Field Evaluation
Kunak Air Pro

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

- From 03/01/2024 to 05/01/2024, three **Kunak Air Pro** 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.

- Kunak Air Pro (*3 units tested*):
  - Gas Sensors: Electrochemical (Alphasense, non-FEM)
  - PM: Optical (Alphasense OPC-N3, non-FEM)
  - Each unit measures: CO (ppb), O_3 (ppb), NO (ppb), NO_2 (ppb), NO_x (ppb), $PM_{1.0}$ (µg/m^3), $PM_{2.5}$ (µg/m^3), PM_{10} (µg/m^3), T (°C), RH (%)
  - Unit cost (as-tested): $8,500 ($9400 w/ cloud)
  - Time resolution: 1-min
  - Units IDs: 1, 2, and 3

- **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
  - PM instrument (Teledyne API T640; FEM $PM_{2.5}$, hereinafter FEM T640); cost: $21,000
    - Time resolution: 1-min
    - Measures $PM_{1.0}$, $PM_{2.5}$, PM_{10} (µg/m^3)
  - PM instrument (Met One BAM; FEM $PM_{2.5}$ & PM_{10}); cost: $20,000
    - Time resolution: 1-hr
    - Measures $PM_{2.5}$, PM_{10} (µg/m^3)
  - Met station (T, RH, P, WS, WD); cost: ~$5,000
    - Time resolution: 1-min

Data Handling

- The Kunak Air Pro sensors possess configuration capabilities for a local calibration before the evaluation that were not performed. Testing with calibrated sensors may achieve different results.
- A baseline adjustment for NO_2 was not performed because the diurnal minima were zero in the sensor data that was retrieved from the online dashboard.
- Kunak's user manual outlines detailed instruction on calibration and baseline adjustment. Users are recommended to reach out to Kunak for assistance with sensor calibration/baseline adjustment using the Kunak online dashboard.
- All values below the manufacturer stated limit of detection were excluded from data analysis but did not count against data recovery

Carbon Monoxide (CO) in Kunak Air Pro

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 1, Unit 2 and Unit 3 was ~98.2%, ~97.8% and ~97.1%, respectively
- Values below manufacturer stated limit of detection were excluded from further analysis but do not count against data recovery

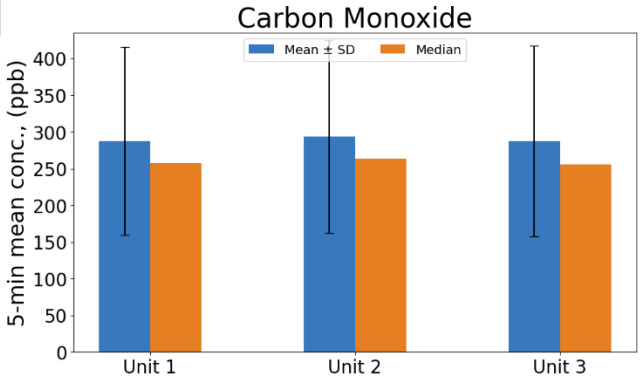
Kunak Air Pro; Intra-model variability

- Absolute intra-model variability was ~3.64 ppb for the CO measurements

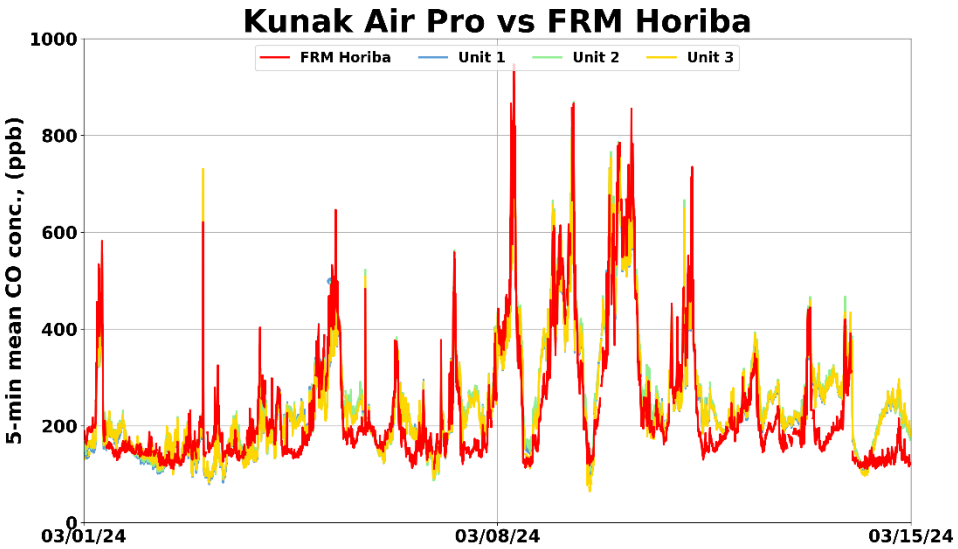
(calculated as the standard deviation of the three sensor means)

- Relative intra-model variability was ~1.26% for the CO measurements

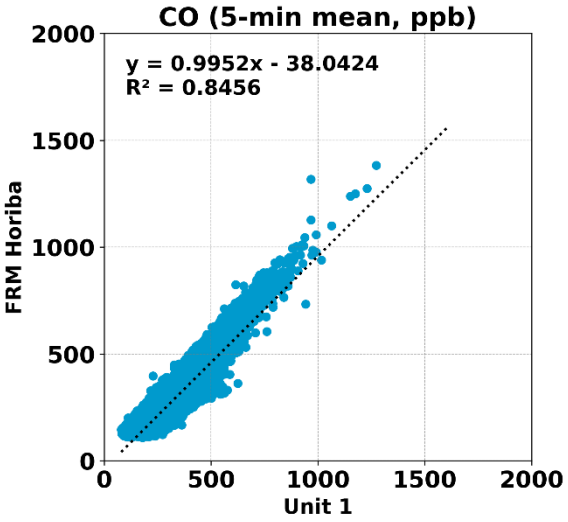
(calculated as the absolute intra-model variability relative to the mean of the three sensor means)

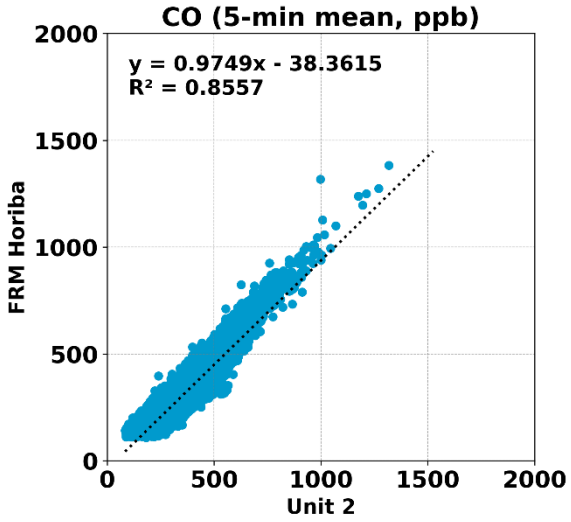


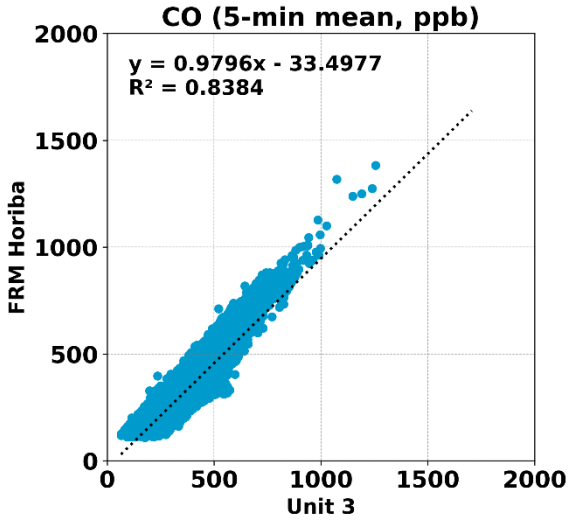
Kunak Air Pro vs FRM Horiba (CO; 5-min mean)



