Assessment of the continuous $PM_{2.5}$ Met One BAM 1020 sampler performance in the State of Alaska Air monitoring Network

2009-2015

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Introduction

$PM_{2.5}$ is a mass based standard. It is the measurement of particulate matter with an aerodynamic diameter of 2.5 micrometers (μm) or less. The samples are measured in units of micrograms of $PM_{2.5}$ per cubic meter ($\mu g/m^3$). When EPA made $PM_{2.5}$ a criteria pollutant in 1997 (62 CFR 38652), the 24 hour standard was 65 $\mu g/m^3$ and the annual standard was 15 $\mu g/m^3$. The 24-hour standard is probabilistic where the 98^{th} percentile is averaged over three years to determine a design value. At the time of promulgation of the $PM_{2.5}$ standard, sampling technology was based on gravimetric analysis. After pre-weighing in the lab, filters were deployed for 24 hours (usually midnight to midnight), retrieved and shipped to a lab where they were they were equilibrated to a standard temperature and relative humidity before final weighing. The time between the monitored day and the filter weighing was a minimum of four days and often much longer. A desire for real-time data led to the development of semi-continuous particulate monitors. Filter-based Federal Reference Method (FRM) data were used in health studies to establish the NAAQS. To compare with health data on which the NAQQS are based, these new monitors needed to yield results as close to the FRM as possible. Several different approaches led to reference or equivalent methods like BAM (based on beta ray attenuation), nephelometer (based on laser measuring light scatter of particles) and TEOM-FDMS (based on the changing frequency of an oscillating microbalance). The Met One BAM 1020 provides hourly data and is designated as a federal equivalent method (FEM) for $PM_{2.5}$ when paired with a very sharp cut cyclone (VSCC). The Met One BAM 1020 was put into use in Alaska as an FEM starting in 2009. It is used at eleven to thirteen sites for monitoring $PM_{2.5}$ concentrations.

Following guidance in the National Monitoring Strategy, Alaska began adding continuous $PM_{2.5}$ analyzers to Federal Reference Method (FRM) monitoring sites. The national long range plan was to convert all manual samplers to continuous analyzers to provide a more comprehensive monitoring database, increasing the monitoring data threefold from sampling every three days to daily and even hourly sampling. The strategy required a collocation of continuous samplers with FRM monitors to determine if a bias existed in the collected data. EPA approved several continuous samplers as Federal Equivalent Methods (FEM). FEM designation is attained by the vendors and includes three FRM and three candidate samplers at four sites (with five campaigns total) distributed across the country and across seasons. A FEM is performance criteria based

(multiplicative bias, additive bias and correlation of 23 valid data sets per campaign) (Wayland, 2008).

Even after FEM designation, agencies in the lower 48 states noticed that the newer technology analyzers were producing significant data disparities. In some cases, substantial discrepancies exist between FRM and FEM data (Hanley and Reff, 2011). While analyzers and guidance on how to operate them in various climates have improved their operation, collocation with an FRM sampler is still preferred by DEC to validate their performance as Alaska continues to experience disagreement between methods. Continuous $PM_{2.5}$ analyzers are now in place at two monitoring sites in the Anchorage network, two sites in the Fairbanks North Star Borough, two sites in the Mat-Su Valley, and one site in Juneau.

Instrumentation

R &P Partisol 2000

EPA designated the Thermo Scientific Inc. Partisol 2000 (previously Rupprecht and Pattaschnick, R&P) with a BGI Inc. very sharp cut cyclone (VSSC) as Federal Reference Method (FRM) April 3, 2002. Prior to then the WINS impactor was the standard FRM method for Partisols. The State of Alaska has operated a network of three to seven Partisols with VSCC to measure $PM_{2.5}$.

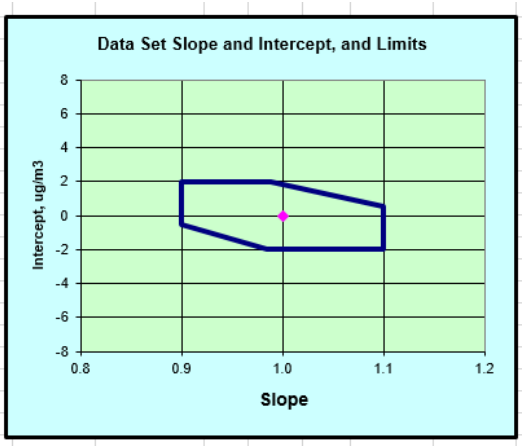
Met One Beta Attenuation Monitor 1020

For hourly data recording the State mainly uses the $PM_{2.5}$ Met One Beta Attenuation Monitors (BAM 1020) which EPA designated as Federal Equivalent Method (FEM) March 12, 2008 (EQPM-0308-170). The State of Alaska has operated a network of seven to ten Met One BAMs.

