Multi-year Performance Evaluation of Three Types of FEM $PM_{2.5}$ Monitors Operating Within the South Coast Air Basin

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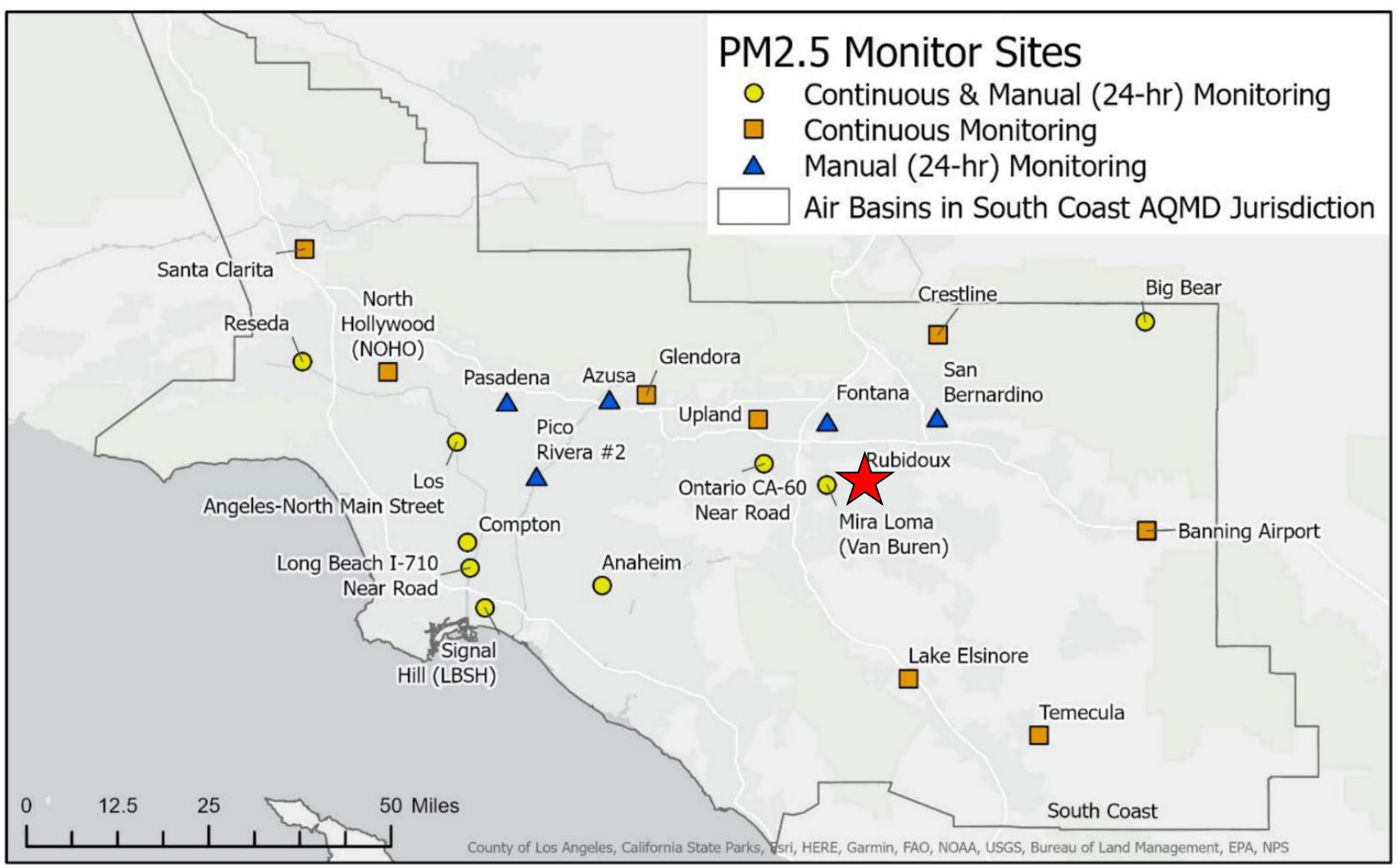
Quality Assurance, Monitoring and Analysis Division

South Coast Air Quality Management District

South Coast AQMD's Air Monitoring Network



- **35+** permanent air monitoring sites
- **17** FRM $PM_{2.5}$ stations
- **19** continuous $PM_{2.5}$ stations
  - 9 Non-FEM
  - 10 FEM
- In Rubidoux, $PM_{2.5}$ is measured using the FRM filter-based method, Met One BAM-1020, Teledyne T640, and GRIMM EDM model 180.

Filter-based Federal Reference Method (FRM)

- Deposit $PM_{2.5}$ from ambient air onto a filter
- Filter is weighed before and after sampling to determine $PM_{2.5}$ mass
- 24-hour sample collection period
- “Gold standard” for $PM_{2.5}$ measurements, directly comparable to federal standards
- Labor intensive and slow-reporting process

Partisol® Plus 2025 Sequential Sampler (Thermo 2018). Photo adapted from Department of Ecology, State of Washington: https://apps.ecology.wa.gov/publications/documents/1802020.pdf

Automated Continuous Federal Equivalent Method (FEM)

