

Implementing a Continuous PM_{2.5} Federal Equivalent Method (FEM) for NAAQS Comparisons and AQI Reporting in the Missouri Ambient Air Monitoring Network

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**Missouri Department of Natural Resources
Environmental Services Program**

Benefits of Using a Continuous PM_{2.5} FEM

- Increases quantity of 24-hr NAAQS data
- Monitor and report diurnal PM_{2.5} hourly concentrations
- Ability to report real time data to AirNow and have it “match” what is reported to AQS for NAAQS purposes
- Data Quality Indicators for the FEM are reported consistently to AQS
- Reduced redundancy in 24-hr integrated PM_{2.5} measurements
- Reduced network operating costs

(9) PM2.5 Continuous Monitors
7-FEM (FDMS-8500C)
1-SHARP
1-TEOM-SES

St. Joseph
(FEM)

Liberty
(FEM)

Troost
(FEM)

RG-South
(FEM)

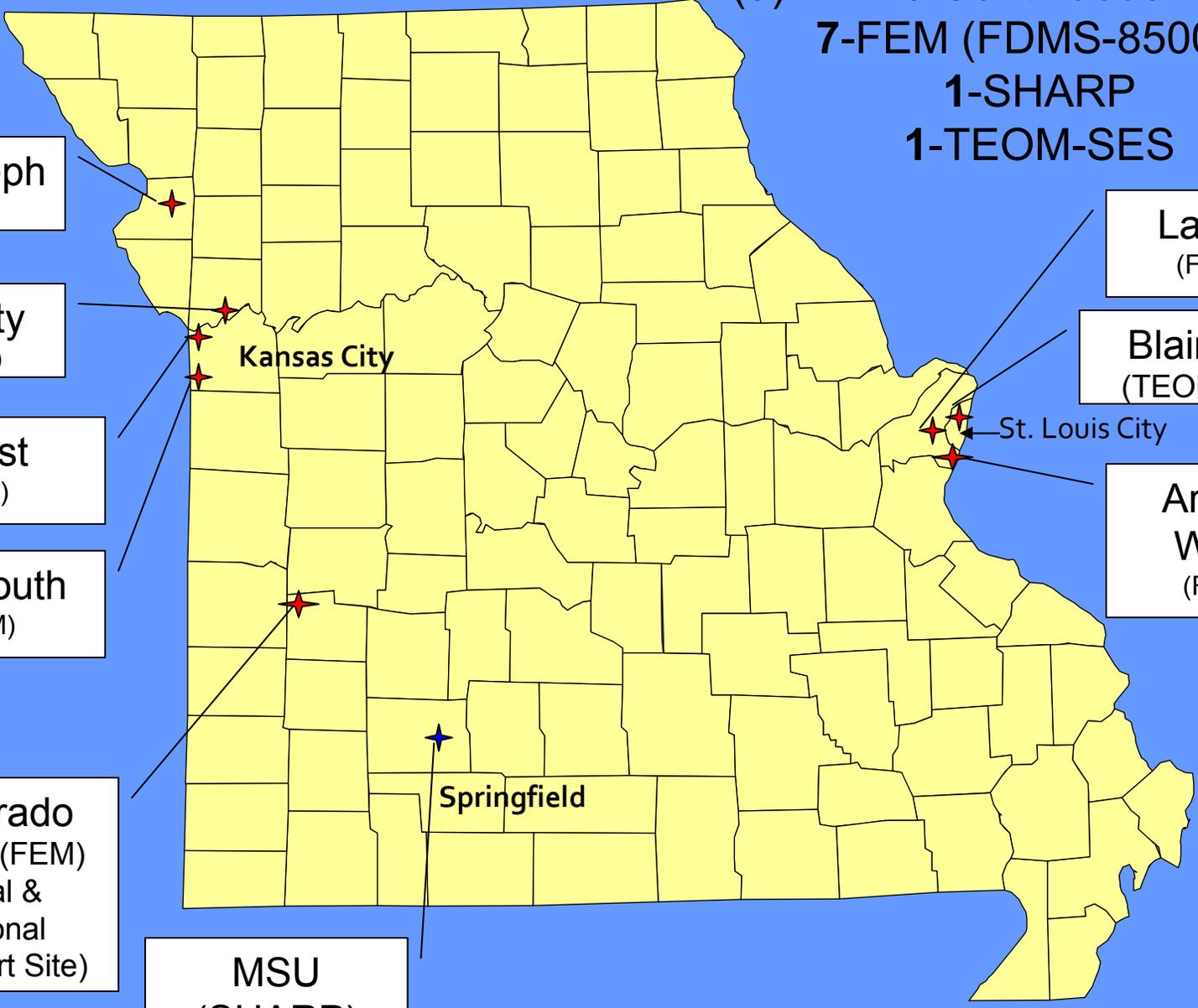
El Dorado
Springs (FEM)
(Rural &
Regional
Transport Site)

MSU
(SHARP)

Ladue
(FEM)

Blair Ave.
(TEOM-SES)

Arnold
West
(FEM)



Observations

- Continuous FEMs do not always perform “exactly” the same as agency operated PM_{2.5} FRMs.
- EPA’s FEM Test was performed with single filter FRMs. (Filter preservation techniques and sampling time frames differ between the FEM test campaigns and the way our agency operates multi-filter sequential FRMs.)
- More meta data should be monitored to ensure the best FEM performance.
- Data Quality Indicators in 40 CFR Part 58 Appendix A were typically applied to filter based FRM/FEM collocated pairs. FRM/FEM(continuous) pairs may yield higher CV and Bias results due to different methods.
- Evaluate the FEM method to understand how these issues affect the FRM/FEM comparability in your region.

Historic PM_{2.5} Method Performance in MO

“Winter” - FDMS Mass concentration data more closely matches filter-based FRM data when ambient temperatures are colder. Volatile/semi-volatile aerosol is more likely retained on FRM filter before being weighed.

“Summer” - FDMS mass concentration data is generally higher than filter based FRM when ambient temperatures are higher. Volatile/semi-volatile aerosol not as likely to be retained on FRM filter before being weighed.

FRM/FDMS comparability - Strongly correlated with ambient temperature over all “seasons” in our region. (Apparently, this was not true for the data fit for the FEM test, but it is true for our state over all seasons.)

Historic Missouri Solution

State Method (proposed ARM): Corrects FDMS-8500B mass concentration data in real time-based on temperature to account for what the FRM is not measuring. (Using Tim Hanley's algorithm-EPA-OAQPS)

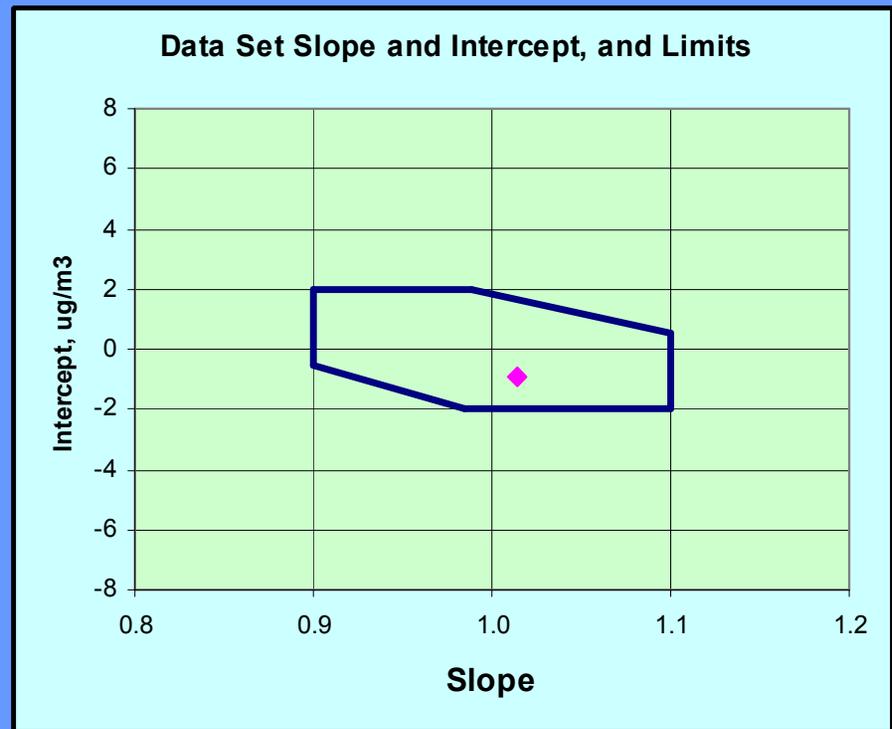
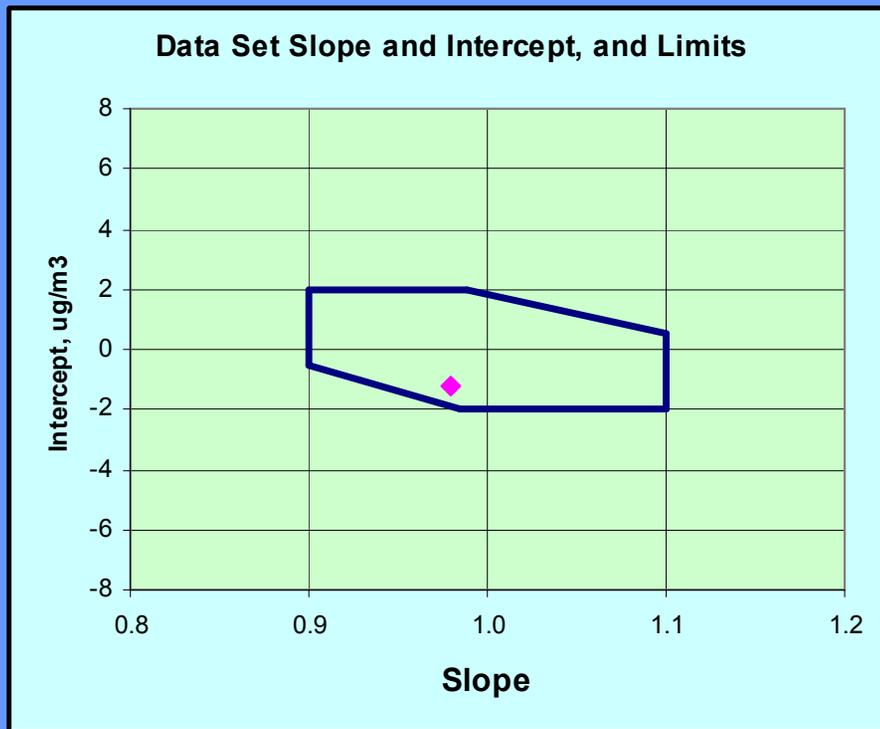
FDMS-8500C FEM: Corrects mass concentration data using a power algorithm which is not temperature dependent.

