Sensor Evaluations: The Impact of $PM_{2.5}$ Monitor Type

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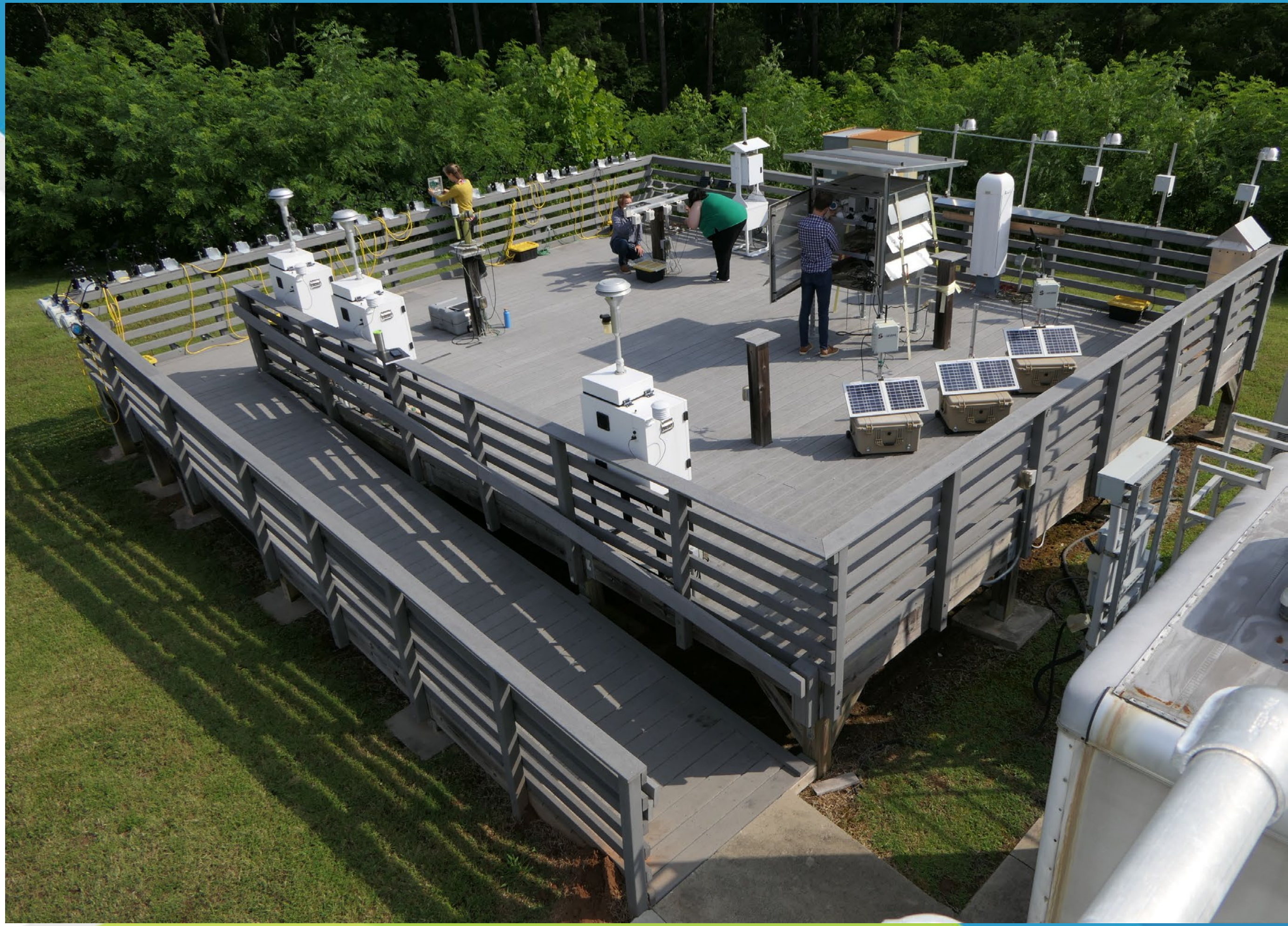
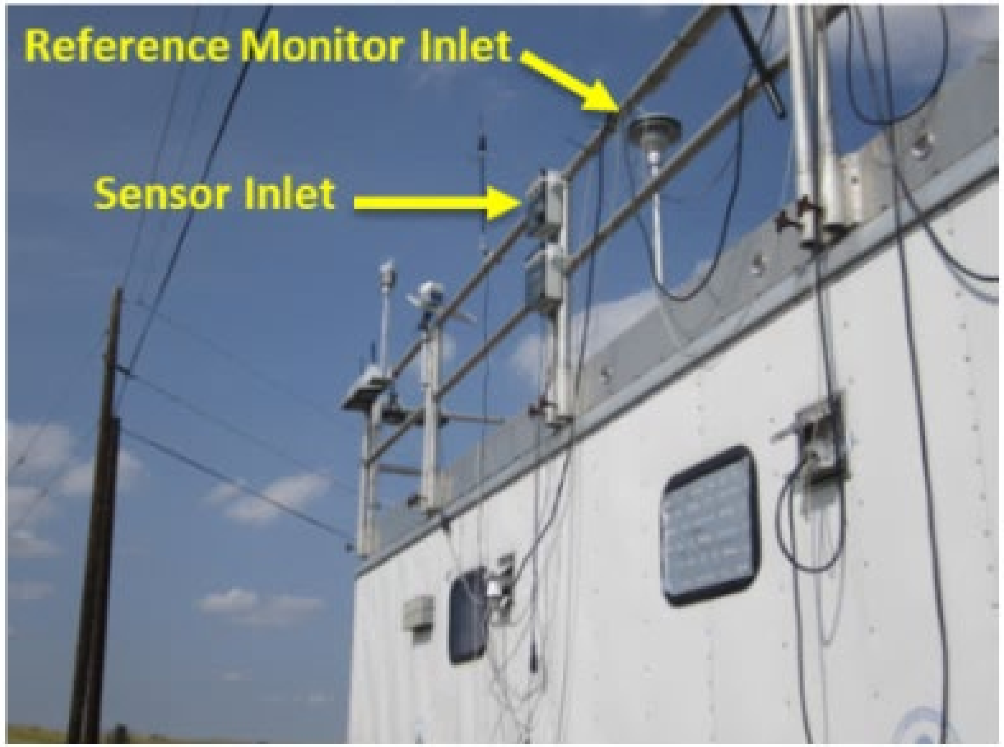


