Field Evaluation
Tera Sensor - NextPM

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

- From 09/29/2021 to 11/28/2021, three **Tera Sensor - NextPM (hereinafter NextPM)** 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

- NextPM (*3 units tested*):
  - Particle sensor: optical; non-FEM (Tera Sensor - NextPM)
  - Each unit reports: $PM_{1.0}$, $PM_{2.5}$ and PM_{10} ($\mu g/m^3$)
  - Unit cost: ~$70
  - Time resolution: 10 seconds
  - Units IDs: 1207, 1222, 1342

- GRIMM EDM 180 (*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

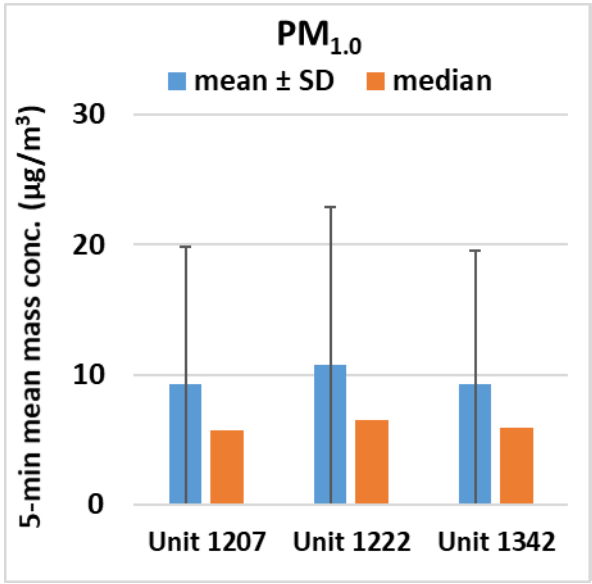
- Teledyne API T640 (*reference instrument*):
  - Optical particle counter (FEM $PM_{2.5}$)
  - Measures $PM_{1.0}$, $PM_{2.5}$ and PM_{10} ($\mu g/m^3$)
  - Cost: ~$21,000
  - Time resolution: 1-min

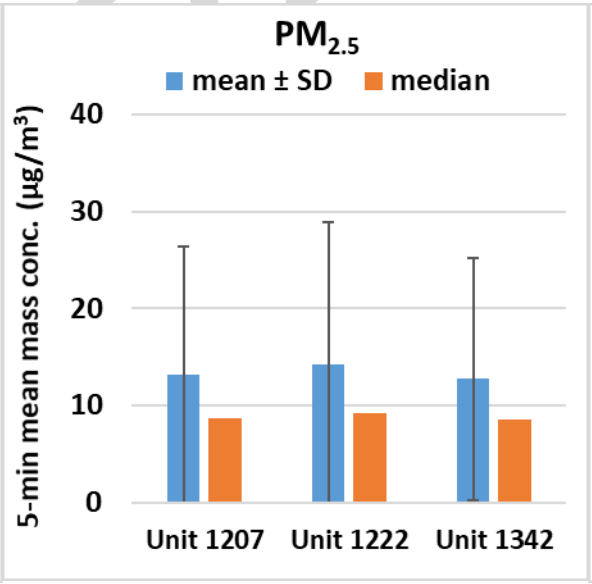
Data validation & recovery

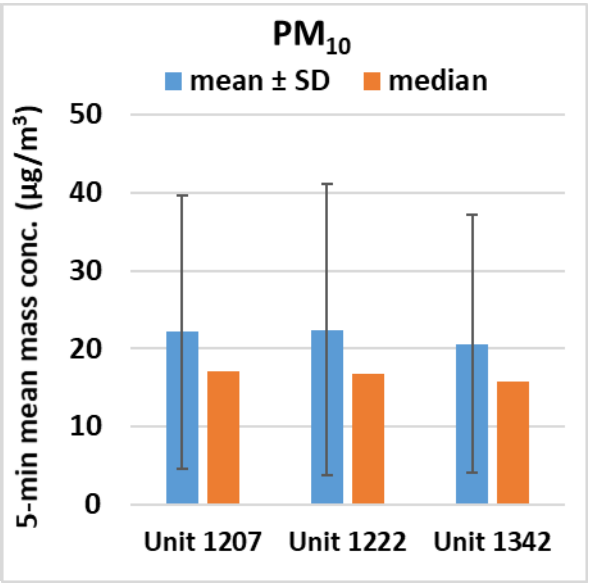
- Basic QA/QC procedures were used to validate the collected data (i.e. obvious outliers, negative values and invalid data-points were eliminated from the data-set)
- Data recovery from Unit 1207, Unit 1222 and Unit 1342 was ~ 95%, 96% and 96% for all PM measurements, respectively.

NextPM; intra-model variability

- Absolute intra-model variability was ~ 0.67, 0.65 and 0.81 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 ~ 6.9%, 4.8% and 3.8% 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)

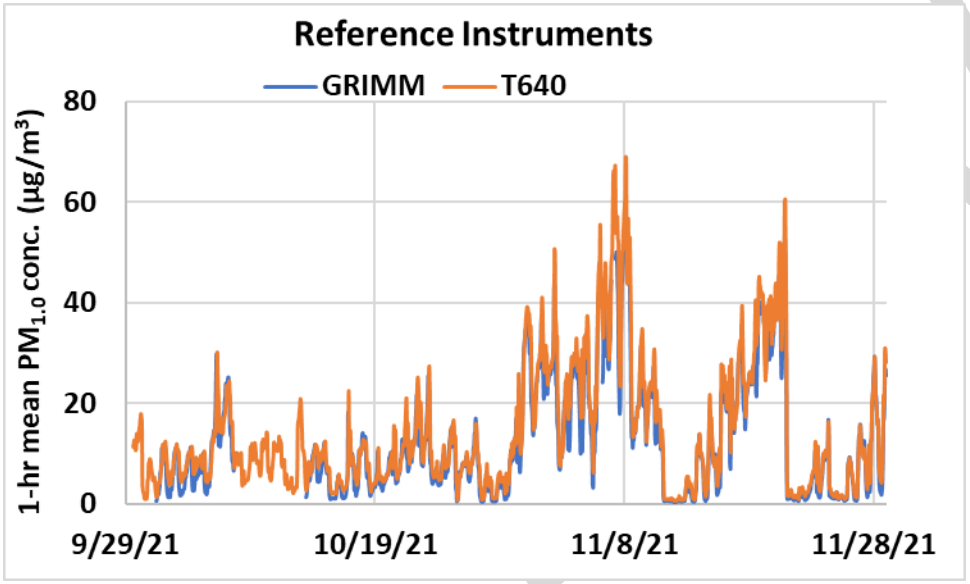


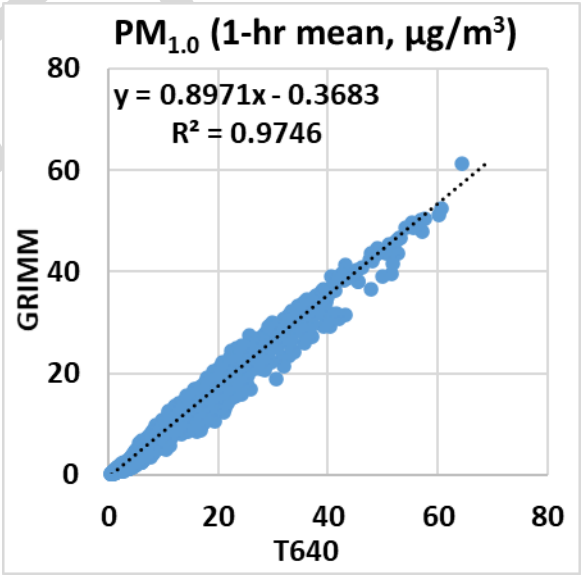




Reference Instruments: $PM_{1.0}$ GRIMM and T640

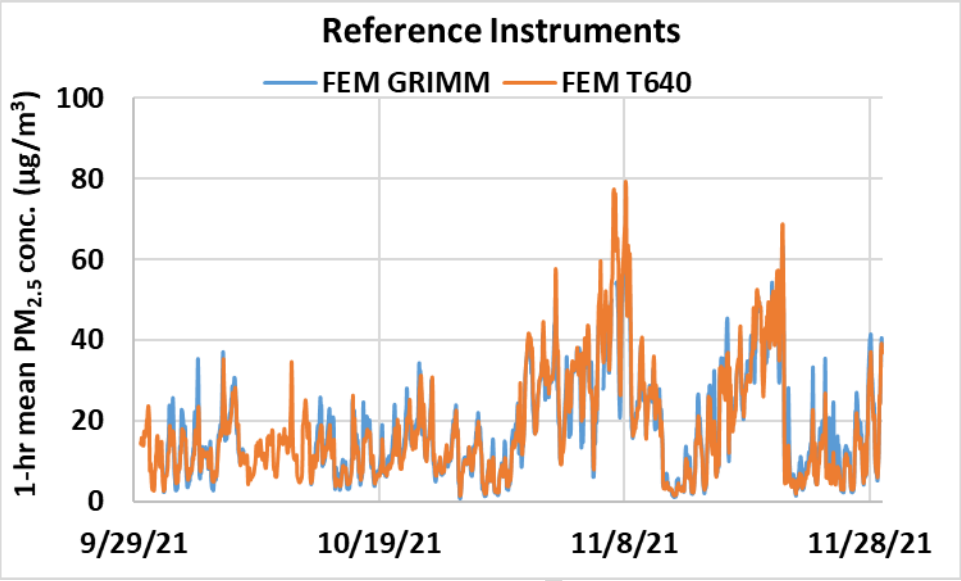
- Data recovery for $PM_{1.0}$ from GRIMM and T640 was ~ 88% and 100%, respectively.
- Very strong correlations between the reference instruments for $PM_{1.0}$ measurements (R^2 ~ 0.97) were observed.

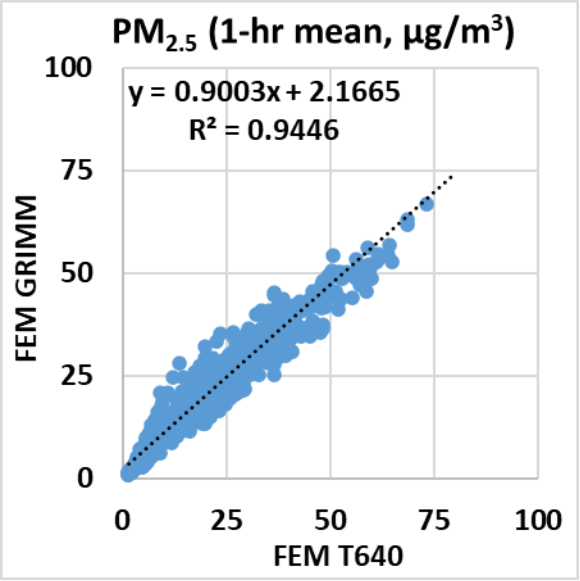




Reference Instruments: $PM_{2.5}$ FEM GRIMM and FEM T640

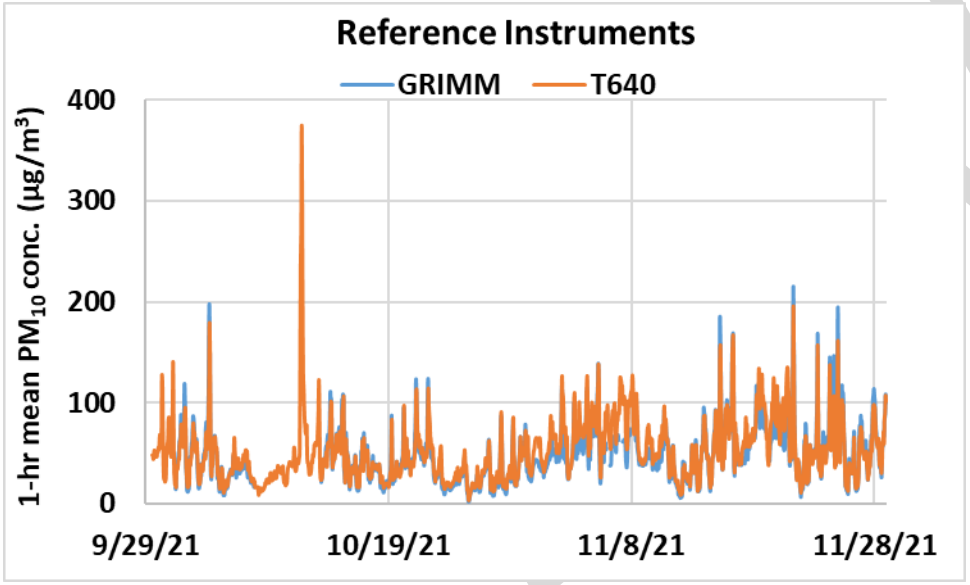
- Data recovery for $PM_{2.5}$ from FEM GRIMM and FEM T640 was ~ 88% and 100%, respectively.
- Very strong correlations between the reference instruments for $PM_{2.5}$ measurements (R^2 ~ 0.94) were observed.

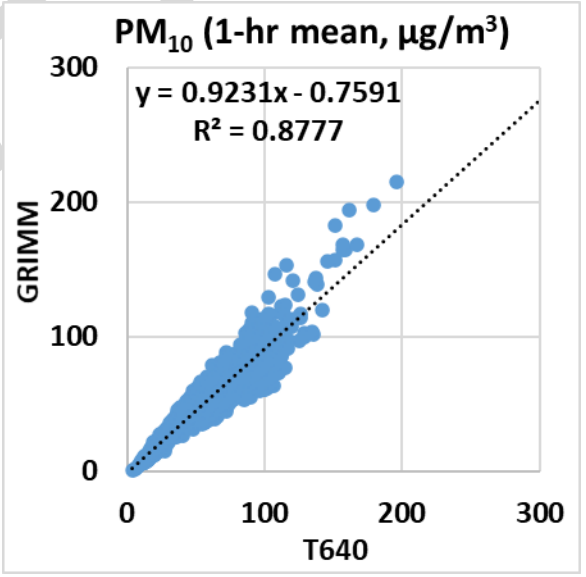




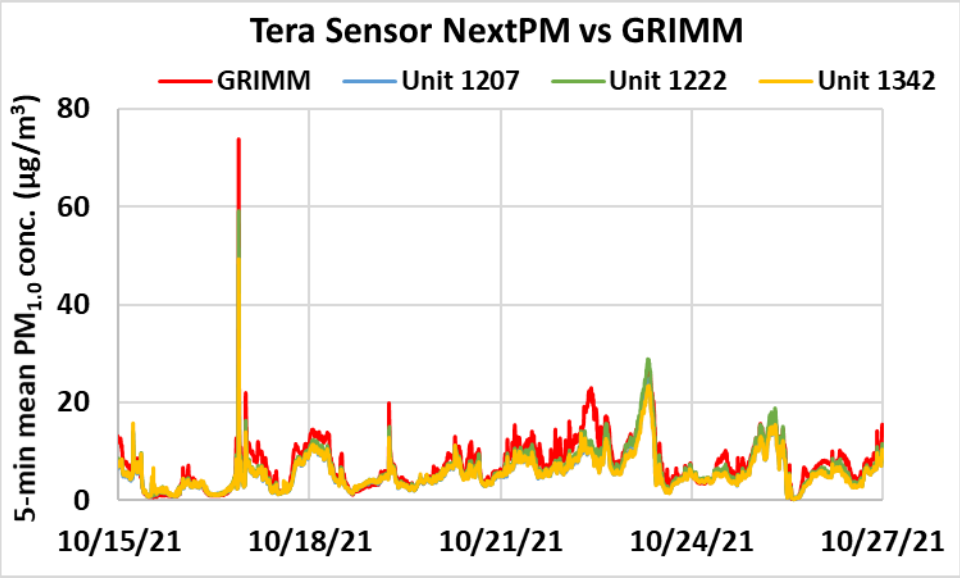
Reference Instruments: PM_{10} GRIMM and T640

- Data recovery for PM_{10} from GRIMM and T640 was ~ 88% and 100%, respectively.
- Strong correlations between the reference instruments for PM_{10} measurements (R^2 ~ 0.88) were observed.

