Field Evaluation
Oizom – Polludrone Smart

South Coast AQMD

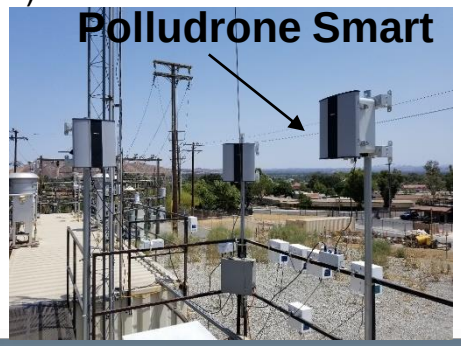
AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

- From 07/31/2021 to 09/29/2021, three **Oizom Polludrone Smart** (**hereinafter Polludrone Smart**) multi-sensor pods 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

- Polludrone Smart (*3 units tested*):
  - Sensors: CO – Electrochemical (Alphasense B4, non-FEM)
    O_3 – Electrochemical (Alphasense B4, non-FEM)
    NO – Electrochemical (Alphasense B4, non-FEM)
    NO_2 – Electrochemical (Alphasense B4, non-FEM)
  - PM Sensors – Optical Particle Counter (Wuhan Cubic PM3006S)
  - Each unit measures: **CO (ppm), O_3 (ppb), NO and NO_2 (ppb),** $PM_{1.0}$, $PM_{2.5}$ and PM_{10} ($\mu g/m^3$), T (°C), RH (%)
  - Unit cost: $8,000 (PM + Gas sensors)
  - Time resolution: 1-min
  - Units IDs: 0001, 0002, 0003

- South Coast AQMD Reference instruments:
  - CO instrument (FRM); cost: ~$7,000
    - Time resolution; 1-min
  - O_3 instrument (FEM); cost: ~$7,000
    - Time resolution; 1-min
  - NO_X instrument (FRM NO_2); cost: ~$13,000
    - Time resolution: 1-min
  - Met station (T, RH, P, WS, WD); cost: ~$5,000
    - Time resolution: 1-min



Carbon Monoxide (CO) in Polludrone Smart

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 0001, Unit 0002 and Unit 0003 was ~ 99%, 95% and 99%, respectively

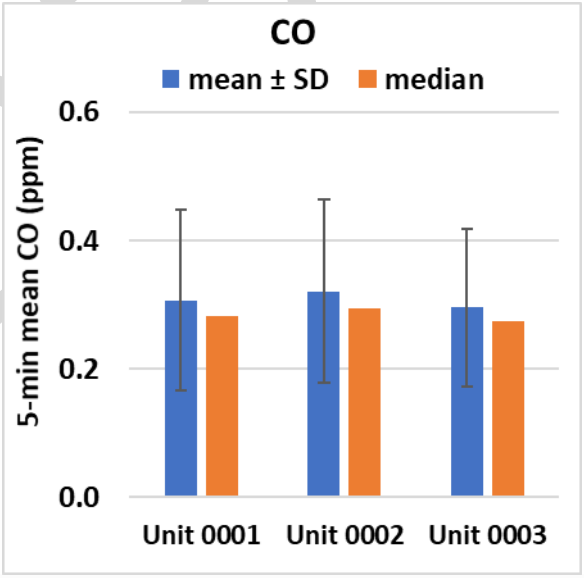
Polludrone Smart; Intra-model variability

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

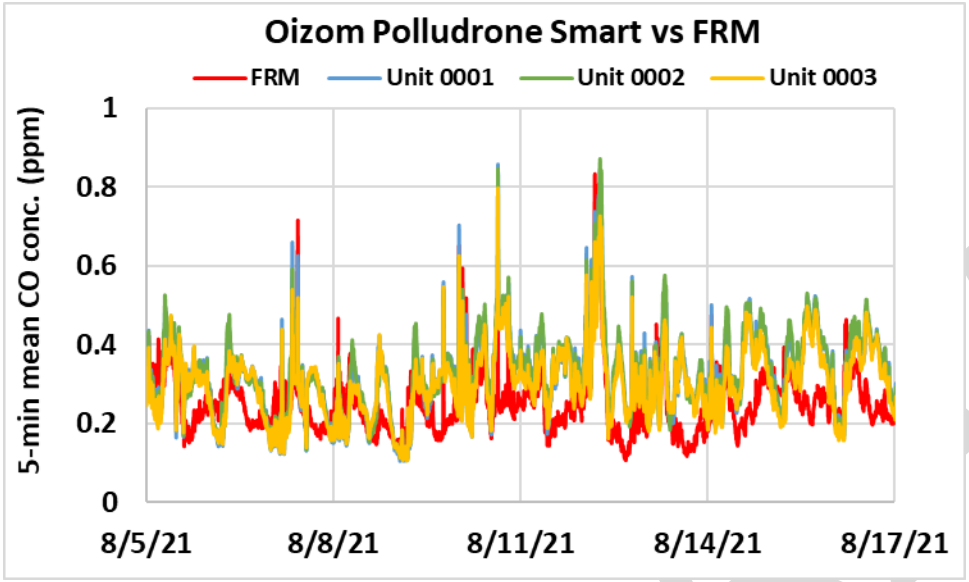
(calculated as the standard deviation of the three sensor means)

- Relative intra-model variability was ~ 3.4% for the CO measurements

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

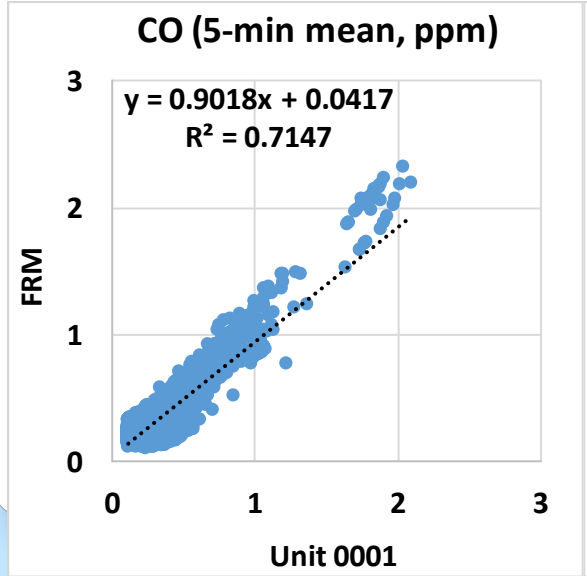


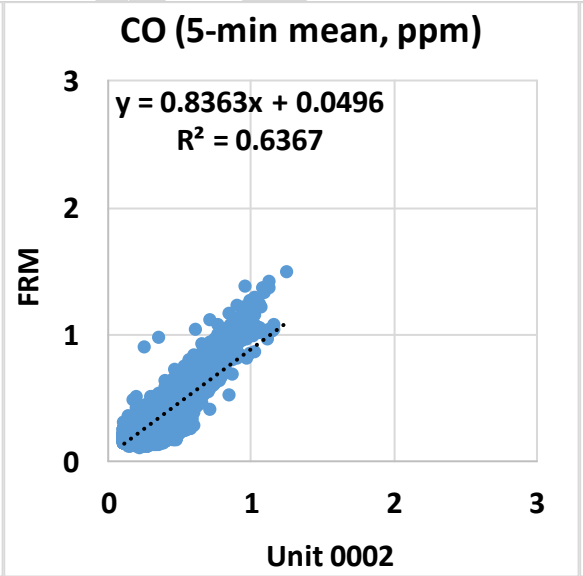
Polludrone Smart vs FRM (CO; 5-min mean)

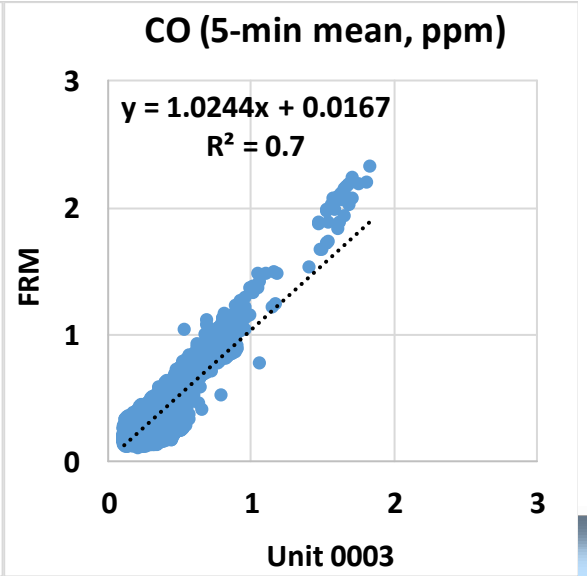


- The Polludrone Smart sensors showed moderate to strong correlations with the corresponding FRM CO data ($0.63 < R^2 < 0.72$)
- Overall, the Polludrone Smart sensors underestimated the CO concentrations as measured by the FRM CO instrument
- The Polludrone Smart sensors seemed to track the diurnal CO variations as recorded by the FRM CO instrument

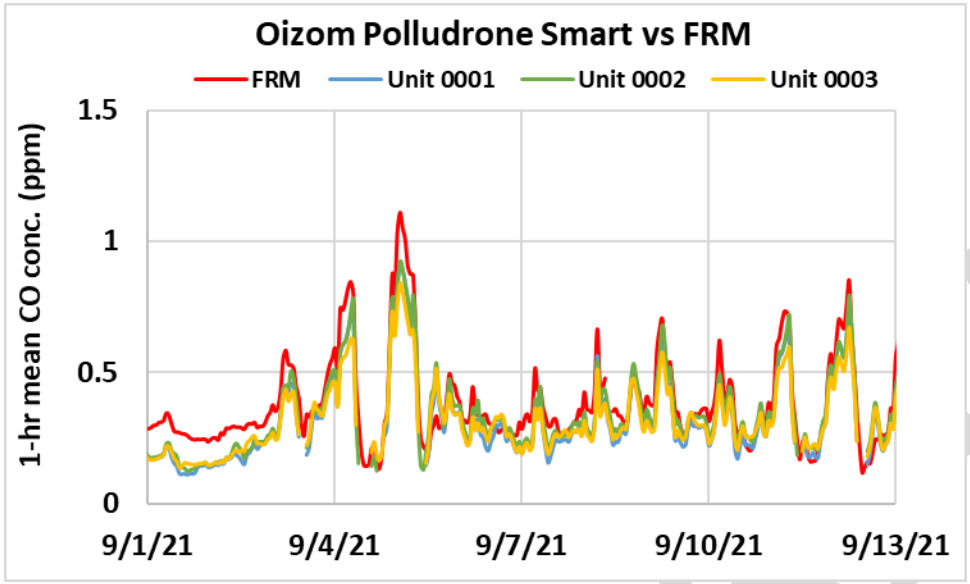
Note: Values that were below the manufacturer's stated Limit of Detection (LOD) were removed and not included in this analysis





