Field Evaluation
Blues Wireless - Airnote

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

- From 05/27/2021 to 07/27/2021, three **Blues Wireless Airnote (hereinafter Airnote)** 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

- Airnote (*3 units tested*):
  - Particle sensor: optical; non-FEM (PMS7003M, Plantower)
  - Each unit reports: $PM_{1.0}$, $PM_{2.5}$ and PM_{10} (µg/m^3), Temperature (°C), RH (%)
  - Unit cost: $149 (includes 10-year cellular data)
  - Time resolution: 1-min
  - Units IDs: 1791, 3705, 7411

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

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

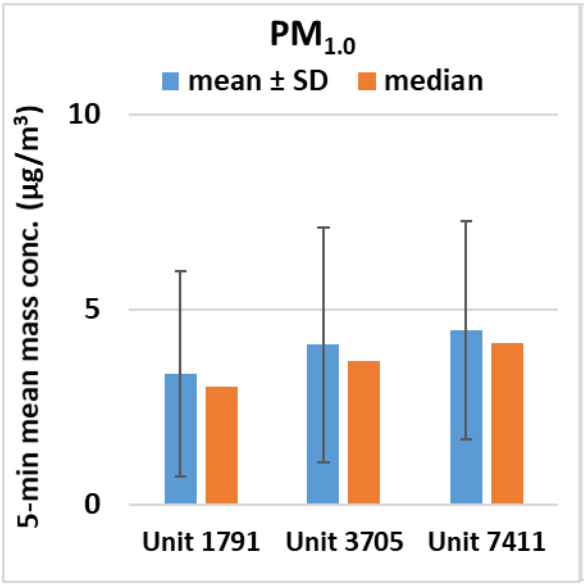
Data validation & recovery

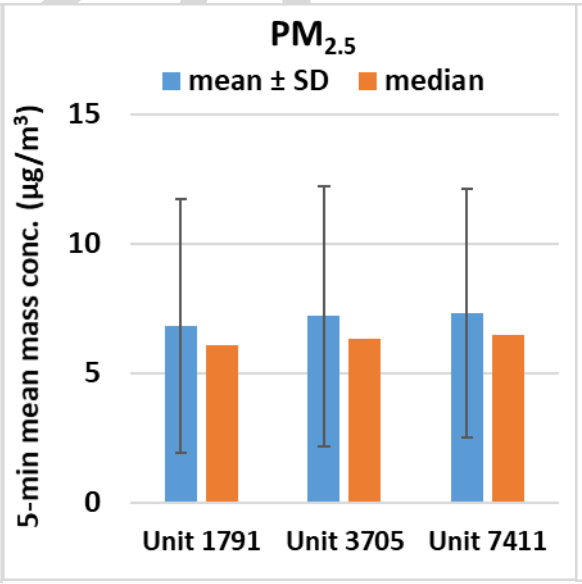
- Basic QA/QC procedures were used to validate the collected data (i.e. obvious outliers, negative values and invalid data-points were eliminated from the data-set)
- Data recovery from all units was ~ 100% for all PM measurements

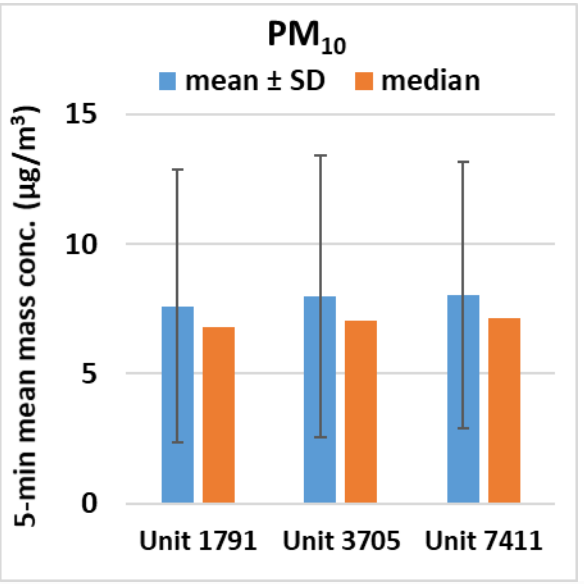
Note: Data from 7/4/2021 20:00 to 7/5/2021 12:59 PST were excluded from data analysis for all sensors and reference instruments to exclude the effect of 4th of July activities.

Airnote; intra-model variability

- Absolute intra-model variability was ~ 0.46, 0.21 and 0.20 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 ~ 11.6%, 3.0% and 2.5% 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)

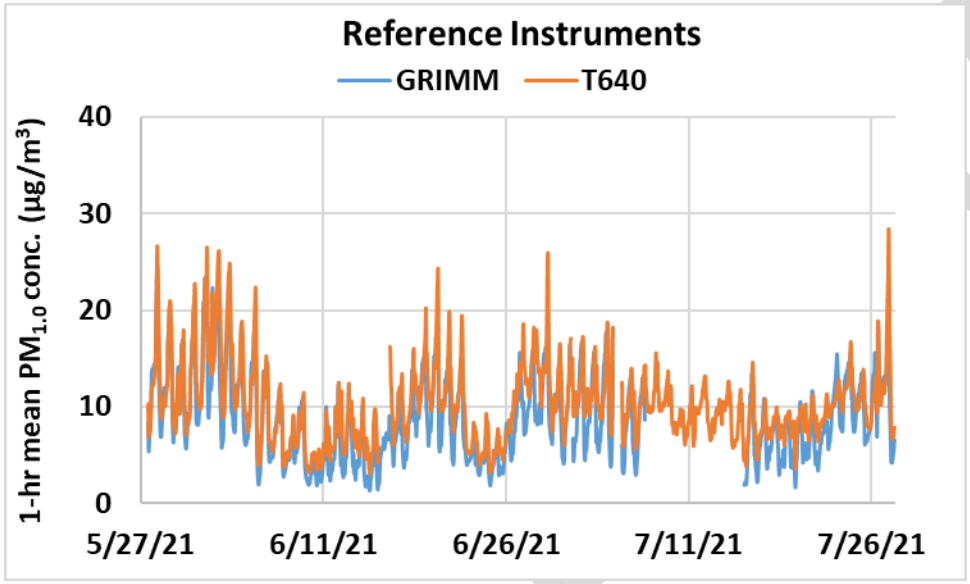


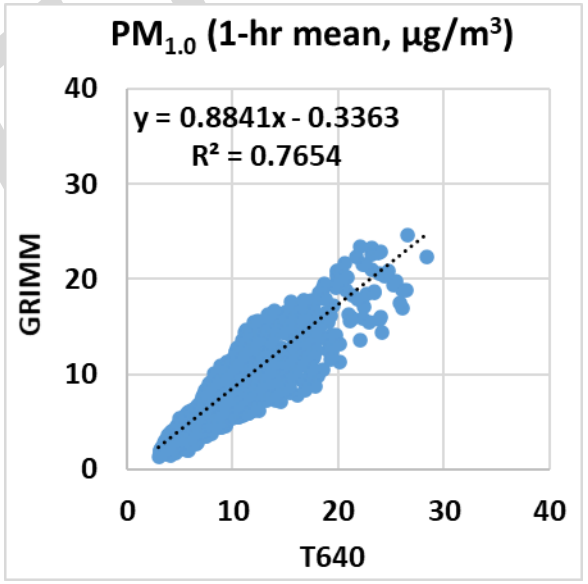




Reference Instruments: $PM_{1.0}$ GRIMM and T640

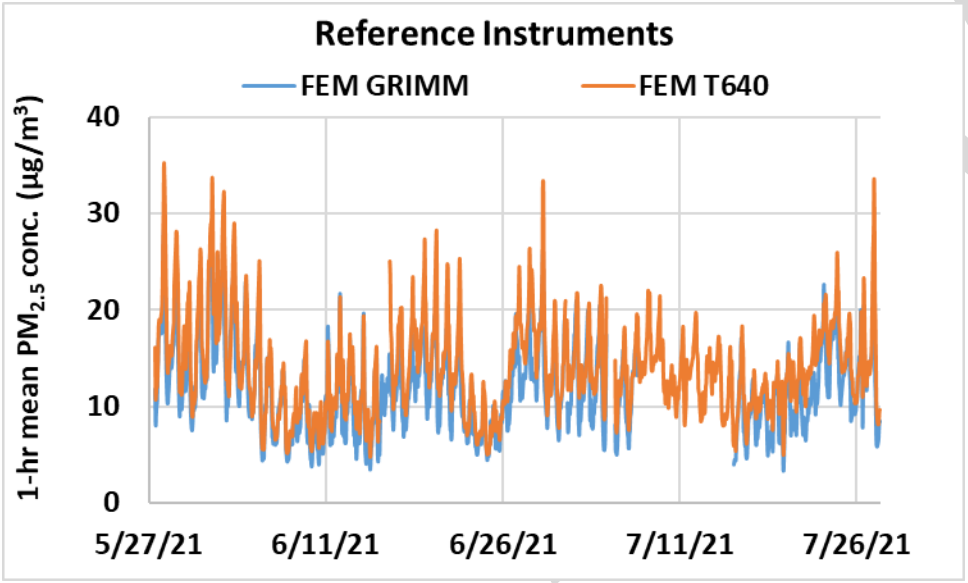
- Data recovery for $PM_{1.0}$ from GRIMM and T640 was ~ 87% and 99%, respectively.
- Strong correlations between the reference instruments for $PM_{1.0}$ measurements (R^2 ~ 0.77) were observed.

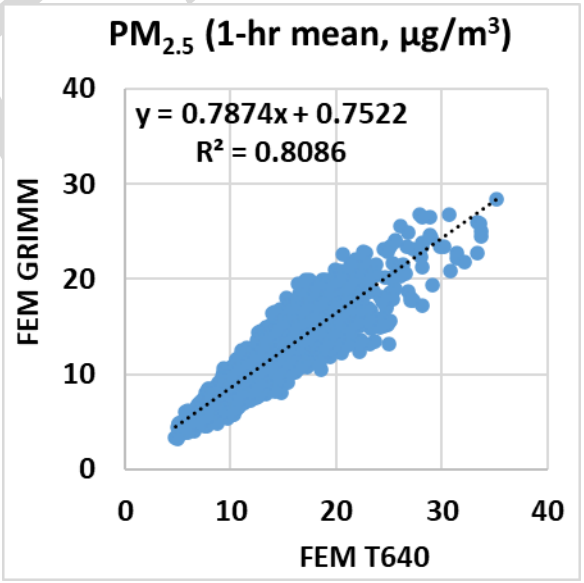




Reference Instruments: $PM_{2.5}$ FEM GRIMM and FEM T640

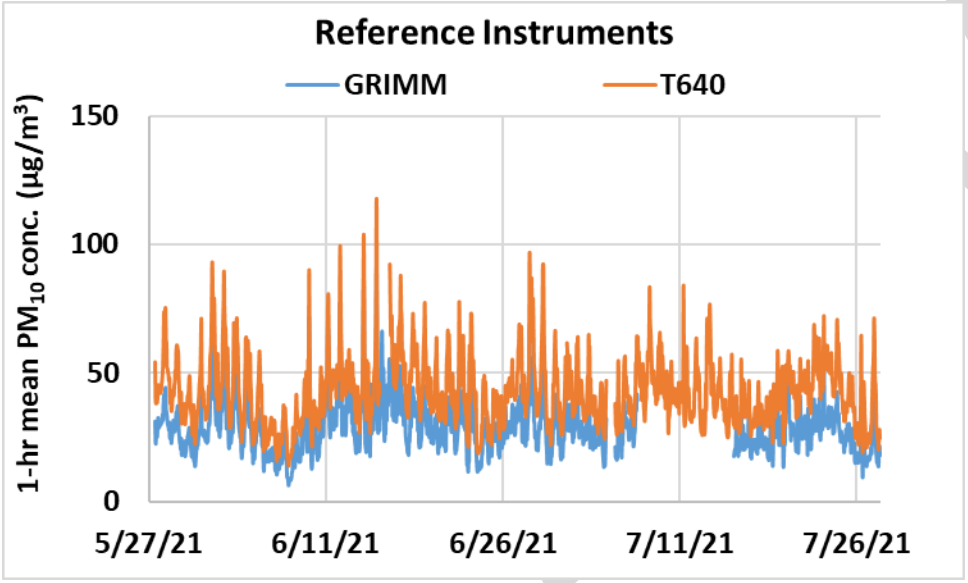
- Data recovery for $PM_{2.5}$ from FEM GRIMM and FEM T640 was ~ 87% and 99%, respectively.
- Strong correlations between the reference instruments for $PM_{2.5}$ measurements (R^2 ~ 0.81) were observed.

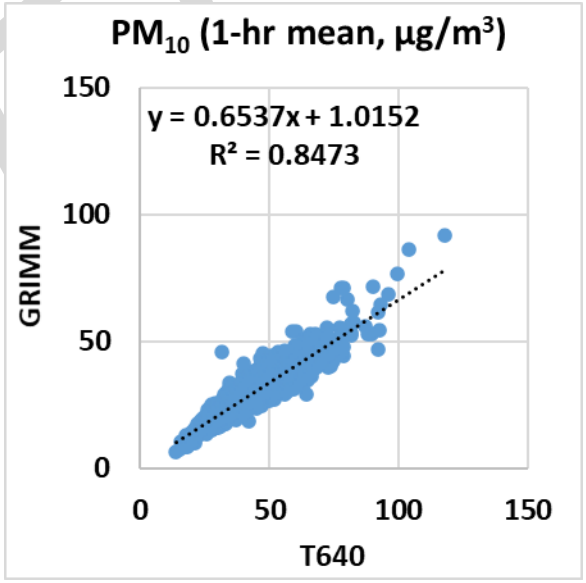




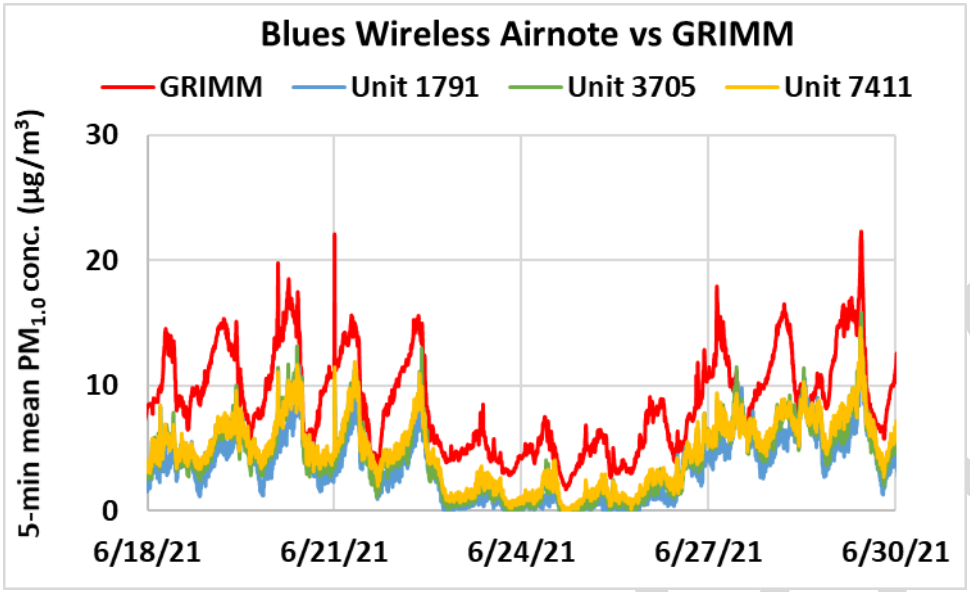
Reference Instruments: PM_{10} GRIMM and T640

- Data recovery for PM_{10} from GRIMM and T640 was ~ 87% and 99%, respectively.
- Strong correlations between the reference instruments for PM_{10} measurements (R^2 ~ 0.85) were observed.