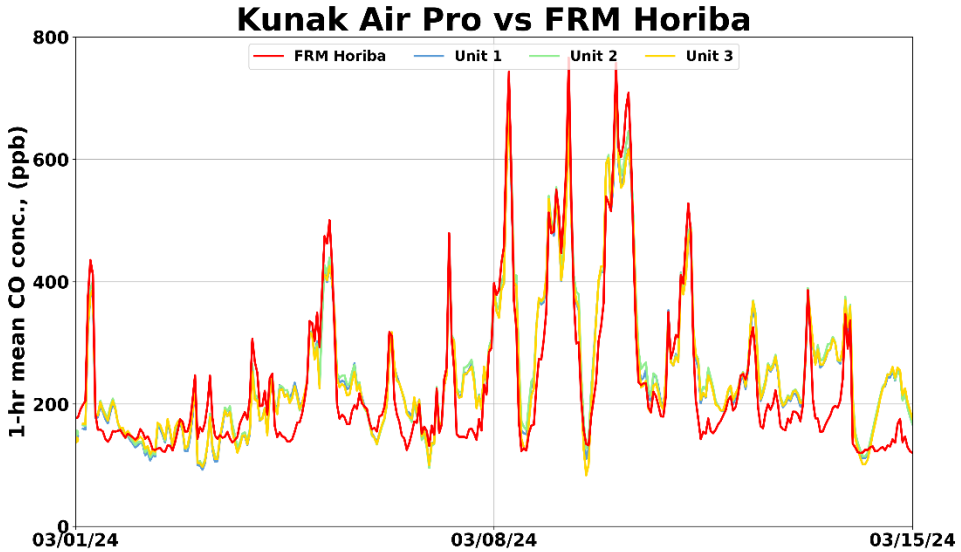
- The Kunak Air Pro sensors showed strong correlation with the corresponding FRM Horiba CO data ($0.83 < R^2 < 0.86$)
- Overall, the Kunak Air Pro sensors overestimated the CO concentration as measured by the FRM Horiba CO instrument
- The Kunak Air Pro sensors seemed to track the diurnal CO variations as recorded by the FRM Horiba instrument







Kunak Air Pro vs FRM Horiba (CO; 1-hr mean)



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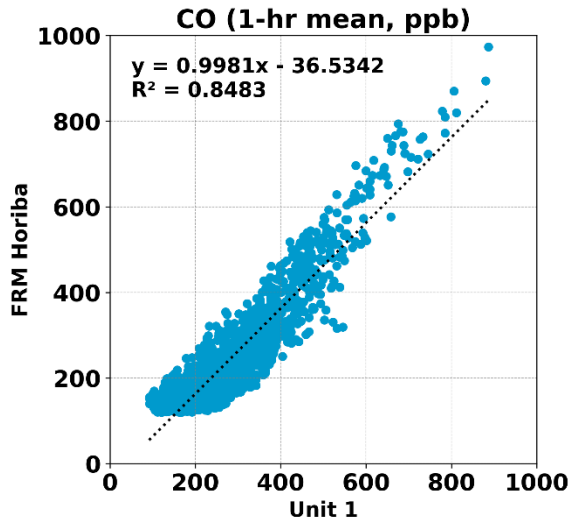
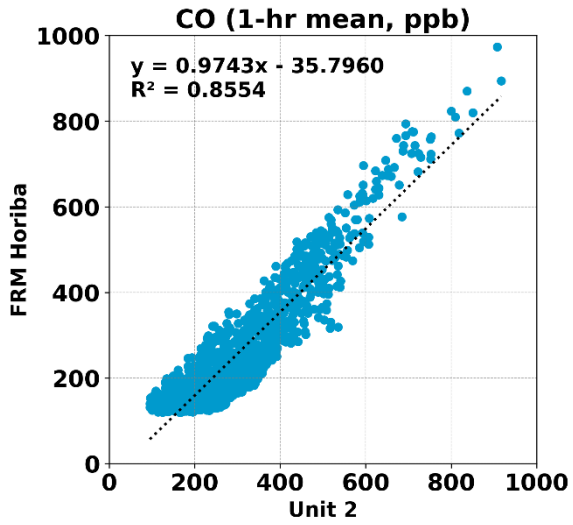
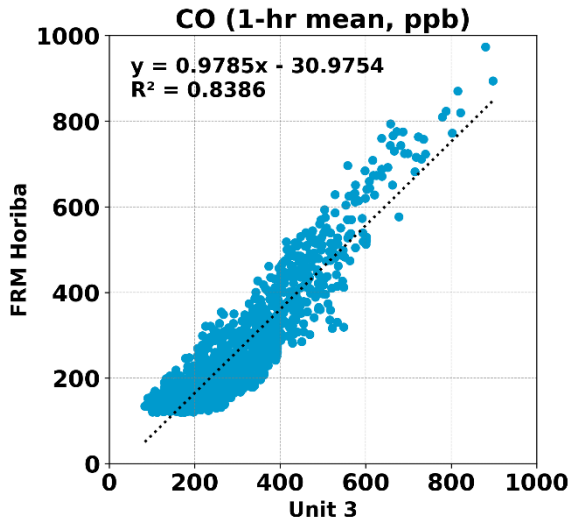
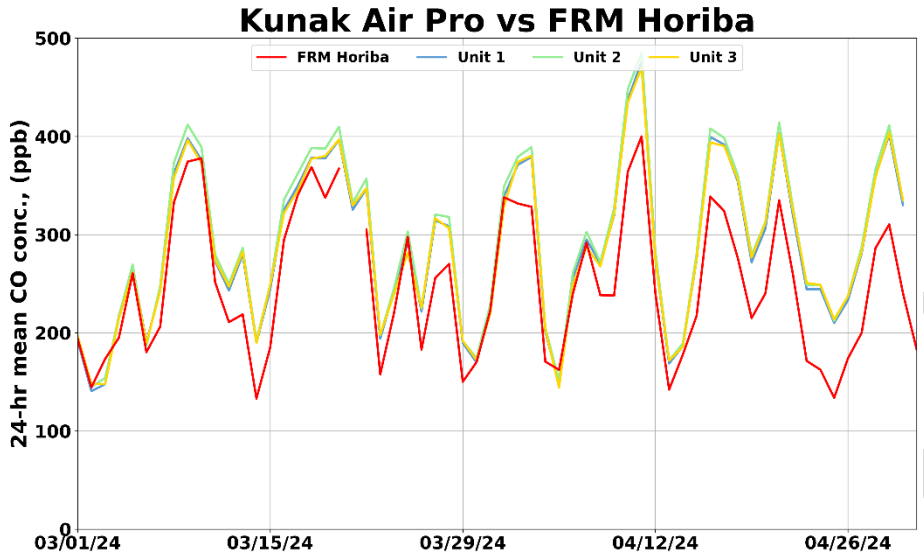


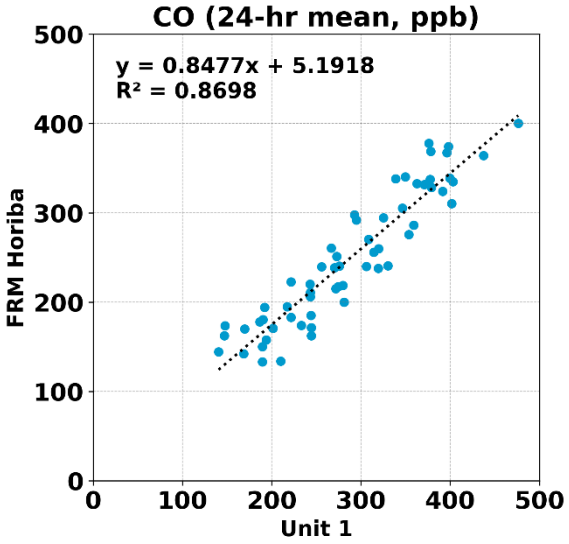


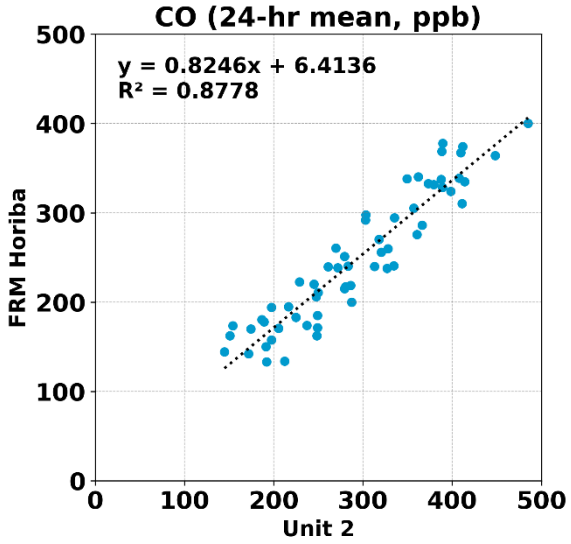


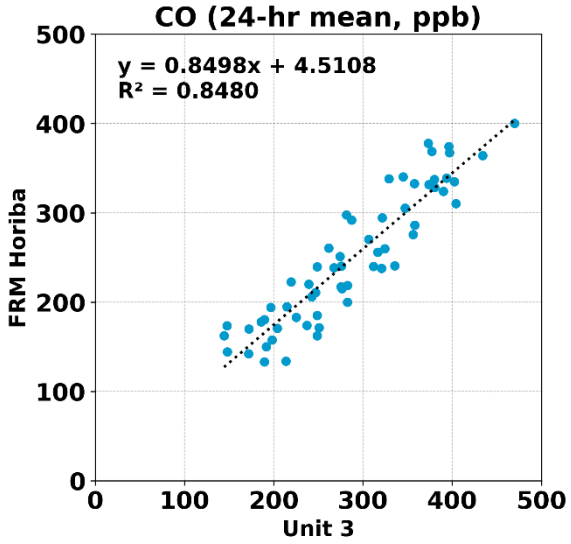
Kunak Air Pro vs FRM Horiba (CO; 24-hr mean)