How do we evaluate $PM_{2.5}$ air sensor accuracy?

- Compare to $PM_{2.5}$ monitors

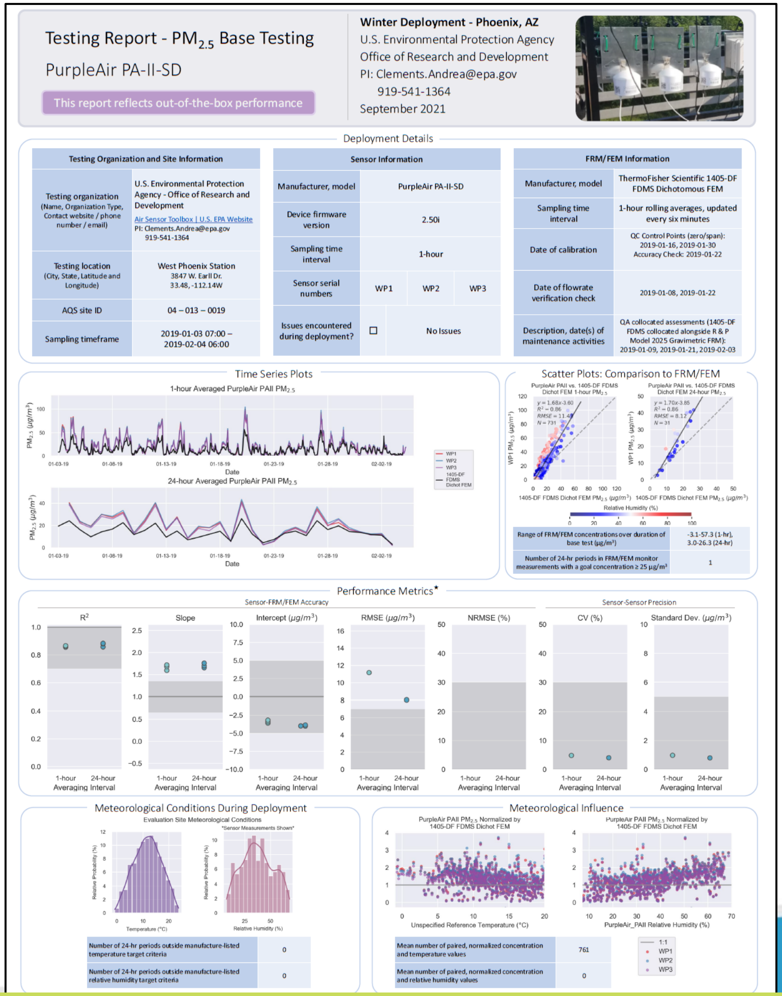


Air sensors collocation
Sensors near regulatory monitors in Denver, Colorado (USA)

How do we evaluate $PM_{2.5}$ air sensor accuracy?

- Compare to $PM_{2.5}$ monitors
- Can use EPA's Air Sensor Performance targets
  - Linear regression: y=mx+b
  - Coefficient of variation (R^2)
  - Root Mean Squared Error (RMSE) & Normalized RMSE (NRMSE)
  - Sensor-Sensor precision not discussed in today's talk
  - Recommend using 24-hr or 1-hr average measurements with FRM or FEM
    - Note: there is no hourly standards for $PM_{2.5}$ measurement performance for FEM monitors

U.S. EPA Sensor Evaluation Report (Example)



FEM= Federal Equivalent Method
FRM=Federal Reference Method

EPA Sensor Performance Metrics Report
https://www.epa.gov/air-sensor-toolbox/air-sensor-performance-targets-and-testing-protocols