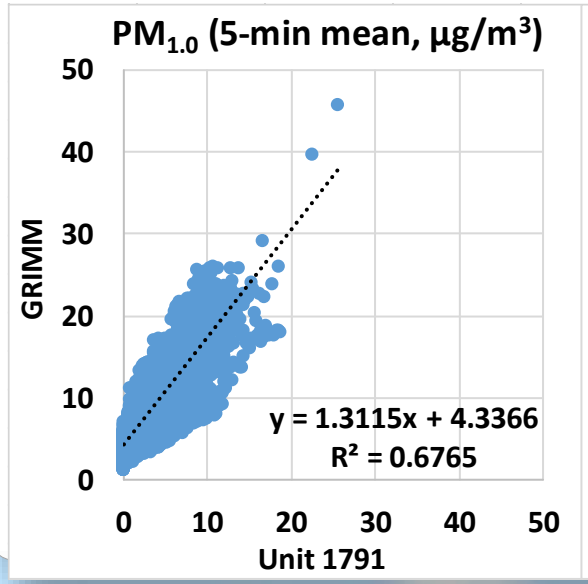


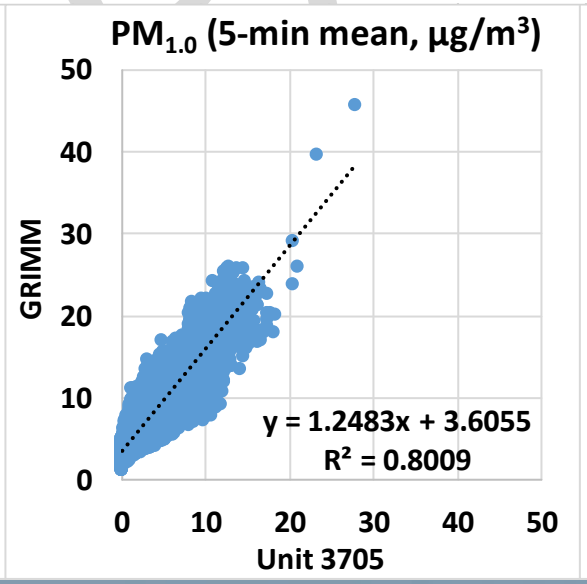


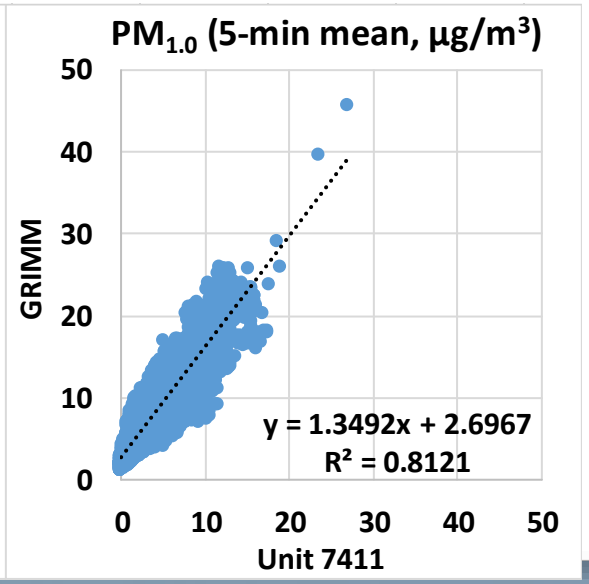
Airnote vs GRIMM ($PM_{1.0}$; 5-min mean)



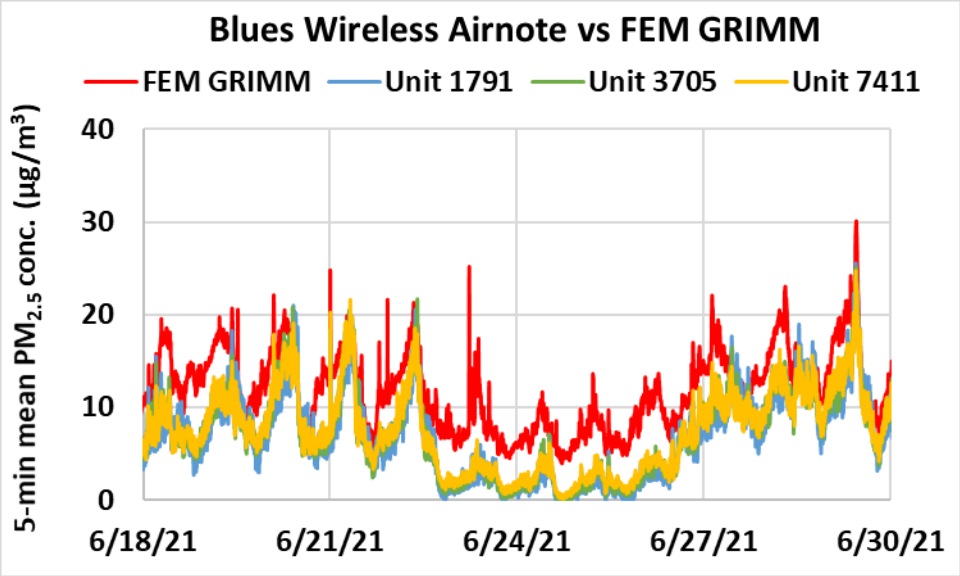
- The Airnote sensors showed moderate to strong correlations with the corresponding GRIMM data ($0.67 < R^2 < 0.82$)
- Overall, the Airnote sensors underestimated the $PM_{1.0}$ mass concentrations as measured by GRIMM
- The Airnote sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by GRIMM



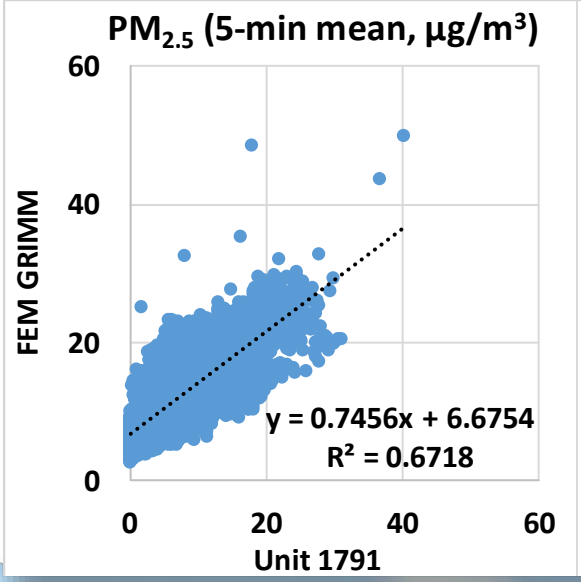


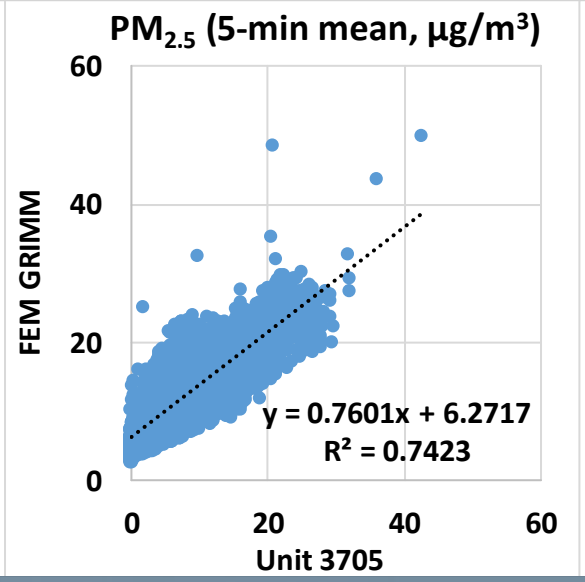


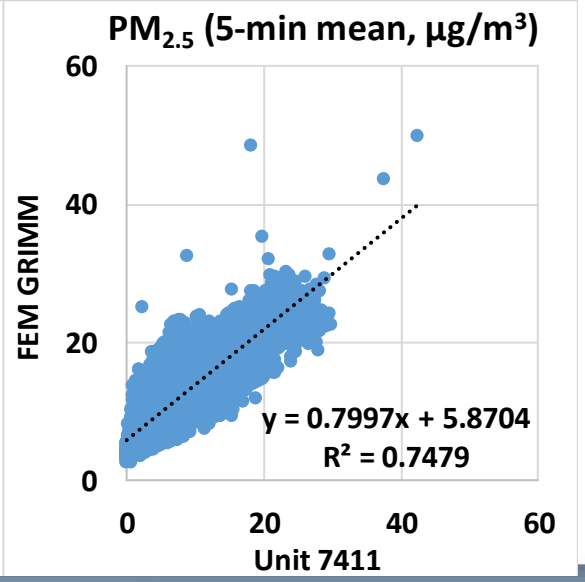
Airnote vs FEM GRIMM ($PM_{2.5}$; 5-min mean)



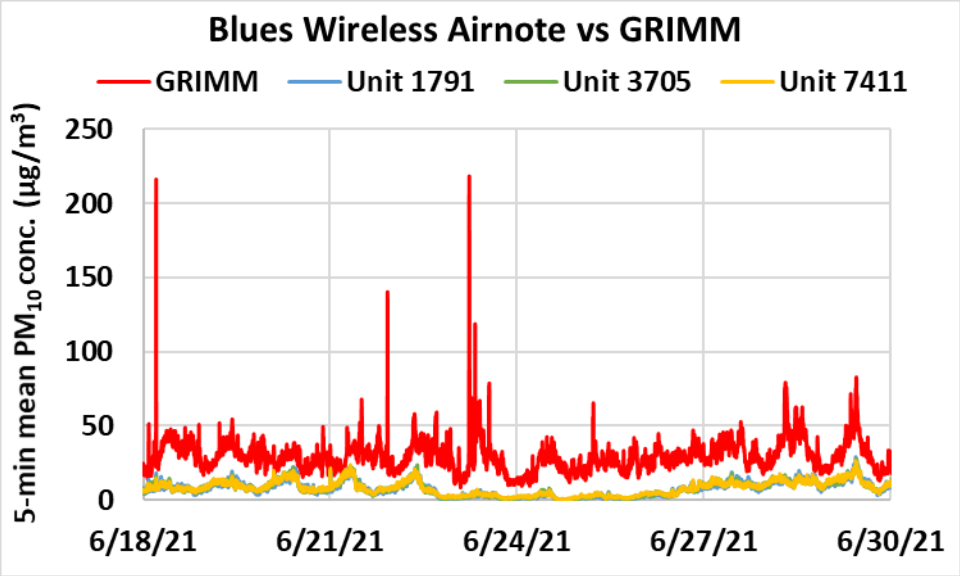
- The Airnote sensors showed moderate to strong correlations with the corresponding FEM GRIMM data ($0.67 < R^2 < 0.75$)
- Overall, the Airnote sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM GRIMM
- The Airnote sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM GRIMM



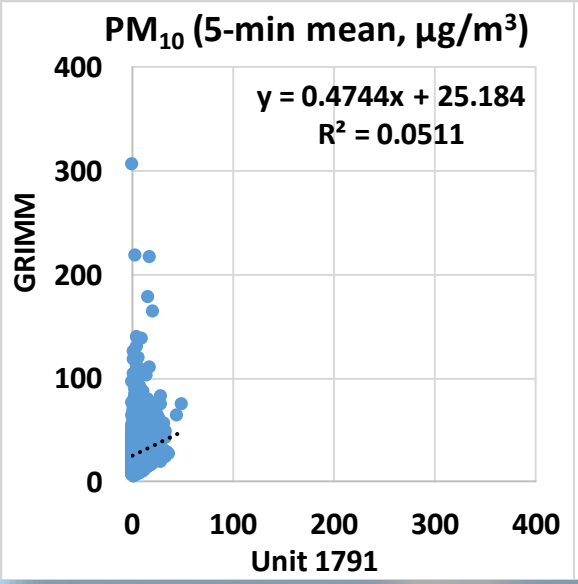


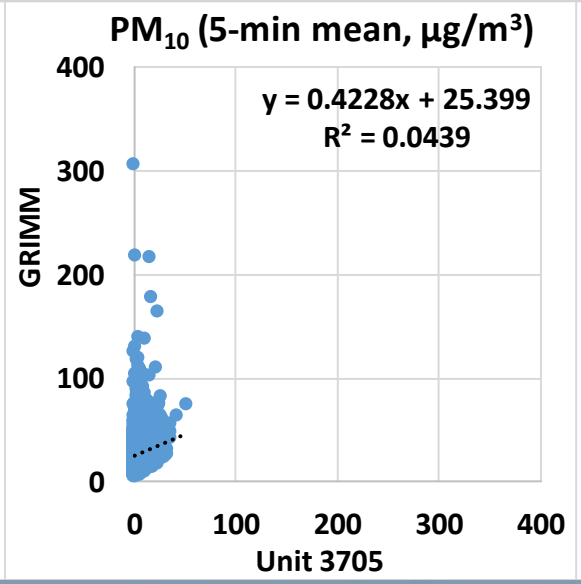


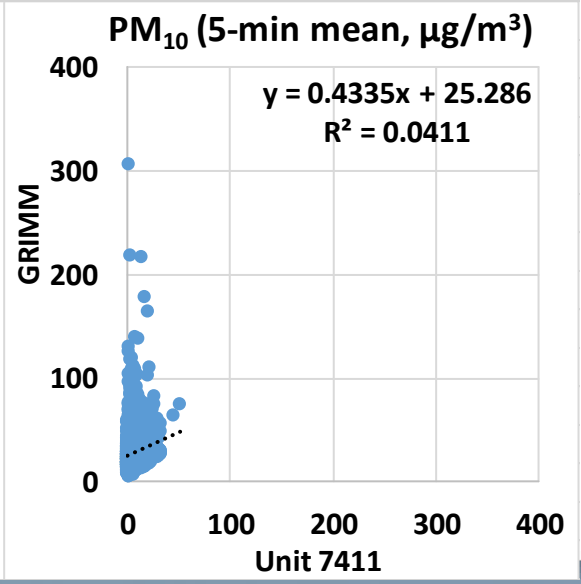
Airnote vs GRIMM (PM_{10}; 5-min mean)



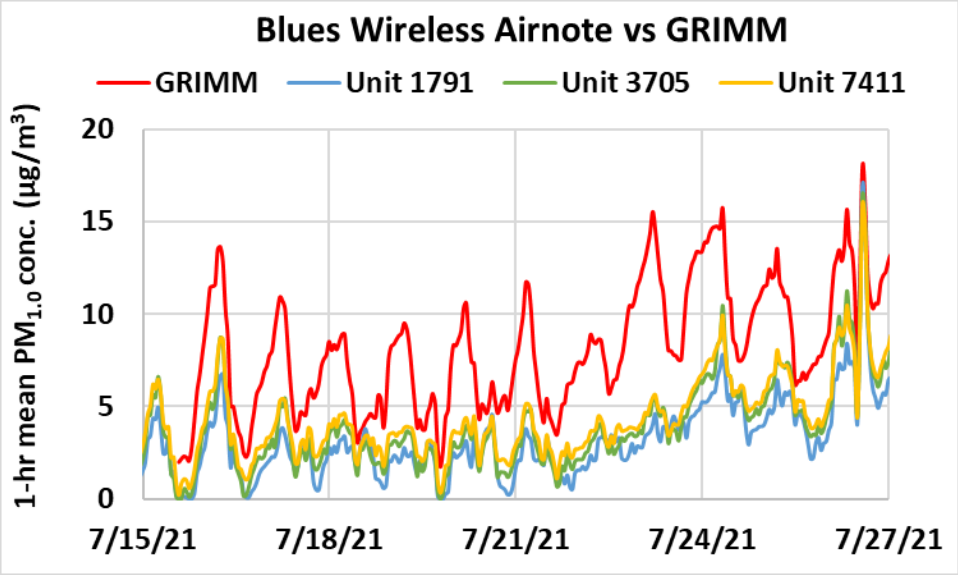
- The Airnote sensors did not correlate with the corresponding GRIMM data ($0.04 < R^2 < 0.06$)
- Overall, the Airnote sensors underestimated the PM_{10} mass concentrations as measured by GRIMM
- The Airnote sensors did not seem to track the PM_{10} diurnal variations as recorded by GRIMM



