DRAFT – A review of recent TEOM and laser particle counter performance, and implications for recent coal-train observations and future monitoring

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What I am NOT saying…

- I am NOT claiming that coal trains are free from environmental or human health impacts. We have concerns (to be addressed in SEPA process).
- I am NOT claiming the proposed coal terminal is free from environmental or human health impacts. We have concerns (to be addressed in SEPA process).
- I am NOT claiming that I have compelling evidence for or against the proposed coal train terminal. We have concerns(to be addressed in SEPA process).

What I AM saying…

- Our review of our TEOM instrument, laser particle counter evaluations, and recent observations raised concerns about their accuracy and uncertainty.
- There is a lack of direct, high-quality information on emissions from coal-trains and coal loading facilities.
- We have concerns about the impacts of coal trains and loading facilities, and further monitoring is warranted (to be addressed in SEPA process).

PM Measurement Challenges:
(a gentle reminder)

- particles that are routinely measured have sizes that span 3 orders of magnitude, 0.01 um – 10 um
- a 1 um particle has same mass as 1,000,000 particles that are 0.01 um
- “a lot of” ultrafine particles may translate into essentially <u>no fine PM mass</u>
- semi-volatile nature can produce artifacts
- Health effects evidence, and the NAAQS are mass based (at least for now)

Challenges with PM Measurements

- Condensation Particle Counters (CPCs) are good at counting number (0.01-1 um), but give no mass or size information
- filters give mass, but not size/count, can get composition ($)
- scattering measurements have to make assumptions about scattering:mass or scattering:size:mass
- the scattering of a particle, and thus scattering:mass, can vary considerably based on particle and instrument properties:
  - particle size (in Rayleigh regime, scat $\propto D_p^4$)
  - particle shapes (but not for $D_p << \lambda$)
  - particle composition (changes the refractive index)
  - scattering angle (much more forward at 1 um than 0.1 um)
  - wavelength (scattering intensity can fall as λ^4)

Measuring scattering/count is easy and popular, but what does it mean?

- must "calibrate" scattering measurement in identical particle population to get a mass value with an accuracy that is better than +/- 100%
- small, portable laser particle counters actually rely on scattering as well
  - count individual scattering events (particles) and then assign a mass/scattering category/ratio based on the magnitude of the spike

How good is laser particle counter data?

- E.g. DustTrak 8533/8520, Dylos 1700
- Literature reports DustTrak requires substantial correction factors from the default “dust” factor
- Reported correction factors span 2.2-4.6 (220% to 460%) for combustion sources, with std. dev. of +/- 30% in the slope.
- “… the factory calibration using Arizona road dust does not appear suitable for the type of combustion aerosols generated from fires involving coal, wood, and rubber, and most probably other combustion sources, because of their smaller particle size (≤ 0.5 μm).”

Heal et al, 2000; Chang 2001; Kingham 2006; Perera and Litton 2013

Table 1. Scattering, Extinction and Absorption coefficients for aerosols from the different combustion sources.

Flaming	**σ_{ext}(532 nm)**	**σ_{sca}(520nm)**	**σ_{abs}(532nm)**	**σ_{ext}(visible)**	**Albedo**	**OD**
Douglas Fir	16.70	3.30	13.40	13.70	0.198	0.073
Pgh Coal	12.86	4.47	8.34	11.20	0.347	0.058
SBR Rubber	16.06	5.45	10.62	11.10	0.339	0.070
Polypropylene	26.61	7.29	18.33	17.77	0.274	0.092
No. 2 Diesel Fuel	22.13	5.48	16.65	20.15	0.248	0.096
Non-Flaming						
Douglas Fir	7.59	6.61	0.99	4.27	0.870	0.033
Pgh Coal	7.04	6.21	0.82	5.22	0.883	0.031
SBR Rubber	8.27	7.17	1.11	4.51	0.866	0.036
Polypropylene	15.67	14.14	1.54	10.49	0.902	0.068

Perera and Litton, 2011

How good is a TEOM (tapered element oscillating microbalance)?

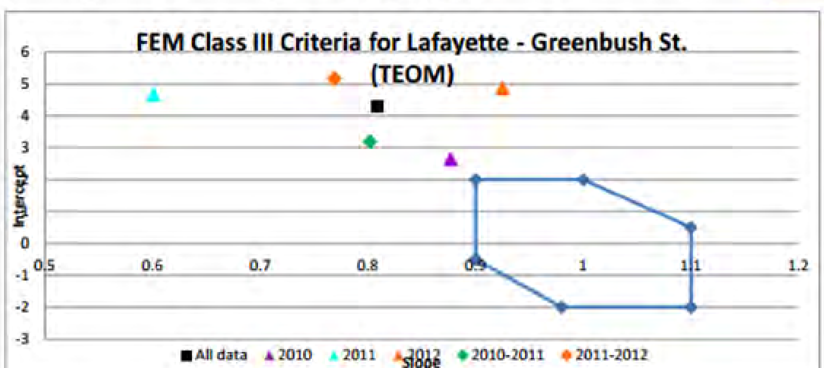
- approved and widely used as Federal Equivalent Method, but…
- inlet moisture can produce biases
- pump vacuum needs to be strong and stable
- leaks, filter problems
- dryers can fail or degrade
- e.g. State of IN petitioned to have 3 years of TEOM data thrown out because of rising offsets and poor slopes.
- Intercept (zero) was as high as 5 ug/m^3.

