Field Evaluation
PM Monitor – iMonPM

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

- From 03/17/2022 to 05/17/2022, three **PM Monitor – iMonPM (hereinafter iMonPM)** 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

- iMonPM (*3 units tested*):
  - Particle sensor: optical; non-FEM (Wuhan Cubic PM3006S)
  - Each unit reports: $PM_{1.0,}$ $PM_{2.5}$ and PM_{10} ($\mu g/m^3$), T (°C), RH (%)
  - Unit cost: $1,995
  - Time resolution: 1-min
  - Units IDs: 0028, 0029, 0030

- 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

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

FEM GRIMM

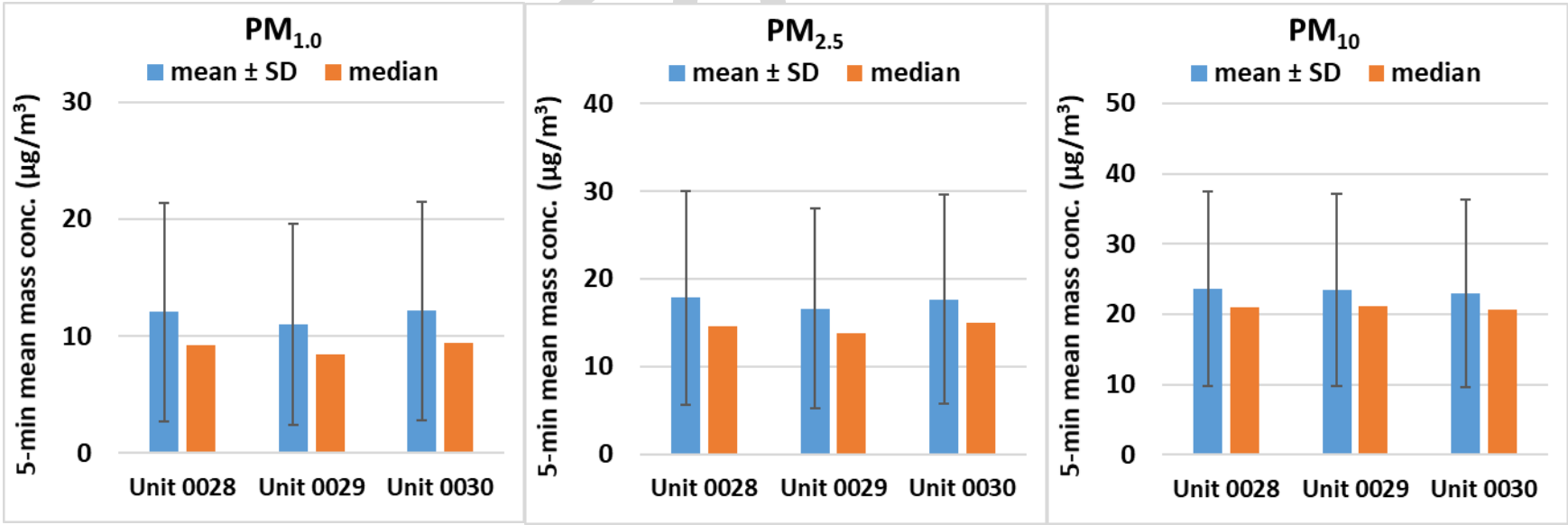
FEM T640

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 0028, Unit 0029 and Unit 0030 was ~97.5%, respectively for all PM measurements

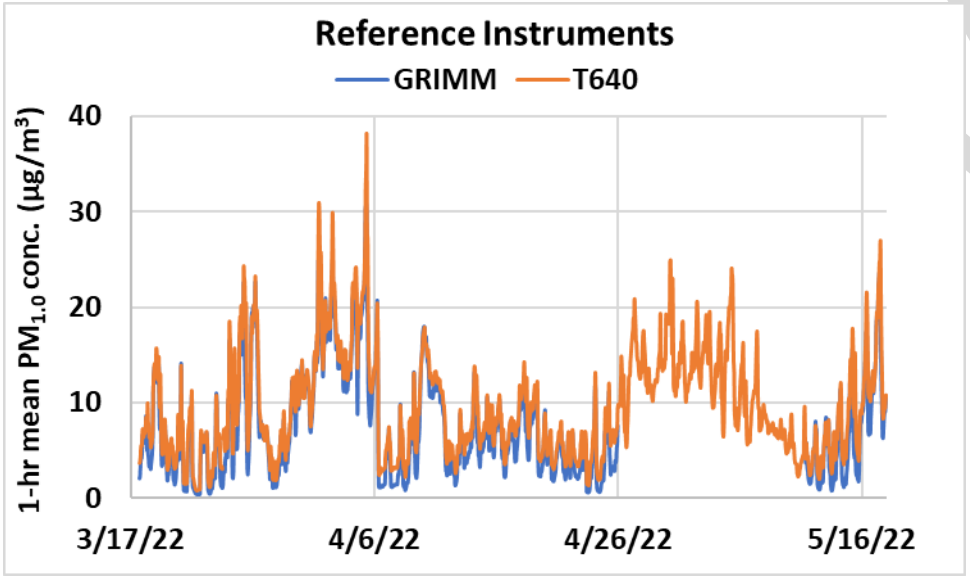
iMonPM; intra-model variability

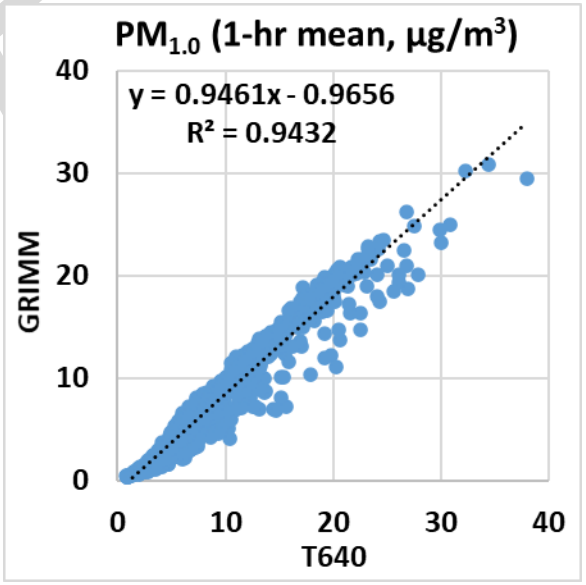
- Absolute intra-model variability was ~0.53, ~0.55 and ~0.27 µg/m^3 for $PM_{1.0}$, $PM_{2.5}$ and $PM_{10,}$ respectively (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was ~4.5%, ~3.2% and ~1.2% for $PM_{1.0}$, $PM_{2.5}$ and $PM_{10,}$ respectively (calculated as the absolute intra-model variability relative to the mean of the three sensor means)



Reference Instruments: $PM_{1.0}$ GRIMM and T640

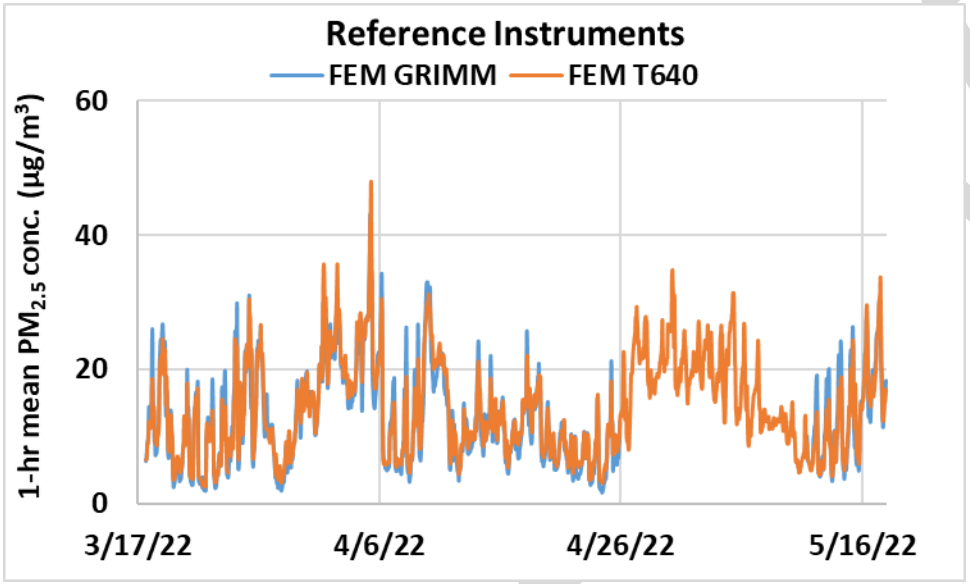
- Data recovery for $PM_{1.0}$ from GRIMM and T640 was ~100%.
- Very strong correlations between the reference instruments for $PM_{1.0}$ measurements (R^2 ~0.94) were observed.

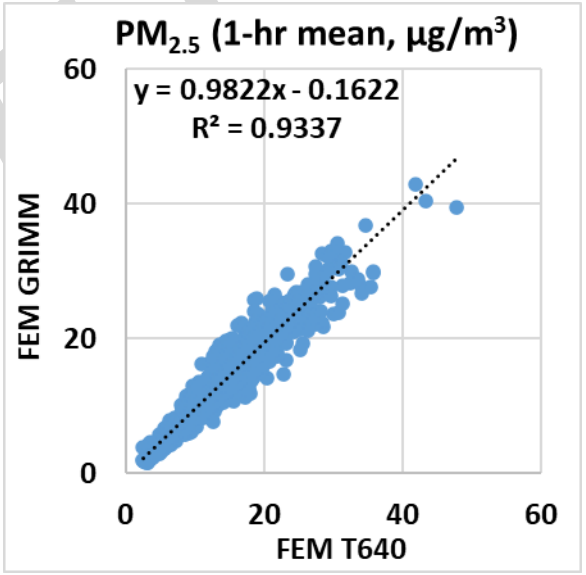




Reference Instruments: $PM_{2.5}$ FEM GRIMM and FEM T640

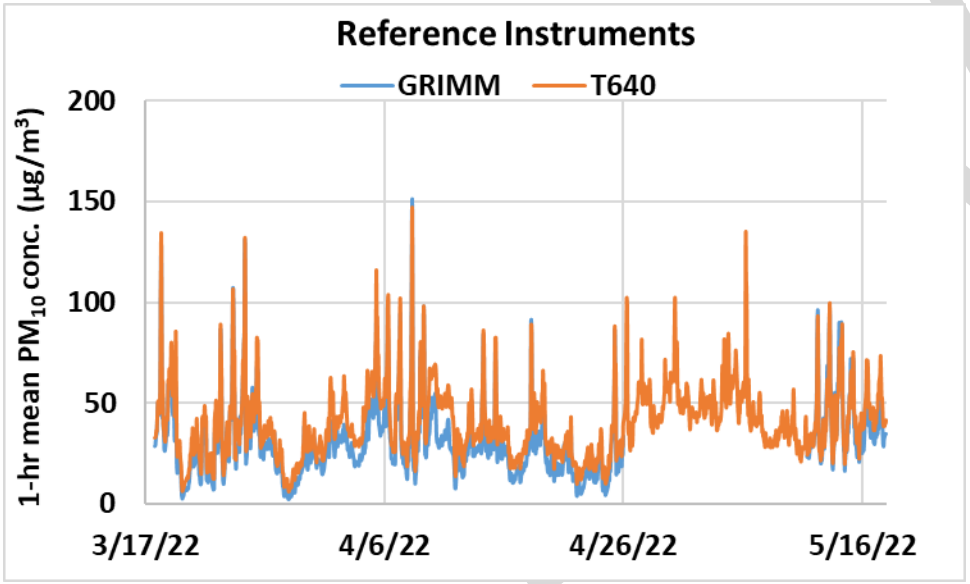
- Data recovery for $PM_{2.5}$ from FEM GRIMM and FEM T640 was ~100%.
- Very strong correlations between the reference instruments for $PM_{2.5}$ measurements (R^2 ~0.93) were observed.

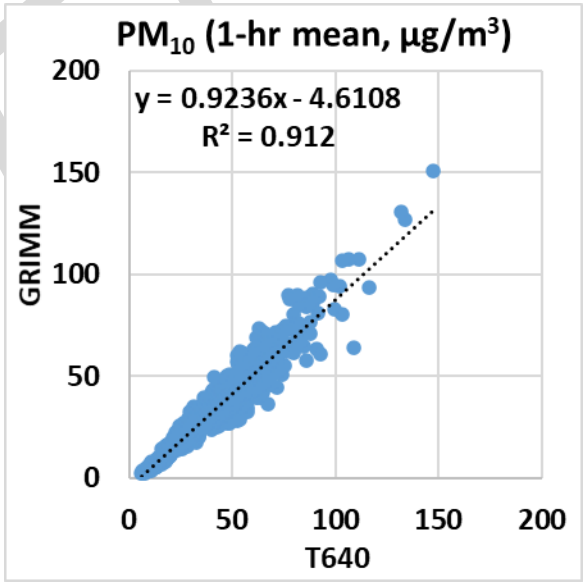




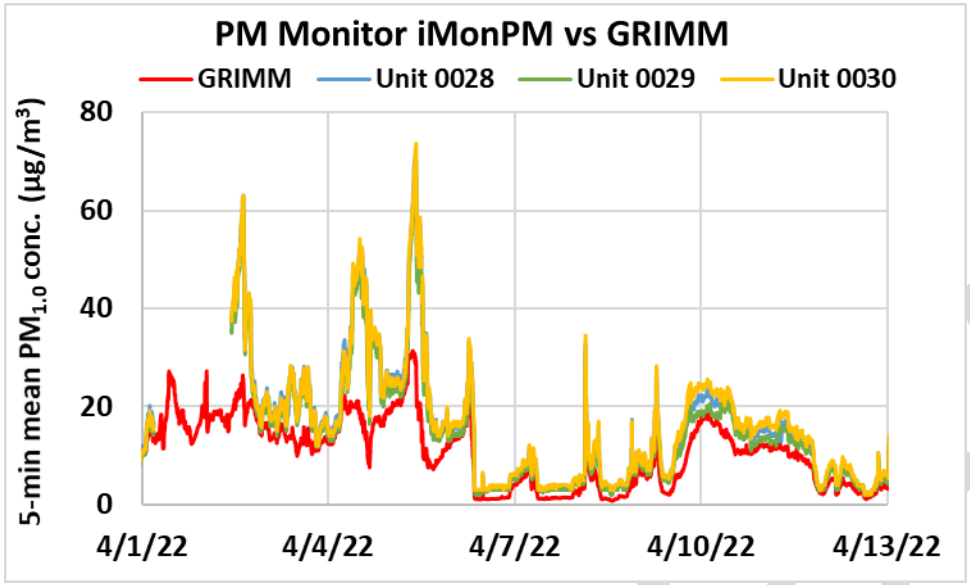
Reference Instruments: PM_{10} GRIMM and T640

- Data recovery for PM_{10} from GRIMM and T640 was ~100%.
- Very strong correlations between the reference instruments for PM_{10} measurements (R^2 ~0.91) were observed.