Met One BAM-1020

Teledyne T640

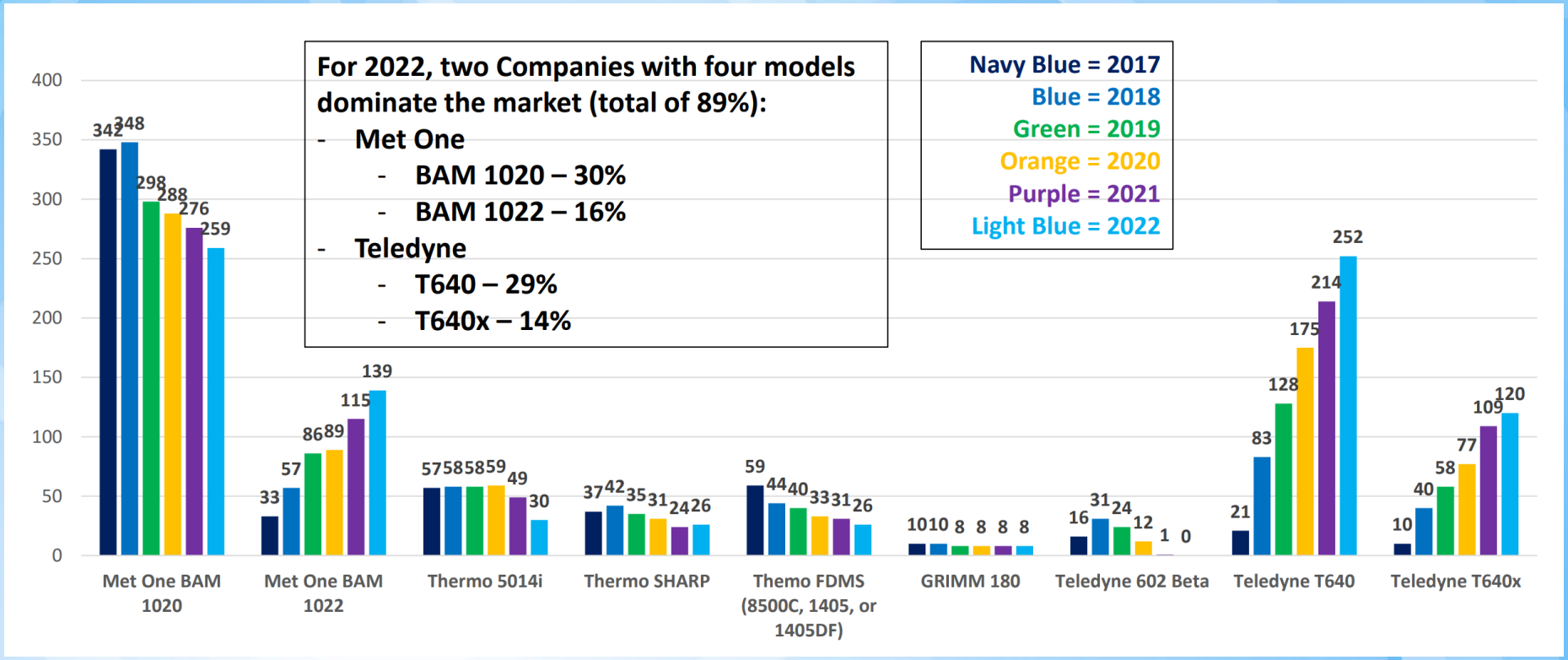
GRIMM EDM Model 180

- Can be used to supplement FRM when needed, if performance checks are passed
- Provides near real-time data, useful for public information
- Less labor-intensive than FRM
- Potential bias due to sampling process difference from FRM, particle source variations and environmental conditions

Sources of instrument photos: Met One BAM-1020 http://www.vcapcd.org/aq_monitoring.htm; Teledyne T640 https://www.cleanair.com/product/teledyne-api-t640x/; GRIMM EDM Model 180 https://www.environmental-expert.com/products/grimm-model-edm180-environmental-dust-monitor-for-approved-pm-measurements-ams-699121.

Why compare FEM to FRM?

- Met One and Teledyne are the largest suppliers of FEM $PM_{2.5}$ instruments
- Provides an assessment on biases between two methods
- Informs decisions on purchasing FEM monitors
- Replacing FRM with FEM reduces labor but may impact design values



$PM_{2.5}$ Continuous FEMs Reporting to AQS parameter code 88101 from 2017 to 2022. *Figure credit: Tim Hanley, EPA-OAQPS-AQAD, Ambient Air Monitoring Group.*

Rubidoux Air Monitoring Station

RIVR Site Survey Report

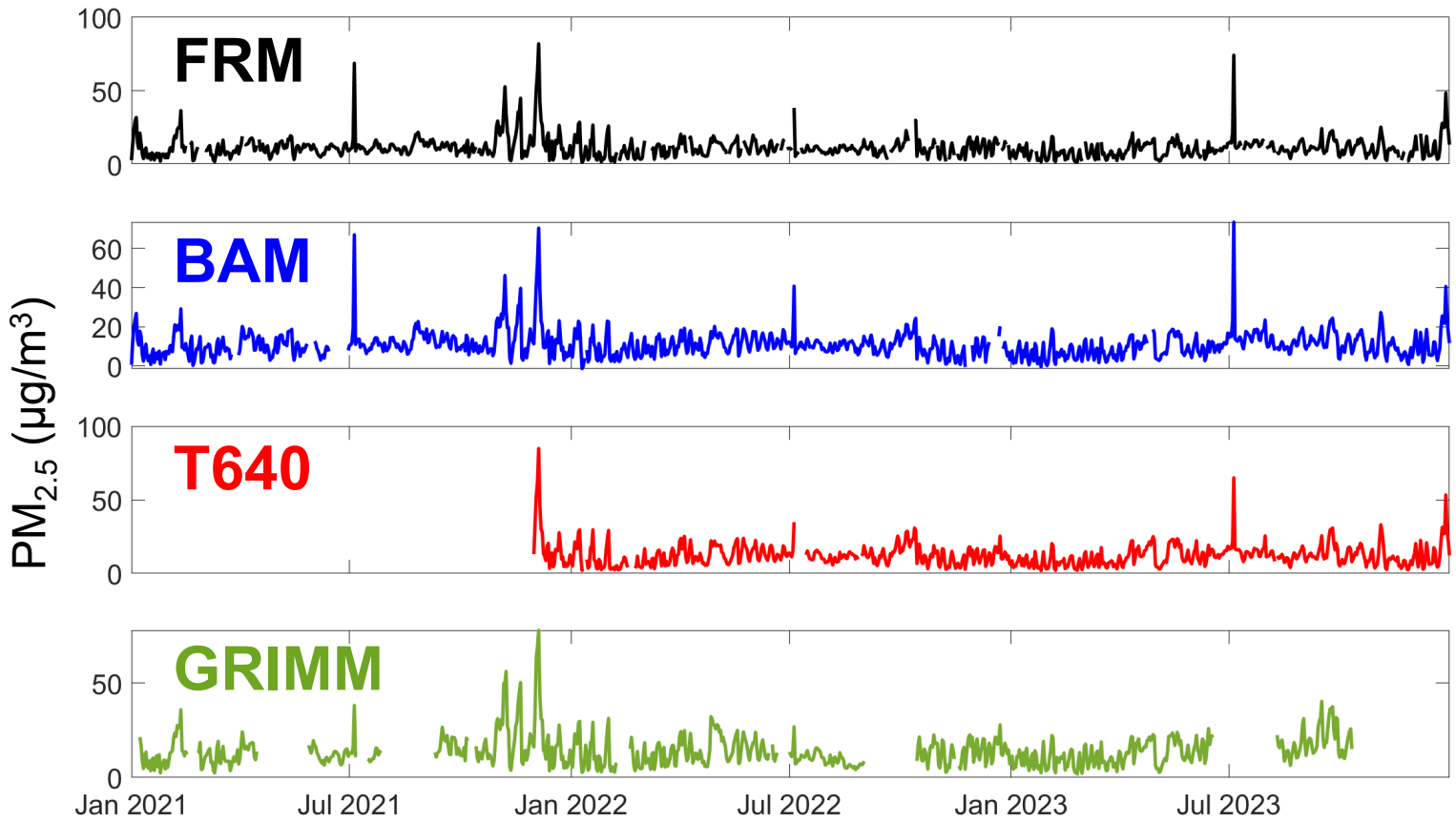
- Highest $PM_{2.5}$ pollution in the South Coast Air Basin
- Residential neighborhood next to busy highway
- Measures $PM_{2.5}$ using filter-based FRM and three FEM monitors (BAM1020, GRIMM, and T640)
- Site also monitors for:
  - $PM_{2.5}$ speciation
  - Other criteria pollutants (e.g., NOx and CO)
  - Meteorological conditions (mixing layer height wind speed and direction, RH, temperature, etc.)
  - VOCs, and other air toxics
- Primary field site for testing low-cost sensors under the AQ-SPEC program

