Field Evaluation
Vaisala Air Quality Transmitter AQT530

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

- From 1/14/2022 to 3/25/2022, three **Vaisala Air Quality Transmitter AQT530 (hereinafter Vaisala AQT530)** 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. A software malfunction occurred from 2/7/2022 to 2/17/2022 in which the data cloud platform did not collect transmitted sensor data, so the field evaluation was extended by 10 days beyond the typical 8-week test period.

- Vaisala AQT530 (*3 units tested*):
  - Gas Sensors: Electrochemical; non-FEM
  - Each unit measures: O_3 (ppb), NO (ppb), NO_2 (ppb), CO (ppb), T (°C), RH (%)
  - Unit cost: $3,500 as-tested (Price ranges from $3,500-$6,500 depending on sensor configuration and addition of PM sensor)
  - Time resolution: 1-min
  - Units IDs: 673, 885, and 847

- South Coast AQMD Reference instruments:
  - O_3 instrument (Teledyne T400, hereinafter FEM T400); cost: ~$7,000
    - Time resolution; 1-min
  - CO instrument (Horiba APMA 370, hereinafter FRM Horiba); cost: ~$10,000
    - Time resolution; 1-min
  - NO/NO_2 instrument (Teledyne T200, hereinafter FRM T200); cost: ~$11,000
    - Time resolution: 1-min
  - Met station (T, RH, P, WS, WD); cost: ~$5,000
    - Time resolution: 1-min

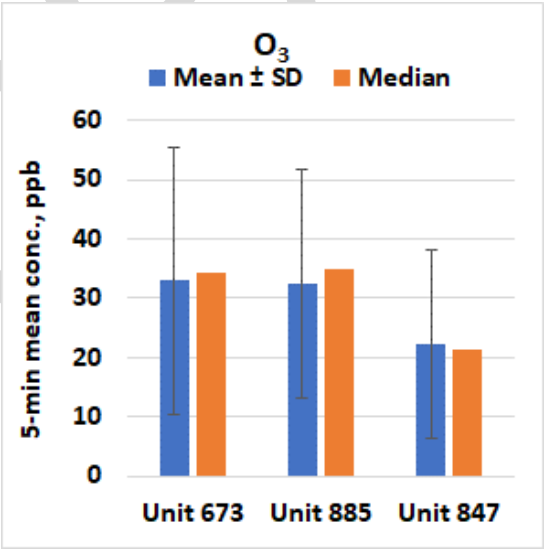
Ozone (O_3) in Vaisala AQT530

Data validation & recovery

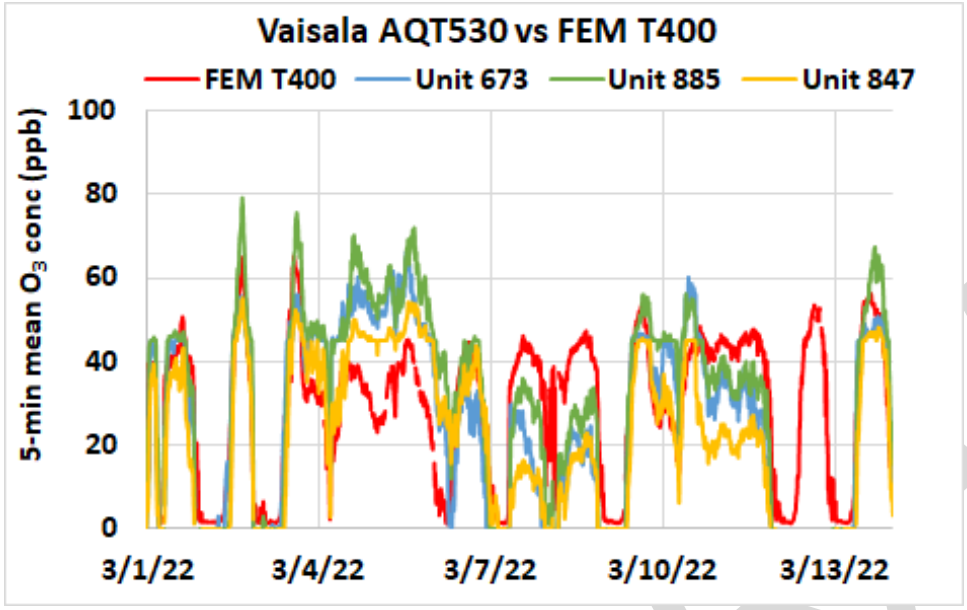
- Basic QA/QC procedures were used to validate the collected data (i.e., obvious outliers, negative values, and invalid data-points were eliminated from the data-set)
- Data recovery for O_3 from Unit 673, Unit 885 and Unit 847 was ~ 86%, 89% and 86% respectively (excluding the software malfunction period)

Vaisala AQT530; Intra-model variability

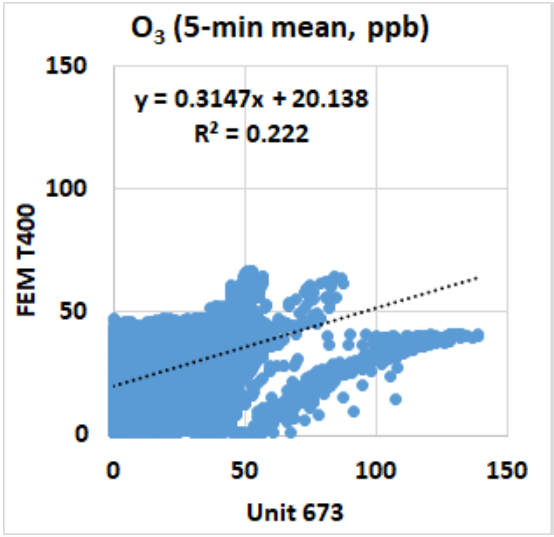
- Absolute intra-model variability was ~ 6.0 ppb for the ozone measurements (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was ~ 20.5% for the ozone measurements (calculated as the absolute intra-model variability relative to the mean of the three sensor means)

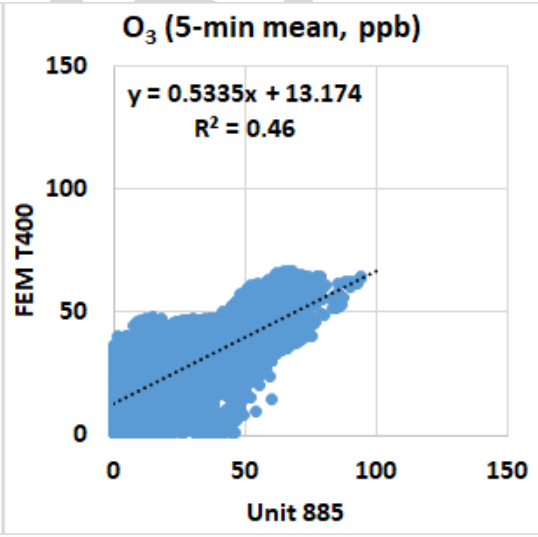


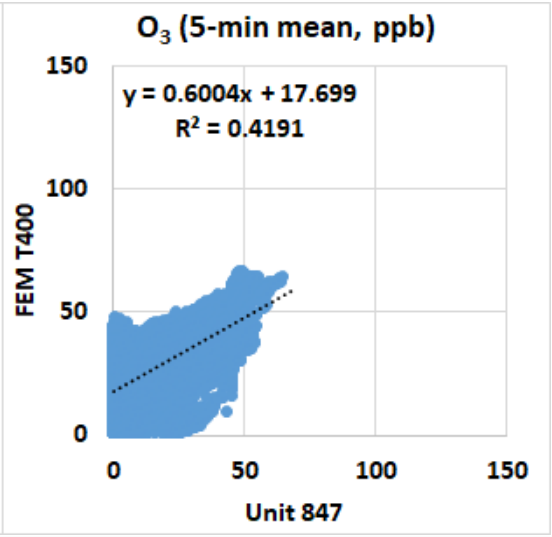
Vaisala AQT530 vs FEM T400 (Ozone; 5-min mean)



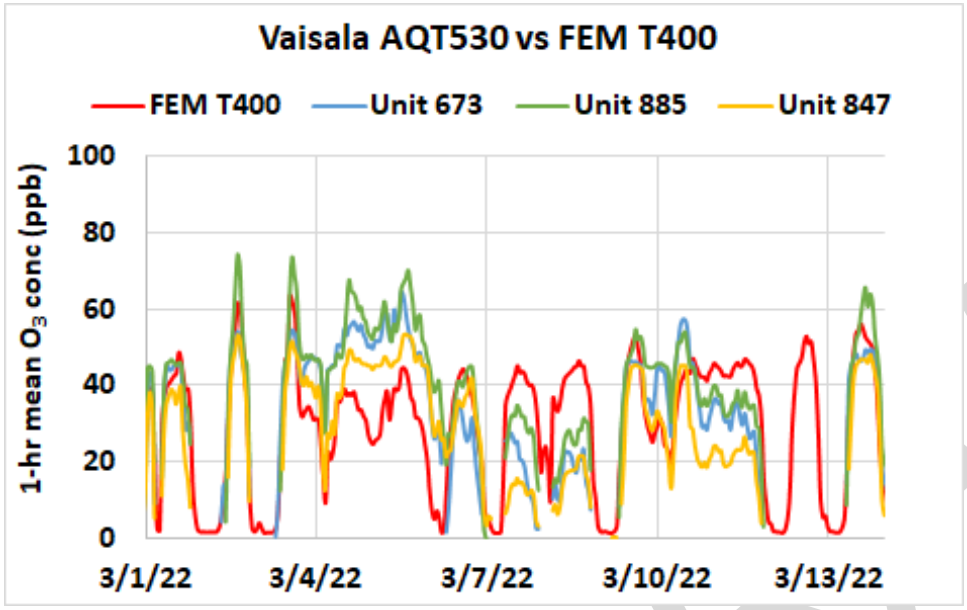
- Vaisala AQT530 sensors showed very weak to weak correlation with the corresponding FEM T400 ozone data ($0.22 < R^2 < 0.47$)
- Overall, Units 673 and 885 overestimated, while Unit 847 underestimated the ozone concentration as measured by the FEM T400 ozone instrument
- The Vaisala AQT530 sensors sometimes seemed to track the diurnal ozone variations as recorded by the FEM T400 instrument



