Field Evaluation
Liveable Cities - SLX-$PM_{2.5}$

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

- From 11/20/2021 to 1/19/2022, three **Liveable Cities SLX-$PM_{2.5}$** sensors were deployed at the South Coast AQMD stationary ambient monitoring site in Rubidoux and were run side-by-side with Federal Equivalent Method (FEM) instruments measuring the same pollutants

- Liveable Cities SLX-$PM_{2.5}$ (*3 units tested*):
  - Particle sensor: optical; non-FEM (Alphasense OPC-R2)
  - Each unit reports: $PM_{2.5}$ and PM_{10} ($\mu g/m^3$)
  - Unit cost: ~$954 + $309/year for software, reporting and cellular data
  - Time resolution: 1-min
  - Units IDs: 023A, 0238, 0239

- GRIMM EDM180 (*reference instrument*):
  - Optical particle counter (FEM $PM_{2.5}$)
  - Measures $PM_{1.0}$, $PM_{2.5}$, and PM_{10} ($\mu g/m^3$)
  - Cost: ~$25,000 and up
  - Time resolution: 1-min

- Teledyne API T640 (*reference instrument*):
  - Optical particle counter (FEM $PM_{2.5}$)
  - Measures $PM_{1.0}$, $PM_{2.5}$ and PM_{10} ($\mu g/m^3$)
  - Cost: ~$21,000
  - Time resolution: 1-min

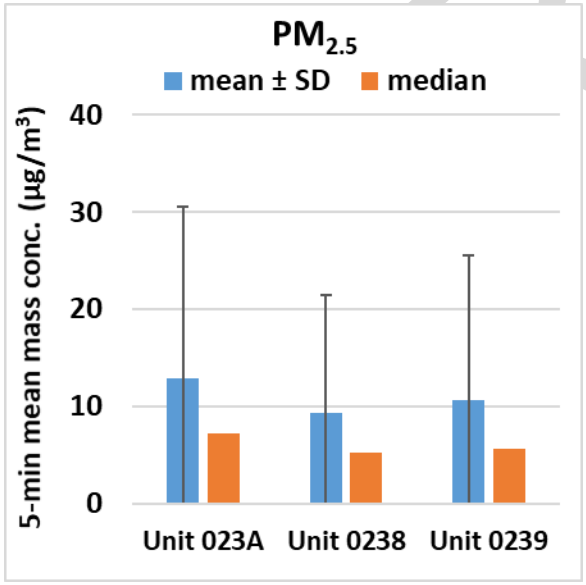
- MetOne BAM (reference instrument):
  - Beta-attenuation monitor (FEM $PM_{2.5}$, FEM PM_{10})
  - Measures $PM_{2.5}$ and PM_{10} ($\mu g/m^3$)
  - Unit cost: ~$20,000
  - Time resolution: 1-hr

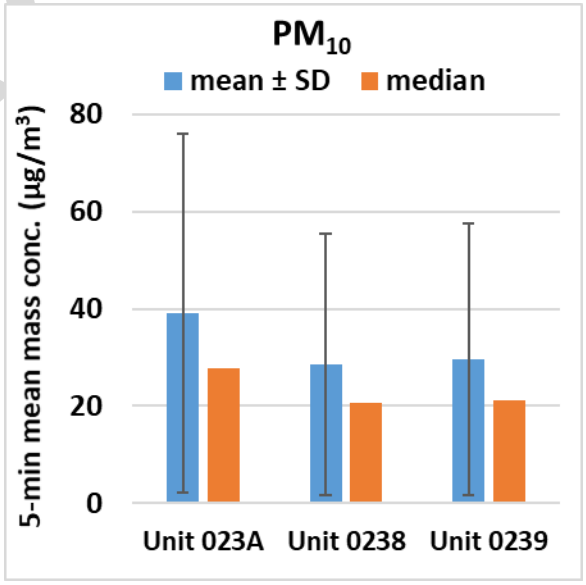
Data validation & recovery

- Basic QA/QC procedures were used to validate the collected data (i.e. obvious outliers, negative values and invalid data-points were eliminated from the data-set)
- Data recovery from Unit 023A, Unit 0238 and Unit 0239 was ~ 89%, 85% and 90%, respectively for all PM measurements

Liveable Cities SLX-$PM_{2.5}$; intra-model variability

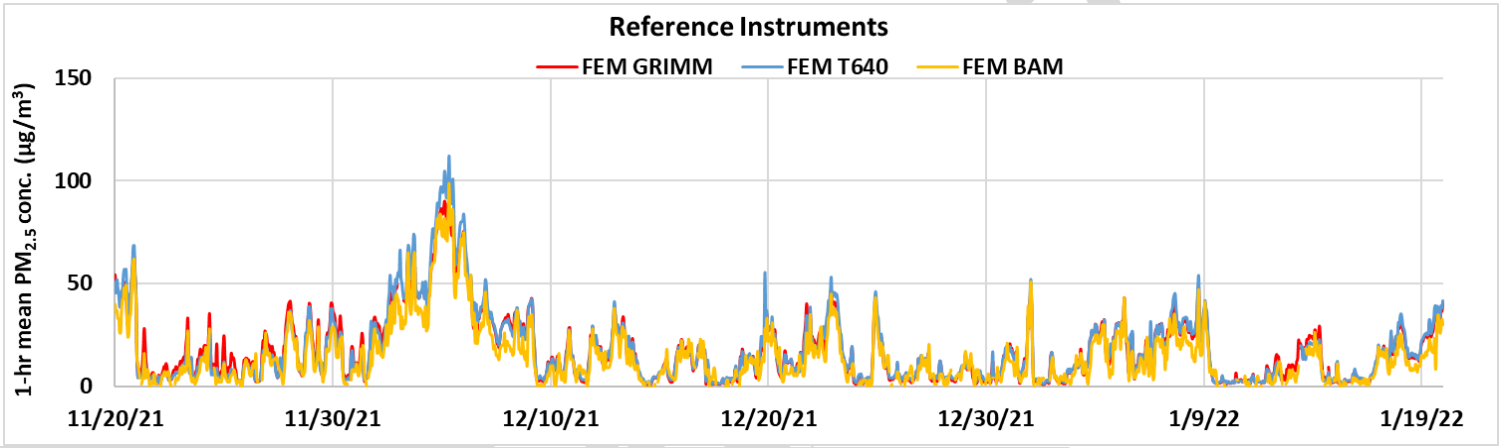
- Absolute intra-model variability was ~ 1.52 and 4.75 µg/m^3 for $PM_{2.5}$ and $PM_{10,}$ respectively (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was ~ 13.8% and 14.6% for $PM_{2.5}$ and $PM_{10,}$ respectively (calculated as the absolute intra-model variability relative to the mean of the three sensor means)

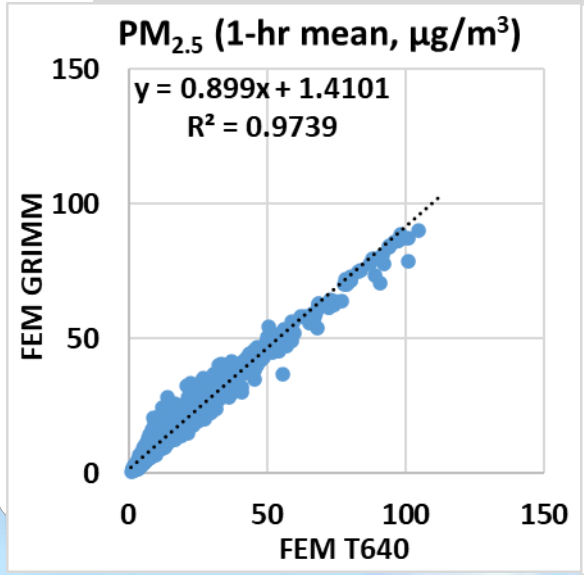


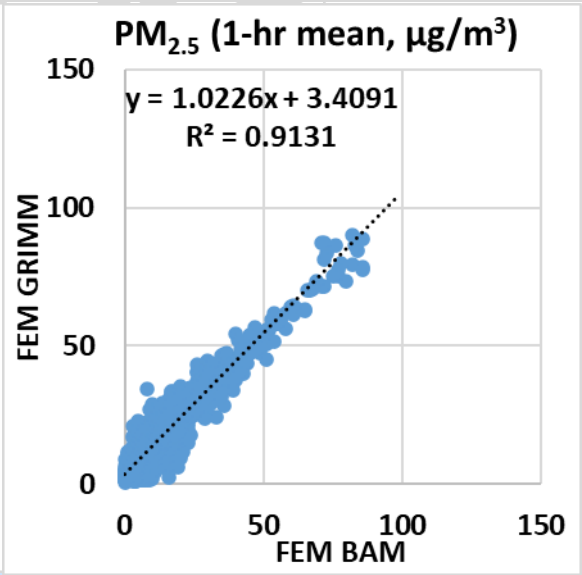


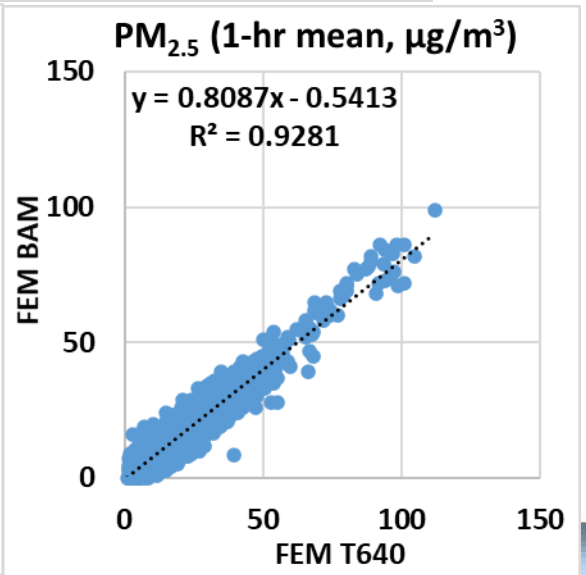
Reference Instruments: $PM_{2.5}$ FEM BAM, FEM GRIMM and FEM T640

- Data recovery for $PM_{2.5}$ from FEM BAM, FEM GRIMM and FEM T640 was ~ 90%, 100% and 98%, respectively.
- Very strong correlations between the reference instruments for $PM_{2.5}$ measurements ($0.91 < R^2 < 0.98$) were observed.



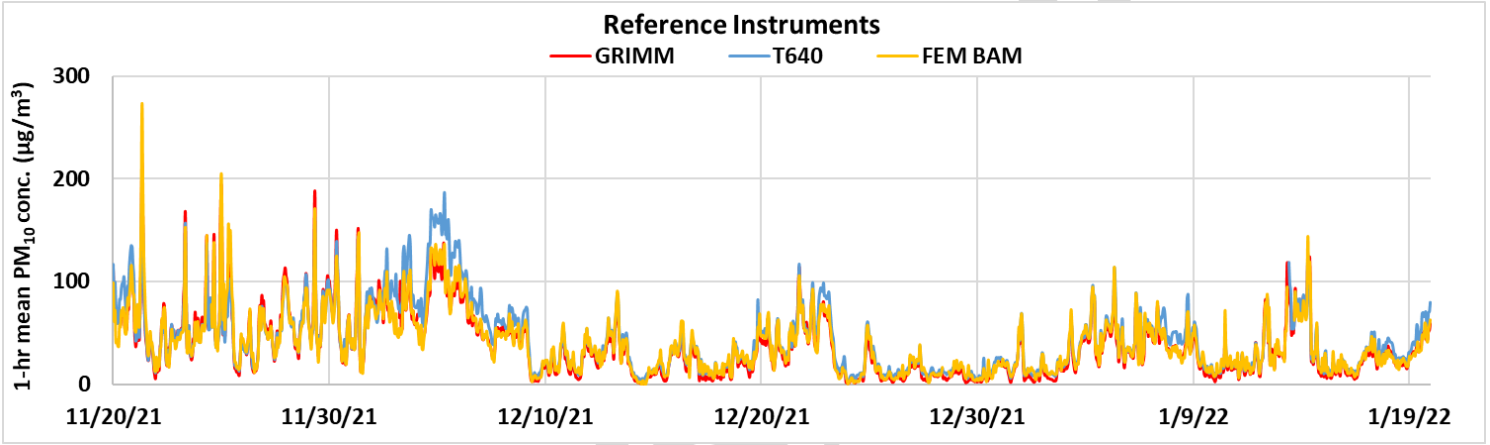


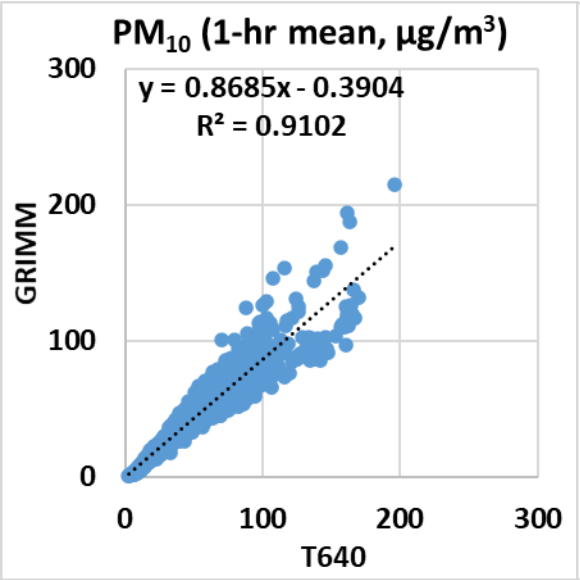


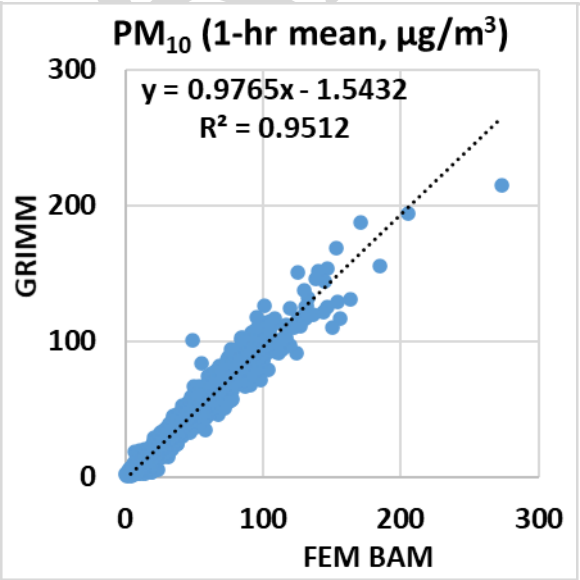


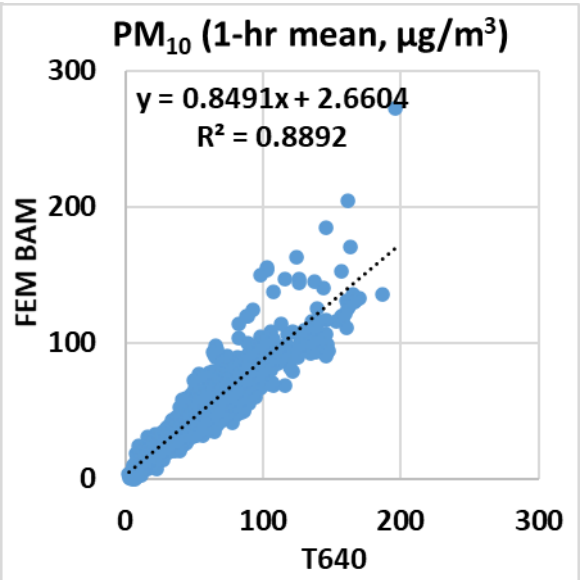
Reference Instruments: PM_{10} FEM BAM, GRIMM and T640

- Data recovery for PM_{10} from FEM BAM, GRIMM and T640 was ~ 99%, 100% and 98%, respectively.
- Strong to very strong correlations between the reference instruments for PM_{10} measurements ($0.88 < R^2 < 0.96$) were observed.