Research Questions

How do $PM_{2.5}$ measurements from 2021-2023 collected by three FEM monitors at Rubidoux compare to FRM $PM_{2.5}$ data?

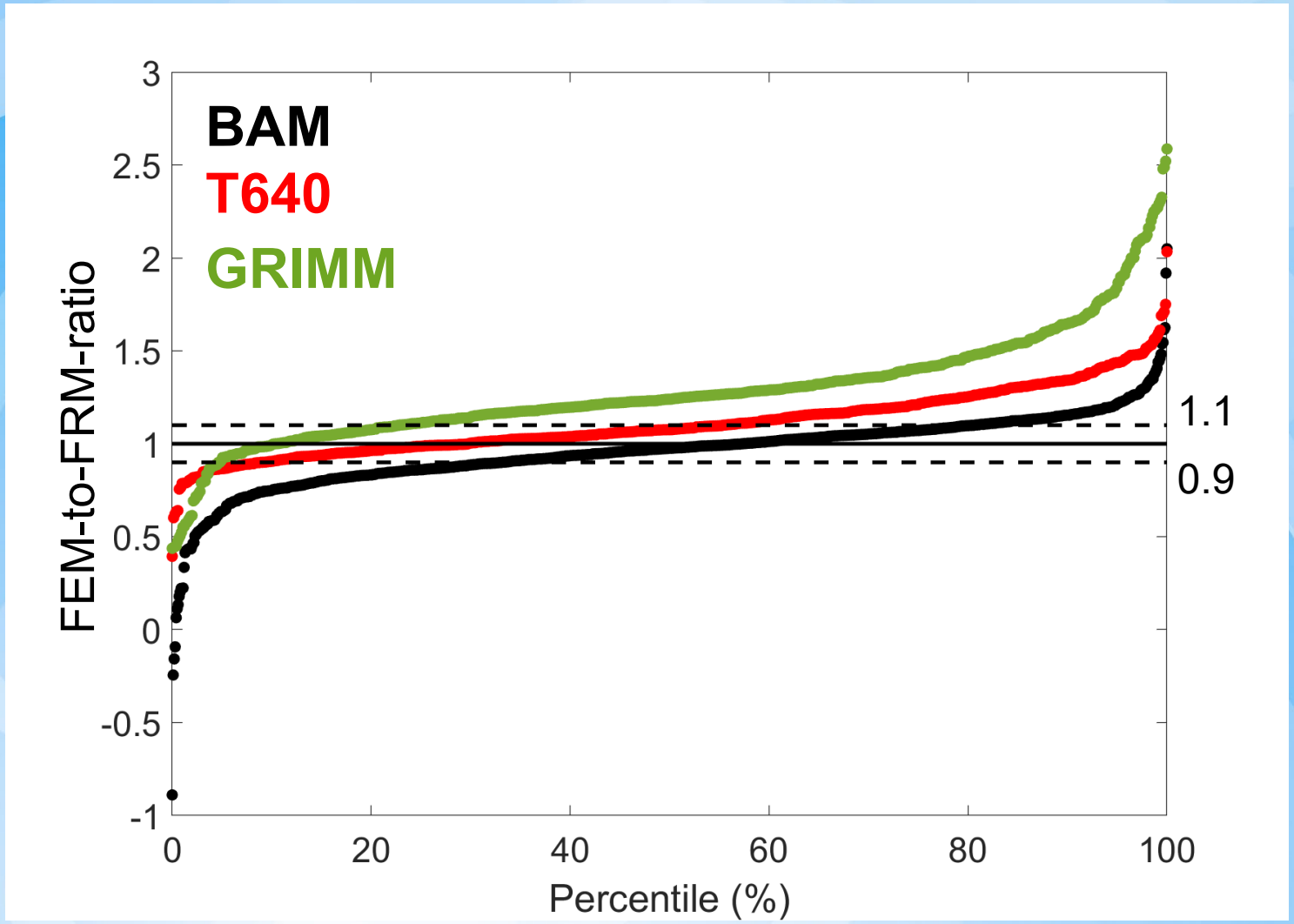
- How do FEM $PM_{2.5}$ monitors perform relative to FRM?
- Are there any differences/biases in $PM_{2.5}$ measurements among FEM monitors?
- Do FEM-to-FRM differences follow any patterns (e.g., seasonal, weekday/weekend, diurnal)?
- Are FEM-to-FRM differences related to meteorological conditions such as relative humidity? Are differences related to $PM_{2.5}$ speciation?

$PM_{2.5}$ Data Used in This Study



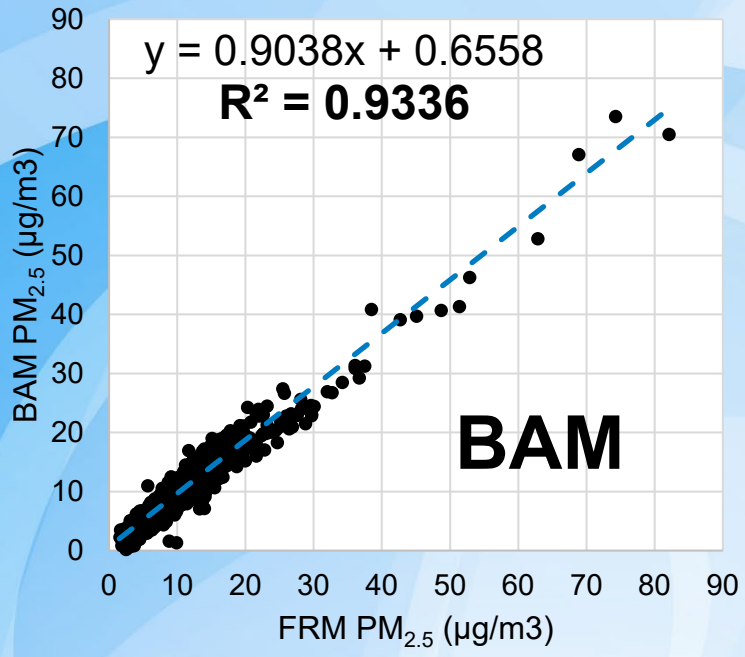
- Data collected from 2021 to 2023
- FRM and BAM1020 have almost complete data coverage
- T640 data started in December 2021 for this analysis
- GRIMM data capture impacted by frequent factory calibration/maintenance
- U.S. EPA correction factor was applied to all T640 data used in this study

