Field Evaluation
APT MINIMA

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

- From 10/30/2020 to 12/29/2020, three **Applied Particle Technology MINIMA (hereinafter APT MINIMA)** 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

- APT MINIMA (*3 units tested*):
  - Particle sensor: optical; non-FEM
  - Each unit reports: $PM_{1.0}$, $PM_{2.5}$ and PM_{10} ($\mu g/m^3$)
  - Unit cost: $995 (hardware only)
  - Time resolution: 15-sec
  - Units IDs: BW28, BW29, BW31

- MetOne BAM (*reference instrument*):
  - Beta-attenuation monitor (FEM $PM_{2.5}$ & PM_{10})
  - Measures $PM_{2.5}$ & PM_{10} ($\mu g/m^3$)
  - Unit cost: ~$20,000
  - Time resolution: 1-hr

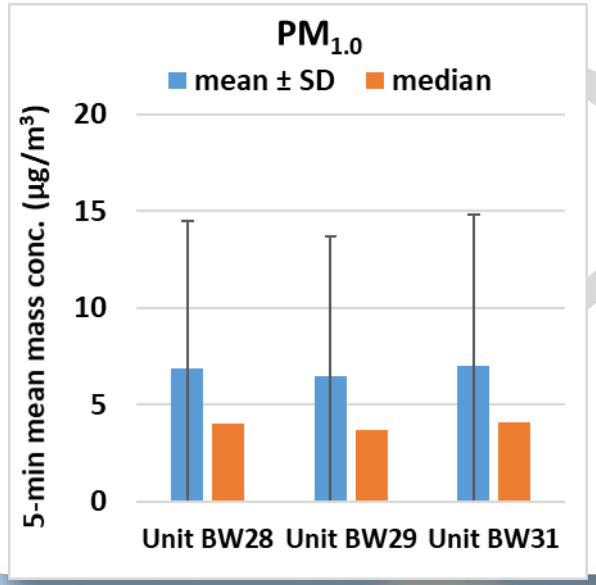
- Teledyne API T640 (*reference instrument*):
  - Optical particle counter (FEM $PM_{2.5}$)
  - Measures $PM_{2.5}$ & PM_{10} ($\mu g/m^3$)
  - Unit cost: ~$21,000
  - Time resolution: 1-min

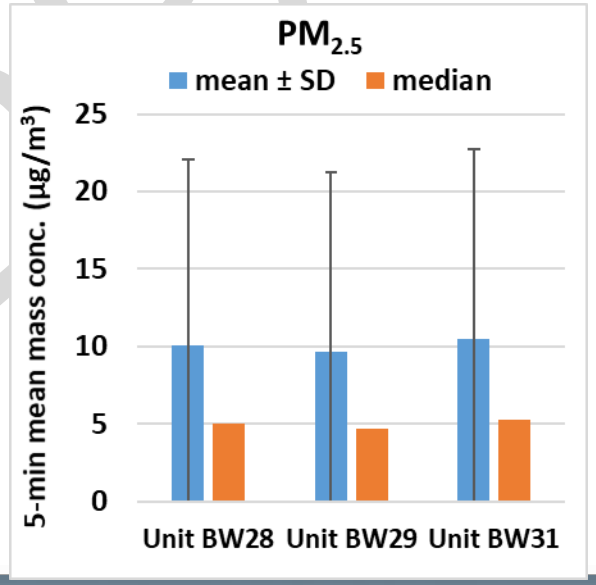
Data validation & recovery

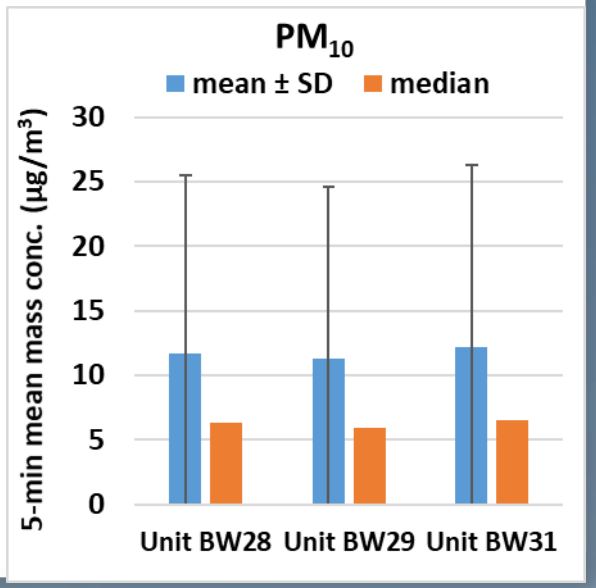
- Basic QA/QC procedures were used to validate the collected data (i.e. obvious outliers, negative values and invalid data-points were eliminated from the data-set)
- Data recovery from all units was ~ 100% for all PM measurements

APT MINIMA; intra-model variability

- Absolute intra-model variability was ~ 0.24, 0.33 and 0.37 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 ~ 3.5%, 3.3% and 3.2 % 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)

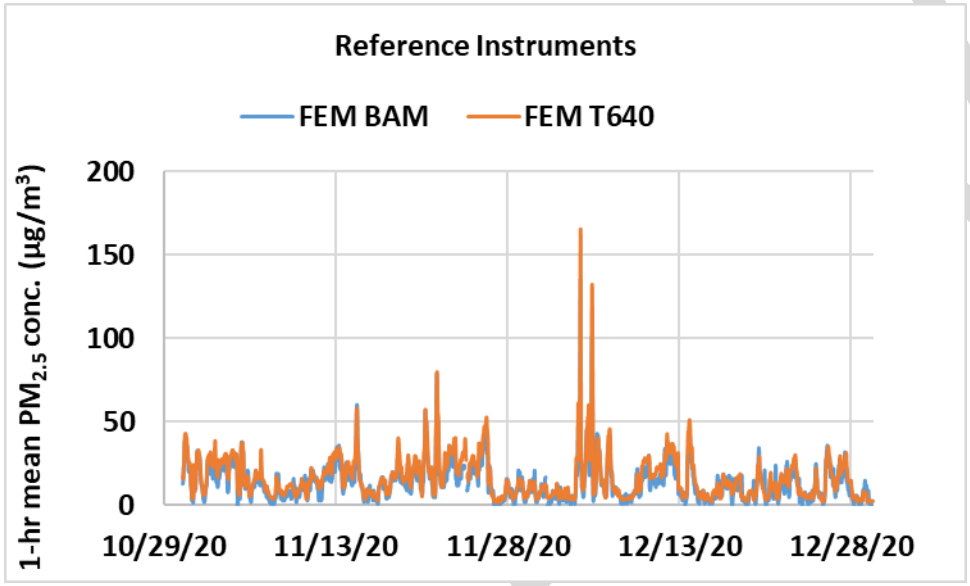


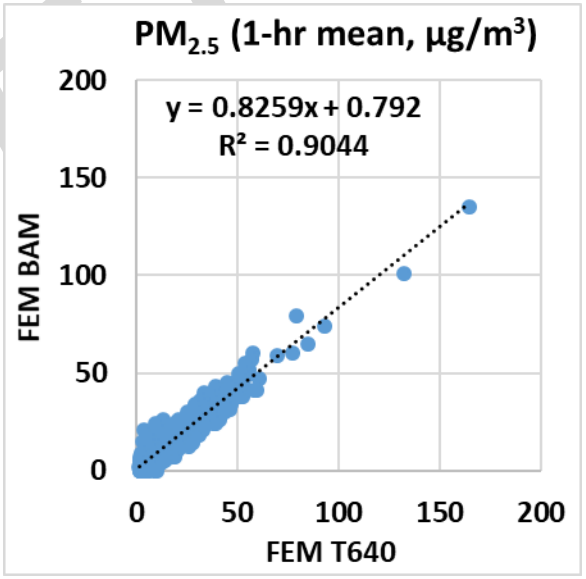




Reference Instruments: $PM_{2.5}$ FEM BAM and FEM T640

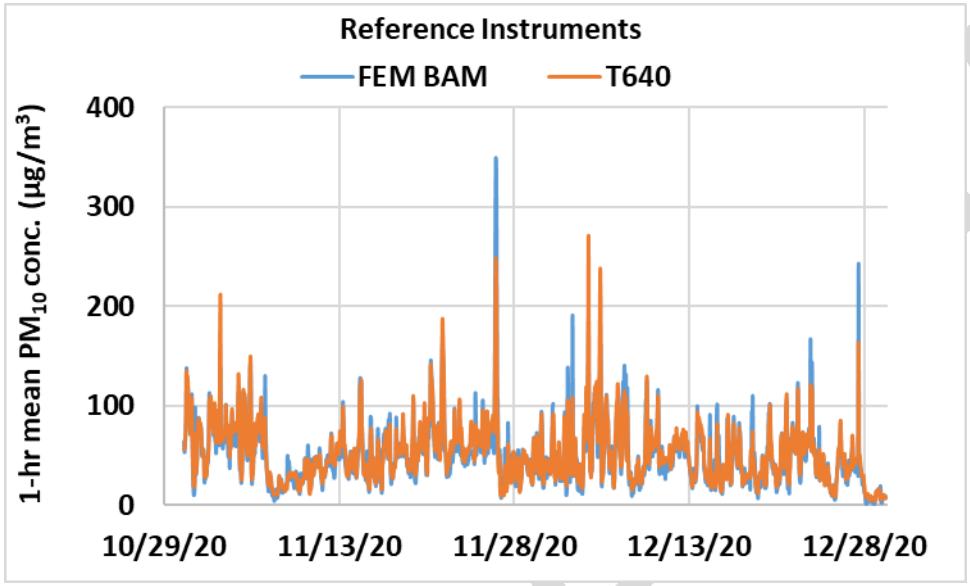
- Data recovery for $PM_{2.5}$ from FEM BAM and FEM T640 was ~ 98% and ~ 100%, respectively.
- Very strong correlations between the reference instruments for $PM_{2.5}$ measurements (R^2 ~ 0.90) were observed.

