Field Evaluation
Sensirion SEN44

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

- From 11/08/2023 to 12/10/2023, and then from 3/6/2024 to 04/06/2024, three **Sensirion SEN44** 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 SEN44 (*3 units tested*):**
  - PM – Optical (Sensirion SEN44, non-FEM)
  - Each unit measures: $PM_{1.0}$ ($\mu g/m^3$), $PM_{2.5}$ ($\mu g/m^3$), PM_{10} ($\mu g/m^3$), T (°C), RH (%)
  - Also reports: $PM_{4.0}$ ($\mu g/m^3$), VOC index
  - Unit cost: ~$53
  - Time resolution: 1 second
  - Units IDs: DD78, 8E94, and 20B0

Sensirion SEN44

- **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 PM_{10} ($\mu g/m^3$)
  - Cost: ~$21,000
  - Time resolution: 1-min

- Met Station (T, RH, P, WS, WD):
 - Cost: ~$5,000
  - Time resolution: 1-min

FEM T640

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 DD78, Unit 8E94 and Unit 20B0 was ~93.6%, ~93.6% and ~93.6%, respectively for all PM measurements
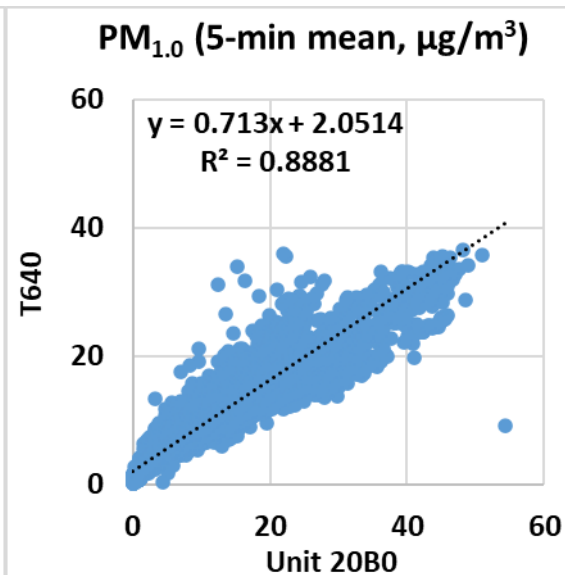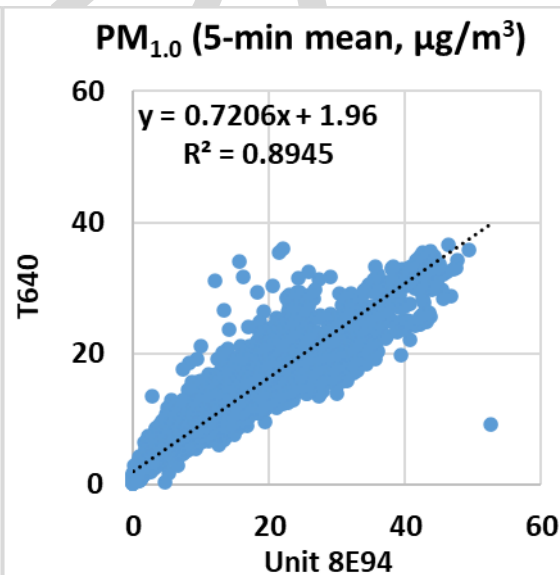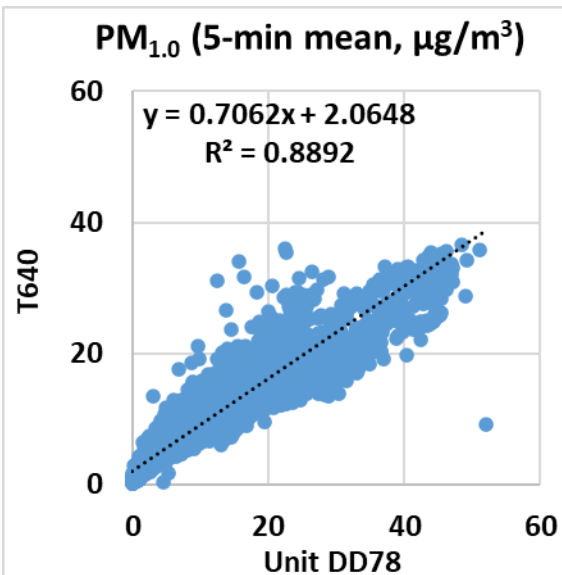
Sensirion SEN44; intra-model variability

- Absolute intra-model variability was ~0.03, ~0.04 and ~0.06 µg/m^3 for $PM_{1.0}$, $PM_{2.5}$ and $PM_{10,}$ respectively (calculated as the standard deviation of the three sensor means)