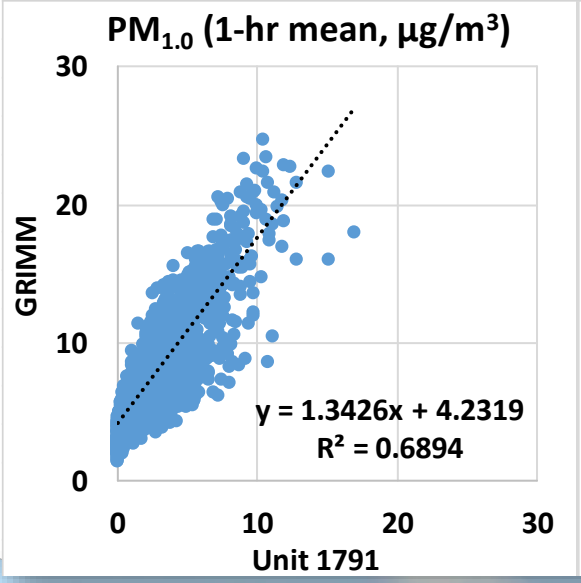


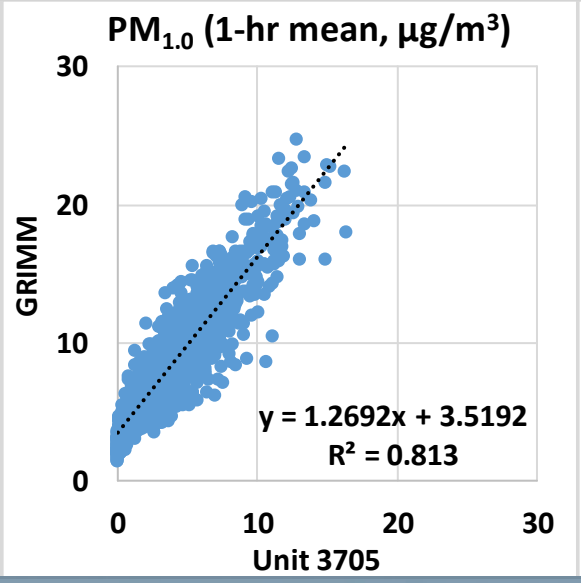


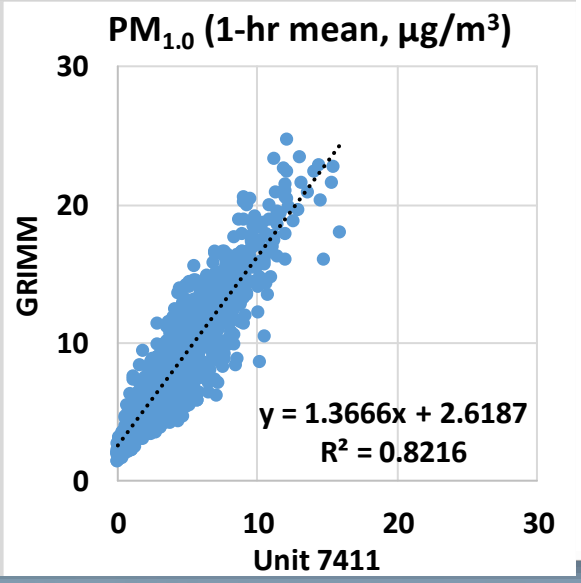
Airnote vs GRIMM ($PM_{1.0}$; 1-hr mean)



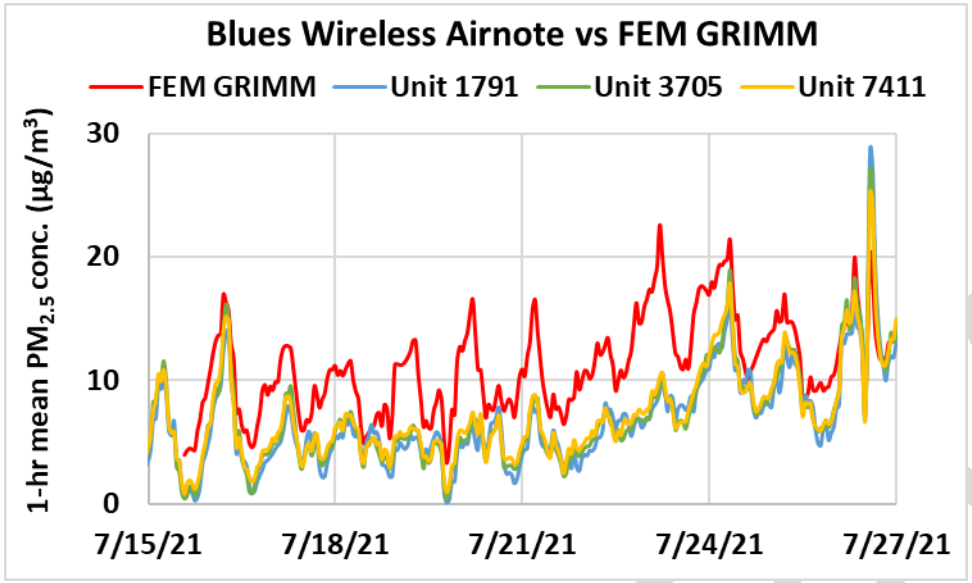
- The Airnote sensors showed moderate to strong correlations with the corresponding GRIMM data ($0.68 < R^2 < 0.83$)
- Overall, the Airnote sensors underestimated the $PM_{1.0}$ mass concentrations as measured by GRIMM
- The Airnote sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by GRIMM



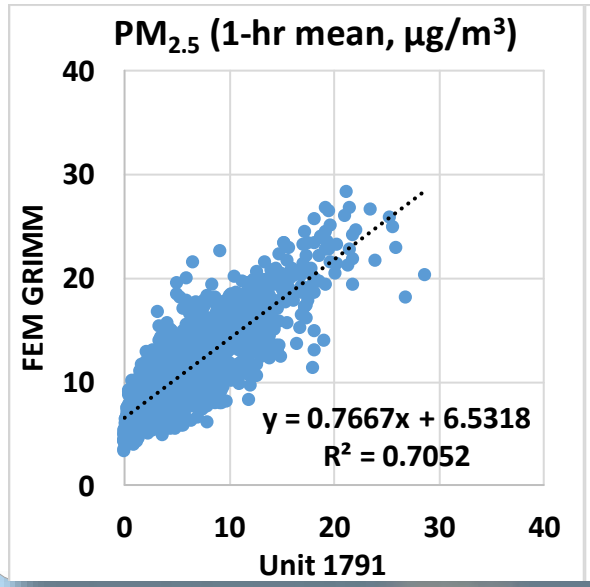


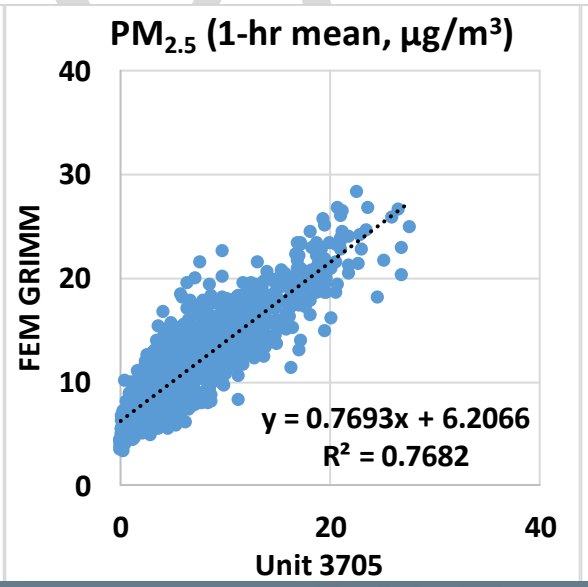


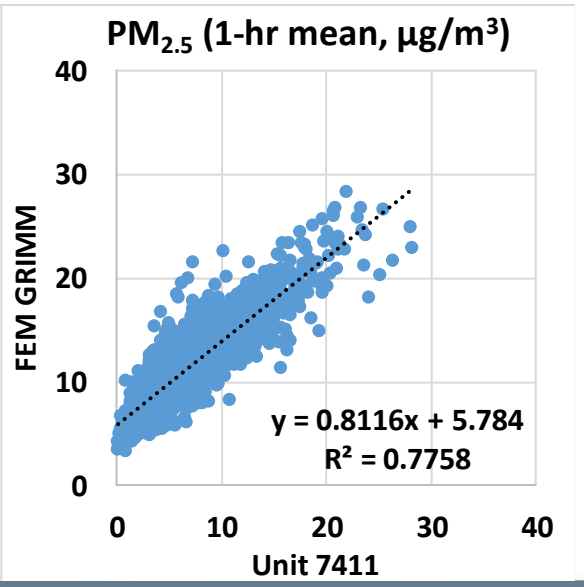
Airnote vs FEM GRIMM ($PM_{2.5}$; 1-hr mean)



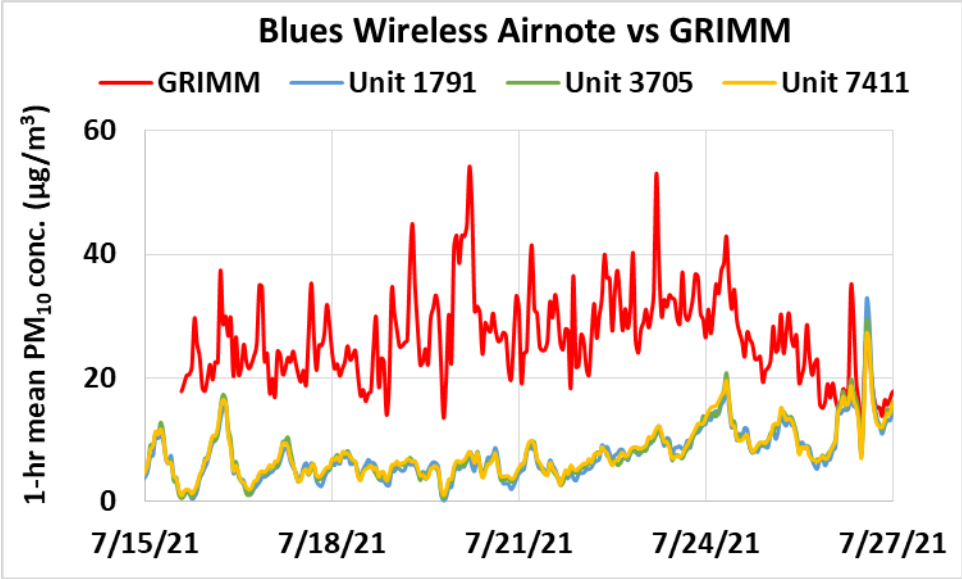
- The Airnote sensors showed strong correlations with the corresponding FEM GRIMM data ($0.70 < R^2 < 0.78$)
- Overall, the Airnote sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM GRIMM
- The Airnote sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM GRIMM



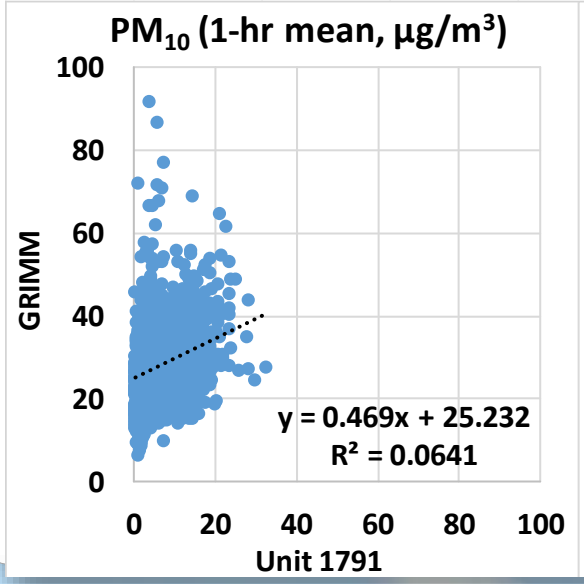


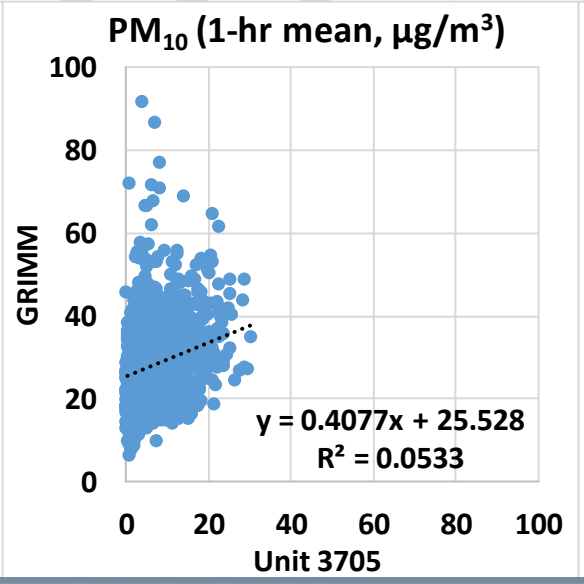


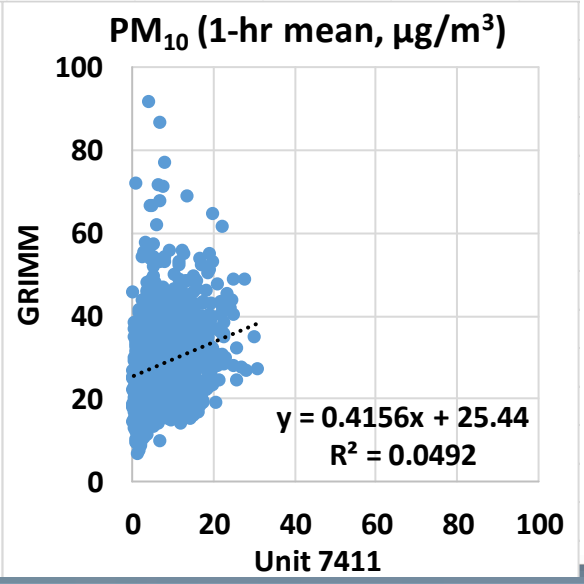
Airnote vs GRIMM (PM_{10}; 1-hr mean)



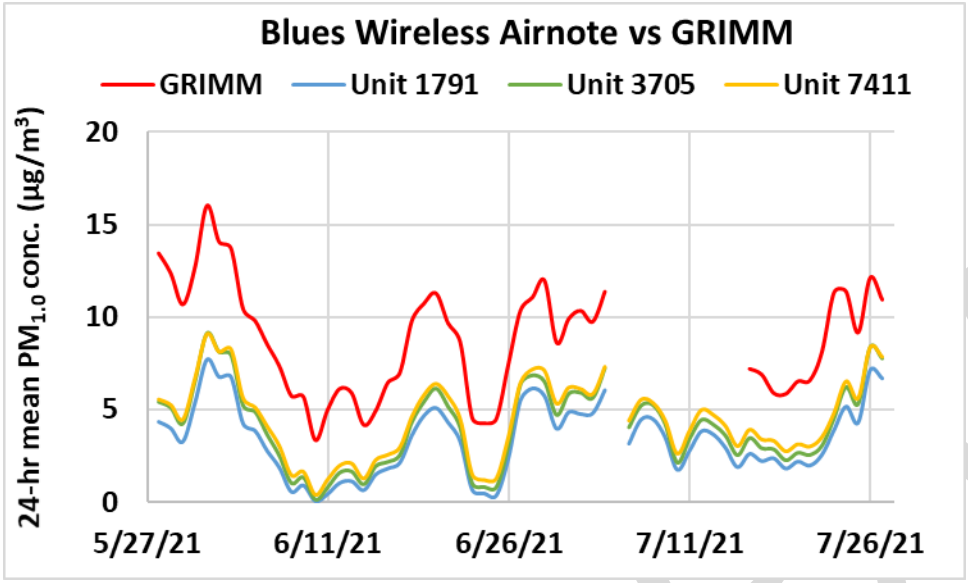
- The Airnote sensors did not correlate with the corresponding GRIMM data ($0.04 < R^2 < 0.07$)
- Overall, the Airnote sensors underestimated the PM_{10} mass concentrations as measured by GRIMM
- The Airnote sensors did not seem to track the PM_{10} diurnal variations as recorded by GRIMM



