

Field Evaluation Sensirion SEN54



Background

- From 11/08/2023 to 12/10/2023, and then from 6/14/2024 to 7/19/2024, three **Sensirion SEN54** units 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.
- **Sensirion SEN54 (3 units tested):**
 - PM – **Optical (Sensirion SEN54, non-FEM)**
 - Each unit measures: PM_{1.0} (µg/m³), PM_{2.5} (µg/m³), PM₁₀ (µg/m³), T (°C), RH (%)
 - Also reports: PM_{4.0} (µg/m³), VOC index
 - **Unit cost: ~\$23**
 - Time resolution: 1 second
 - Units IDs: 2B7D, 1F07, and 415B
- **South Coast AQMD Reference instruments:**
 - 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
 - MetOne BAM:
 - Beta-attenuation (**FEM PM_{2.5} & PM₁₀**)
 - Measures PM_{2.5}, and PM₁₀ (µg/m³)
 - **Cost: ~\$20,000**
 - Time resolution: 1-hr
 - **Met Station (T, RH, P, WS, WD):**
 - **Cost: ~\$5,000**
 - Time resolution: 1-min



Sensirion SEN54

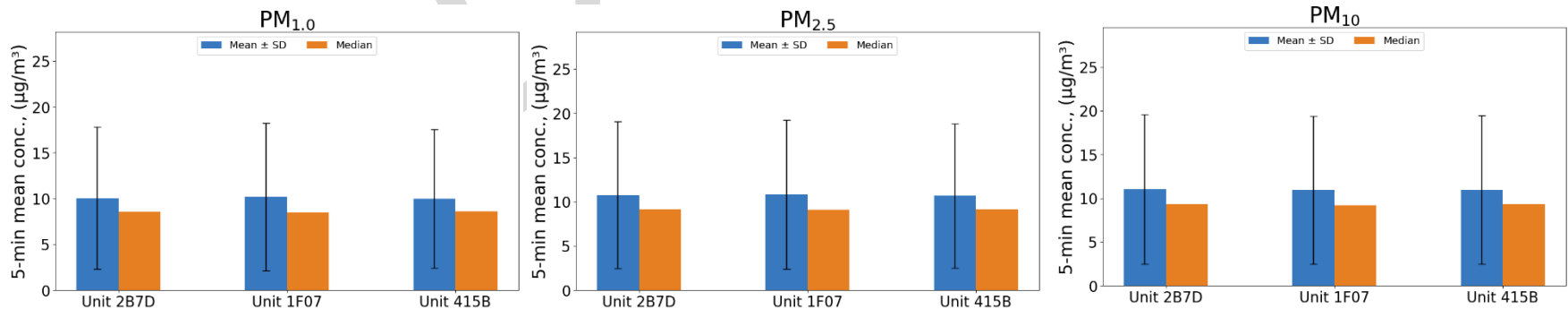


Data validation & recovery

- 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 2B7D, Unit 1F07 and Unit 415B was ~94.5% respectively for all PM measurements
- Data related to 4th of July activities were excluded from data analysis for all sensors and reference instruments

Sensirion SEN54; intra-model variability

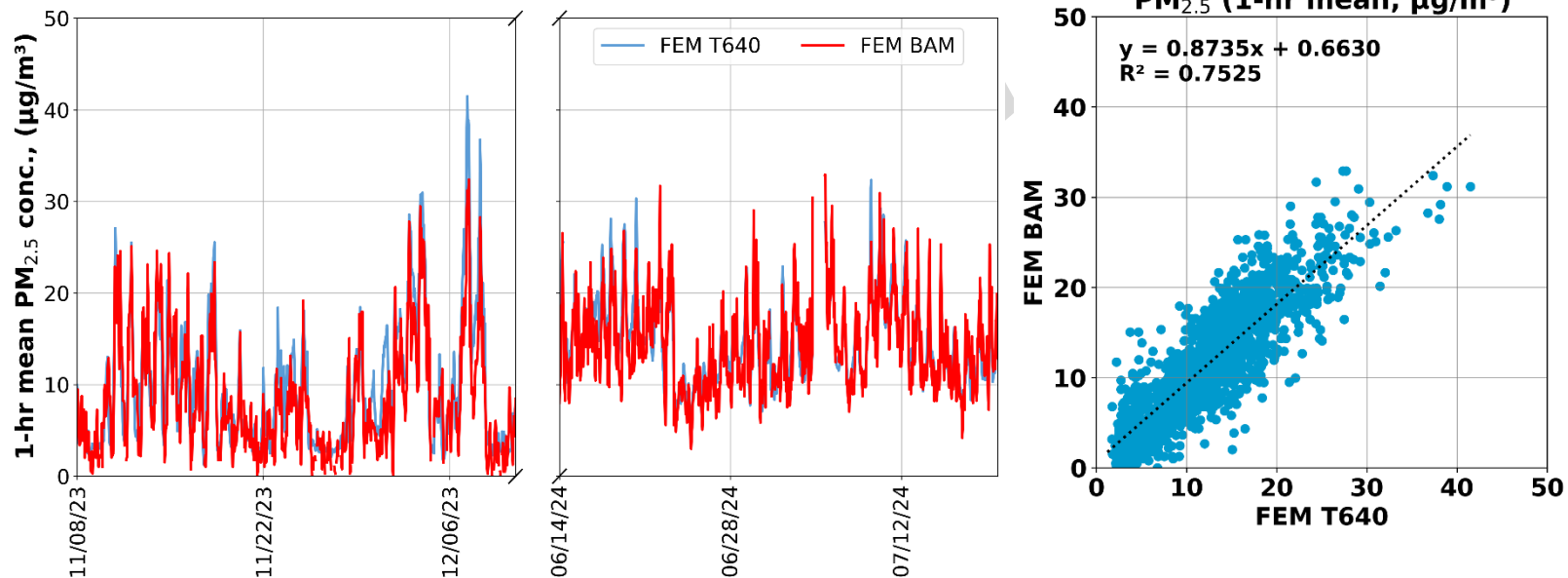
- Absolute intra-model variability was ~0.11, ~0.06 and ~0.05 $\mu\text{g}/\text{m}^3$ for $\text{PM}_{1.0}$, $\text{PM}_{2.5}$ and PM_{10} , respectively (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was ~1.09%, ~0.56% and ~0.46% for $\text{PM}_{1.0}$, $\text{PM}_{2.5}$ 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 ~ 91.1% and 99.8%, respectively.
- Strong correlations between the reference instruments for PM_{2.5} measurements ($R^2 \sim 0.75$) were observed.

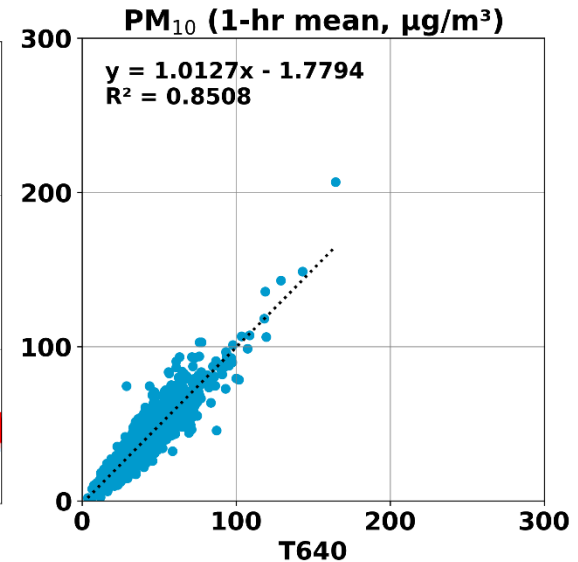
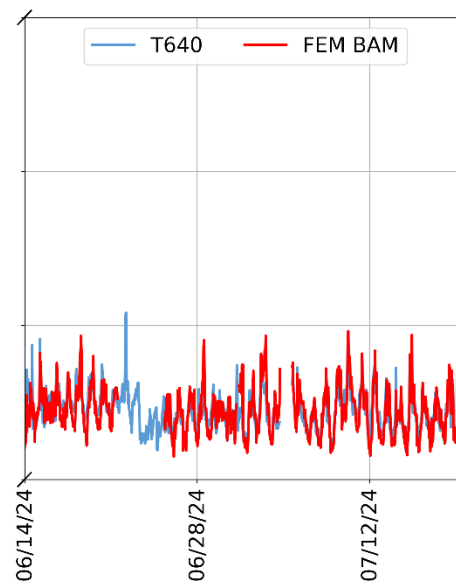
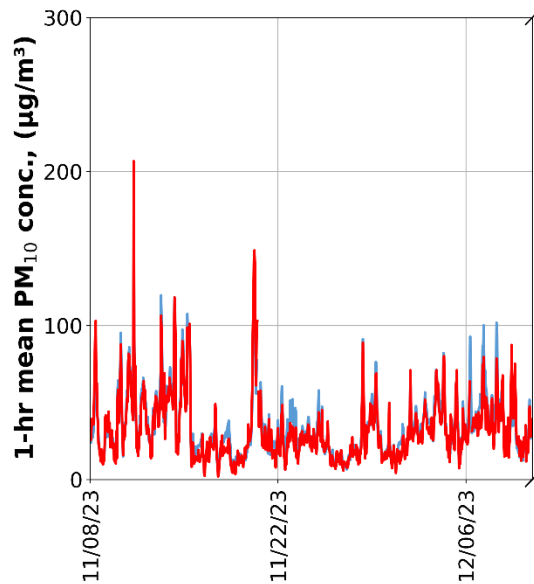
Reference Instruments



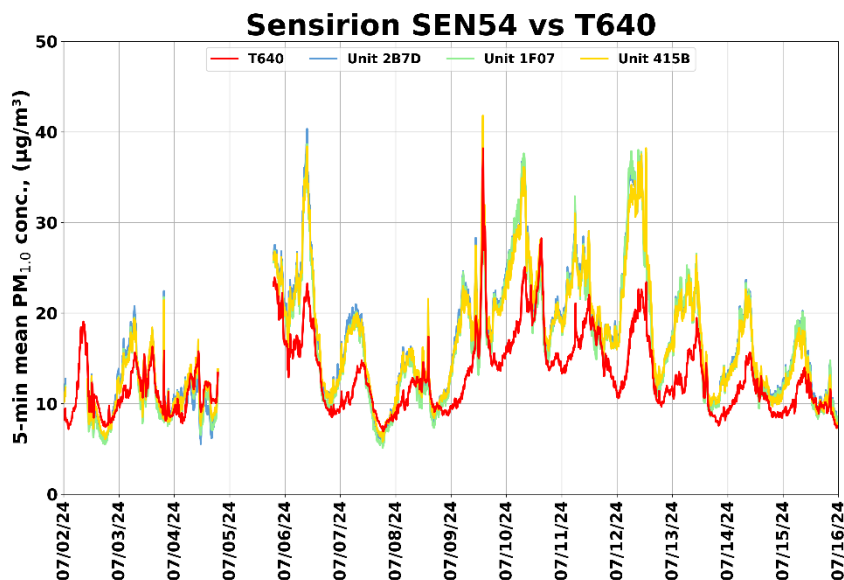
Reference Instruments: PM₁₀ FEM BAM and T640

- Data recovery for PM₁₀ from FEM BAM and T640 was ~ 93.9% and 99.7%, respectively.
- Strong correlations between the reference instruments for PM₁₀ measurements ($R^2 \sim 0.85$) were observed.