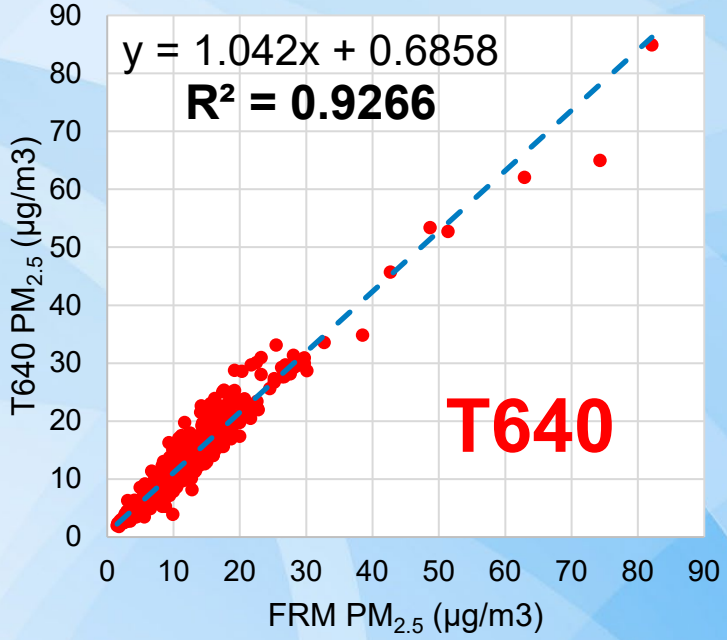
FEM-to-FRM-Ratio for Different FEM Monitors

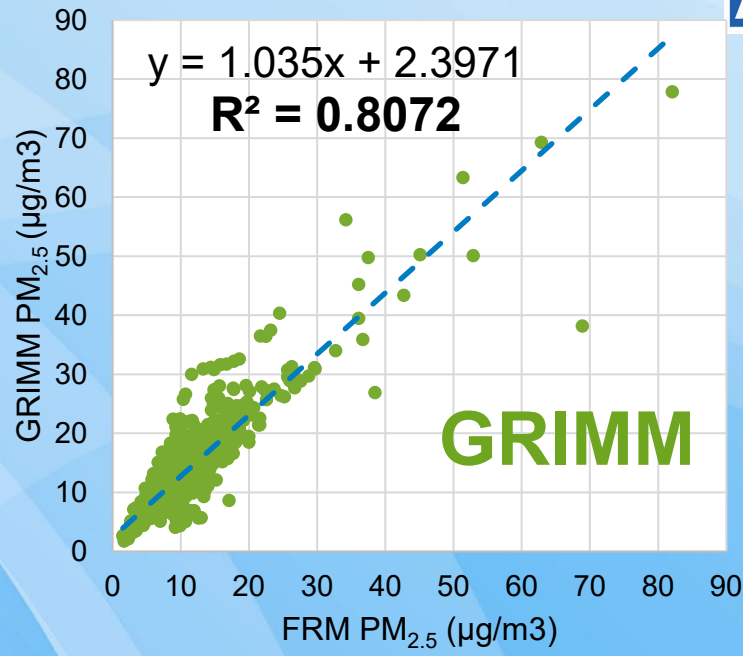


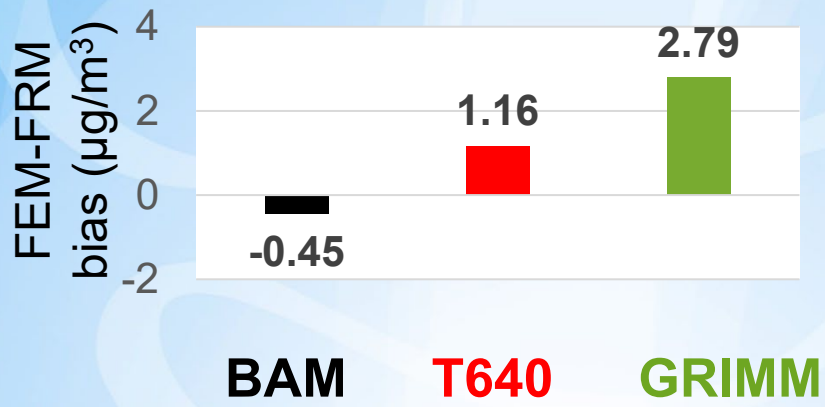
- GRIMM monitor has the highest FEM-to-FRM-ratio, while BAM1020 has the lowest
- Concentrations measured by T640 and GRIMM are generally higher than FRM measurements

