

Field Evaluation Gonggam Sensors Co., Ltd. – TAM 1



Background

- From 11/04/2023 to 01/04/2024, three **Gonggam Sensors Co., Ltd. – Tiny Aerosol Conditioner inside Air Monitor 1 (hereinafter GG Sensors - TAM)** 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

GGsensors - TAM (3 units tested):

- PM Sensors – Optical (**non-FEM**)
- Each unit measures: PM_{1.0}, PM_{2.5}, PM_{4.0} and PM₁₀ (µg/m³), T (°C), RH (%)
- **Unit cost: \$7,999**
- Time resolution: 5 seconds
- Units IDs: 95, 96, 97



South Coast AQMD Reference Instruments:

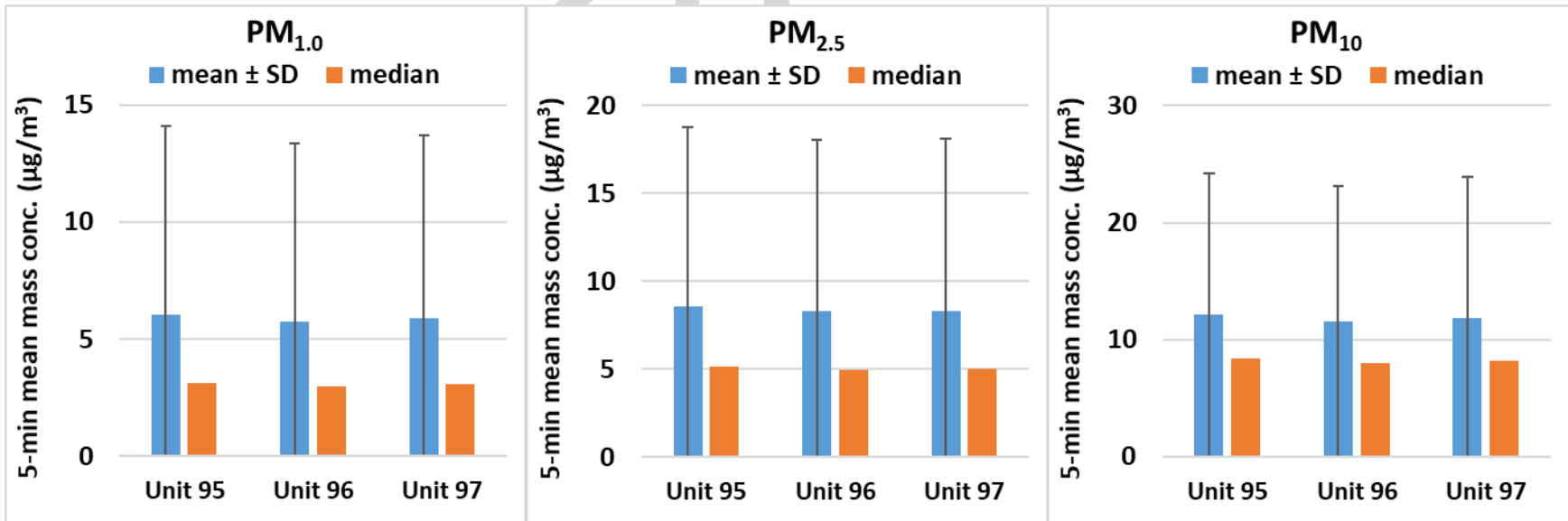
- MetOne BAM:
 - Beta-attenuation (**FEM PM_{2.5} & PM₁₀**)
 - Measures PM_{2.5}, and PM₁₀ (µg/m³)
 - **Cost: ~\$20,000**
 - Time resolution: 1-hr
- Teledyne API T640 (*hereinafter FEM T640 for PM_{2.5}, T640 otherwise*):
 - Optical particle counter (**FEM PM_{2.5}**)
 - Measures PM_{1.0}, PM_{2.5} and PM₁₀ (µg/m³)
 - **Cost: ~\$21,000**
 - Time resolution: 1-min
- Met Station (T, RH, P, WS, WD):
 - **Cost: ~\$5,000**
 - Time resolution: 1-min

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 95, Unit 96 and Unit 97 was 99.1%, 99.2% and 99.3%, respectively, for all PM measurements

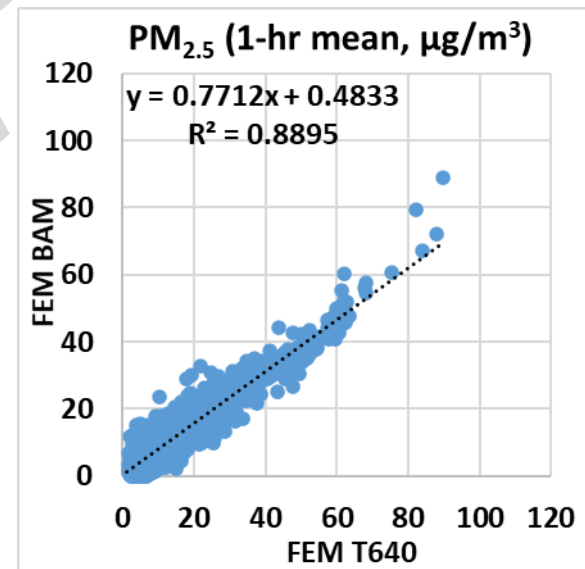
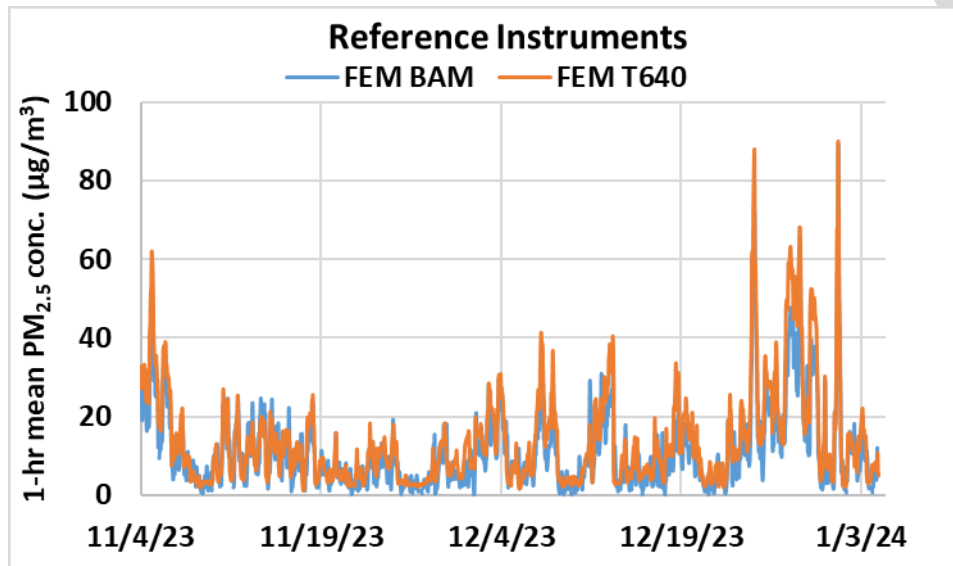
GG Sensors - TAM; intra-model variability

- Absolute intra-model variability was ~ 0.14 , 0.18 and $0.28 \mu\text{g}/\text{m}^3$ for $\text{PM}_{1.0}$, $\text{PM}_{2.5}$ and PM_{10} , respectively (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was $\sim 2.4\%$, 2.1% and 2.4% for $\text{PM}_{1.0}$, $\text{PM}_{2.5}$ and PM_{10} , respectively (calculated as the absolute intra-model variability relative to the mean of the three sensor means)



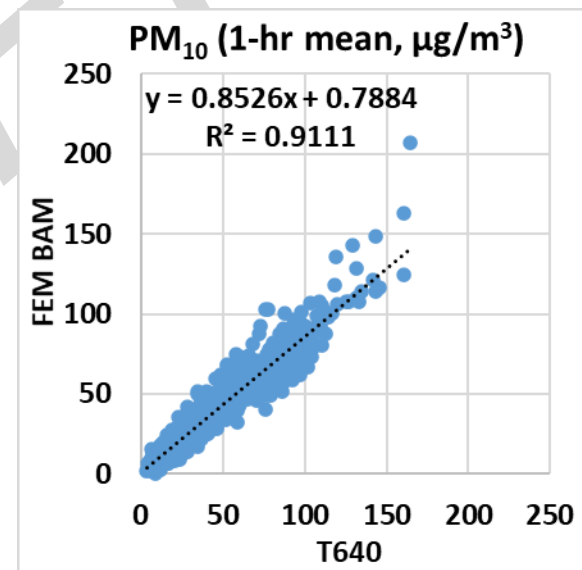
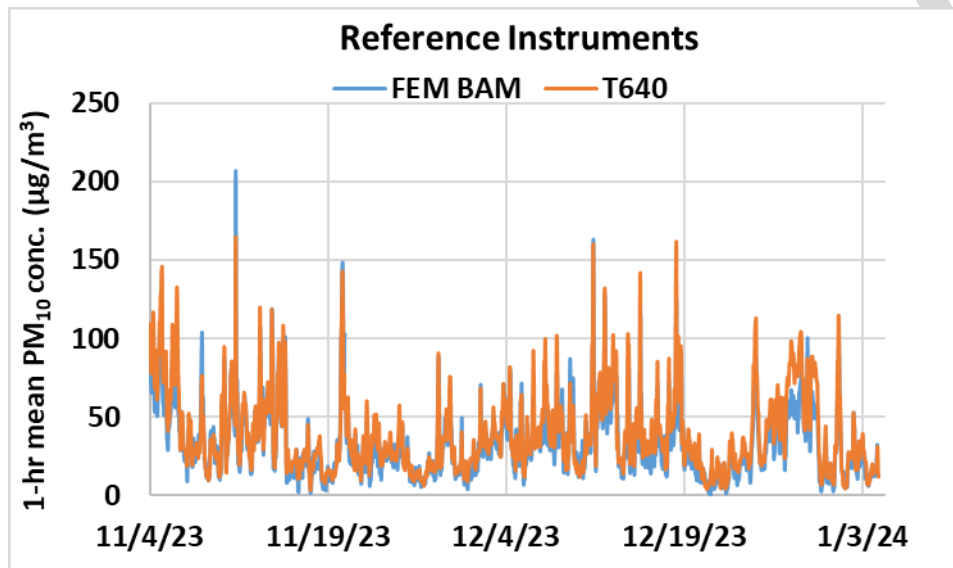
Reference Instruments: PM_{2.5} FEM BAM and FEM T640

- Data recovery for PM_{2.5} from FEM BAM and FEM T640 was 95.3% and 99.8%, respectively.
- Strong correlations between the reference instruments for PM_{2.5} measurements ($R^2 \sim 0.89$) were observed.

