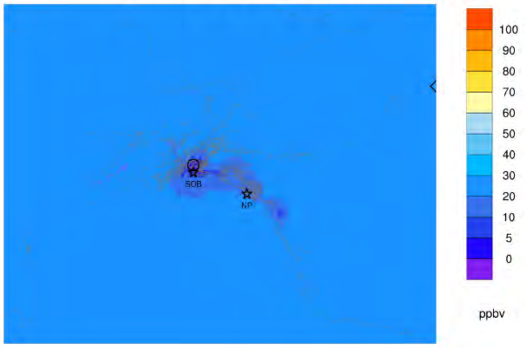
◇ max(98,96) = 48.9 ppbv
○ min(69,42) = 14.2 ppbv

Episode average O3
episode1_Jan23_to_Feb11_BM



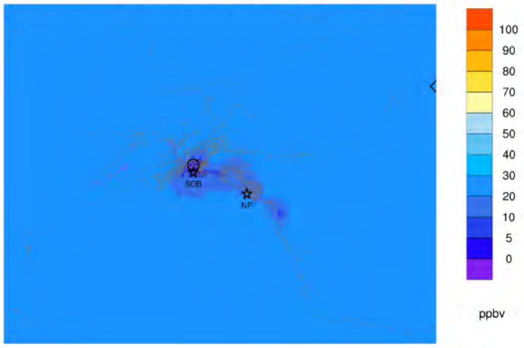
◇ max(97,96) = 29.2 ppbv
○ min(54,51) = 4.8 ppbv

Episode average O3
episode2_Nov2_to_Nov22_org_emc



◇ max(122,73) = 29.0 ppbv
○ min(54,51) = 2.7 ppbv

Episode average O3
episode2_Nov2_to_Nov22_particle

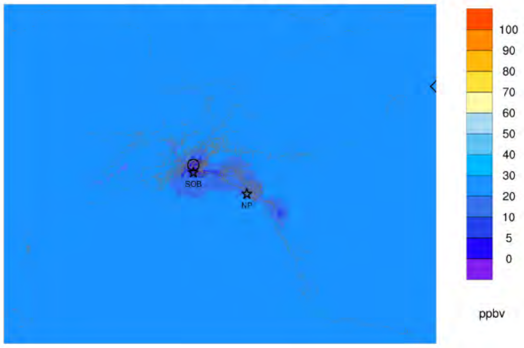


◇ max(122,73) = 29.0 ppbv
○ min(54,51) = 2.7 ppbv

Episode average O3
episode2_Nov2_to_Nov22_v471

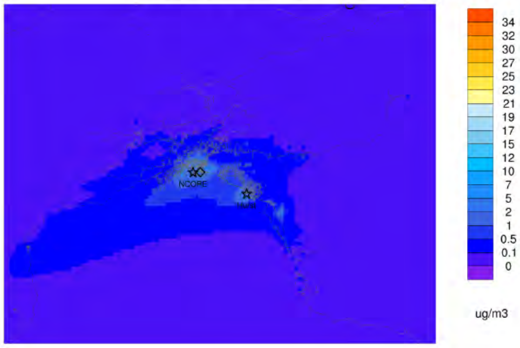
◇ max(97,96) = 47.5 ppbv
○ min(56,52) = 11.3 ppbv

Episode average O3
episode2_Nov2_to_Nov22_BM



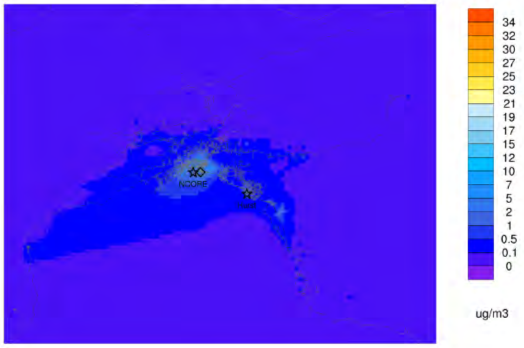
◇ max(122,73) = 29.0 ppbv
○ min(54,51) = 2.7 ppbv

Episode average PM25_OTH
ep1_Jan23_to_Feb11v471



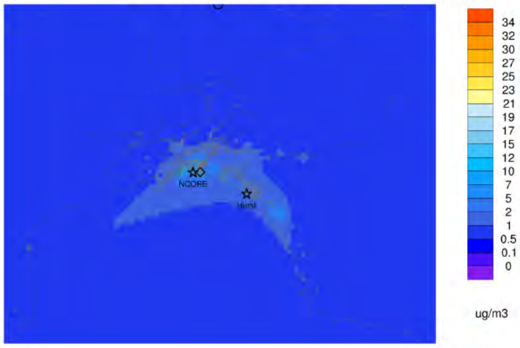
◇ max(56,49) = 5.8 ug/m3
○ min(98,96) = 0.0 ug/m3

Episode average PM25_OTH
ep2_Nov2_to_Nov22v471



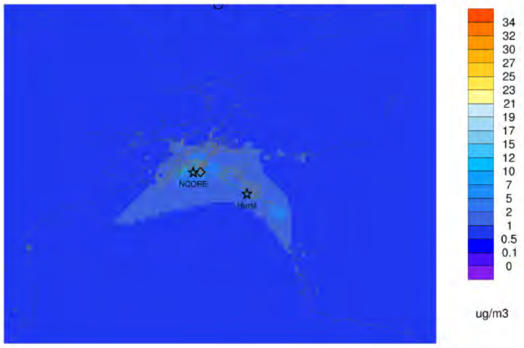
◇ max(56,49) = 5.8 ug/m3
○ min(122,75) = 0.0 ug/m3

Episode average PM25_OTHIJ
ep1_Jan23_to_Feb11_org_emc

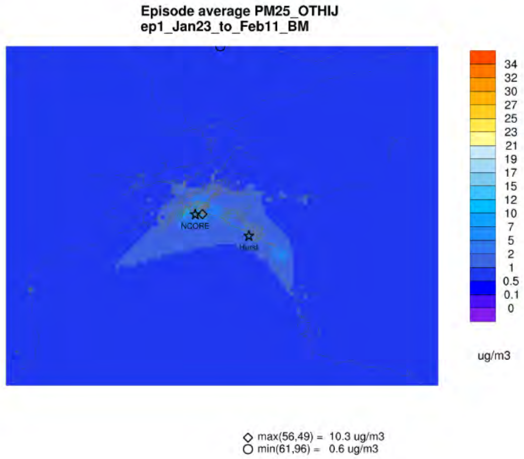


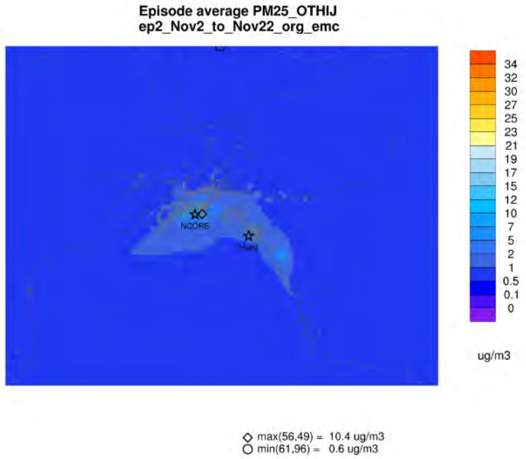
◇ max(56,49) = 10.4 ug/m3
○ min(61,96) = 0.6 ug/m3

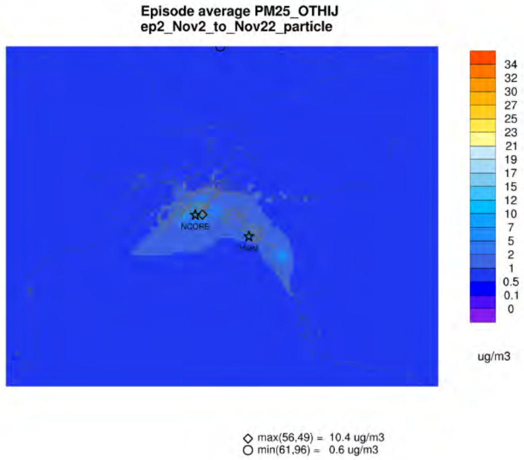
Episode average PM25_OTHIJ
ep1_Jan23_to_Feb11_particle

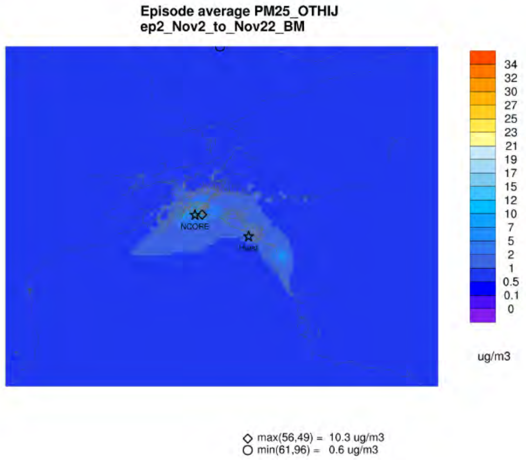


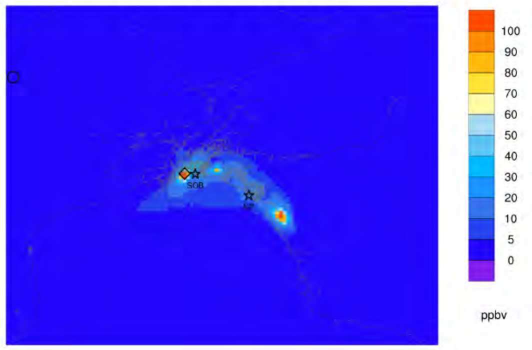
◇ max(56,49) = 10.3 ug/m3
○ min(61,96) = 0.6 ug/m3


Episode average PM25_OTHIJ
ep1_Jan23_to_Feb11_BM
34
32
30
27
25
23
21
19
17
15
12
10
7
5
2
1
0.5
0.1
0
ug/m3
NCORE
max(56,49) = 10.3 ug/m3
min(61,96) = 0.6 ug/m3

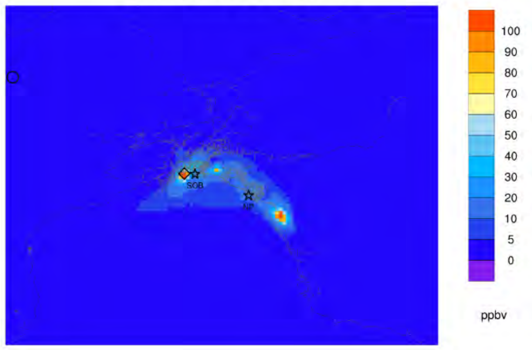

Episode average PM25_OTHIJ
ep2_Nov2_to_Nov22_org_emc
34
32
30
27
25
23
21
19
17
15
12
10
7
5
2
1
0.5
0.1
0
ug/m3
NCORE
max(56,49) = 10.4 ug/m3
min(61,96) = 0.6 ug/m3


Episode average PM25_OTHIJ
ep2_Nov2_to_Nov22_particle
34
32
30
27
25
23
21
19
17
15
12
10
7
5
2
1
0.5
0.1
0
ug/m3
NCORE
max(56,49) = 10.4 ug/m3
min(61,96) = 0.6 ug/m3

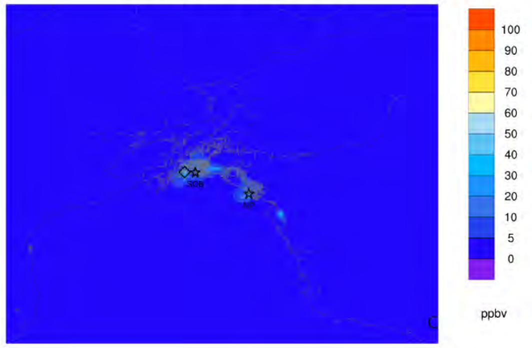

Episode average PM25_OTHIJ
ep2_Nov2_to_Nov22_BM
34
32
30
27
25
23
21
19
17
15
12
10
7
5
2
1
0.5
0.1
0
ug/m3
NCORE
max(56,49) = 10.3 ug/m3
min(61,96) = 0.6 ug/m3


Episode average SO2
episode1_Jan23_to_Feb11_org_emc

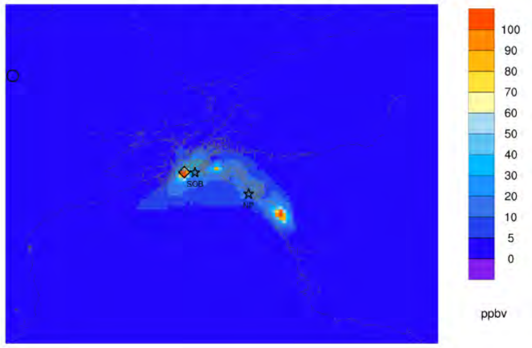
◇ max(51,49) = 264.2 ppbv
○ min(3,76) = 0.0 ppbv


Episode average SO2
episode1_Jan23_to_Feb11_particle

◇ max(51,49) = 264.2 ppbv
○ min(3,76) = 0.0 ppbv

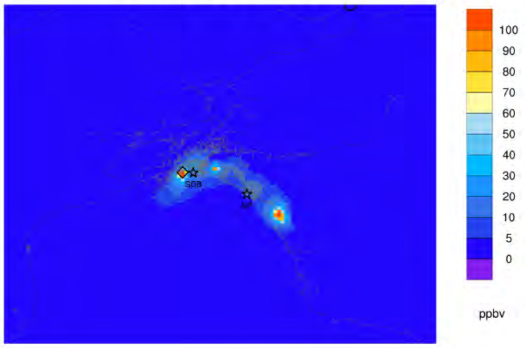

Episode average SO2
episode1_Jan23_to_Feb11_v471

◇ max(51,49) = 44.1 ppbv
○ min(121,7) = 0.0 ppbv


Episode average SO2
episode1_Jan23_to_Feb11_BM

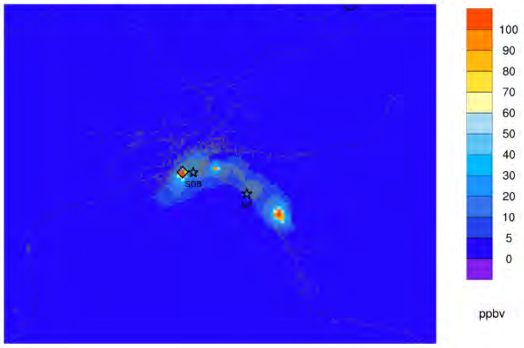
◇ max(51,49) = 264.2 ppbv
○ min(3,76) = 0.0 ppbv

Episode average SO2
episode2_Nov2_to_Nov22_org_emc



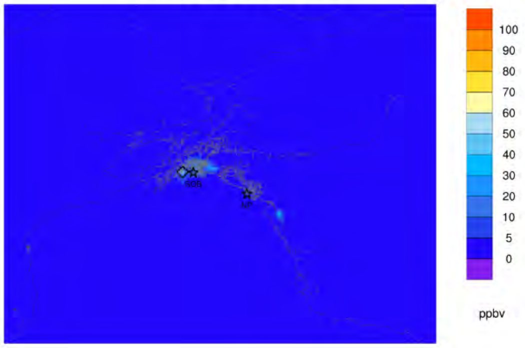
◇ max(51,49) = 268.6 ppbv
○ min(98,96) = 0.0 ppbv

Episode average SO2
episode2_Nov2_to_Nov22_particle



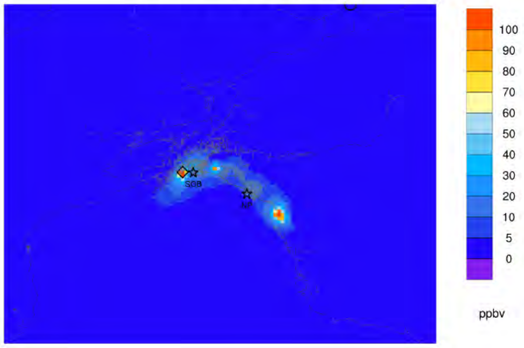
◇ max(51,49) = 268.6 ppbv
○ min(98,96) = 0.0 ppbv

Episode average SO2
episode2_Nov2_to_Nov22_v471



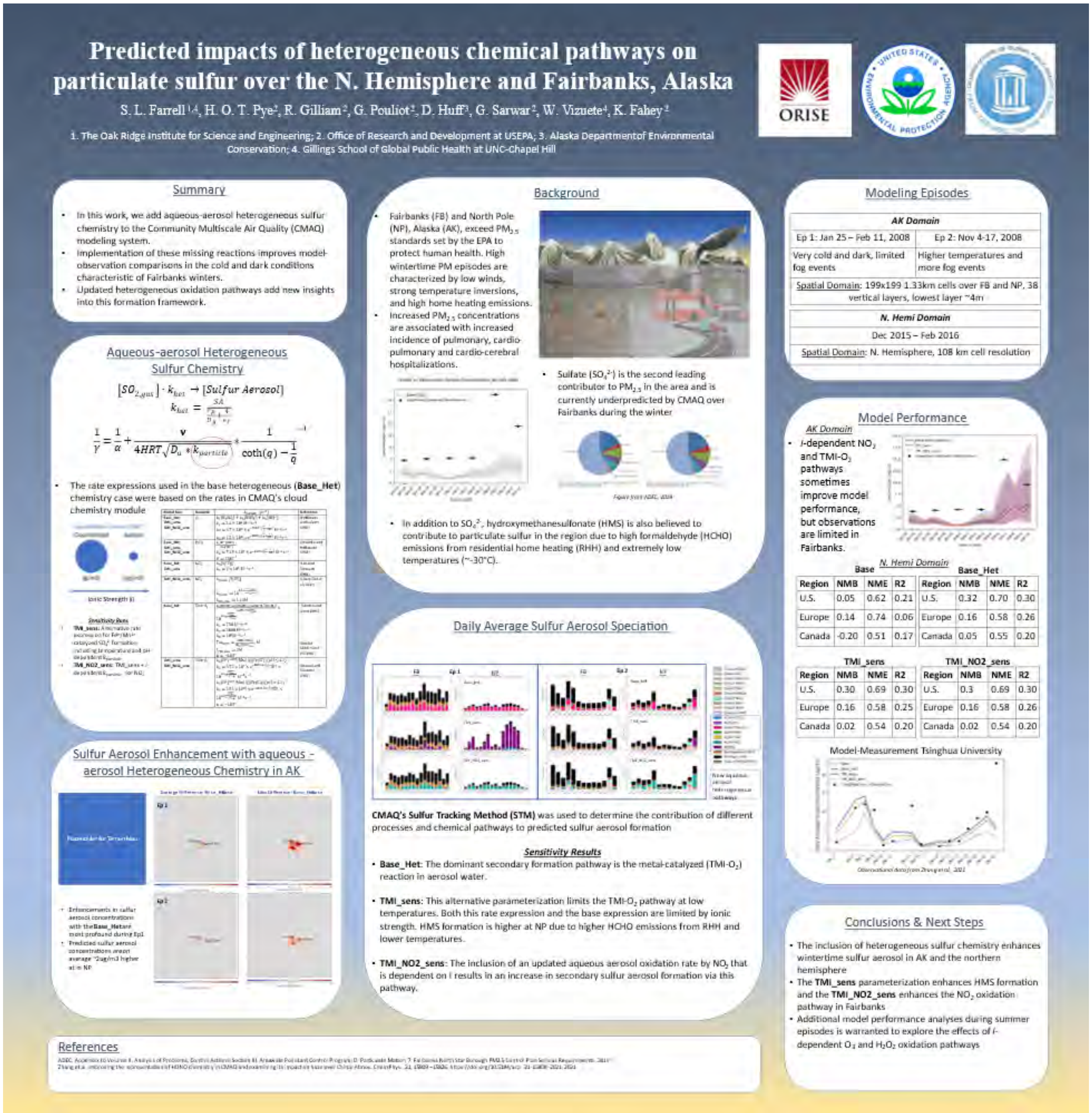
◇ max(51,49) = 41.0 ppbv
○ min(122,7) = 0.0 ppbv

Episode average SO2
episode2_Nov2_to_Nov22_BM



◇ max(51,49) = 268.6 ppbv
○ min(98,96) = 0.0 ppbv

5. USEPA WRF Poster



Predicted impacts of heterogeneous chemical pathways on particulate sulfur over the N. Hemisphere and Fairbanks, Alaska

S. L. Farrell[1,4], H. O. T. Pye[2], R. Gilliam[2], G. Pouliot[2], D. Huff[3], G. Sarwar[2], W. Vizuete[4], K. Fahey[2]

1. The Oak Ridge Institute for Science and Engineering; 2. Office of Research and Development at USEPA; 3. Alaska Departmentof Environmental Conservation; 4. Gillings School of Global Public Health at UNC-Chapel Hill

Summary

- In this work, we add aqueous-aerosol heterogeneous sulfur chemistry to the Community Multiscale Air Quality (CMAQ) modeling system.
- Implementation of these missing reactions improves model-observation comparisons in the cold and dark conditions characteristic of Fairbanks winters.
- Updated heterogeneous oxidation pathways add new insights into this formation framework.