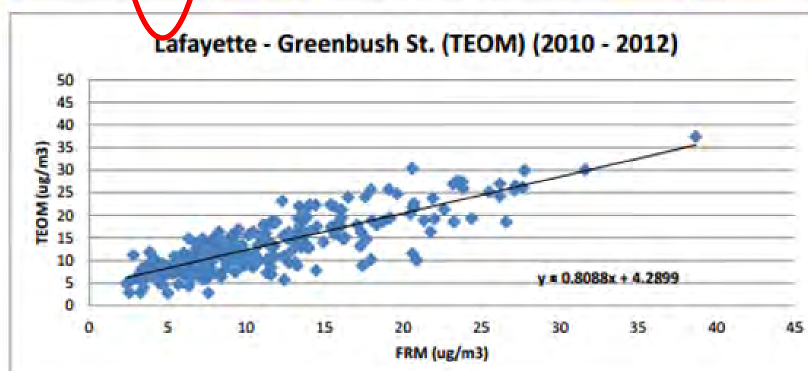
- TEOM-FRM comparison shows ongoing bias (offset) wrt FRM

Table 13
Lafayette - Greenbush St.

Site Name	**Lafayette - Greenbush St.**
City	**Lafayette**
AQS #	**181570008**
POC	**4**
Instrument	**R&P 1400a TEOM w/ FDMS**
Method Description	**TEOM**

PM2.5 Continuous Data Period			Continuous/FRM Sample Pairs Per Season			Slope Criteria			Intercept Criteria			Correlation Criteria				
Data Period	Begin Date	End Date	Season	# of Pairs	Meets Req?	Acceptable Range	Slope (m)	Meets Req?	Acceptable Range	Intercept (y)	Meets Req?	CCV	Acceptable Correlation Range	Correlation	Meets Req?	Data Status
2010	1/1/2010	12/12/2010	Winter = Spring = Summer = Fall = Total =	25 29 20 29 103	No	1 +/-0.10	0.8799	No	2.0000 to -0.1899	2.6580	No	0.595	>=0.9500	0.9451	No	Incomplete Data / Not Acceptable
2011	1/1/2011	12/31/2011	Winter = Spring = Summer = Fall = Total =	10 0 20 29 59	No	1 +/-0.10	0.6010	No	2.0000 to 4.6407	4.6706	No	0.568	>=0.9500	0.6552	No	Incomplete Data / Not Acceptable
2012	1/1/2012	12/31/2012	Winter = Spring = Summer = Fall = Total =	29 25 28 29 111	Yes	1 +/-0.10	0.9251	Yes	2.0000 to -0.9727	4.8819	No	0.558	>=0.9500	0.9012	No	Not Acceptable
2010 - 2011	1/1/2010	12/31/2011	Winter = Spring = Summer = Fall = Total =	35 29 40 58 162	Yes	1 +/-0.10	0.8019	No	2.0000 to 1.1611	3.1901	No	0.587	>=0.9500	0.8582	No	Not Acceptable
2011-2012	1/1/2011	12/31/2012	Winter = Spring = Summer = Fall = Total =	39 25 48 58 170	Yes	1 +/-0.10	0.7689	No	2.0000 to 1.7327	5.1721	No	0.563	>=0.9500	0.7634	No	Not Acceptable
2010 - 2012	1/1/2010	12/31/2012	Winter = Spring = Summer = Fall = Total =	64 54 68 87 273	Yes	1 +/-0.10	0.8088	No	2.0000 to 1.0416	4.2899	No	0.583	>=0.9500	0.8402	No	Exclude