- The Kunak Air Pro sensors showed strong correlation with the corresponding FRM Horiba CO data ($0.84 < R^2 < 0.88$)
- Overall, the Kunak Air Pro sensors overestimated the CO concentration as measured by the FRM Horiba CO instrument
- The Kunak Air Pro sensors seemed to track the daily CO variations as recorded by the FRM Horiba instrument







Summary: CO

	Average of 3 Sensors, CO		Kunak Air Pro vs FRM Horiba, CO						FRM Horiba, CO (ppb)		
	Average (ppb)	SD (ppb)	R^2	Slope	Intercept	MBE[1] (ppb)	MAE[2] (ppb)	RMSE[3] (ppb)	FRM Horiba Average	FRM Horiba SD	Range during the field evaluation
5-min	290.0	129.6	0.84 to 0.86	0.97 to 1.00	-38.4 to -33.5	39.4 to 45.7	54.6 to 57.5	66.7 to 69.6	247.3	137.2	108.3 to 1382.1
1-hr	290.1	125.1	0.84 to 0.86	0.97 to 1.00	-36.5 to -31.0	37.1 to 43.3	52.4 to 55.0	64.0 to 67.0	250.5	134.0	119.7 to 973.3
24-hr	290.2	81.6	0.85 to 0.88	0.82 to 0.85	4.5 to 6.4	38.6 to 45.1	40.4 to 46.2	48.4 to 54.0	248.8	74.2	133.0 to 400.0

[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.

Ozone (O_3) in Kunak Air Pro

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 1, Unit 2 and Unit 3 was ~97.6%, ~97.4% and ~96.6%, respectively
- Values below manufacturer stated limit of detection were excluded from further analysis but do not count against data recovery

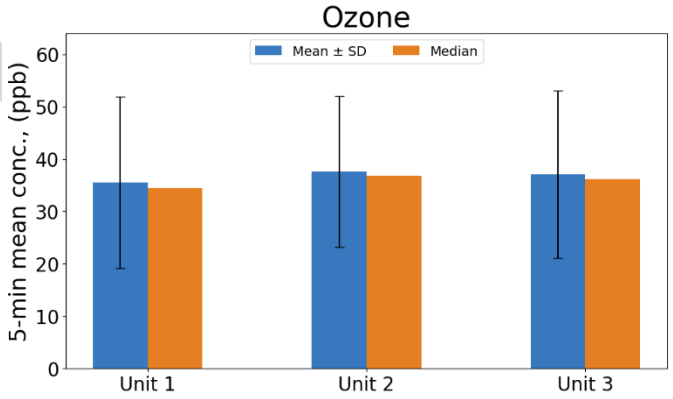
Kunak Air Pro; Intra-model variability

- Absolute intra-model variability was ~1.09 ppb for the ozone measurements

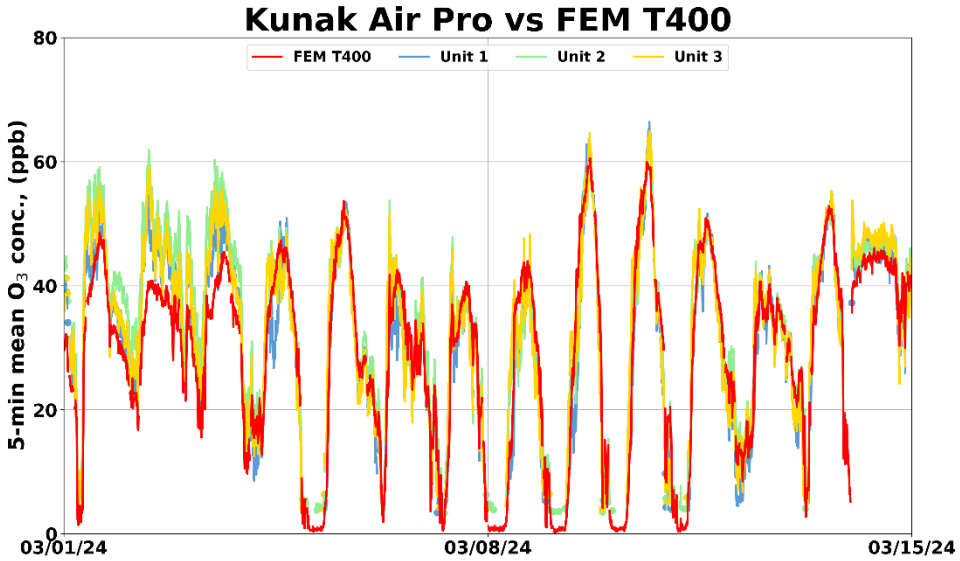
(calculated as the standard deviation of the three sensor means)

- Relative intra-model variability was ~2.97% for the ozone measurements

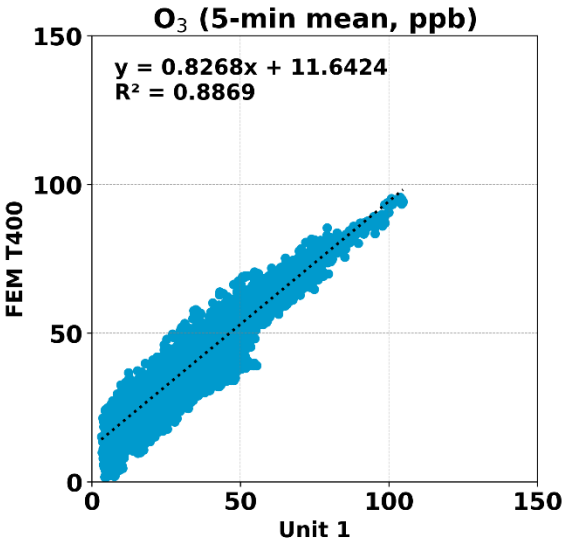
(calculated as the absolute intra-model variability relative to the mean of the three sensor means)

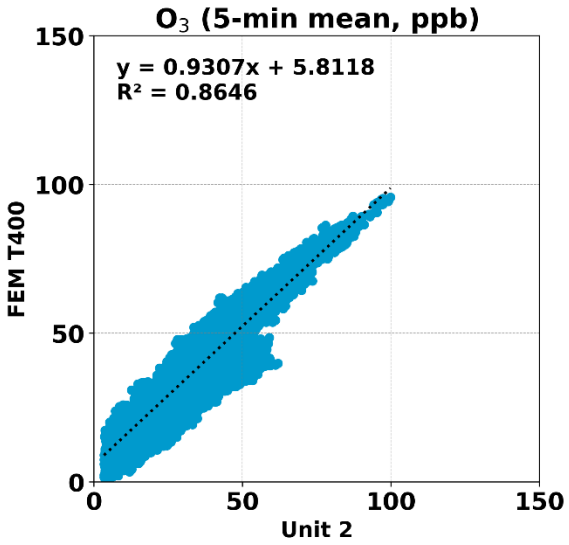


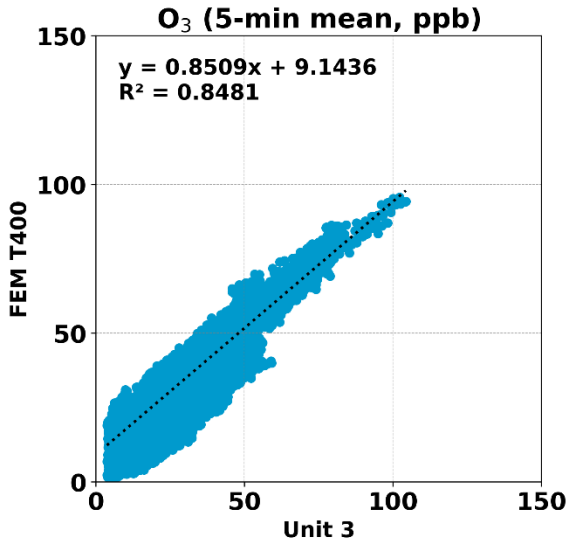
Kunak Air Pro vs FEM T400 (Ozone; 5-min mean)