Correlations Between FEM and FRM Monitors



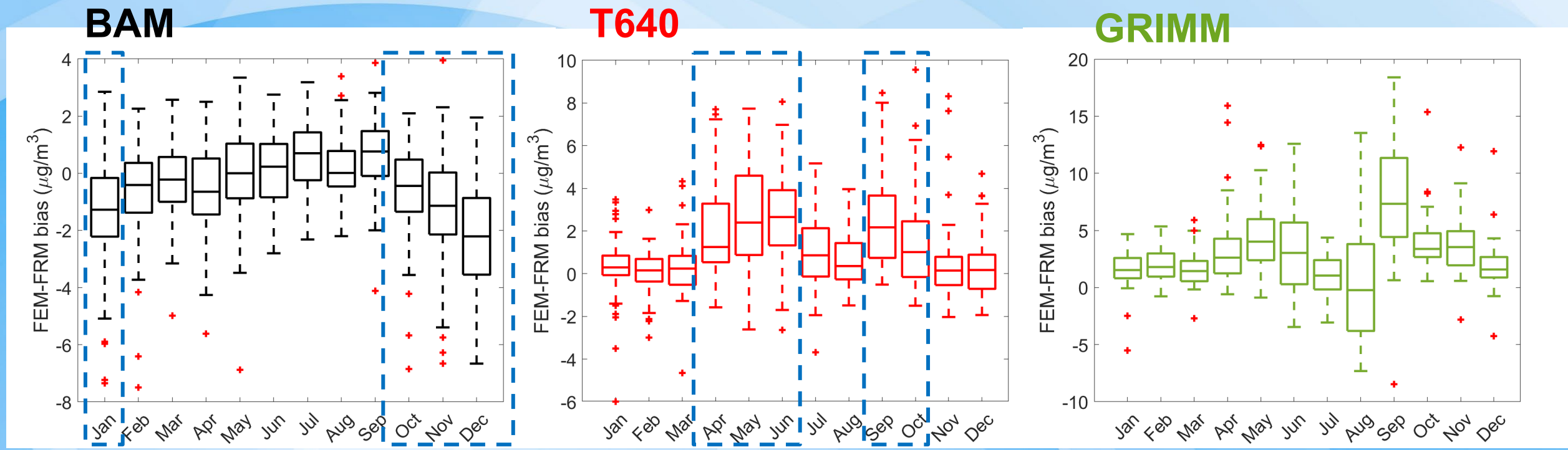






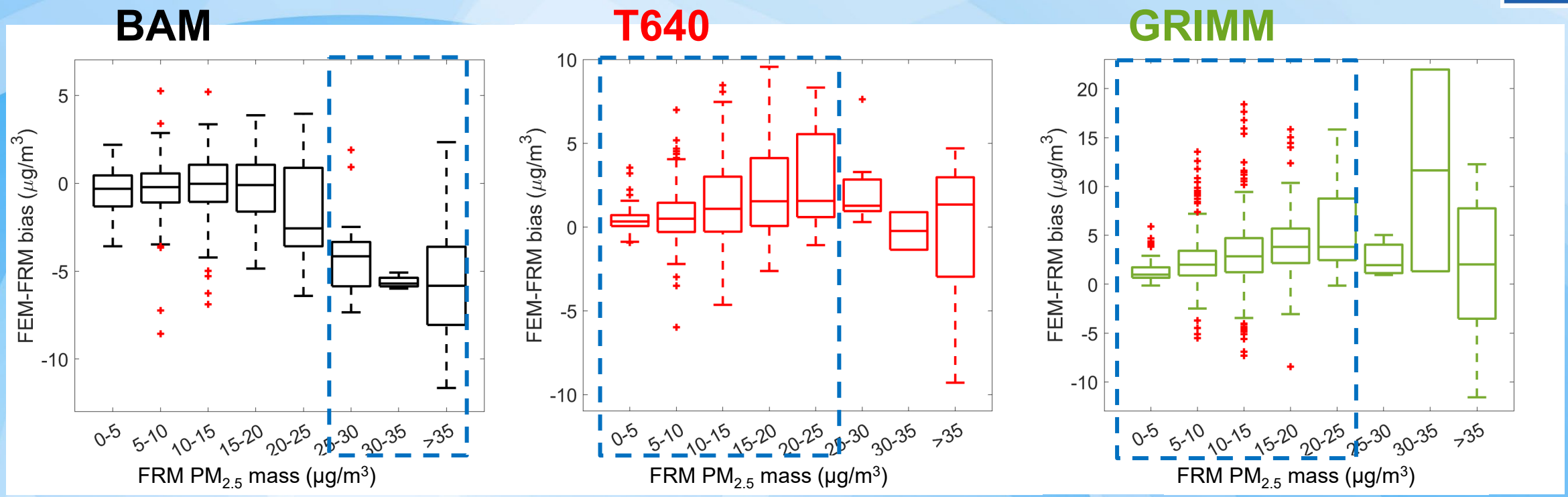
- BAM1020 measures slightly lower $PM_{2.5}$ concentrations compared to FRM, while T640 and GRIMM measure higher $PM_{2.5}$

Seasonal Patterns of FEM-to-FRM Difference



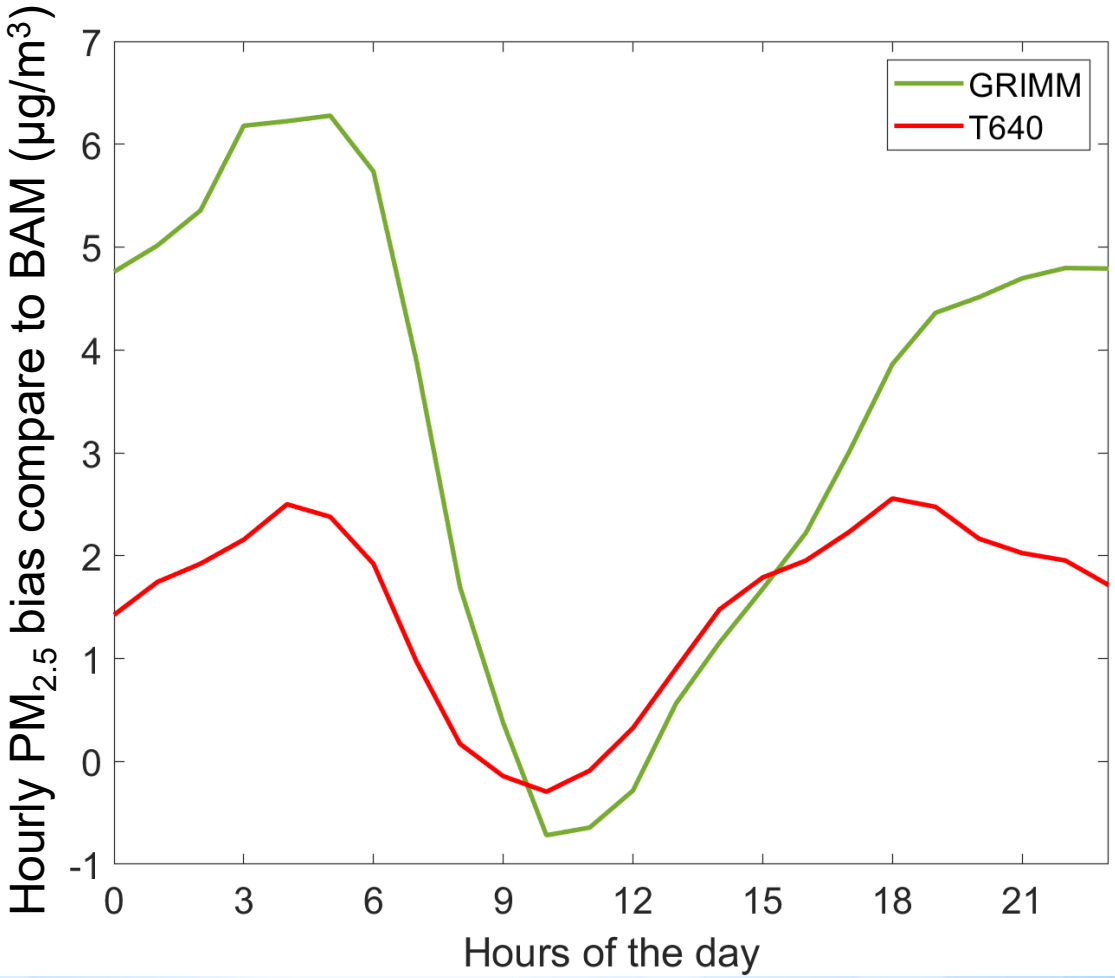
- BAM1020 tends to measure lower $PM_{2.5}$ than FRM in winter months and slightly higher in summer months
- T640 tends to measure higher $PM_{2.5}$ than FRM in April-June and September-October
- GRIMM monitor does not show a strong seasonal pattern