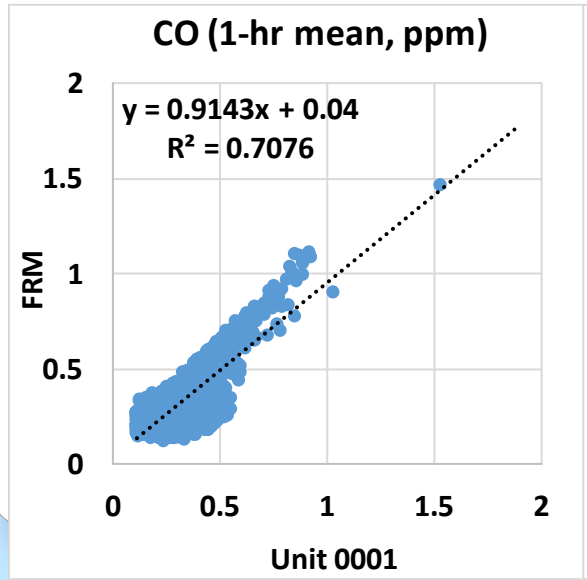


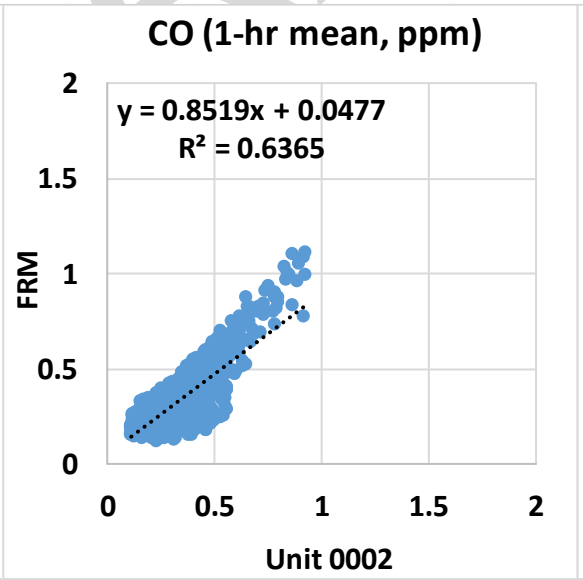
Polludrone Smart vs FRM (CO; 1-hr mean)

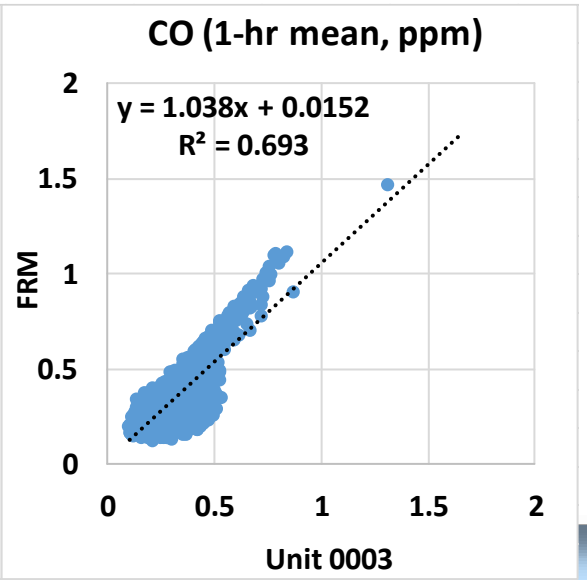


- The Polludrone Smart sensors showed moderate to strong correlations with the corresponding FRM CO data ($0.63 < R^2 < 0.71$)
- Overall, the Polludrone Smart sensors underestimated the CO concentrations as measured by the FRM CO instrument
- The Polludrone Smart sensors seemed to track the diurnal CO variations as recorded by the FRM CO instrument

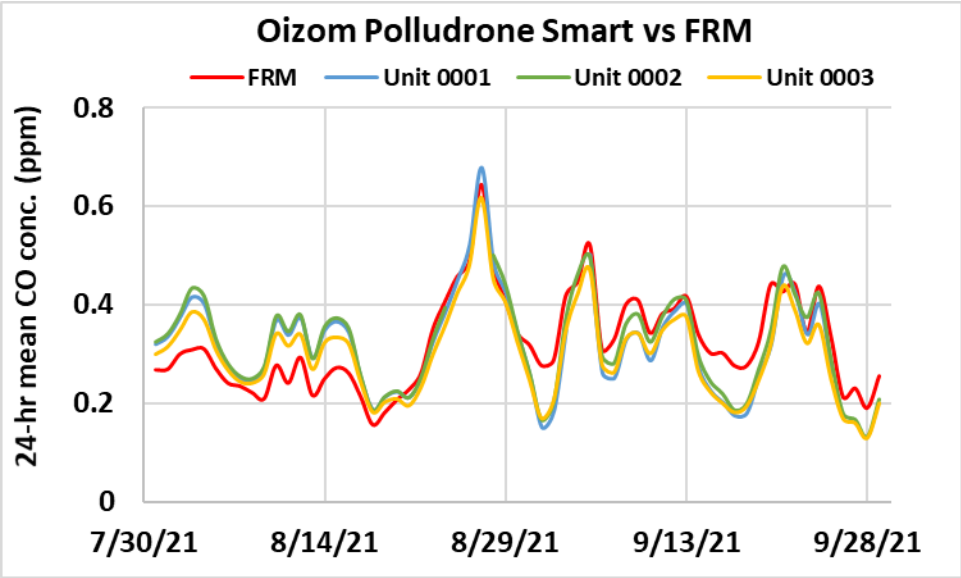
Note: Values that were below the manufacturer's stated Limit of Detection (LOD) were removed and not included in this analysis





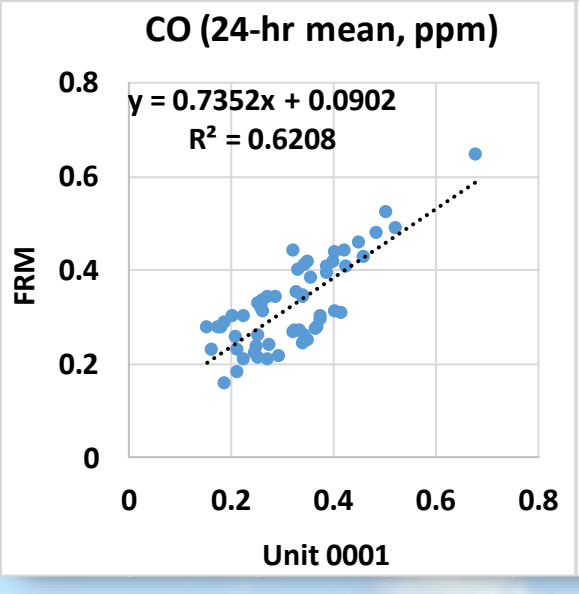


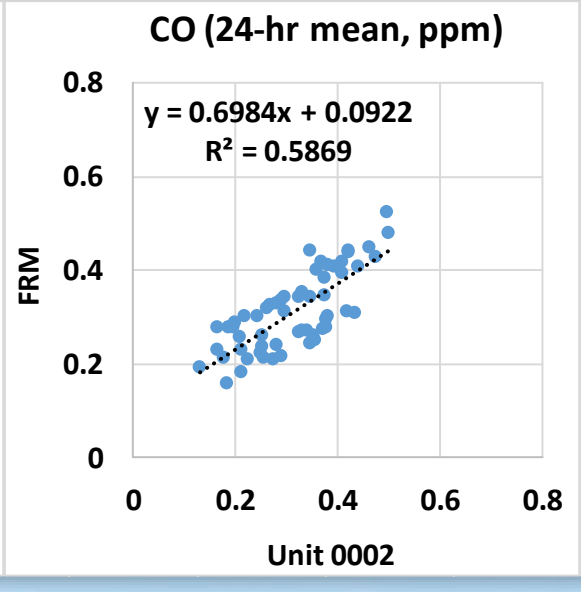
Polludrone Smart vs FRM (CO; 24-hr mean)

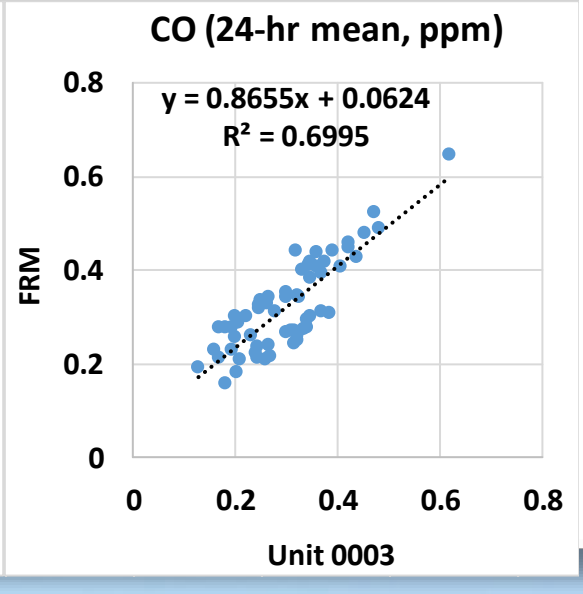


- The Polludrone Smart sensors showed moderate correlations with the corresponding FRM CO data ($0.58 < R^2 < 0.70$)
- Overall, the Polludrone Smart sensors underestimated the CO concentrations as measured by the FRM CO instrument
- The Polludrone Smart sensors seemed to track the diurnal CO variations as recorded by the FRM CO instrument

Note: Values that were below the manufacturer's stated Limit of Detection (LOD) were removed and not included in this analysis







Summary: CO

	Average of 3 Sensors, CO		Polludrone Smart vs FRM, CO						FRM CO (ppm)		
	Average (ppm)	SD (ppm)	R^2	Slope	Intercept	MBE[1] (ppm)	MAE[2] (ppm)	RMSE[3] (ppm)	FRM Average	FRM SD	Range during the field evaluation
5-min	0.31	0.15	0.64 to 0.71	0.84 to 1.02	0.02 to 0.05	-0.02 to 0.003	0.076 to 0.081	0.093 to 0.098	0.32	0.17	0.10 to 2.33
1-hr	0.31	0.14	0.64 to 0.71	0.85 to 1.04	0.02 to 0.05	-0.03 to -0.001	0.075 to 0.080	0.090 to 0.097	0.33	0.17	0.12 to 2.10
24-hr	0.31	0.09	0.59 to 0.70	0.70 to 0.87	0.06 to 0.09	-0.02 to 0.003	0.051 to 0.054	0.058 to 0.064	0.32	0.10	0.16 to 0.65

[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.

