Field Evaluation
Aeroqual AQY-R

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

- From 04/14/2022 to 06/12/2022, three **Aeroqual AQY-R** multi-sensor units were deployed at the South Coast AQMD stationary ambient monitoring site in Rubidoux and were run side-by-side with Federal Equivalent Method (FEM) and Federal Reference Method (FRM) instruments measuring the same pollutants.

- Aeroqual AQY-R (*3 units tested*):
  - Gas Sensors: Ozone – Gas Sensitive Semiconductor (Aeroqual; MOx/GSS); NO_2 – Gas Sensitive Electrochemical (Aeroqual NO_2/MA-2, non-FEM/non-FRM)
  - $PM_{2.5}$ – Laser Particle Counter (LPC) (Nova Fitness SDS011, non-FEM)
  - Each unit measures: O_3 (ppb), NO_2 (ppb), $PM_{2.5}$ ($\mu g/m^3$), T (°C), RH (%)
  - Unit cost: $5,000 + $1000 - $2000/year for cloud data and services
  - Time resolution: 1-min
  - Units IDs: 0193, 0194, and 0195

- South Coast AQMD Reference instruments:
  - O_3 instrument (Teledyne T400, hereinafter FEM T400); cost: ~$7,000
    - Time resolution; 1-min
  - NO/NO_2 instrument (Teledyne T200, hereinafter FRM T200); cost: ~$11,000
    - Time resolution: 1-min
  - PM Instrument (GRIMM EDM 180; FEM $PM_{2.5}$, hereinafter FEM GRIMM); cost: $25,000 and up
    - Time resolution: 1-min
  - PM instrument (Teledyne API T640; FEM $PM_{2.5}$, hereinafter FEM T640); cost: $21,000
    - Time resolution: 1-min
  - Met station (T, RH, P, WS, WD); cost: ~$5,000
    - Time resolution: 1-min

FEM GRIMM

FEM T640

FEM T400

FRM T200

Ozone (O_3) in Aeroqual AQY-R

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 for O_3 from Unit 0193, Unit 0194 and Unit 0195 was ~93.7%, ~93.8% and ~95.1%, respectively

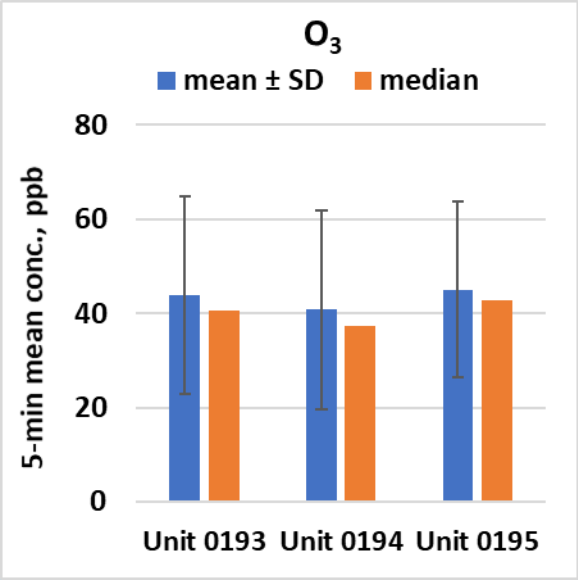
Aeroqual AQY-R; Intra-model variability

- Absolute intra-model variability was ~1.8 ppb for the ozone measurements

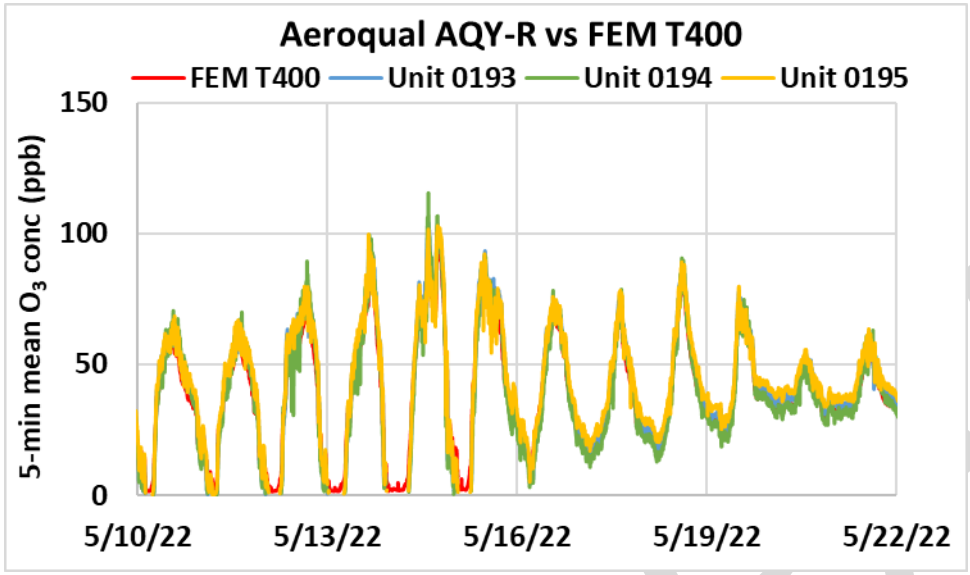
(calculated as the standard deviation of the three sensor means)

- Relative intra-model variability was ~4.2% for the ozone measurements

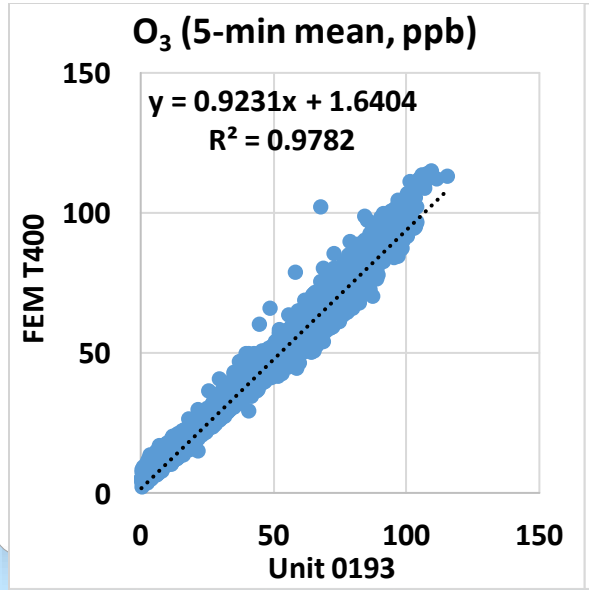
(calculated as the absolute intra-model variability relative to the mean of the three sensor means)

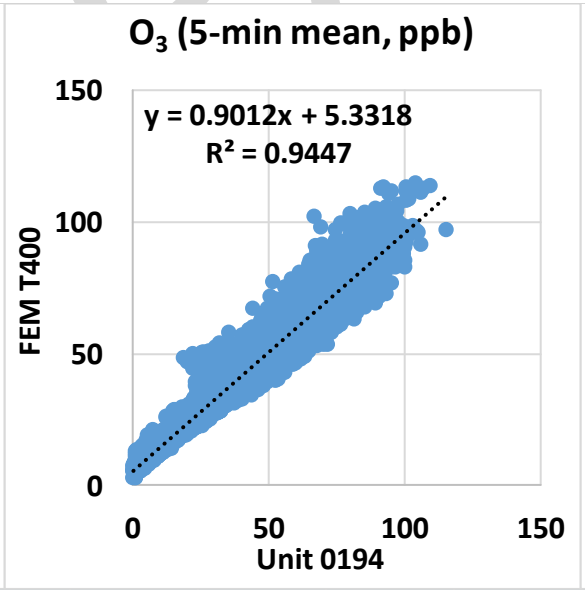


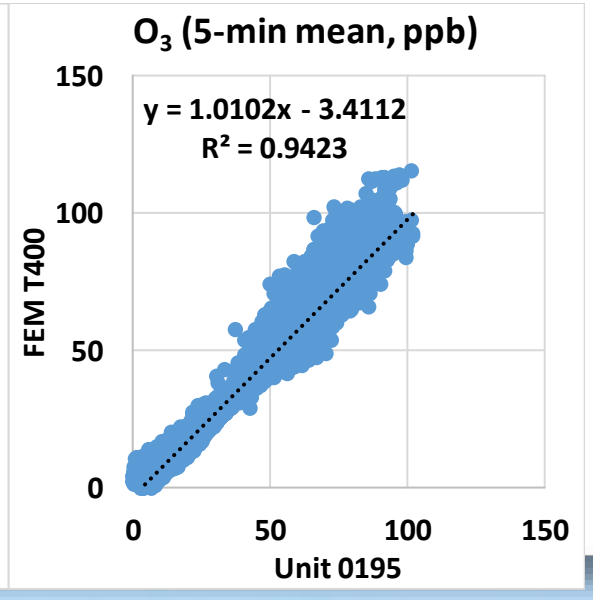
Aeroqual AQY-R vs FEM T400 (Ozone; 5-min mean)



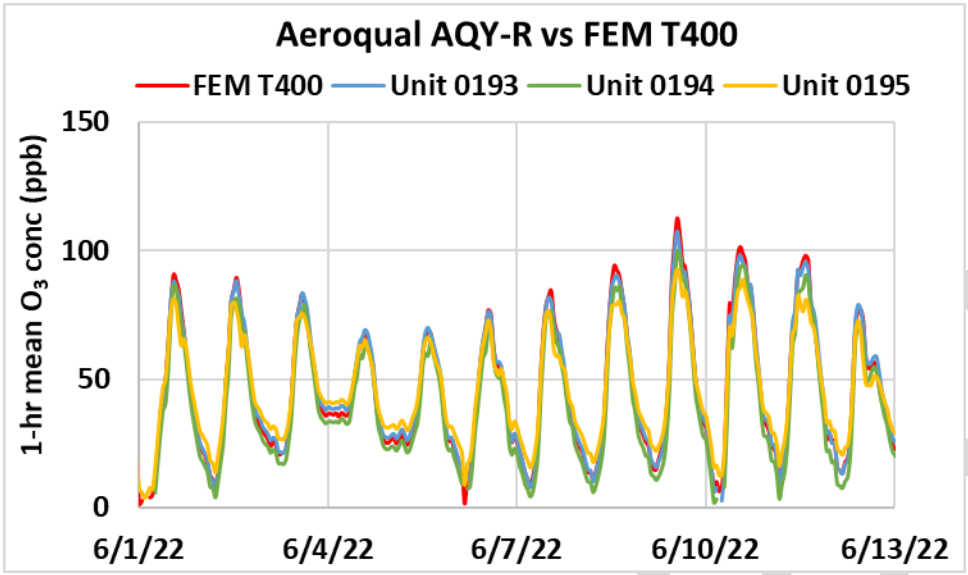
- The Aeroqual AQY-R sensors showed very strong correlations with the corresponding FEM T400 ozone data ($0.94 < R^2 < 0.98$)
- Overall, the Aeroqual AQY-R sensors overestimated the ozone concentration as measured by the FEM T400 ozone instrument
- The Aeroqual AQY-R sensors seemed to track the diurnal ozone variations as recorded by the FEM T400 instrument