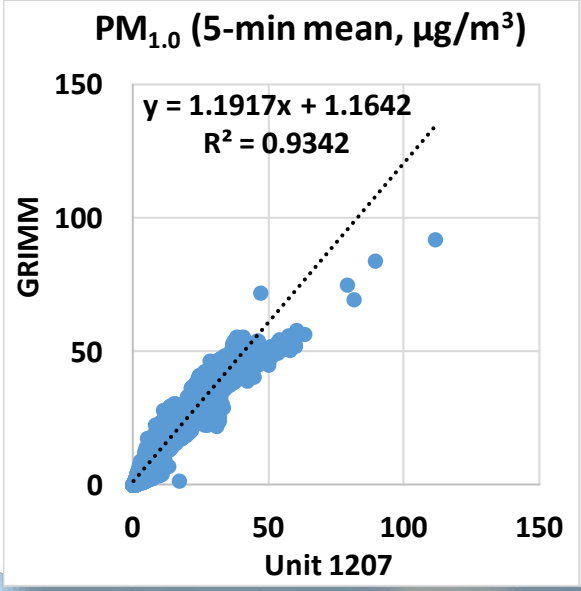


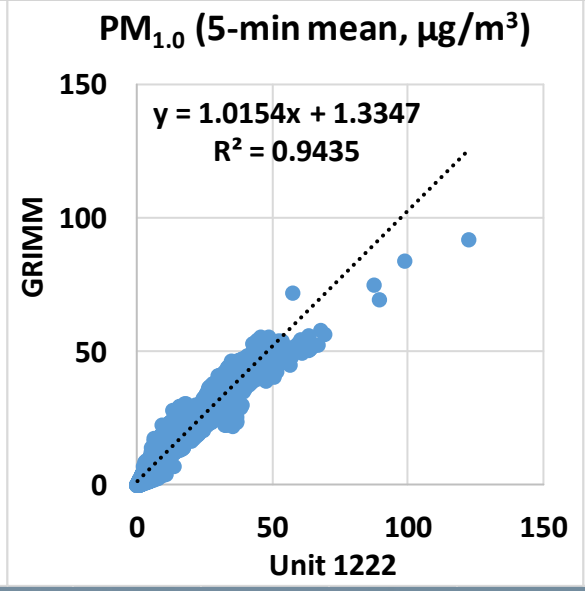


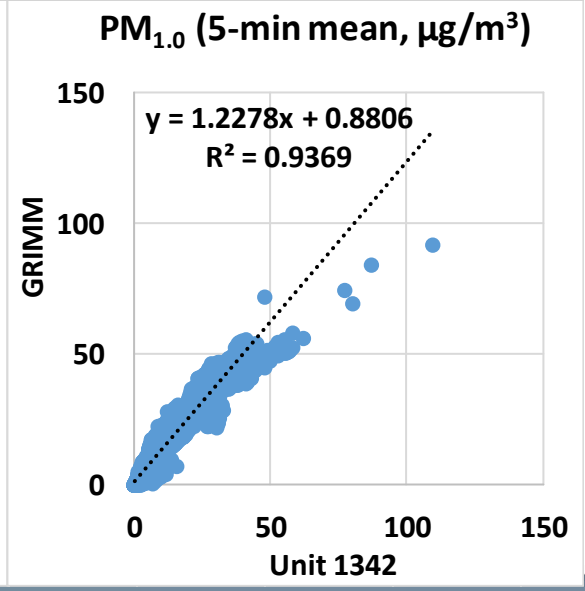
NextPM vs GRIMM ($PM_{1.0}$; 5-min mean)



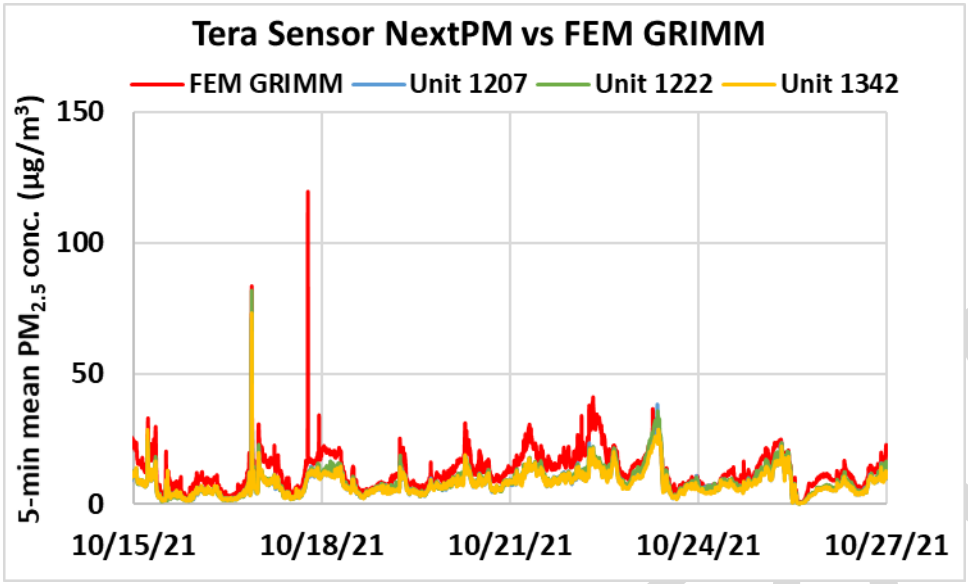
- The NextPM sensors showed very strong correlations with the corresponding GRIMM data ($0.93 < R^2 < 0.95$)
- Overall, the NextPM sensors underestimated the $PM_{1.0}$ mass concentrations as measured by GRIMM
- The NextPM sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by GRIMM



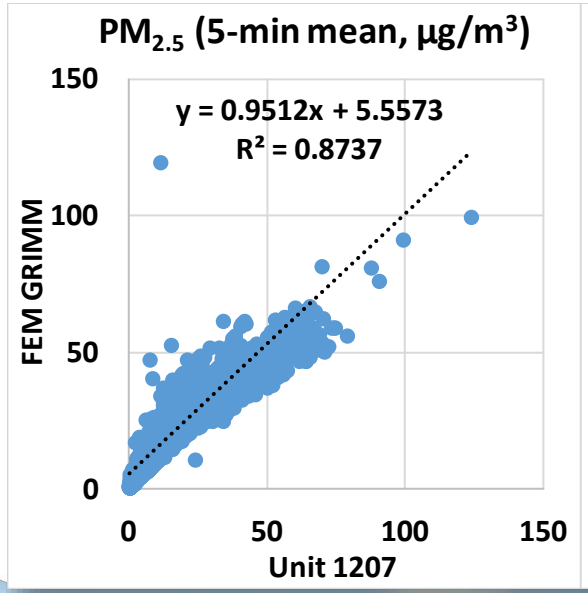


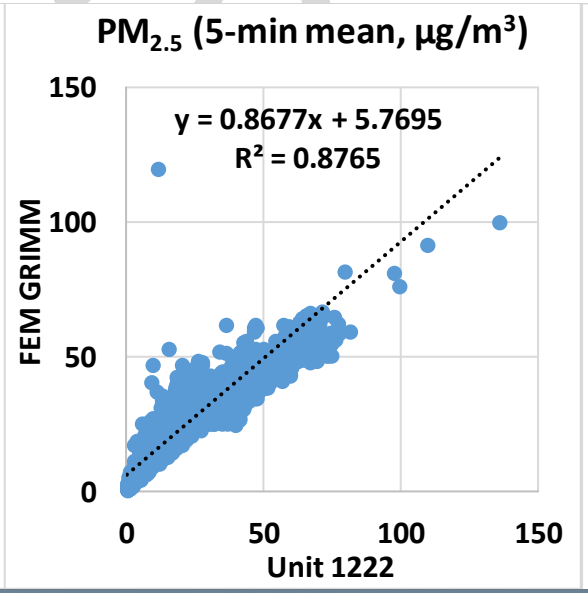


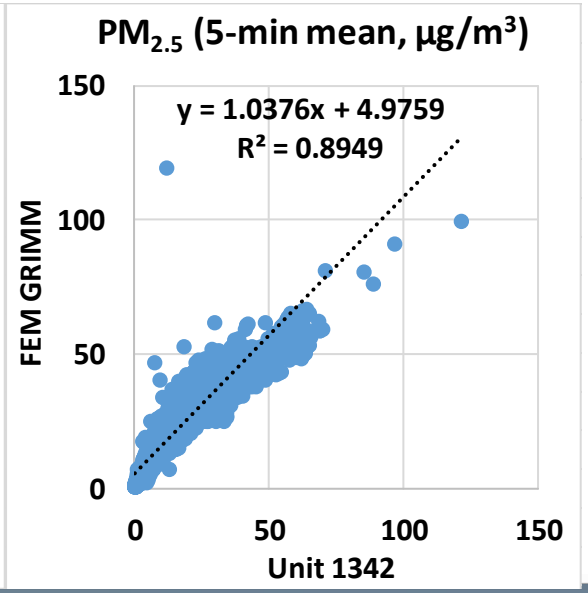
NextPM vs FEM GRIMM ($PM_{2.5}$; 5-min mean)



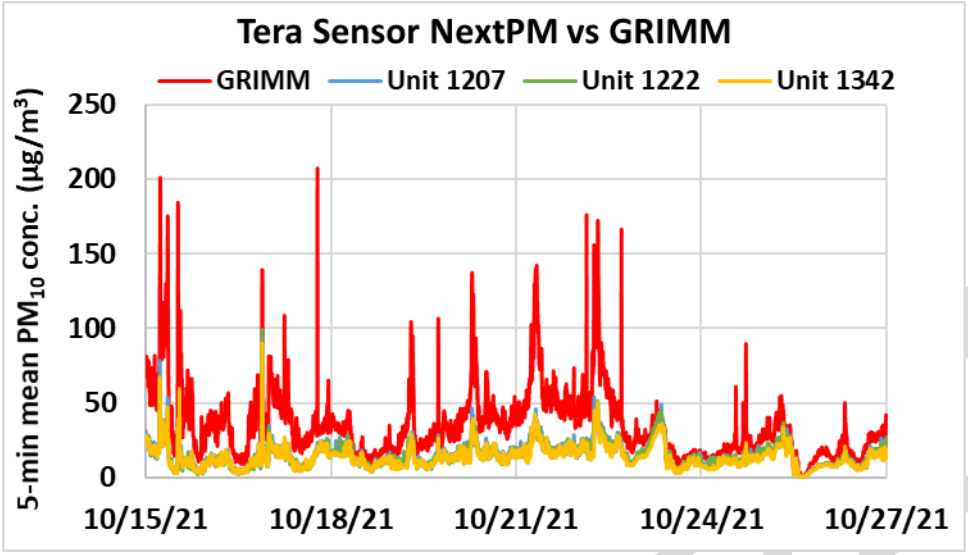
- The NextPM sensors showed strong correlations with the corresponding FEM GRIMM data ($0.87 < R^2 < 0.90$)
- Overall, the NextPM sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM GRIMM
- The NextPM sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM GRIMM



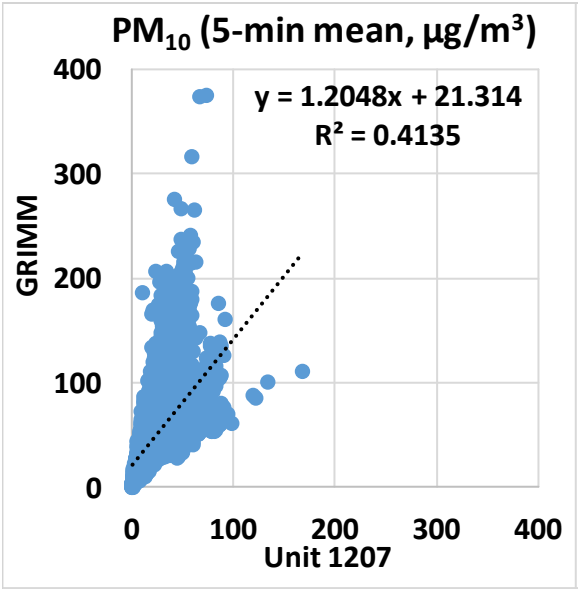


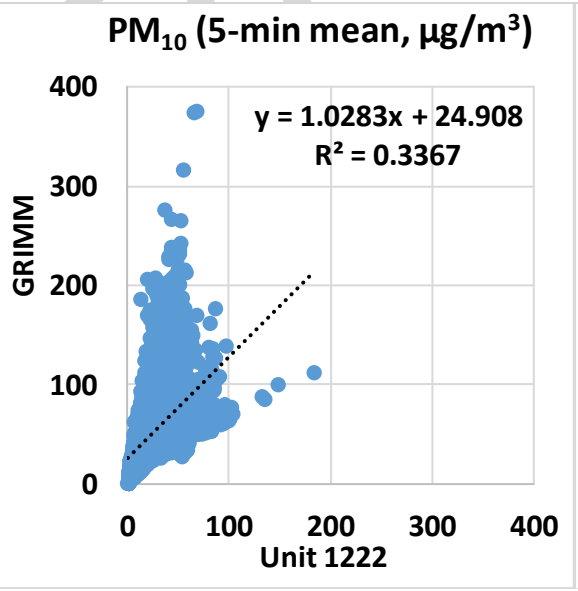


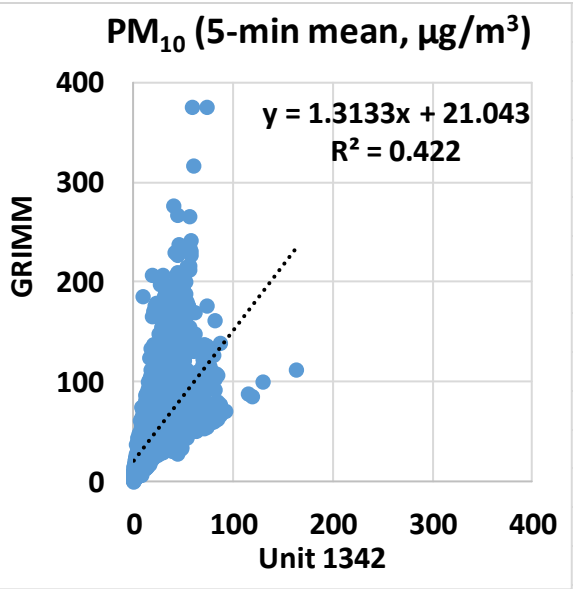
NextPM vs GRIMM (PM_{10}; 5-min mean)