Ozone (O_3) in Polludrone Smart

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 ozone from Unit 0001, Unit 0002 and Unit 0003 was ~ 99%, 95% and 99%, respectively

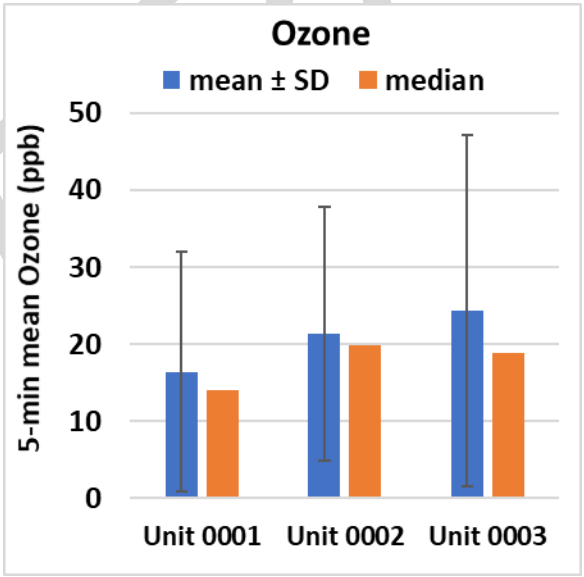
Polludrone Smart; Intra-model variability

- Absolute intra-model variability was ~ 3.3 ppb for the ozone measurements

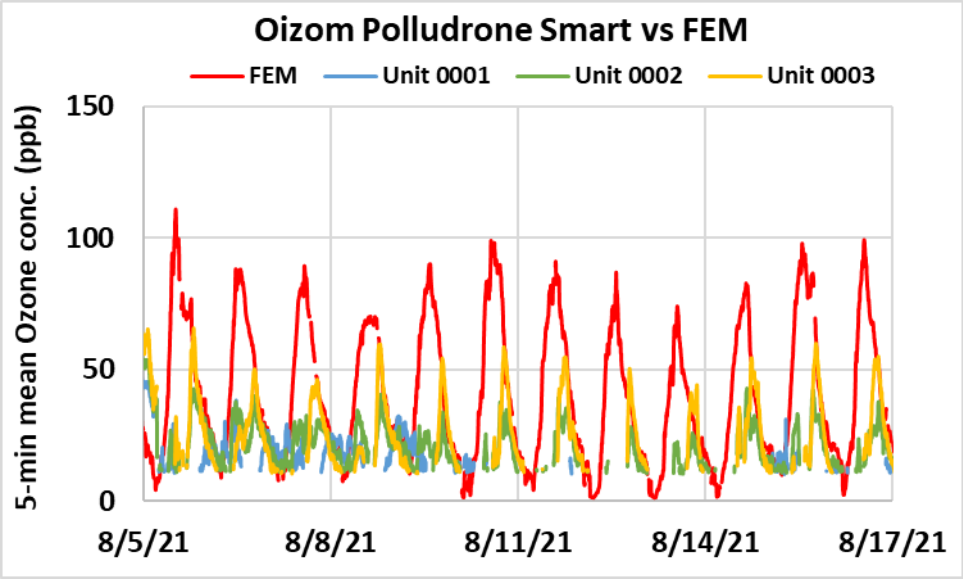
(calculated as the standard deviation of the three sensor means)

- Relative intra-model variability was ~ 15.7% for the ozone measurements

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

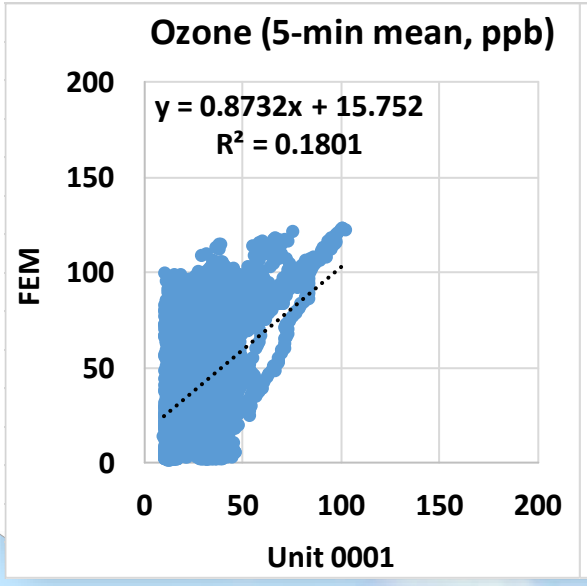


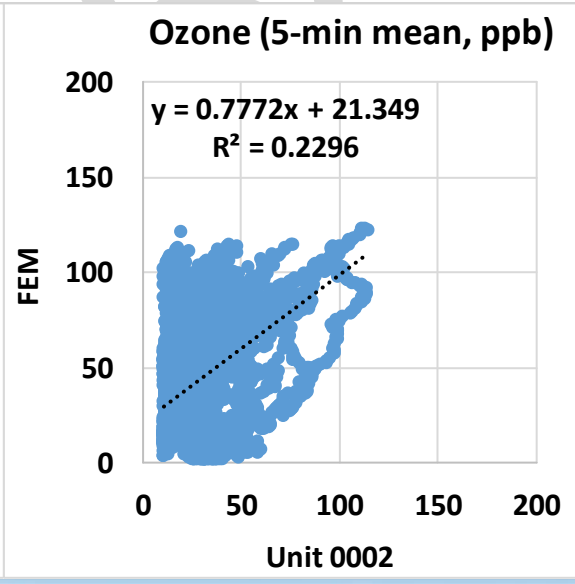
Polludrone Smart vs FEM (Ozone; 5-min mean)

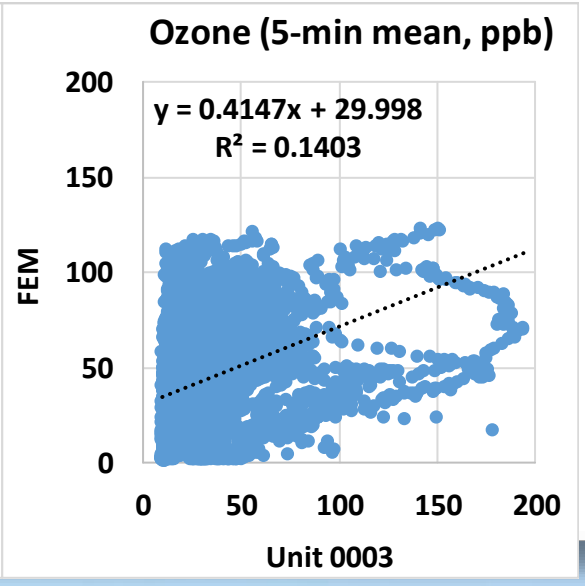


- The Polludrone Smart sensors showed very weak correlations with the corresponding FEM ozone data ($0.14 < R^2 < 0.23$)
- Overall, the Polludrone Smart sensors underestimated the ozone concentrations as measured by the FEM ozone instrument
- The Polludrone Smart sensors did not seem to track the diurnal ozone variations as recorded by the FEM ozone instrument

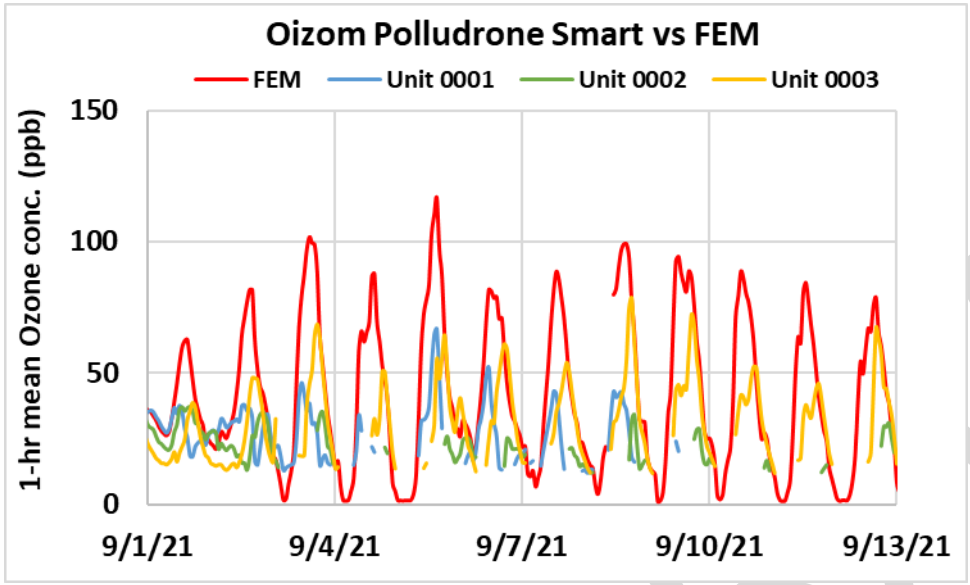
Note: Values that were below the manufacturer's stated Limit of Detection (LOD) were removed and not included in this analysis





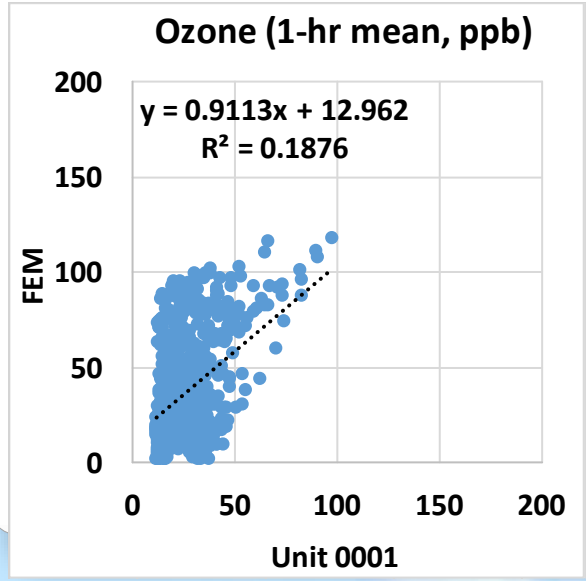


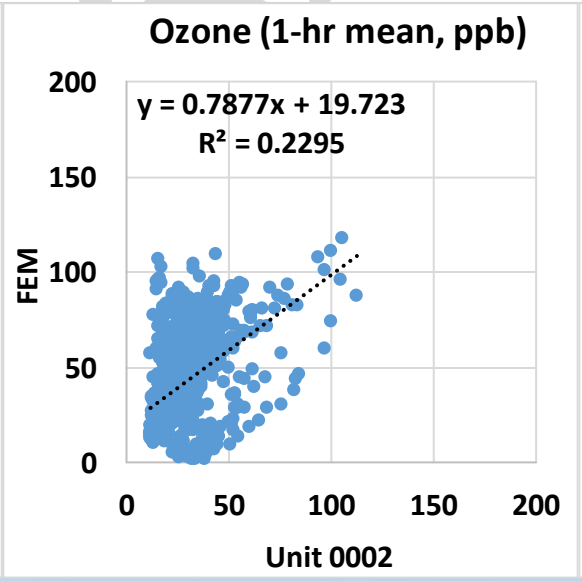
Polludrone Smart vs FEM (Ozone; 1-hr mean)