FEM performance criteria

Federal Equivalent Monitor (FEM) approval is given to more recent instrumentation that meets within a set tolerances the original Federal Reference Method instrumentation conditions that were designated by EPAS to measure concentrations of criteria pollutants for meeting NAAQ Standards. The performance criteria for FEM approval for Class III sites must meet the key statistical metrics for multiplicative bias (slope) between 0.9 and 1.1 and an additive bias (intercept) between -2.00 and 2.00 (40 CFR Part 58.11 e, 40 CFR Part 53 Subpart C Figure C-2). In addition for the slope and intercept the correlation between the FRM and FEM should be

greater than or equal to 0.95000. However failure to meet the correlation does not cause a monitor to fail FEM requirements. It cannot be used as a reason to exclude data from a continuous FEM monitor (40 CFR part 58.11 e). All ADEC monitoring $PM_{2.5}$ BAMs are Class III (continuous monitors). Initially upon FEM designation of the Met One BAM, EPA said the BAM could be designated as the primary sampler in lieu of an FRM without any evaluation period since a comparison should have been already conducted in the network in which it is to be used (EPA, July 24, 2008). Alternatively, it could be collocated with a SLAMS FRM monitor. Because Alaska has such a wide range of extreme weather conditions, ADEC decided to collocate all $PM_{2.5}$ BAMs with FRMs until acceptable slope and intercept between the instruments has been obtained.



Regression statistics		Slope[1]	Intercept[2]	Correlation (r)
Statistics for this test site:				
Limits for	Upper:	1.100		
Class III	Lower:	0.900		
Test Results (Pass/Fail):				

[1]Multiplicative bias [2]Additive bias

Figure 1 EXCELTM FEM performance criteria; EPA Spreadsheet Template, Summary sheet

EPA FRM FEM Regression Workbook

EPA published an Excel™ template for calculating results related to a request for approval of an Approved Regional Method (ARM) for $PM_{2.5}$ to aid in meeting the requirements laid out in 40 CFR 58, Appendix C (Figure 1; EPA, 2013). ADEC uses the spreadsheet for calculation of the correlation between FRM and FEM $PM_{2.5}$ monitors. Alaska runs Thermo Scientific (formerly Rupert & Patashnick) Partisol 2000 monitors with very sharp cut cyclones (VSCC) as FRM monitors and MetOne BAM1020 instruments as FEM monitors.

Results

Except for Fairbanks (2009-2013) and North Pole (2009-2015) sites, ADEC found that all other Alaskan $PM_{2.5}$ BAM sites met FEM performance requirements. The gay box in all the figures represents Class III acceptable limits for slope and intercept for $PM_{2.5}$ methods. The Floyd Dryden BAM in Juneau, Garden BAM in Anchorage and the Matanuska-Susitna (Mat-Su) Valley BAMs at Butte, Palmer and Wasilla all met the slope and intercept performance criteria for $PM_{2.5}$ FEM (Figure 2 and Table 1). FEM designation does not require but recommends a correlation of greater than or equal to 0.9500 (40 CFR Part 53 Subpart C Section 53.35). Correlations (r) for Butte, Juneau, and Anchorage ranged from 0.9530 to 0.9804 meeting FEM requirements but Wasilla and Palmer had lower correlations of 0.8616 and 0.9365 respectively. ADEC attributes this low correlation to the lack of many high concentrations measured at the sites. Of Wasilla's 91 valid pairs (31 had less than 3 $\mu g/m^3$ and were excluded) only three contained concentrations greater than 15 μg/m3. The Palmer site had an FRM collocated with an FEM BAM until December 31, 2014. Palmer has a correlation (r) of 0.90126. Like the Wasilla site, the Palmer site has more than enough valid pairs (127 valid with 68 excluded because of concentrations less than 3 $\mu g/m^3$) available but only a single pair had a concentration higher than 12 $\mu g/m^3$ (12/17/2012 FRM = 18.5 g/m^3 and BAM = 19.5 $\mu g/m^3$).