Aqueous-aerosol Heterogeneous Sulfur Chemistry

$$[SO_{2,gas}] \cdot k_{het} \rightarrow [Sulfur\ Aerosol]$$

$$k_{het} = \frac{SA}{\frac{r_p}{D_g} + \frac{4}{v\gamma}}$$

$$\frac{1}{\gamma} = \frac{1}{\alpha} + \left[\frac{v}{4HRT\sqrt{D_a * k_{particle}}} * \frac{1}{\coth(q) - \frac{1}{q}}\right]^{-1}$$

- The rate expressions used in the base heterogeneous (**Base_Het**) chemistry case were based on the rates in CMAQ's cloud chemistry module

Ionic Strength (I)

Sensitivity Runs

Background

- Fairbanks (FB) and North Pole (NP), Alaska (AK), exceed $PM_{2.5}$ standards set by the EPA to protect human health. High wintertime PM episodes are characterized by low winds, strong temperature inversions, and high home heating emissions.
- Increased $PM_{2.5}$ concentrations are associated with increased incidence of pulmonary, cardio-pulmonary and cardio-cerebral hospitalizations.
- Sulfate (SO_4^{2-}) is the second leading contributor to $PM_{2.5}$ in the area and is currently underpredicted by CMAQ over Fairbanks during the winter

Figure from ADEC, 2019

- In addition to SO_4^{2-}, hydroxymethanesulfonate (HMS) is also believed to contribute to particulate sulfur in the region due to high formaldehyde (HCHO) emissions from residential home heating (RHH) and extremely low temperatures (~-30°C).

Modeling Episodes

AK Domain	
Ep 1: Jan 25 – Feb 11, 2008	Ep 2: Nov 4-17, 2008
Very cold and dark, limited fog events	Higher temperatures and more fog events
Spatial Domain: 199x199 1.33km cells over FB and NP, 38 vertical layers, lowest layer ~4m	

N. Hemi Domain
Dec 2015 – Feb 2016
Spatial Domain: N. Hemisphere, 108 km cell resolution

Sulfur Aerosol Enhancement with aqueous - aerosol Heterogeneous Chemistry in AK

Ep1

Ep2

- Enhancements in sulfur aerosol concentrations with the **Base_Het** are most profound during Ep1
- Predicted sulfur aerosol concentrations are on average ~2ug/m3 higher at in NP

Daily Average Sulfur Aerosol Speciation

FB Ep 1 NP

FB Ep 2 NP

CMAQ's Sulfur Tracking Method (STM) was used to determine the contribution of different processes and chemical pathways to predicted sulfur aerosol formation

Sensitivity Results

- **Base_Het**: The dominant secondary formation pathway is the metal-catalyzed ($TMI\text{-}O_2$) reaction in aerosol water.
- **TMI_sens**: This alternative parameterization limits the $TMI\text{-}O_2$ pathway at low temperatures. Both this rate expression and the base expression are limited by ionic strength. HMS formation is higher at NP due to higher HCHO emissions from RHH and lower temperatures.
- **TMI_NO2_sens**: The inclusion of an updated aqueous aerosol oxidation rate by NO_2 that is dependent on I results in an increase in secondary sulfur aerosol formation via this pathway.

Model Performance

AK Domain

- *I*-dependent NO_2 and $TMI\text{-}O_2$ pathways sometimes improve model performance, but observations are limited in Fairbanks.

N. Hemi Domain

Base

Region	NMB	NME	R2
U.S.	0.05	0.62	0.21
Europe	0.14	0.74	0.06
Canada	-0.20	0.51	0.17

Base_Het

Region	NMB	NME	R2
U.S.	0.32	0.70	0.30
Europe	0.16	0.58	0.26
Canada	0.05	0.55	0.20

TMI_sens

Region	NMB	NME	R2
U.S.	0.30	0.69	0.30
Europe	0.16	0.58	0.25
Canada	0.02	0.54	0.20

TMI_NO2_sens

Region	NMB	NME	R2
U.S.	0.3	0.69	0.30
Europe	0.16	0.58	0.26
Canada	0.02	0.54	0.20

Model-Measurement Tsinghua University

Observational data from Zhang et al., 2021

Conclusions & Next Steps

- The inclusion of heterogeneous sulfur chemistry enhances wintertime sulfur aerosol in AK and the northern hemisphere
- The **TMI_sens** parameterization enhances HMS formation and the **TMI_NO2_sens** enhances the NO_2 oxidation pathway in Fairbanks
- Additional model performance analyses during summer episodes is warranted to explore the effects of *I*-dependent O_3 and H_2O_2 oxidation pathways

References

Modeling the wintertime meteorology for the 2022 Alaskan Layered Pollution and Chemical Analysis (ALPACA) campaign

Robert Gilliam, Kathleen Fahey, George Pouliot, Havala Pye, Nicole Briggs, Deanne Huff and Sara Farrell

Fairbanks, Alaska is a nonattainment area for the 24-hour PM2.5 National Ambient Air Quality Standards (NAAQS). Violations of the NAAQS typically occur in winter when the cold conditions are associated with strong temperature inversions and air stagnation that are often difficult to simulate. These weather regimes in urban areas of higher emissions (i.e.; residential wood combustion, mobile sources and energy production) result in a buildup of particulate pollution at the surface. The Alaskan Layered Pollution and Chemical Analysis (ALPACA) field campaign was conducted in January and February of 2022 to address some of the knowledge gaps with a focus on better understanding emissions, meteorology, and atmospheric chemistry.

Notes on US EPA WRF modeling for Fairbanks, AK (Dec 2019-Feb 2020)

Introduction

Final narrative of WRF modeling for Dec 2019-Feb 2020 SIP modeling period for Fairbanks, AK. The ALPACA field campaign in early 2022 provided an opportunity to refine our fine-scale modeling in complex winter regimes where strong temperature inversions limit vertical mixing of surface-based emissions and cause high concentration of PM2.5 and other pollutants. Using field campaign data for evaluation and then observational nudging, the result was a new model configuration with adjustments to the observation nudging settings and enabling FDDA with constraints on how close to the surface grid-based nudging is applied. Because these settings proved to improve model performance, dramatically in some cases, we have applied this configuration to the 2019-2020 SIP modeling period for the State of Alaska. Original modeling for Alaska was done by Ramboll and documented in a 2021 report. This will be referenced in the narrative below where appropriate.

Configuration & Issues

General WRF configuration follows the original modeling done by Penn State under a US EPA contract completed in 2010. This research defined a quality WRF model configuration to model Fairbanks, AK based on a simulation of a 2008 winter case study. The configuration at the time was a 12 km coarse domain with 4 and 1.33 km nested where the finest scale domain was centered over Fairbanks. Should be noted that Ramboll also used the 12-4-1.33 km domain configuration. In recent years, we have found that the 12 km outer domain is not required. The US EPA has been running a 4 to 1.33 km configuration (Figure 1) with good results when the 2008 case study was revisited with a WRF model code that had 10 years of development since the original modeling in 2010. Both ALPACA and the US EPA modeling for 2019-2020 used this new domain configuration.

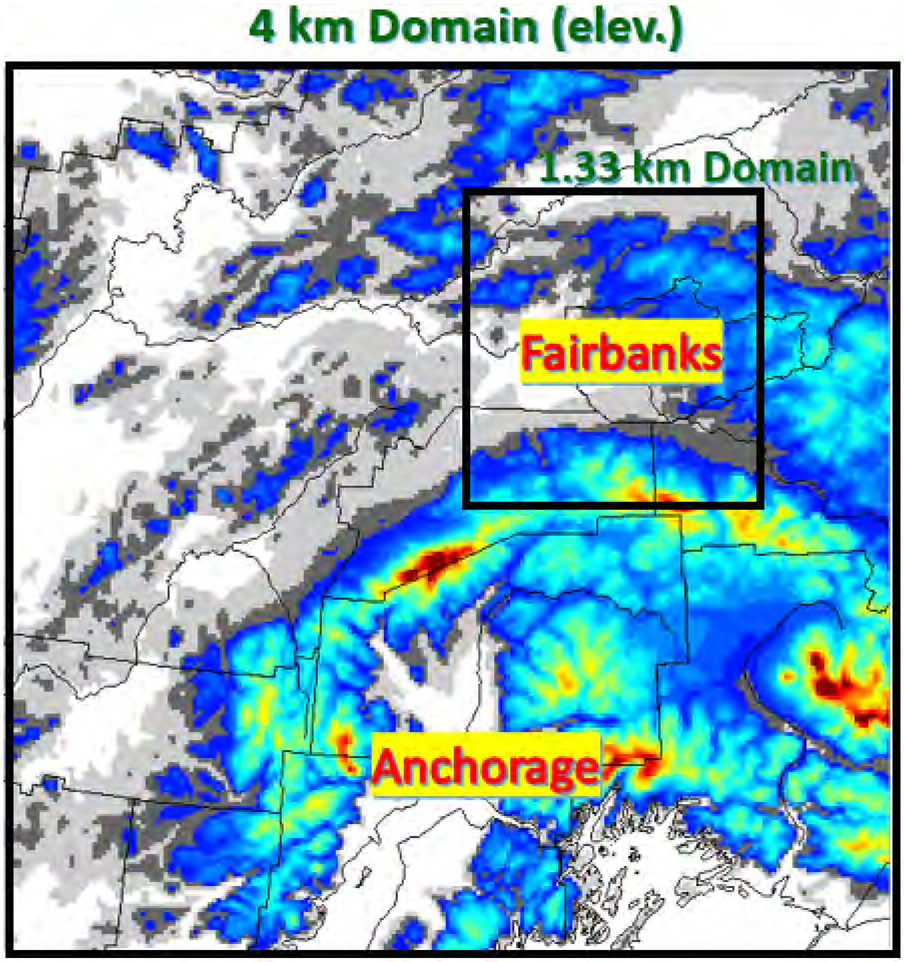


Figure 1: US EPA domain configuration with 4 km outer domain with a 1.33 km nested domain centered over Fairbanks, AK.

Another distinction is the vertical grid structure. Ramboll ran into model run stability issues using the Penn State 39 vertical layer structure where our typical 10 m thick first layer was split into three layers with center point at approx. 3, 6 and 9 m. The US EPA did not experience the same stabilty issues, so this 39-layer structure was preserved. This was used not only for the idealistic view that more detail near the surface will improve boundary layer modeling where strong inversions exist. It was used because Alaska Dept of Env. Conservation observations at NCore, AStreet and Hurst Rd have multi-level temperature and wind data at about 3, 6, 10, 23 m. Having model levels near the level of these observations so close to the surface should help refine model stability in Fairbanks in the lower 23 m of the atmosphere where emissions are released if the nudging is done correctly.

The US EPA modeling had a slight deviation from the Ramboll modeling in that the underlying global analysis for FDDA on the 4 km domain used 6-hourly GFS nudging of wind, temp and moisture above the boundary layer. Ramboll used ERA5 or ECMWF-based analyses. We used GFS for ALPACA 2022 and that worked well, so that was not changed for the 2019-2020 period. The US EPA did test a special version ERA5 with much finer vertical information. But some odd features in the temperature field was noted and the results of that test were on par with the GFS if not worse in terms of error. This would not matter much if the original configuration of "observational nudging only" on the 1.33 km domain was used, but US EPA found a benefit in the ALPACA modeling of using FDDA-based grid nudging with constraints that it is never applied below vertical level 9 of the model (~ 250 m). This allows the near-surface observation nudging to run without interference from FDDA that is based on coarse analyses.

US EPA run based on the 2008 configuration used the RUC land-surface model where Ramboll used the Noah LSM. But the US EPA did follow the same updated PBL scheme as Ramboll. The US EPA run used 24-class USGS landuse where Ramboll updated to the MODIS 20 class landuse. We do not think these are as important with deep snow cover for the winter period except for the PBL scheme where we did find improvements when we tested the Ramboll settings for the MYNN 2.5 TKE closure scheme.

The US EPA modeling is completely distinct from Ramboll in that all inputs were developed independently. The WRF modeling started by doing a full spin-up from Nov 10-30, 2019 (20 day). This allows the model to develop the snowpack at the model resolution rather than poorly defined snow from coarse analyses. It also spins up all the surface properties like soil and surface temperature. WRF was then reinitialized on Nov 30, 2019 with these spun up values for the key Dec 2019 through Feb 13, 2020 modeling period for CMAQ. The reinitialization was done because we found some issues restarting WRF with restart files and the observation nudging. At least on the US EPA supercomputer we found the observational nudging does not work properly when WRF is restarted. So, we run via reinitialization for the complete SIP modeling period without any restarting. For contrast, Ramboll ran fifteen, 5.5 overlapping run segments to cover the 74-day modeling period. From the Ramboll report, these segments were run concurrently because of computational limitation so completely independent of each other. Evidence documented by Otte (2008) found continuity issue running

5.5 overlapping run segments for CMAQ modeling. In WRF, the surface properties like temperature, snow, moisture, etc are reinitialized from coarse analyses each run segment rather than carried over in a more continuous manner. The US EPA model simulation has no breaks and will not suffer any negative impacts of reinitialization.

Several issues were found during the US EPA's testing. A primary issue was the nudging files. We used the observations in the nudging file to evaluate the initial WRF simulation. It was discovered (Figure 2) that ADEC observations seemed to have an offset relative to the WRF simulation. This is clear in the Hurst Road timeseries in Figure 2 for Dec 2019. A comparison with nearby NOAA sites discovered that the date/time stamp of the Astreet, NCore and Hurst Rd sites were in local time, not UTC. This effectively causes WRF to nudge towards ADEC temperatures 9 hours earlier than reality. This impact would probably be greatest on days of the period with the most sunlight as WRF would think it is mid-day as an example but being nudged towards near-surface temperature that is at night, so cooling the model when it should be warming. Now there are other observations in the area that would blunt the impact some, but in our testing, the wrong time of day increases model error substantially based on all observation sites around Fairbanks. In the timeseries below the RMSE of 3-m temperature is 4 K. When we fixed this issue, the RMSE dropped significantly to about 1.75 K. These are critical for surface stability, so it is expected that these improvements will improve the representation of mixing in CMAQ.

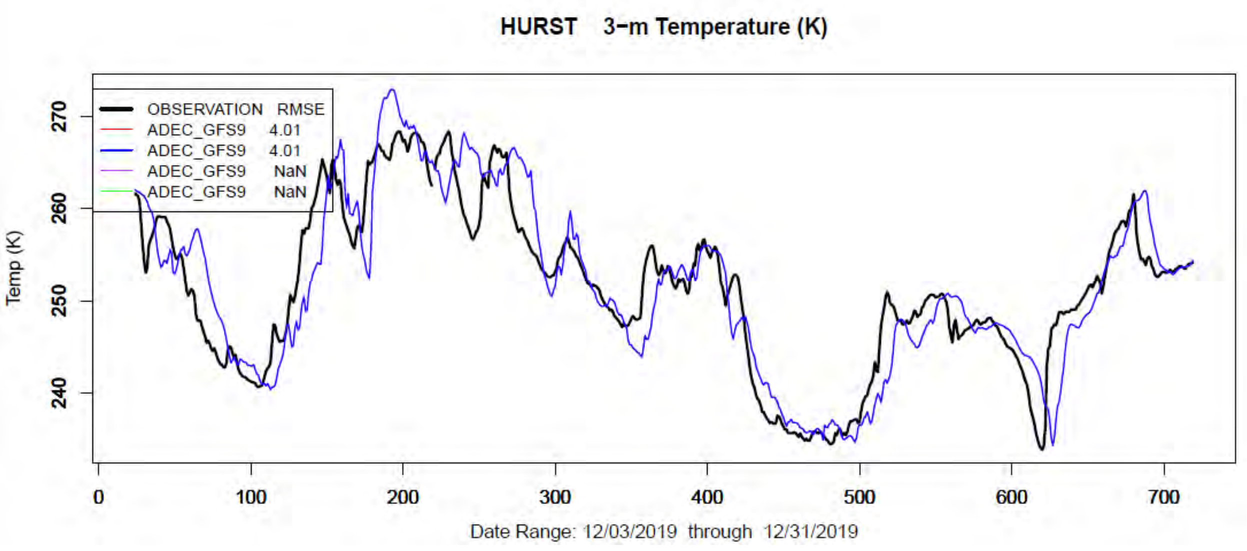


Figure 2: US EPA domain configuration with 4 km outer domain with a 1.33 km nested domain centered over Fairbanks, AK.

The US EPA leveraged the raw ADEC measurements in several text files to develop a new observational nudging file for the whole period that also include all MADIS observations including NOAA and Mesonet sites and the twice-daily PAFA upper-air sounding. The US EPA did not use the Ramboll observation nudging records from NOAA and Mesonet sites and elected to use an internal MADIS2LITTLER code that extracts these observations for a specified domain. From a look at the Ramboll files, they may have used a database of LittleR files directly. It was not clear if all Mesonet sites in MADIS were included in Ramboll's files, so safe to just recreated knowing all data available was included. We also cast ADEC 3-m observations as 2-m observation nudging records as well as a multi-level observation per sensitivity testing of the ALPACA period that showed some benefit. To be clear on other differences based on ALPACA testing, the US EPA limited obs nudging of surface data to the lower 50 m of the atmosphere rather than Ramboll's setting of 500 m (obs_nudgezmax =50). The MM5 vertical obs spreading scheme was used instead of default option. And finally, the time window for an observation to be nudged was doubled from 40 min to 80 min. In ALPACA testing this smooth the WRF temperature time series and improve the representation of temperature.

One last issue was found in the Ramboll nudging file that may have impacted results. It seems that many hourly observations were set to missing during the Obsgrid development of observation nudging files. The US EPA found this in their initial development of these files because QA gross and buddy checks were too strict for a Fairbanks in winter where temperature frequently varies by 5 deg or more over small distances. And the QA is done using a coarse analysis. When we completely turned off QA many observations were uncovered that were previously set to missing. The US EPA decided to relax QA rather than completely turn off. Gross temperature difference for example between the observation and analysis was increased from 4 to 8 K. The fact that so many observations were missing in the observation nudging file may explain some of the poor statistics in the Ramboll modeling at a site like PAFA.

Results: Model Evaluation & Discussion

Key metrics in this evaluation is the temperature near the surface. Evaluation has been done in the past on how PAFA RAOB compares with WRF using observation nudging and the twice daily sounding indicates solid if not outstanding model performance on average over winter period. An indication that observational nudging is effective. Figure 3 is an example using temperature where RMSE is near 1 K at the surface and decreases aloft to around 0.50 K. The bias is also low and distribution of model difference with the observed temperature show tight distribution where the model is almost never more than 1 deg from the observed profile. WRF similarly performed well for moisture and wind.

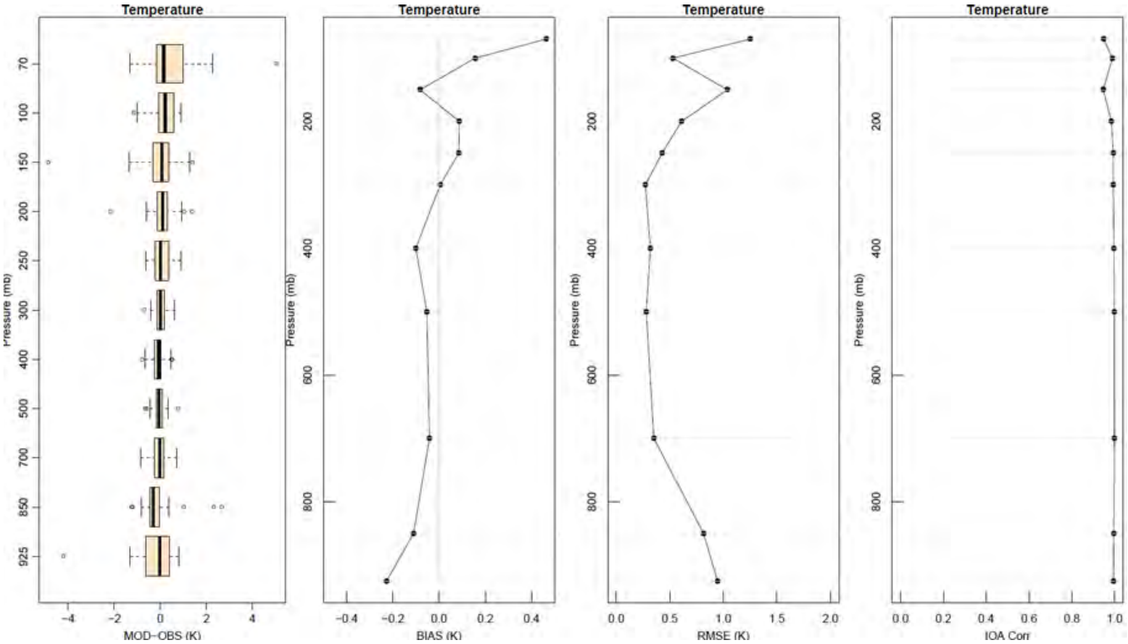


Figure 3: Temperature profile statistics for the modeling period at PAFA. Tiles include the distribution of temperature difference (mod-obs), model bias, error (RMSE) and index of agreement.