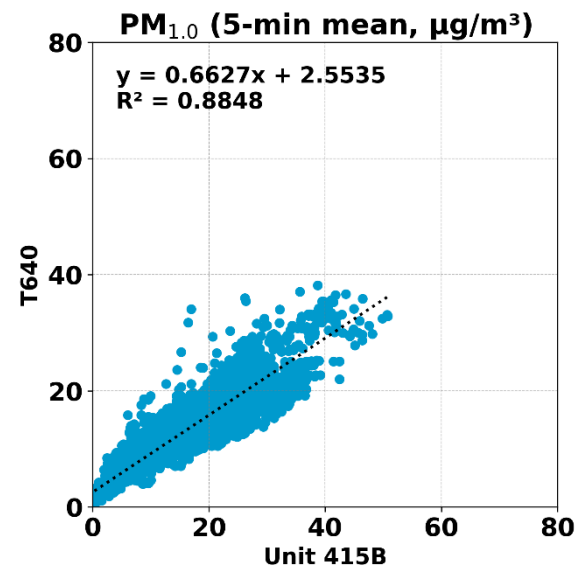
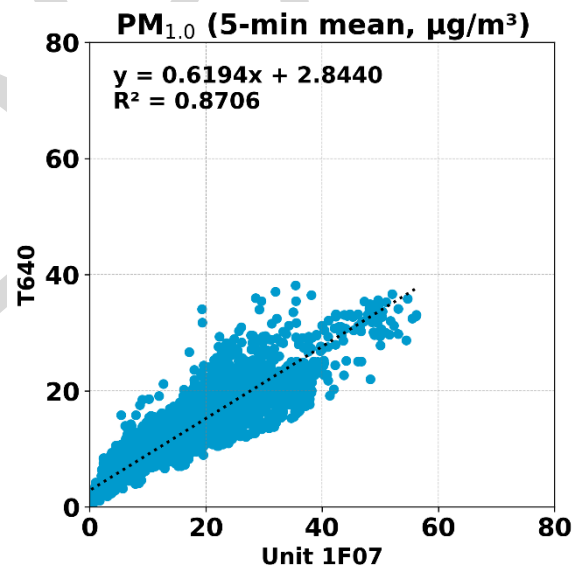
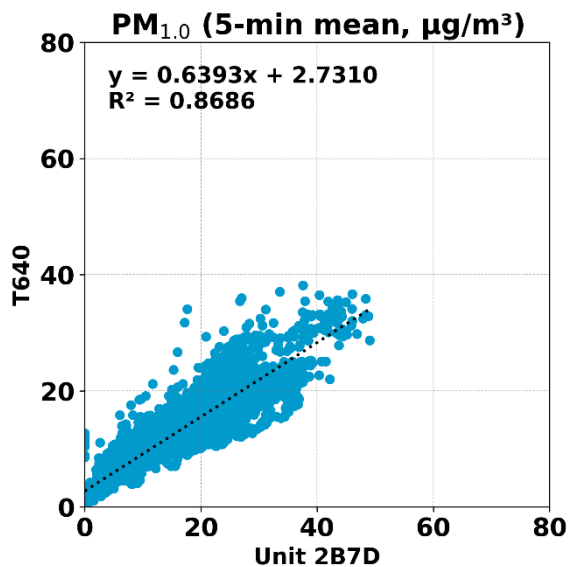
Reference Instruments



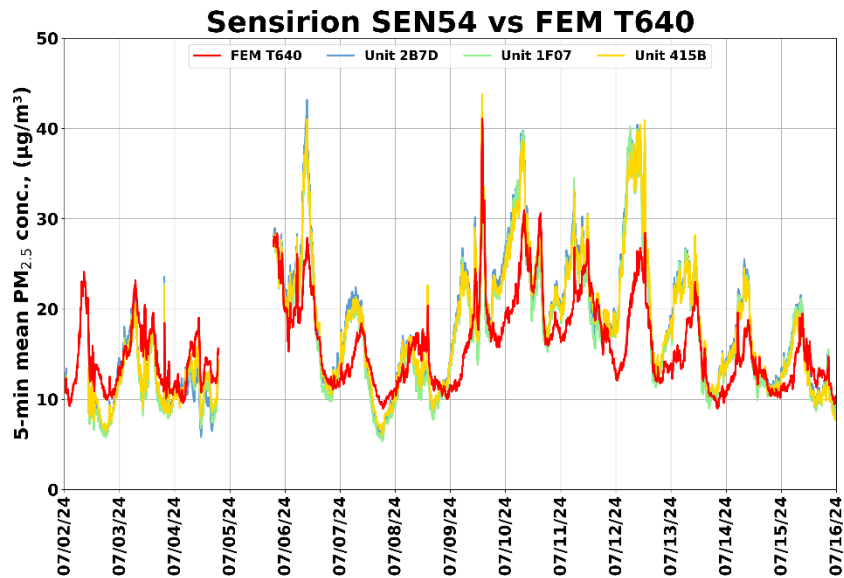
Sensirion SEN54 vs T640 (PM_{1.0}; 5-min mean)



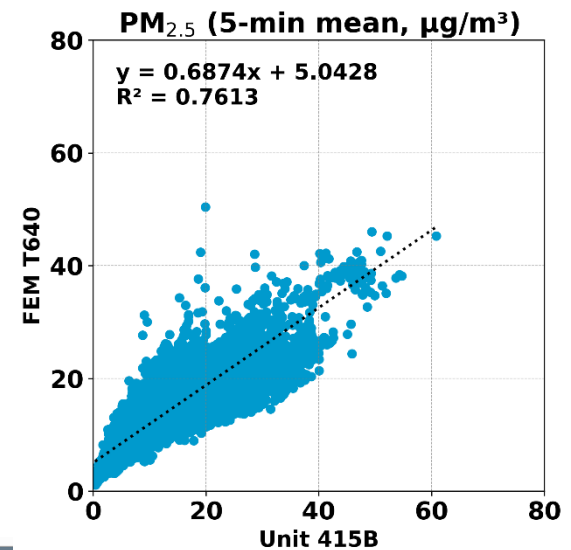
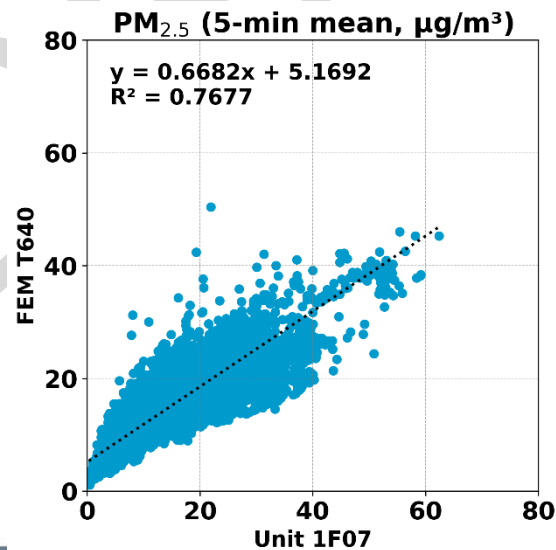
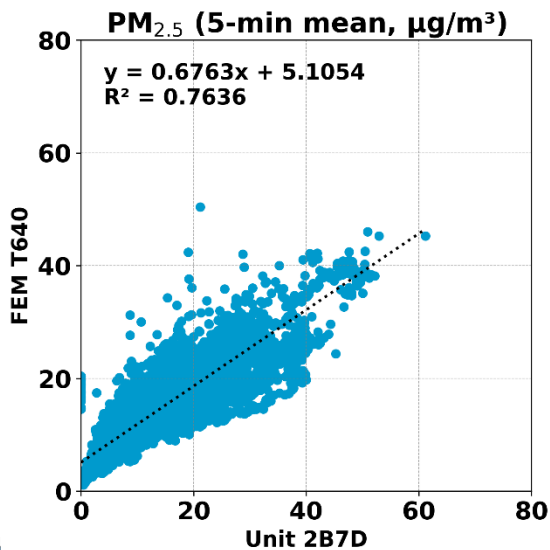
- The Sensirion SEN54 sensors showed strong correlations with the corresponding T640 data ($0.86 < R^2 < 0.89$)
- Overall, the Sensirion SEN54 sensors overestimated the PM_{1.0} mass concentrations as measured by T640
- The Sensirion SEN54 sensors seemed to track the PM_{1.0} diurnal variations as recorded by T640



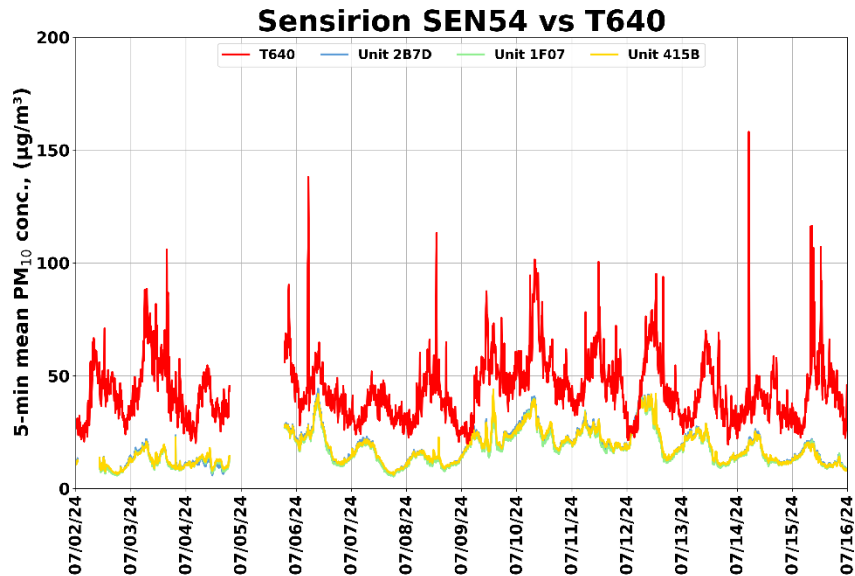
Sensirion SEN54 vs FEM T640 (PM_{2.5}; 5-min mean)



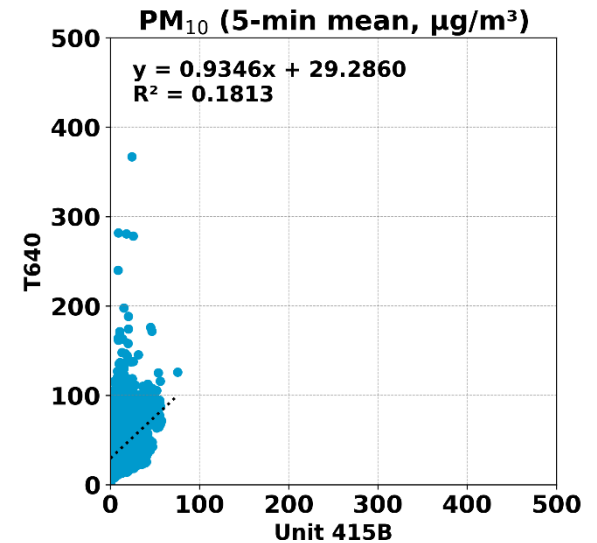
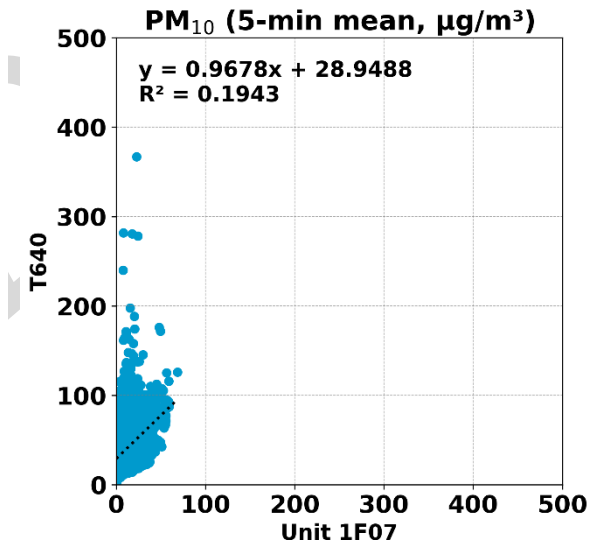
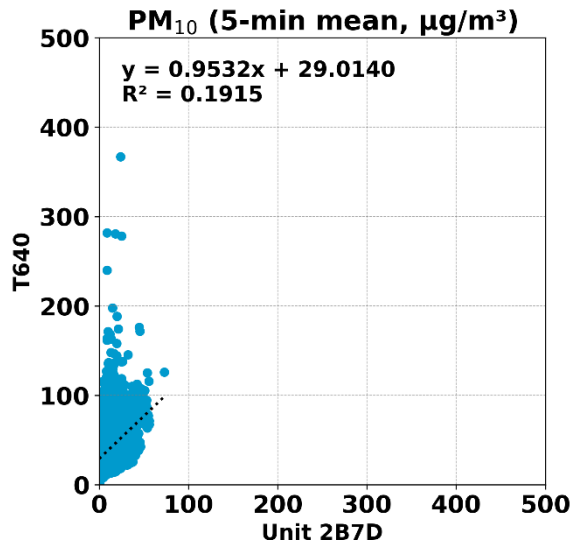
- The Sensirion SEN54 sensors showed strong correlations with the corresponding FEM T640 data ($0.76 < R^2 < 0.77$)
- Overall, the Sensirion SEN54 sensors underestimated the PM_{2.5} mass concentrations as measured by FEM T640
- The Sensirion SEN54 sensors seemed to track the PM_{2.5} diurnal variations as recorded by FEM T640



