Approaches to Determining Threshold Values for Snap-Shot Emissions Measurements

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“High Emitter” Problem

Small fraction of fleet emits disproportionately greater amounts of pollutants such as Black Carbon (BC) and Nitrogen Oxides (NO_X) relative to remainder of fleet.

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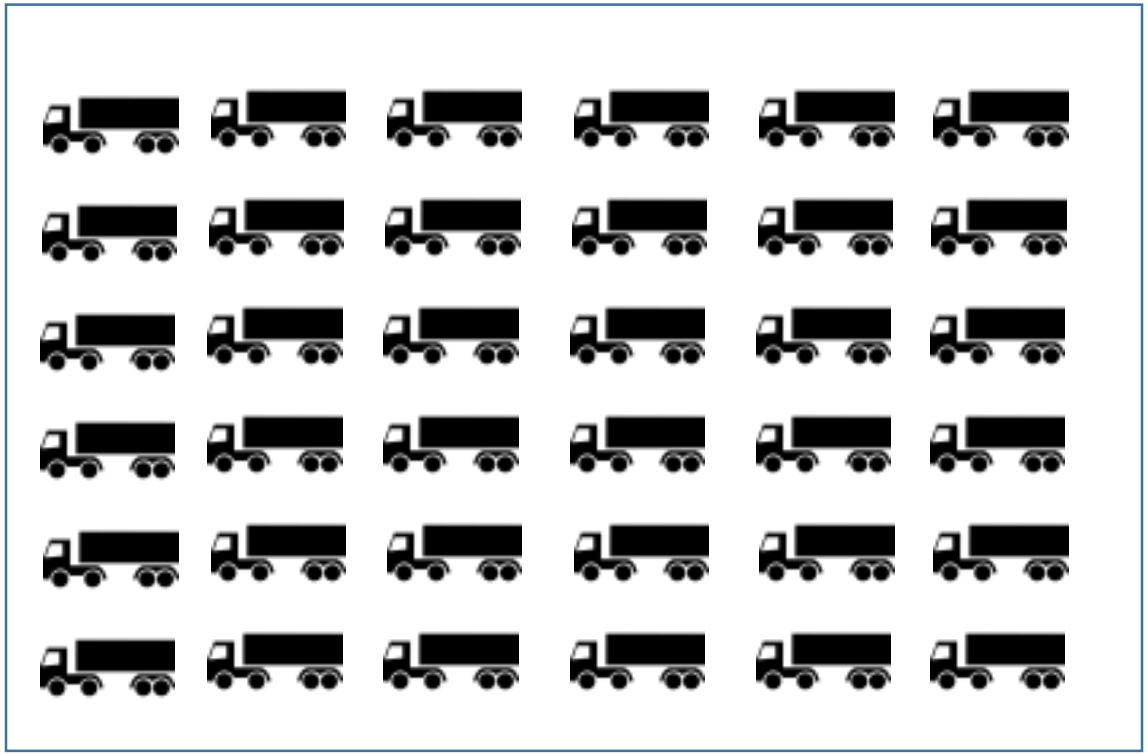

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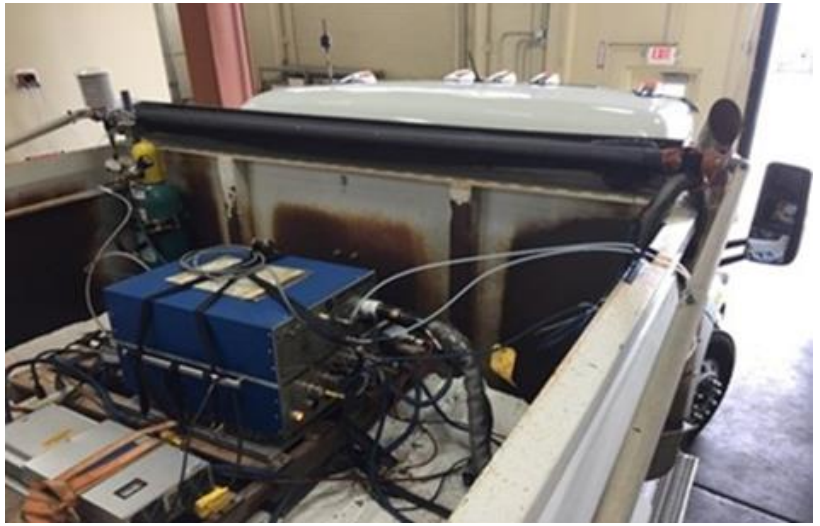
Ban-Weiss, George et al. *Measurement of Black Carbon and Particle Number Emission Factors from Individual Heavy-Duty Trucks*. ES&T 2009.

Preble, Chelsea et al. *Effects of Particle Filters and Selective Catalytic Reduction on Heavy-Duty Diesel Drayage Truck Emissions at the Port of Oakland.* ES&T. 2015.

Emissions Testing Systems

- Develop road-side plume capture system to support CARB:
  - Targeted heavy-duty vehicle screening and inspection tool
  - Aid in community air quality monitoring



- PEMs Testing
  - Test conducted in the Sacramento area out of the Depot Park Lab
  - Four Routes and 14 individual tests