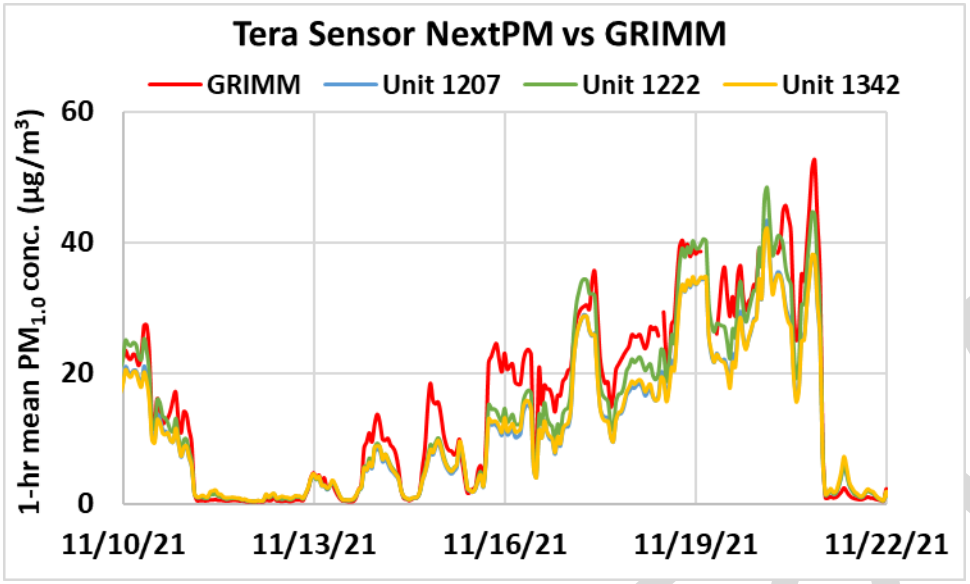
- The NextPM sensors showed weak correlations with the corresponding GRIMM data ($0.33 < R^2 < 0.43$)
- Overall, the NextPM sensors underestimated the PM_{10} mass concentrations as measured by GRIMM
- The NextPM sensors did not seem to track the PM_{10} diurnal variations as recorded by GRIMM



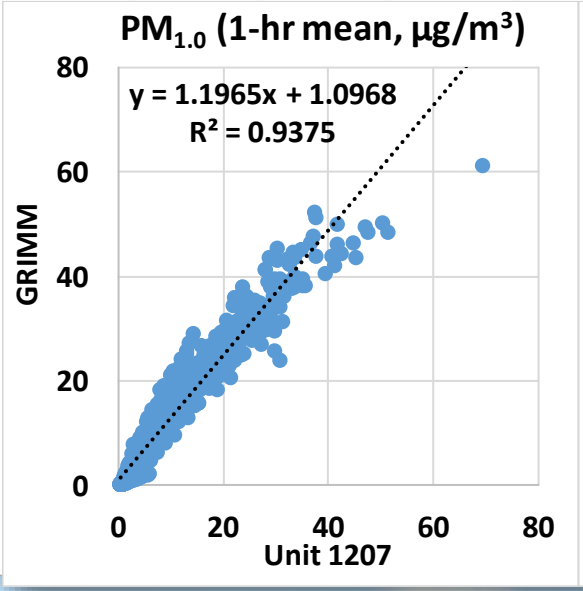


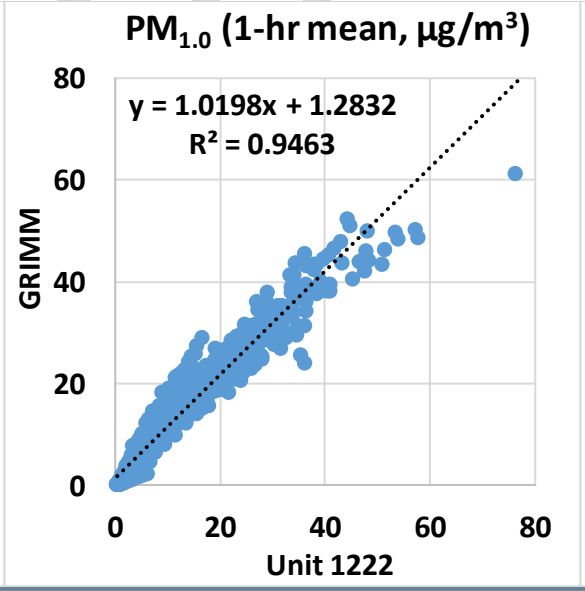


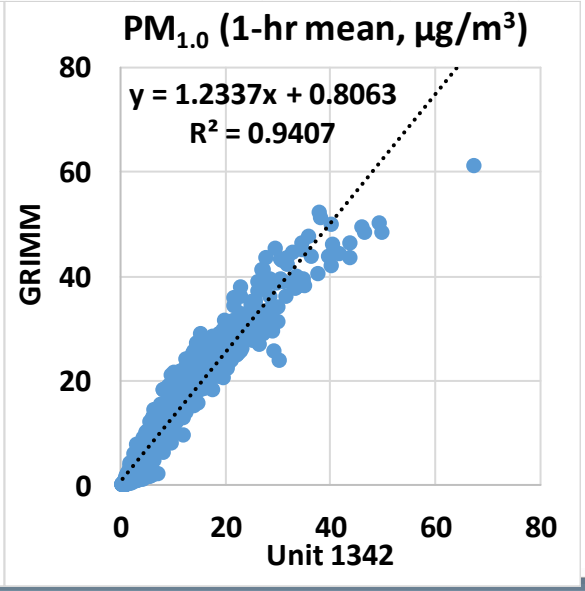
NextPM vs GRIMM ($PM_{1.0}$; 1-hr mean)



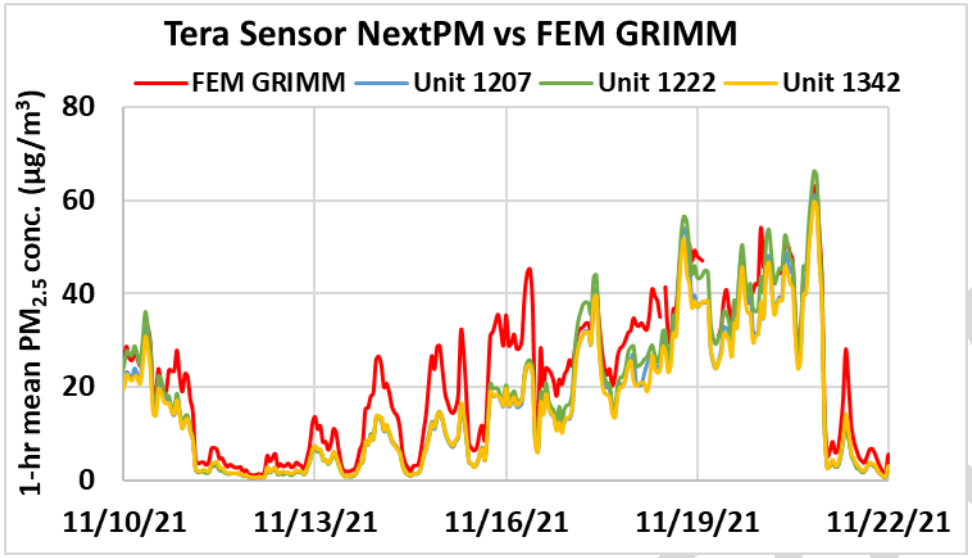
- The NextPM sensors showed very strong correlations with the corresponding GRIMM data ($0.93 < R^2 < 0.95$)
- Overall, the NextPM sensors underestimated the $PM_{1.0}$ mass concentrations as measured by GRIMM
- The NextPM sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by GRIMM



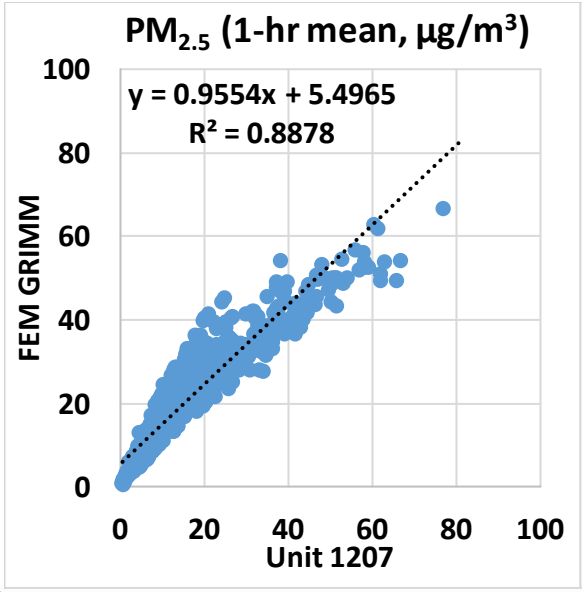


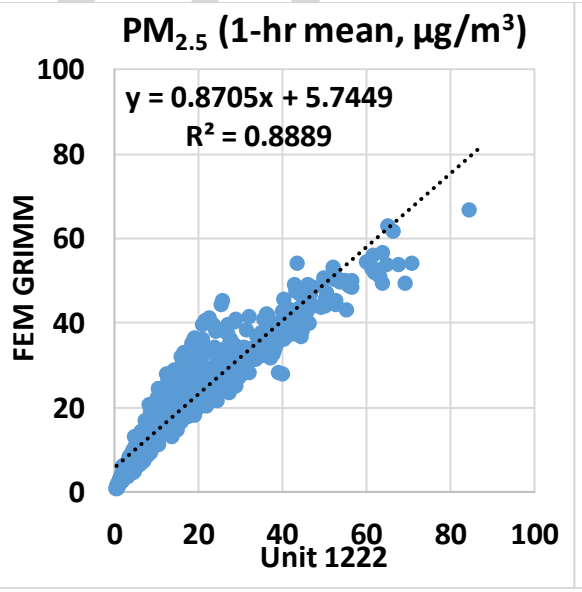


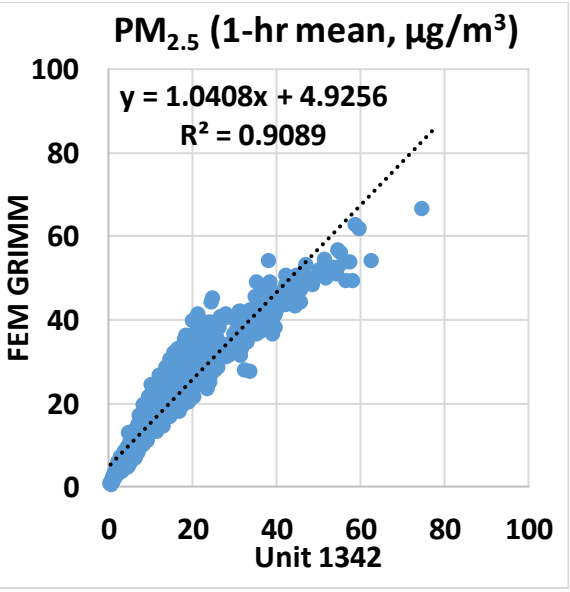
NextPM vs FEM GRIMM ($PM_{2.5}$; 1-hr mean)



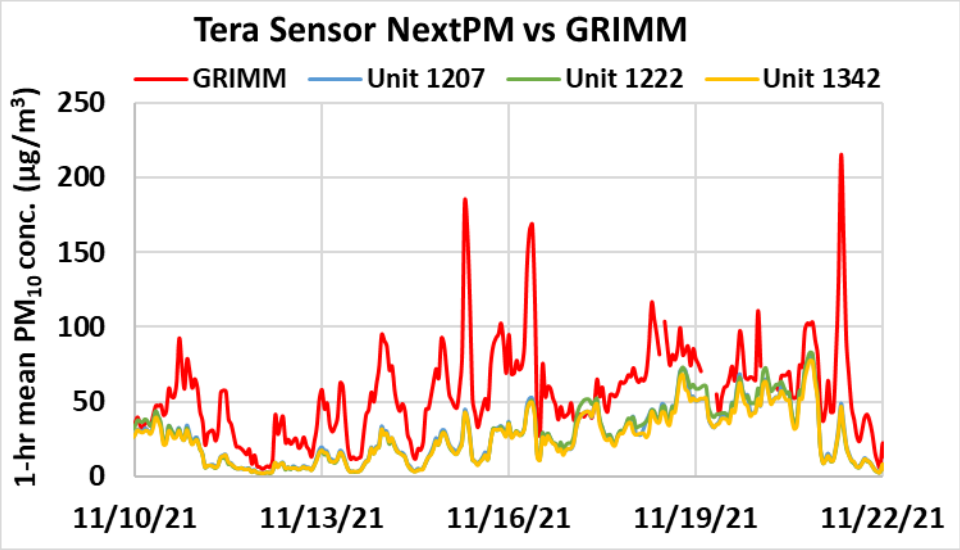
- The NextPM sensors showed strong to very strong correlations with the corresponding FEM GRIMM data ($0.88 < R^2 < 0.91$)
- Overall, the NextPM sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM GRIMM
- The NextPM sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM GRIMM