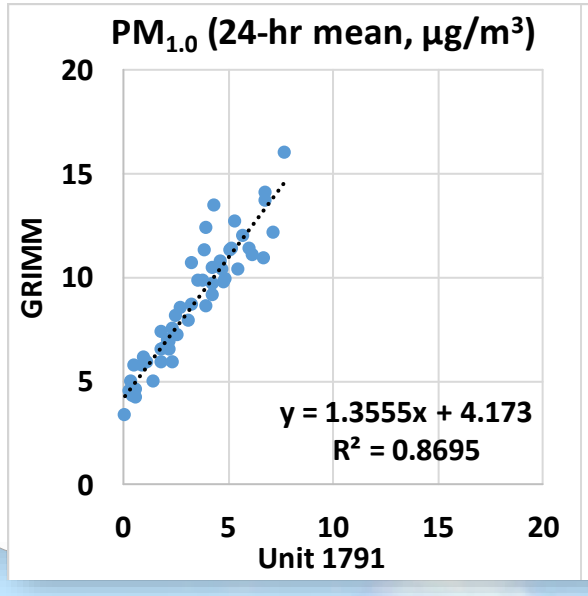


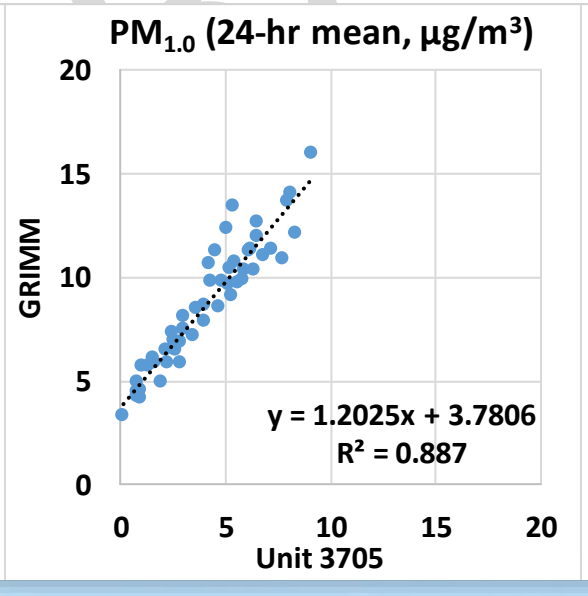


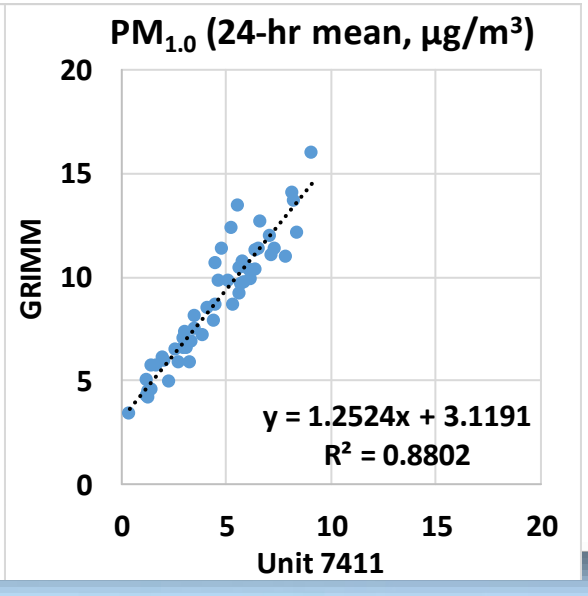
Airnote vs GRIMM ($PM_{1.0}$; 24-hr mean)



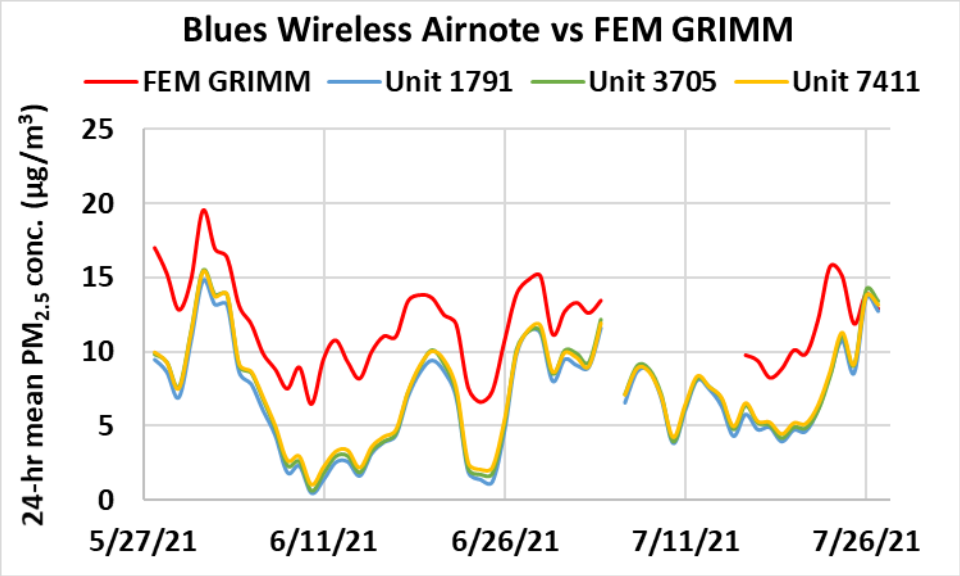
- The Airnote sensors showed strong correlations with the corresponding GRIMM data ($0.86 < R^2 < 0.89$)
- Overall, the Airnote sensors underestimated the $PM_{1.0}$ mass concentrations as measured by GRIMM
- The Airnote sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by GRIMM



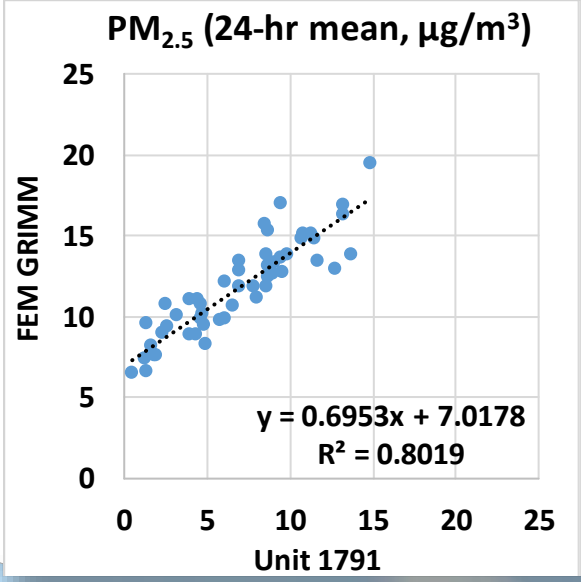


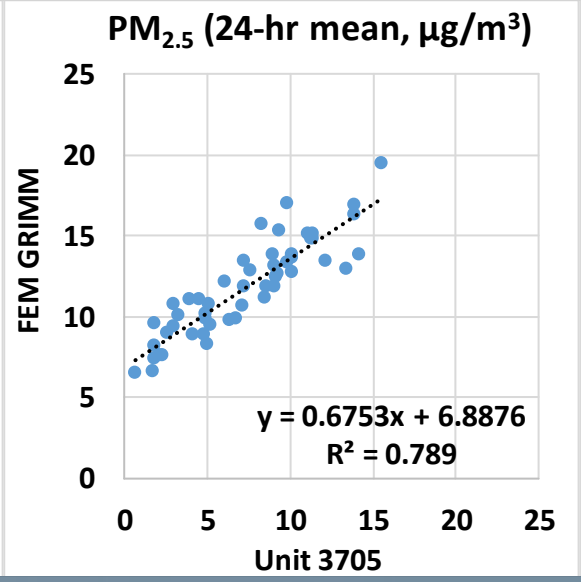


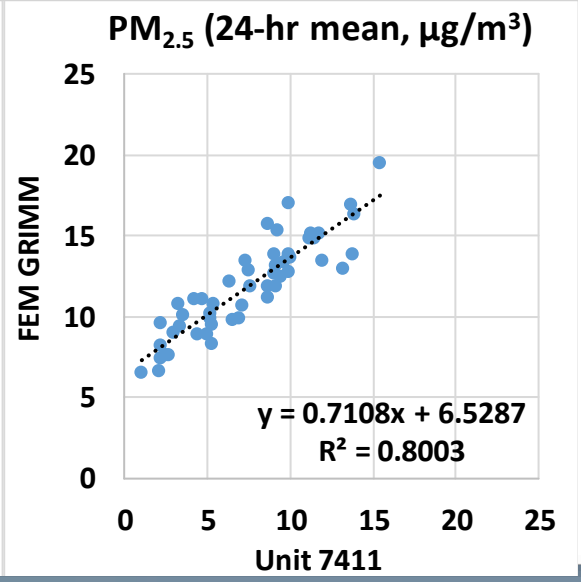
Airnote vs FEM GRIMM ($PM_{2.5}$; 24-hr mean)



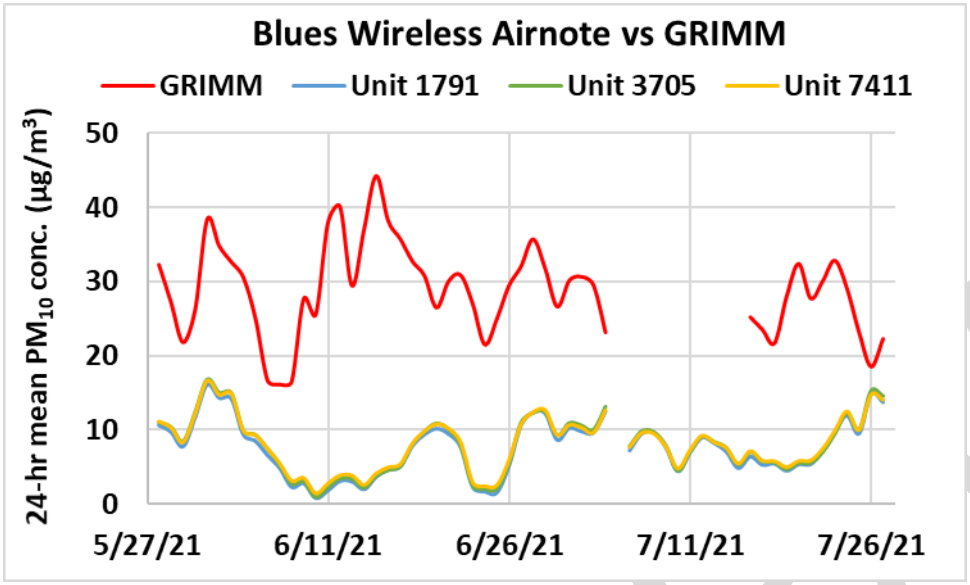
- The Airnote sensors showed strong correlations with the corresponding FEM GRIMM data ($0.78 < R^2 < 0.81$)
- Overall, the Airnote sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM GRIMM
- The Airnote sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM GRIMM



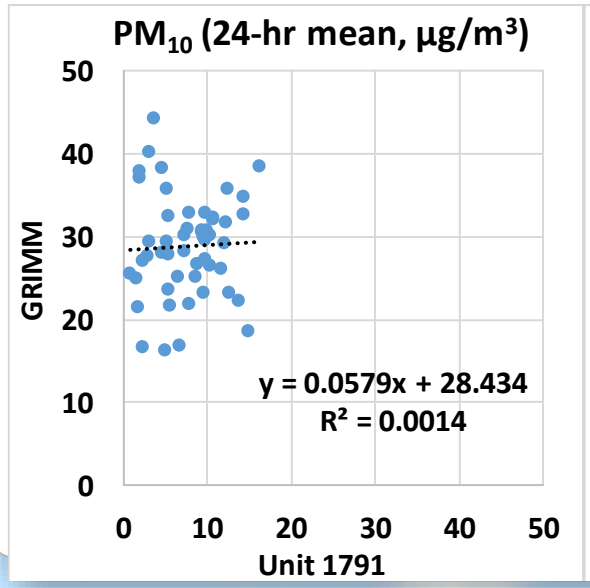


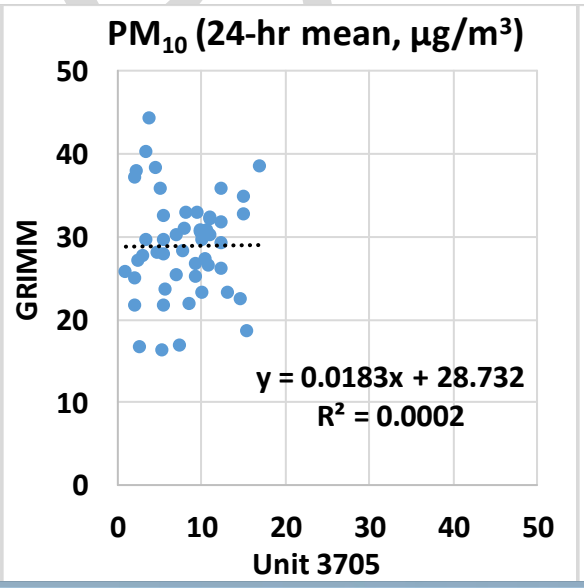


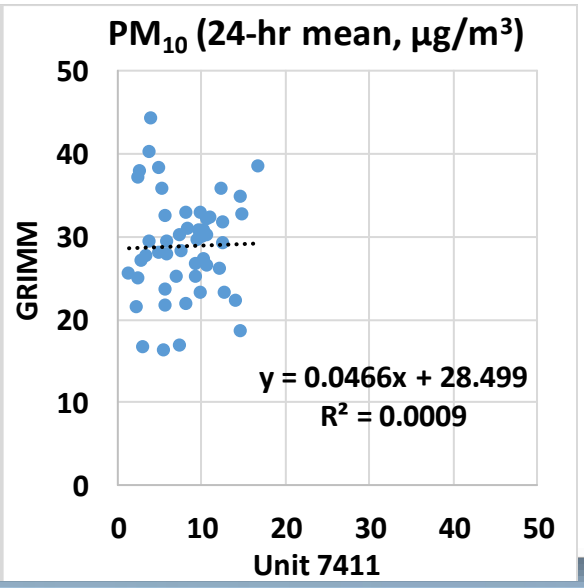
Airnote vs GRIMM (PM_{10}; 24-hr mean)