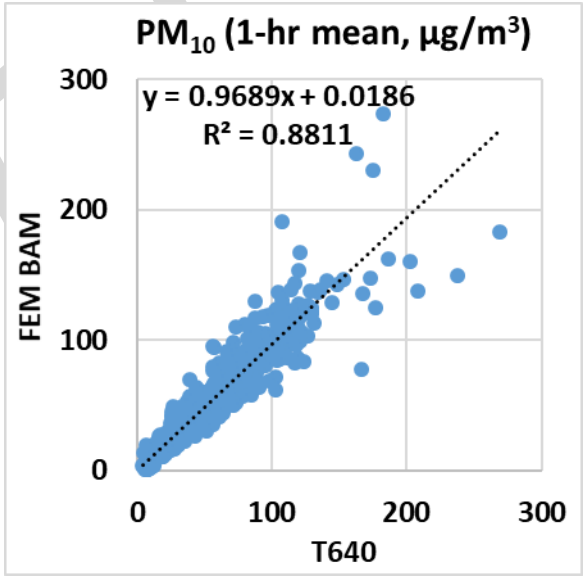




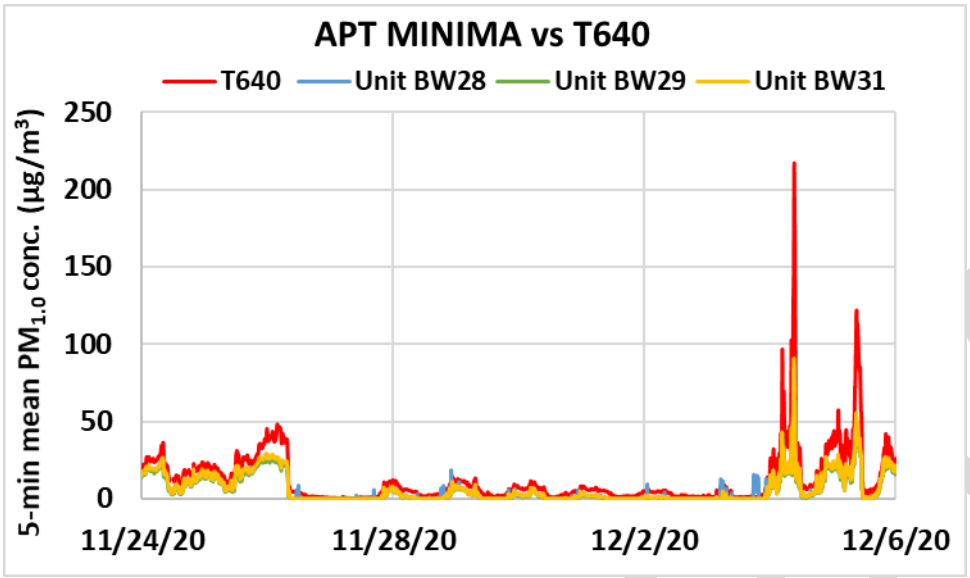
Reference Instruments: PM_{10} FEM BAM and T640

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

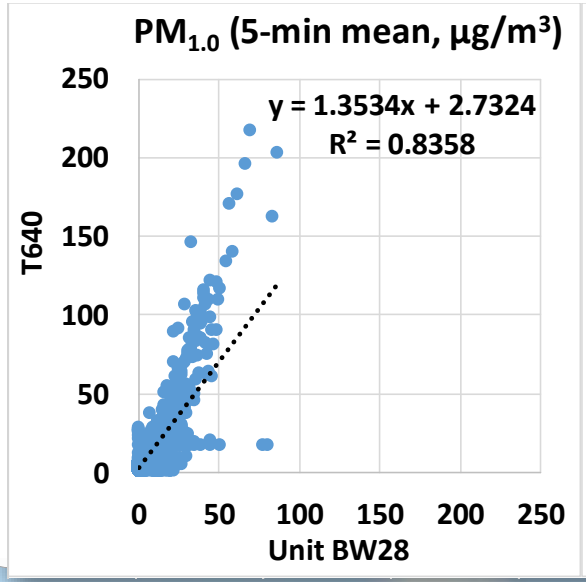


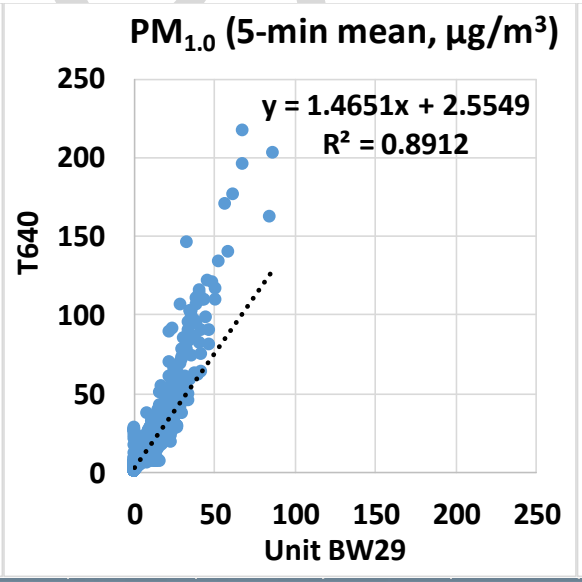


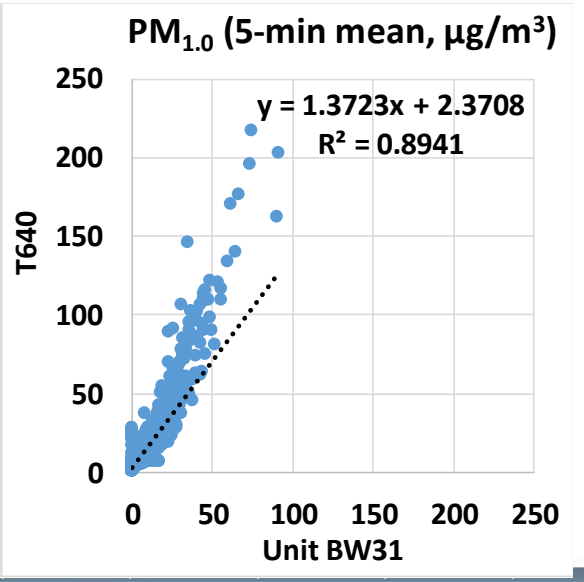
APT MINIMA vs T640 ($PM_{1.0}$; 5-min mean)



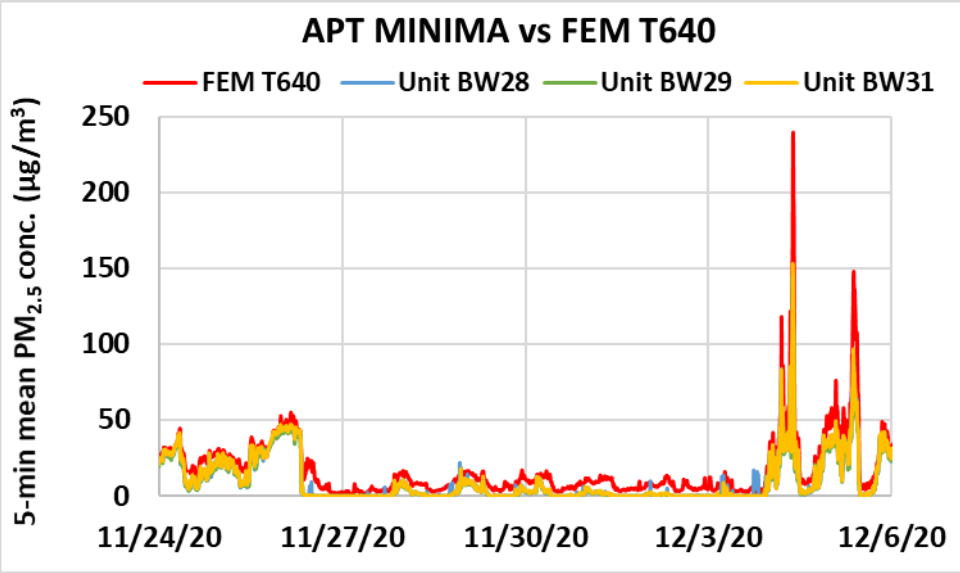
- APT MINIMA sensors showed strong correlations with the corresponding T640 data ($0.83 < R^2 < 0.90$)
- Overall, the APT MINIMA sensors underestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The APT MINIMA sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by T640



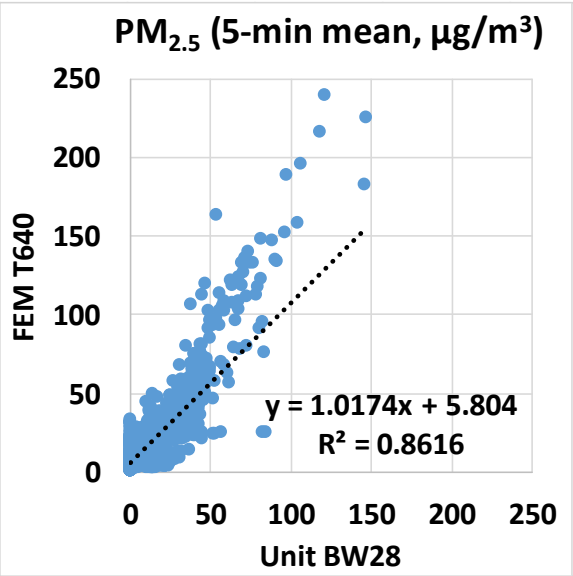


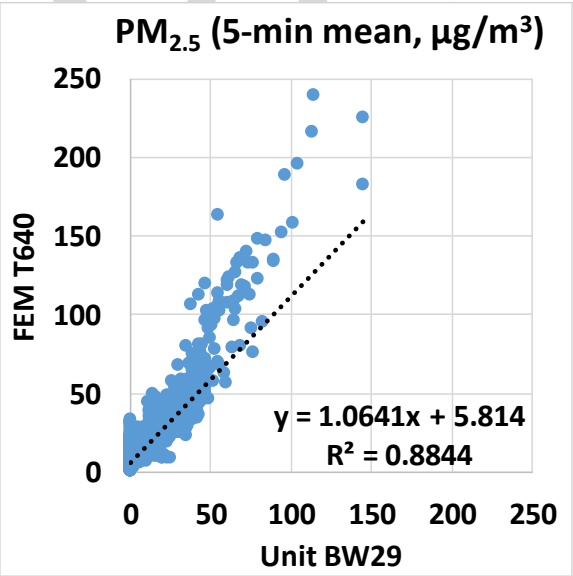


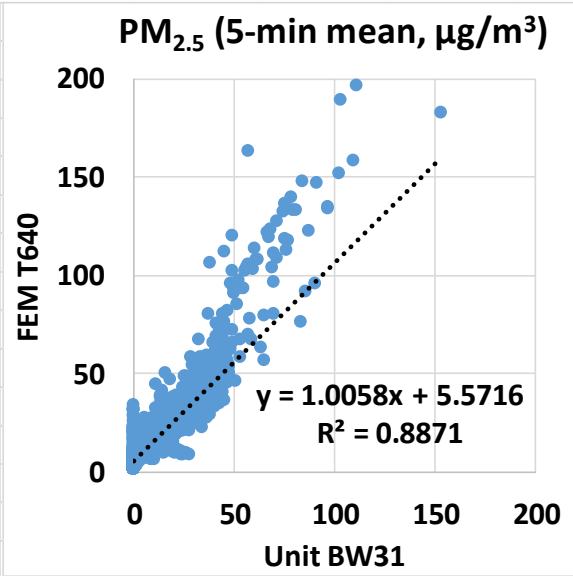
APT MINIMA vs FEM T640 ($PM_{2.5}$; 5-min mean)



