THE PREFERRED ALTERNATIVE METHOD FOR MEASURING PAVED ROAD DUST EMISSIONS FOR EMISSIONS INVENTORIES:

"*Mobile Technologies vs. The Traditional AP-42 Methodology*"

Presenters:

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Dennis Fitz (UCR)

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INTRODUCTION & BACKGROUND

Rodney Langston (DAQEM)

Clark County PM_{10} Problem

- Las Vegas Valley – Serious PM_{10} Nonattainment Area
- Valley experiencing rapid growth
- Paved road dust is a significant PM_{10} source category
- Realistic paved road dust emissions estimates and projections - critical for successful air quality program

Clark County Work: AP-42

- Quarterly silt sampling from 2001-2006
- Sampling conducted by Clark County staff and UNLV engineering department
- Silt sampling method – dangerous, expensive and time consuming:
  - Cannot sample high ADT congested roads
  - Method results in limited sample data points
  - Public critical of limited data points – not good science

Other AP-42 Limitations

- Method does not provide for sufficient samples to compare developing areas, transitional areas, and built out areas for future projections
- Equation does not account for vehicle speed – a proven significant variable
- Equation assumes free flowing traffic
  - Requirement seldom met in urban areas
  - Induced estimation error likely significant

Previous Clark County Studies

- **Phase I: Method evaluation study**
  - Evaluated very clean and very dirty roads
  - Demonstrated technology feasible
  - Measurements reflected real world conditions
- **Phase II: Valley wide sampling study**
  - Improved data collection
  - Less noise in data
  - Enhanced AP-42 comparison sampling

Previous Studies (cont.)

- **Phase III: Focused on road infrastructure and land use characteristics**
  - Study included concurrent silt sampling
  - Sampling route mapped in detail
  - Evaluated weekday and weekend emissions
- **Phase IV: Controlled measurements study**
  - Previous work identified need for comparison measurements under controlled conditions
  - Tower, mobile system and silt measurements
  - Controlled silt loadings and sampling speeds

AP-42 Sampling Video

Mobile Technologies (SCAMPER) Video

AP-42 Methods

Dr. David James (UNLV)

Study Objectives

1. Examine and quantify relationships between vehicle-based technologies for paved road dust emission measurement and silt loading techniques.

2. Evaluate the reduction of paved road dust emissions over time in the absence of replenishing sources.

3. Determine and quantify the relationships among emissions measured using PM10 horizontal flux tower techniques, mobile measurement systems, and AP-42 silt loading methods.

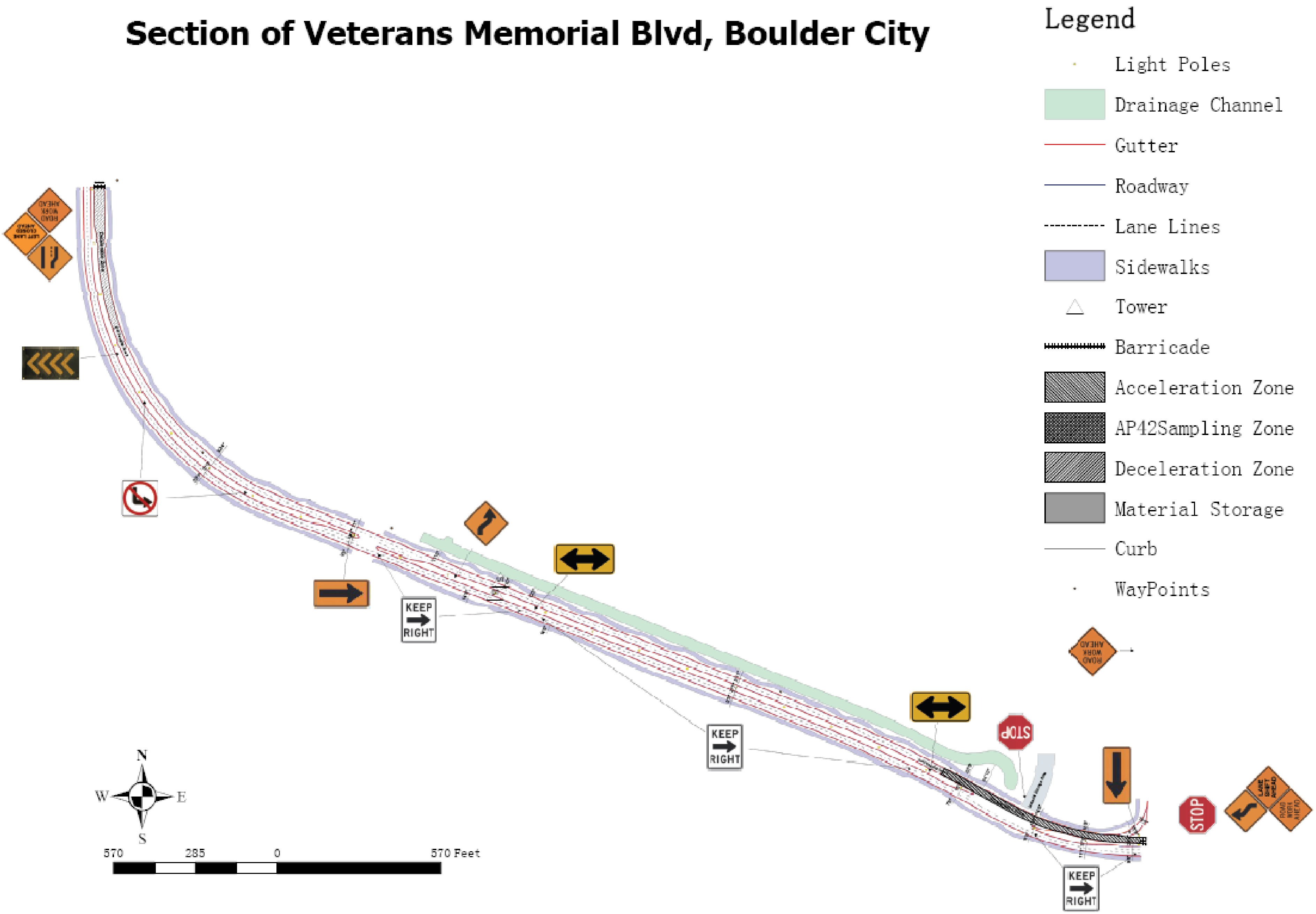
Study Site Roadway Selection

- Perpendicular prevailing wind direction
- No obstructions in close proximity
- No significantly elevated topography in close proximity
- Four-lane road divided by a median
- Light traffic so that can block two lanes on one side
- No elevated background PM10 sources
- Uninterrupted distance at least ¾ mile (1.2 km)

Study Site Layout

- Southeast to Northwest orientation
- Acceleration zone – 543 feet
- Constant speed zone – 3188 feet
  - AP42 south sampling zone - 120 feet
  - Straightaway
  - AP42 north sampling zone - 120 feet
- Deceleration zone – 500 feet
- Total length – 4481 feet

Section of Veterans Memorial Blvd, Boulder City



Soil Selection

- Investigated five sites
- Criteria
  - 50th percentile silt content from 2005-6 AP42 monitoring of collector roads – 13% from 15 samples
  - Accessible for excavation
  - Sufficient material for excavation
- Selected Sunset Park site, sandy soil, in Wind Erodibility Group 2
  - 14% average silt content from 6 of 50 buckets

AP42 EF Equation

$$E = k\ (sL/2)^{0.65}\ (W/3)^{1.5} - C$$

- where:
- E = particulate emission factor
- k = base emission factor for particle size range and units of interest
- sL = road surface silt loading (grams per square meter) (g/m^2),
- W = average weight (tons) of the vehicles traveling the road
- C = emission factor for 1980's vehicle fleet exhaust, brake wear and tire wear.

Mobile Technologies Vehicle Weights, W

- SCAMPER - 2.5 tons
- TRAKER I - 3.4 tons
- TRAKER II - 2.5 tons
- Fleet average - 2.88 tons

AP42 Restricted To:

- **Silt loading: 0.02 - 400 g/m^2**
  0.03 – 570 gr/ft^2
- **Mean vehicle weight: 2.0 – 42 tons**
- **Mean vehicle speed: 6 – 88 km/hr**
  10 – 55 mph

AP42 sampling methods

- AP42 Appendix 13.2.1 followed for
  - Large plot sampling area
  - Sieve stack
- Modifications
  - 4-pass recovery by vacuum cleaner
  - Full size plot (10 ft long x 13.5 ft wide) delineation with fixed size string square
  - 7 plots at fixed separations in each zone
- Additional sampling
  - Quickie strips – 2 ft long x 13.5 ft wide to measure silt depletion – located between full size plots

Experimental Design

Initial silt load (g/m^2) Speed (mph)		0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5
25		**Set 7** **9/13**					**Set 5** **9/12**
35		**Set 3** **9/11,** **Set 9&10** **9/14**					
vary 25-35-45					**Set 13** **9/15**	**Set 12** **9/14**	
45		**Set 6** **9/13**	**Set 8** **9/13**		**Set 4** **9/12**		

SCAMPER Mobile Technology

Dennis Fitz (UCR)

SCAMPER:
System for Continuous Aerosol Measurement of Particulate Emissions from Roadways

SCAMPER Approach Inspiration

SCAMPER Approach

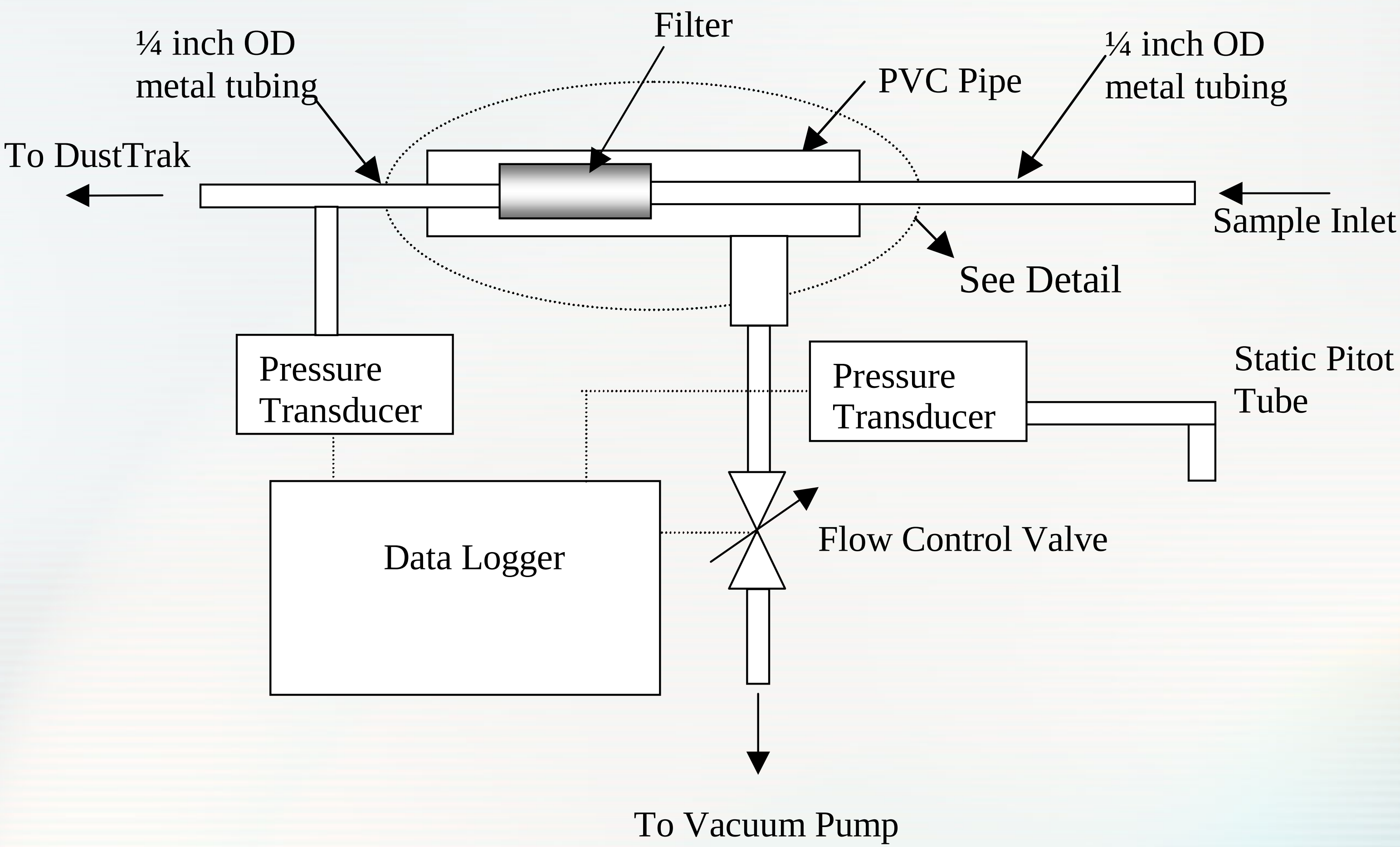
- **Method to rapidly evaluate the PM emission rates from roads using real-time sensors in front and behind a test vehicle**
  - Measure PM directly in front of and behind a test vehicle with an Isokinetic sampling probe
  - Use real-time sensors to quickly accumulate large amounts of PM data
  - Determine emission factors based on the concentration within the vehicle's wake
  - Determine location by GPS
  - PC to log all data at 1-second intervals