As a consequence, modeling past data using the FEM algorithm was beneficial to understanding the likely effect of switching to the FEM method.

FDMS-8500B (June 2008 to June 2009)

Arnold West (FMDS corrected by **FEM power algorithm** (310 sample pairs) (St. Louis)

Arnold West (FMDS corrected by **ARM algorithm** (310 sample pairs) (St. Louis)



Regression statistics		Slope ¹	Intercept ²	Correlation (r)
Statistics for this test site:		0.979	-1.219	0.98063
Limits for Class III	Upper:	1.100	2.000	
	Lower:	0.900	-1.915	0.94976
Test Results (Pass/Fail):		PASS	PASS	PASS

¹Multiplicative bias ²Additive bias

Regression statistics		Slope ¹	Intercept ²	Correlation (r)
Statistics for this test site:		1.014	-0.880	0.98519
Limits for Class III	Upper:	1.100	1.669	
	Lower:	0.900	-2.000	0.94940
Test Results (Pass/Fail):		PASS	PASS	PASS

¹Multiplicative bias ²Additive bias

Precision & Accuracy Model

FEM Algorithm: applied to raw ARM test data-Arnold West June 2008 through June 2009

ARM Algorithm: applied to Arnold West data June 2008 through June 2009

CV (%) (Eqn 11)
9.75

Bias (%) (Eqn 3)
16.84

Signed Bias (%)
-16.84

Precision and Bias
Statistics 40 CFR Part 58
Appendix A. Section 4.3.1

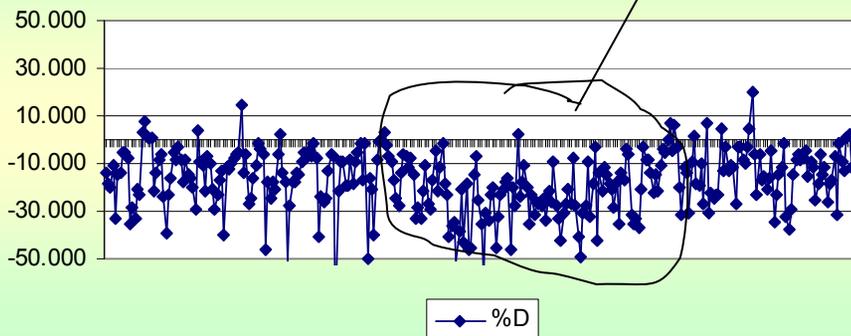
CV (%) (Eqn 11)
7.17

Bias (%) (Eqn 3)
8.16

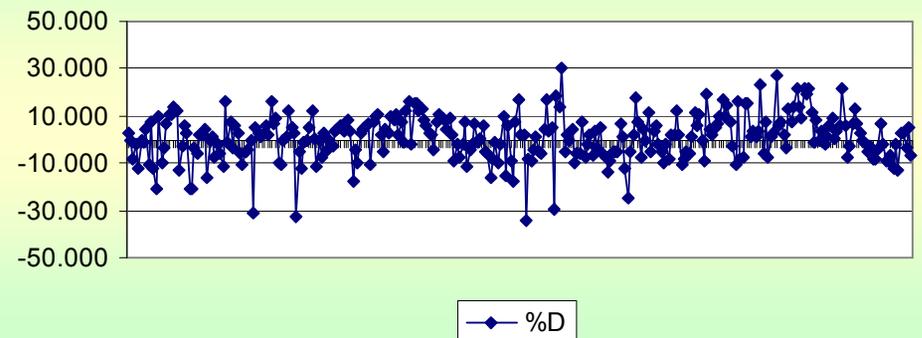
Signed Bias (%)
+/-8.16

24hr-Avg.
Ambient temp.
low (Nov-Feb)

Relative Percent Differences

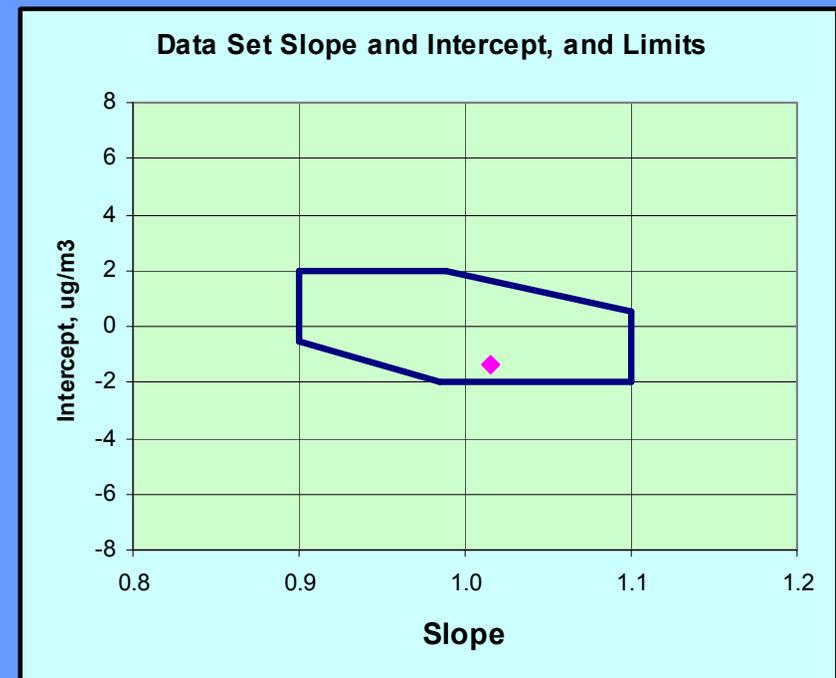
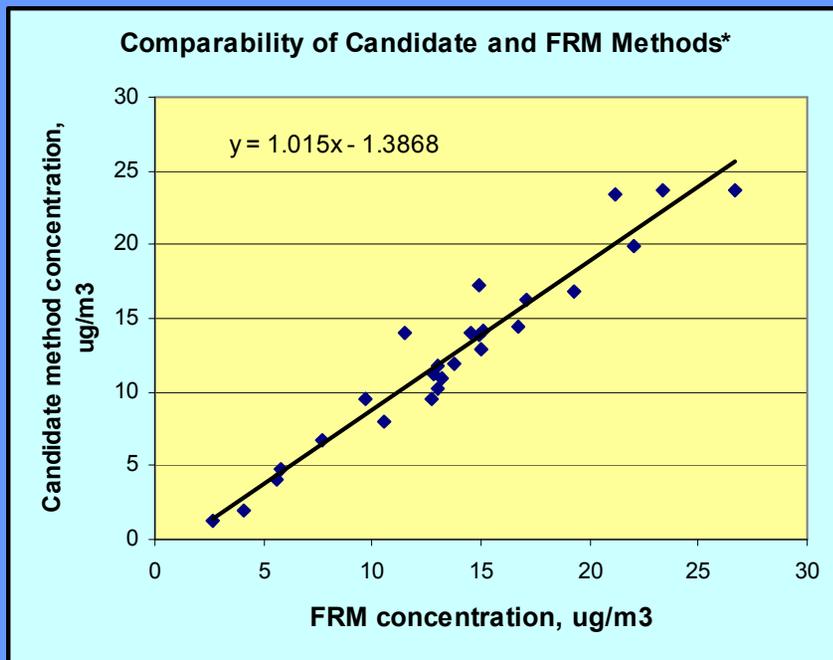


Relative Percent Differences



Other Midwest Testing - March 2007

- Concurrent with FEM test Campaign C (different site)
- FDMS-8500B corrected using FEM power algorithm
- Avg. ambient 24-hr temperature for month: 12.9 °C.
- Only one day when 24-hr avg. ambient temperature was below 0 °C.