Impact of PM2.5 Mass to the FEM-to-FRM Difference



- BAM1020 measures lower $PM_{2.5}$ than FRM when FRM $PM_{2.5}$ is over 25 μg/m^3
- For T640 and GRIMM monitors, the FEM-to-FRM difference increases with higher $PM_{2.5}$ concentrations when FRM $PM_{2.5}$ concentrations are below 25 μg/m^3

Diurnal Trend of FEM Measurements

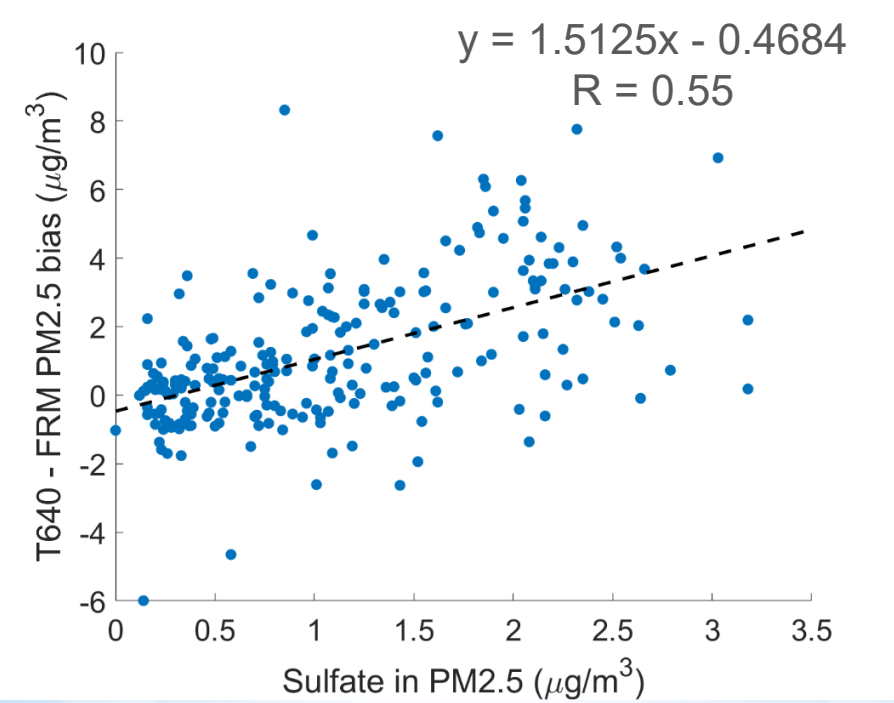


- For this plot, BAM1020 is used as a benchmark
  - Green line: difference between GRIMM and BAM1020 readings
  - Red line: difference between T640 and BAM1020 readings
- GRIMM monitor tends to measure higher PM2.5 levels
- Nighttime and early morning are colder and more humid, which increases the amount of liquid water and, consequently, enhances aerosol light scattering.

Other Factors Impacting FEM-to-FRM Comparison

Correlation Coefficient (R):

	T	RH	OC	EC	Nitrate	Sulfate	Ammonium Ion
BAM	0.35	-0.18	-0.03	-0.20	-0.38	0.18	-0.34
T640	0.15	0.28	0.16	-0.20	0.34	0.55	0.43
GRIMM	-0.03	0.24	0.19	-0.05	0.37	0.38	0.39



- Increased humidity enhances particle light scattering
- Cold and humid conditions tend to increase inorganic ions concentration in $PM_{2.5}$

Conclusions

- FEM and FRM measurements were strongly correlated.
- Understanding FEM-to-FRM differences is important for:
  - Informing decisions on purchasing FEM monitors
  - Assessing the impact on Design Values if FRM samplers are replaced by FEM monitors
- Overestimations of PM2.5 concentrations by light scattering FEM instruments are probably caused by several factors, including relative humidity (RH) and the presence of inorganic ions.
  - Increased RH enhances $PM_{2.5}$ light scattering
  - Inorganic ion concentrations in $PM_{2.5}$ are higher under cold and humid weather conditions

Acknowledgement

From left:

Kyle Ryan, Air Quality Instrument Specialist;

Matthew Prather, Senior Air Quality Instrument Specialist;

Michael Koch, Senior Air Quality Instrument Specialist;

Not in the photo:

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From right:

Brandon Feenstra, Ph.D., Quality Assurance Manager;

Xiang Li, Ph.D., Program Supervisor;

Brian Vlasich, Air Quality Specialist;