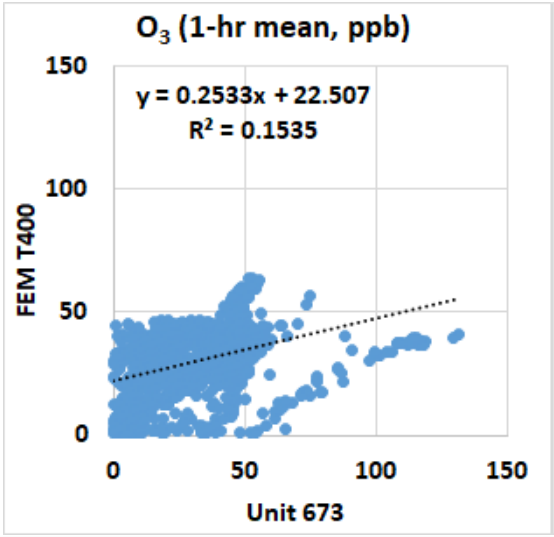


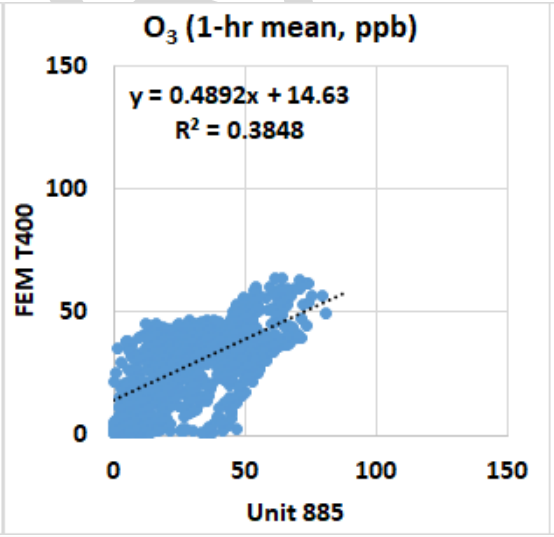


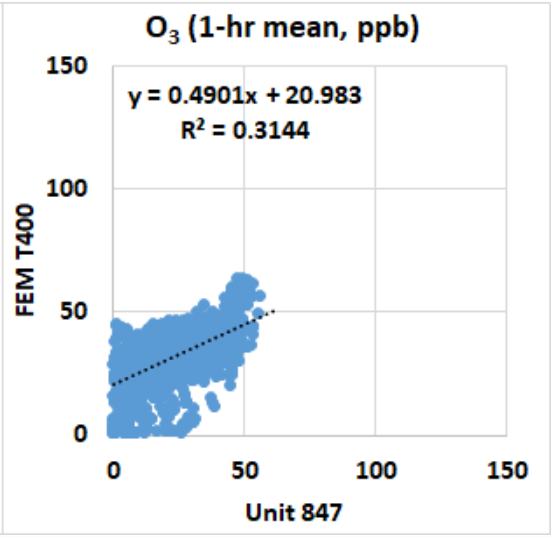
Vaisala AQT530 vs FEM T400 (Ozone; 1-hr mean)



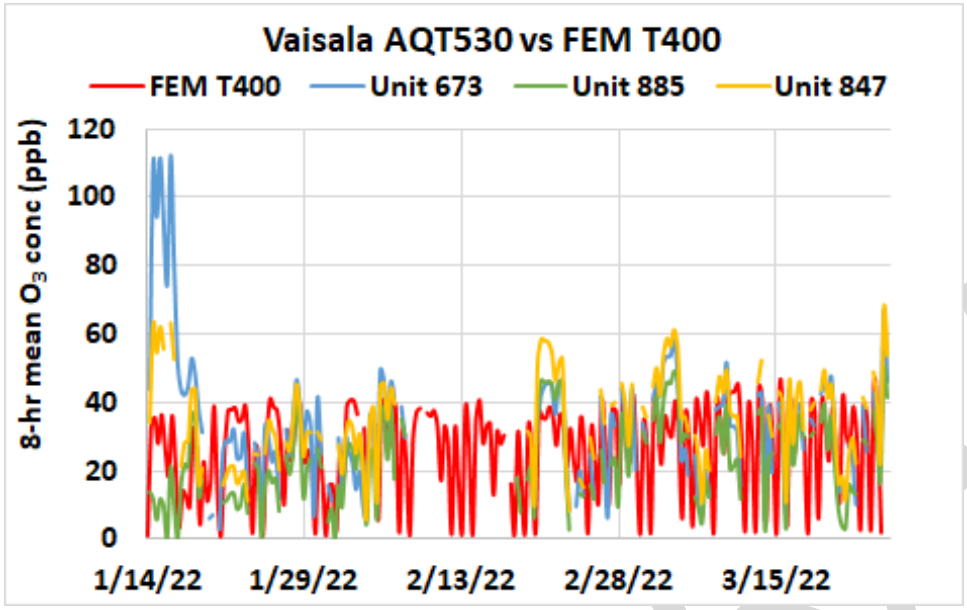
- Vaisala AQT530 sensors showed very weak to weak correlation with the corresponding FEM T400 ozone data ($0.15 < R^2 < 0.39$)
- Overall, Units 673 and 885 overestimated, while Unit 847 underestimated the ozone concentration as measured by the FEM T400 ozone instrument
- The Vaisala AQT530 sensors sometimes seemed to track the diurnal ozone variations as recorded by the FEM T400 instrument



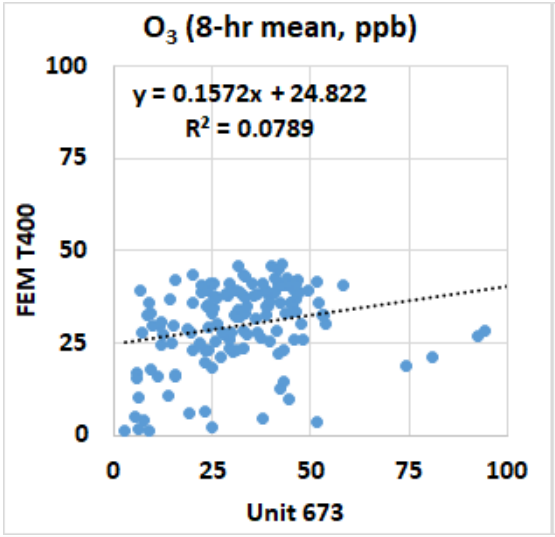


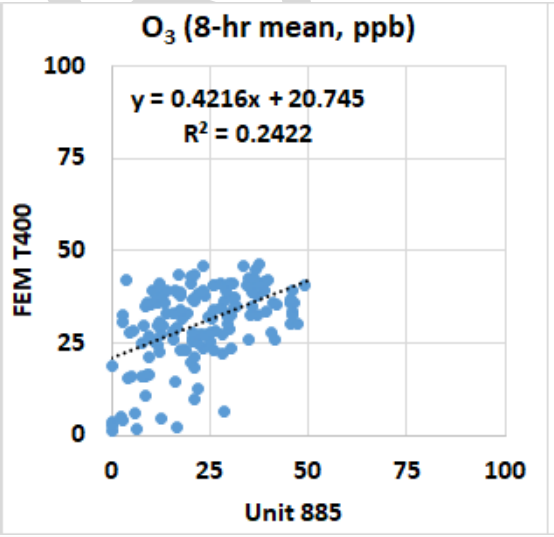


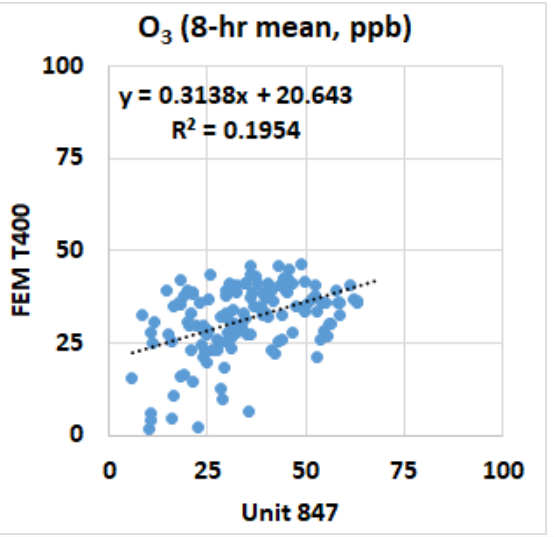
Vaisala AQT530 vs FEM T400 (Ozone; 8-hr mean)



- Vaisala AQT530 sensors showed no to very weak correlation with the corresponding FEM T400 ozone data ($0.07 < R^2 < 0.25$)
- Overall, Units 673 and 847 overestimated, while Unit 885 underestimated the ozone concentration as measured by the FEM T400 ozone instrument
- The Vaisala AQT530 sensors sometimes seemed to track the diurnal ozone variations as recorded by the FEM T400 instrument







Summary: Ozone

	Average of 3 Sensors, Ozone		Vaisala AQT530 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	29.2	20.1	0.22 to 0.46	0.31 to 0.60	13.2 to 20.1	-8.7 to 2.6	11.2 to 13.8	14.3 to 20.6	27.3	16.6	0.7 to 66.8
1-hr	31.4	18.9	0.15 to 0.38	0.25 to 0.49	14.6 to 22.5	-8.5 to 3.4	11.4 to 14.2	14.4 to 21.0	26.4	16.5	1.0 to 64.1
8-hr	30.4	16.5	0.08 to 0.24	0.16 to 0.42	20.6 to 24.8	-7.6 to 3.6	10.2 to 12.9	13.1 to 19.7	26.5	13.3	1.3 to 46.4

[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.