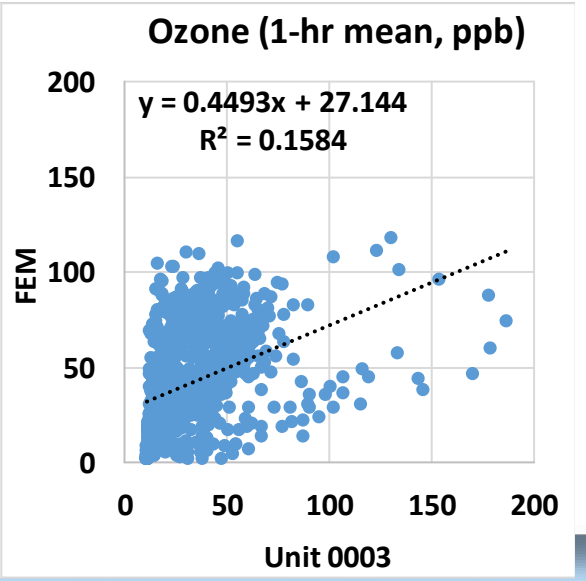


- The Polludrone Smart sensors showed very weak correlations with the corresponding FEM ozone data ($0.15 < R^2 < 0.23$)
- Overall, the Polludrone Smart sensors underestimated the ozone concentrations as measured by the FEM ozone instrument
- The Polludrone Smart sensors did not seem to track the diurnal ozone variations as recorded by the FEM ozone instrument

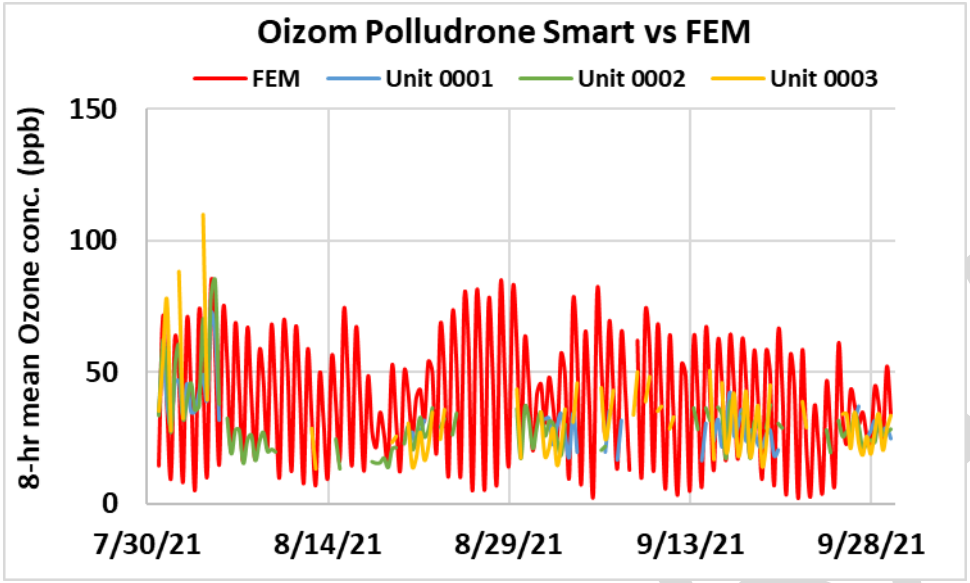
Note: Values that were below the manufacturer's stated Limit of Detection (LOD) were removed and not included in this analysis





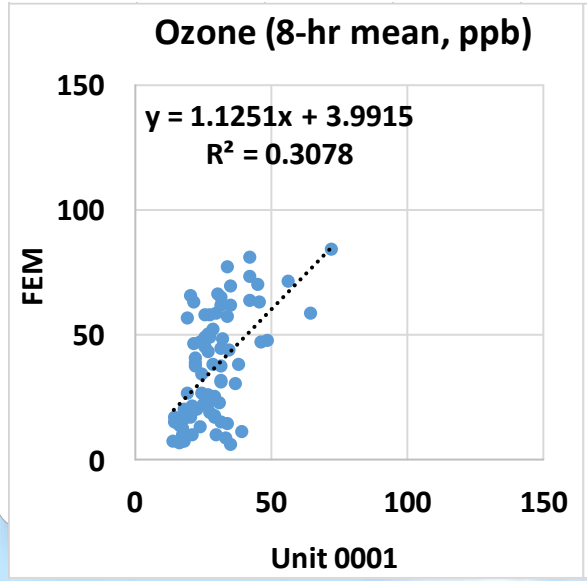


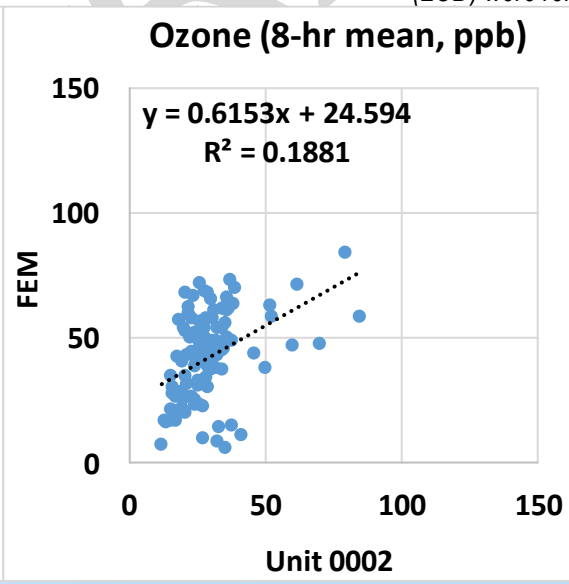
Polludrone Smart vs FEM (Ozone; 8-hr mean)

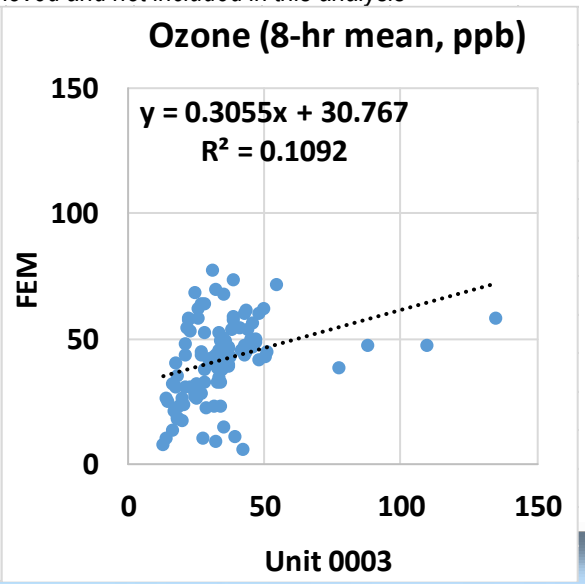


- The Polludrone Smart sensors showed very weak to weak correlations with the corresponding FEM ozone data ($0.10 < R^2 < 0.31$)
- Overall, the Polludrone Smart sensors underestimated the ozone concentrations as measured by the FEM ozone instrument
- The Polludrone Smart sensors did not seem to track the diurnal ozone variations as recorded by the FEM ozone instrument

Note: Values that were below the manufacturer's stated Limit of Detection (LOD) were removed and not included in this analysis







Summary: Ozone

	Average of 3 Sensors, Ozone		Polludrone Smart vs FEM, Ozone						FEM Ozone (ppb)		
	Average (ppb)	SD (ppb)	R^2	Slope	Intercept	MBE[1] (ppb)	MAE[2] (ppb)	RMSE[3] (ppb)	FEM Average	FEM SD	Range during the field evaluation
5-min	29.4	16.3	0.14 to 0.23	0.41 to 0.87	15.8 to 30.0	-15.0 to -12.3	18.9 to 19.7	25.6 to 28.9	41.1	27.3	1.1 to 123.1
1-hr	29.9	16.0	0.16 to 0.23	0.45 to 0.91	13.0 to 27.1	-13.6 to -8.9	17.9 to 18.4	24.5 to 27.2	39.5	26.9	1.2 to 117.5
8-hr	31.3	13.3	0.11 to 0.31	0.31 to 1.13	4.0 to 30.8	-13.2 to -6.7	14.8 to 17.3	15.6 to 20.9	39.6	22.2	2.3 to 84.1

[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 Polludrone Smart

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 0001, Unit 0002 and Unit 0003 was ~ 99%, 95% and 99%, respectively

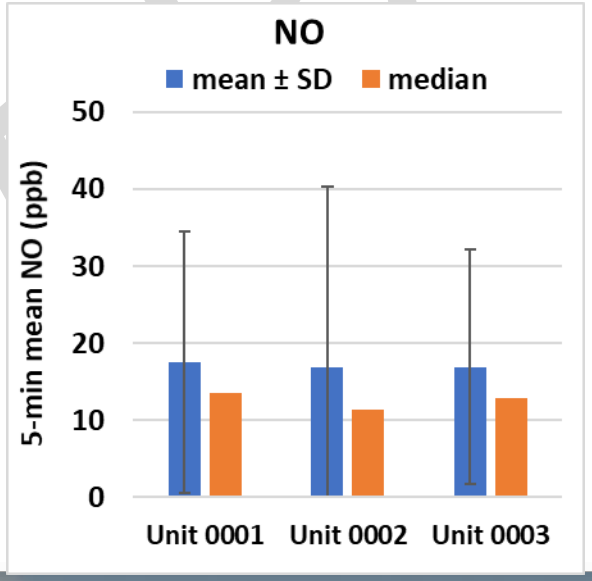
Polludrone Smart; Intra-model variability

- Absolute intra-model variability was ~ 0.3 ppb for the NO measurements

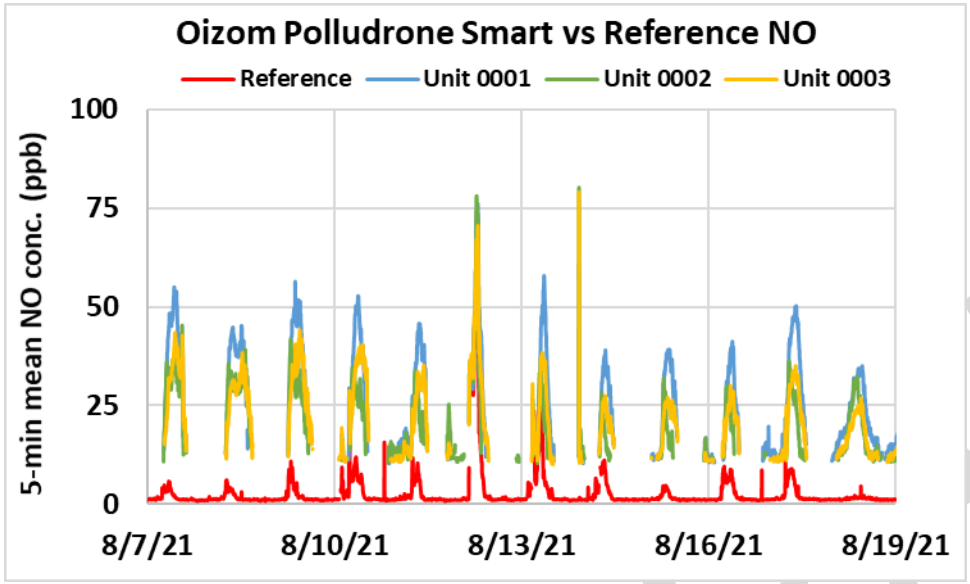
(calculated as the standard deviation of the three sensor means)