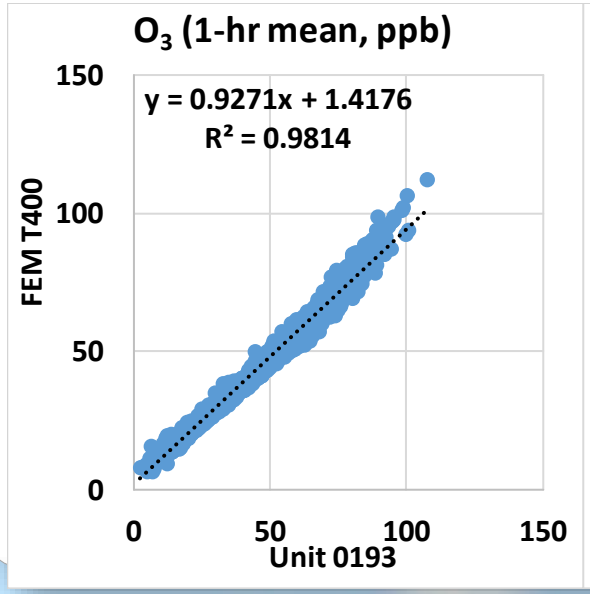


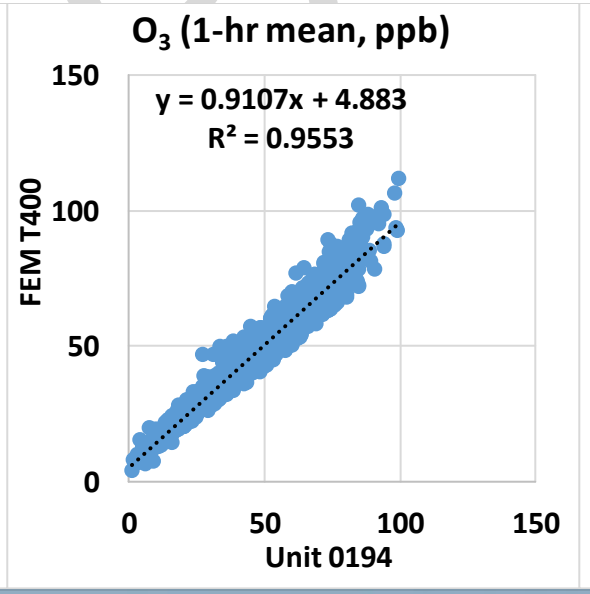


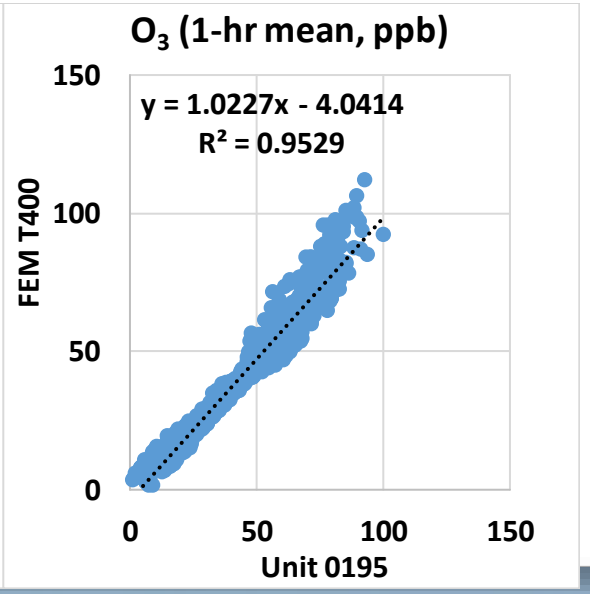
Aeroqual AQY-R vs FEM T400 (Ozone; 1-hr mean)



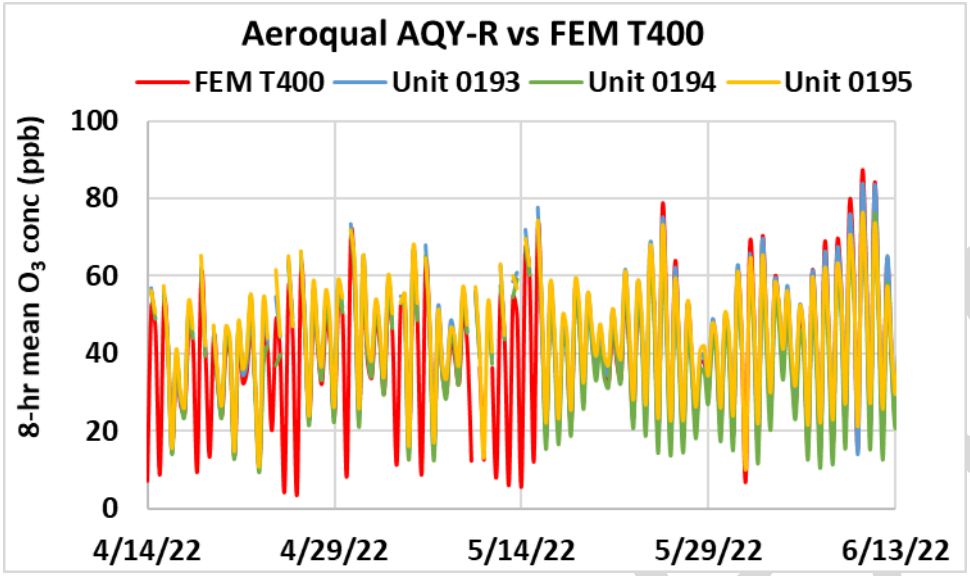
- The Aeroqual AQY-R sensors showed very strong correlations with the corresponding FEM T400 ozone data ($0.95 < R^2 < 0.99$)
- Overall, the Aeroqual AQY-R sensors overestimated the ozone concentration as measured by the FEM T400 ozone instrument
- The Aeroqual AQY-R sensors seemed to track the diurnal ozone variations as recorded by the FEM T400 instrument



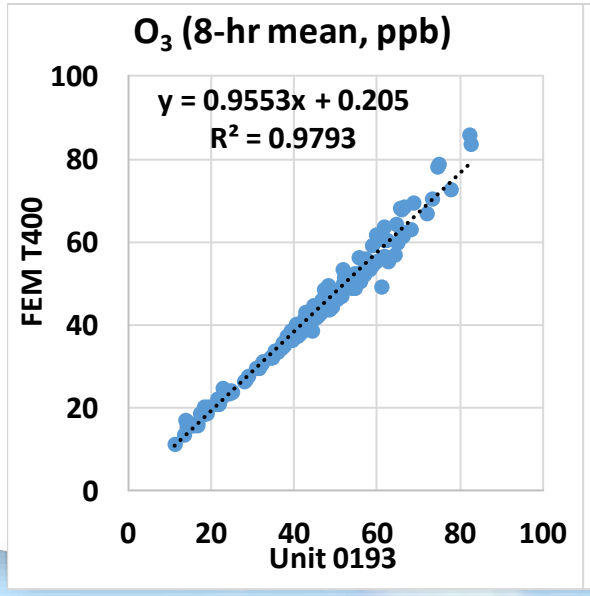


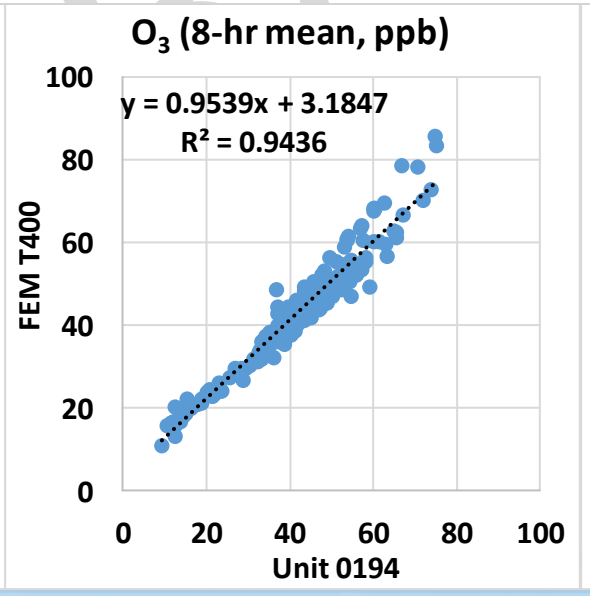


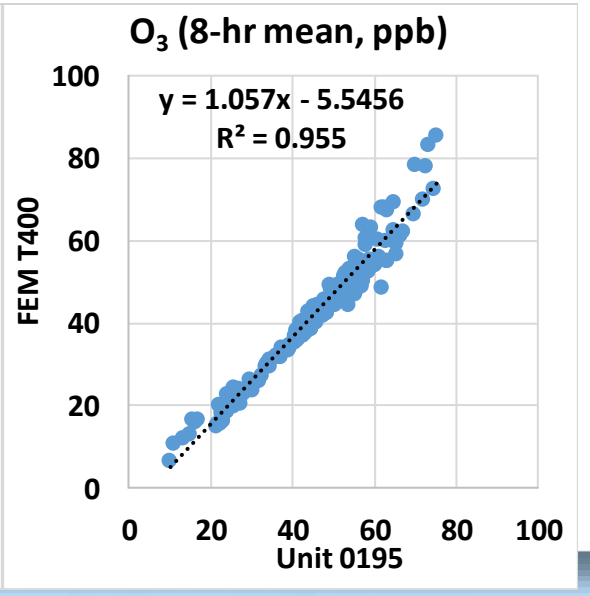
Aeroqual AQY-R vs FEM T400 (Ozone; 8-hr mean)



- The Aeroqual AQY-R sensors showed very strong correlations with the corresponding FEM T400 ozone data ($0.94 < R^2 < 0.98$)
- Overall, the Aeroqual AQY-R sensors overestimated the ozone concentration as measured by the FEM T400 ozone instrument
- The Aeroqual AQY-R sensors seemed to track the diurnal ozone variations as recorded by the FEM T400 instrument







Summary: Ozone

	Average of 3 Sensors, Ozone		Aeroqual AQY-R vs FEM T400, Ozone						FEM T400, Ozone (ppb)		
	Average (ppb)	SD (ppb)	R^2	Slope	Intercept	MBE[1] (ppb)	MAE[2] (ppb)	RMSE[3] (ppb)	FEM T400 Average	FEM T400 SD	Range during the field evaluation
5-min	42.9	20.5	0.94 to 0.98	0.90 to 1.01	-3.4 to 5.3	-1.2 to 3.0	3.0 to 4.8	3.8 to 5.7	40.6	21.4	0.2 to 115.5
1-hr	43.2	20.1	0.95 to 0.98	0.91 to 1.02	-4.0 to 4.9	-1.2 to 3.0	2.8 to 4.5	3.5 to 5.3	39.2	21.1	1.5 to 112.4
8-hr	44.0	15.5	0.94 to 0.98	0.95 to 1.06	-5.5 to 3.2	-1.3 to 3.0	2.4 to 4.0	1.6 to 5.3	39.3	17.9	3.5 to 85.9

[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.