Correlation data were calculated for the Juneau $PM_{2.5}$ FRM and FEM monitors. Results from the linear regression analysis were well within EPA requirements and, as a result, operation of the $PM_{2.5}$ FRM manual sampler was discontinued April 1, 2011.

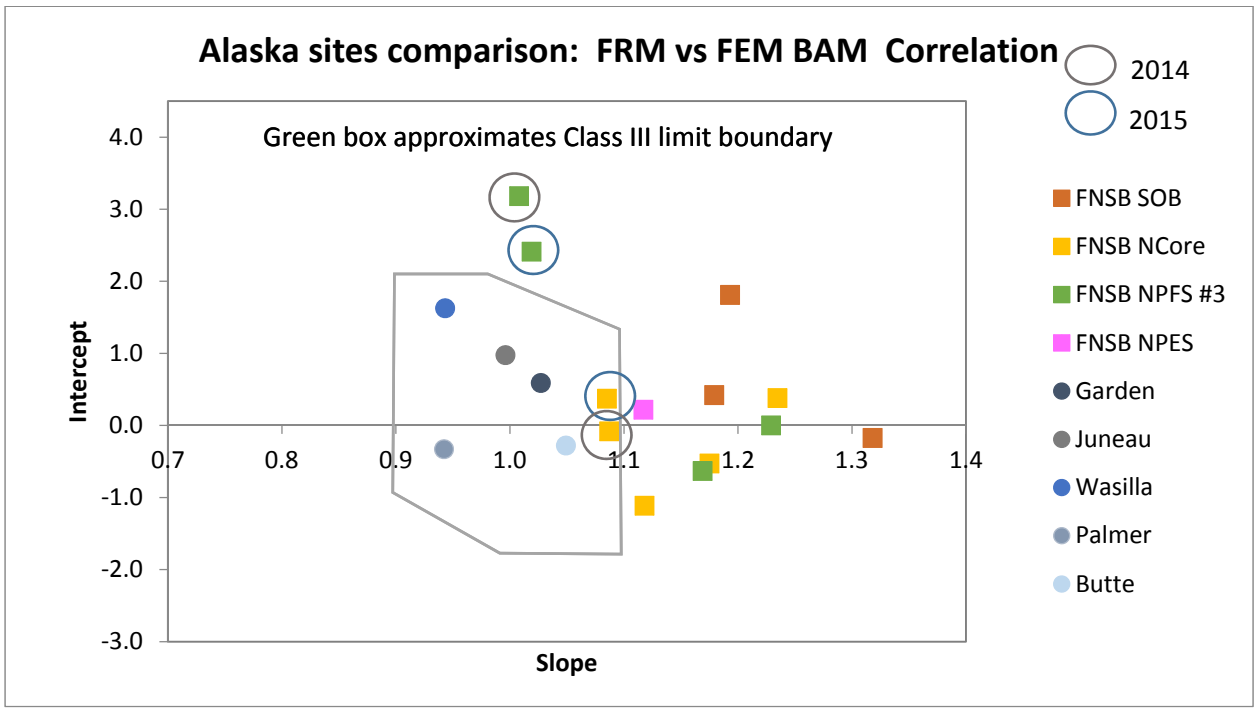


Figure 2 Alaska FRM FEM Correlations; the gray box shows Class III performance criteria

Table 1 Correlation comparison: Alaska FRM (Partisol 2000) vs FEM (Met One BAM)

Correlation comparison: Alaska FRM (Partisol 2000) vs FEM (MetOne BAM)