Sensors can have bias and random noise

Sensor and monitor with **perfect agreement**

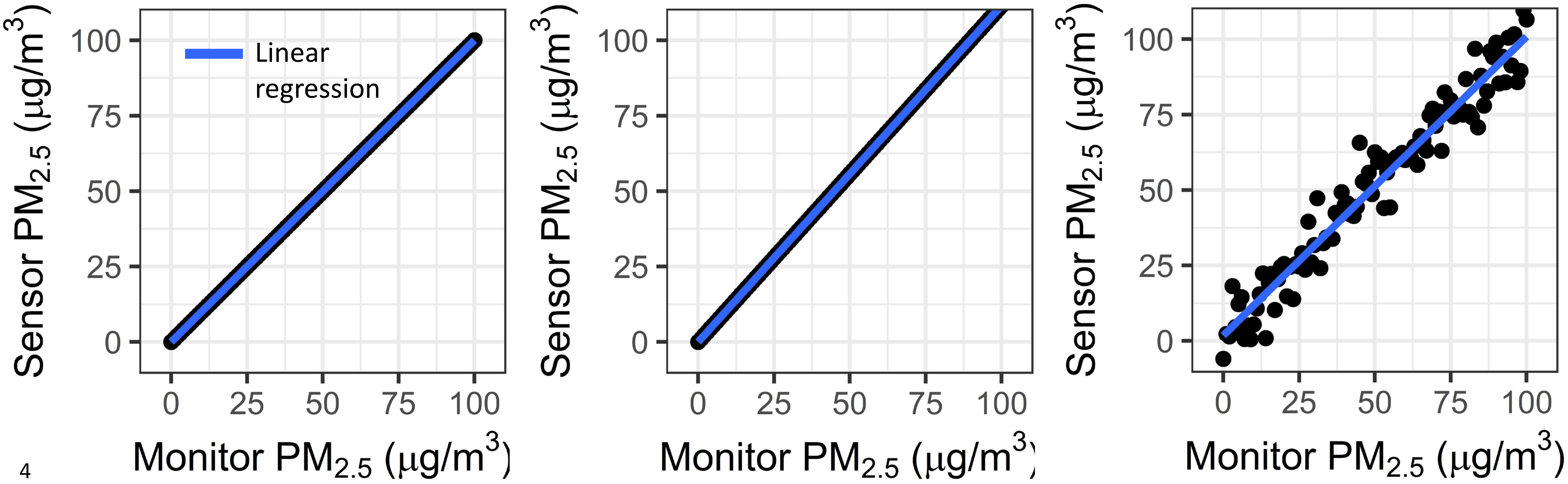
$Y=1*x + 0$
$R^2= 1.00$
RMSE= 0 µg/m³

Sensor with **bias** compared to the monitor (slope and/or intercept)