Nitrogen Dioxide (NO_2) in Aeroqual AQY-R

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 for NO_2 from Unit 0193, Unit 0194 and Unit 0195 was ~95.5%, ~95.9% and ~95.1%, respectively

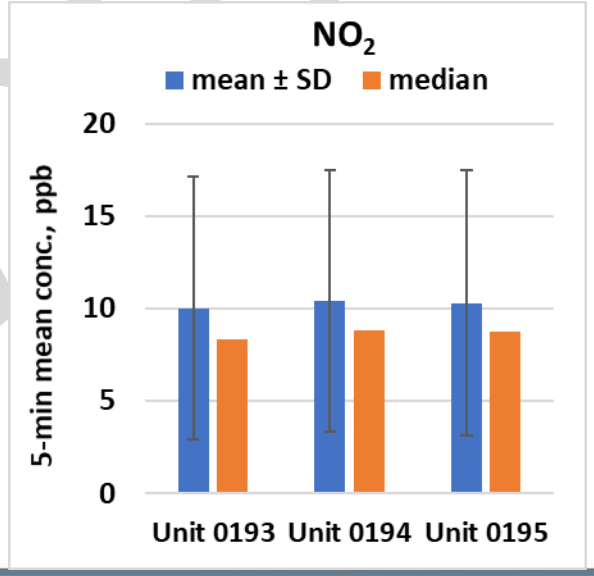
Aeroqual AQY-R; Intra-model variability

- Absolute intra-model variability was ~0.17 ppb for the NO_2 measurements

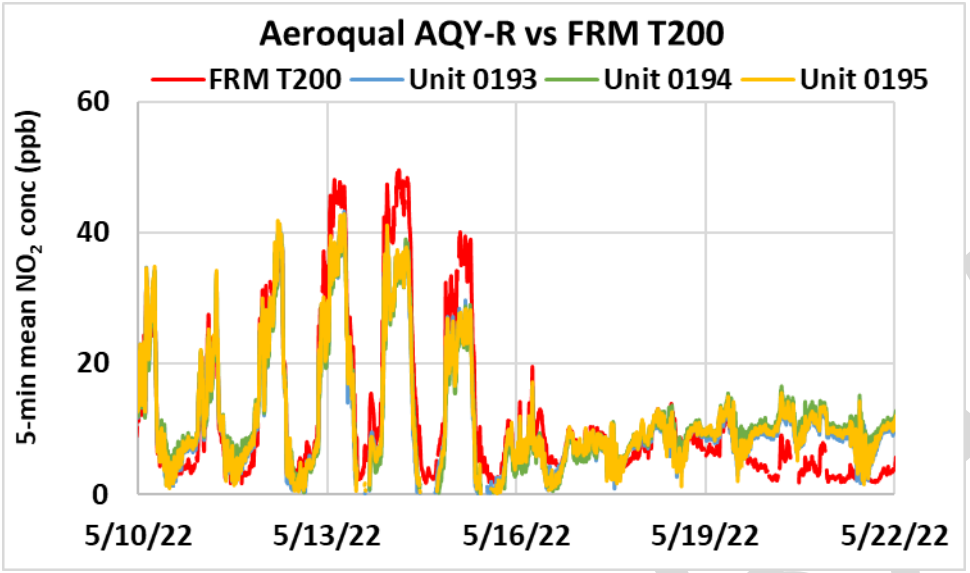
(calculated as the standard deviation of the three sensor means)

- Relative intra-model variability was ~1.7% for the NO_2 measurements

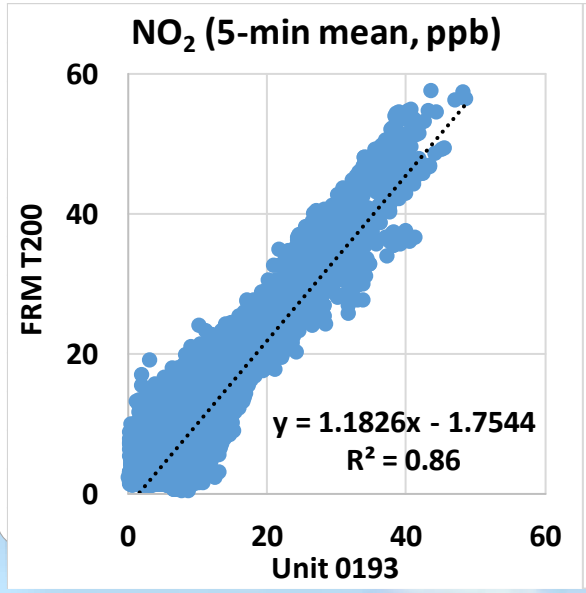
(calculated as the absolute intra-model variability relative to the mean of the three sensor means)

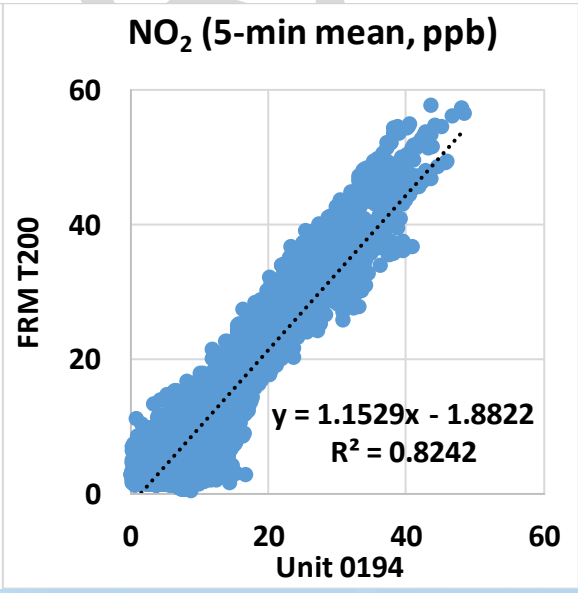


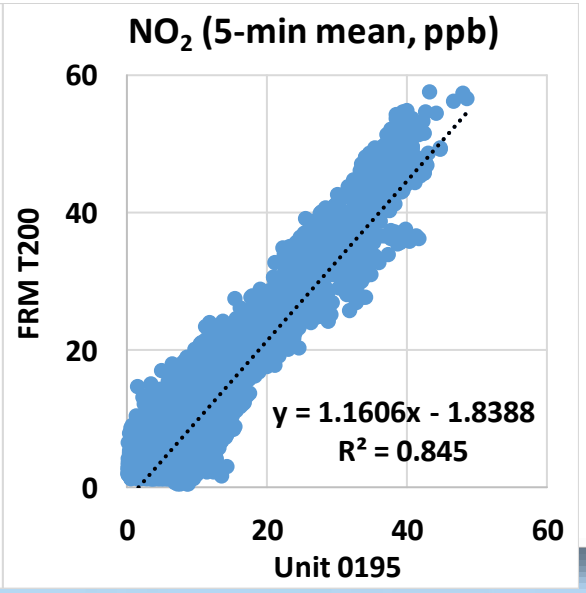
Aeroqual AQY-R vs FRM T200 (NO_2; 5-min mean)



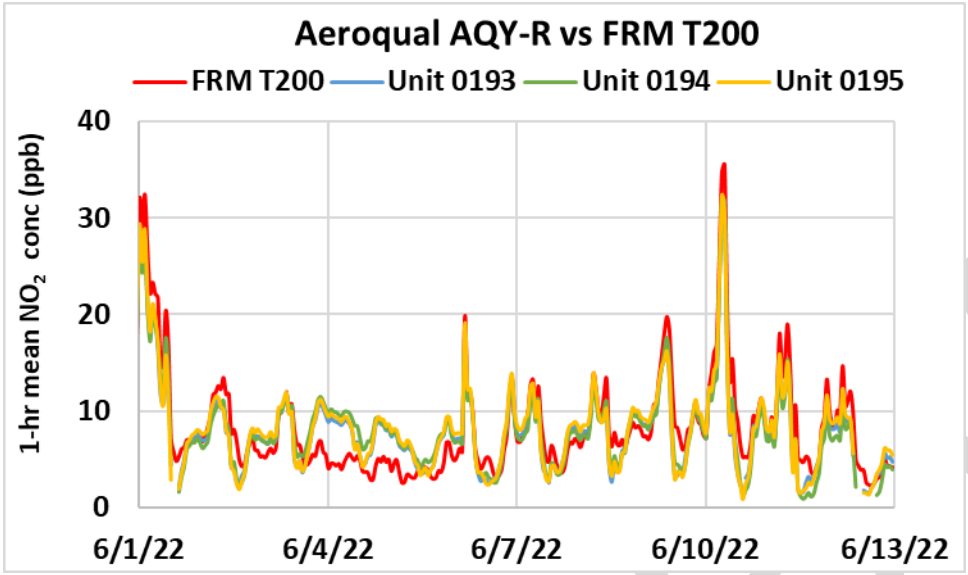
- The Aeroqual AQY-R sensors showed strong correlations with the corresponding FRM T200 NO_2 data ($0.82 < R^2 < 0.87$)
- Overall, the Aeroqual AQY-R sensors slightly overestimated the NO_2 concentration as measured by the FRM T200 instrument (see calculated MBE values, slide 14)
- The Aeroqual AQY-R sensors seemed to track the diurnal NO_2 variations as recorded by the FRM T200 instrument



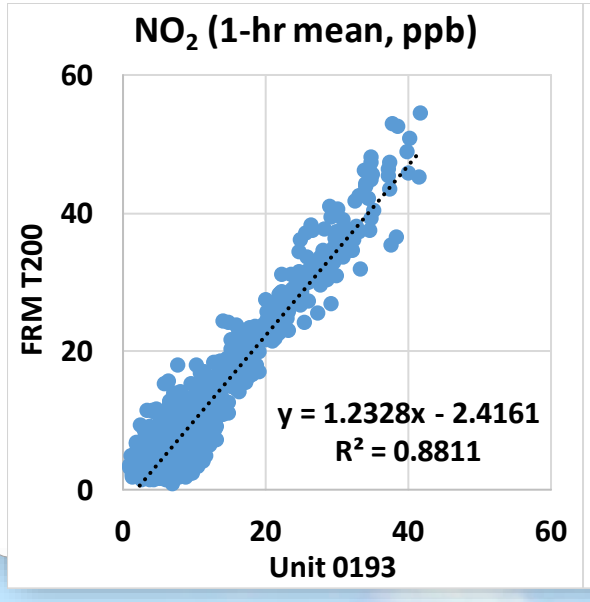


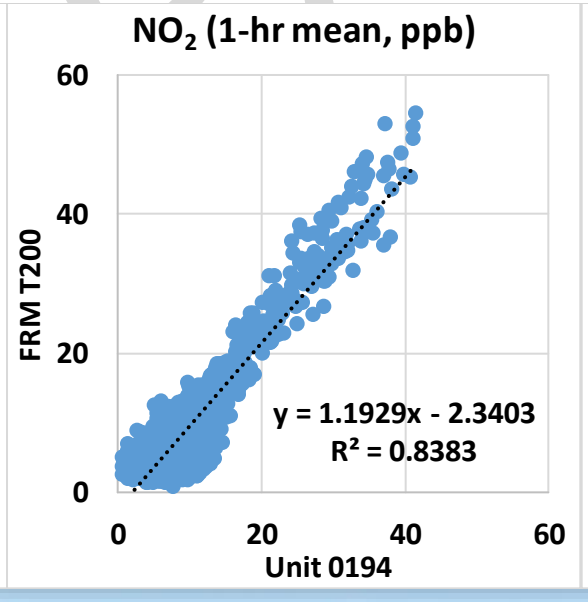


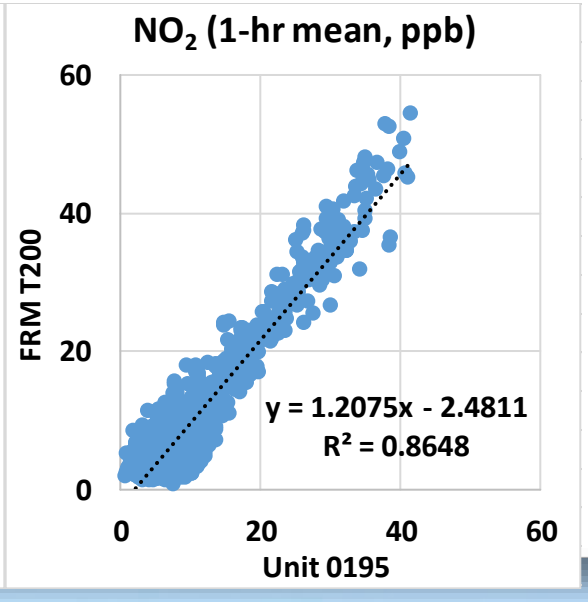
Aeroqual AQY-R vs FRM T200 (NO_2; 1-hr mean)