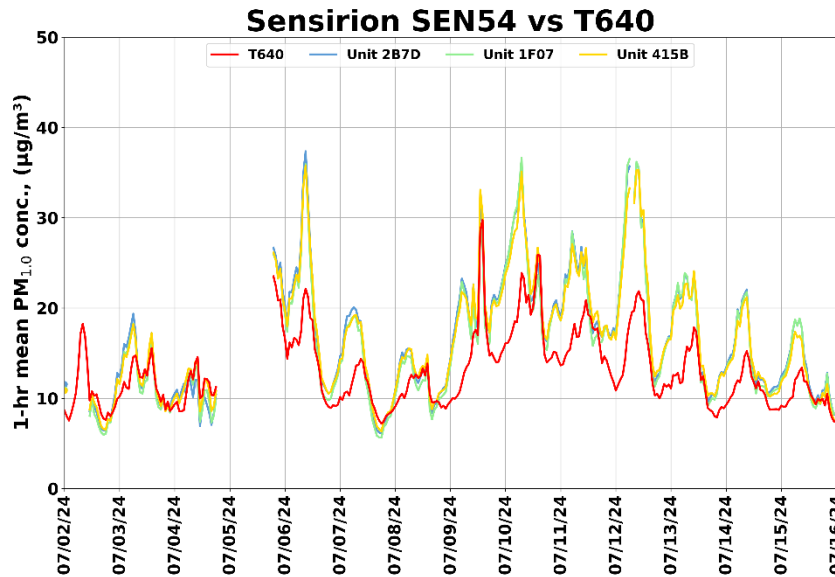
Sensirion SEN54 vs T640 (PM₁₀; 5-min mean)



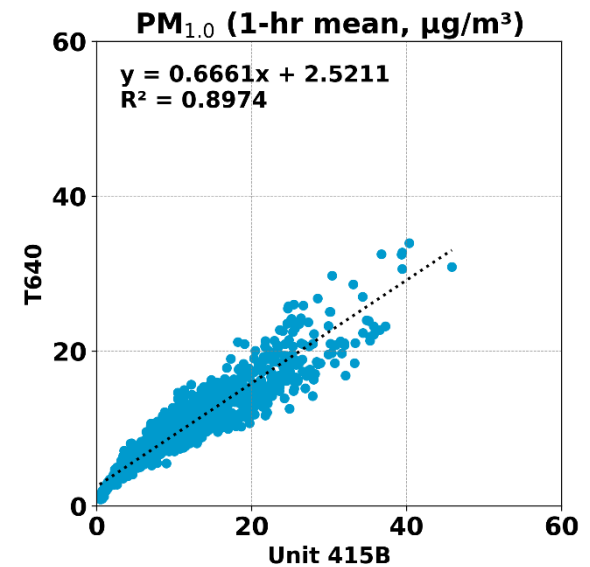
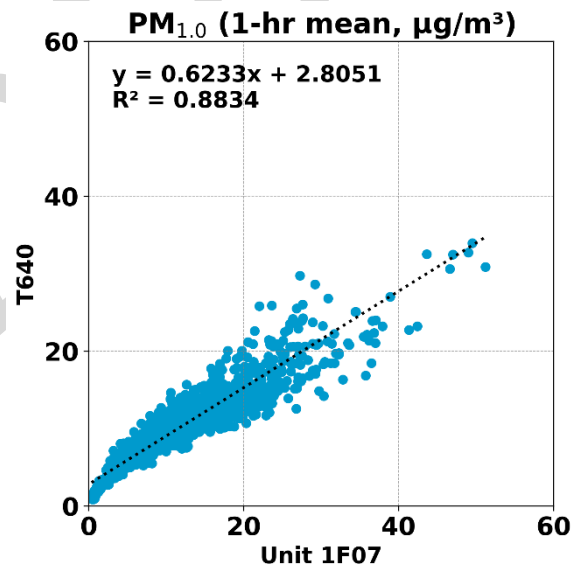
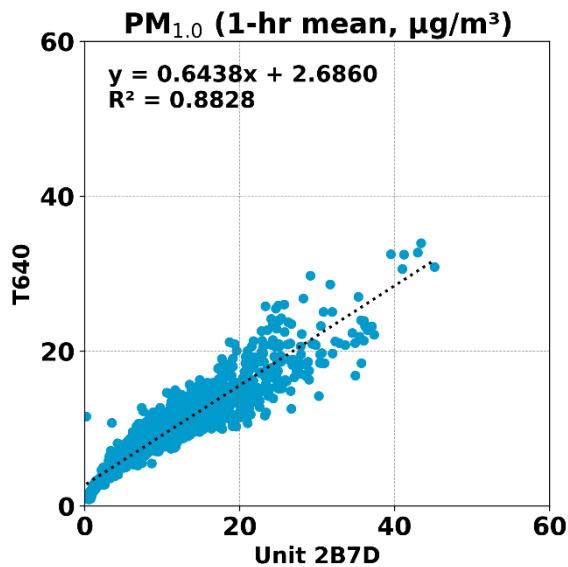
- The Sensirion SEN54 sensors showed very weak correlations with the corresponding T640 data ($0.18 < R^2 < 0.20$)
- Overall, the Sensirion SEN54 sensors underestimated the PM₁₀ mass concentrations as measured by T640
- The Sensirion SEN54 sensors did not seem to track the PM₁₀ diurnal variations as recorded by T640



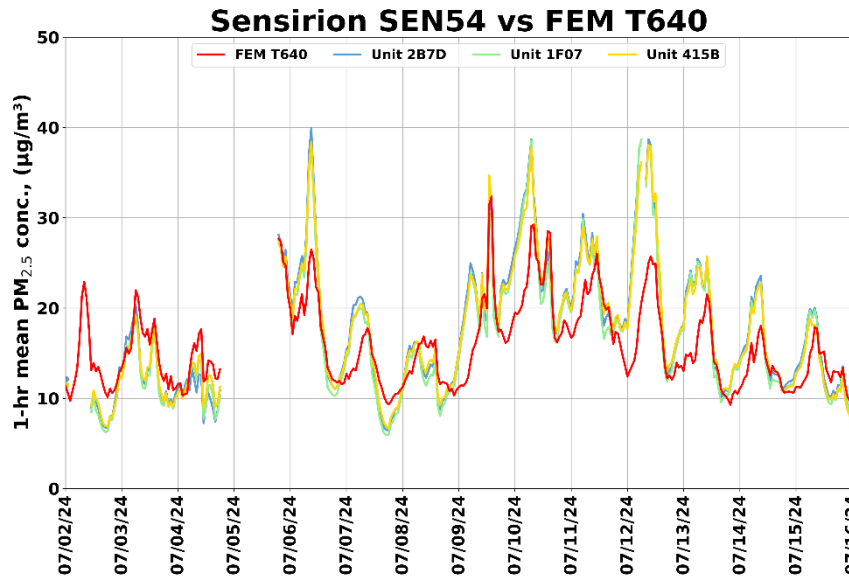
Sensirion SEN54 vs T640 (PM_{1.0}; 1-hr mean)



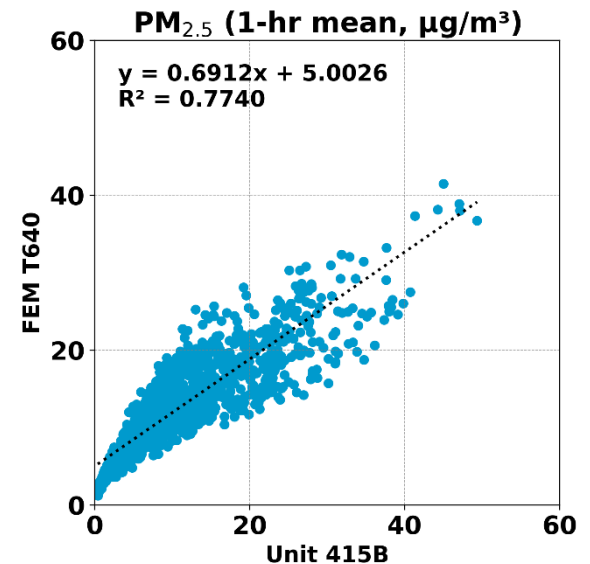
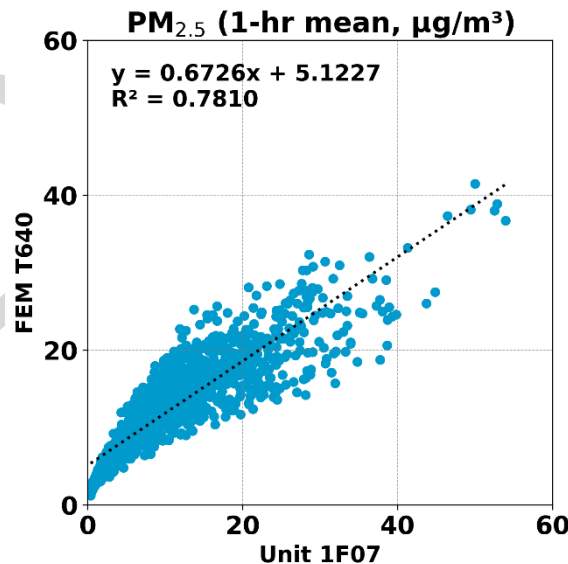
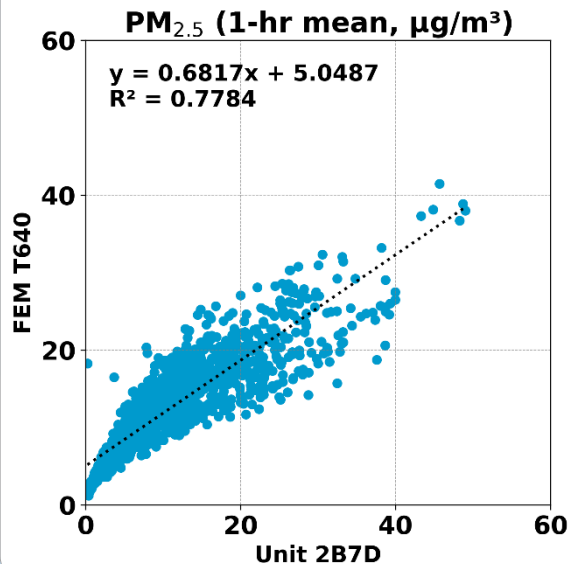
- The Sensirion SEN54 sensors showed strong correlations with the corresponding T640 data ($0.88 < R^2 < 0.90$)
- Overall, the Sensirion SEN54 sensors overestimated the PM_{1.0} mass concentrations as measured by T640
- The Sensirion SEN54 sensors seemed to track the PM_{1.0} diurnal variations as recorded by T640