$Y=1.12*x + 0$
$R^2= 1.00$
RMSE= 6.7 µg/m³

Sensor with **random noise** compared to the monitor

$Y=0.99*x + 1.80$
$R^2= 0.95$
RMSE= 6.8 µg/m³

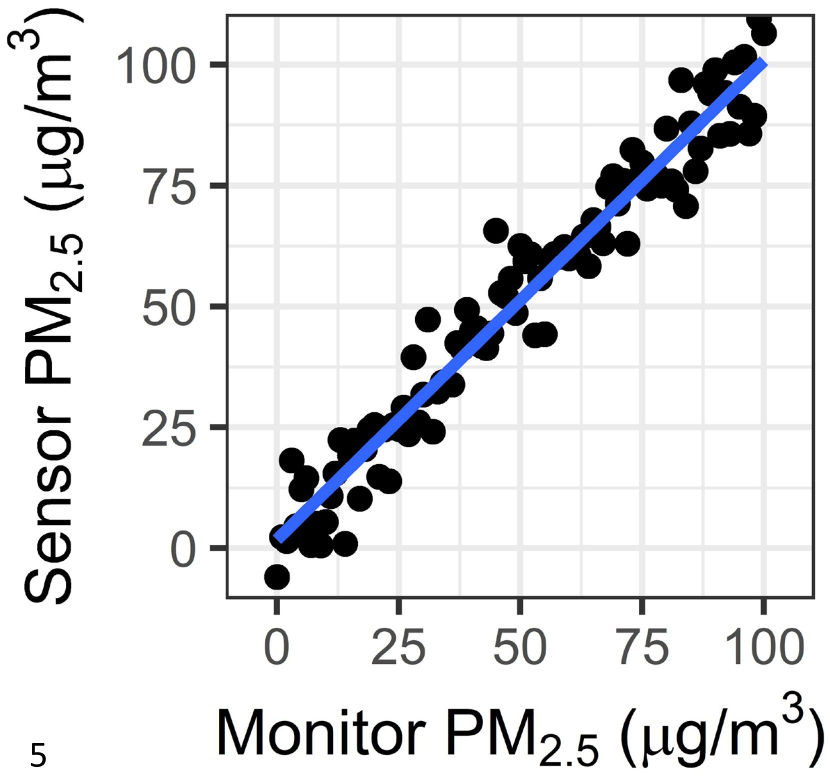


Monitors can have random noise and bias

Challenge to isolate sensor bias/noise

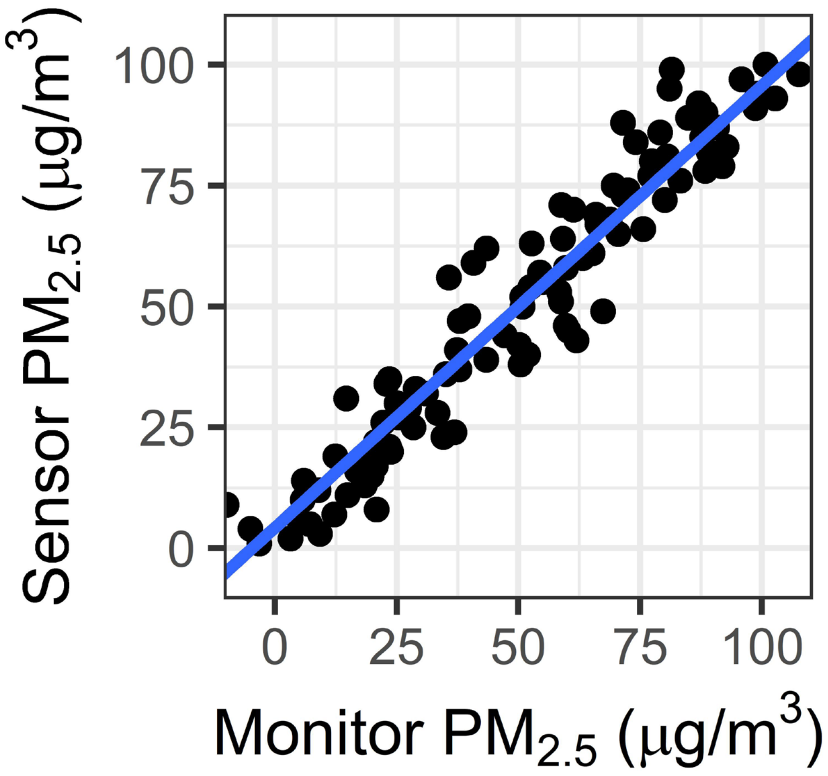
Sensor with **random noise** compared to the monitor