Figure 4: Location of key observation sites used to evaluate the 2019-2020 WRF simulations.

Table 1 provides the most direct comparison with the Ramboll simulation(s) and demonstrates model performance gains with the updated US EPA configuration. This is most clear comparing the WRF simulations at the standardized NOAA sites PAFA, PAFB and PAEI. No large difference at PAEI. This site is away from Fairbanks more than all others, so was likely not affected by the date/time issue for the ADEC sites in the nudging file. The smaller, but clear improvement at PAEI likely reflects the change of the nudging configuration options more than any fixes to the observation nudging file. The Ramboll files has PAEI represented the same as the US EPA nudging file.

Fairbanks International (PAFA) indicates a significant improvement in the WRF representation of near surface temperature. The 2.20-2.40 K monthly RMSE is much lower than the ~3.55-4.70 K values reported by Ramboll. It was found that PAFA had many missing values in the Ramboll observation nudging file share with the US EPA. This was corrected with relaxed QA in Obsgrid and a full record was found in the US EPA nudging file. PAFB sits on the east side of Fairbanks and indicates this area is one where WRF performs the best with monthly RMSE values between 1.70 to 1.90 K. Ramboll has errors from ~2.40 to 2.70 K. This site surely suffered some in the Ramboll run with nearby Astreet and NCore data being nudged 9 hours early.

Table 1: WRF RMSE of 2-m temperature at key observation sites around Fairbanks. ADEC values are based on the 2021 Ramboll report. USEPA is the best US EPA simulation with corrections to observation nudging files and updated configuration.

2-m Temp RMSE	ADEC	USEPA	ADEC	USEPA	ADEC	USEPA
	Dec	Dec	Jan	Jan	Feb	Feb
PAFA	4.38/3.55	2.20	4.70/3.84	2.60	4.41/3.56	2.40
PAFB	2.77/2.41	1.70	3.09/2.56	1.90	2.82/2.73	1.70
PAEI	2.68/2.57	2.40	2.94/2.13	2.20	3.36/3.03	2.70
ASTREET (10m)	1.54	NA/2.54	1.39	2.63	2.15	1.90
NCORE (3/10m)	1.23	1.72/2.09	1.32	2.22/2.69	2.00	1.39
HURST (3/10/23m)	2.34	2.02/1.96/1.96	2.39	1.66/1.52/1.40	2.66	1.65/1.48/1.32
BRHA2	X	1.70	X	1.90	X	2.00
FAEA2	X	2.30	X	2.10	X	1.60
AWCA2*	X	2.80*	X	X	X	X
LTPA2	X	2.10	X	2.10	X	2.30*
F4513	X	1.90	X	2.10	X	1.70
F3318	X	1.90	X	1.90	X	1.60

The ADEC sites and model performance is a key in this model evaluation. US EPA run verified extremely well at Hurst Rd. The Jan and Feb model performance is as precise as any modeling in terms of temperature error. The 3, 10, 23-meter temperature RMSE is 1.66, 1.52 and 1.40 K in January 2020. The mean absolute error is close to 1 K. Specific times will be discussed in a time series analysis, but for context, WRF is performing perhaps best during the cold periods over this 23 m layer above the surface. This informs that the temperature inversion and stability are well represented in WRF. NCore only has two levels (3 and 10 m), but both are simulated well in Dec. The errors rise in January (significant missing data) and fall again in Feb. The timeseries analysis will analyze this in more detail. Astreet has a lot of missing data including all 3 m temperature in the file shared with the US EPA. It is unclear how Ramboll derived statistics, but the Ramboll errors are quite low in most cases. The US EPA run is much lower across the board at all levels (Ramboll only reports what is assumed 3 m temperature statistics). Ramboll reports lower errors in general at NCore and Astreet. More discussion in the timeseries analysis at NCore and Hurst Rd.

Other observation sites listed are Mesonet sites around Fairbanks. We do not have specific errors at these sites based on the Ramboll simulations, but confirm these sites were used in their nudging. However, the monthly temperature RMSE at other sites in Fairbanks are as low as 1.60 K. Most monthly errors (9 of 14) are below 2 K which signifies quality temperature modeling. A few are just above 2 K. Note that site F3318 is near the ADEC Hurst Rd monitor. The monthly statistics at F3318 are in line with Hurst Rd performance with temperature error between 1.6 and 2.0 K. Several values with asterisks are questionable after looking at the observations where odd features exist (spikes) and large consistent bias (AWCA2) not seen at sites within a few kilometers that suggest site data quality issues. Overall, these statistics are consistent with the other observation platforms.

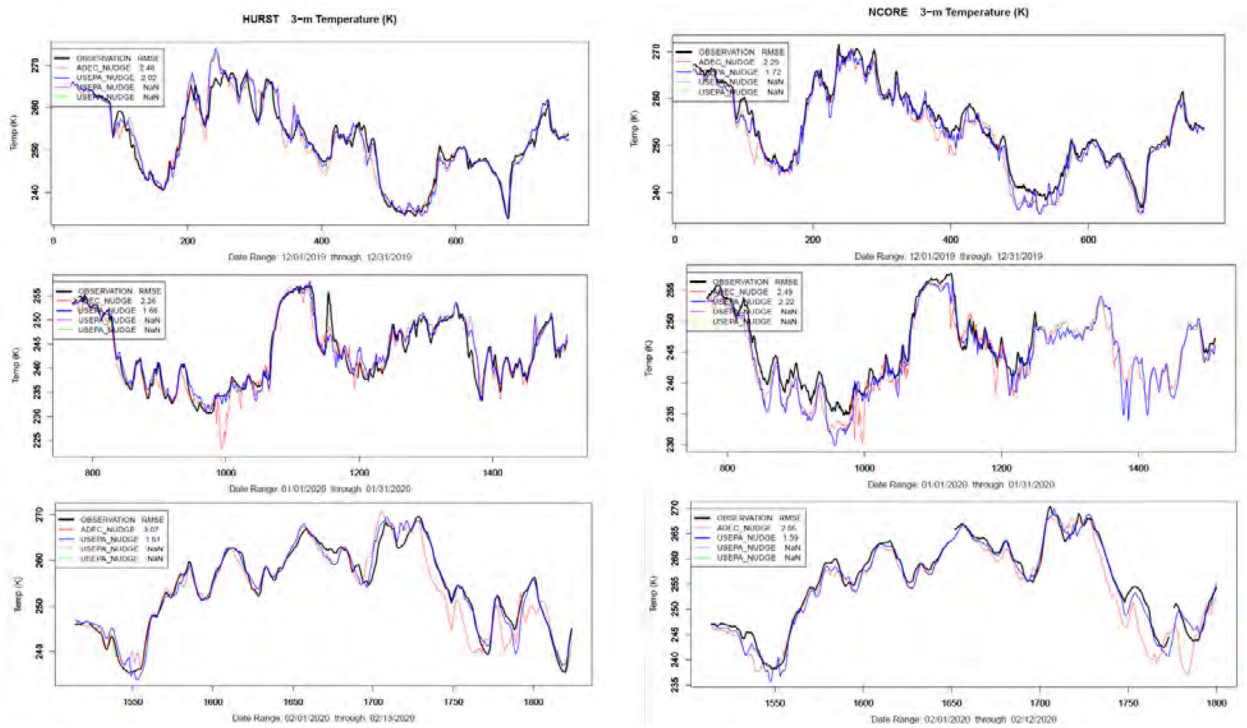


Figure 5: Temperature timeseries at Hurst Rd and NCore sites for Dec (top), Jan (middle) and Feb (bottom). RMSE values are provided for the WRF simulation that used the ADEC observation nudging file (red) and the US EPA develop observation nudging file (blue).

Timeseries at the two ADEC sites, NCore and Hurst Rd that have close to complete 3-m temperature records are provided for each month in Figure 5. The RMSE for both sites for all months are around 1.75 K. This level of error is superb. Looking closer at cold periods, US EPA WRF has a clear cold bias during the early Jan 2020 cold pool event. This event is examined closer with Ramboll modeling next, but otherwise, US EPA WRF captures other cold periods with high precision, especially at Hurst Rd.

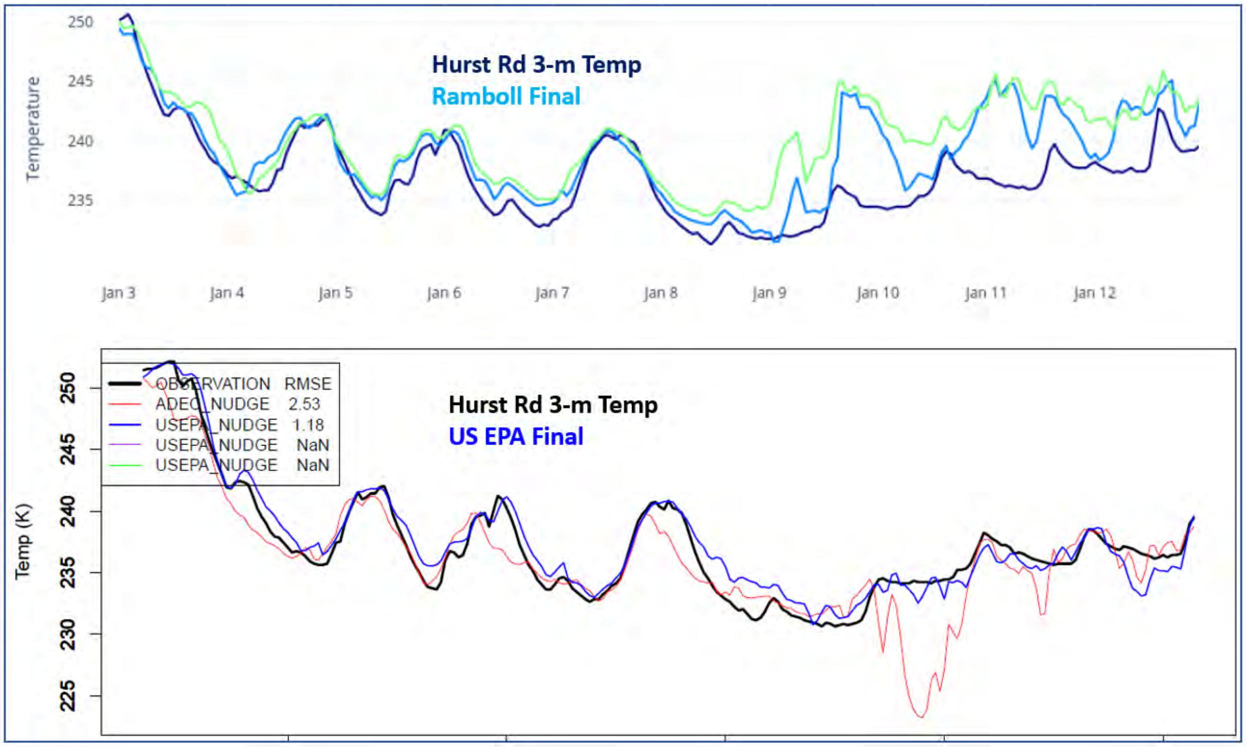


Figure 6: 3-m temperature timeseries at Hurst Rd. from the Ramboll report (top) and US EPA WRF (bottom).

Using the Ramboll report, a case study comparison is provided at several key sites where a more direct comparison of the US EPA and Ramboll simulations can be done. This case study is the Jan 3-12, 2020 period shown in section 6.3.2 of the Ramboll report. Hurst Rd. comparisons are presented in **Figure 6**. US EPA simulation has a low RMSE at 1.18 K and follows the observed temperature closely over this period. The Ramboll simulation performs well for the first half of the period, but a warm bias of almost 10 K spikes on Jan 10 and 11, where the US EPA run is almost exact.

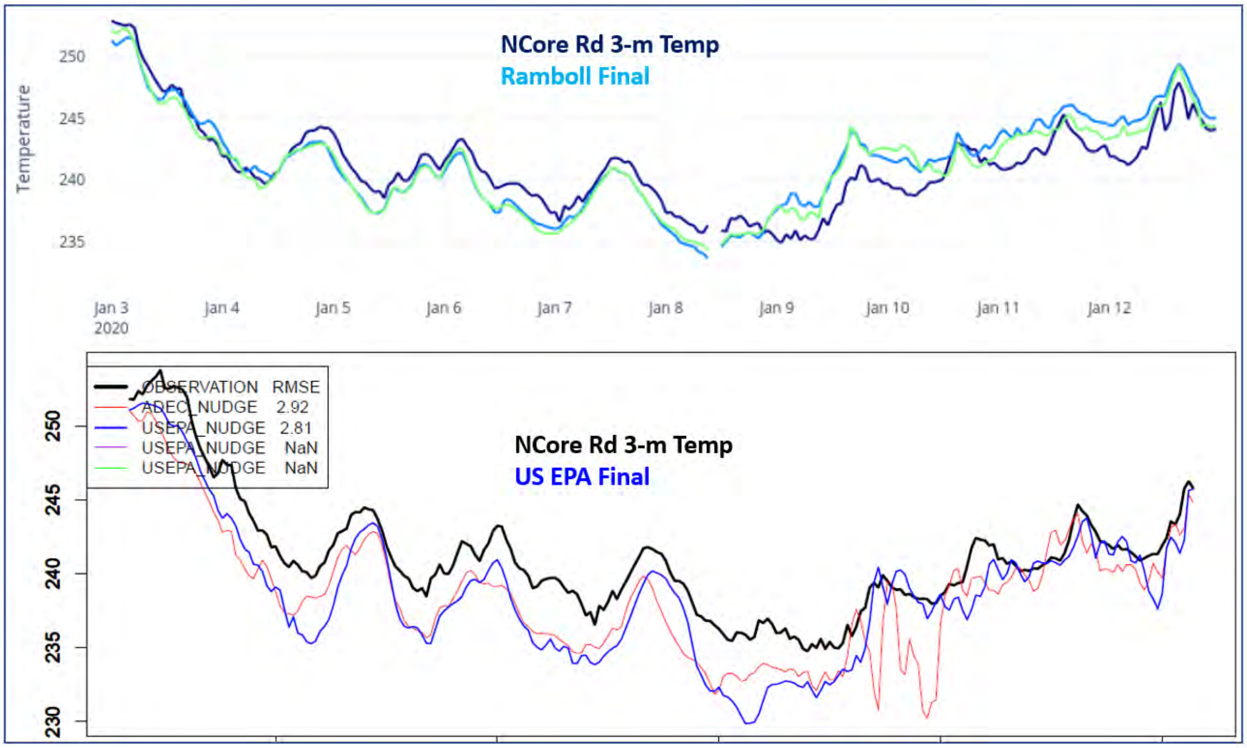


Figure 7: 3-m temperature timeseries at NCore from the Ramboll report (top) and US EPA WRF (bottom).

NCore comparison for the same case is presented in **Figure 7**. In this case the US EPA simulation performs the worst of the whole modeling period as already discussed using full period timeseries in Figure 5. A cold bias of about 5 K over these few days, but the US EPA simulation does match NCore well after Jan 9. Ramboll simulation also has a consistent cold bias but slightly better for the first part of this period and slightly worse perhaps the second part. It is not clear on why the US EPA run had issues for these few days, but the comparison below at PAFB may provide some clues.

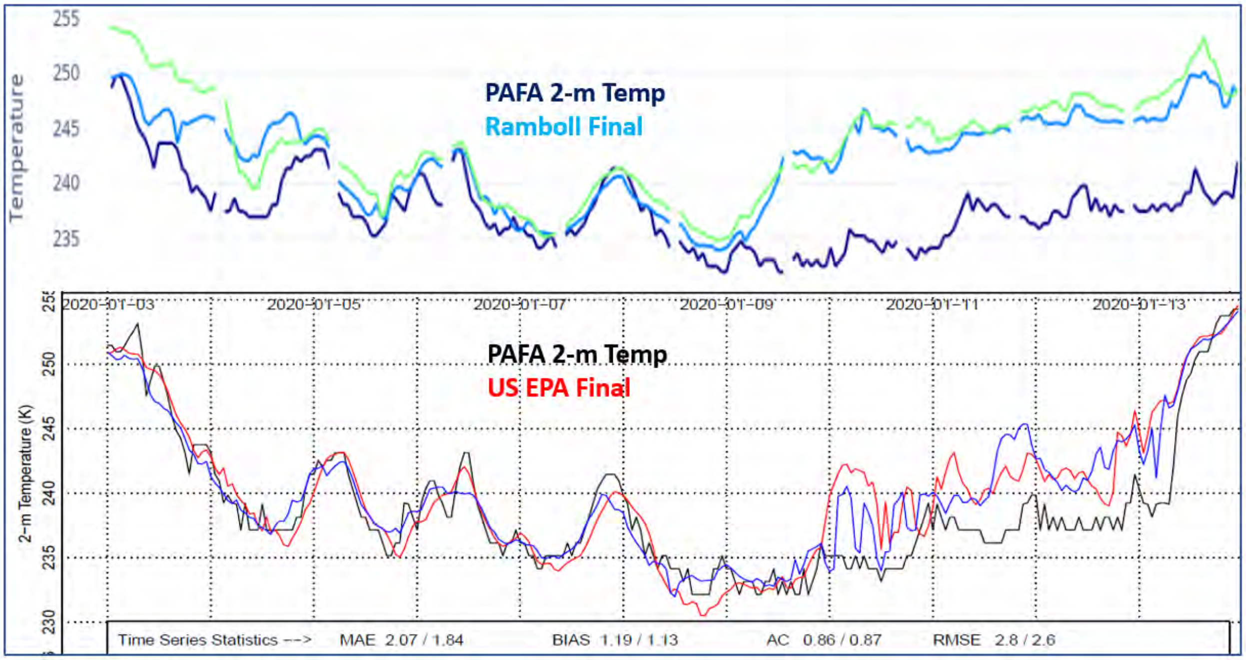


Figure 8: 3-m temperature timeseries at Fairbanks International (PAFA). from the Ramboll report (top) and US EPA WRF (bottom).

In **Figure 8**, the same comparison is provided for PAFA. Here Ramboll and US EPA final perform similarly well Jan 5-8, but the US EPA final run performs much better otherwise. The Ramboll simulation has a large warm bias Jan 3-4 and Jan 9-12. The US EPA run is almost exact on Jan 3-4 and has a warm bias Jan 9-12, but about half the Ramboll warm bias.

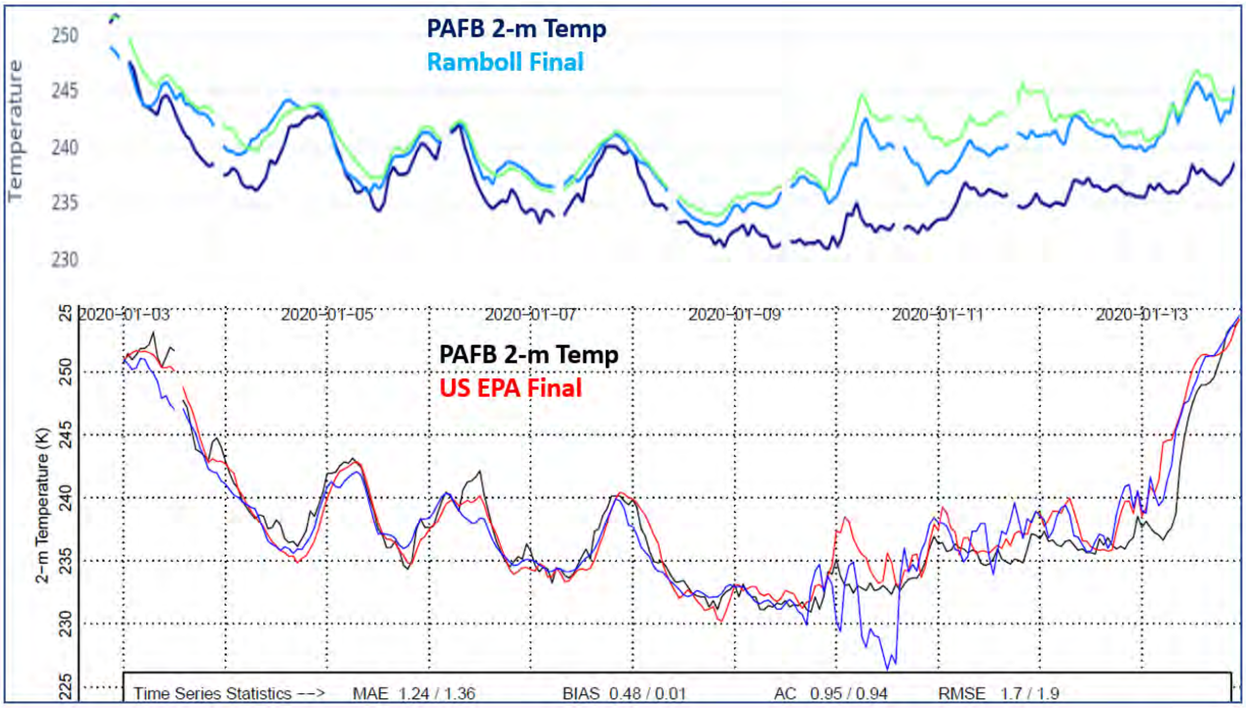


Figure 9: 3-m temperature timeseries at Hurst Rd. from the Ramboll report (top) and US EPA WRF (bottom).