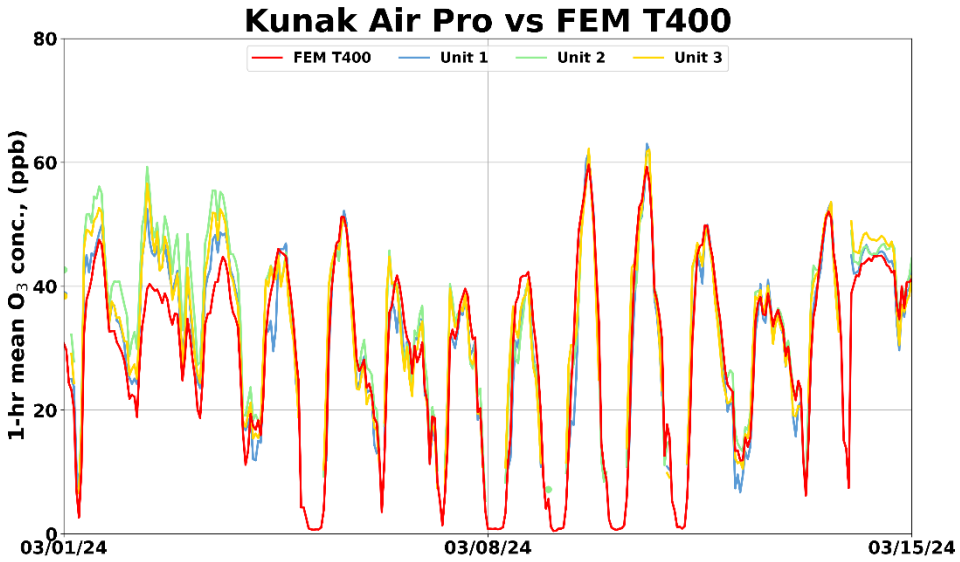
- The Kunak Air Pro sensors showed strong correlation with the corresponding FEM T400 ozone data ($0.84 < R^2 < 0.89$)
- Overall, the Kunak Air Pro sensors underestimated the ozone concentration as measured by the FEM T400 ozone instrument
- The Kunak Air Pro sensors seemed to track the diurnal ozone variations as recorded by the FEM T400 instrument



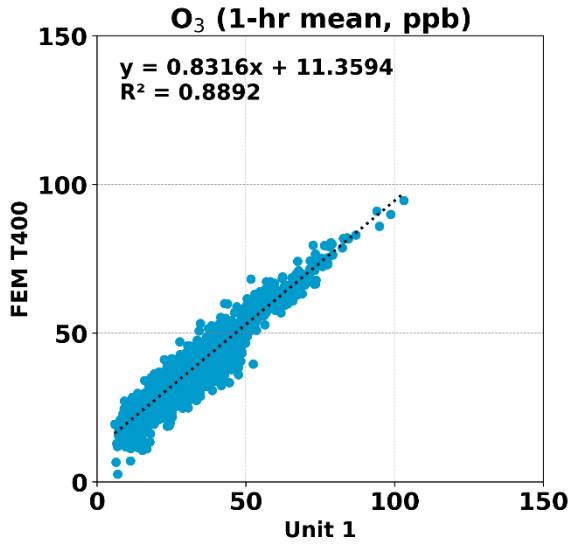


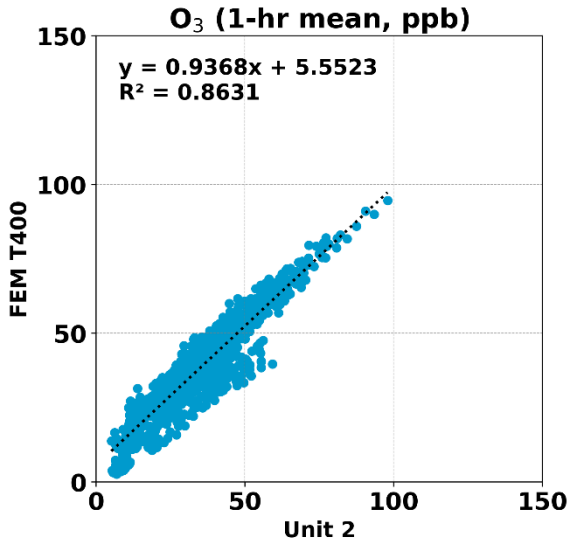


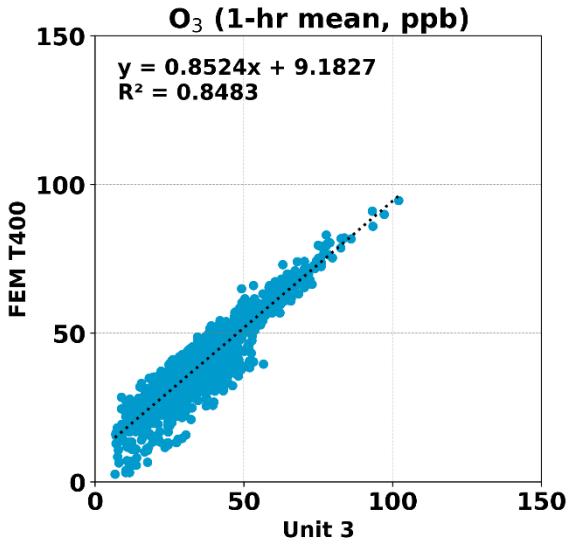
Kunak Air Pro vs FEM T400 (Ozone; 1-hr mean)



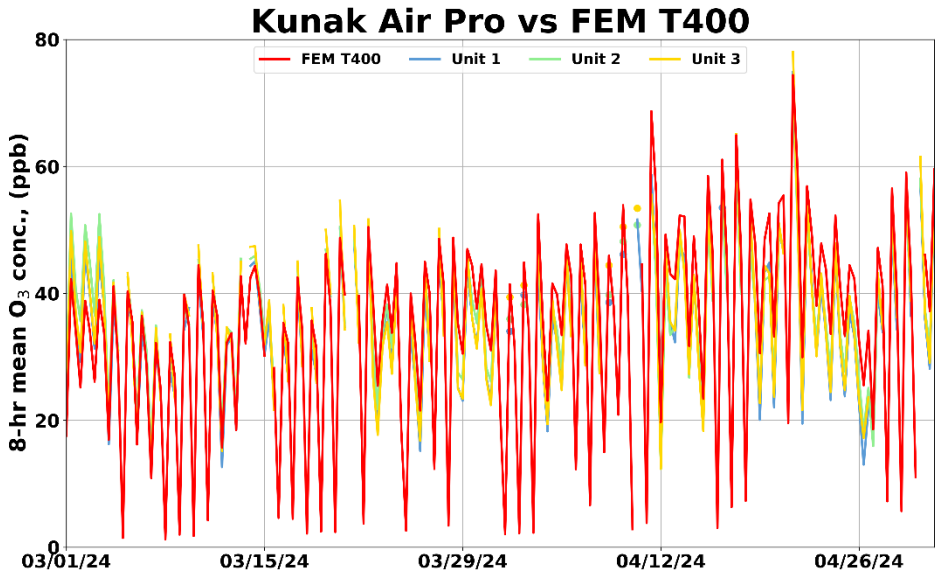
- The Kunak Air Pro sensors showed strong correlation with the corresponding FEM T400 ozone data ($0.84 < R^2 < 0.89$)
- Overall, the Kunak Air Pro sensors underestimated the ozone concentration as measured by the FEM T400 ozone instrument
- The Kunak Air Pro sensors seemed to track the diurnal ozone variations as recorded by the FEM T400 instrument