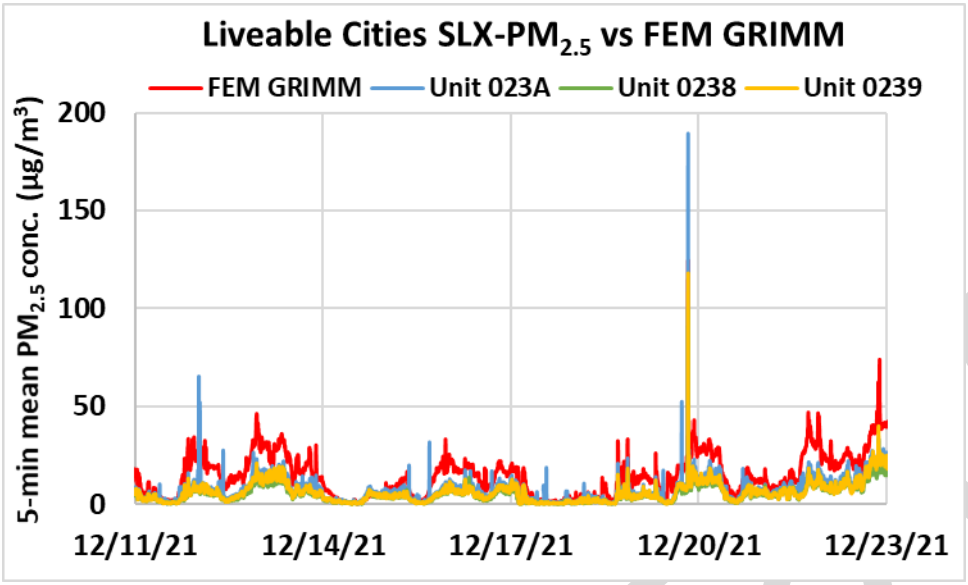




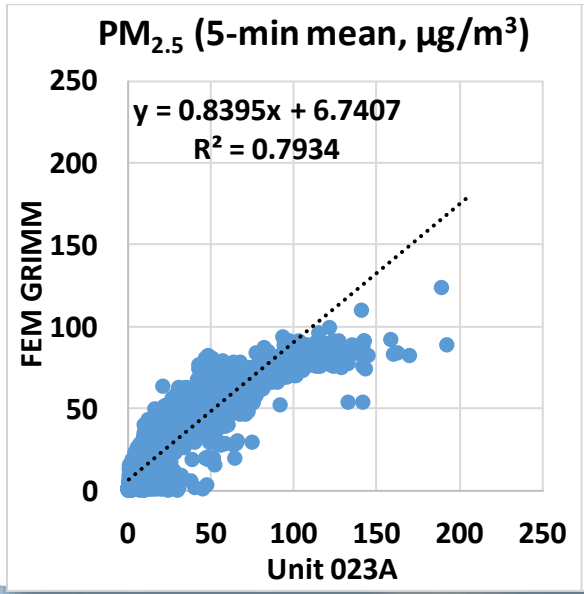


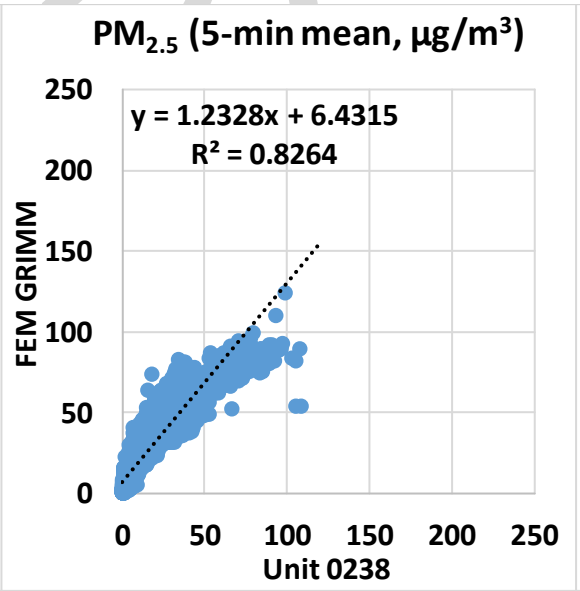


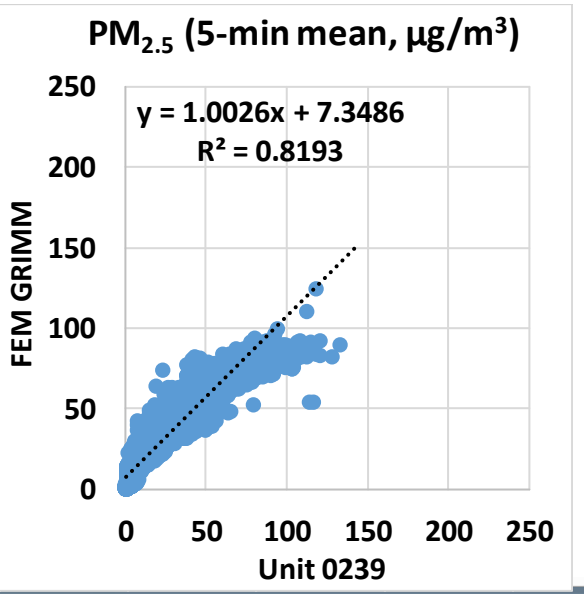
Liveable Cities SLX-$PM_{2.5}$ vs FEM GRIMM ($PM_{2.5}$; 5-min mean)



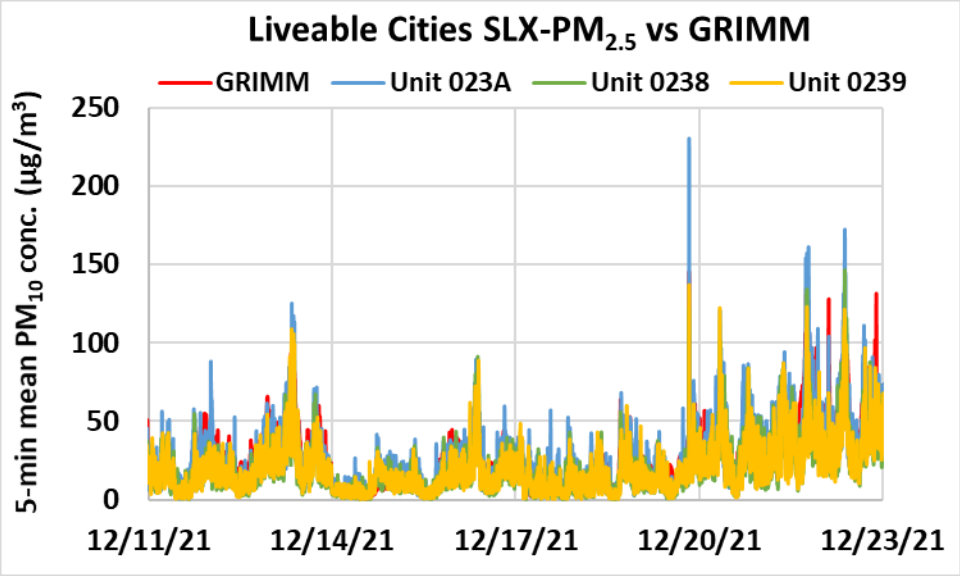
- The Liveable Cities SLX-$PM_{2.5}$ sensors showed strong correlations with the corresponding FEM GRIMM data ($0.79 < R^2 < 0.83$)
- Overall, the Liveable Cities SLX-$PM_{2.5}$ sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM GRIMM
- The Liveable Cities SLX-$PM_{2.5}$ sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM GRIMM



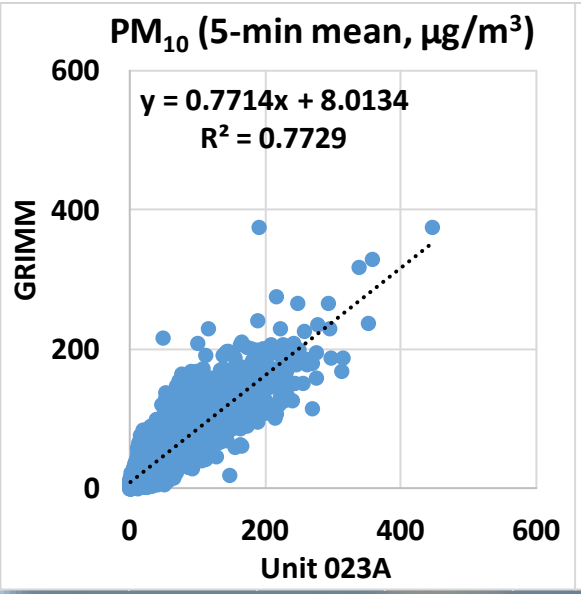


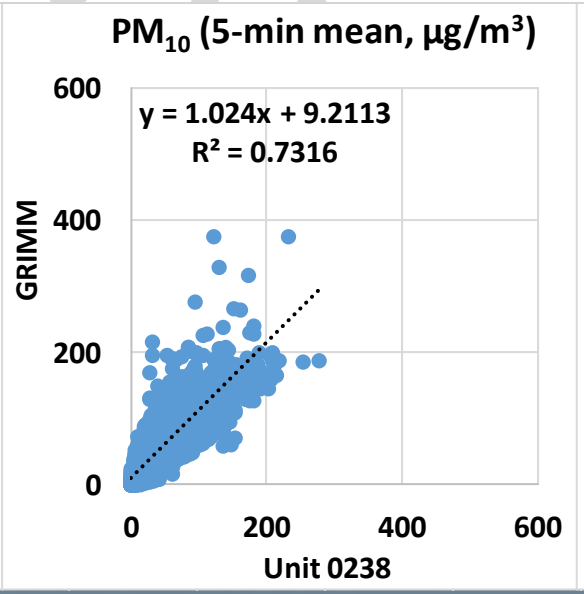


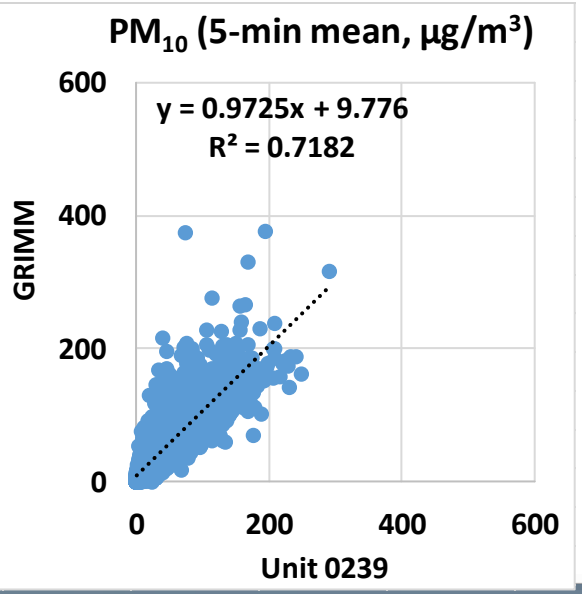
Liveable Cities SLX-$PM_{2.5}$ vs GRIMM (PM_{10}; 5-min mean)