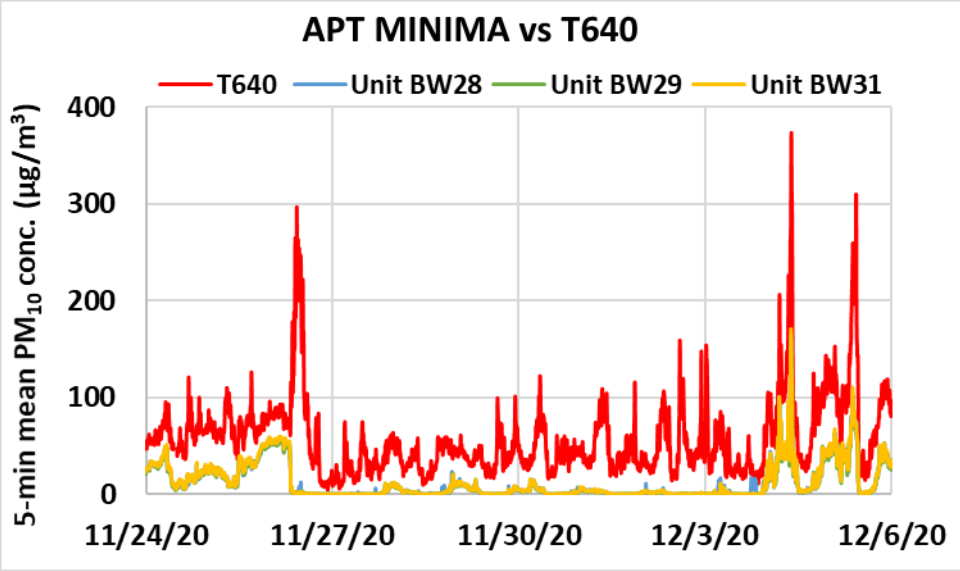
- APT MINIMA sensors showed strong correlations with the corresponding FEM T640 data ($0.86 < R^2 < 0.89$)
- Overall, the APT MINIMA sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The APT MINIMA sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



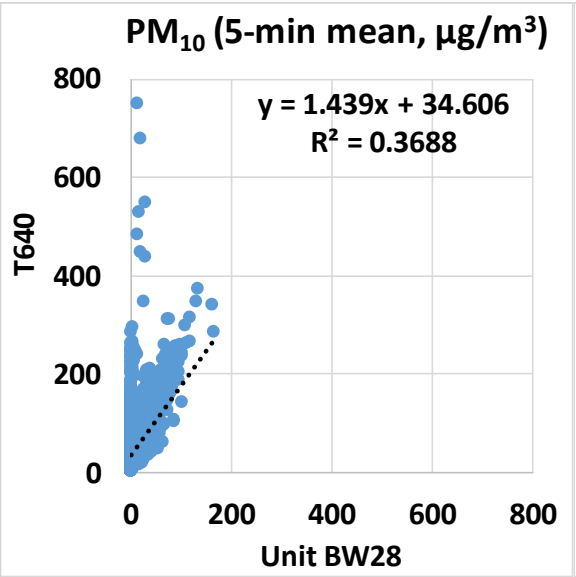


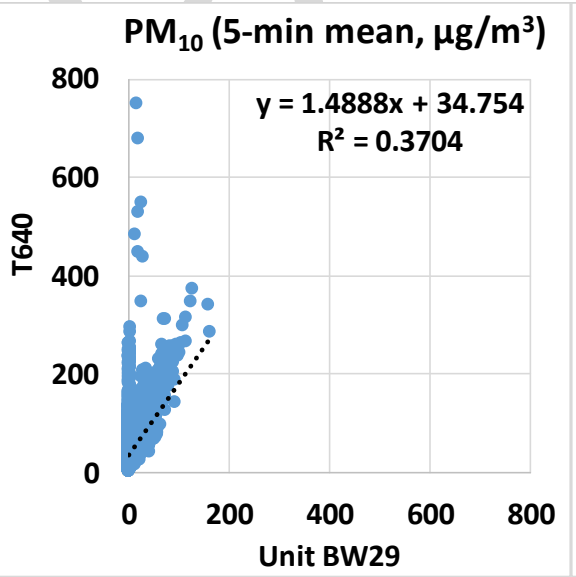


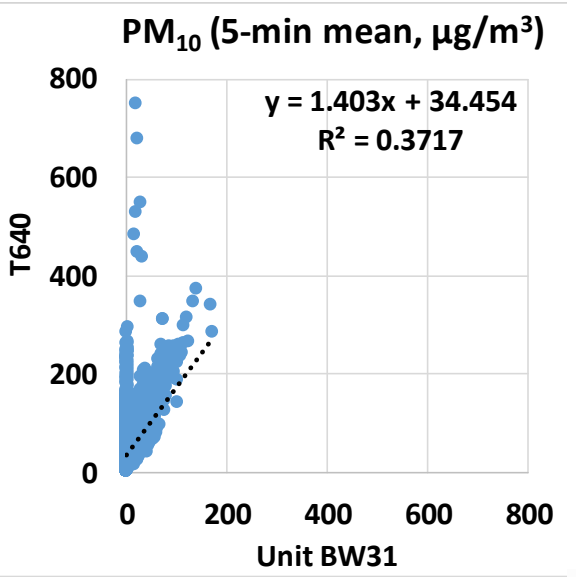
APT MINIMA vs T640 (PM_{10}; 5-min mean)



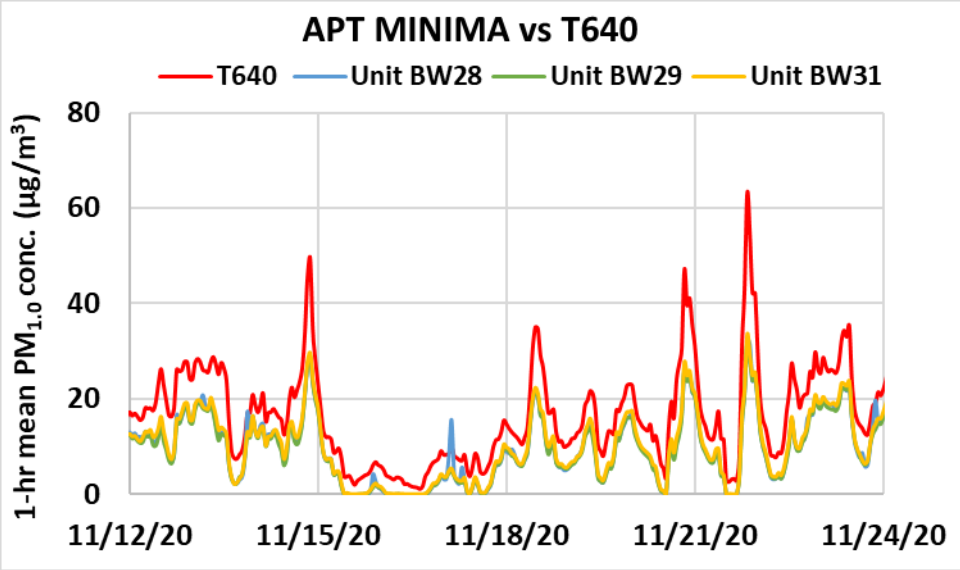
- APT MINIMA sensors showed weak correlations with the corresponding T640 data ($0.36 < R^2 < 0.38$)
- Overall, the APT MINIMA sensors underestimated the PM_{10} mass concentrations as measured by T640
- The APT MINIMA sensors did not seem to track the PM_{10} diurnal variations as recorded by T640



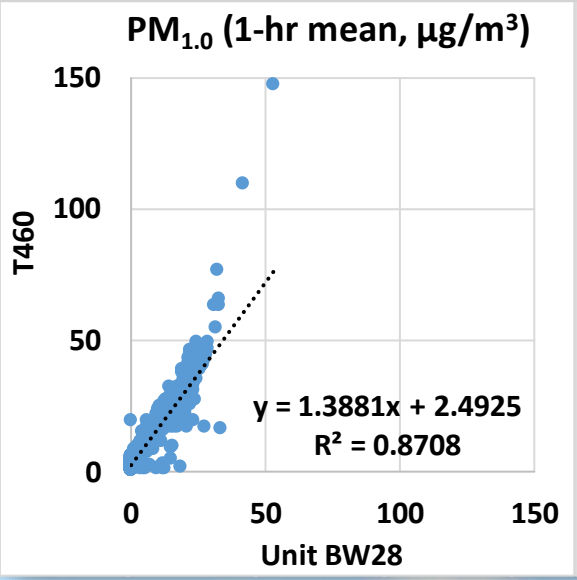


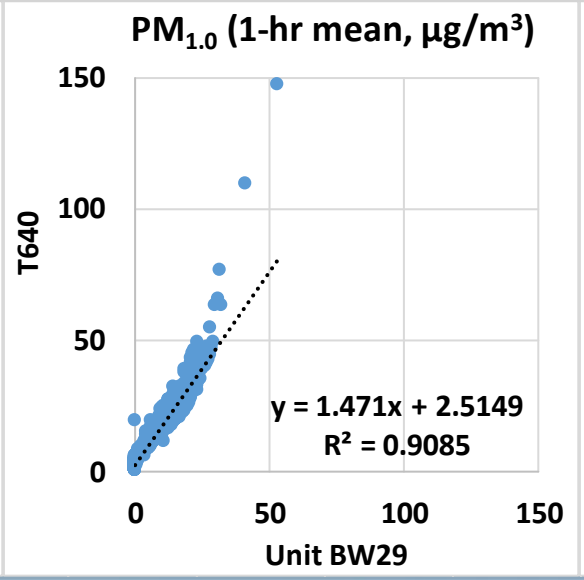


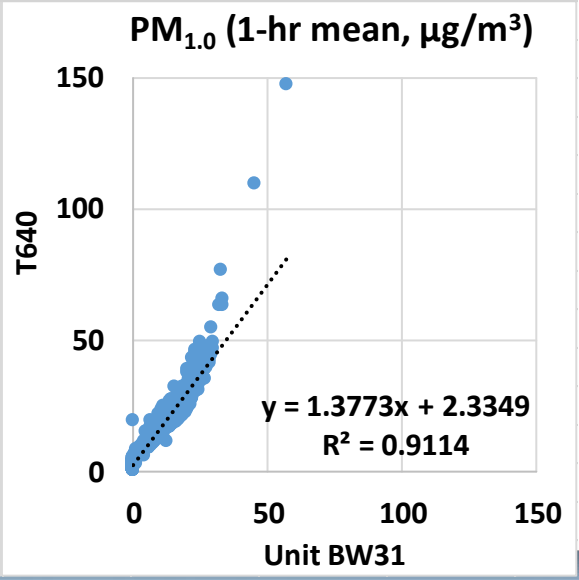
APT MINIMA vs T640 ($PM_{1.0}$; 1-hr mean)