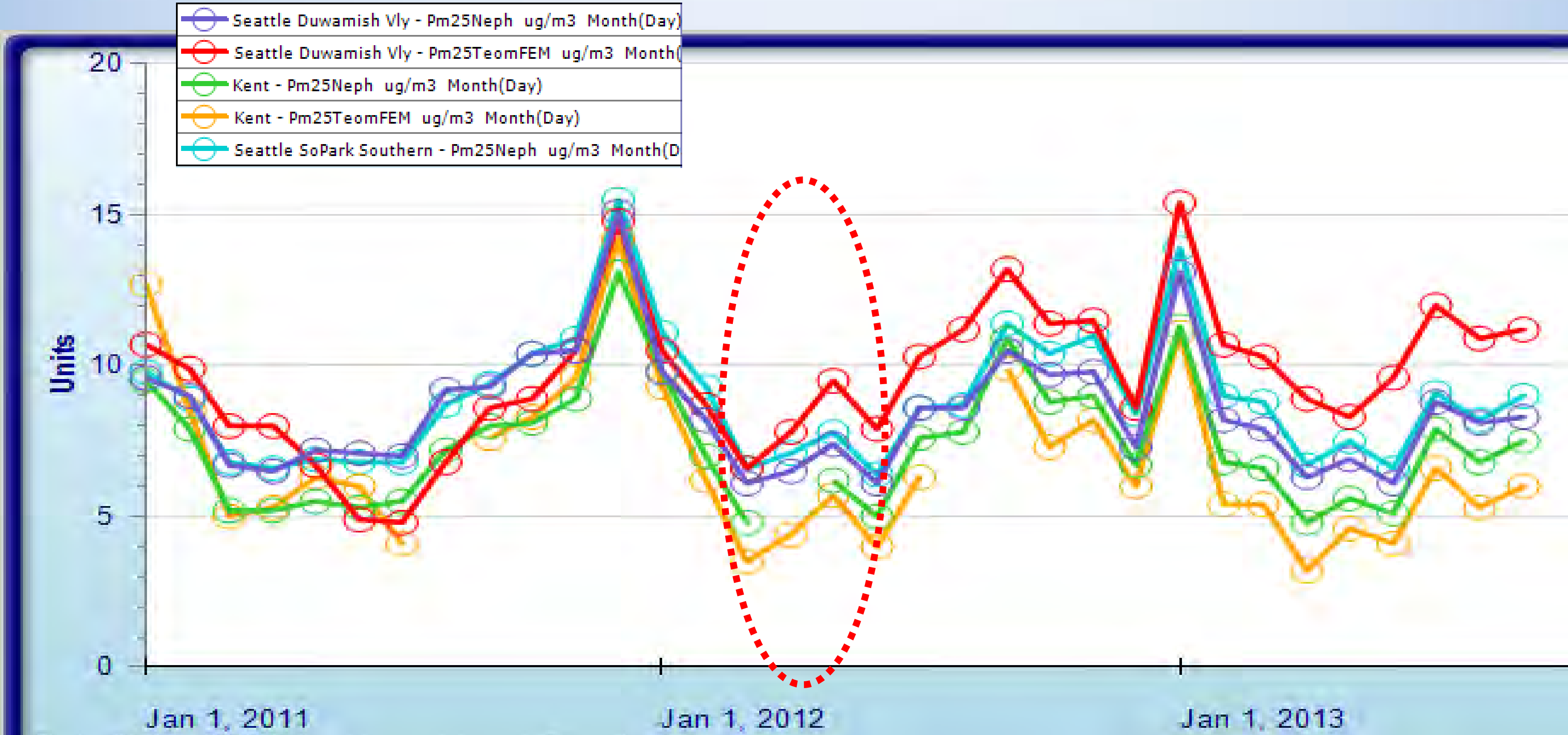




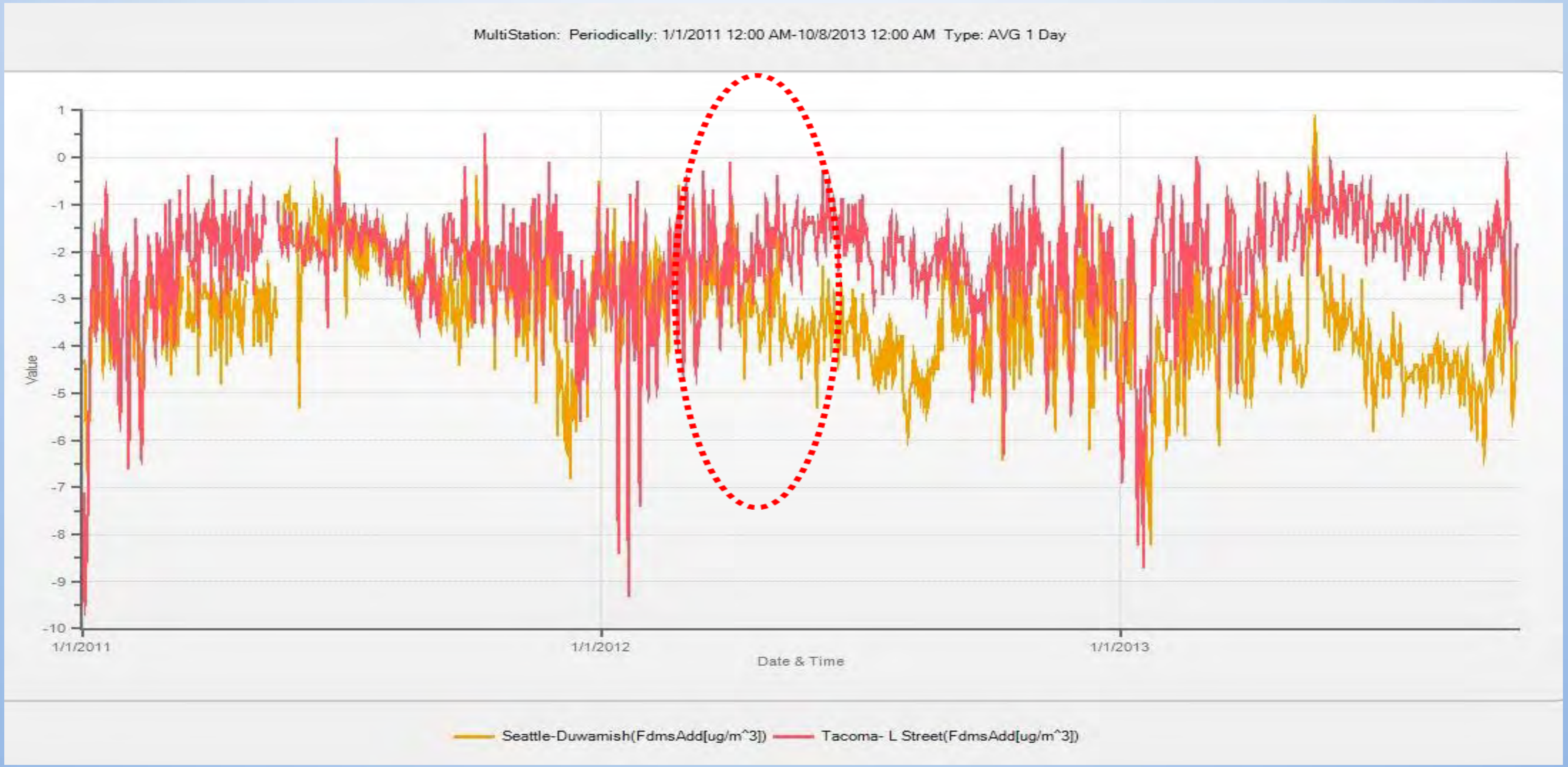
Potential problems with our TEOM ?

- Appeared there was a growing discrepancy between Duwamish TEOM and collocated neph, and nearby TEOM and nephs
- at end of 2013 averaged 3-5 ug/m^3 higher than comparable monitors
- nephs average within ~1-2 ug/m^3 of each other (quarterly average)
- could be a bias of 2+ ug/m^3 in the TEOM?
- this bias can be acceptable, but when values approach the NAAQS, or is used as reference (absolute accuracy) w.r.t. similar concentrations, could easily be a problem