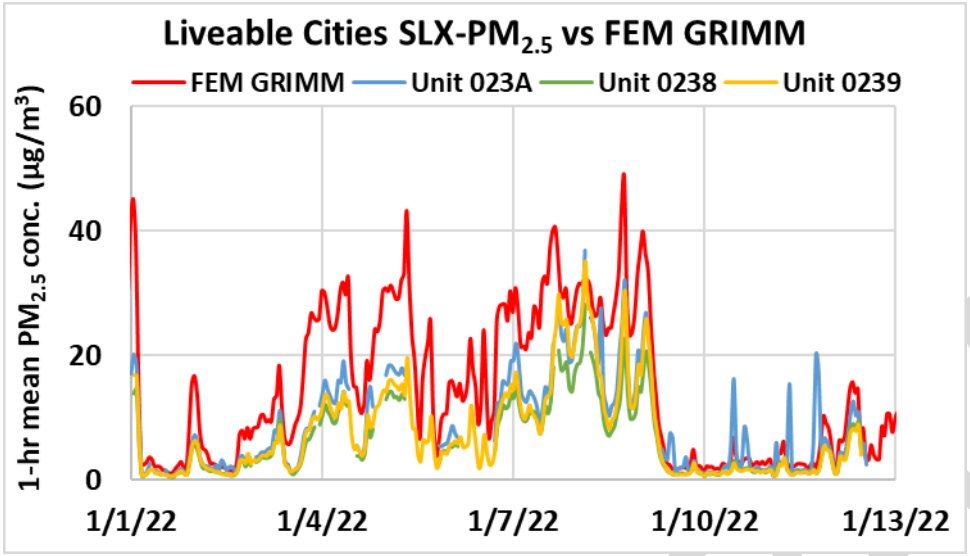
- The Liveable Cities SLX-$PM_{2.5}$ sensors showed strong correlations with the corresponding GRIMM data ($0.71 < R^2 < 0.78$)
- Overall, the Liveable Cities SLX-$PM_{2.5}$ sensors underestimated the PM_{10} mass concentrations as measured by GRIMM
- The Liveable Cities SLX-$PM_{2.5}$ sensors seemed to track the PM_{10} diurnal variations as recorded by GRIMM



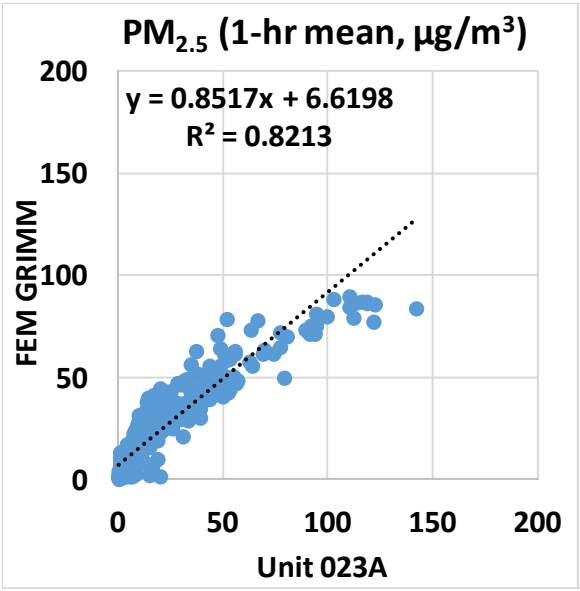


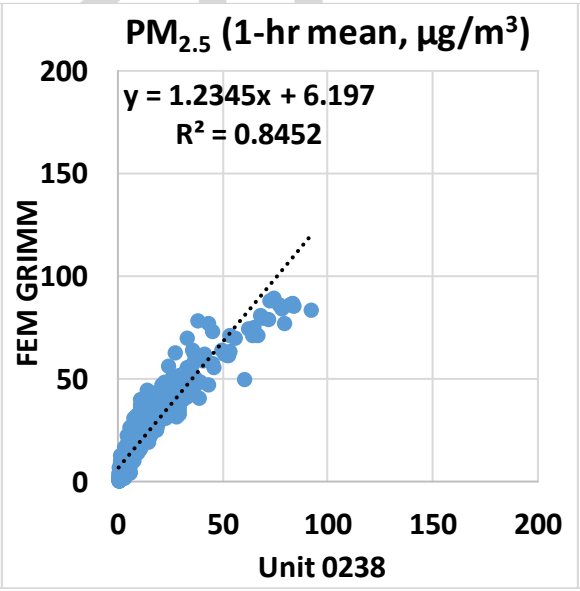


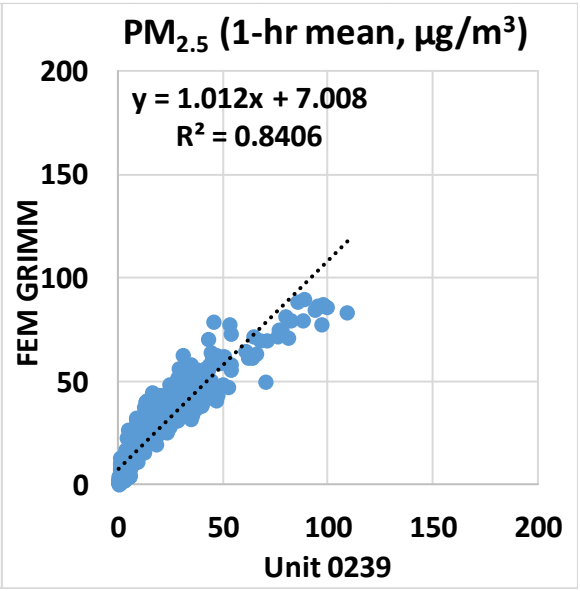
Liveable Cities SLX-$PM_{2.5}$ vs FEM GRIMM ($PM_{2.5}$; 1-hr mean)



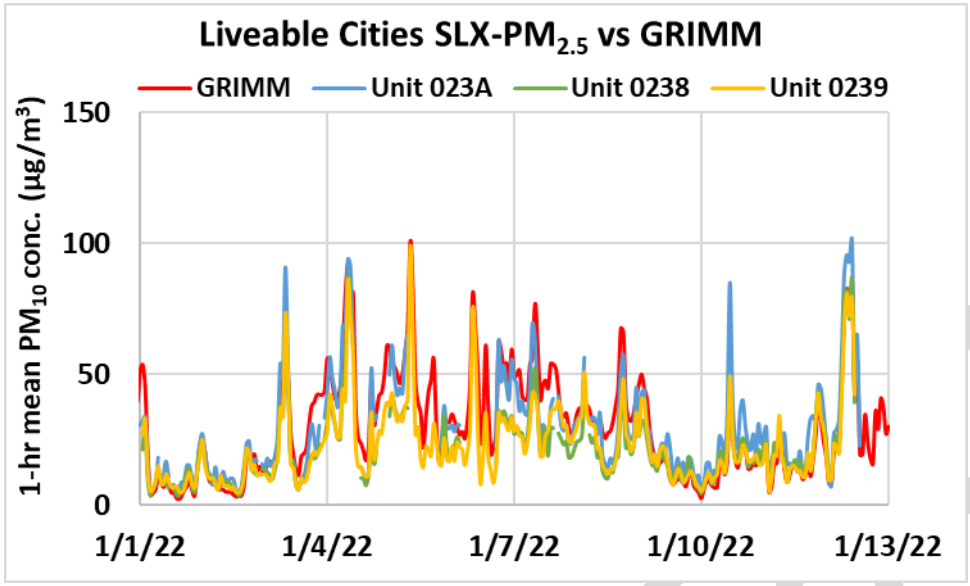
- The Liveable Cities SLX-$PM_{2.5}$ sensors showed strong correlations with the corresponding FEM GRIMM data ($0.82 < R^2 < 0.85$)
- Overall, the Liveable Cities SLX-$PM_{2.5}$ sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM GRIMM
- The Liveable Cities SLX-$PM_{2.5}$ sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM GRIMM



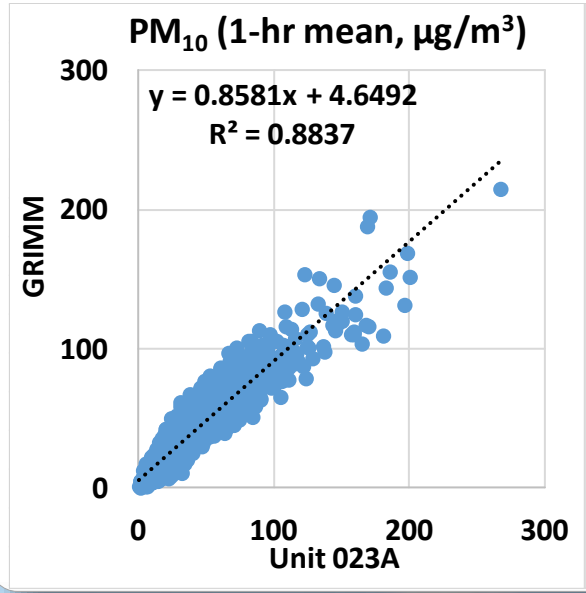


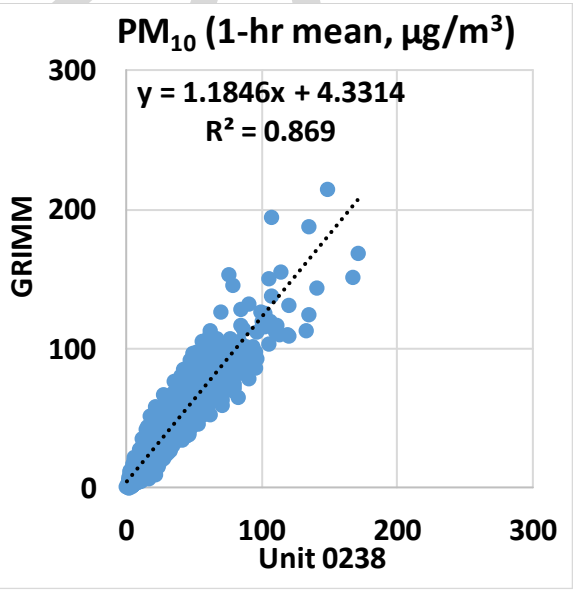


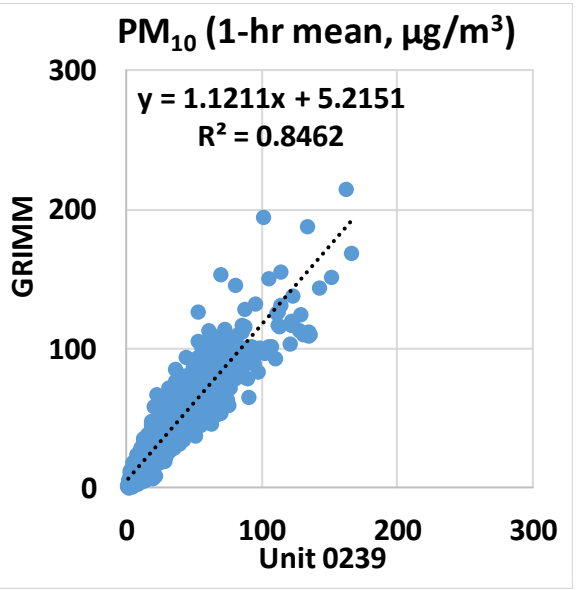
Liveable Cities SLX-$PM_{2.5}$ vs GRIMM (PM_{10}; 1-hr mean)



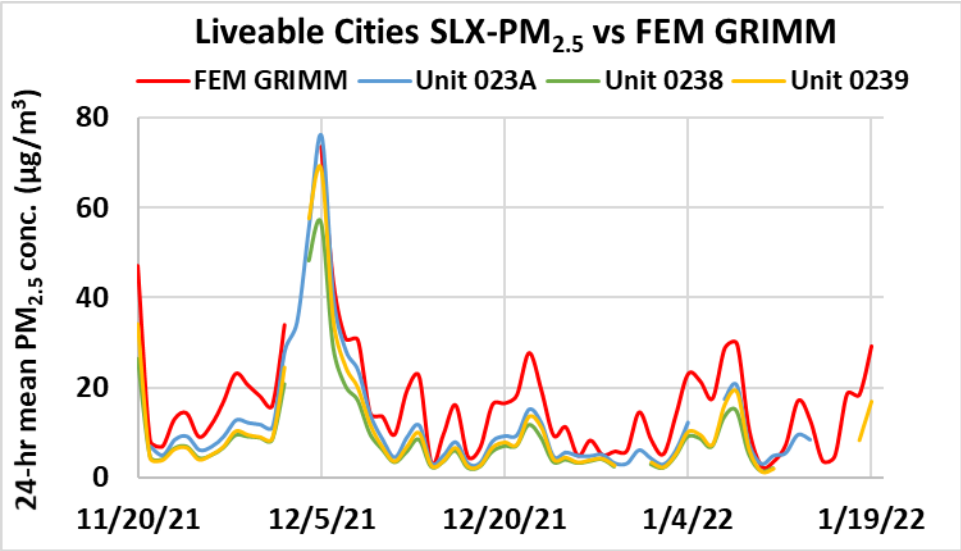
- The Liveable Cities SLX-$PM_{2.5}$ sensors showed strong correlations with the corresponding GRIMM data ($0.84 < R^2 < 0.89$)
- Overall, the Liveable Cities SLX-$PM_{2.5}$ sensors underestimated the PM_{10} mass concentrations as measured by GRIMM
- The Liveable Cities SLX-$PM_{2.5}$ sensors seemed to track the PM_{10} diurnal variations as recorded by GRIMM