- Relative intra-model variability was ~0.48%, ~0.61% and ~0.85% for $PM_{1.0}$, $PM_{2.5}$ and $PM_{10,}$ respectively (calculated as the absolute intra-model variability relative to the mean of the three sensor means)
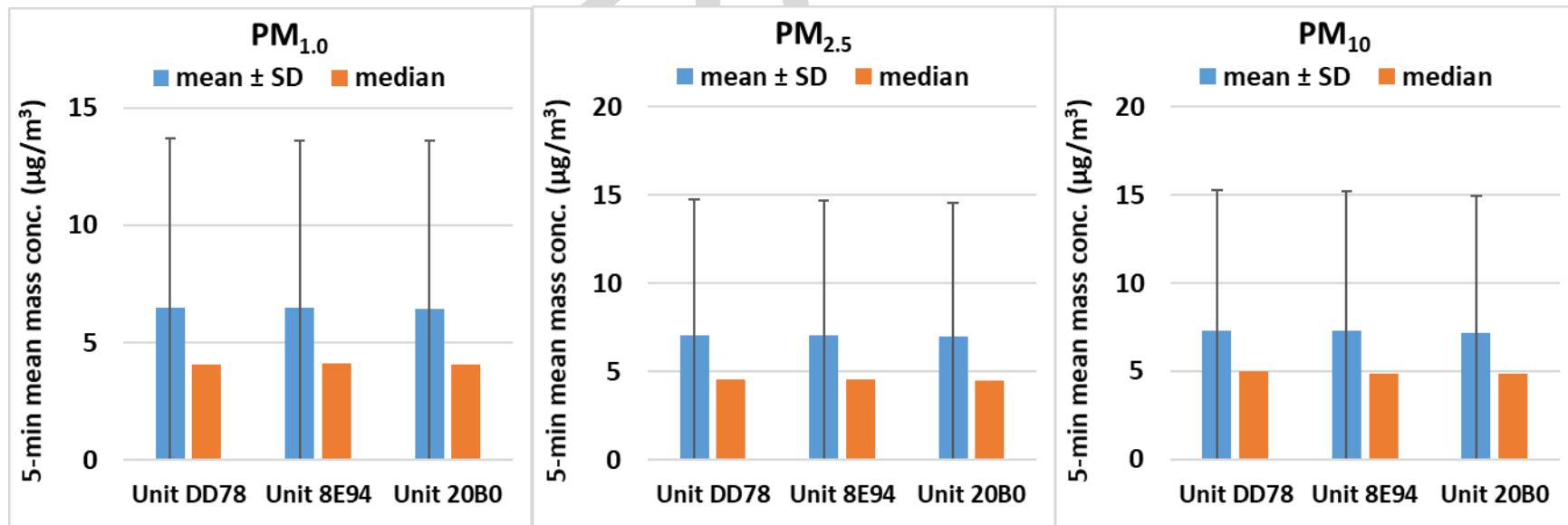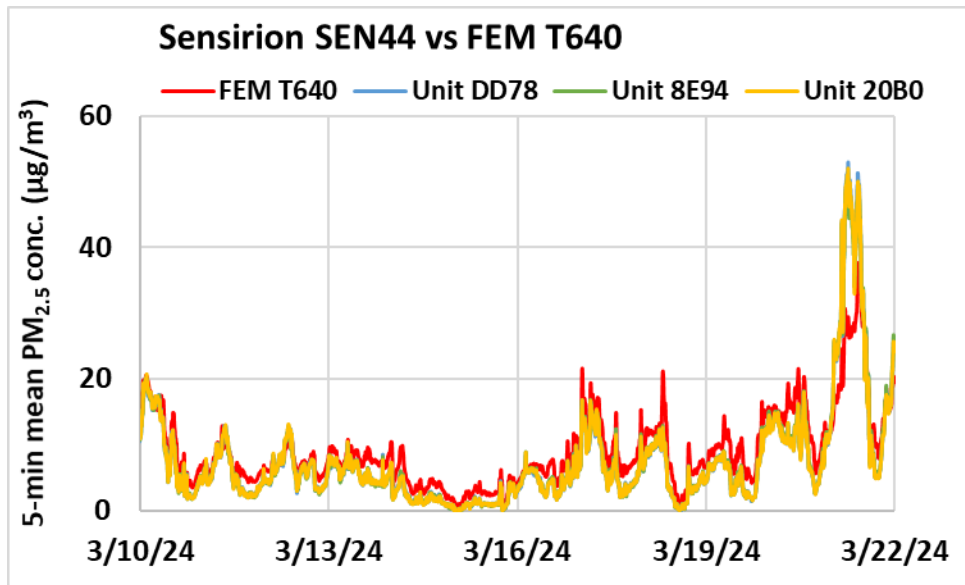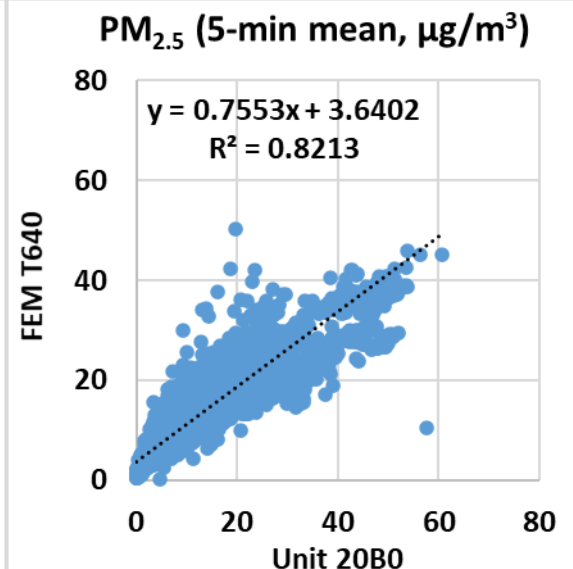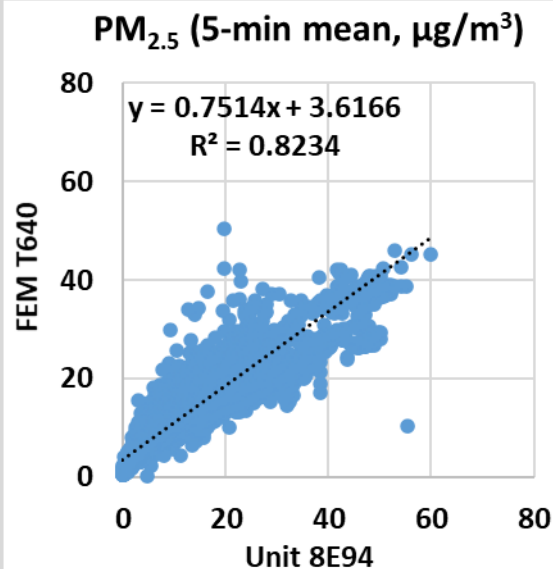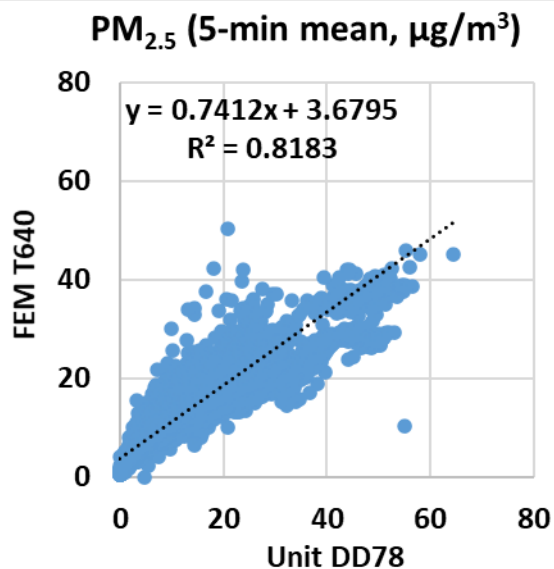
Sensirion SEN44 vs T640 (PM$_{1.0}$; 5-min mean)
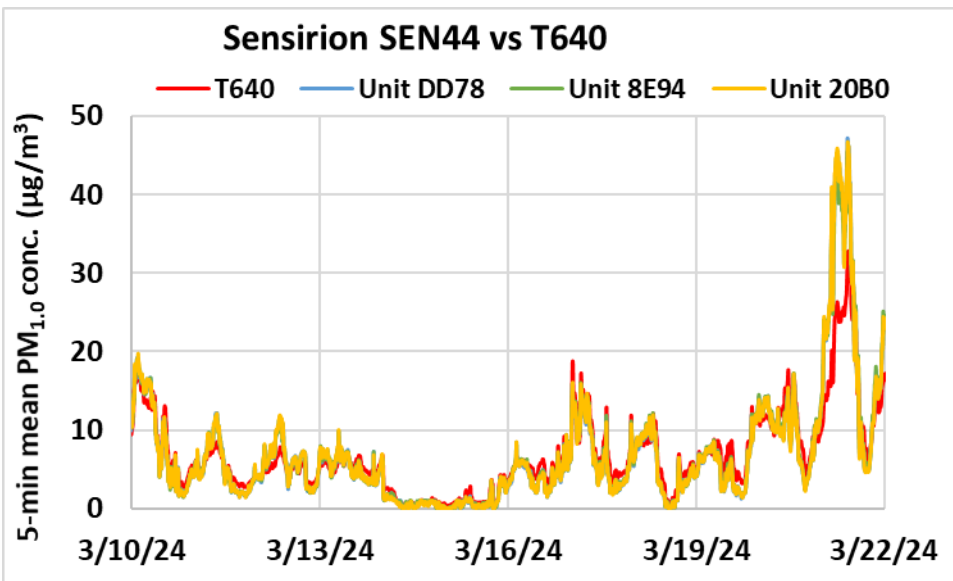
Sensirion SEN44 vs T640

- The Sensirion SEN44 sensors showed strong correlations with the corresponding T640 data (0.88 < R^2 < 0.90)
- Overall, the Sensirion SEN44 sensors underestimated the PM$_{1.0}$ mass concentrations as measured by T640
- The Sensirion SEN44 sensors seemed to track the PM$_{1.0}$ diurnal variations as recorded by T640

PM$_{1.0}$ (5-min mean, µg/m^3)

$y = 0.7062x + 2.0648$
$R^2 = 0.8892$

PM$_{1.0}$ (5-min mean, µg/m^3)

$y = 0.7206x + 1.96$
$R^2 = 0.8945$

PM$_{1.0}$ (5-min mean, µg/m^3)

$y = 0.713x + 2.0514$
$R^2 = 0.8881$

Sensirion SEN44 vs FEM T640 (PM$_{2.5}$; 5-min mean)

Sensirion SEN44 vs FEM T640

Legend: FEM T640 | Unit DD78 | Unit 8E94 | Unit 20B0

- The Sensirion SEN44 sensors showed strong correlations with the corresponding FEM T640 data ($0.81 < R^2 < 0.83$)

- Overall, the Sensirion SEN44 sensors underestimated the PM$_{2.5}$ mass concentrations as measured by FEM T640

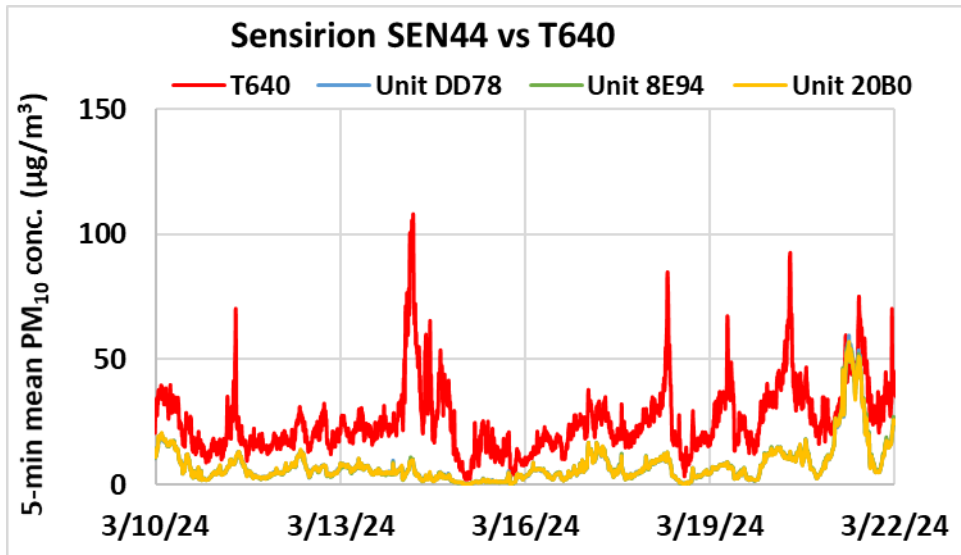- The Sensirion SEN44 sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM T640
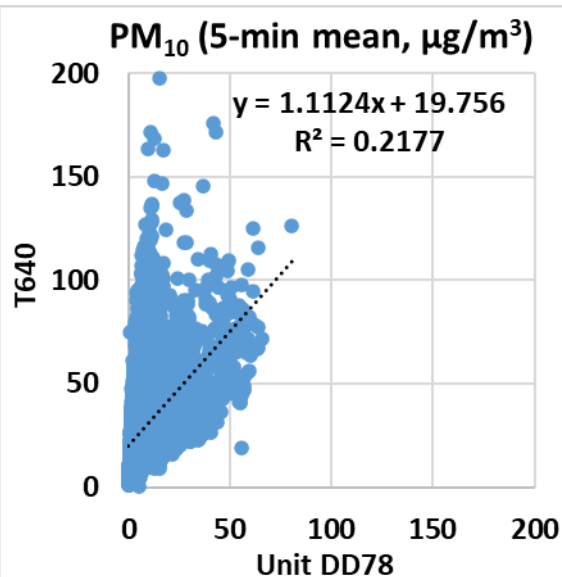
PM$_{2.5}$ (5-min mean, µg/m^3)
$y = 0.7412x + 3.6795$
$R^2 = 0.8183$
Unit DD78