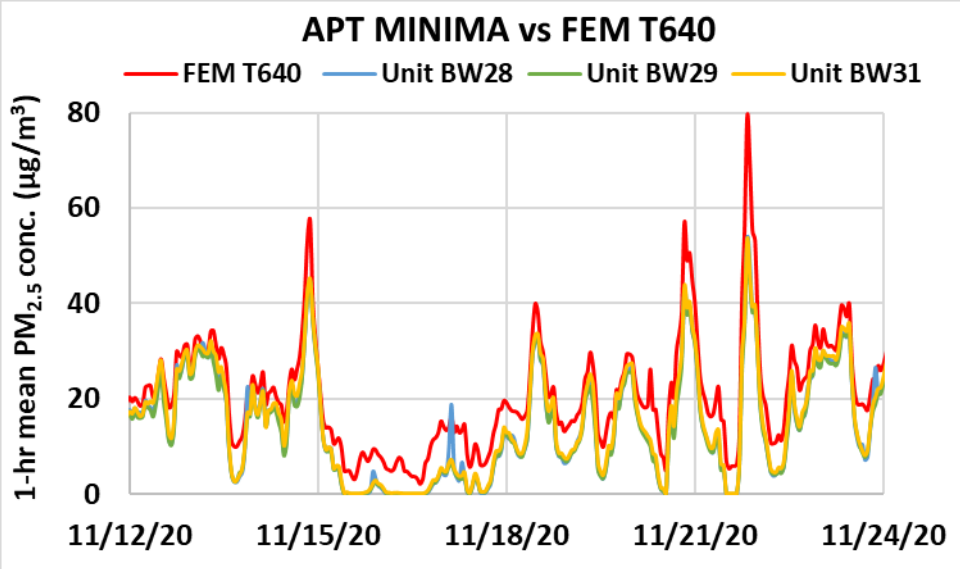
- APT MINIMA sensors showed strong to very strong correlations with the corresponding T640 data ($0.87 < R^2 < 0.92$)
- Overall, the APT MINIMA sensors underestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The APT MINIMA sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by T640



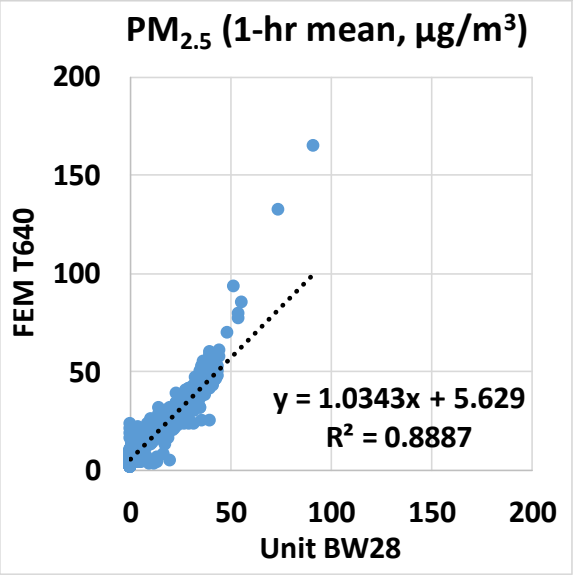


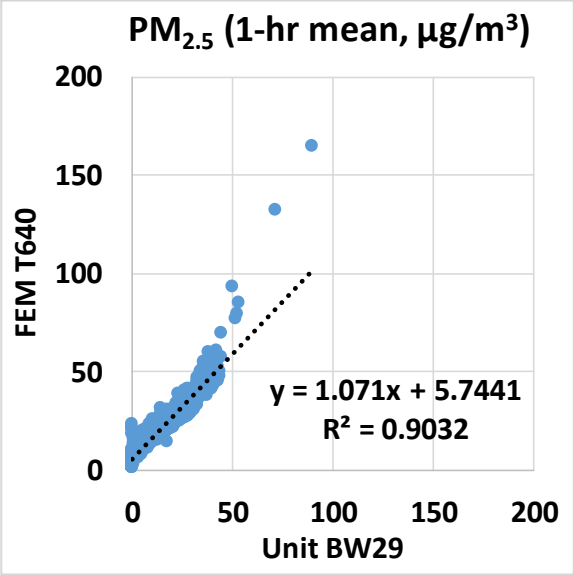


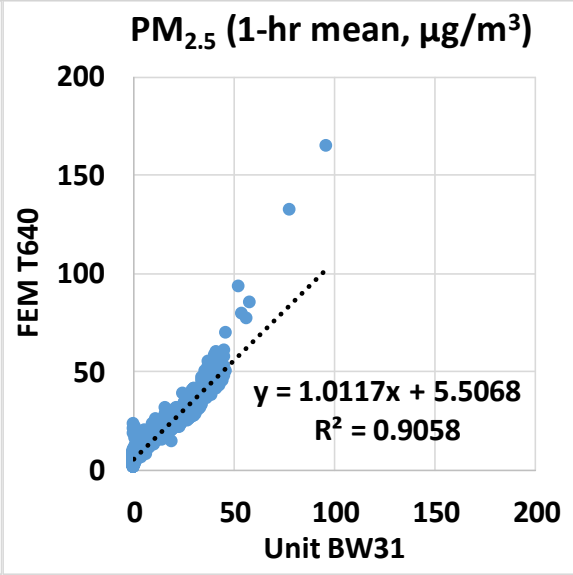
APT MINIMA vs FEM T640 ($PM_{2.5}$; 1-hr mean)



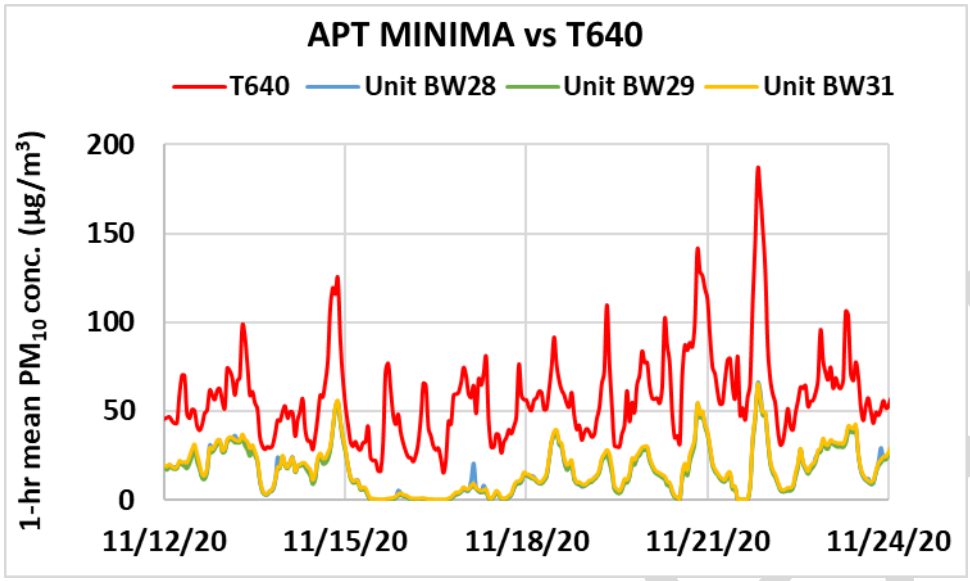
- APT MINIMA sensors showed strong to very strong correlations with the corresponding FEM T640 data ($0.88 < R^2 < 0.91$)
- Overall, the APT MINIMA sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The APT MINIMA sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



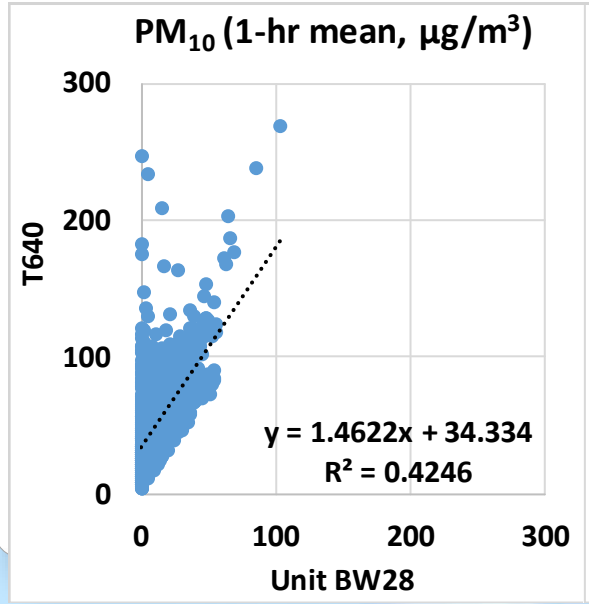


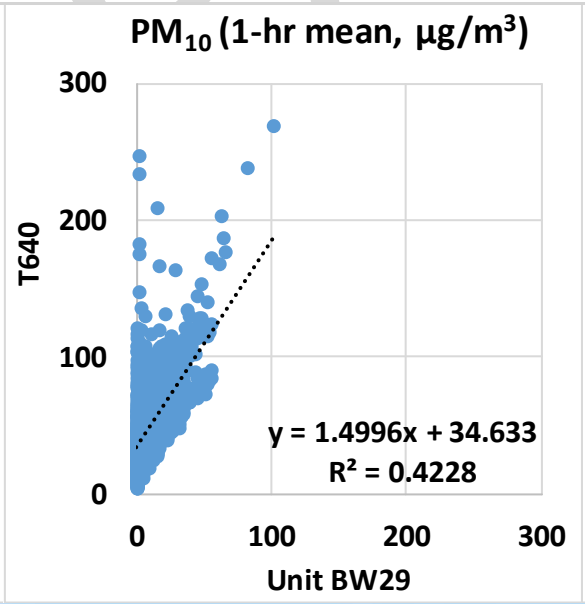


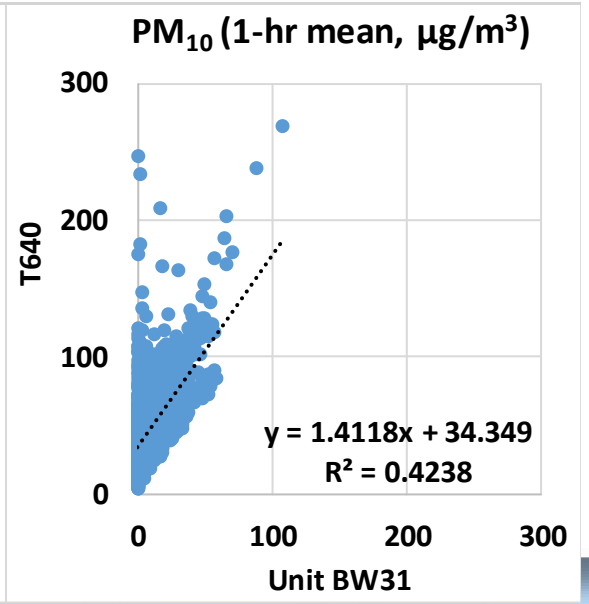
APT MINIMA vs T640 (PM_{10}; 1-hr mean)