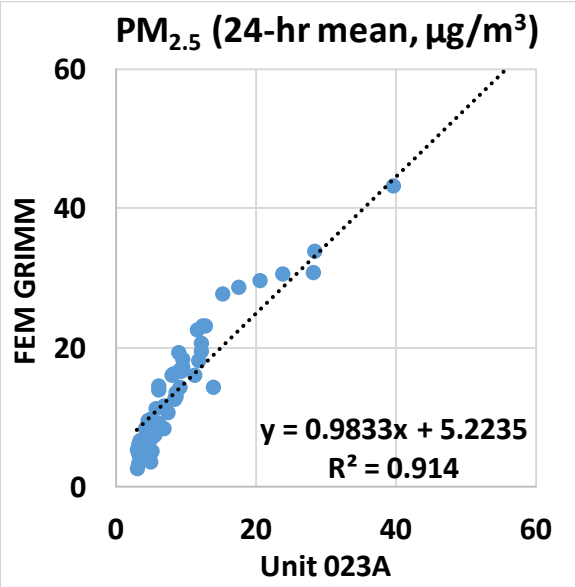


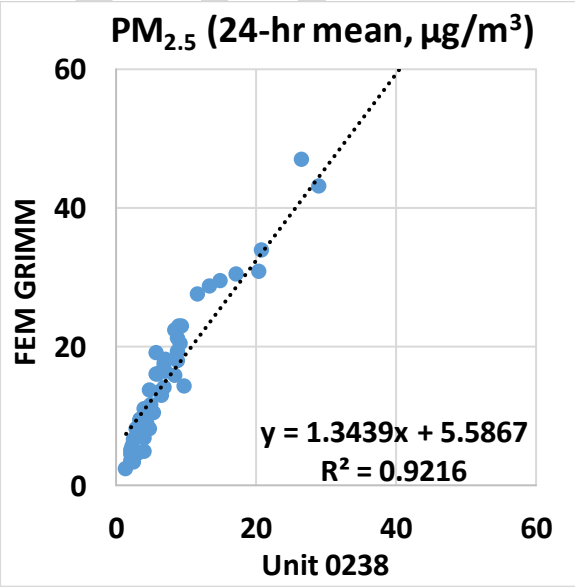


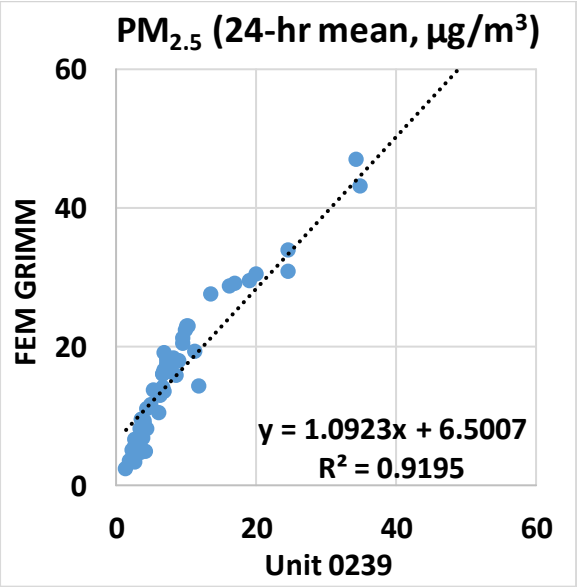
Liveable Cities SLX-$PM_{2.5}$ vs FEM GRIMM ($PM_{2.5}$; 24-hr mean)



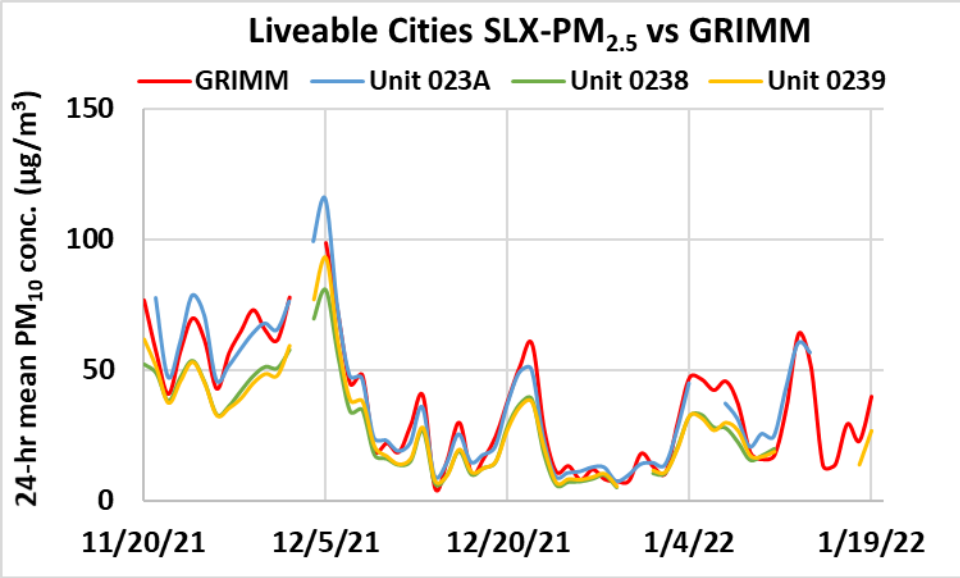
- The Liveable Cities SLX-$PM_{2.5}$ sensors showed very strong correlations with the corresponding FEM GRIMM data ($0.91 < R^2 < 0.93$)
- Overall, the Liveable Cities SLX-$PM_{2.5}$ sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM GRIMM
- The Liveable Cities SLX-$PM_{2.5}$ sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM GRIMM



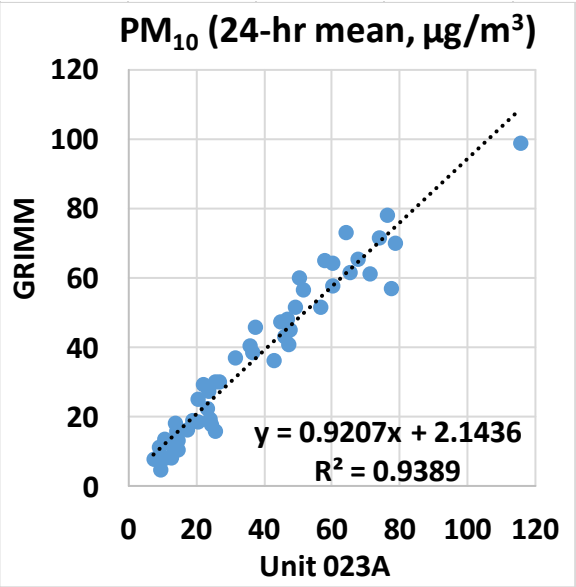


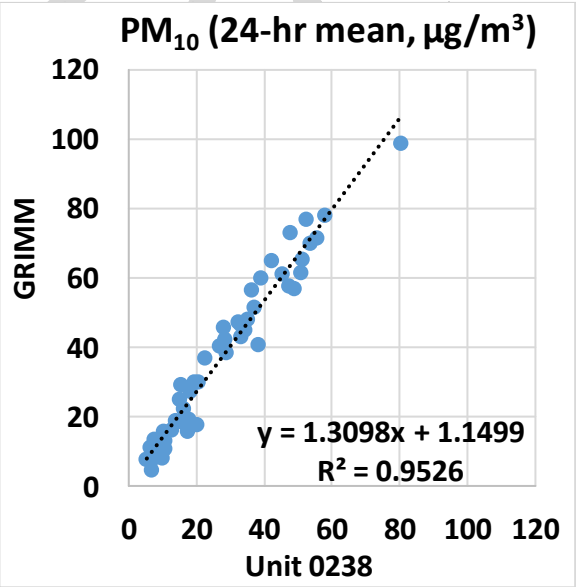


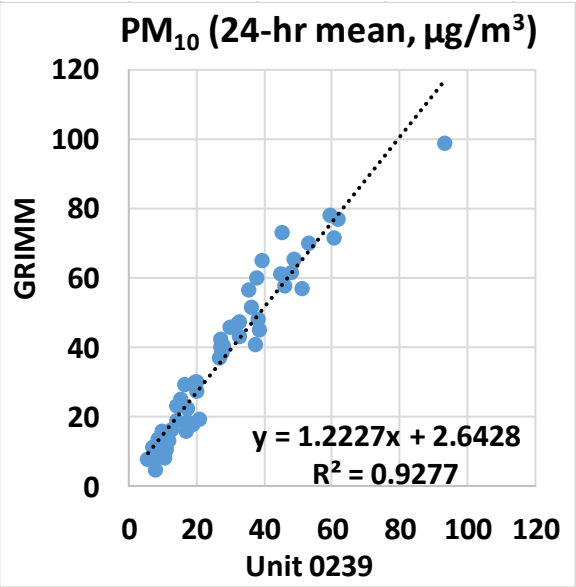
Liveable Cities SLX-$PM_{2.5}$ vs GRIMM (PM_{10}; 24-hr mean)



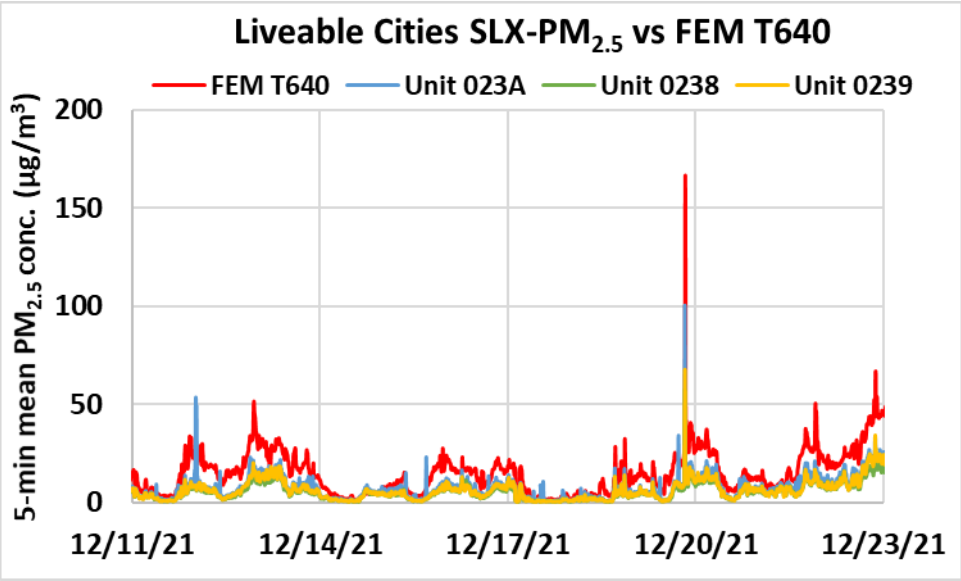
- The Liveable Cities SLX-$PM_{2.5}$ sensors showed very strong correlations with the corresponding GRIMM data ($0.92 < R^2 < 0.96$)
- Overall, the Liveable Cities SLX-$PM_{2.5}$ sensors underestimated the PM_{10} mass concentrations as measured by GRIMM
- The Liveable Cities SLX-$PM_{2.5}$ sensors seemed to track the PM_{10} diurnal variations as recorded by GRIMM



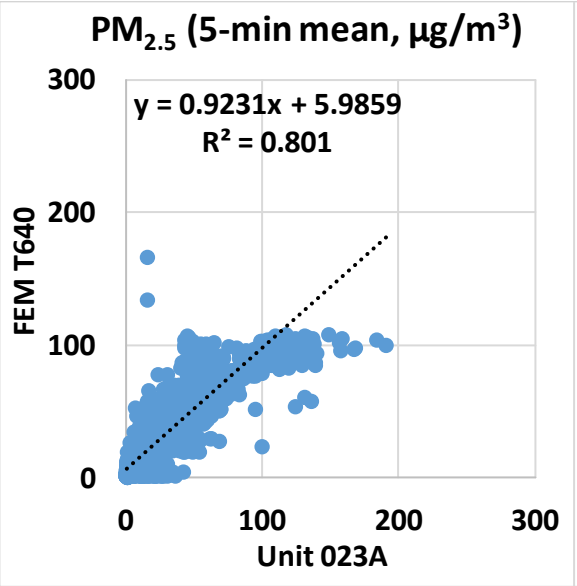


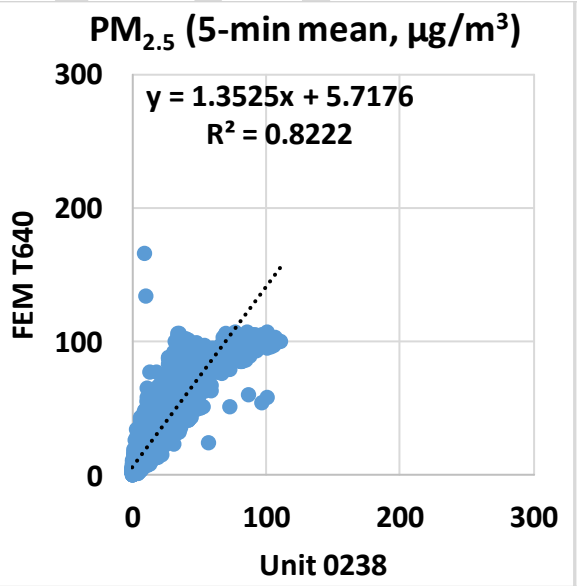


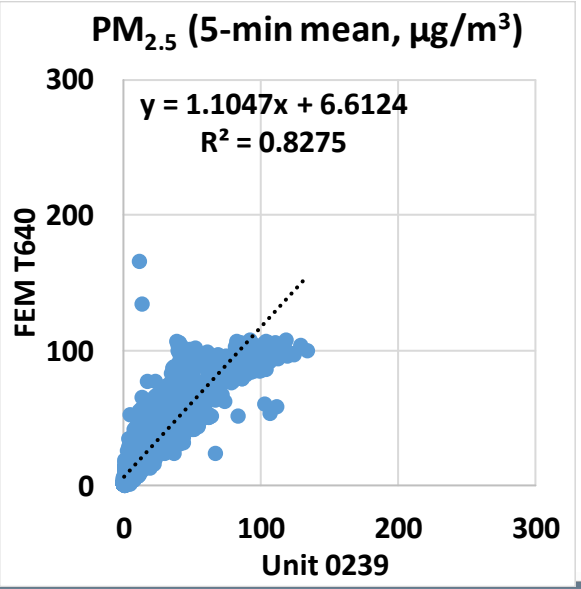
Liveable Cities SLX-$PM_{2.5}$ vs FEM T640 ($PM_{2.5}$; 5-min mean)