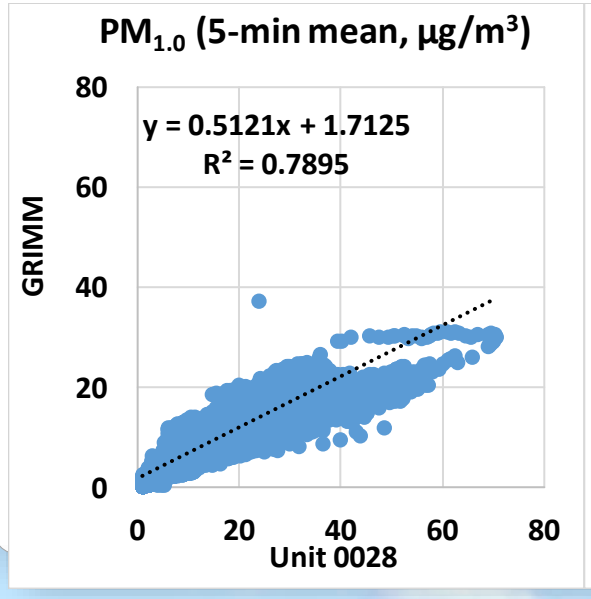


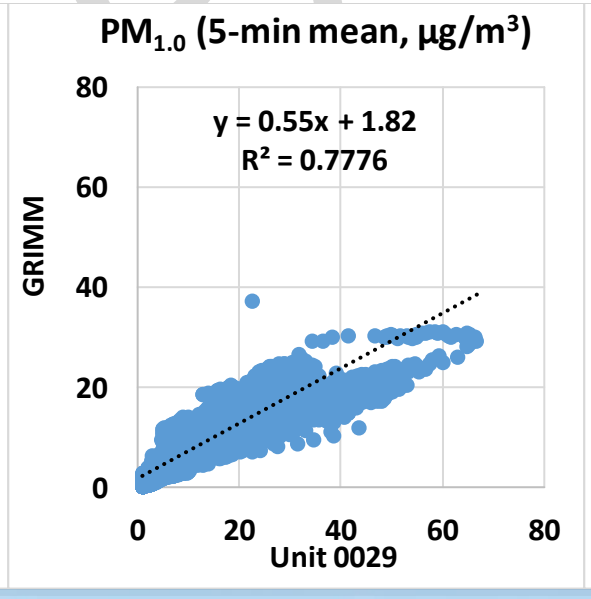


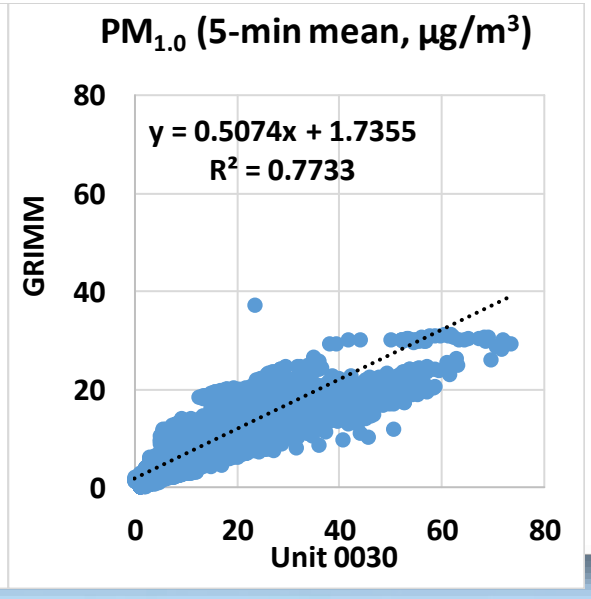
iMonPM vs GRIMM ($PM_{1.0}$; 5-min mean)



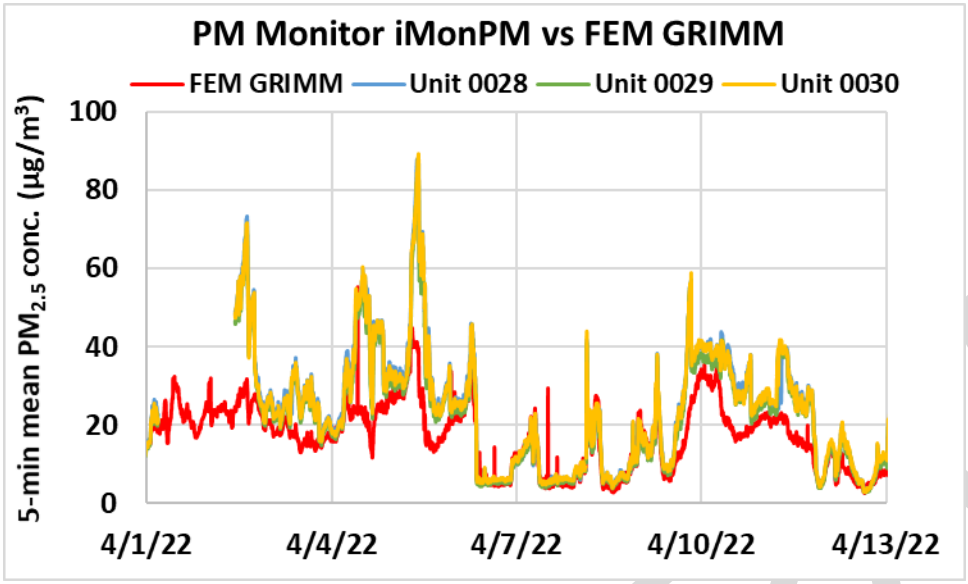
- The iMonPM sensors showed strong correlations with the corresponding GRIMM data ($0.77 < R^2 < 0.79$)
- Overall, the iMonPM sensors overestimated the $PM_{1.0}$ mass concentrations as measured by GRIMM
- The iMonPM sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by GRIMM



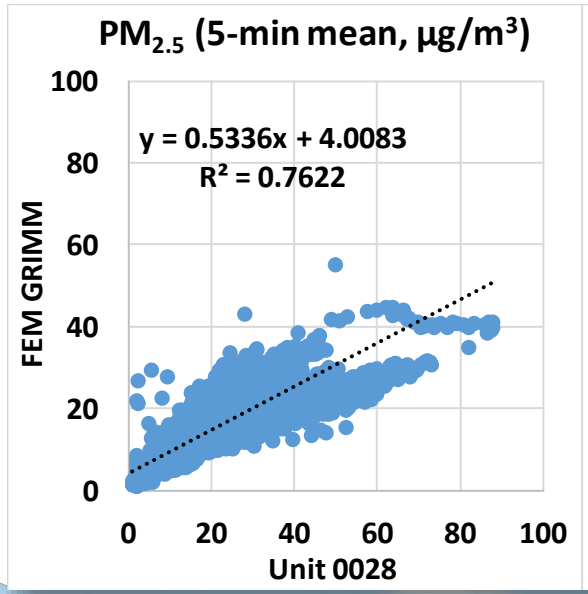


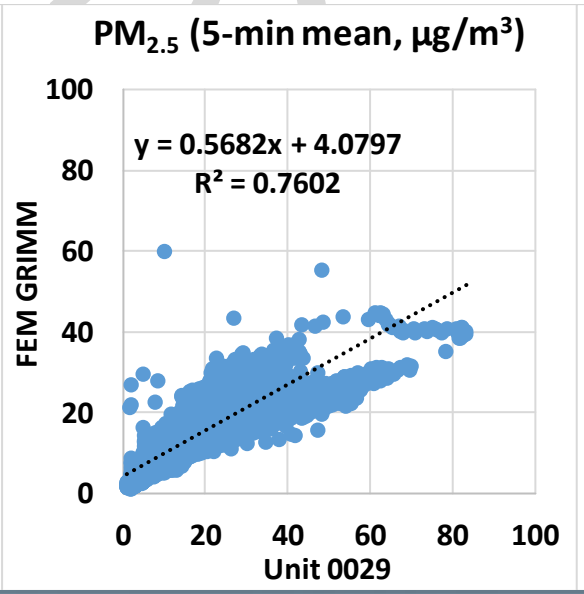


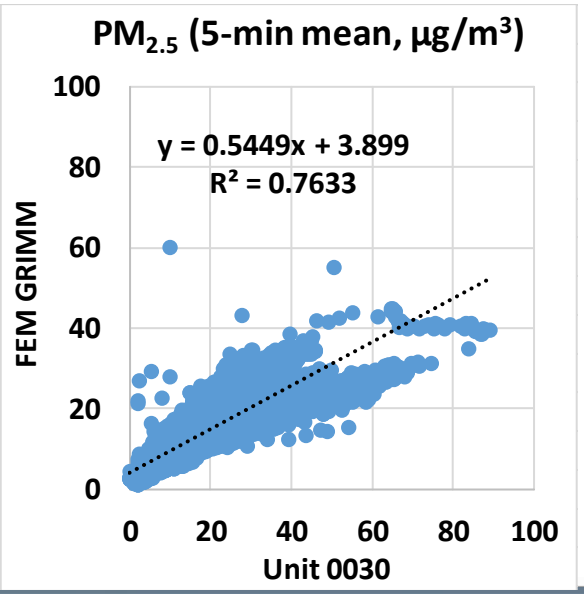
iMonPM vs FEM GRIMM ($PM_{2.5}$; 5-min mean)



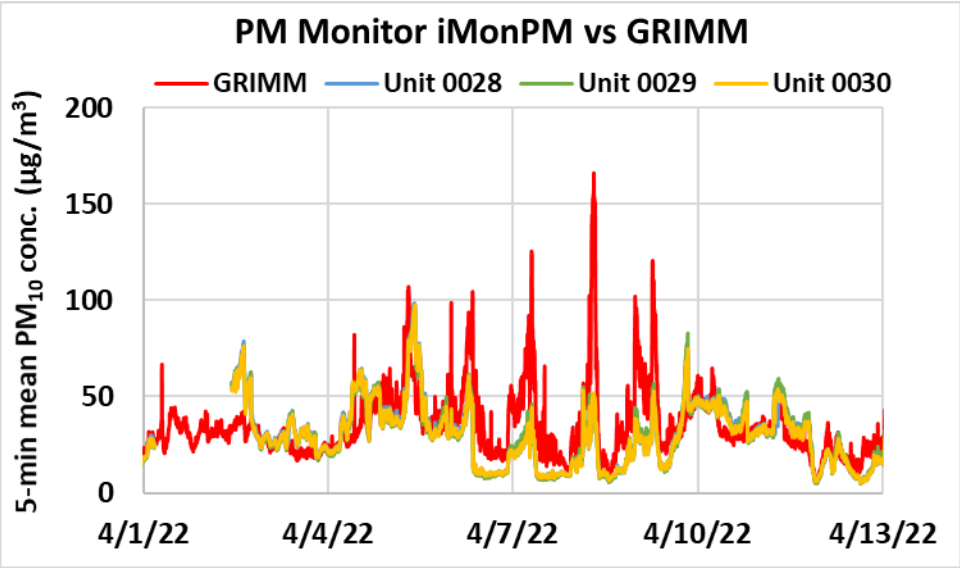
- The iMonPM sensors showed strong correlations with the corresponding FEM GRIMM data ($0.76 < R^2 < 0.77$)
- Overall, the iMonPM sensors overestimated the $PM_{2.5}$ mass concentrations as measured by FEM GRIMM
- The iMonPM sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM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



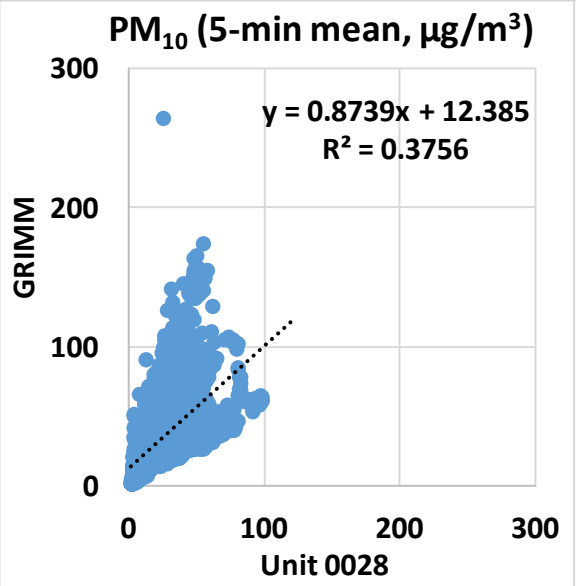


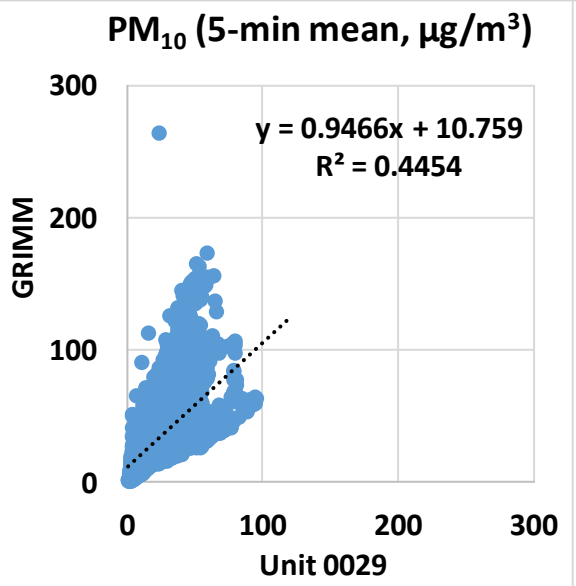


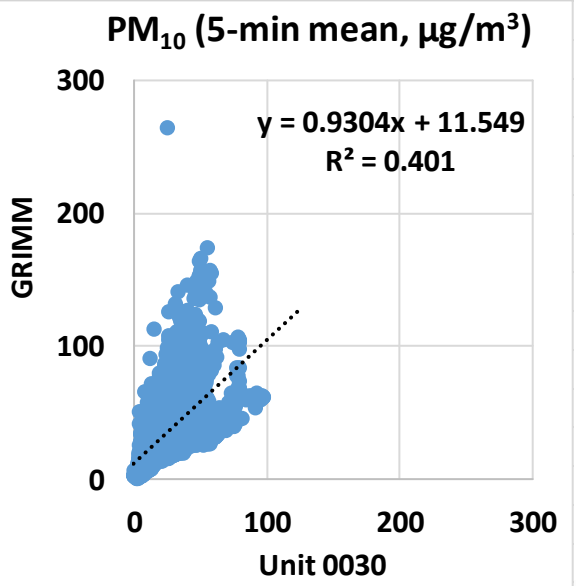
iMonPM vs GRIMM (PM_{10}; 5-min mean)



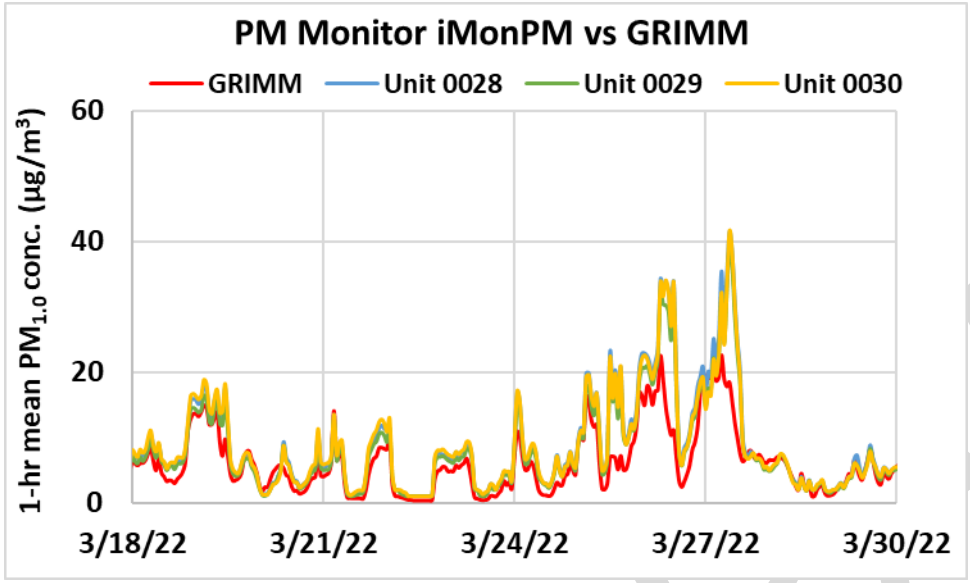
- The iMonPM sensors showed weak correlations with the corresponding GRIMM data ($0.37 < R^2 < 0.45$)
- Overall, the iMonPM sensors underestimated the PM_{10} mass concentrations as measured by GRIMM
- The iMonPM sensors sometimes seemed to track the PM_{10} diurnal variations as recorded by GRIMM