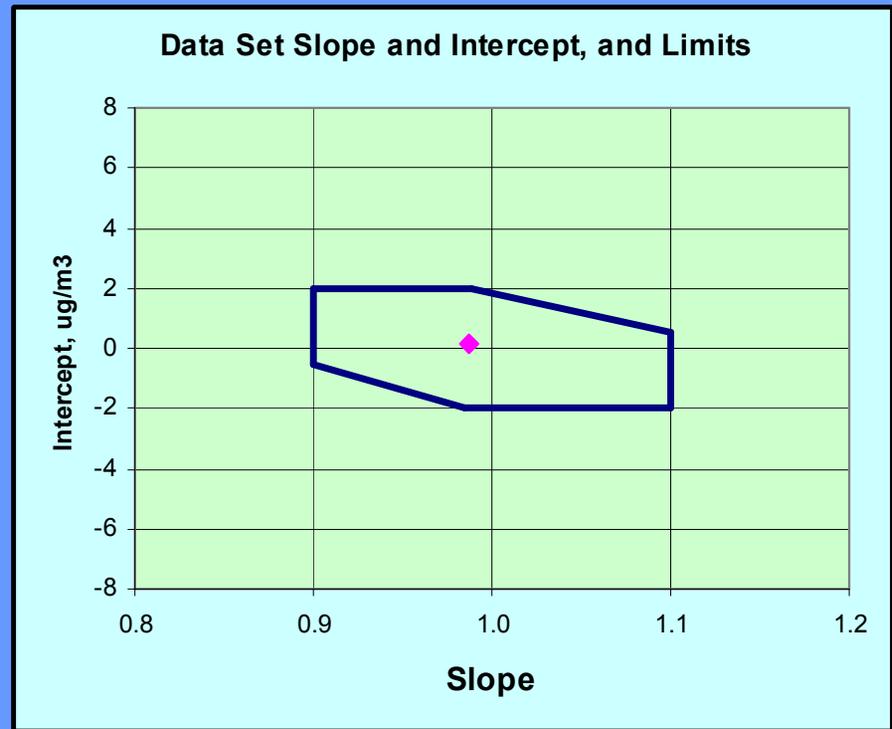
Regression statistics		Slope ¹	Intercept ²	Correlation (r)
Statistics for this test site:		1.015	-1.387	0.96743
Limits for Class III	Upper:	1.100	1.652	
	Lower:	0.900	-2.000	0.93539
Test Results (Pass/Fail):		PASS	PASS	PASS

¹Multiplicative bias ²Additive bias

FDMS-8500C FEM Burn-in

Arnold West (St. Louis) (FMDS-8500C FEM) 124 valid pairs (Aug.to Dec. 2009)

Arnold West (St. Louis) (FMDS-8500C ARM) (Aug.to Dec. 2009)



Regression statistics		Slope ¹	Intercept ²	Correlation (r)
Statistics for this test site:		0.899	-0.150	0.98379
Limits for Class III	Upper:	1.100	2.000	
	Lower:	0.900	-0.519	0.95000
Test Results (Pass/Fail):		FAIL	PASS	PASS

Regression statistics		Slope ¹	Intercept ²	Correlation (r)
Statistics for this test site:		0.988	0.122	0.98850
Limits for Class III	Upper:	1.100	2.000	
	Lower:	0.900	-2.000	0.95000
Test Results (Pass/Fail):		PASS	PASS	PASS

Precision & Accuracy FRM/FEM-Burn-in

FEM Method FDMS-8500C –October 2009 through December 2009 (N=68 pairs) Arnold West St. Louis

CV (%) (Eqn 11)

8.68

Bias (%) (Eqn 3)

13.26

Signed Bias (%)

-13.26

ARM Method- FDMS-8500C - October 2009 through December 2009 (N=68 pairs) Arnold West St. Louis

CV (%) (Eqn 11)

6.74

Bias (%) (Eqn 3)

8.88

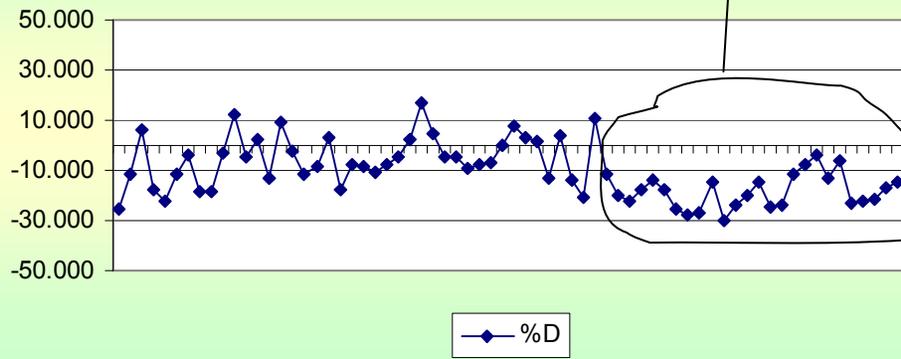
Signed Bias (%)

+/-8.88

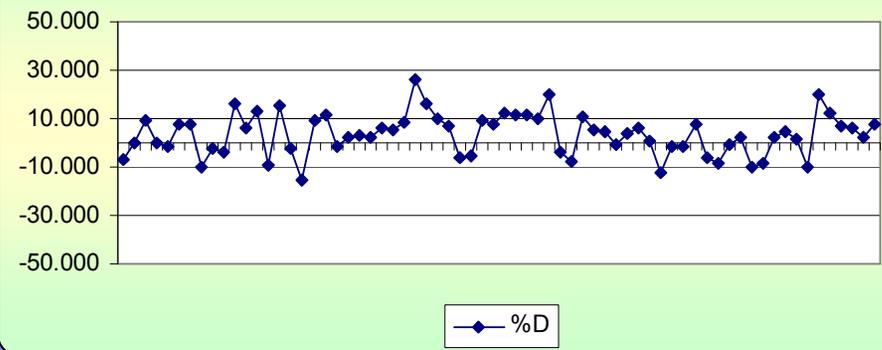
Precision and Bias
Statistics 40 CFR Part 58
Appendix A. Section 4.3.1

24hr-Avg.
Ambient temp.
low (Nov-Dec)