SCAMPER Approach

- **SCAMPER**
  - System for Continuous Aerosol Measurement of Particulate Emissions from Roadways

SCAMPER Approach:

- **Needed an Isokinetic Sampling Probe**



SCAMPER Front Probe Assembly

SCAMPER Full View

SCAMPER Emission Factor Calculation

$ER\ (mg/m) = (PM10_r - PM10_f) * c * A_f$

where:

ER = PM_{10} Emission Rate

$PM10_r$ = PM_{10} concentration, rear DustTrak

$PM10_f$ = PM_{10} concentration, front DustTrak

c = Calibration factor to relate DustTrak response to filter-based PM_{10} mass measurement

A_f = Frontal area of the test vehicle (based on wake homogeneity testing)

Quality Control

- **Routine DustTrak zero and flow rate test**
- **Collocated DustTraks**
- **PM_{10} Filter Collection**
  - EPA approved inlet
  - Collocated with rear DustTrak
  - Teflo filters equilibrated and weighed according to EPA methods

Data Validation

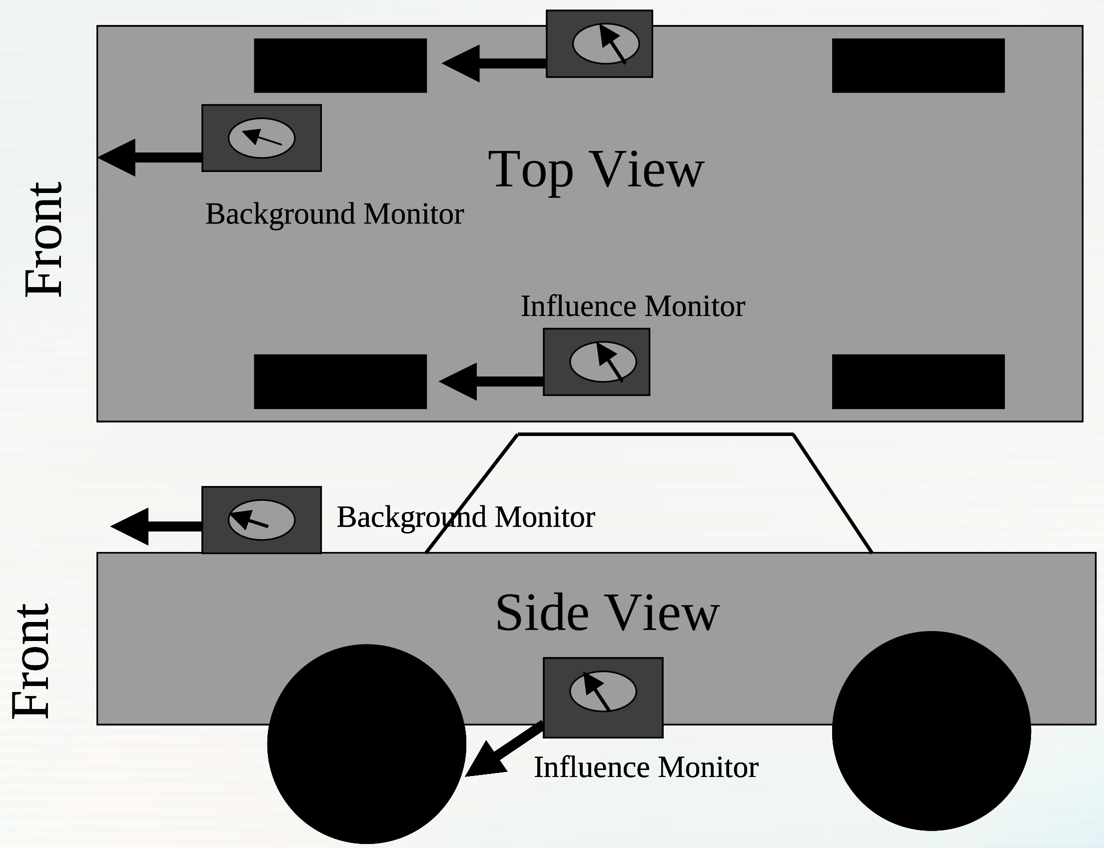
- To remove spurious DustTrak data, the data was reported as the 5-second running average of a 5-second running median.
- All questionable data was flagged
- When GPS signals not received the data was averaged for the missing 1-second interval
- For reporting emission rates only good data were used that were above 10 mph

TRACKER I & TRACKER II

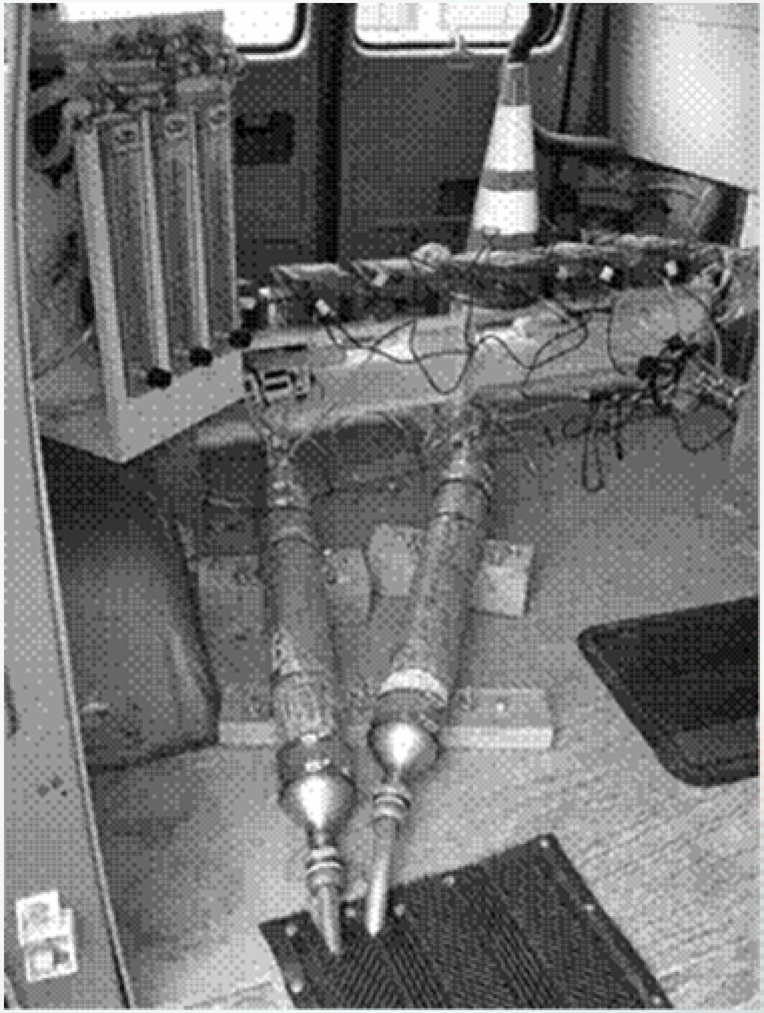
Vic Etyemezian (DRI)

TRAKER Concept

- PM_{10} measured behind front tires is influenced by road dust
- Subtracting “background” PM_{10} allows quantifying road dust contribution



TRAKER I



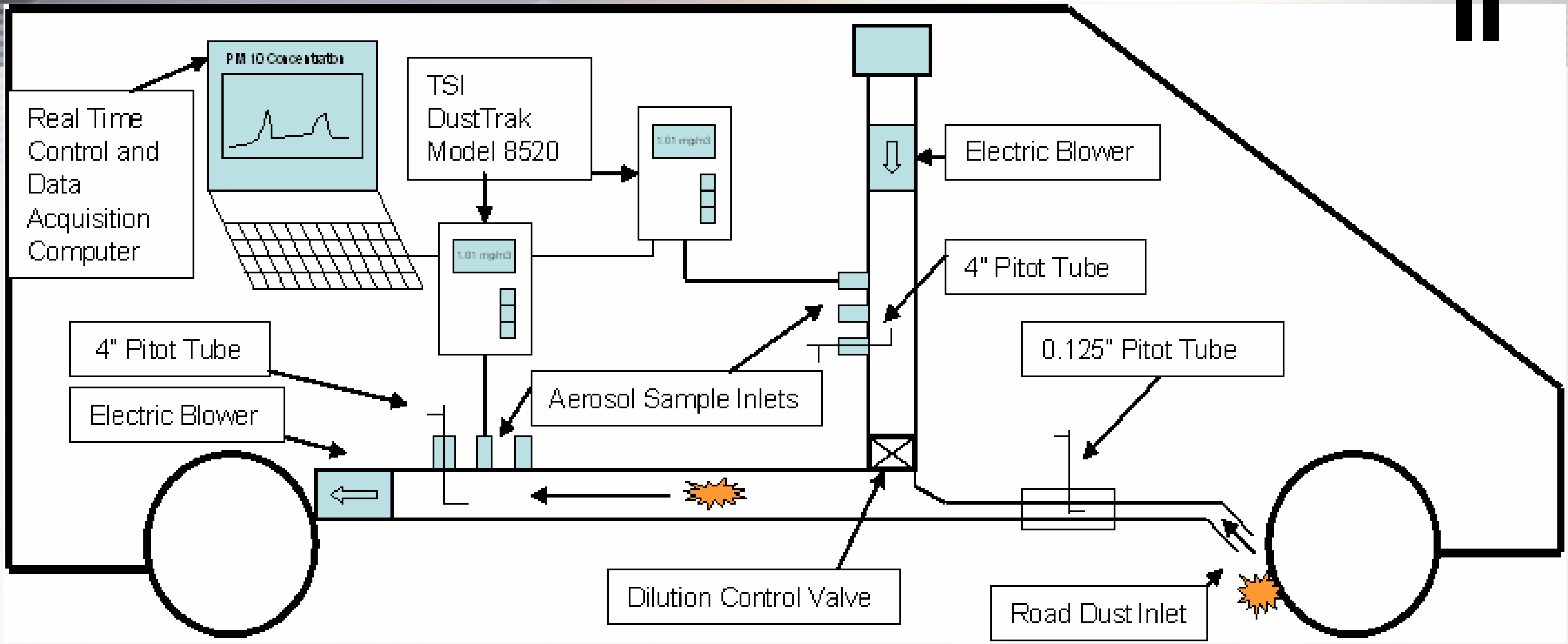
- DustTrak (DT) on each inlet
- Flow controllers (manual)
- GPS
- Laptop to collect all data
- Nominal 1-second resolution