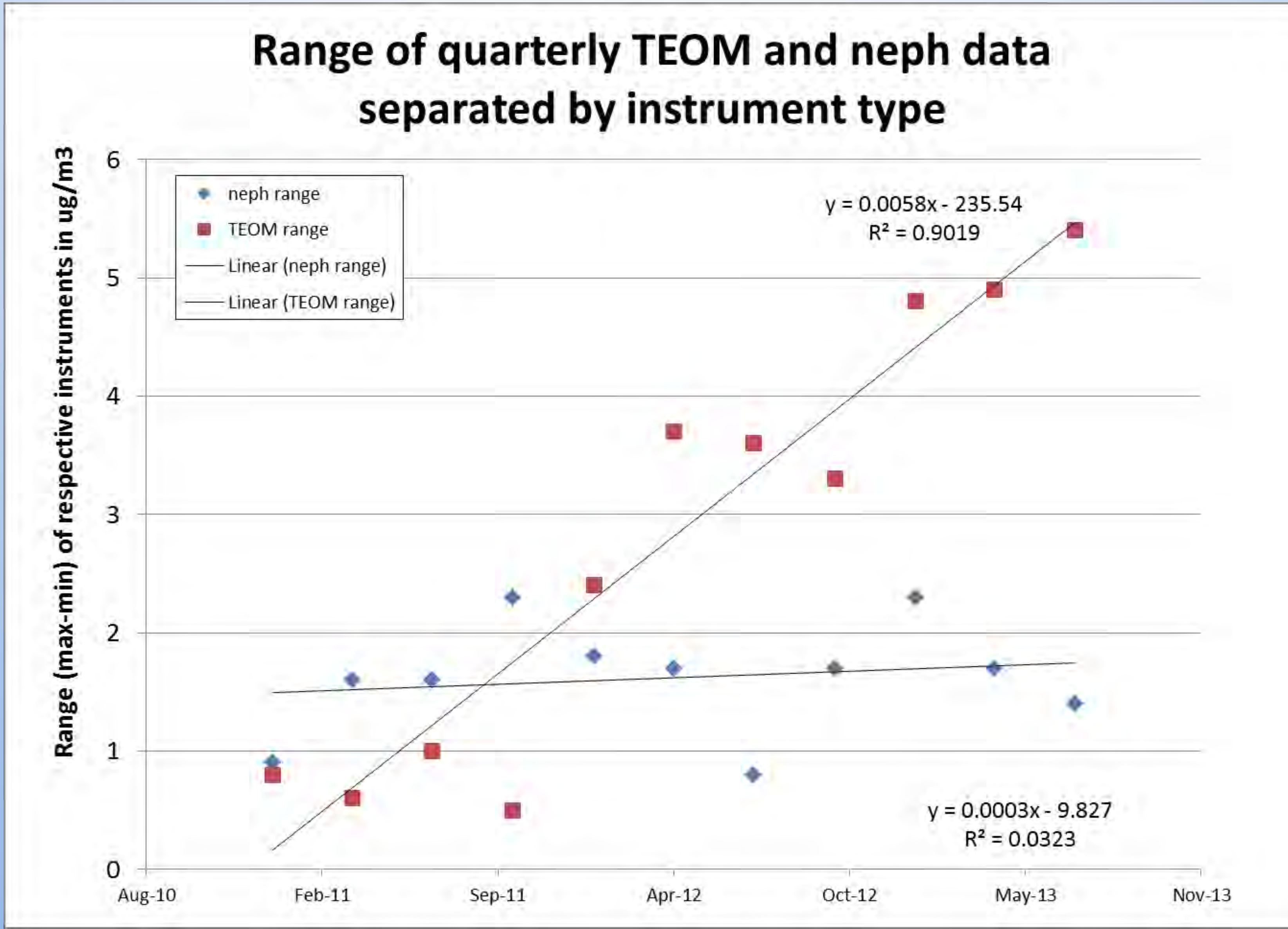
TEOM and nephelometer data from Duwamish, Kent, and South Park from 2011-2013



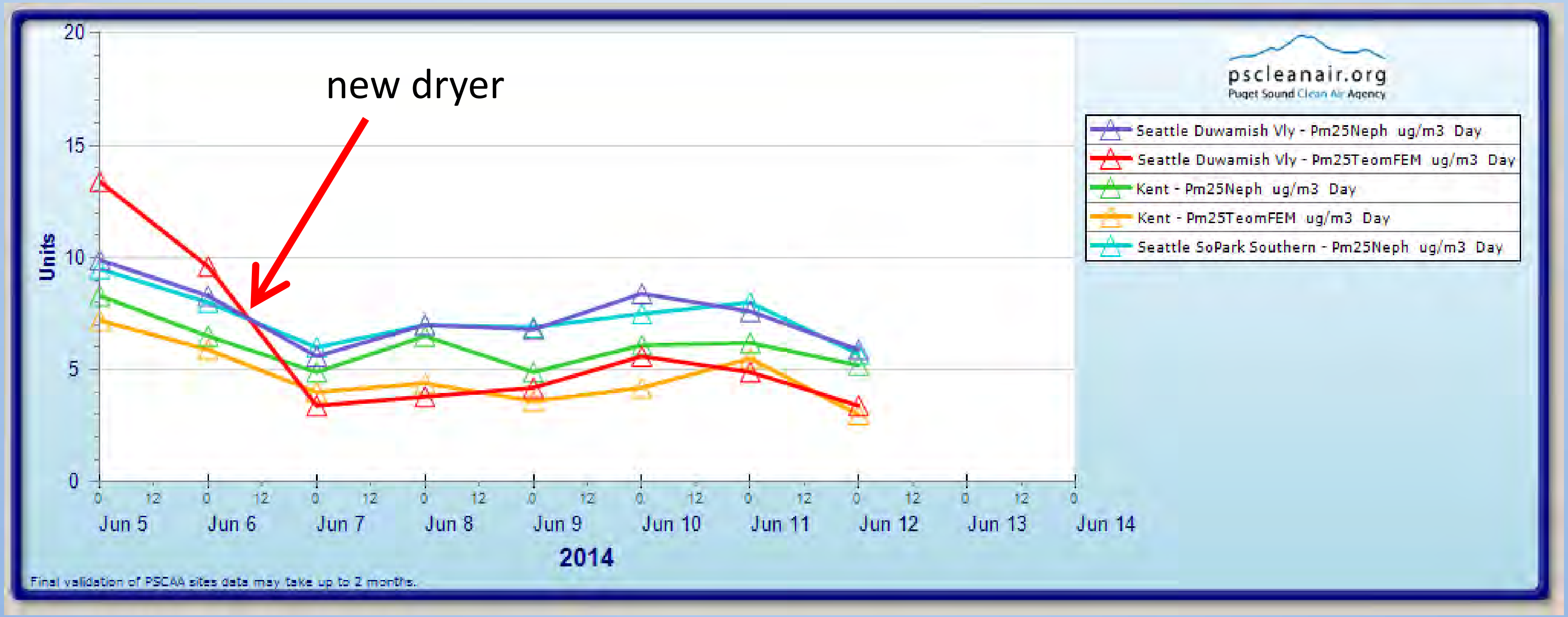
Problems with the Add-In channel??