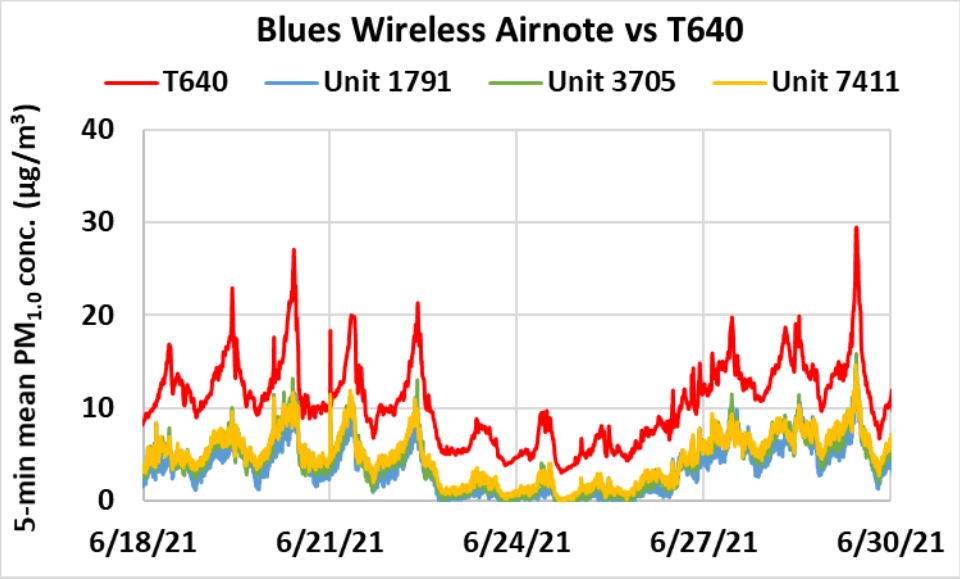
- The Airnote sensors did not correlate with the corresponding GRIMM data ($R^2 \sim 0$)
- Overall, the Airnote sensors underestimated the PM_{10} mass concentrations as measured by GRIMM
- The Airnote sensors did not seem to track the PM_{10} diurnal variations as recorded by GRIMM



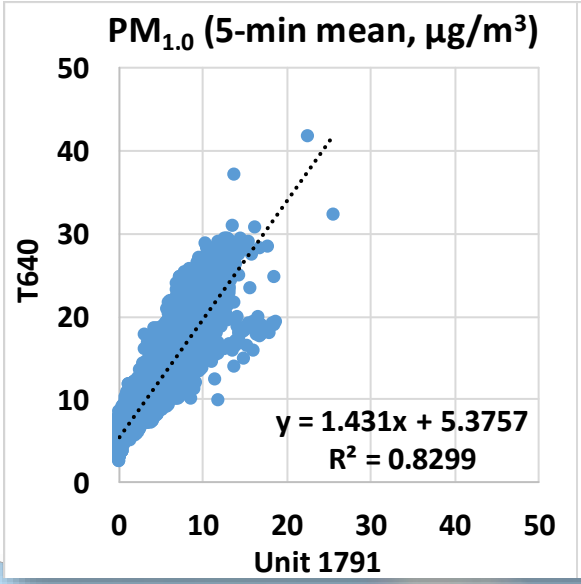


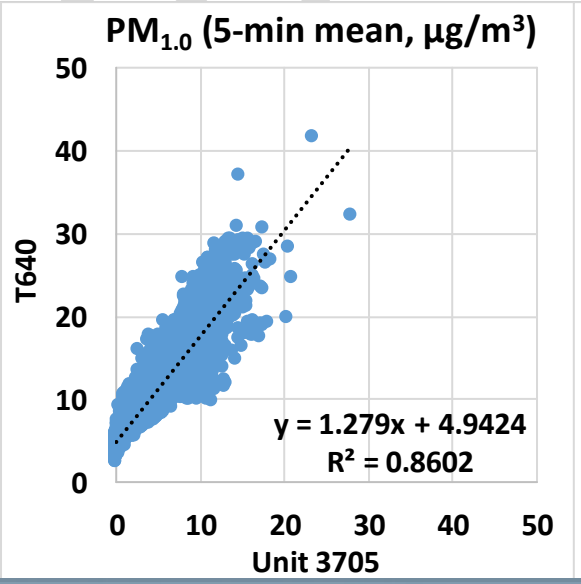


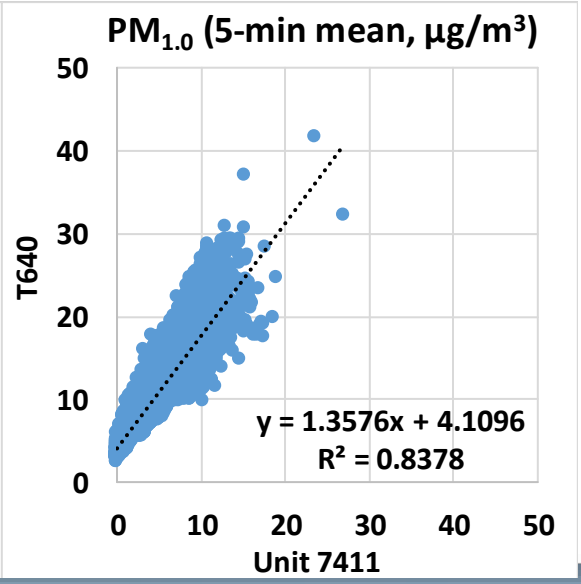
Airnote vs T640 ($PM_{1.0}$; 5-min mean)



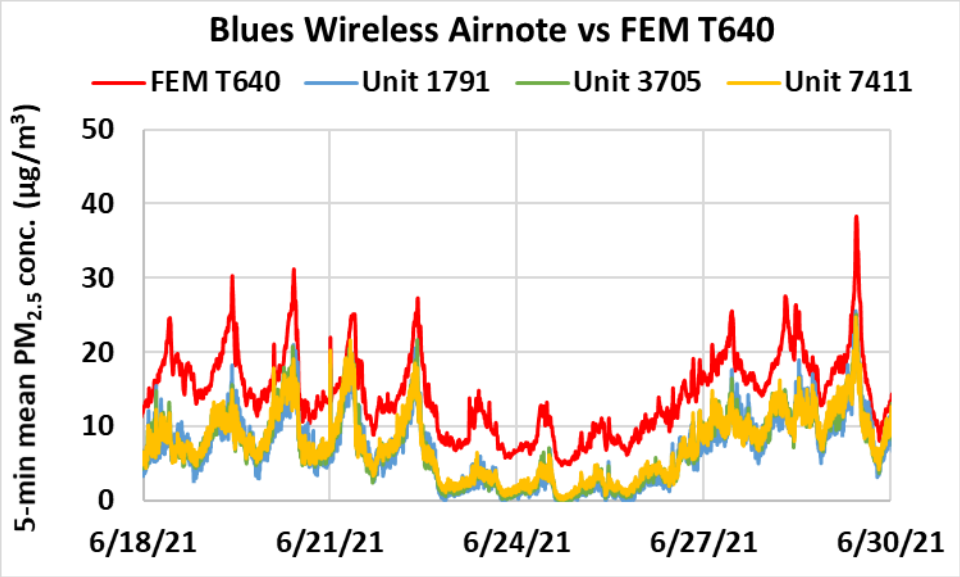
- The Airnote sensors showed strong correlations with the corresponding T640 data ($0.82 < R^2 < 0.87$)
- Overall, the Airnote sensors underestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The Airnote sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by T640



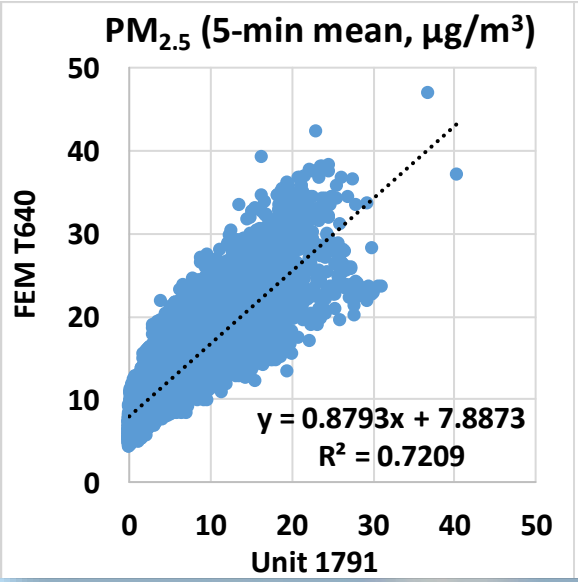


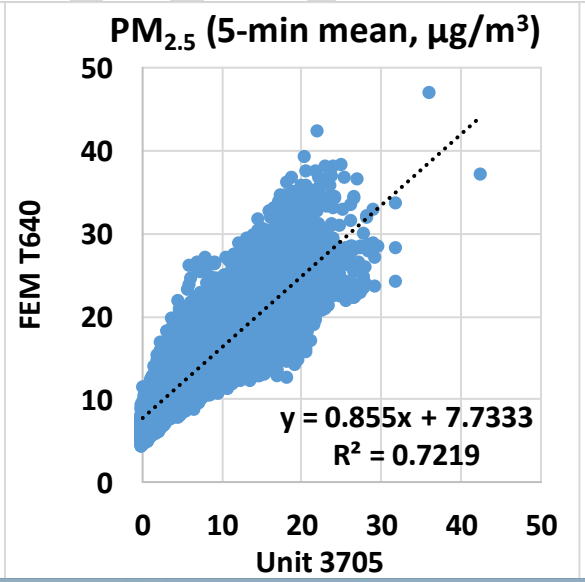


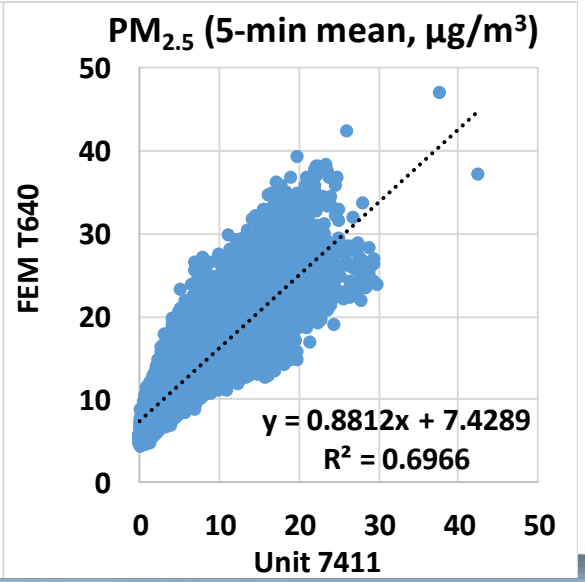
Airnote vs FEM T640 ($PM_{2.5}$; 5-min mean)



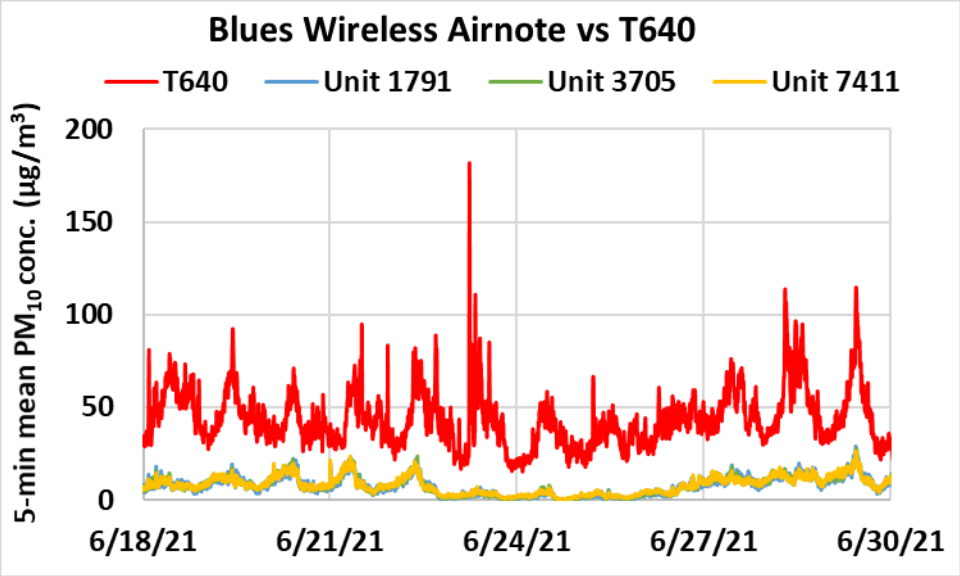
- The Airnote sensors showed moderate to strong correlations with the corresponding FEM T640 data ($0.69 < R^2 < 0.73$)
- Overall, the Airnote sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The Airnote sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



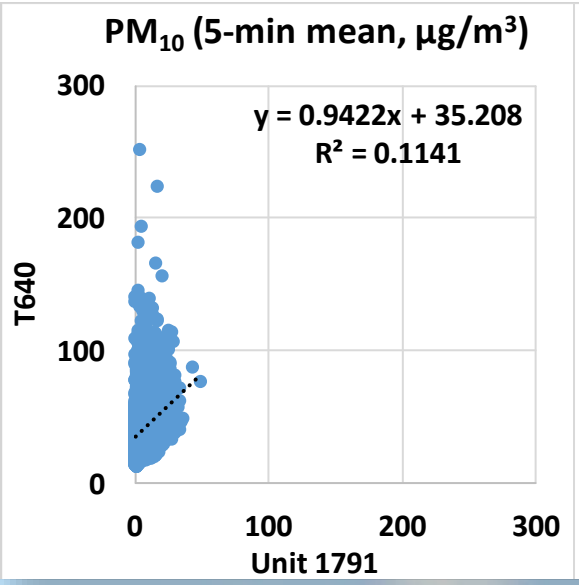


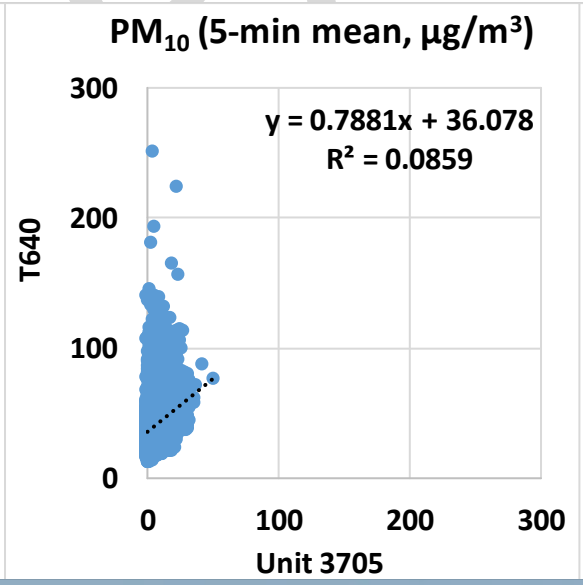


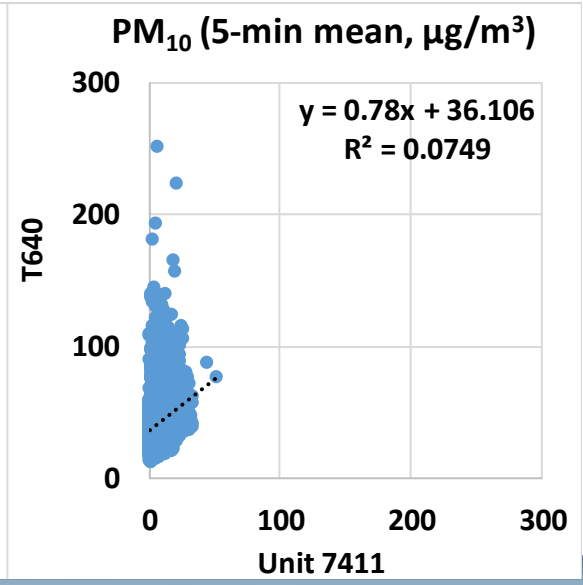
Airnote vs T640 (PM_{10}; 5-min mean)