TRAKER I

- Signal calculated as DustTrak PM_{10} behind front tires (average left and right) corrected for PM_{10} (DT) in background air
  - RS = (Left_PM_{10}+Right_PM_{10})/2-BG_PM_{10}
- Requires calibration to a “known” standard
- Until now, calibration using paved road unavailable
- Emission Factors for previous studies calculated by extrapolating data from unpaved roads

TRAKER II Vs. TRAKER I

TRAKER II	TRAKER I
• 2005 Dodge Sprinter Van • Inlet ~ 11 cm behind tire • Background PM measured at roof • Flow control auto • Automatic dilution setting integrated into design • Low power blowers allow battery operation • Misc: A/C, power locks/windows, emission controls, seat belts	• 1979 Chevy Van • Inlet ~ 5 cm behind tire • Background PM measured at bumper • Flow control manual • Cumbersome procedure for dilution on dirty roads • Requires generator for high power pumps • Misc: vent window on passenger side, yellow, emergency lights, AAA platinum

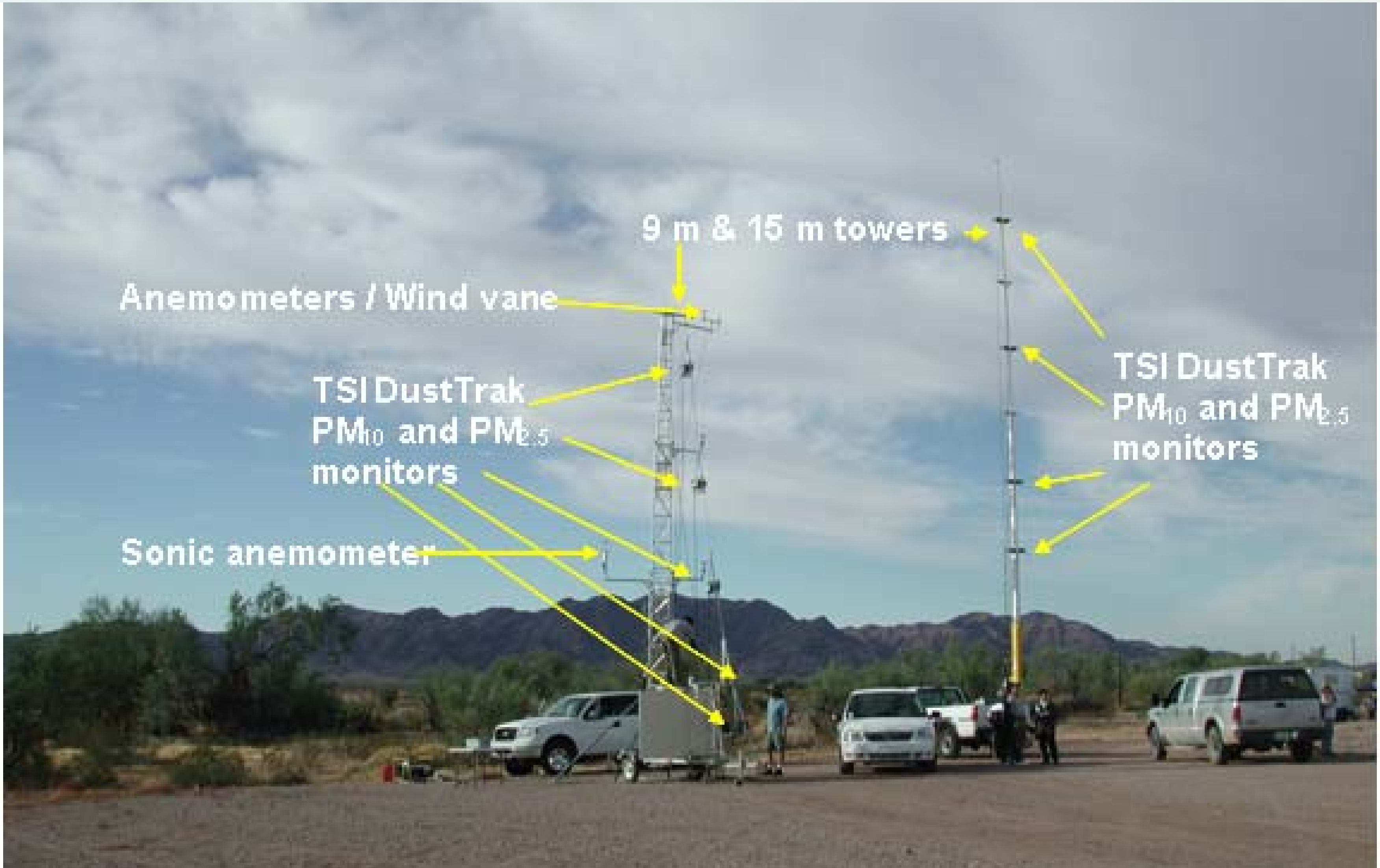


PM 10 Concentration
Real Time Control and Data Acquisition Computer
TSI DustTrak Model 8520
1.01 mg/m3
1.01 mg/m3
Electric Blower
4" Pitot Tube
4" Pitot Tube
Electric Blower
Aerosol Sample Inlets
0.125" Pitot Tube
Dilution Control Valve
Road Dust Inlet

Tower Instrumentation

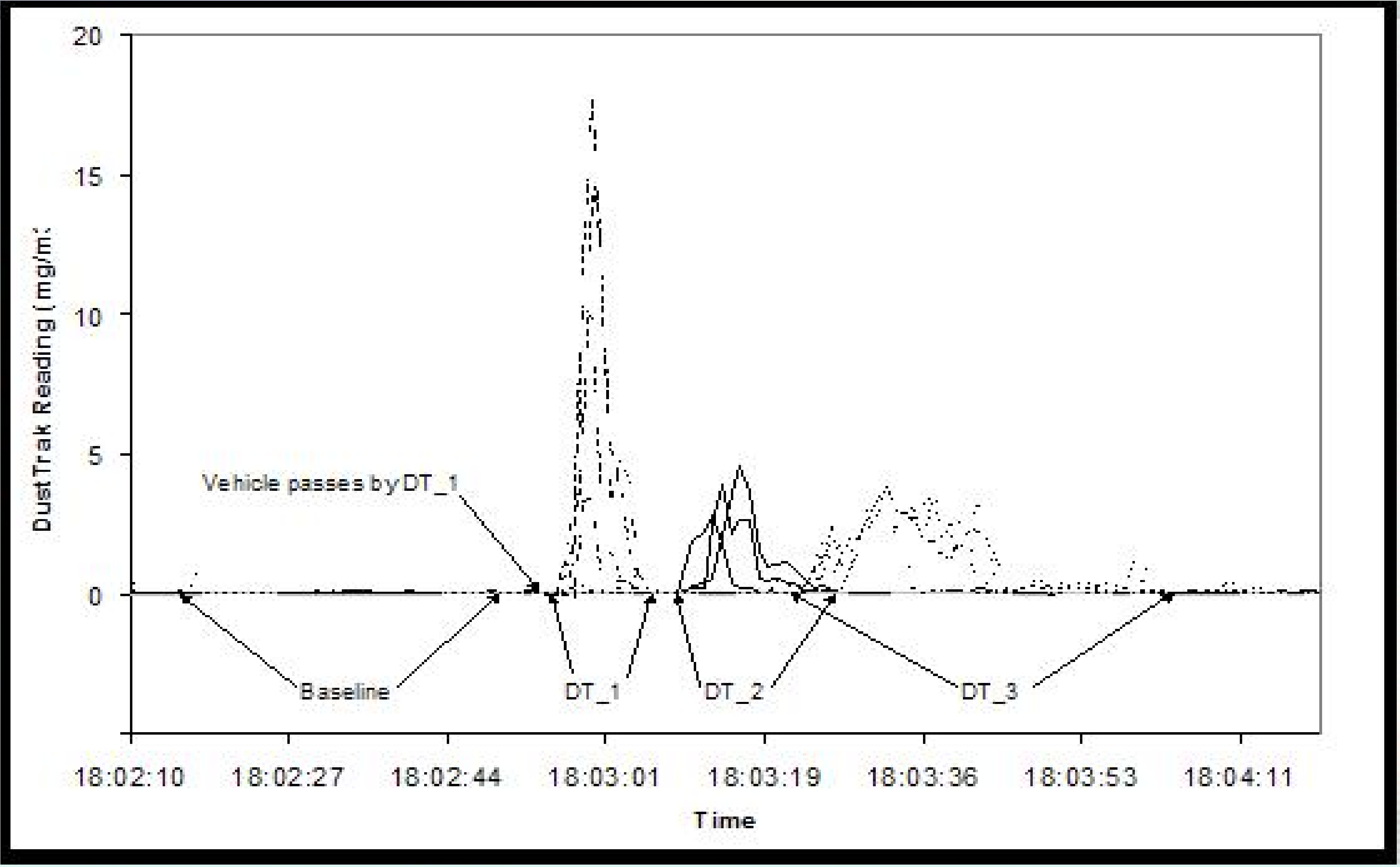
- TSI DustTrak (DT) at 5 heights
  - 0.7, 2.1, 3.4, 6.4, and 9.8 m (AGL)
  - Nominal PM_{10} inlets
- Cup anemometers for Wind Speed
  - Five ~ collocated with DTs
- Wind vane at 9.8 m – wind direction
- TEOM
  - At 2.3 m AGL near DT
  - PM_{10} Inlet

Tower Measurements



Flux Tower Principle

- Flux across a vertical surface when wind is perpendicular =
  PM_{10} concentration X wind speed X Area of Surface
- In practice, need corrections for:
  - Wind direction
  - Finite length of vertical surface
  - Limited resolution of concentration and wind data in vertical direction (I.e. must discretize flux)



Dust Trak Reading (mg/m³)
20
15
10
5
0
Vehicle passes by DT_1
Baseline
DT_1
DT_2
DT_3
18:02:10
18:02:27
18:02:44
18:03:01
18:03:19
18:03:36
18:03:53
18:04:11
Time

$$EF = \alpha \left[\sum_{i=1}^{5} \sum_{t=t_{begin}}^{t_{end}} u_{t,i} \cdot \left(C_{t,i} - C_{0,i,,t_{begin}-t_{end}} \right) \cdot H_i \cdot \cos(\theta) \right] \times 1000$$

- Dividing Tower length into 5 discrete sections,

H_i = Height of section i (m)

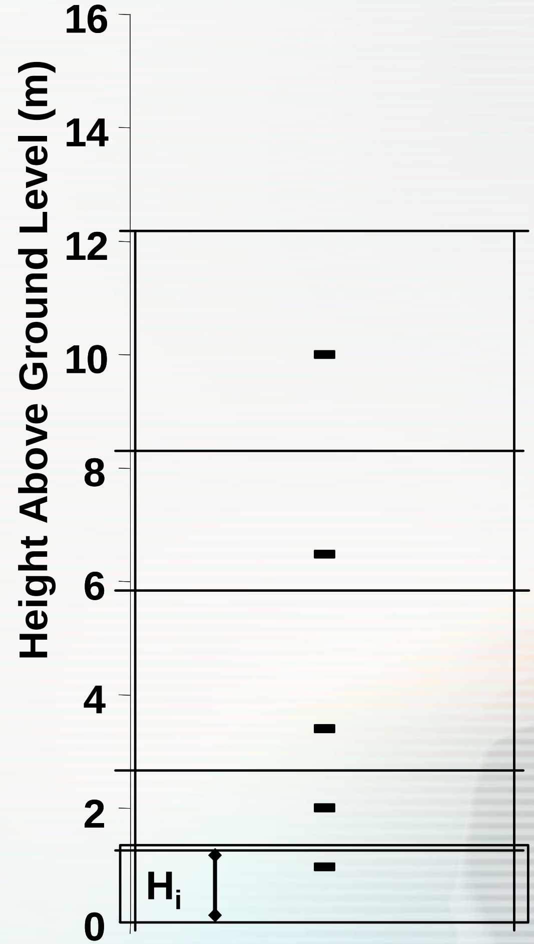
θ = Angle of wind w/respect to road

u_i = Wind Speed at Section i

$C_{t,i}$ = Instantaneous concentration at i

$C_{0,i}$ = Background Concentration at I obtained from periods w/o vehicle influence