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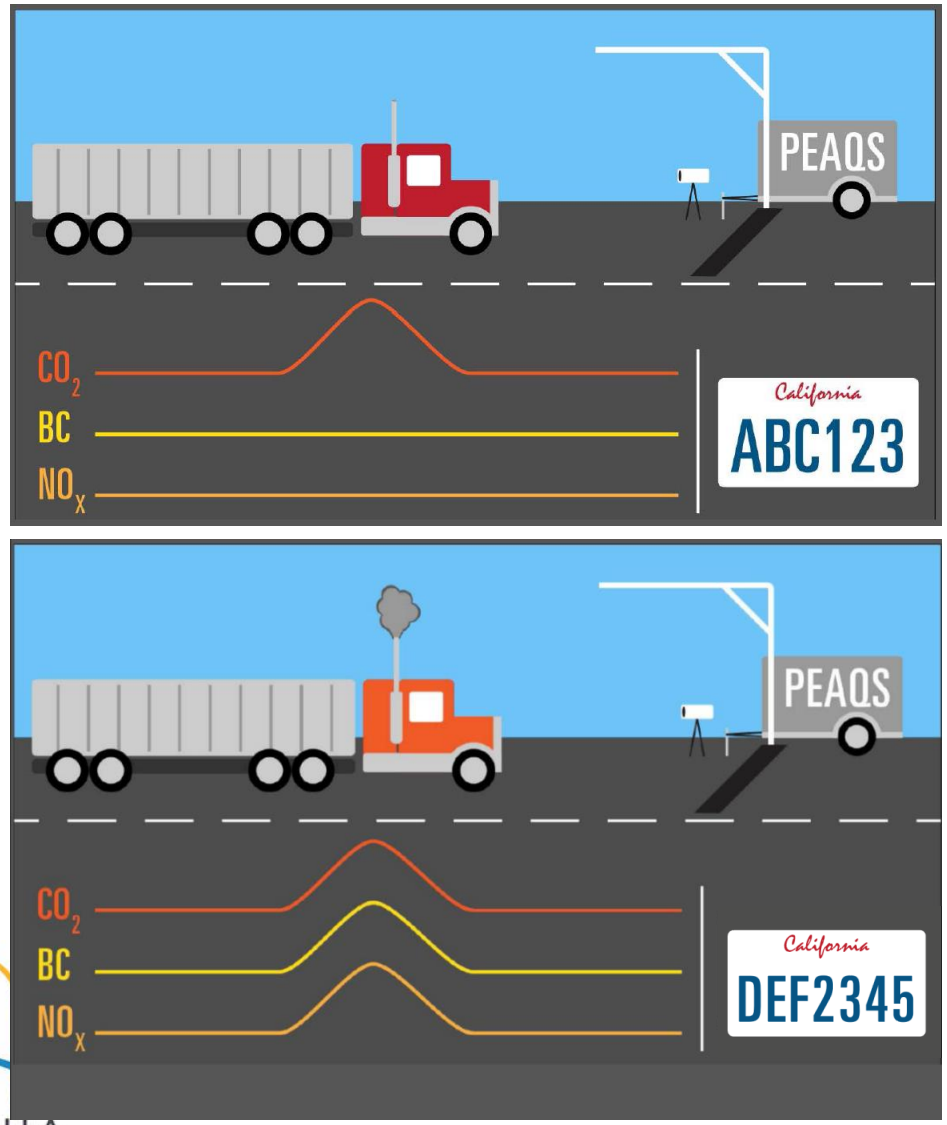
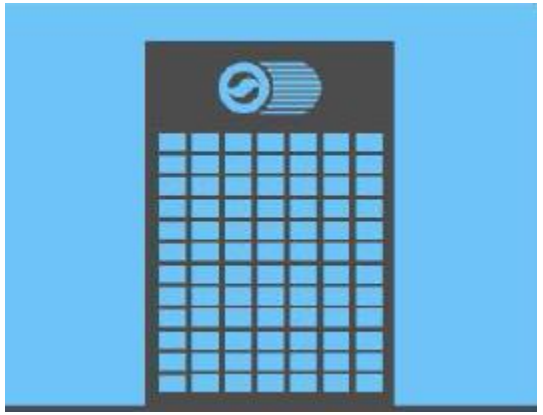
PEAQS Components



Species	Instrument
CO_2	Licor-840
BC	Magee AE-33 AethLabs AE-51
NO_X	CAI CLD-64 EcoPhysics CLD-60
Other	Geovision Camera Doppler Radar, Lidar



Additional Inspection

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Top Percentile

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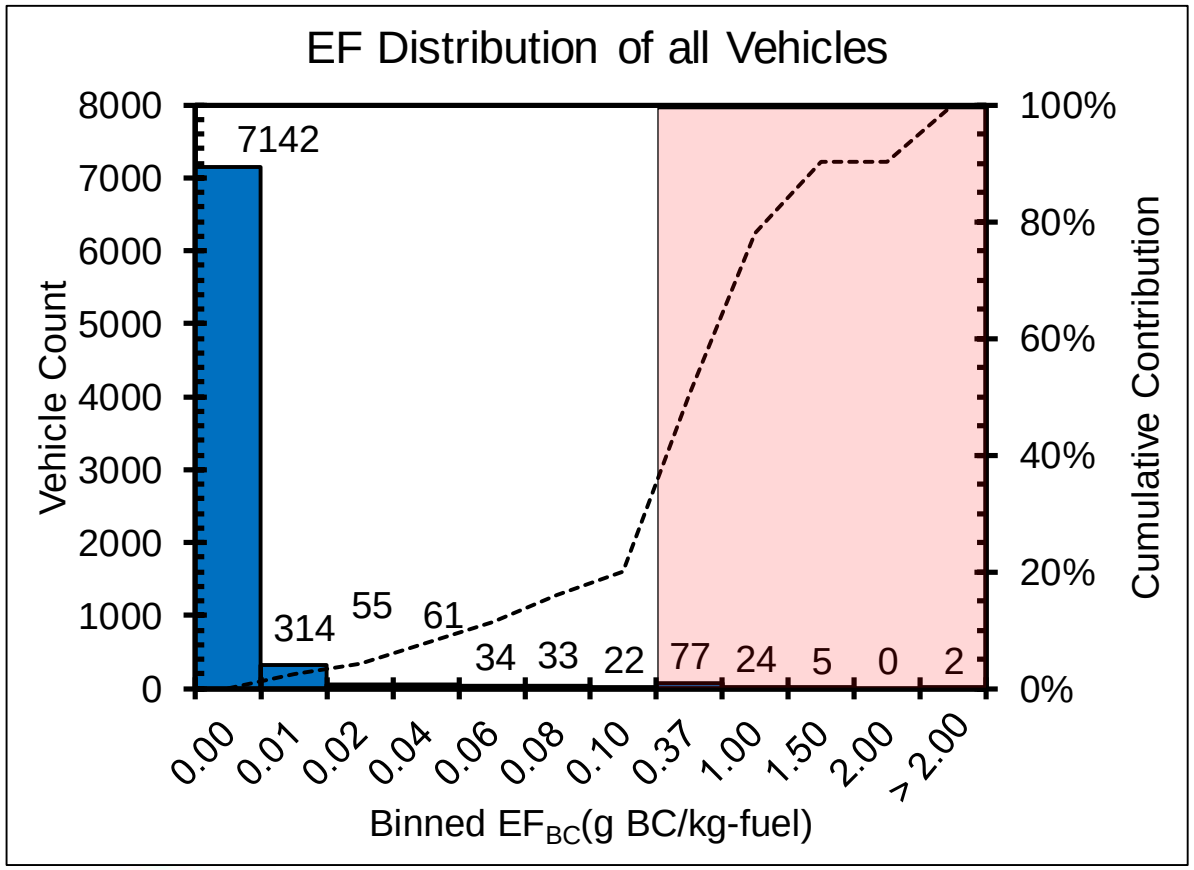
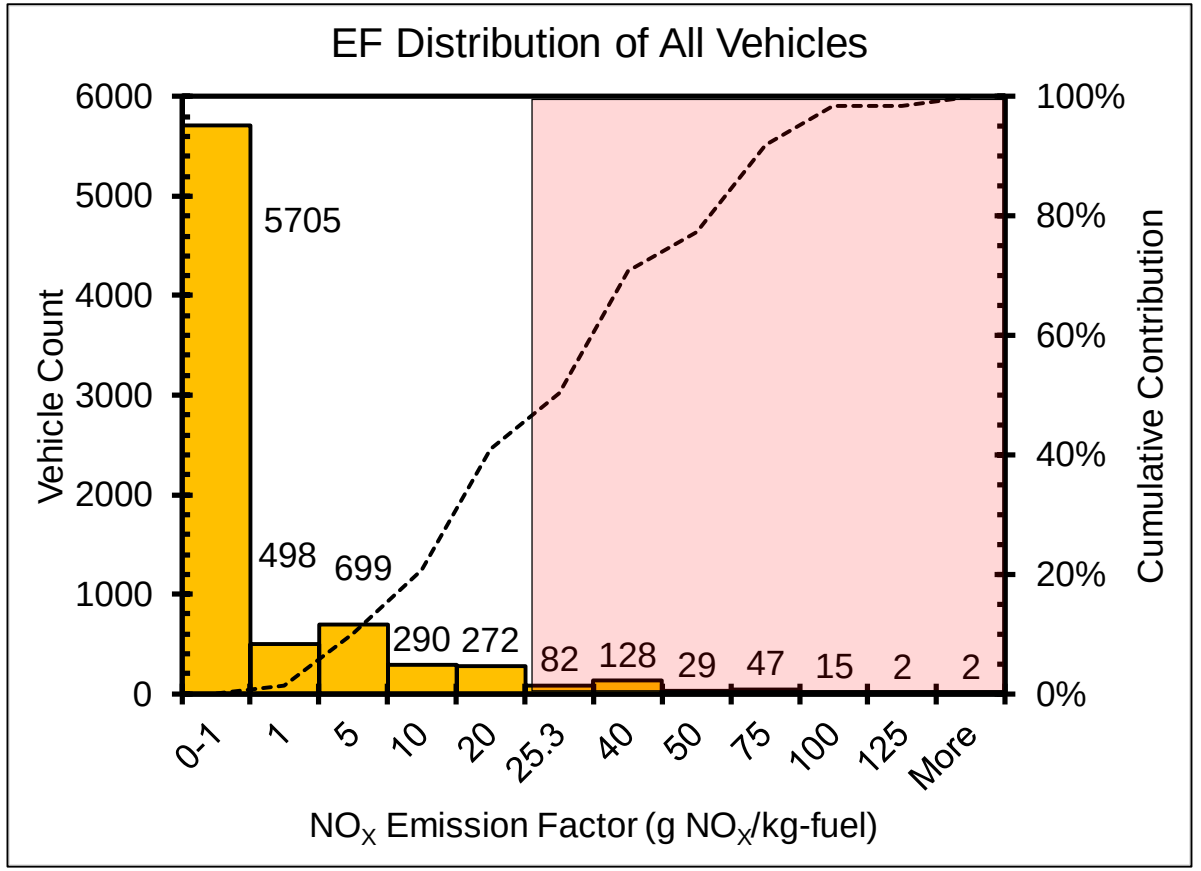
RSD Data Application: Highest Emitter Identification