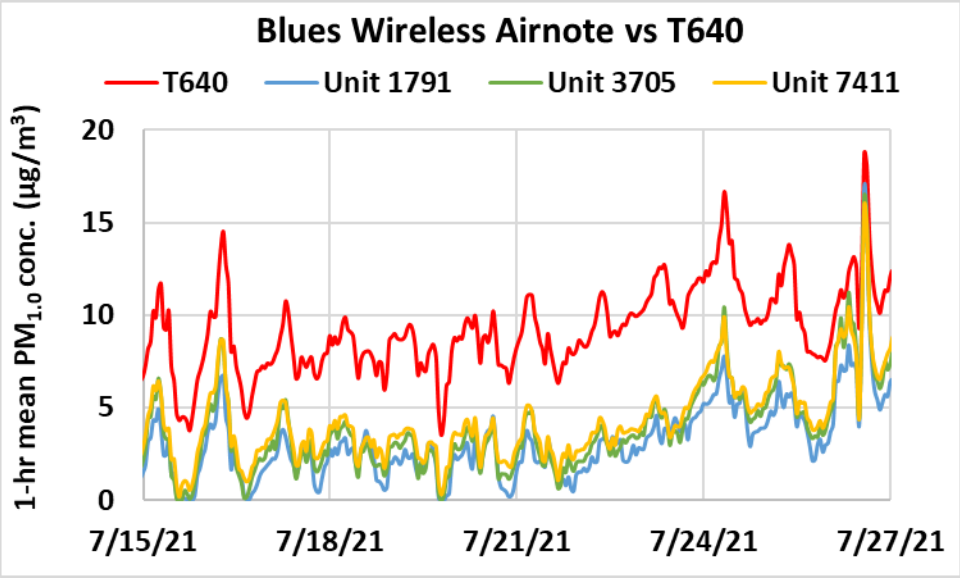
- Airnote sensors showed no to very weak correlations with the corresponding T640 data ($0.07 < R^2 < 0.12$)
- Overall, the Airnote sensors underestimated the PM_{10} mass concentrations as measured by T640
- The Airnote sensors did not seem to track the PM_{10} diurnal variations as recorded by T640



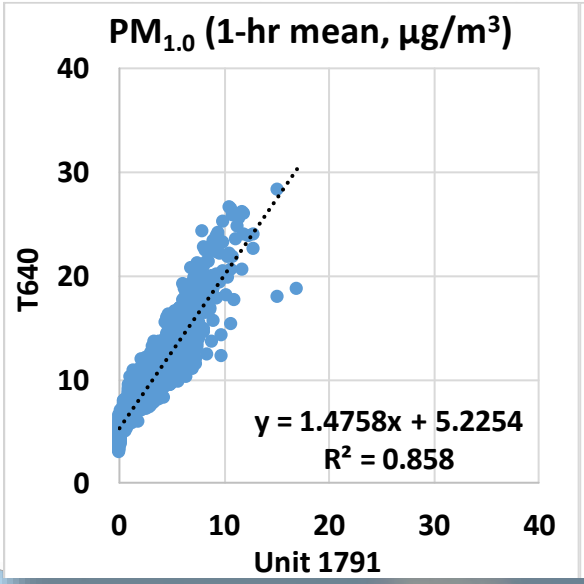


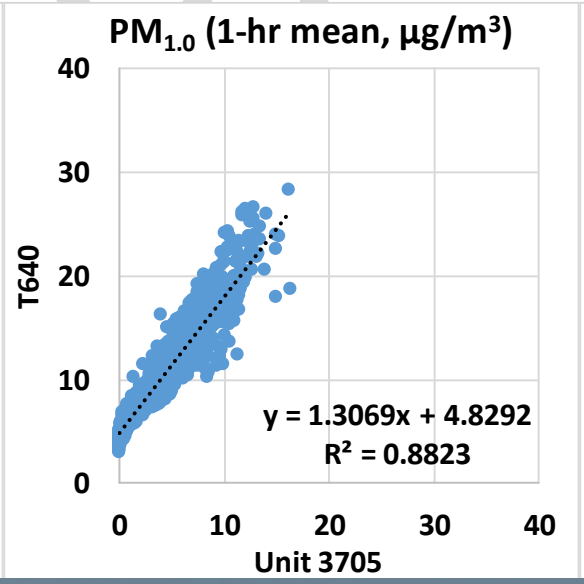


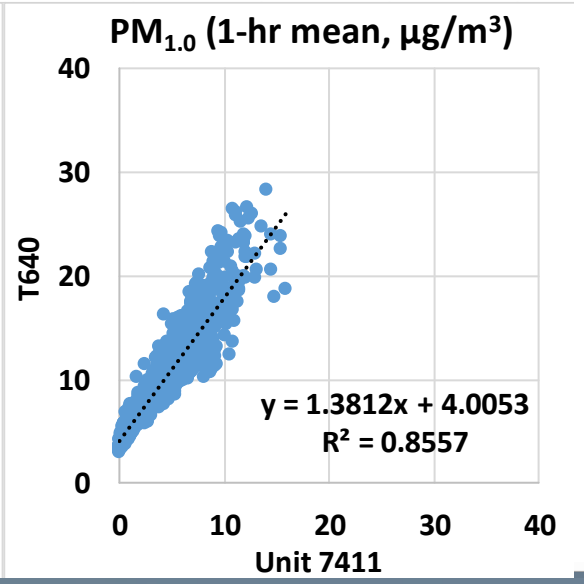
Airnote vs T640 ($PM_{1.0}$; 1-hr mean)



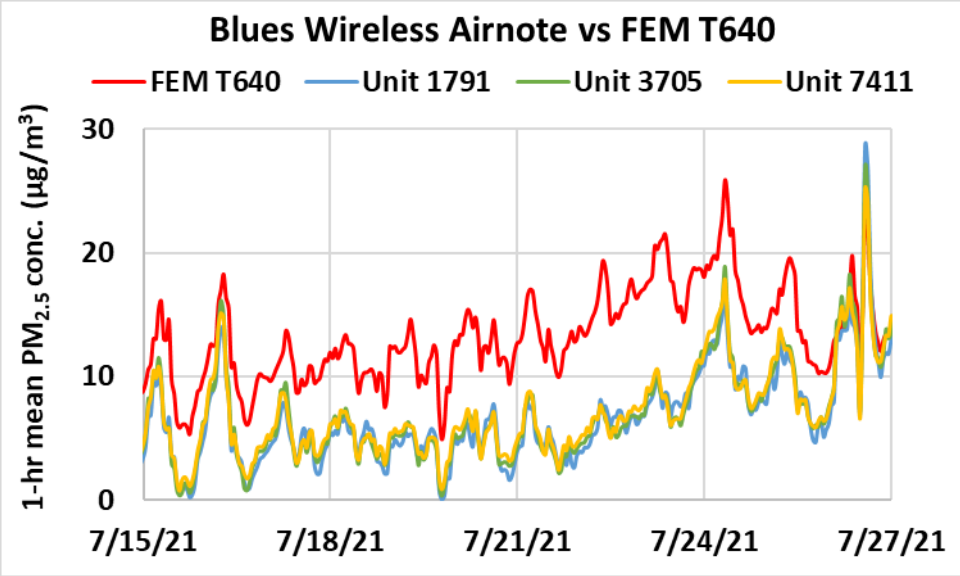
- The Airnote sensors showed strong correlations with the corresponding T640 data ($0.85 < R^2 < 0.89$)
- Overall, the Airnote sensors underestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The Airnote sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by T640



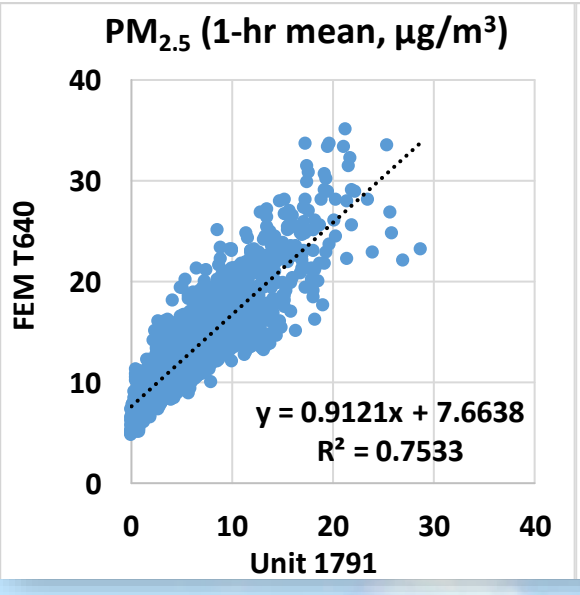


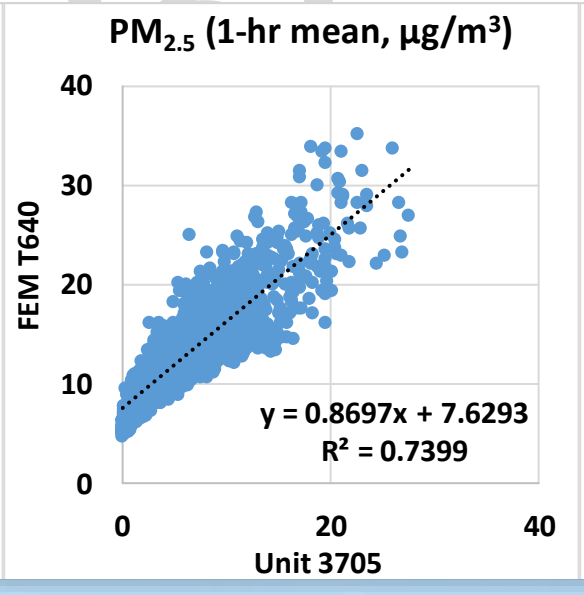


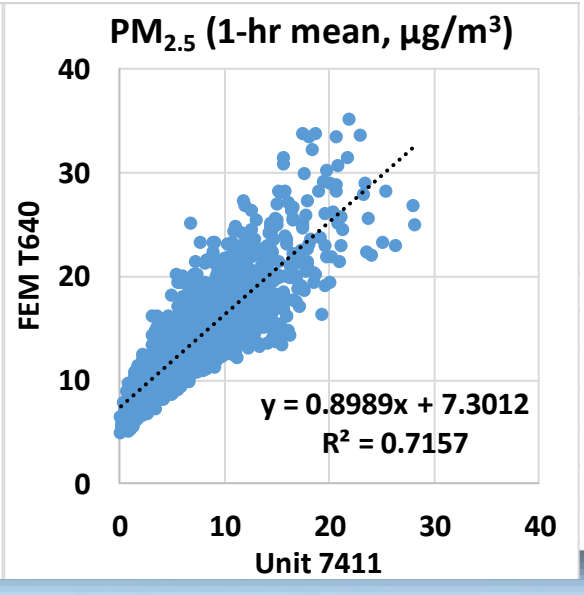
Airnote vs FEM T640 ($PM_{2.5}$; 1-hr mean)



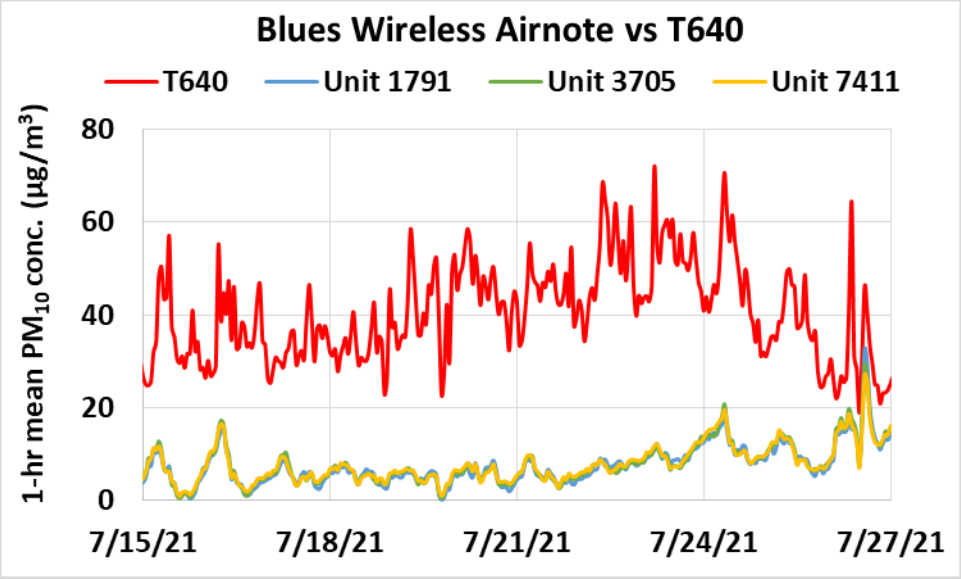
- The Airnote sensors showed strong correlations with the corresponding FEM T640 data ($0.71 < R^2 < 0.76$)
- Overall, the Airnote sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The Airnote sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



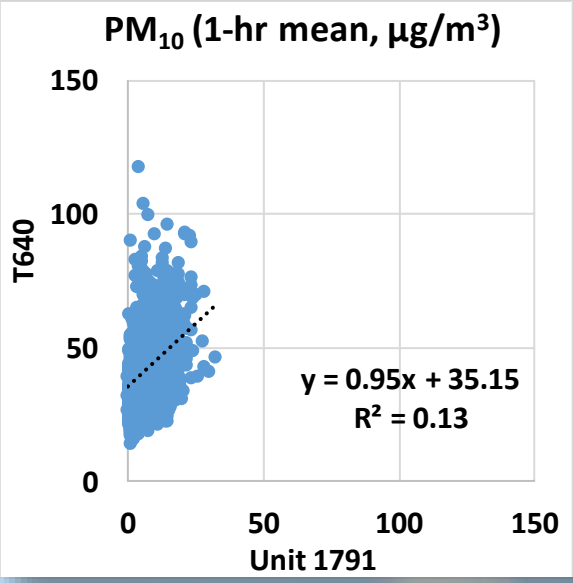


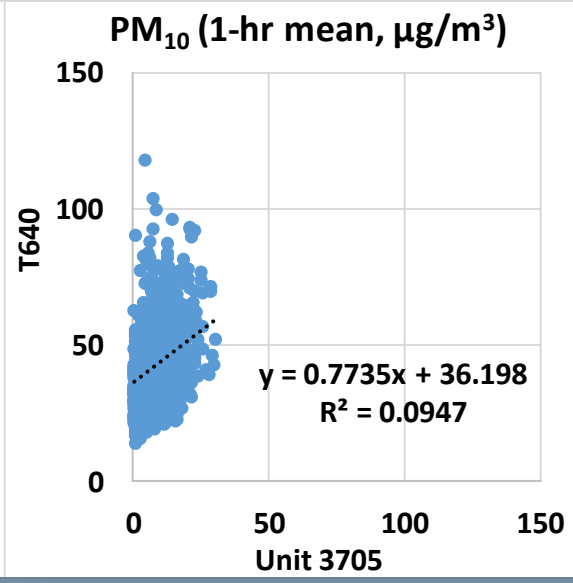


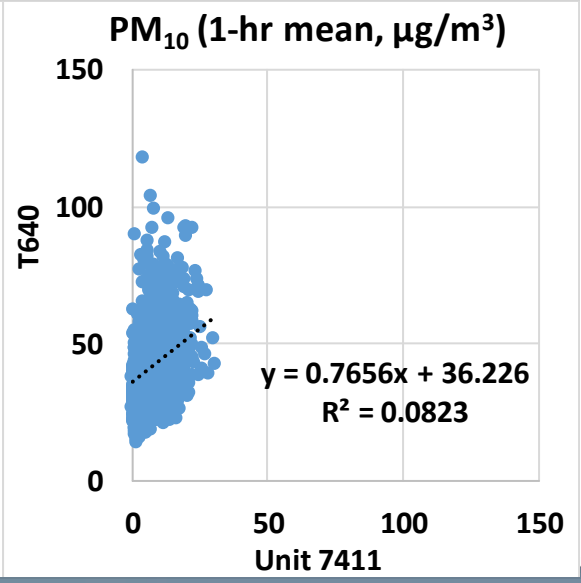
Airnote vs T640 (PM_{10}; 1-hr mean)