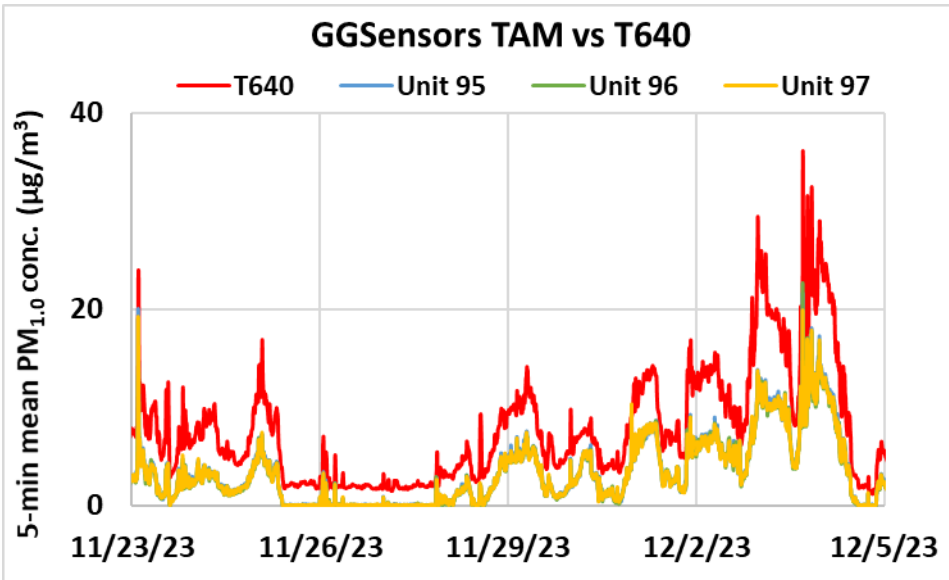


Reference Instruments: PM₁₀ FEM BAM and T640

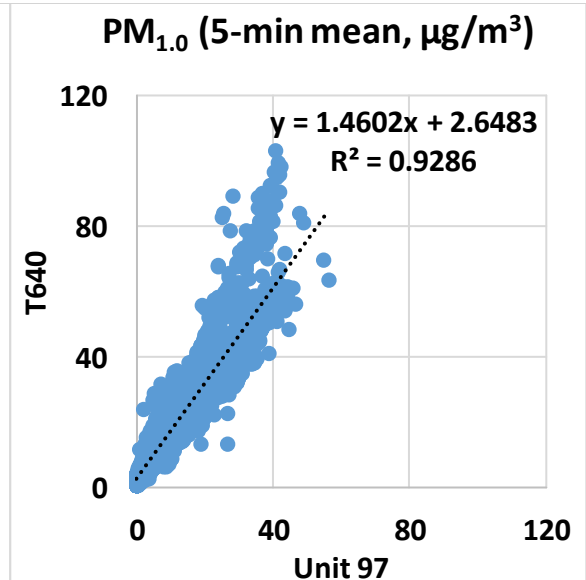
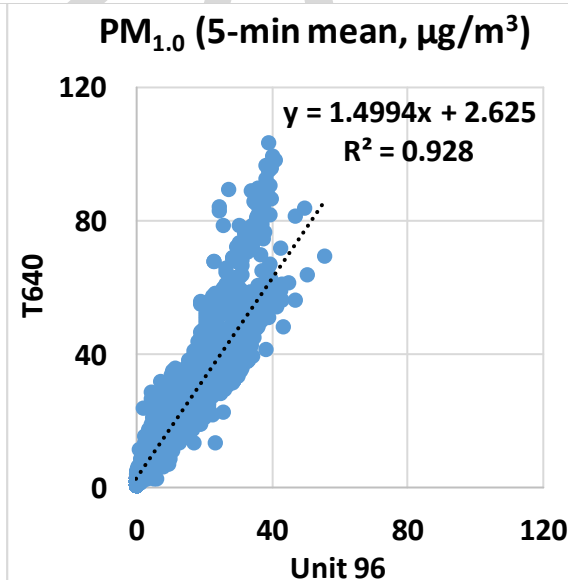
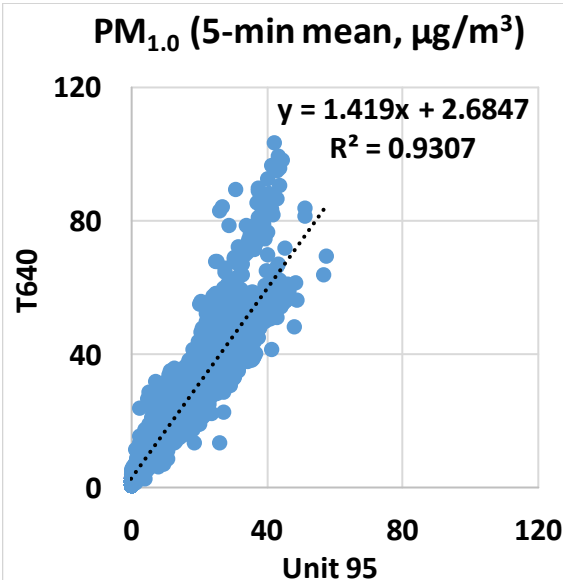
- Data recovery for PM₁₀ from FEM BAM and T640 was 99.1% and 99.8%, respectively.
- Very strong correlations between the reference instruments for PM₁₀ measurements ($R^2 \sim 0.91$) were observed.



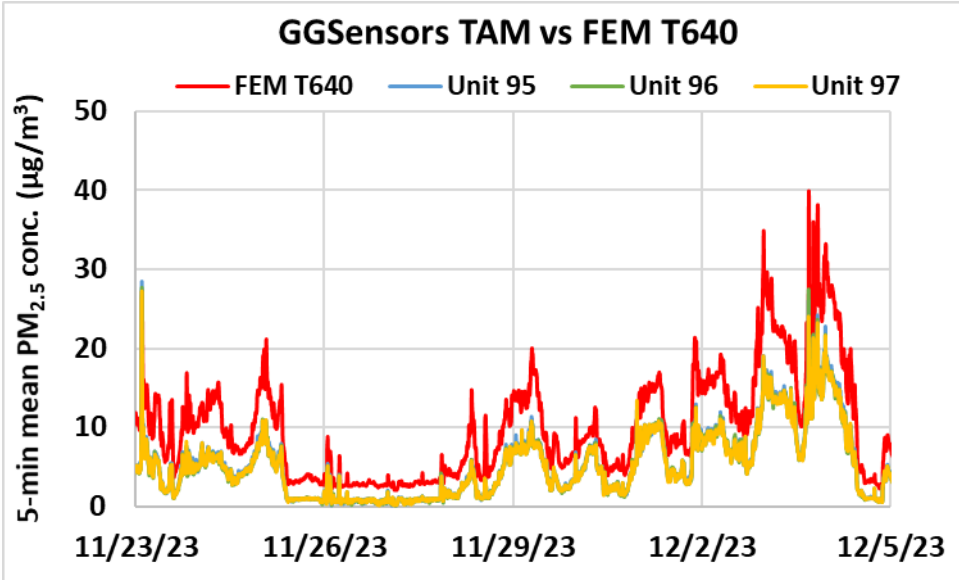
GG Sensors - TAM vs T640 (PM_{1.0}; 5-min mean)



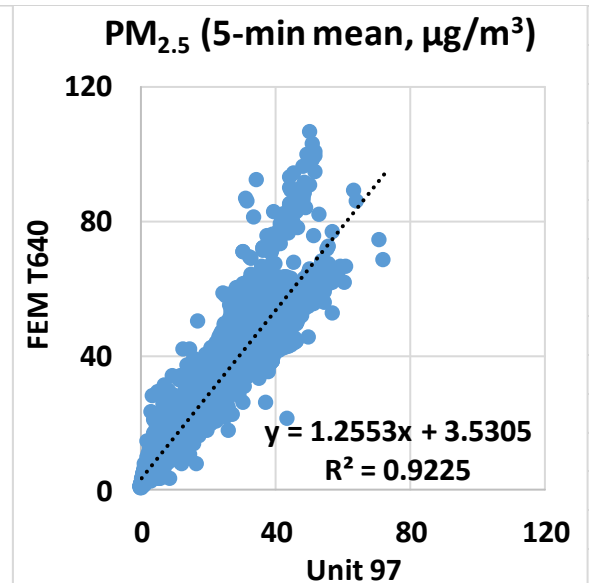
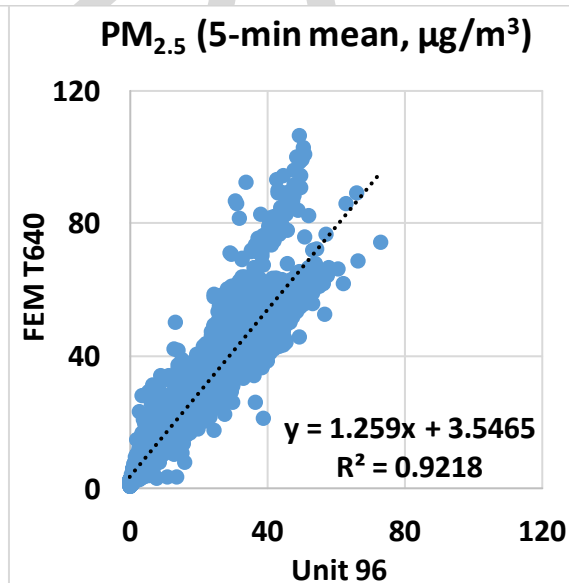
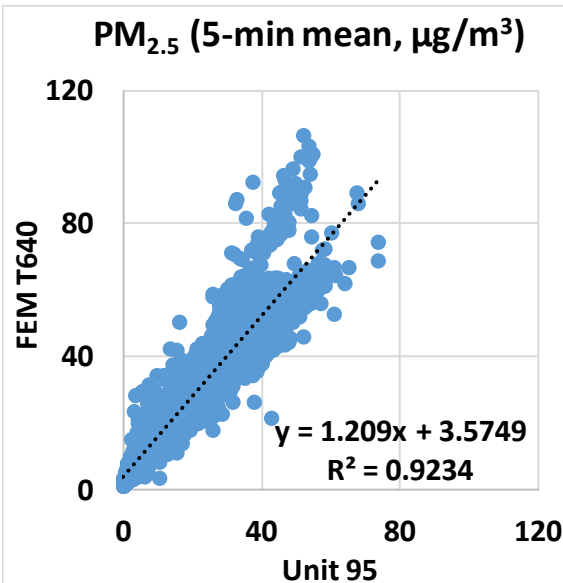
- The GG Sensors - TAM sensors showed very strong correlations with the corresponding T640 data ($0.92 < R^2 < 0.94$)
- Overall, the GG Sensors - TAM sensors underestimated the PM_{1.0} mass concentrations as measured by T640
- The GG Sensors - TAM sensors seemed to track the PM_{1.0} diurnal variations as recorded by T640



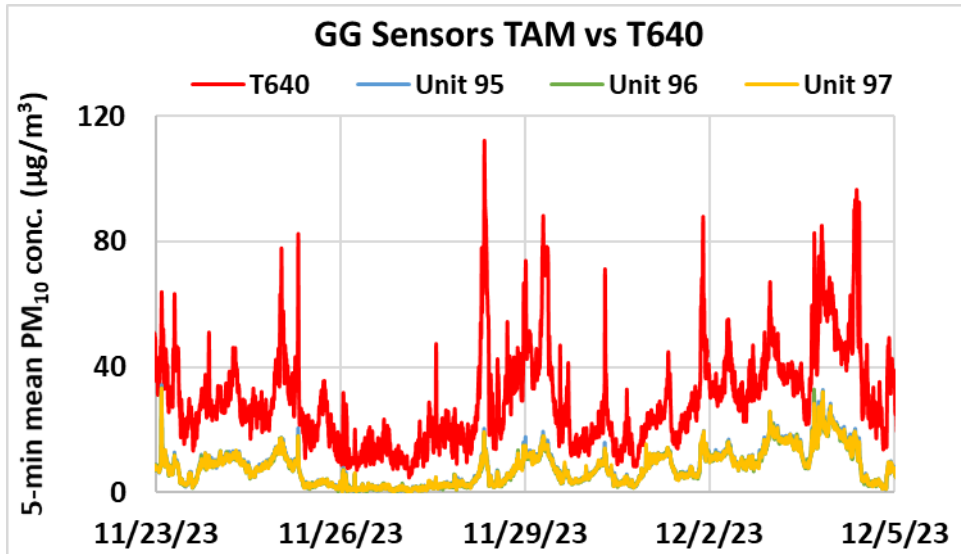
GGensors - TAM vs FEM T640 (PM_{2.5}; 5-min mean)