Relative Percent Differences



Relative Percent Differences

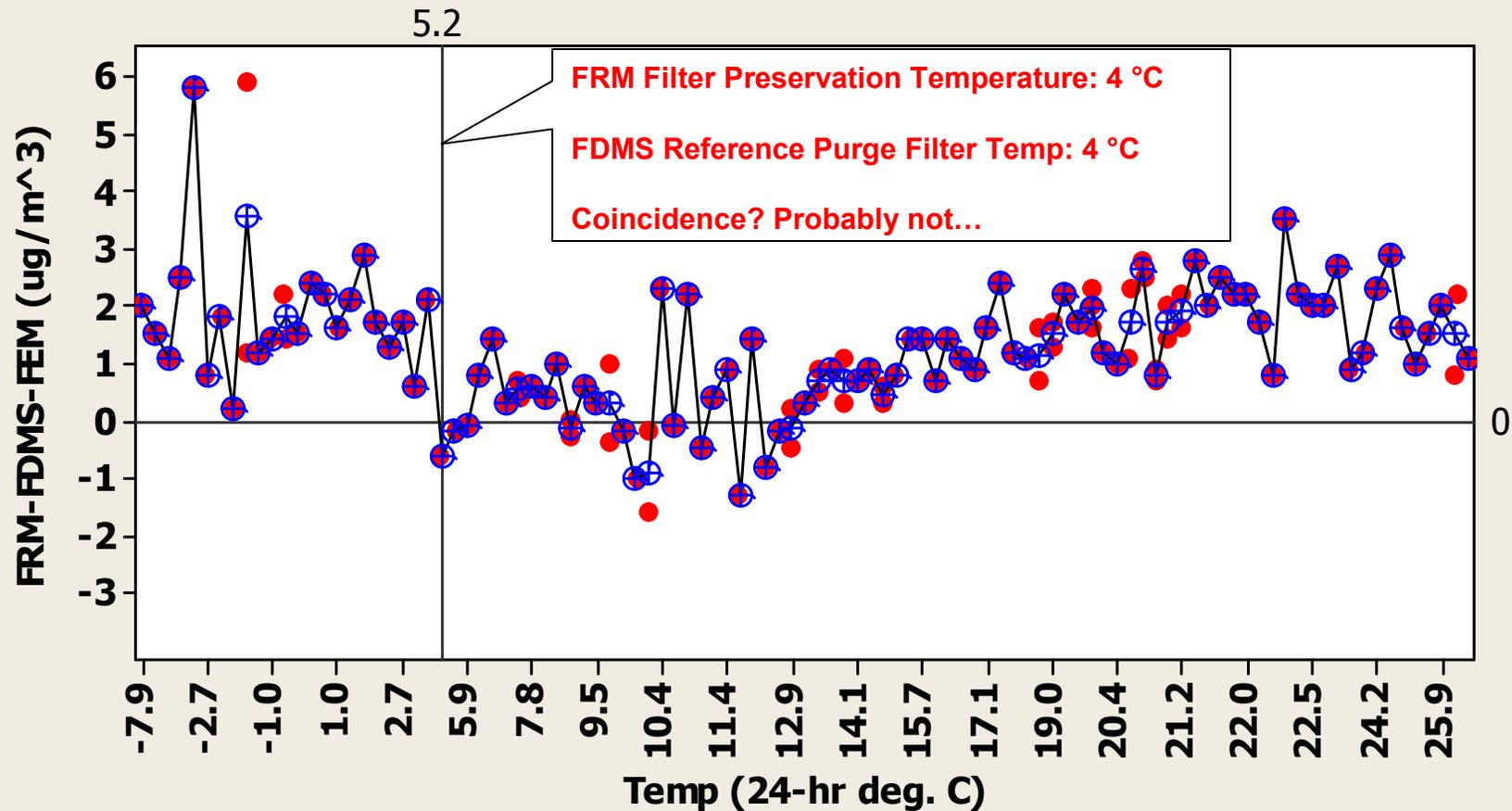


What is Going On?

Difference (FRM-FDMS(FEM) vs Ambient Temperature)

ArnoldWest 8-1-09 through 12-31-09

FEM method corrects raw data (independent of temperature)

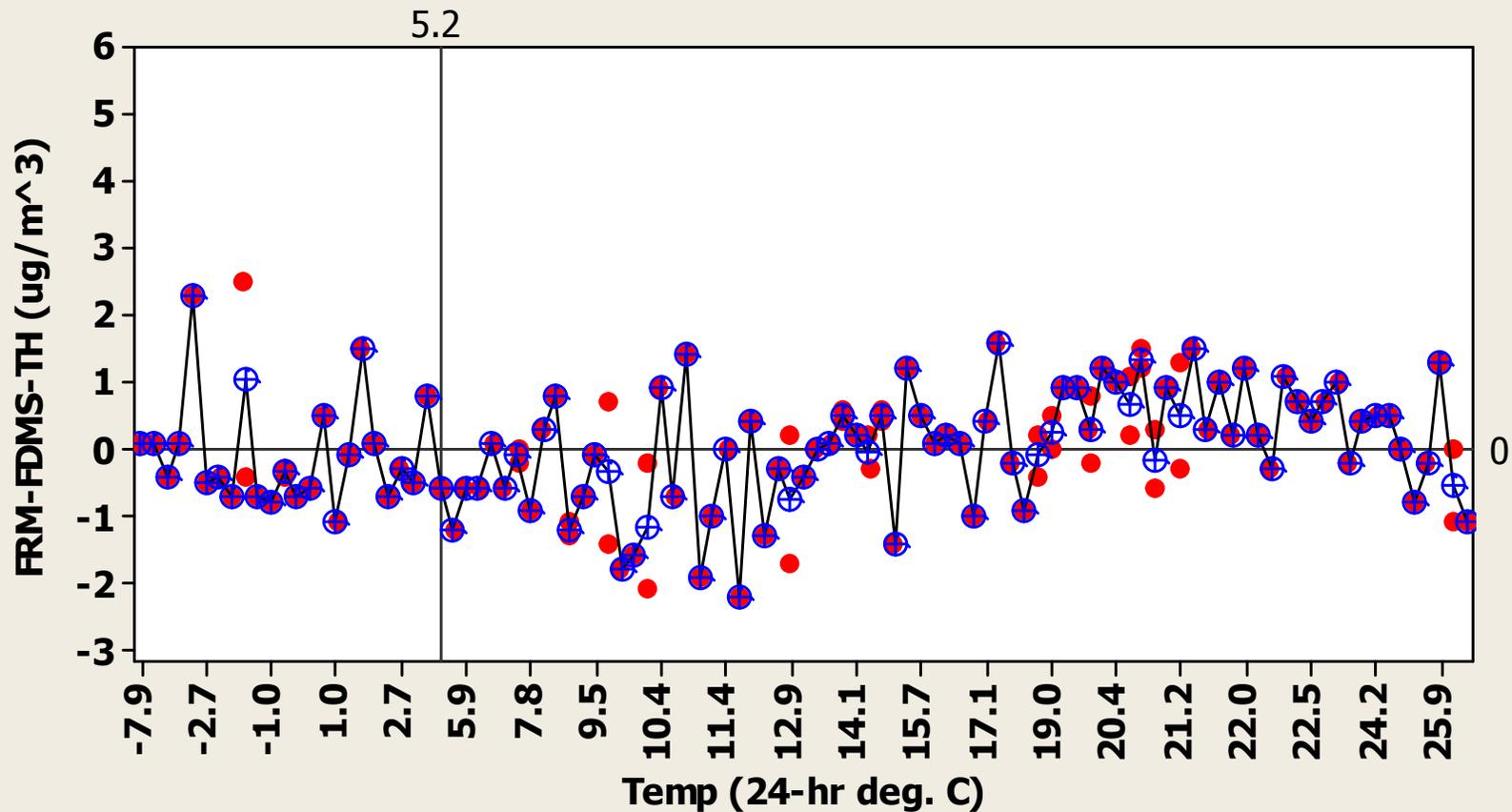


Regional Method Corrects FDMS-8500C for Temperature Effect

Difference (FRM-FDMS(ARM Method) vs Ambient Temperature)

ArnoldWest 8-1-09 through 12-31-09

Tim Hanley's method- corrects based on ambient temperature

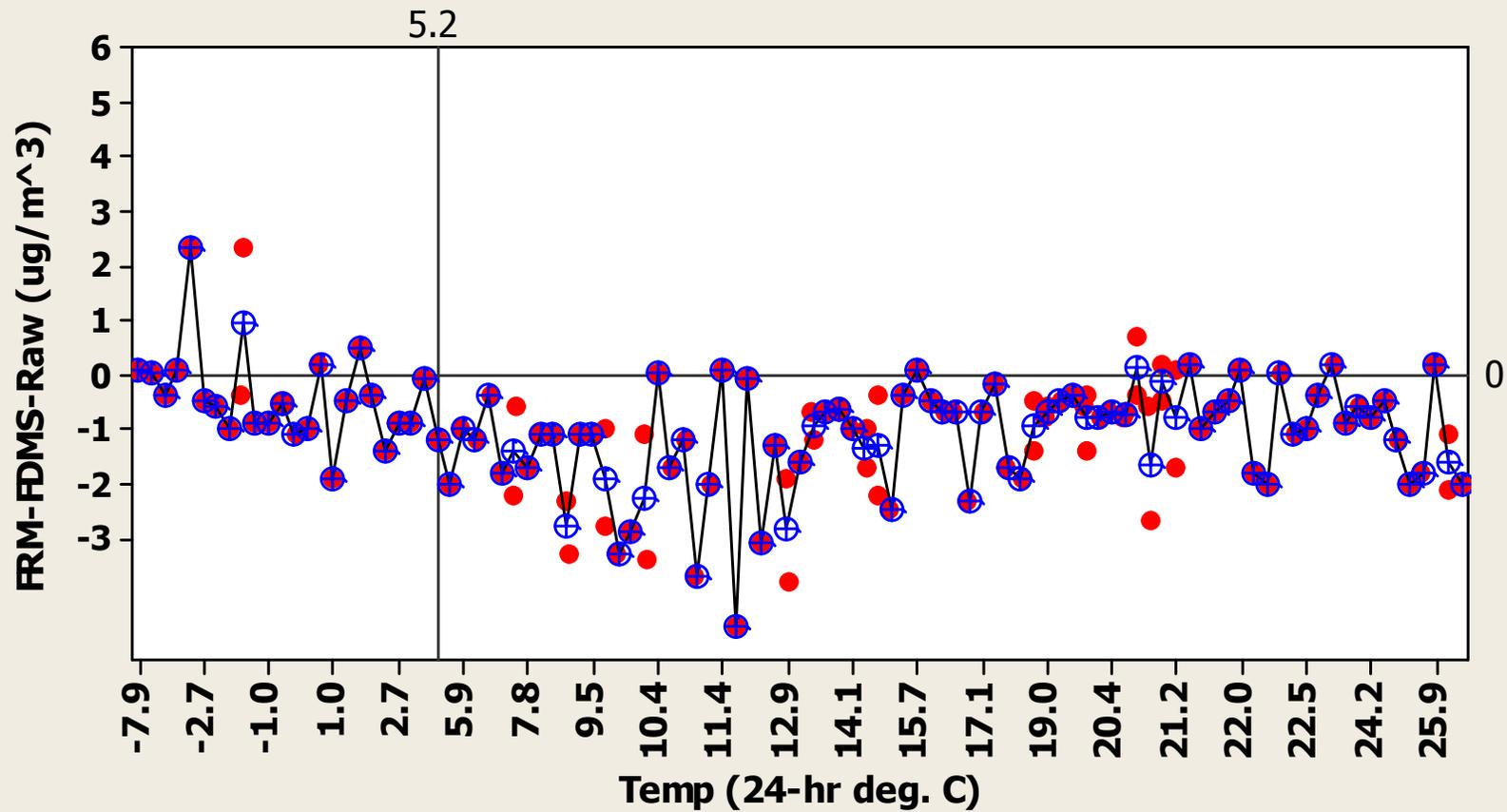


Raw FDMS-8500C

Difference (FRM-FDMS(Raw Data) vs Ambient Temperature)