The final comparison for this case study is at PAFB (Ladd Army Airfield) in **Figure 9**. The 2-m temperature at PAFB is simulated similarly as PAFA in the Ramboll model run. A clear warm bias early and late in the period, with better performance Jan 5-8. Again, like PAFA, the US EPA final simulation at PAFB is quite accurate where on average the model is within 1.25 K of the observed temperature. The bias is small at about +0.50, but most of that is a slight warm bias after Jan 10 with most of that a spike in warm bias early on Jan 10.

Figure 10: Temperature timeseries at PAFA (left - black) and PAFB (right - black) for the full modeling period along with the US EPA final simulation (red).

Figure 10 provides the full timeseries over the modeling period for the two NOAA sites in Fairbanks. These two sites also represent how WRF performs on both the east (PAFB) and west (PAFA) side of Fairbanks. If the focus is on cold period modeling, the US EPA final WRF simulation simulates 2-m temperature with high precision for the three cold periods Dec. 2019. The Dec 14-22, 2019 period was discussed in the Ramboll report in section 6.3.1 where their best simulation had a consistent warm bias in the 2.0-5.0 K range at PAFA. The warm bias is slightly less at PAFB (+1-2 K bias). The US EPA final run may have a slight warm bias for this period (1.5 K at PAFA and 0.5 K at PAFB), but matches the reported temperature better, especially the cold period starting on Dec 20 where the lowest temperatures are captured by WRF. A possible reason for the better performance in the US EPA simulation could be the largely incomplete record of temperature in the observation nudging file for PAFA. These were fixed in the US EPA observation nudging file by relaxing the QA in Obsgrid. As indicated before, stricter QA may have filtered many observations from the Ramboll observation nudging file.

January and the early cold pool period was discussed already. The US EPA final run did not perform as well for the early part of Jan, but does very well capturing the cold temperature at the end of Jan and all of Feb. at PAFB and PAFA, but does have a slight warm bias several days in Feb.

For completeness, a few other meteorological variables are examined and errors documented in **Table 2**. Wind measurements as Ramboll states, have some issues in this region where cold = calm wind. Wind speed and direction errors below have many missing hourly values because of the reporting protocols. The US EPA cannot verify that the data count is the same. The Atmospheric Model Evaluation Tool (AMET) filtered out low wind speed observations < 0.5 m/s and associated wind directions. From timeseries in the Ramboll report (Fig 16-9) it appears many wind observations were missing in their PAFA, PAFB and PAEI statistics. With that said, the observations available show comparable errors with low levels over all. However, it is difficult to conclude if one run is better than the other based on the small sample of data. This obviously holds true for the wind direction as well and also acknowledged in the Ramboll report in section 6.2.2.

Mixing ratio and relative humidity are the two moisture variables we can evaluate using AMET. Ramboll reports errors of water vapor mixing ratio, but not in a table for each sites. In their Figure 6.8 the RMSE of moisture is generally around 0.25 g/kg and as high as 0.50 g/kg. Table 2 has the RH error for the US EPA final run as well as for water vapor mixing ratio. We cannot compare RH, but error levels in the US EPA final run where WRF is on average within 4-5% of the reported relative humidity seems reasonably accurate. The water vapor mixing ratio RMSE of the US EPA final run is extremely low because water vapor is low in cold air. But, these are complete time series and the comparison with Ramboll is direct. The US EPA run has errors around 0.1 g/kg at the PAFA, PAFB and PAEI sites. Ramboll modeling had these same metrics mostly 0.30 to 0.40 g/kg.

Table 2: WRF RMSE of 10-m wind speed and MAE of direction at key observation sites around Fairbanks. Also provided are moisture errors. ADEC values are based on the 2021 Ramboll report. USEPA is the best US EPA WRF simulation with corrections to observation nudging files and updated configuration.

10-m WS RMSE	ADEC	USEPA	ADEC	USEPA	ADEC	USEPA
	Dec	**Dec**	**Jan**	**Jan**	**Feb**	**Feb**
PAFA*	1.7	1.3	1.8	1.4	1.7	1.2

PAFB*	1.4	1.6	1.6	1.8	1.5	1.9
PAEI*	1.3	1.4	1.2	1.0	1.3	0.7
10-m WD MAE	ADEC	USEPA	ADEC	USEPA	ADEC	USEPA
PAFA*	X	40	X	52	X	35
PAFB*	X	38	X	57	X	50
PAEI*	X	44	X	50	X	51
2-m RH/Q MAE/RMSE	ADEC	USEPA	ADEC	USEPA	ADEC	USEPA
PAFA	NA / ~0.4	5 / 0.07	NA / ~0.3	4 / 0.07	NA / ~0.4	5 / 0.23
PAFB	NA / ~0.3	5 / 0.15	NA / ~0.2	4 / 0.06	NA / ~0.3	4 / 0.13
PAEI	NA / ~0.4	5 /0.16	NA / ~0.2	4 /0.06	NA / ~0.4	5 / 0.23

Conclusions

The US EPA identified a few issues with the observation nudging file that were tested and resolved. Additionally, an observation nudging strategy developed from the evaluation of ALPACA period modeling was tested. The evaluation and comparison with prior modeling by Ramboll show some key areas where temperature modeling near the surface was improved. The most impressive WRF results were at the Hurst Rd site where temperature modeling at 3, 11 and 23 m was constant and accurate. There are also significant improvements in the temperature modeling at both PAFA and PAFB sites. Perhaps the more dissident result was the model performance at NCore and Astreet. The Ramboll error numbers were very small (~1.2-1.5 K) considering the time series examples presented in sections 6.3.1, 6.3.2 and 6.3.3. However, US EPA final runs performed well, but lowest monthly error levels were 1.39 K at NCore (3-m) in Feb and 1.32 K at Hurst Rd. (23 m) in Feb. Most monthly errors were in the 1.6-2.2 K range. When using this data and trying to interpret results though, it will be useful to look at the timeseries. In most cases the US EPA final simulation captures the cold period very well.

References

Gaudet, B., Stauffer, D., Seaman, N., Deng, A., Schere, K., Gilliam, R., Pleim, J. and Elleman, R., 18.1 MODELING EXTREMELY COLD STABLE BOUNDARY LAYERS OVER INTERIOR ALASKA USING A WRF FDDA SYSTEM. AMS 13th Conf. Mesoscale Processes, Salt Lake City, UT, Aug 17-20, 2009.

Otte, Tanya L. “The Impact of Nudging in the Meteorological Model for Retrospective Air Quality Simulations. Part I: Evaluation against National Observation Networks.” Journal of Applied Meteorology and Climatology, vol. 47, no. 7, 2008, pp. 1853–67. JSTOR, http://www.jstor.org/stable/26172706. Accessed 14 Feb. 2023.

Modeling the wintertime meteorology for the 2022 ALPACA campaign & 2019-2020 AK Winter

Robert Gilliam, Kathleen Fahey, George Pouliot, Havala Pye, Nicole Briggs, Sara Farrell, Deanna Huff, William Simpson and Meeta Cesler-Maloney

Eric Engman/Fairbanks Daily News-Miner via AP

UAF, Geophysical Institute

Outline

- Meteorology model (WRF) configuration(s)
- Initial WRF simulation post-ALPACA
- WRF evaluation using independent ALPACA observations
- Using ALPACA observations in the data assimilation
- Using ALPACA modeling for 2019-2020 winter case

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Roman Pohorsky, Andrea Baccarini & Julia Schmale for **Helikite Profile measurements**
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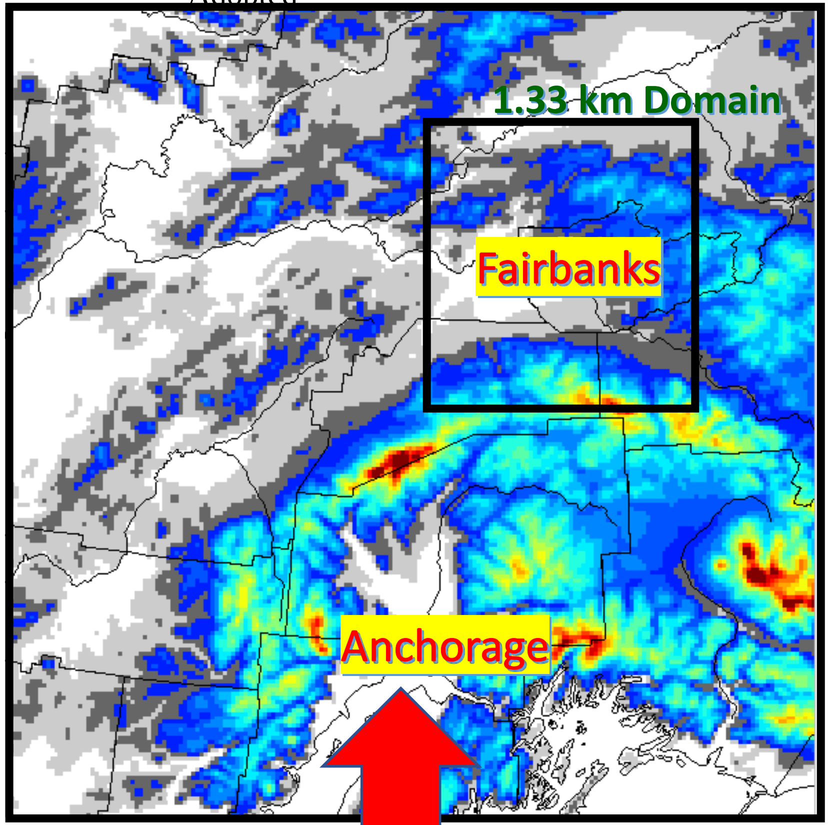
Alaska Dept. of Environ. Conservation (AK DEC) for **Hurst, NCore and A-Street measurements**
Meeta Cesler-Maloney, William Simpson & Univ. Alaska - Fairbanks for **CTC measurements**
ADEC & Rambol Group (Bart Brashers) for consulting on Fairbanks **WRF configurations**
ADEC E. Dieudonne & H. Delbarre @ LPCA/ULCO for **Doppler LIDAR measurements**

WRF Configuration

4 km Domain (elev.)



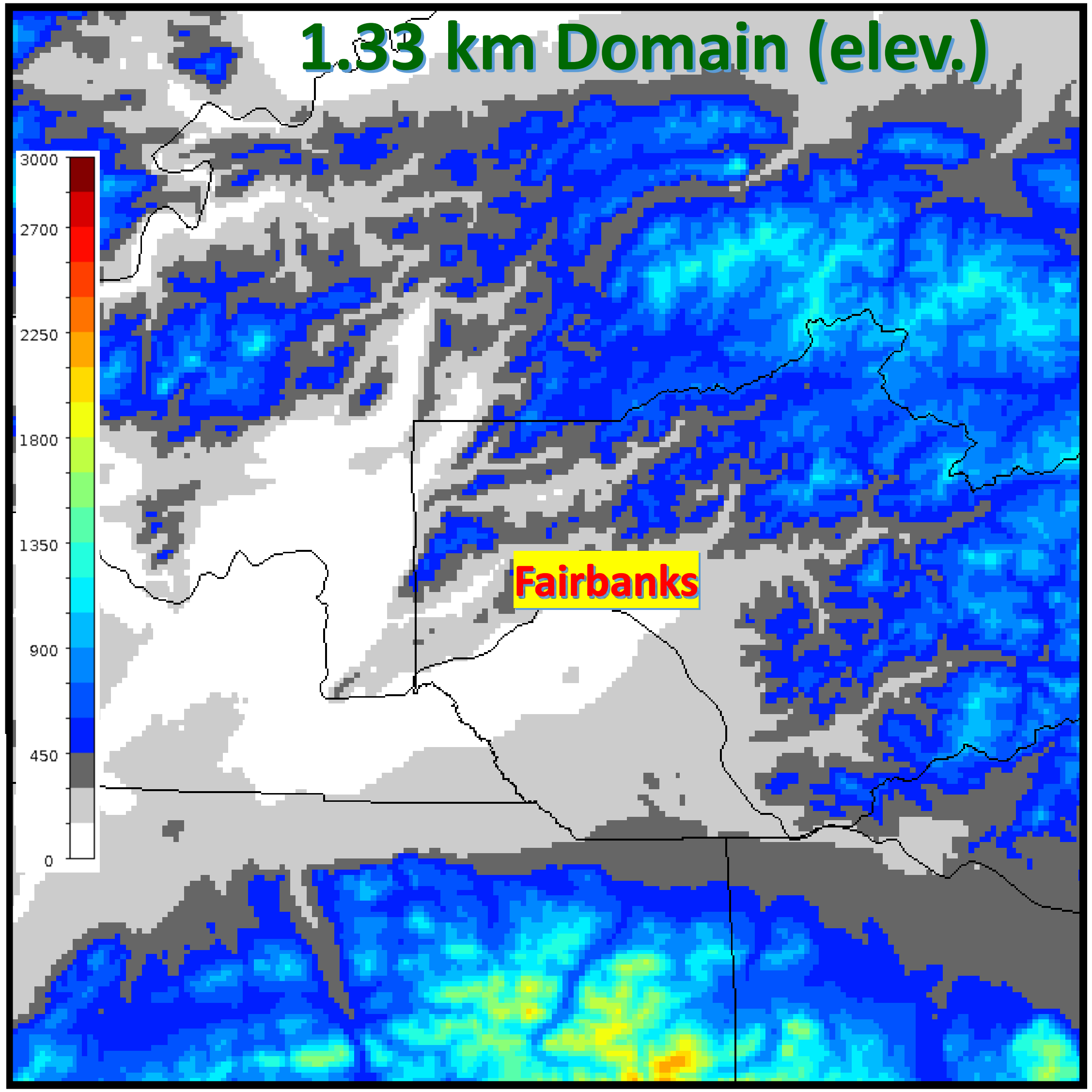
WRF/CMAQ model omain

- 4 km outer domai h nested 1.33 km centered over Fairb

- WRF Jan 1-Feb 28 for ALPACA (Jan 17-Feb 28)

- 38 total vertical levels with extra fine spacing below 500 m

- 11 lowest layers @ approx. 2, 5, 9, 17, 32, 52, 82, 132, 207, 311, 433, 555 meters



WRF Physics (WRFv4.3)

- RUC LSM
- MYNN TKE PBL
- Morrison Mp
- RRTMG SW/LW
- No subgrid Cp scheme

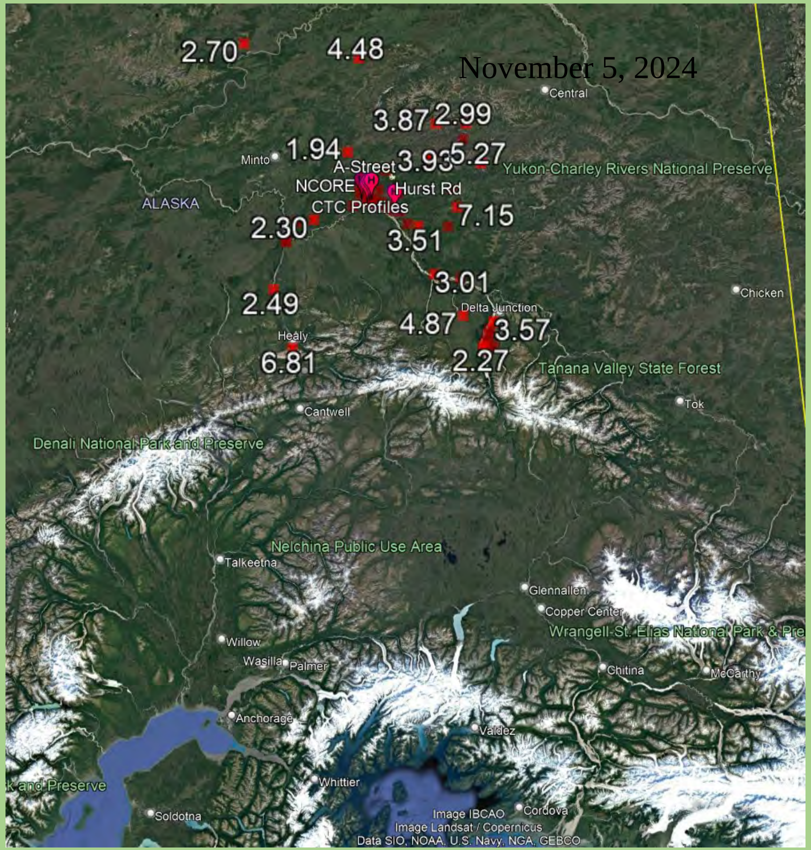
BC & Data Assimilation (DA)

- NCEP GFS boundaries
- GFS FDDA (4 km)
- Obs nudging (1.33 km): METAR and Mesonet
- Obs nudging (1.33 km): RAOB (PAFA)

Simulations

- Daily DA simulations with 72 hr forecast during ALPACA
- Continuous Obs Nudging run post-ALPACA
- 1.33 km Sensitivities
  - No DA
  - FDDA Only
  - FDDA + ON
- **DA with ALPACA field campaign obs**

Post-ALPACA continuous 1.33 km WRF simulation using a base model configuration



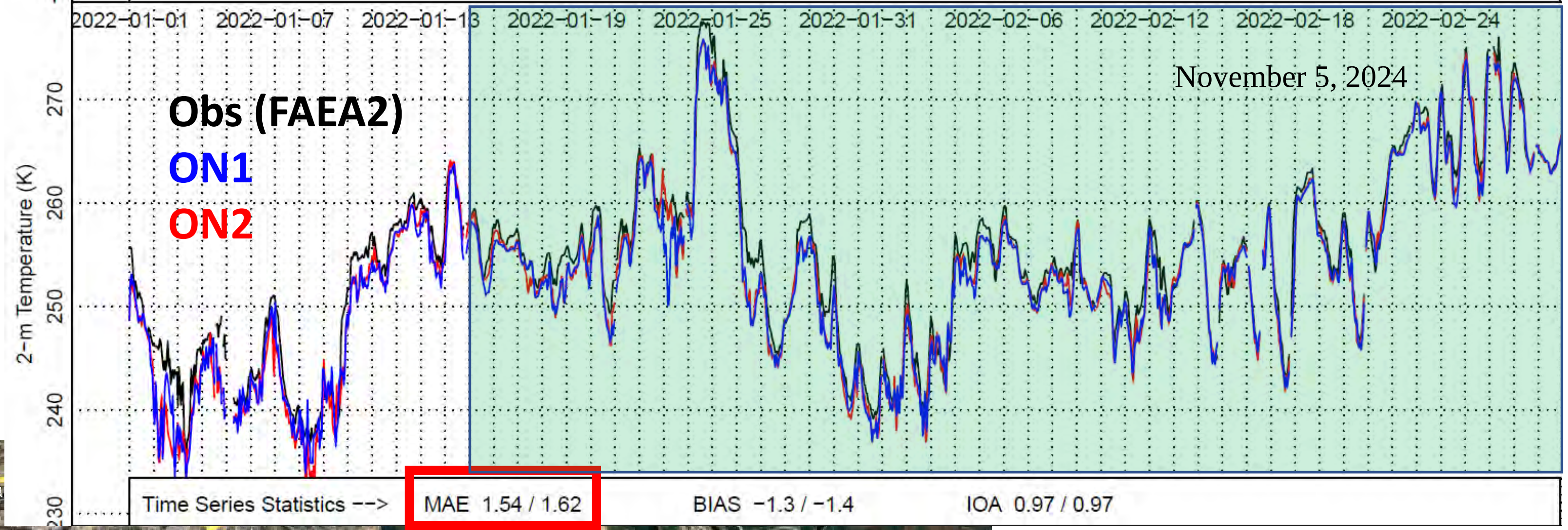
WRF configuration was based on a Feb 2008 case study & more recent Ramboll testing

Gaudet, B., Stauffer, D., Seaman, N., Deng, A., Schere, K., Gilliam, R., Pleim, J. and Elleman, R., 18.1 MODELING EXTREMELY COLD STABLE BOUNDARY LAYERS OVER INTERIOR ALASKA USING A WRF FDDA SYSTEM. AMS 13th Conf. Mesoscale Processes, Salt Lake City, UT, Aug 17-20, 2009.