1.4% of Trucks Emit 50% of all BC

Top Percentile appears to be location dependent

3.9% of Trucks Emit 50% of all NO_X

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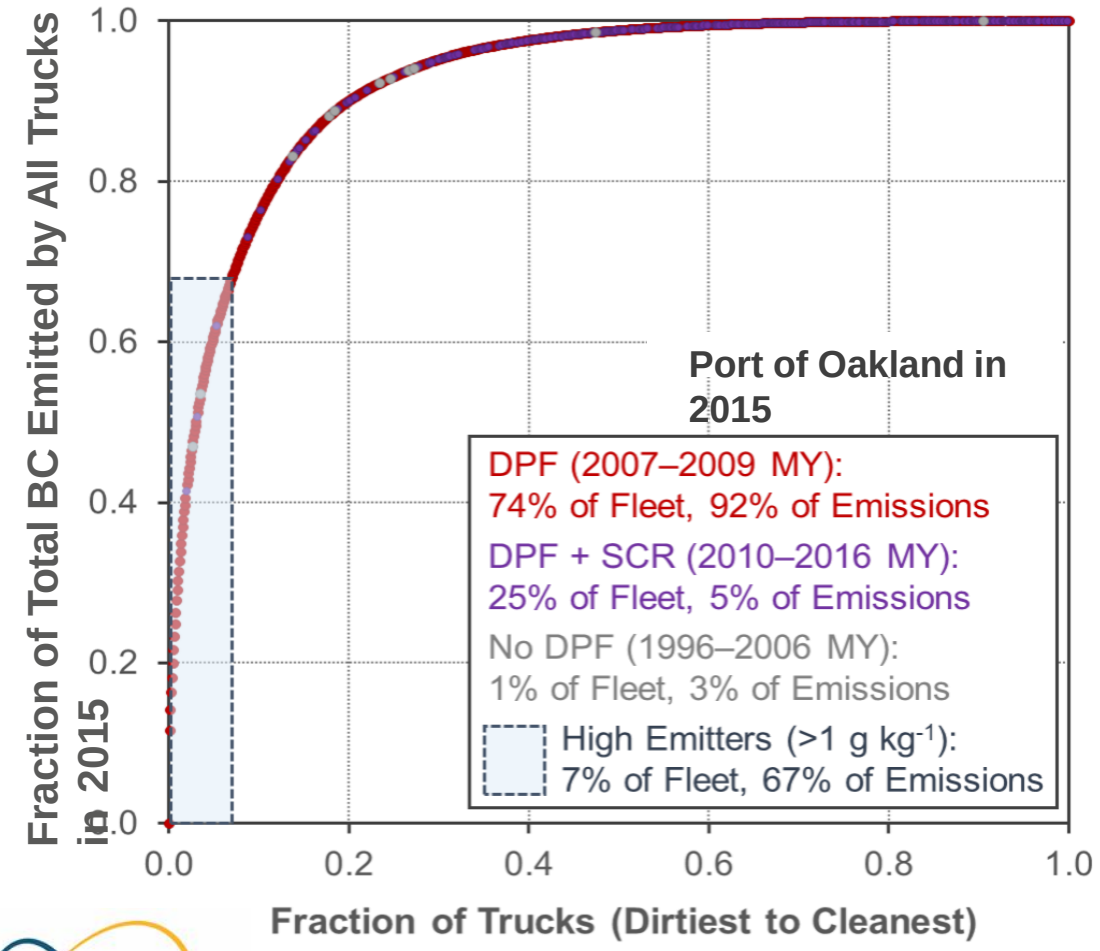
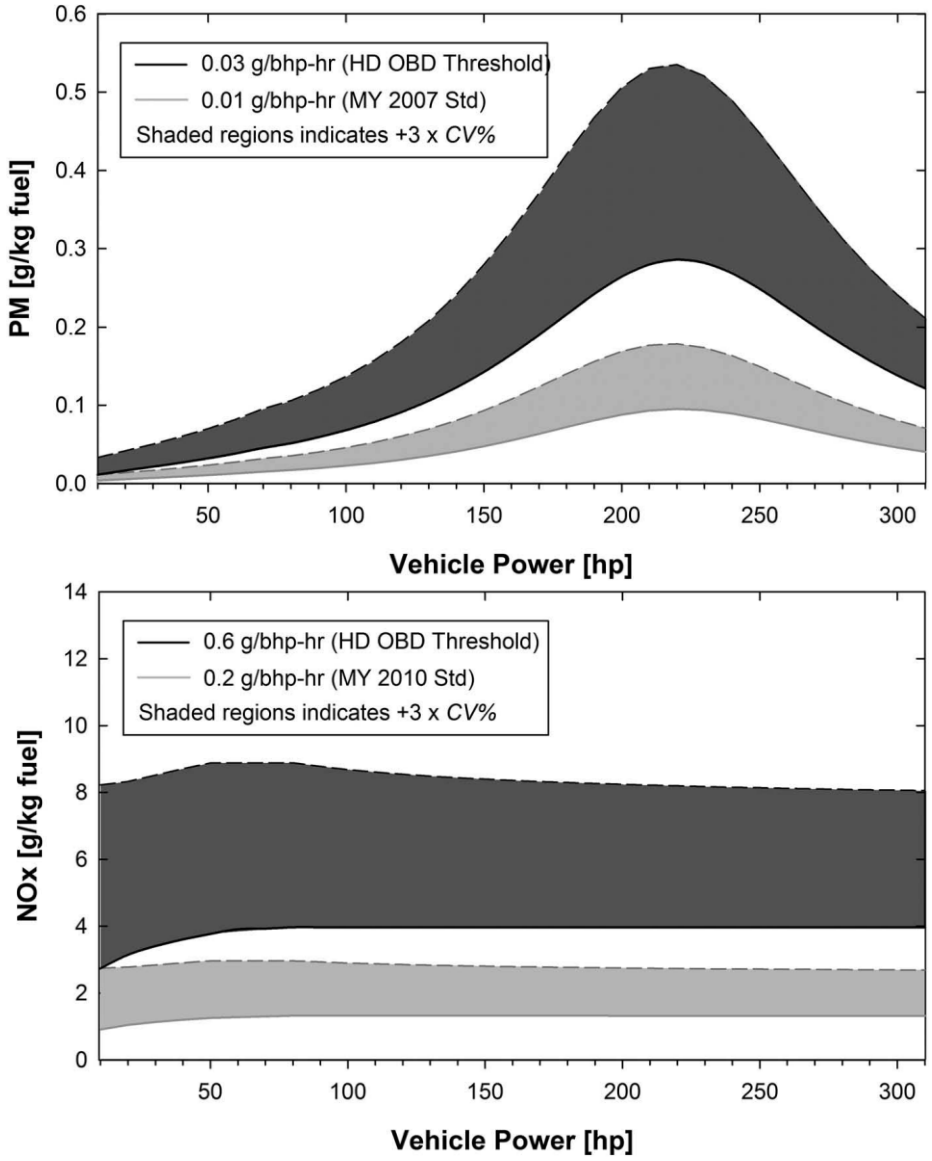
Results Consistent with Literature