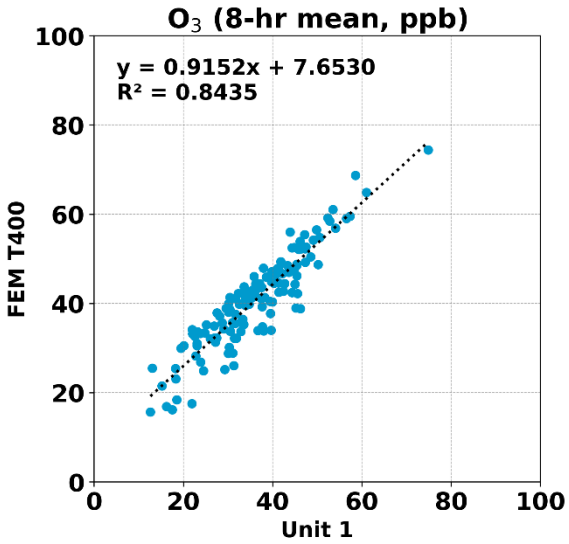


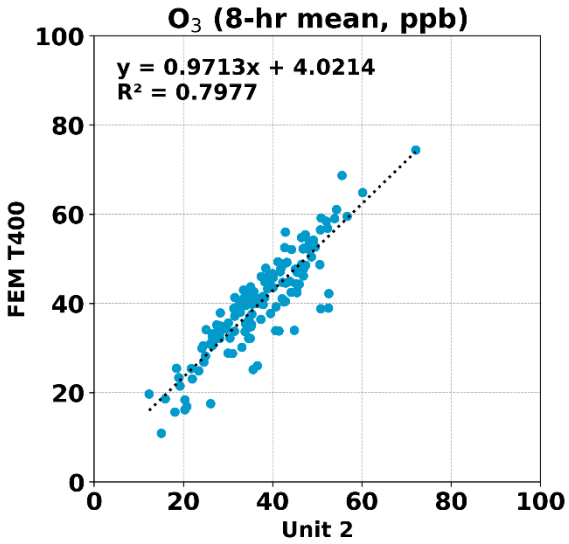


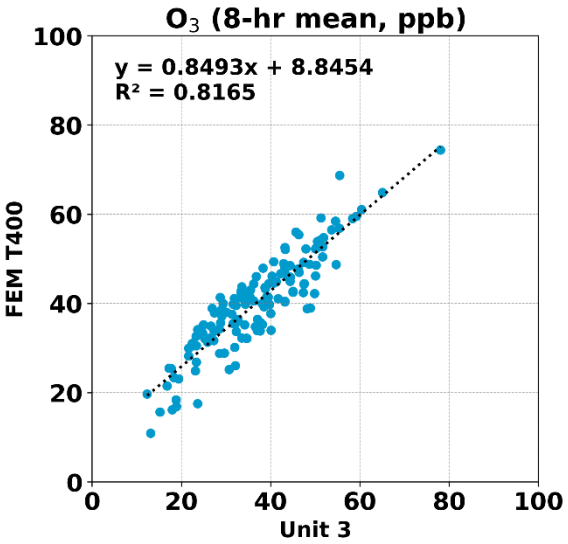
Kunak Air Pro vs FEM T400 (Ozone; 8-hr mean)



- The Kunak Air Pro sensors showed strong correlation with the corresponding FEM T400 ozone data ($0.79 < R^2 < 0.85$)
- Overall, the Kunak Air Pro sensors underestimated the ozone concentration as measured by the FEM T400 ozone instrument
- The Kunak Air Pro sensors seemed to track the daily ozone variations as recorded by the FEM T400 instrument







Summary: Ozone

	Average of 3 Sensors, Ozone		Kunak Air Pro 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	36.0	16.2	0.85 to 0.89	0.83 to 0.93	5.8 to 11.6	-5.4 to -3.3	5.6 to 6.5	6.7 to 7.8	35.0	19.2	0.1 to 95.7
1-hr	36.5	15.6	0.85 to 0.89	0.83 to 0.94	5.6 to 11.4	-5.3 to -3.2	5.5 to 6.3	6.5 to 7.6	33.9	19.2	0.5 to 94.6
8-hr	37.0	10.9	0.80 to 0.84	0.85 to 0.97	4.0 to 8.8	-4.6 to -3.0	4.9 to 5.4	5.8 to 6.3	34.0	16.3	1.2 to 74.4

[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.

Nitrogen Dioxide (NO_2) in Kunak Air Pro

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 1, Unit 2 and Unit 3 was ~97.6%, ~97.4% and ~96.6%, respectively
- Values below manufacturer stated limit of detection were excluded from further analysis but do not count against data recovery

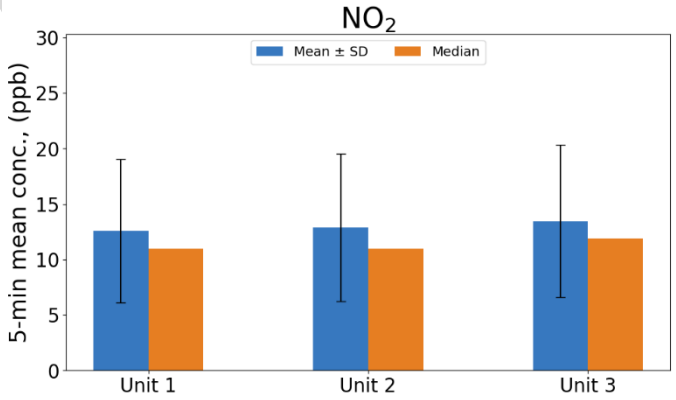
Kunak Air Pro; Intra-model variability

- Absolute intra-model variability was ~0.45 ppb for the NO_2 measurements

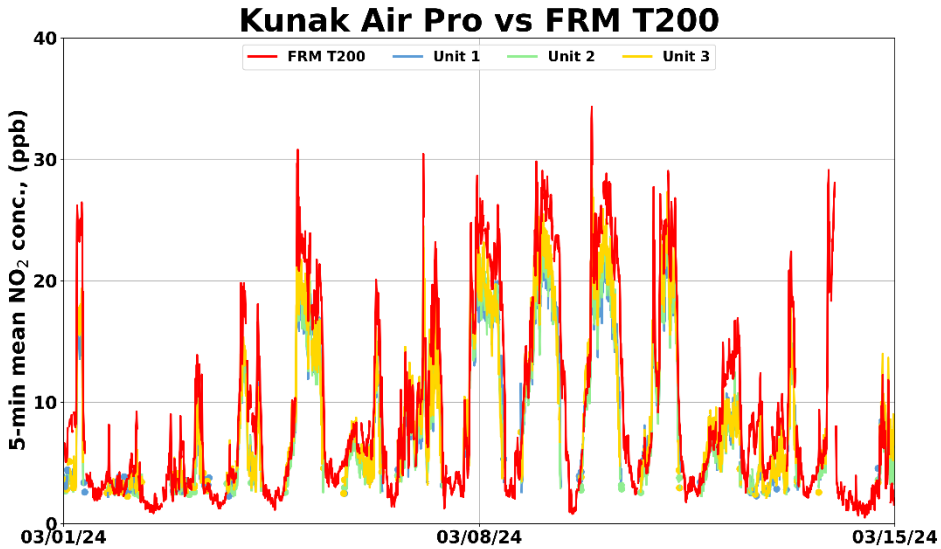
(calculated as the standard deviation of the three sensor means)

- Relative intra-model variability was ~3.47% for the NO_2 measurements

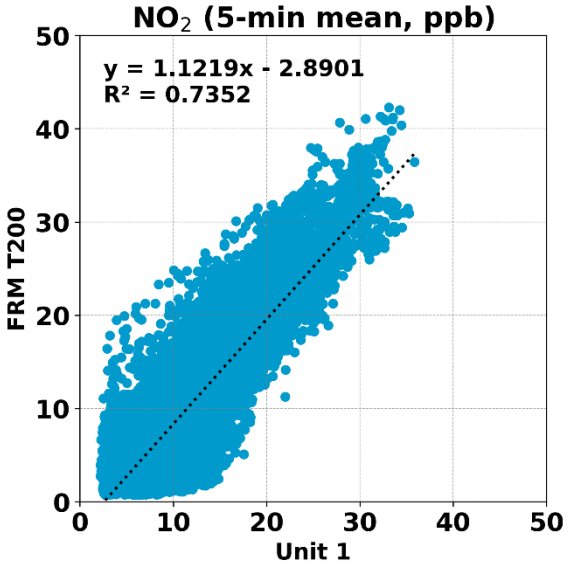
(calculated as the absolute intra-model variability relative to the mean of the three sensor means)

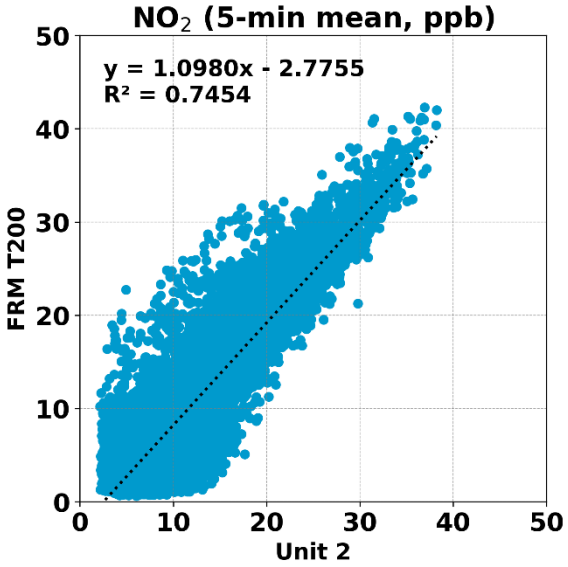


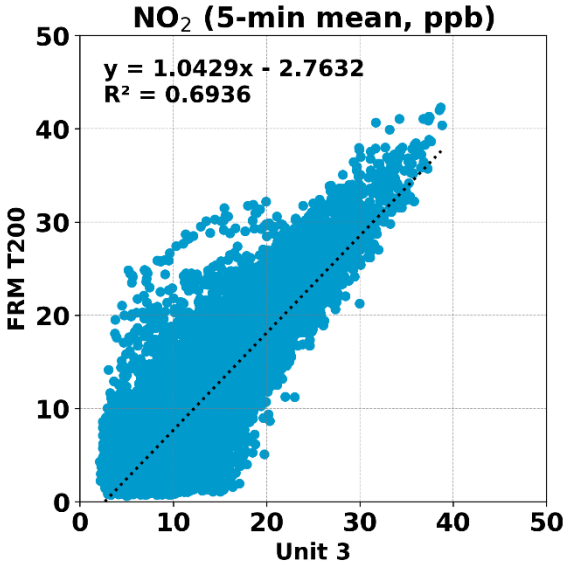
Kunak Air Pro vs FRM T200 (NO_2; 5-min mean)