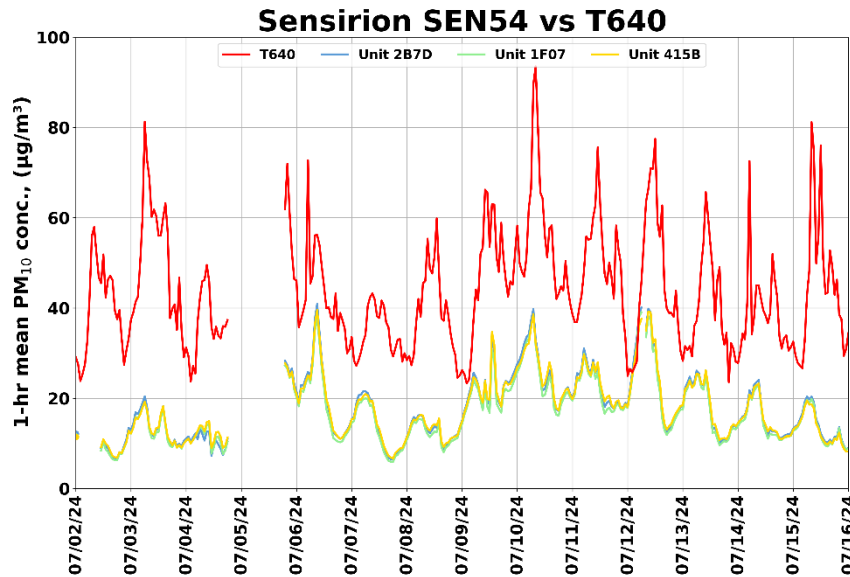
Sensirion SEN54 vs FEM T640 (PM_{2.5}; 1-hr mean)



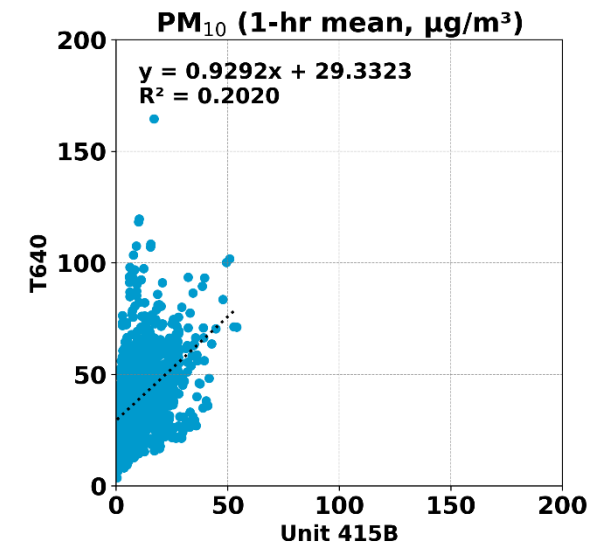
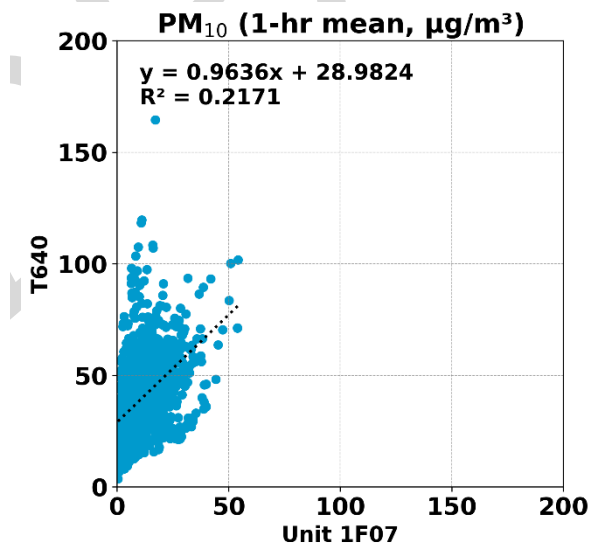
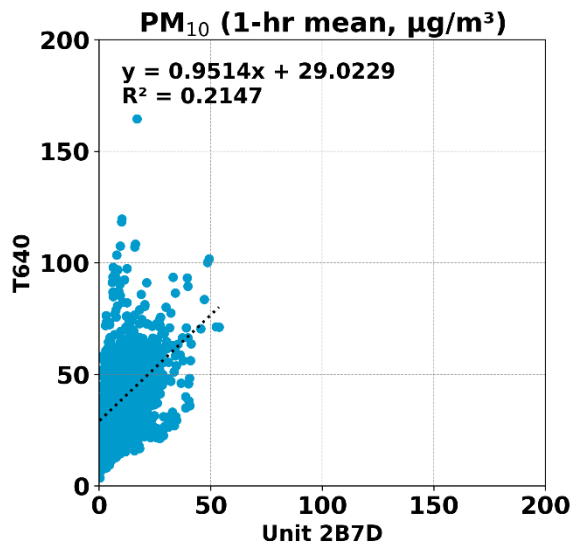
- The Sensirion SEN54 sensors showed strong correlations with the corresponding FEM T640 data ($0.77 < R^2 < 0.79$)
- Overall, the Sensirion SEN54 sensors underestimated the PM_{2.5} mass concentrations as measured by FEM T640
- The Sensirion SEN54 sensors seemed to track the PM_{2.5} diurnal variations as recorded by FEM T640



Sensirion SEN54 vs T640 (PM₁₀; 1-hr mean)

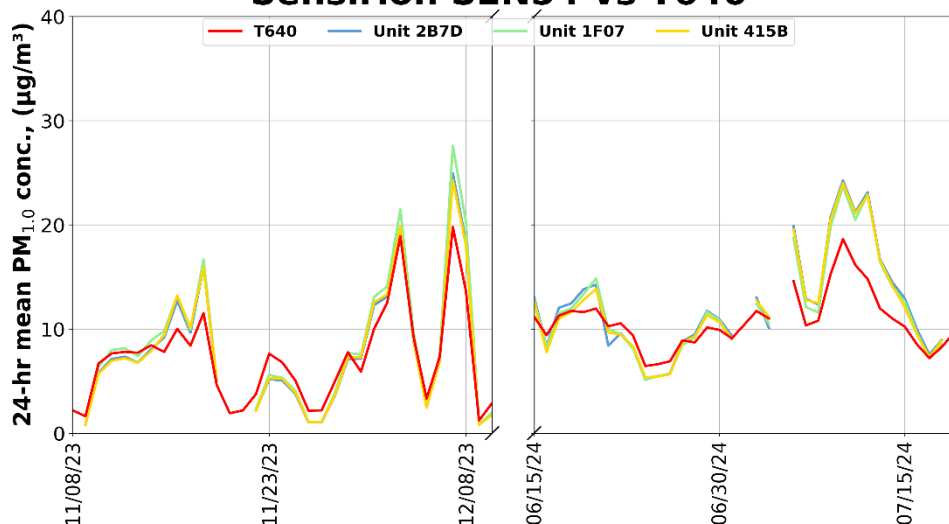


- The Sensirion SEN54 sensors showed very weak correlations with the corresponding T640 data ($0.20 < R^2 < 0.22$)
- Overall, the Sensirion SEN54 sensors underestimated the PM₁₀ mass concentrations as measured by T640
- The Sensirion SEN54 sensors did not seem to track the PM₁₀ diurnal variations as recorded by T640

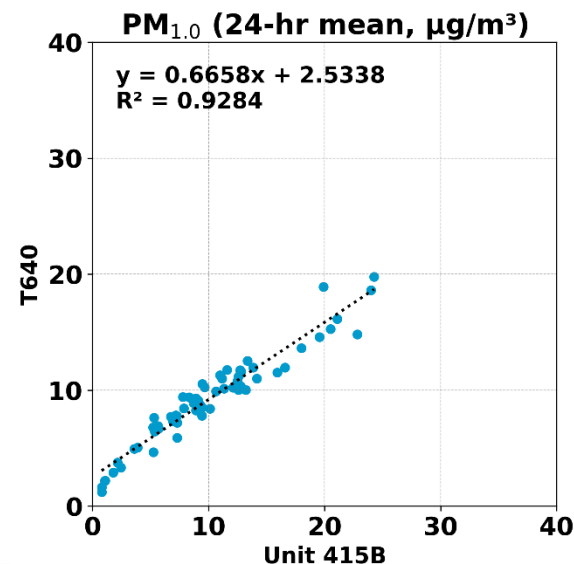
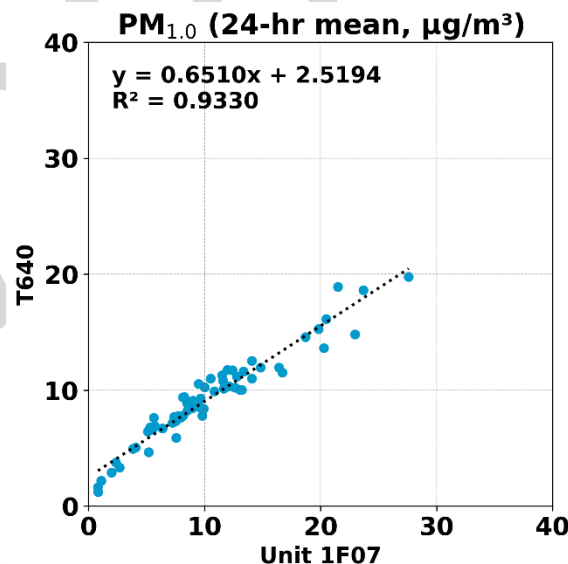
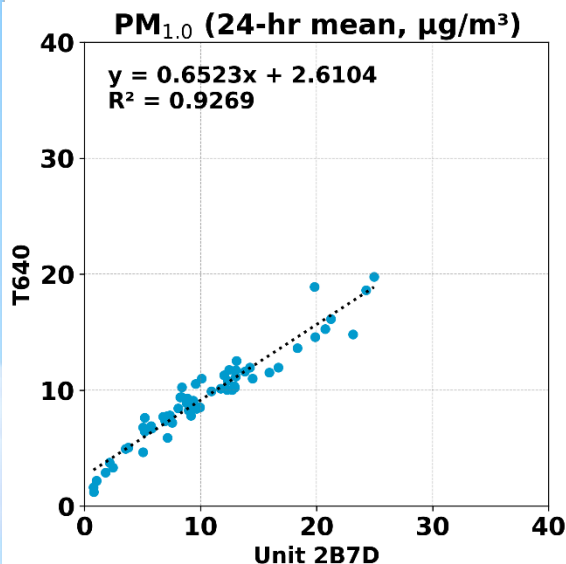


Sensirion SEN54 vs T640 (PM_{1.0}; 24-hr mean)