(Preble et al., ES&T 2018)



(Quiros et al., JAWMA 2018)



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Plume Capture and Opacity

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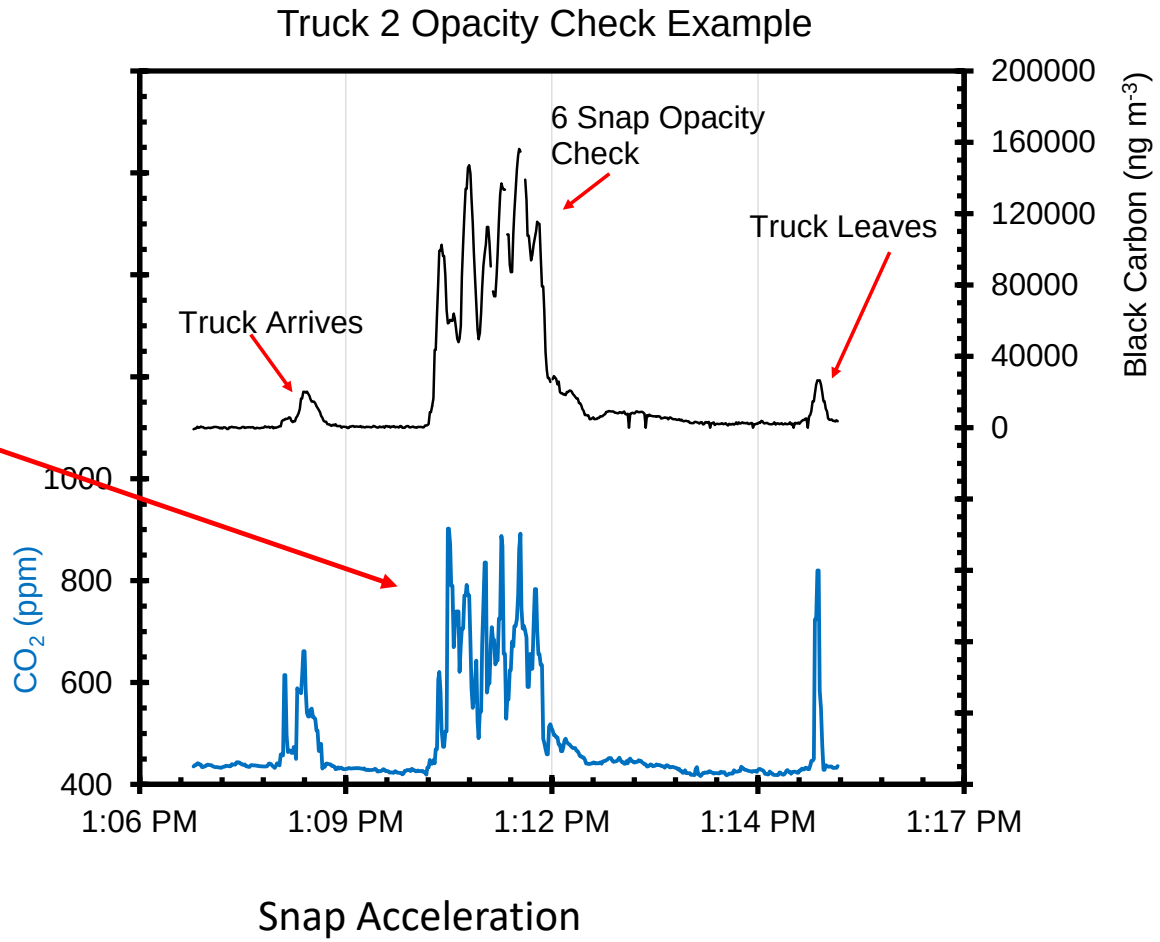
PEAQs and Opacity: Real-world testing example