ArnoldWest 8-1-09 through 12-31-09

No Data Corrections



Troost (Kansas City) FRM/FEM-Burn in

FEM Method FDMS-8500C -October 2009 through January 2010 (N=53 pairs)

CV (%) (Eqn 11)
9.32

Bias (%) (Eqn 3)
17.38

Signed Bias (%)
-17.38

Precision and Bias Statistics
40 CFR Part 58 Appendix A.
Section 4.3.1

ARM Method- FDMS-8500C - October 2009 through January 2010 (N=53 pairs)

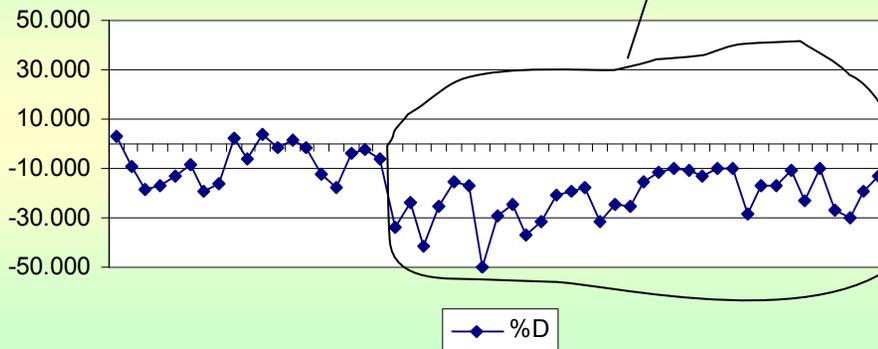
CV (%) (Eqn 11)
6.58

Bias (%) (Eqn 3)
7.36

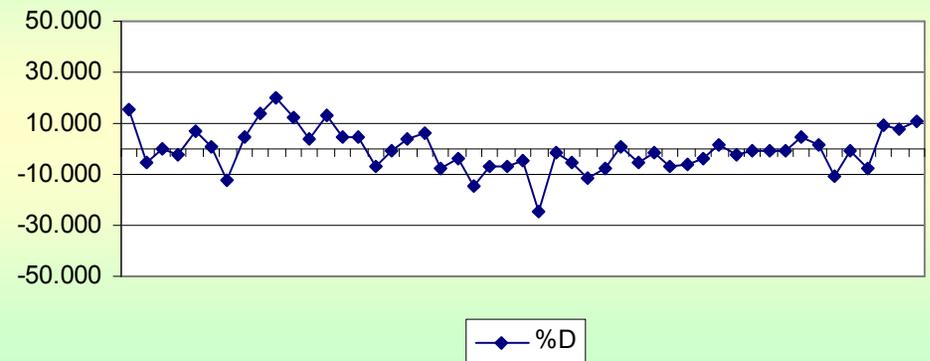
Signed Bias (%)
+/-7.36

24hr-Avg.
Ambient temp.
low (Nov-Jan)

Relative Percent Differences



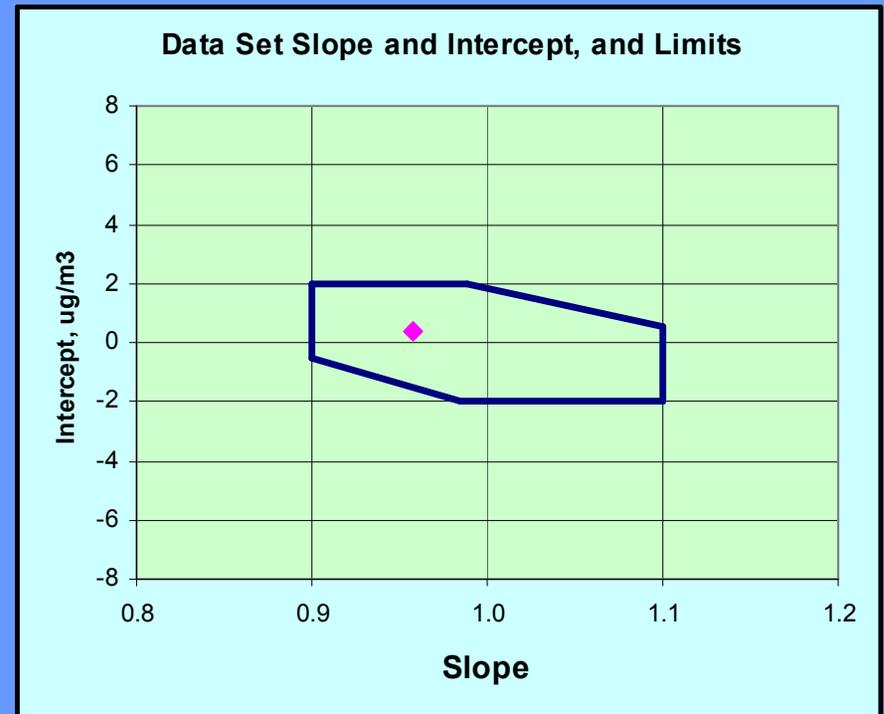
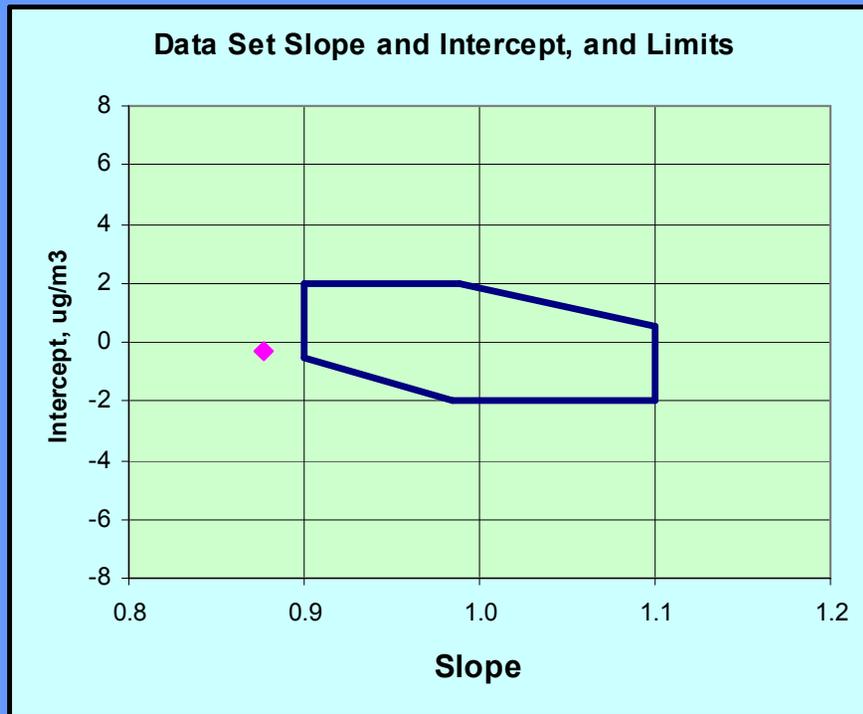
Relative Percent Differences



Western MO “Left Shift” (Nitrate?)