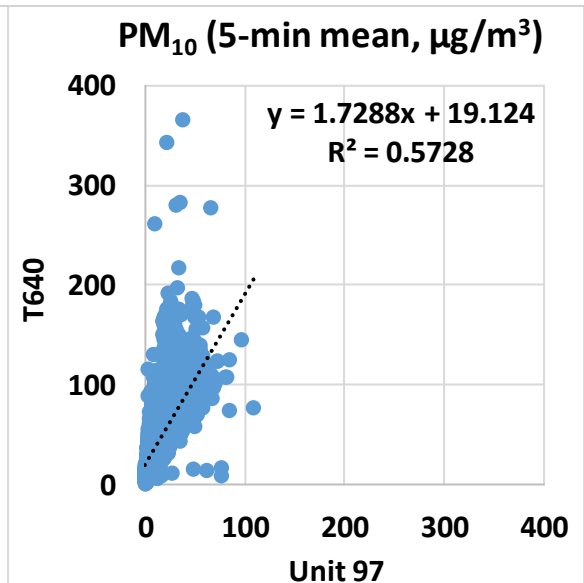
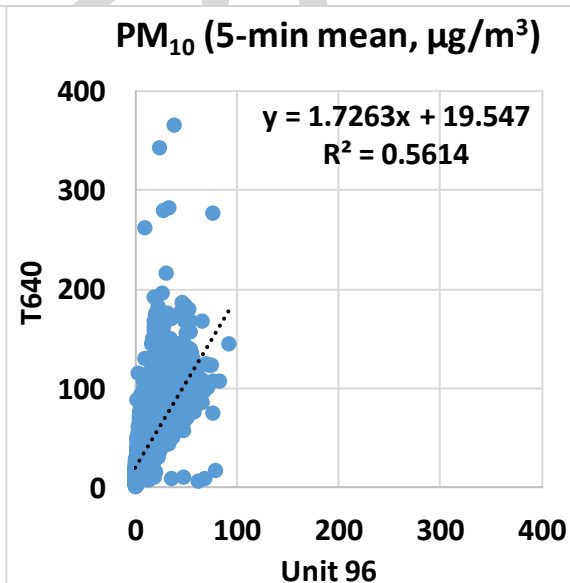
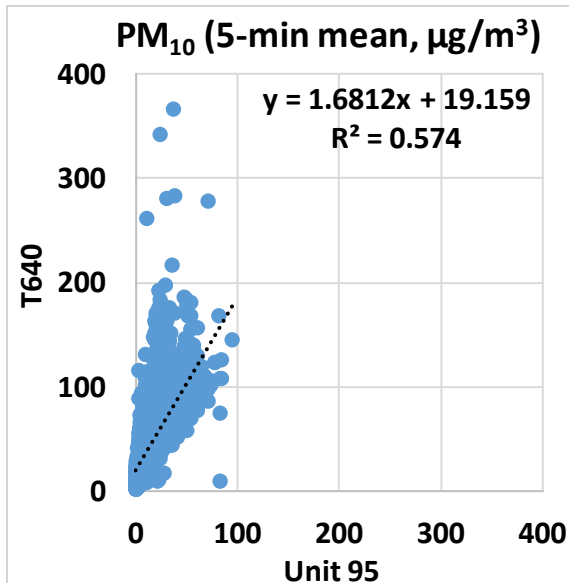
- The GGensors - TAM sensors showed very strong correlations with the corresponding FEM T640 data ($0.92 < R^2 < 0.93$)
- Overall, the GGensors - TAM sensors underestimated the PM_{2.5} mass concentrations as measured by FEM T640
- The GGensors - TAM sensors seemed to track the PM_{2.5} diurnal variations as recorded by FEM T640



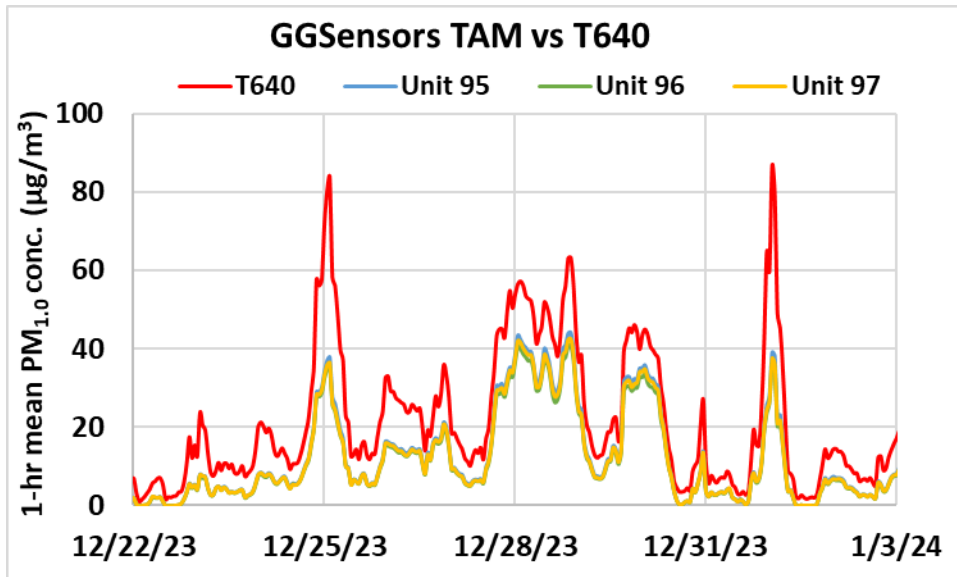
GG Sensors - TAM vs T640 (PM₁₀; 5-min mean)



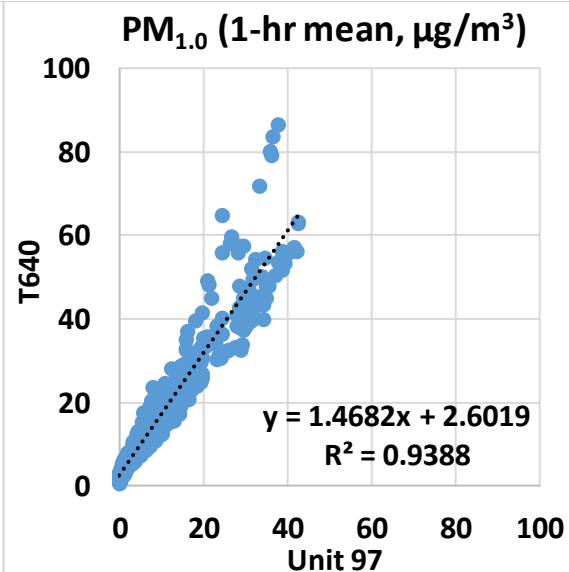
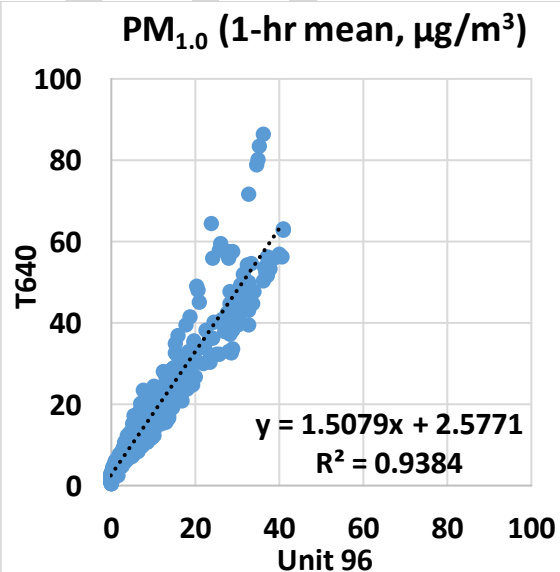
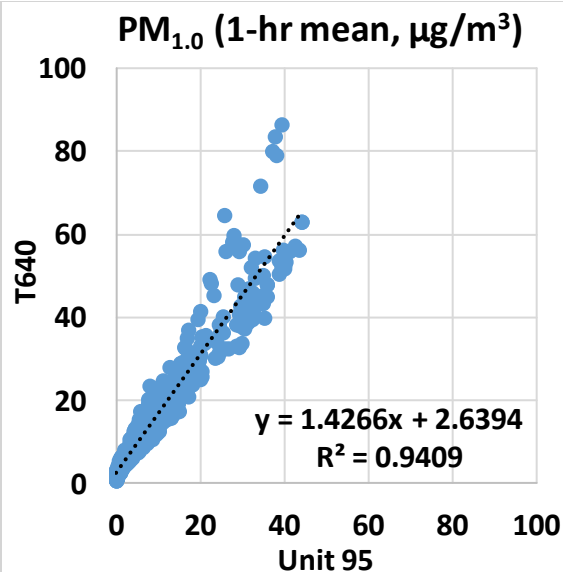
- GGSensors - TAM sensors showed moderate correlations with the corresponding T640 data ($0.56 < R^2 < 0.58$)
- Overall, the GGSensors - TAM sensors underestimated the PM₁₀ mass concentrations as measured by T640
- The GGSensors - TAM sensors seemed to track the PM₁₀ diurnal variations as recorded by T640



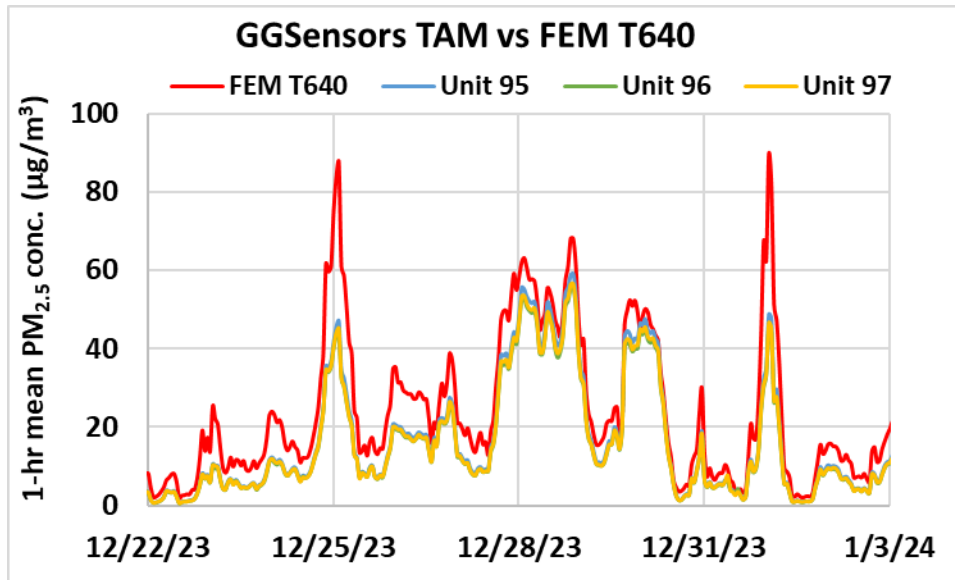
GGensors - TAM vs T640 (PM_{1.0}; 1-hr mean)