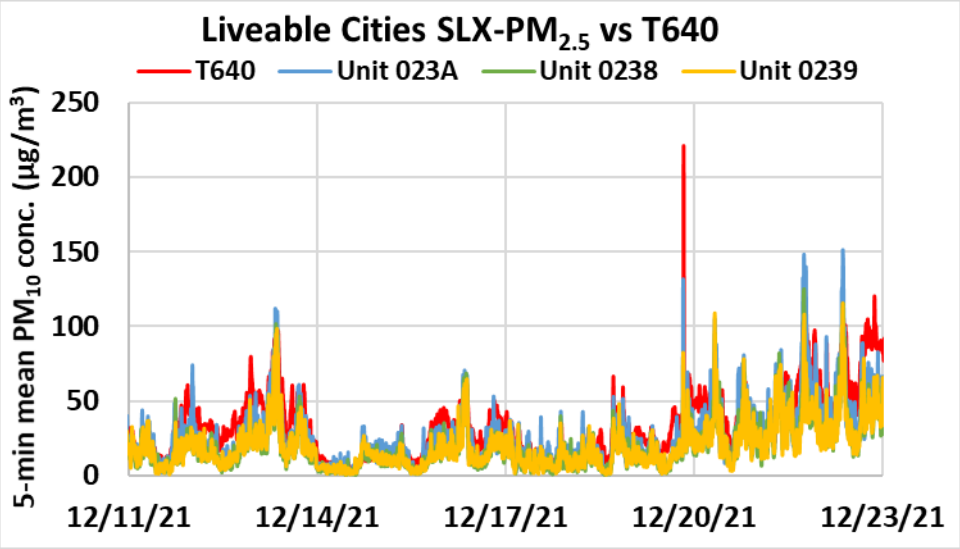
- The Liveable Cities SLX-$PM_{2.5}$ sensors showed strong correlations with the corresponding FEM T640 data ($0.80 < R^2 < 0.83$)
- Overall, the Liveable Cities SLX-$PM_{2.5}$ sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The Liveable Cities SLX-$PM_{2.5}$ sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



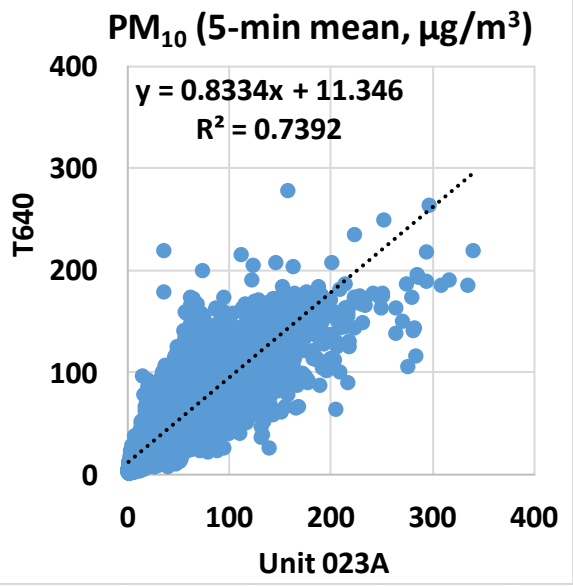


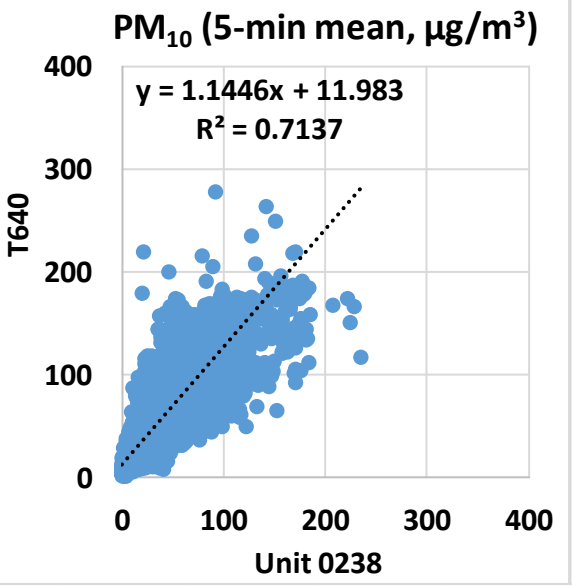


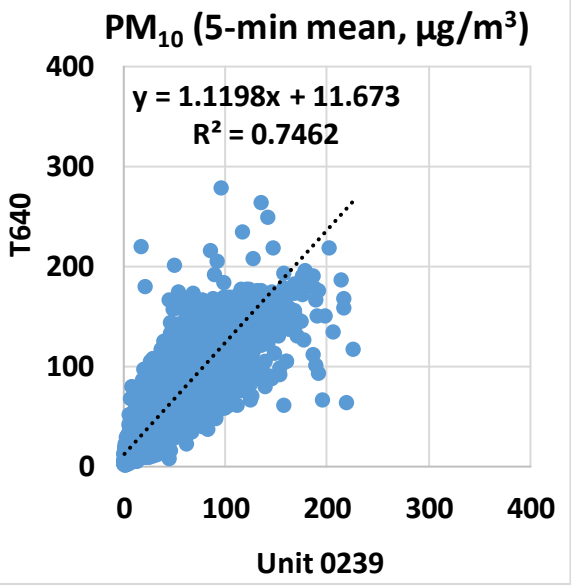
Liveable Cities SLX-$PM_{2.5}$ vs T640 (PM_{10}; 5-min mean)



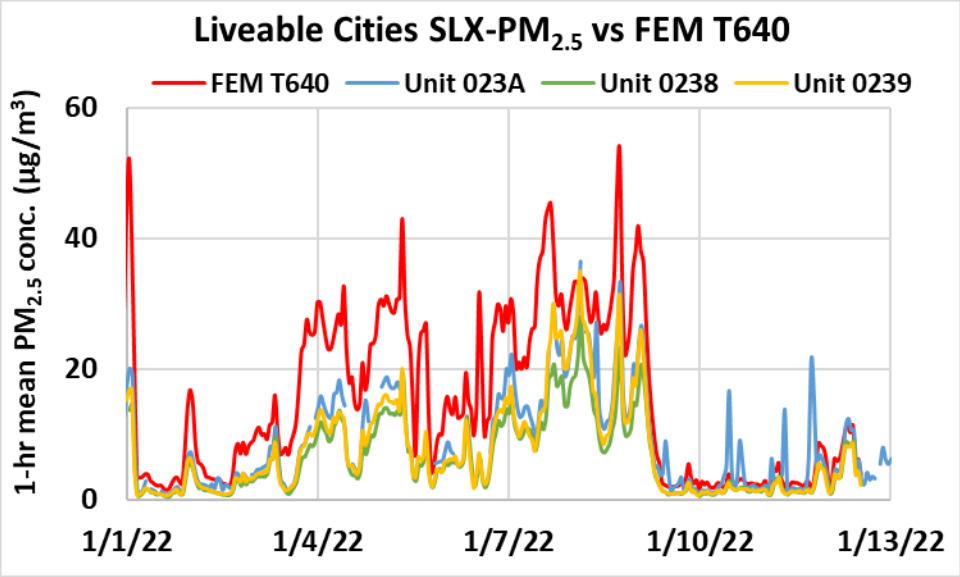
- Liveable Cities SLX-$PM_{2.5}$ sensors showed strong correlations with the corresponding T640 data ($0.71 < R^2 < 0.75$)
- Overall, the Liveable Cities SLX-$PM_{2.5}$ sensors underestimated the PM_{10} mass concentrations as measured by T640
- The Liveable Cities SLX-$PM_{2.5}$ sensors seemed to track the PM_{10} diurnal variations as recorded by T640



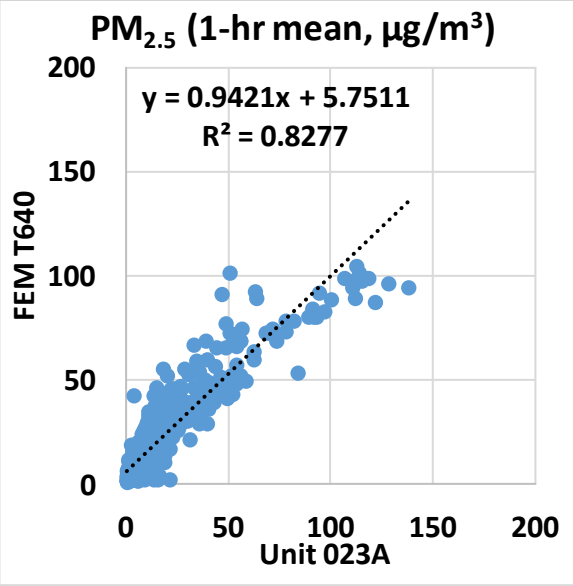


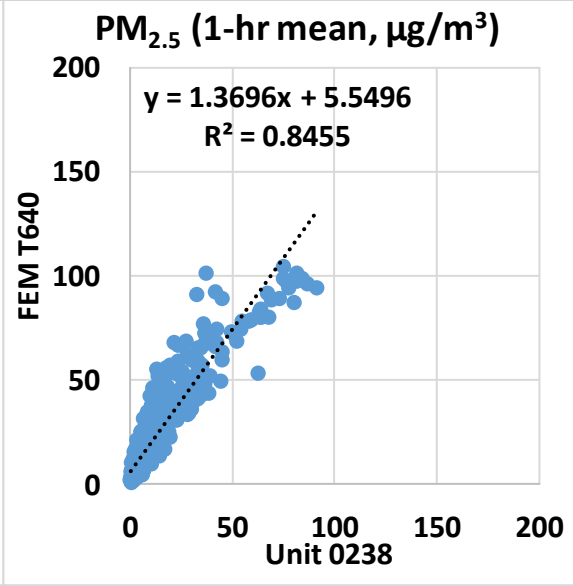


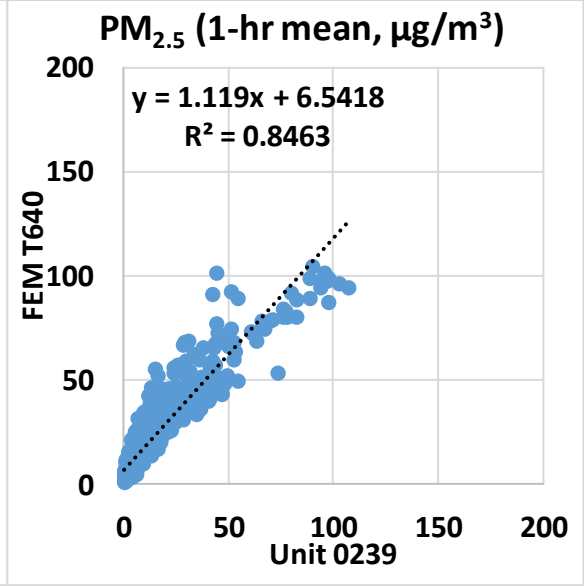
Liveable Cities SLX-$PM_{2.5}$ vs FEM T640 ($PM_{2.5}$; 1-hr mean)



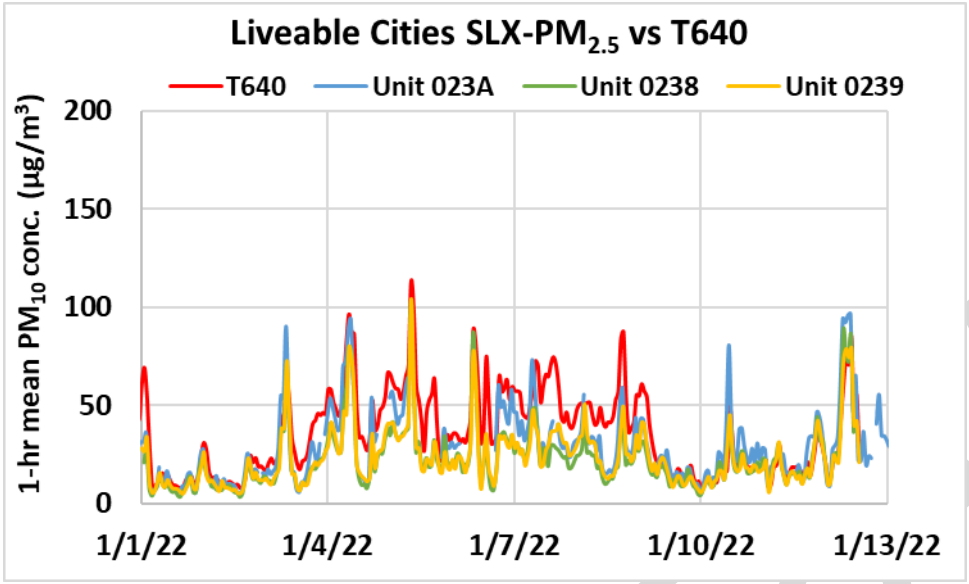
- The Liveable Cities SLX-$PM_{2.5}$ sensors showed strong correlations with the corresponding FEM T640 data ($0.82 < R^2 < 0.85$)
- Overall, the Liveable Cities SLX-$PM_{2.5}$ sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The Liveable Cities SLX-$PM_{2.5}$ sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