Troost (Kansas City) (FDMS-8500C **FEM**)
53 valid pairs (Oct. 2009 to Jan. 2010)

Troost (Kansas City) (FDMS-8500C **ARM**)
53 valid pairs (Oct. 2009 to Jan. 2010)



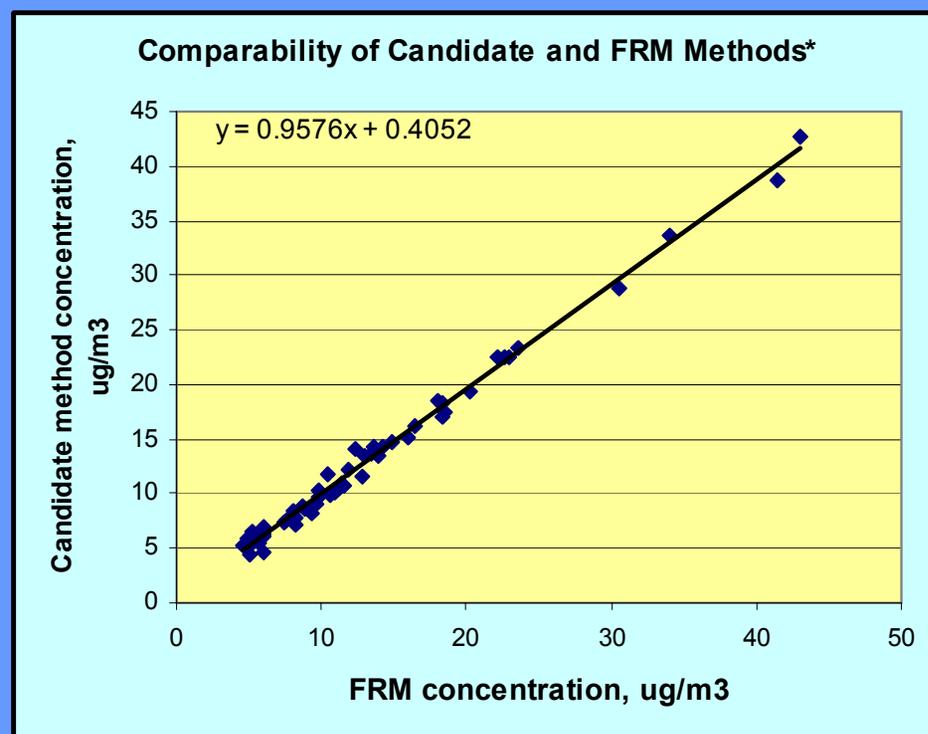
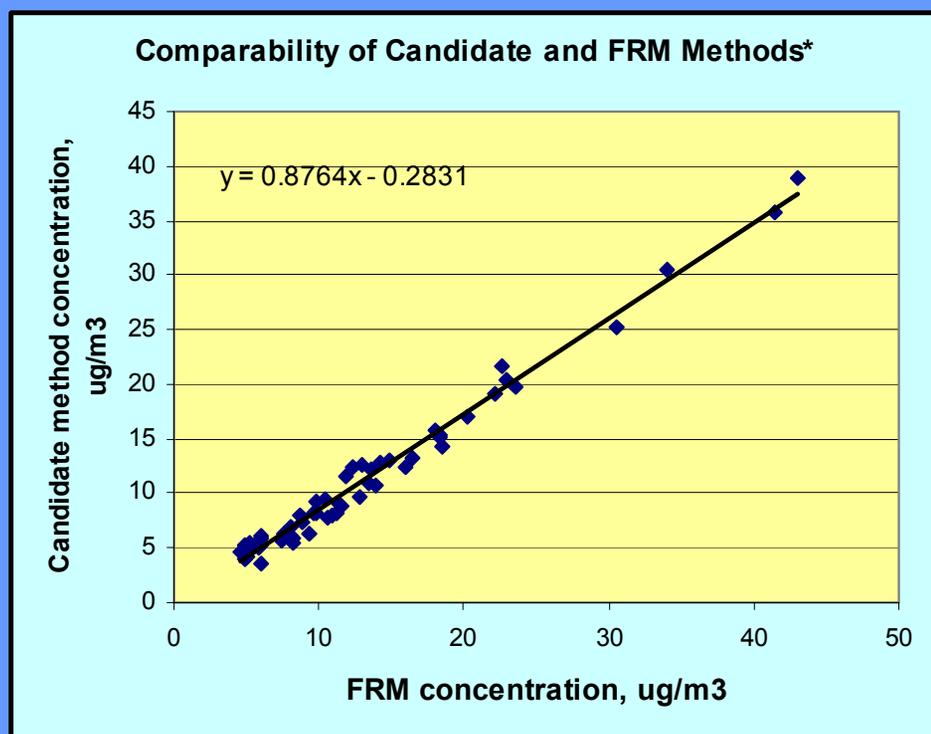
Regression statistics		Slope ¹	Intercept ²	Correlation (r)
Statistics for this test site:		0.876	-0.283	0.99165
Limits for Class III	Upper:	1.100	2.000	
	Lower:	0.900	-0.129	0.95000
Test Results (Pass/Fail):		FAIL	FAIL	PASS

Regression statistics		Slope ¹	Intercept ²	Correlation (r)
Statistics for this test site:		0.958	0.405	0.99632
Limits for Class III	Upper:	1.100	2.000	
	Lower:	0.900	-1.535	0.95000
Test Results (Pass/Fail):		PASS	PASS	PASS

Troost (Kansas City)

Troost (Kansas City) (FDMS-8500C **FEM**)
(Oct. 2009 to Jan. 2010)

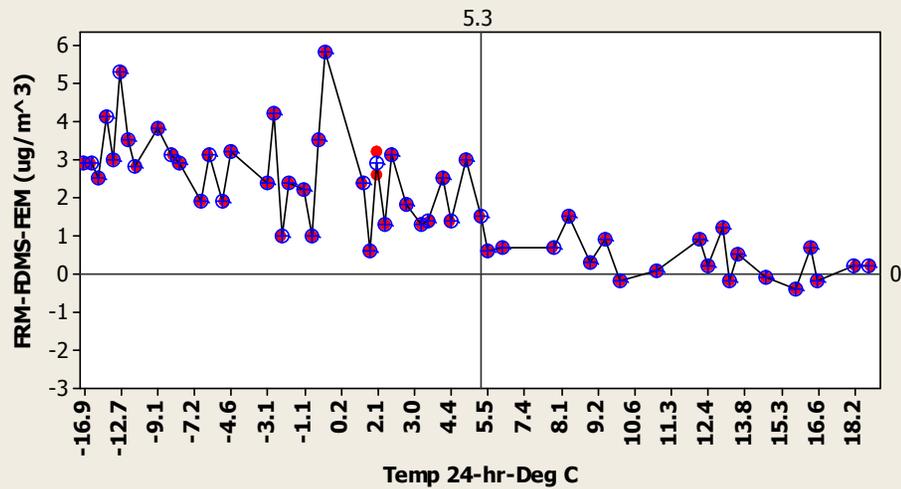
Troost (Kansas City) (FDMS-8500C **ARM**)
(Oct. 2009 to Jan. 2010)



Difference (FRM-FDMS(FEM) vs. Ambient Temperature)

Valid Data Pairs 9-25-2009 through 1-31-2010

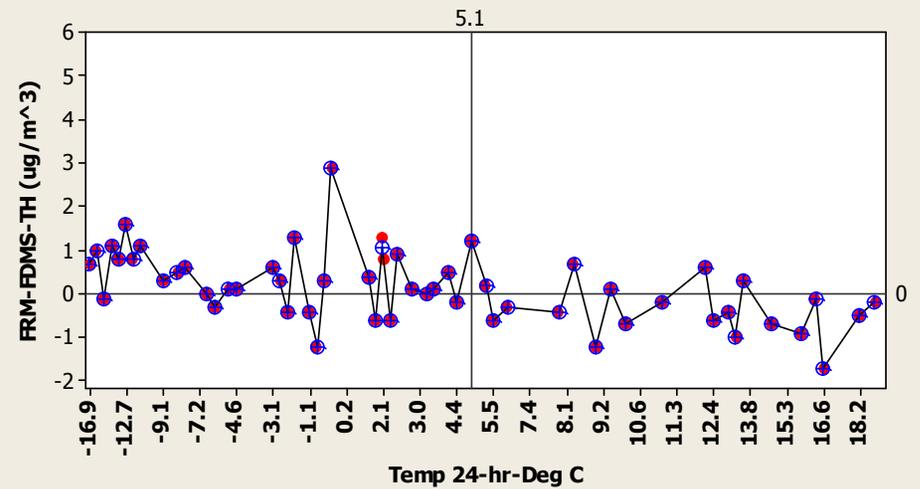
Troost (Kansas City)-FEM method corrects raw data (independent of temperature)



Difference (FRM-FDMS(ARM) vs. Ambient Temperature)

Valid Data Pairs 9-25-2009 through 1-31-2010

Troost (Kansas City)-Tim Hanley's method- corrects based on ambient temperature



Regional P&A Statistics Summary

(For burn-in period, using 40 CFR Part 58 Appendix A. Section 4.3.1 and 4.3.2)

- FRM/FEM Collocated Precision **CV: <10%**

PEP Bias - Audit Conc. 6.41µg/m³

Nov. 3, 2009, Avg. 24-hr temp: 10.3 °C

FRM/PEP: -17.6% (FRM Conc. 5.28µg/m³)

FEM/PEP: -14.2% (FEM Conc. 5.5µg/m³)

ARM/PEP: -6.4% (ARM Conc. 6.0µg/m³)

Raw/PEP: +12.3% (Raw Conc. 7.2µg/m³)