Sensirion SEN54 vs T640

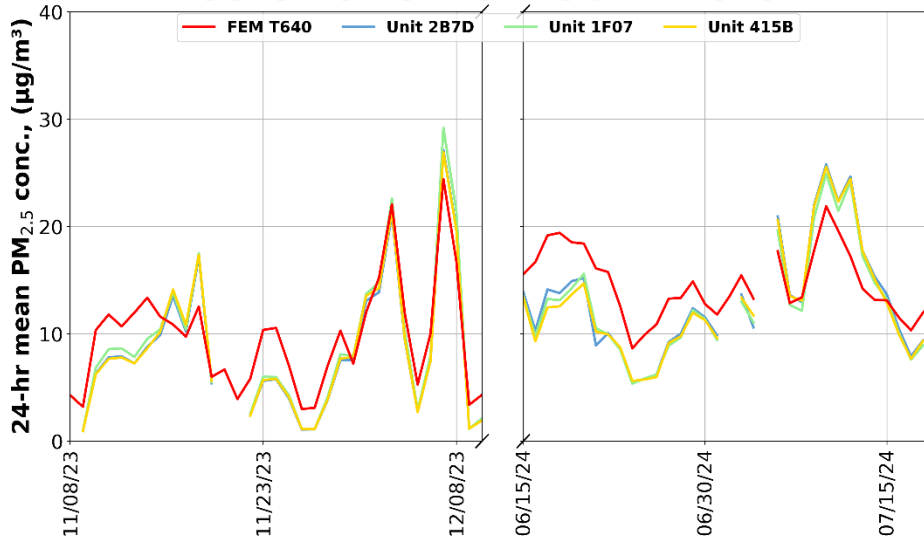


- The Sensirion SEN54 sensors showed very strong correlations with the corresponding T640 data ($0.92 < R^2 < 0.94$)
- Overall, the Sensirion SEN54 sensors overestimated the PM_{1.0} mass concentrations as measured by T640
- The Sensirion SEN54 sensors seemed to track the PM_{1.0} daily variations as recorded by T640

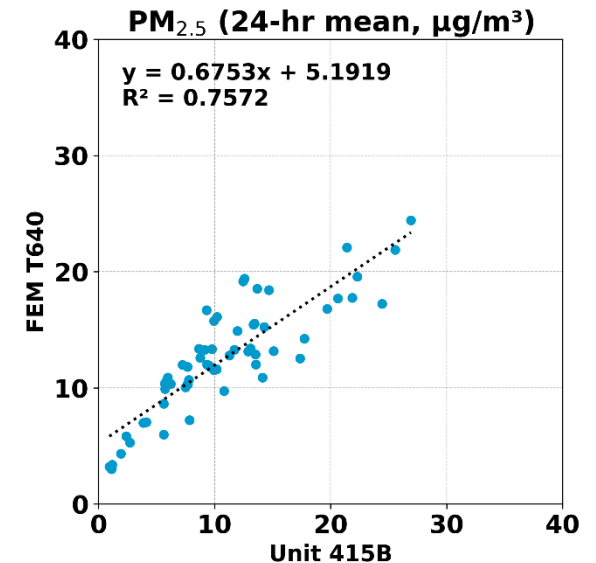
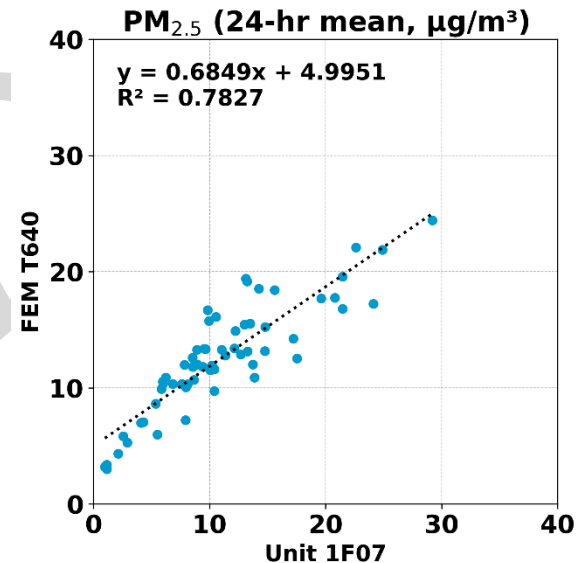
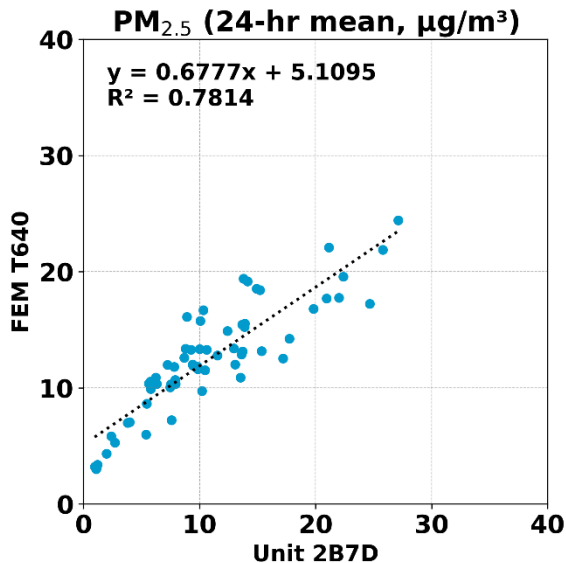


Sensirion SEN54 vs FEM T640 (PM_{2.5}; 24-hr mean)

Sensirion SEN54 vs FEM T640

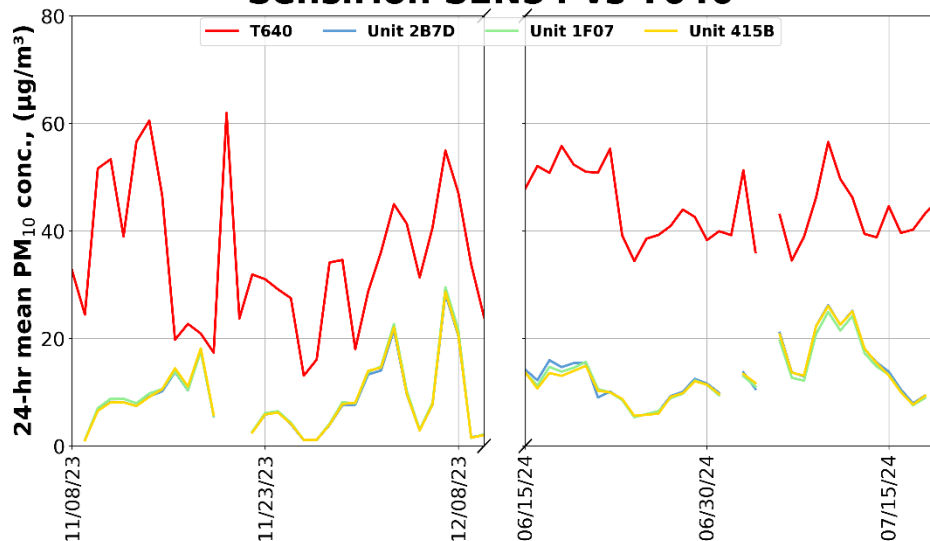


- The Sensirion SEN54 sensors showed strong correlations with the corresponding FEM T640 data ($0.75 < R^2 < 0.79$)
- Overall, the Sensirion SEN54 sensors underestimated the PM_{2.5} mass concentrations as measured by FEM T640
- The Sensirion SEN54 sensors seemed to track the PM_{2.5} daily variations as recorded by FEM T640

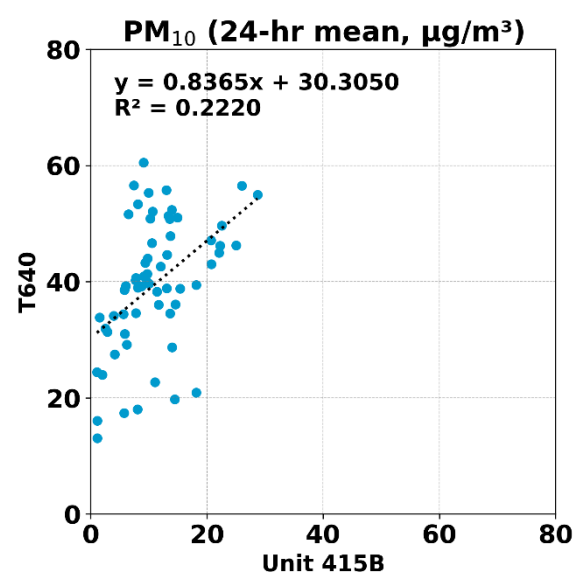
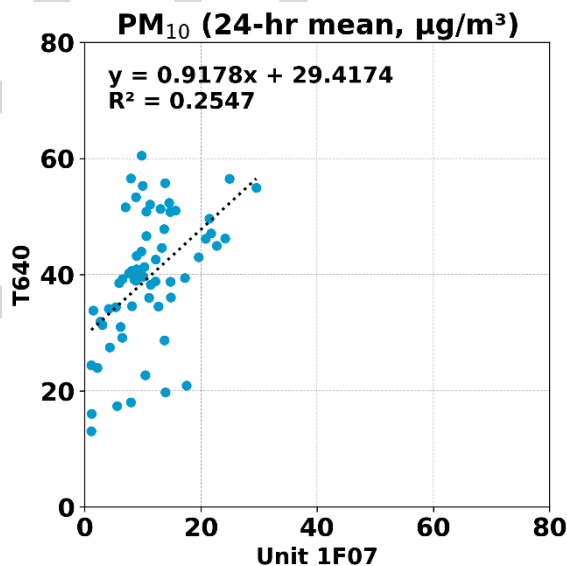
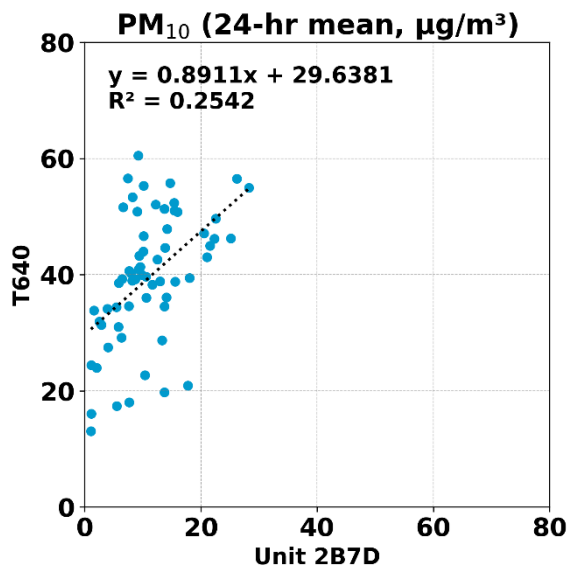


Sensirion SEN54 vs T640 (PM₁₀; 24-hr mean)