	N		Regression Statistics FRM, BAM‡		Comments
FNSB	**All data pairs***	**Pairs <3 ug/m3**	**Slope**	**Intercept**	
FNSB SOB					
2011 all	**119**	22	1.179	0.423	
2012 all	**115**	28	1.318	-0.173	
2013 1/1/13 - 4/28/13	38	2	1.193	1.812	BAM removed 5/1/13
FNSB NCore					
2011 all	69	0	1.175	**-0.527**	
2012 all	**118**	22	1.235	**0.380**	
2013 all	**112**	12	1.118	-1.113	
2014 all	**118**	23	**1.087**	**-0.081**	
2015 all	**103**	16	**1.085**	**0.371**	
FNSB NPFS #3					
2012 all	**108**	22	1.169	-0.633	
2013 1Q & 4Q	49	4	1.229	0.000	winter only
2014 1Q & 4Q	57	9	**1.008**	3.182	winter only
2015 all	**108**	23	**1.022**	1.930	7/5 outlier removed
FNSB NPES					
2012 only 1Q &2Q	45	6	1.117	**0.219**	Jan -April 15, 2012
Mat-Su Valley					
Wasilla 2011	**91**	32	**0.943**	**1.628**	
Palmer 10-2012 to 3-2015	**127**	68	**0.942**	**-0.328**	Partisol removed 4/1/15
Butte 8-2011 to 12-2013	**127**	61	**1.049**	**-0.277**	
Juneau					
Floyd Dryden 10/2009 - 5/2011	**109**	59	**0.996**	**0.977**	
MOA					
Garden 1-2009 to 6-2011	**149**	32	**1.027**	0.591	

* 90 pairs are required as sufficient data according to EPA's spreadsheet; **bold PASS criteria**

‡ Regression statistics within acceptable limits; **bold PASS criteria**

FNSB operated several $PM_{2.5}$ sites over the recent years. This document looks at the main four longer term sites: State Office Building (SOB), NCore, North Pole Elementary (NPE) and North Pole Fire Station #3 (NPFS). Most sites have a Met One BAM 1020 while the NCore site has a Coarse Met One BAM pair. The FNSB non-attainment area experiences very high wintertime and occasional summertime high $PM_{2.5}$ concentrations due to primarily home-heating/vehicle exhaust and wildfires respectively. These concentrations are obviously above the NAAQS and are some of the highest concentrations in the United States at times during extreme winter inversions. With the exception of NCore in 2014 (Figure 2), none of the sites have met both FEM additive and multiplicative bias criteria. ADEC decided to calculate annual correlations whenever possible. The results, either of all the data for Fairbanks and North Pole BAMs, or split out by calendar year, have not met the slope requirement for FEM designation since 2009 except for 2014 & 2015 NCore (Table 1). The intercepts and correlations do meet the requirements for FEM designation (except for North Pole Elementary School in 2013 and NCore in 2014 and 2015). MetOne BAMs have a tendency to bias high especially in extreme conditions of humidity and temperature (Gobeli, 2008). The last two winters in the Fairbanks North Star Borough have been relatively mild.