- Relative intra-model variability was ~ 1.8% for the NO measurements

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

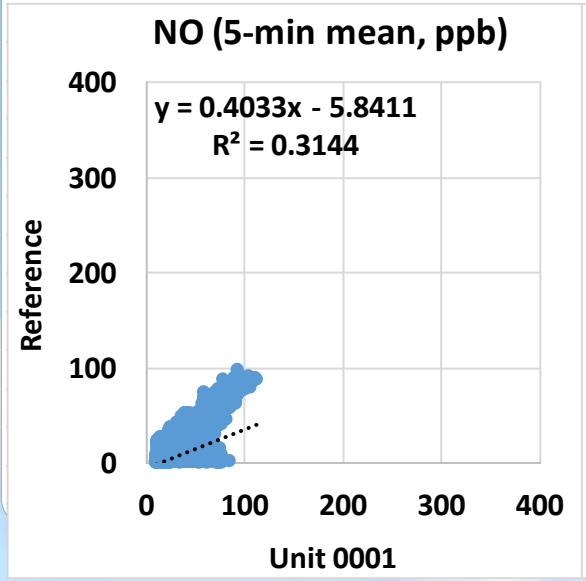


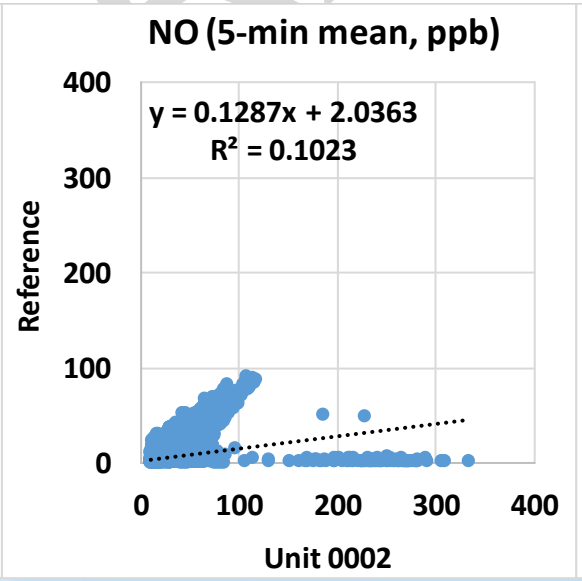
Polludrone Smart vs Reference (NO; 5-min mean)

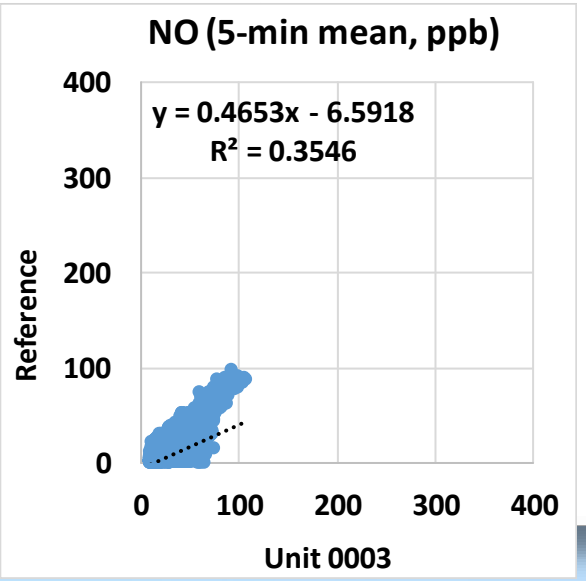


- The Polludrone Smart sensors showed very weak to weak correlations with the corresponding reference NO data ($0.10 < R^2 < 0.36$)
- Overall, the Polludrone Smart sensors overestimated the NO concentrations as measured by the reference instrument
- The Polludrone Smart sensors did not seem to track the diurnal NO variations as recorded by the reference instrument

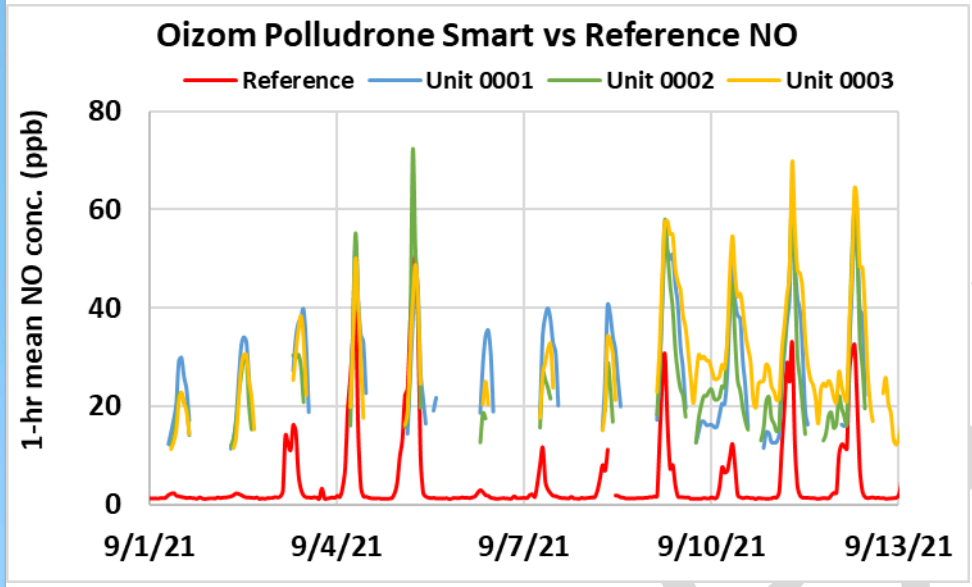
Note: Values that were below the manufacturer's stated Limit of Detection (LOD) were removed and not included in this analysis. 24-hr data not shown as a result of lack of data from the sensors due to values below LOD being removed.





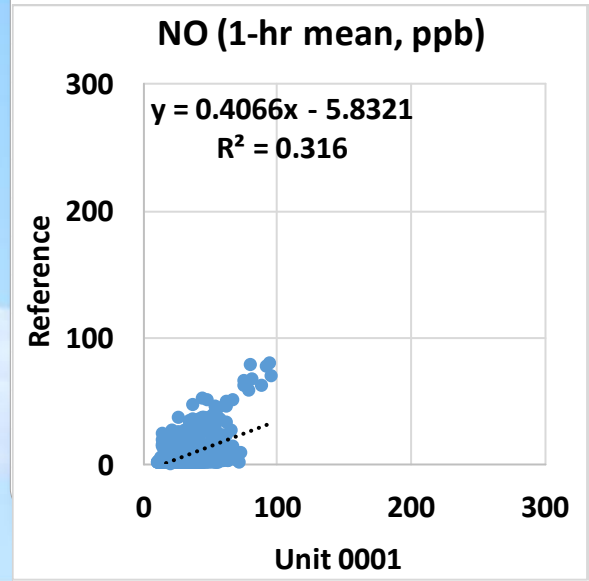


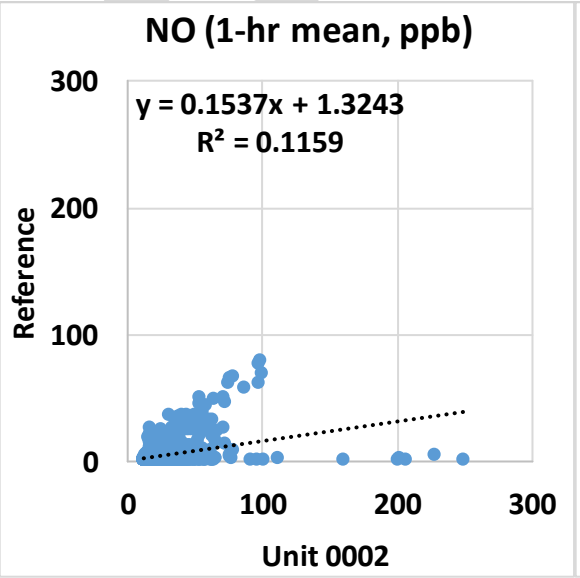
Polludrone Smart vs Reference (NO; 1-hr mean)

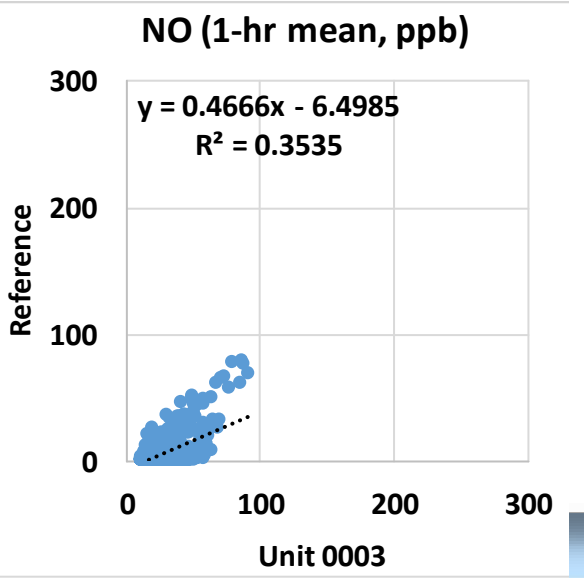


- The Polludrone Smart sensors showed very weak to weak correlations with the corresponding reference NO data ($0.11 < R^2 < 0.36$)
- Overall, the Polludrone Smart sensors overestimated the NO concentrations as measured by the reference instrument
- The Polludrone Smart sensors did not seem to track the diurnal NO variations as recorded by the reference instrument

Note: Values that were below the manufacturer's stated Limit of Detection (LOD) were removed and not included in this analysis. 24-hr data not shown as a result of lack of data from the sensors due to values below LOD being removed.