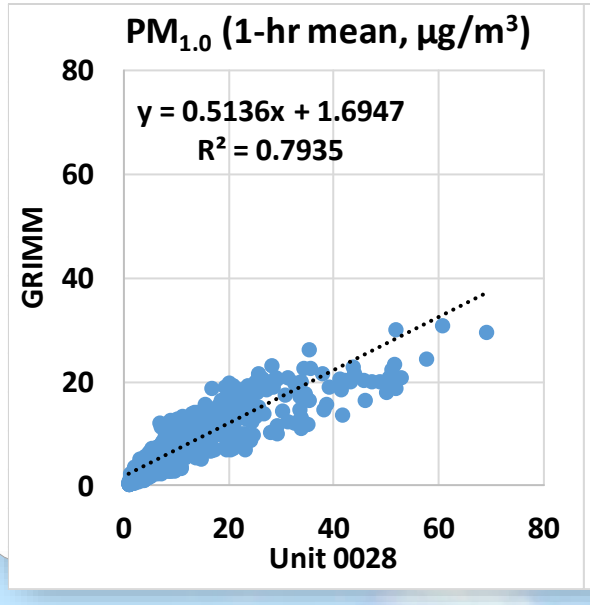


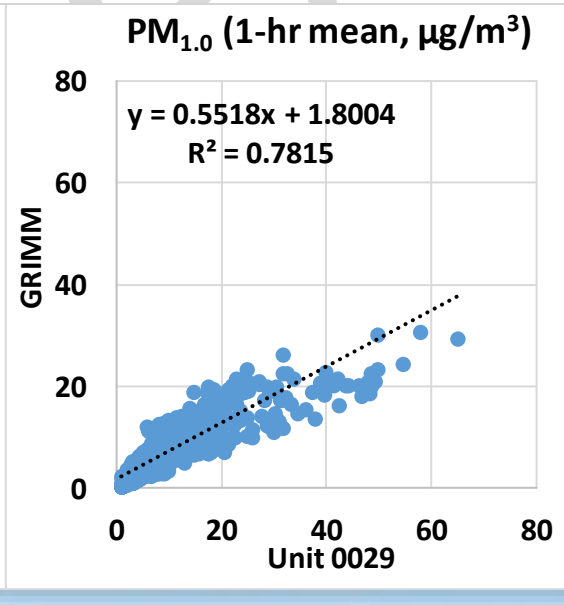


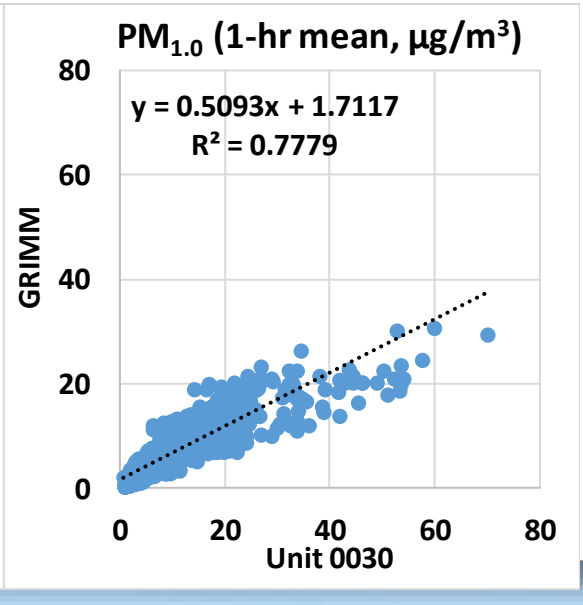
iMonPM vs GRIMM ($PM_{1.0}$; 1-hr mean)



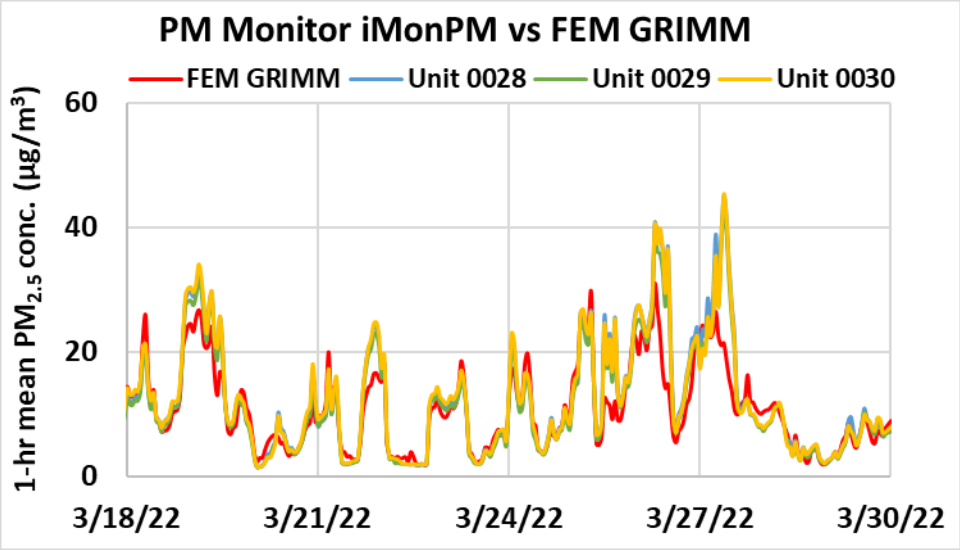
- The iMonPM sensors showed strong correlations with the corresponding GRIMM data ($0.77 < R^2 < 0.80$)
- Overall, the iMonPM sensors overestimated the $PM_{1.0}$ mass concentrations as measured by GRIMM
- The iMonPM sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by GRIMM



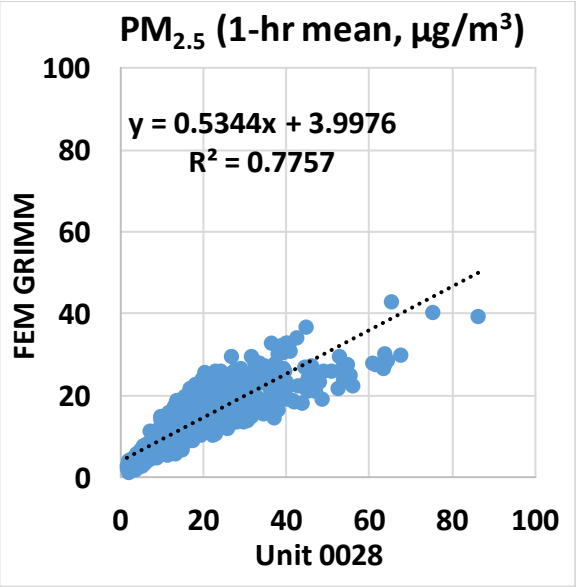


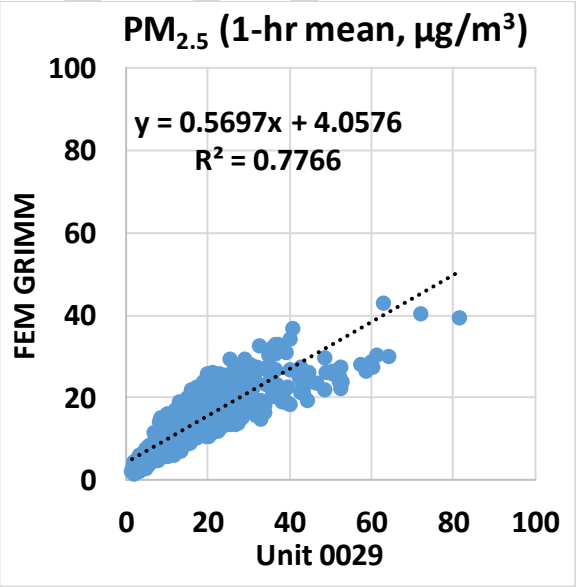


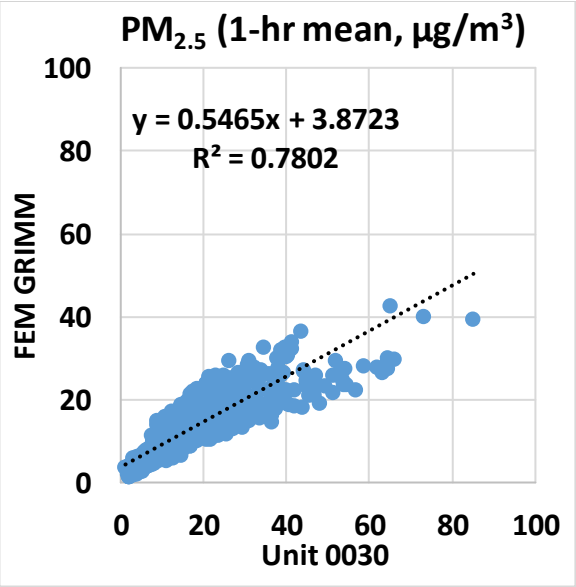
iMonPM vs FEM GRIMM ($PM_{2.5}$; 1-hr mean)



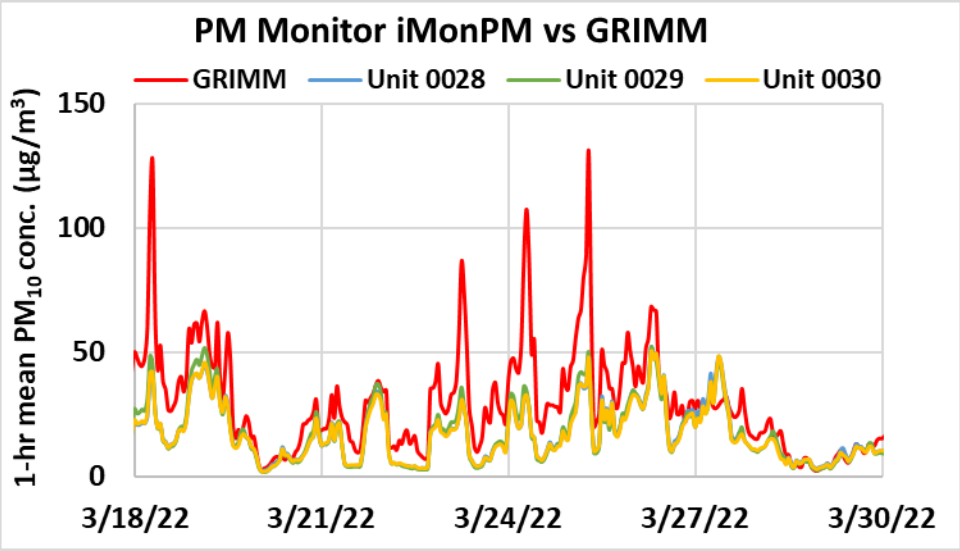
- The iMonPM sensors showed strong correlations with the corresponding FEM GRIMM data ($0.77 < R^2 < 0.79$)
- Overall, the iMonPM sensors overestimated the $PM_{2.5}$ mass concentrations as measured by FEM GRIMM
- The iMonPM sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM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



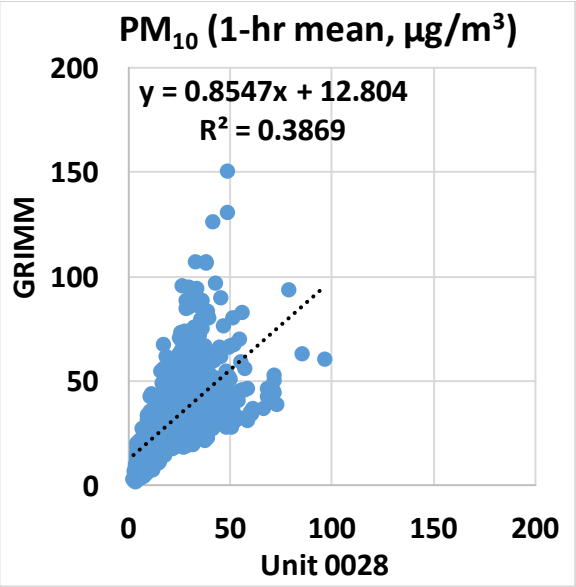


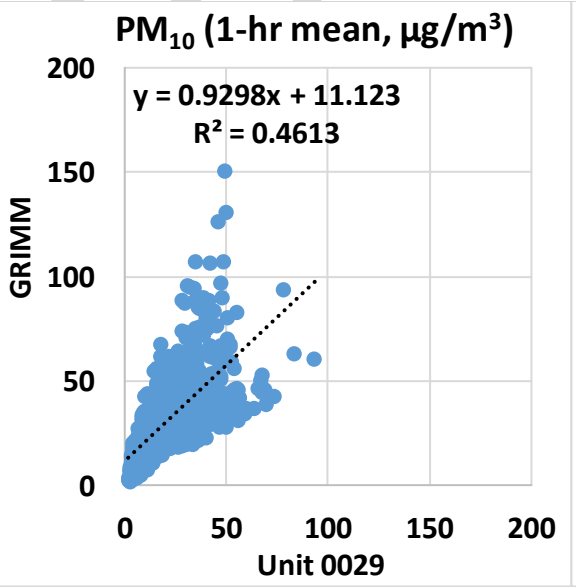


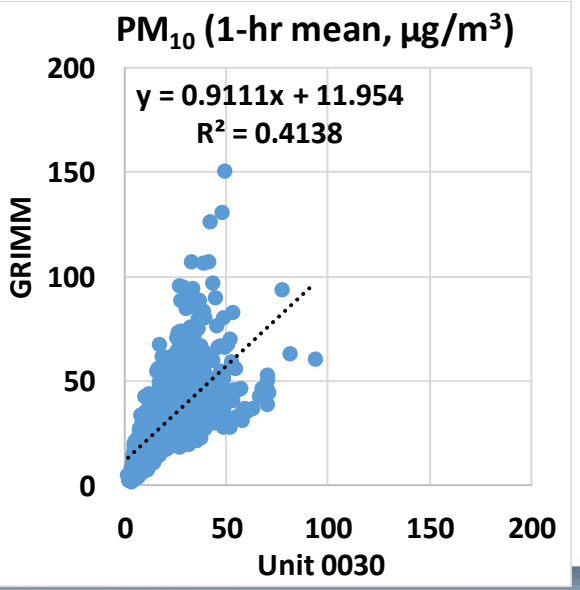
iMonPM vs GRIMM (PM_{10}; 1-hr mean)



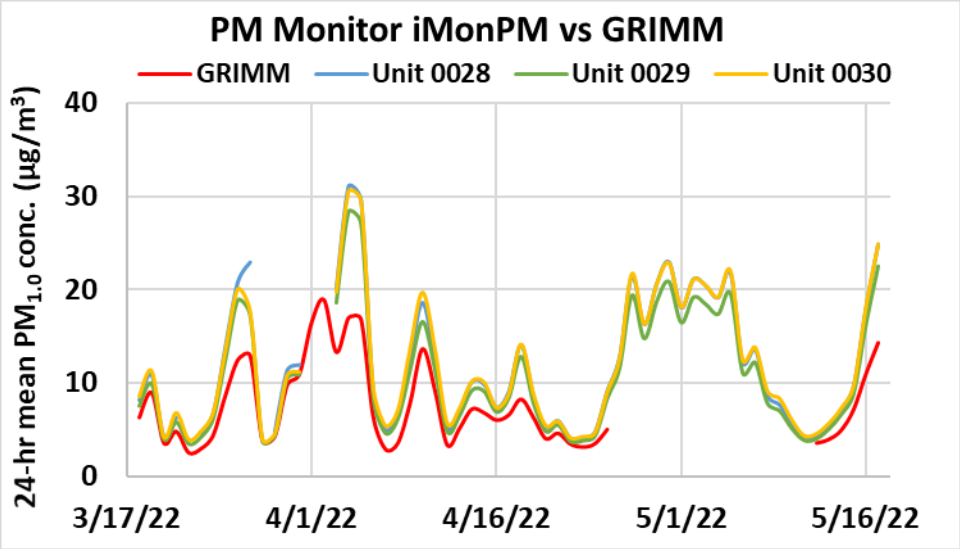
- The iMonPM sensors showed weak correlations with the corresponding GRIMM data ($0.38 < R^2 < 0.47$)
- Overall, the iMonPM sensors underestimated the PM_{10} mass concentrations as measured by GRIMM
- The iMonPM sensors sometimes seemed to track the PM_{10} diurnal variations as recorded by GRIMM