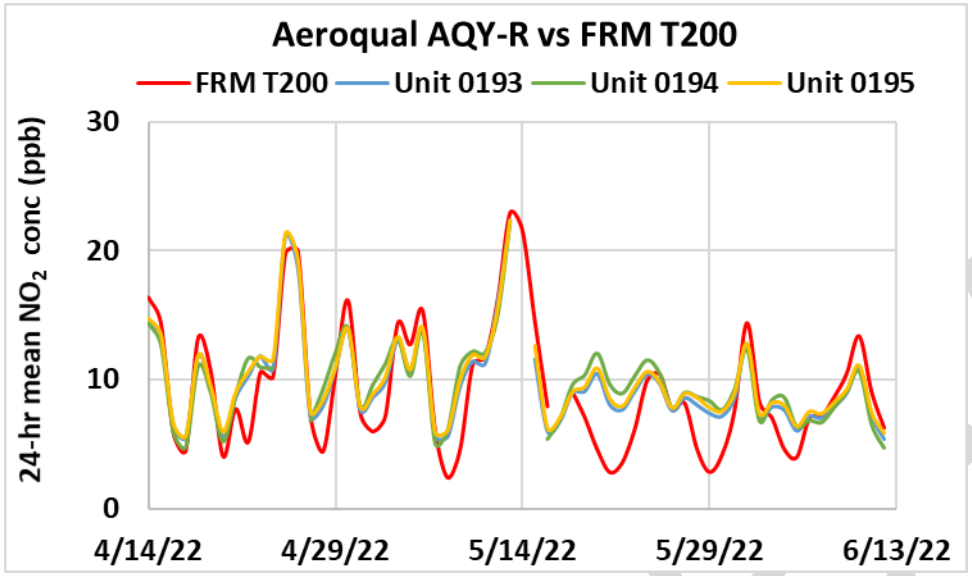
- The Aeroqual AQY-R sensors showed strong correlations with the corresponding FRM T200 NO_2 data ($0.83 < R^2 < 0.89$)
- Overall, the Aeroqual AQY-R sensors slightly overestimated the NO_2 concentration as measured by the FRM T200 instrument (see calculated MBE values, slide 14)
- The Aeroqual AQY-R sensors seemed to track the diurnal NO_2 variations as recorded by the FRM T200 instrument



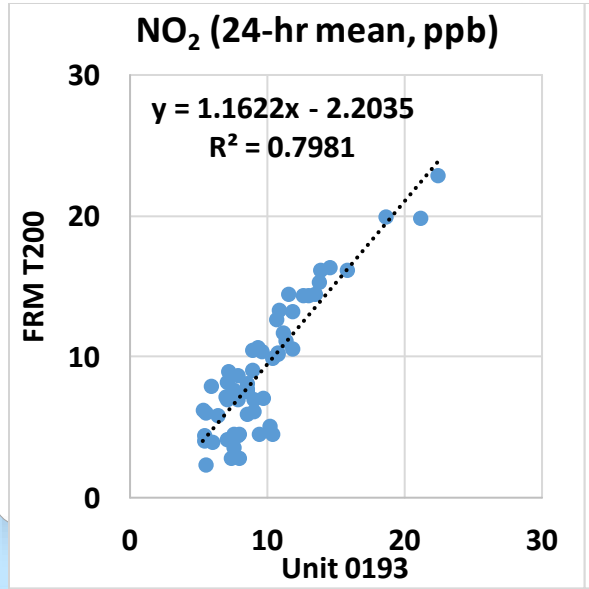


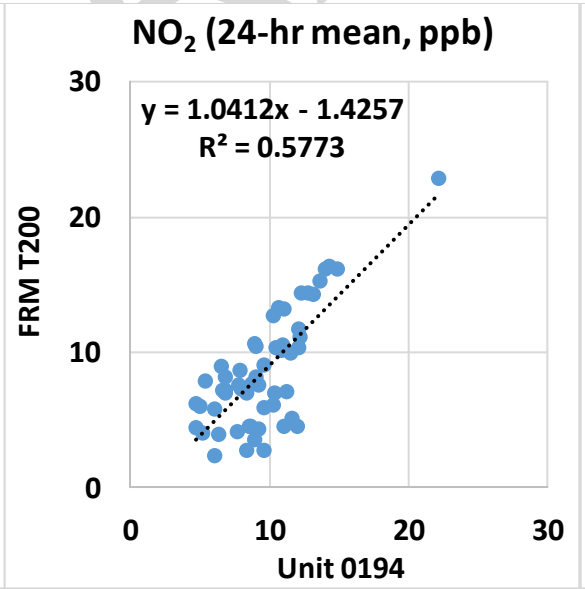


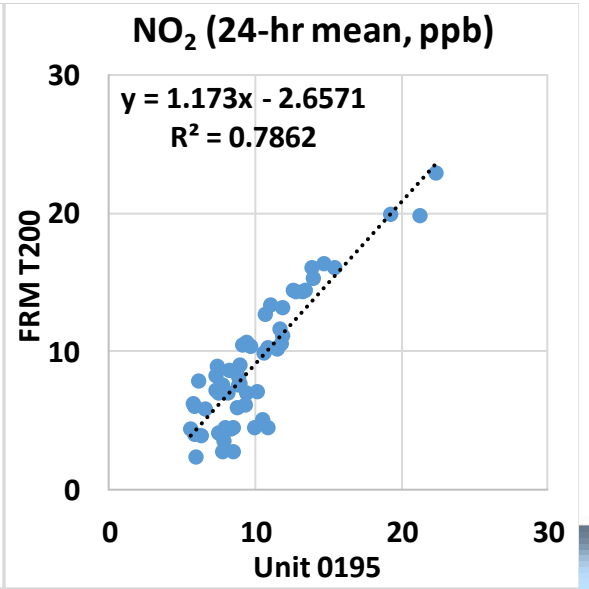
Aeroqual AQY-R vs FRM T200 (NO_2; 24-hr mean)



- The Aeroqual AQY-R sensors showed moderate to strong correlations with the corresponding FRM T200 NO_2 data ($0.57 < R^2 < 0.80$)
- Overall, the Aeroqual AQY-R sensors slightly overestimated the NO_2 concentration as measured by the FRM T200 instrument (see calculated MBE values, slide 14)
- The Aeroqual AQY-R sensors seemed to track the daily NO_2 variations as recorded by the FRM T200 instrument







Summary: NO_2

	Average of 3 Sensors, NO_2		Aeroqual AQY-R vs FRM T200, NO_2						FRM T200, NO_2 (ppb)		
	Average (ppb)	SD (ppb)	R^2	Slope	Intercept	MBE[1] (ppb)	MAE[2] (ppb)	RMSE[3] (ppb)	FRM T200 Average	FRM T200 SD	Range during the field evaluation
5-min	10.0	7.2	0.82 to 0.86	1.15 to 1.18	-1.9 to -1.8	-0.01 to 0.36	2.8 to 3.1	3.6 to 3.9	9.3	8.9	0.6 to 57.8
1-hr	10.1	7.0	0.84 to 0.88	1.19 to 1.23	-2.5 to -2.3	0.09 to 0.37	2.7 to 3.1	3.6 to 3.9	9.5	9.0	0.8 to 54.7
24-hr	9.8	3.4	0.58 to 0.80	1.04 to 1.17	-2.7 to -1.4	0.6 to 1.03	1.7 to 2.3	2.2 to 2.9	9.4	4.9	2.4 to 23.0

[1] Mean Bias Error (MBE): the difference between the sensors and the reference instruments. MBE indicates the tendency of the sensors to underestimate (negative MBE values) or overestimate (positive MBE values).
[2] Mean Absolute Error (MAE): the absolute difference between the sensors and the reference instruments. The larger MAE values, the higher measurement errors as compared to the reference instruments.
[3] Root Mean Square Error (RMSE): another metric to calculate measurement errors.

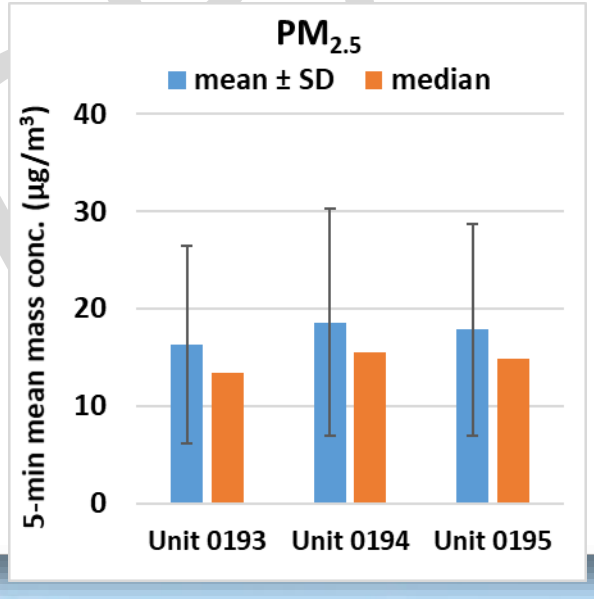
Particulate Matter (PM) in Aeroqual AQY-R

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 $PM_{2.5}$ measurements.

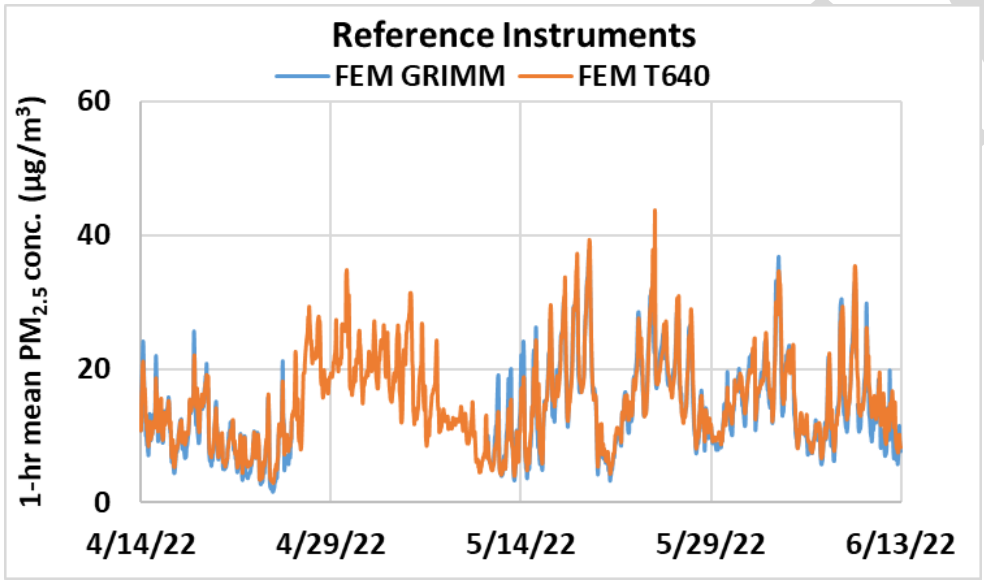
Aeroqual AQY-R; intra-model variability

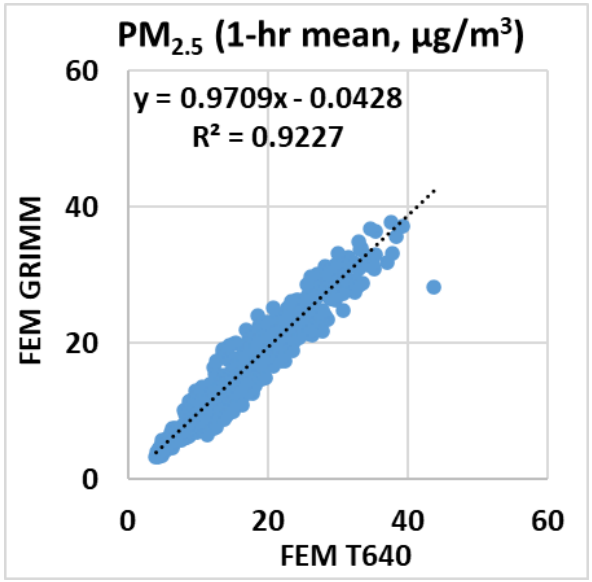
- Absolute intra-model variability was ~0.96 µg/m^3 for $PM_{2.5}$ measurements (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was ~5.5% for $PM_{2.5}$ measurements (calculated as the absolute intra-model variability relative to the mean of the three sensor means)



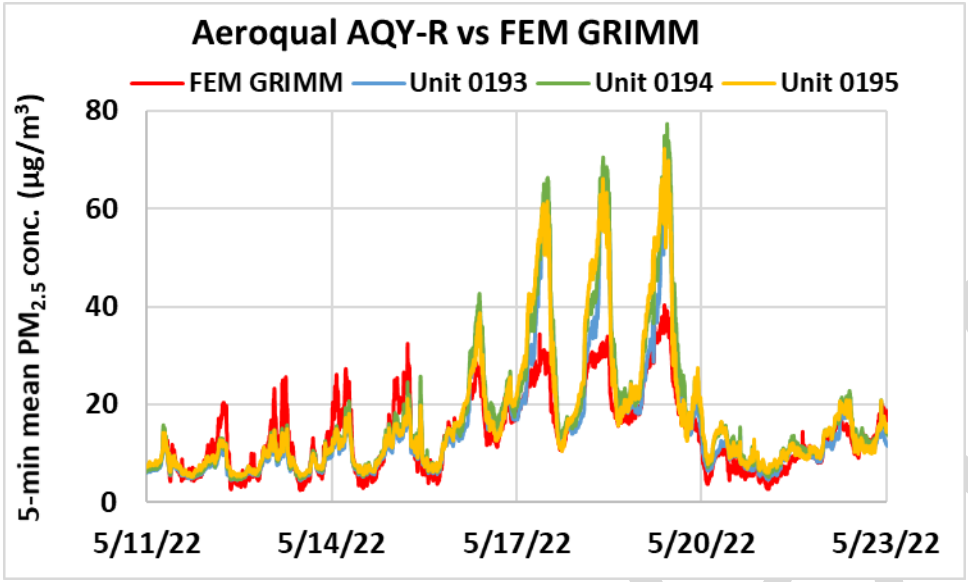
Reference Instruments: $PM_{2.5}$ FEM GRIMM and FEM T640

- Data recovery for $PM_{2.5}$ from FEM GRIMM and FEM T640 was ~100%.
- Very strong correlations between the reference instruments for $PM_{2.5}$ measurements (R^2 ~0.92) were observed.