α = Factor to convert DT data to equivalent mass-based concentration



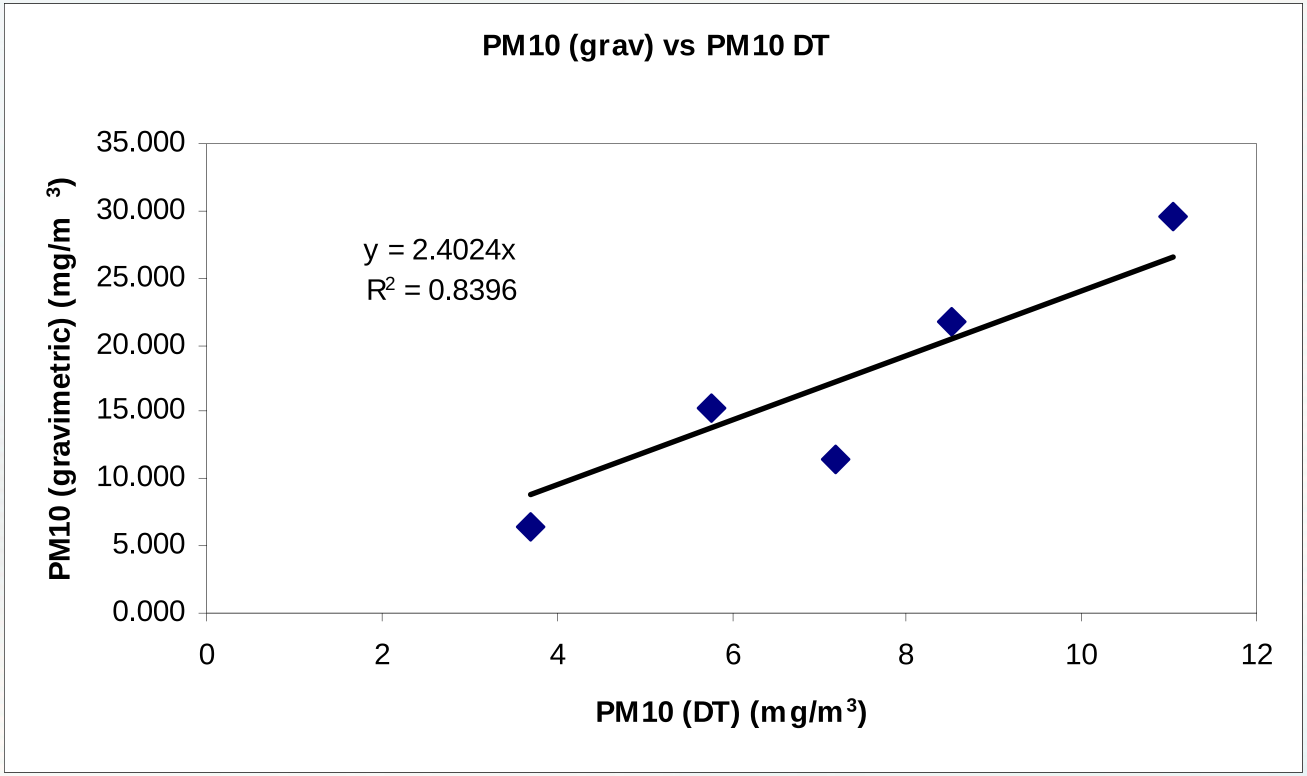
Converting DT:

Measured PM_{10} to Mass Equivalent PM_{10}

- Road silt material used in study was re-suspended in special chamber
  - Simultaneously,
    - DT w/ PM_{10} and $PM_{2.5}$ inlet
    - Filter sample with PM_{10} and $PM_{2.5}$ inlet
- Also, during field study
  - PM_{10} TEOM ~ collocated w/ DT at ~ 2.1 m
- Also, SCAMPER DT collocated w/ PM_{10} filter sampler

Resuspension Results:

- **Multiplier of <u>2.4;</u> Consistent with**
  - **TEOM collocation in field and (~ 2.8)**
  - **SCAMPER DT collocated with filter (2 – 3 depending on study area)**



RESULTS

Vic Etyemezian (DRI)

Results: Terminology

- **"Raw" Data**
  - **Silt: silt loading g / m^2**
  - **Mobile Systems**
    - Corrected DustTrak PM_{10} Signal (mg/m^3)
      - SCAMPER: behind vehicle (trailer) minus in front of car
      - TRAKER I: left and right tires (ave) minus front bumper
      - TRAKER II: left and right tires (ave) minus roof inlet
  - **Tower fluxes**
    - PM_{10} horizontal flux (g/km) = Emission Factor (g/vkt)
      - DustTrak Data on Tower corrected for mass (resuspension chamber)

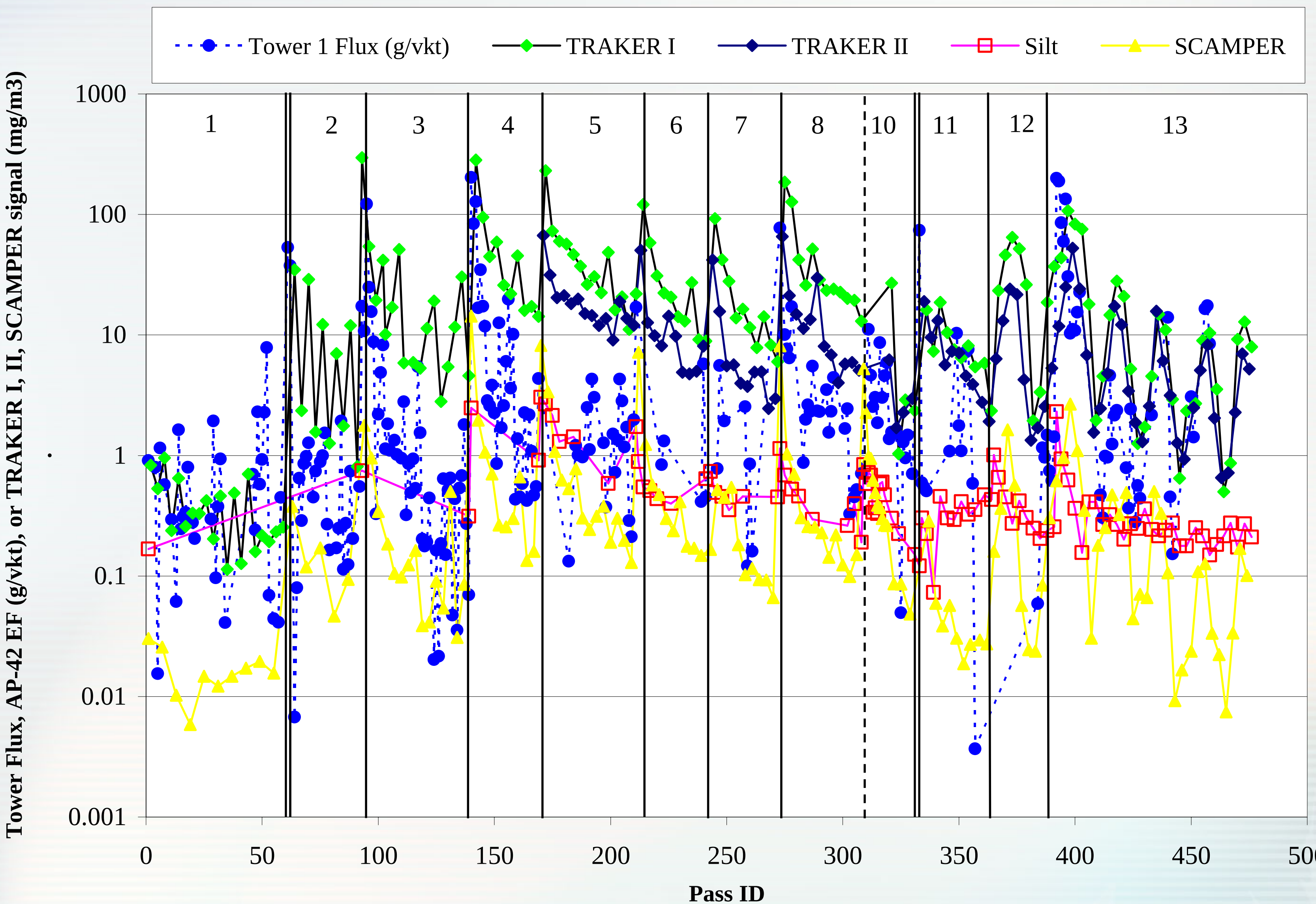
Results: Terminology

- **Emission Factors**
  - Silt: Using AP-42 Equations with measured silt loading
  - Mobile Systems
    - Calibrated against tower measurements
      - SCAMPER, TRAKER I, TRAKER II: Based on linear regression of “raw” signals versus Tower fluxes

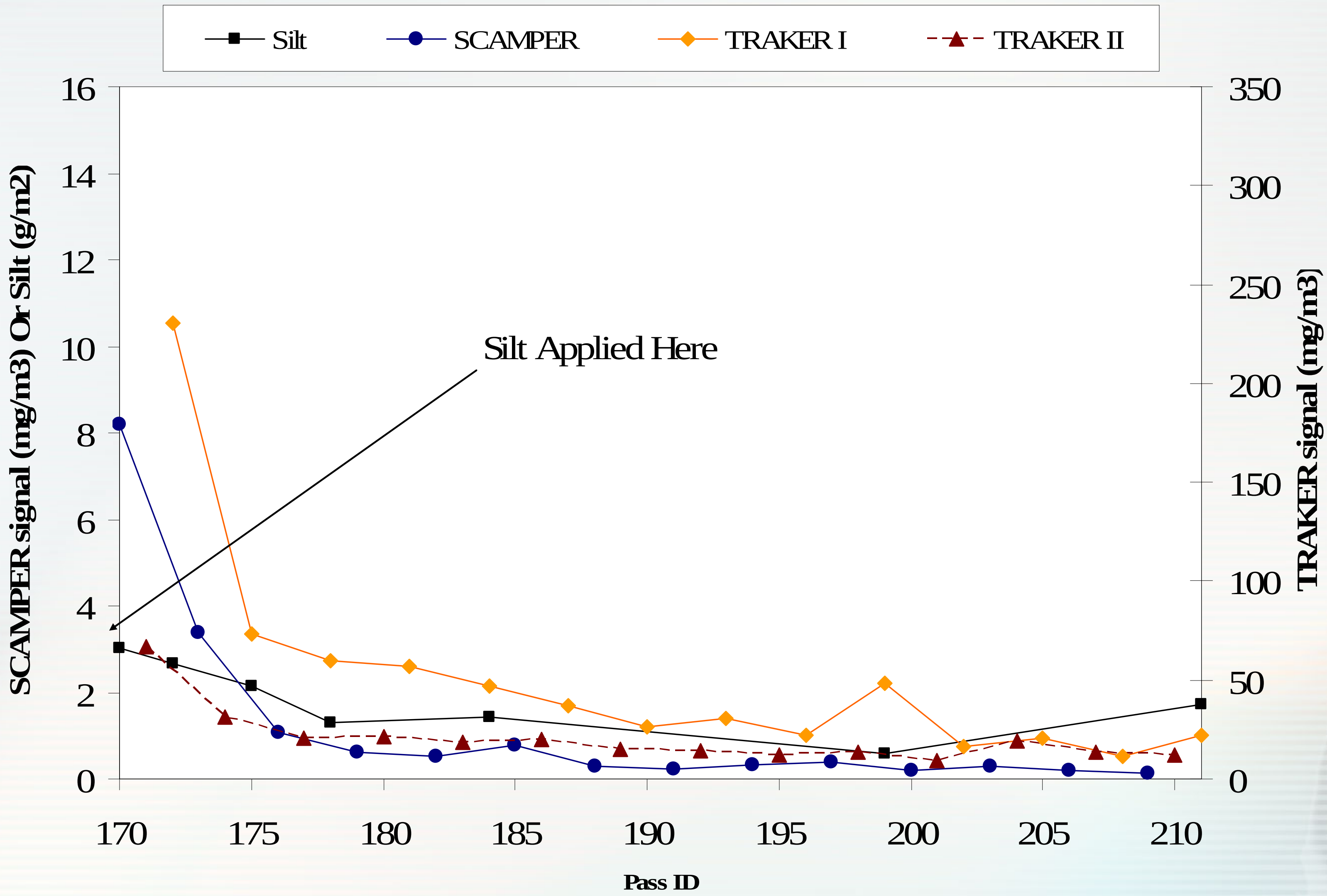
Results: Terminology

- **Pass: One vehicle traversing entire course one time**
  - Pass-averaged: average of measurement over entire pass
    - For Mobile systems: average of 1-second data
    - For Tower: One measurement of flux
    - For Silt: Result from most recent measurement prior to pass
- **Set: All passes between after silt was applied to road**
  - Set-averaged:
    - For Mobile systems: Average of individual passes
    - For Tower: Average for all passes – all vehicles
    - For silt: Average of two measurements at beginning and end of set