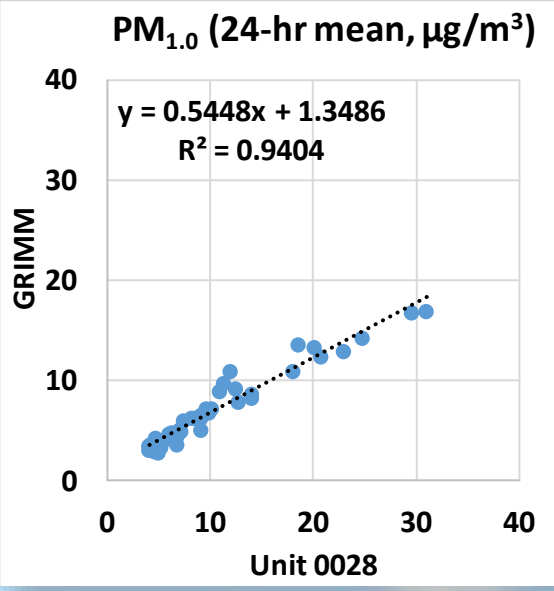


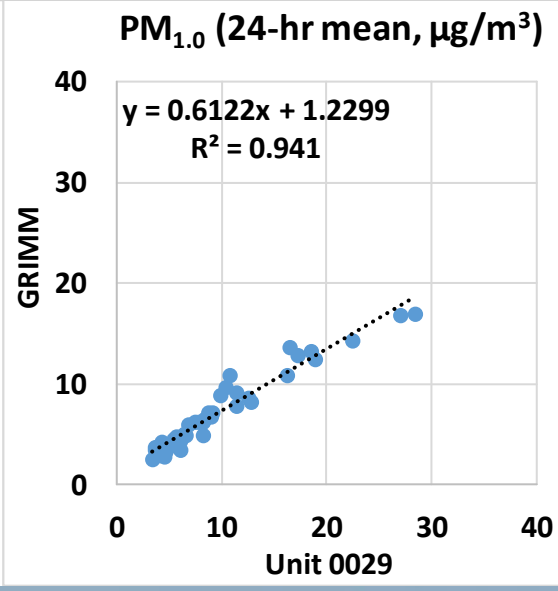


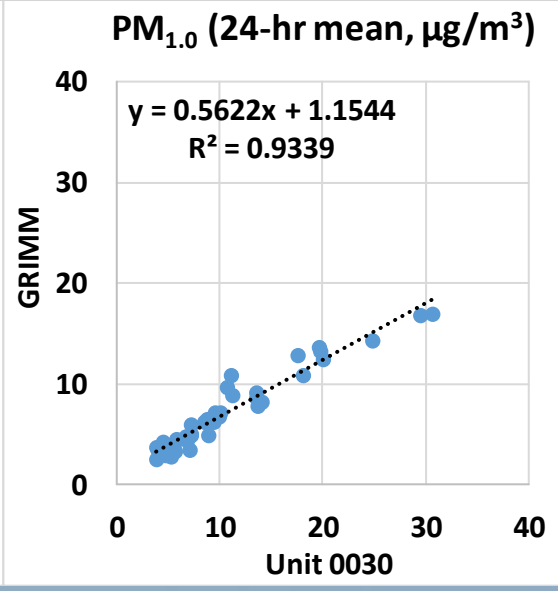
iMonPM vs GRIMM ($PM_{1.0}$; 24-hr mean)



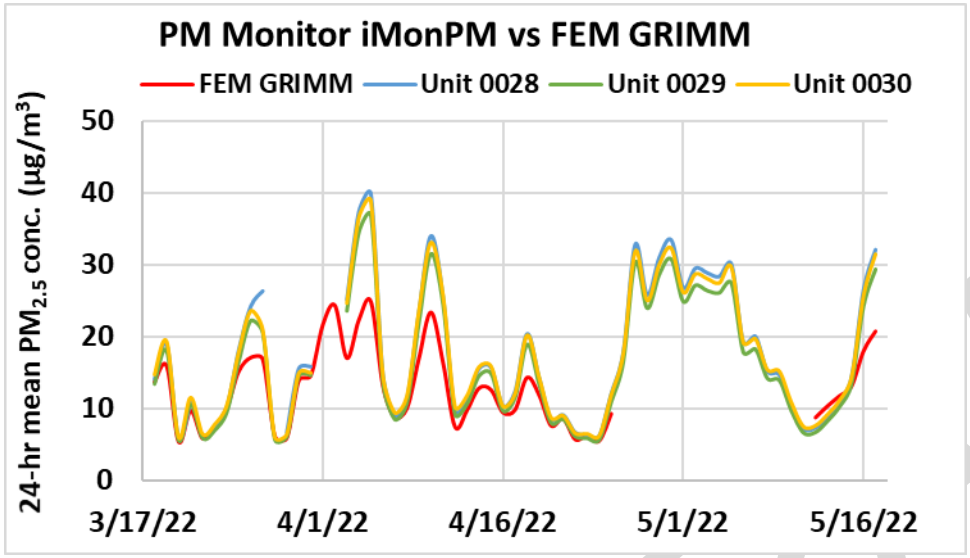
- The iMonPM sensors showed very strong correlations with the corresponding GRIMM data ($0.93 < R^2 < 0.95$)
- Overall, the iMonPM sensors overestimated the $PM_{1.0}$ mass concentrations as measured by GRIMM
- The iMonPM sensors seemed to track the $PM_{1.0}$ daily variations as recorded by GRIMM



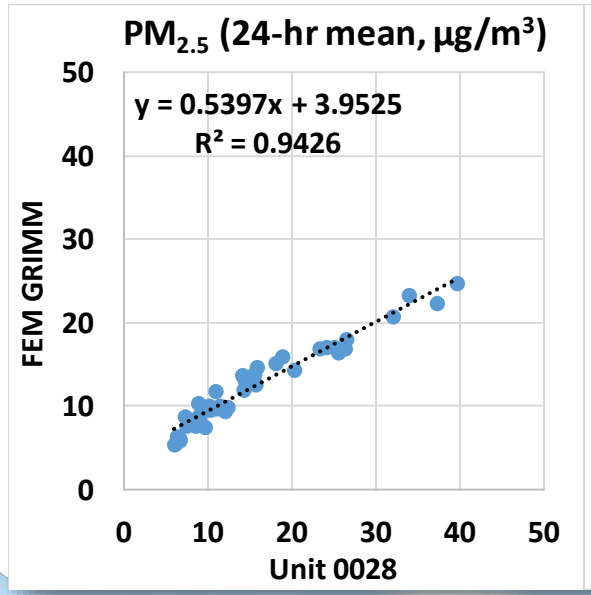


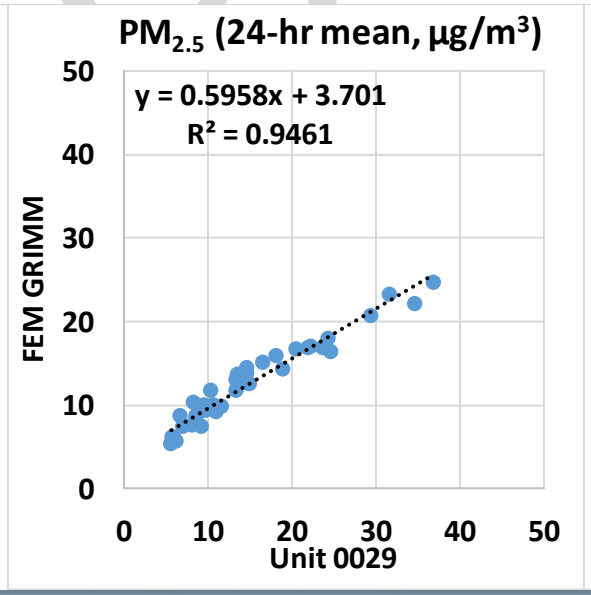


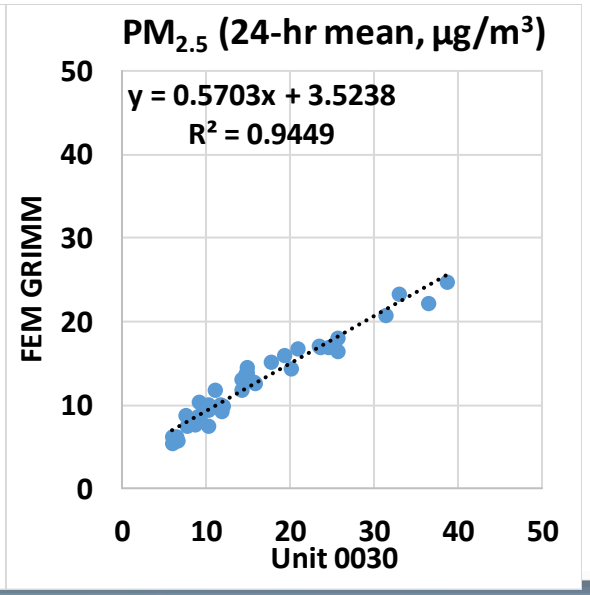
iMonPM vs FEM GRIMM ($PM_{2.5}$; 24-hr mean)



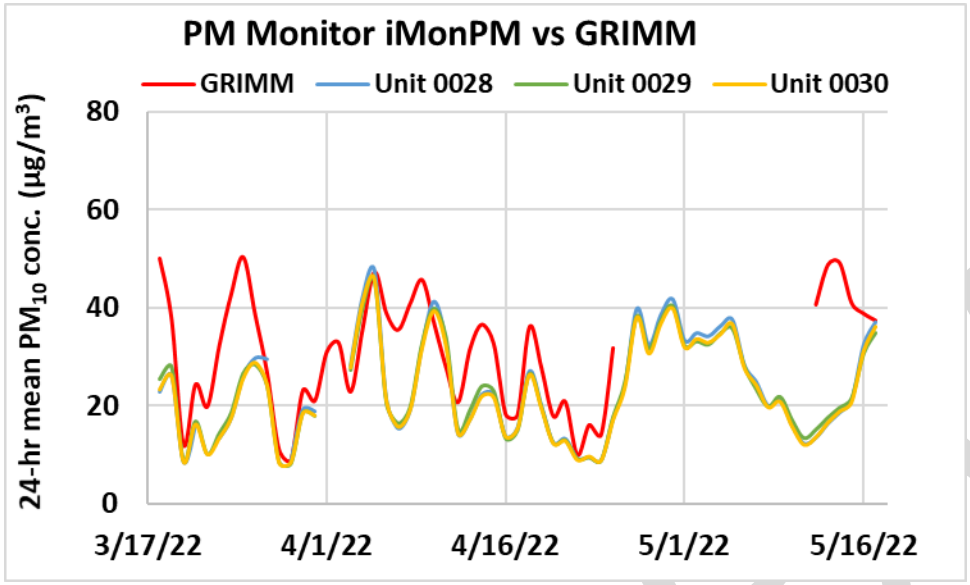
- The iMonPM sensors showed very strong correlations with the corresponding FEM GRIMM data ($0.94 < R^2 < 0.95$)
- Overall, the iMonPM sensors overestimated the $PM_{2.5}$ mass concentrations as measured by FEM GRIMM
- The iMonPM sensors seemed to track the $PM_{2.5}$ daily variations as recorded by FEM GRIMM



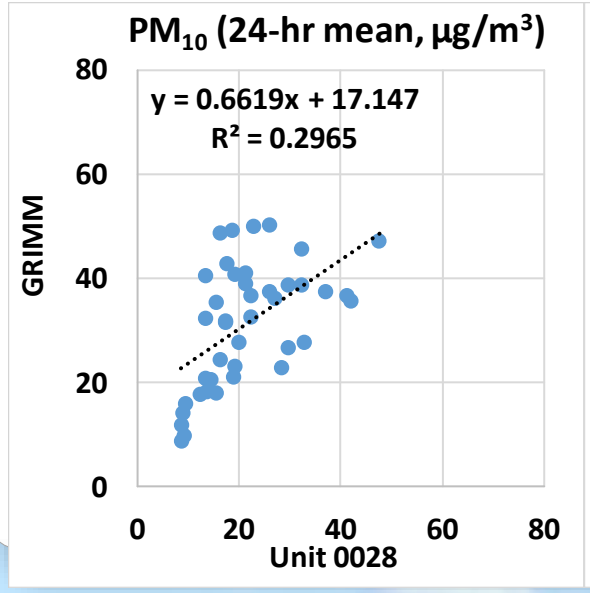


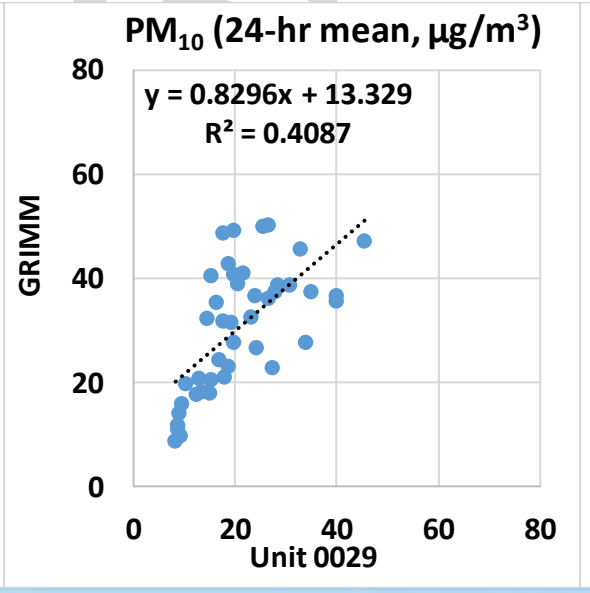


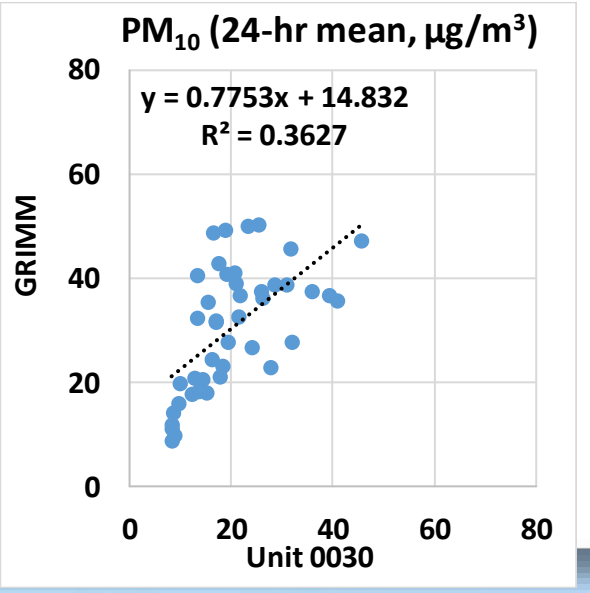
iMonPM vs GRIMM (PM_{10}; 24-hr mean)



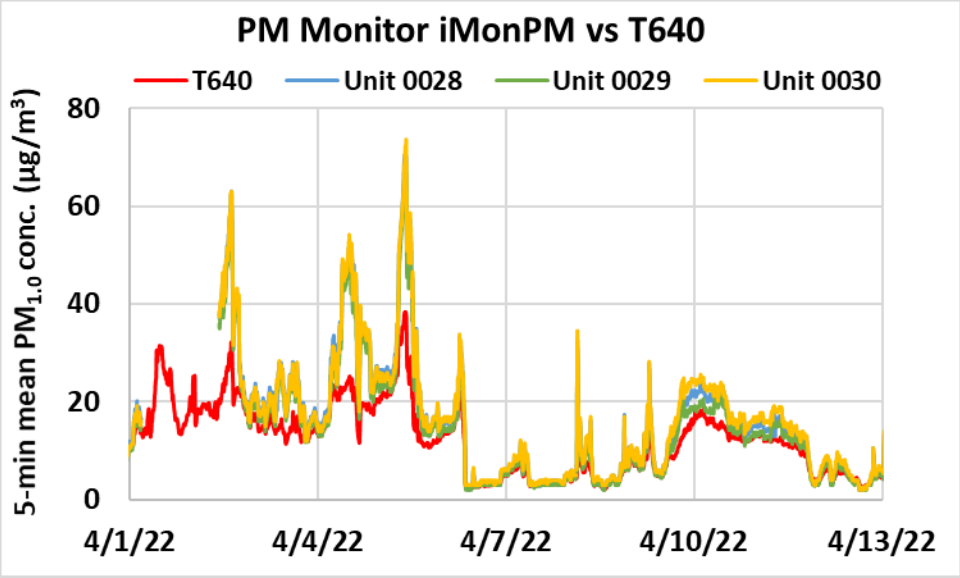
- The iMonPM sensors showed very weak to weak correlations with the corresponding GRIMM data ($0.29 < R^2 < 0.41$)
- Overall, the iMonPM sensors underestimated the PM_{10} mass concentrations as measured by GRIMM
- The iMonPM sensors sometimes seemed to track the PM_{10} daily variations as recorded by GRIMM