PM$_{2.5}$ (5-min mean, µg/m^3)
$y = 0.7514x + 3.6166$
$R^2 = 0.8234$
Unit 8E94

PM$_{2.5}$ (5-min mean, µg/m^3)
$y = 0.7553x + 3.6402$
$R^2 = 0.8213$
Unit 20B0

Sensirion SEN44 vs T640 (PM$_{10}$; 5-min mean)

Sensirion SEN44 vs T640

Legend: T640 — Unit DD78 — Unit 8E94 — Unit 20B0

- The Sensirion SEN44 sensors showed very weak correlations with the corresponding T640 data ($0.21 < R^2 < 0.23$)
- Overall, the Sensirion SEN44 sensors underestimated the PM$_{10}$ mass concentrations as measured by T640
- The Sensirion SEN44 sensors did not seem to track the PM$_{10}$ diurnal variations as recorded by T640

PM$_{10}$ (5-min mean, µg/m^3)

$y = 1.1124x + 19.756$
$R^2 = 0.2177$

Unit DD78

PM$_{10}$ (5-min mean, µg/m^3)

$y = 1.1155x + 19.785$
$R^2 = 0.2174$

Unit 8E94

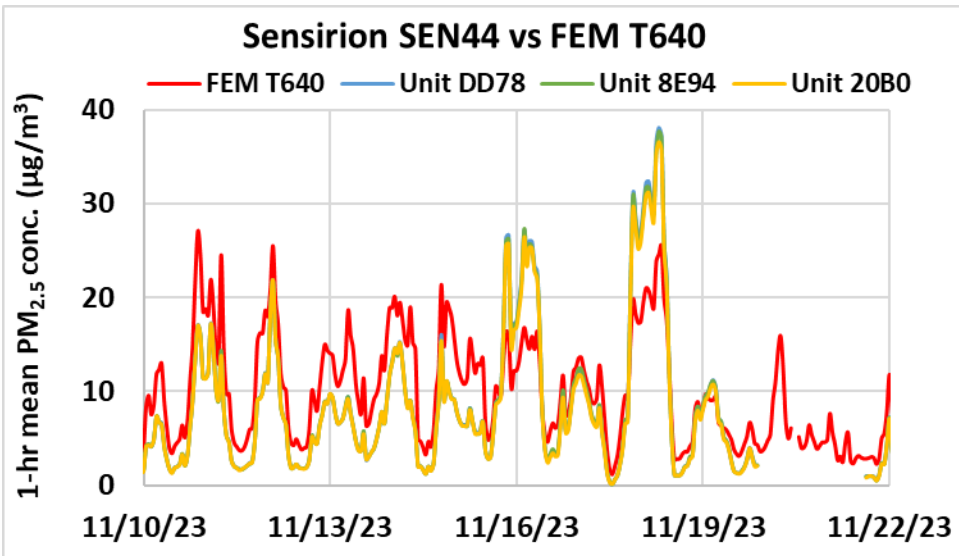**PM$_{10}$ (5-min mean, µg/m^3)**

$y = 1.1494x + 19.626$
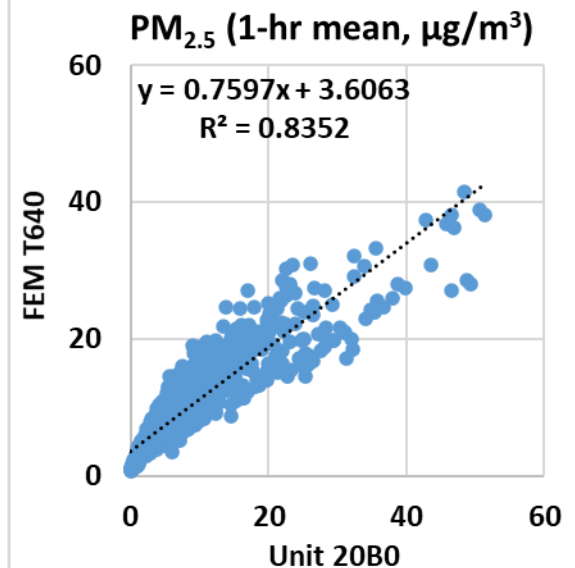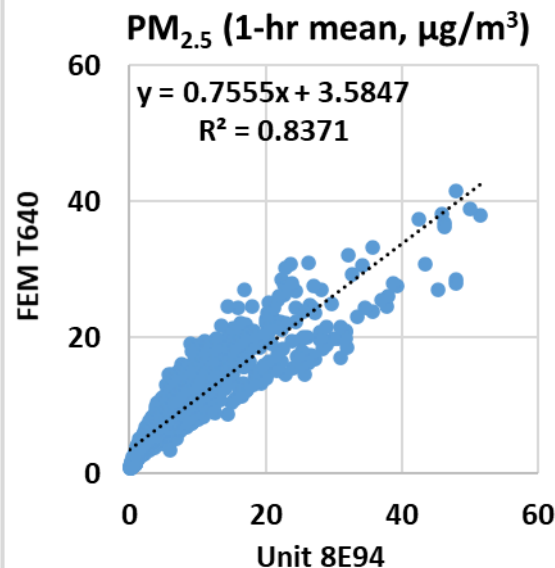$R^2 = 0.2207$