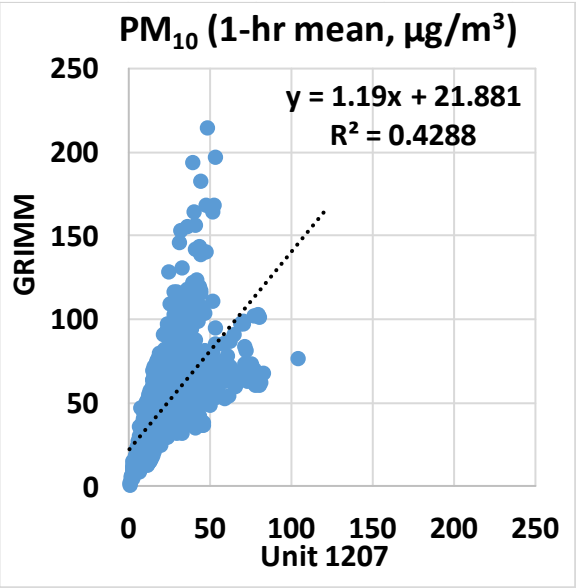


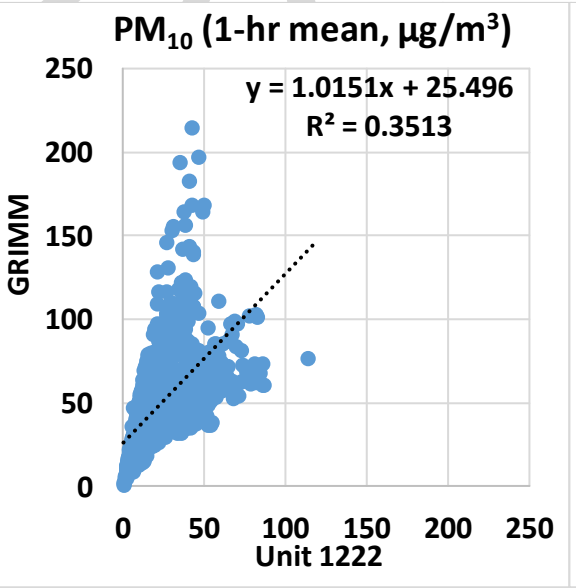


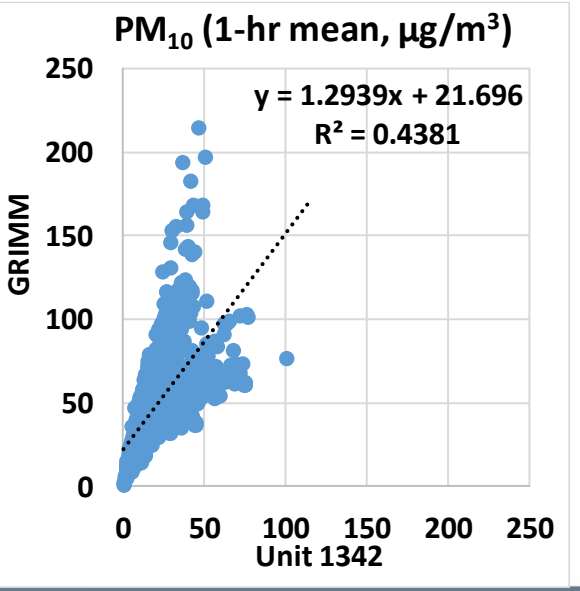
NextPM vs GRIMM (PM_{10}; 1-hr mean)



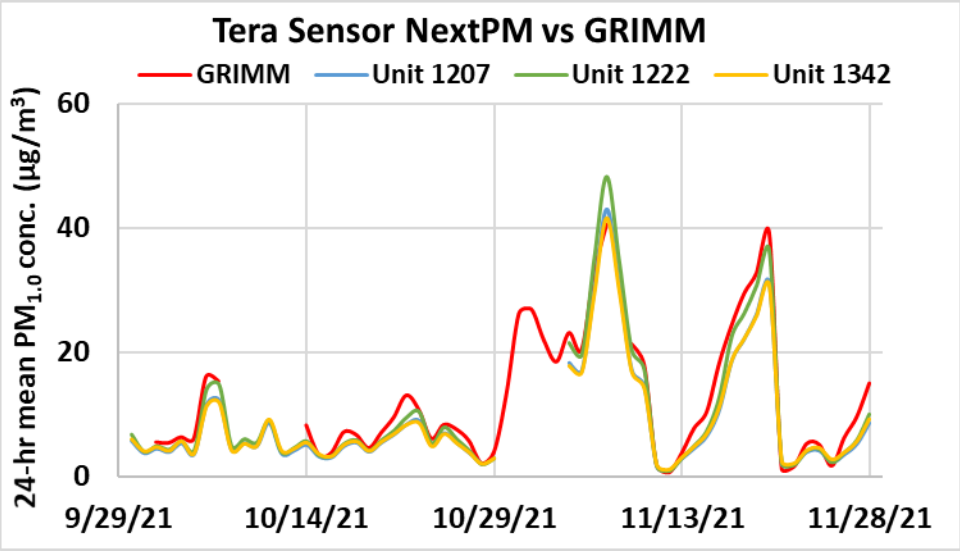
- The NextPM sensors showed weak correlations with the corresponding GRIMM data ($0.35 < R^2 < 0.44$)
- Overall, the NextPM sensors underestimated the PM_{10} mass concentrations as measured by GRIMM
- The NextPM sensors did not seem to track the PM_{10} diurnal variations as recorded by GRIMM



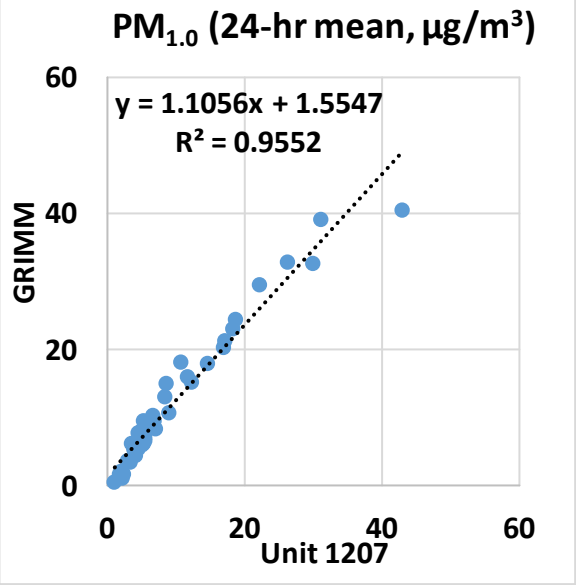


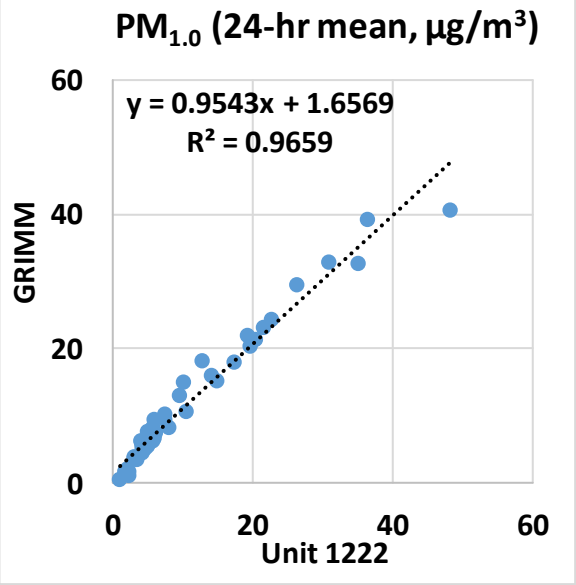


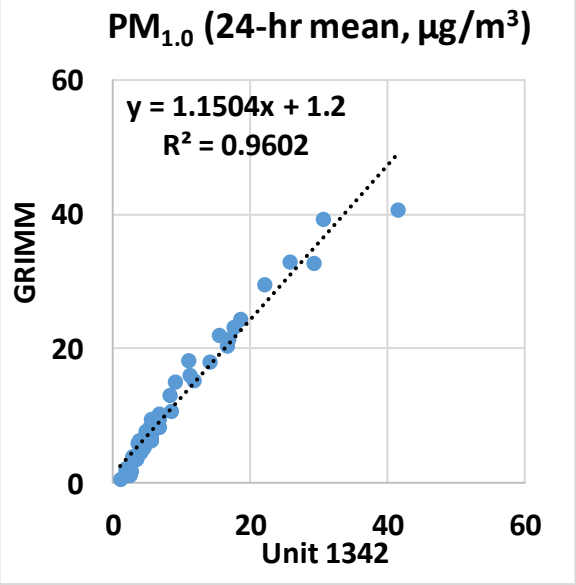
NextPM vs GRIMM ($PM_{1.0}$; 24-hr mean)



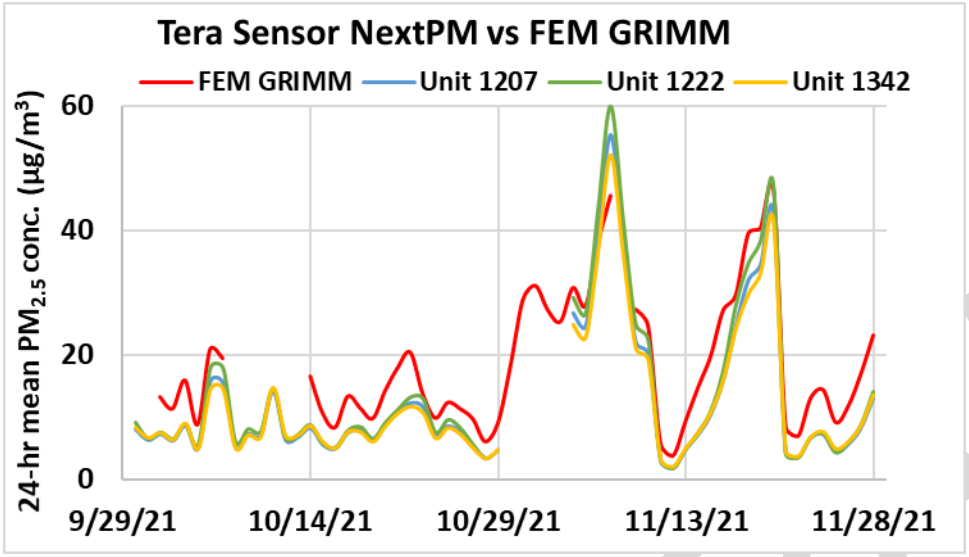
- The NextPM sensors showed very strong correlations with the corresponding GRIMM data ($0.95 < R^2 < 0.97$)
- Overall, the NextPM sensors underestimated the $PM_{1.0}$ mass concentrations as measured by GRIMM
- The NextPM sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by GRIMM



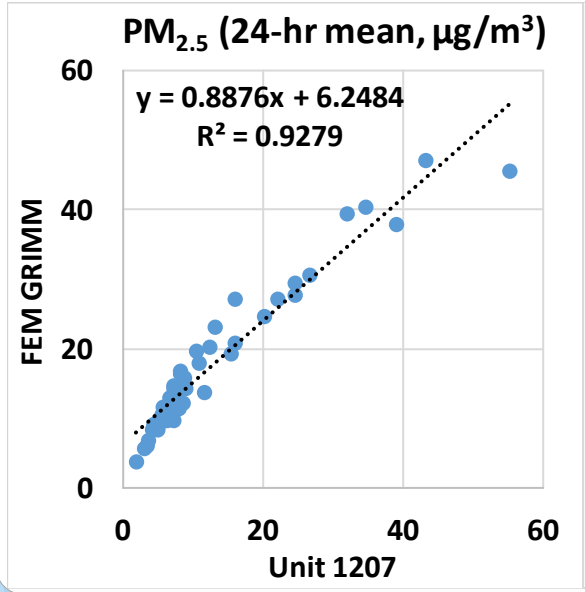


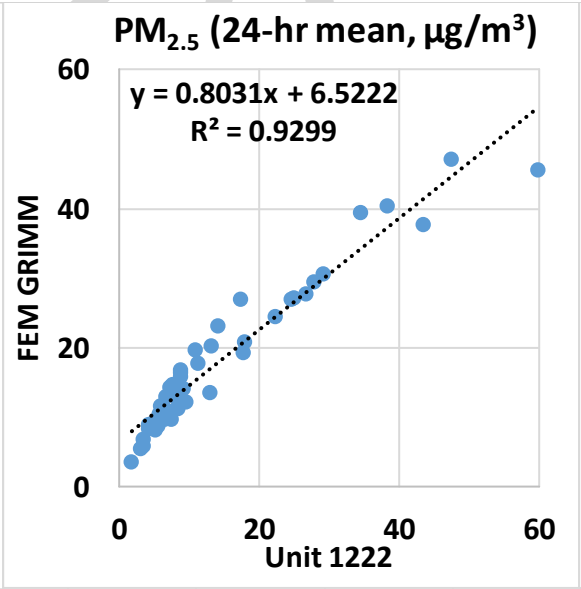


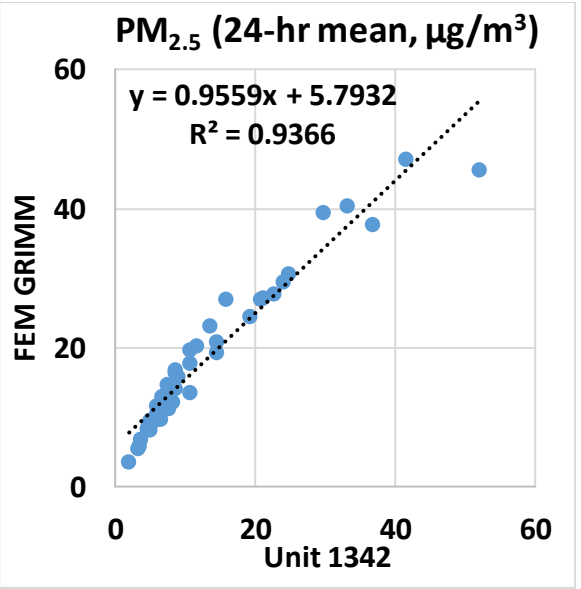
NextPM vs FEM GRIMM ($PM_{2.5}$; 24-hr mean)



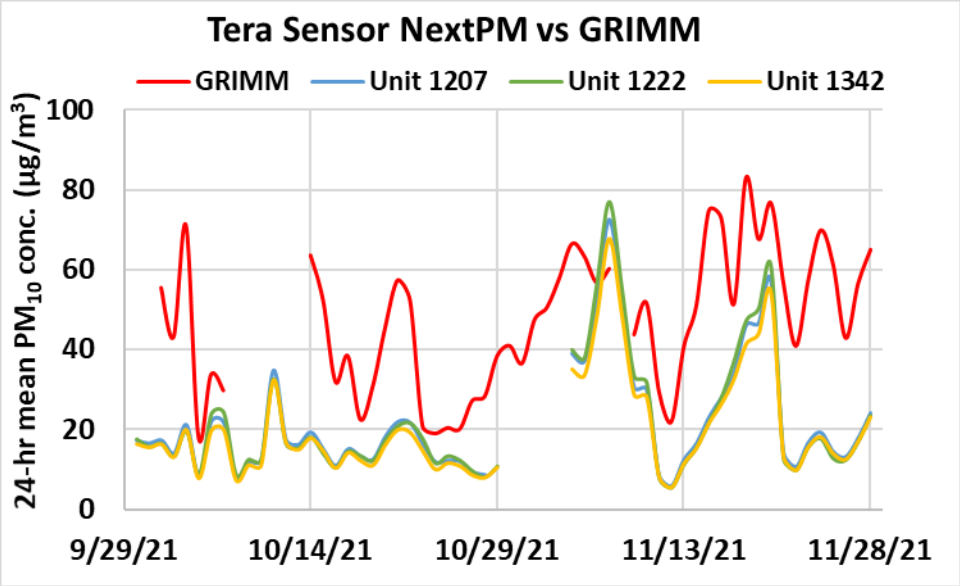
- The NextPM sensors showed very strong correlations with the corresponding FEM GRIMM data ($0.92 < R^2 < 0.94$)
- Overall, the NextPM sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM GRIMM
- The NextPM sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM GRIMM