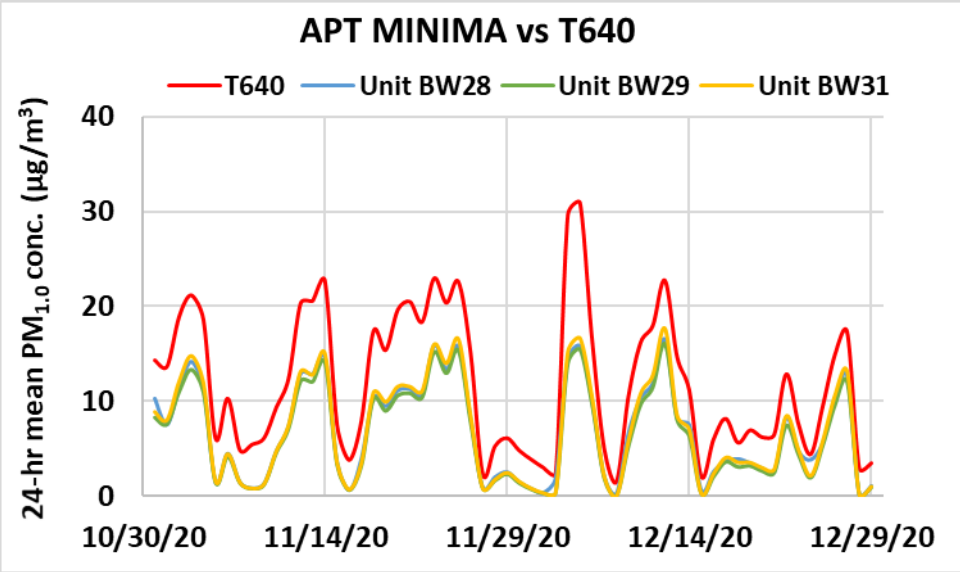
- APT MINIMA sensors showed weak correlations with the corresponding T640 data (R^2 ~ 0.42)
- Overall, the APT MINIMA sensors underestimated the PM_{10} mass concentrations as measured by T640
- The APT MINIMA sensors did not seem to track the PM_{10} diurnal variations as recorded by T640



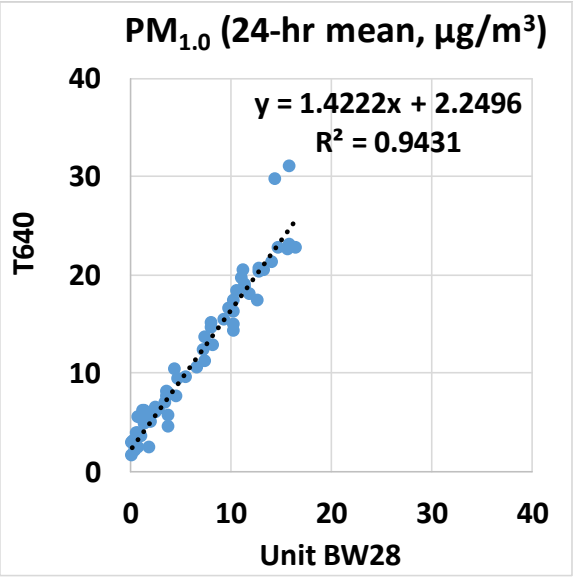


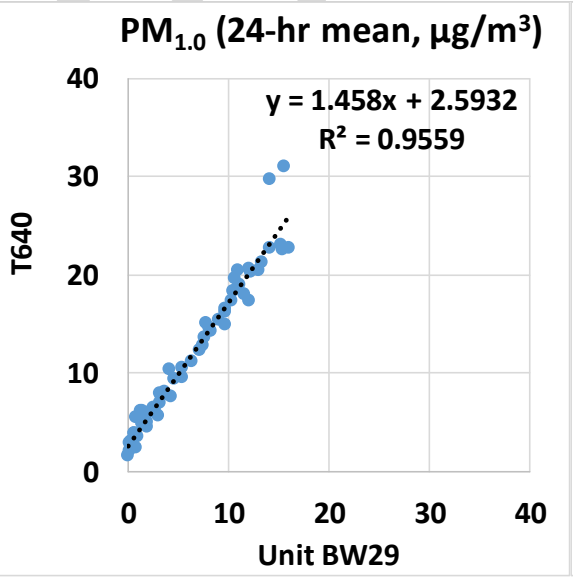


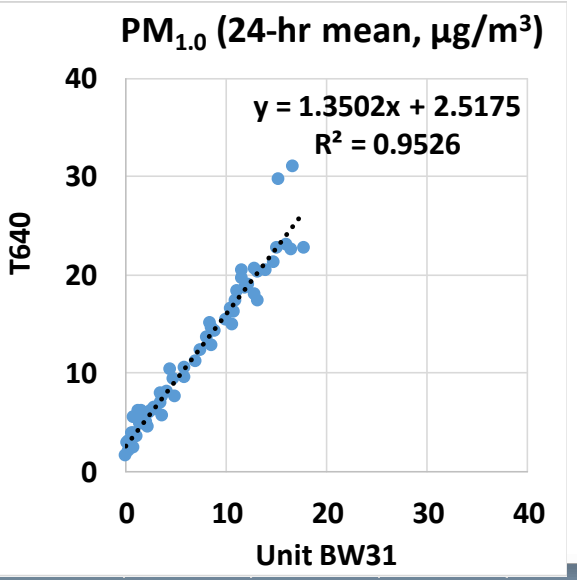
APT MINIMA vs T640 ($PM_{1.0}$; 24-hr mean)



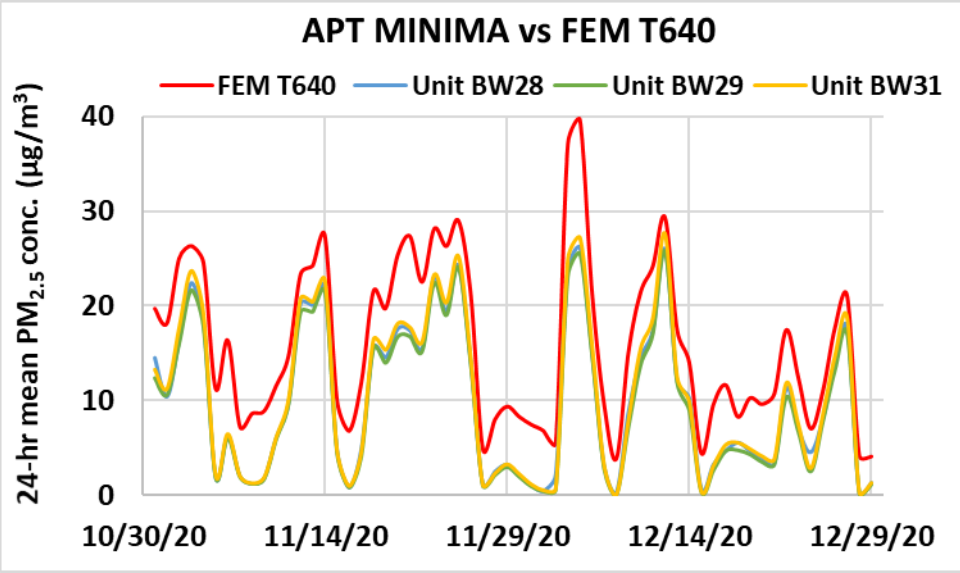
- APT MINIMA sensors showed very strong correlations with the corresponding T640 data ($0.94 < R^2 < 0.96$)
- Overall, the APT MINIMA sensors underestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The APT MINIMA sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by T640



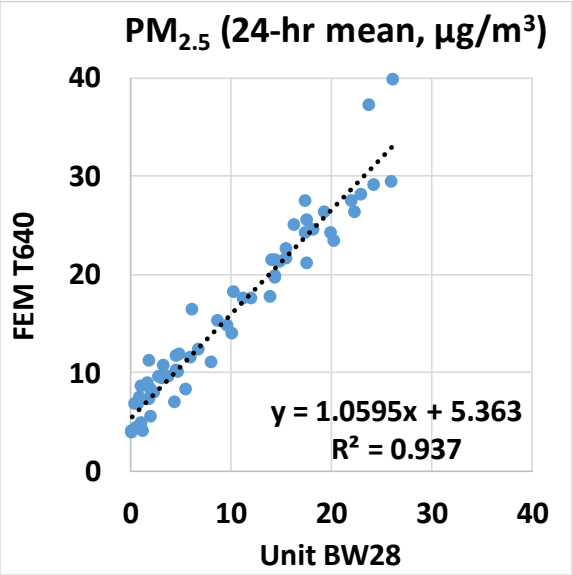


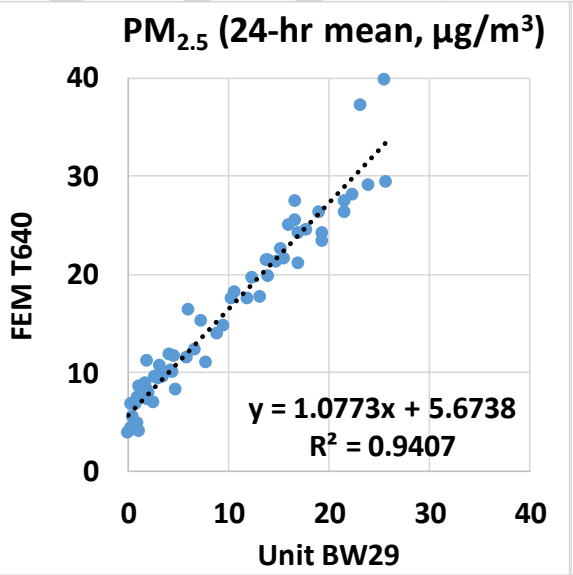


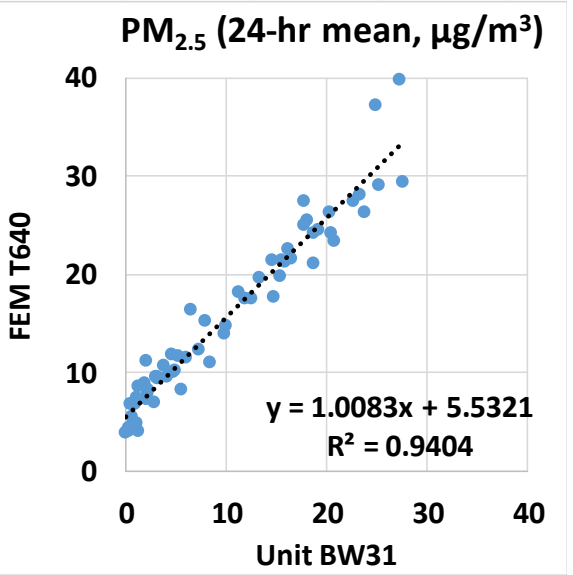
APT MINIMA vs FEM T640 ($PM_{2.5}$; 24-hr mean)