All Results: Pass-Averaged Raw Signals

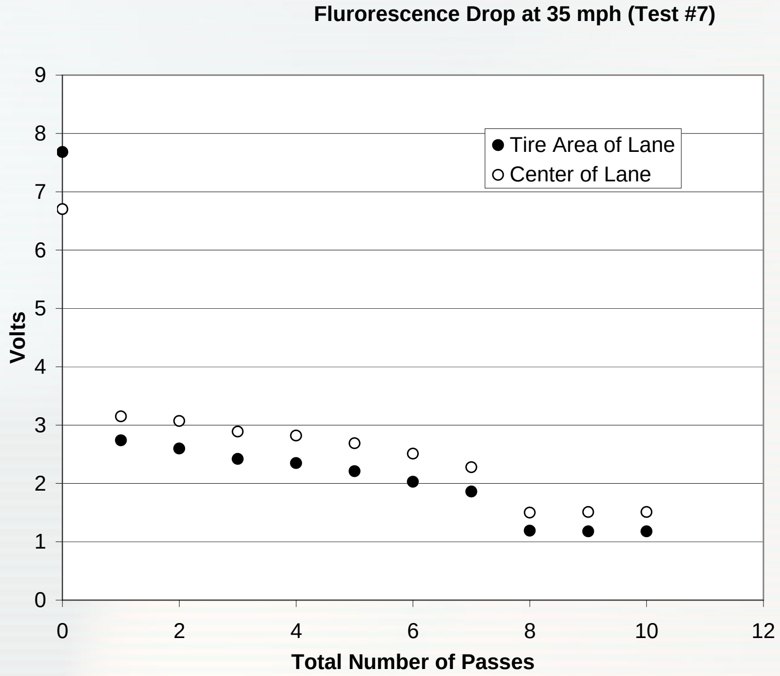


Clear Effect of Silt Application: Set 5 Example

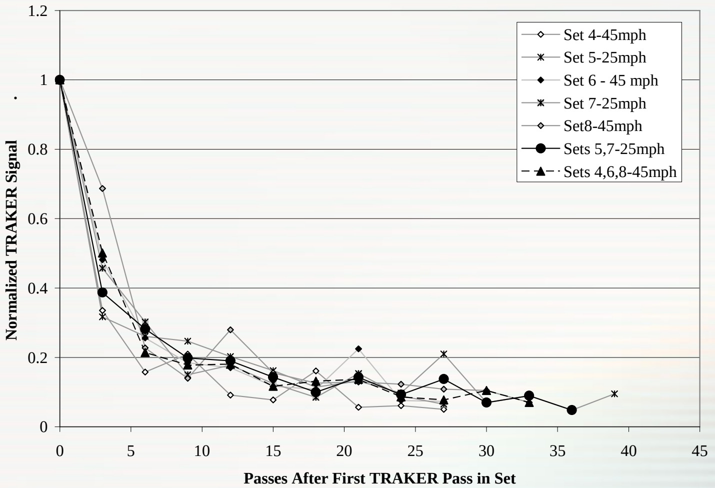


Silt Loading:

Red – First 9 passes
Blue – After First 9
Passes

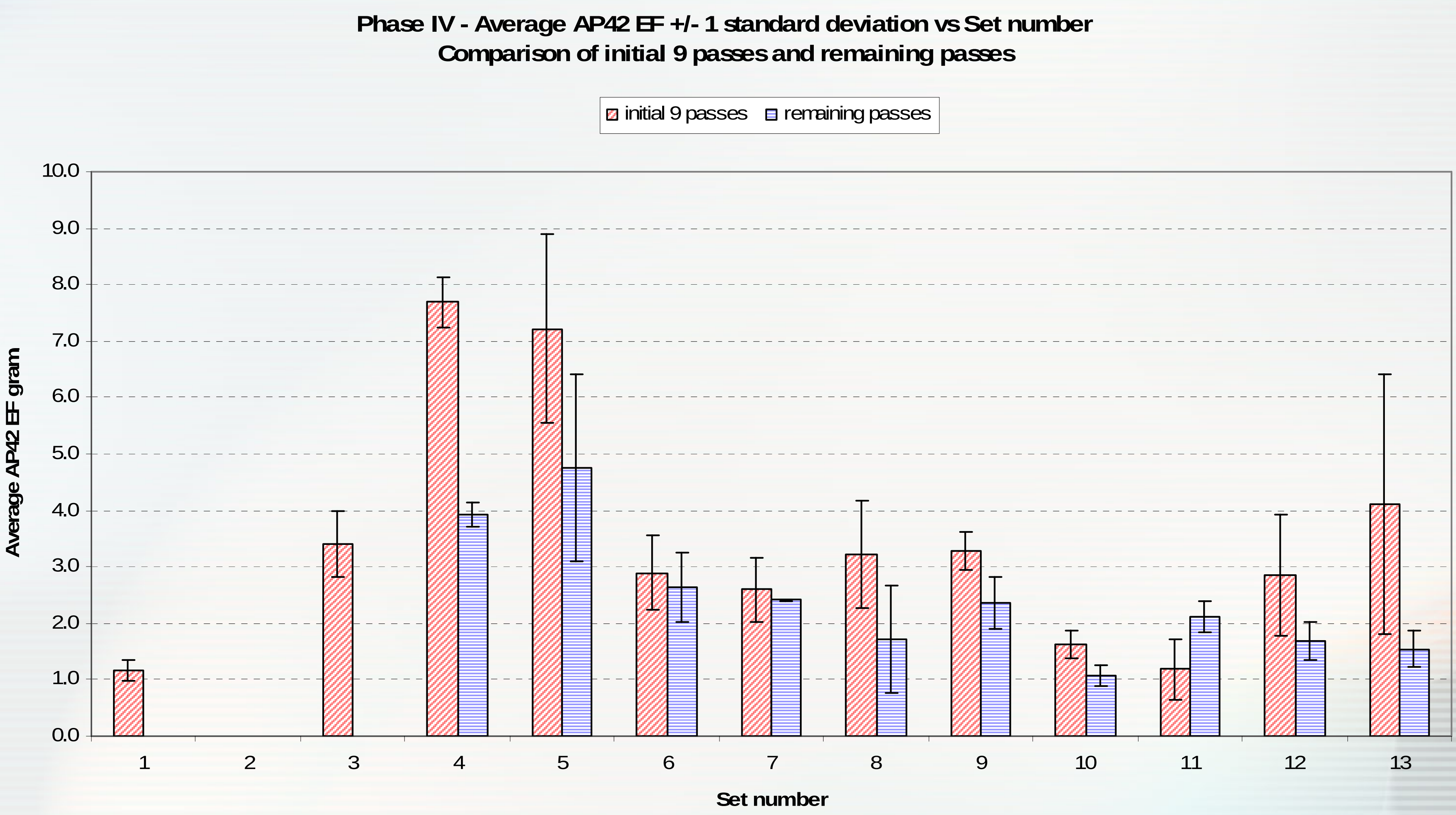


Fluorescent Powder Placed on Road after silt application

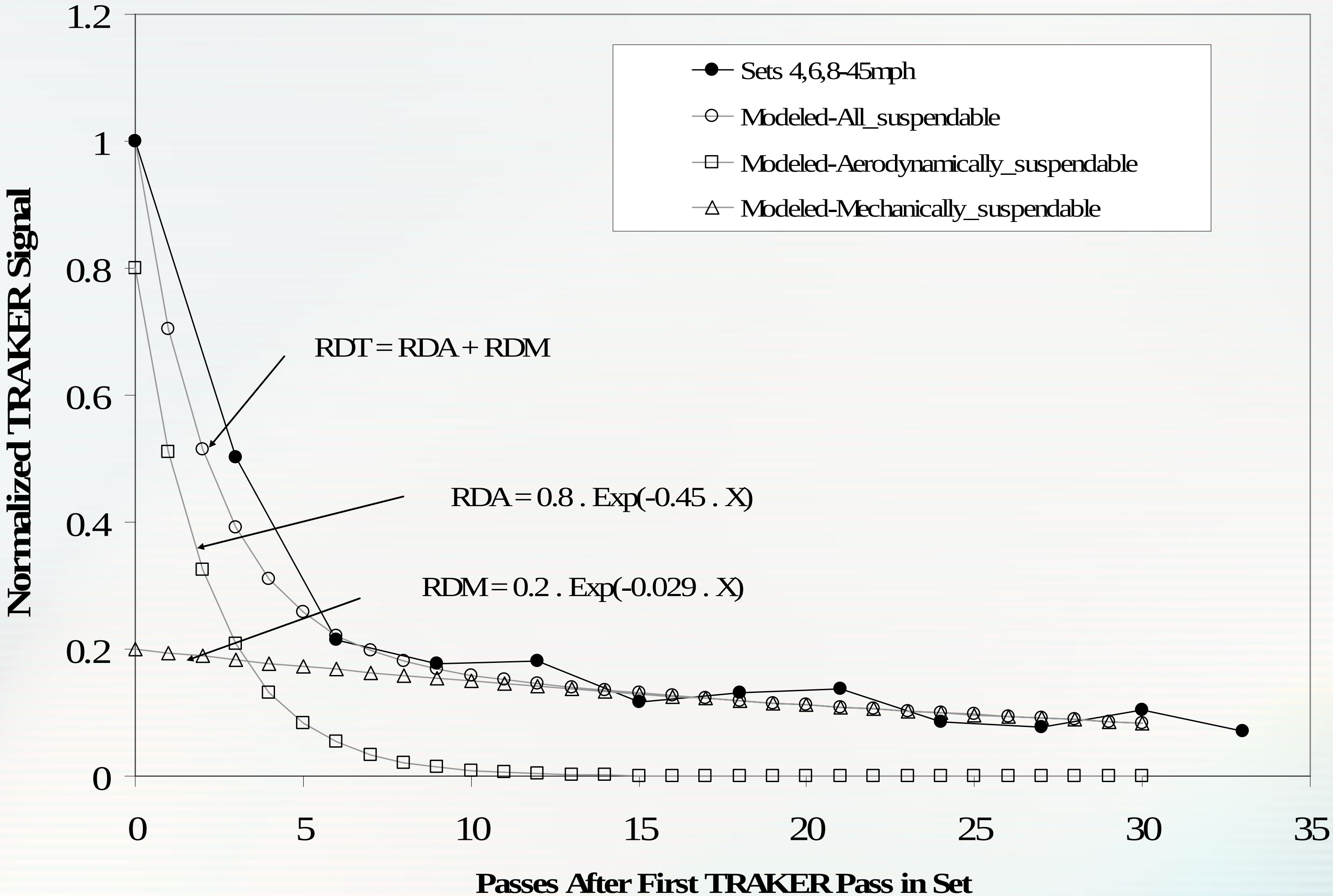


Mobile Data: Normalized Decay curves for Sets 4-8

Silt Loadings:



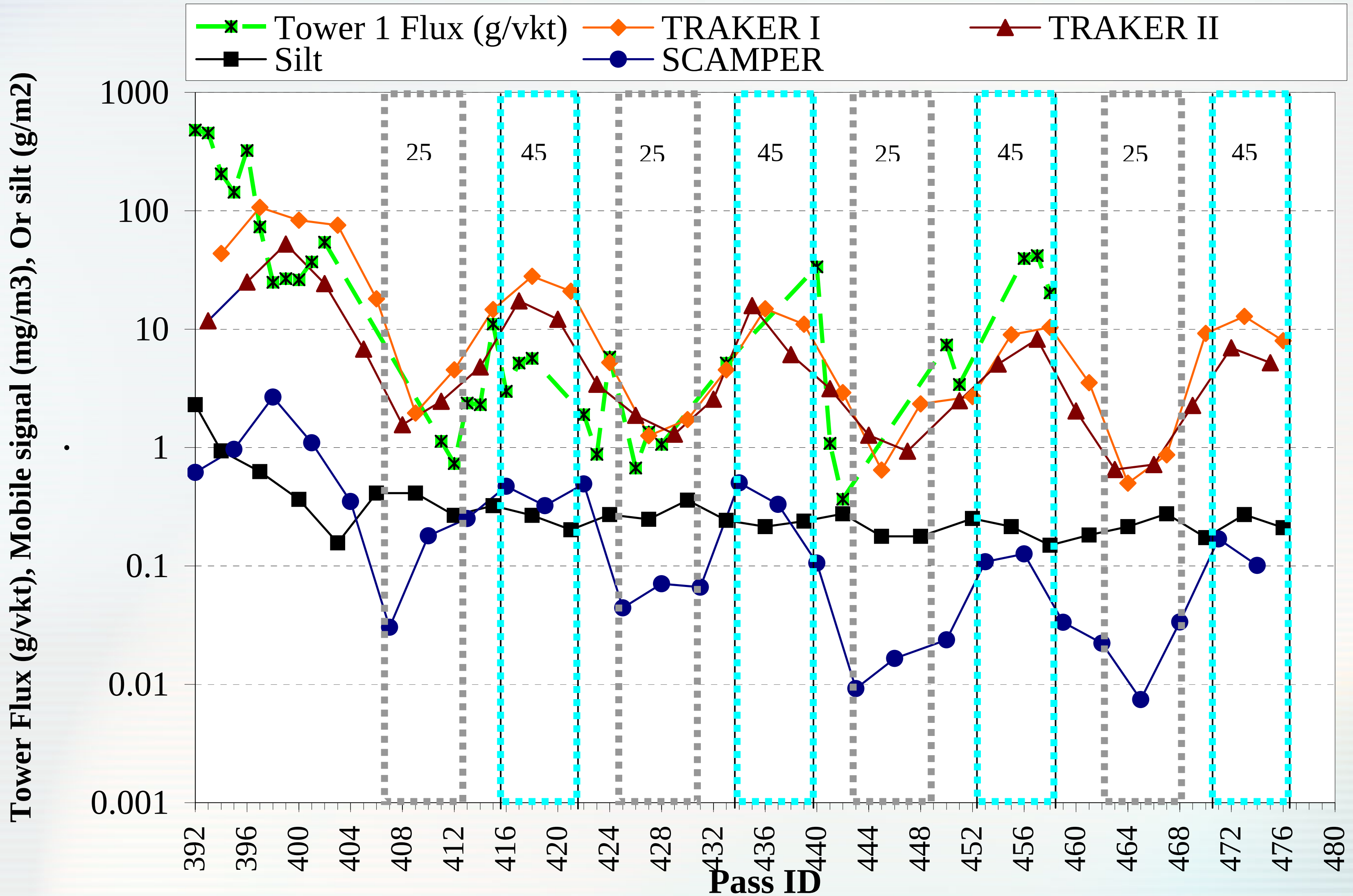
Suggests Two Regimes for Emissions



Effect of Silt Application

- **Results suggest two stages of emissions**
- **First ~ 9 vehicle passes**
  - Large emissions
  - Rapid Decay
  - “Aerodynamic Suspension”
- **After first ~ 9 passes**
  - Lower emissions
  - Slower decay
  - “Contact Emissions” – Tire contacting surface
- **Most roads NOT in “Aerodynamic Suspension” Regime**
- <u>For being closer to Real- World, better not to use data from first 9 passes after silt application</u>

Set 13: Vary Speed, 25, 35, 45 mph



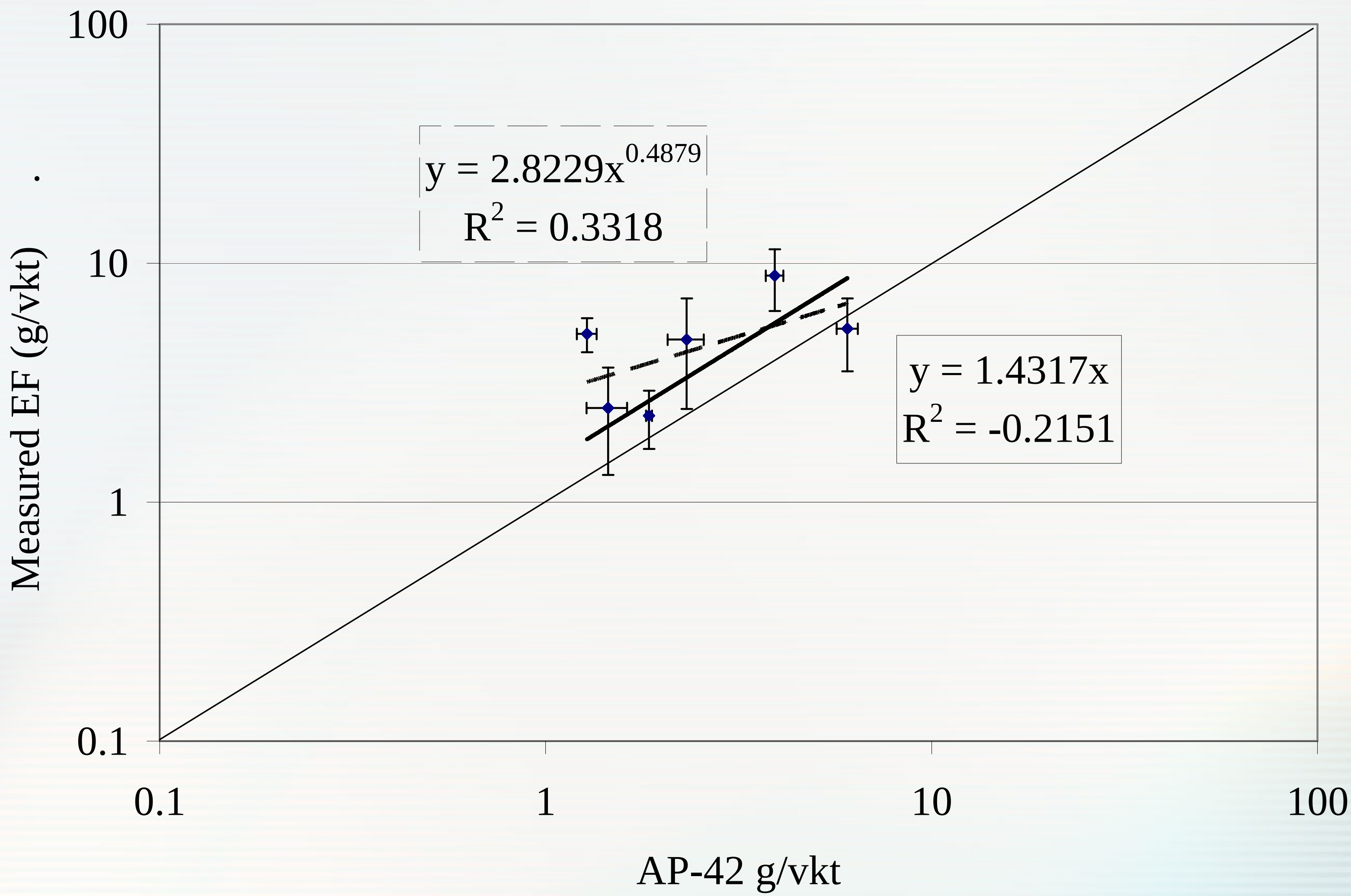
Effect of Speed

- All three mobile systems show increase of “raw” signal with speed for same road
- Tower-measured emission factors show increase with speed
- Silt measurements do not capture effect of speed

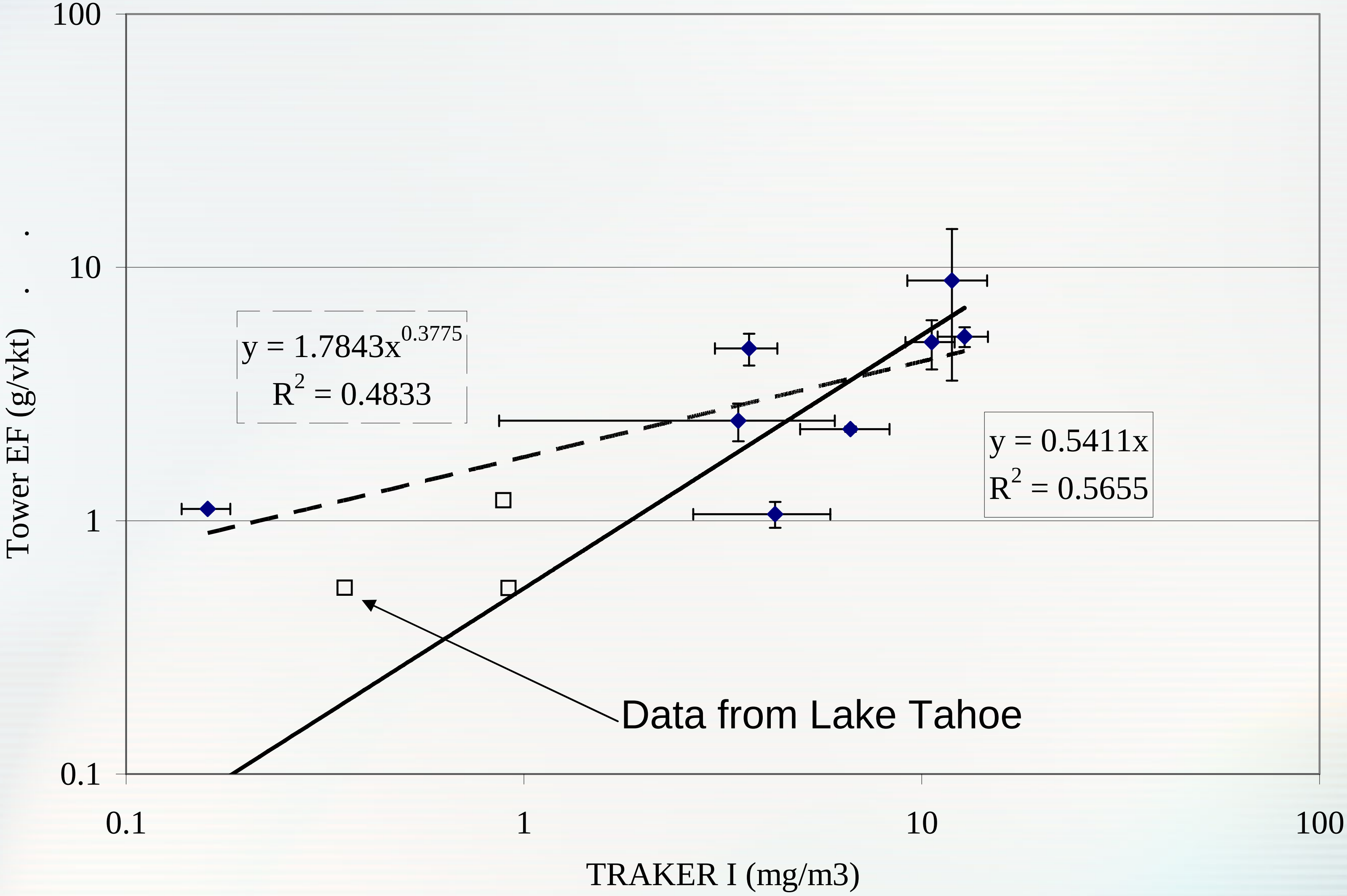
Comparing AP-42 and Mobile Methods to Direct Tower Measurements