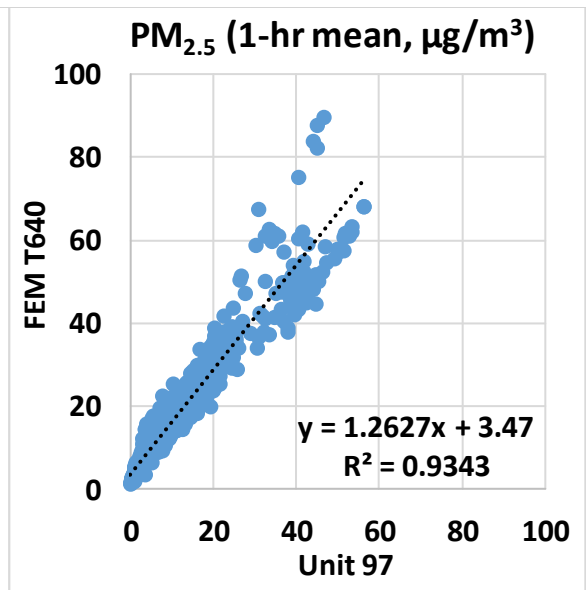
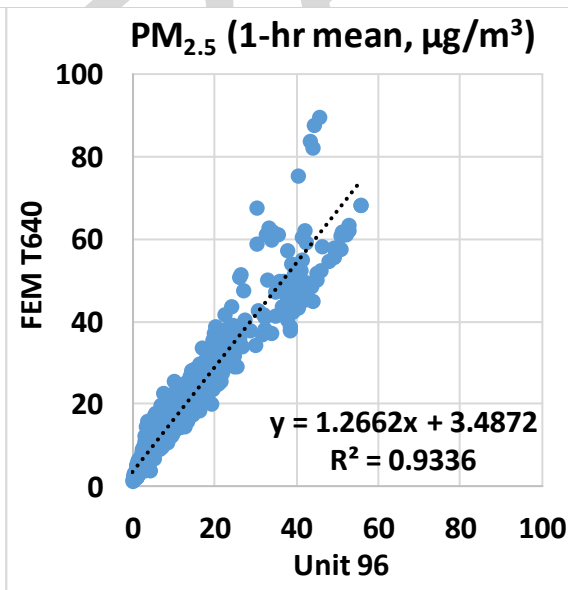
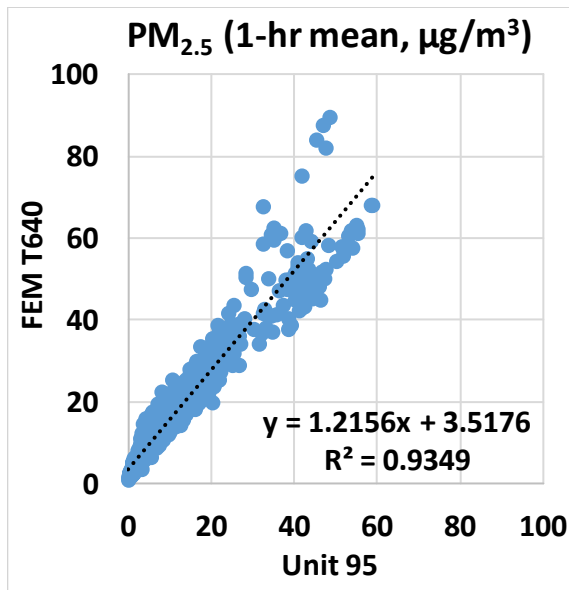
- The GGensors - TAM sensors showed very strong correlations with the corresponding T640 data ($0.93 < R^2 < 0.95$)
- Overall, the GGensors - TAM sensors underestimated the PM_{1.0} mass concentrations as measured by T640
- The GGensors - TAM sensors seemed to track the PM_{1.0} diurnal variations as recorded by T640



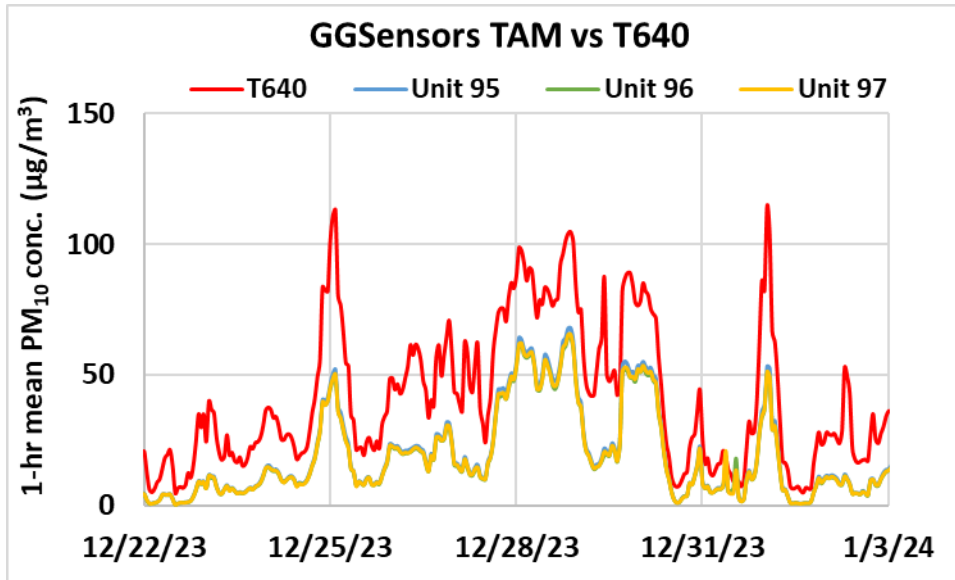
GG Sensors - TAM vs FEM T640 (PM_{2.5}; 1-hr mean)



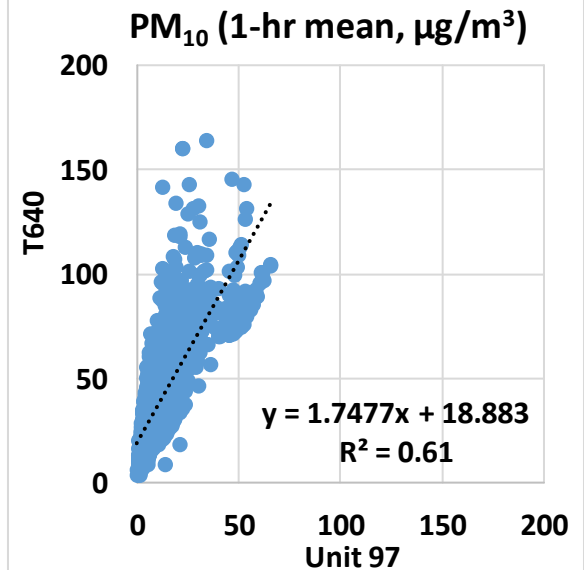
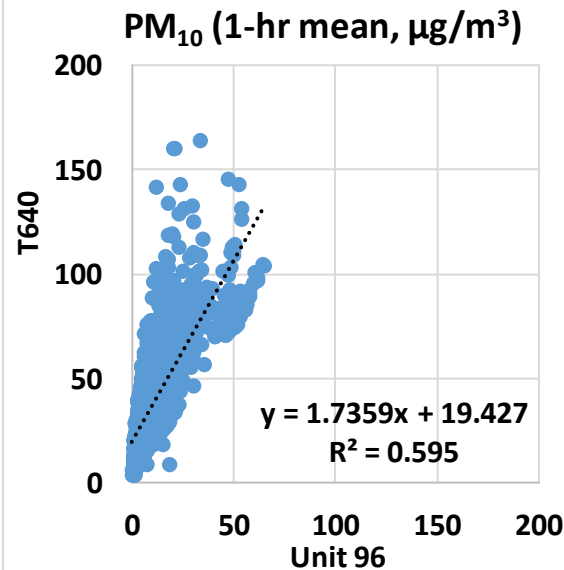
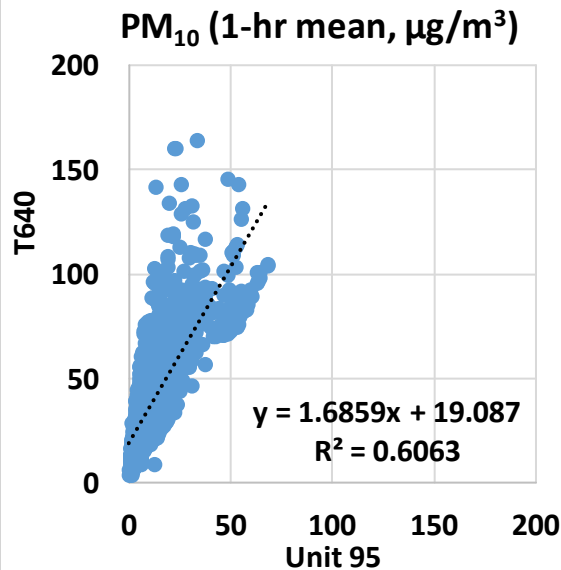
- The GG Sensors - TAM sensors showed very strong correlations with the corresponding FEM T640 data ($0.93 < R^2 < 0.94$)
- Overall, the GG Sensors - TAM sensors underestimated the PM_{2.5} mass concentrations as measured by FEM T640
- The GG Sensors - TAM sensors seemed to track the PM_{2.5} diurnal variations as recorded by FEM T640



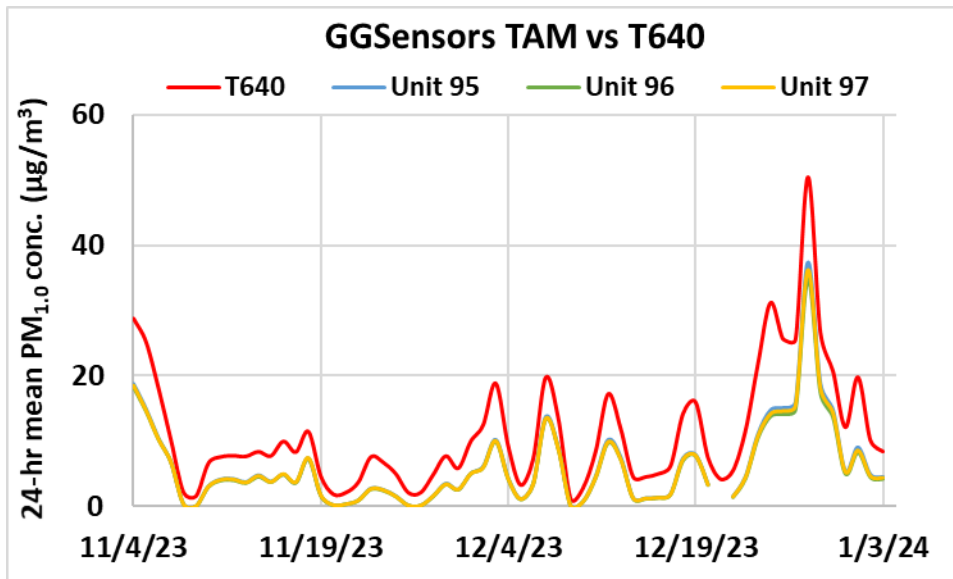
GGensors - TAM vs T640 (PM₁₀; 1-hr mean)



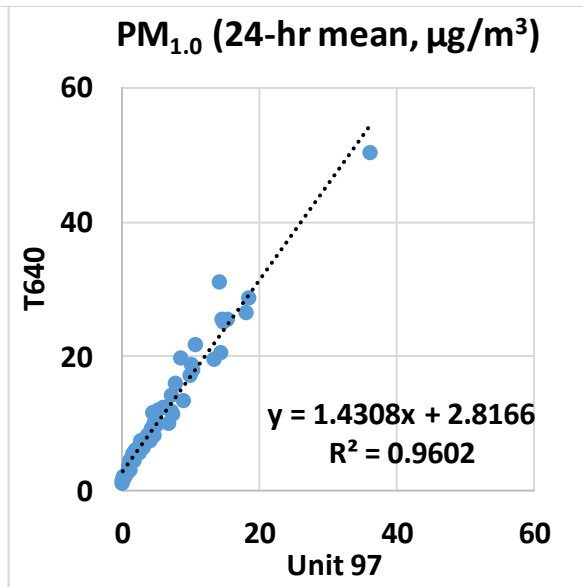
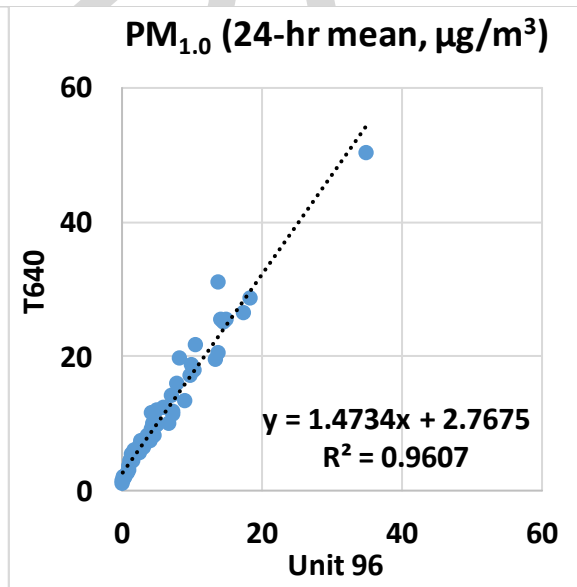
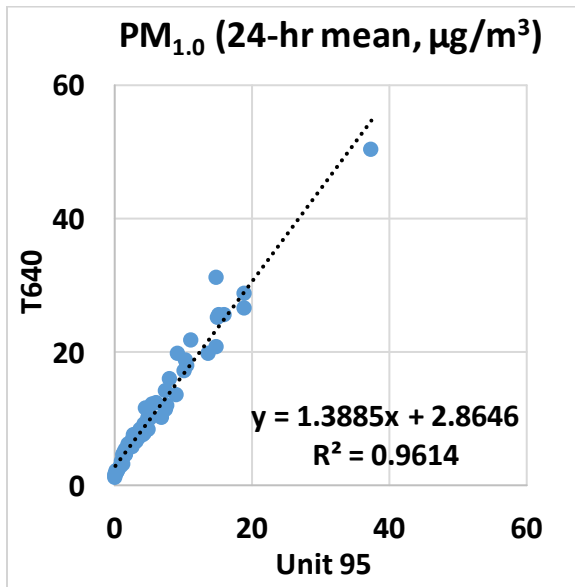
- The GGensors - TAM sensors showed moderate correlations with the corresponding T640 data ($0.59 < R^2 < 0.62$)
- Overall, the GGensors - TAM sensors underestimated the PM₁₀ mass concentrations as measured by T640
- The GGensors - TAM sensors seemed to track the PM₁₀ diurnal variations as recorded by T640