Nitric Oxide (NO) in Vaisala AQT530

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 from Unit 673, Unit 885 and Unit 847 was ~ 94%, 98% and 98% respectively (excluding the software malfunction period)

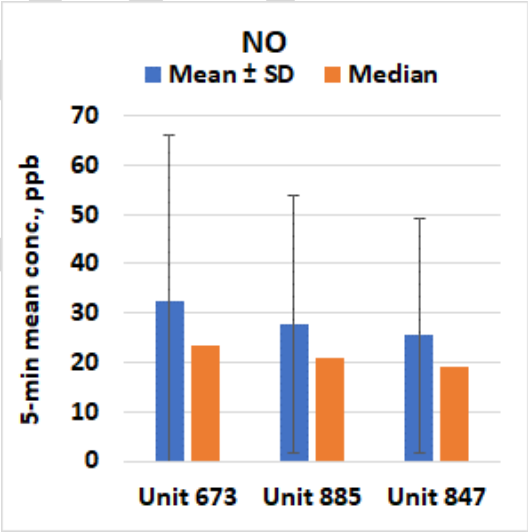
Vaisala AQT530; Intra-model variability

- Absolute intra-model variability was ~ 3.6 ppb for the NO measurements

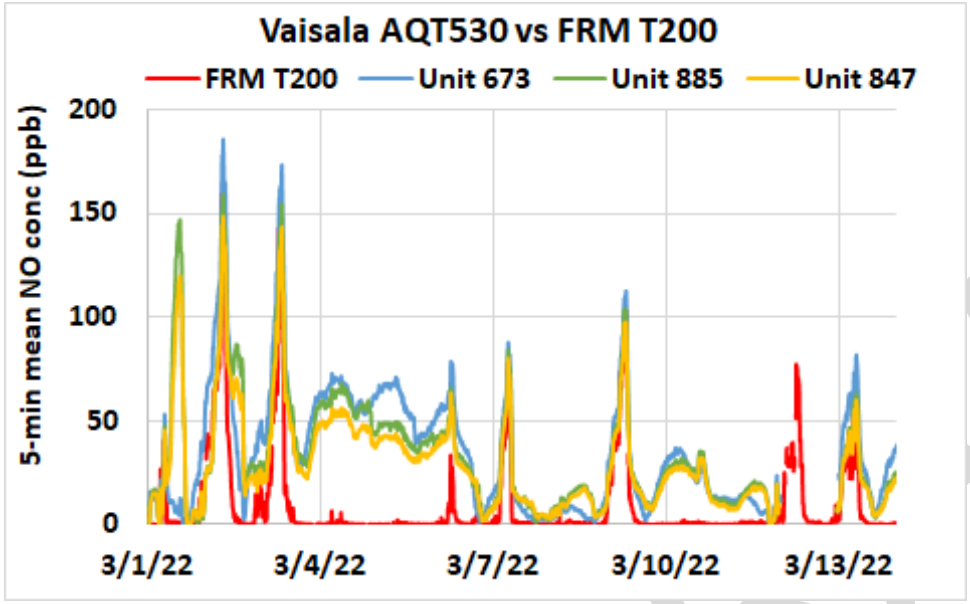
(calculated as the standard deviation of the three sensor means)

- Relative intra-model variability was ~ 12.6% for the NO measurements

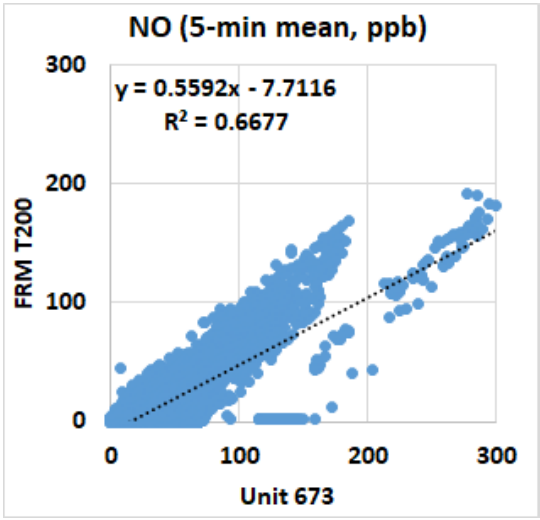
(calculated as the absolute intra-model variability relative to the mean of the three sensor means)

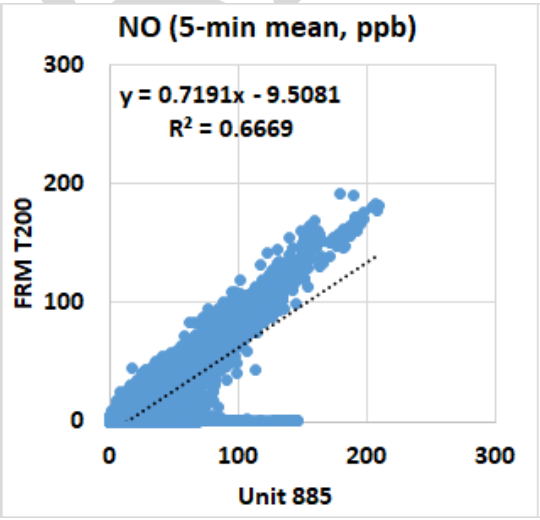


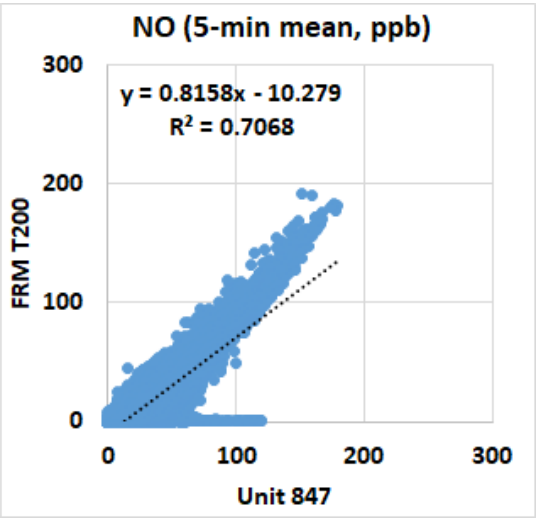
Vaisala AQT530 vs FRM T200 (NO; 5-min mean)



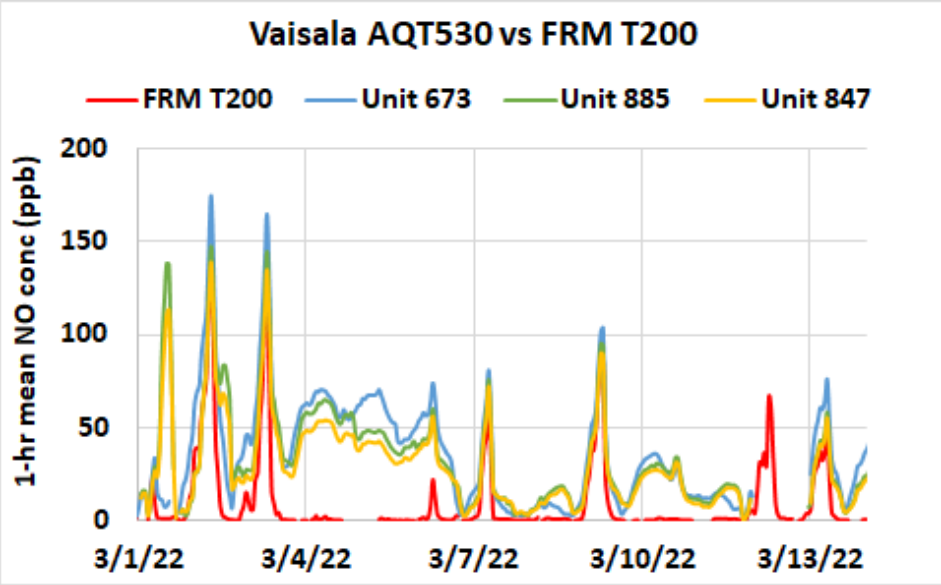
- Vaisala AQT530 sensors showed moderate to strong correlations with the corresponding FRM T200 NO data ($0.66 < R^2 < 0.71$)
- Overall, the Vaisala AQT530 sensors overestimated the NO concentration as measured by the FRM T200 instrument
- The Vaisala AQT530 sensors sometimes seemed to track the diurnal NO variations as recorded by the FRM T200 instrument



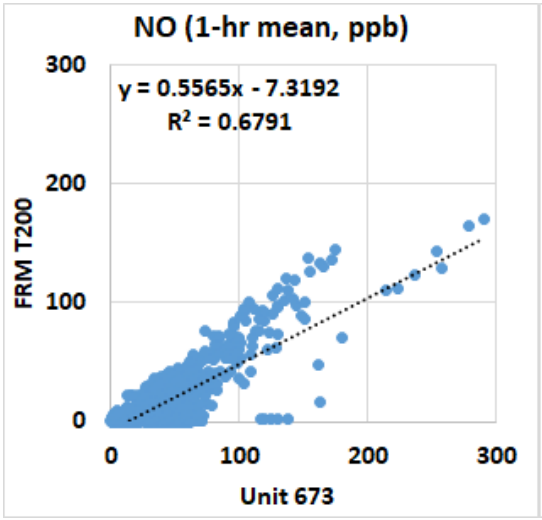


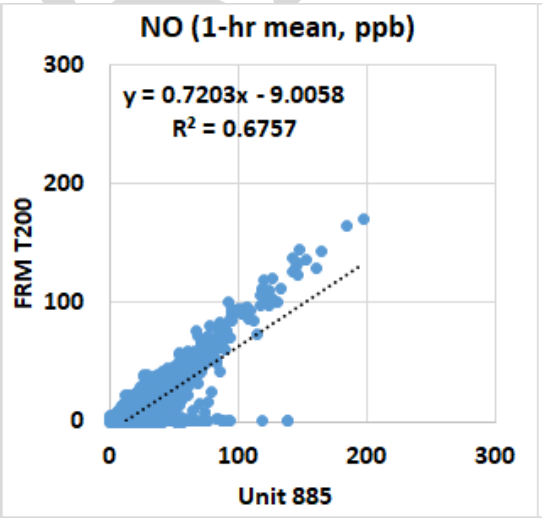


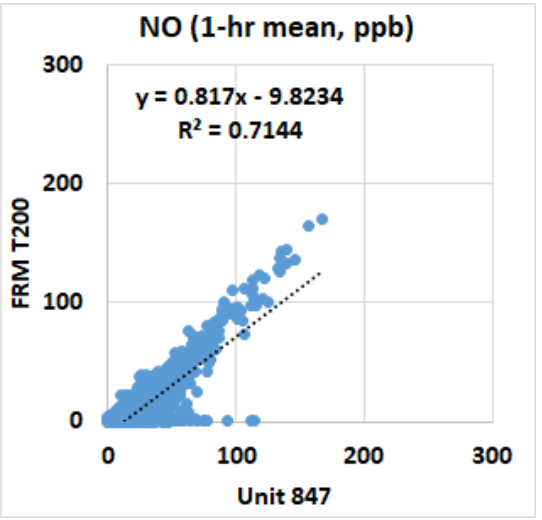
Vaisala AQT530 vs FRM T200 (NO; 1-hr mean)