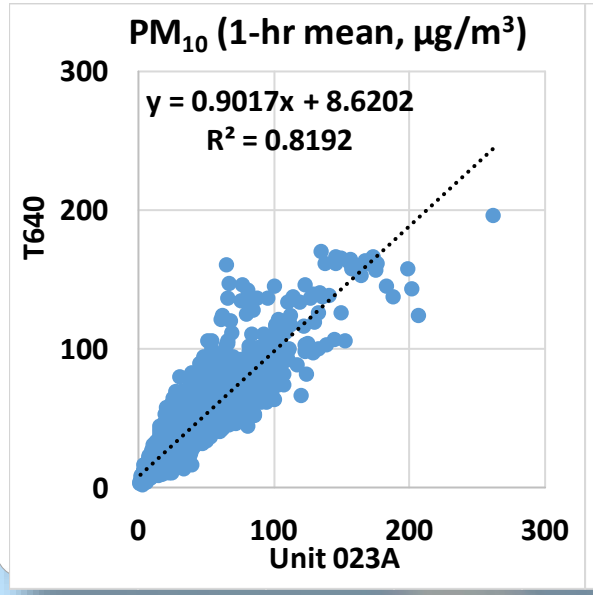


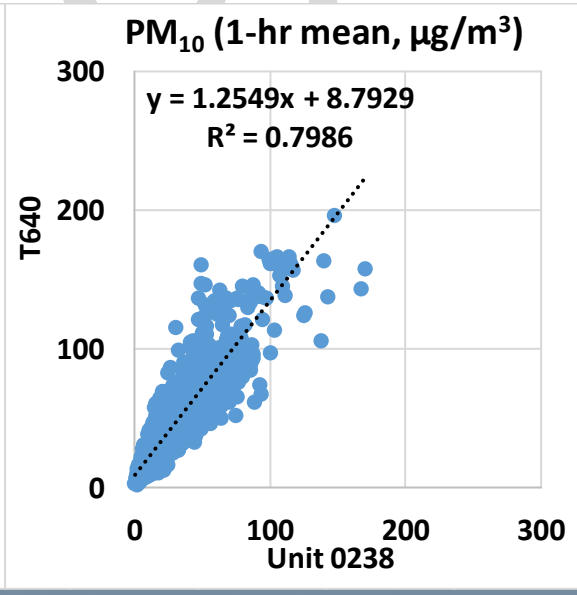


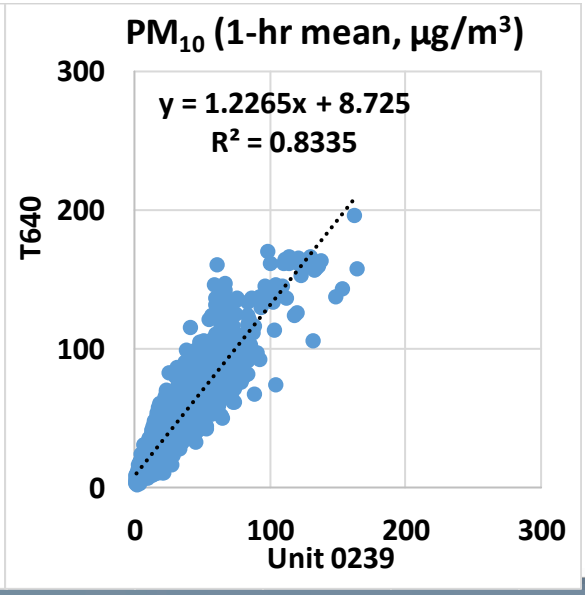
Liveable Cities SLX-$PM_{2.5}$ vs T640 (PM_{10}; 1-hr mean)



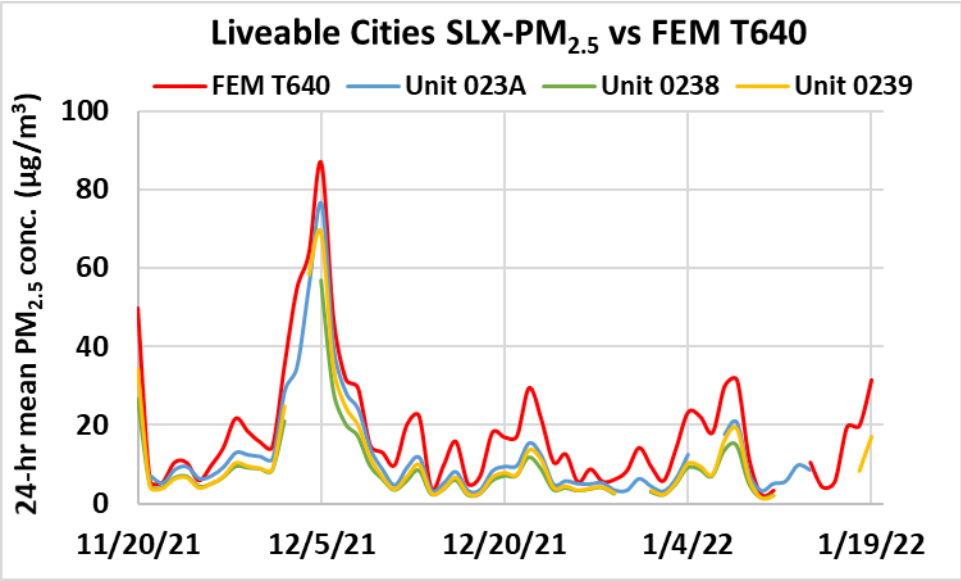
- The Liveable Cities SLX-$PM_{2.5}$ sensors showed strong correlations with the corresponding T640 data ($0.79 < R^2 < 0.84$)
- Overall, the Liveable Cities SLX-$PM_{2.5}$ sensors underestimated the PM_{10} mass concentrations as measured by T640
- The Liveable Cities SLX-$PM_{2.5}$ sensors seemed to track the PM_{10} diurnal variations as recorded by T640



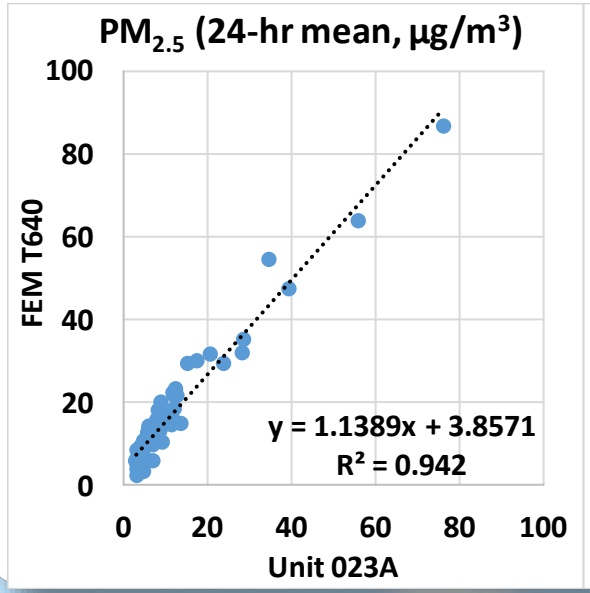


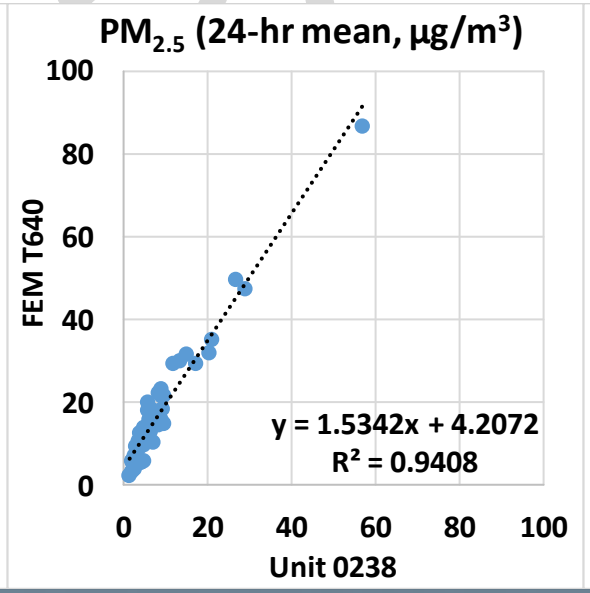


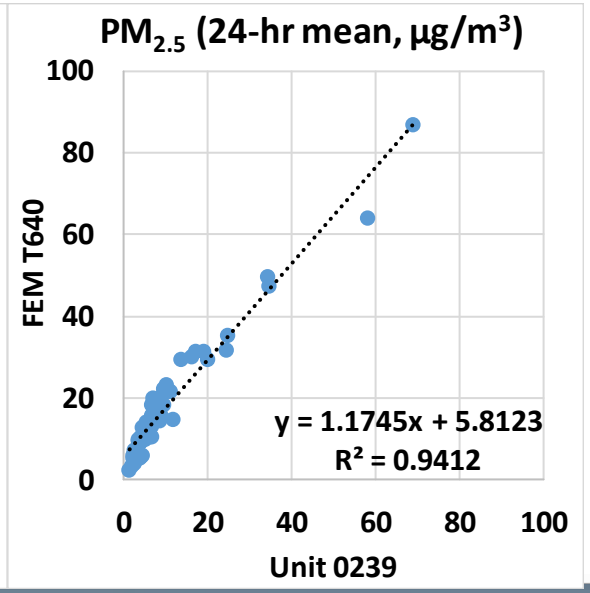
Liveable Cities SLX-$PM_{2.5}$ vs FEM T640 ($PM_{2.5}$; 24-hr mean)



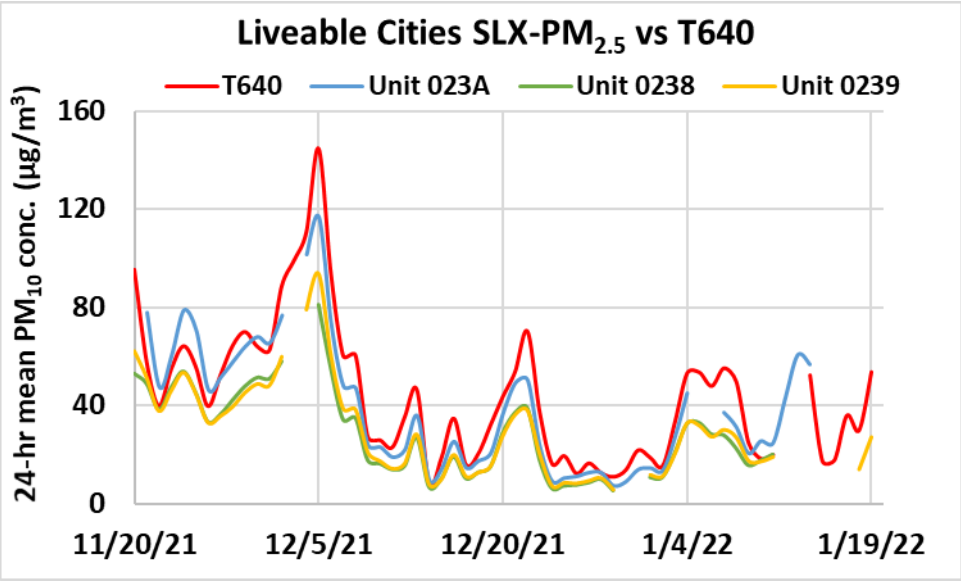
- The Liveable Cities SLX-$PM_{2.5}$ sensors showed very strong correlations with the corresponding FEM T640 data ($0.94 < R^2 < 0.95$)
- Overall, the Liveable Cities SLX-$PM_{2.5}$ sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The Liveable Cities SLX-$PM_{2.5}$ sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



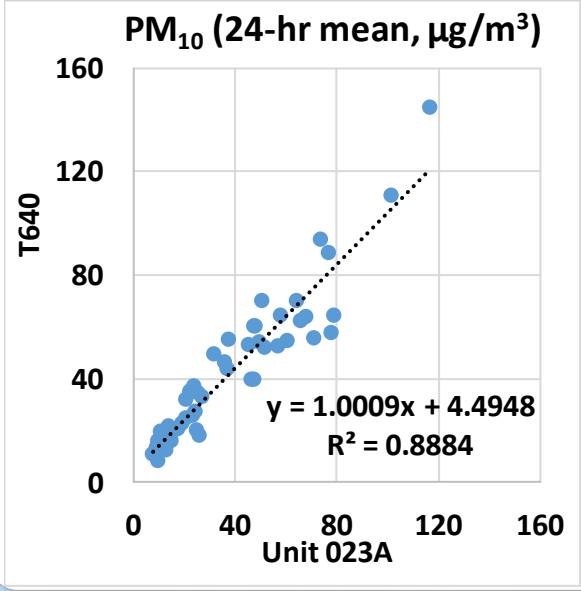


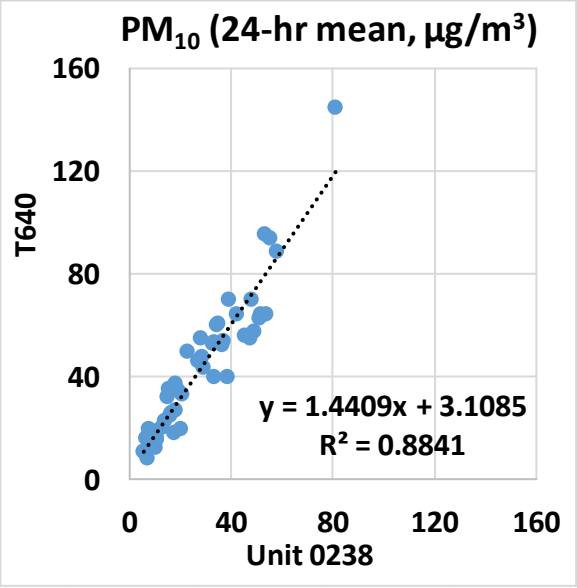


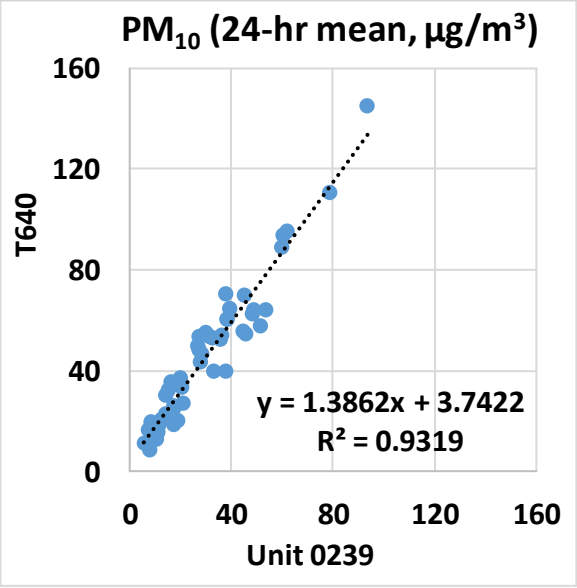
Liveable Cities SLX-$PM_{2.5}$ vs T640 (PM_{10}; 24-hr mean)