- Opacity is measured during SAE J1667 'snap accels'
- Note sharp peaks in BC and CO_2 during snaps
- Total BC and CO_2 mass during snaps are used for calculations



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Theory: Co-located Opacity vs PEAQS Data

- Regression analysis using theoretical relationship between opacity light absorption and BC light absorption:

- From SAE J1667 protocol:

$$\textbf{Opacity} = 100 * (1 - e^{-kL})$$

Where *k* is smoke density and L is optical path-length

- From light-absorption theory (abbreviated):

$$\text{Opacity (\%)} = 100 * (1 - \text{Transmittance})$$

$$\text{Transmittance (T)} = \frac{\text{Measured Light flux}}{\text{Reference Light flux}}$$

$$\text{Absorbance} \approx \text{Attenuation (ATN)} \approx \ln(T)$$

$$T = e^{-ATN}$$

ATN within aethalometer is used for BC quantification

- Thus, we can estimate:

$$\textbf{Opacity} = 100 * (1 - e^{-ATN})$$

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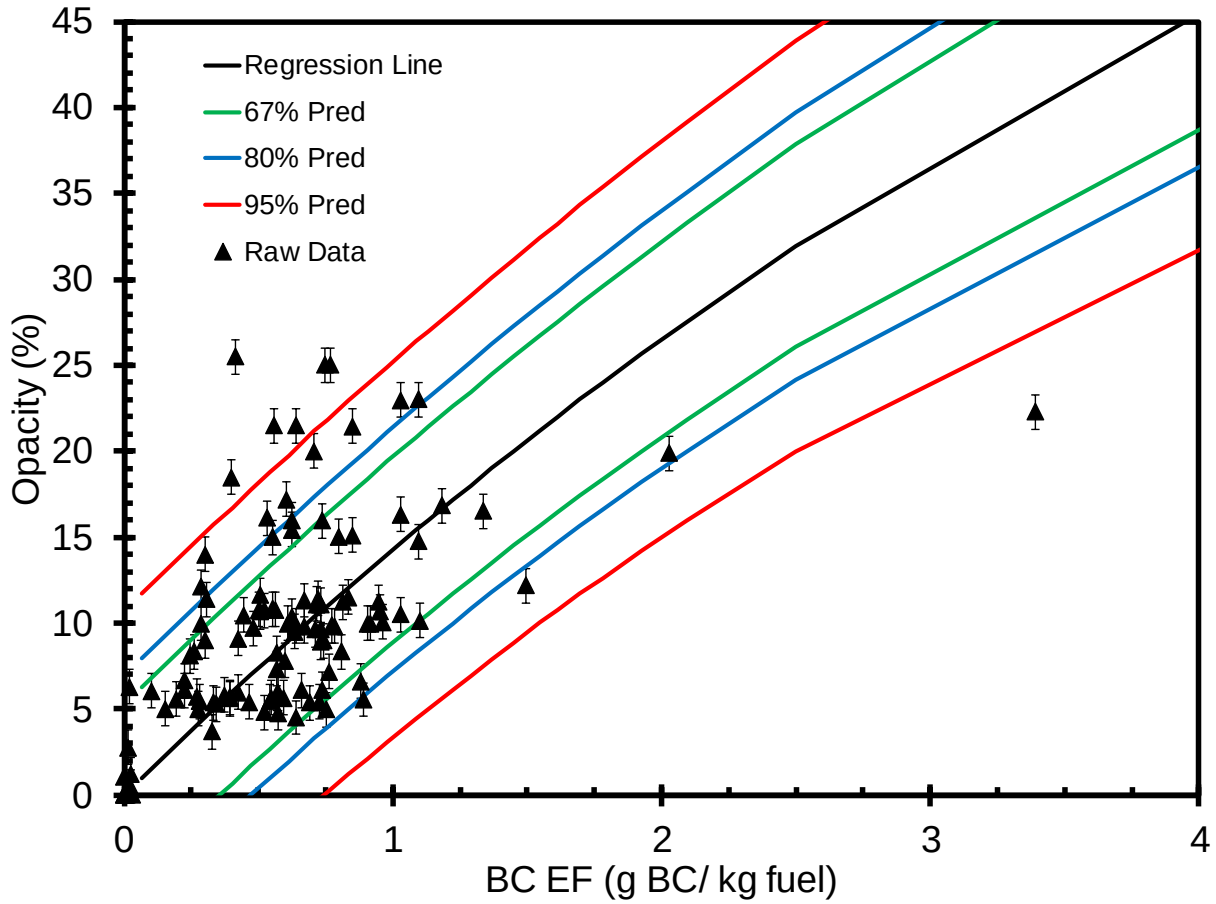
Smoke Opacity vs PEAQS

- Prediction Intervals are used for estimating future measurements within the data field
- The smoke opacity is highly variable
  - At 5% opacity, variability can ± 2.5%
- Opacity threshold values determined at lower bound of prediction interval



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PEAQS Threshold Values

- The table below contains the lower EF_{BC} cutoff for each opacity prediction interval and corresponding confidence the EF_{BC} will be > than the desired opacity

	EF_{BC} (g BC /kg fuel)		
Confidence Level	5% Opacity	10% Opacity	20% Opacity
67 %	0.709	1.087	1.926
80%	0.835	1.215	2.093
95%	1.131	1.524	2.500