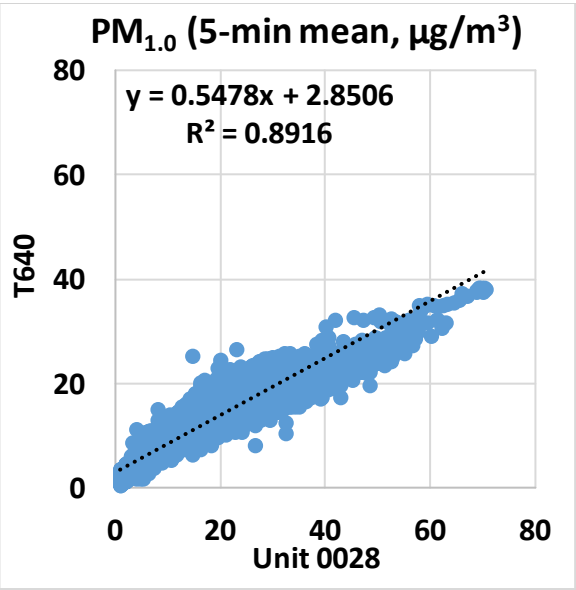


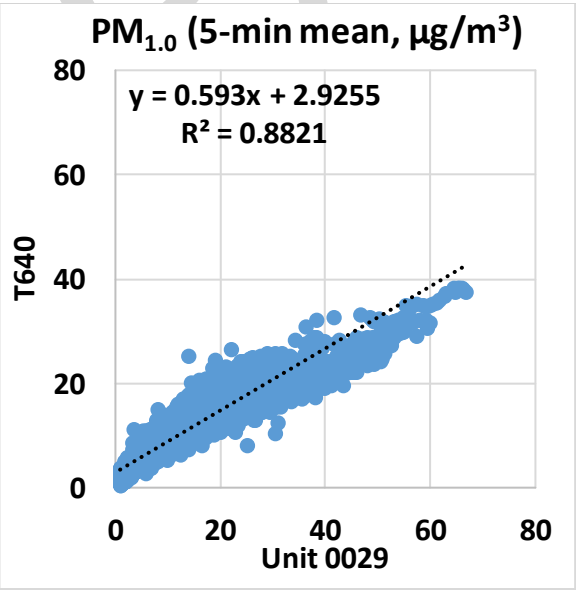


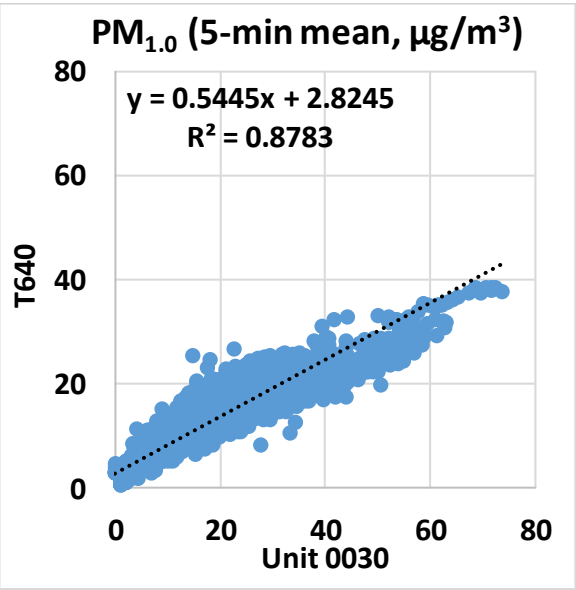
iMonPM vs T640 ($PM_{1.0}$; 5-min mean)



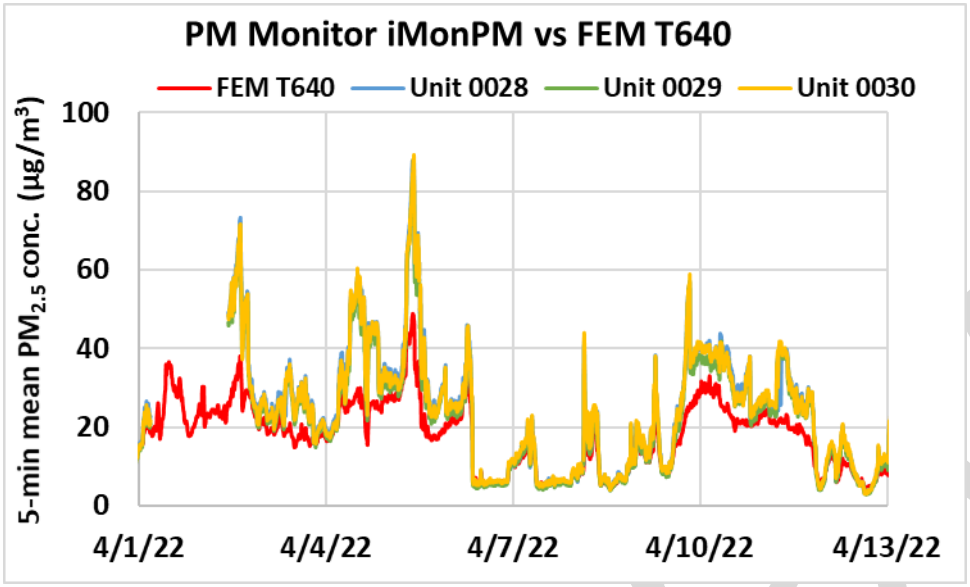
- The iMonPM sensors showed strong correlations with the corresponding T640 data ($0.87 < R^2 < 0.90$)
- Overall, the iMonPM sensors overestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The iMonPM sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by T640



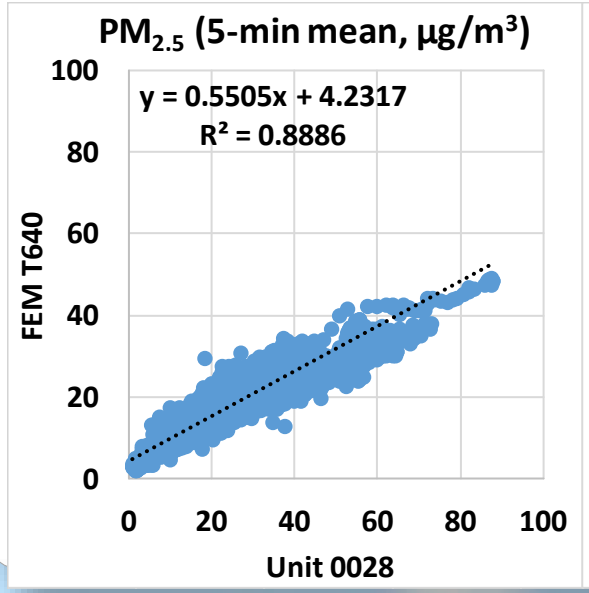


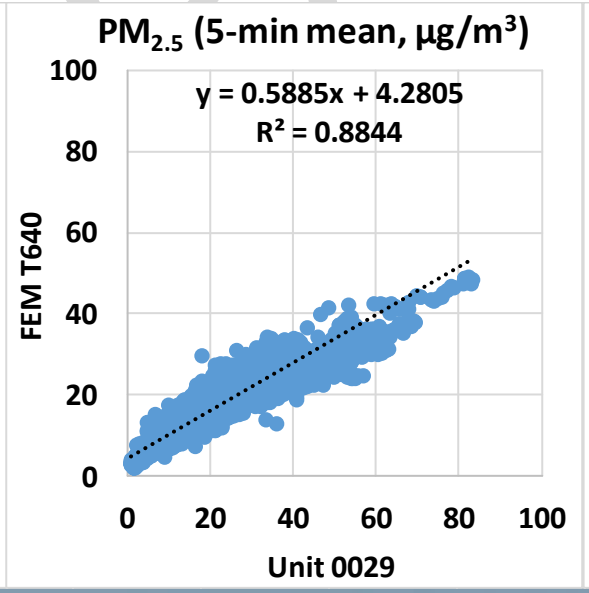


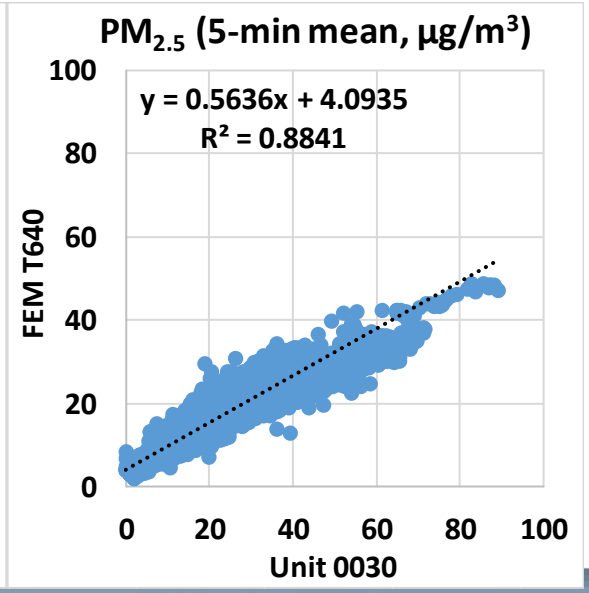
iMonPM vs FEM T640 ($PM_{2.5}$; 5-min mean)



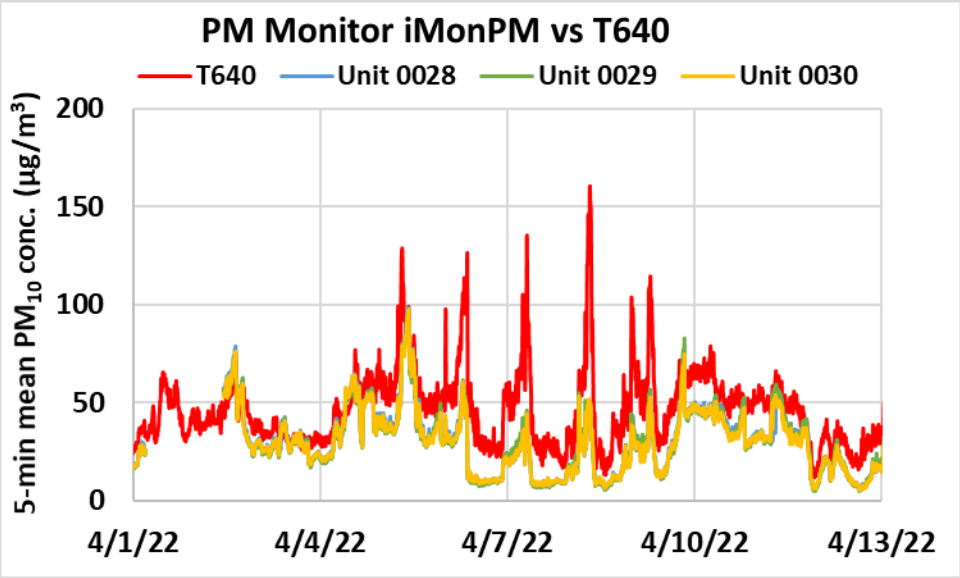
- The iMonPM sensors showed strong correlations with the corresponding FEM T640 data ($0.88 < R^2 < 0.89$)
- Overall, the iMonPM sensors overestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The iMonPM sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



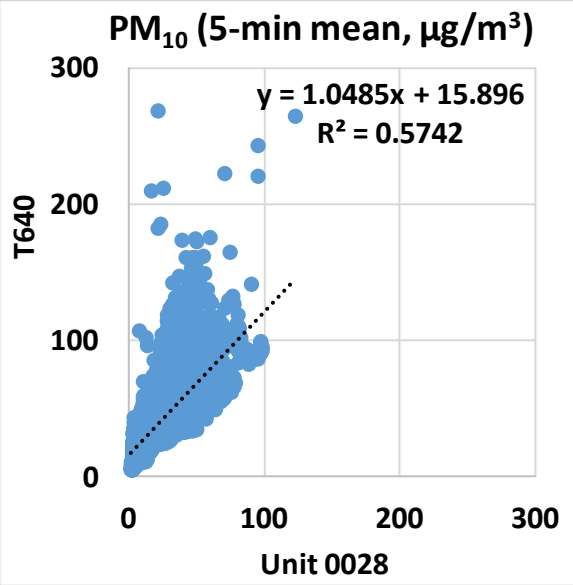


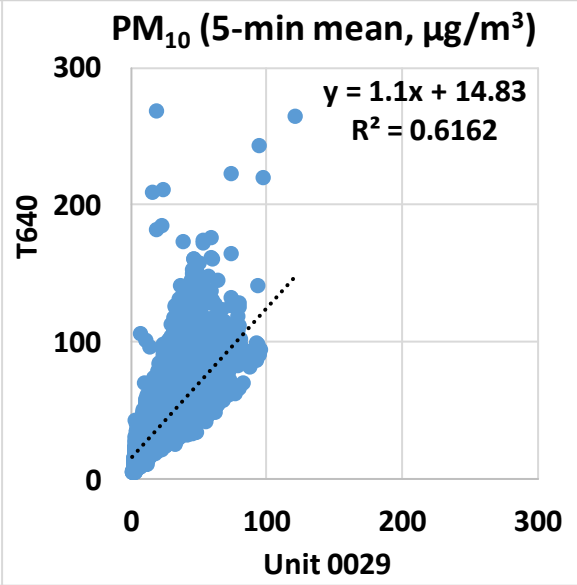


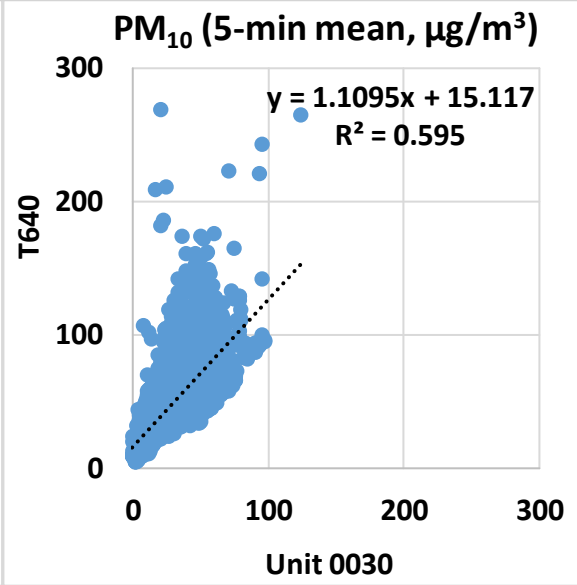
iMonPM vs T640 (PM_{10}; 5-min mean)