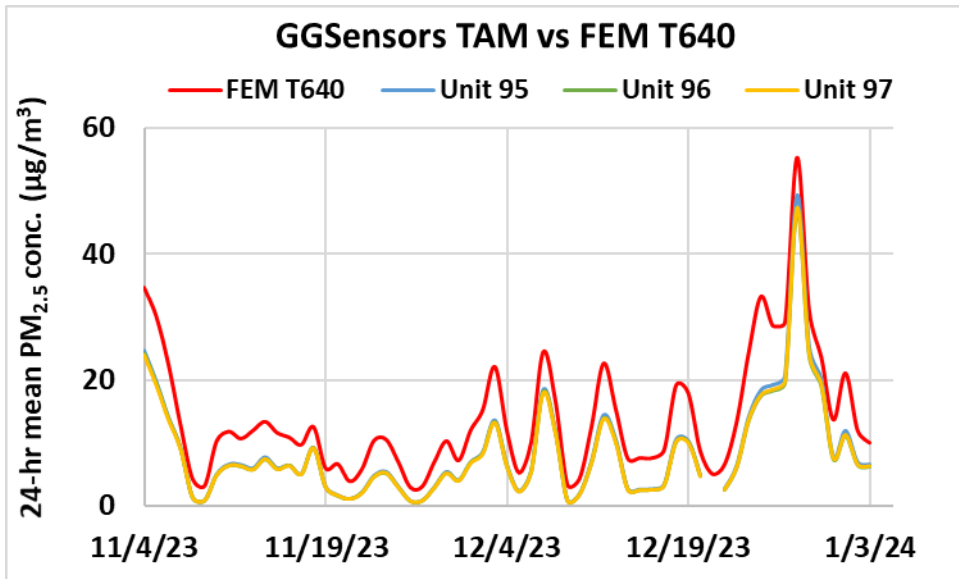
GG Sensors - TAM vs T640 (PM_{1.0}; 24-hr mean)



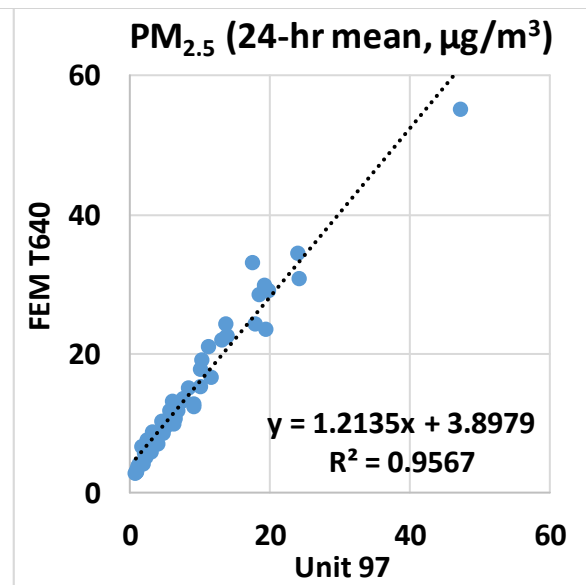
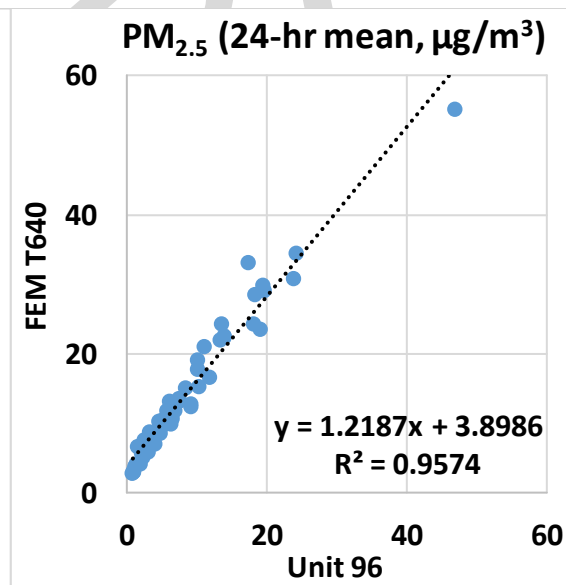
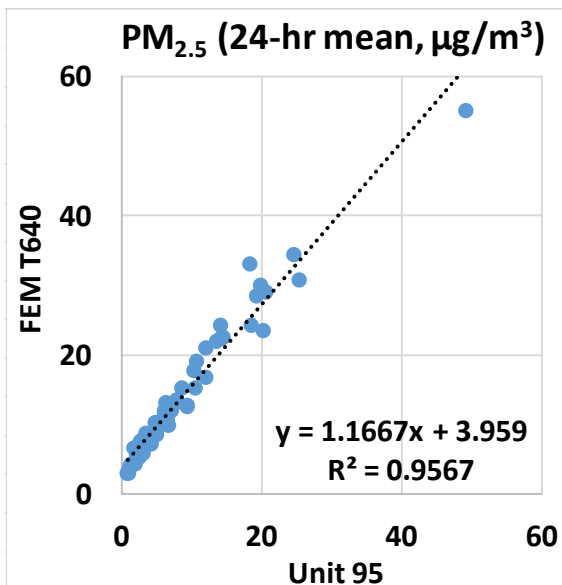
- The GG Sensors - TAM sensors showed very strong correlations with the corresponding T640 data ($0.96 < R^2 < 0.97$)
- Overall, the GG Sensors - TAM sensors underestimated the PM_{1.0} mass concentrations as measured by T640
- The GG Sensors - TAM sensors seemed to track the PM_{1.0} diurnal variations as recorded by T640



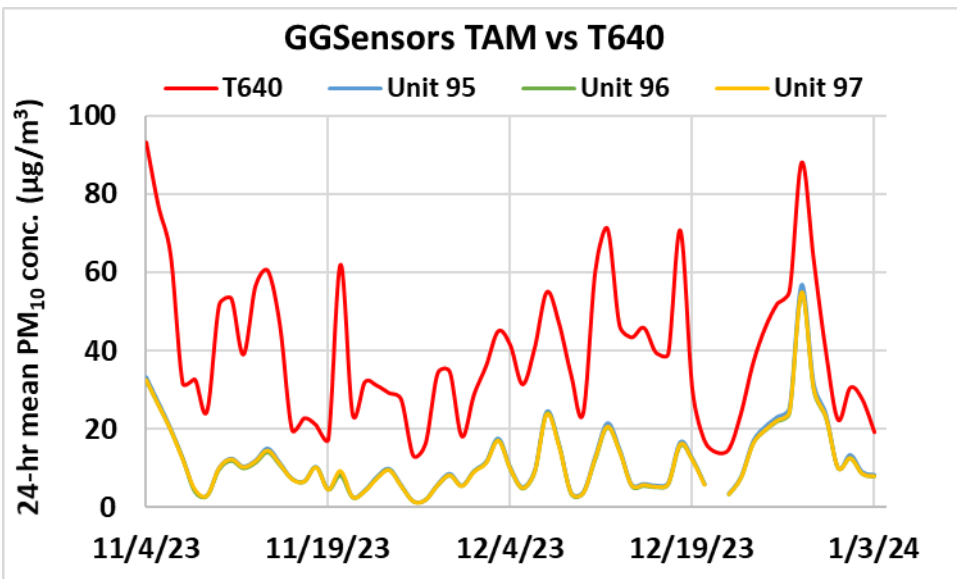
GGensors - TAM vs FEM T640 (PM_{2.5}; 24-hr mean)



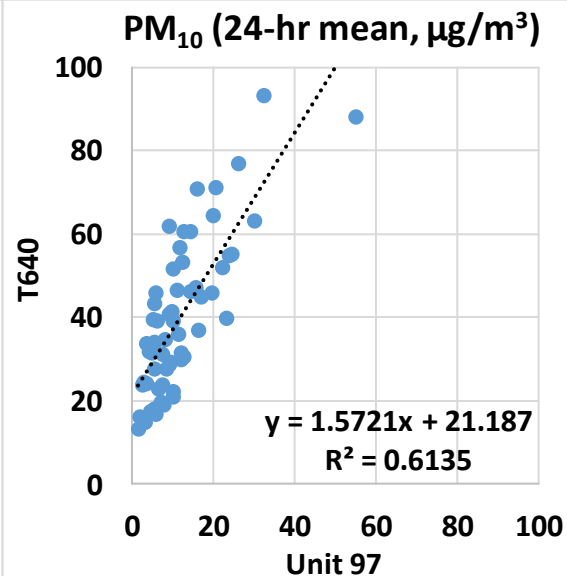
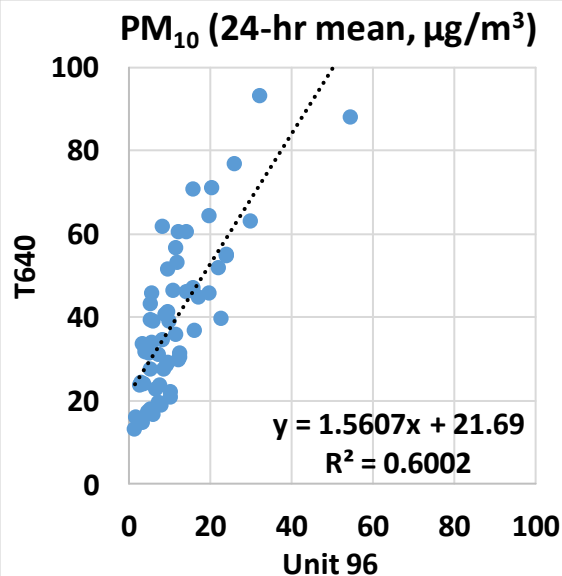
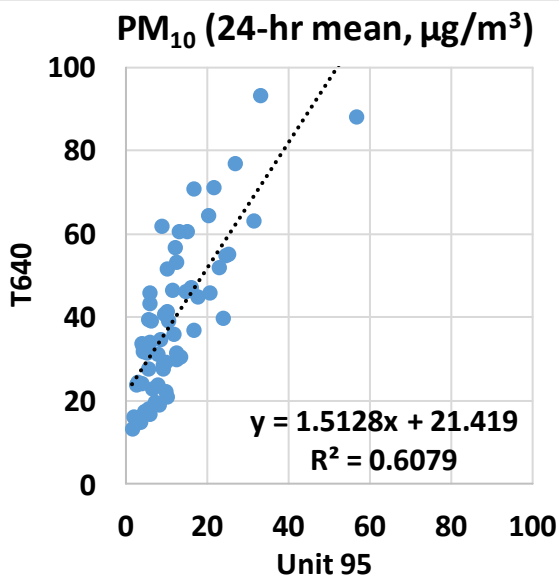
- The GGensors - TAM sensors showed very strong correlations with the corresponding FEM T640 data ($0.95 < R^2 < 0.96$)
- Overall, the GGensors - TAM sensors underestimated the PM_{2.5} mass concentrations as measured by FEM T640
- The GGensors - TAM sensors seemed to track the PM_{2.5} diurnal variations as recorded by FEM T640