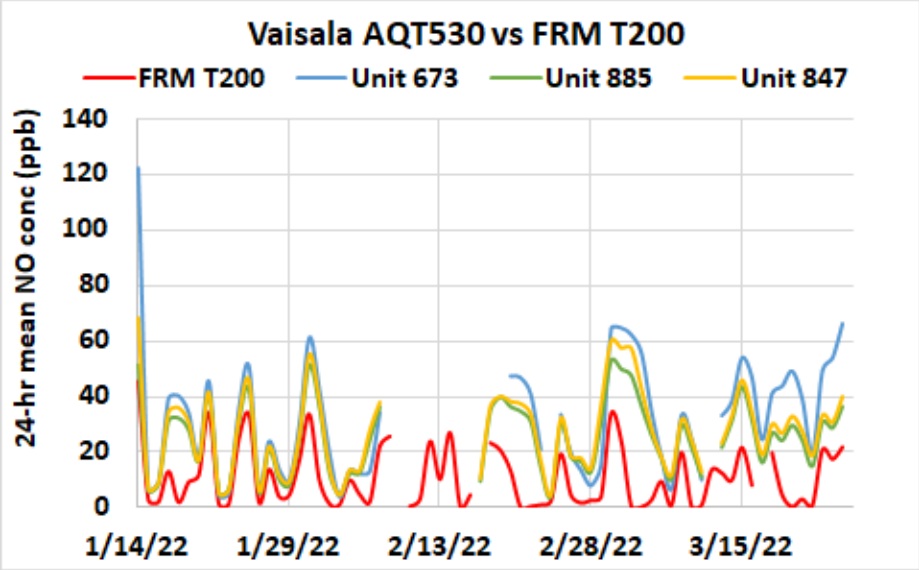
- Vaisala AQT530 sensors showed moderate to strong correlations with the corresponding FRM T200 NO data ($0.67 < R^2 < 0.72$)
- Overall, the Vaisala AQT530 sensors overestimated the NO concentration as measured by the FRM T200 instrument
- The Vaisala AQT530 sensors sometimes seemed to track the diurnal NO variations as recorded by the FRM T200 instrument



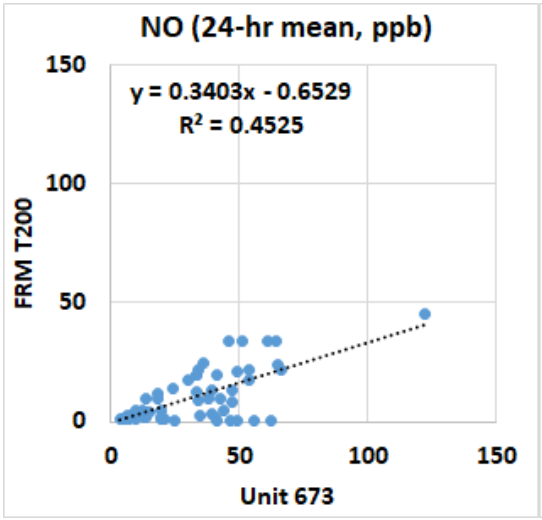


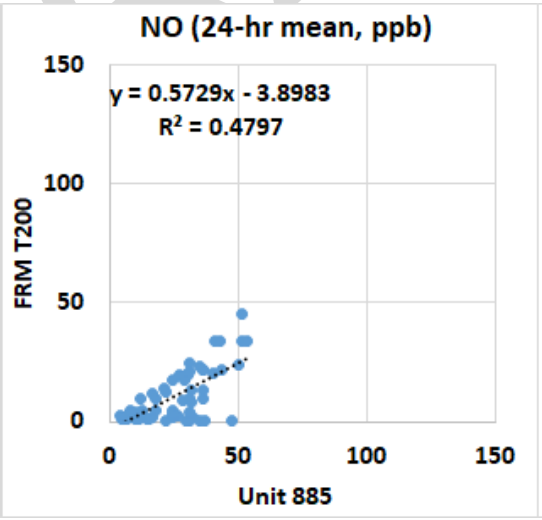


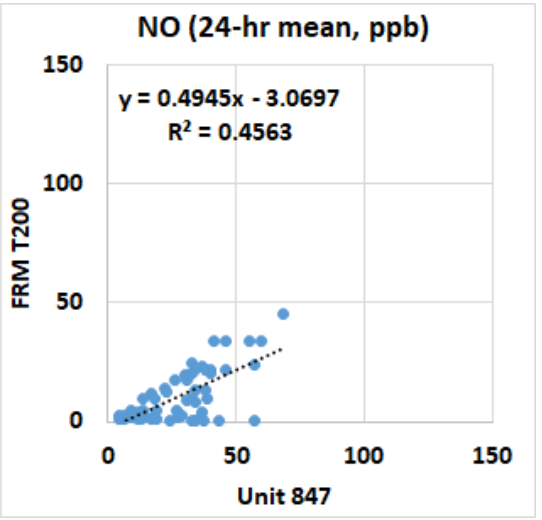
Vaisala AQT530 vs FRM T200 (NO; 24-hr mean)



- Vaisala AQT530 sensors showed weak correlations with the corresponding FRM T200 NO data ($0.45 < R^2 < 0.48$)
- Overall, the Vaisala AQT530 sensors overestimated the NO concentration as measured by the FRM T200 instrument
- The Vaisala AQT530 sensors sometimes seemed to track the diurnal NO variations as recorded by the FRM T200 instrument







Summary: NO

	Average of 3 Sensors, NO		Vaisala AQT530 vs FRM T200, NO						FRM T200, NO (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	28.5	28.3	0.67 to 0.71	0.56 to 0.82	-10.3 to -7.7	15.1 to 22.2	15.6 to 22.3	20.4 to 30.2	11.0	23.7	0.0 to 192.4
1-hr	28.6	28.1	0.68 to 0.71	0.56 to 0.82	-9.8 to -7.3	14.6 to 22.0	15.0 to 22.1	19.7 to 29.9	11.5	23.3	0.1 to 169.9
24-hr	28.5	17.2	0.45 to 0.48	0.34 to 0.57	-3.9 to -0.7	14.9 to 22.4	14.9 to 22.4	17.8 to 27.8	11.0	11.0	0.3 to 45.5

[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 Vaisala AQT530

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 673, Unit 885 and Unit 847 was ~ 94%, 98% and 98% respectively (excluding the software malfunction period)

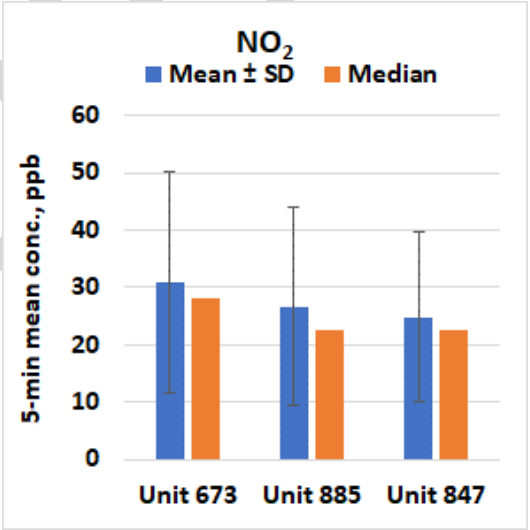
Vaisala AQT530; Intra-model variability

- Absolute intra-model variability was ~ 3.1 ppb for the NO_2 measurements

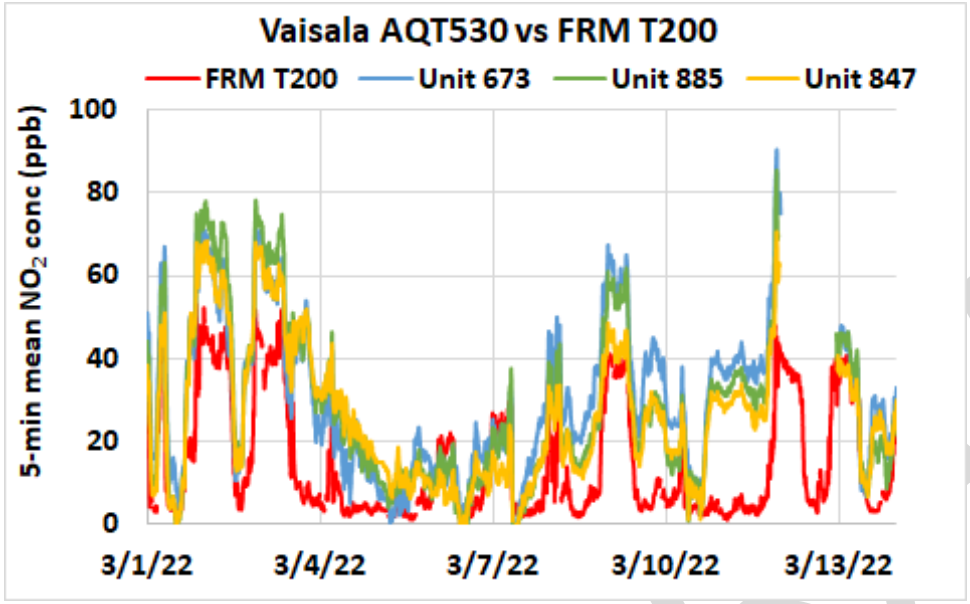
(calculated as the standard deviation of the three sensor means)

- Relative intra-model variability was ~ 11.3% for the NO_2 measurements

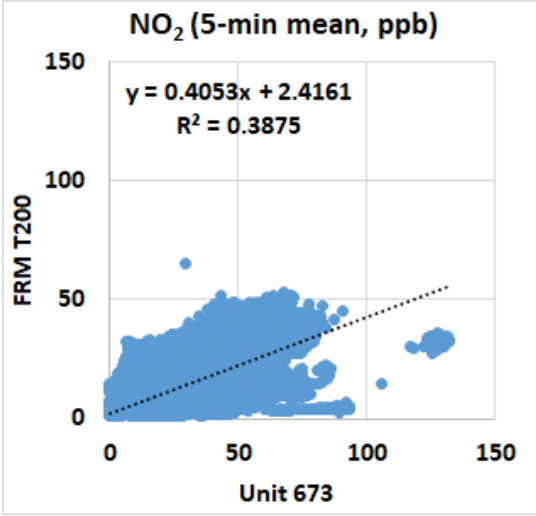
(calculated as the absolute intra-model variability relative to the mean of the three sensor means)