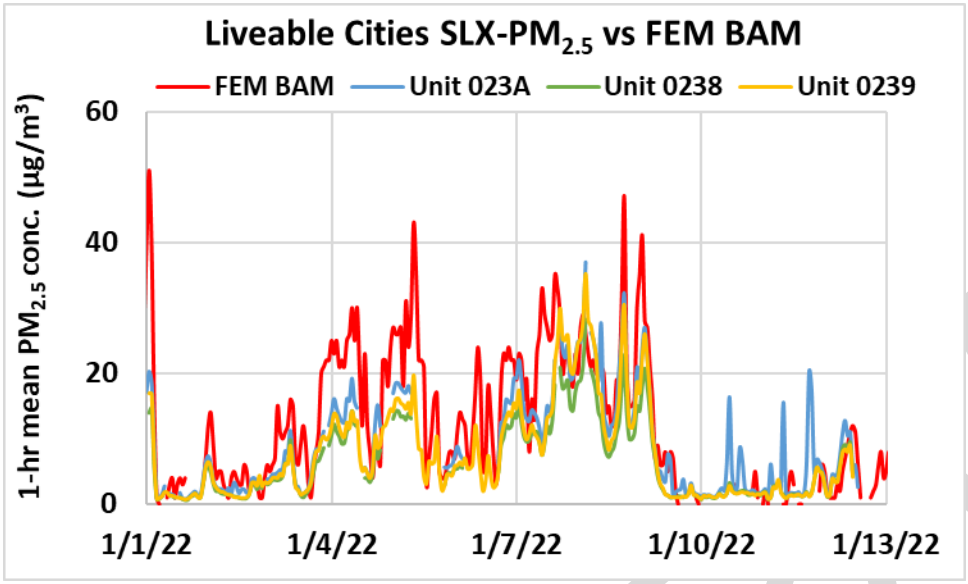
- The Liveable Cities SLX-$PM_{2.5}$ sensors showed strong to very strong correlations with the corresponding T640 data ($0.88 < R^2 < 0.94$)
- Overall, the Liveable Cities SLX-$PM_{2.5}$ sensors underestimated the PM_{10} mass concentrations as measured by T640
- The Liveable Cities SLX-$PM_{2.5}$ sensors seemed to track the PM_{10} diurnal variations as recorded by T640



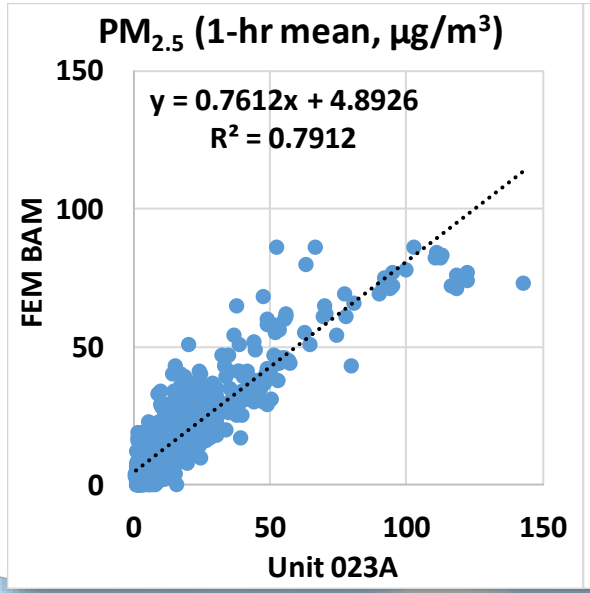


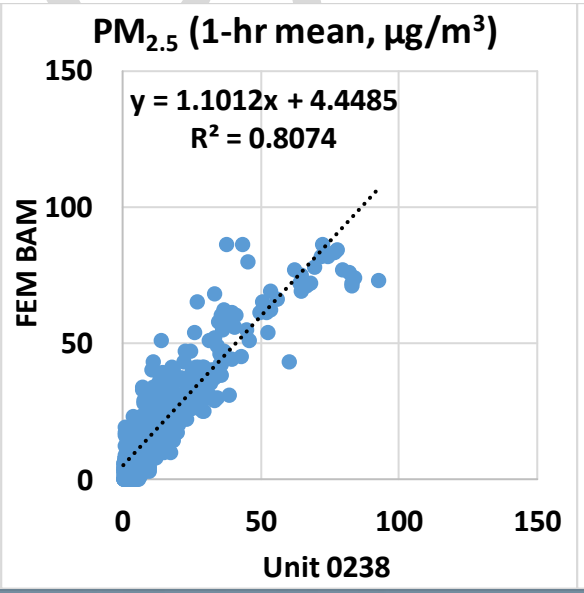


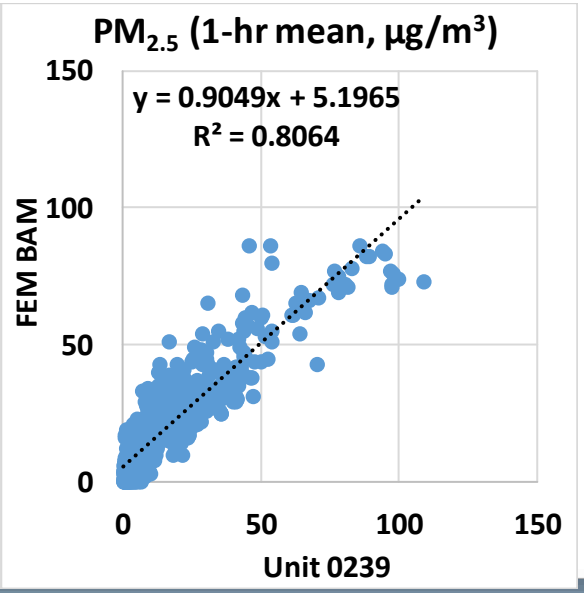
Liveable Cities SLX-$PM_{2.5}$ vs FEM BAM ($PM_{2.5}$; 1-hr mean)



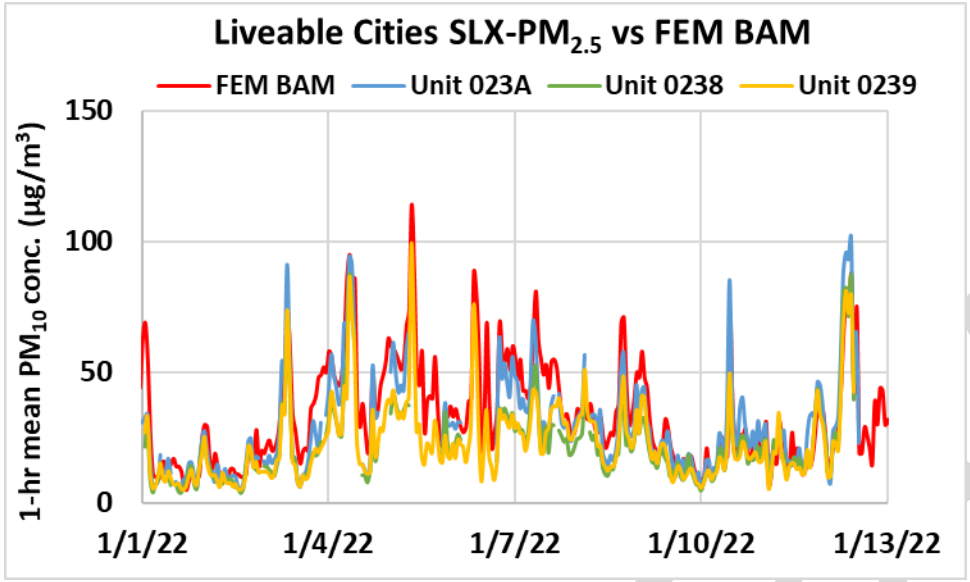
- The Liveable Cities SLX-$PM_{2.5}$ sensors showed strong correlations with the corresponding FEM BAM data ($0.79 < R^2 < 0.81$)
- Overall, the Liveable Cities SLX-$PM_{2.5}$ sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM BAM
- The Liveable Cities SLX-$PM_{2.5}$ sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM BAM



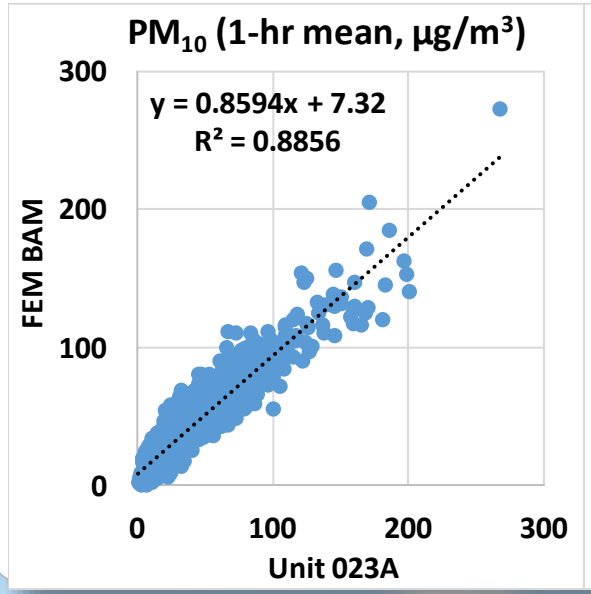


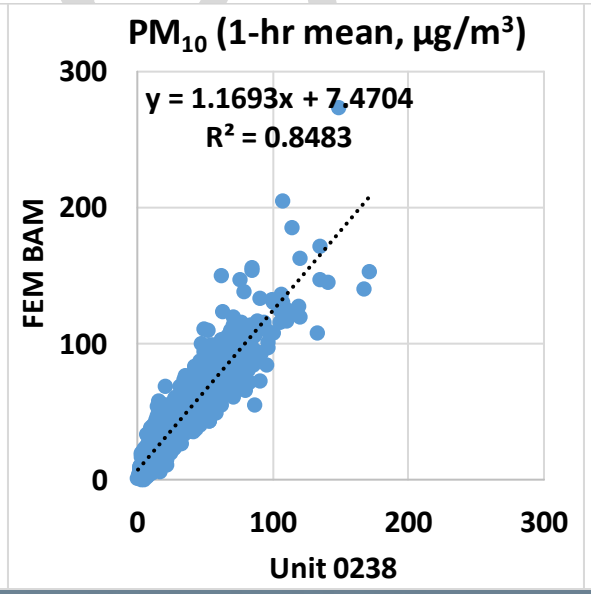


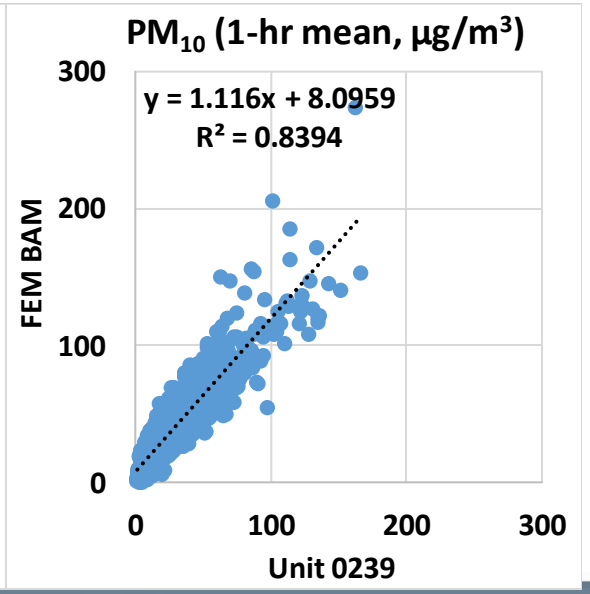
Liveable Cities SLX-$PM_{2.5}$ vs FEM BAM (PM_{10}; 1-hr mean)



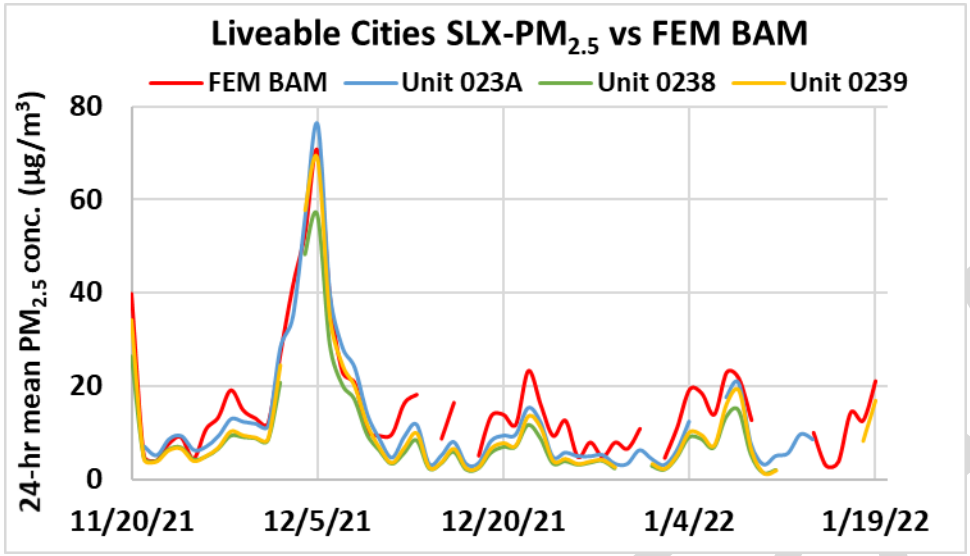
- The Liveable Cities SLX-$PM_{2.5}$ sensors showed strong correlations with the corresponding FEM BAM data ($0.83 < R^2 < 0.89$)
- Overall, the Liveable Cities SLX-$PM_{2.5}$ sensors underestimated the PM_{10} mass concentrations as measured by FEM BAM
- The Liveable Cities SLX-$PM_{2.5}$ sensors seemed to track the PM_{10} diurnal variations as recorded by FEM BAM