- First 9 passes after silt application are in different regime
  - Only consider passes after 9
- Tower Data show a lot of pass to pass noise
  - Factor of 2.4 to convert DustTrak data to PM_{10} mass equivalent
  - Use average measured emission factors for entire Set
  - Take Set average to include all passes (> 9) for all vehicles
    - Vehicles (tons): TRI: 3.4, TRII: 2.75, SCM: 2.5, Ave: 2.88
- For Mobile Data take average of passes (>9) for given set
- For AP-42 (silt-based)
  - Apply AP-42 equations (W= 2.88 tons) to first silt measurement and last silt measurement of Set
  - Use average to represent Set

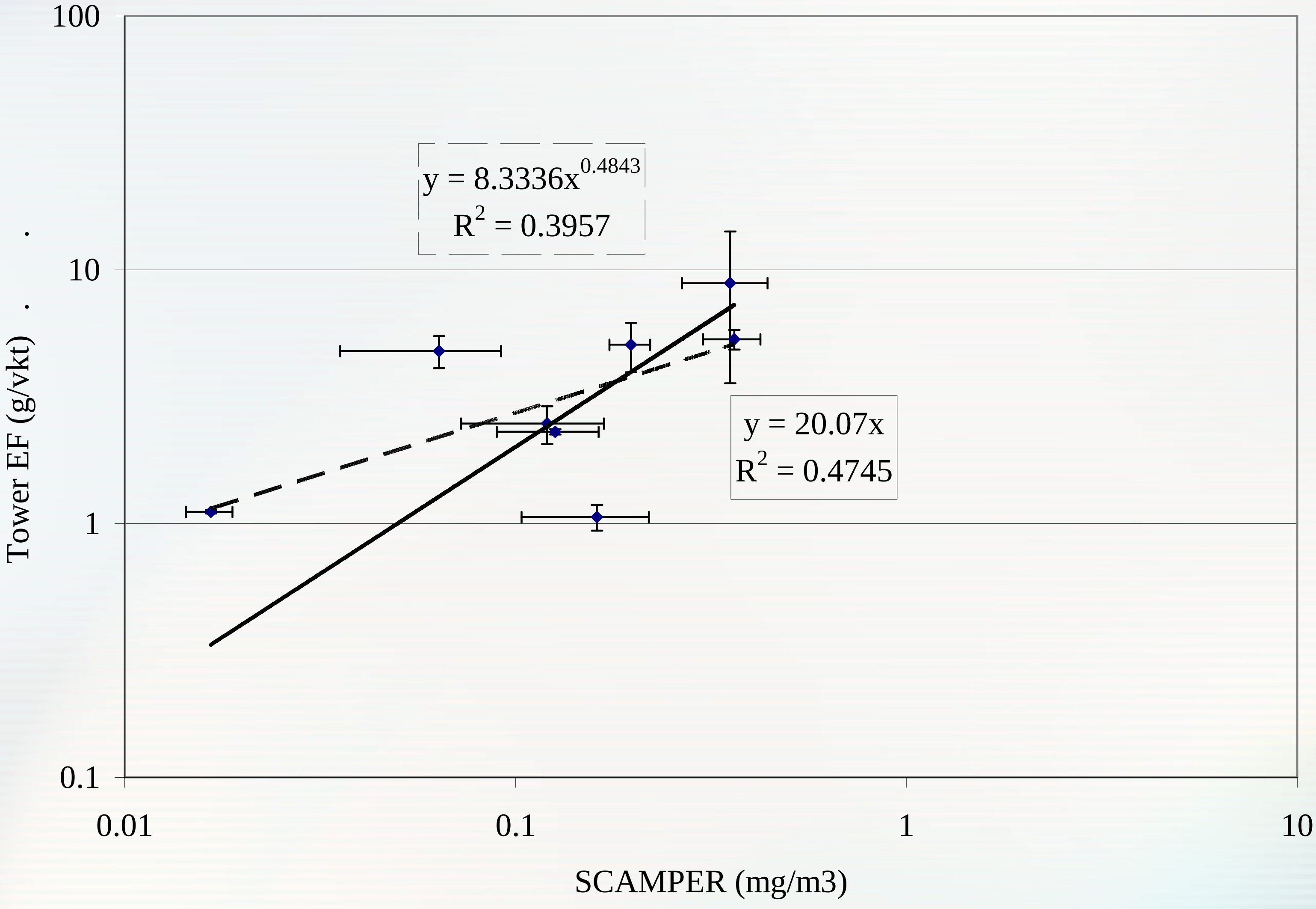
Silt-derived Emissions (AP-42) vs. Directly Measured Emissions – Set-Averaged



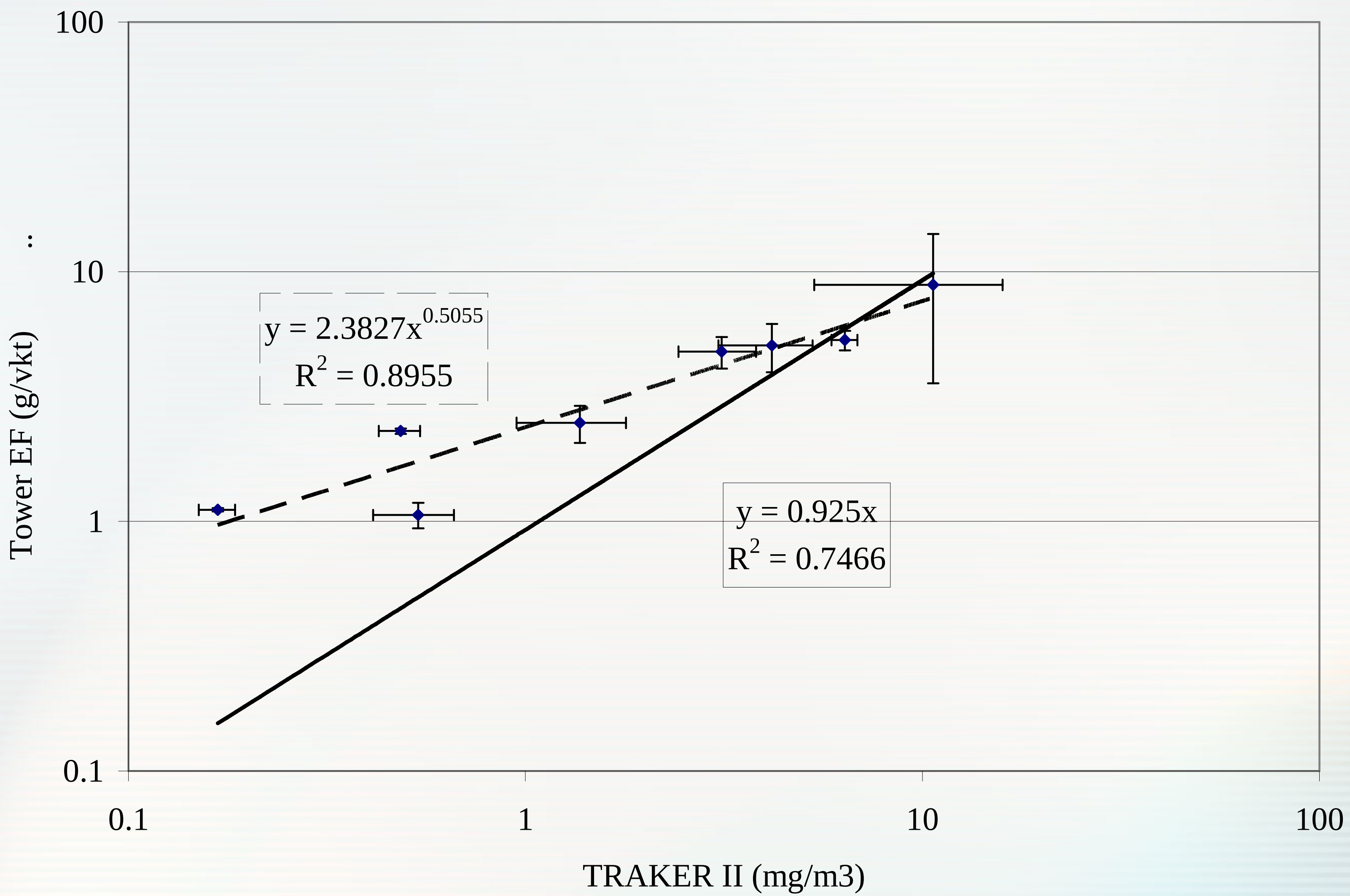
TRAKER I vs. Tower



SCAMPER Versus Tower



TRAKER II vs. Tower



Calibration Equations For Mobile Systems

$EF_{10}=(RS_i)(X_i)$

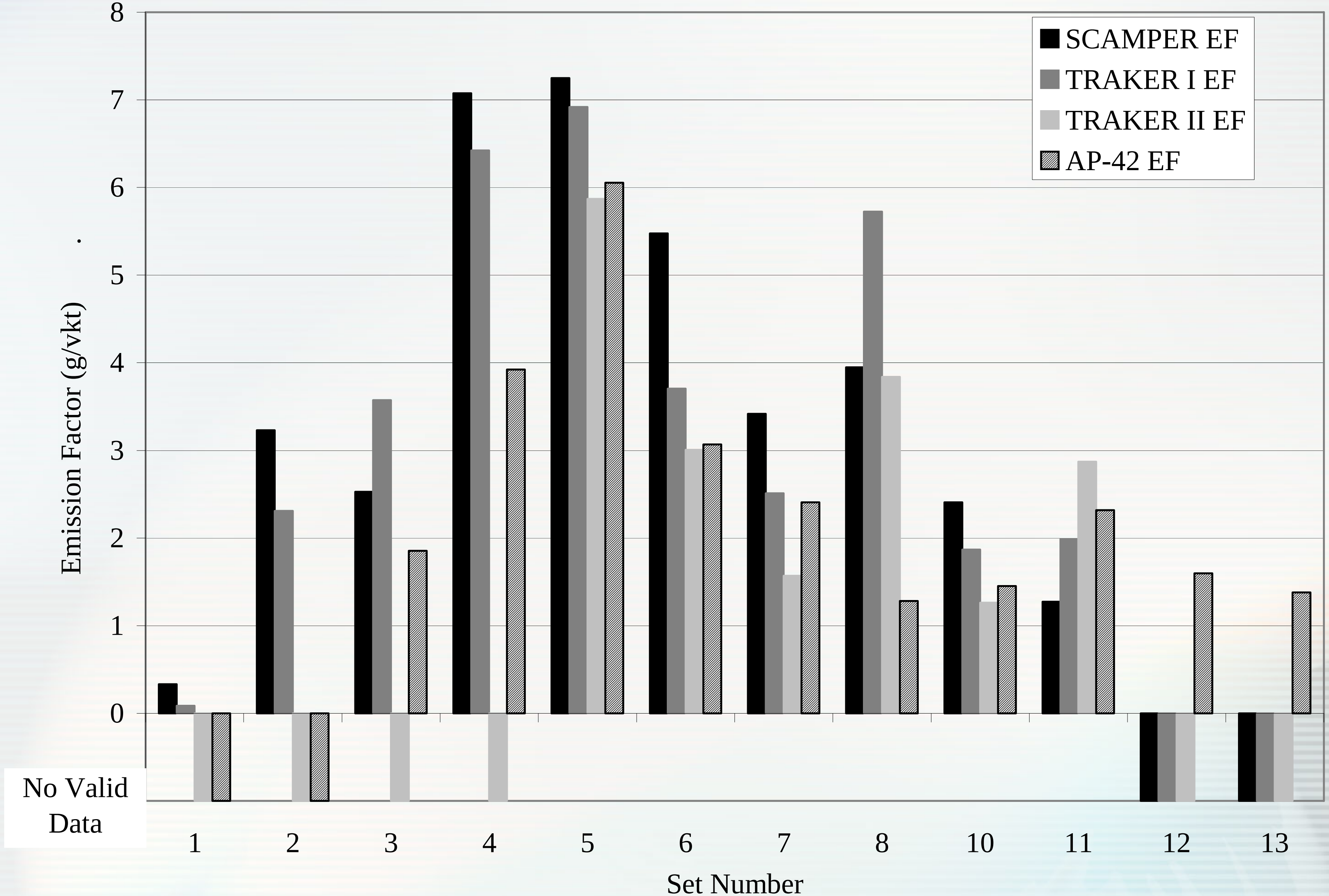
Where EF_{10} = PM_{10} Emission Factor (g/vkt or g/vmt)