Y=0.99*x + 1.80
R^2= 0.95
RMSE= 6.8 μg/m³



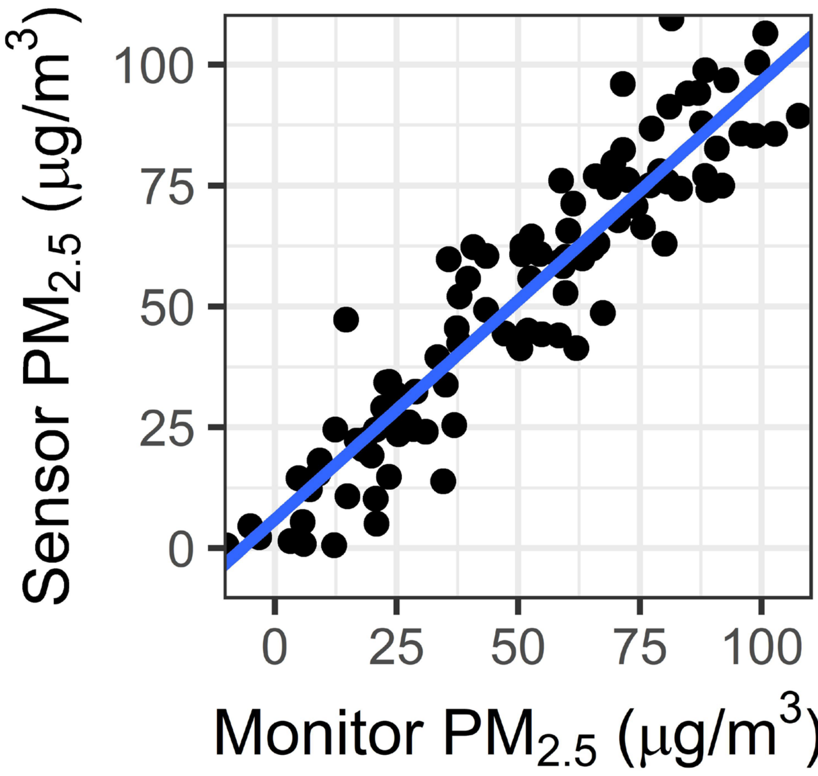
Monitor with **random noise**

Y=0.91*x + 4.27
R^2= 0.92
RMSE= 8.8 μg/m³



Sensor and monitor with **random noise**

Y=0.91*x + 6.00
R^2= 0.87
RMSE= 11 μg/m³



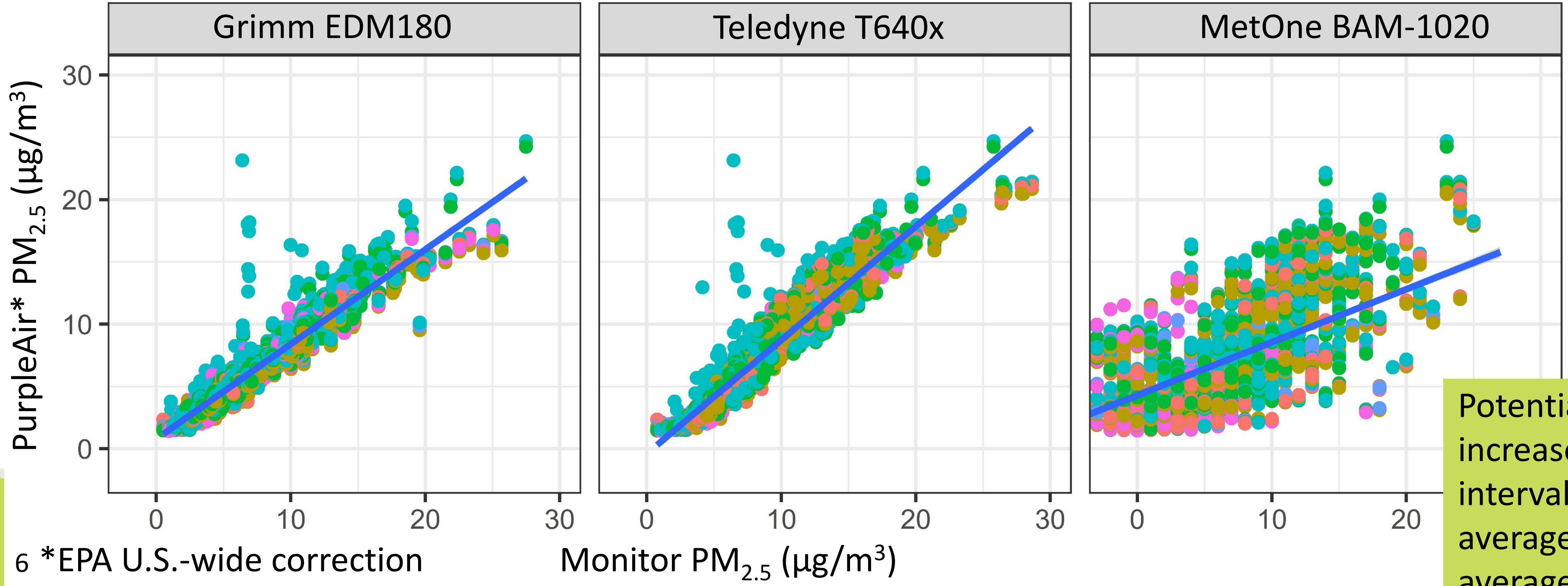
Research Triangle Park Example (Jan-March 2018)

1-hr evaluations would meet EPA performance targets when compared to the Grimm or T640 but not the BAM due to noise in hourly BAM measurements