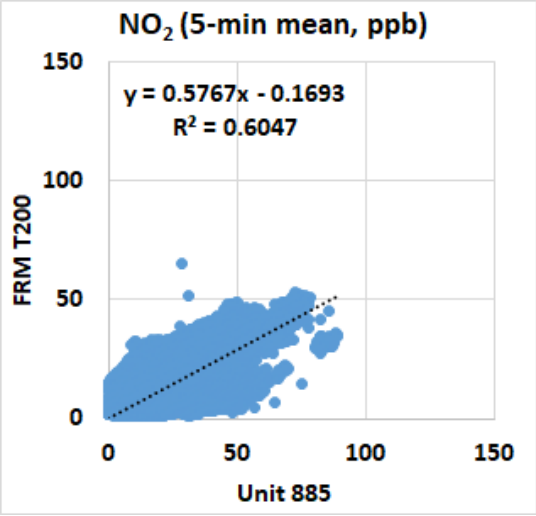


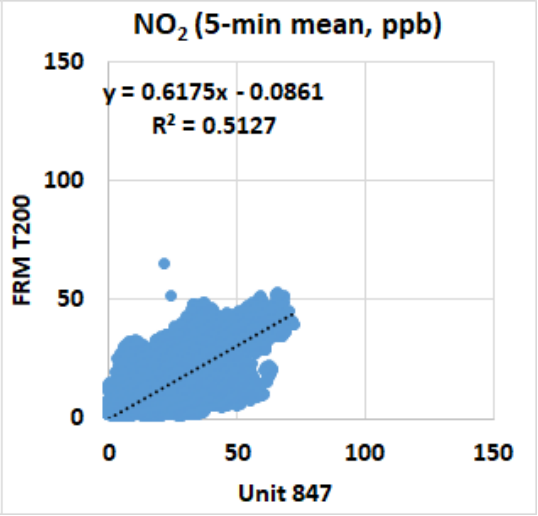
Vaisala AQT530 vs FRM T200 (NO_2; 5-min mean)



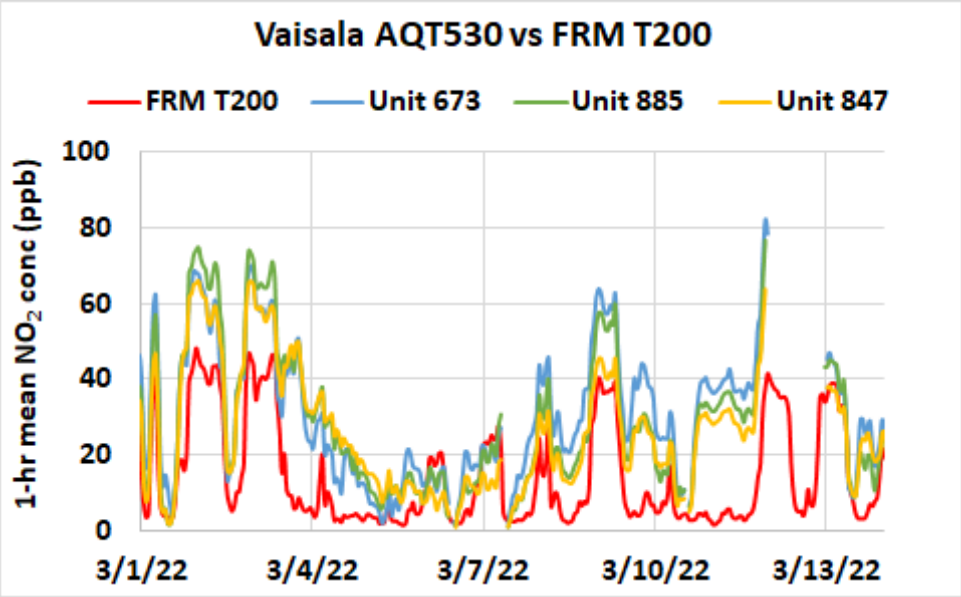
- Vaisala AQT530 sensors showed weak to moderate correlations with the corresponding FRM T200 NO_2 data ($0.38 < R^2 < 0.61$)
- Overall, the Vaisala AQT530 sensors overestimated the NO_2 concentration as measured by the FRM T200 instrument
- The Vaisala AQT530 sensors sometimes seemed to track the diurnal NO_2 variations as recorded by the FRM T200 instrument



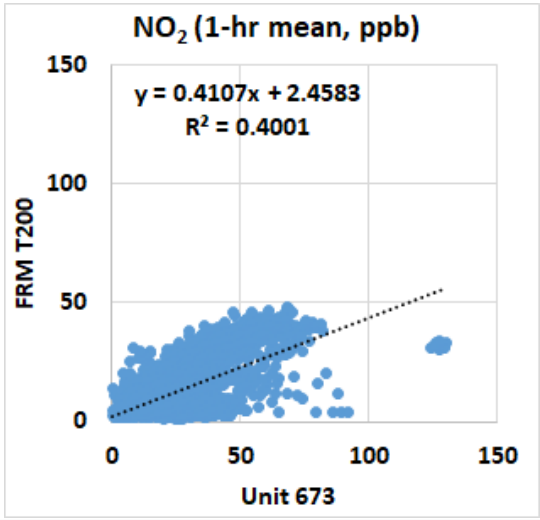


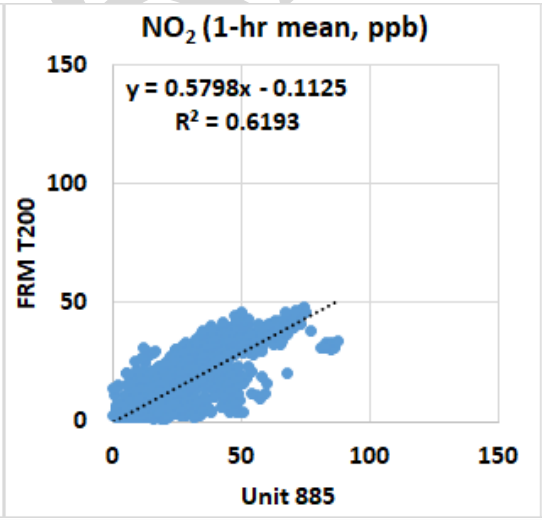


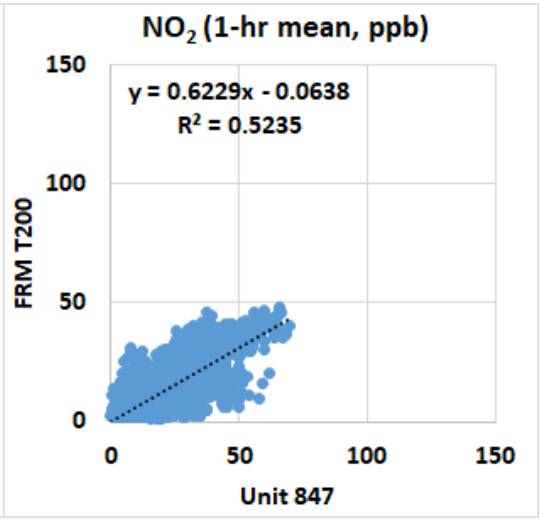
Vaisala AQT530 vs FRM T200 (NO_2; 1-hr mean)



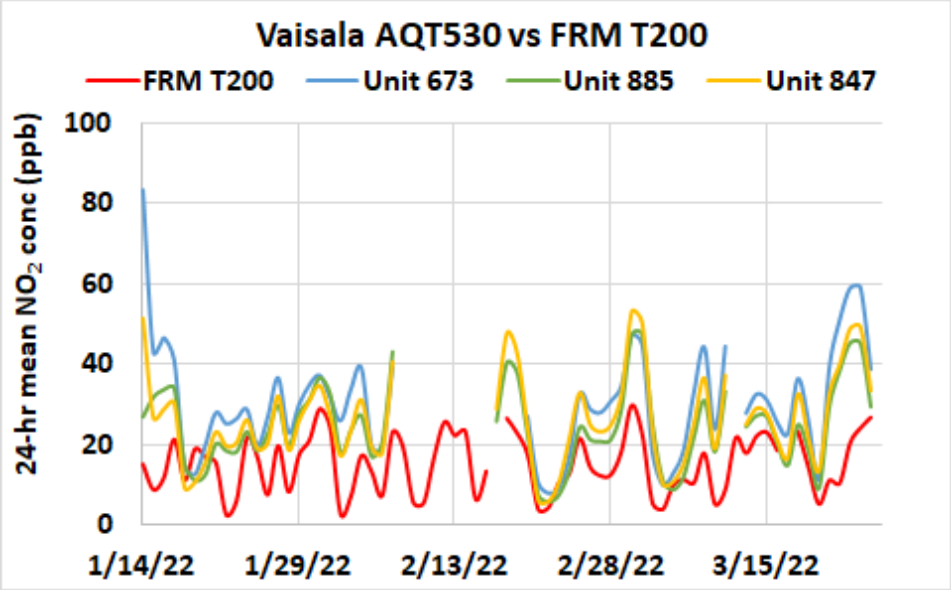
- Vaisala AQT530 sensors showed weak to moderate correlations with the corresponding FRM T200 NO_2 data ($0.40 < R^2 < 0.62$)
- Overall, the Vaisala AQT530 sensors overestimated the NO_2 concentration as measured by the FRM T200 instrument
- The Vaisala AQT530 sensors sometimes seemed to track the diurnal NO_2 variations as recorded by the FRM T200 instrument