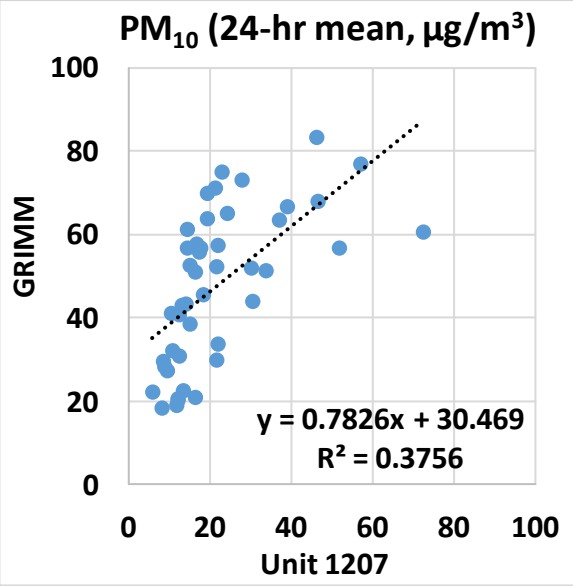


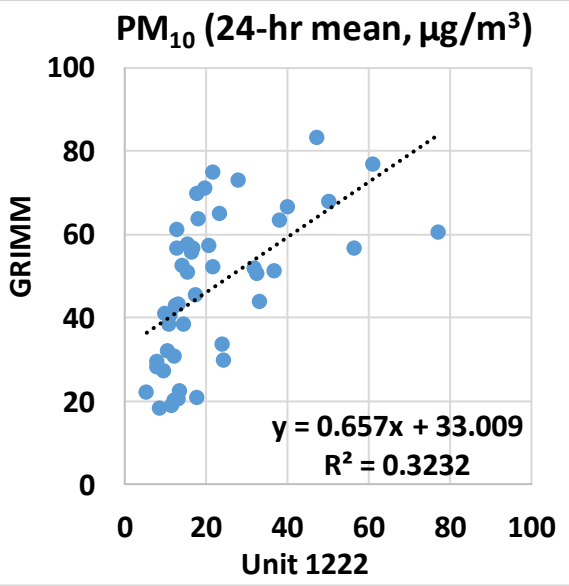


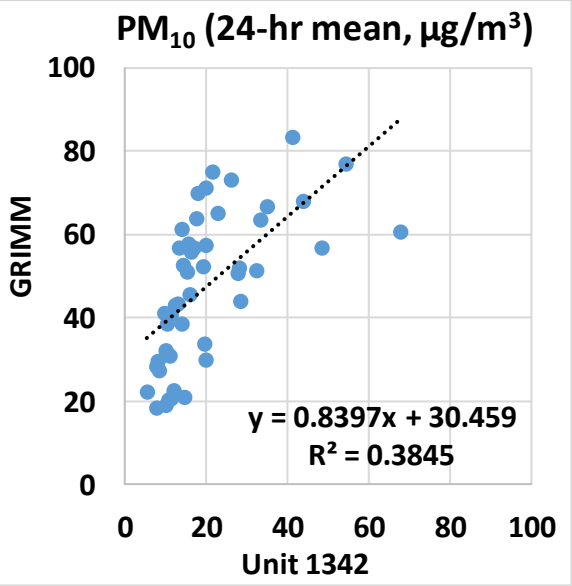
NextPM vs GRIMM (PM_{10}; 24-hr mean)



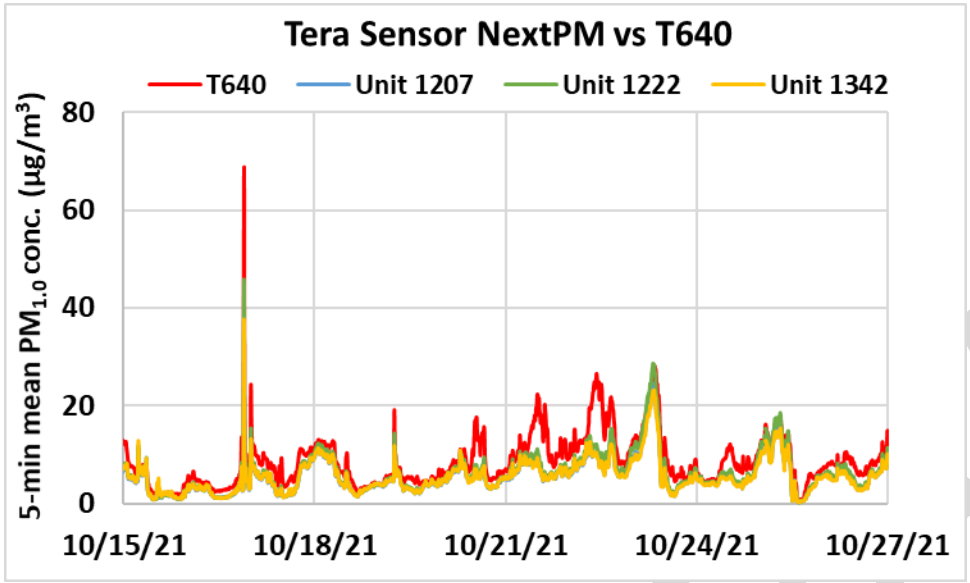
- The NextPM sensors showed weak correlations with the corresponding GRIMM data ($0.32 < R^2 < 0.38$)
- Overall, the NextPM sensors underestimated the PM_{10} mass concentrations as measured by GRIMM
- The NextPM sensors did not seem to track the PM_{10} diurnal variations as recorded by GRIMM



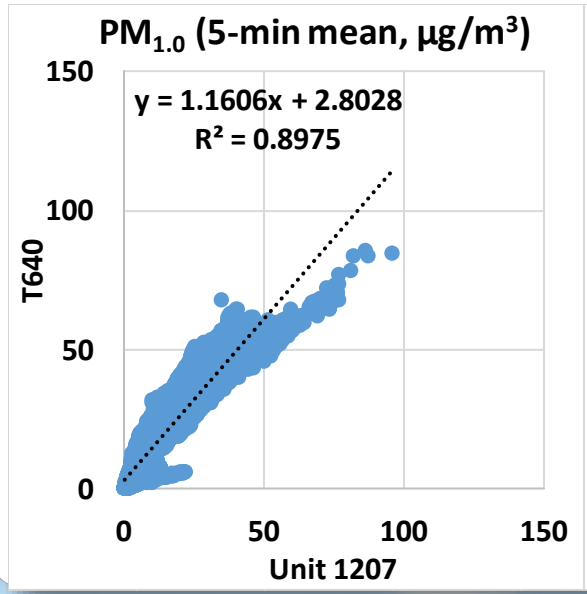


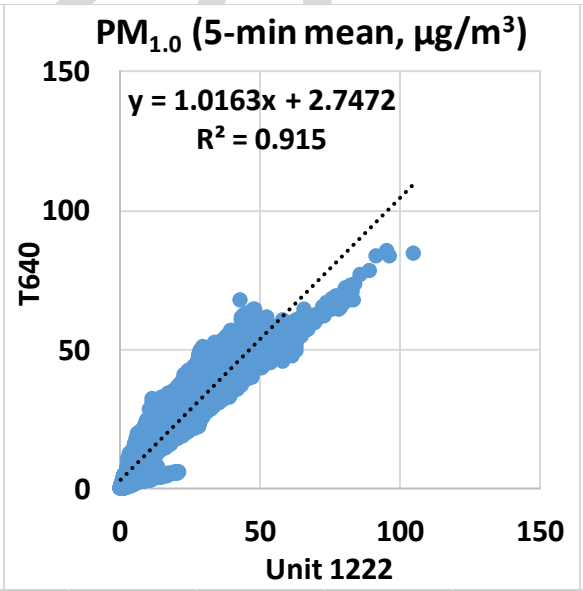


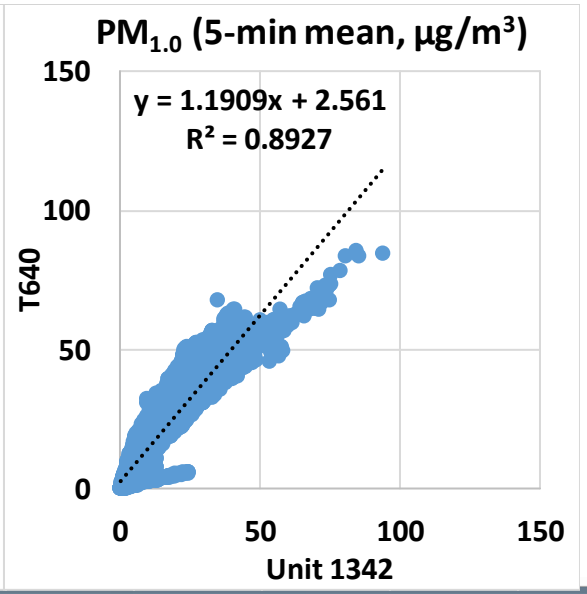
NextPM vs T640 ($PM_{1.0}$; 5-min mean)



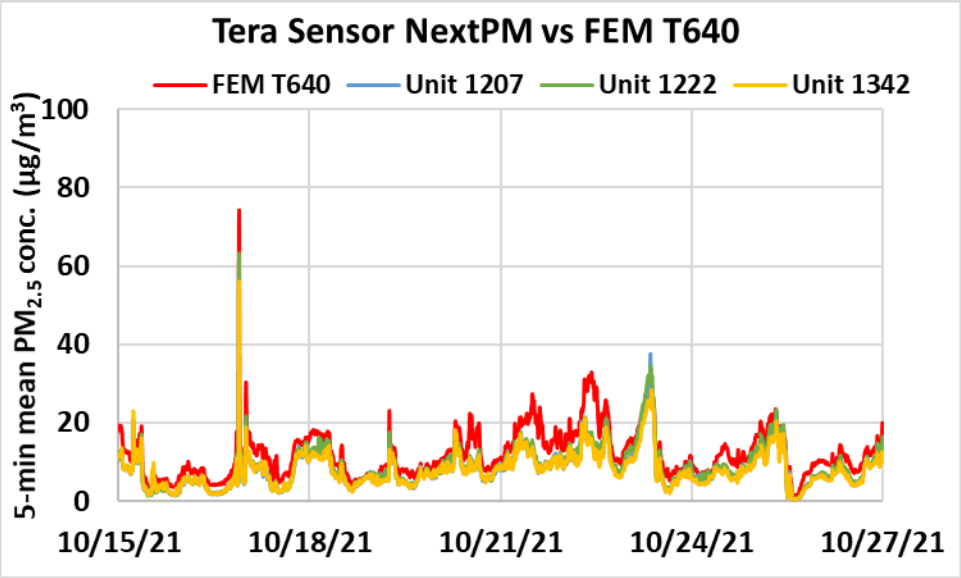
- The NextPM sensors showed strong to very strong correlations with the corresponding T640 data ($0.89 < R^2 < 0.92$)
- Overall, the NextPM sensors underestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The NextPM sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by T640



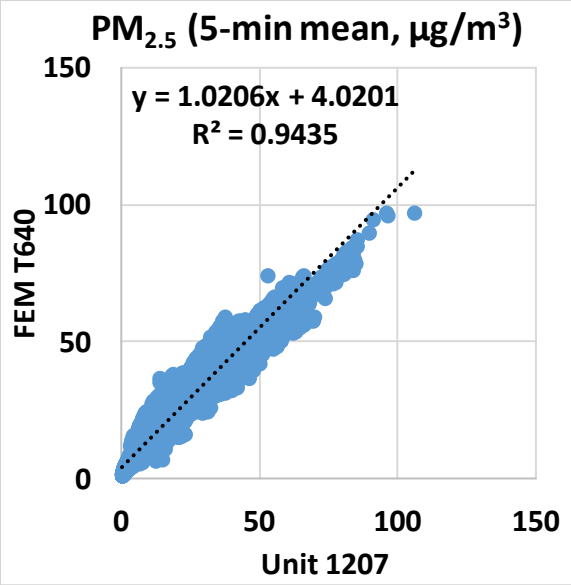


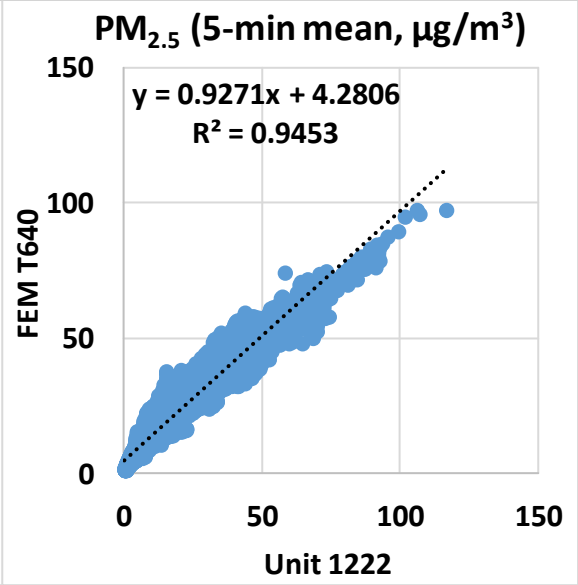


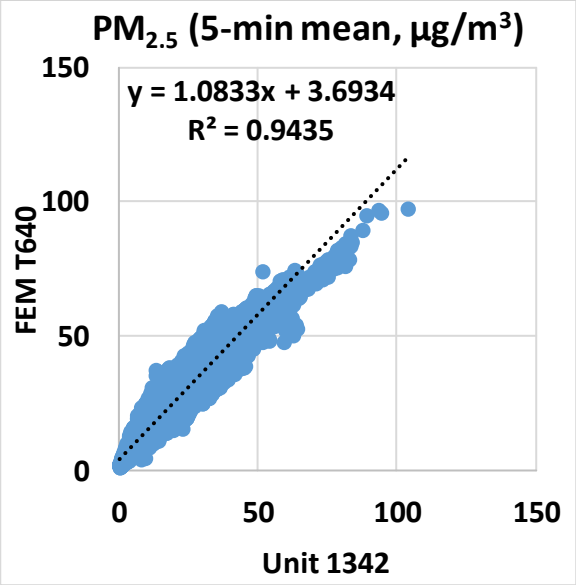
NextPM vs FEM T640 ($PM_{2.5}$; 5-min mean)