A growing discrepancy?
Comparable nephs don't diverge, but TEOMS do

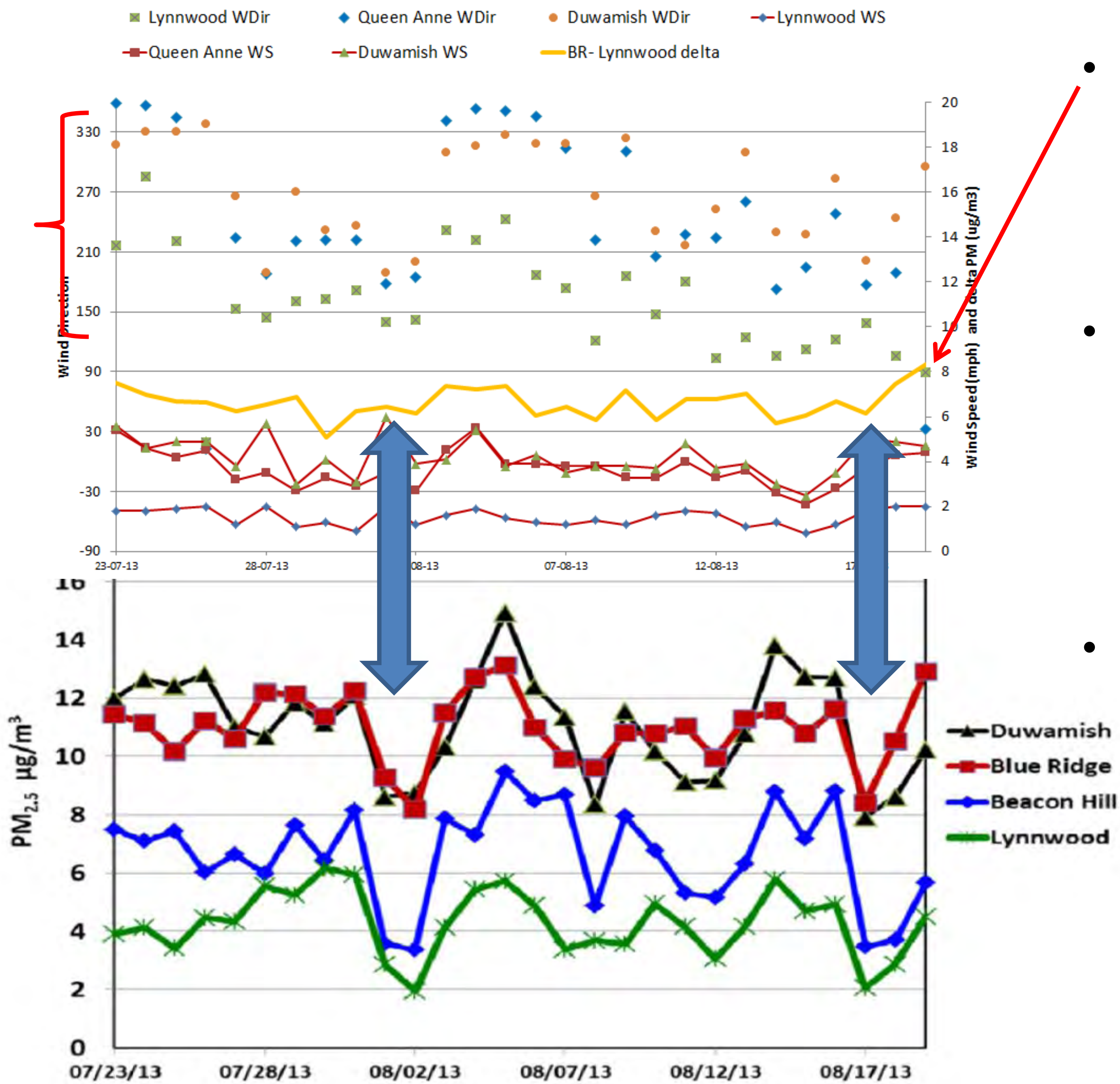


Redeployed this TEOM with new dryer, shows lower values more consistent with historical data