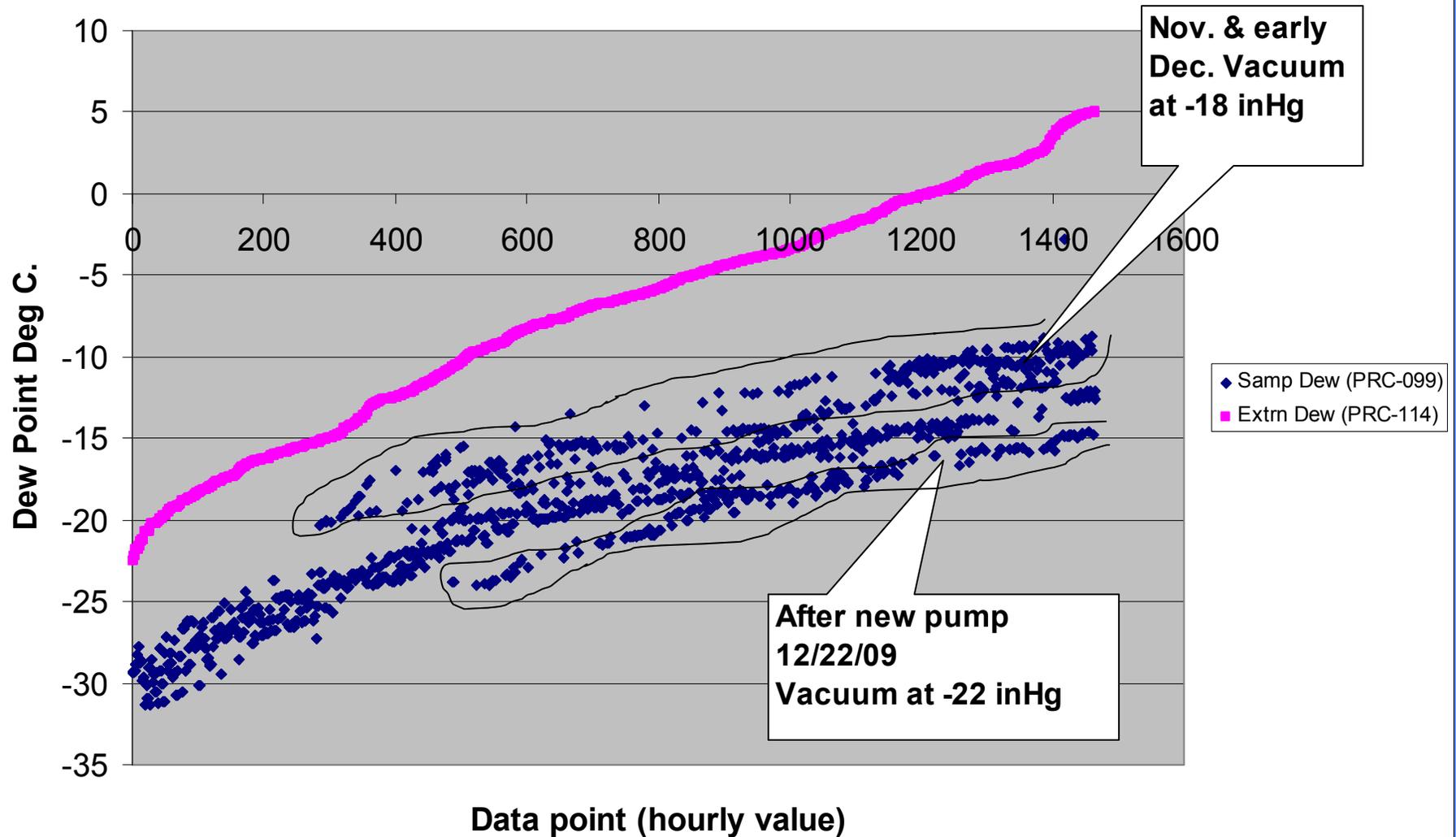
- FRM/FEM Bias (Absolute Method): Between 10% and 20%

Important Meta Data to Monitor for Best FEM Performance

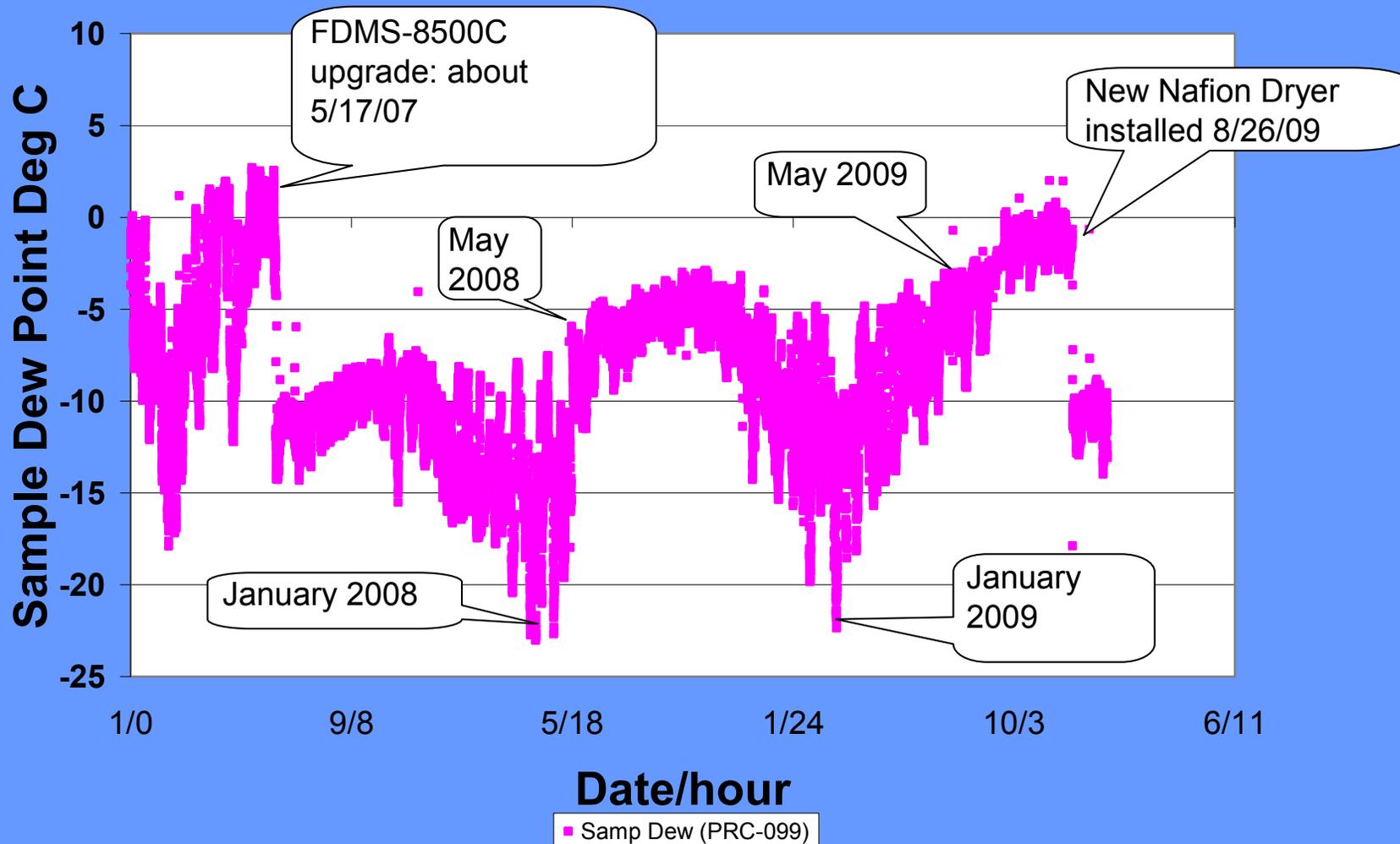
- **Dryer Efficiency** - Monitor Dew Points! (not discussed in FDMS manual)
- **Dryer Purge Line Vacuum** - MUST MONITOR!
(maintain 80% to 70% of ambient pressure, about 20 inHg vacuum or better)
- **Noise (Frequency)** (<0.10 per manual, but <0.030 is better, 0.004 to 0.007 is typical of our monitors)
- **Filter Loading** (<100% per manual, <60% is better, or once per month whichever is sooner)
- **Flow Rates** (not usually a problem)

Purge Line Vacuum Effect on Dryer Efficiency

FDMS-RG South-Sample Dew Point as a function of rank ordering the External Dew point



Sample Dew Point vs. Time -Ladue FDMS-8500C "Age" Effect on Nafion Dryer (12/29/06 to 10/2/09)