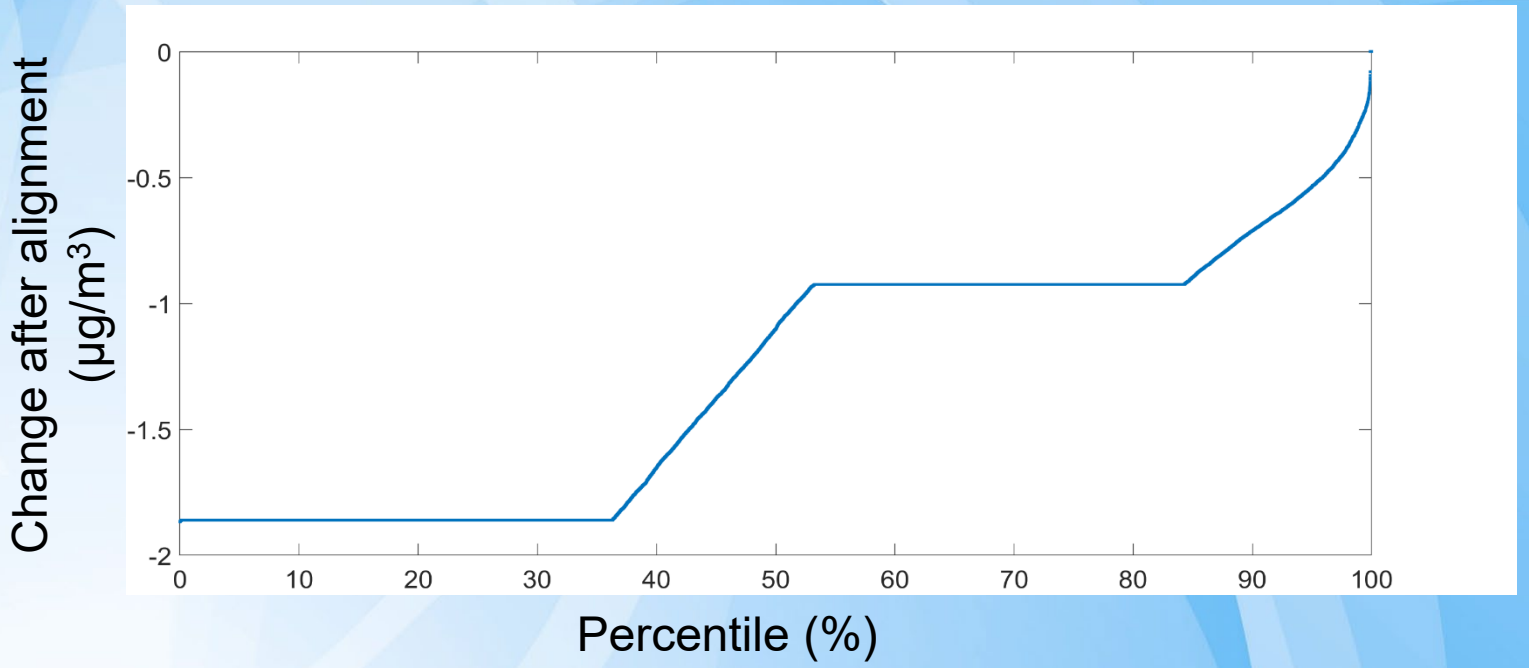
Raul Dominguez, Ph.D., Senior Air Quality Chemist

If you have questions, please contact Dr. Xiang Li at xli@aqmd.gov.

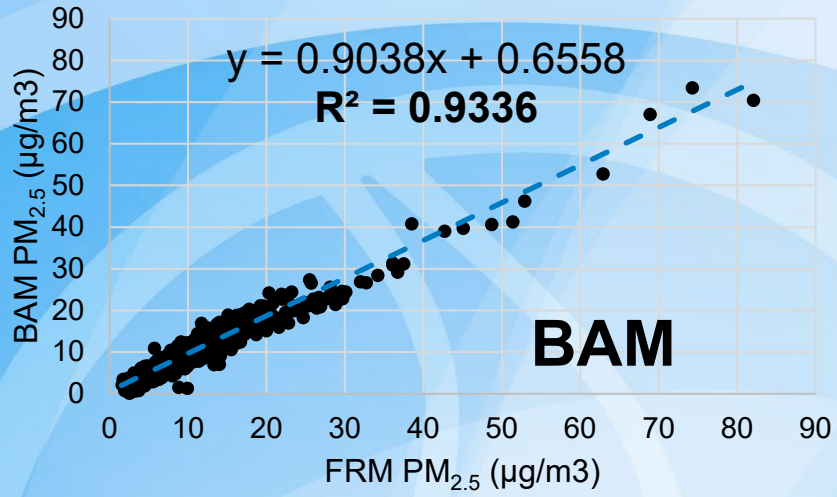
Back-up slides

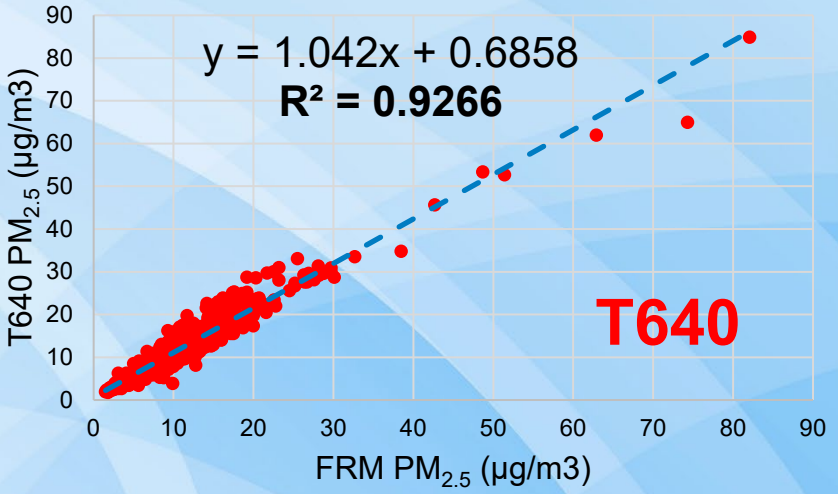
T640 Data Alignment

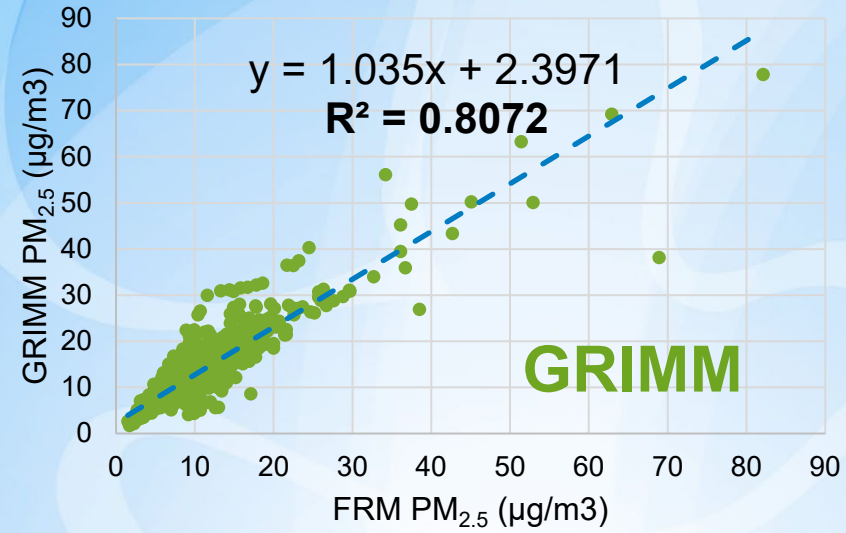
- On May 13, 2024, EPA retroactively applied a correction factor to all $PM_{2.5}$ mass data collected using Teledyne T640 monitors reported to AQS
- Correction factor calculations dependent on ambient temperature and the raw $PM_{2.5}$ value
- The correction factor was applied to all T640 data used in this study