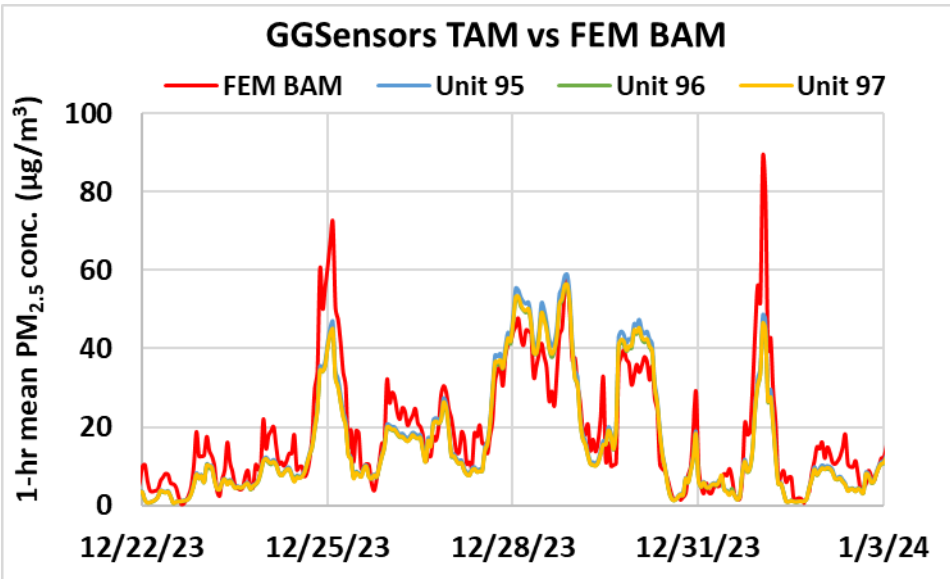
GG Sensors - TAM vs T640 (PM₁₀; 24-hr mean)



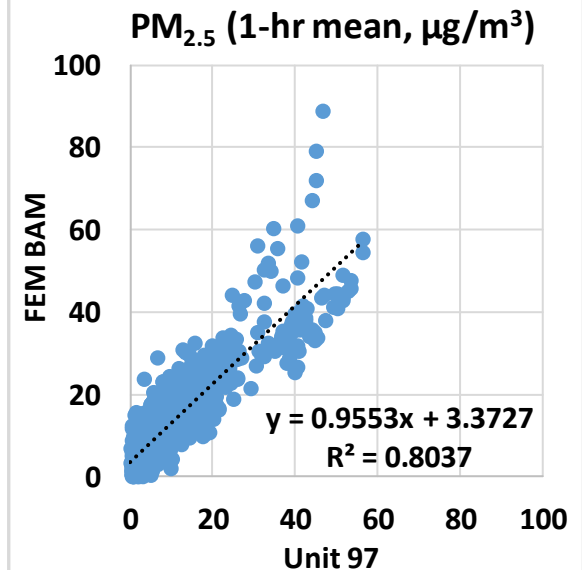
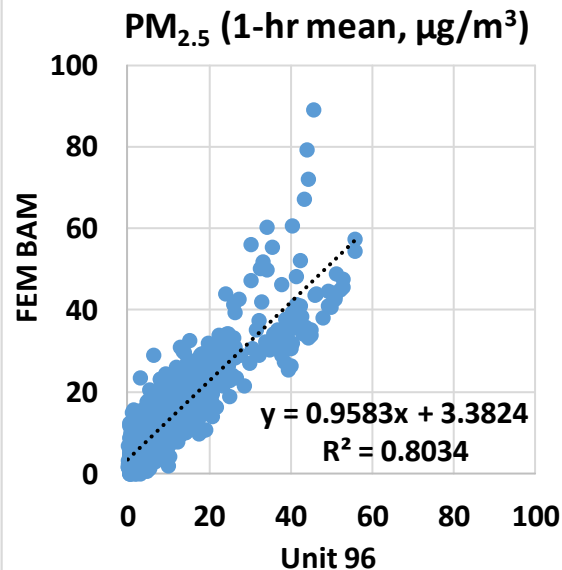
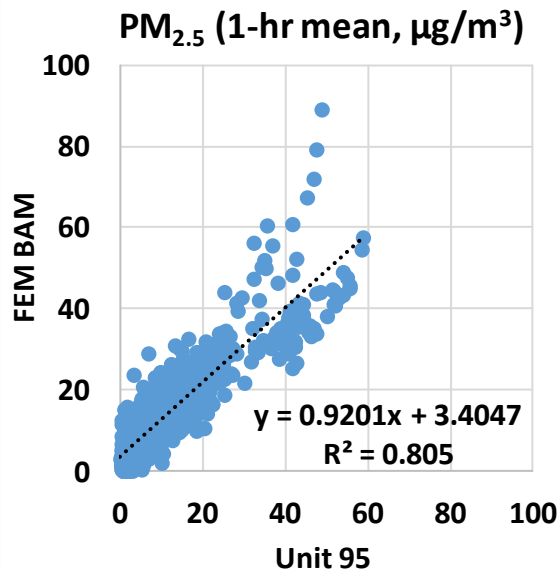
- The GG Sensors - TAM sensors showed moderate correlations with the corresponding T640 data ($0.60 < R^2 < 0.62$)
- Overall, the GG Sensors - TAM sensors underestimated the PM₁₀ mass concentrations as measured by T640
- The GG Sensors - TAM sensors seemed to track the PM₁₀ diurnal variations as recorded by T640



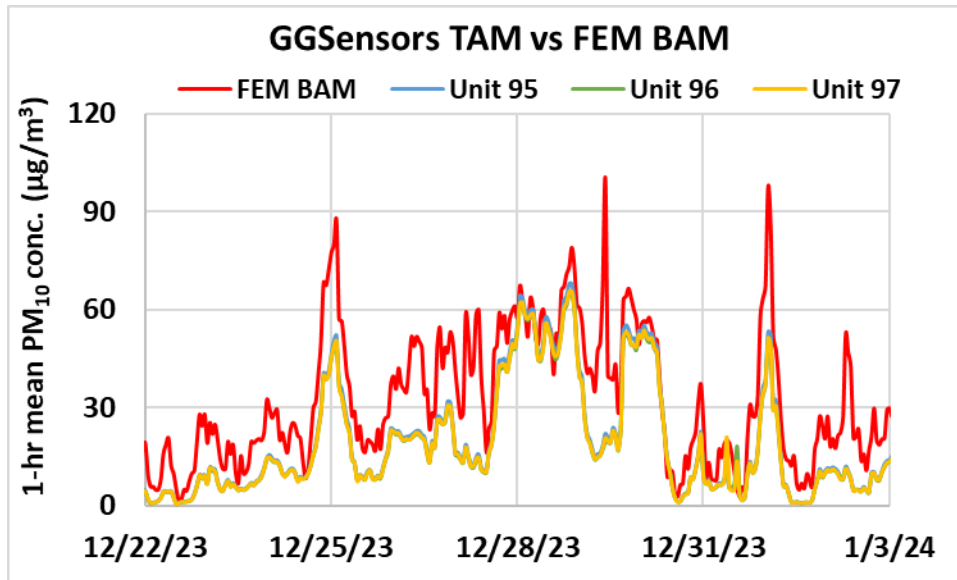
GGensors - TAM vs FEM BAM (PM_{2.5}; 1-hr mean)



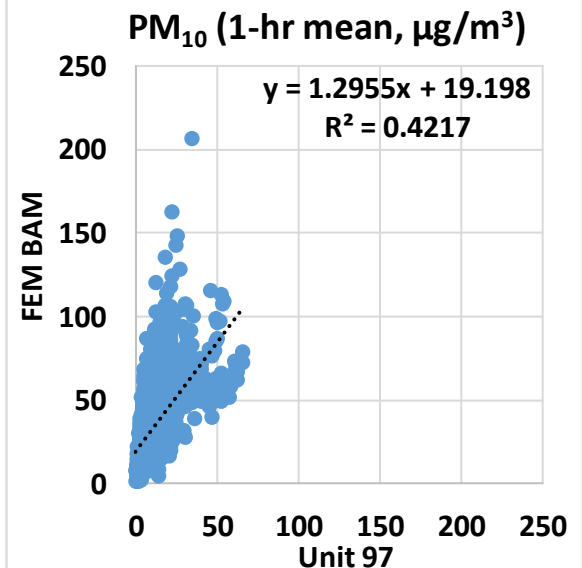
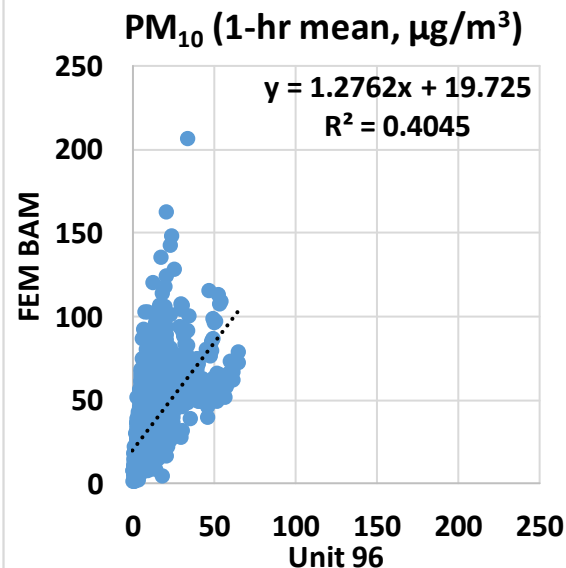
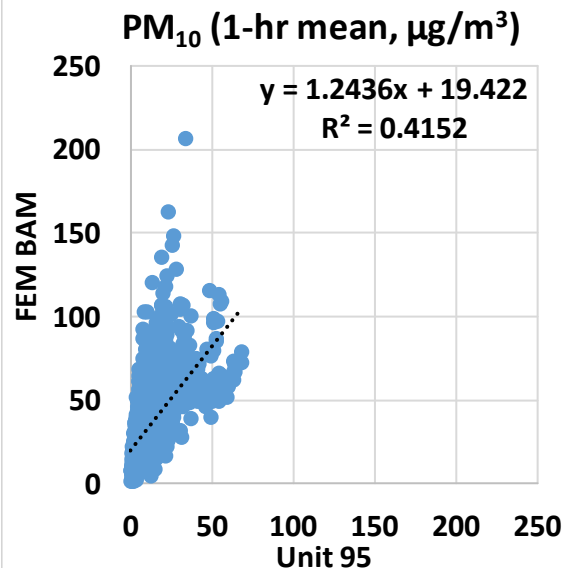
- The GGensors - TAM sensors showed strong correlations with the corresponding FEM BAM data ($0.80 < R^2 < 0.81$)
- Overall, the GGensors - TAM sensors underestimated the PM_{2.5} mass concentrations as measured by FEM BAM
- The GGensors - TAM sensors seemed to track the PM_{2.5} diurnal variations as recorded by FEM BAM



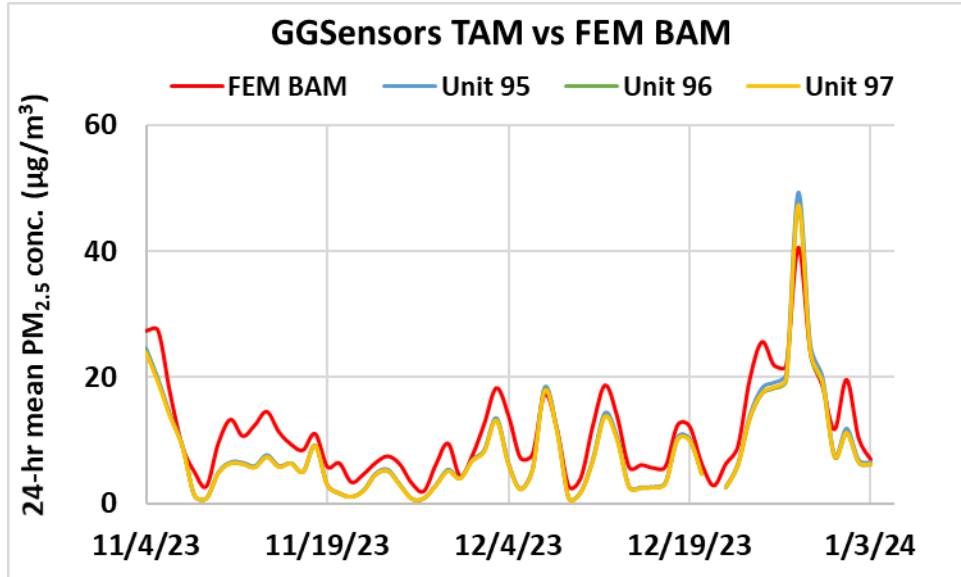
GG Sensors - TAM vs FEM BAM (PM₁₀; 1-hr mean)