Adopted

November 5, 2024

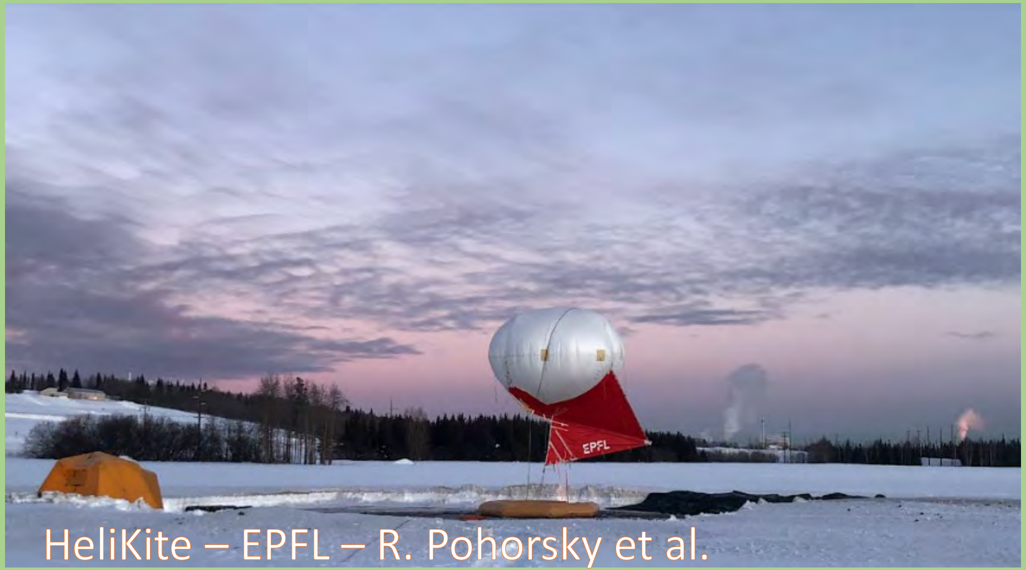
2-m Temperature RMSE
(Jan 1-Feb 28, 2022)



Best WRF performance @FAEA2

RMSE = 2.16 K
MAE = 1.54 K
BIAS = -1.3 K
IOA = 0.97


Alaska DEC – Hurst Rd


HeliKite – EPFL – R. Pohorsky et al.


Wind LIDAR – LPCA/ULCO

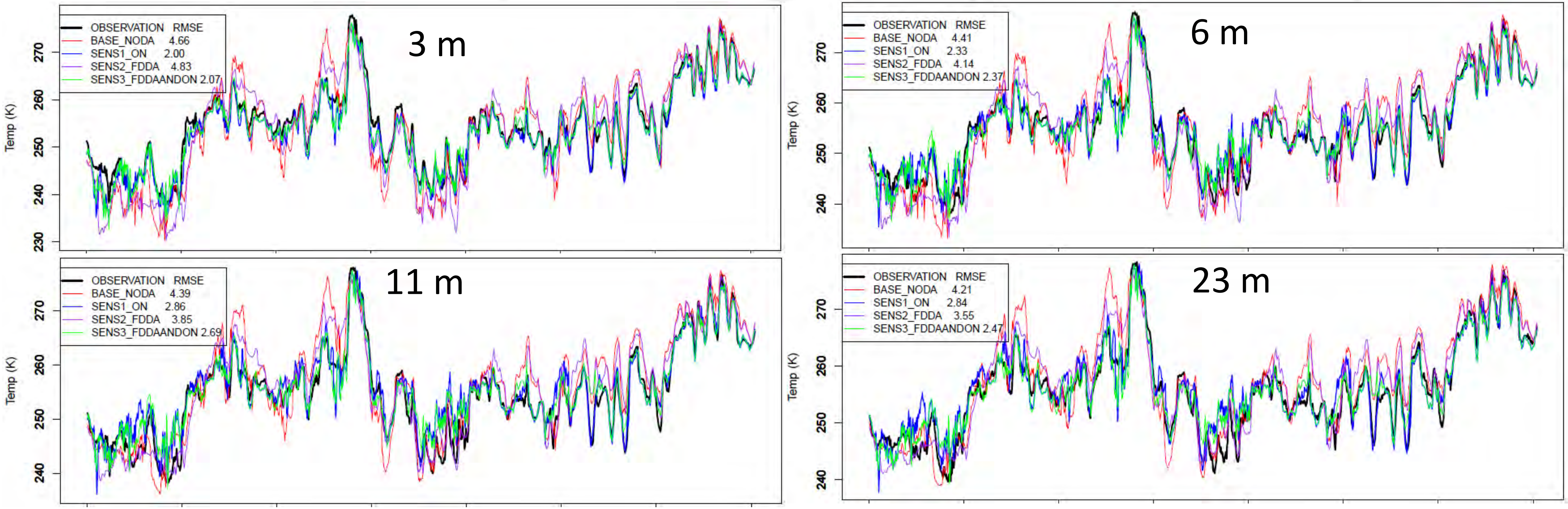
Evaluation of WRF using independent ALPACA field data


CTC site – UAF

WRF Sensitivity Experiments

- No data assimilation on the nested 1.33 km grid. FDDA was used on the 4 km parent grid **(BASE_NODA)**
- Observation nudging on the 1.33 km grid using standard NOAA observations and local mesonet measurements + PAFA sounding twice daily **(SENS1_ON)**
- Grid nudging on the 1.33 km grid similar as the parent 4 km grid. Grid nudging or four-dimensional data assimilation is done using global GFS analyses every 3 hours and applied only above the planetary boundary layer on both domains **(SENS2_FDDA)**
- FDDA like above with observation nudging **(SENS3 FDDAANDON)**

WRF Temperature @ CTC (Jan-Feb 2022)



GREEN -- Lowest Error

BLUE -- 2nd Lowest Error

YELLOW -- 2nd Highest Error

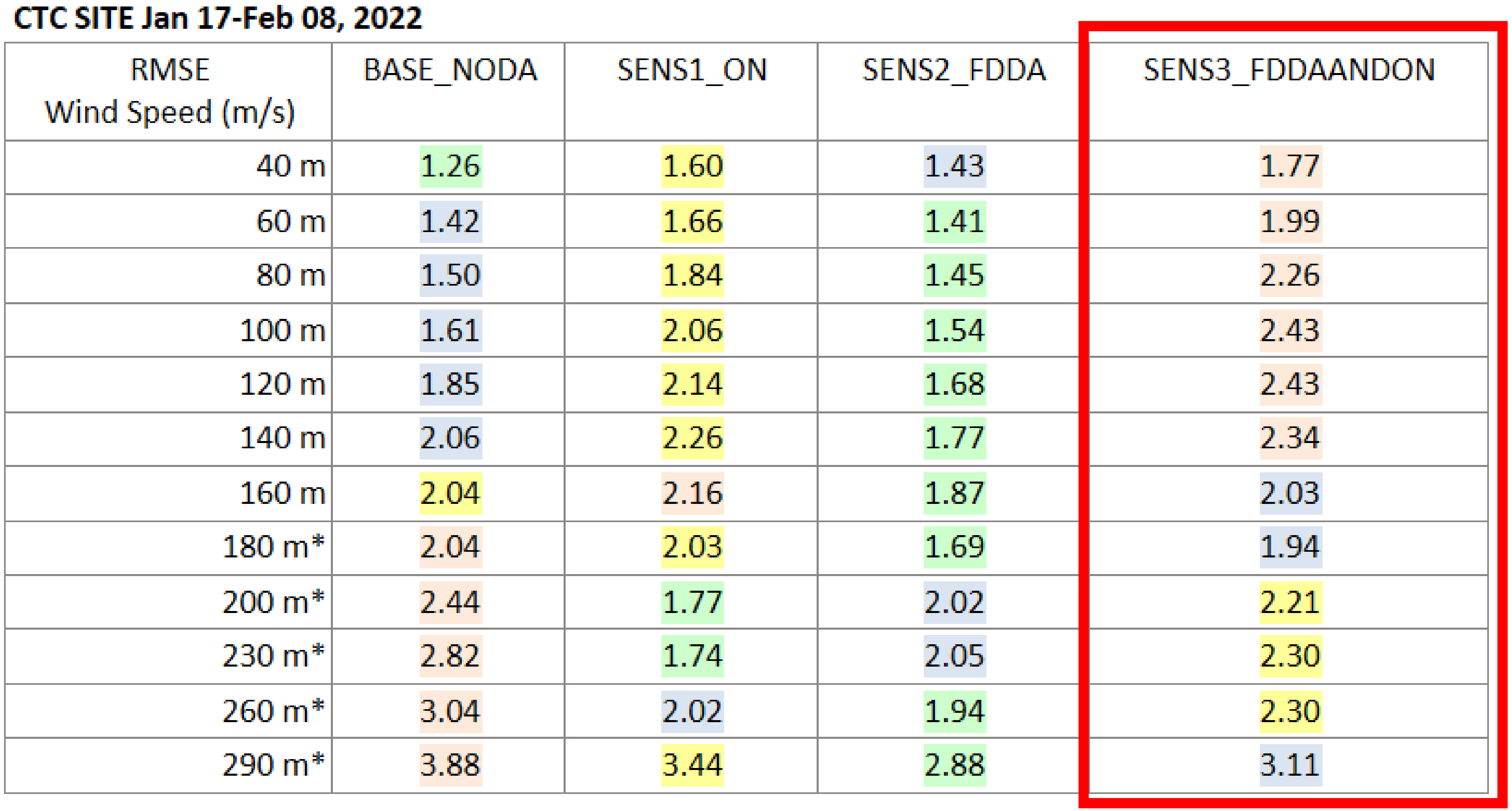
PEACH -- Highest Error

Temperature RMSE (K)	CTC	CTC	CTC	CTC	A-ST	A-ST	NCORE	NCORE	HURST	HURST	HURST	AVG
Simulation	3m	6m	11m	23m	3m	10m	3m	10m	3m	10m	23m	
BASE_NODA	4.66	4.41	4.39	4.21	4.64	4.74	4.81	4.80	5.34	4.80	4.60	**4.67**
SENS1_ON	2.00	2.33	2.86	2.84	1.99	3.73	1.71	3.13	2.73	3.11	2.83	**2.66**
SENS2_FDDA	4.83	4.14	3.85	3.55	4.51	4.09	4.57	4.08	6.42	5.05	4.47	**4.51**
SENS3_FDDAANDON	2.07	2.37	2.69	2.47	2.08	3.34	1.83	2.86	2.98	3.09	2.78	**2.60**

WRF Wind Profiles vs. Independent LIDAR CTC Site (Jan 17- Feb 08, 2022)

GREEN -- Lowest Error
BLUE -- 2nd Lowest Error
YELLOW -- 2nd Highest Error
PEACH -- Highest Error

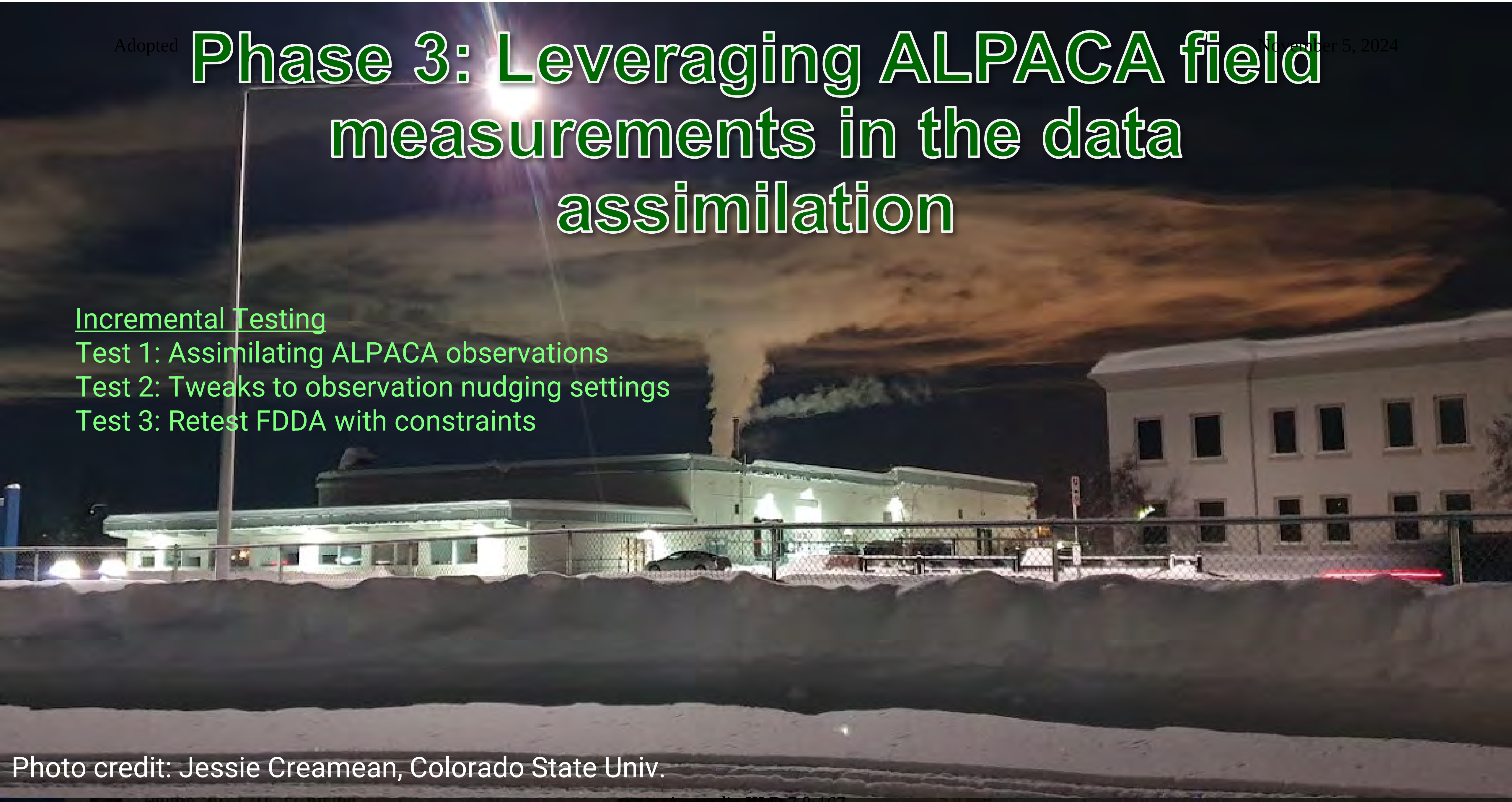
- FDDA only generally results in the lowest wind speed error
- ON and FDDAANDON configs increase error… in some cases substantially
- NODA has lower error than the ON and FDDAANDON sensitivities below ~200 m



CTC SITE Jan 17-Feb 08, 2022

RMSE Wind Speed (m/s)	BASE_NODA	SENS1_ON	SENS2_FDDA	SENS3_FDDAANDON
40 m	1.26	1.60	1.43	1.77
60 m	1.42	1.66	1.41	1.99
80 m	1.50	1.84	1.45	2.26
100 m	1.61	2.06	1.54	2.43
120 m	1.85	2.14	1.68	2.43
140 m	2.06	2.26	1.77	2.34
160 m	2.04	2.16	1.87	2.03
180 m*	2.04	2.03	1.69	1.94
200 m*	2.44	1.77	2.02	2.21
230 m*	2.82	1.74	2.05	2.30
260 m*	3.04	2.02	1.94	2.30
290 m*	3.88	3.44	2.88	3.11

Phase 3: Leveraging ALPACA field measurements in the data assimilation



Incremental Testing

Test 1: Assimilating ALPACA observations

Test 2: Tweaks to observation nudging settings

Test 3: Retest FDDA with constraints

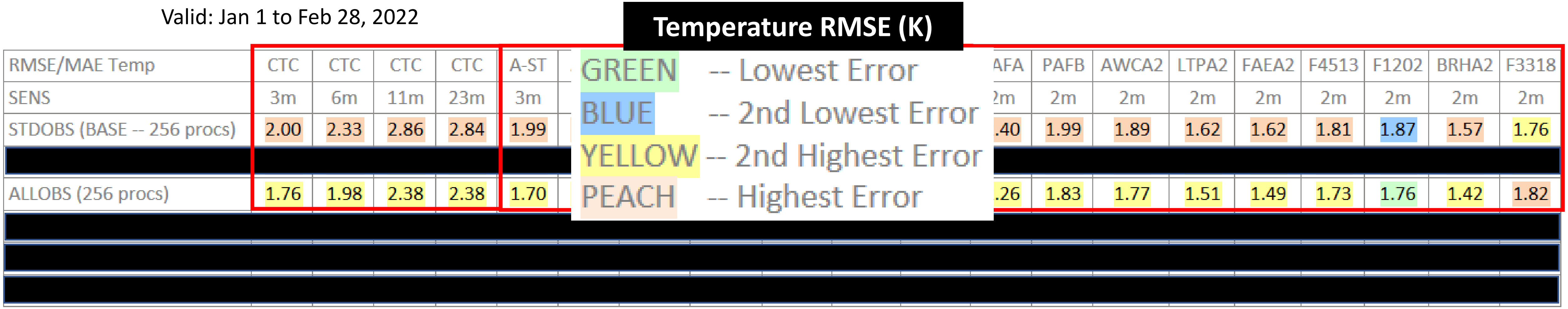
Photo credit: Jessie Creamean, Colorado State Univ.

Test 1: Assimilating ALPACA Observations

Standard Obs Nudging (STDOBS)
Standard + ALPACA Obs (ALLOBS)
Valid: Jan 1 to Feb 28, 2022

The comparison below of temperature and wind error at each observation site in Fairbanks tests the impact of adding ALPACA field measurements (CTC, ADEC and Wind LIDAR) to the observation nudging input file.

Temperature RMSE (K)



RMSE/MAE Temp	CTC	CTC	CTC	CTC	A-ST	AFA	PAFB	AWCA2	LTPA2	FAEA2	F4513	F1202	BRHA2	F3318
SENS	3m	6m	11m	23m	3m	m	2m	2m	2m	2m	2m	2m	2m	2m
STDOBS (BASE -- 256 procs)	2.00	2.33	2.86	2.84	1.99	.40	1.99	1.89	1.62	1.62	1.81	1.87	1.57	1.76
[redacted]														
ALLOBS (256 procs)	1.76	1.98	2.38	2.38	1.70	.26	1.83	1.77	1.51	1.49	1.73	1.76	1.42	1.82
[redacted]														
[redacted]														
[redacted]														

GREEN -- Lowest Error
BLUE -- 2nd Lowest Error
YELLOW -- 2nd Highest Error
PEACH -- Highest Error

Wind Speed Error (MAE – m/s)

MAE WS	PAFA	PAFB	AWCA2	LTPA2	FAEA2	F4513	BRHA2
SENS	10m	10m	10m	10m	10m	10m	10m
STDOBS (BASE -- 256 procs)	1.12	1.78	1.55	2.09	2.21	3.27	1.98
[redacted]							
ALLOBS (256 procs)	1.11	1.74	1.54	2.10	2.16	3.12	1.74
[redacted]							
[redacted]							
[redacted]							

Wind Direction Error (MAE -- deg)

MAE WD	PAFA	PAFB	AWCA2	LTPA2	FAEA2	F4513	BRHA2
SENS	10m	10m	10m	10m	10m	10m	10m
STDOBS (BASE -- 256 procs)	37	43	59	45	118	34	65
[redacted]							
ALLOBS (256 procs)	35	43	58	46	123	39	64
[redacted]							
[redacted]							
[redacted]							

Wind sample sizes are highly variable because of frequent calm reports

Test 2: Alternative Obs Nudging Settings

Standard + ALPACA Obs (ALLOBS)
Obs nudging settings (ALLOBS TWEAKS)
Valid: Jan 1 to Feb 28, 2022

The comparison below tests the impact of “tweaks” to the observation nudging impact model error. Tweaks include (1) Alternative vertical spreading of nudging term, (2) limit vertical extent of nudging at 50 m AGL instead of default 200 m and (3) larger time window and (4) cast 3m temperature obs as surface-base 2m obs

Temperature RMSE (K)

GREEN -- Lowest Error
BLUE -- 2nd Lowest Error
YELLOW -- 2nd Highest Error
PEACH -- Highest Error

RMSE/MAE Temp	CTC	CTC	CTC	CTC	A-ST							AFA	PAFB	AWCA2	LTPA2	FAEA2	F4513	F1202	BRHA2	F3318
SENS	3m	6m	11m	23m	3m							2m	2m	2m	2m	2m	2m	2m	2m	2m
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]							[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]							[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
ALLOBS (256 procs)	1.76	1.98	2.38	2.38	1.70							.26	1.83	1.77	1.51	1.49	1.73	1.76	1.42	1.82
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
ALLOBS TWEAKS (256 procs)	1.64	1.66	1.79	1.86	1.48	2.37	1.43	2.07	2.35	1.77	1.53	2.12	1.73	1.62	1.38	1.36	1.59	2.01	1.45	1.59
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Wind Speed Error (MAE – m/s)

MAE WS	PAFA	PAFB	AWCA2	LTPA2	FAEA2	F4513	BRHA2
SENS	10m	10m	10m	10m	10m	10m	10m
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
ALLOBS (256 procs)	1.11	1.74	1.54	2.10	2.16	3.12	1.74
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
ALLOBS TWEAKS (256 procs)	1.17	1.72	1.59	2.28	2.25	3.44	1.55
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Wind Direction Error (MAE -- deg)

MAE WD	PAFA	PAFB	AWCA2	LTPA2	FAEA2	F4513	BRHA2
SENS	10m	10m	10m	10m	10m	10m	10m
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
ALLOBS (256 procs)	35	43	58	46	123	39	64
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
ALLOBS TWEAKS (256 procs)	38	50	60	46	119	42	67
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Test 3: FDDA/Grid Nudging with Contraints

Obs nudging settings (TWEAKS)
Tweaks + FDDA (TWEAKS FDDA9)
Valid: Jan 1 to Feb 28, 2022

This tests FDDA/Grid nudging in addition to Obs Nudging on model levels above level 9 (~ 300 m) or above the PBL if higher than level 9.