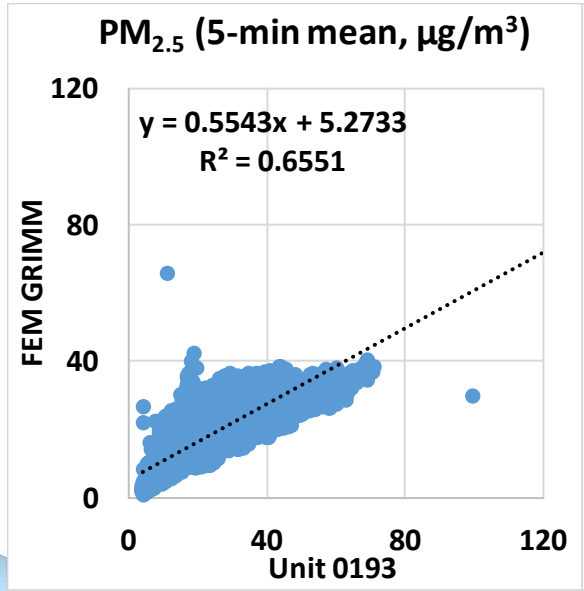


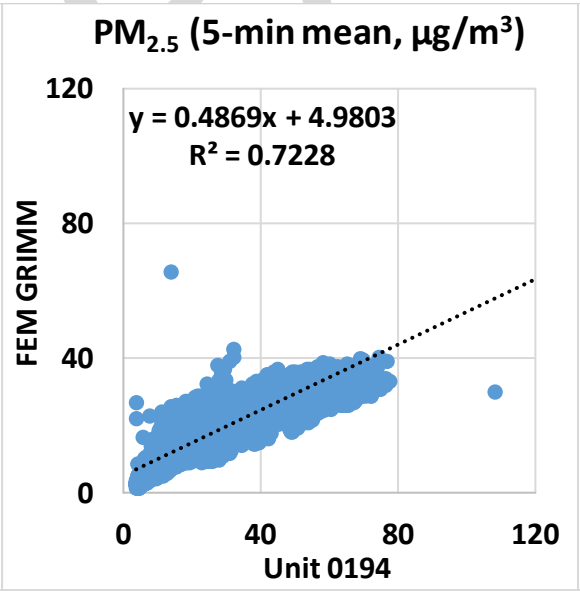


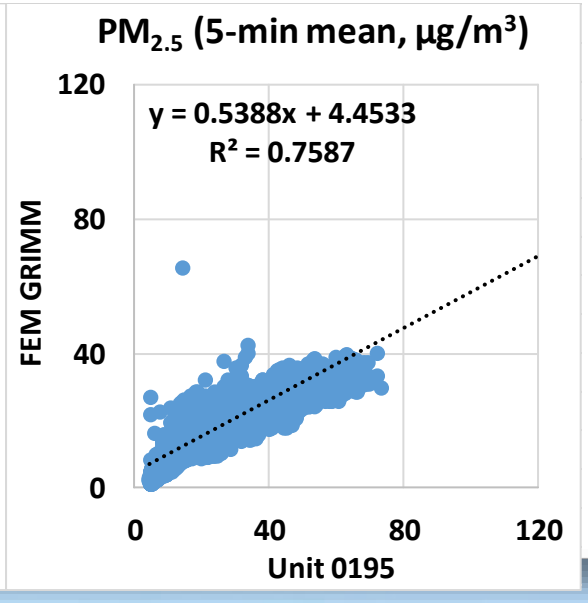
Aeroqual AQY-R vs FEM GRIMM ($PM_{2.5}$; 5-min mean)



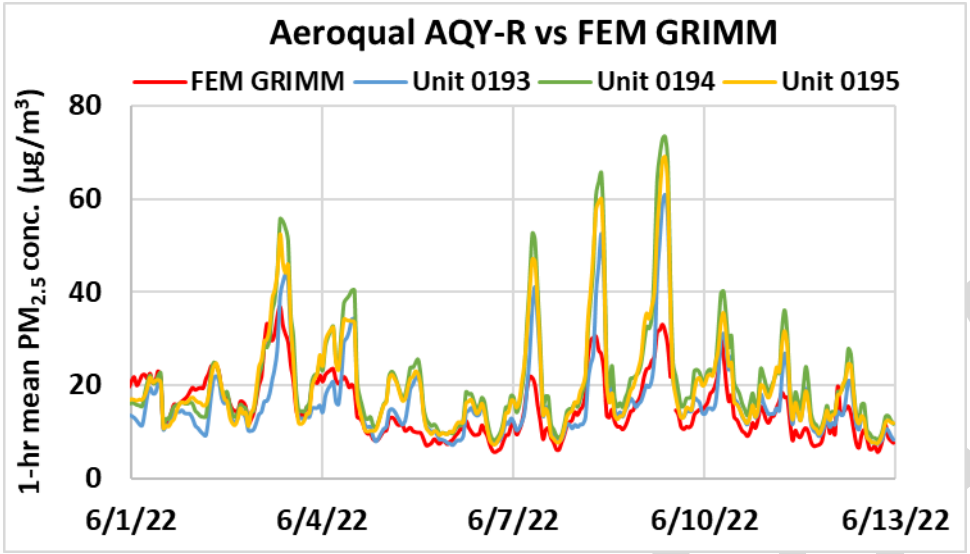
- The Aeroqual AQY-R sensors showed moderate to strong correlations with the corresponding FEM GRIMM data ($0.65 < R^2 < 0.76$)
- Overall, the Aeroqual AQY-R sensors overestimated the $PM_{2.5}$ mass concentrations as measured by FEM GRIMM
- The Aeroqual AQY-R sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM GRIMM



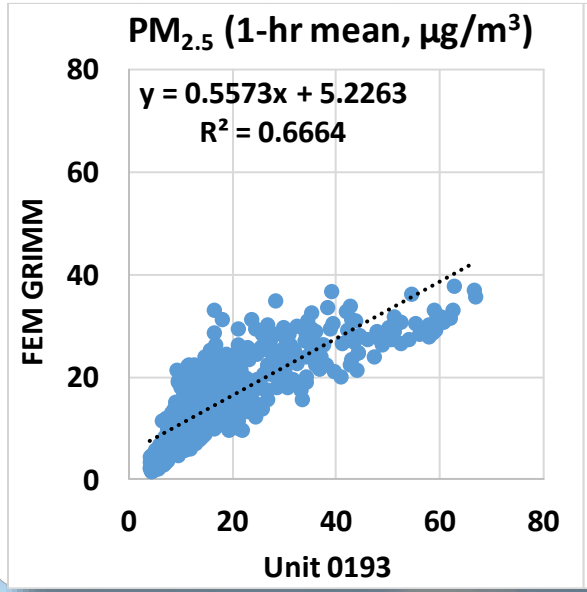


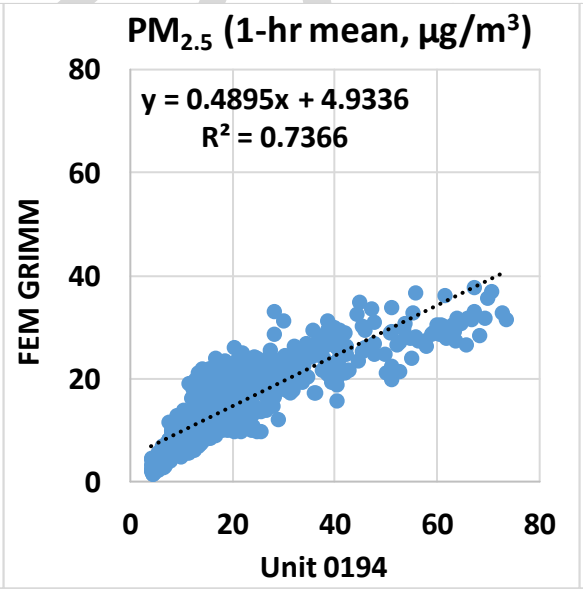


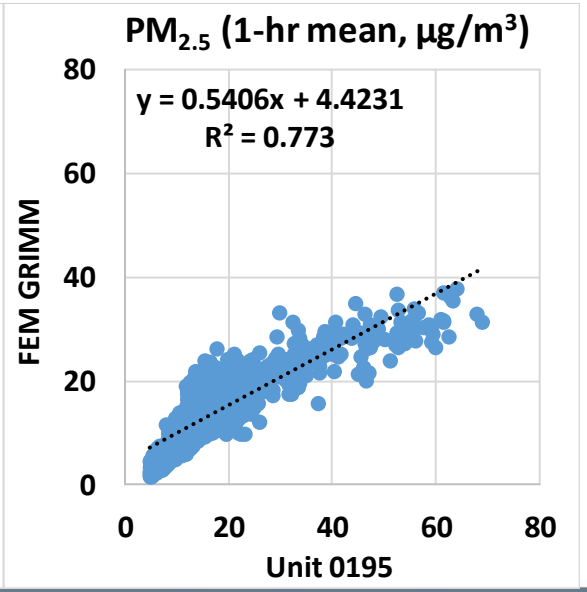
Aeroqual AQY-R vs FEM GRIMM ($PM_{2.5}$; 1-hr mean)



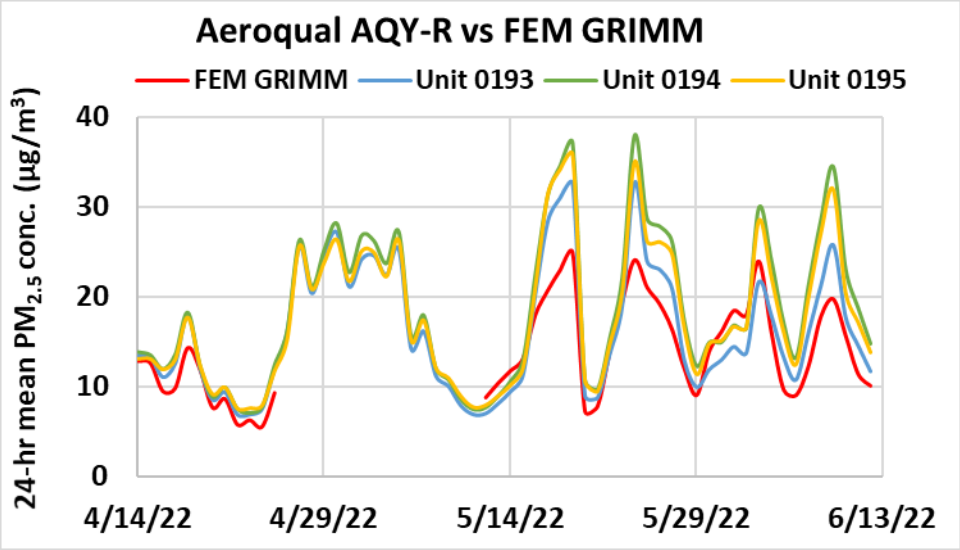
- The Aeroqual AQY-R sensors showed moderate to strong correlations with the corresponding FEM GRIMM data ($0.66 < R^2 < 0.78$)
- Overall, the Aeroqual AQY-R sensors overestimated the $PM_{2.5}$ mass concentrations as measured by FEM GRIMM
- The Aeroqual AQY-R sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM GRIMM