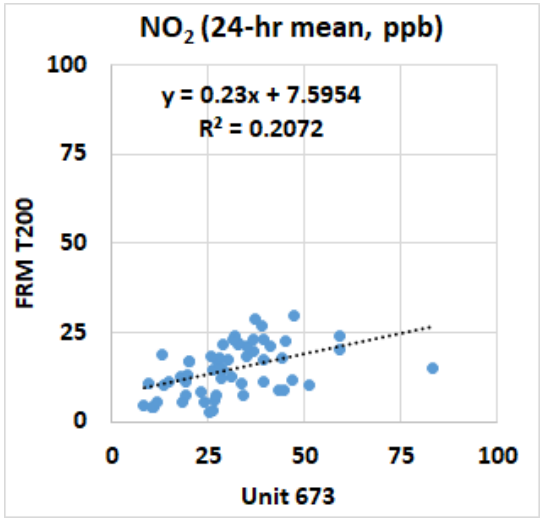


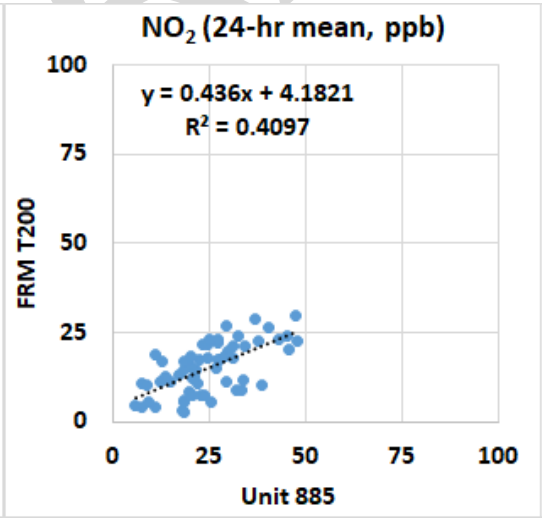


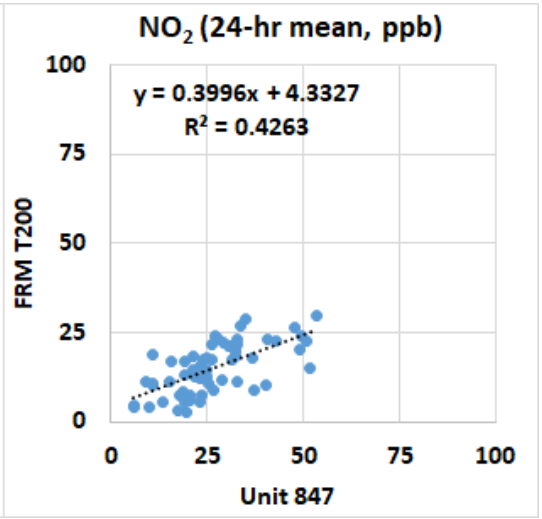
Vaisala AQT530 vs FRM T200 (NO_2; 24-hr mean)



- Vaisala AQT530 sensors showed very weak to weak correlations with the corresponding FRM T200 NO_2 data ($0.20 < R^2 < 0.43$)
- Overall, the Vaisala AQT530 sensors overestimated the NO_2 concentration as measured by the FRM T200 instrument
- The Vaisala AQT530 sensors sometimes seemed to track the diurnal NO_2 variations as recorded by the FRM T200 instrument







Summary: NO_2

	Average of 3 Sensors, NO_2		Vaisala AQT530 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	27.4	17.5	0.39 to 0.60	0.41 to 0.62	-0.2 to 2.4	9.4 to 15.6	11.3 to 16.7	14.2 to 21.8	15.1	13.0	1.1 to 65.0
1-hr	27.5	17.3	0.40 to 0.62	0.41 to 0.62	-0.1 to 2.5	9.5 to 15.8	11.2 to 16.7	14.1 to 21.8	15.6	12.9	1.3 to 48.5
24-hr	27.3	12.2	0.21 to 0.43	0.23 to 0.44	4.2 to 7.6	9.8 to 16.1	10.4 to 16.4	12.7 to 20.3	15.2	7.2	2.7 to 29.7

[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.

Carbon Monoxide (CO) in Vaisala AQT530

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 CO from Unit 673, Unit 885 and Unit 847 was ~ 93%, 97% and 97% respectively (excluding the software malfunction period)

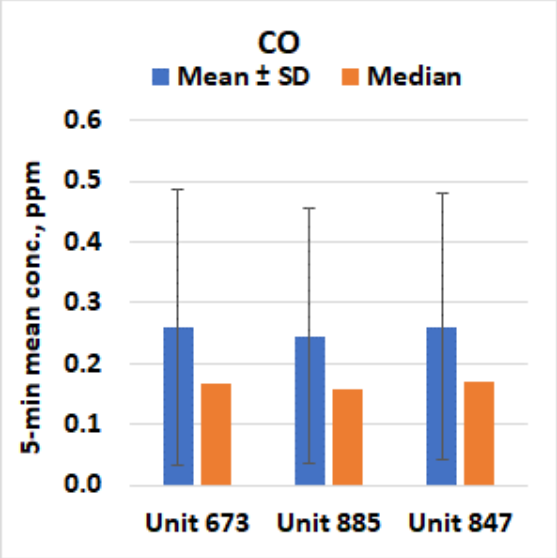
Vaisala AQT530; Intra-model variability

- Absolute intra-model variability was ~ 0.01 ppm for the CO measurements

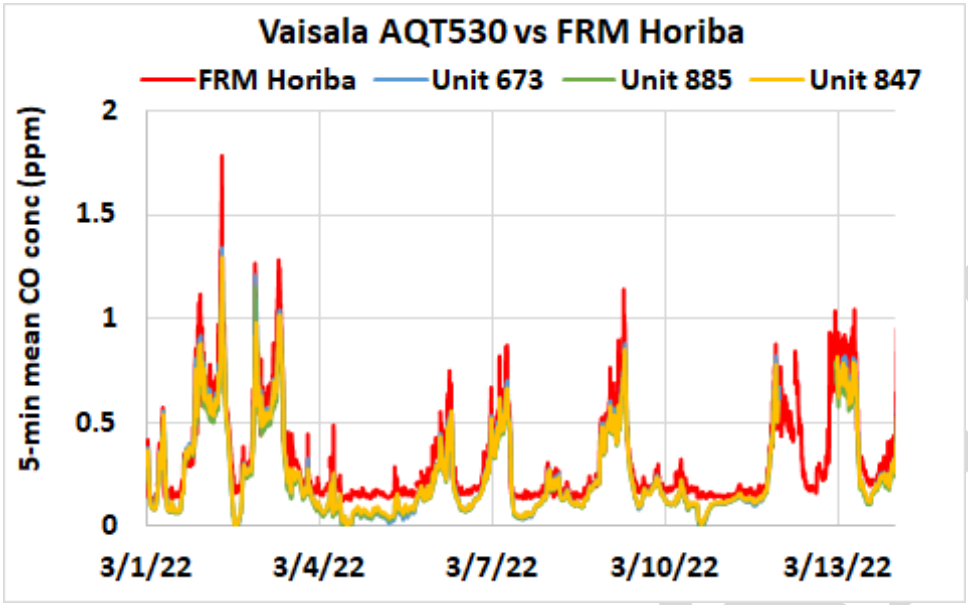
(calculated as the standard deviation of the three sensor means)

- Relative intra-model variability was ~ 3.3% for the CO measurements

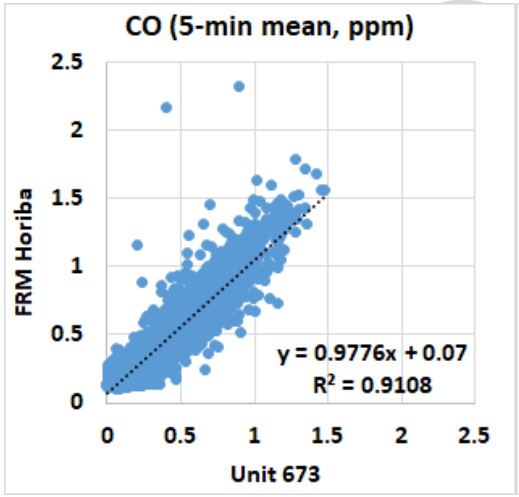
(calculated as the absolute intra-model variability relative to the mean of the three sensor means)

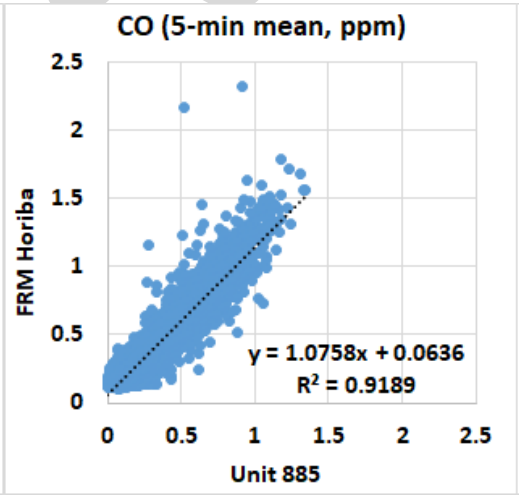


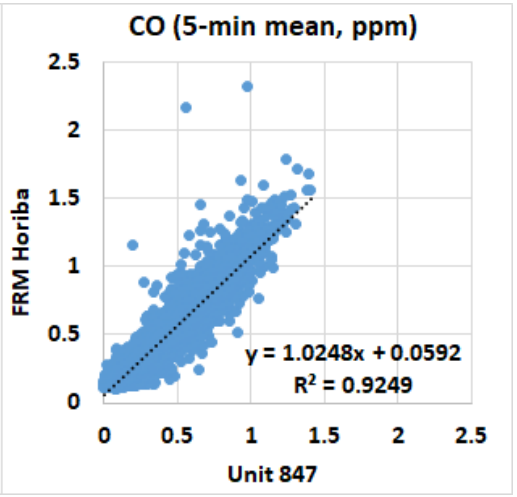
Vaisala AQT530 vs FRM Horiba (CO; 5-min mean)



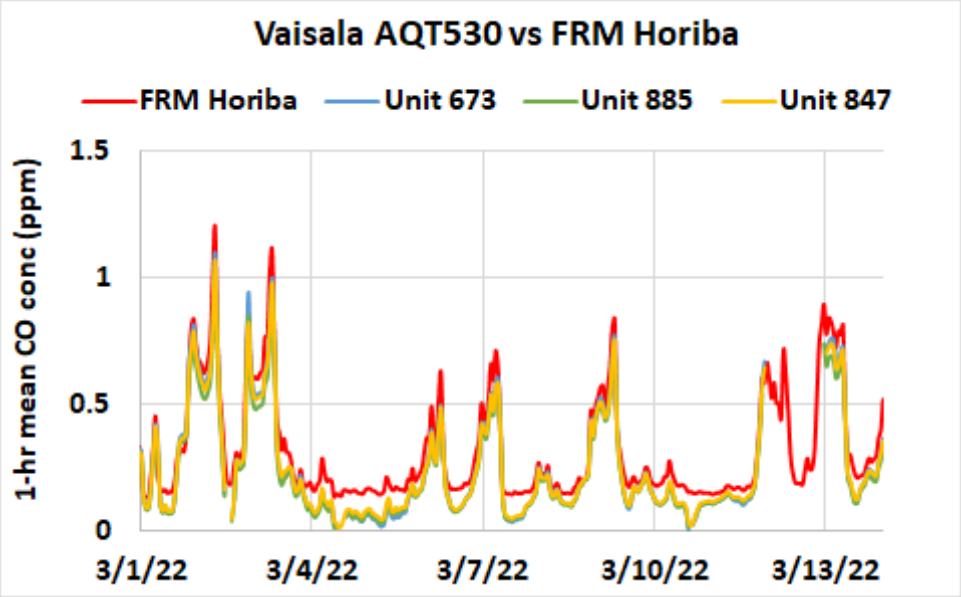
- Vaisala AQT530 sensors showed very strong correlations with the corresponding FRM Horiba CO data ($0.91 < R^2 < 0.93$)
- Overall, the Vaisala AQT530 sensors underestimated the CO concentration as measured by the FRM Horiba instrument
- The Vaisala AQT530 sensors seemed to track the diurnal CO variations as recorded by the FRM Horiba instrument