Unit 20B0
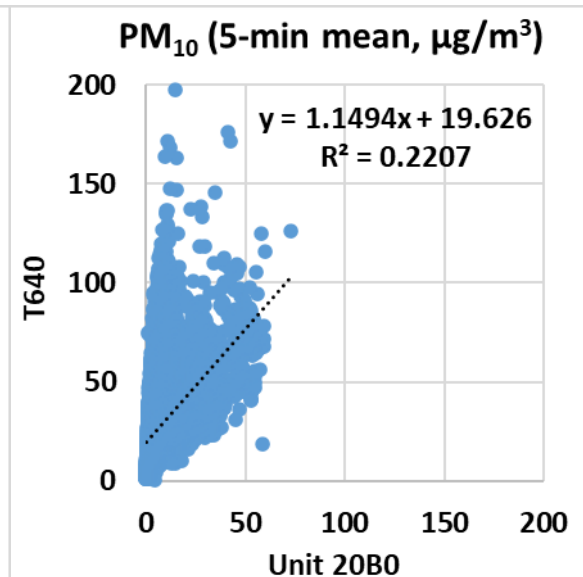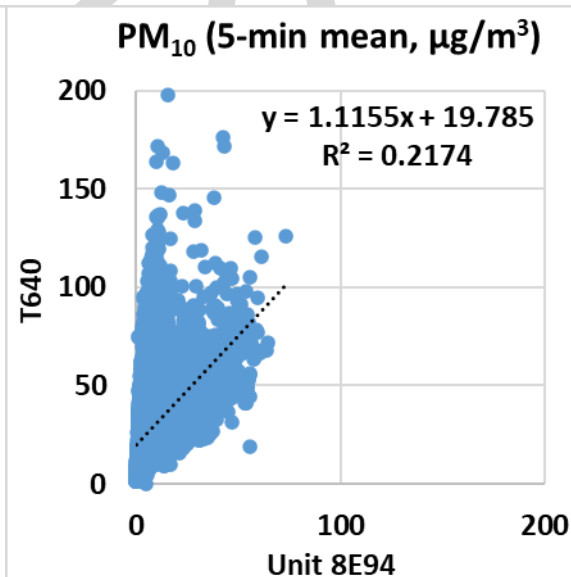
Sensirion SEN44 vs T640 (PM$_{1.0}$; 1-hr mean)
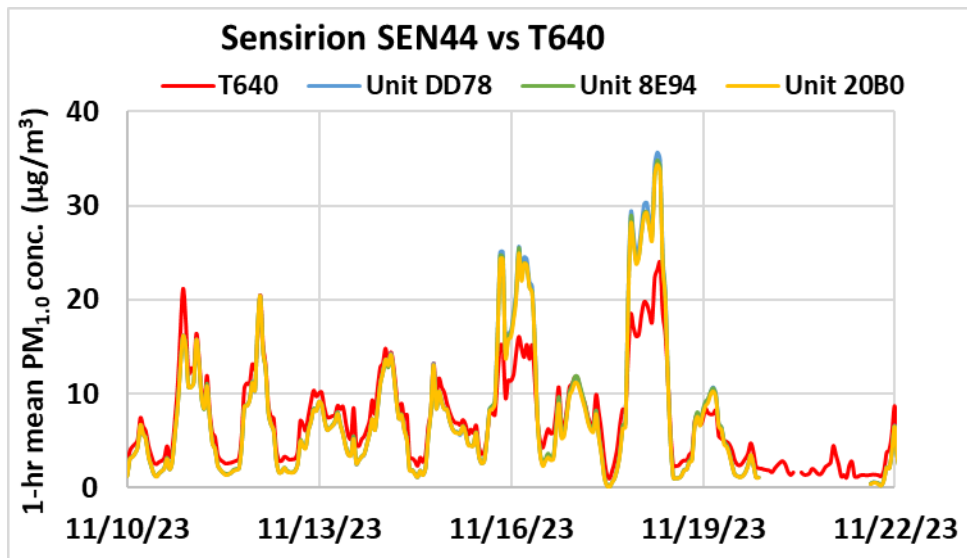
- The Sensirion SEN44 sensors showed very strong correlations with the corresponding T640 data ($0.90 < R^2 < 0.91$)

- Overall, the Sensirion SEN44 sensors underestimated the PM$_{1.0}$ mass concentrations as measured by T640

- The Sensirion SEN44 sensors seemed to track the PM$_{1.0}$ diurnal variations as recorded by T640
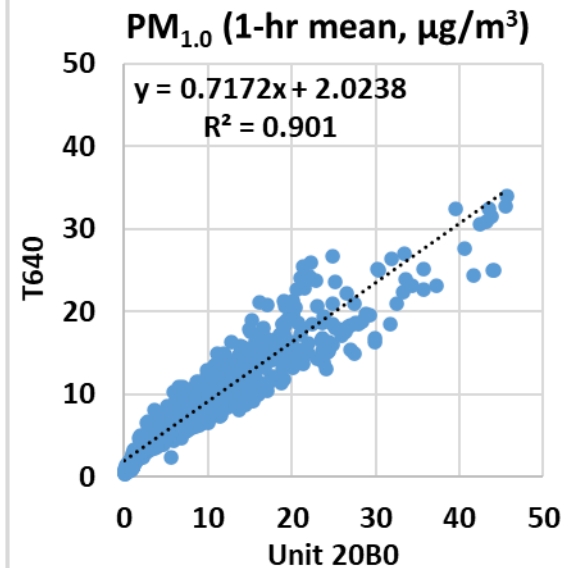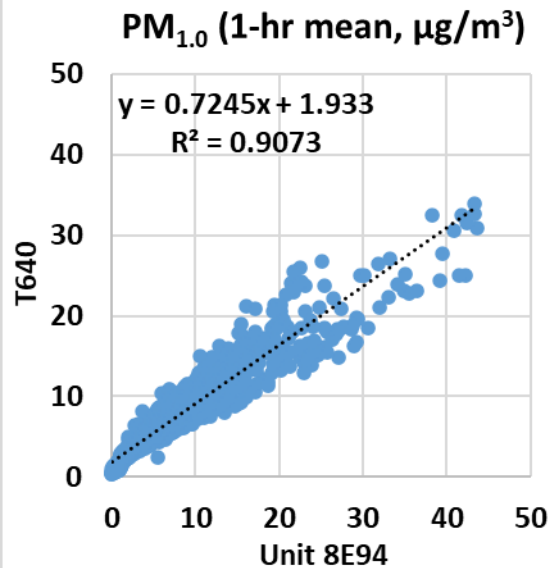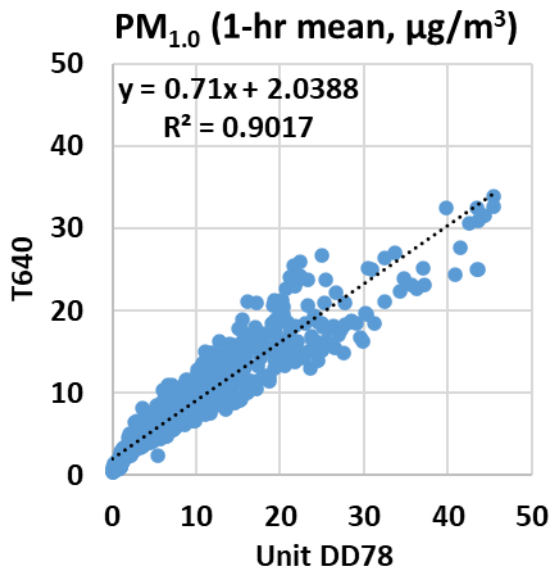
Sensirion SEN44 vs FEM T640 (PM$_{2.5}$; 1-hr mean)

- The Sensirion SEN44 sensors showed strong correlations with the corresponding FEM T640 data ($0.83 < R^2 < 0.84$)
- Overall, the Sensirion SEN44 sensors underestimated the PM$_{2.5}$ mass concentrations as measured by FEM T640
- The Sensirion SEN44 sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM T640
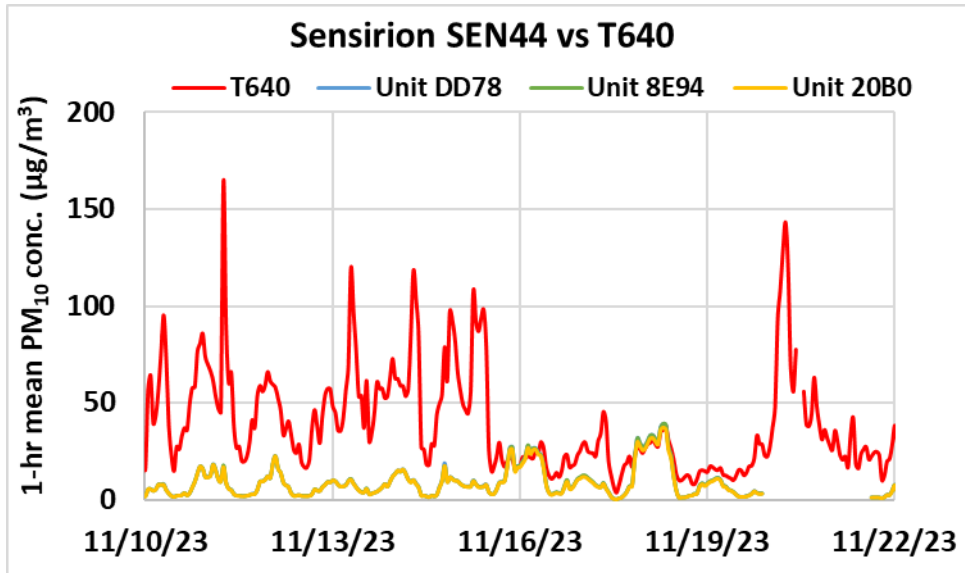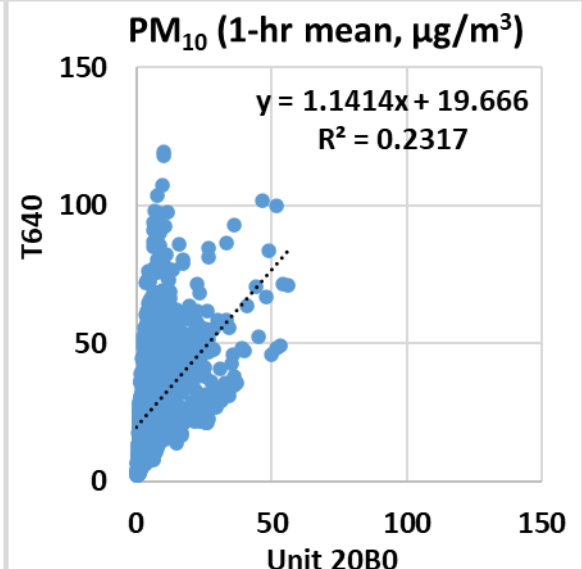
Sensirion SEN44 vs T640 (PM_{10}; 1-hr mean)