RS_i is the Raw Signal from Mobile System *i*

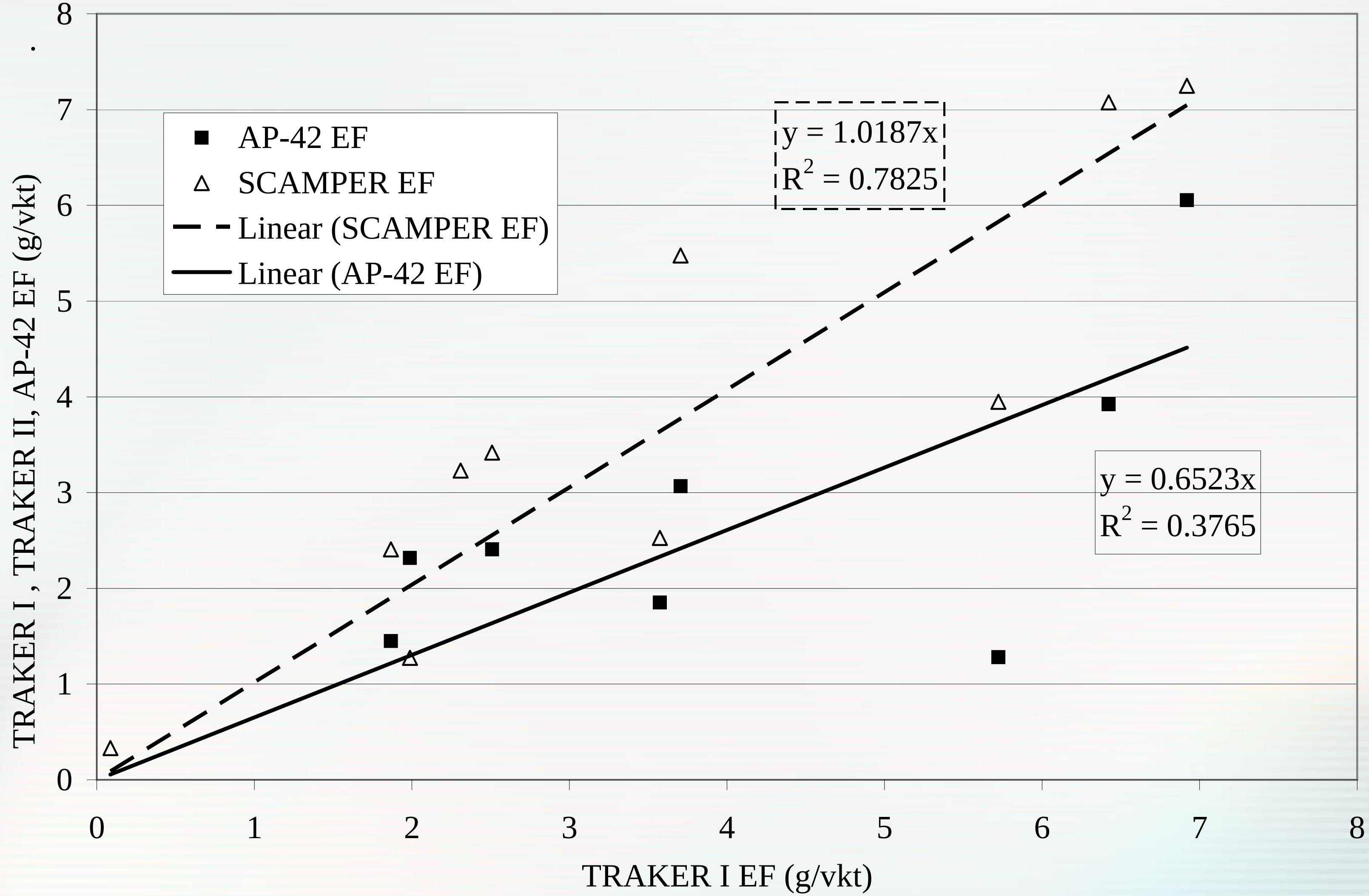
X_i = Multiplier for Mobile System *i*

System	Raw Signal (mg/m^3) multiplier to get PM_{10} emission factor in g/vkt (or g/vmt)	Approximate Distance from Tire(s) to Inlet (m)
TRAKER I	**0.54 (0.86)**	**0.06**
TRAKER II	**0.92 (1.5)**	**0.12**
SCAMPER	**20 (32)**	**5**

Comparing Predicted EF: Boulder City Study



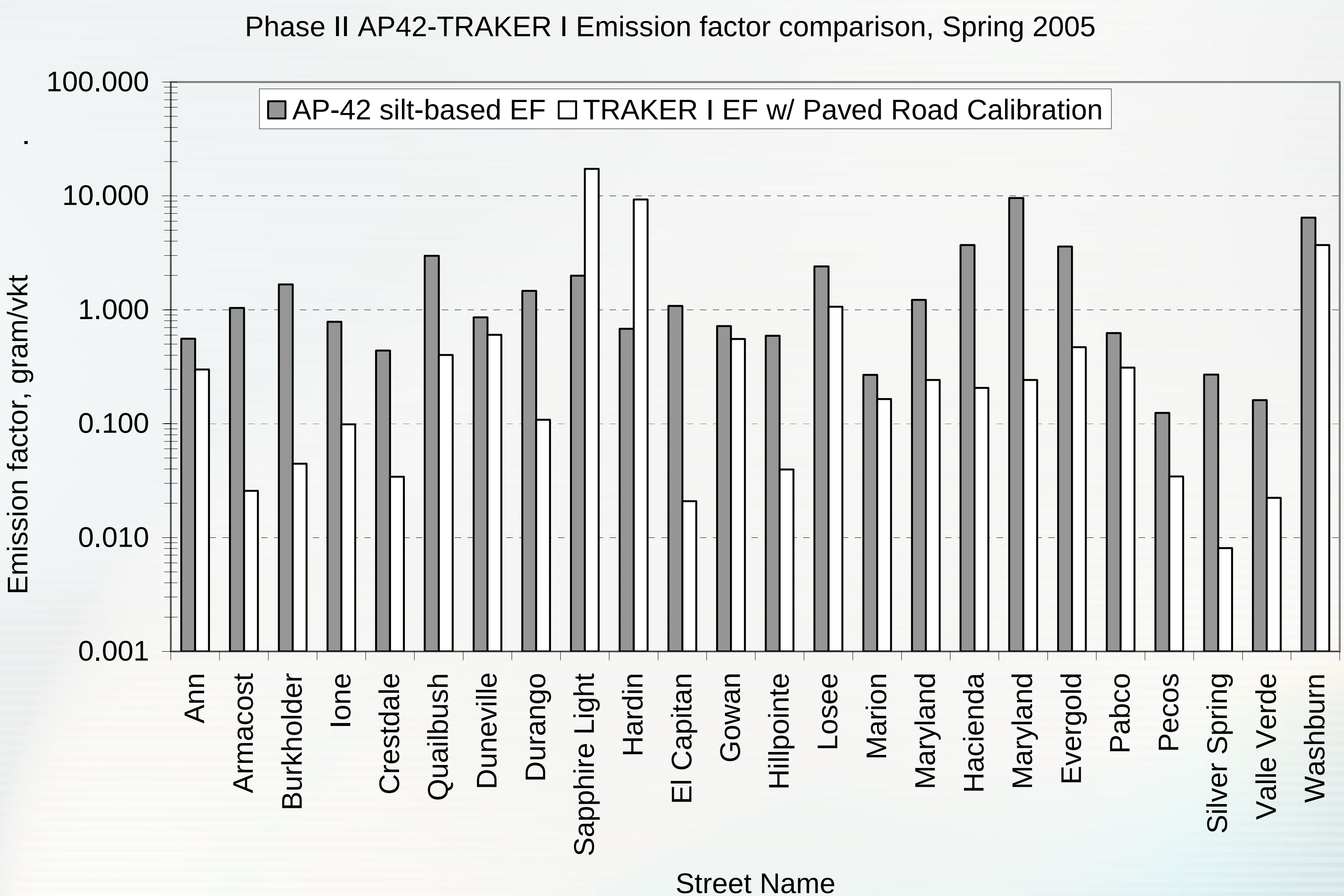
Comparing Predicted EF



Real-World Comparison

- **In 2005, Clark County conducted a different study**
  - SCAMPER and TRAKER I were used to traverse ~ 150 km loop of roads in Clark County
  - Silt Measurements were collected at 24 sites along the same loop
  - What happens if we use current calibration to compare mobile system measurements to silt-based Emission Factors

Real-World Comparison of Mobile Systems and AP-42



SUMMARY & CONCLUSIONS

Summary I

- **Time series suggest two modes of emission**
  - First ~ 9 passes after silt application PM_{10} emissions large and decay rapidly
  - After initial rapid decay, emissions decrease and decay more slowly (~ Factor of 20 slower)
  - Possible Implications for material deposited on roads in pulses – E.g. debris from haul trucks
- **Emissions depend on speed**
  - For same road conditions, horizontal flux measurements and all three mobile systems showed clear dependence on travel speed
  - Silt measurements unable to capture speed dependence

Summary II

- **Using AP-42 equations with measured silt gives slightly lower, but comparable values to direct EF measurement (Towers)**
- **Mobile Systems: Raw signals appear to scale linearly with measured EF**
  - Corroborated with data from other studies (E.g. Lake Tahoe)
  - Multipliers for mobile systems related to distance between inlets and source of road dust (i.e. tires).
  - Raw Signal (mg/m^3) multipliers to obtain EF (g/vkt;g/vmt)
    - TRAKER I: 0.54; 0.86
    - TRAKER II: 0.92; 1.5
    - SCAMPER: 20; 32

Summary III

- **Comparing mobile system EF obtained with these calibrations to silt-based EF gives comparable results for high loading conditions of Phase IV study**

- ***BUT***

- **Using same calibrations, comparing mobile system EF to silt-based EF (AP-42) for Real-World roads in Clark County indicates that:**
  - Mobile system EF > silt EF only for “very dirty” roads
    - Likely, VMT on “dirty roads” not very high
    - Taking VMT weighted average for EF, mobile system EF < silt EF

Conclusions

- Prior to Phase IV study
  - Data available for TRAKER I only allowed extrapolation of unpaved road calibration to paved road
  - SCAMPER EF was calculated based on a first principles approach and simple assumptions
  - Not possible to quantitatively compare EF estimates obtained with silt to mobile systems

Conclusions

- After Phase IV
  - Three mobile systems calibrated against common, accepted tower standard on a paved road
  - Mobile systems are comparable in ability to:
    - Detect changes in EF over time
    - Quantify changes in EF associated with travel speed
  - Silt-based EF
    - Correlates with PM_{10} emissions for given set of conditions
      - Size distribution of soil material
      - Road condition
    - Not directly linked to PM_{10} emissions
    - Does not (directly) capture effects of speed

QUESTIONS?

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