Temperature RMSE (K)

GREEN -- Lowest Error
BLUE -- 2nd Lowest Error
YELLOW -- 2nd Highest Error
PEACH -- Highest Error

RMSE/MAE Temp	CTC	CTC	CTC	CTC	A-ST							AFA	PAFB	AWCA2	LTPA2	FAEA2	F4513	F1202	BRHA2	F3318
SENS	3m	6m	11m	23m	3m							m	2m	2m	2m	2m	2m	2m	2m	2m
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]							[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]							[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]							[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
ALLOBS TWEAKS (256 procs)	1.64	1.66	1.79	1.86	1.48	2.37	1.43	2.07	2.35	1.77	1.53	2.12	1.73	1.62	1.38	1.36	1.59	2.01	1.45	1.59
ALLOBS TWEAKS FDDA9	1.68	1.52	1.46	1.54	1.50	2.07	1.40	1.72	2.32	1.76	1.42	2.03	1.73	1.62	1.41	1.35	1.58	2.11	1.46	1.63

Wind Speed Error (MAE – m/s)

MAE WS	PAFA	PAFB	AWCA2	LTPA2	FAEA2	F4513	BRHA2
SENS	10m	10m	10m	10m	10m	10m	10m
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
ALLOBS TWEAKS (256 procs)	1.17	1.72	1.59	2.28	2.25	3.44	1.55
ALLOBS TWEAKS FDDA9	1.12	1.79	1.58	2.34	2.36	3.79	1.67

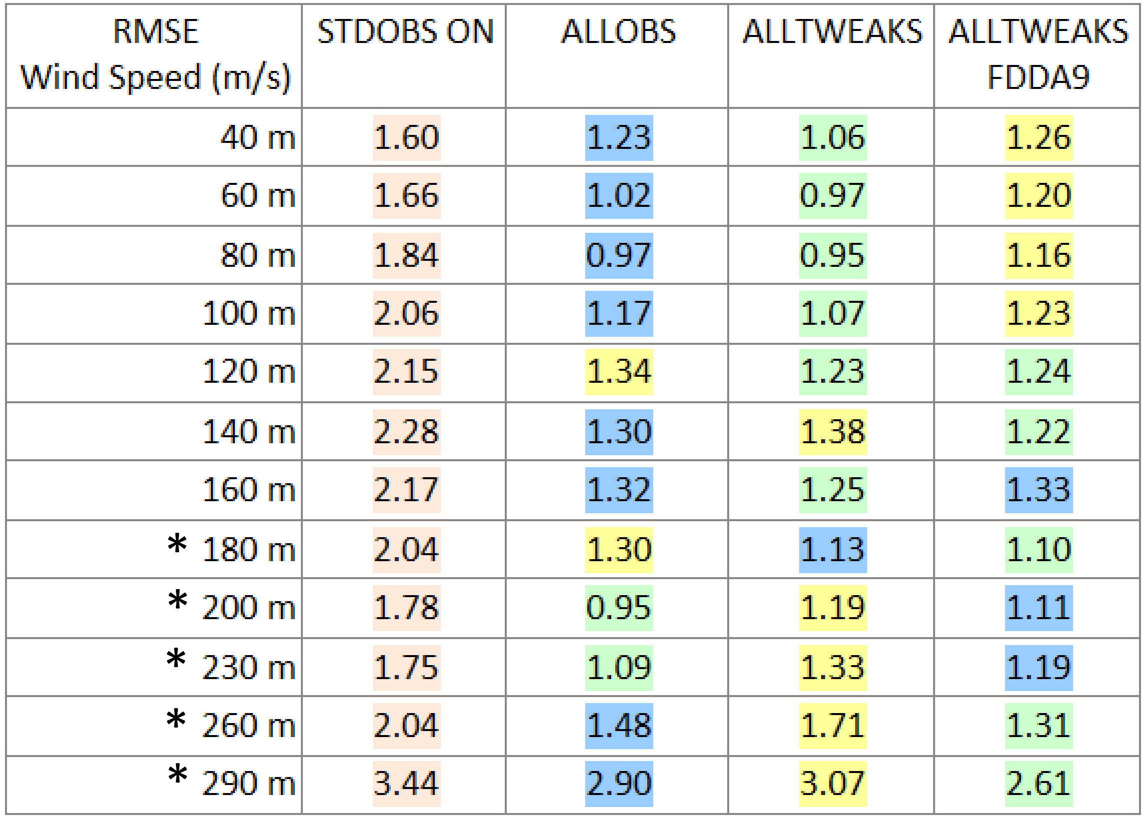
Wind Direction Error (MAE -- deg)

MAE WD	PAFA	PAFB	AWCA2	LTPA2	FAEA2	F4513	BRHA2
SENS	10m	10m	10m	10m	10m	10m	10m
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
ALLOBS TWEAKS (256 procs)	38	50	60	46	119	42	67
ALLOBS TWEAKS FDDA9	36	35	58	53	127	26	63

Evaluation using CTC & FARM LIDAR Wind

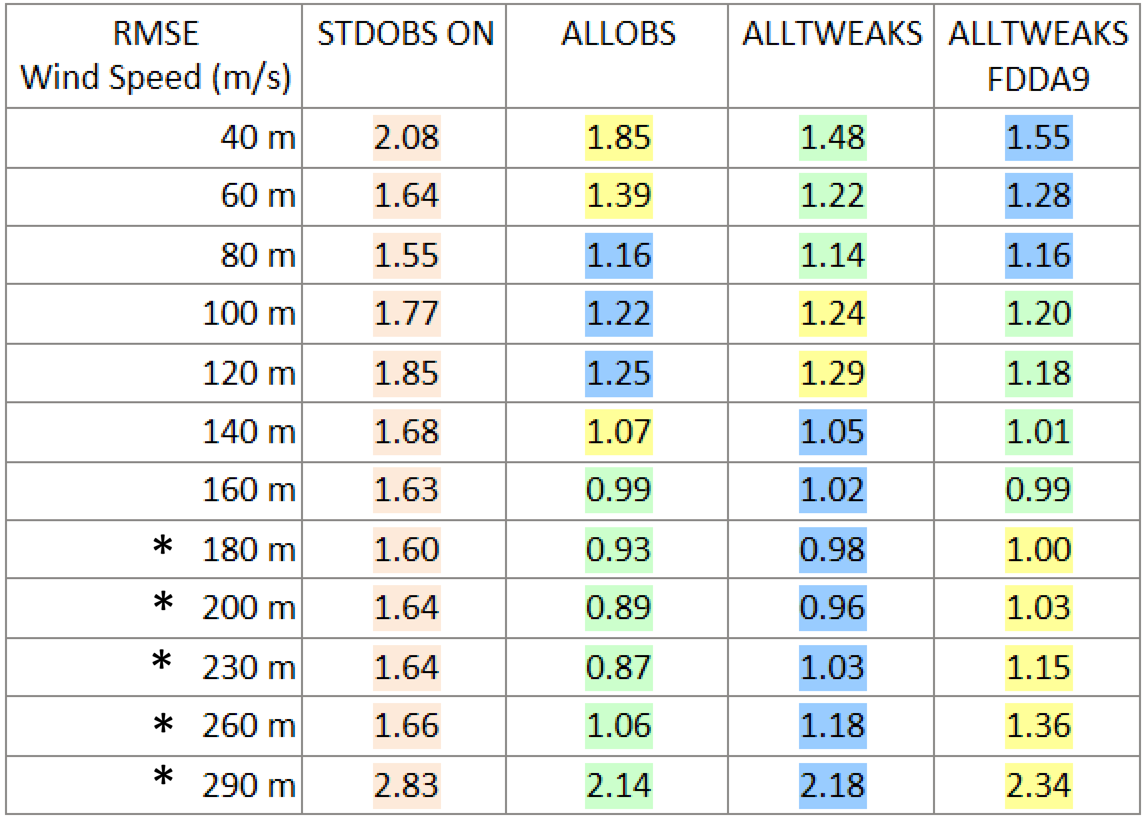
*Wind sample size (hourly) is significantly smaller above 160 m

CTC SITE Jan 17-Feb 08, 2022



RMSE Wind Speed (m/s)	STDOBS ON	ALLOBS	ALLTWEAKS	ALLTWEAKS FDDA9
40 m	1.60	1.23	1.06	1.26
60 m	1.66	1.02	0.97	1.20
80 m	1.84	0.97	0.95	1.16
100 m	2.06	1.17	1.07	1.23
120 m	2.15	1.34	1.23	1.24
140 m	2.28	1.30	1.38	1.22
160 m	2.17	1.32	1.25	1.33
* 180 m	2.04	1.30	1.13	1.10
* 200 m	1.78	0.95	1.19	1.11
* 230 m	1.75	1.09	1.33	1.19
* 260 m	2.04	1.48	1.71	1.31
* 290 m	3.44	2.90	3.07	2.61

FARM SITE Feb 10-28, 2022



RMSE Wind Speed (m/s)	STDOBS ON	ALLOBS	ALLTWEAKS	ALLTWEAKS FDDA9
40 m	2.08	1.85	1.48	1.55
60 m	1.64	1.39	1.22	1.28
80 m	1.55	1.16	1.14	1.16
100 m	1.77	1.22	1.24	1.20
120 m	1.85	1.25	1.29	1.18
140 m	1.68	1.07	1.05	1.01
160 m	1.63	0.99	1.02	0.99
* 180 m	1.60	0.93	0.98	1.00
* 200 m	1.64	0.89	0.96	1.03
* 230 m	1.64	0.87	1.03	1.15
* 260 m	1.66	1.06	1.18	1.36
* 290 m	2.83	2.14	2.18	2.34

GREEN -- Lowest Error
BLUE -- 2nd Lowest Error
YELLOW -- 2nd Highest Error
PEACH -- Highest Error

- Assimilation of LIDAR is working – significant decrease in errors from approx. 2 to 1 m/s
- Obs nudging “TWEAKS” help reduce error slightly
- FDDA9 impact is mixed – either does not degrade wind error much or improves slightly

Using knowledge gained from ALPACA for the 2019-2020 modeling period

Key Observation Sites in/around Fairbanks

ADEC

Mesonet

NOAA

Initial Simulation

- Inputs were developed independently using GFS ~25 km analyses (Ramboll used ERA)
- No 12 km parent domain.
- Nov 15-30 spinup for snow cover and surface fields
- Final ALPACA WRF configuration
- ADEC observation nudging files (5.5 day concatenated to full period)

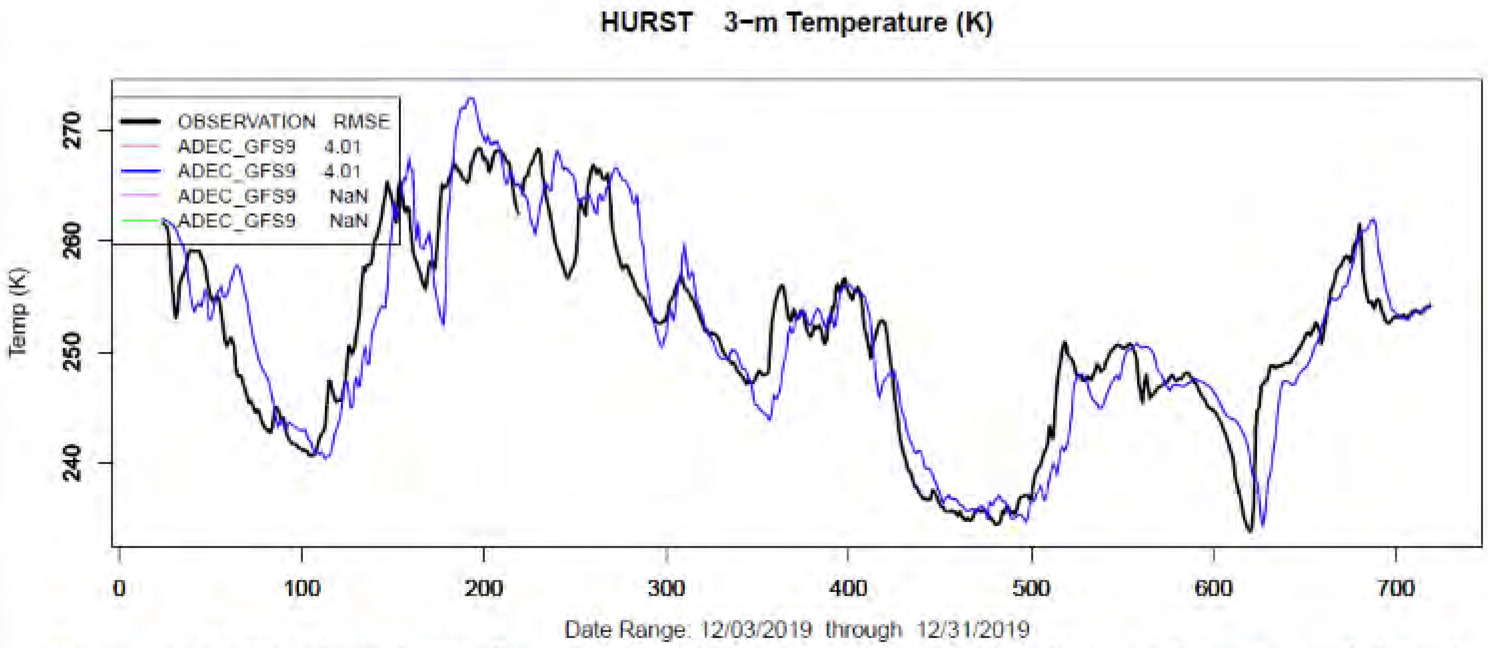
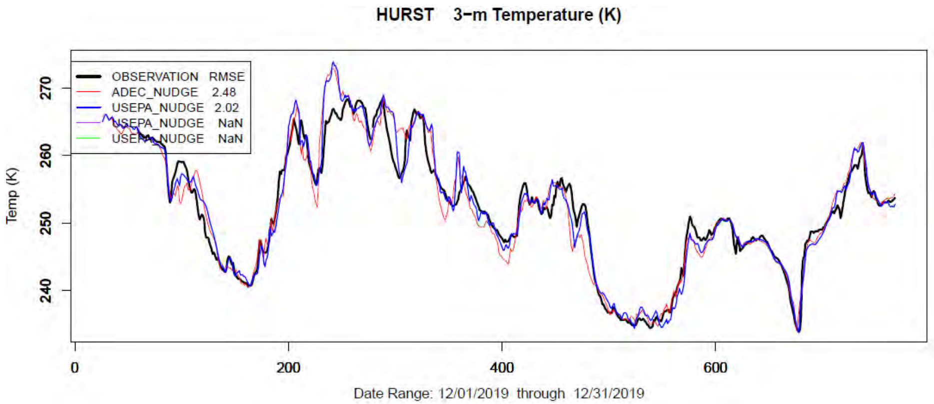
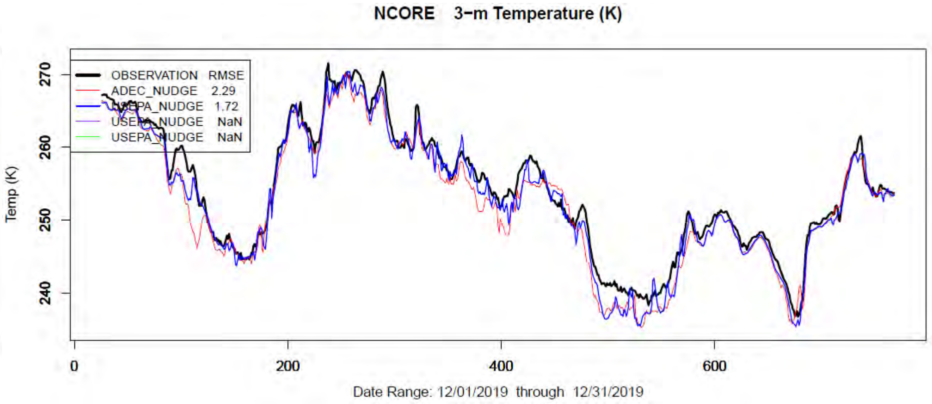


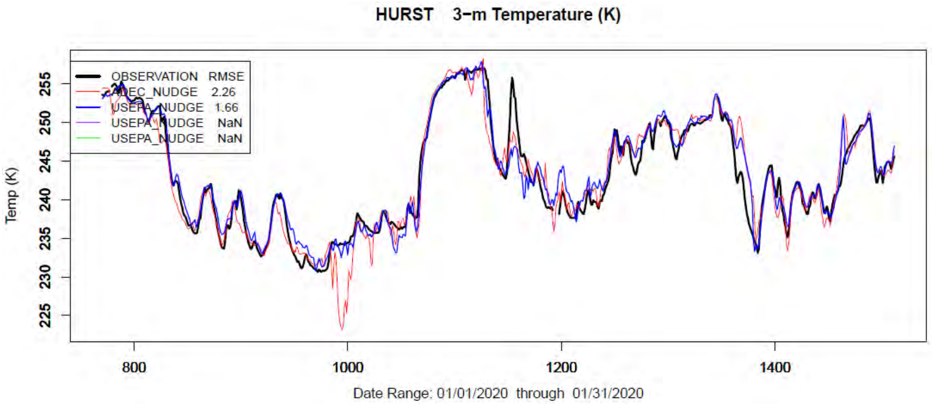
Figure 2: US EPA domain configuration with 4 km outer domain with a 1.33 km nested domain centered over Fairbanks, AK.