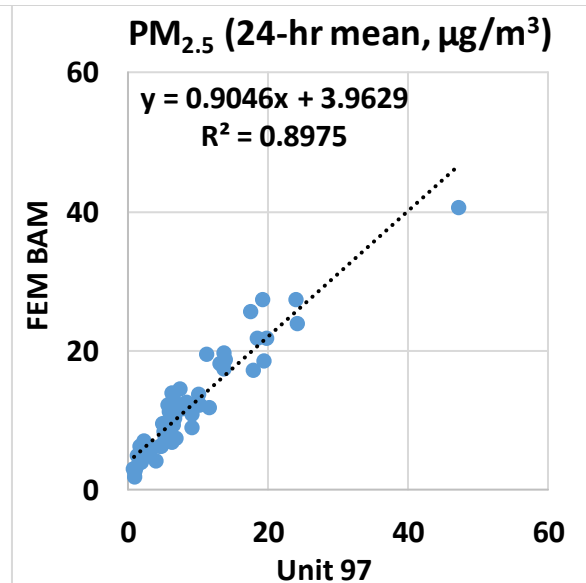
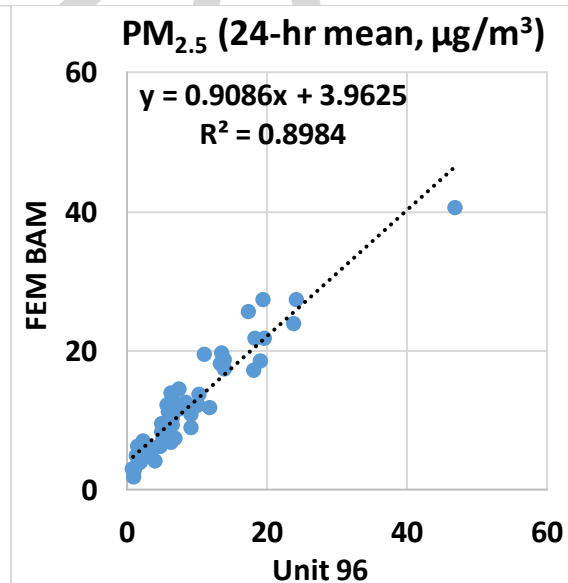
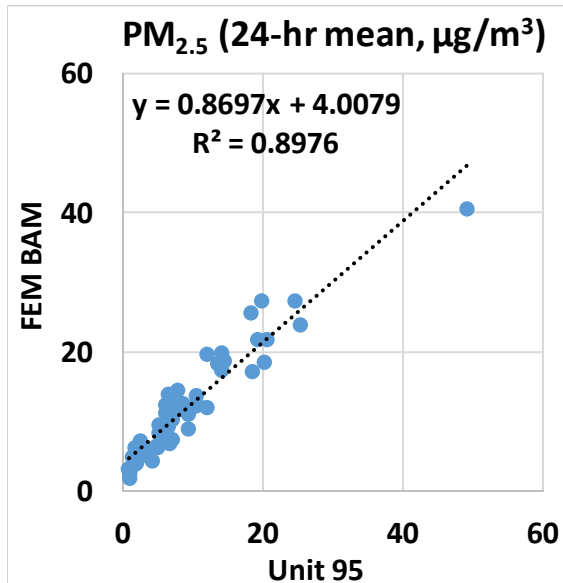
- The GG Sensors - TAM sensors showed weak correlations with the corresponding FEM BAM data ($0.40 < R^2 < 0.43$)
- Overall, the GG Sensors - TAM sensors underestimated the PM₁₀ mass concentrations as measured by FEM BAM
- The GG Sensors - TAM sensors seemed to track the PM₁₀ diurnal variations as recorded by FEM BAM



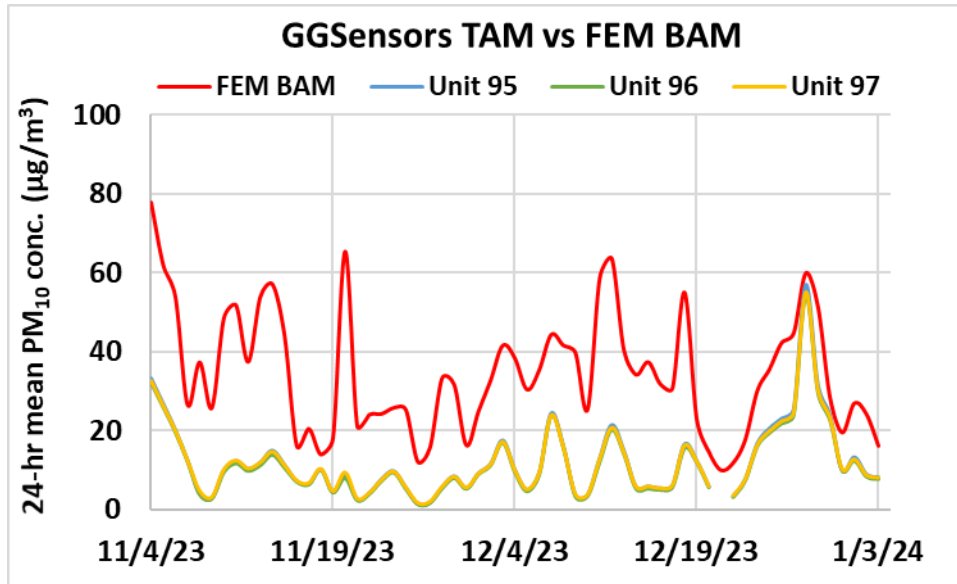
GG Sensors - TAM vs FEM BAM (PM_{2.5}; 24-hr mean)



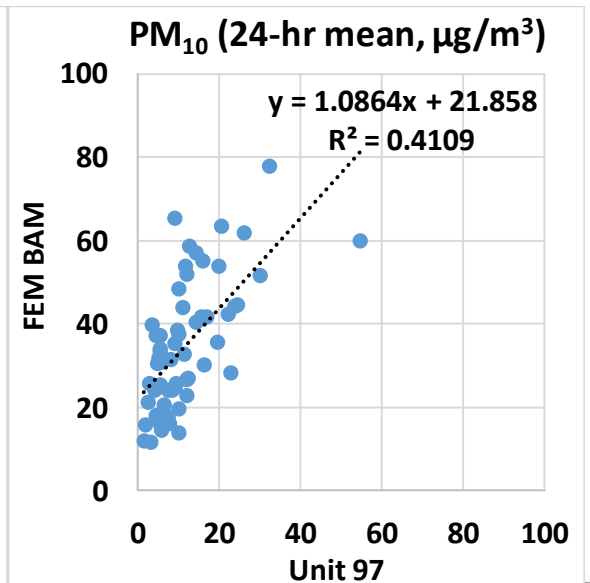
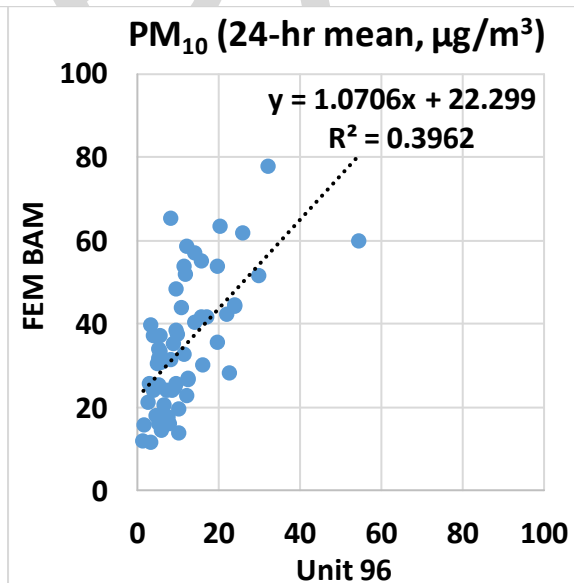
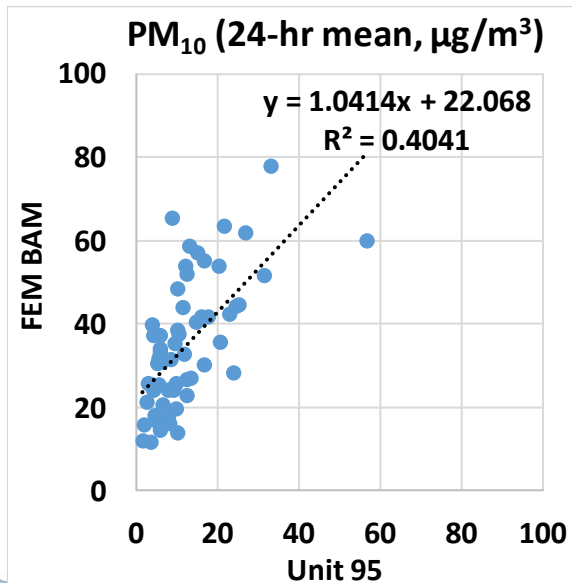
- The GG Sensors - TAM sensors showed strong correlations with the corresponding FEM BAM data ($0.89 < R^2 < 0.90$)
- Overall, the GG Sensors - TAM sensors underestimated the PM_{2.5} mass concentrations as measured by FEM BAM
- The GG Sensors - TAM sensors seemed to track the PM_{2.5} diurnal variations as recorded by FEM BAM



GGensors - TAM vs FEM BAM (PM₁₀; 24-hr mean)



- The GGensors - TAM sensors showed weak correlations with the corresponding FEM BAM data ($0.39 < R^2 < 0.42$)
- Overall, the GGensors - TAM sensors underestimated the PM₁₀ mass concentrations as measured by FEM BAM
- The GGensors - TAM sensors seemed to track the PM₁₀ diurnal variations as recorded by FEM BAM