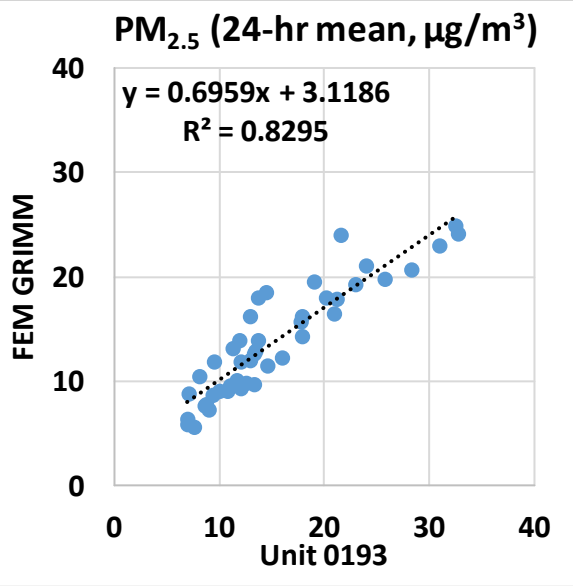


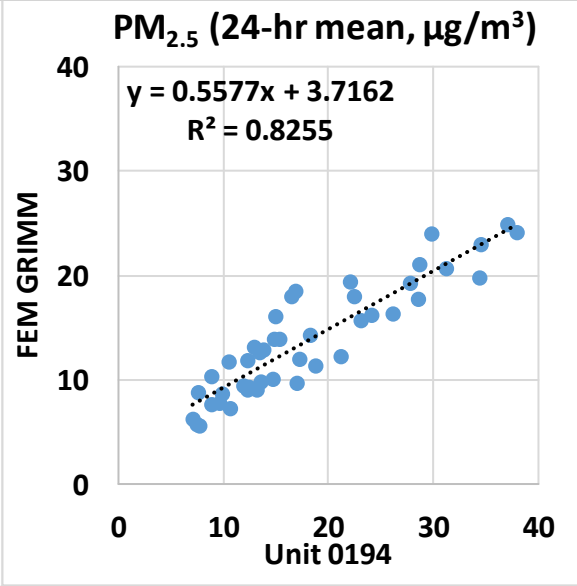


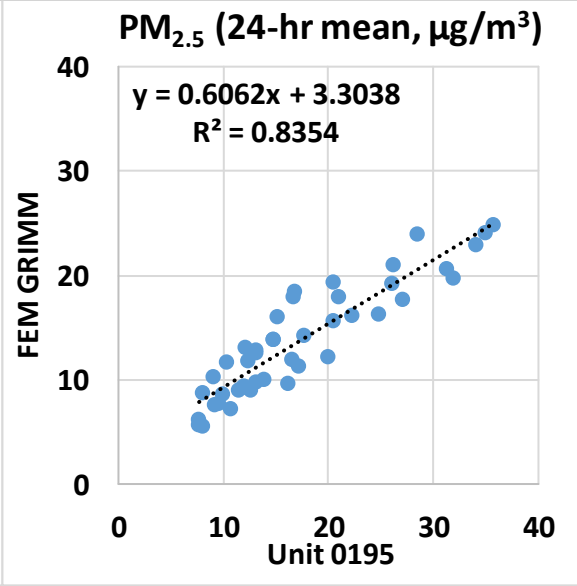
Aeroqual AQY-R vs FEM GRIMM ($PM_{2.5}$; 24-hr mean)



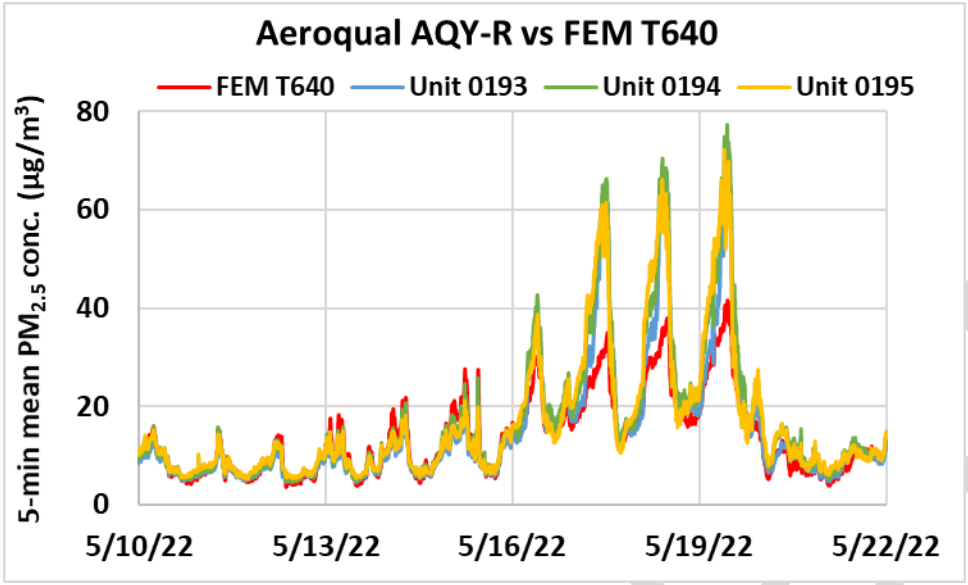
- The Aeroqual AQY-R sensors showed strong correlations with the corresponding FEM GRIMM data ($0.82 < R^2 < 0.84$)
- Overall, the Aeroqual AQY-R sensors overestimated the $PM_{2.5}$ mass concentrations as measured by FEM GRIMM
- The Aeroqual AQY-R sensors seemed to track the $PM_{2.5}$ daily variations as recorded by FEM GRIMM



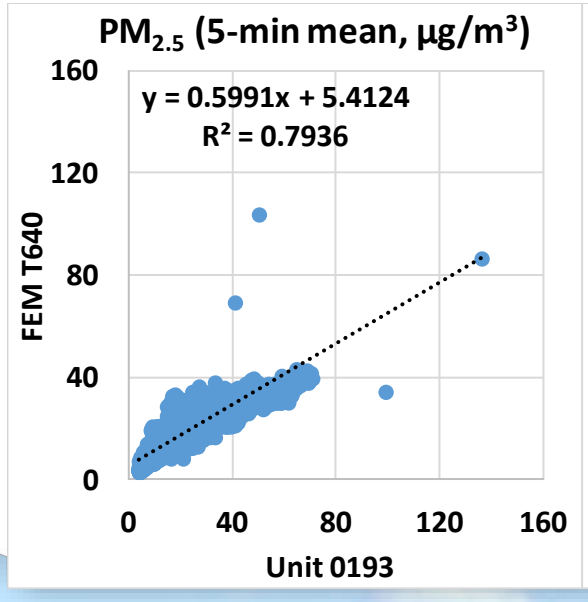


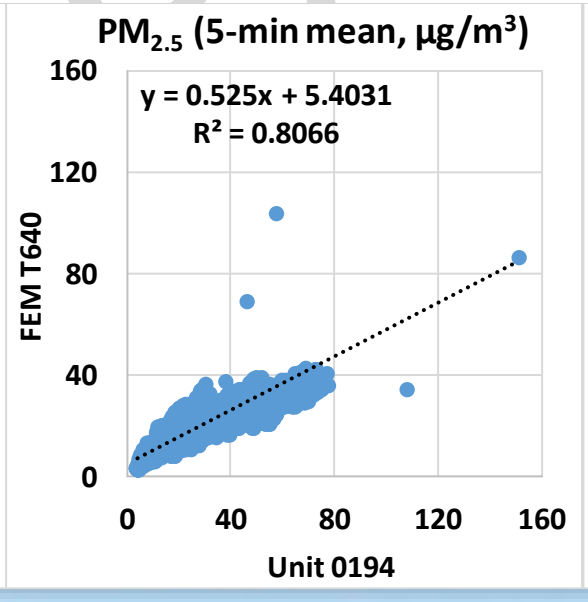


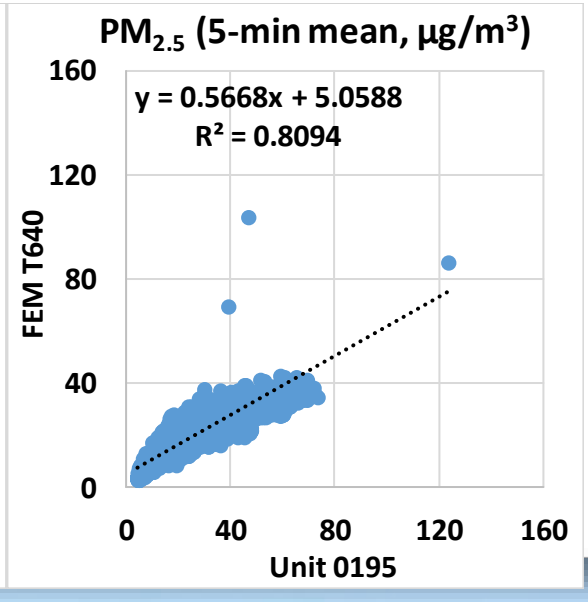
Aeroqual AQY-R vs FEM T640 ($PM_{2.5}$; 5-min mean)



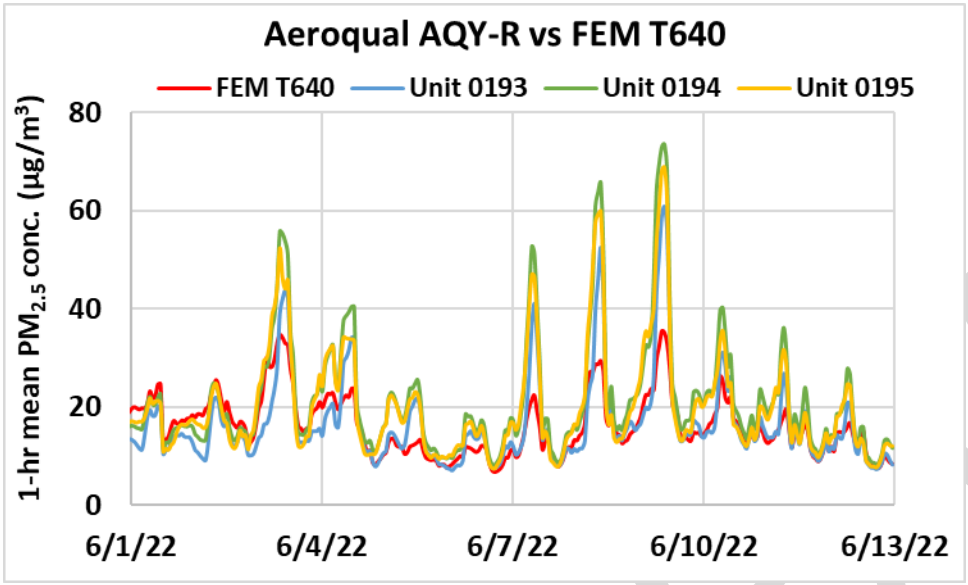
- The Aeroqual AQY-R sensors showed strong correlations with the corresponding FEM T640 data ($0.79 < R^2 < 0.81$)
- Overall, the Aeroqual AQY-R sensors overestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The Aeroqual AQY-R sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