Summary: NO

	Average of 3 Sensors, NO		Polludrone Smart vs Reference, NO						Reference NO (ppb)		
	Average (ppb)	SD (ppb)	R^2	Slope	Intercept	MBE[1] (ppb)	MAE[2] (ppb)	RMSE[3] (ppb)	FRM Average	FRM SD	Range during the field evaluation
5-min	28.3	18.6	0.10 to 0.35	0.13 to 0.47	-6.6 to 2.0	21.0 to 24.5	21.1 to 24.6	23.9 to 35.3	4.1	8.7	0.01 to 97.1
1-hr	28.7	17.1	0.12 to 0.35	0.15 to 0.47	-6.5 to 1.3	20.7 to 24.6	20.8 to 24.7	23.4 to 32.9	4.0	8.2	0.2 to 79.3

[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 Polludrone Smart

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 0001, Unit 0002 and Unit 0003 was ~ 99%, 95% and 99%, respectively

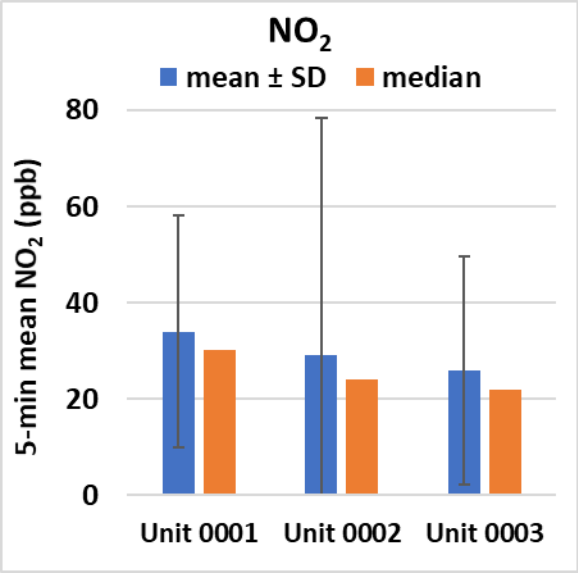
Polludrone Smart; Intra-model variability

- Absolute intra-model variability was ~ 3.3 ppb for the NO_2 measurements

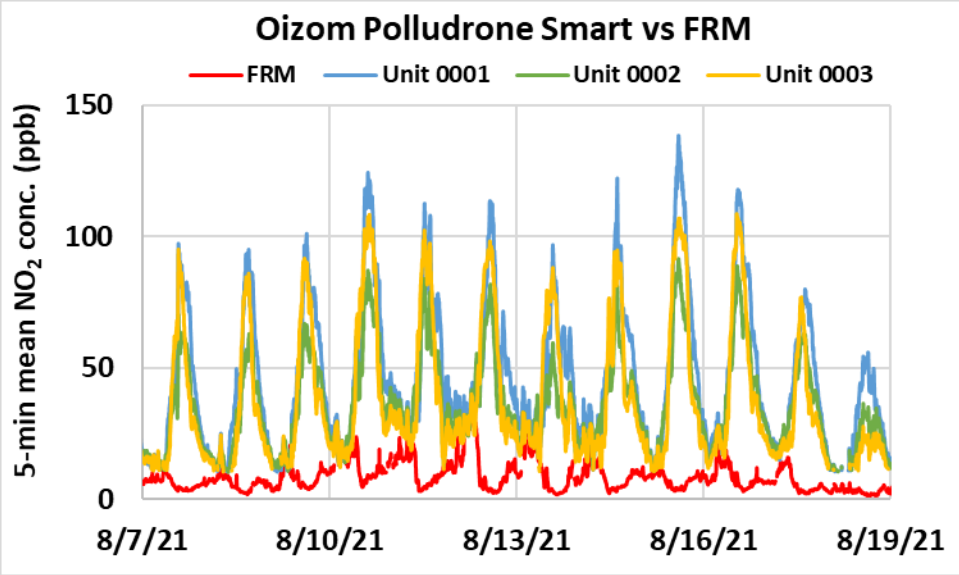
(calculated as the standard deviation of the three sensor means)

- Relative intra-model variability was ~ 11.2% for the NO_2 measurements

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

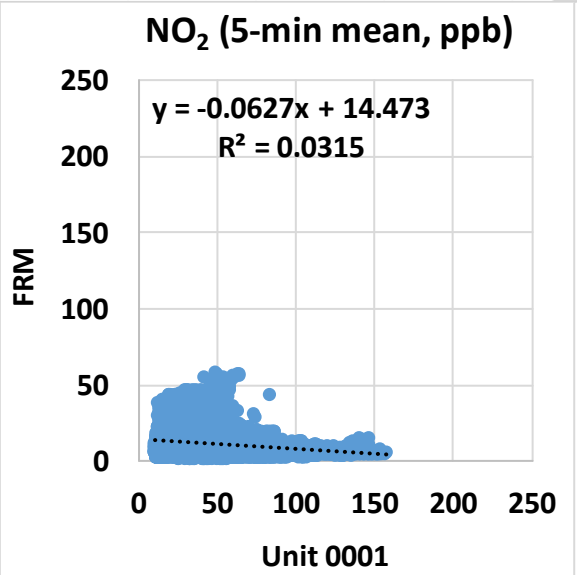


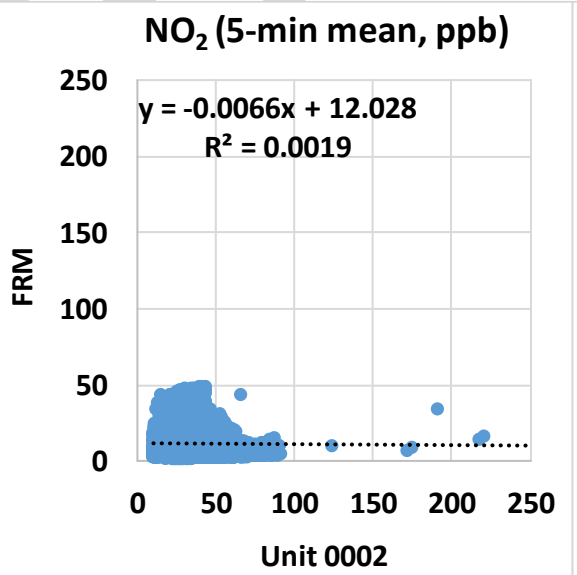
Polludrone Smart vs FRM (NO_2; 5-min mean)

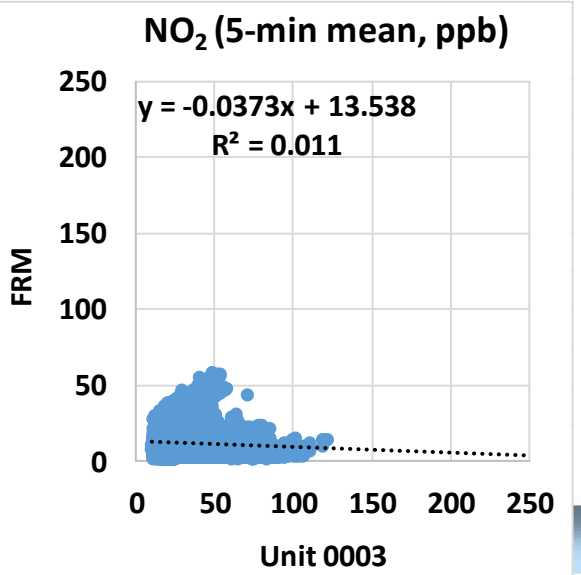


- The Polludrone Smart sensors did not correlate with the corresponding FRM NO_2 data ($0.001 < R^2 < 0.04$)
- Overall, the Polludrone Smart sensors overestimated the NO_2 concentrations as measured by the FRM instrument
- The Polludrone Smart sensors did not seem to track the diurnal NO_2 variations as recorded by the FRM instrument

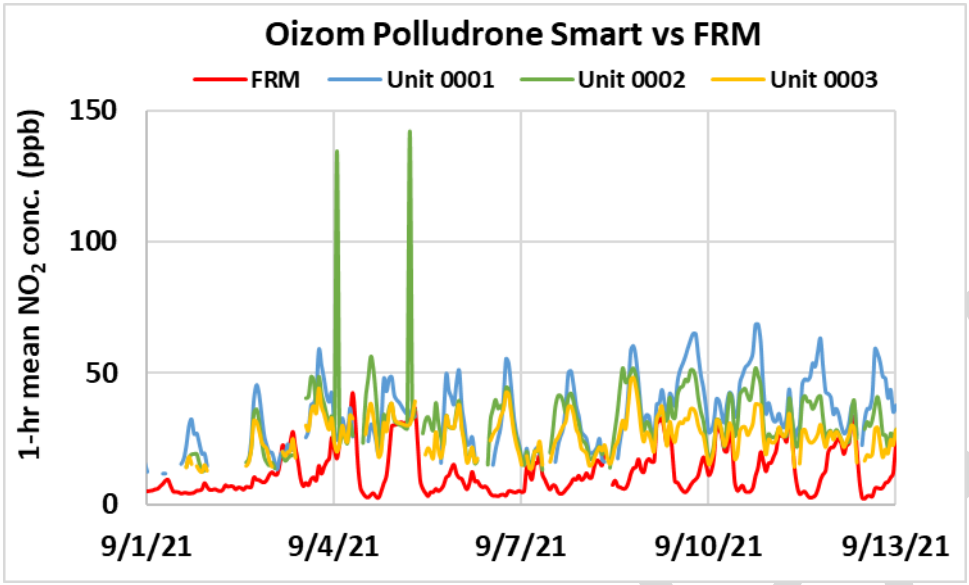
Note: Values that were below the manufacturer's stated Limit of Detection (LOD) were removed and not included in this analysis





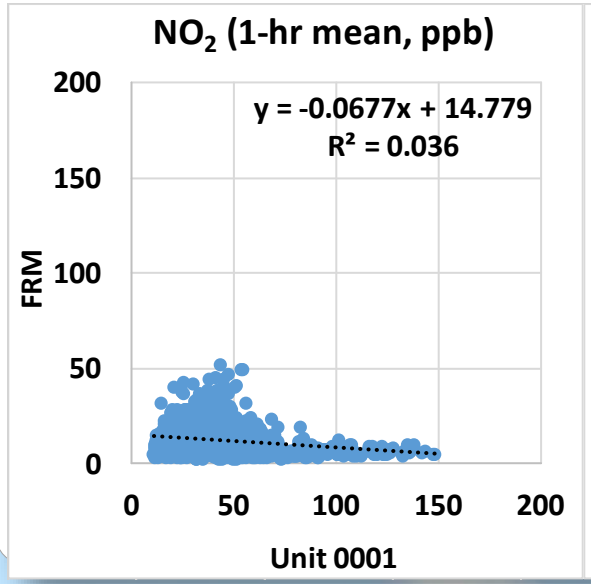


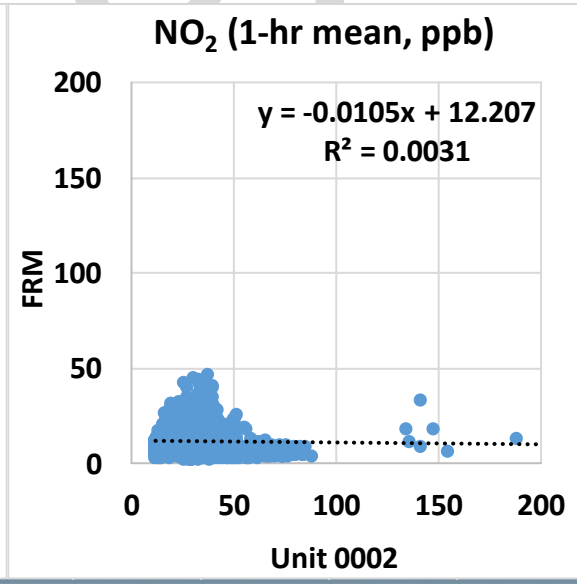
Polludrone Smart vs FRM (NO_2; 1-hr mean)