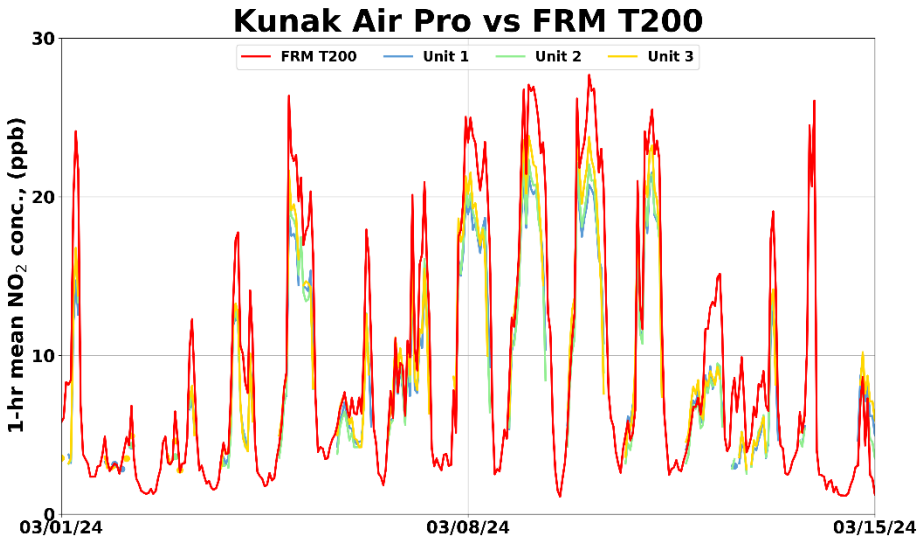
- The Kunak Air Pro sensors showed moderate to strong correlations with the corresponding FRM T200 NO_2 data ($0.69 < R^2 < 0.75$)
- Overall, the Kunak Air Pro sensors overestimated the NO_2 concentration as measured by the FRM T200 instrument
- The Kunak Air Pro sensors seemed to track the diurnal NO_2 variations as recorded by the FRM T200 instrument



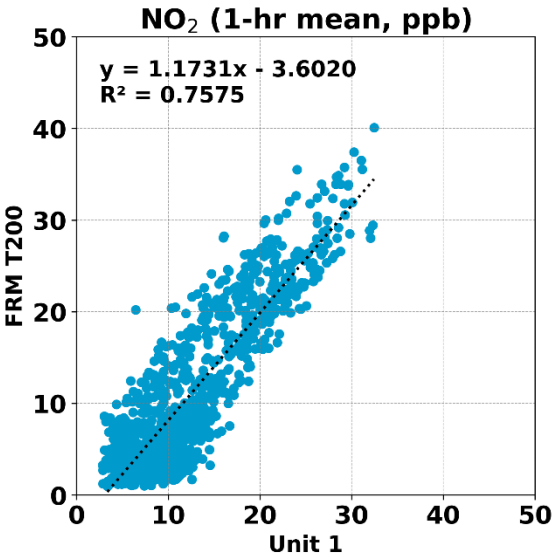


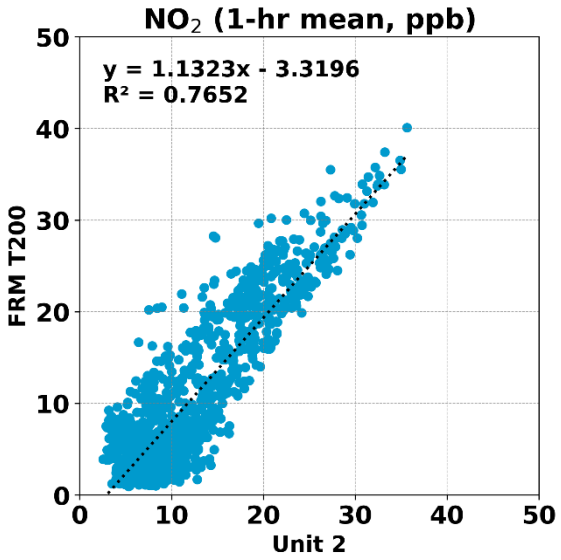


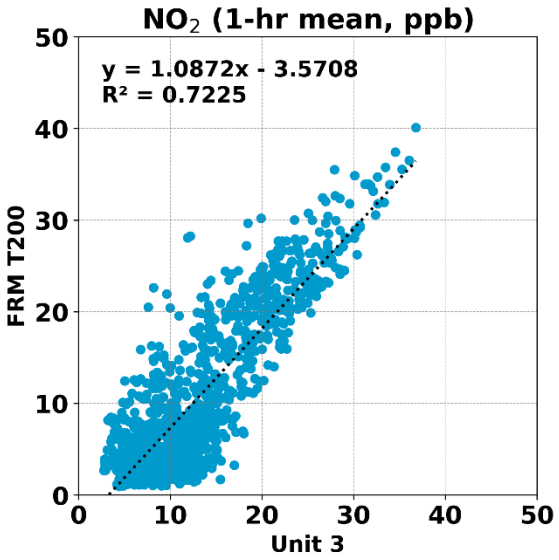
Kunak Air Pro vs FRM T200 (NO_2; 1-hr mean)



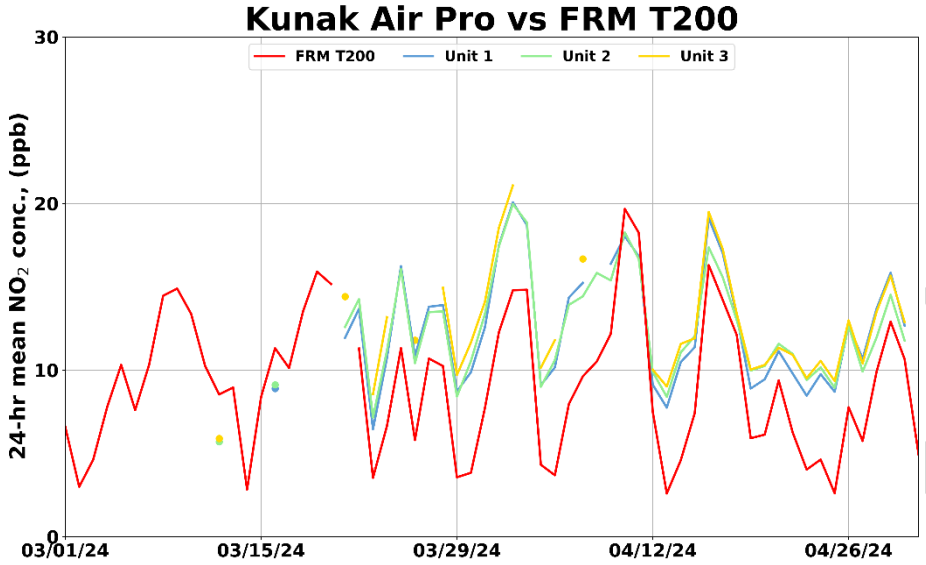
- The Kunak Air Pro sensors showed strong correlations with the corresponding FRM T200 NO_2 data ($0.72 < R^2 < 0.77$)
- Overall, the Kunak Air Pro sensors overestimated the NO_2 concentration as measured by the FRM T200 instrument
- The Kunak Air Pro sensors seemed to track the diurnal NO_2 variations as recorded by the FRM T200 instrument