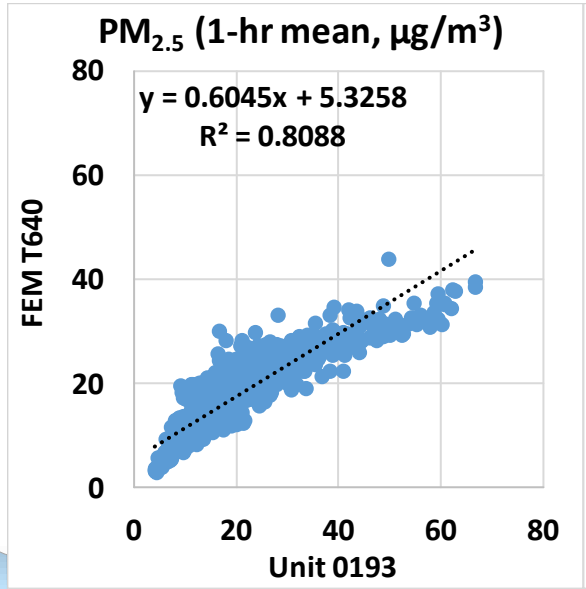


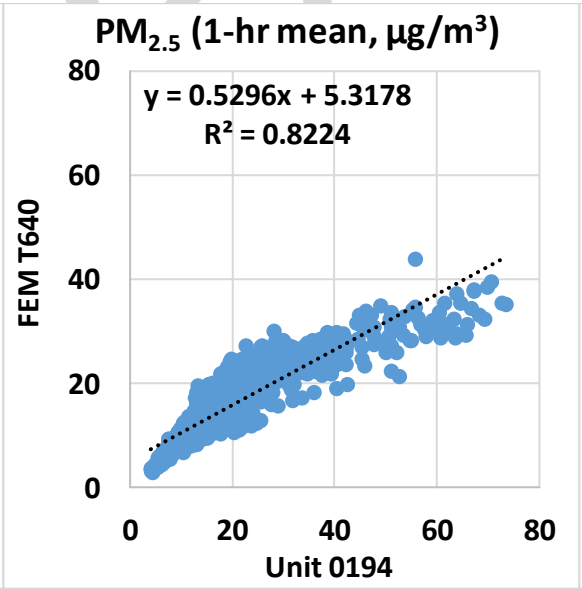


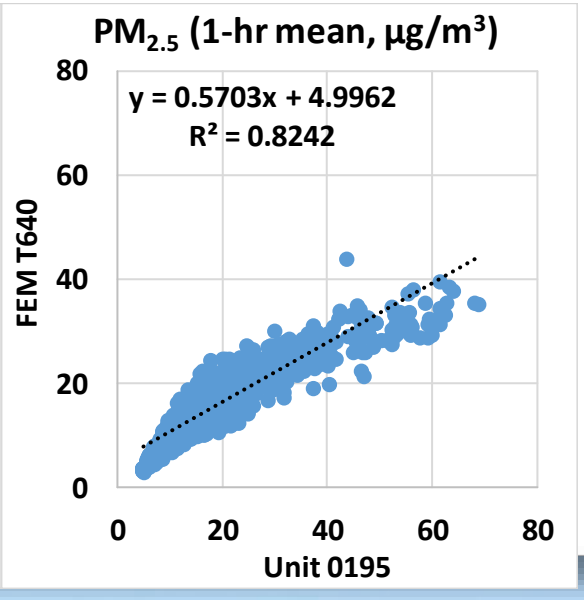
Aeroqual AQY-R vs FEM T640 ($PM_{2.5}$; 1-hr mean)



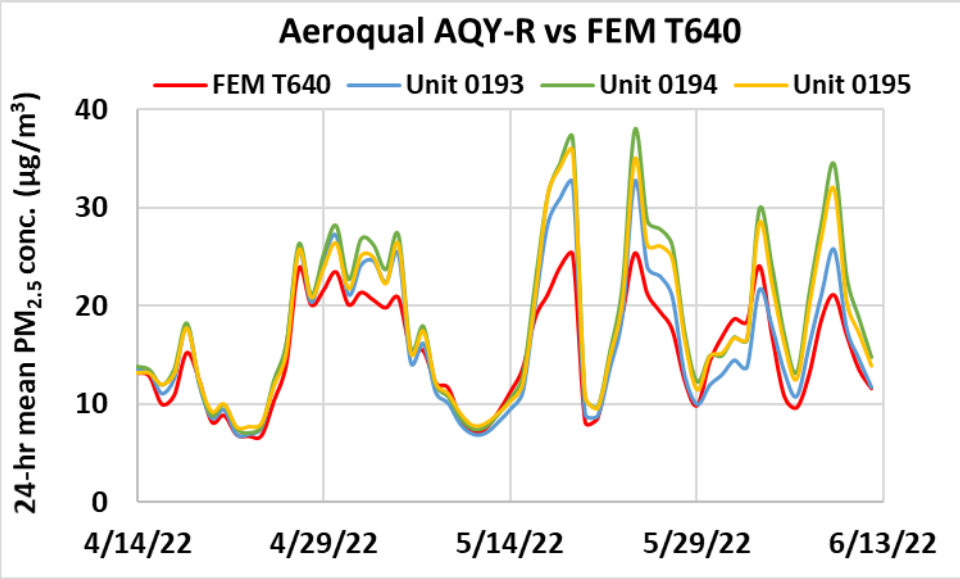
- The Aeroqual AQY-R sensors showed strong correlations with the corresponding FEM T640 data ($0.80 < R^2 < 0.83$)
- Overall, the Aeroqual AQY-R sensors overestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The Aeroqual AQY-R sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



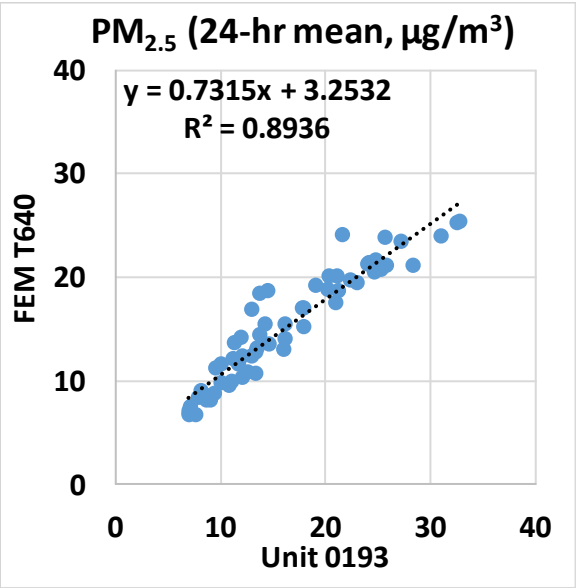


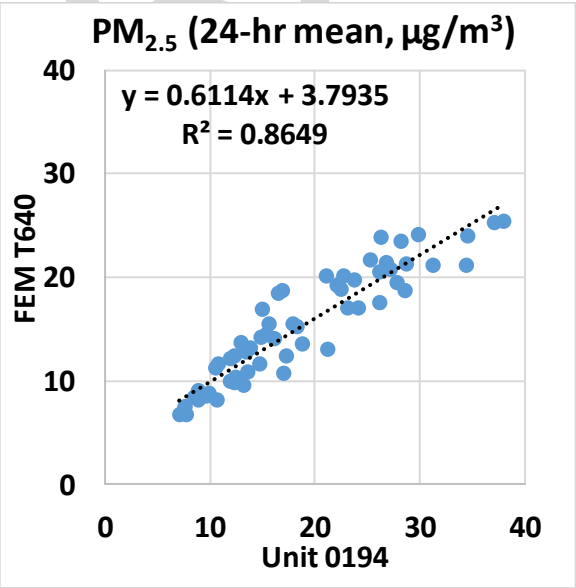


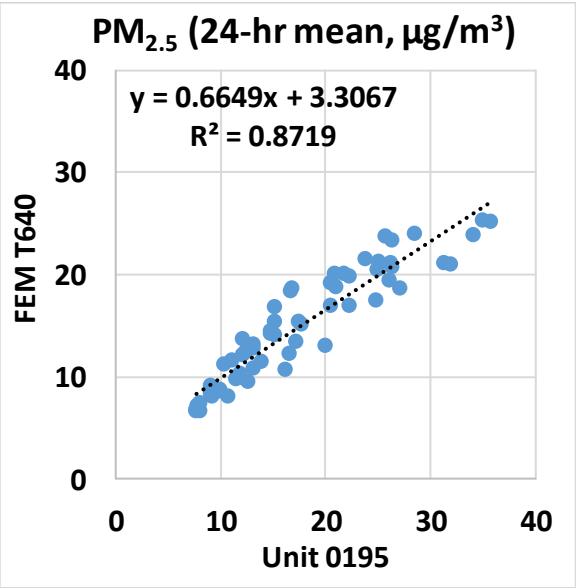
Aeroqual AQY-R vs FEM T640 ($PM_{2.5}$; 24-hr mean)



- The Aeroqual AQY-R sensors showed strong correlations with the corresponding FEM T640 data ($0.86 < R^2 < 0.90$)
- Overall, the Aeroqual AQY-R sensors overestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The Aeroqual AQY-R sensors seemed to track the $PM_{2.5}$ daily variations as recorded by FEM T640





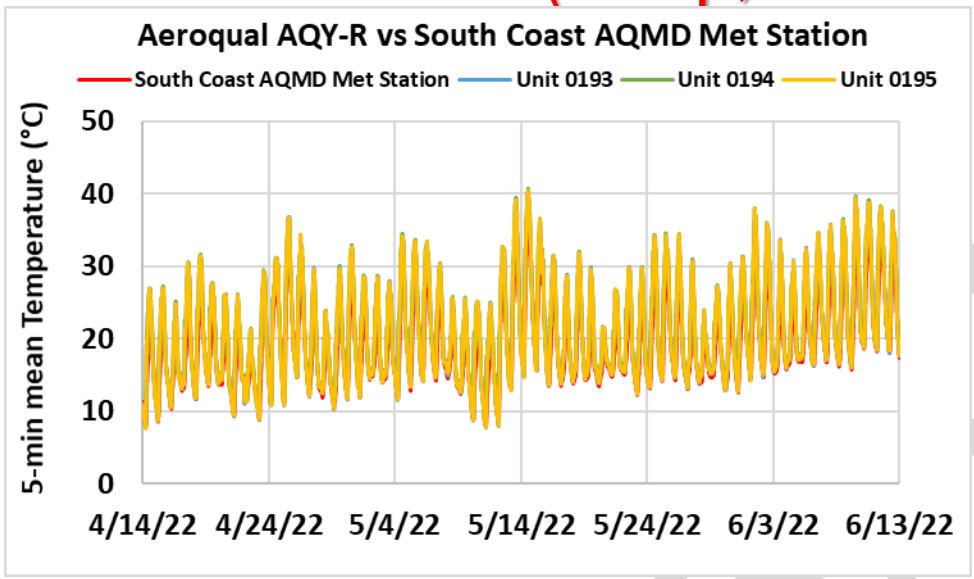


Summary: PM

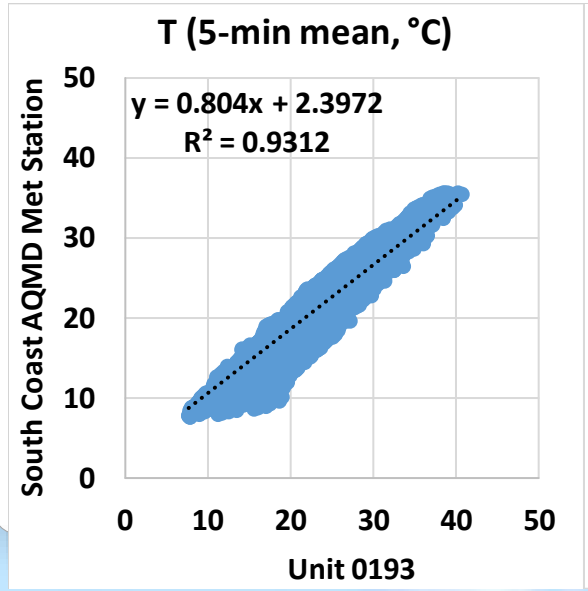
	Average of 3 Sensors, $PM_{2.5}$		Aeroqual AQY-R vs FEM GRIMM & FEM T640, $PM_{2.5}$						FEM GRIMM & FEM T640 ($PM_{2.5}$, $\mu g/m^3$)		
	Average ($\mu g/m^3$)	SD ($\mu g/m^3$)	R^2	Slope	Intercept	MBE[1] ($\mu g/m^3$)	MAE[2] ($\mu g/m^3$)	RMSE[3] ($\mu g/m^3$)	Ref. Average	Ref. SD	Range during the field evaluation
5-min	17.6	10.9	0.66 to 0.81	0.49 to 0.60	4.5 to 5.4	1.1 to 4.3	2.9 to 5.1	5.2 to 8.5	13.8 to 15.2	6.9 to 7.1	1.2 to 103.6
1-hr	17.6	10.8	0.67 to 0.82	0.49 to 0.60	4.4 to 5.3	1.1 to 4.3	2.9 to 5.0	5.1 to 8.3	13.7 to 15.2	6.8 to 6.9	1.5 to 43.8
24-hr	17.6	7.6	0.83 to 0.89	0.56 to 0.73	3.1 to 3.8	1.1 to 4.3	2.1 to 4.7	2.8 to 6.2	13.9 to 15.2	5.3 to 5.4	5.6 to 25.4