Y=0.76*x + 0.79
R^2= 0.91
RMSE= 1.8 μg/m^3

Y=0.91*x – 0.39
R^2= 0.92
RMSE= 1.6 μg/m^3

Y=0.43*x + 4.29
R^2= 0.39
RMSE= 4.9 μg/m^3

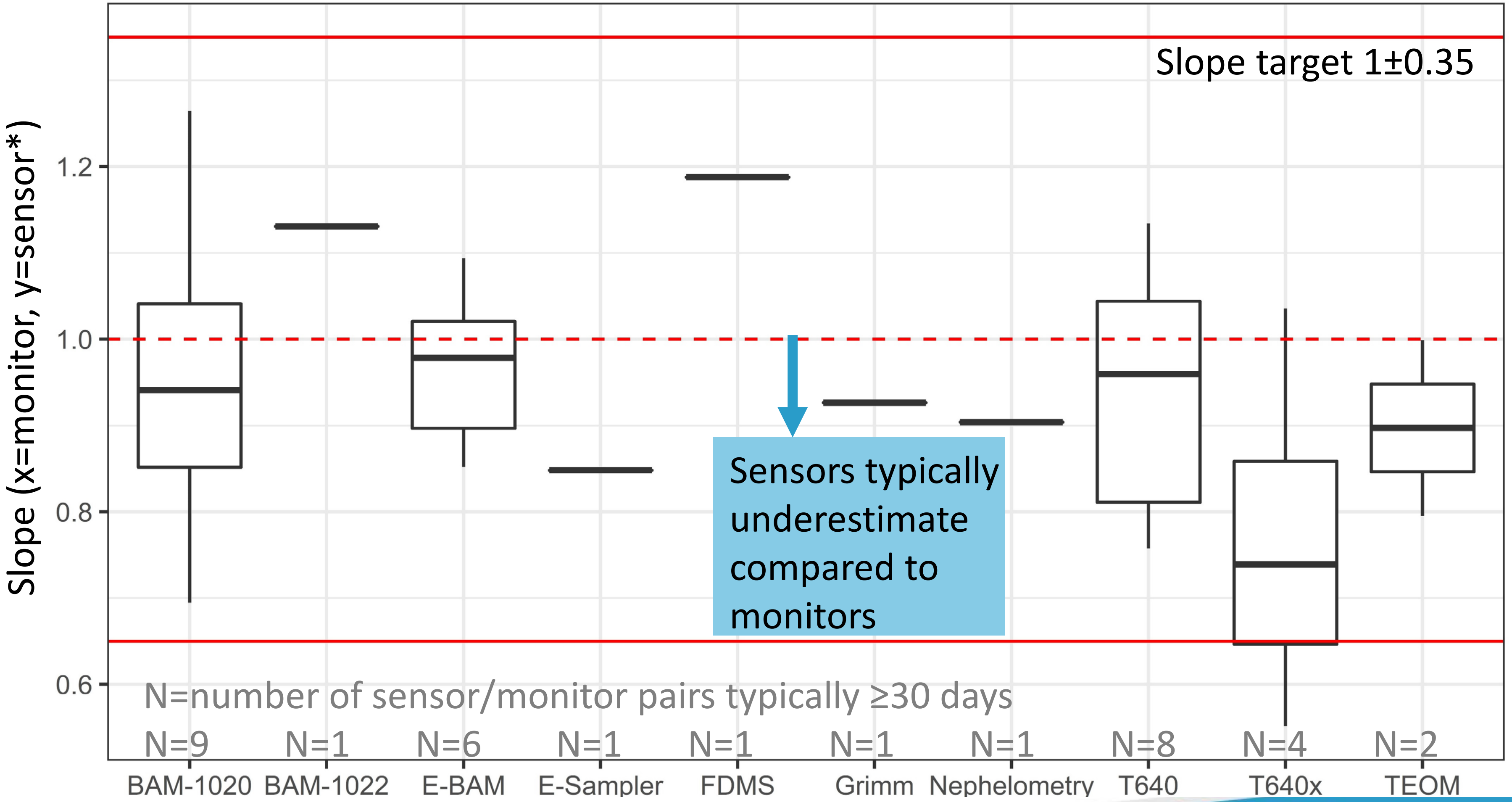


Potential solution: increase averaging interval (e.g., 4-hr average, 24-hr average)

*EPA U.S.-wide correction

Performance of sensors across the U.S. and during smoke impacts (hourly average monitor range: <detection limit -1506 µg/m^3)

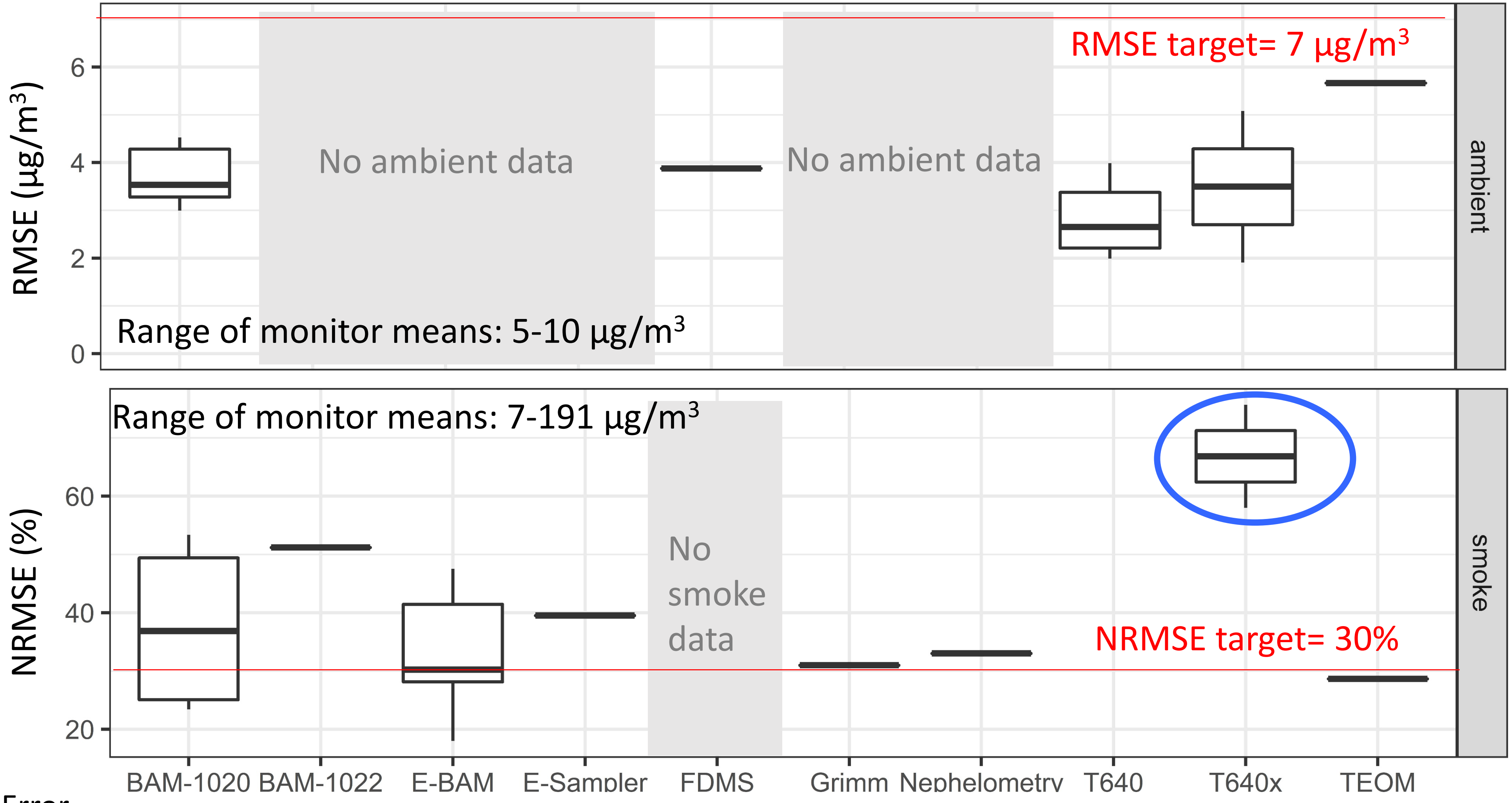
- 34 PurpleAir sensors collocated/nearby monitors
- Slopes are typically within the performance targets
- Stronger underestimation as compared to T640x



*PurpleAir sensors corrected using nonlinear extended U.S.-wide correction
Low N limits broad applicability of findings for some monitor types
E-BAM, E-Sampler are temporary smoke monitors, Nephelometry is non-FEM