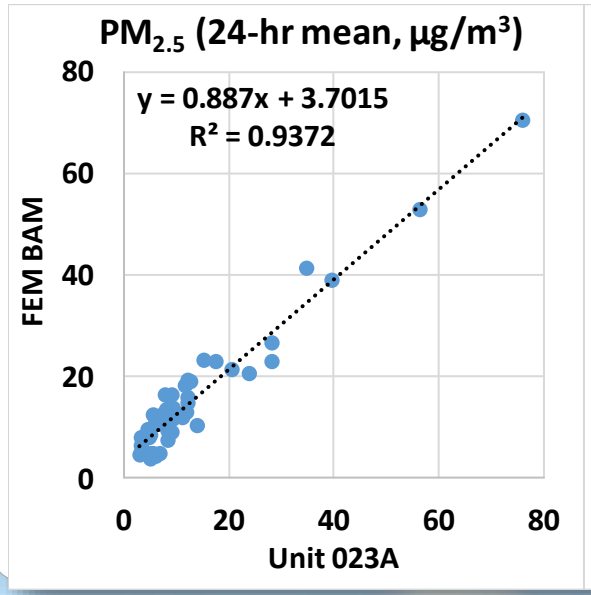


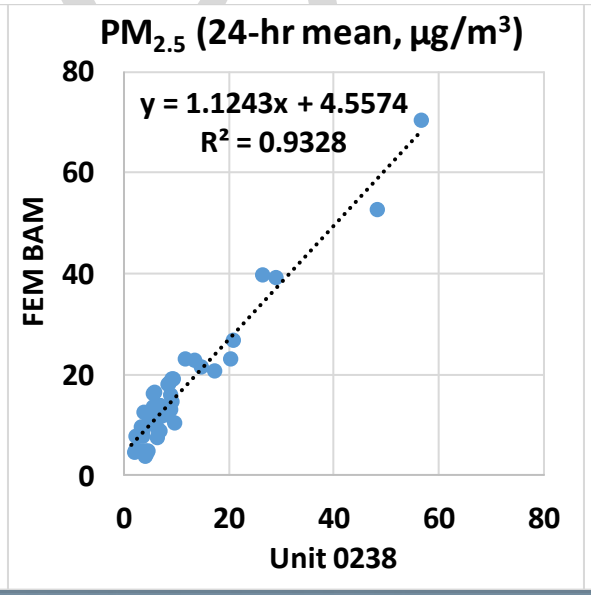


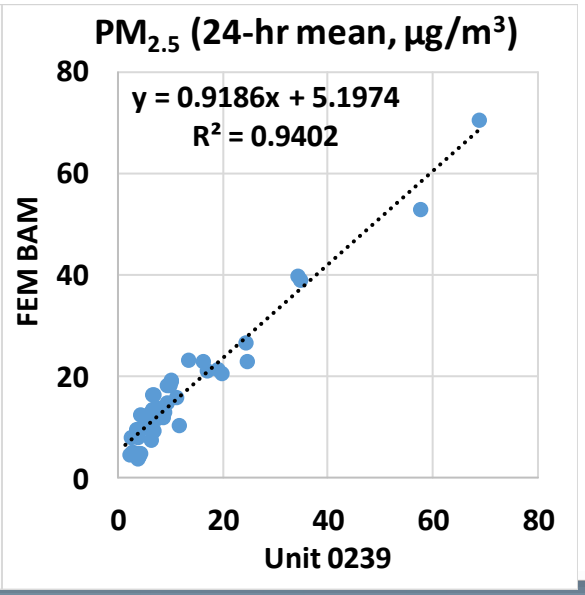
Liveable Cities SLX-$PM_{2.5}$ vs FEM BAM ($PM_{2.5}$; 24-hr mean)



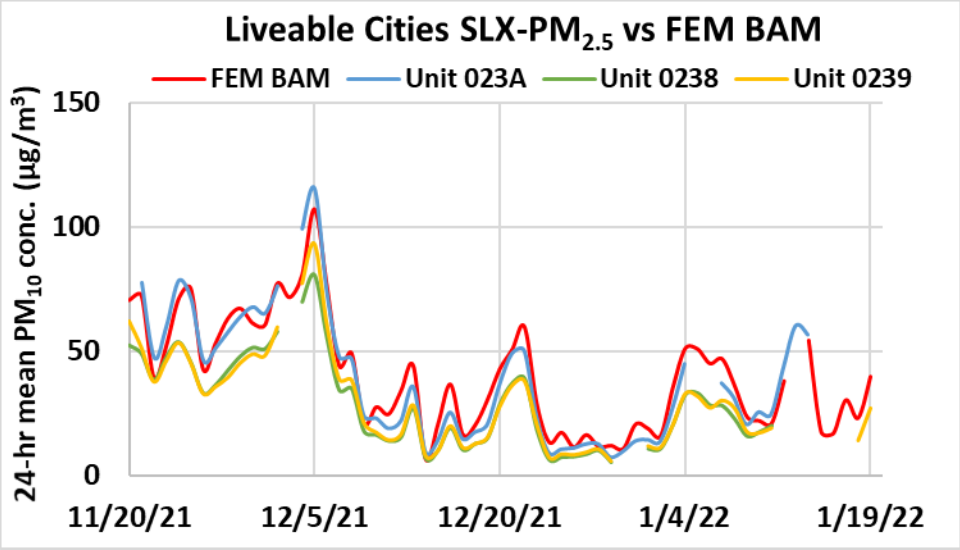
- The Liveable Cities SLX-$PM_{2.5}$ sensors showed very strong correlations with the corresponding FEM BAM data ($0.93 < R^2 < 0.95$)
- Overall, the Liveable Cities SLX-$PM_{2.5}$ sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM BAM
- The Liveable Cities SLX-$PM_{2.5}$ sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM BAM



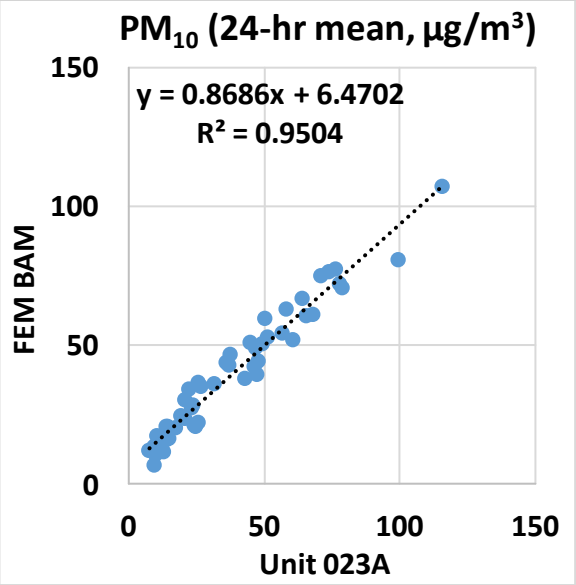


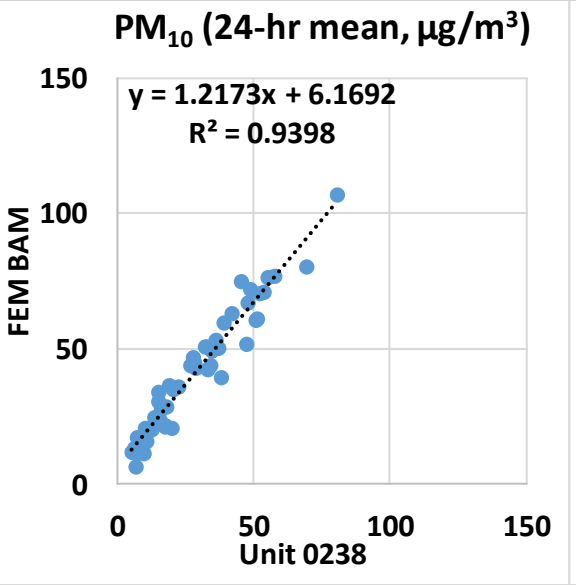


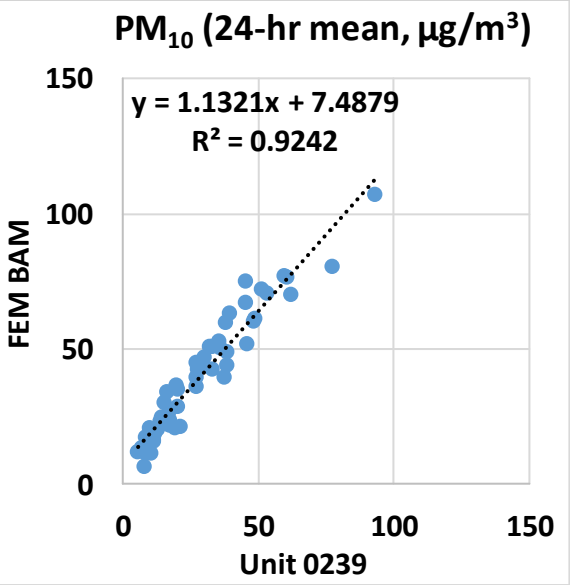
Liveable Cities SLX-$PM_{2.5}$ vs FEM BAM (PM_{10}; 24-hr mean)



- The Liveable Cities SLX-$PM_{2.5}$ sensors showed very strong correlations with the corresponding FEM BAM data ($0.92 < R^2 < 0.96$)
- Overall, the Liveable Cities SLX-$PM_{2.5}$ sensors underestimated the PM_{10} mass concentrations as measured by FEM BAM
- The Liveable Cities SLX-$PM_{2.5}$ sensors seemed to track the PM_{10} diurnal variations as recorded by FEM BAM







Summary

	Average of 3 Sensors, $PM_{2.5}$		Liveable Cities SLX-$PM_{2.5}$ vs FEM BAM, FEM GRIMM & FEM T640, $PM_{2.5}$						FEM BAM, FEM GRIMM & FEM T640 ($PM_{2.5}$, µg/m^3)		
	Average (µg/m^3)	SD (µg/m^3)	R^2	Slope	Intercept	MBE[1] (µg/m^3)	MAE[2] (µg/m^3)	RMSE[3] (µg/m^3)	Ref. Average	Ref. SD	Range during the field evaluation
5-min	11.0	14.6	0.79 to 0.83	0.84 to 1.35	5.7 to 7.3	-9.0 to -4.7	6.4 to 9.1	9.1 to 12.6	17.4 to 18.5	15.7 to 17.8	0.4 to 165.7
1-hr	11.0	14.6	0.79 to 0.85	0.76 to 1.37	4.4 to 7.0	-9.0 to -1.2	5.5 to 9.1	8.0 to 12.3	15.5 to 18.5	15.0 to 17.7	0 to 112.2
24-hr	11.0	12.3	0.91 to 0.94	0.89 to 1.53	3.7 to 6.5	-8.9 to -2.2	3.5 to 8.9	6.4 to 11.6	15.5 to 18.6	12.2 to 15.7	2.4 to 86.7
	Average of 3 Sensors, PM_{10}		Liveable Cities SLX-PM_{10} vs FEM BAM, GRIMM & T640, PM_{10}						FEM BAM, GRIMM & T640 (PM_{10}, µg/m^3)		
	Average (µg/m^3)	SD (µg/m^3)	R^2	Slope	Intercept	MBE[1] (µg/m^3)	MAE[2] (µg/m^3)	RMSE[3] (µg/m^3)	Ref. Average	Ref. SD	Range during the field evaluation
5-min	32.5	30.4	0.71 to 0.77	0.77 to 1.14	8.0 to 12.0	-16.2 to 0.9	11.9 to 18.1	17.5 to 25.0	37.7 to 44.4	31.3 to 34.2	0.6 to 376.1
1-hr	32.6	28.0	0.80 to 0.89	0.86 to 1.25	4.3 to 8.8	-16.2 to 0.9	8.2 to 16.8	11.7 to 23.2	37.7 to 44.4	30.0 to 33.5	0 to 273
24-hr	32.5	20.9	0.88 to 0.95	0.87 to 1.44	1.1 to 7.5	-15.6 to 0.8	4.7 to 15.6	6.1 to 19.6	36.7 to 44.1	22.3 to 27.8	4.9 to 144.8

[1] Mean Bias Error (MBE): the difference between the sensors and the reference instruments. MBE indicates the tendency of the sensors to underestimate (negative MBE values) or overestimate (positive MBE values).
[2] Mean Absolute Error (MAE): the absolute difference between the sensors and the reference instruments. The larger MAE values, the higher measurement errors as compared to the reference instruments.
[3] Root Mean Square Error (RMSE): another metric to calculate measurement errors.

Discussion

- The three **Liveable Cities SLX-$PM_{2.5}$** sensors' data recovery from Unit 023A, Unit 0238 and Unit 0239 was ~ 89%, 85% and 90%, respectively for all PM measurements
- The absolute intra-model variability was ~ 1.52 and 4.75 µg/m^3 for $PM_{2.5}$ and $PM_{10,}$ respectively
- Very strong correlations between FEM BAM, FEM GRIMM and FEM T640 for $PM_{2.5}$ ($0.91 < R^2 < 0.98$, 1-hr mean) and strong to very strong correlations between FEM BAM, GRIMM and T640 for PM_{10} ($0.88 < R^2 < 0.96$, 1-hr mean) mass concentration measurements
- $PM_{2.5}$ mass concentrations measured by the Liveable Cities SLX-$PM_{2.5}$ sensors showed strong correlations with the corresponding FEM GRIMM, FEM T640 and FEM BAM data ($0.79 < R^2 < 0.85$, 1-hr mean). The sensors underestimated $PM_{2.5}$ mass concentrations as measured by FEM GRIMM, FEM T640 and FEM BAM
- PM_{10} mass concentrations measured by the Liveable Cities SLX-$PM_{2.5}$ sensors showed strong correlations with the corresponding GRIMM, T640 and FEM BAM data ($0.79 < R^2 < 0.89$; 1-hr mean). The sensors underestimated PM_{10} mass concentrations as measured by GRIMM, T640 and FEM BAM
- No sensor calibration was performed by South Coast AQMD Staff for this evaluation
- Laboratory chamber testing is necessary to fully evaluate the performance of these sensors under known aerosol concentrations and controlled temperature and relative humidity conditions

- All results are still preliminary