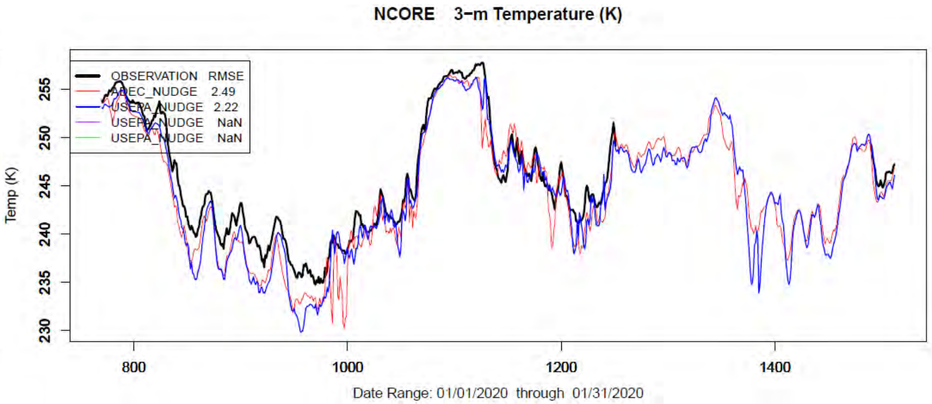
Offline R script that reads WRF and Hurt obs showed an odd phase shift in the temperature time series

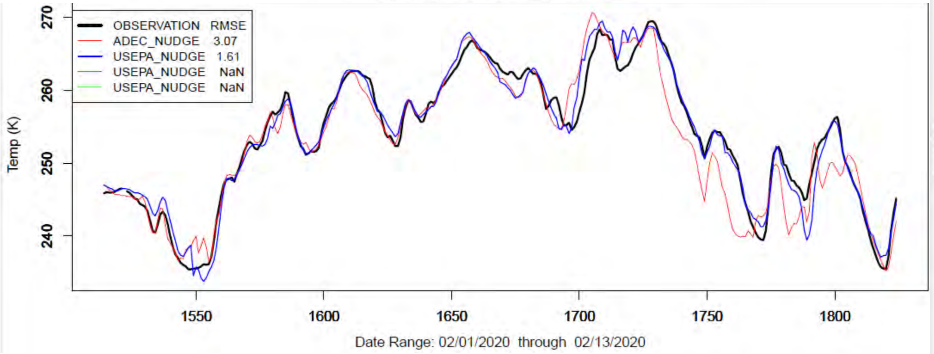
Final Simulations

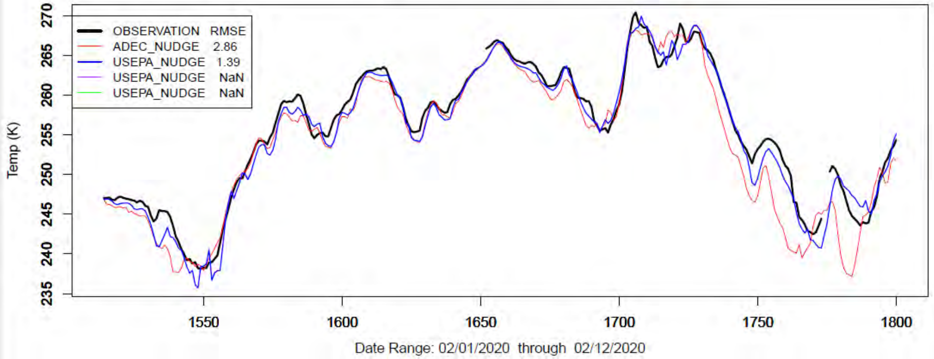












Final Simulation

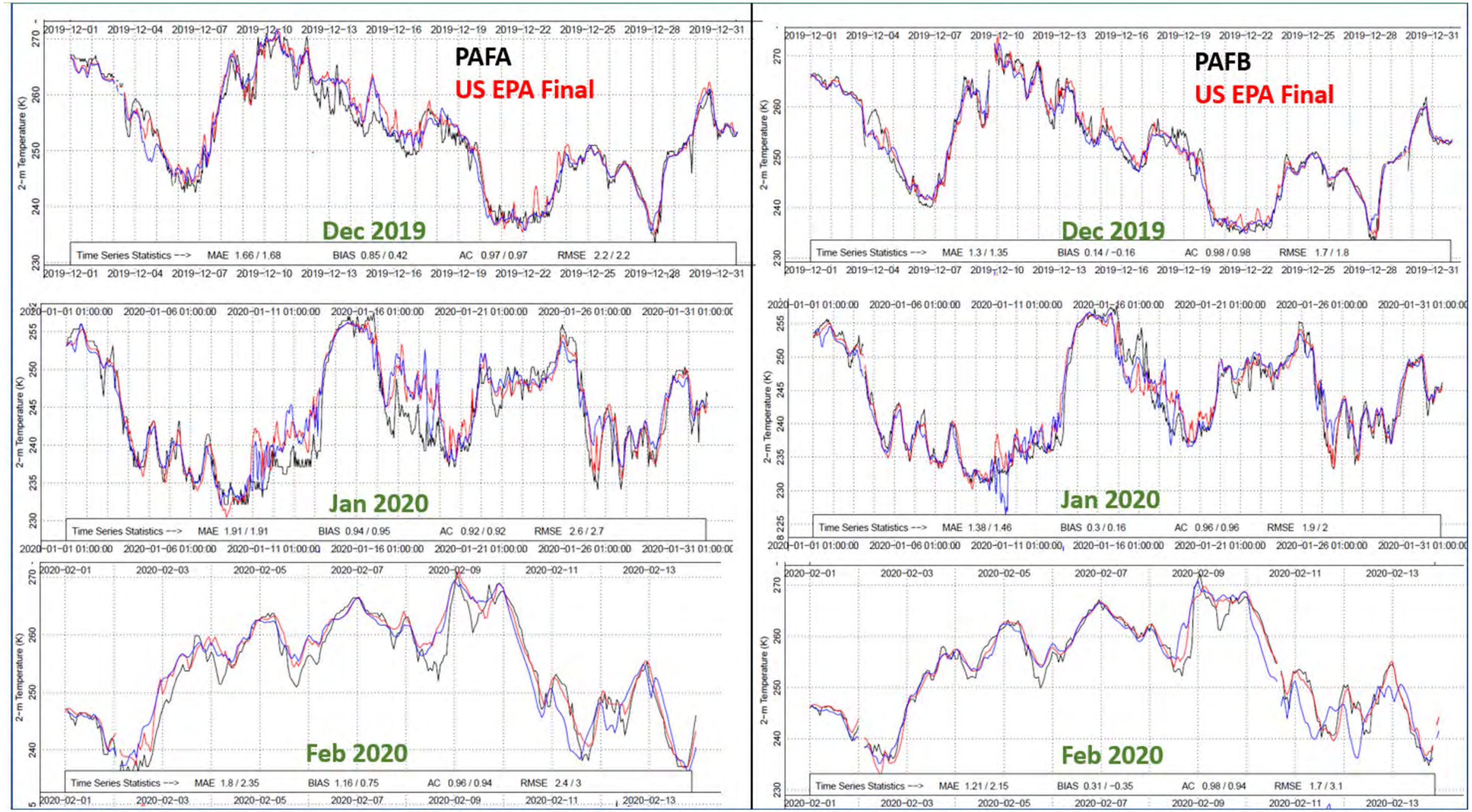


Figure 10: Temperature timeseries at PAFA (left - black) and PAFB (right - black) for the full modeling period along with the US EPA final simulation (red).

Final Simulation

Table 1: WRF RMSE of 2-m temperature at key observation sites around Fairbanks. ADEC values are based on the 2021 Ramboll report. USEPA is the best US EPA simulation with corrections to observation nudging files and updated configuration.

2-m Temp RMSE	ADEC	USEPA	ADEC	USEPA	ADEC	USEPA
	Dec	Dec	Jan	Jan	Feb	Feb
PAFA	4.38/3.55	2.20	4.70/3.84	2.60	4.41/3.56	2.40
PAFB	2.77/2.41	1.70	3.09/2.56	1.90	2.82/2.73	1.70
PAEI	2.68/2.57	2.40	2.94/2.13	2.20	3.36/3.03	2.70
ASTREET (10m)	1.54	NA/2.54	1.39	2.63	2.15	1.90
NCORE (3/10m)	1.23	1.72/2.09	1.32	2.22/2.69	2.00	1.39
HURST (3/10/23m)	2.34	2.02/1.96/1.96	2.39	1.66/1.52/1.40	2.66	1.65/1.48/1.32
BRHA2	X	1.70	X	1.90	X	2.00
FAEA2	X	2.30	X	2.10	X	1.60
AWCA2*	X	2.80*	X	X	X	X
LTPA2	X	2.10	X	2.10	X	2.30*
F4513	X	1.90	X	2.10	X	1.70
F3318	X	1.90	X	1.90	X	1.60

Final Simulation

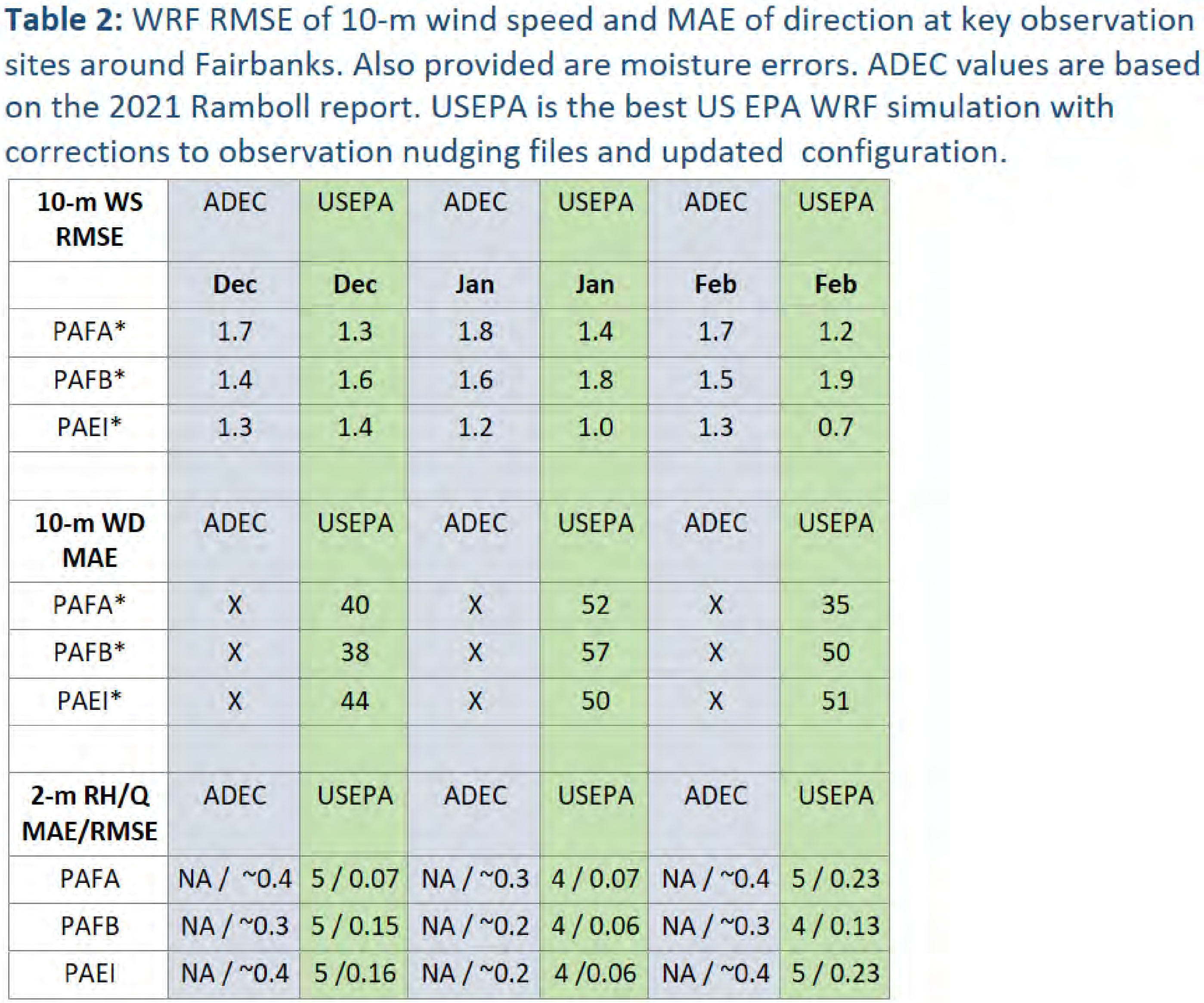
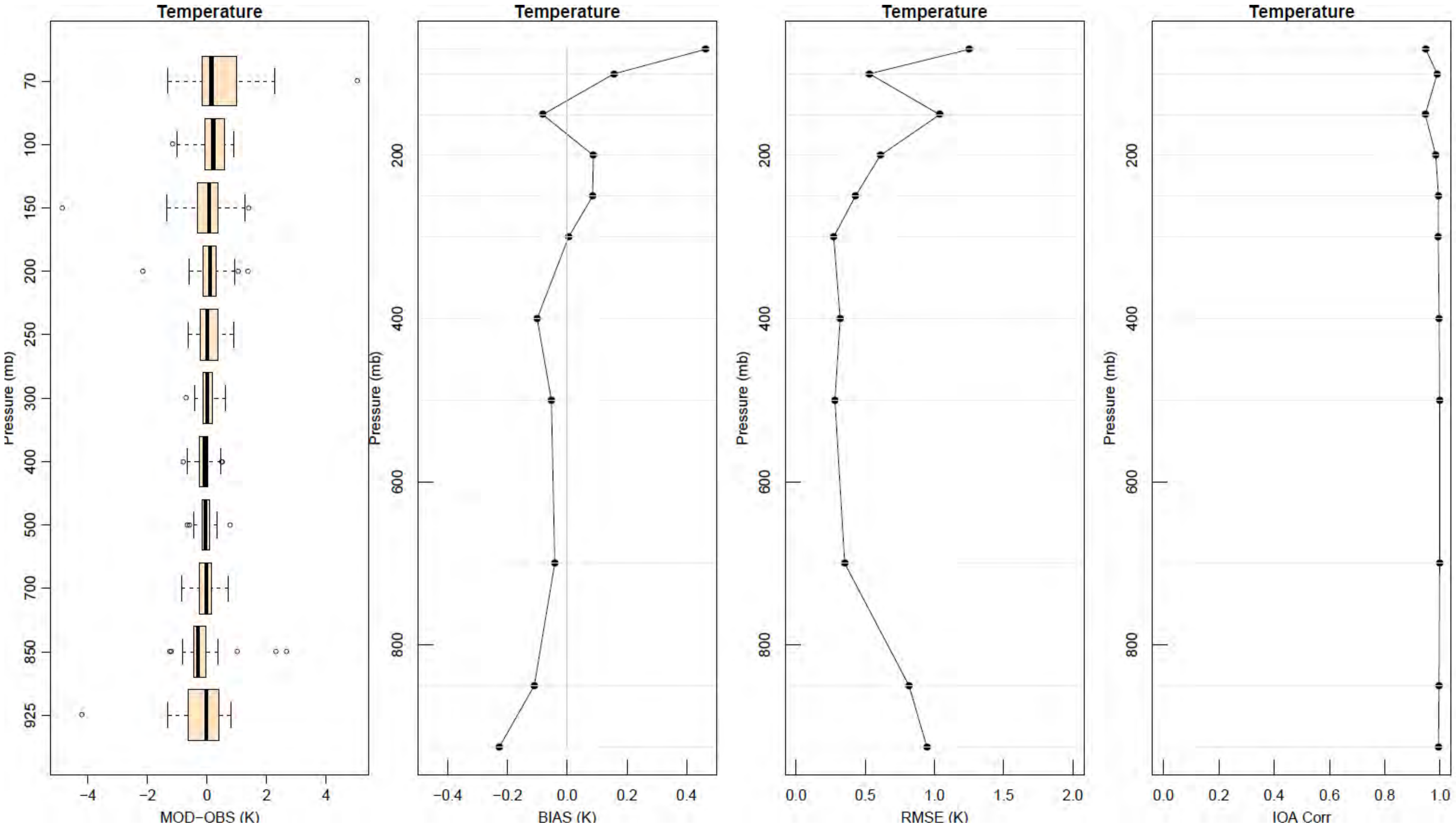


Table 2: WRF RMSE of 10-m wind speed and MAE of direction at key observation sites around Fairbanks. Also provided are moisture errors. ADEC values are based on the 2021 Ramboll report. USEPA is the best US EPA WRF simulation with corrections to observation nudging files and updated configuration.

10-m WS RMSE	ADEC	USEPA	ADEC	USEPA	ADEC	USEPA
	Dec	**Dec**	**Jan**	**Jan**	**Feb**	**Feb**
PAFA*	1.7	1.3	1.8	1.4	1.7	1.2
PAFB*	1.4	1.6	1.6	1.8	1.5	1.9
PAEI*	1.3	1.4	1.2	1.0	1.3	0.7
10-m WD MAE	ADEC	USEPA	ADEC	USEPA	ADEC	USEPA
PAFA*	X	40	X	52	X	35
PAFB*	X	38	X	57	X	50
PAEI*	X	44	X	50	X	51
2-m RH/Q MAE/RMSE	ADEC	USEPA	ADEC	USEPA	ADEC	USEPA
PAFA	NA / ~0.4	5 / 0.07	NA / ~0.3	4 / 0.07	NA / ~0.4	5 / 0.23
PAFB	NA / ~0.3	5 / 0.15	NA / ~0.2	4 / 0.06	NA / ~0.3	4 / 0.13
PAEI	NA / ~0.4	5 /0.16	NA / ~0.2	4 /0.06	NA / ~0.4	5 / 0.23

Final Simulation



Temperature profile statistics for the Dec-Feb modeling period at PAFA. Tiles include the distribution of temperature difference (mod-obs), model bias, error (RMSE) and index of agreement.

Notes on Obs Nudging, ETC

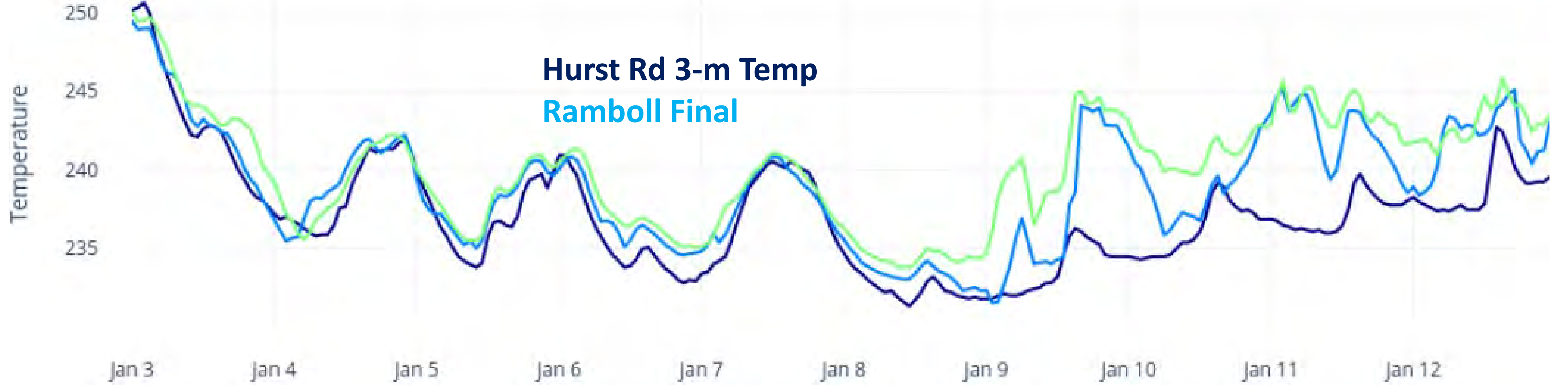
- Observational nudging breaks when WRF is restarted
- Observational nudging files should not have any overlapping times like concatenating 5.5 day Obs nudging files for a long simulation
- Obsgrid only outputs 99 hours of obs nudging files in a single run. So we run daily in a loop over a period.
- Hourly obs are concatenated in a single daily obs nudging file.
- These can be concatenated into a single file for the period of the simulation, but the way Obsgrid runs from 00 UTC to 00 UTC, that last 00 hour for the next day is removed in the daily file.

Supplementary Slides

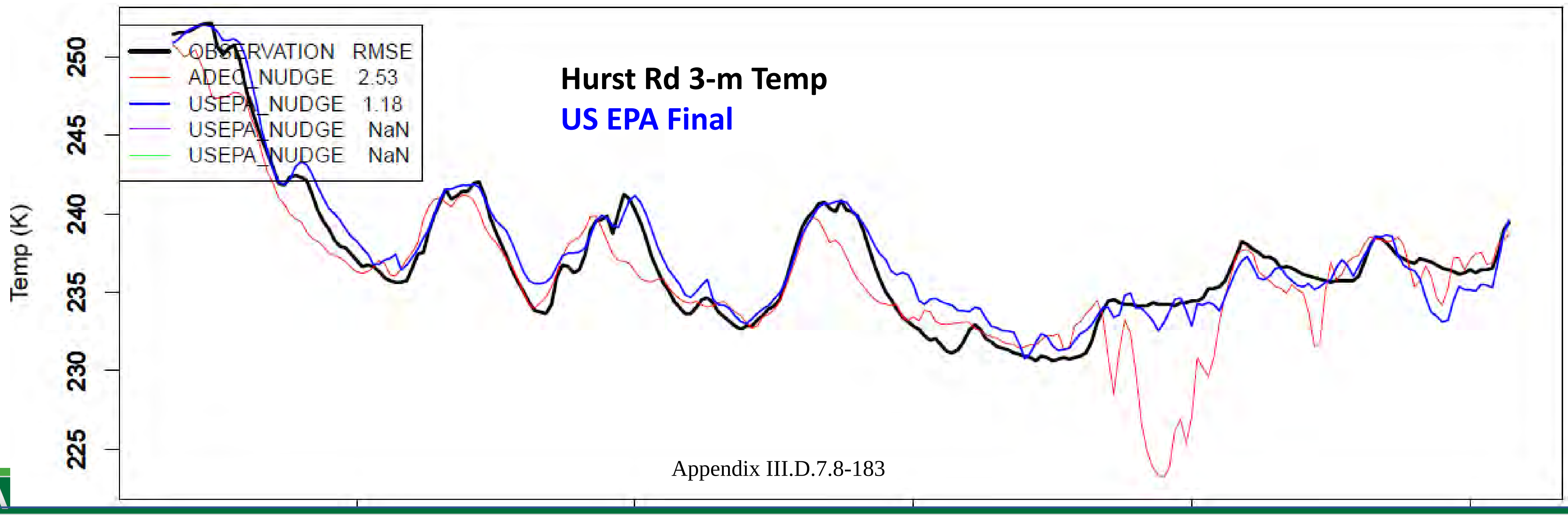
1. The contractors report has timeseries in local time. It appears WRF was adjusted to local time in their figure for Hurst above. ADEC and other observations were not converted to WRF UTC for the evaluation. Per contractor report Fig 6-15, PAFA reaches peak temp at 1200 Local time. So I assume everything in the report (PAFA sounding support this as well) is local time.