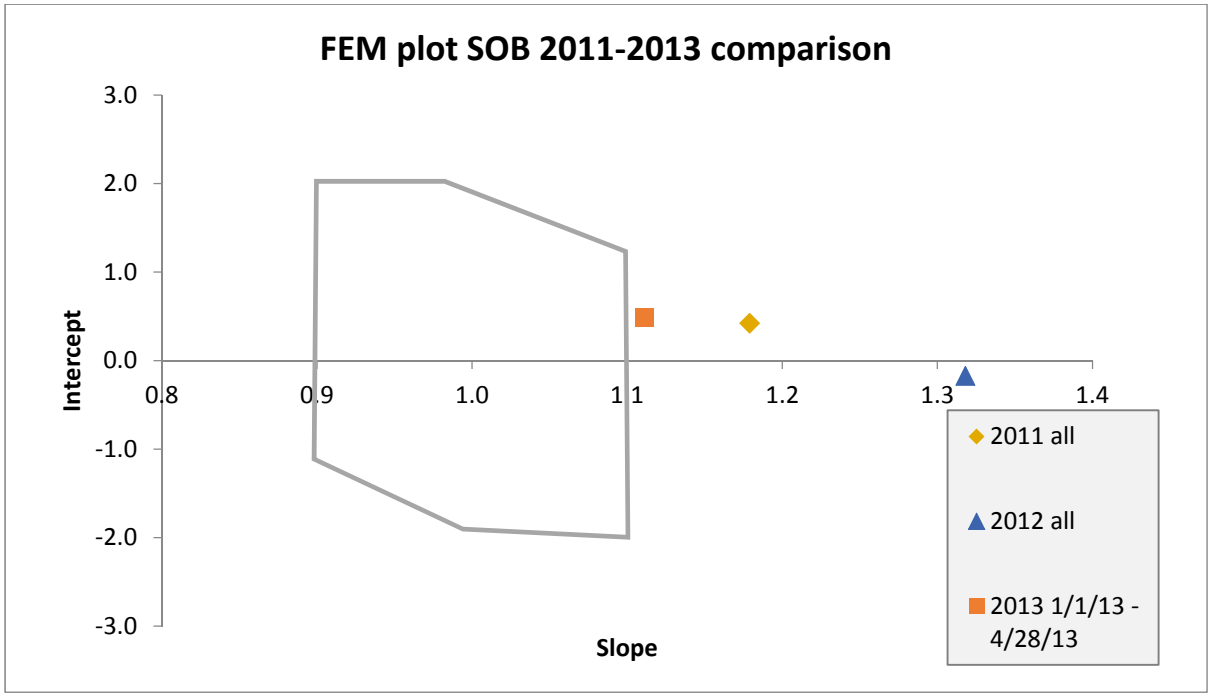


Figure 3 SOB FRM FEM Bias Plot; the gray box represents the bounds of Class III performance criteria

The State Office Building site was installed October 23, 1998 to demonstrate attainment of the 24-hour $PM_{2.5}$ NAAQS (65 $\mu g/m^3$) promulgated July 18, 1997. The NAAQS were strengthened in 2006 lowering the 24-hour $PM_{2.5}$ level to 35 $\mu g/m^3$ which caused the Fairbanks area to go into nonattainment after three years. Correlations between the primary FRM and the FEM BAM were calculated for 2011 through 2013 (Figure 3 and Table 2). Bold text indicates the statistical parameters which met FEM criteria on all the tables in this report.

Table 2 SOB Correlation Summary

SOB FRM- BAM Correlation Summary

Year	2011	2012	2013
Valid data sets	**119**	**115**	38
Enough valid data sets?	**sufficient**	**sufficient**	insufficient
Excluded (< 3 $\mu g/m^3$)	22	28	2
Slope	1.179	1.318	1.812
Intercept	0.423	-0.173	-1.113
Correlation r	**0.98885**	**0.98666**	**0.96764**
Slope P/F	Fail	Fail	Fail
Intercept P/F	**Pass**	**Pass**	**Pass**
Correlation P/F	**Pass**	**Pass**	**Pass**

* began sampling 2/20/2011

ADEC was required to establish a multi pollutant site in the state by January 1, 2010. Because of its air quality issues, ADEC chose Fairbanks as the location for this site. NCore sites are intended to be located with the Chemical Speciation Sites (CSN), which in Alaska was still part of the SOB site. Due to building logistics, the multi-pollutant site could not be added to the SOB, therefore the NCore site was established in close proximity to the SOB. The NCore site was established in late 2010 with the intent of eventually absorbing all the functions of the SOB site. A pair of Coarse Met One BAMs (PM_{10} and $PM_{2.5}$) started monitoring on February 15, 2011 at the NCore site located just across the Chena River from the State Office Building and behind the main FNSB building. In addition to measuring PM_{10} and $PM_{2.5}$ the NCore site also houses trace level SO_2, O_3, CO, NO_2, NO_x, and NO_y as well as meteorological monitors. NCore speciation monitoring began November 3, 2013 and the CSN site officially moved over to the NCore site starting January 1, 2015.

Probably due to severe weather conditions in winter causing longer inversions, the 2012 FEM FRM correlation shows the most extreme slope for both sites (1.318 and 1.235 for SOB and the NCore site respectively). The NCore slope converges on the high side of the Class III boundary in 2013 and was inside the box in 2014 and 2015. FNSB staff added heat tape to the BAM down tubes at NCore to drive off volatiles in the air stream all the way to the BAM tape where beta attenuation is measured in 2013 (Hanley and Reff, 2011; Gobeli et al,2008). Unfortunately, the SOB BAM was in a shelter on the building and the heater could not keep up with the cold weather; it most likely measure more volatiles driving the concentration higher in comparison to the FRM measurements. In 2013 the SOB slope was 1.193 and NCore slope was 1.113 (see Table 2 and Table 3). Additionally, more frequent zero air tests and subsequent background adjustments were done to address the changes in humidity between seasons (Hanley and Reff, 2011).