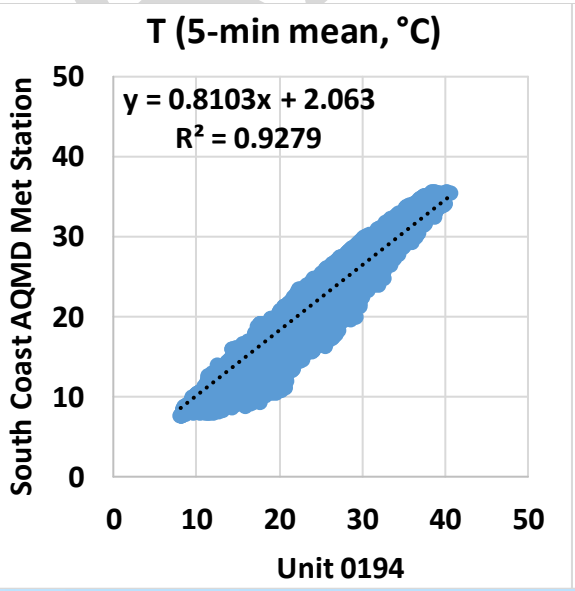
[1] Mean Bias Error (MBE): the difference between the sensors and the reference instruments. MBE indicates the tendency of the sensors to underestimate (negative MBE values) or overestimate (positive MBE values).
[2] Mean Absolute Error (MAE): the absolute difference between the sensors and the reference 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.

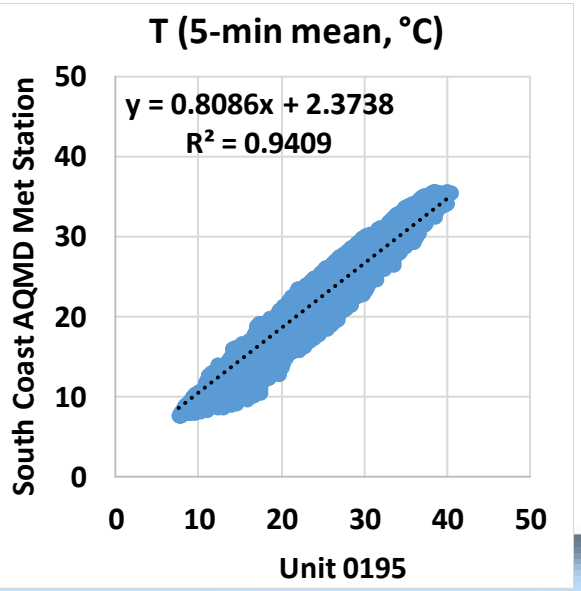
Aeroqual AQY-R vs South Coast AQMD Met Station (Temp; 5-min mean)



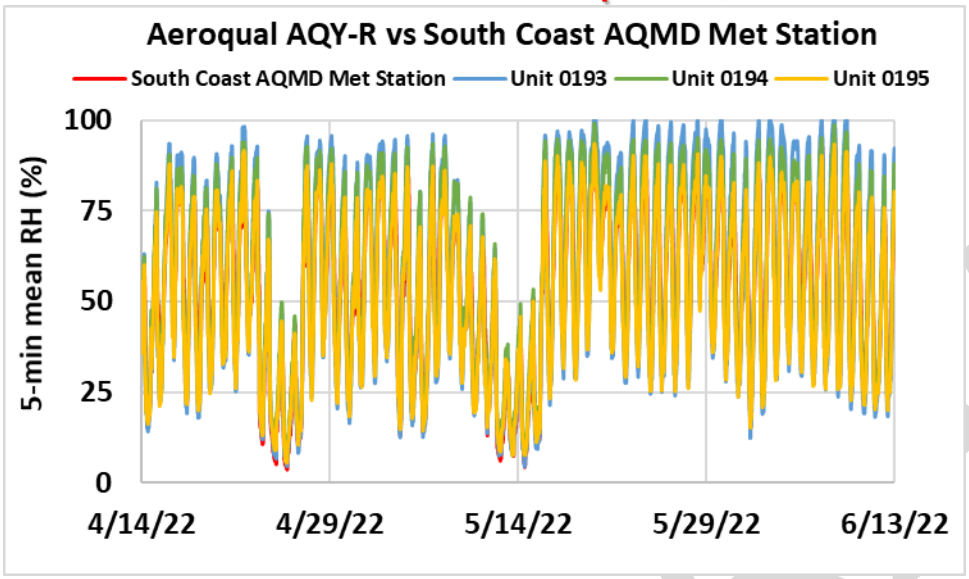
- The Aeroqual AQY-R sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($0.92 < R^2 < 0.95$)
- Overall, the Aeroqual AQY-R sensors overestimated the temperature measurement as recorded by South Coast AQMD Met Station
- The Aeroqual AQY-R sensors seemed to track the diurnal temperature variations as recorded by South Coast AQMD Met Station



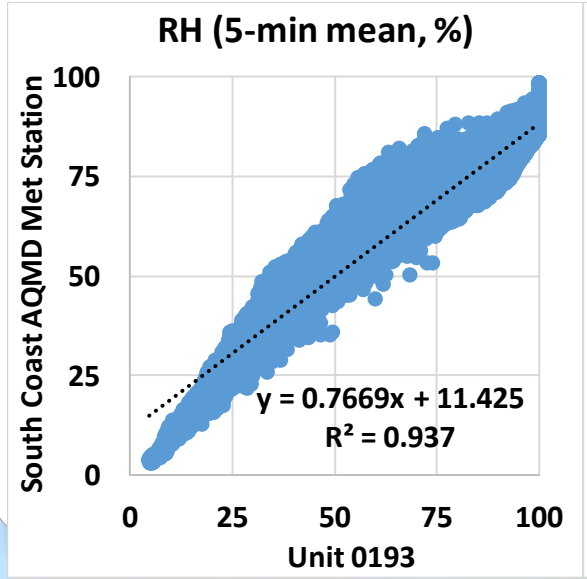


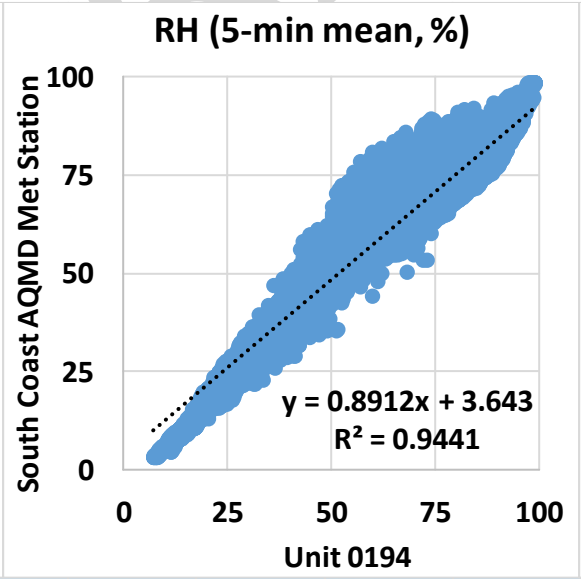


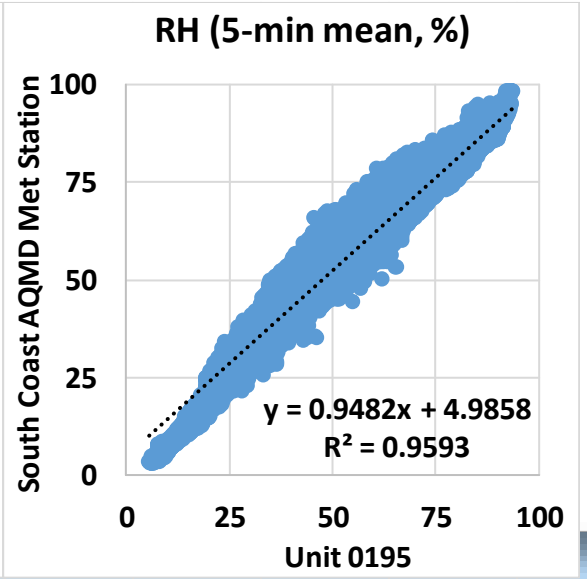
Aeroqual AQY-R vs South Coast AQMD Met Station (RH; 5-min mean)



- Aeroqual AQY-R sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($0.93 < R^2 < 0.96$)
- Overall, the Aeroqual AQY-R sensors overestimated the RH measurement as recorded by South Coast AQMD Met Station
- The Aeroqual AQY-R sensors seemed to track the diurnal RH variations as recorded by South Coast AQMD Met Station







Discussion

- The three **Aeroqual AQY-R** sensors' data recovery for O_3 and NO_2 was ~94% and ~95.5%, respectively; and for $PM_{2.5}$ measurements was 100%.
- The absolute intra-model variability for O_3 and NO_2 was ~1.8 ppb and ~0.17 ppb, respectively. Absolute intra-model variability for $PM_{2.5}$ measurements was ~0.96 µg/m^3.
- Reference instruments: very strong correlations between FEM GRIMM and FEM T640 for $PM_{2.5}$ (R^2 ~0.92, 1-hr mean) mass concentration measurements
- During the entire field deployment testing period:
  - Ozone sensors showed very strong correlations with the FEM T400 instrument ($0.94 < R^2 < 0.98$, 5-min mean) and generally overestimated the corresponding FEM T400 data
  - NO_2 sensors showed strong correlations with the FRM T200 instrument ($0.82 < R^2 < 0.87$, 5-min mean) and overestimated the corresponding FRM T200 data
  - The Aeroqual AQY-R sensors showed moderate to strong correlations with the corresponding reference $PM_{2.5}$ data ($0.66 < R^2 < 0.83$, 1-hr mean). The sensors overestimated $PM_{2.5}$ mass concentrations as measured by FEM GRIMM and FEM T640
  - Temperature and relative humidity sensors showed very strong correlations with the South Coast AQMD Met Station T and RH data (R^2 ~0.93 for T and R^2 ~0.95 for RH) and overestimated the T and RH data as recorded by the South Coast AQMD Met Station
- No sensor calibration was performed by South Coast AQMD staff for this evaluation.
- A MOMA calibration for O_3, NO_2 and $PM_{2.5}$ was performed prior to the beginning of this evaluation.
- Laboratory chamber testing is necessary to fully evaluate the performance of these sensors under controlled T and RH conditions, and known target and interferent pollutants concentrations.
- These results are still preliminary