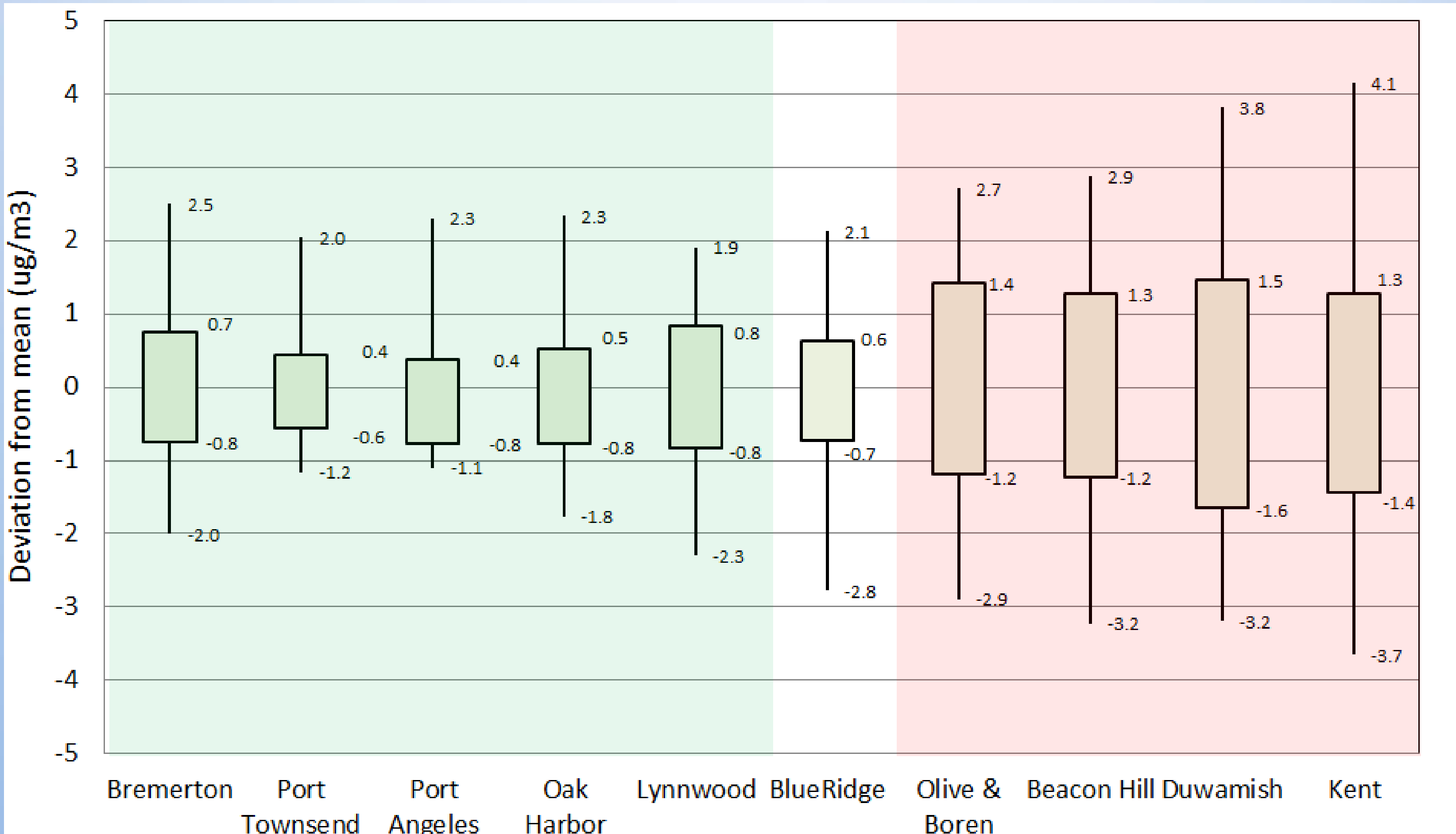
Implications for recent observations

- Jaffe et al 2014, use DustTrak, 25m from tracks in Blue Ridge, July 23 - Aug 19, 2013
- report an excess of 6.8 ug/m^3 over background
- used correlation with our TEOM at Duwamish site to generate a calibration factor (has offset of 4.4 ug/m^3)
- further review reveals some concerns



- Orange line shows the difference between Blue Ridge and Lynnwood
- the difference remains in a small range (+/- 10%), despite a range of wind directions and speeds
- during synoptic events that cleared the region, the difference is indistinguishable from rest of campaign

Blue Ridge has distribution of data similar to background, not elevated sites



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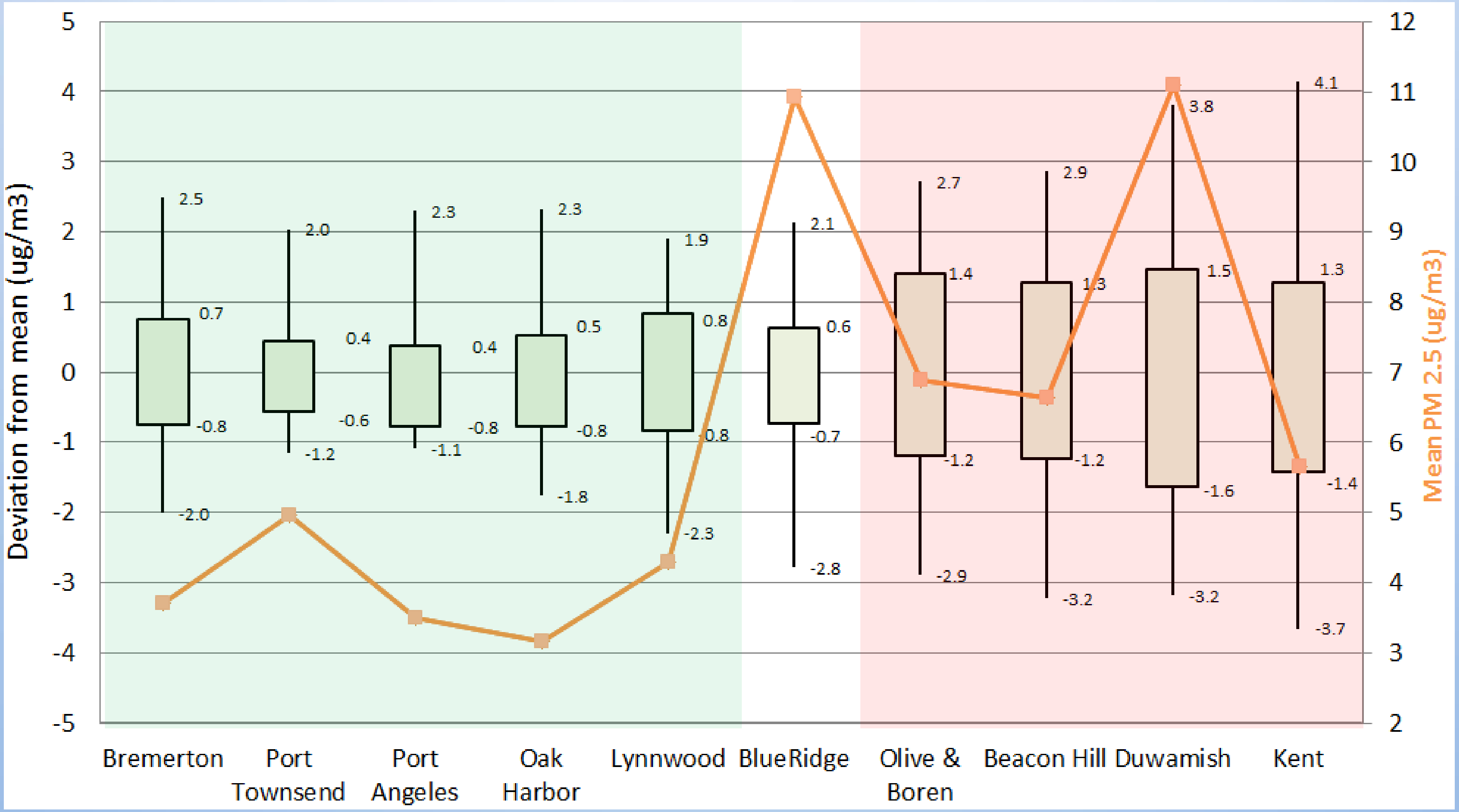