Table 3 NCore Correlation Summary

NCore FRM- BAM Correlation

Year	2011	2012	2013	2014	2015
Valid data sets	69*	**118**	**112**	**118**	**103**
Enough valid data sets?	insufficient	**sufficient**	**sufficient**	**sufficient**	**sufficient**
Excluded (< 3 μg/m^3)	0	22	12	23	16
Slope	1.175	1.235	1.118	**1.087**	**1.085**
Intercept	**-0.527**	**0.380**	**-1.113**	**-0.081**	**0.371**
Correlation r	**0.98152**	**0.99376**	**0.98884**	**0.99327**	**0.99555**
Slope P/F	Fail	Fail	Fail	**Pass**	**Pass**
Intercept P/F	**Pass**	**Pass**	**Pass**	**Pass**	**Pass**
Correlation P/F	**Pass**	**Pass**	**Pass**	**Pass**	**Pass**

* began sampling 2/20/2011

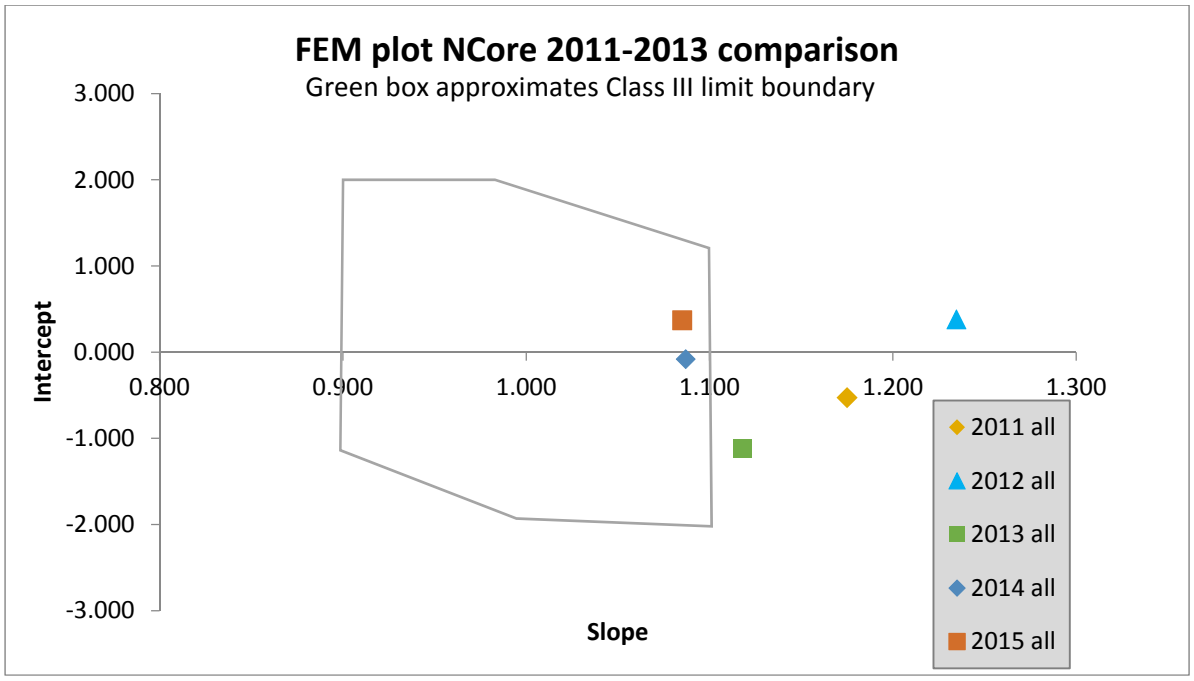


Figure 4 NCore FRM FEM Bias Plot; the gray box represents the bounds of Class III performance criteria

Heated down tubes and increased frequency of zero air tests and subsequent background corrections appeared to improve the performance of the Met One BAM 1020 at the NCore site in 2014 to within the bias tolerances required for FEM designation. Unfortunately, the improvements described for the FNSB BAMs were not sufficient to bring the North Pole Fire station BAM into the acceptable range of the performance criteria. The winters of 2013-14 and 2014-15 and October through December of the winter 2015-16 had unusually mild temperatures and therefore less smoke from home heating could be a confounding factor. Often the highest $PM_{2.5}$ concentrations occur during the winter inversions. The slope measured in the 2012 calendar year was 1.169 and increased in the winter quarters of 2013 to 1.229 (Table 4 and 5). It may be that 2013 was a much harsher winter than 2012 and the inversions caused higher $PM_{2.5}$ concentrations. The BAMs appear to be biased high, especially at higher $PM_{2.5}$ concentrations. It also may be that the sources and source distribution near the sites have changed and contain more volatiles.