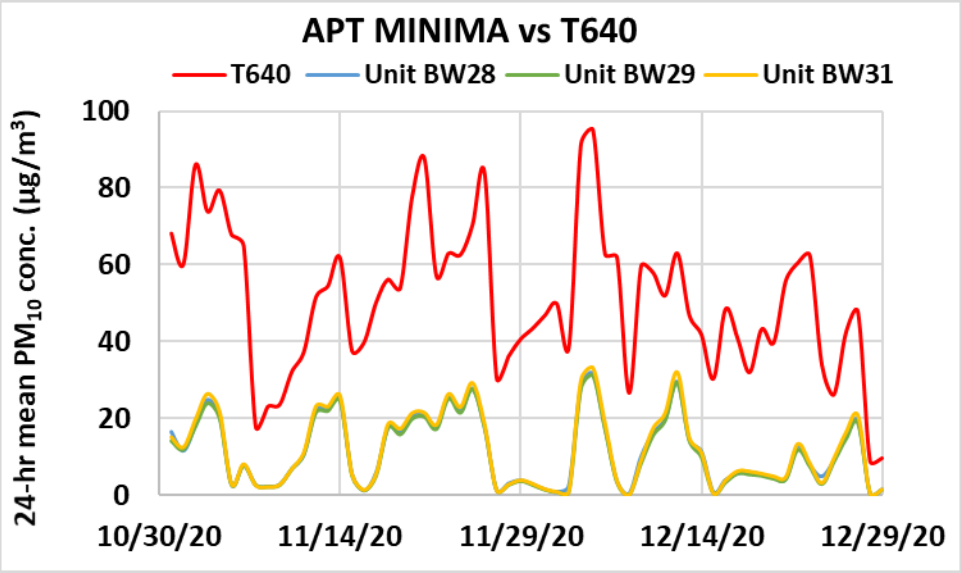
- APT MINIMA sensors showed very strong correlations with the corresponding FEM T640 data (R^2 ~ 0.94)
- Overall, the APT MINIMA sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The APT MINIMA sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by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



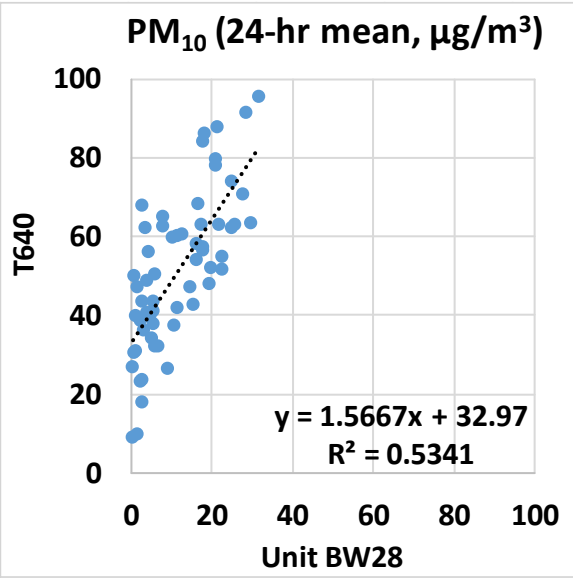


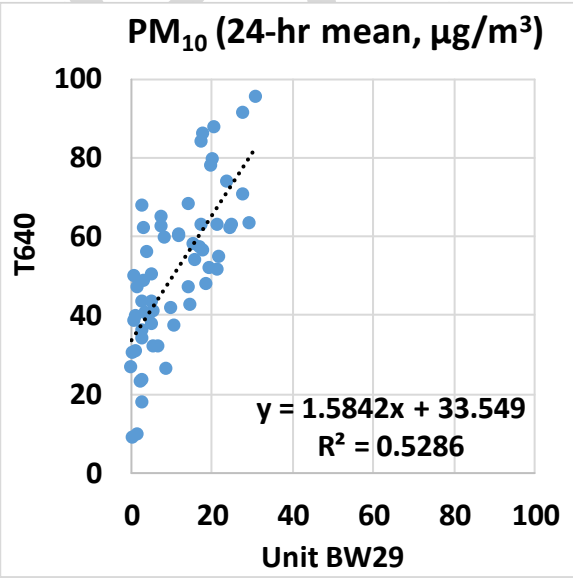


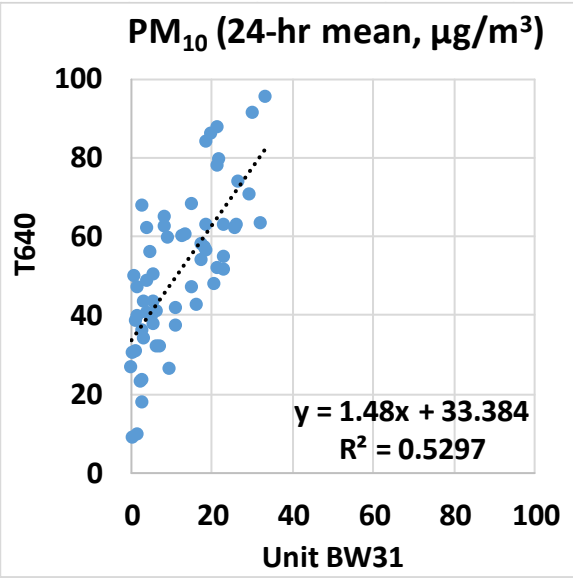
APT MINIMA vs T640 (PM_{10}; 24-hr mean)



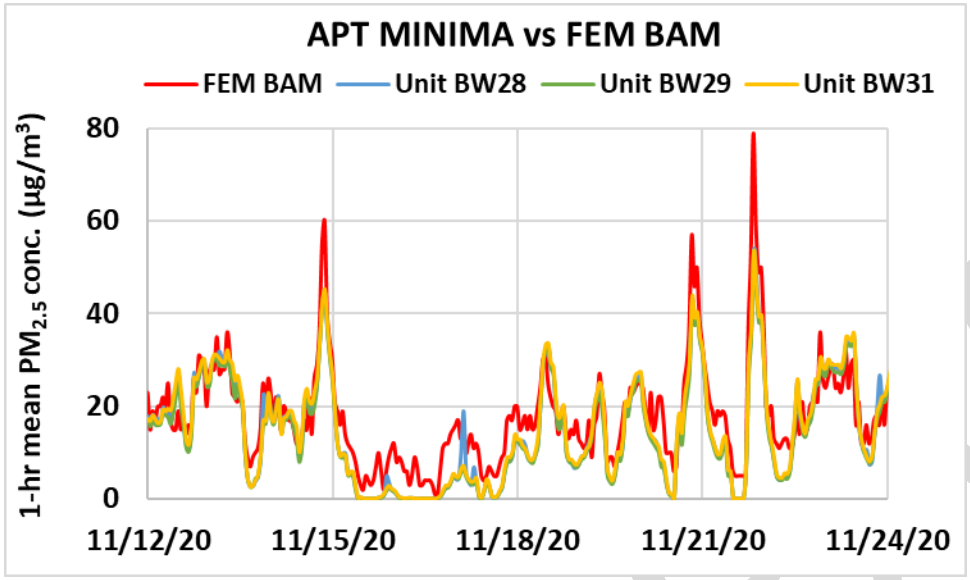
- APT MINIMA sensors showed moderate correlations with the corresponding T640 data (R^2 ~ 0.53)
- Overall, the APT MINIMA sensors underestimated the PM_{10} mass concentrations as measured by T640
- The APT MINIMA sensors seemed to track the PM_{10} diurnal variations as recorded by T640



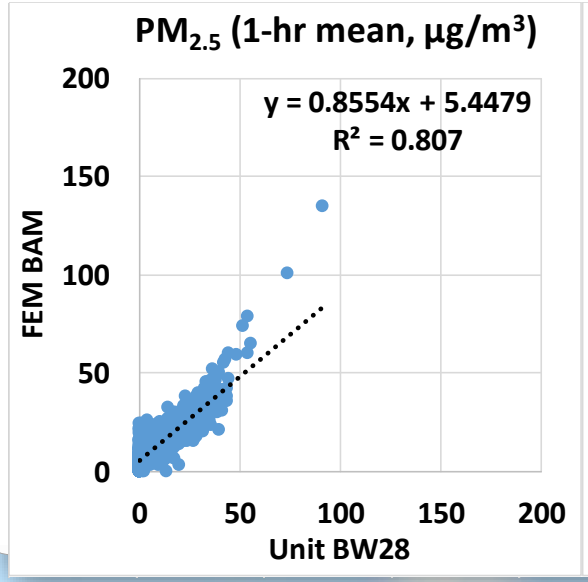


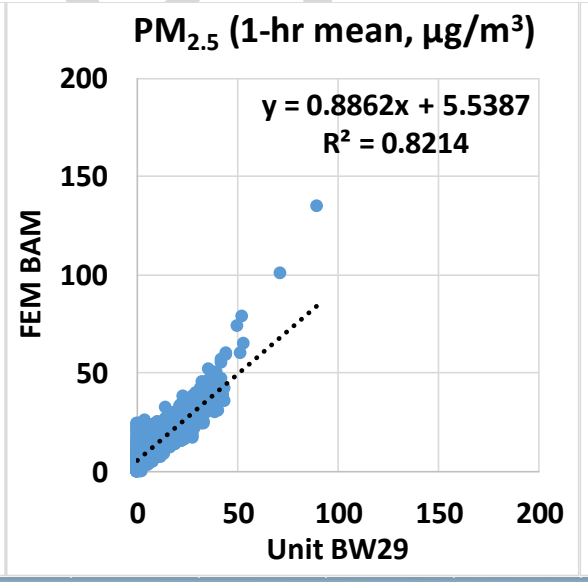


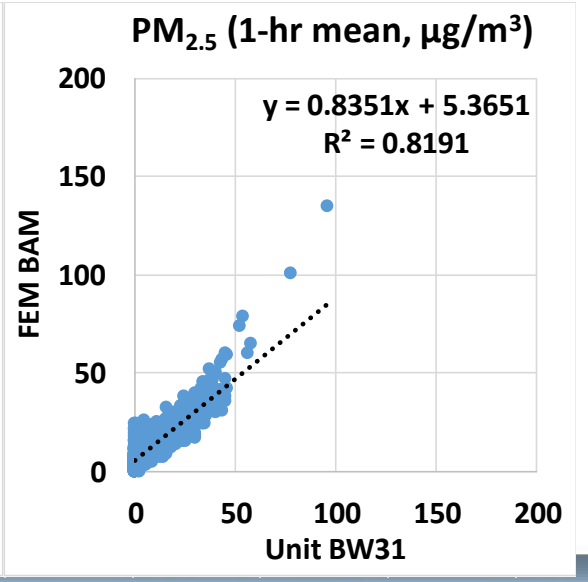
APT MINIMA vs FEM BAM ($PM_{2.5}$; 1-hr mean)