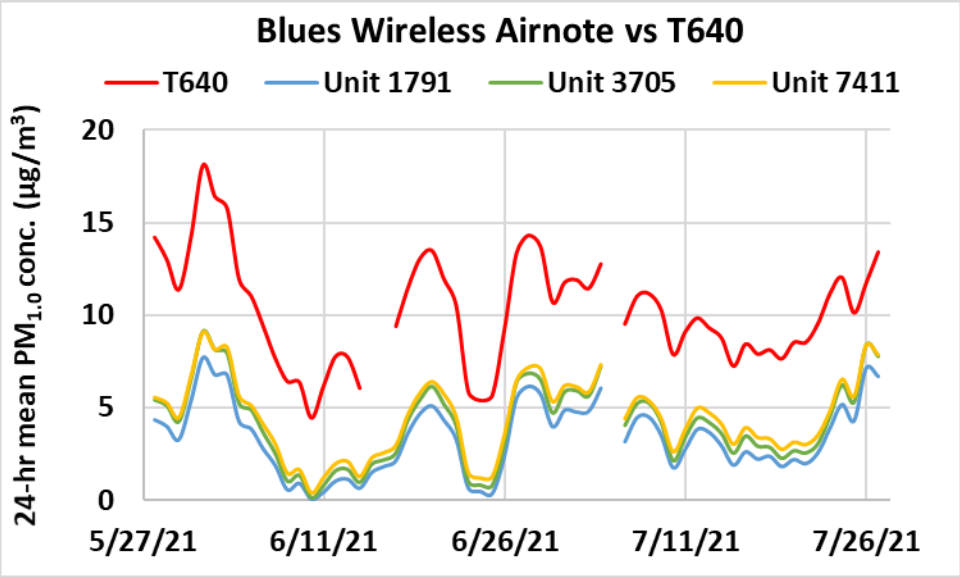
- The Airnote sensors showed no to very weak correlations with the corresponding T640 data ($0.08 < R^2 < 0.14$)
- Overall, the Airnote sensors underestimated the PM_{10} mass concentrations as measured by T640
- The Airnote sensors did not seem to track the PM_{10} diurnal variations as recorded by T640



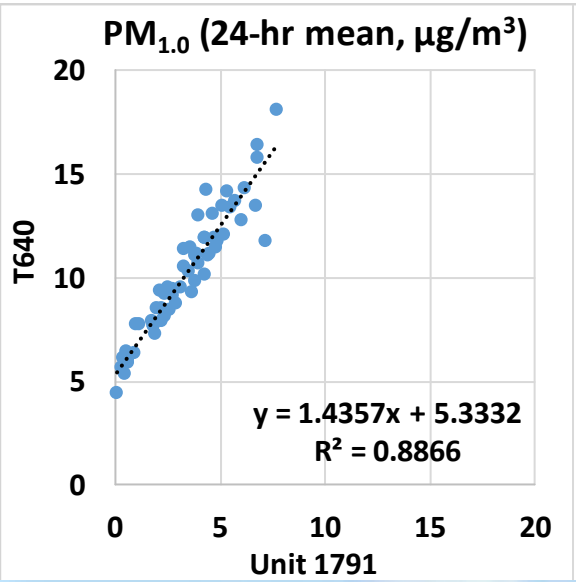


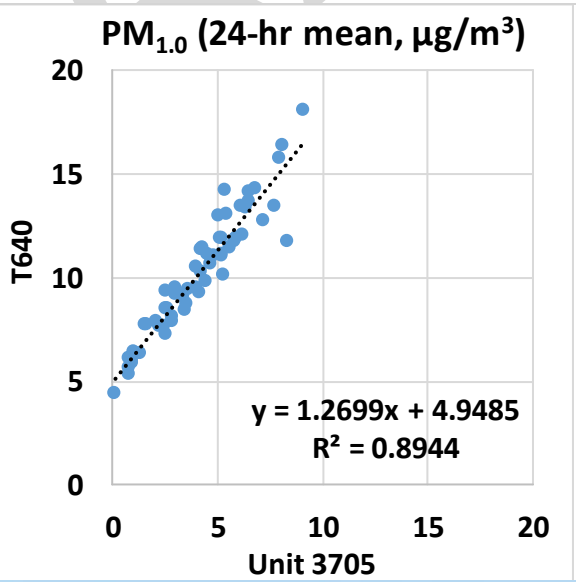


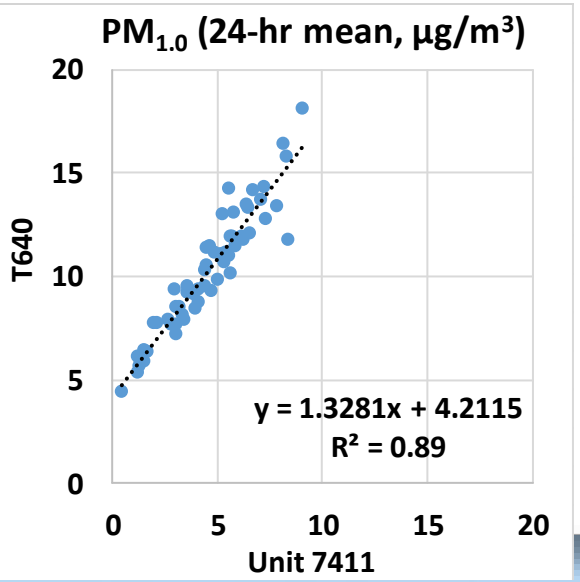
Airnote vs T640 ($PM_{1.0}$; 24-hr mean)



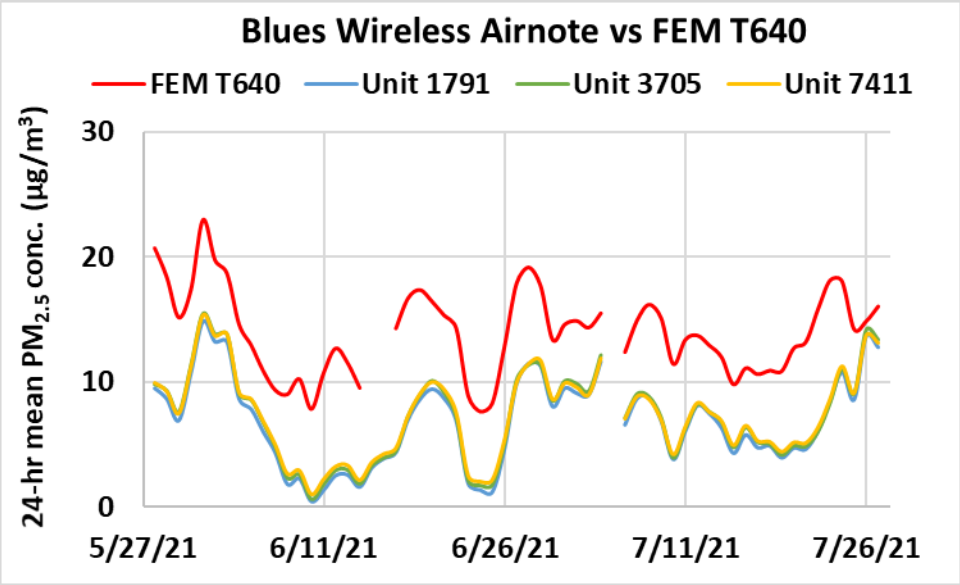
- The Airnote sensors showed strong correlations with the corresponding T640 data ($0.88 < R^2 < 0.90$)
- Overall, the Airnote sensors underestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The Airnote sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by T640



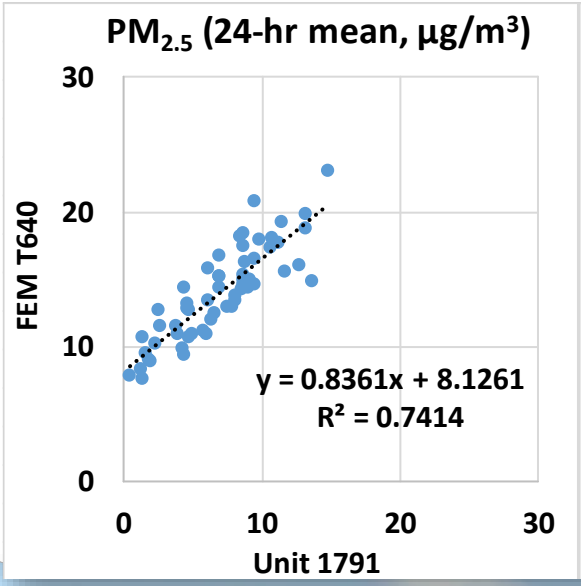


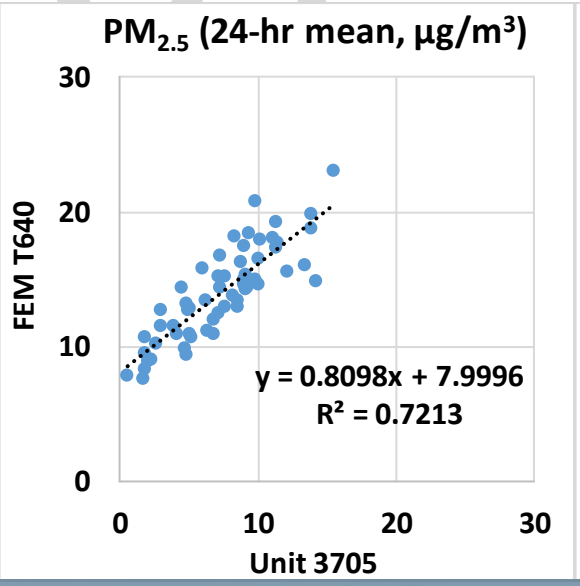


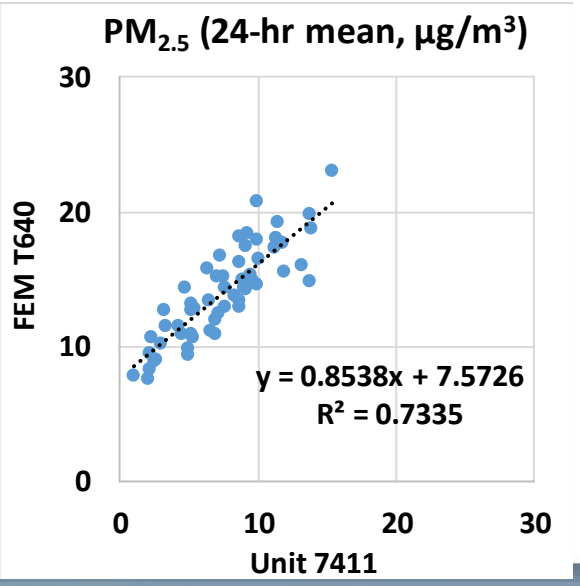
Airnote vs FEM T640 ($PM_{2.5}$; 24-hr mean)



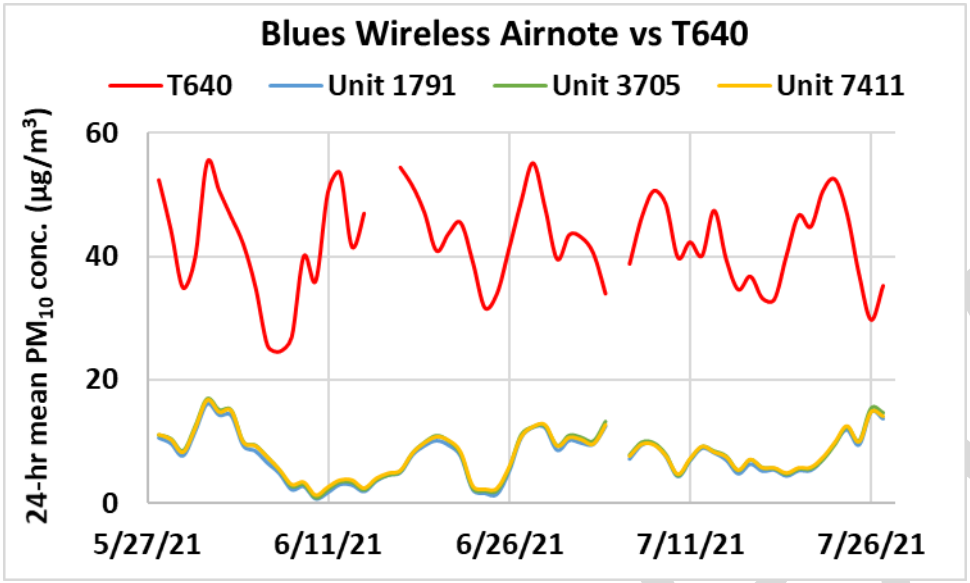
- The Airnote sensors showed strong correlations with the corresponding FEM T640 data ($0.72 < R^2 < 0.75$)
- Overall, the Airnote sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The Airnote sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



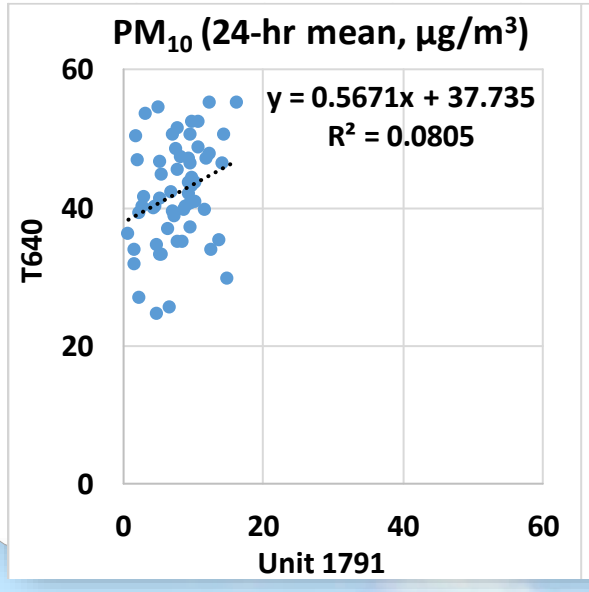


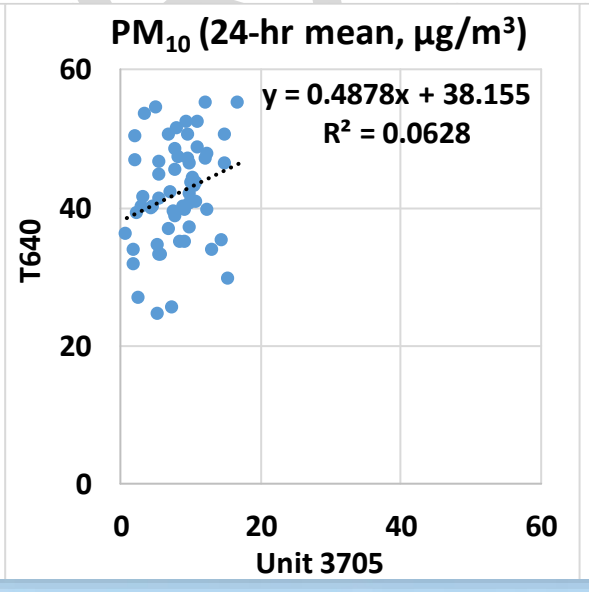


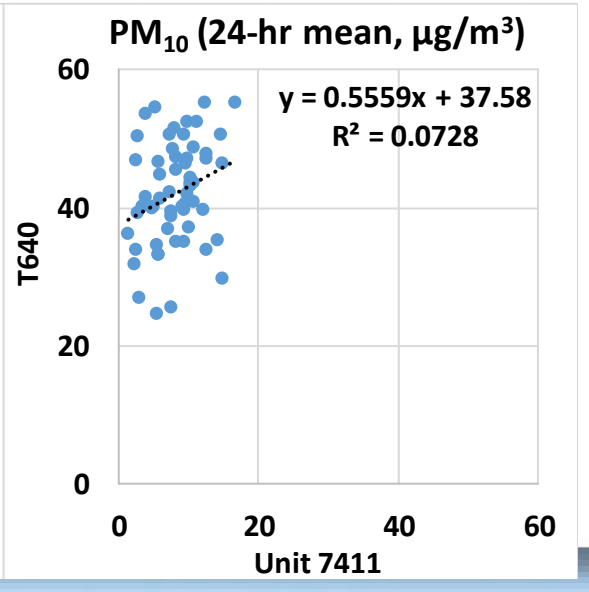
Airnote vs T640 (PM_{10}; 24-hr mean)