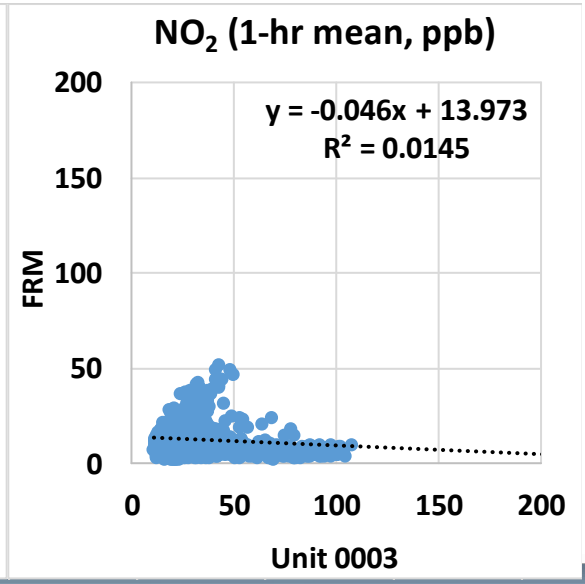


- The Polludrone Smart sensors did not correlate with the corresponding FRM NO_2 data ($0.003 < R^2 < 0.04$)
- Overall, the Polludrone Smart sensors overestimated the NO_2 concentrations as measured by the FRM instrument
- The Polludrone Smart sensors did not seem to track the diurnal NO_2 variations as recorded by the FRM instrument

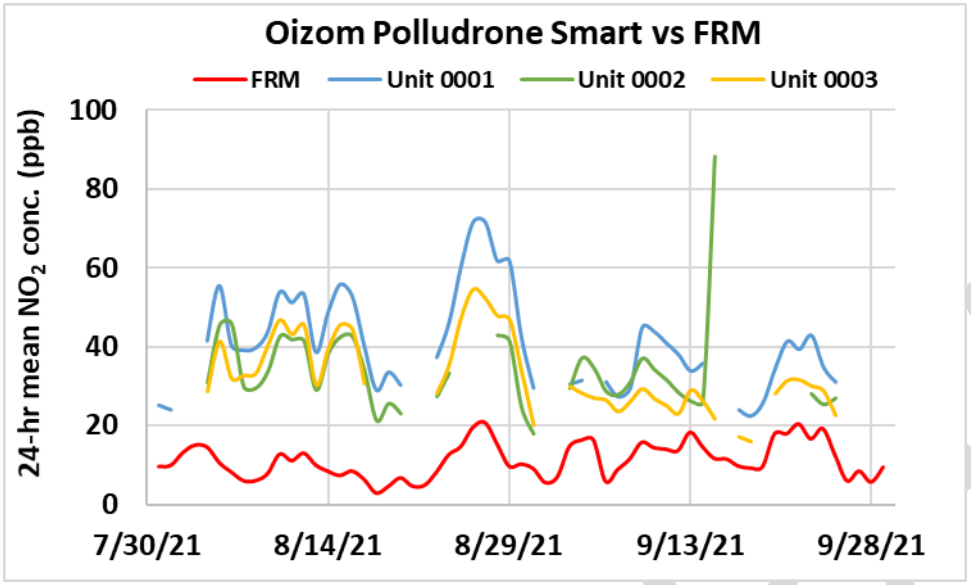
Note: Values that were below the manufacturer's stated Limit of Detection (LOD) were removed and not included in this analysis





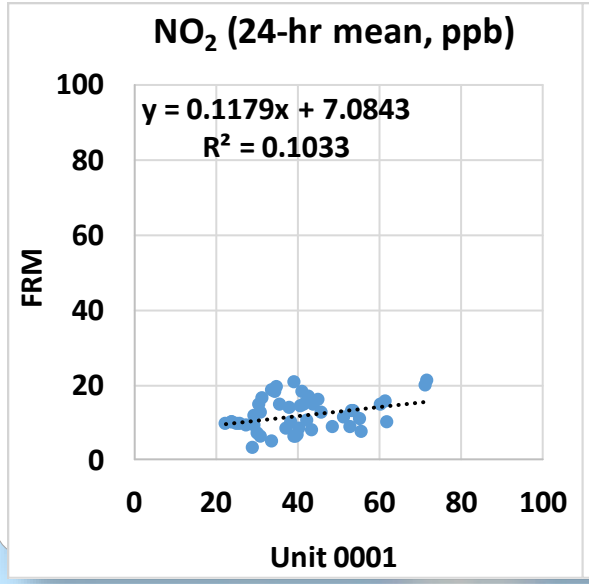


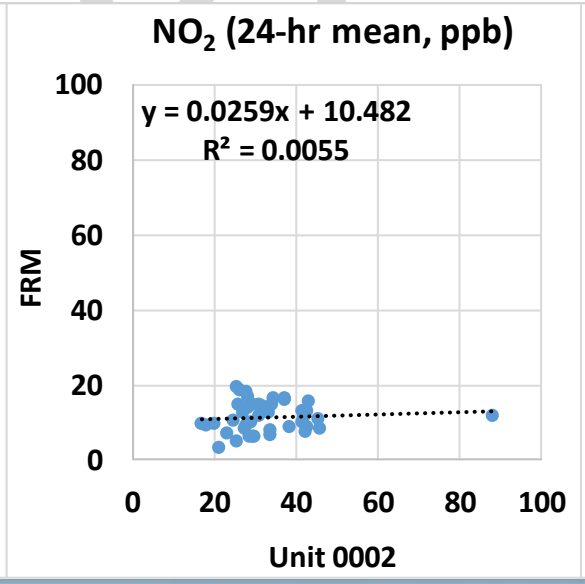
Polludrone Smart vs FRM (NO_2; 24-hr mean)

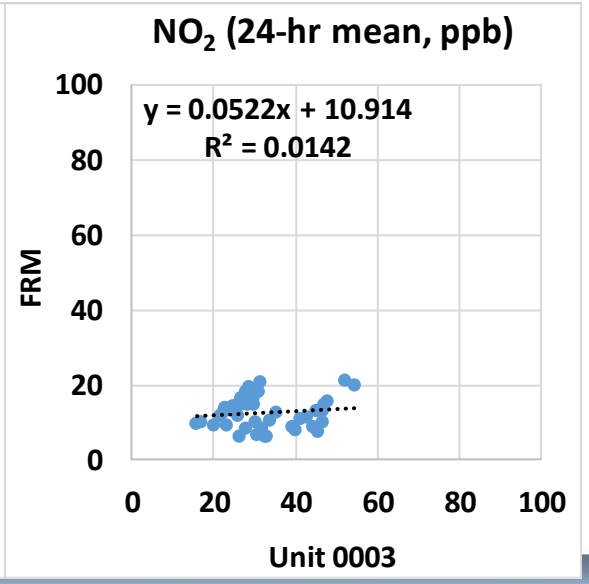


- The Polludrone Smart sensors showed no to very weak correlations with the corresponding FRM NO_2 data ($0.005 < R^2 < 0.11$)
- Overall, the Polludrone Smart sensors overestimated the NO_2 concentrations as measured by the FRM instrument
- The Polludrone Smart sensors did not seem to track the diurnal NO_2 variations as recorded by the FRM instrument

Note: Values that were below the manufacturer's stated Limit of Detection (LOD) were removed and not included in this analysis





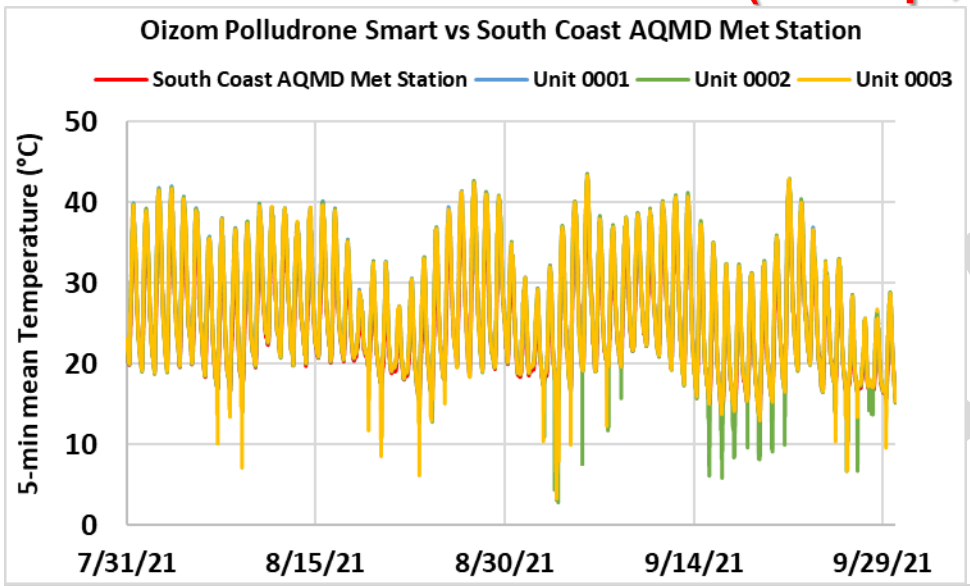


Summary: NO_2

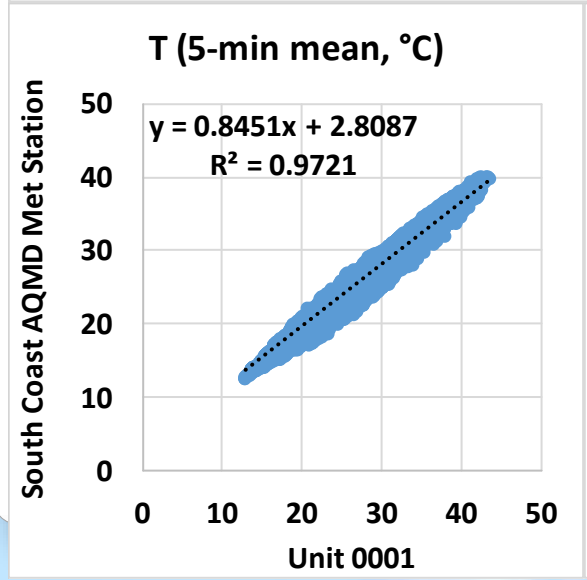
	Average of 3 Sensors, NO_2		Polludrone Smart vs FRM, NO_2						FRM NO_2 (ppb)		
	Average (ppb)	SD (ppb)	R^2	Slope	Intercept	MBE[1] (ppb)	MAE[2] (ppb)	RMSE[3] (ppb)	FRM Average	FRM SD	Range during the field evaluation
5-min	35.5	34.4	0.002 to 0.03	-0.06 to -0.01	12.0 to 14.5	20.0 to 28.7	20.6 to 29.1	33.6 to 60.0	11.4	8.3	1.3 to 58.0
1-hr	35.6	29.4	0.003 to 0.04	-0.07 to -0.01	12.2 to 14.8	19.4 to 28.2	19.8 to 28.5	31.6 to 49.0	11.5	8.1	1.5 to 51.4
24-hr	35.7	10.9	0.01 to 0.10	0.03 to 0.12	7.1 to 10.9	20.2 to 29.0	22.1 to 26.9	22.5 to 31.2	11.4	4.4	3.0 to 20.9