Summary

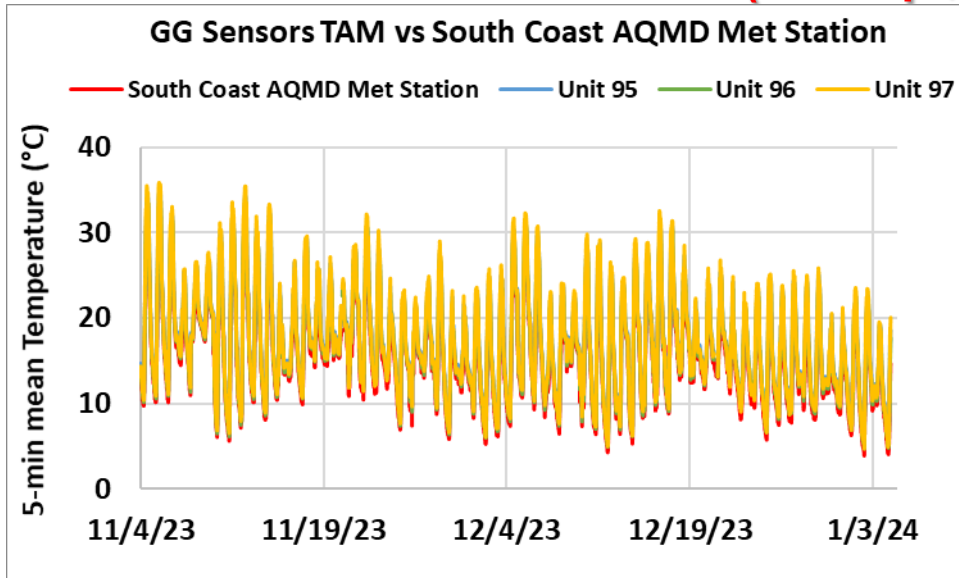
	Average of 3 Sensors, PM _{1.0}		GGSensors - TAM vs T640, PM _{1.0}						T640 (PM _{1.0} , µg/m ³)		
	Average (µg/m ³)	SD (µg/m ³)	R ²	Slope	Intercept	MBE ¹ (µg/m ³)	MAE ² (µg/m ³)	RMSE ³ (µg/m ³)	Ref. Average	Ref. SD	Range during the field evaluation
5-min	5.9	7.8	0.93	1.42 to 1.50	2.6 to 2.7	-5.5 to -5.2	5.2 to 5.5	6.9 to 7.4	11.2	11.8	0.8 to 103.5
1-hr	5.9	7.8	0.94	1.43 to 1.51	2.6	-5.5 to -5.2	5.2 to 5.5	6.9 to 7.3	11.2	11.7	0.9 to 86.6
24-hr	6.0	6.3	0.96	1.39 to 1.47	2.8 to 2.9	-5.5 to -5.2	5.2 to 5.5	6.1 to 6.5	11.3	9.1	1.2 to 50.5
	Average of 3 Sensors, PM _{2.5}		GGSensors - TAM vs FEM BAM & FEM T640, PM _{2.5}						FEM BAM & 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	8.4	9.9	0.92	1.21 to 1.26	3.5 to 3.6	-5.7 to -5.4	5.4 to 5.7	6.8 to 7.2	13.9	12.8	1.1 to 106.7
1-hr	8.4	9.8	0.80 to 0.93	0.92 to 1.27	3.4 to 3.5	-5.7 to -2.7	3.9 to 5.7	5.4 to 7.0	11.5 to 13.9	10.4 to 12.7	0 to 89.8
24-hr	8.5	8.0	0.90 to 0.96	0.87 to 1.22	3.9 to 4.0	-5.7 to -2.9	3.3 to 5.7	3.9 to 6.3	11.4 to 14.0	7.6 to 9.8	1.9 to 55.2
	Average of 3 Sensors, PM ₁₀		GGSensors - TAM vs FEM BAM & T640, PM ₁₀						FEM BAM & 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	11.8	11.8	0.56 to 0.57	1.68 to 1.73	19.1 to 19.5	-27.9 to -27.4	27.4 to 28.0	33.5 to 34.1	39.4	26.7	2.1 to 366.9
1-hr	11.8	11.6	0.40 to 0.61	1.24 to 1.75	18.9 to 19.7	-27.9 to -22.4	22.5 to 28.0	28.6 to 33.4	34.4 to 39.4	23.0 to 25.7	0 to 206.7
24-hr	12.0	9.2	0.40 to 0.61	1.04 to 1.57	21.2 to 22.3	-28.3 to -22.6	22.6 to 28.3	25.5 to 30.9	34.4 to 39.5	15.7 to 18.5	9.9 to 93.2

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).

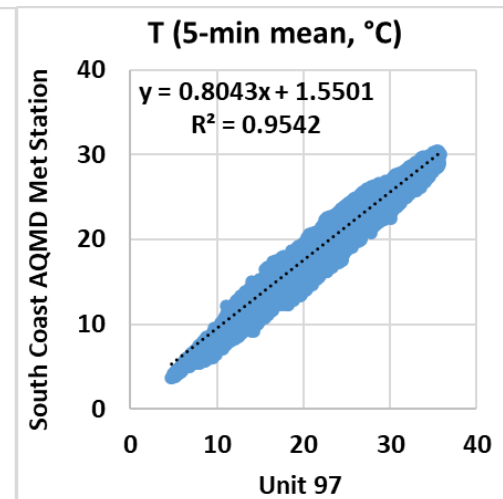
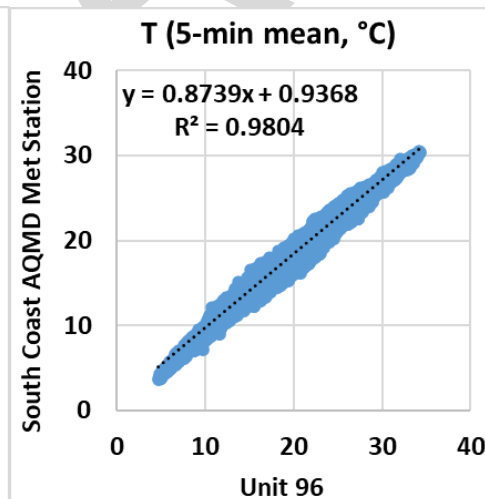
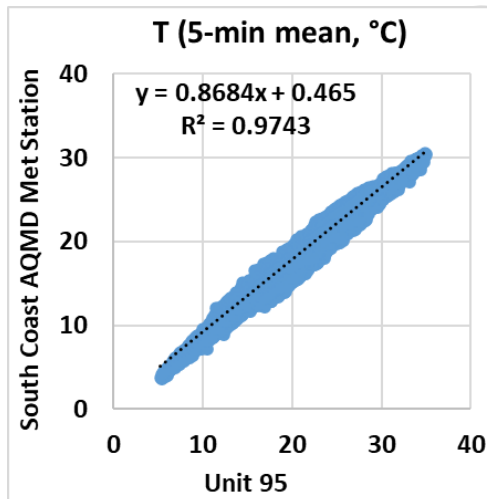
² Mean Absolute Error (MAE): the absolute difference between the sensors and the reference instruments. The larger MAE values, the higher measurement errors as compared to the reference instruments.

³ Root Mean Square Error (RMSE): another metric to calculate measurement errors.

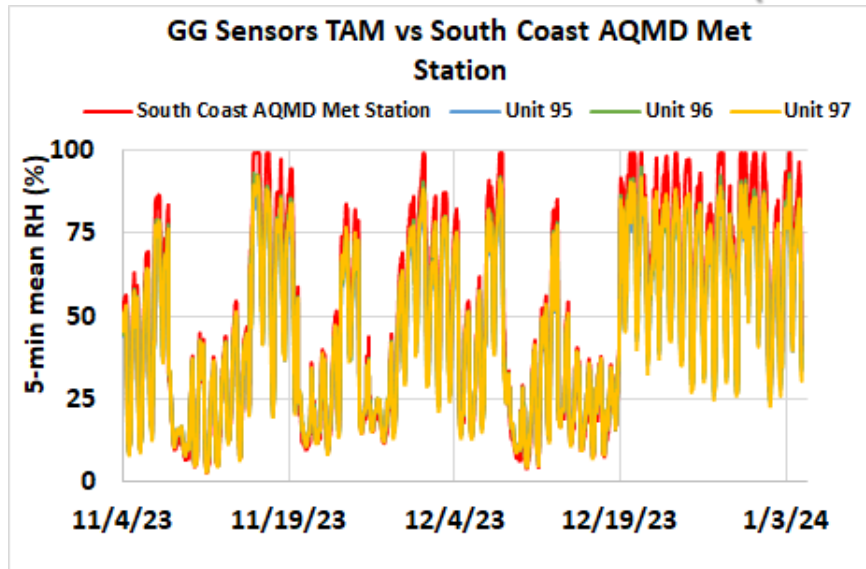
GG Sensors - TAM vs South Coast AQMD Met Station (Temp; 5-min mean)



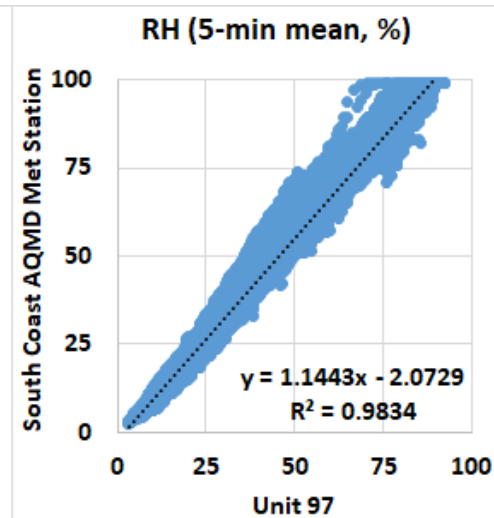
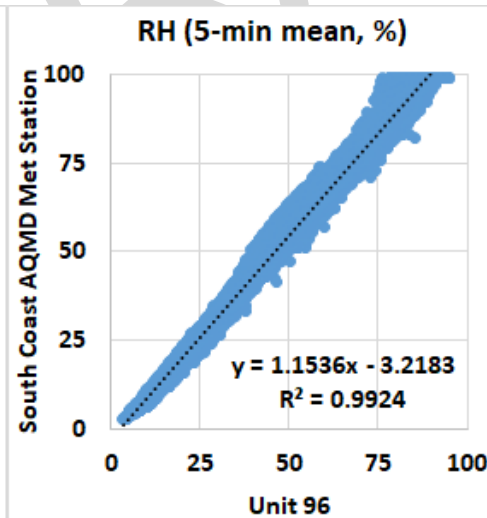
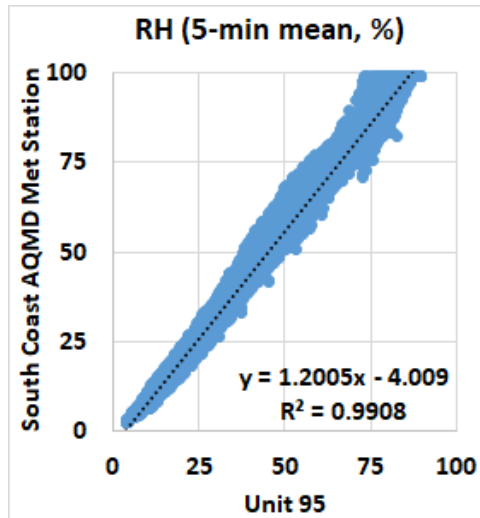
- The GGSensors - TAM sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($0.95 < R^2 < 0.99$)
- Overall, the GGSensors - TAM temperature measurements overestimated the corresponding South Coast AQMD Met Station data
- The GGSensors - TAM sensors seemed to track the temperature diurnal variations as recorded by South Coast AQMD Met Station



GG Sensors - TAM vs South Coast AQMD Met Station (RH; 5-min mean)



- The GGSensors - TAM sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($R^2 \sim 0.99$)
- Overall, the GGSensors - TAM RH measurements underestimated the corresponding South Coast AQMD Met Station data
- The GGSensors - TAM sensors seemed to track the RH diurnal variations as recorded by South Coast AQMD Met Station



Discussion

- The three **GGensors - TAM** sensors' data recovery from Unit 95, Unit 96 and Unit 97 was 99.1%, 99.2% and 99.3%, respectively, for all PM measurements
- The absolute intra-model variability was ~ 0.14 , 0.18 and $0.28 \mu\text{g}/\text{m}^3$ for $\text{PM}_{1.0}$, $\text{PM}_{2.5}$ and PM_{10} , respectively
- $\text{PM}_{1.0}$ mass concentrations measured by the GGensors - TAM sensors showed very strong correlations with the corresponding T640 data ($0.93 < R^2 < 0.95$, 1-hr mean). The sensors underestimated $\text{PM}_{1.0}$ mass concentrations as measured by T640
- $\text{PM}_{2.5}$ mass concentrations measured by the GGensors - TAM sensors showed strong to very strong correlations with the corresponding FEM BAM and FEM T640 data ($0.80 < R^2 < 0.94$, 1-hr mean). The sensors underestimated $\text{PM}_{2.5}$ mass concentrations as measured by FEM BAM and FEM T640
- PM_{10} mass concentrations measured by the GGensors - TAM sensors showed weak to moderate correlations with the corresponding FEM BAM and T640 data ($0.40 < R^2 < 0.62$; 1-hr mean). The sensors underestimated PM_{10} mass concentrations as measured by FEM BAM and T640
- 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