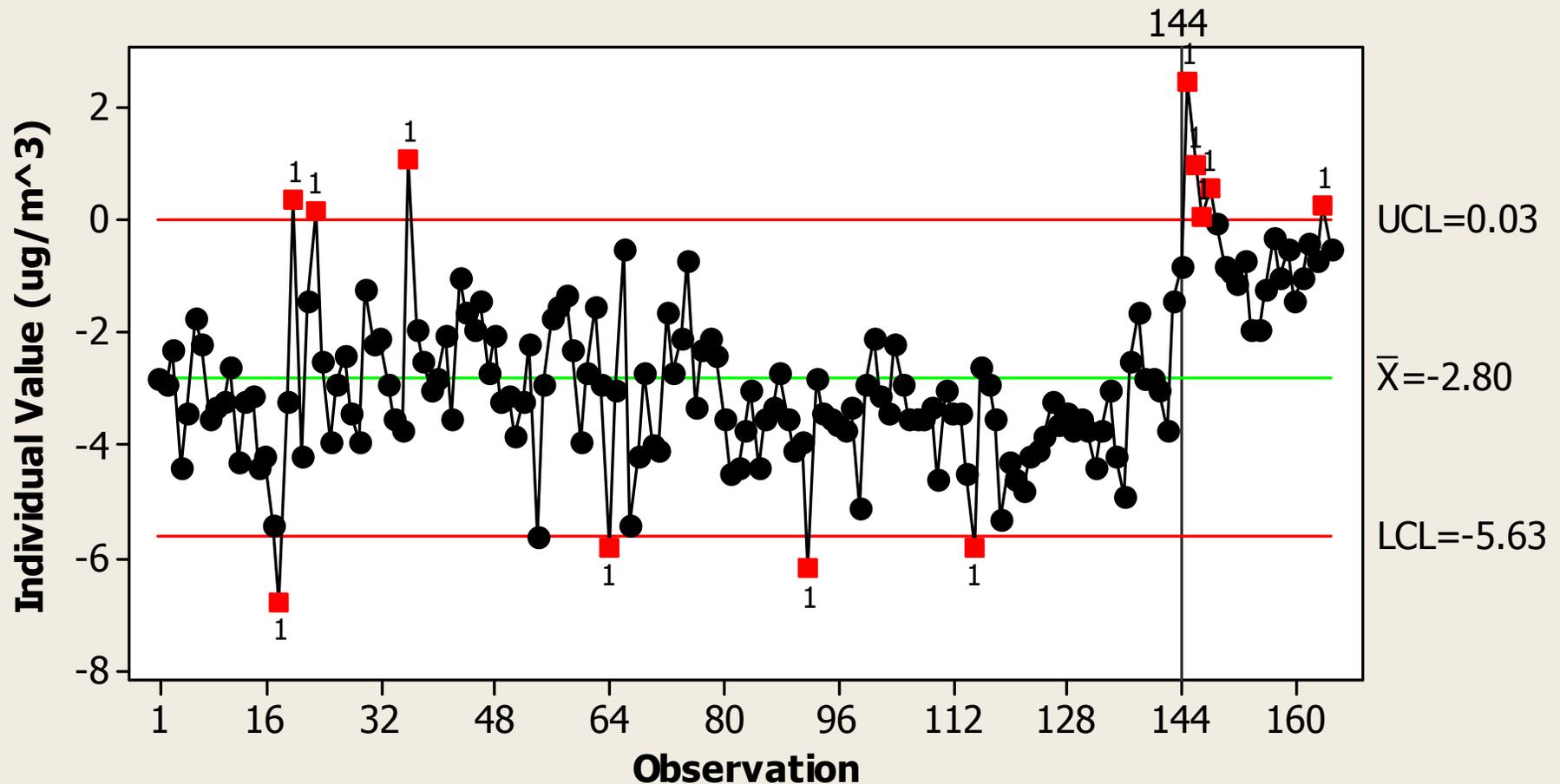
Dryer "Age Effect" on FDMS Reference Channel

Ladue TEOM-FDMS-8500C Reference Channel

Average 24 hr. Reference channel mass concentration ($\mu\text{g}/\text{m}^3$)

Dryer Replaced at Reference Line 144 (8/26/09)

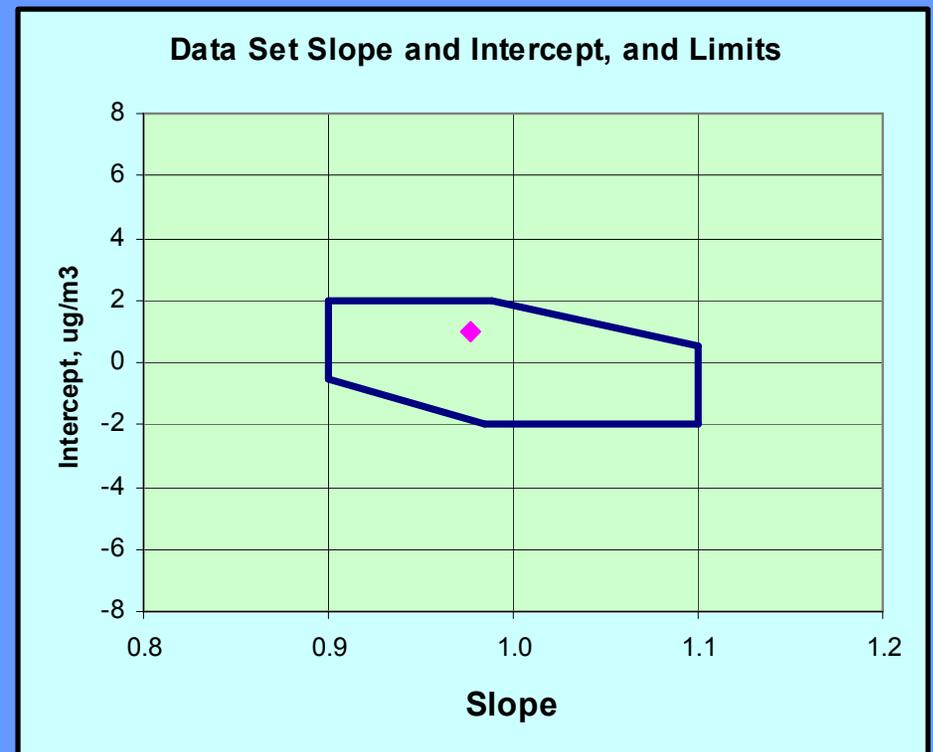
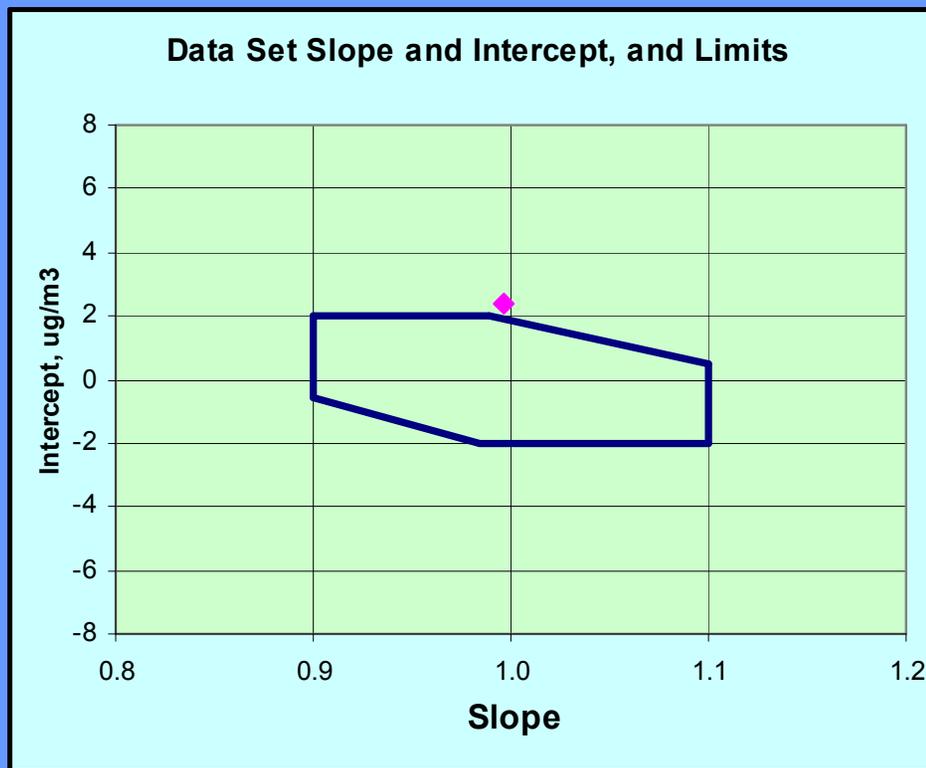
Period 4/1/09 to 9/17/09



FRM Comparability - Dryer Efficiency

Less Efficient Dryer
(typically yields greater additive bias)

Efficient Dryer
(normal additive bias)



General Network Issues

- Presently maintain FRM/FEM collocation at design value site in Kansas City MSA for quality assurance requirements and FEM performance monitoring.
- Report Regional Method (not an approved ARM) to AQS under Parameter Code 88502 for the FRM/FEM collocated site. (To support a potential modification of methods by user request if cold weather bias is a problem for NAAQS attainment decisions)
- Report PM_{2.5} Volatile Channel (reference) as AQS Parameter Code 88503
- Report PM_{2.5} Total Atmospheric (uncorrected) as AQS Parameter Code 88500 (meets Class III equivalency in colder months)

Conclusions

- The FEM in MO is comparable to the FRM averaged over all seasons, but its use may be less desirable if concentrations are close to attainment due to cold weather bias.
- There are several TEOM-FDMS methods that are comparable to the FRM but only the FEM is approved for NAAQS comparisons.
- Monitor dryer performance and/or replace dryer annually.
- Options:
 - Continue with FEM “as is” and accept the bias.
 - Start new ARM test with FDMS-8500C (Best solution but is too costly).
 - Propose a Modification of Method by User: Substitute raw FDMS data (already reported to AQS under method code 88500) at the applicable temperature threshold.