Accounting of the variance

- the variance (std dev squared) of the difference between two sites is:

  variance of actual difference +

  variance of random instrument fluctuations +

  covariance of the two

In equation form:

$$\sigma^2_{BR-bg} = \sigma^2_{TrueDif} + \sigma^2_{Inst} + 2cov_{TrueDif-Inst}$$

the variance of measured difference (Blue Ridge – Lynnwood) is 0.46, so:

$$0.46 = \sigma^2_{TrueDif} + \sigma^2_{Inst} + 2cov_{TrueDif-Inst}$$

Accounting of the variance…

rearranging:

$$\sigma^2_{TrueDif} = 0.46 - \sigma^2_{Inst} - 2cov_{TrueDif-Inst}$$

conservatively assuming the covariance is 0, we set an upper limit:

$$\sigma^2_{TrueDif} < 0.46 - \sigma^2_{Inst}$$

from the DustTrak-TEOM intercomparison at Duwamish, the variances were 0.50 and 0.84 for two DustTraks, this yields:

$$\sigma^2_{TrueDif} < 0$$

… which requires/implies a physical source with zero variability over 28 days under varying wind speeds and directions, and with a number of source variability terms => not consistent with a large source

(Note this is consistent with the Blue Ridge data failing Chi-square and F-tests for differences in variance compared to Lynnwood.)

Do the individual train events support the calibration (implying an accumulation)?

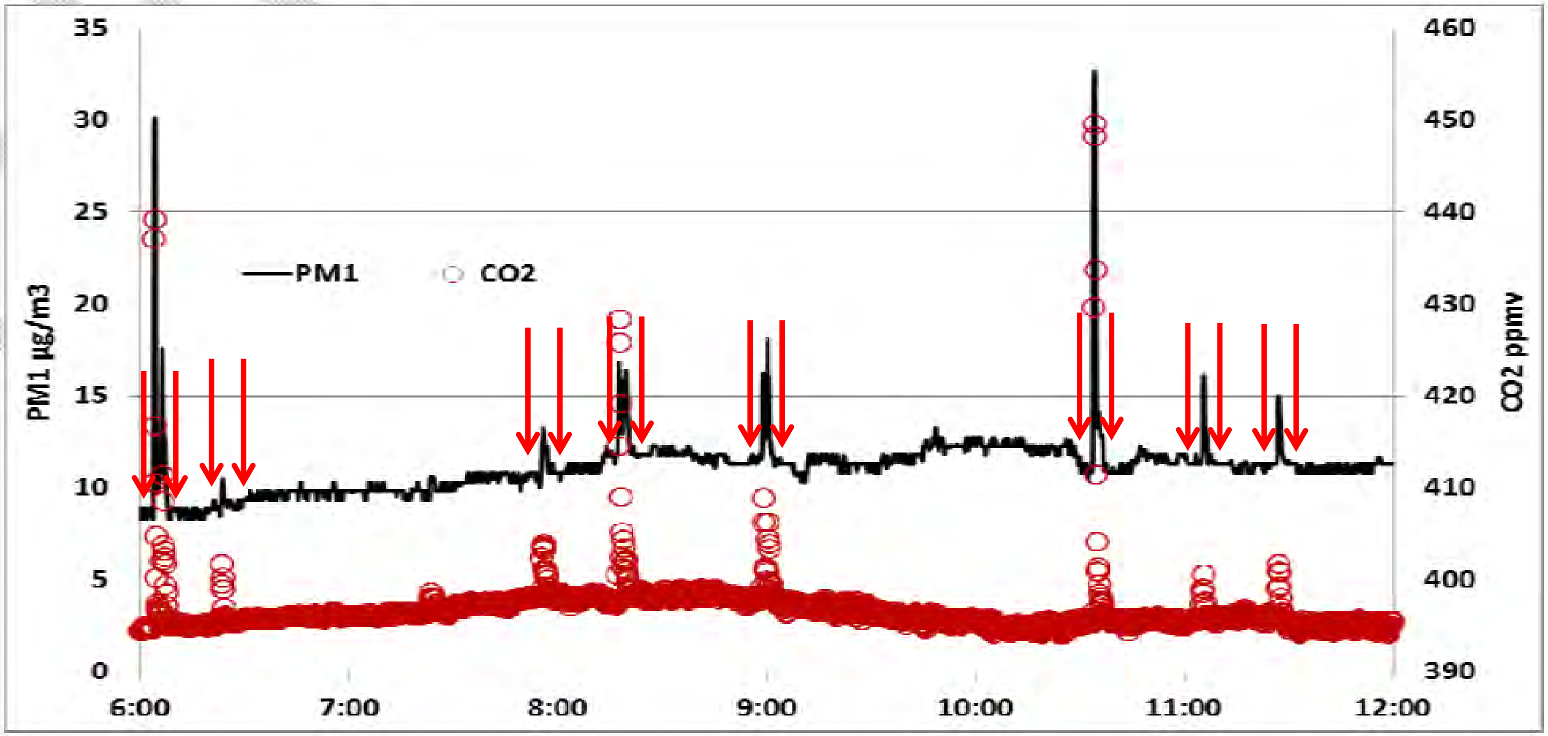


Figure 3. PM_1 ($\mu g/m^3$) and CO_2 (ppmv) data (10-second averages) from the Blue Ridge site for July 25, 2013, between 06:00 and 12:00 local time. During this period, we identified 8 trains from the atmospheric data and confirmed by video images.