- The Airnote sensors did not correlate with the corresponding T640 data ($0.06 < R^2 < 0.09$)
- Overall, the Airnote sensors underestimated the PM_{10} mass concentrations as measured by T640
- The Airnote sensors did not seem to track the PM_{10} diurnal variations as recorded by T640







Summary

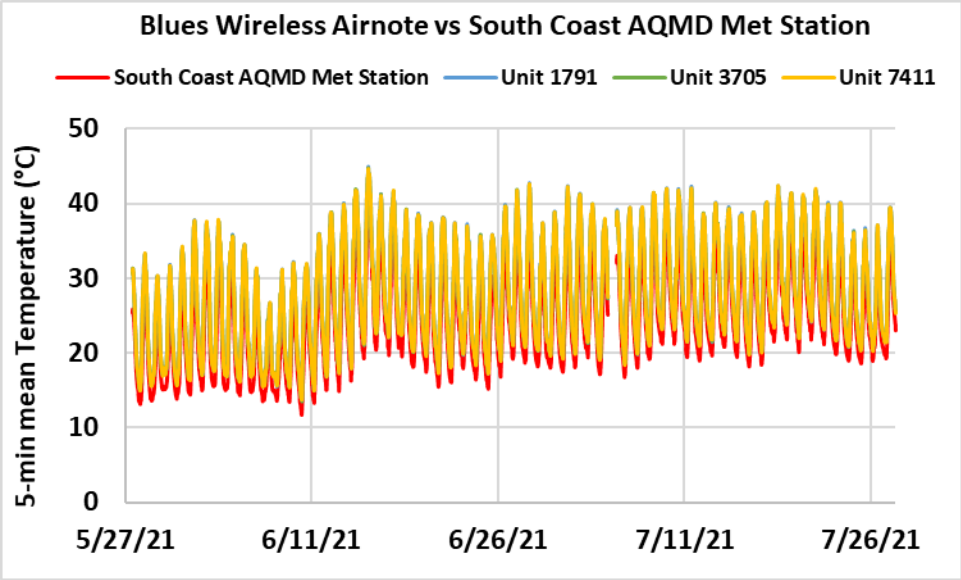
	Average of 3 Sensors, $PM_{1.0}$		Airnote vs GRIMM & T640, $PM_{1.0}$						GRIMM & T640 ($PM_{1.0}$, $\mu g/m^3$)		
	Average ($\mu g/m^3$)	SD ($\mu g/m^3$)	R^2	Slope	Intercept	MBE[1] ($\mu g/m^3$)	MAE[2] ($\mu g/m^3$)	RMSE[3] ($\mu g/m^3$)	Ref. Average	Ref. SD	Range during the field evaluation
5-min	4.0	2.8	0.68 to 0.86	1.25 to 1.43	2.7 to 5.4	-6.8 to - 4.2	4.3 to 6.8	4.8 to 7.1	8.7 to 10.2	4.2 to 4.4	1.1 to 45.8
1-hr	4.0	2.7	0.69 to 0.88	1.27 to 1.48	2.6 to 5.2	-6.8 to -4.3	4.3 to 6.8	4.8 to 7.1	8.7 to 10.2	4.1 to 4.4	1.4 to 28.3
24-hr	4.0	2.1	0.87 to 0.89	1.20 to 1.44	3.1 to 5.3	-6.8 to -4.3	4.3 to 6.8	4.4 to 7.0	8.8 to 10.3	2.9 to 3.0	3.4 to 18.1
	Average of 3 Sensors, $PM_{2.5}$		Airnote 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	7.1	4.9	0.67 to 0.75	0.75 to 0.88	5.9 to 7.9	-7.0 to -4.4	4.4 to 7.1	5.1 to 7.6	11.8 to 13.9	4.7 to 5.1	2.5 to 49.9
1-hr	7.1	4.8	0.71 to 0.78	0.77 to 0.91	5.8 to 7.7	-7.1 to -4.4	4.5 to 7.1	5.0 to 7.5	11.8 to 13.9	4.5 to 5.0	3.3 to 35.1
24-hr	7.2	3.5	0.72 to 0.80	0.68 to 0.85	6.5 to 8.1	-7.0 to -4.4	4.4 to 7.0	4.7 to 7.2	11.8 to 14.0	2.9 to 3.4	6.5 to 23.0
	Average of 3 Sensors, PM_{10}		Airnote 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	7.9	5.3	0.04 to 0.11	0.42 to 0.94	25.2 to 36.1	-34.7 to -20.7	20.2 to 34.8	23.8 to 37.4	28.8 to 42.4	11.6 to 14.7	5.5 to 306.4
1-hr	7.9	5.1	0.05 to 0.13	0.41 to 0.95	25.2 to 36.2	-34.8 to -20.7	20.2 to 34.8	23.0 to 36.9	28.8 to 42.4	9.9 to 13.4	6.5 to 117.7
24-hr	7.9	3.7	0 to 0.08	0.02 to 0.57	28.4 to 38.2	-34.4 to -20.7	20.2 to 34.4	21.9 to 35.1	28.9 to 42.1	6.0 to 7.5	16.2 to 55.2

[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).

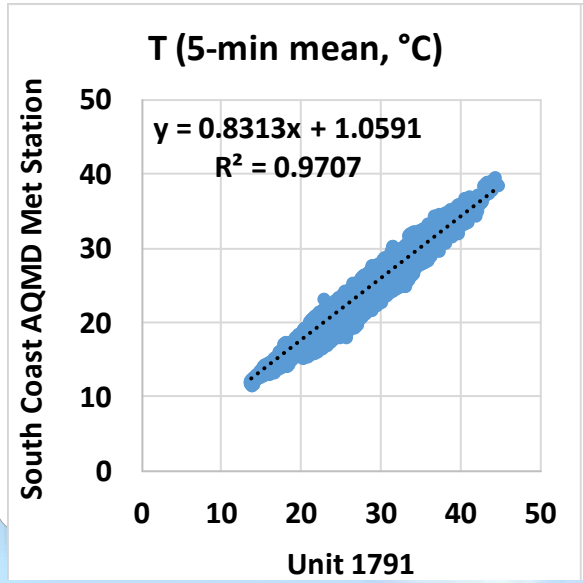
[2] Mean Absolute Error (MAE): the absolute difference between the sensors and the reference instruments. The larger MAE values, the higher measurement errors as compared to the reference instruments.

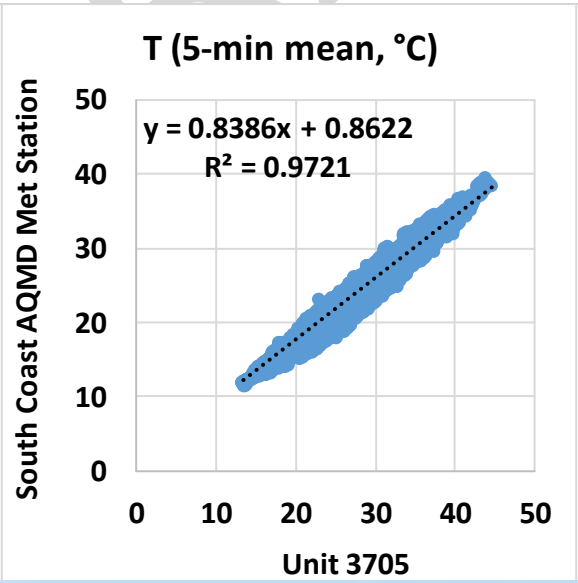
[3] Root Mean Square Error (RMSE): another metric to calculate measurement errors.

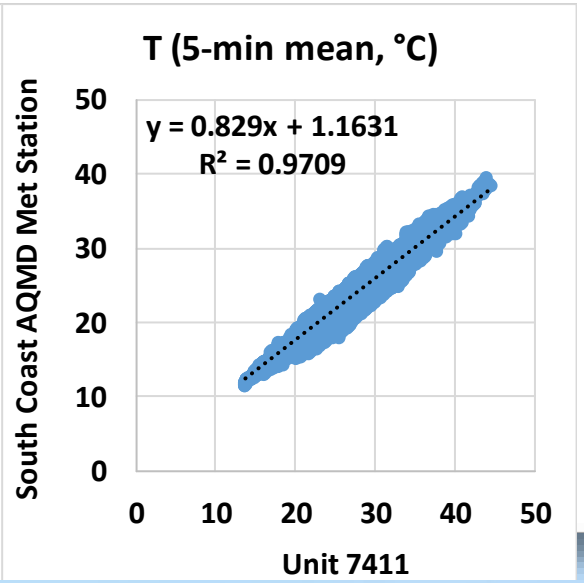
Airnote vs South Coast AQMD Met Station (Temp; 5-min mean)



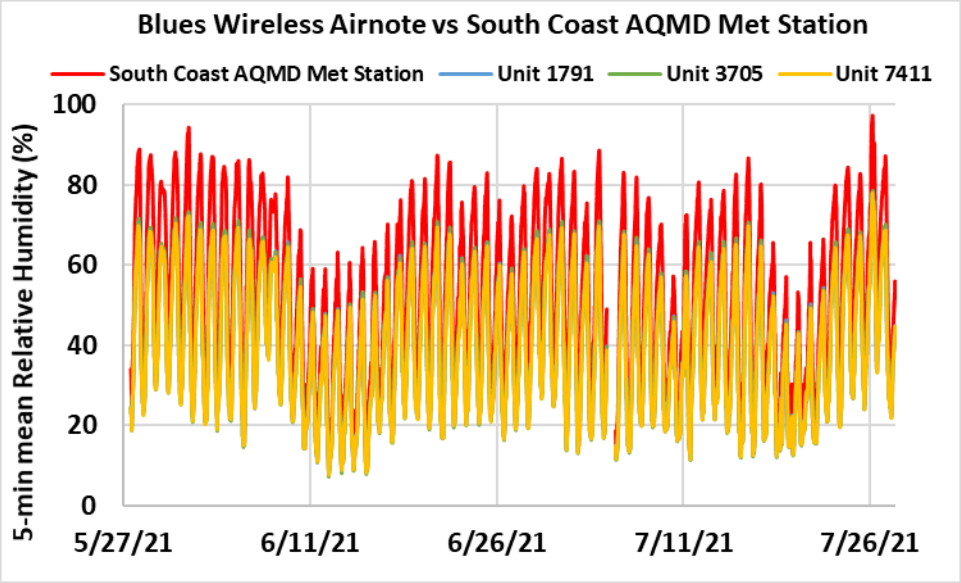
- The Airnote sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data (R^2 ~ 0.97)
- Overall, the Airnote sensors overestimated the temperature measurement as recorded by South Coast AQMD Met Station
- The Airnote sensors seemed to track the diurnal temperature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



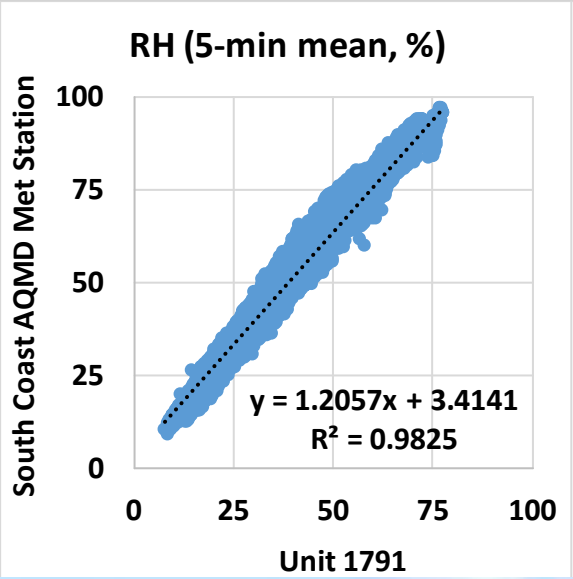


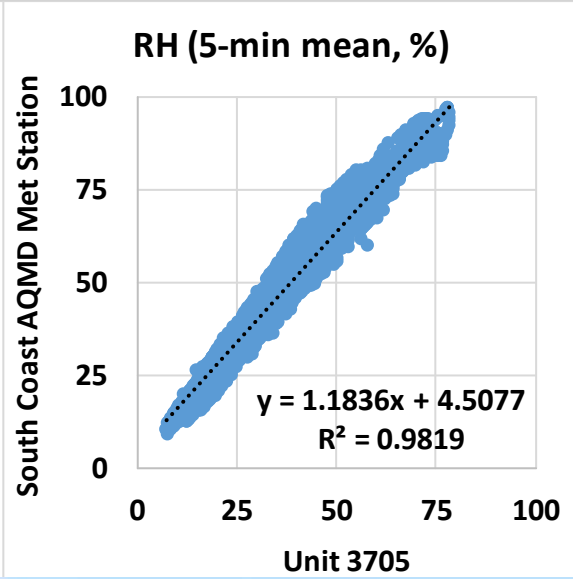


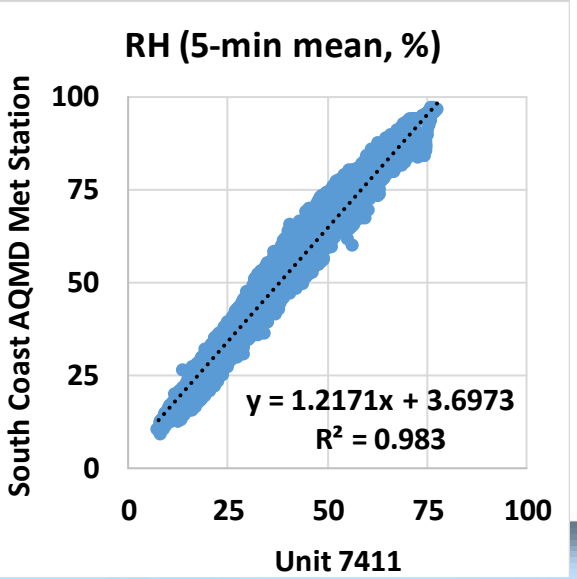
Airnote vs South Coast AQMD Met Station (RH; 5-min mean)



- The Airnote sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data (R^2 ~ 0.98)
- Overall, the Airnote sensors underestimated the RH measurement as recorded by South Coast AQMD Met Station
- The Airnote sensors seemed to track the diurnal RH variations as recorded by South Coast AQMD Met Station







Discussion

- The three **Airnote** sensors' data recovery from all units was ~ 100% for all PM measurements
- The absolute intra-model variability was ~ 0.46, 0.21 and 0.20 µg/m^3 for $PM_{1.0}$, $PM_{2.5}$ and $PM_{10,}$ respectively
- Strong correlations between GRIMM and T640 for $PM_{1.0}$ (R^2 ~ 0.77, 1-hr mean); strong correlations between FEM GRIMM and FEM T640 for $PM_{2.5}$ (R^2 ~ 0.81, 1-hr mean) and strong correlations between GRIMM and T640 for PM_{10} (R^2 ~ 0.85, 1-hr mean) mass concentration measurements
- $PM_{1.0}$ mass concentrations measured by the Airnote sensors showed moderate to strong correlations with the corresponding GRIMM and T640 data ($0.68 < R^2 < 0.89$, 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 Airnote sensors showed strong correlations with the corresponding FEM GRIMM and FEM T640 data ($0.70 < R^2 < 0.78$, 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 Airnote sensors showed no to very weak correlations with the corresponding GRIMM and T640 data ($0.04 < R^2 < 0.14$; 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 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