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PEAQS and PEMS

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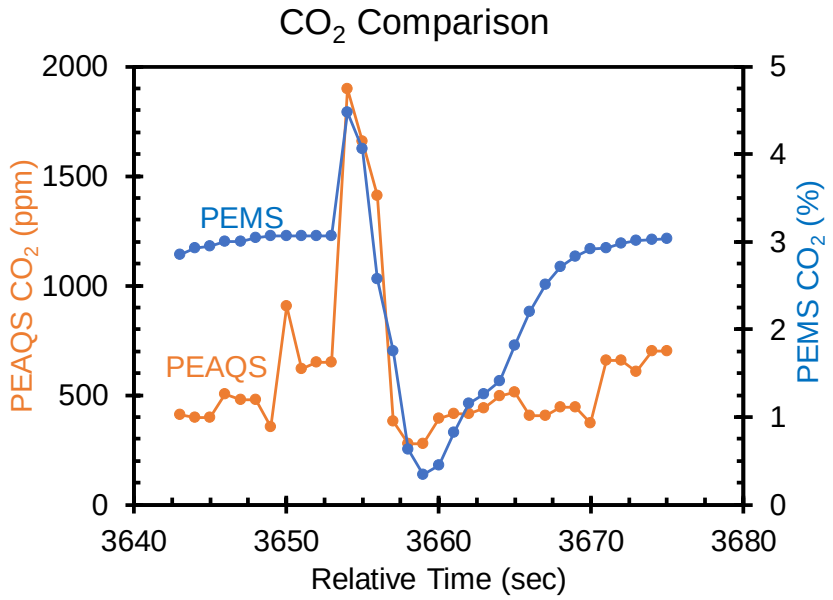
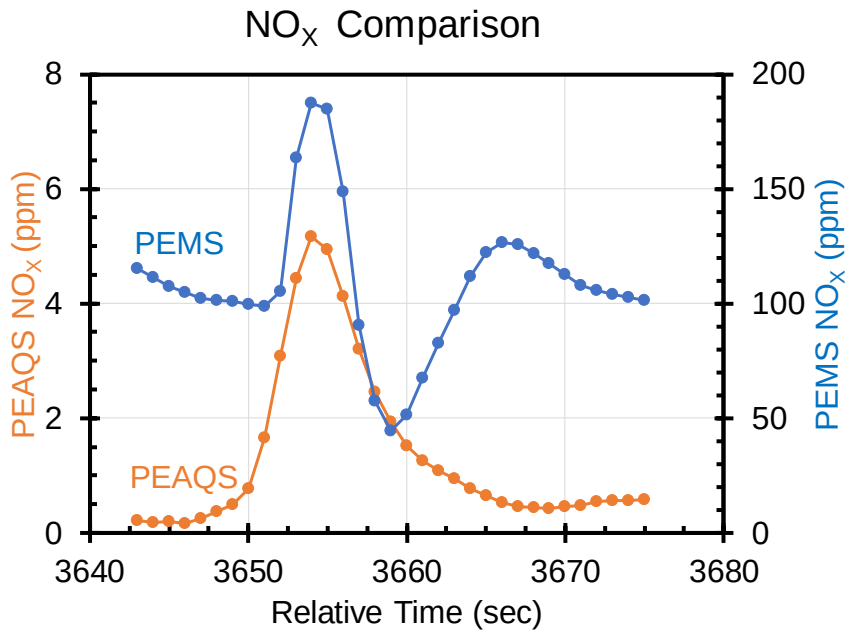
Results: Time Alignment

- Time Alignment is critical for accurate analysis
  - Difficult as the PEMS data and PEAQS data are on different computers
- Equipped both systems with a GPS receiver and time aligned all data with GPS derived time
- Each instrument has an associated time lag and response time lag
  - Snap accelerations used to match up peak responses
- Note very long tail of NOX peak within the PEAQS system





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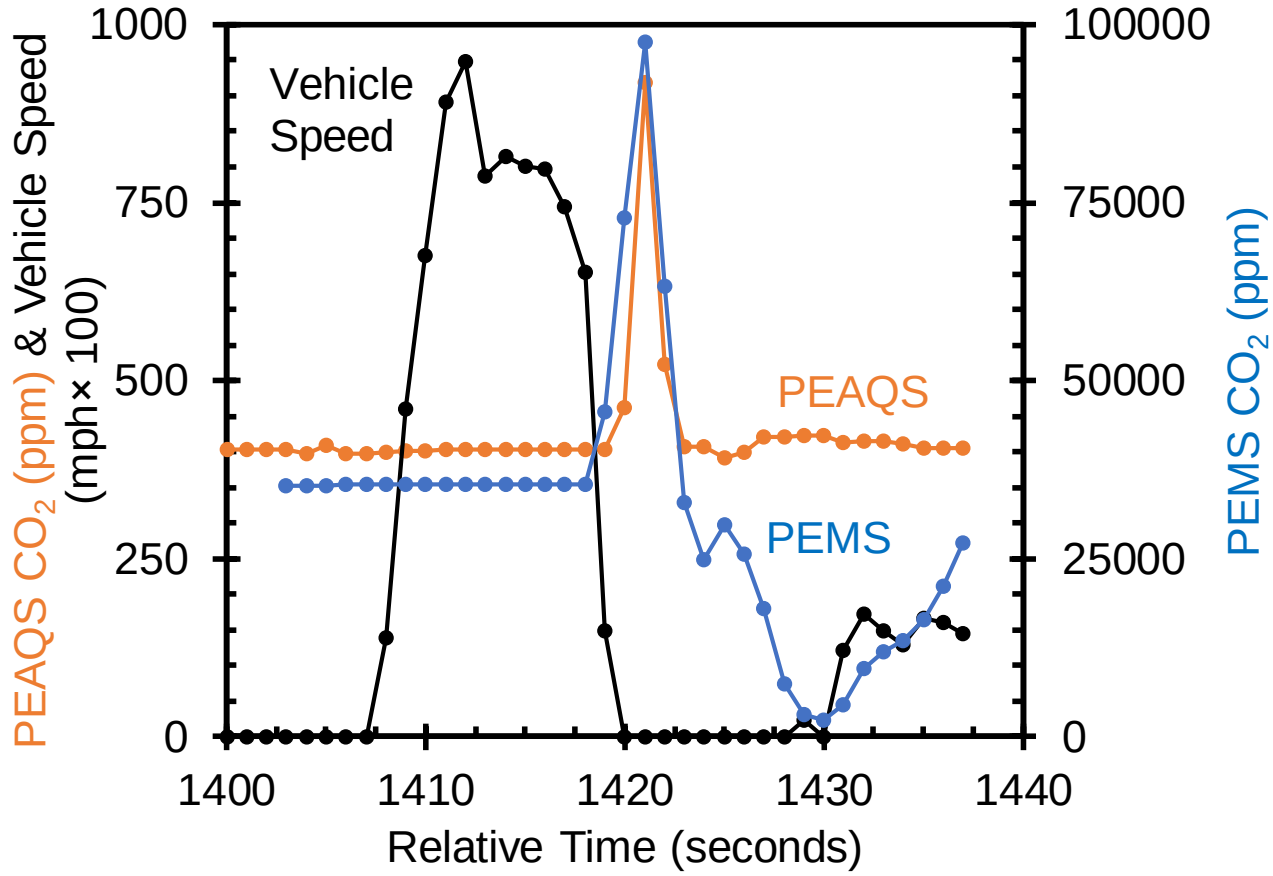
Results: Passing Plume Capture

- Exhaust plumes were successfully captured for passing truck
- Note: Vehicle speed was found with Doppler and has not been time aligned in this figure
- Dilution factor was consistently near 100 for all passes