- The Sensirion SEN44 sensors showed very weak correlations with the corresponding T640 data ($0.22 < R^2 < 0.24$)
- Overall, the Sensirion SEN44 sensors underestimated the PM_{10} mass concentrations as measured by T640
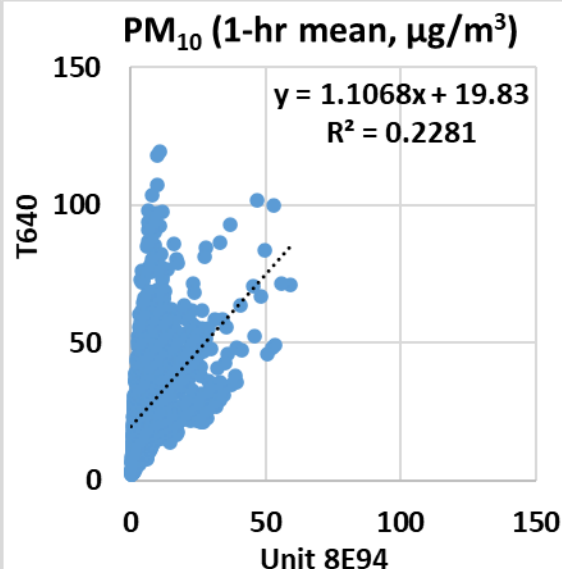- The Sensirion SEN44 sensors did not seem to track the PM_{10} diurnal variations as recorded by T640

Sensirion SEN44 vs T640 ($PM_{1.0}$; 24-hr mean)

Sensirion SEN44 vs T640

— T640 — Unit DD78 — Unit 8E94 — Unit 20B0

- The Sensirion SEN44 sensors showed very strong correlations with the corresponding T640 data ($0.92 < R^2 < 0.93$)

- Overall, the Sensirion SEN44 sensors underestimated the $PM_{1.0}$ mass concentrations as measured by T640

- The Sensirion SEN44 sensors seemed to track the $PM_{1.0}$ daily variations as recorded by T640

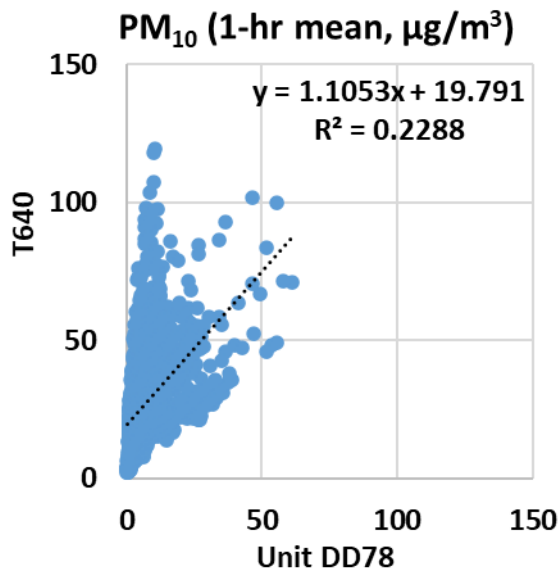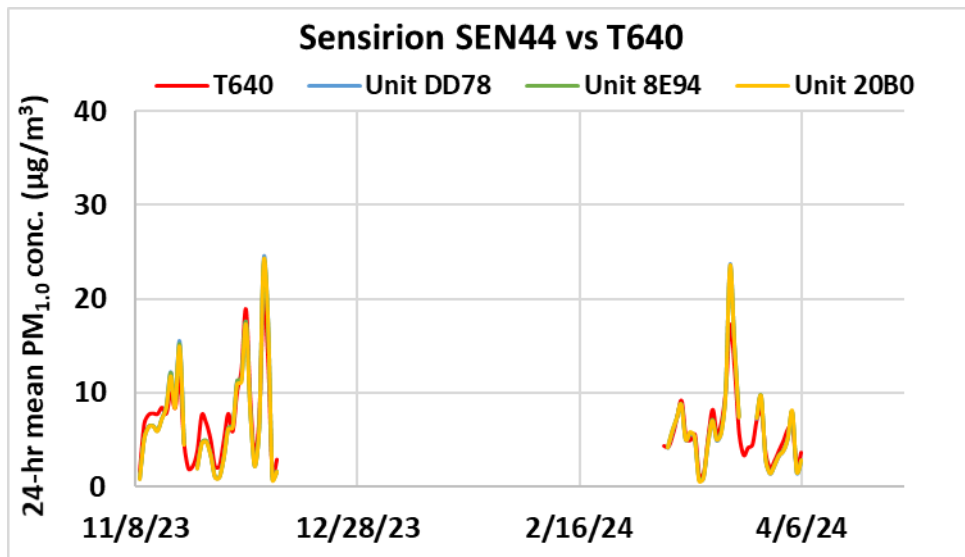$PM_{1.0}$ (24-hr mean, $\mu g/m^3$)

$y = 0.7496x + 1.7993$
$R^2 = 0.9208$

$PM_{1.0}$ (24-hr mean, $\mu g/m^3$)

$y = 0.7617x + 1.7068$
$R^2 = 0.9251$

$PM_{1.0}$ (24-hr mean, $\mu g/m^3$)

$y = 0.7596x + 1.7669$
$R^2 = 0.921$

Sensirion SEN44 vs FEM T640 ($PM_{2.5}$; 24-hr mean)

Sensirion SEN44 vs FEM T640

Legend: FEM T640 — Unit DD78 — Unit 8E94 — Unit 20B0

24-hr mean $PM_{2.5}$ conc. ($\mu g/m^3$) vs dates: 11/8/23, 12/28/23, 2/16/24, 4/6/24
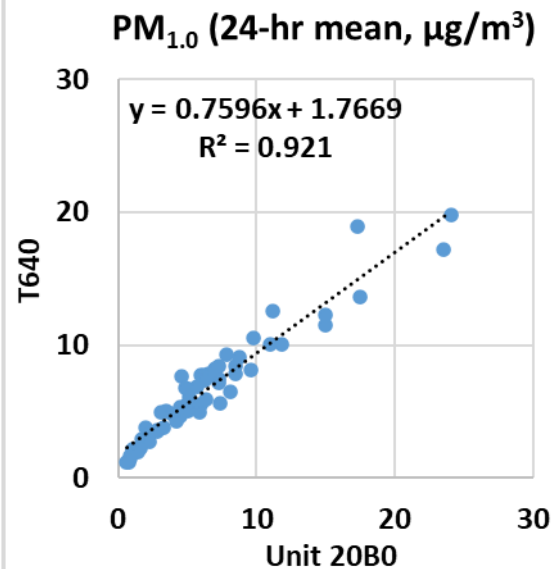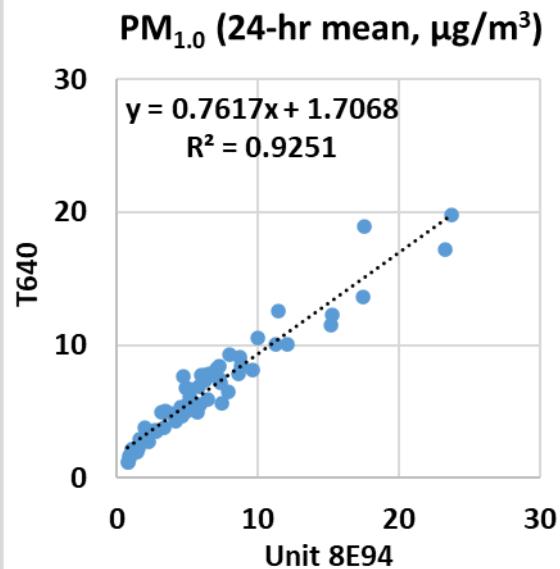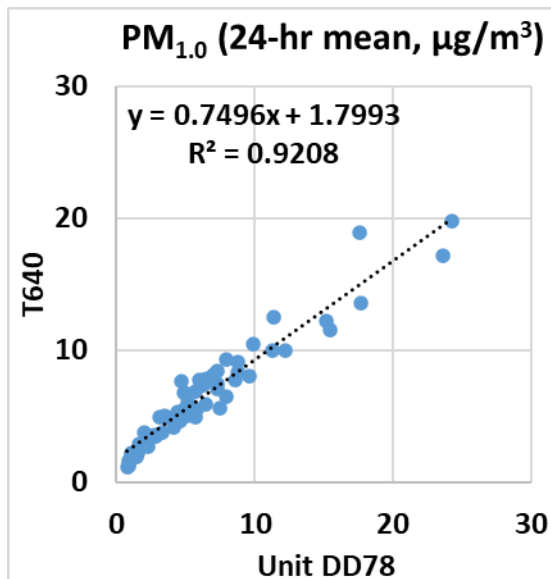
- The Sensirion SEN44 sensors showed strong correlations with the corresponding FEM T640 data ($0.85 < R^2 < 0.86$)