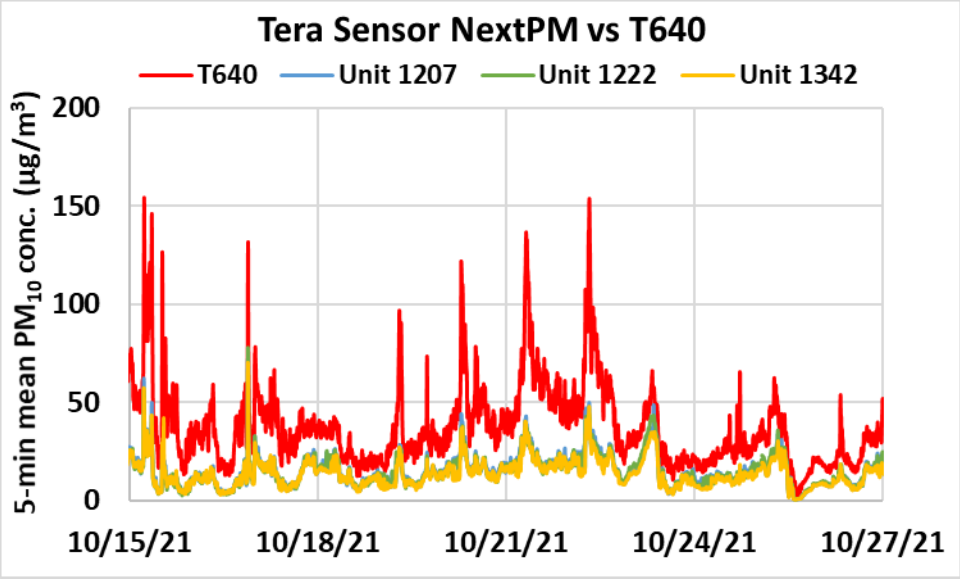
- The NextPM sensors showed very strong correlations with the corresponding FEM T640 data ($0.94 < R^2 < 0.95$)
- Overall, the NextPM sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The NextPM sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by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



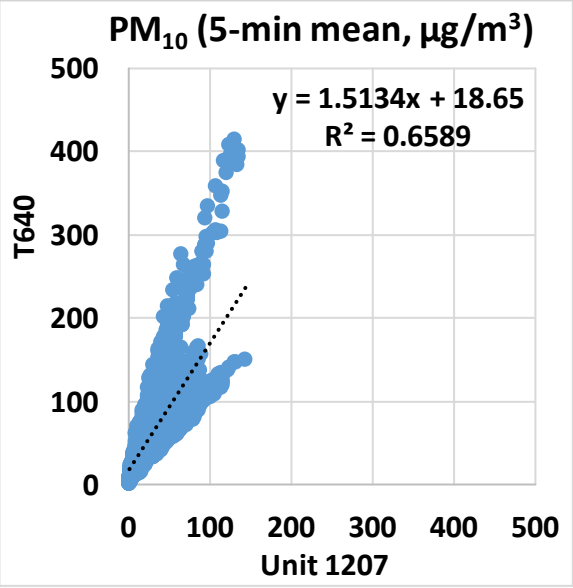


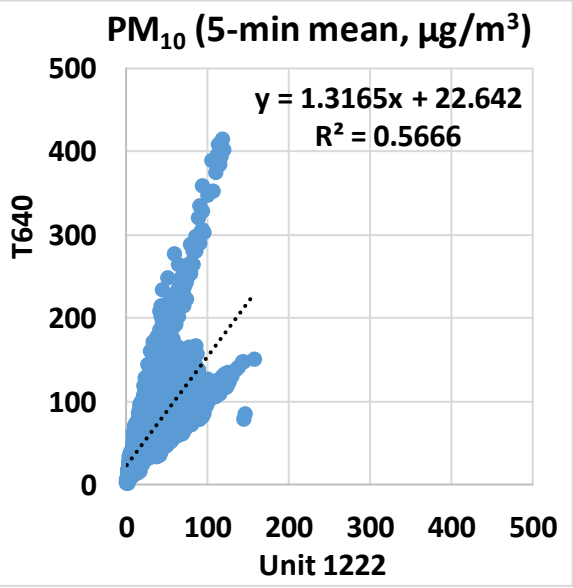


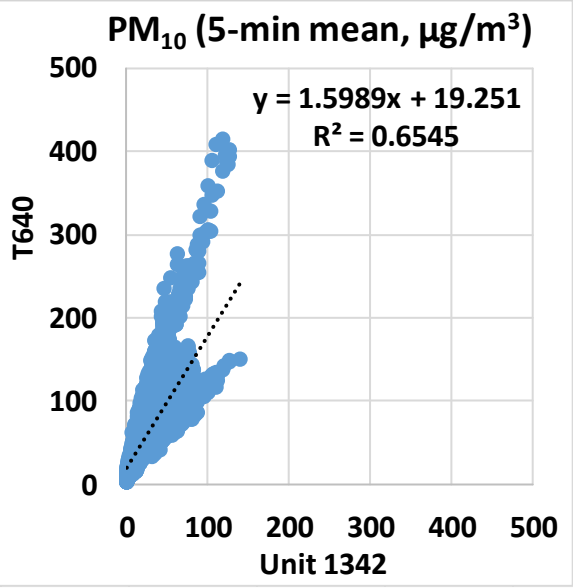
NextPM vs T640 (PM_{10}; 5-min mean)



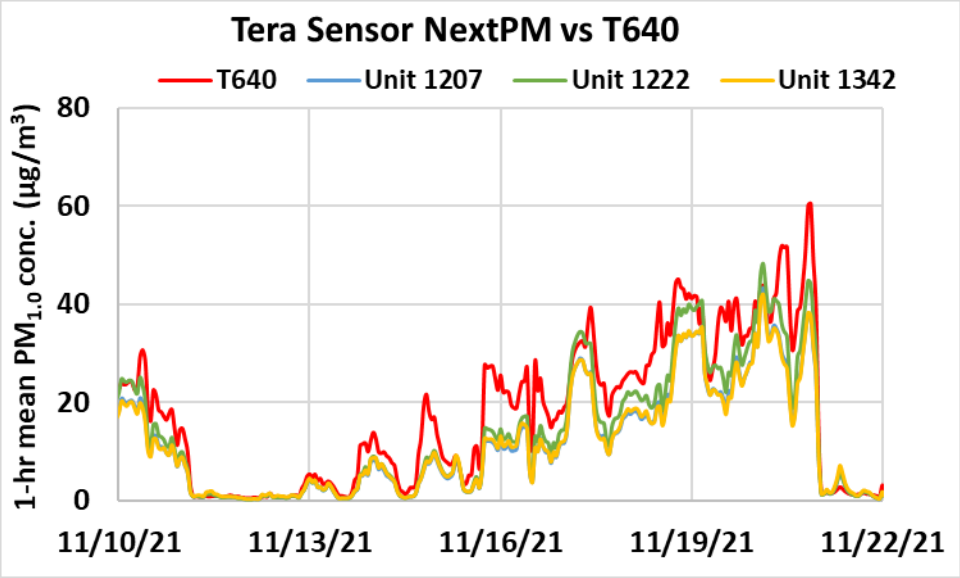
- NextPM sensors showed moderate correlations with the corresponding T640 data ($0.56 < R^2 < 0.66$)
- Overall, the NextPM sensors underestimated the PM_{10} mass concentrations as measured by T640
- The NextPM sensors seemed to track the PM_{10} diurnal variations as recorded by T640



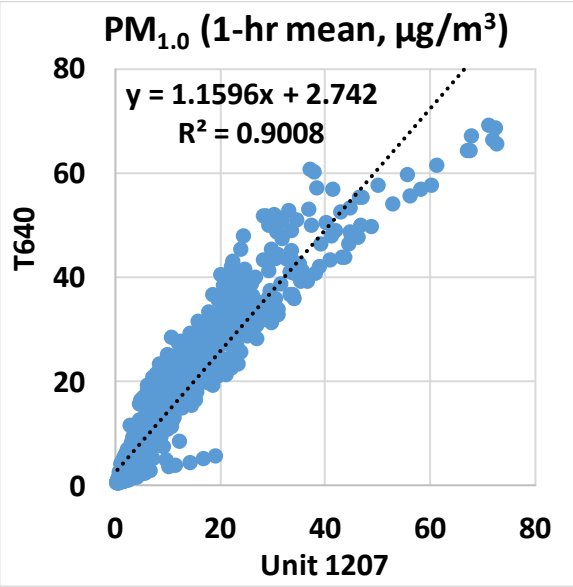


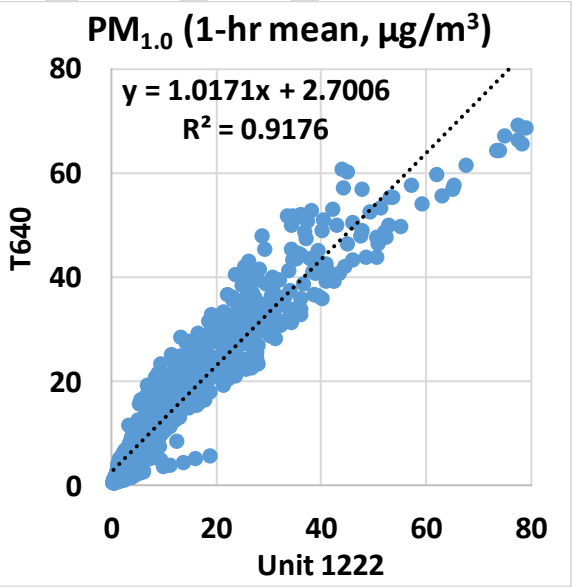


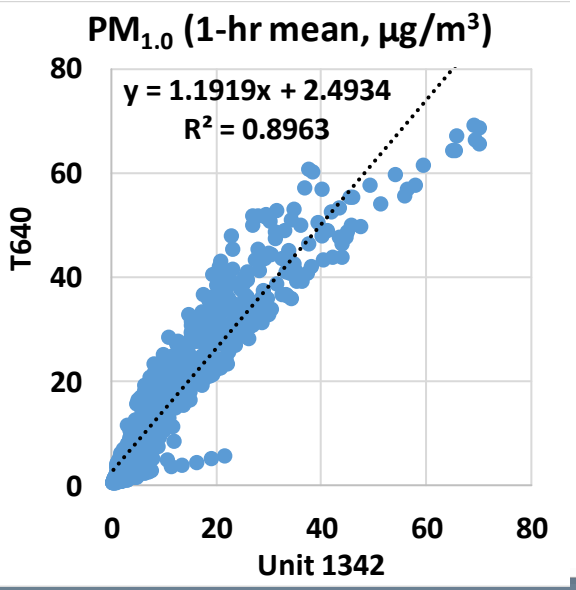
NextPM vs T640 ($PM_{1.0}$; 1-hr mean)



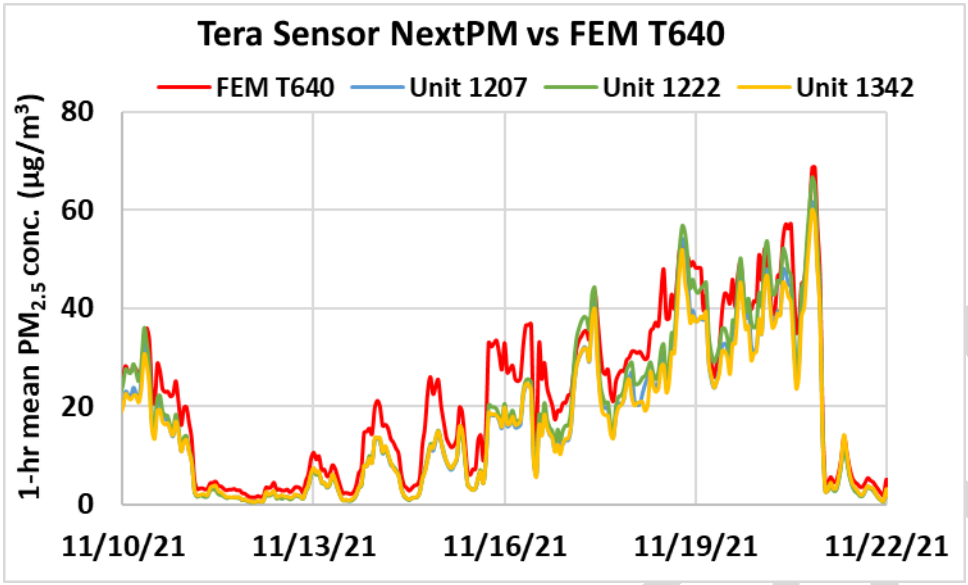
- The NextPM sensors showed strong to very strong correlations with the corresponding T640 data ($0.89 < R^2 < 0.92$)
- Overall, the NextPM sensors underestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The NextPM sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by T640