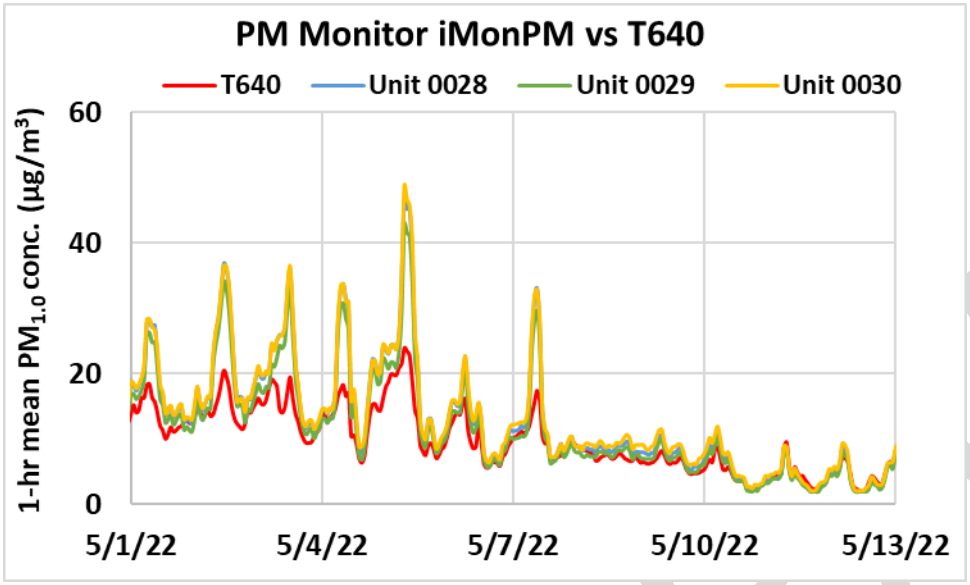
- The iMonPM sensors showed moderate correlations with the corresponding T640 data ($0.57 < R^2 < 0.62$)
- Overall, the iMonPM sensors underestimated the PM_{10} mass concentrations as measured by T640
- The iMonPM sensors seemed to track the PM_{10} diurnal variations as recorded by T640



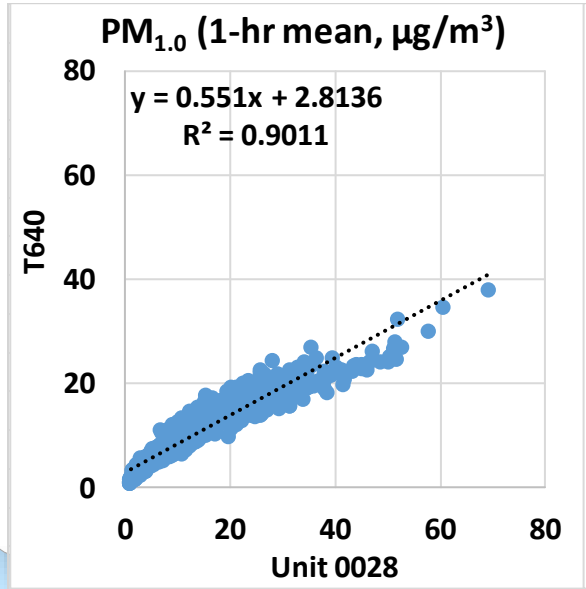


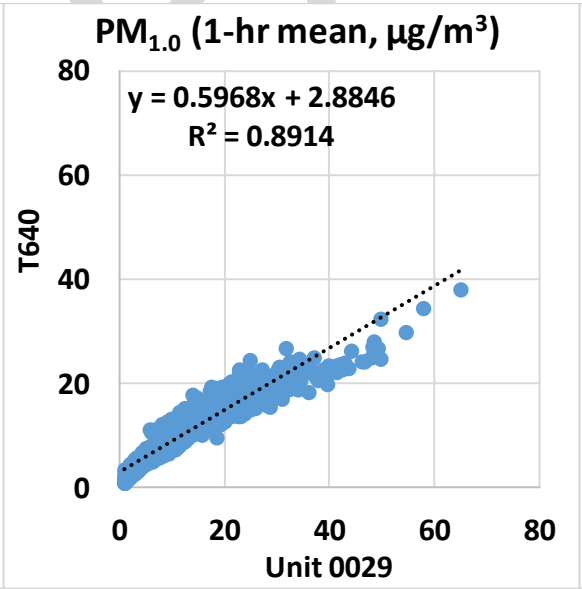


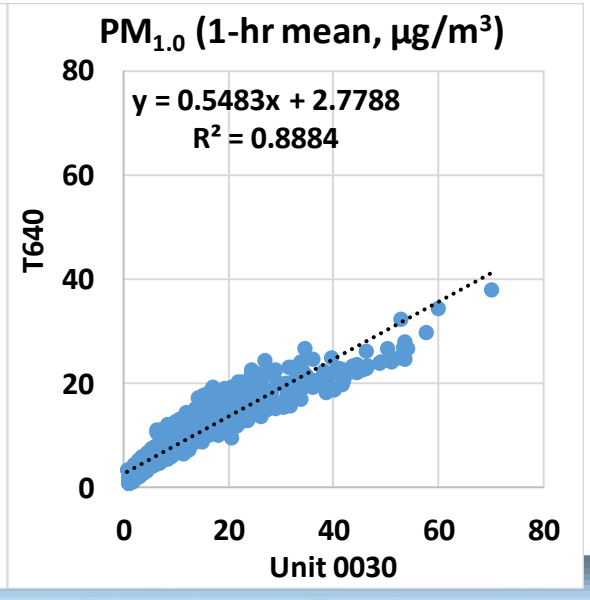
iMonPM vs T640 ($PM_{1.0}$; 1-hr mean)



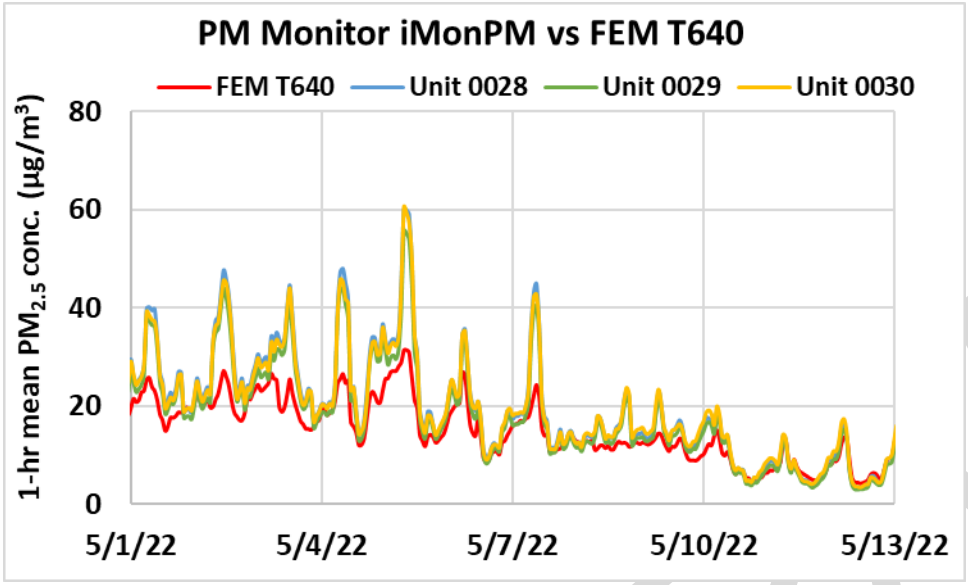
- The iMonPM sensors showed strong to very strong correlations with the corresponding T640 data ($0.88 < R^2 < 0.91$)
- Overall, the iMonPM sensors overestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The iMonPM sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by T640



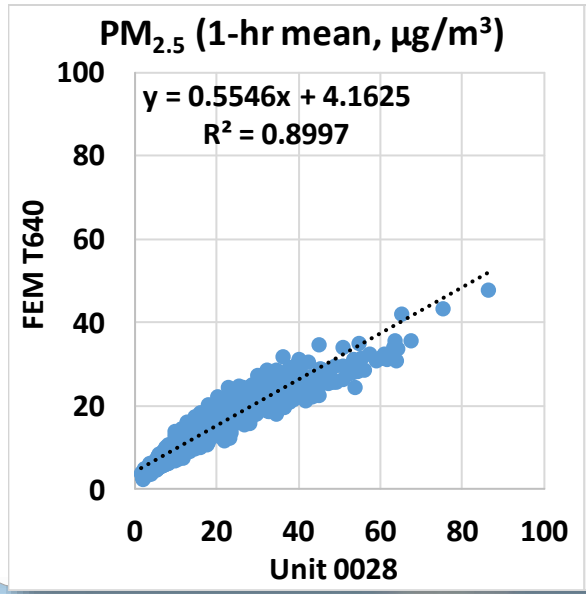


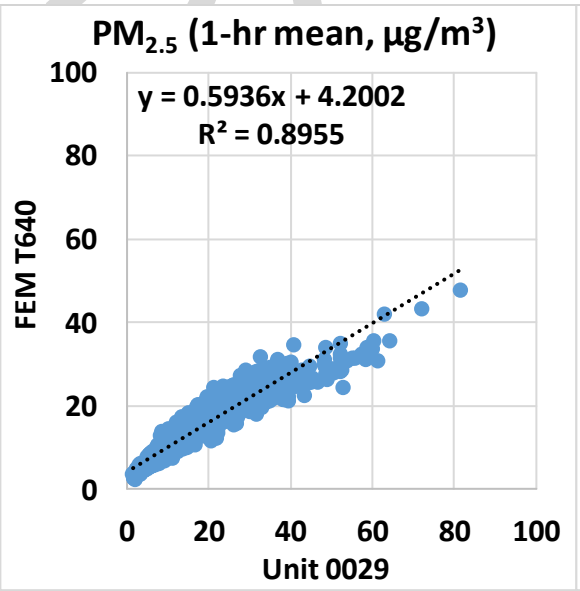


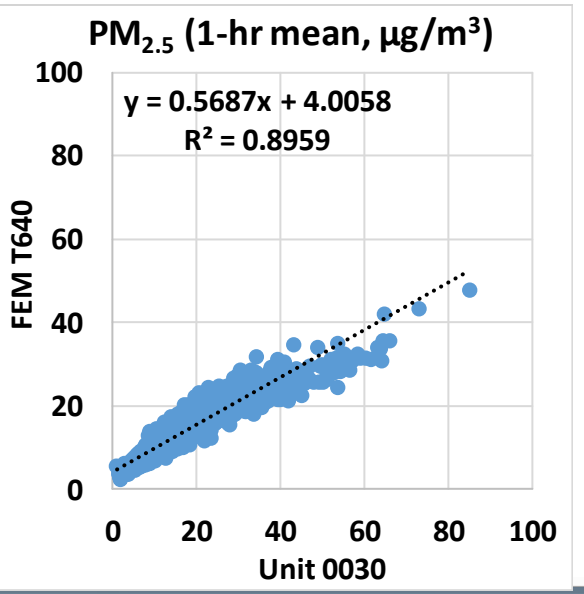
iMonPM vs FEM T640 ($PM_{2.5}$; 1-hr mean)



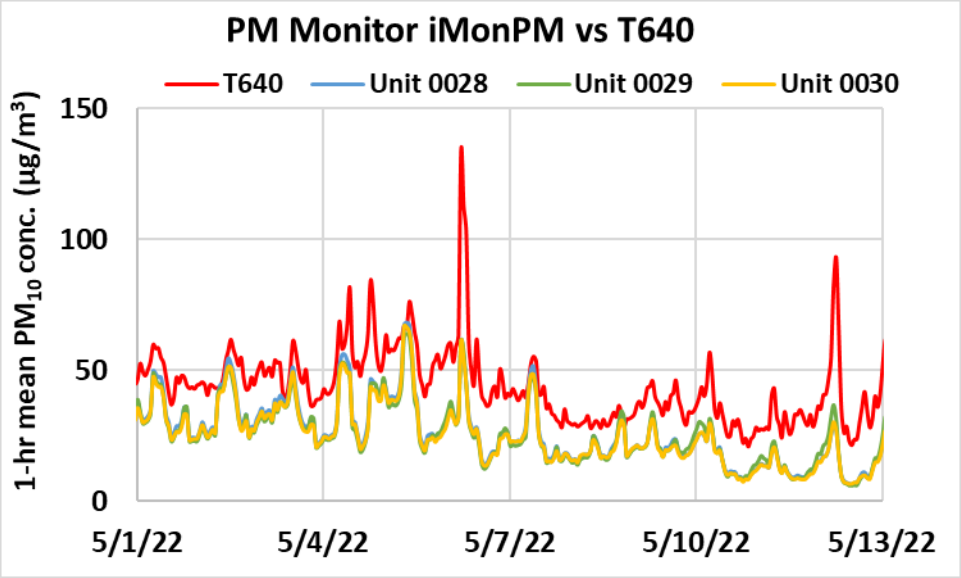
- The iMonPM sensors showed strong correlations with the corresponding FEM T640 data ($0.89 < R^2 < 0.90$)
- Overall, the iMonPM sensors overestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The iMonPM sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



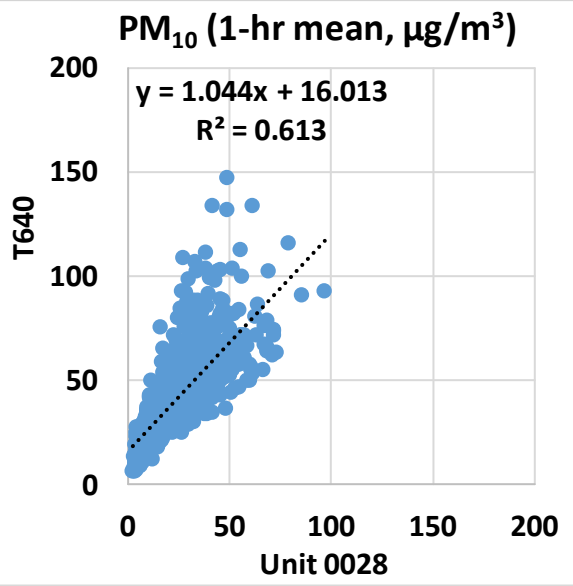


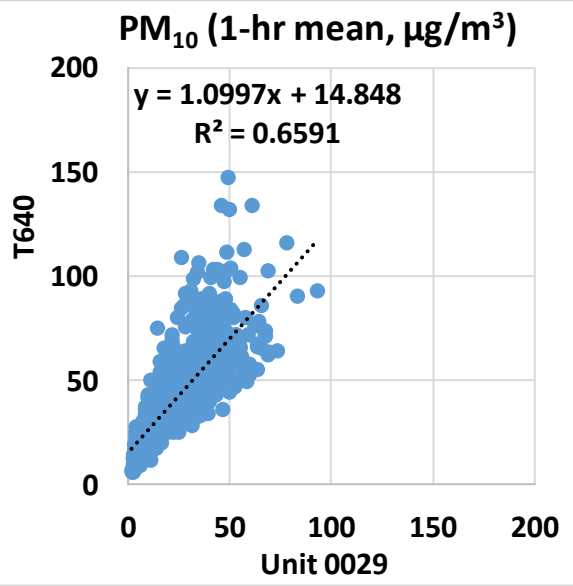


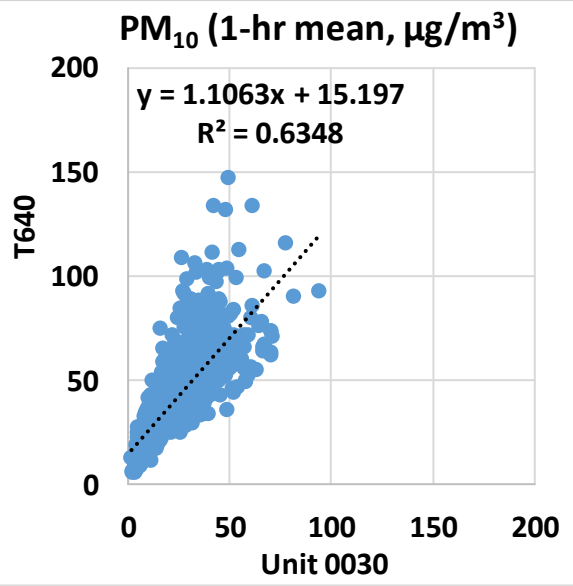
iMonPM vs T640 (PM_{10}; 1-hr mean)