Performance of sensors across the U.S. and during smoke impacts (hourly average)

- Error (RMSE) within target across ambient sites
- Smoke sites typically above Error (NRMSE) target
- T640x largest error during smoke

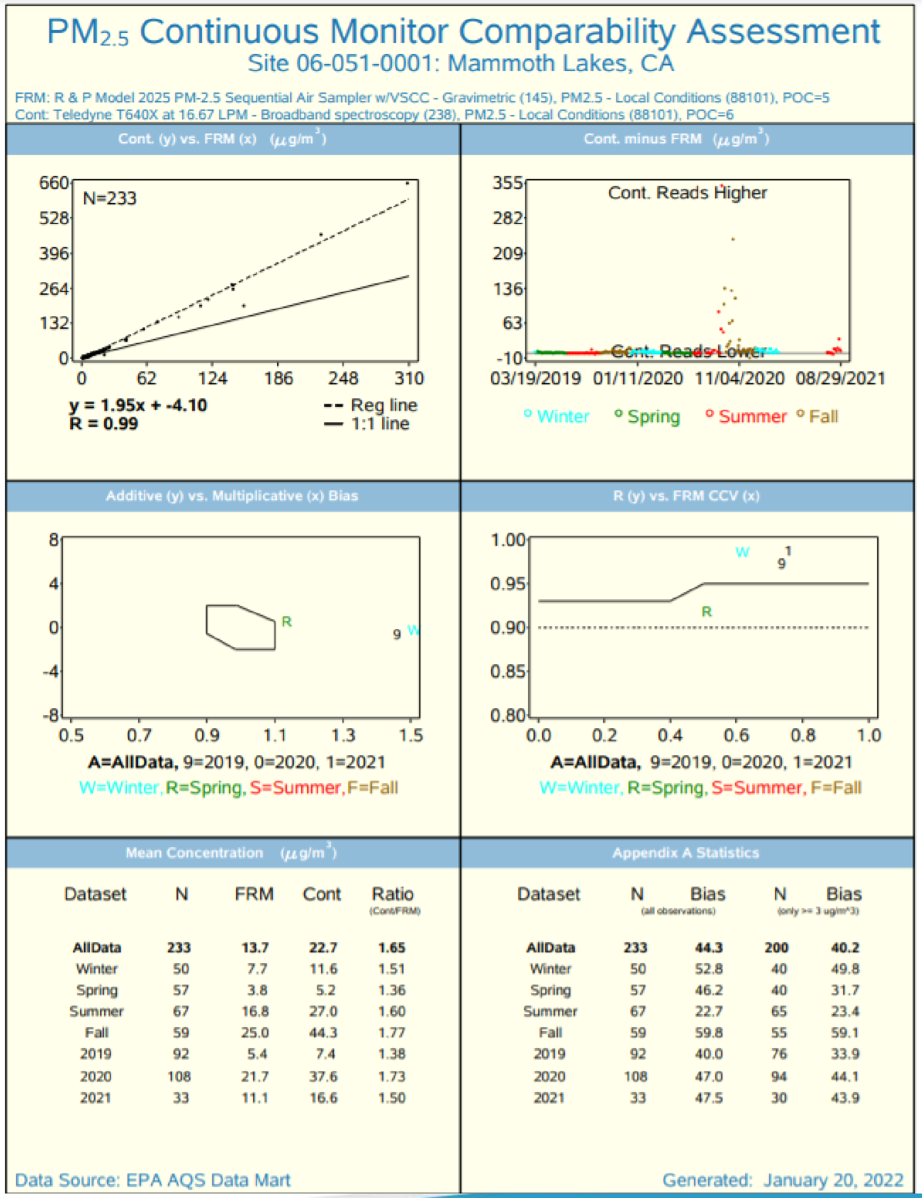


RMSE=Root Mean Squared Error
NRMSE=Normalized Root Mean Squared Error

Low N limits broad applicability of findings for some monitor types

How do we understand the performance of Monitors?

- Compare with FRMs
  - Requires simultaneously running sensor(s) for evaluation, monitor, and FRM
  - Ideally multiple comparisons at a range of concentrations
- Can compare using the comparability assessment tool (if monitor and FRM sent to AQS) or can do your own comparison
- Not available at all sites