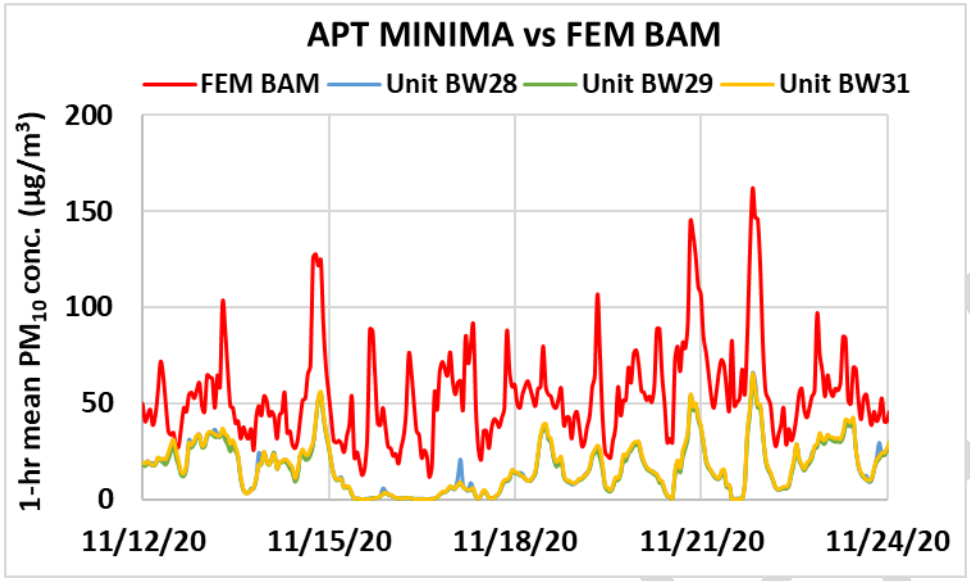
- APT MINIMA sensors showed strong correlations with the corresponding FEM BAM data ($0.80 < R^2 < 0.83$)
- Overall, the APT MINIMA sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM BAM
- The APT MINIMA sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM BAM



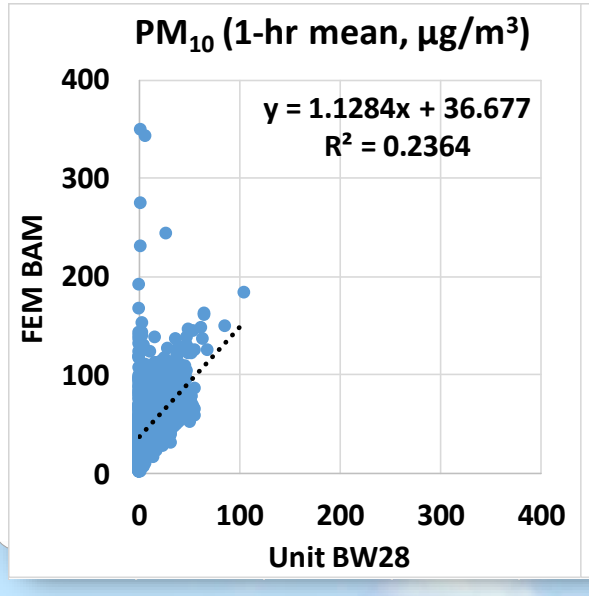


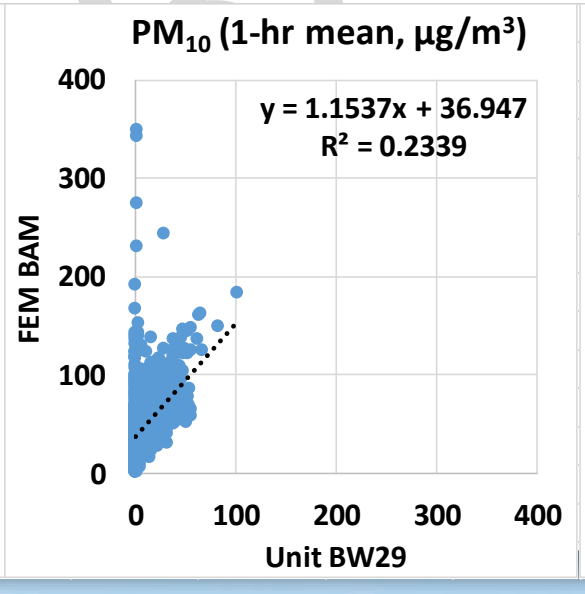


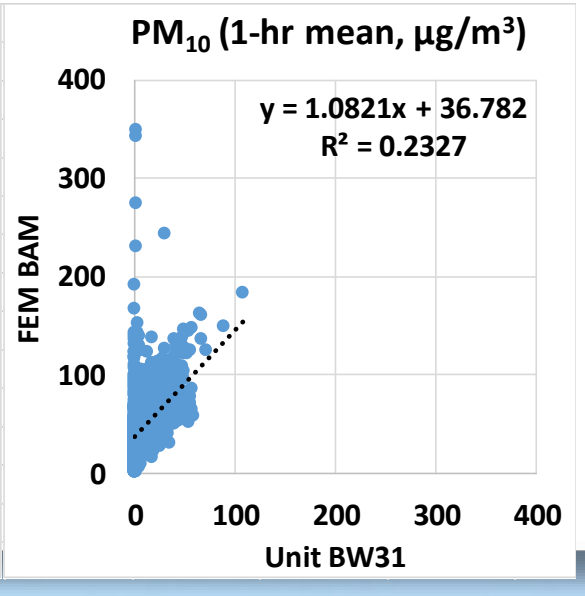
APT MINIMA vs FEM BAM (PM_{10}; 1-hr mean)



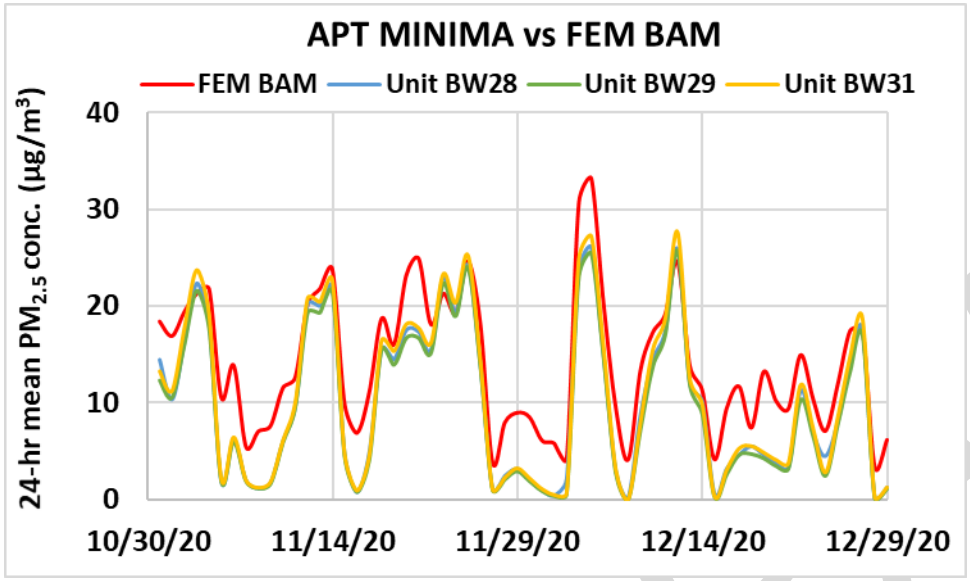
- APT MINIMA sensors showed very weak correlations with the corresponding FEM BAM data (R^2 ~ 0.23)
- Overall, the APT MINIMA sensors underestimated the PM_{10} mass concentrations measured by FEM BAM
- The APT MINIMA sensors did not seem to track the PM_{10} diurnal variations as recorded by FEM BAM



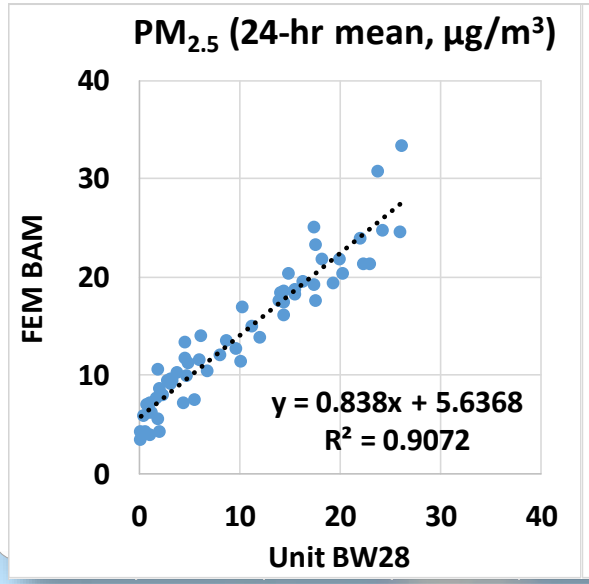


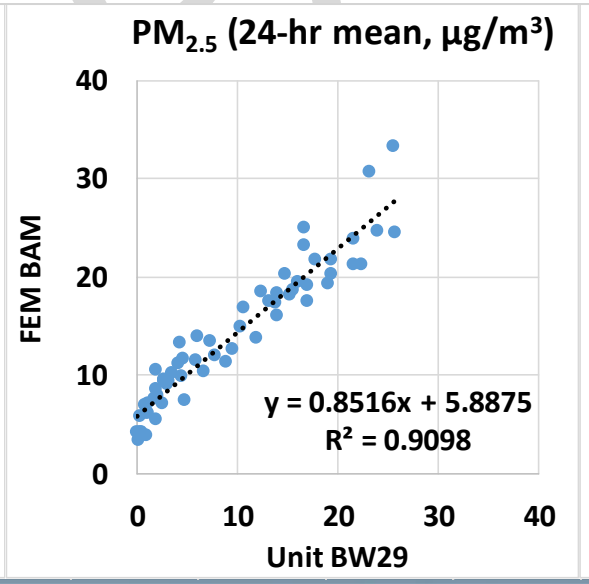


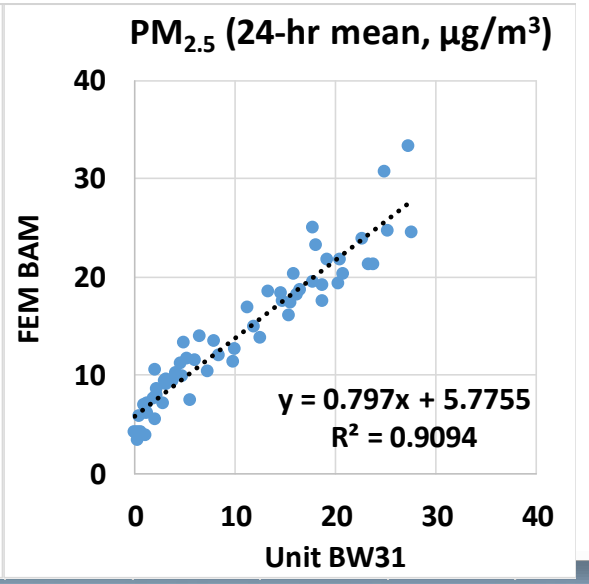
APT MINIMA vs FEM BAM ($PM_{2.5}$; 24-hr mean)