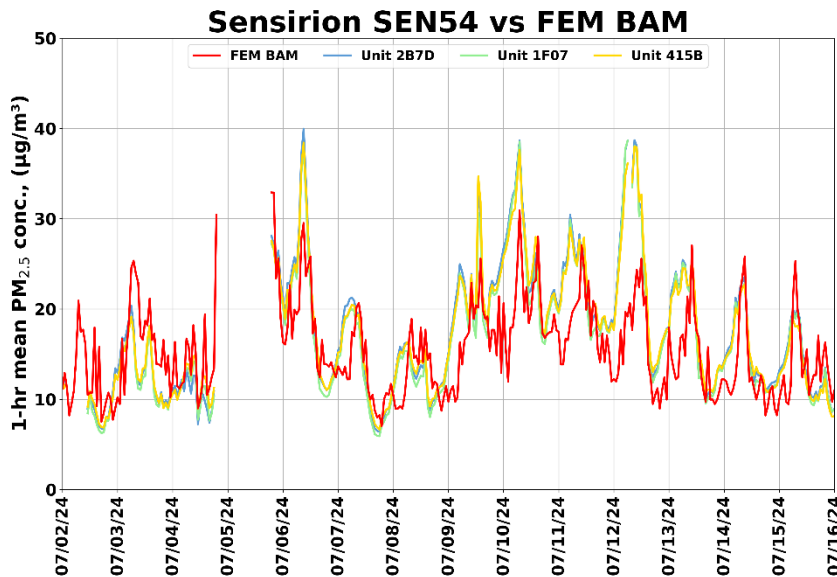
Sensirion SEN54 vs T640



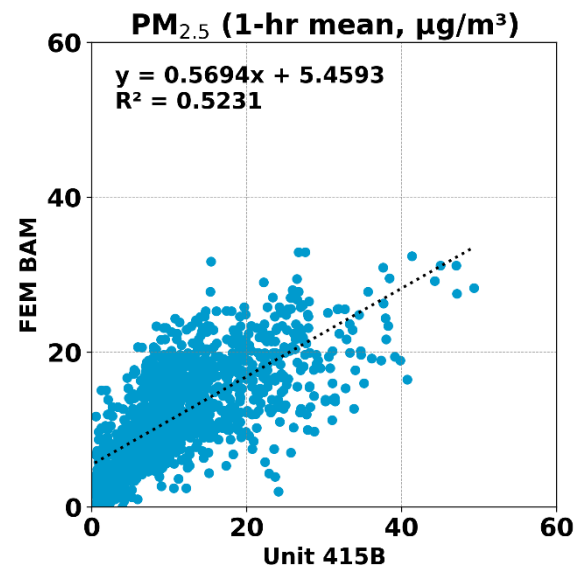
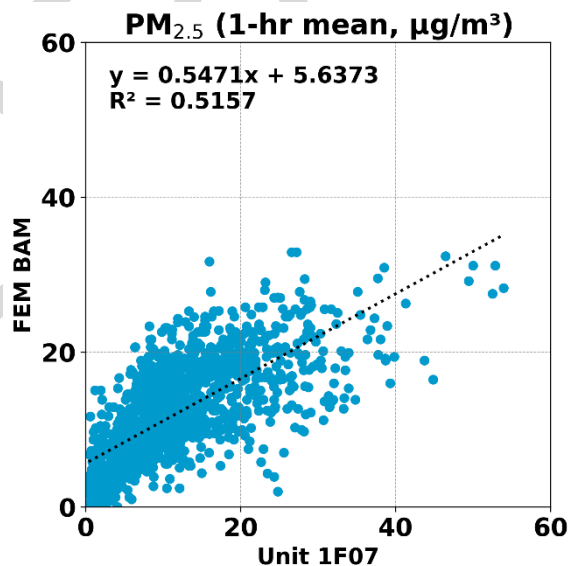
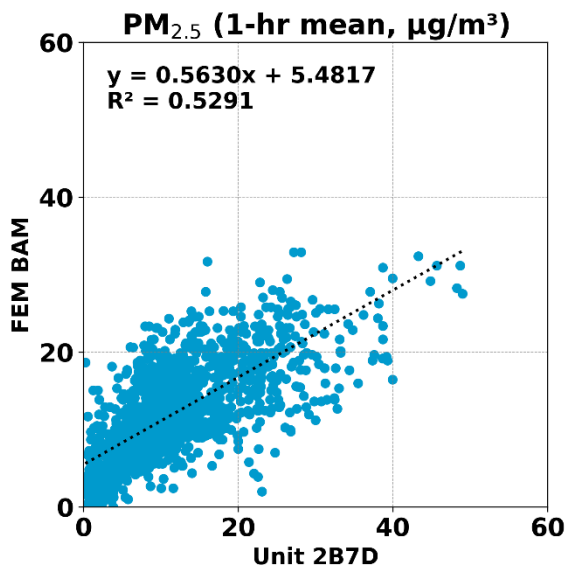
- The Sensirion SEN54 sensors showed very weak correlations with the corresponding T640 data ($0.22 < R^2 < 0.26$)
- Overall, the Sensirion SEN54 sensors underestimated the PM₁₀ mass concentrations as measured by T640
- The Sensirion SEN54 sensors did not seem to track the PM₁₀ daily variations as recorded by T640



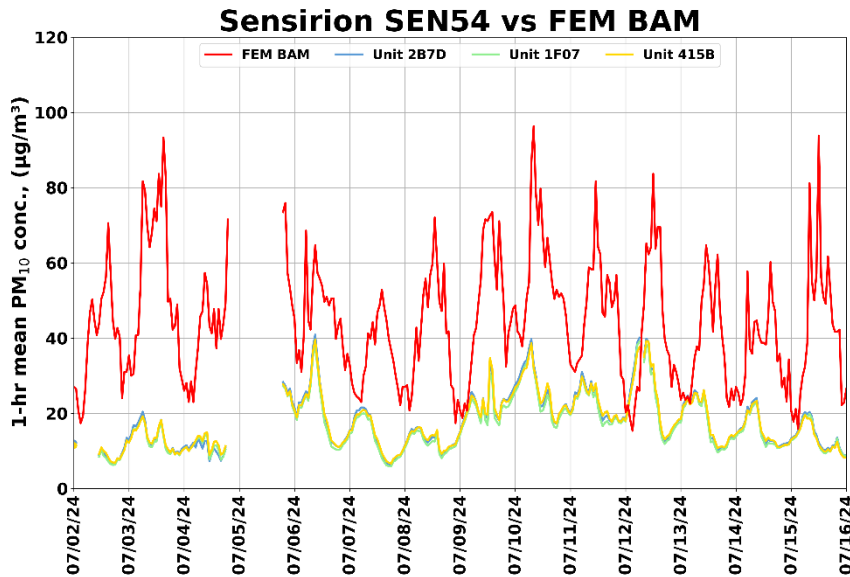
Sensirion SEN54 vs FEM BAM (PM_{2.5}; 1-hr mean)



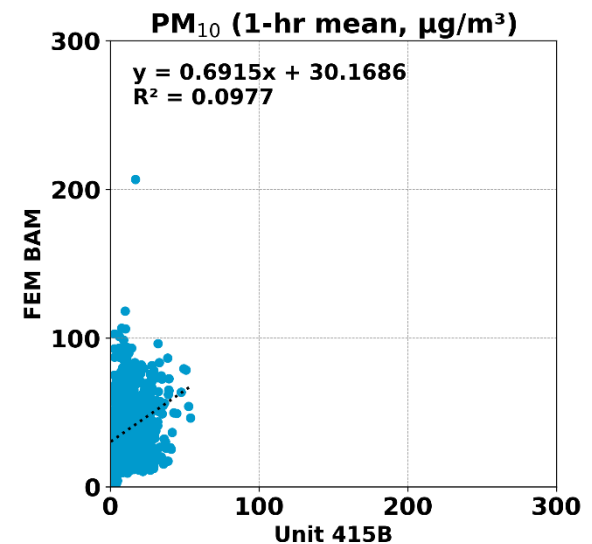
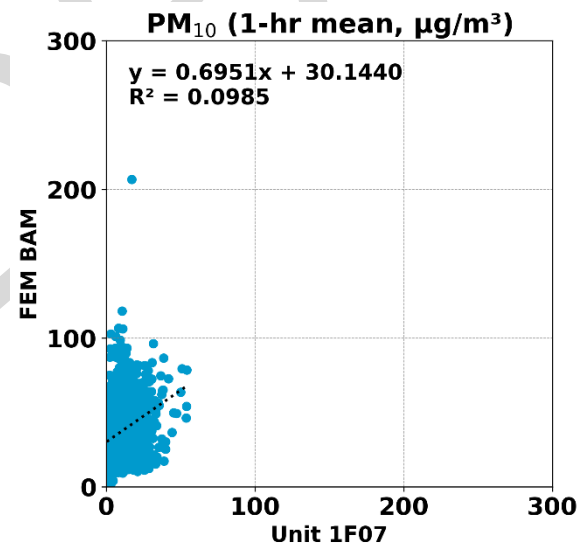
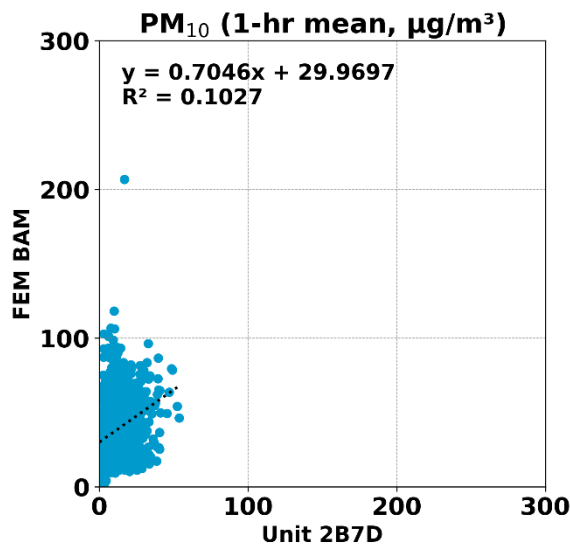
- The Sensirion SEN54 sensors showed moderate correlations with the corresponding FEM BAM data ($0.51 < R^2 < 0.53$)
- Overall, the Sensirion SEN54 sensors underestimated the PM_{2.5} mass concentrations as measured by FEM BAM
- The Sensirion SEN54 sensors seemed to track the PM_{2.5} diurnal variations as recorded by FEM BAM



Sensirion SEN54 vs FEM BAM (PM₁₀; 1-hr mean)

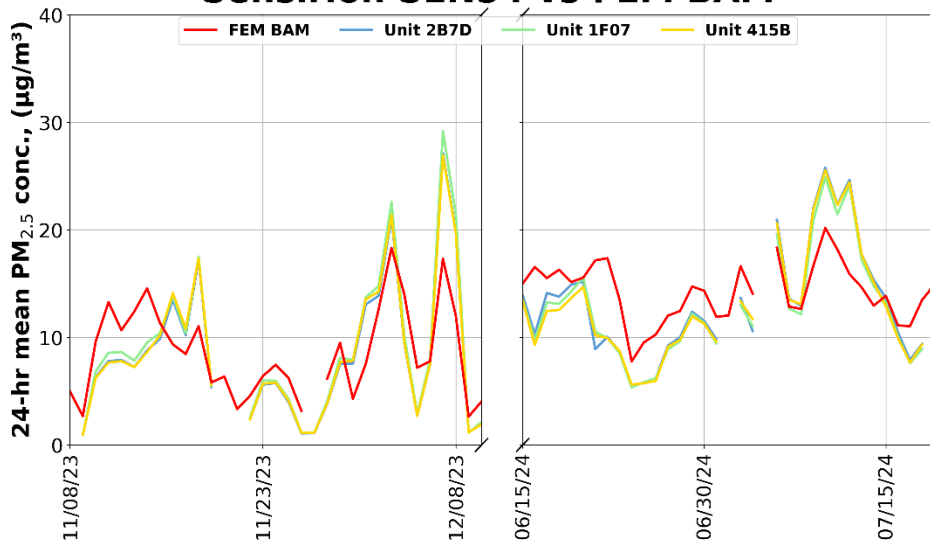


- The Sensirion SEN54 sensors showed no to very weak correlations with the corresponding FEM BAM data ($0.09 < R^2 < 0.11$)
- Overall, the Sensirion SEN54 sensors underestimated the PM₁₀ mass concentrations as measured by FEM BAM
- The Sensirion SEN54 sensors did not seem to track the PM₁₀ diurnal variations as recorded by FEM BAM