2. We went back and reexamined the observation nudging file provide to the US EPA by ADEC. It is assumed this file was used in The contractors nudging (file directory and name from tarball is 2020-01-04/ALL_OBS_DOMAIN301). We confirm that on Jan 7, the ADEC site Hurst Rd reached peak temperature at about 12 UTC per nudging file date/time. IN the same file the PAFA report reached a peak temperature about 9 hours later… 22-23 UTC. This a clear evidence the ADEC obs had a date/time 9 hours too early in the nudging file.

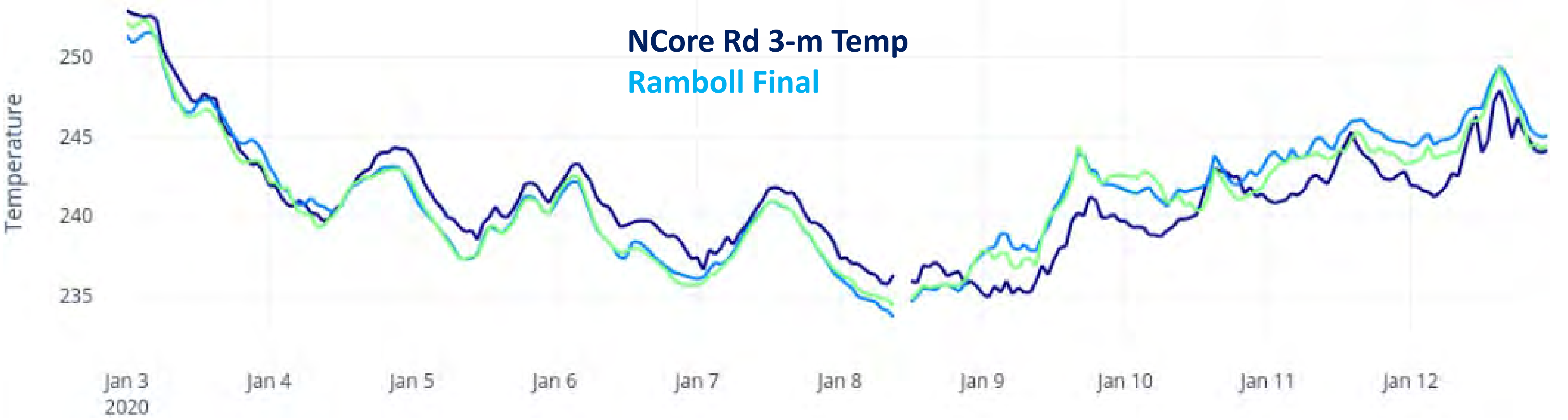
3. The big question in the contractors report is why does WRF agree with ADEC measurements relatively well. And in some cases, the error level lower than we see in almost all of our modeling if there were some flaws in the nudging file. The evidence above suggests that they adjusted WRF to local time. They adjusted NOAA obs like PAFA, PAFB and PAEI to local time for the evaluation. I'm not sure how METSTAT works, but ADEC obs were in local time. So it is theorized that the decent comparison of ADEC with WRF is because WRF was adjusted back to local time which would align WRF with ADEC obs in the nudging file. At PAFA for example, the Obs time and WRF were both moved back 9 hours to local time, so peak on Jan 7 and time series is correct in those figures (Fig 6-15). The problem is in WRF, the nudging of the 3 ADEC sites (Astreet, Ncore and Hurst) is still 9 hours early. One can imagine how it "shakes up" WRF. Midday in WRF for days with solar radiation for example would be warming, but grid cells impact by ADEC obs nudging would be pushed towards cooler temperatures of ADEC obs that have a bad time 9 hour in the future which would be at night in this example. Or, a rapid cool down after a front would be initiated early in WRF where ADEC sites have influence in terms of nudging. But other observations that are accurately represented in time would reflect be pre-frontal, warmer conditions. Essentially a really bad offset to the diurnal and synoptic temperature signal is likely in the Ramboll run near the surface. Aloft the model is not affected, so I suspect there are really poor representations of the temperature profiles of the lower atmosphere. This should have a direct negative impact on dispersion. This does not even get into any obs nudging of wind where transport would be impacted too.



Hurst Rd 3-m Temp
Ramboll Final

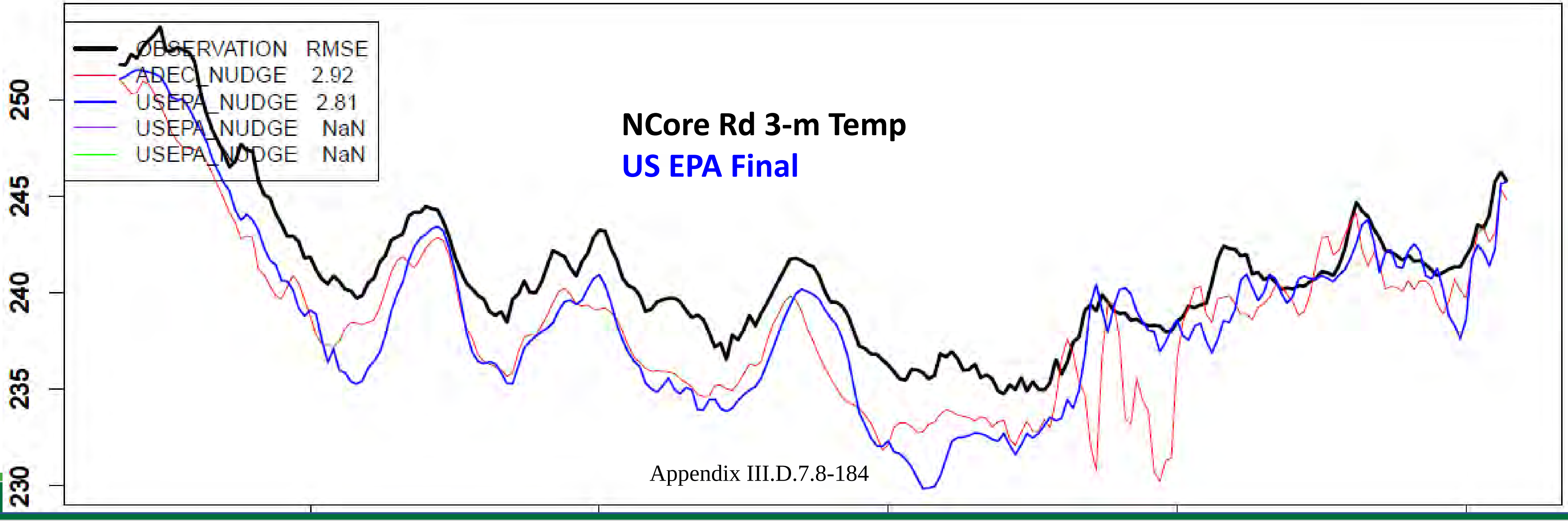


Hurst Rd 3-m Temp
US EPA Final



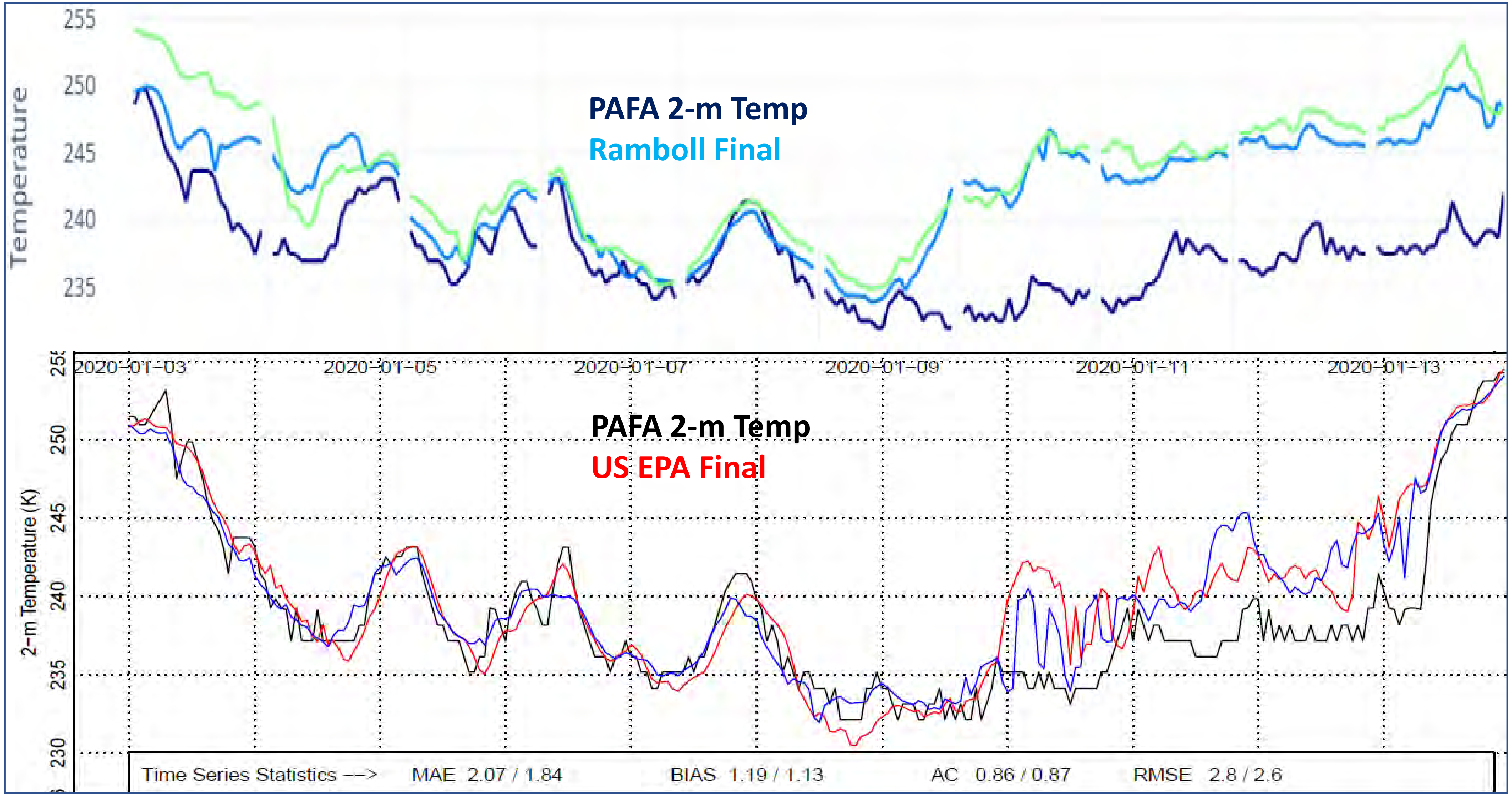
NCore Rd 3-m Temp

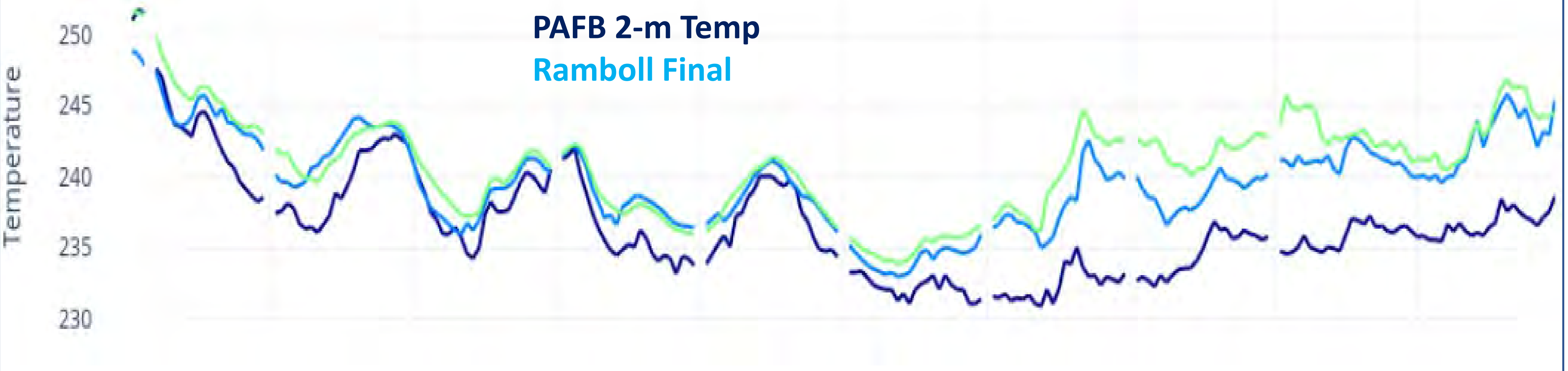
Ramboll Final



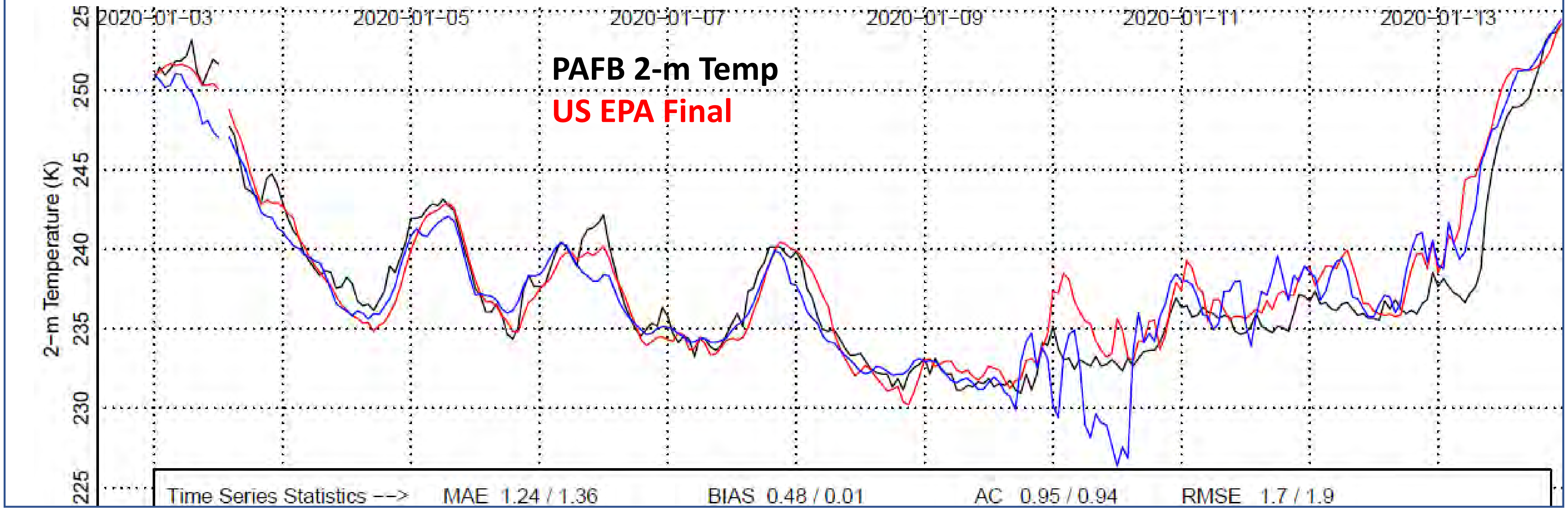
NCore Rd 3-m Temp

US EPA Final


255
250
245
240
235
Temperature
PAFA 2-m Temp
Ramboll Final
2020-01-03
2020-01-05
2020-01-07
2020-01-09
2020-01-11
2020-01-13
255
250
245
240
235
230
2-m Temperature (K)
PAFA 2-m Temp
US EPA Final
Time Series Statistics --> MAE 2.07 / 1.84 BIAS 1.19 / 1.13 AC 0.86 / 0.87 RMSE 2.8 / 2.6

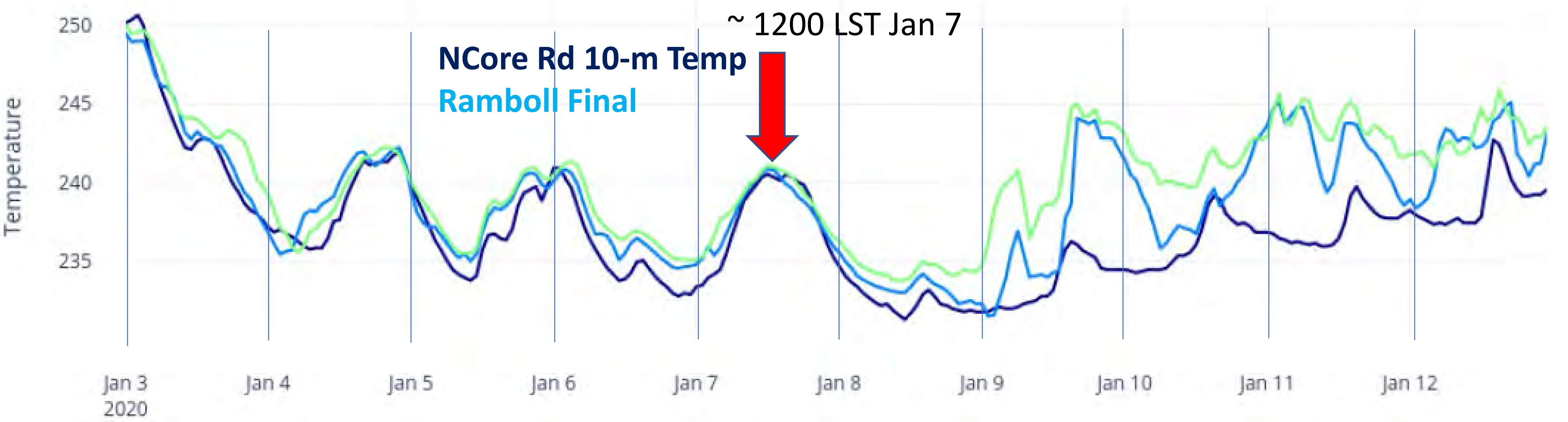


PAFB 2-m Temp
Ramboll Final



PAFB 2-m Temp
US EPA Final

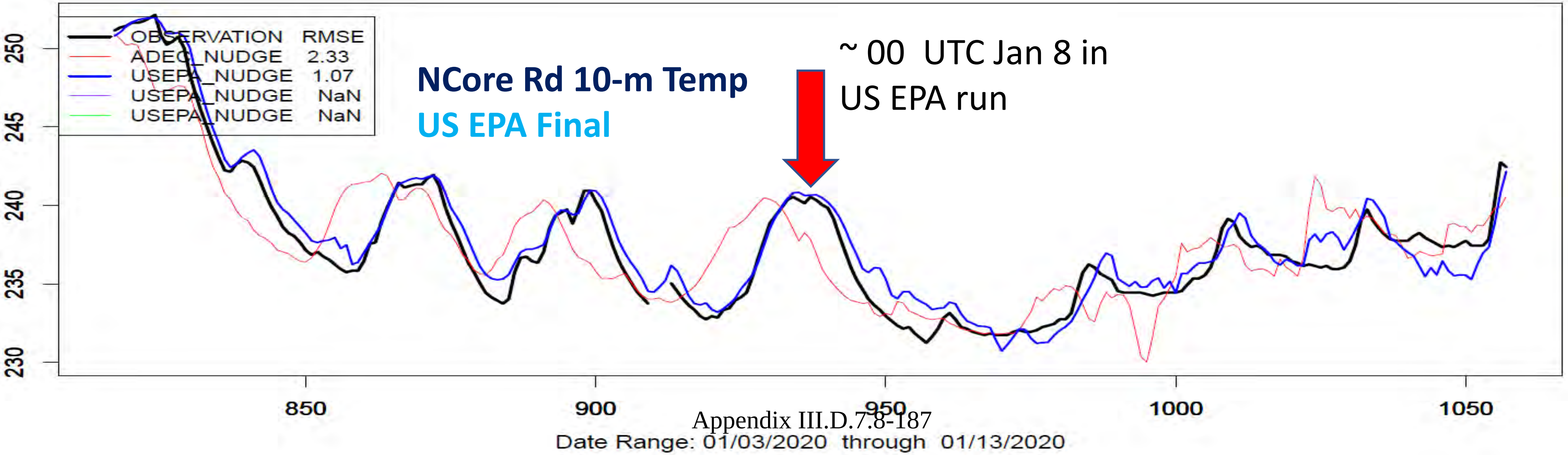
Time Series Statistics --> MAE 1.24 / 1.36 BIAS 0.48 / 0.01 AC 0.95 / 0.94 RMSE 1.7 / 1.9



NCore Rd 10-m Temp

Ramboll Final

~ 1200 LST Jan 7



NCore Rd 10-m Temp

US EPA Final

~ 00 UTC Jan 8 in US EPA run