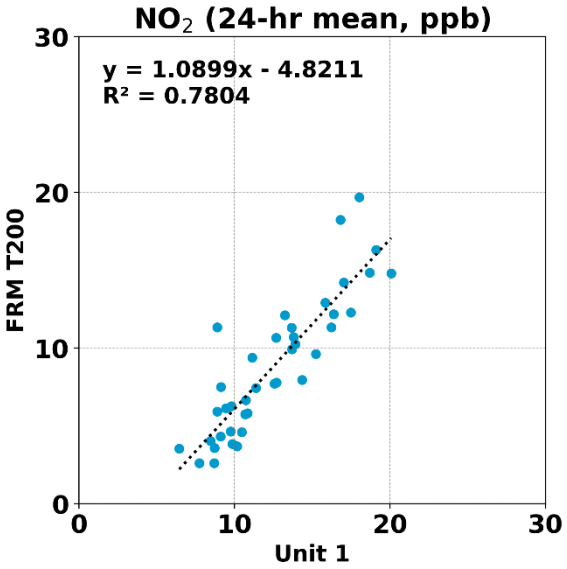


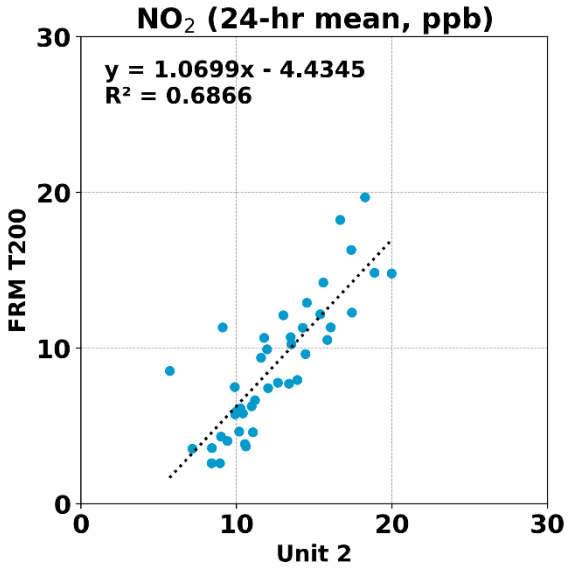


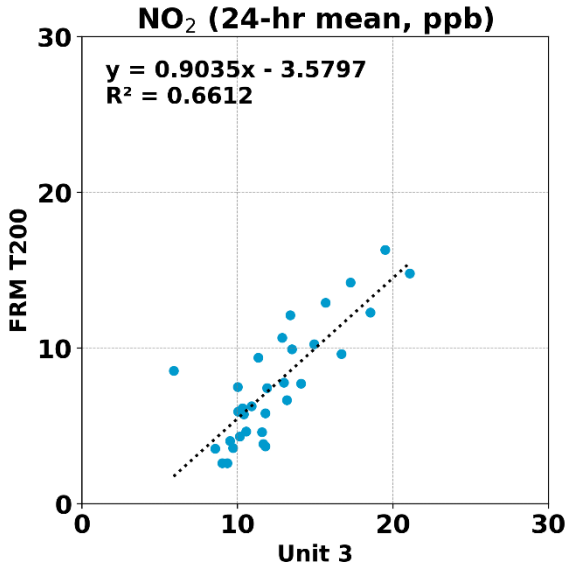
Kunak Air Pro vs FRM T200 (NO_2; 24-hr mean)



- The Kunak Air Pro sensors showed moderate to strong correlations with the corresponding FRM T200 NO_2 data ($0.66 < R^2 < 0.79$)
- Overall, the Kunak Air Pro sensors overestimated the NO_2 concentration as measured by the FRM T200 instrument
- The Kunak Air Pro 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		Kunak Air Pro 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	12.5	6.8	0.69 to 0.75	1.04 to 1.12	-2.9 to -2.8	1.4 to 2.2	3.9 to 4.3	4.6 to 5.2	9.1	8.1	0.5 to 42.3
1-hr	12.7	6.5	0.72 to 0.77	1.09 to 1.17	-3.6 to -3.3	1.5 to 2.4	3.8 to 4.3	4.5 to 5.1	9.4	8.1	1.0 to 40.1
24-hr	12.5	3.4	0.66 to 0.78	0.90 to 1.09	-4.8 to -3.6	3.6 to 4.8	3.9 to 4.9	4.2 to 5.3	9.2	4.2	2.6 to 19.7

[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.

Nitric Oxide (NO) in Kunak Air Pro

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 1, Unit 2 and Unit 3 was ~98.2%, ~ 97.8% and ~97.1%, respectively
- Values below manufacturer stated limit of detection were excluded from further analysis but do not count against data recovery
- Note: a significant portion of the sensor NO data were below the manufacturer stated limit of detection, therefore, the 24-hour average analysis was not done due to the lack of data points.

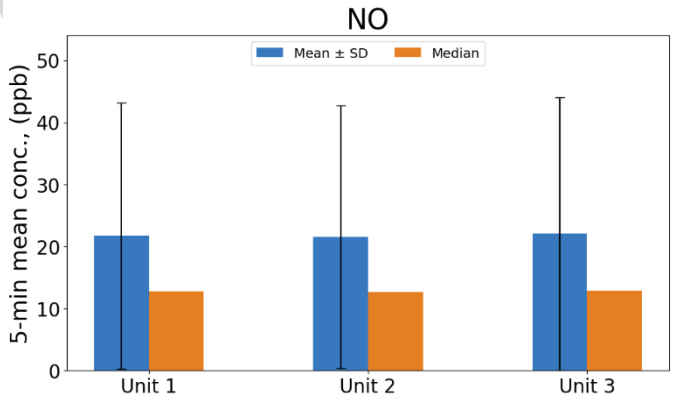
Kunak Air Pro; Intra-model variability

- Absolute intra-model variability was ~0.27 ppb for the NO measurements

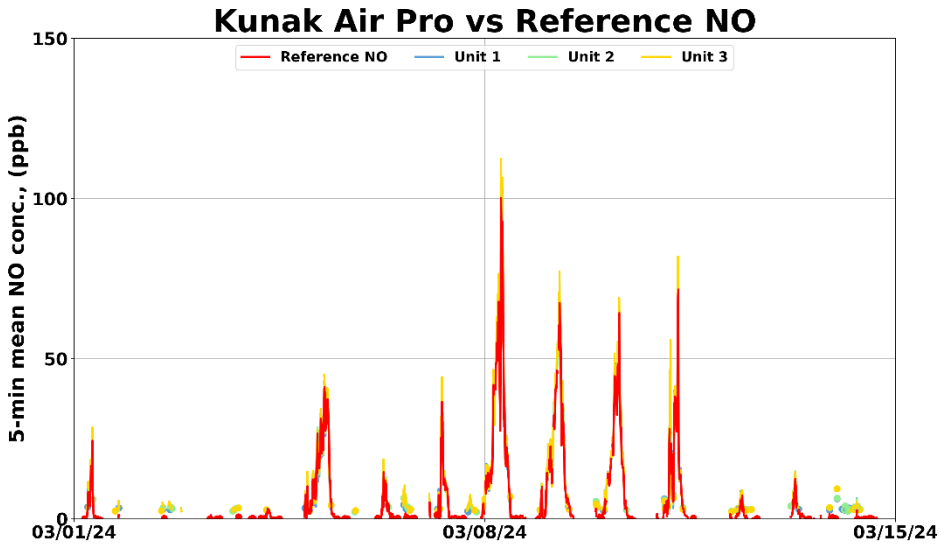
(calculated as the standard deviation of the three sensor means)

- Relative intra-model variability was ~1.24% for the NO measurements

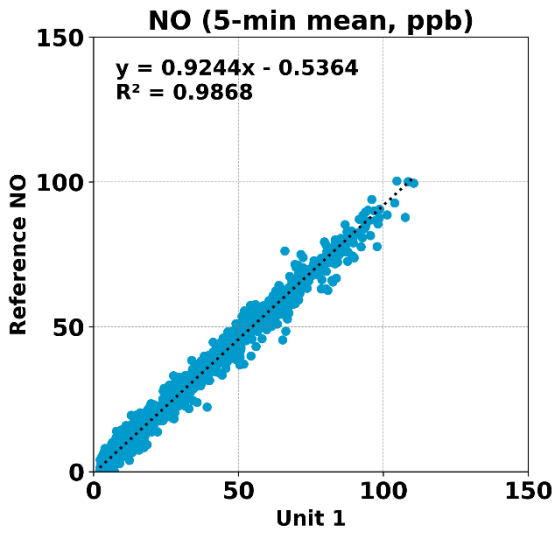
(calculated as the absolute intra-model variability relative to the mean of the three sensor means)