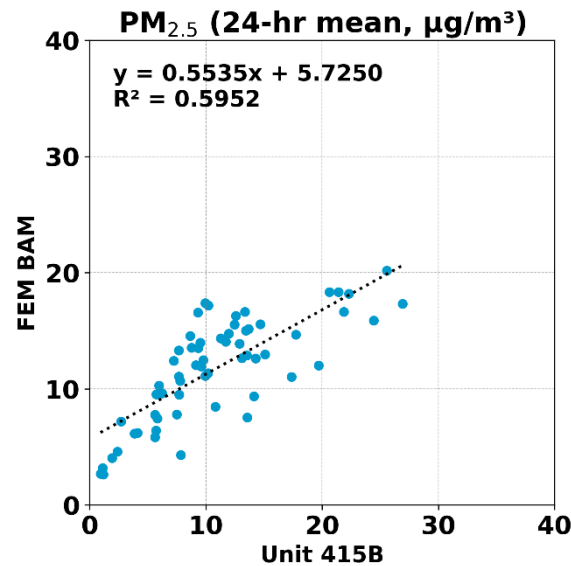
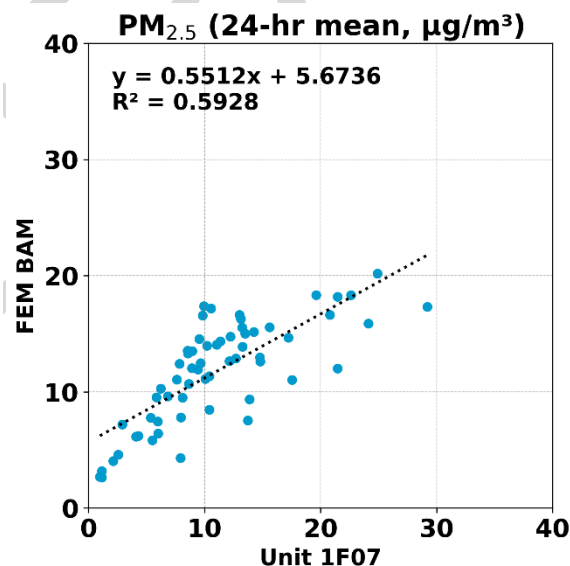
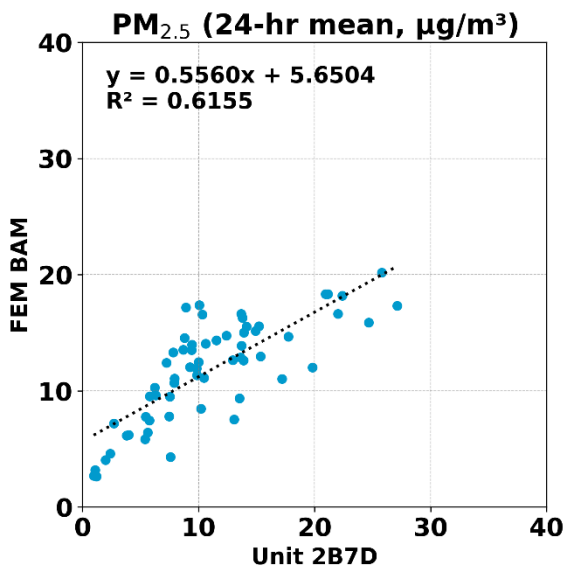


Sensirion SEN54 vs FEM BAM (PM_{2.5}; 24-hr mean)

Sensirion SEN54 vs FEM BAM

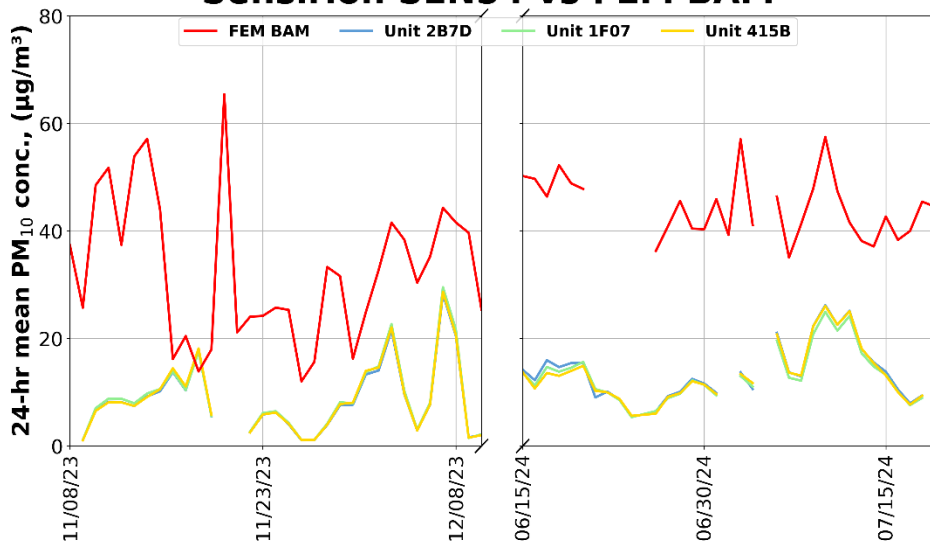


- The Sensirion SEN54 sensors showed moderate correlations with the corresponding FEM BAM data ($0.59 < R^2 < 0.62$)
- Overall, the Sensirion SEN54 sensors underestimated the PM_{2.5} mass concentrations as measured by FEM BAM
- The Sensirion SEN54 sensors seemed to track the PM_{2.5} diurnal variations as recorded by FEM BAM

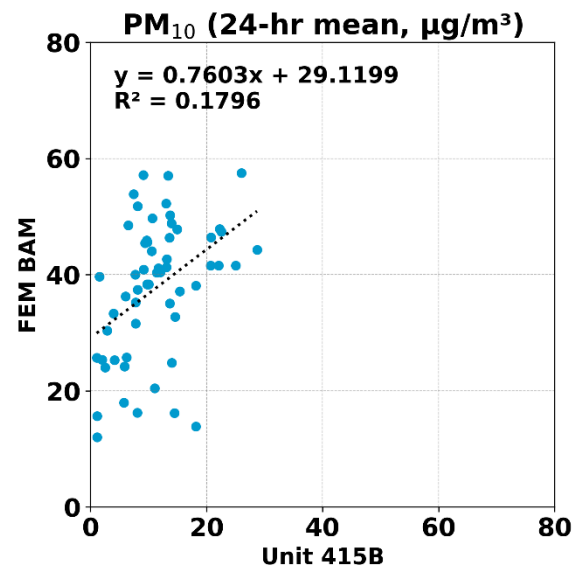
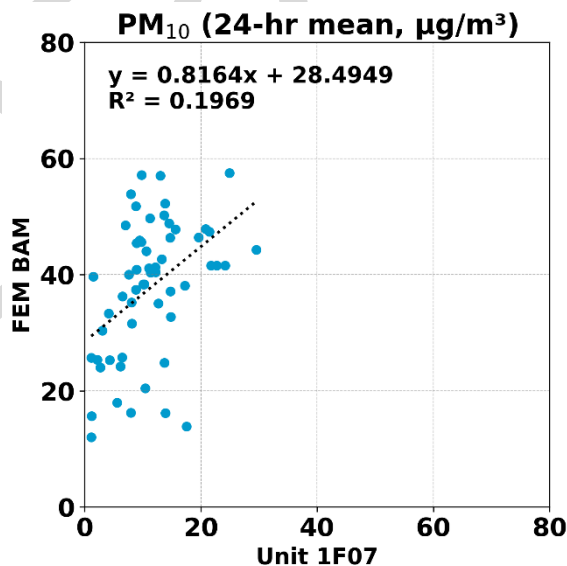
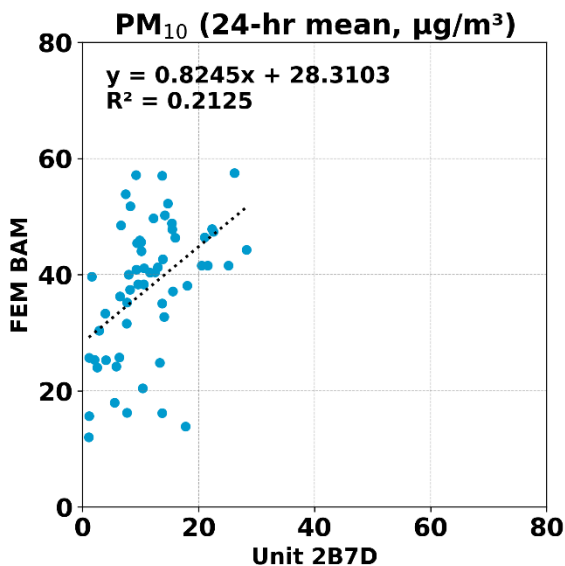


Sensirion SEN54 vs FEM BAM (PM₁₀; 24-hr mean)

Sensirion SEN54 vs FEM BAM



- The Sensirion SEN54 sensors showed very weak correlations with the corresponding FEM BAM data ($0.17 < R^2 < 0.22$)
- Overall, the Sensirion SEN54 sensors underestimated the PM₁₀ mass concentrations as measured by FEM BAM
- The Sensirion SEN54 sensors did not seem to track the PM₁₀ diurnal variations as recorded by FEM BAM



Summary: PM

	Average of 3 Sensors, PM _{1.0}		Sensirion SEN54 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	10.1	7.8	0.87 to 0.88	0.62 to 0.66	2.6 to 2.8	0.8 to 1.0	2.1 to 2.4	3.2 to 3.8	9.0	5.4	0.8 to 38.2
1-hr	10.1	7.7	0.88 to 0.90	0.62 to 0.67	2.5 to 2.8	0.8 to 1.0	2 to 2.3	3.1 to 3.6	9.0	5.3	0.9 to 33.9
24-hr	10.2	5.9	0.93	0.65 to 0.67	2.5 to 2.6	0.8 to 1.1	1.7 to 1.8	2.4 to 2.5	9.0	4.1	1.2 to 19.8
	Average of 3 Sensors, PM _{2.5}		Sensirion SEN54 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	10.8	8.3	0.76 to 0.77	0.67 to 0.69	5.0 to 5.2	-1.7 to -1.6	3.52 to 3.54	4.4 to 4.5	12.2	6.5	1.1 to 50.4
1-hr	10.7	8.2	0.52 to 0.78	0.55 to 0.69	5.0 to 5.6	-1.7 to -0.6	3.5 to 4.2	4.3 to 5.8	11.6 to 12.2	6.3 to 6.4	0 to 41.5
24-hr	10.9	6.3	0.59 to 0.78	0.55 to 0.68	5.0 to 5.7	-1.7 to -0.7	2.9 to 3.4	3.4 to 4.0	11.5 to 12.2	4.5 to 4.9	2.6 to 24.4
	Average of 3 Sensors, PM ₁₀		Sensirion SEN54 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	8.5	0.18 to 0.19	0.93 to 0.97	29.0 to 29.3	-28.6 to -28.5	28.6 to 28.7	33.0 to 33.2	39.7	19.0	2.1 to 366.9
1-hr	11.0	8.4	0.10 to 0.22	0.69 to 0.96	29.0 to 30.2	-28.6 to -26.7	27.3 to 28.7	32.2 to 32.5	38.2 to 39.7	17.7 to 19.5	1.9 to 206.7
24-hr	11.1	6.4	0.18 to 0.25	0.76 to 0.92	28.3 to 30.3	-28.5 to -26.3	26.4 to 28.5	28.3 to 30.2	38.1 to 39.7	11.4 to 12.0	12.0 to 65.4

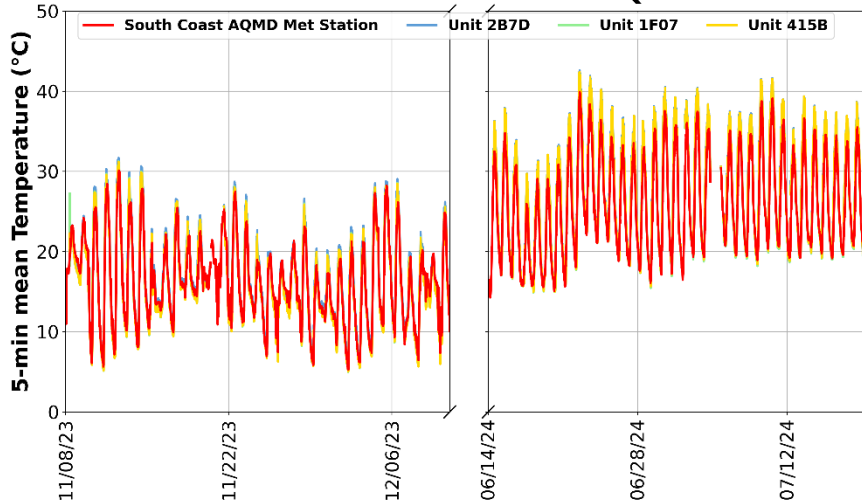
¹ Mean Bias Error (MBE): the difference between the sensors and the reference instruments. MBE indicates the tendency of the sensors to underestimate (negative MBE values) or overestimate (positive MBE values).