- Overall, the Sensirion SEN44 sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640

- The Sensirion SEN44 sensors seemed to track the $PM_{2.5}$ daily variations as recorded by FEM T640

$PM_{2.5}$ (24-hr mean, $\mu g/m^3$)

$y = 0.7856x + 3.392$
$R^2 = 0.8554$

FEM T640 vs Unit DD78

$PM_{2.5}$ (24-hr mean, $\mu g/m^3$)

$y = 0.7917x + 3.356$
$R^2 = 0.8578$

FEM T640 vs Unit 8E94

$PM_{2.5}$ (24-hr mean, $\mu g/m^3$)
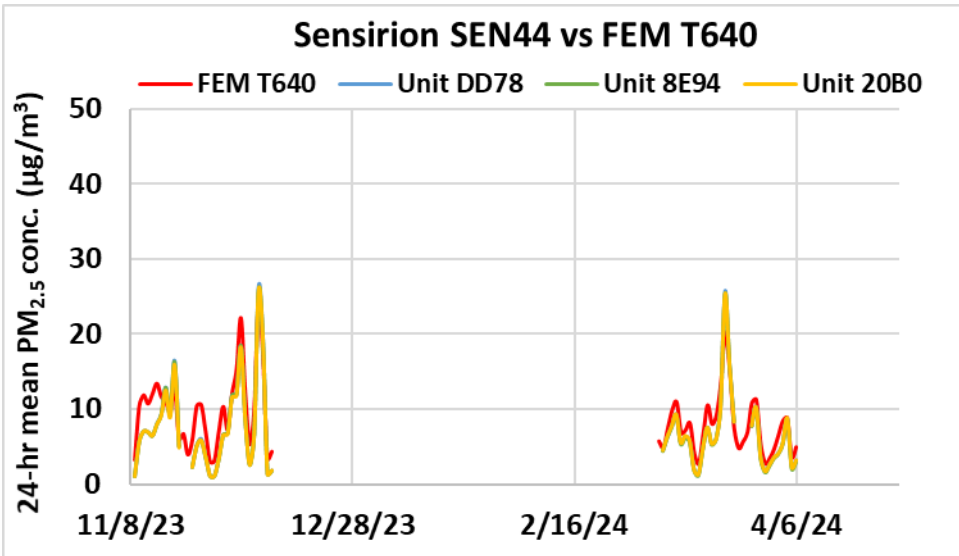
$y = 0.8021x + 3.3371$
$R^2 = 0.8587$

FEM T640 vs Unit 20B0
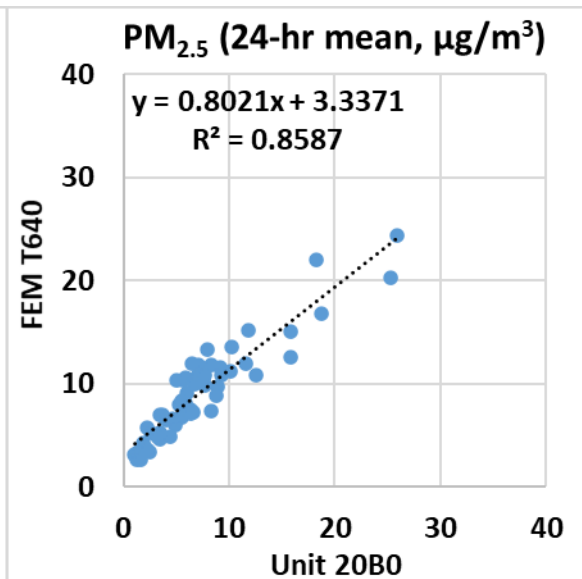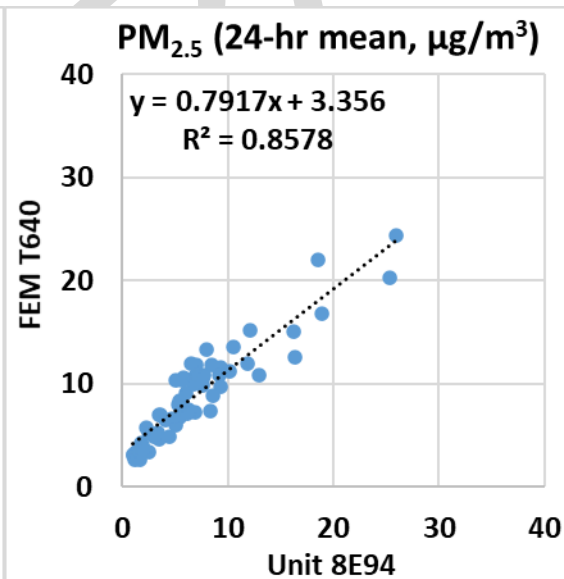
Sensirion SEN44 vs T640 (PM_{10}; 24-hr mean)

- The Sensirion SEN44 sensors showed very weak correlations with the corresponding T640 data ($0.22 < R^2 < 0.24$)

- Overall, the Sensirion SEN44 sensors underestimated the PM_{10} mass concentrations as measured by T640