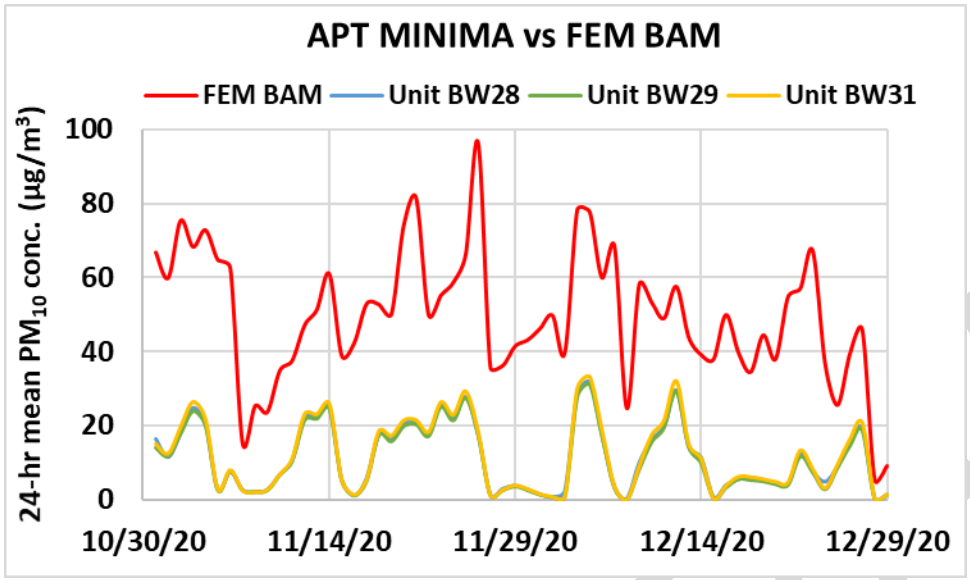
- APT MINIMA sensors showed very strong correlations with the corresponding FEM BAM data (R^2 ~ 0.91)
- Overall, the APT MINIMA sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM BAM
- The APT MINIMA sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM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



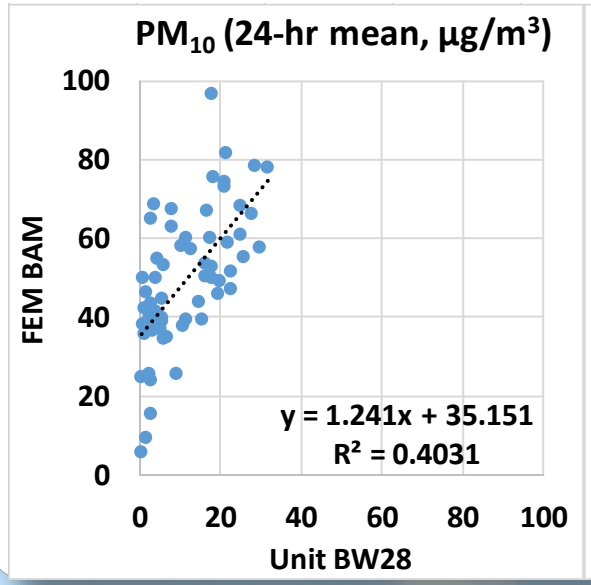


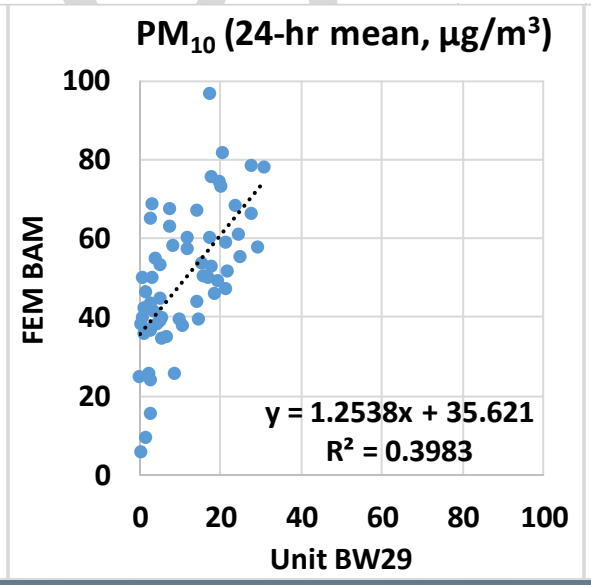


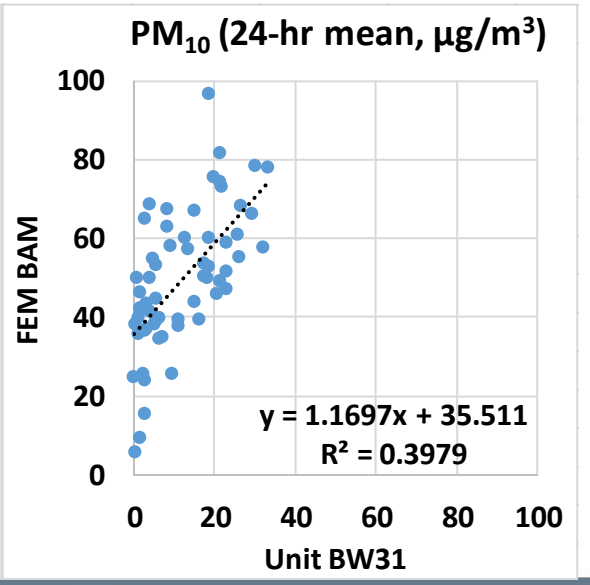
APT MINIMA vs FEM BAM (PM_{10}; 24-hr mean)



- APT MINIMA sensors showed weak correlations with the corresponding FEM BAM data (R^2 ~ 0.40)
- Overall, the APT MINIMA sensors underestimated the PM_{10} mass concentrations measured by FEM BAM
- The APT MINIMA sensors did not seem to track the PM_{10} diurnal variations as recorded by FEM BAM







Summary

	Average of 3 Sensors, $PM_{1.0}$		APT MINIMA vs T640, $PM_{1.0}$						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	6.8	7.6	0.84 to 0.89	1.35 to 1.47	2.4 to 2.7	-5.6 to -5.0	5.0 to 5.6	6.8 to 7.5	12.0	11.3	0.4 to 217
1-hr	6.8	7.4	0.87 to 0.91	1.38 to 1.47	2.3 to 2.5	-5.6 to -5.0	5.0 to 5.6	6.6 to 7.3	12.0	11.1	0.4 to 147
24-hr	6.7	5.1	0.94 to 0.96	1.35 to 1.46	2.3 to 2.6	-5.6 to -5.0	5.0 to 5.5	5.5 to 6.2	11.9	7.4	1.5 to 30.9
	Average of 3 Sensors, $PM_{2.5}$		APT MINIMA vs FEM BAM & FEM T640, $PM_{2.5}$						FEM BAM & 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	10.1	11.9	0.86 to 0.89	1.01 to 1.06	5.6 to 5.8	-6.4 to -5.6	5.8 to 6.5	7.1 to 7.9	16.1	13.1	1.1 to 239
1-hr	10.1	11.7	0.81 to 0.90	0.84 to 1.07	5.4 to 5.7	-6.4 to -3.6	5.0 to 6.4	5.0 to 7.6	14.2 to 16.1	11.1 to 12.8	0 to 165
24-hr	10.0	8.0	0.91 to 0.94	0.80 to 1.08	5.4 to 5.9	-6.4 to -3.7	4.0 to 6.4	4.0 to 6.8	14.0 to 16.0	7.0 to 8.7	3.4 to 39.7
	Average of 3 Sensors, PM_{10}		APT MINIMA vs FEM BAM & T640, PM_{10}						FEM BAM and 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	11.7	13.7	~0.37	1.40 to 1.49	34.5 to 34.7	-40.3 to -39.4	39.4 to 40.3	47.4 to 48.3	51.5	32.6	2.4 to 749
1-hr	11.7	13.5	0.23 to 0.42	1.08 to 1.50	34.3 to 36.9	-40.3 to -37.8	37.8 to 40.3	37.8 to 46.8	49.9 to 51.5	30.2 to 31.2	1.0 to 349
24-hr	11.6	9.2	0.40 to 0.53	1.17 to 1.58	32.9 to 35.6	-40.3 to -37.6	37.6 to 40.3	37.6 to 42.5	49.6 to 51.2	17.7 to 19.4	5.4 to 96

[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 **APT MINIMA** sensors' data recovery from all units was ~ 100% for all PM measurements
- The absolute intra-model variability was ~ 0.24, 0.33 and 0.37 µg/m^3 for $PM_{1.0}$, $PM_{2.5}$ and $PM_{10,}$ respectively
- Very strong correlations between FEM BAM and FEM T640 for $PM_{2.5}$ (R^2 ~ 0.90, 1-hr mean) and strong correlations between FEM BAM and T640 for PM_{10} (R^2 ~ 0.88, 1-hr mean) mass concentration measurements
- $PM_{1.0}$ mass concentrations measured by APT MINIMA sensors showed strong to very strong correlations with the corresponding T640 data ($0.87 < R^2 < 0.92$, 1-hr mean). The sensors underestimated $PM_{1.0}$ mass concentrations as measured by T640
- $PM_{2.5}$ mass concentrations measured by APT MINIMA sensors showed strong to very strong correlations with the corresponding FEM T640 and FEM BAM data ($0.80 < R^2 < 0.91$, 1-hr mean). The sensors underestimated $PM_{2.5}$ mass concentrations as measured by FEM T640 and FEM BAM
- PM_{10} mass concentrations measured by APT MINIMA sensors showed very weak to weak correlations with the corresponding T640 and FEM BAM data ($0.23 < R^2 < 0.42$; 1-hr mean) and underestimated PM_{10} mass concentrations as measured by T640 and FEM BAM
- No sensor calibration was performed by South Coast AQMD Staff prior to the beginning of this test
- 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