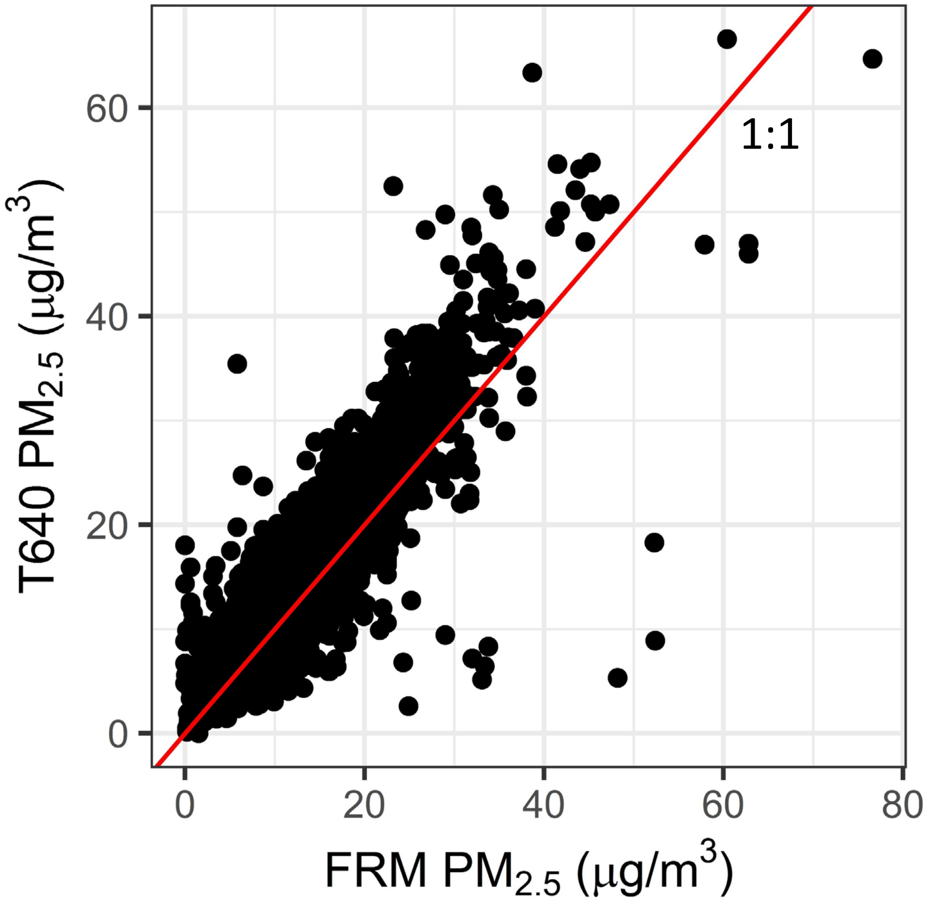


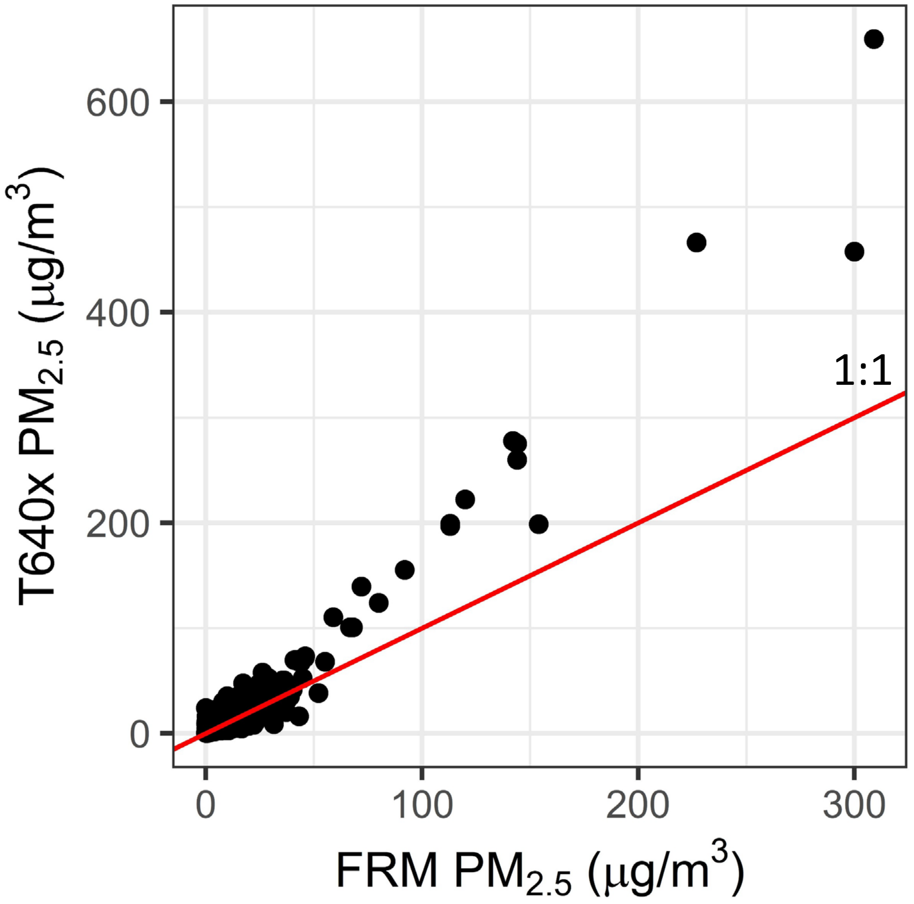
24-hr averaged performance of T640x versus gravimetric measurements (https://www.epa.gov/outdoor-air-quality-data/pm25-continuous-monitor-comparability-assessments).

Bias of T640/T640x across the U.S.

(Data from AQS 2019-2021)

- T640 and T640x show overestimation above ~35 µg/m^3
- Segmented regression suggests nonlinear relationship with different slopes by concentration range





Conclusions

- We cannot expect better performance from sensors than FEMs
- Monitor bias and noise impacts perceived sensor performance
- Optical methods may be valuable for sensor evaluations at low concentrations (~<35 µg/m^3) due to their low noise at low concentrations
- Other FEM methods and temporary smoke monitors may be more valuable at high concentrations where bias in the T640 and T640x may impact results
- There is value in running simultaneous FEM and FRM measurements

Questions?

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