- compare values before and after each spike, what is lasting difference?

Impact of individual trains, values before and after passing

- data from Figure 3, 8 identified trains
- tabulated average value 3-min before train, 3-min after, and peak
- mean delta per train was 0.022 ug/m^3 (+/- 0.071) [which fails a paired t-test p>0.4]
- to reach an accumulation of 6.8 ug/m^3 would require >20 days
- following synoptic event on Aug 1-2, Blue Ridge daily average rises to 11.4 ug/m^3 (which is greater than the mean)
- suggests is in steady-state on timescale of < 24 hours

	PM1 (ug/m3)			
Train #	before	peak	after	delta
1	8.47	30.1	8.59	0.12
2	9.03	9.8	9.00	-0.02
3	10.54	11.8	10.67	0.14
4	11.77	14.7	11.77	0.00
5	11.57	16.3	11.57	0.00
6	10.93	30.4	10.86	-0.07
7	11.21	15.8	11.22	0.01
8	11.29	13.8	11.29	0.00
average delta per train				0.022
Standard deviation				0.071
Composite of all 8 trains				0.18

Summary I

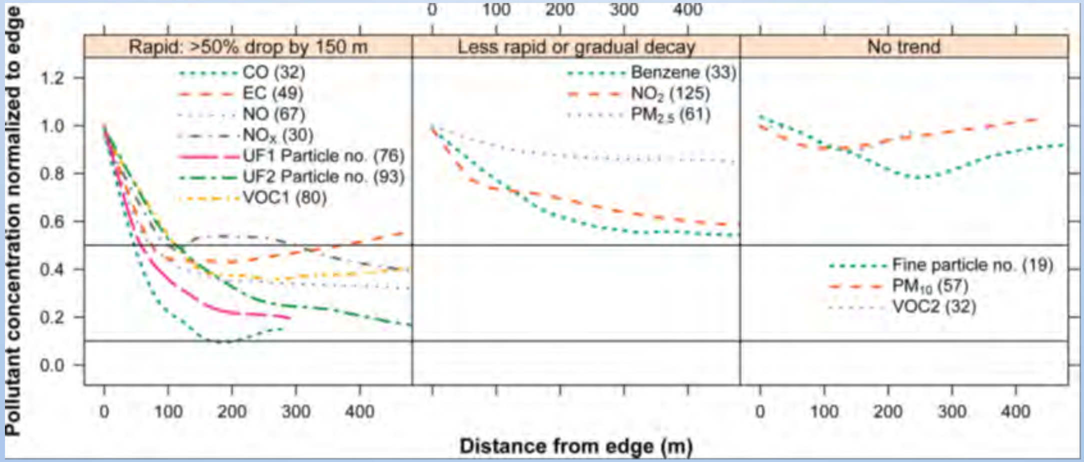
- Laser particle counter: *caveat emptor*, need aerosol population specific calibration and sensitivity information
- TEOMs can perform well, but have also been shown to drift in some cases (QA protocol may need to be revised)
- There are multiple uncertainties and variability in observations with a laser particle counter under these conditions that would be expected, or were observed:
  - PM mass:scattering differences between combustion sources and dust (change from engine to dust from cars)
  - PM1/CO_2 ratio differences, suggesting combustion quality (engine tier, age, throttle?) and aerosol population differences between engines

Summary II

- Low variability of the reported difference does not appear to be consistent with a large ambient source, given variability expected from
  - instrument response to varying aerosol population
  - number and type of engines/trains per day
  - wind speeds, wind direction, vertical mixing
- Offsets can creep up on TEOMs, the reference instrument probably had a positive bias of 2 ug/m^3, perhaps more
- More thorough study is needed to investigate this issue

Considerations for future monitoring

- railroads, like highways, can be modeled as line sources, thin area sources, or volume sources with a regulatory model like AERMOD
- Observations of near-road profiles show highest level pollutants drop off substantially by 100-200 m



Karner, A., Environ. Sci. Technol. 2010, 44, 5334–5344

Considerations II

- So, space observations at distances that can capture exponential decrease
- need <u>direct</u> mass measurements to constrain other proxies:
  - at least at two distances, ideally closest and furthest (or cross reference to existing background)
  - can be integrated over longer duration (high time resolution not needed)
- minimum of 3 points for each side of a profile, perpendicular to the line
  1. as close as possible (10-20 meters) (not eligible for NAAQS comparison)
  2. ~ 100 meters (not eligible for NAAQS comparison)
  3. > 500 m, ideally 0.5 - 2 km, <u>neighborhood scale to make estimate w.r.t. NAAQS</u>
- if possible on both sides of line
  - otherwise, on side in direction of prevailing wind, and a single close point on the opposite

Considerations III

- non-massed based, non-regulatory method should be interpreted cautiously
- light scattering methods need response/calibration information from all types of aerosol populations that are expected to be encountered, automobile, diesel, woodsmoke, dust, etc
- uncertainty needs to include effect of differing aerosol populations within study
- “transfer” standards or cross-calibration instruments should be used during field sampling
- zero levels should be directly verified as part of routine QA/QC
- difference measurements should be interpreted cautiously

Questions, comments, concerns?

- Please call me:
- (206) 689-4085