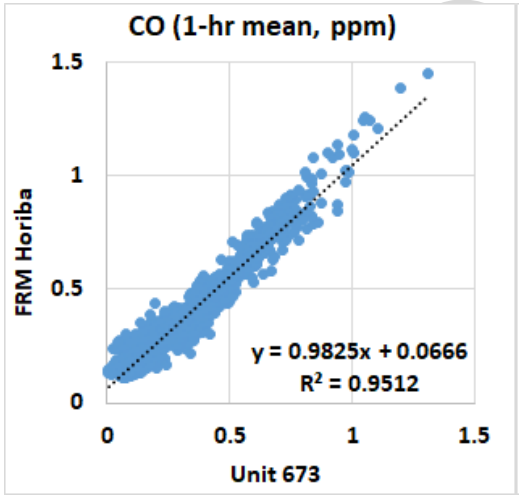


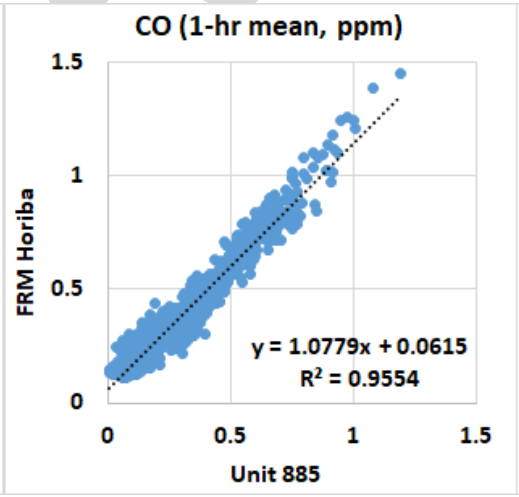


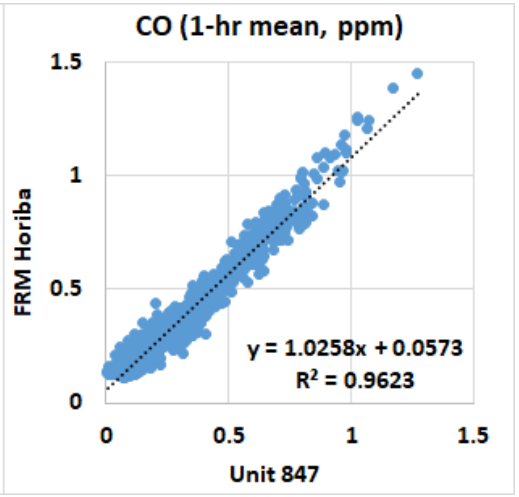
Vaisala AQT530 vs FRM Horiba (CO; 1-hr mean)



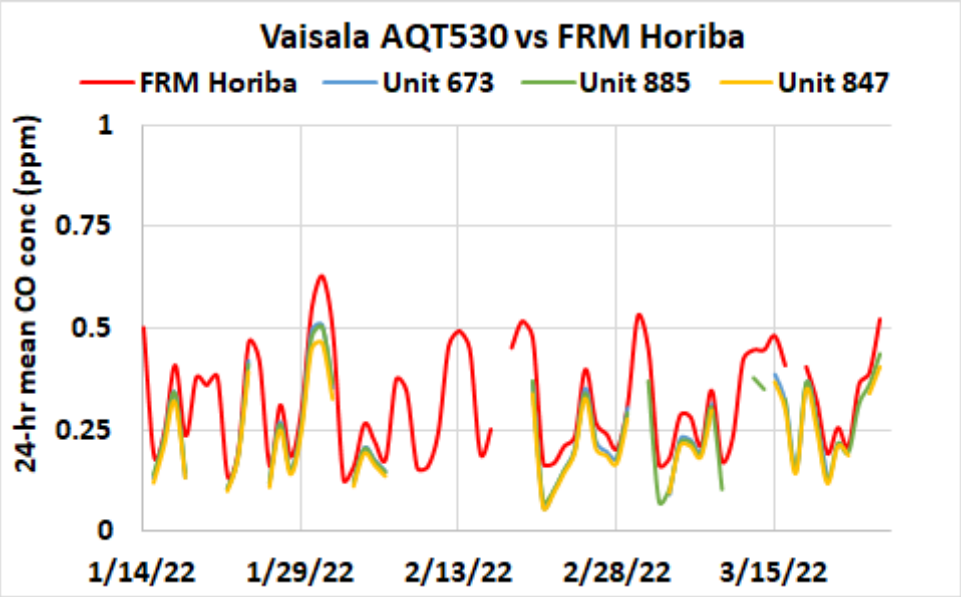
- Vaisala AQT530 sensors showed very strong correlations with the corresponding FRM Horiba CO data ($0.95 < R^2 < 0.97$)
- Overall, the Vaisala AQT530 sensors underestimated the CO concentration as measured by the FRM Horiba instrument
- The Vaisala AQT530 sensors seemed to track the diurnal CO variations as recorded by the FRM Horiba instrument



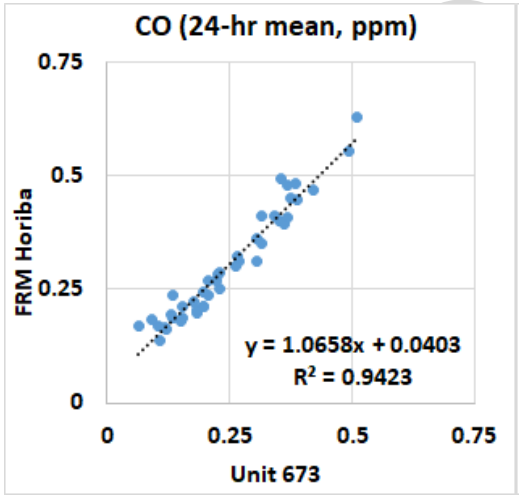


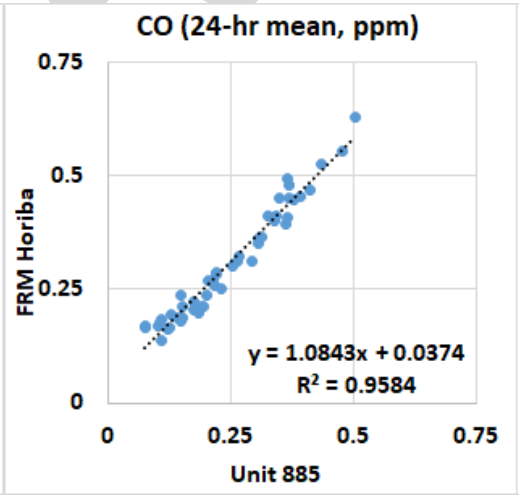


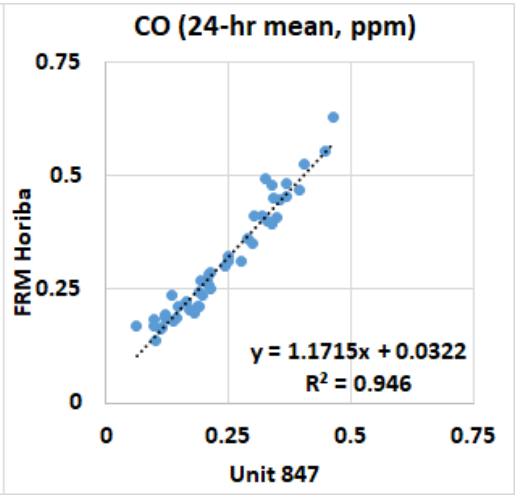
Vaisala AQT530 vs FRM Horiba (CO; 24-hr mean)



- Vaisala AQT530 sensors showed very strong correlations with the corresponding FRM Horiba CO data ($0.94 < R^2 < 0.96$)
- Overall, the Vaisala AQT530 sensors underestimated the CO concentration as measured by the FRM Horiba instrument
- The Vaisala AQT530 sensors seemed to track the diurnal CO variations as recorded by the FRM Horiba instrument