- The Sensirion SEN44 sensors did not seem to track the PM_{10} daily variations as recorded by T640
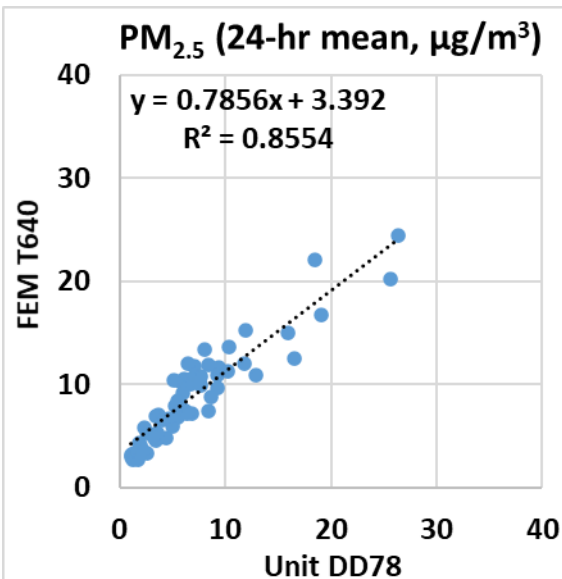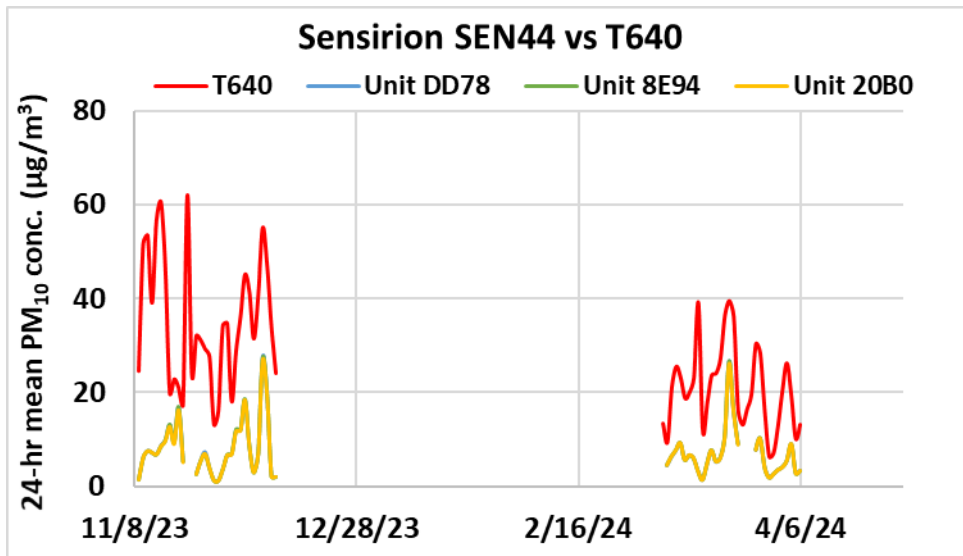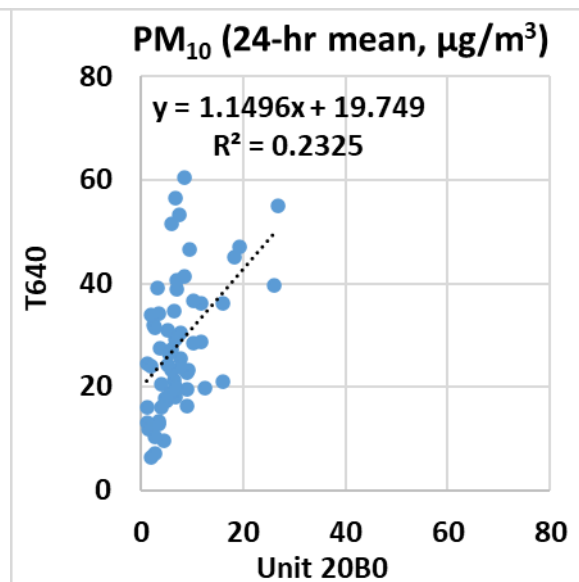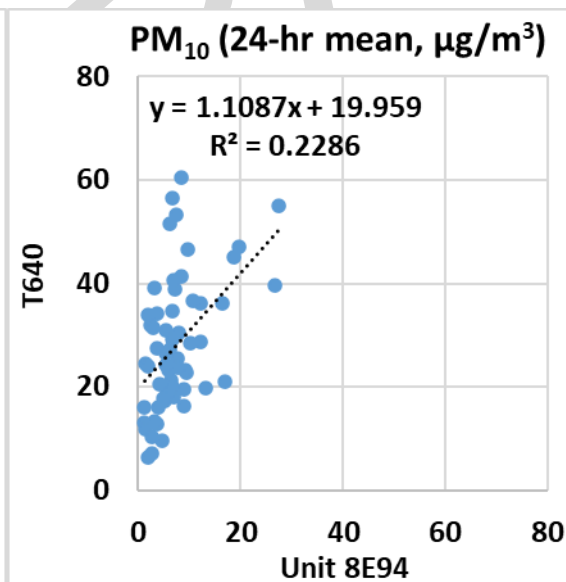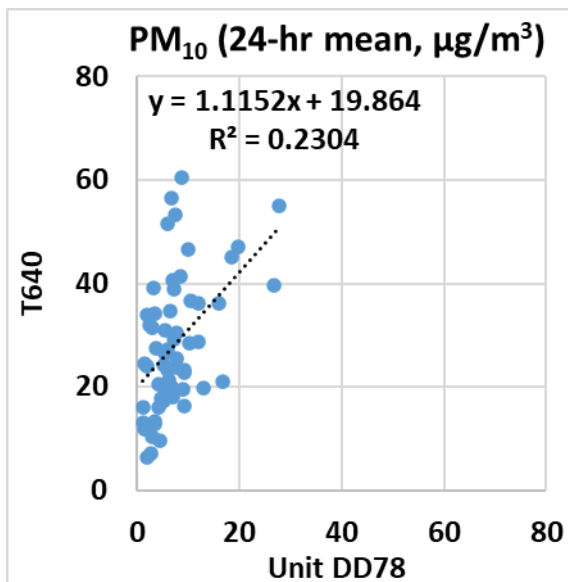
Summary: PM

	Average of 3 Sensors, PM$_{1.0}$		Sensirion SEN44 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	6.5	7.2	0.89	0.71 to 0.72	2.0 to 2.1	-0.20 to -0.14	1.6 to 1.7	2.7 to 2.8	6.4	5.3	0.2 to 36.7
1-hr	6.5	7.1	0.90 to 0.91	0.71 to 0.72	1.9 to 2.0	-0.20 to -0.14	1.6 to 1.7	2.5 to 2.7	6.4	5.2	0.3 to 33.9
24-hr	6.6	5.2	0.92 to 0.93	0.75 to 0.76	1.7 to 1.8	-0.18 to -0.12	1.2 to 1.3	1.6 to 1.7	6.5	4.0	1.1 to 19.8
	Average of 3 Sensors, PM$_{2.5}$		Sensirion SEN44 vs FEM T640, PM$_{2.5}$						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	7.0	7.7	0.82	0.74 to 0.76	3.6 to 3.7	-1.94 to -1.86	2.9 to 3.0	3.8	8.7	6.2	0.1 to 50.4
1-hr	7.0	7.5	0.83 to 0.84	0.75 to 0.76	3.6	-1.93 to -1.85	2.9	3.6 to 3.7	8.7	6.1	0.7 to 41.5
24-hr	7.2	5.5	0.86	0.79 to 0.80	3.3 to 3.4	-1.93 to -1.85	2.4 to 2.5	2.8	8.7	4.6	2.7 to 24.4
	Average of 3 Sensors, PM$_{10}$		Sensirion SEN44 vs T640, PM$_{10}$						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	7.3	7.9	0.22	1.11 to 1.15	19.6 to 19.8	-20.7 to -20.6	20.7 to 20.8	26.5 to 26.6	27.9	19.4	0.2 to 366.9
1-hr	7.3	7.7	0.23	1.11 to 1.14	19.7 to 19.8	-20.7 to -20.6	20.7 to 20.8	25.9 to 26.0	27.9	18.6	2.1 to 164.5
24-hr	7.4	5.6	0.23	1.11 to 1.15	19.7 to 20.0	-20.9 to -20.7	20.7 to 20.9	23.6 to 23.7	27.9	13.5	6.4 to 62.0

[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.

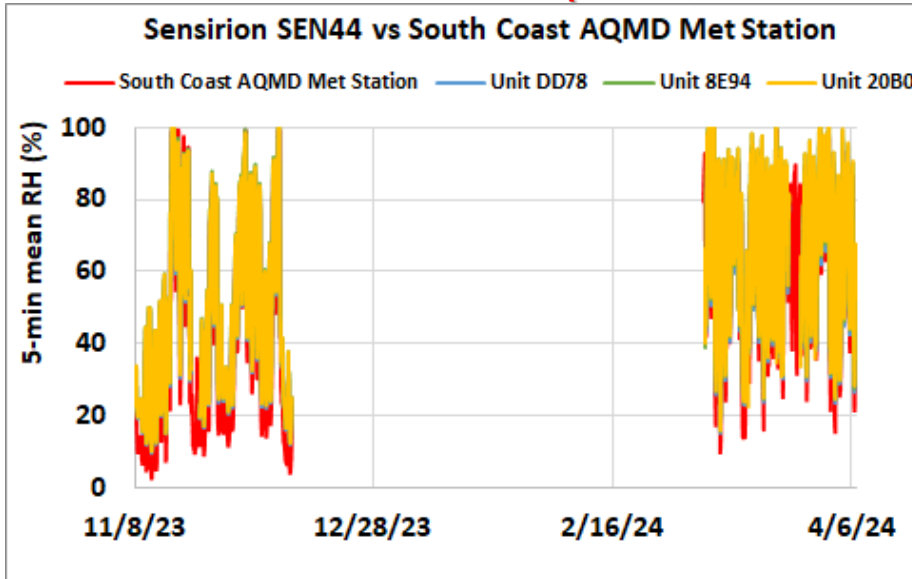# Sensirion SEN44 vs South Coast AQMD Met Station (Temp; 5-min mean)
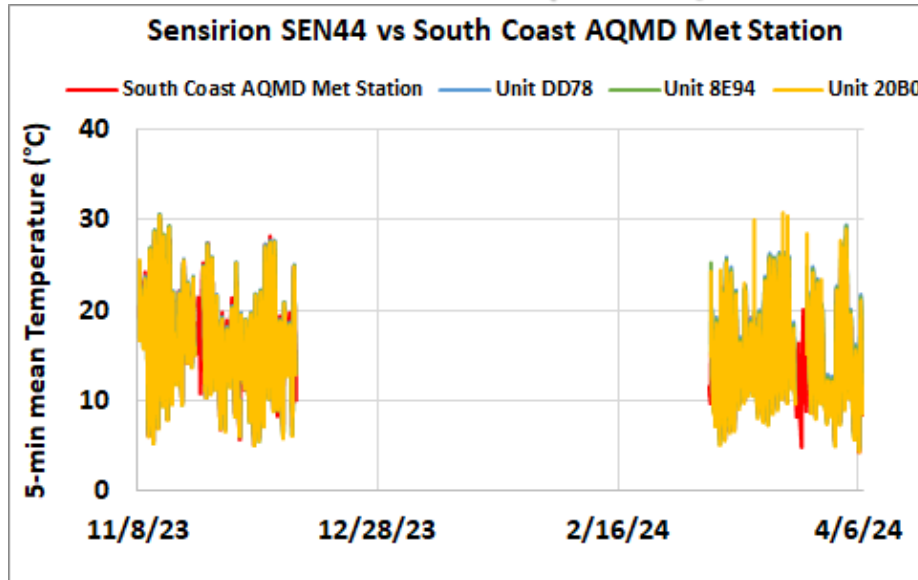
- The Sensirion SEN44 sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($0.95 < R^2 < 0.96$)