Representative plot: 2 ft acceleration, 65,000 lb, 1st geat

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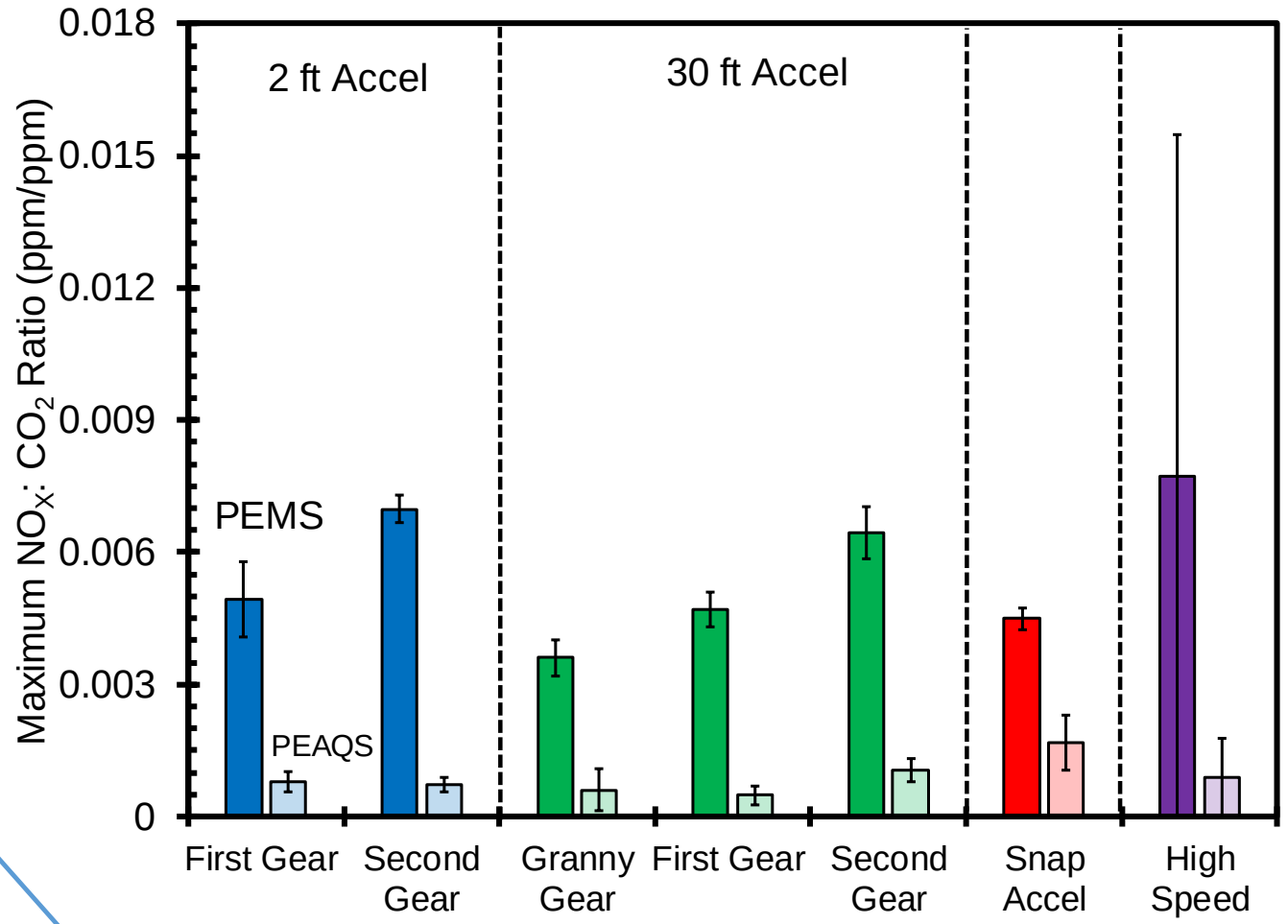
Results: Maximum Value Ratio Comparison

- Goal was to identify any NOX losses between the tailpipe (PEMS measurements) and PEAQS
- Estimation of this loss calculated by the maximum NO_X and CO_2 value ratio for each pass

	Test	% NO_X Loss
30 ft Accel	First Gear	83.8
	Second Gear	89.8
2 ft Accel	Granny Gear	83.4
	First Gear	89.8
	Second Gear	83.6
	Snap Accel	62.8
	High Speed	88.5



Very high loss rates and does not match previous lab results!

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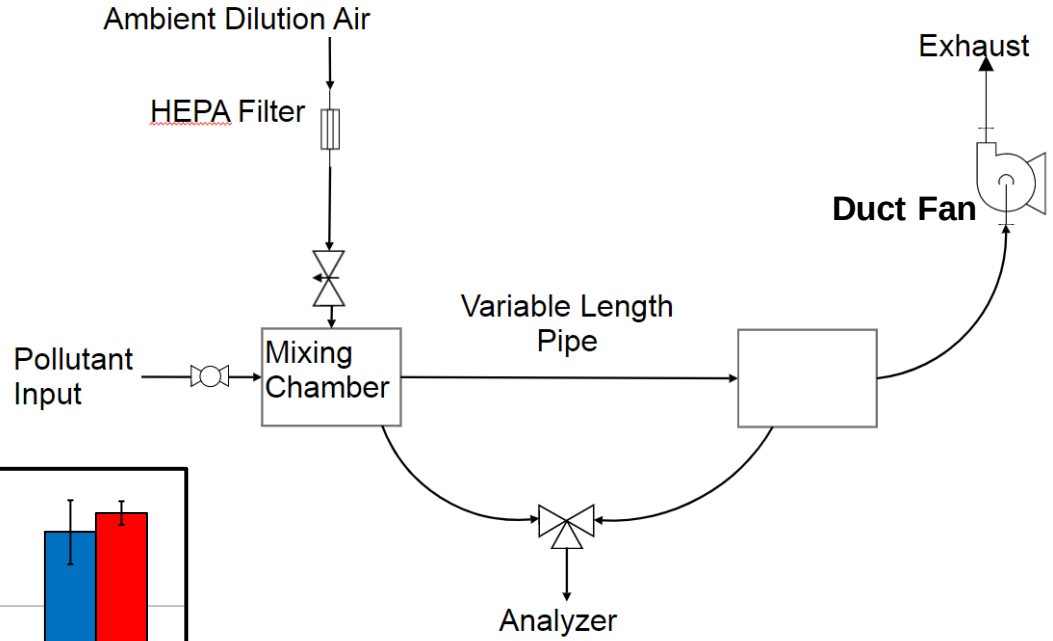
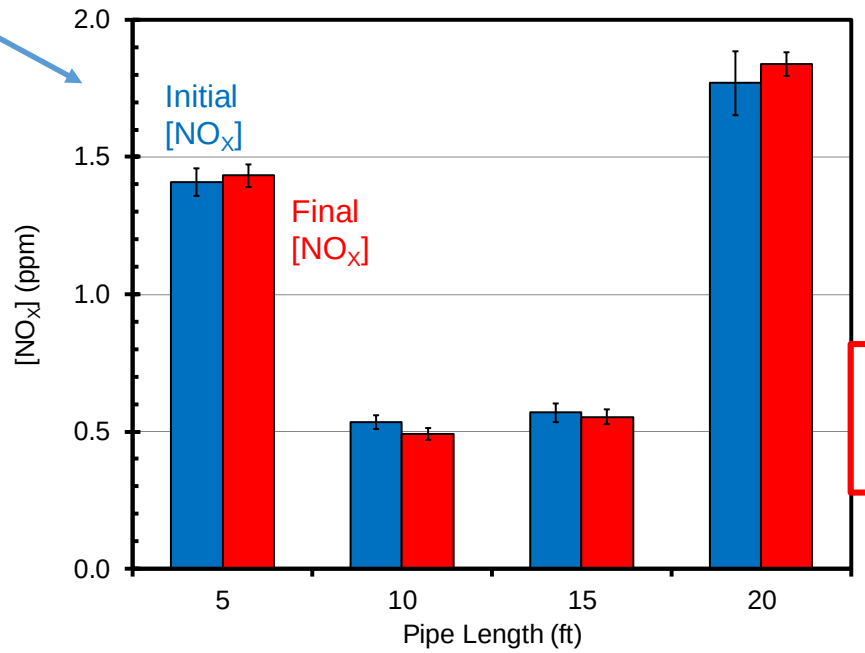
Results: Laboratory Loss Experiments