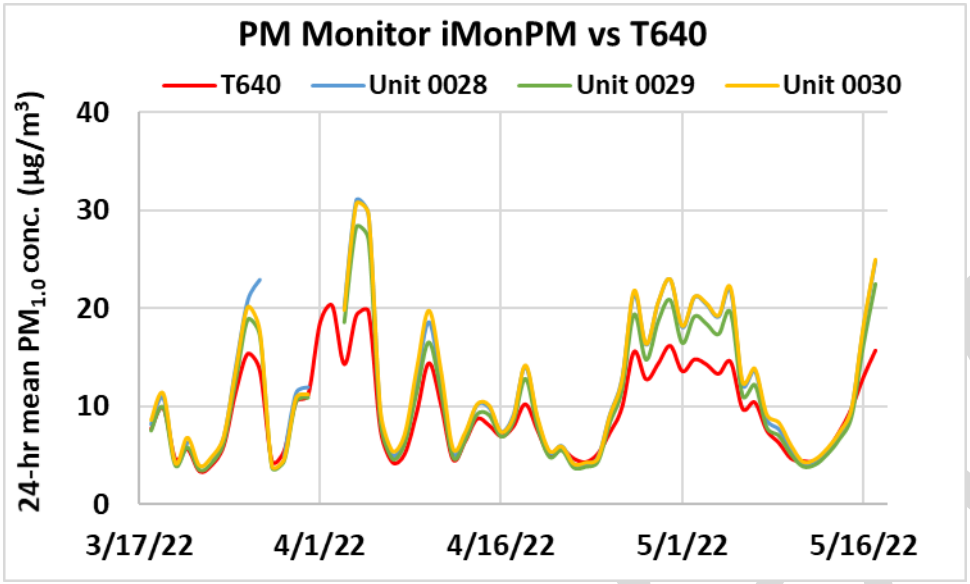
- The iMonPM sensors showed moderate correlations with the corresponding T640 data ($0.61 < R^2 < 0.66$)
- Overall, the iMonPM sensors underestimated the PM_{10} mass concentrations as measured by T640
- The iMonPM sensors seemed to track the PM_{10} diurnal variations as recorded by T640



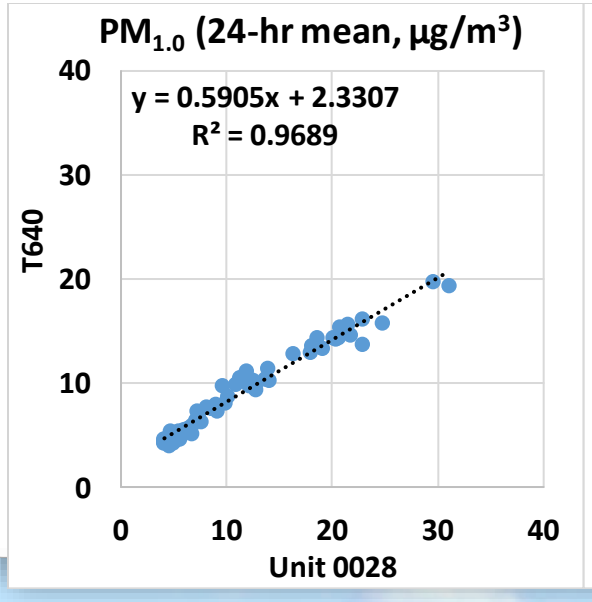


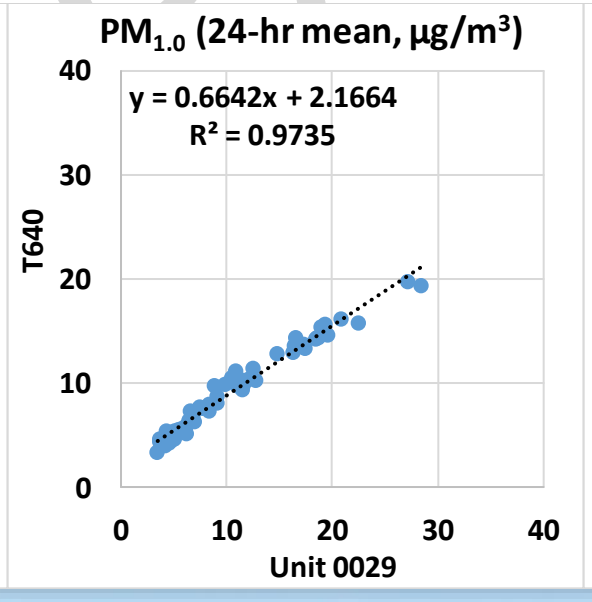


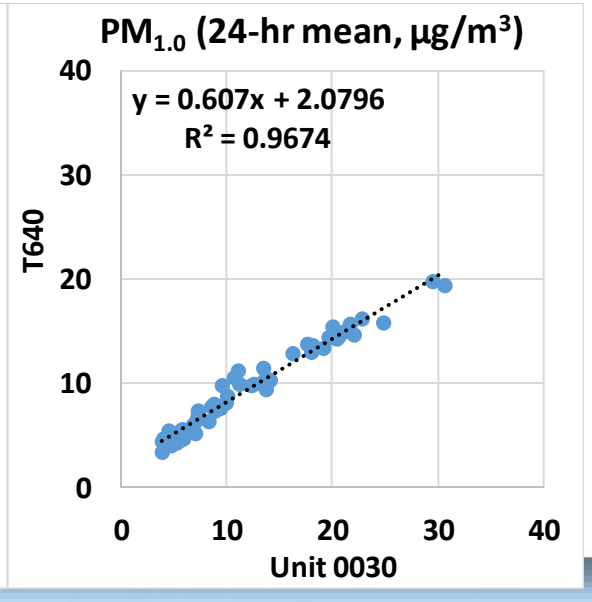
iMonPM vs T640 ($PM_{1.0}$; 24-hr mean)



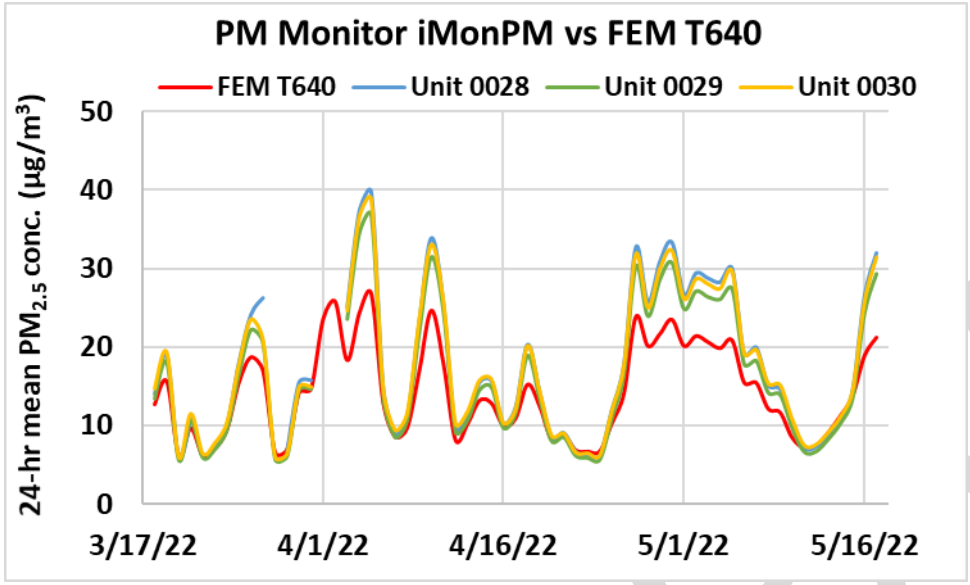
- The iMonPM sensors showed very strong correlations with the corresponding T640 data ($0.96 < R^2 < 0.98$)
- Overall, the iMonPM sensors overestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The iMonPM sensors seemed to track the $PM_{1.0}$ daily variations as recorded by T640



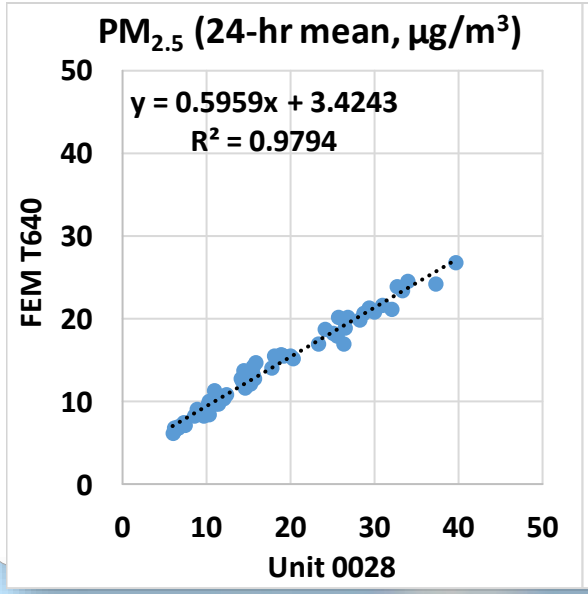


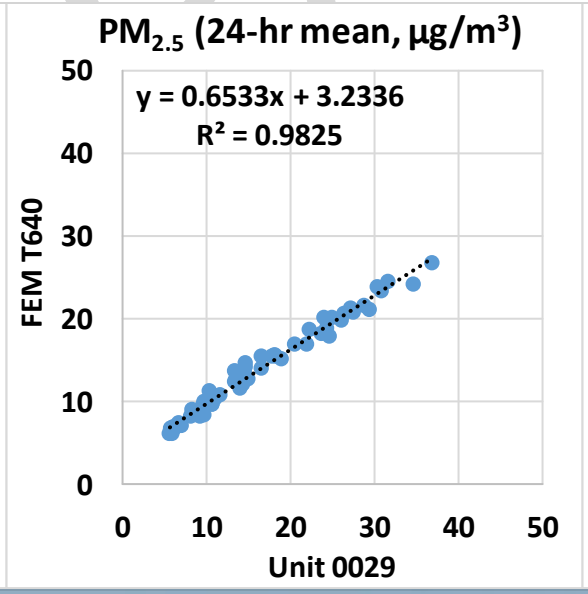


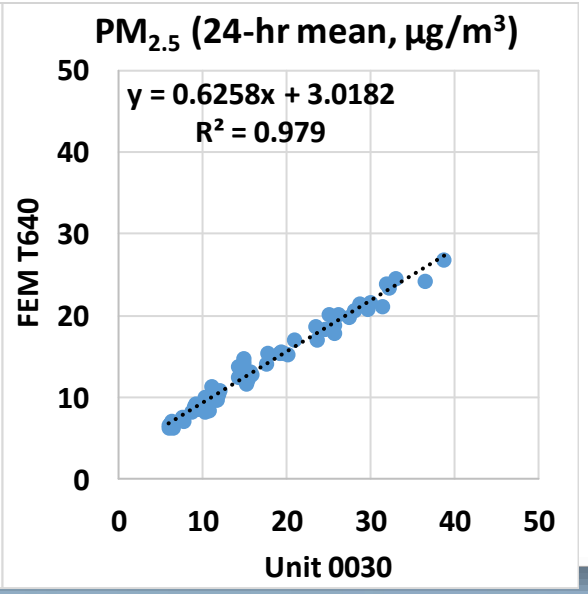
iMonPM vs FEM T640 ($PM_{2.5}$; 24-hr mean)



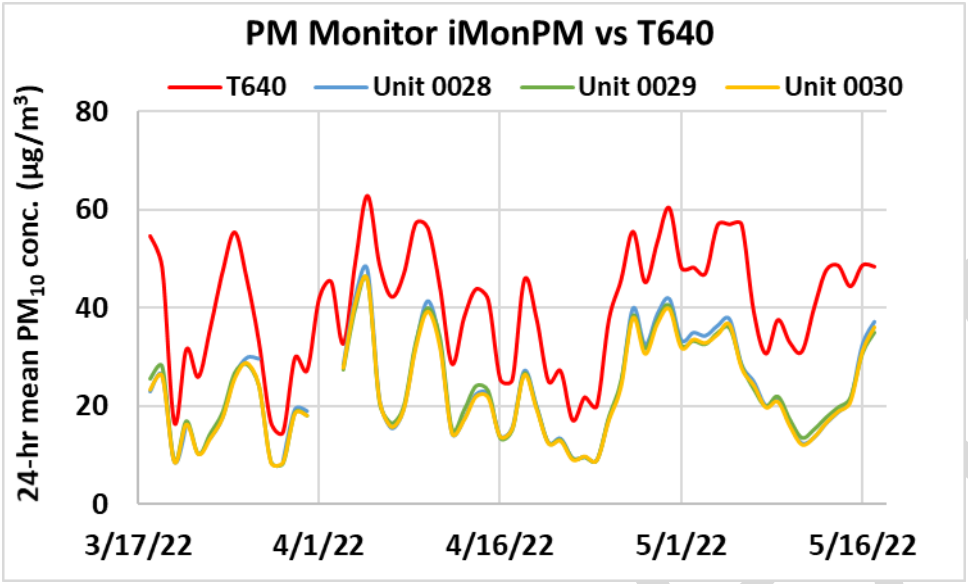
- The iMonPM sensors showed very strong correlations with the corresponding FEM T640 data ($0.97 < R^2 < 0.99$)
- Overall, the iMonPM sensors overestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The iMonPM sensors seemed to track the $PM_{2.5}$ daily variations as recorded by FEM T640



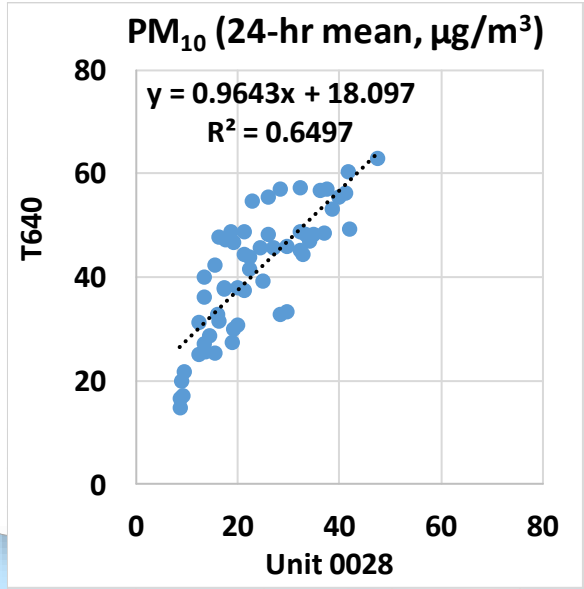


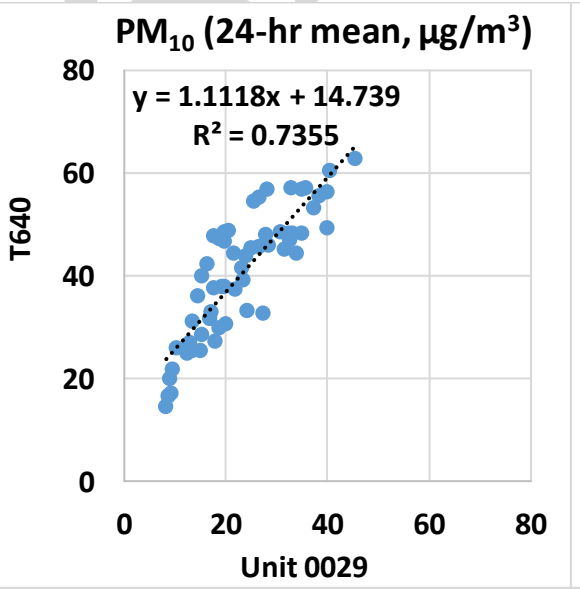


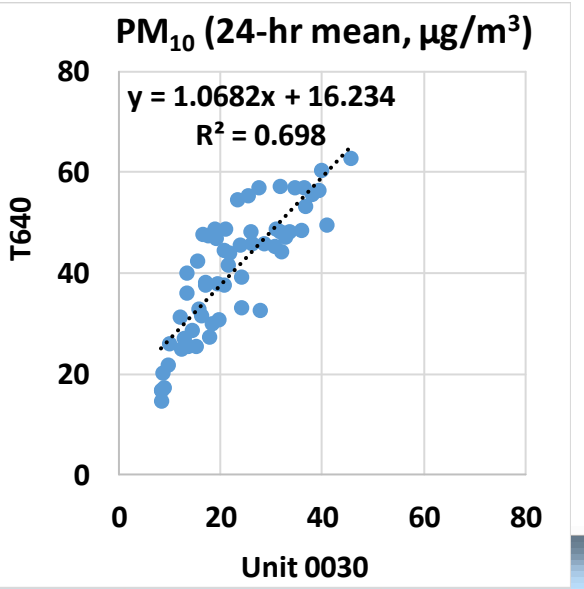
iMonPM vs T640 (PM_{10}; 24-hr mean)