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.

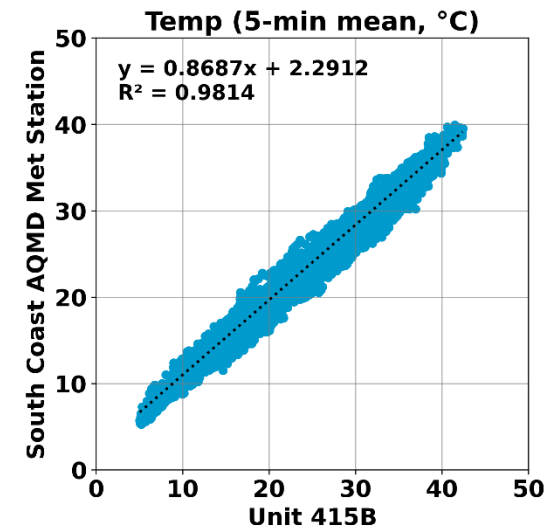
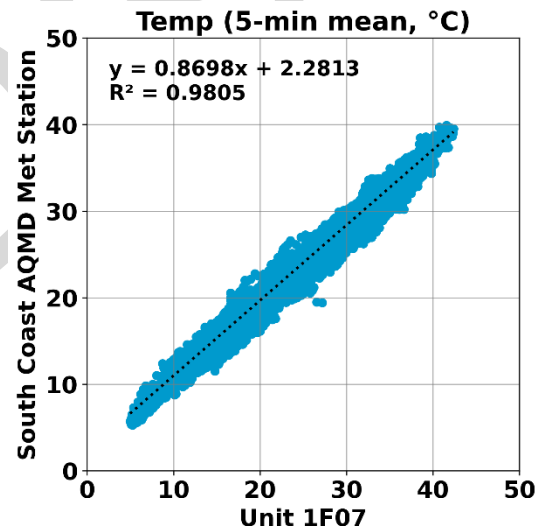
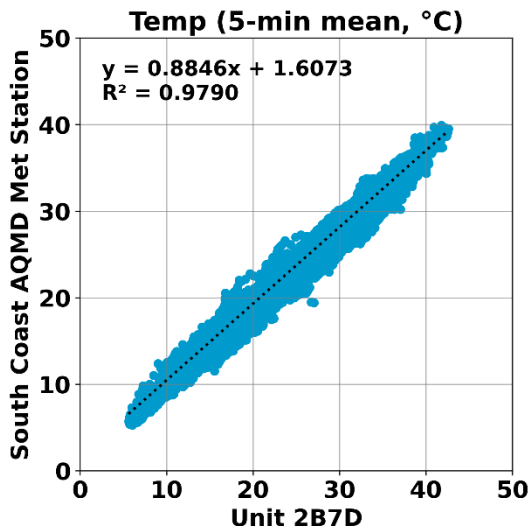
³ Root Mean Square Error (RMSE): another metric to calculate measurement errors.

Sensirion SEN54 vs South Coast AQMD Met Station (Temp; 5-min mean)

Sensirion SEN54 vs. South Coast AQMD Met Station

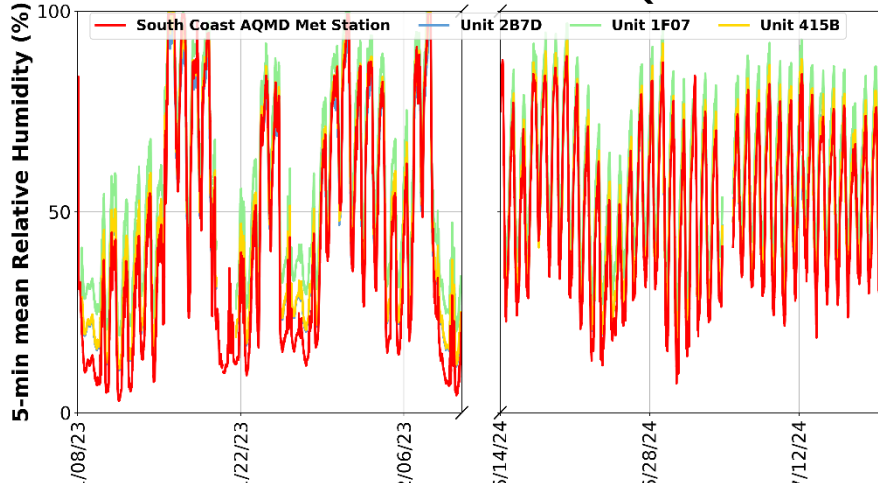


- The Sensirion SEN54 sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($0.97 < R^2 < 0.99$)
- Overall, the Sensirion SEN54 sensors overestimated the temperature measurement as recorded by South Coast AQMD Met Station
- The Sensirion SEN54 sensors seemed to track the diurnal temperature variations as recorded by South Coast AQMD Met Station

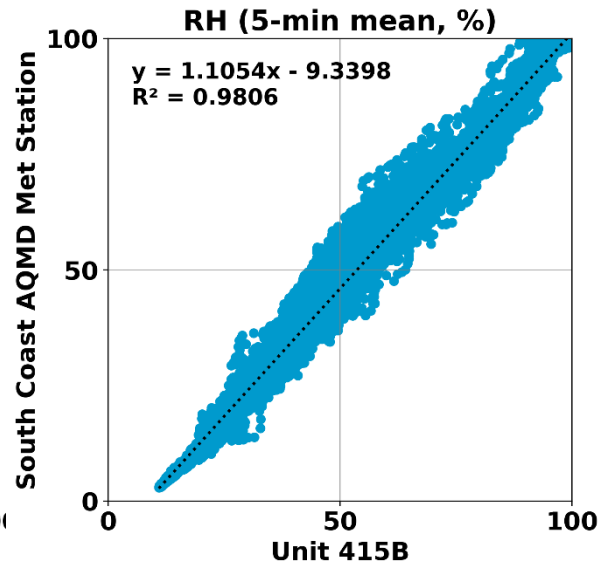
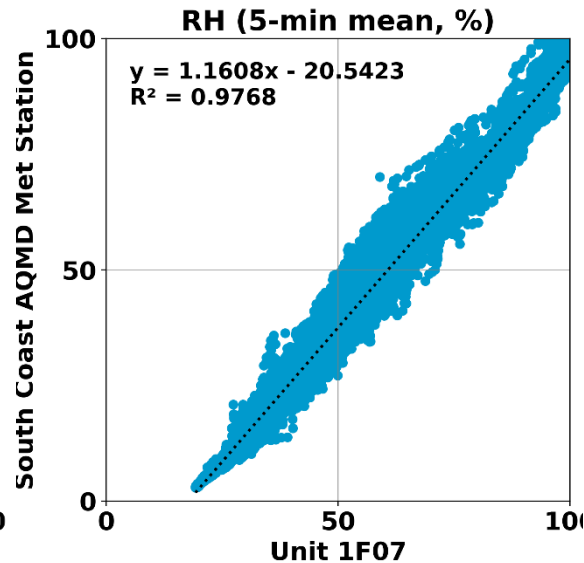
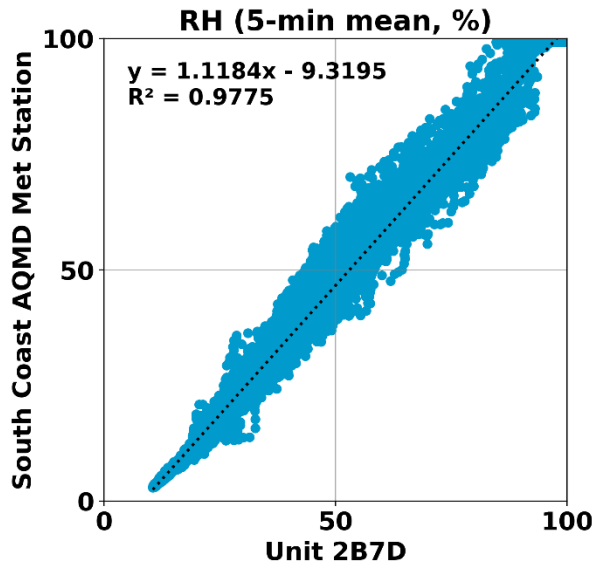


Sensirion SEN54 vs South Coast AQMD Met Station (RH; 5-min mean)

Sensirion SEN54 vs. South Coast AQMD Met Station



- Sensirion SEN54 sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($0.97 < R^2 < 0.99$)
- Overall, the Sensirion SEN54 sensors overestimated the RH measurement as recorded by South Coast AQMD Met Station
- The Sensirion SEN54 sensors seemed to track the diurnal RH variations as recorded by South Coast AQMD Met Station



Discussion

- The three Sensirion SEN54 sensors' data recovery for all PM fractions was ~94.5%.
- The absolute intra-model variability was ~0.11, ~0.06 and ~0.05 $\mu\text{g}/\text{m}^3$ for $\text{PM}_{1.0}$, $\text{PM}_{2.5}$ and PM_{10} , respectively.
- Reference instruments: strong correlations between FEM BAM and FEM T640 for $\text{PM}_{2.5}$ ($R^2 \sim 0.75$, 1-hr mean) and strong correlations between FEM BAM and T640 for PM_{10} ($R^2 \sim 0.85$, 1-hr mean) mass concentration measurements
- The Sensirion SEN54 sensors showed strong correlations with the corresponding reference $\text{PM}_{1.0}$ data ($0.88 < R^2 < 0.90$, 1-hr mean), moderate to strong correlations with the corresponding reference $\text{PM}_{2.5}$ data ($0.52 < R^2 < 0.79$, 1-hr mean) and no to very weak correlations with the corresponding reference PM_{10} data ($0.09 < R^2 < 0.22$, 1-hr mean). The sensors overestimated $\text{PM}_{1.0}$ and underestimated $\text{PM}_{2.5}$ and PM_{10} mass concentrations as measured by the reference instruments.
- Temperature and relative humidity sensors showed very strong correlations with the South Coast AQMD Met Station T and RH data, respectively ($R^2 \sim 0.98$ for T and $R^2 \sim 0.98$ for RH) and overestimated the T and RH data as recorded by the South Coast AQMD Met Station.
- 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 controlled T and RH conditions, and known target and interferent pollutants concentrations.
- These results are still preliminary