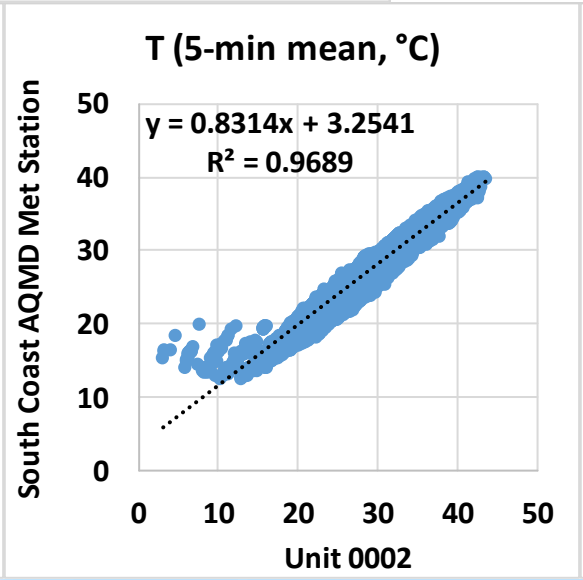
[1] Mean Bias Error (MBE): the difference between the sensors and the reference instruments. MBE indicates the tendency of the sensors to underestimate (negative MBE values) or overestimate (positive MBE values).
[2] Mean Absolute Error (MAE): the absolute difference between the sensors and the reference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

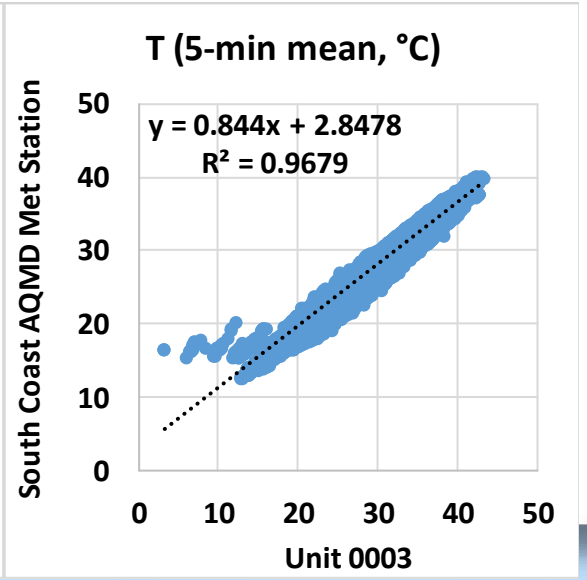
Oizom Polludrone Smart vs South Coast AQMD Met Station (Temp; 5-min mean)



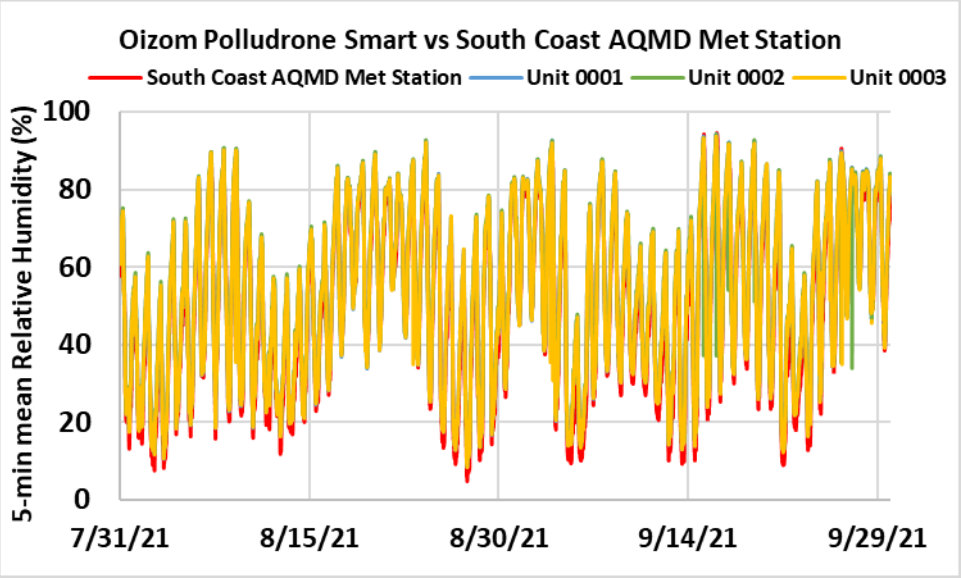
- The Polludrone Smart sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data (R^2 ~ 0.97)
- Overall, the Polludrone Smart temperature measurements overestimated the corresponding South Coast AQMD Met Station data
- The Polludrone Smart sensors seemed to track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



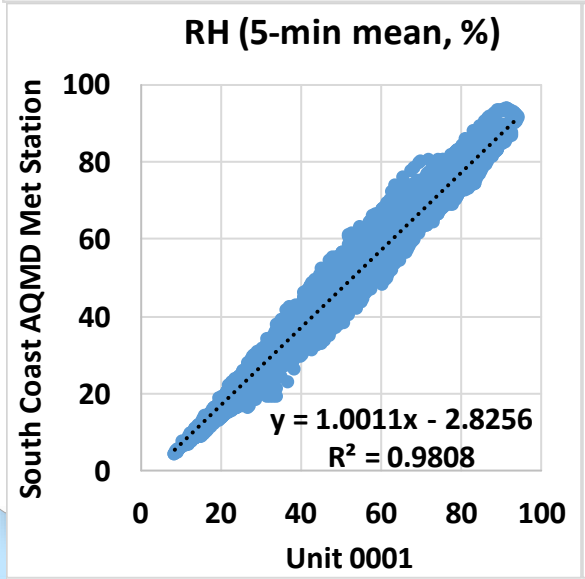


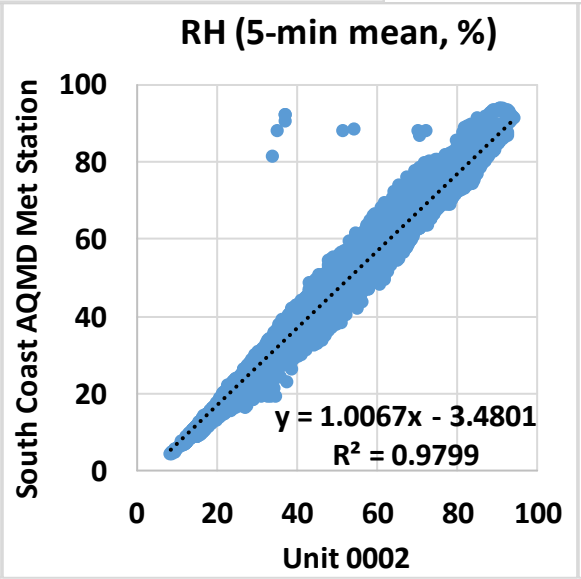


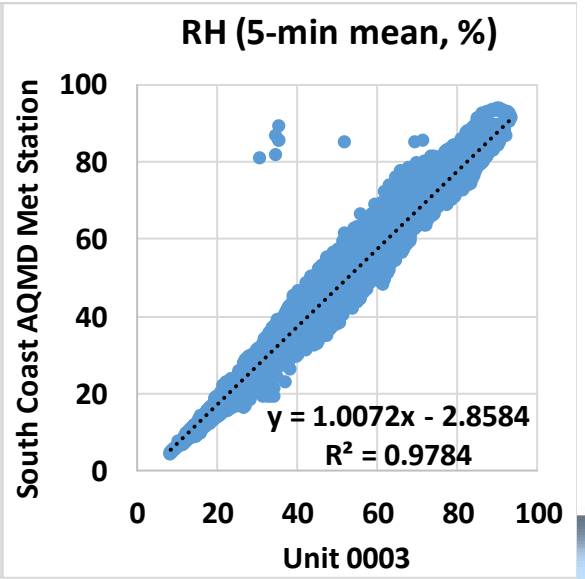
Oizom Polludrone Smart vs South Coast AQMD Met Station (RH; 5-min mean)



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







Discussion

- The average data recovery of three **Polludrone Smart** sensors for CO, ozone, NO, and NO_2 was ~98%.
- The absolute intra-model variability for CO, ozone, NO, and NO_2 was ~ 0.01 ppm, 3.3 ppb, 0.3 ppb, and 3.3 ppb, respectively.
- During the entire field deployment testing period:
  - CO sensors showed moderate to strong correlations with the FRM instrument ($0.63 < R^2 < 0.72$, 5-min mean) and underestimated the corresponding FRM data
  - Ozone sensors showed very weak correlations with the FEM instrument ($0.14 < R^2 < 0.23$, 5-min mean) and underestimated the corresponding FEM data
  - Nitric Oxide (NO) sensors showed very weak to weak correlations with the reference instrument ($0.10 < R^2 < 0.36$, 5-min mean) and overestimated the corresponding reference data
  - NO_2 sensors did not correlate with the FRM instrument ($0.001 < R^2 < 0.04$, 5-min mean) and overestimated the corresponding FRM data
  - Temperature and relative humidity sensors showed very strong correlations with the South Coast AQMD Met Station data (T: $R^2 \sim 0.97$ and RH: $R^2 \sim 0.98$) and overestimated T and RH data as recorded by the South Coast AQMD Met Station
- No sensor calibration was performed by AQ-SPEC prior to the beginning of this field testing.
- 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