North Pole Elementary School also measured very elevated $PM_{2.5}$ concentrations during winter inversions (Table 5 and Figure 6). The North Pole Elementary School site was shut down at the end of March 2013.

Table 4 NPFS#3 FEM FRM Correlation Summary

NP Fire Station #3 FRM- BAM Correlation

Year	2012	2013*	2014*	2015
Valid data sets	**108**	49	57	**108**
Enough valid data sets?	**sufficient**	insufficient	insufficient	**sufficient**
Excluded (< 3 µg/m^3)	22	4	9	23
Slope	1.169	1.229	**1.008**	**1.022**
Intercept	**-0.219**	**2.163**	3.182	1.930
Correlation r	**0.99517**	**0.98336**	**0.99694**	**0.98875**
Slope P/F	Fail	Fail	**Pass**	**Pass**
Intercept P/F	**Pass**	**Pass**	Fail	Fail
Correlation P/F	**Pass**	**Pass**	**Pass**	**Pass**

* Winter only (Oct 1 – Mar 30)

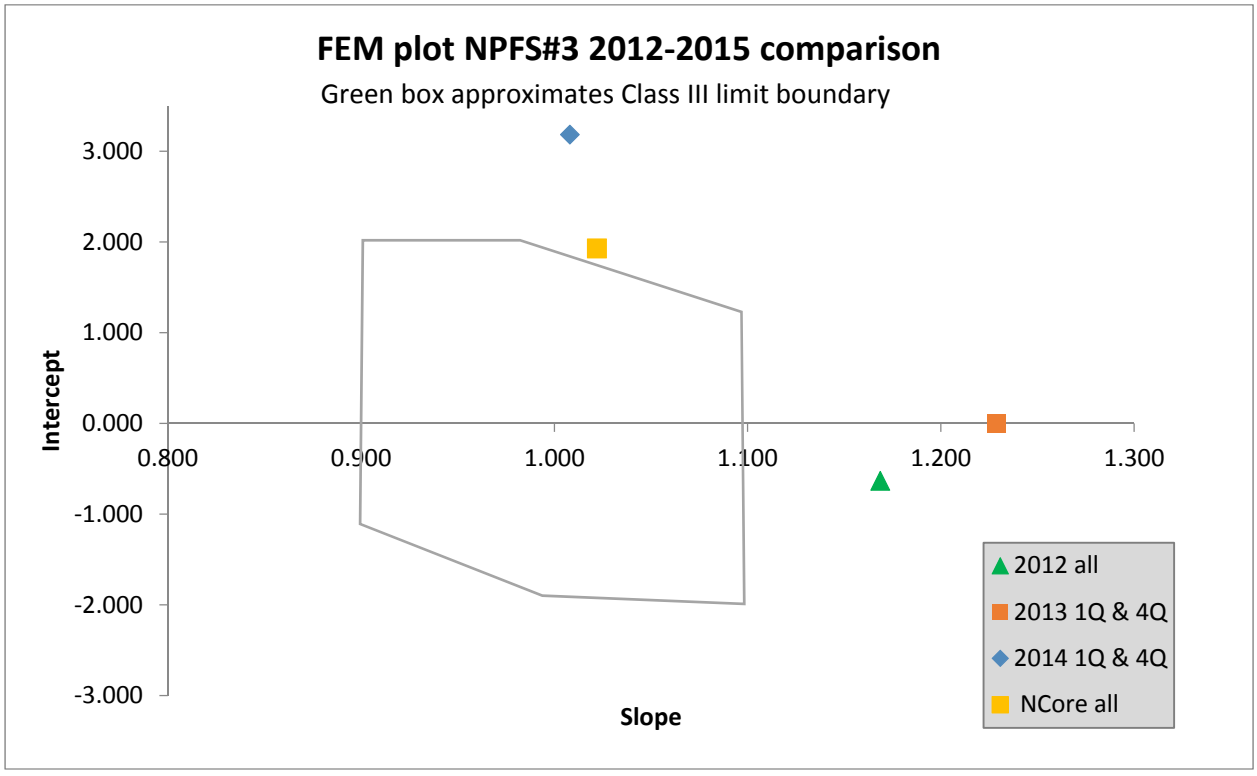


Figure 5 NPFS#3 FRM FEM Bias Plot; the gray box represents the bounds of Class III performance criteria