- NO_X fed into PEAQS PVC sampling system from cylinder to test internal NOX losses at a variety of concentrations
- No significant loss noted during these experiments





These measurements were conducted with EcoPhysics CLD

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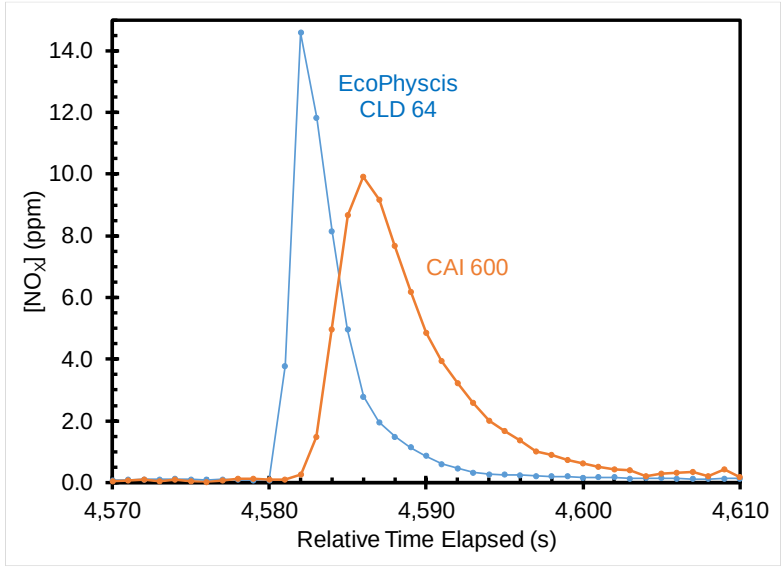
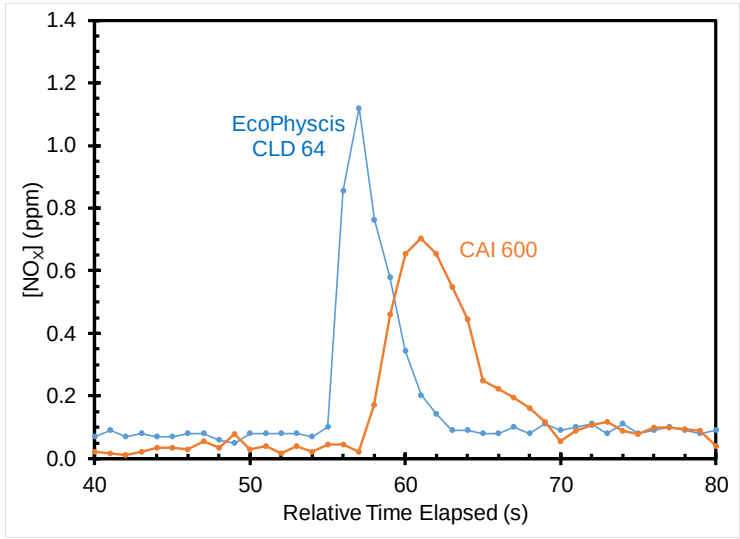
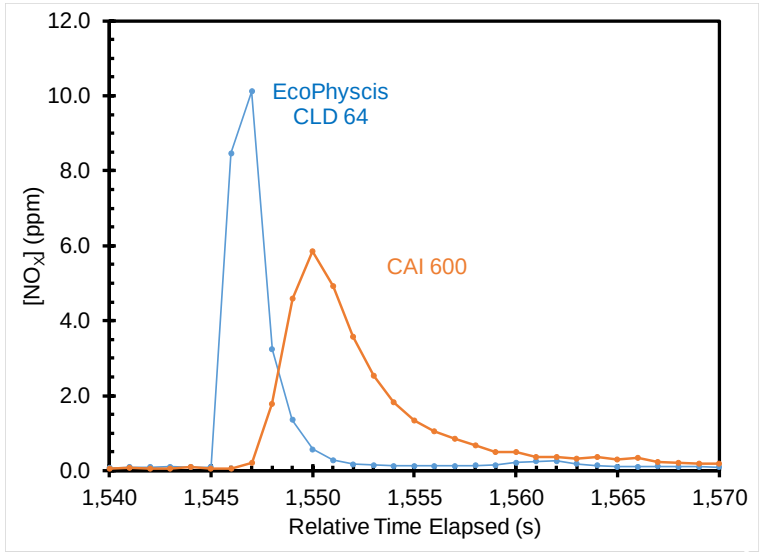
Instrument Comparison

- Systematic under reporting noticed by CAI 600 relative to EcoPhysics 64
- Cause of observed NOX ‘loss’ during PEMS runs, may be an instrument artifact
- Offset looks to be ~50%







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Summary

- A variety of methods can be used to determine high emitters
- Top Percentile
  - Location dependent
  - Verifies that a small percentage of trucks emit >50% of emissions
- PEAQs and Opacity
  - Opacity can be correlated to BC emissions
  - Used as a screening tool to identify vehicles for further emissions testing
- PEMs and PEAQs
  - PEAQs was able to capture passing plume (see CO2)
  - Current version will utilize the EcoPhysics NOx analyzer in upcoming deployments

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Thank you for your time.

Any Questions?