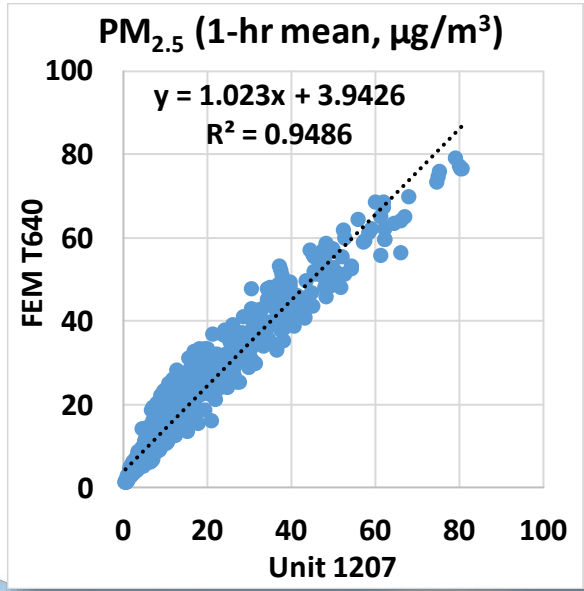


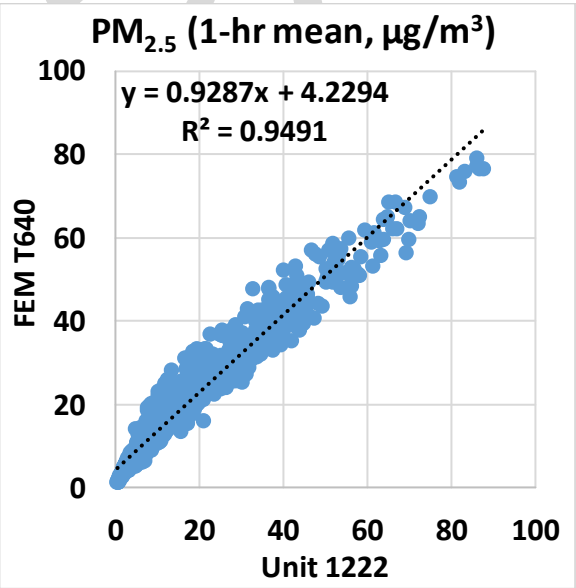


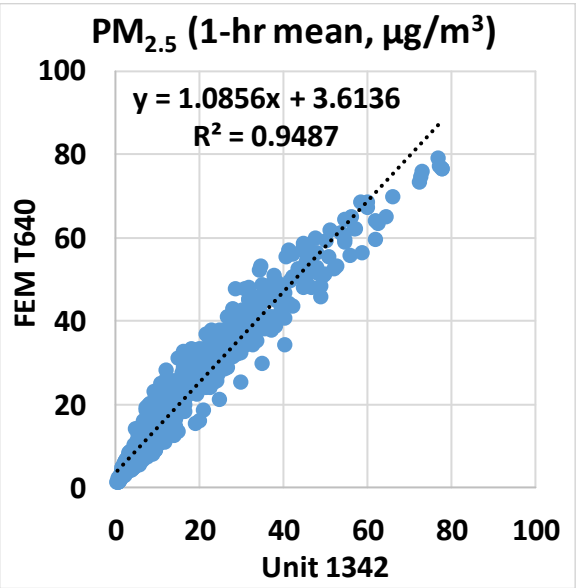
NextPM vs FEM T640 ($PM_{2.5}$; 1-hr mean)



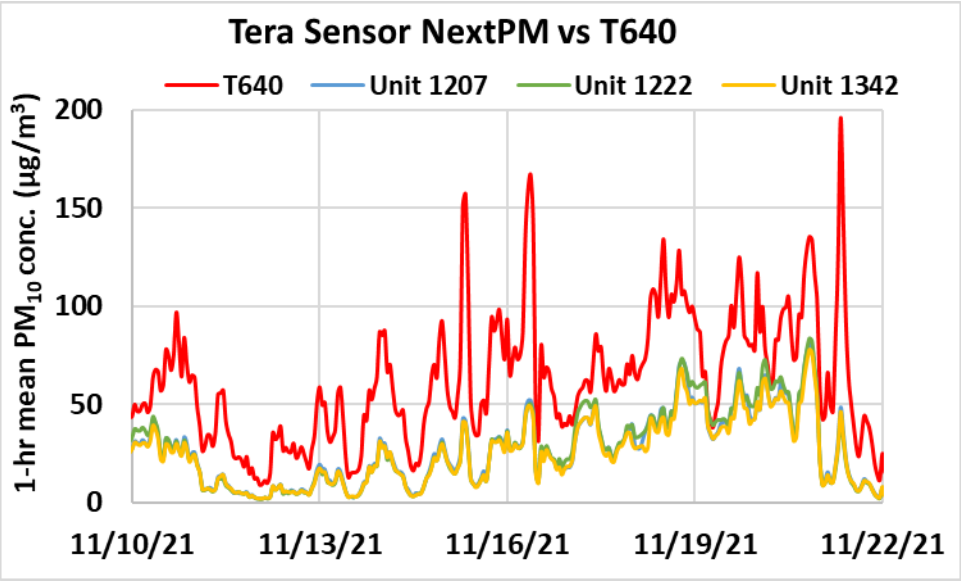
- The NextPM sensors showed very strong correlations with the corresponding FEM T640 data ($0.94 < R^2 < 0.95$)
- Overall, the NextPM sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The NextPM sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by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



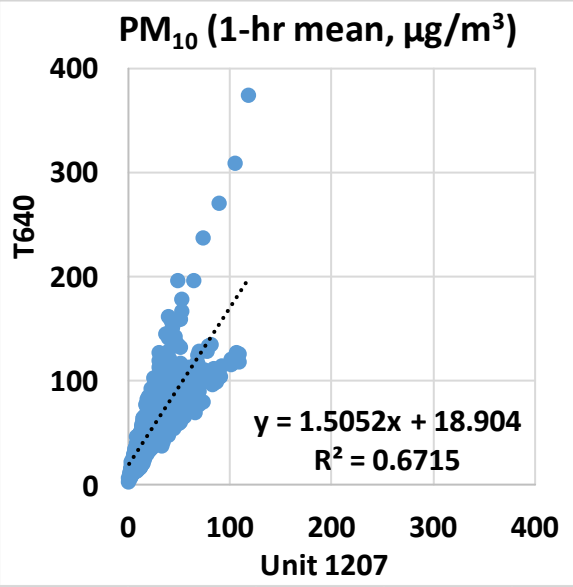


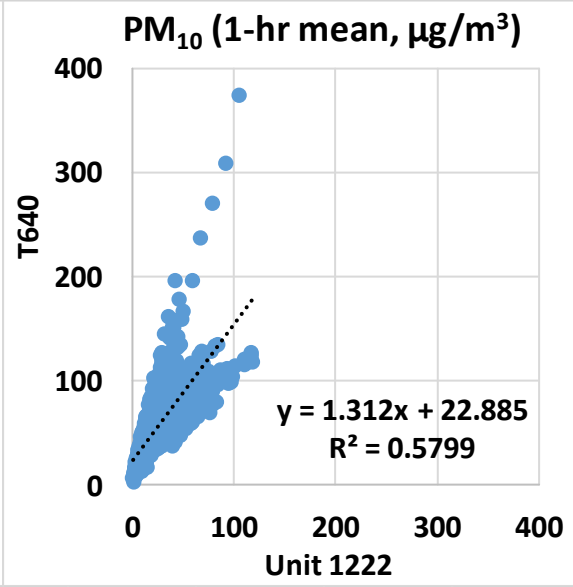


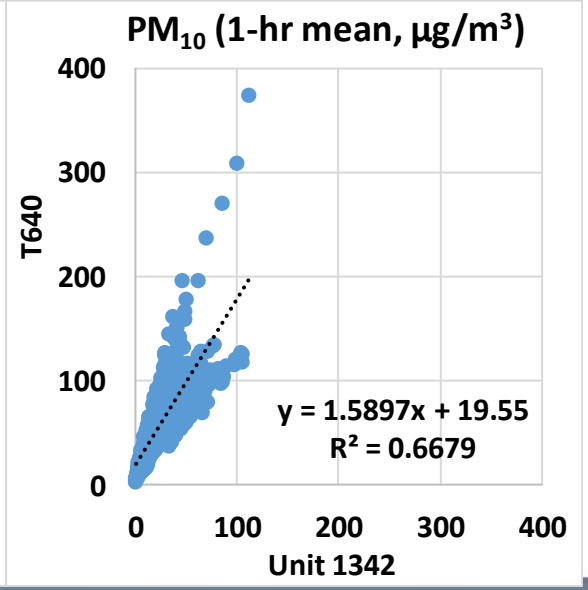
NextPM vs T640 (PM_{10}; 1-hr mean)



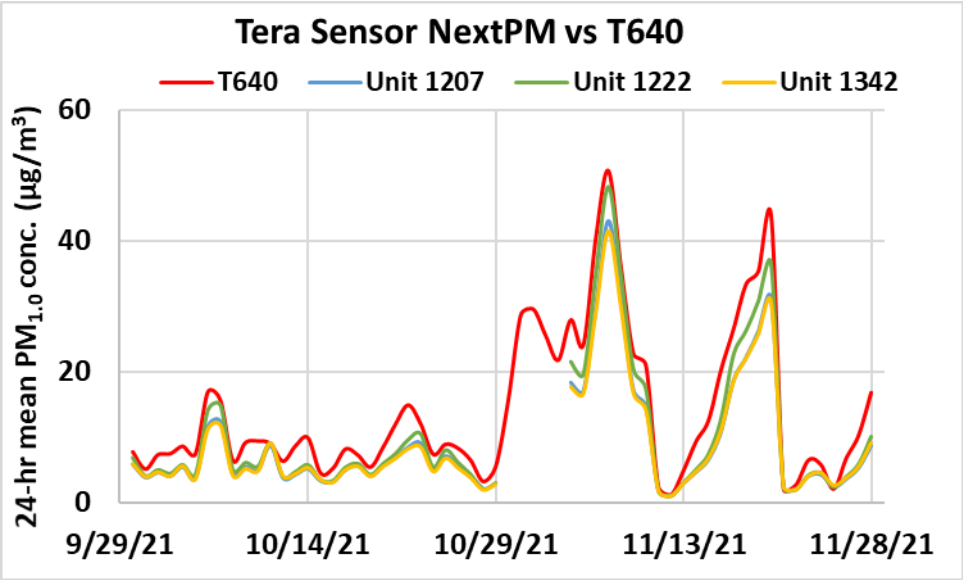
- The NextPM sensors showed moderate correlations with the corresponding T640 data ($0.57 < R^2 < 0.68$)
- Overall, the NextPM sensors underestimated the PM_{10} mass concentrations as measured by T640
- The NextPM sensors seemed to track the PM_{10} diurnal variations as recorded by T640



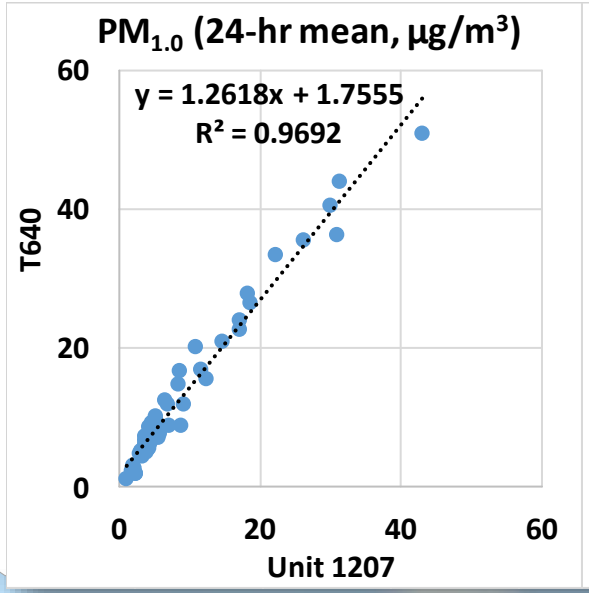


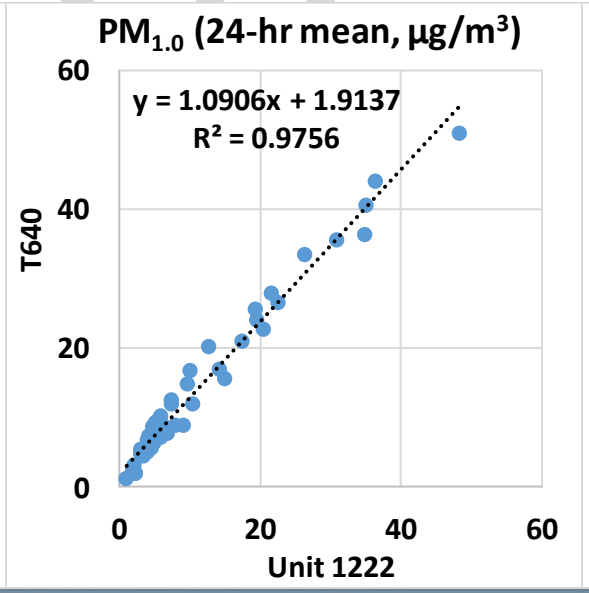


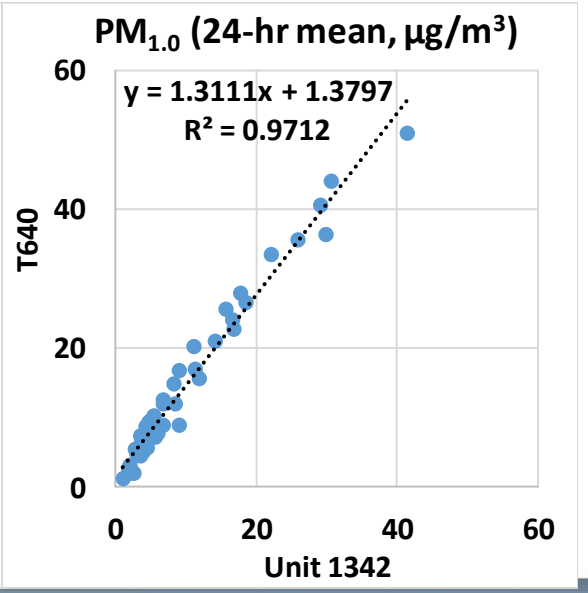
NextPM vs T640 ($PM_{1.0}$; 24-hr mean)



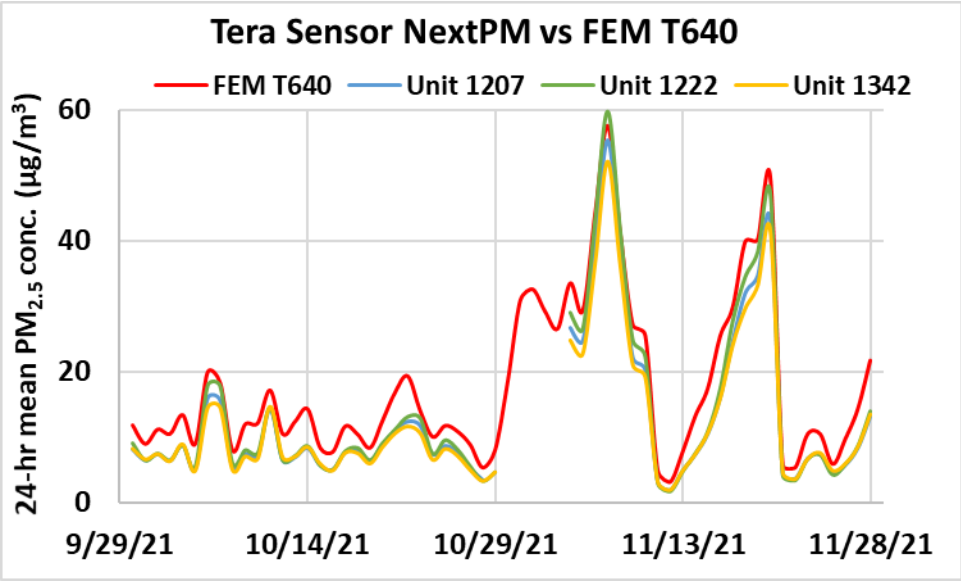
- The NextPM sensors showed very strong correlations with the corresponding T640 data ($0.96 < R^2 < 0.98$)
- Overall, the NextPM sensors underestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The NextPM sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by T640