Table 5 NPE FRM FEM Correlation Summary

NP Elementary School FRM- BAM Correlation (winter only)

Year	1Q & 4Q 2012	1Q2013
Valid data sets	45	29
Enough valid data sets?	insufficient	insufficient
Excluded (< 3 μg/m^3)	6	3
Slope	1.117	**0.219**
Intercept	**0.983**	2.163
Correlation r	**0.99312**	**0.95431**
Slope P/F	Fail	**Pass**
Intercept P/F	**Pass**	Fail
Correlation P/F	**Pass**	**Pass**

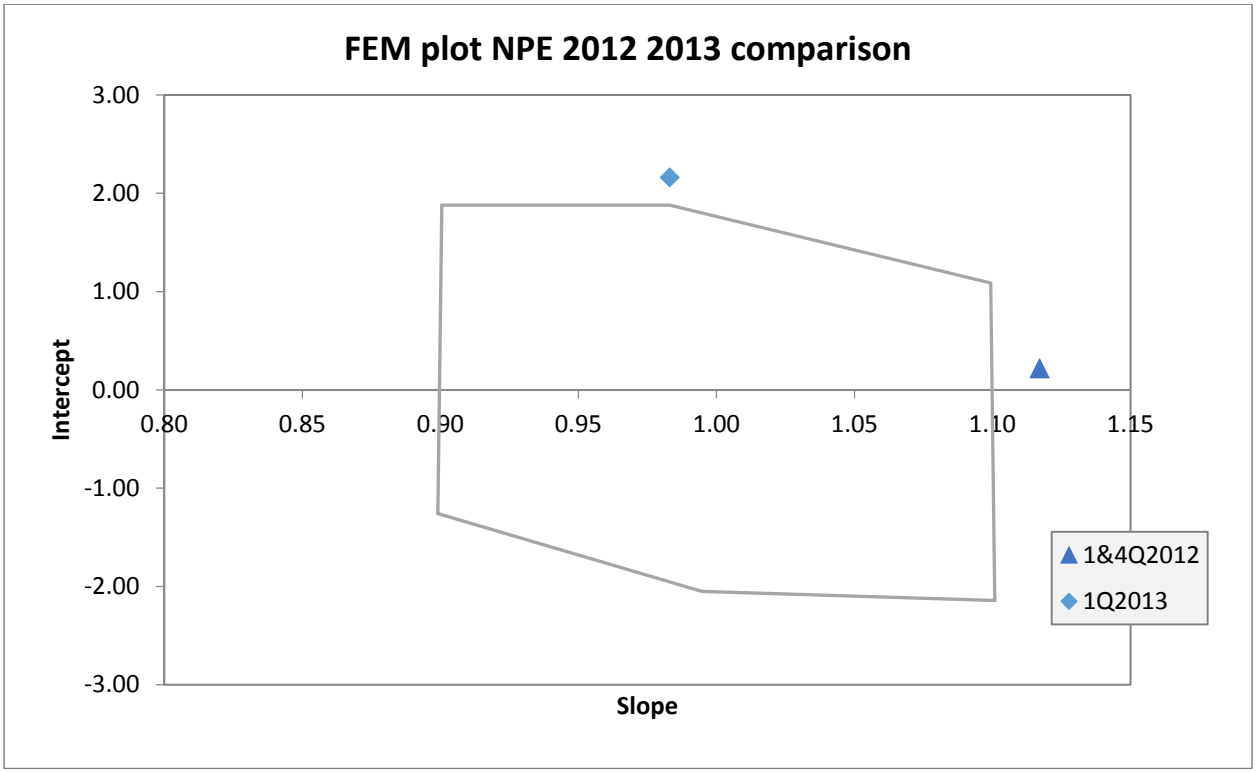


Figure 6 NPES FRM FEM Bias Plot; the gray box represents the bounds of Class III performance criteria

Trends in the FNSB sites may be related to changes in the operation of the BAMs. These include adding heat tape to the down tubes of continuous BAMs and more frequent zero air tests to reflect the changing humidity conditions between winter and summer. Trends may also reflect source changes over the years either in the local area for North Pole sites or neighborhood areas for the Fairbanks sites. Weather variability among years most likely confounds the trends at times. ADEC will continue to look into the data to determine more specific reasons for the NSFB FEM slopes in the future.

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