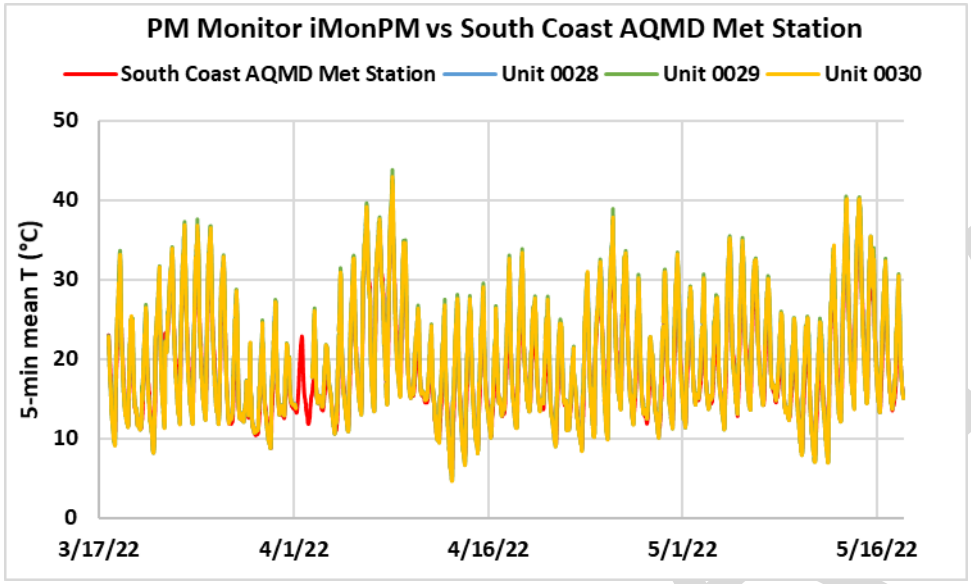
- The iMonPM sensors showed moderate to strong correlations with the corresponding T640 data ($0.64 < R^2 < 0.74$)
- Overall, the iMonPM sensors underestimated the PM_{10} mass concentrations as measured by T640
- The iMonPM sensors seemed to track the PM_{10} daily variations as recorded by T640



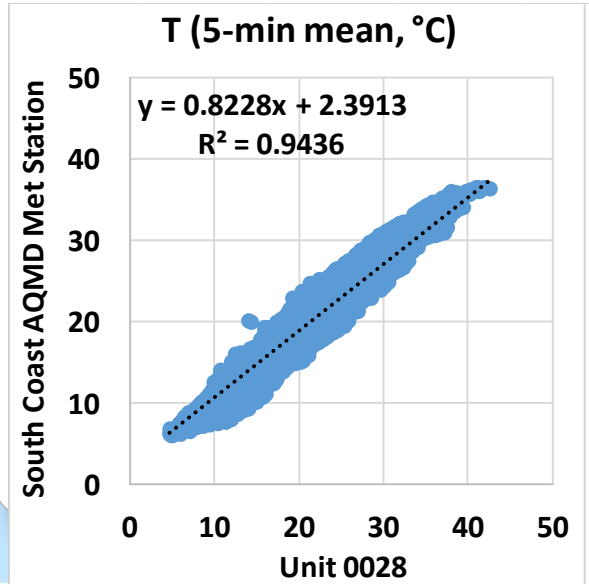


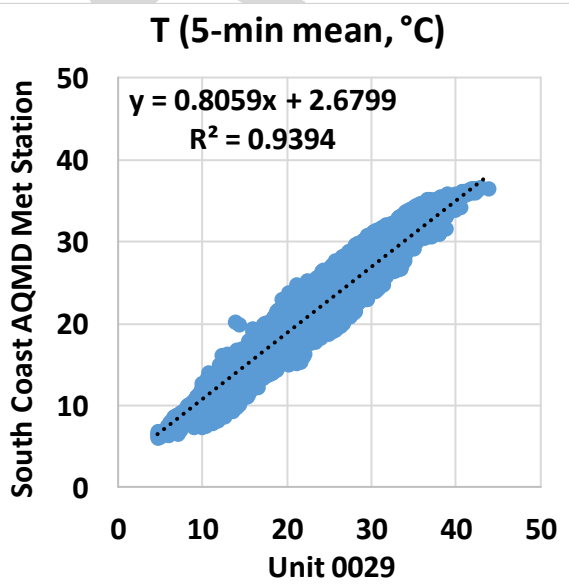


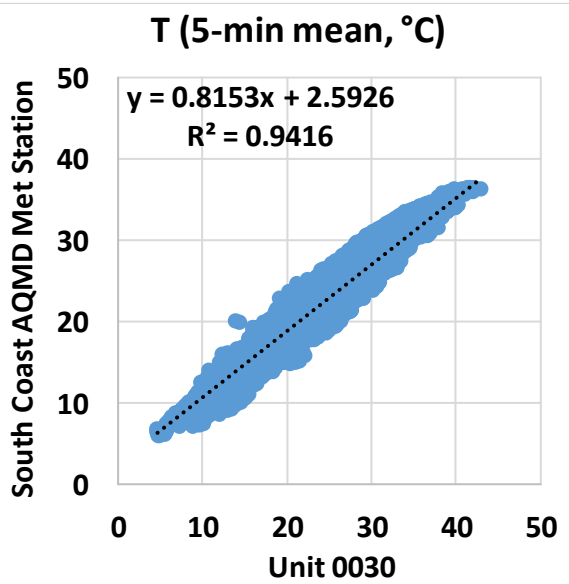
iMonPM vs South Coast AQMD Met Station (Temp; 5-min mean)



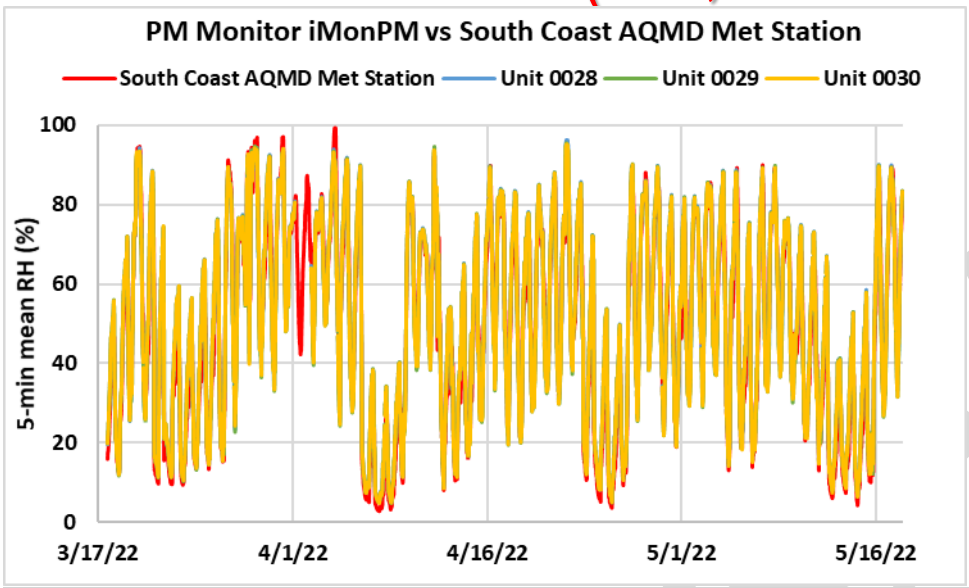
- The iMonPM sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($0.93 < R^2 < 0.95$)
- Overall, the iMonPM sensors overestimated the temperature measurement as recorded by South Coast AQMD Met Station
- The iMonPM sensors seemed to track the diurnal temperature variations as recorded by South Coast AQMD Met Station



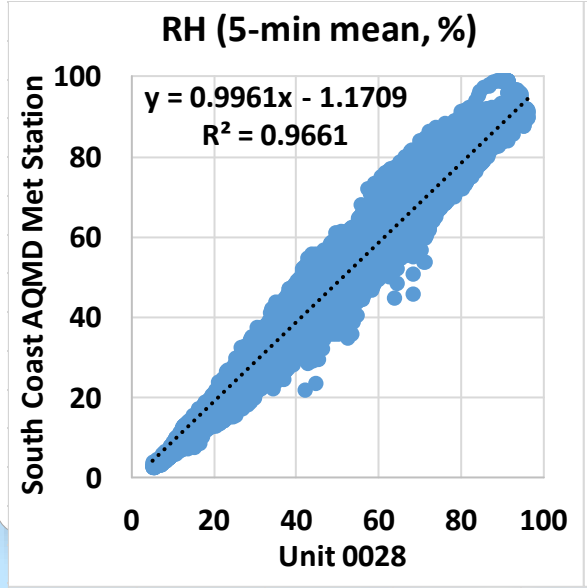


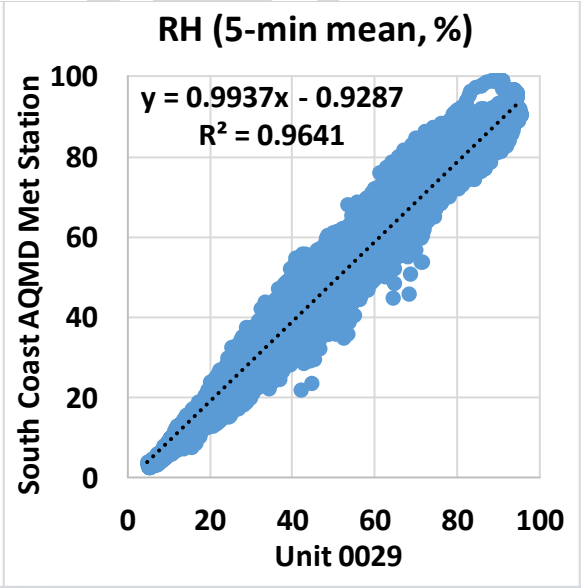


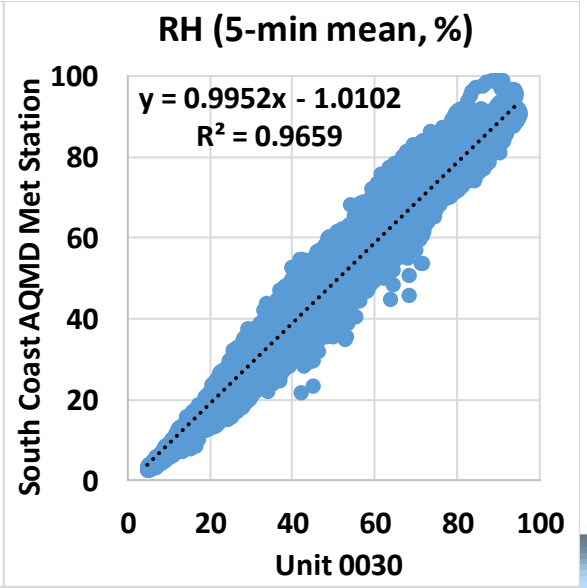
iMonPM vs South Coast AQMD Met Station (RH; 5-min mean)



- The iMonPM sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($0.96 < R^2 < 0.97$)
- Overall, the iMonPM sensors overestimated the RH measurement as recorded by South Coast AQMD Met Station
- The iMonPM sensors seemed to track the diurnal RH variations as recorded by South Coast AQMD Met Station







Summary

	Average of 3 Sensors, $PM_{1.0}$		iMonPM vs GRIMM & T640, $PM_{1.0}$						GRIMM & 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	11.7	9.1	0.77 to 0.89	0.51 to 0.59	1.7 to 2.9	1.5 to 3.5	2.2 to 3.8	4.2 to 6.0	7.5 to 9.6	5.5 to 5.6	0.3 to 38.4
1-hr	11.7	9.0	0.78 to 0.90	0.51 to 0.60	1.7 to 2.9	1.5 to 3.5	2.2 to 3.8	4.0 to 6.0	7.5 to 9.6	5.5	0.4 to 37.9
24-hr	11.6	6.7	0.93 to 0.97	0.54 to 0.66	1.2 to 2.3	1.4 to 3.6	1.8 to 3.6	2.7 to 4.9	7.5 to 9.6	4.4 to 4.6	2.5 to 20.3
	Average of 3 Sensors, $PM_{2.5}$		iMonPM vs FEM GRIMM & FEM T640, $PM_{2.5}$						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	17.3	11.8	0.76 to 0.89	0.53 to 0.59	3.9 to 4.3	2.2 to 3.8	3.4 to 4.3	5.8 to 7.1	12.6 to 14.2	7.2 to 7.3	1.2 to 60.1
1-hr	17.3	11.6	0.78 to 0.90	0.53 to 0.59	3.9 to 4.2	2.2 to 3.8	3.3 to 4.3	5.6 to 7.0	12.6 to 14.2	7.1 to 7.2	1.5 to 47.9
24-hr	17.2	8.9	0.94 to 0.98	0.54 to 0.65	3.0 to 4.0	2.1 to 3.8	2.5 to 3.9	3.9 to 5.4	12.6 to 14.2	5.4 to 5.9	5.5 to 26.7
	Average of 3 Sensors, PM_{10}		iMonPM vs GRIMM & T640, PM_{10}						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	23.2	13.7	0.38 to 0.62	0.87 to 1.11	10.8 to 15.9	-17.6 to -9.6	12.0 to 17.8	17.3 to 21.5	30.7 to 40.5	18.9 to 19.1	1.7 to 268.7
1-hr	23.2	13.4	0.39 to 0.66	0.85 to 1.11	11.1 to 16.0	-17.6 to -9.7	11.8 to 17.8	16.5 to 20.9	30.7 to 40.5	17.9 to 18.0	2.3 to 150.8
24-hr	23.2	9.7	0.30 to 0.74	0.66 to 1.11	13.3 to 18.1	-17.8 to -9.8	10.6 to 17.8	13.5 to 19.0	30.7 to 40.5	11.6 to 12.2	8.9 to 62.8

[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 **iMonPM** sensors' data recovery from Unit 0028, Unit 0029 and Unit 0030 was ~97.5% for all PM measurements
- The absolute intra-model variability was ~0.53, ~0.55 and ~0.27 µg/m^3 for $PM_{1.0}$, $PM_{2.5}$ and $PM_{10,}$ respectively
- Reference instruments: very strong correlations between GRIMM and T640 for $PM_{1.0}$ (R^2 ~0.94, 1-hr mean); very strong correlations between FEM GRIMM and FEM T640 for $PM_{2.5}$ (R^2 ~0.93, 1-hr mean) and very strong correlations between GRIMM and T640 for PM_{10} (R^2 ~0.91, 1-hr mean) mass concentration measurements
- $PM_{1.0}$ mass concentrations measured by the iMonPM sensors showed strong to very strong correlations with the corresponding GRIMM and T640 data ($0.77 < R^2 < 0.91$, 1-hr mean). The sensors overestimated $PM_{1.0}$ mass concentrations as measured by GRIMM and T640
- $PM_{2.5}$ mass concentrations measured by the iMonPM sensors showed strong correlations with the corresponding FEM GRIMM and FEM T640 data ($0.77 < R^2 < 0.90$, 1-hr mean). The sensors overestimated $PM_{2.5}$ mass concentrations as measured by FEM GRIMM and FEM T640
- PM_{10} mass concentrations measured by the iMonPM sensors showed weak to moderate correlations with the corresponding GRIMM and T640 data ($0.38 < R^2 < 0.66$; 1-hr mean). The sensors underestimated PM_{10} mass concentrations as measured by GRIMM 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