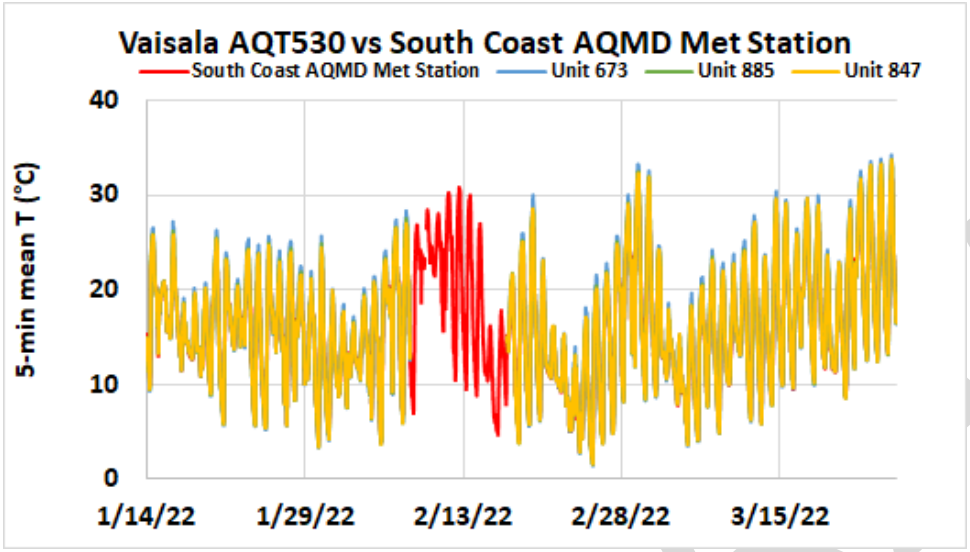


Summary: CO

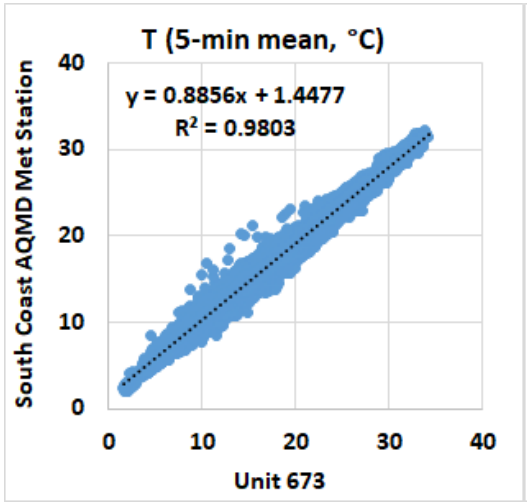
	Average of 3 Sensors, CO		Vaisala AQT530 vs FRM Horiba, CO						FRM CO, Horiba (ppm)		
	Average (ppm)	SD (ppm)	R^2	Slope	Intercept	MBE[1] (ppm)	MAE[2] (ppm)	RMSE[3] (ppm)	FRM Horiba Average	FRM Horiba SD	Range during the field evaluation
5-min	0.25	0.22	0.91 to 0.92	0.98 to 1.08	0.06 to 0.07	-0.08 to -0.06	0.07 to 0.09	0.09 to 0.11	0.32	0.23	0.11 to 2.32
1-hr	0.26	0.22	0.95 to 0.96	0.98 to 1.08	0.06 to 0.07	-0.08 to -0.06	0.07 to 0.08	0.08 to 0.10	0.33	0.23	0.11 to 1.45
24-hr	0.24	0.11	0.94 to 0.96	1.07 to 1.17	0.03 to 0.04	-0.07 to -0.06	0.06 to 0.07	0.06 to 0.08	0.32	0.13	0.13 to 0.63

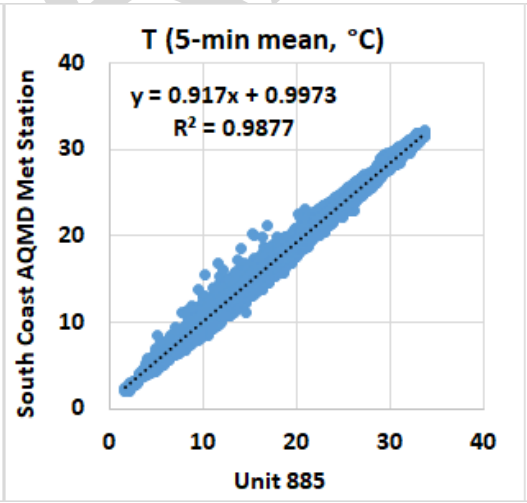
[1] Mean Bias Error (MBE): the difference between the sensors and the reference instruments. MBE indicates the tendency of the sensors to underestimate (negative MBE values) or overestimate (positive MBE values).
[2] Mean Absolute Error (MAE): the absolute difference between the sensors and the reference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

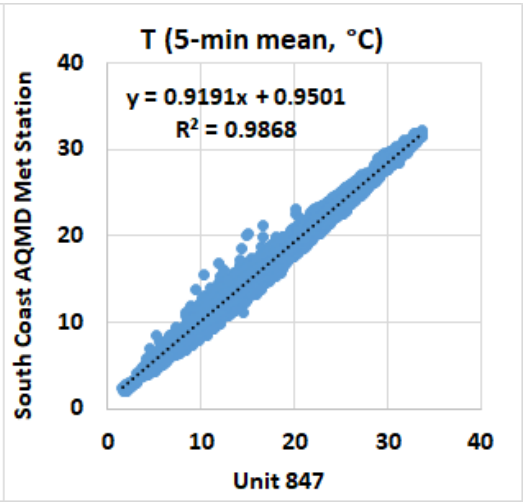
Vaisala AQT530 vs South Coast AQMD Met Station (Temp; 5-min mean)



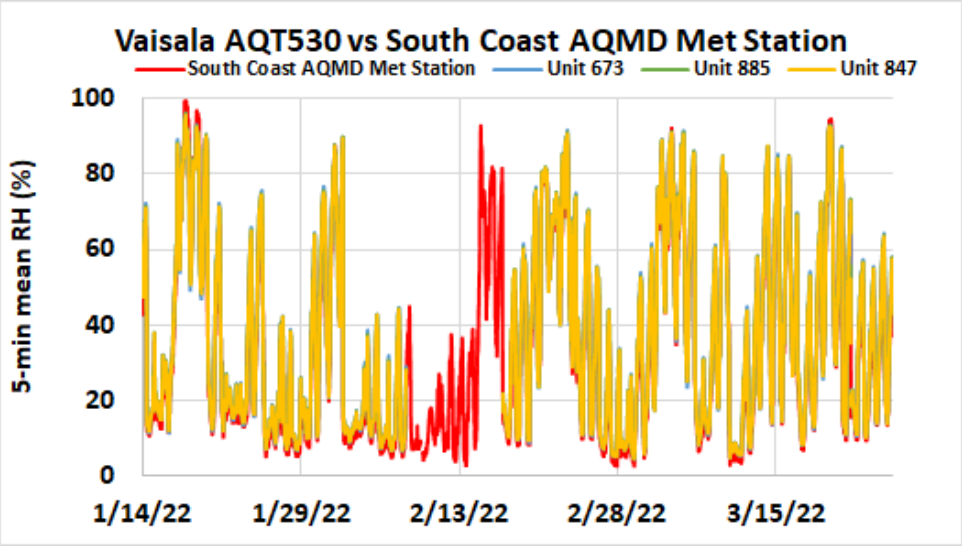
- Vaisala AQT530 sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($R^2 > 0.98$)
- Overall, the Vaisala AQT530 sensors overestimated the temperature measurement as recorded by South Coast AQMD Met Station
- The Vaisala AQT530 sensors seemed to track the diurnal temperature variations as recorded by South Coast AQMD Met Station



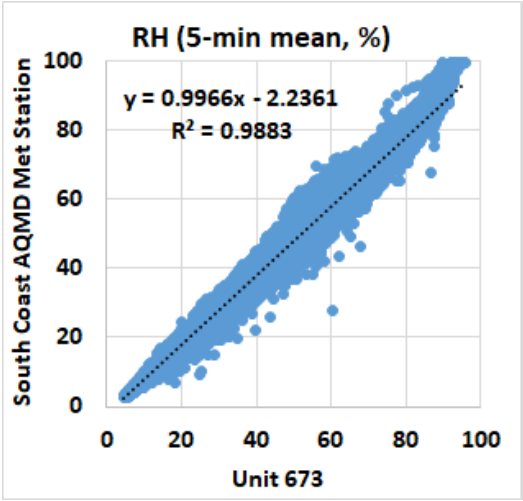


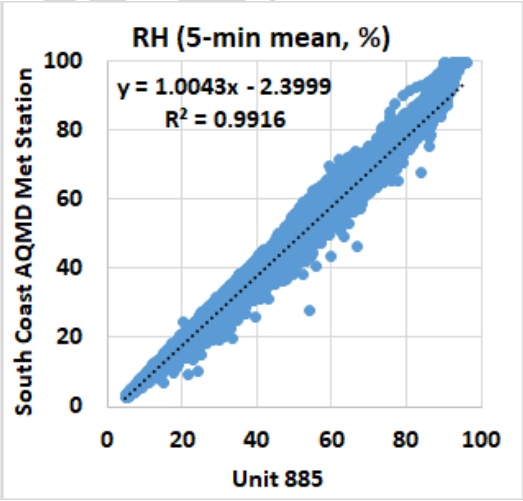


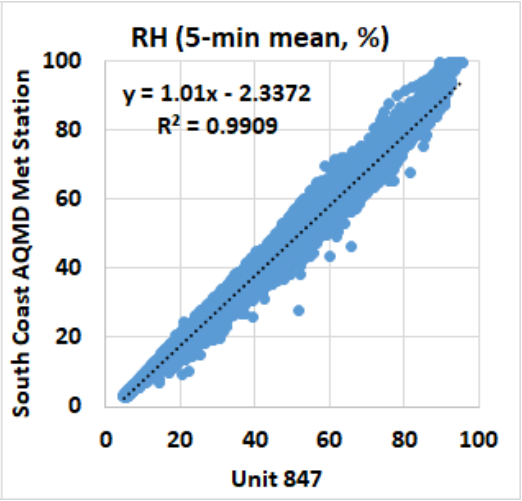
Vaisala AQT530 vs South Coast AQMD Met Station (RH; 5-min mean)



- Vaisala AQT530 sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($R^2 > 0.98$)
- Overall, the Vaisala AQT530 sensors overestimated the RH measurement as recorded by South Coast AQMD Met Station
- The Vaisala AQT530 sensors seemed to track the diurnal RH variations as recorded by South Coast AQMD Met Station







Discussion

- The three **Vaisala AQT530** sensors' data recovery for O_3, NO, NO_2 and CO was 86%-89%, 94%-98%, 94%-98%, and 93%-97%, respectively (excluding the software malfunction period).
- The absolute intra-model variability for O_3, NO, NO_2 and CO was 6.0 ppb, 3.6 ppb, 3.1 ppb, and 0.01 ppm, respectively.
- During the entire field deployment testing period:
  - Ozone sensors showed very weak to weak correlation with the FEM T400 instrument ($0.22 < R^2 < 0.47$, 5-min mean) and generally overestimated the corresponding FEM T400 data
  - NO sensors showed moderate to strong correlations with the FRM T200 instrument ($0.66 < R^2 < 0.71$, 5-min mean) and overestimated the corresponding FRM T200 data
  - NO_2 sensors showed weak to moderate correlations with the FRM T200 instrument ($0.38 < R^2 < 0.61$, 5-min mean) and overestimated the corresponding FRM T200 data
  - CO sensors showed very strong correlations with the FRM Horiba instrument ($0.91 < R^2 < 0.93$, 5-min mean) and underestimated the corresponding FRM data
  - Temperature and relative humidity sensors showed very strong correlations with the South Coast AQMD Met Station data ($R^2 > 0.98$ for both T and 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.
- 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