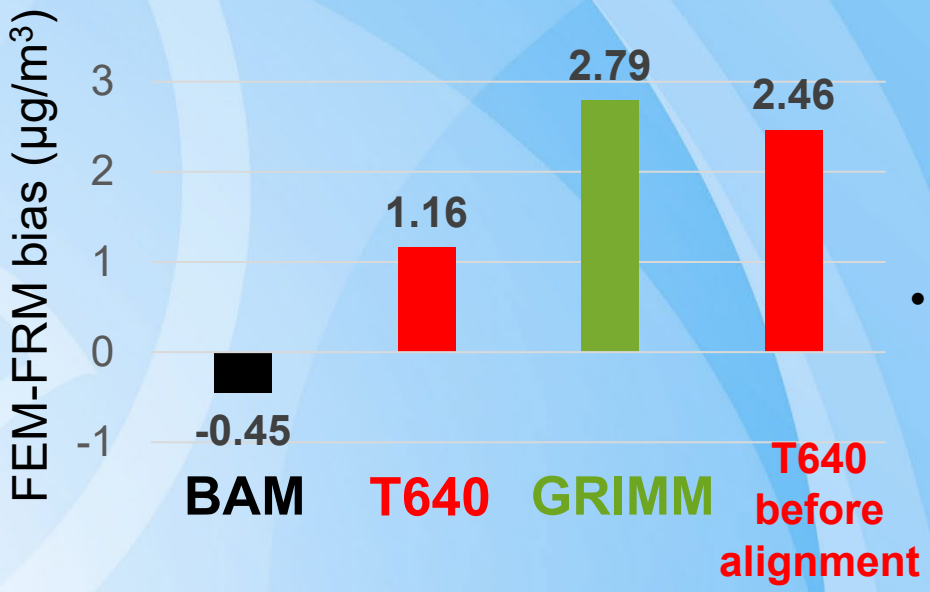


Correlations Between FEM and FRM monitors





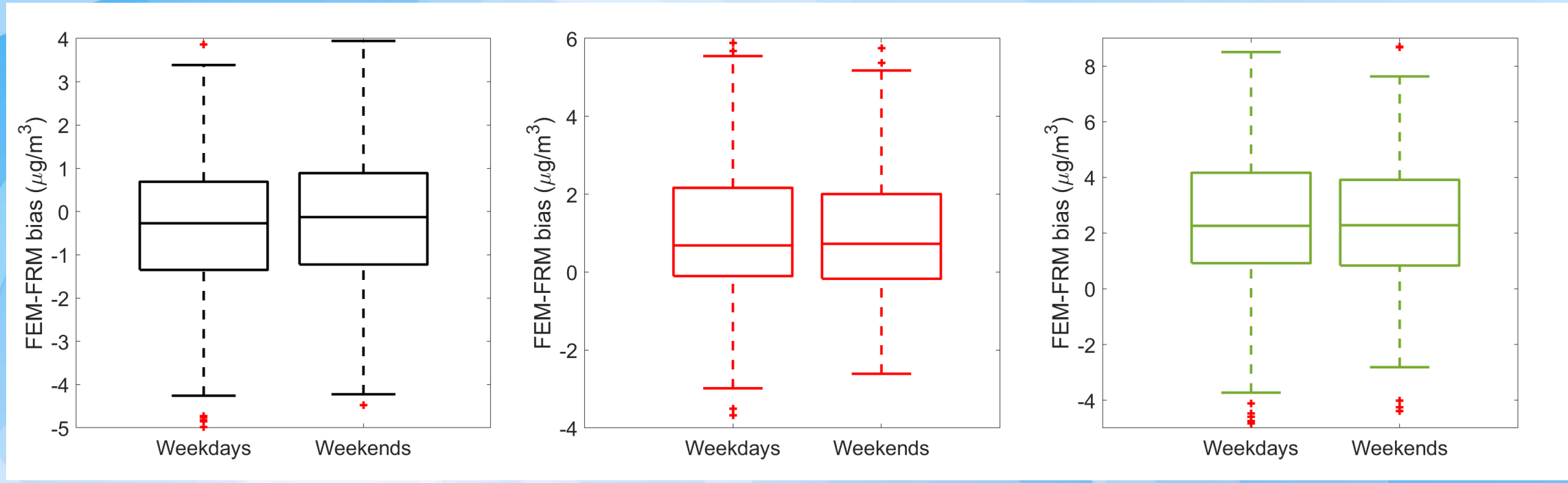




- BAM1020 and T640 have R^2 to FRM measurements >0.9 while the GRIMM monitor R^2 >0.80
- BAM1020 measures slightly lower $PM_{2.5}$ concentrations compared to FRM, while T640 and GRIMM measure higher $PM_{2.5}$
- Data alignment improved T640 comparison to FRM

Weekday and Weekend patterns of FEM-to-FRM Difference

BAM **T640** **GRIMM**



- BAM1020 shows a slightly higher FEM-to-FRM difference on weekends compared to weekdays
- T640 and GRIMM monitors do not show an obvious weekday/weekend trend

Conclusions

- Met One BAM-1020, Teledyne T640, and GRIMM EDM Model 180 show strong correlations with FRM measurements. The BAM-1020 measures lower $PM_{2.5}$ in winter and slightly higher in summer, while the T640 tends to measure higher $PM_{2.5}$ in spring and fall.
- T640 and GRIMM typically measure higher $PM_{2.5}$ compared to the FRM, while BAM-1020 measures slightly lower. The BAM-1020 records lower PM2.5 when concentrations exceed 25 µg/m³. In contrast, T640 and GRIMM show increased FEM-to-FRM differences as $PM_{2.5}$ concentrations increase when FRM $PM_{2.5}$ concentrations are below 25 µg/m³.
- Compared to the BAM-1020, both T640 and GRIMM monitors measure higher $PM_{2.5}$ in the late afternoon and night. FEM-to-FRM differences for T640 and GRIMM correlate with nitrate, sulfate, and ammonium ion.
  - Further analysis is required to confirm these trends and investigate their underlying causes.