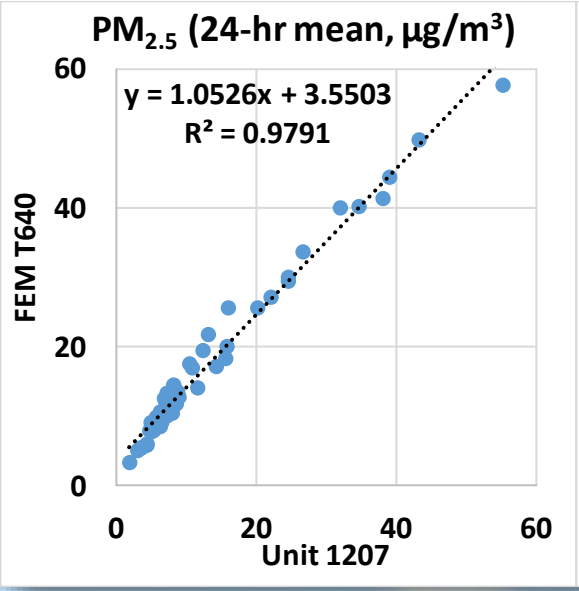


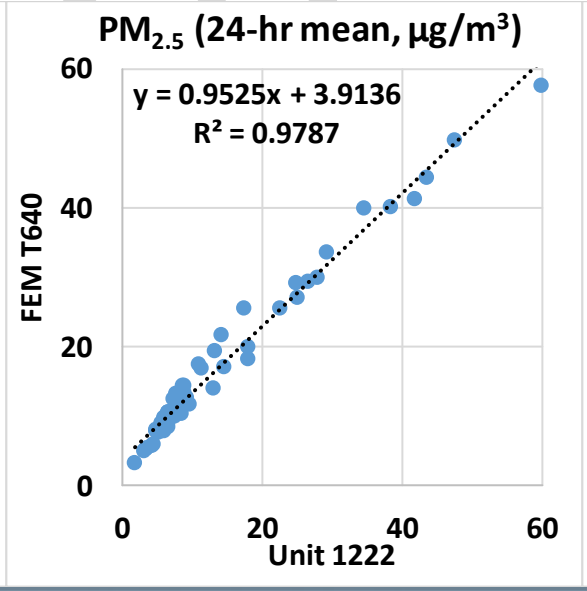


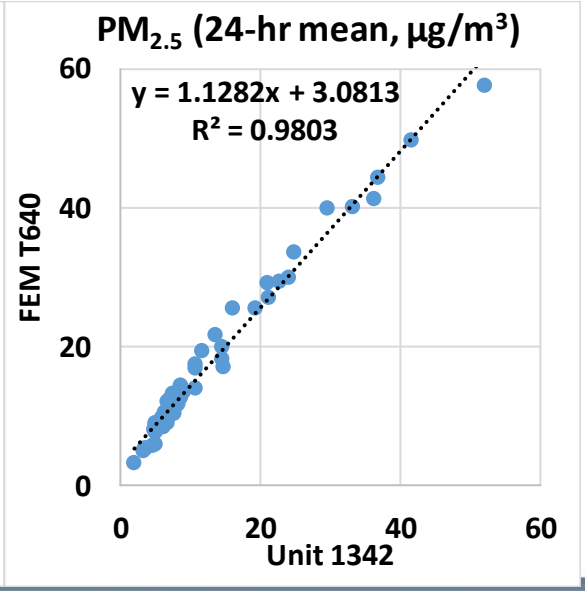
NextPM vs FEM T640 ($PM_{2.5}$; 24-hr mean)



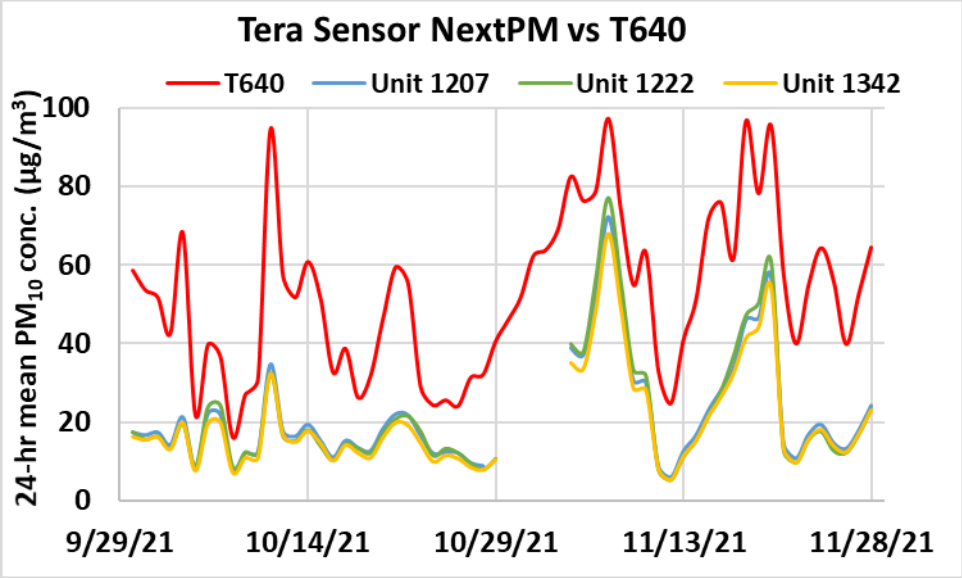
- The NextPM sensors showed very strong correlations with the corresponding FEM T640 data ($0.97 < R^2 < 0.99$)
- Overall, the NextPM sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The NextPM sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by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



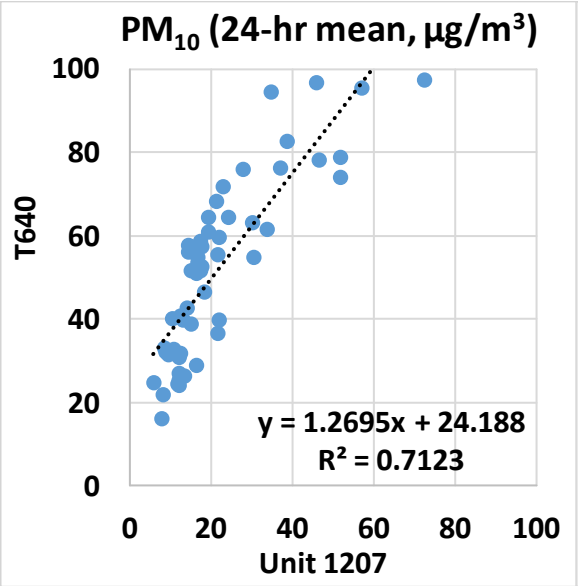


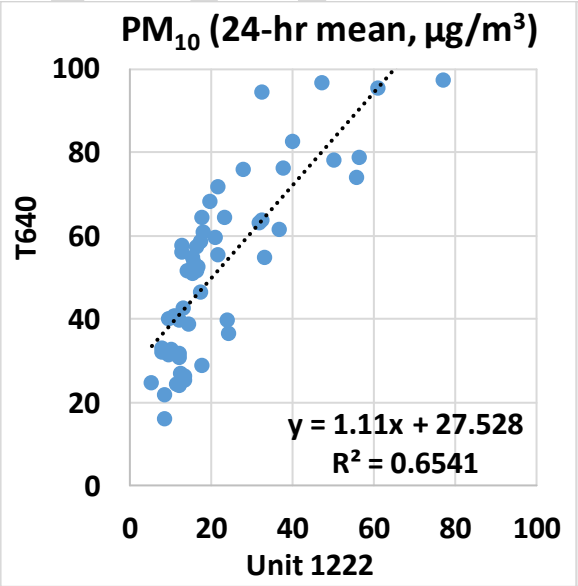


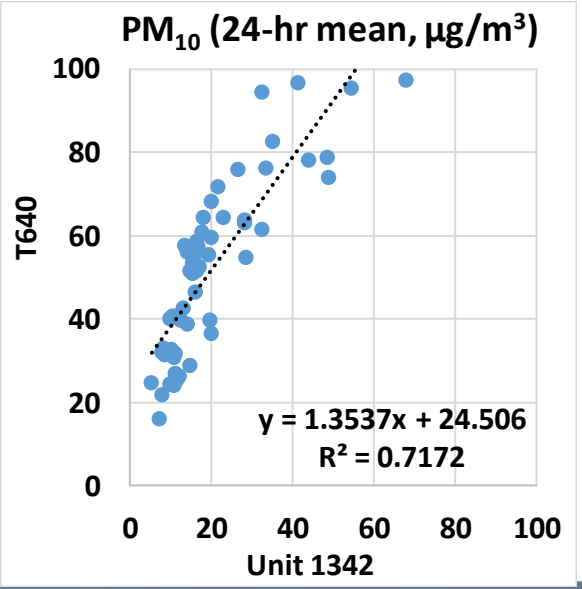
NextPM vs T640 (PM_{10}; 24-hr mean)



- The NextPM sensors showed moderate to strong correlations with the corresponding T640 data ($0.65 < R^2 < 0.72$)
- Overall, the NextPM sensors underestimated the PM_{10} mass concentrations as measured by T640
- The NextPM sensors seemed to track the PM_{10} diurnal variations as recorded by T640







Summary

	Average of 3 Sensors, $PM_{1.0}$		NextPM vs GRIMM & T640, $PM_{1.0}$						GRIMM & T640 ($PM_{1.0}$, $\mu g/m^3$)		
	Average ($\mu g/m^3$)	SD ($\mu g/m^3$)	R^2	Slope	Intercept	MBE[1] ($\mu g/m^3$)	MAE[2] ($\mu g/m^3$)	RMSE[3] ($\mu g/m^3$)	Ref. Average	Ref. SD	Range during the field evaluation
5-min	9.8	11.0	0.89 to 0.94	1.02 to 1.23	0.9 to 2.8	-4.3 to -1.5	2.1 to 4.6	3.1 to 6.4	12.2 to 14.0	11.2 to 12.9	0.2 to 92.1
1-hr	9.6	10.8	0.90 to 0.95	1.02 to 1.23	0.8 to 2.7	-4.3 to -1.5	2.1 to 4.5	3.0 to 6.2	12.2 to 14.0	11.1 to 12.8	0.2 to 69.1
24-hr	9.5	9.3	0.96 to 0.98	0.95 to 1.31	1.2 to 1.9	-4.2 to -1.2	1.7 to 4.3	2.3 to 5.3	12.6 to 14.0	10.2 to 11.4	0.7 to 50.8
	Average of 3 Sensors, $PM_{2.5}$		NextPM vs FEM GRIMM & FEM T640, $PM_{2.5}$						FEM GRIMM & FEM T640 ($PM_{2.5}$, $\mu g/m^3$)		
	Average ($\mu g/m^3$)	SD ($\mu g/m^3$)	R^2	Slope	Intercept	MBE[1] ($\mu g/m^3$)	MAE[2] ($\mu g/m^3$)	RMSE[3] ($\mu g/m^3$)	Ref. Average	Ref. SD	Range during the field evaluation
5-min	13.4	13.5	0.87 to 0.95	0.87 to 1.08	3.7 to 5.8	-5.4 to -3.2	3.9 to 5.6	4.7 to 6.8	17.8 to 18.1	12.5 to 13.9	0.6 to 119.6
1-hr	13.2	13.3	0.89 to 0.95	0.87 to 1.09	3.6 to 5.7	-5.4 to -3.2	3.8 to 5.5	4.6 to 6.6	17.8 to 18.1	12.3 to 13.8	0.9 to 79.2
24-hr	13.7	11.0	0.93 to 0.98	0.80 to 1.13	3.1 to 6.5	-5.2 to -3.3	3.4 to 5.3	3.4 to 5.9	17.8 to 18.6	10.6 to 12.1	3.3 to 57.6
	Average of 3 Sensors, PM_{10}		NextPM vs GRIMM & T640, PM_{10}						GRIMM & T640 (PM_{10}, $\mu g/m^3$)		
	Average ($\mu g/m^3$)	SD ($\mu g/m^3$)	R^2	Slope	Intercept	MBE[1] ($\mu g/m^3$)	MAE[2] ($\mu g/m^3$)	RMSE[3] ($\mu g/m^3$)	Ref. Average	Ref. SD	Range during the field evaluation
5-min	21.7	17.7	0.34 to 0.66	1.03 to 1.60	18.7 to 24.9	-31.6 to -25.5	26.2 to 31.6	34.4 to 38.3	47.1 to 52.3	29.1 to 32.3	0.9 to 414.7
1-hr	21.5	17.4	0.35 to 0.67	1.02 to 1.59	18.9 to 25.5	-31.6 to -25.8	26.3 to 31.6	34.6 to 37.8	47.1 to 52.3	27.3 to 31.2	1.2 to 374.1
24-hr	21.4	14.0	0.32 to 0.72	0.66 to 1.35	24.2 to 33.0	-31.7 to -25.4	26.1 to 31.7	29.5 to 33.9	47.5 to 52.3	17.1 to 20.2	16.0 to 97.4

[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.

Discussion

- The three **NextPM** sensors' data recovery from Unit 1207, Unit 1222 and Unit 1342 was ~ 95%, 96% and 96% for all PM measurements, respectively
- The absolute intra-model variability was ~ 0.67, 0.65 and 0.81 µg/m^3 for $PM_{1.0}$, $PM_{2.5}$ and $PM_{10,}$ respectively
- Very strong correlations between GRIMM and T640 for $PM_{1.0}$ (R^2 ~ 0.97, 1-hr mean); very strong correlations between FEM GRIMM and FEM T640 for $PM_{2.5}$ (R^2 ~ 0.94, 1-hr mean) and strong correlations between GRIMM and T640 for PM_{10} (R^2 ~ 0.88, 1-hr mean) mass concentration measurements
- $PM_{1.0}$ mass concentrations measured by the NextPM sensors showed strong to very strong correlations with the corresponding GRIMM and T640 data ($0.89 < R^2 < 0.95$, 1-hr mean). The sensors underestimated $PM_{1.0}$ mass concentrations as measured by GRIMM and T640
- $PM_{2.5}$ mass concentrations measured by the NextPM sensors showed strong to very strong correlations with the corresponding FEM GRIMM and FEM T640 data ($0.88 < R^2 < 0.95$, 1-hr mean). The sensors underestimated $PM_{2.5}$ mass concentrations as measured by FEM GRIMM and FEM T640
- PM_{10} mass concentrations measured by the NextPM sensors showed weak to moderate correlations with the corresponding GRIMM and T640 data ($0.35 < R^2 < 0.68$; 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