- Overall, the Sensirion SEN44 sensors overestimated the temperature measurement as recorded by South Coast AQMD Met Station

- The Sensirion SEN44 sensors seemed to track the diurnal temperature variations as recorded by South Coast AQMD Met Station


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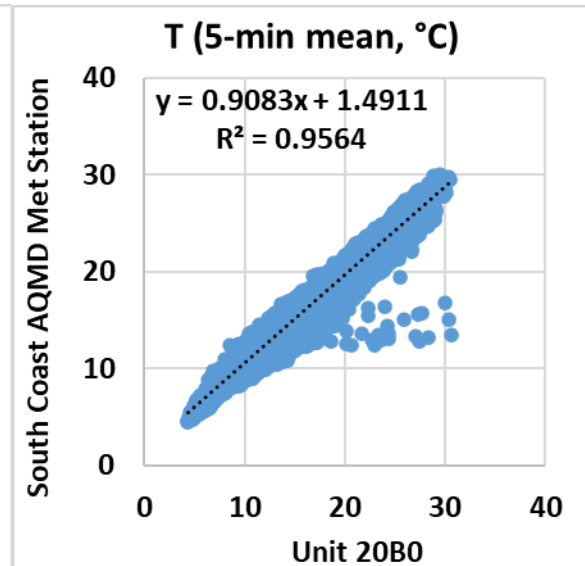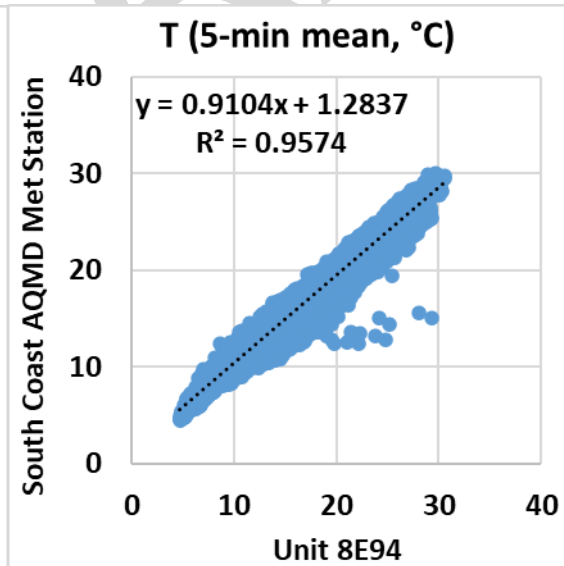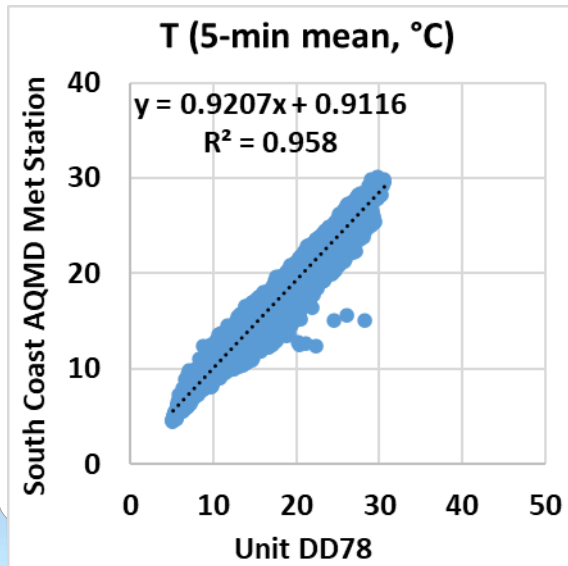
Sensirion SEN44 vs South Coast AQMD Met Station (RH; 5-min mean)

- Sensirion SEN44 sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($0.98 < R^2 < 0.99$)

- Overall, the Sensirion SEN44 sensors overestimated the RH measurement as recorded by South Coast AQMD Met Station

- The Sensirion SEN44 sensors seemed to track the diurnal RH variations as recorded by South Coast AQMD Met Station
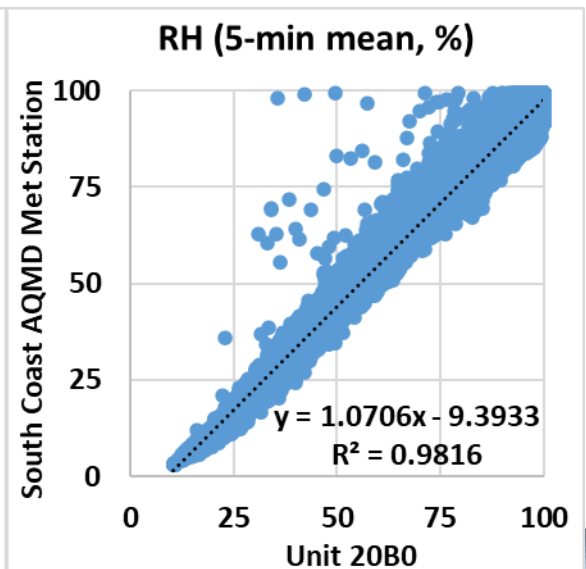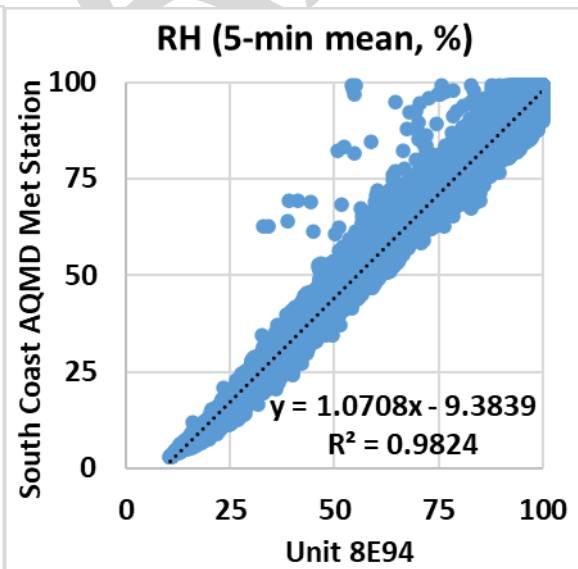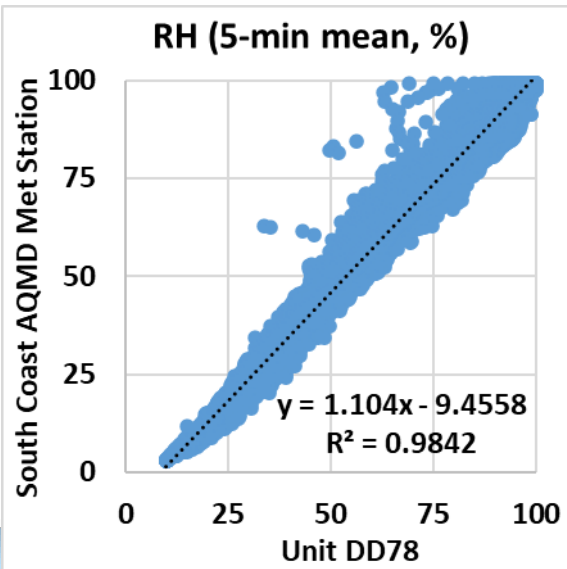
Discussion

- The three **Sensirion SEN44** sensors' data recovery for all PM fractions was ~93.6%.

- The absolute intra-model variability was ~0.03, ~0.04 and ~0.06 $\mu g/m^3$ for $PM_{1.0}$, $PM_{2.5}$ and PM_{10}, respectively

- The Sensirion SEN44 sensors showed very strong correlations with the corresponding reference $PM_{1.0}$ data ($0.90 < R^2 < 0.91$, 1-hr mean), strong correlations with the corresponding $PM_{2.5}$ data ($0.83 < R^2 < 0.84$, 1-hr mean), and very weak correlations with the corresponding reference PM_{10} data ($0.22 < R^2 < 0.24$; 1-hr mean). The sensors underestimated $PM_{1.0}$, $PM_{2.5}$ and PM_{10} mass concentrations as measured by T640

- Temperature and relative humidity sensors showed very strong correlations with the South Coast AQMD Met Station T and RH data ($R^2 \sim 0.96$ 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.

- <u>These results are still preliminary</u>