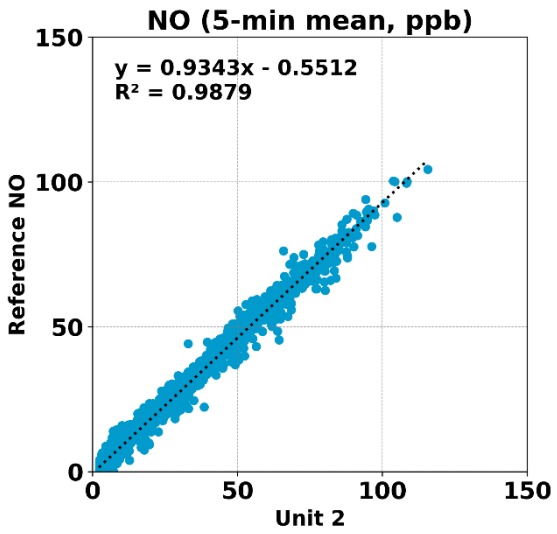


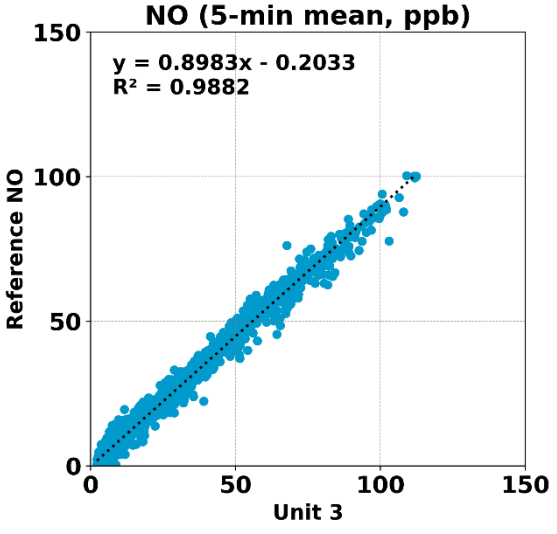
Kunak Air Pro vs Reference NO (5-min mean)



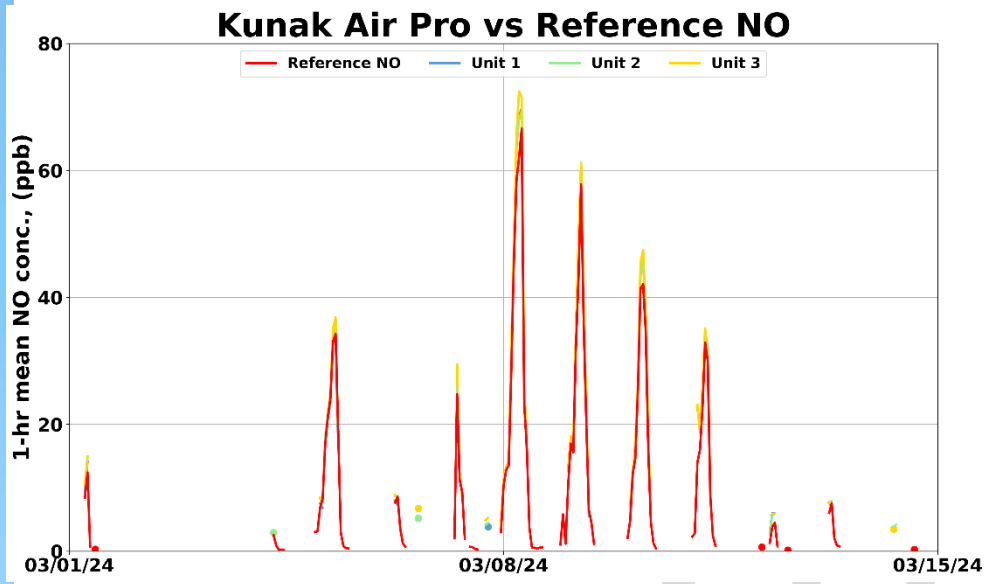
- The Kunak Air Pro sensors showed very strong correlations with the corresponding Reference NO data ($0.98 < R^2 < 0.99$)
- Overall, the Kunak Air Pro sensors overestimated the NO concentration as measured by the Reference NO instrument
- The Kunak Air Pro sensors seemed to track the diurnal NO variations as recorded by the Reference instrument



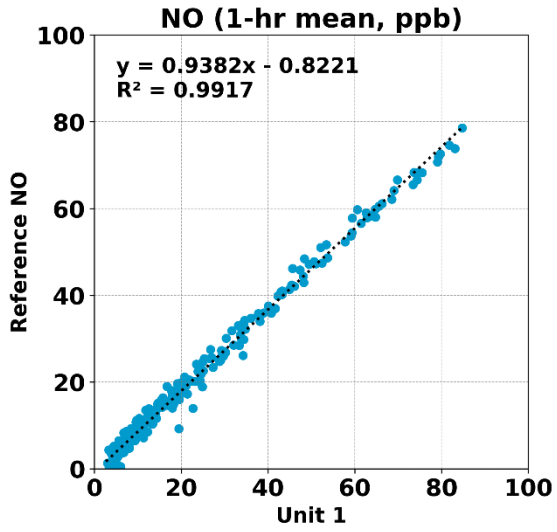


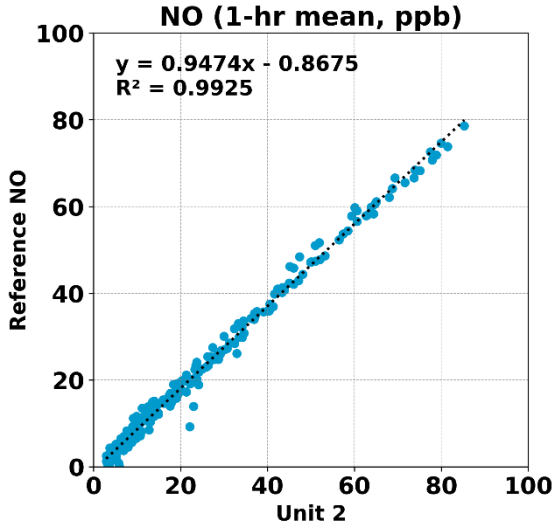


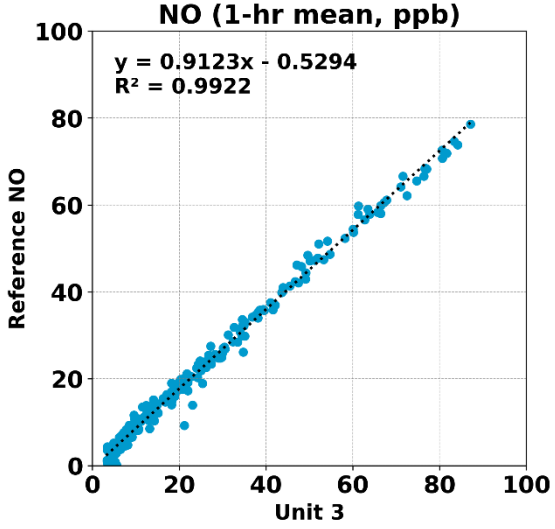
Kunak Air Pro vs Reference NO (1-hr mean)



- The Kunak Air Pro sensors showed very strong correlations with the corresponding Reference NO data ($0.99 < R^2 < 1.0$)
- Overall, the Kunak Air Pro sensors overestimated the NO concentration as measured by the Reference instrument
- The Kunak Air Pro sensors seemed to track the diurnal NO variations as recorded by the Reference instrument







Summary: NO

	Average of 3 Sensors, NO		Kunak Air Pro vs Reference NO						Reference NO (ppb)		
	Average (ppb)	SD (ppb)	R^2	Slope	Intercept	MBE[1] (ppb)	MAE[2] (ppb)	RMSE[3] (ppb)	Reference Average	Reference SD	Range during the field evaluation
5-min	19.4	21.0	0.99	0.90 to 0.93	-0.6 to -0.2	2.0 to 2.5	2.4 to 2.9	3.4 to 4.1	10.9	17.7	0.0 to 104.3
1-hr	22.5	20.8	0.99	0.91 to 0.95	-0.9 to -0.5	2.1 to 2.8	2.3 to 2.9	2.9 to 3.8	13.5	18.0	0.1 to 78.6

[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 Oxides (NO_x) in Kunak Air Pro

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_x from Unit 1, Unit 2 and Unit 3 was ~97.6%, ~97.4% and ~96.6%, respectively
- Values below manufacturer stated limit of detection were excluded from further analysis but do not count against data recovery

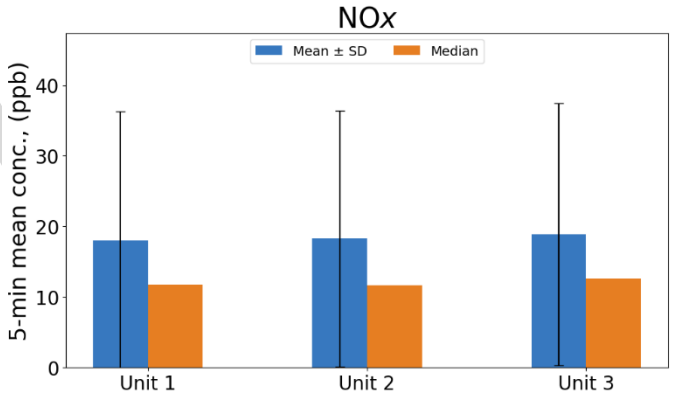
Kunak Air Pro; Intra-model variability

- Absolute intra-model variability was ~0.42 ppb for the NO_x measurements

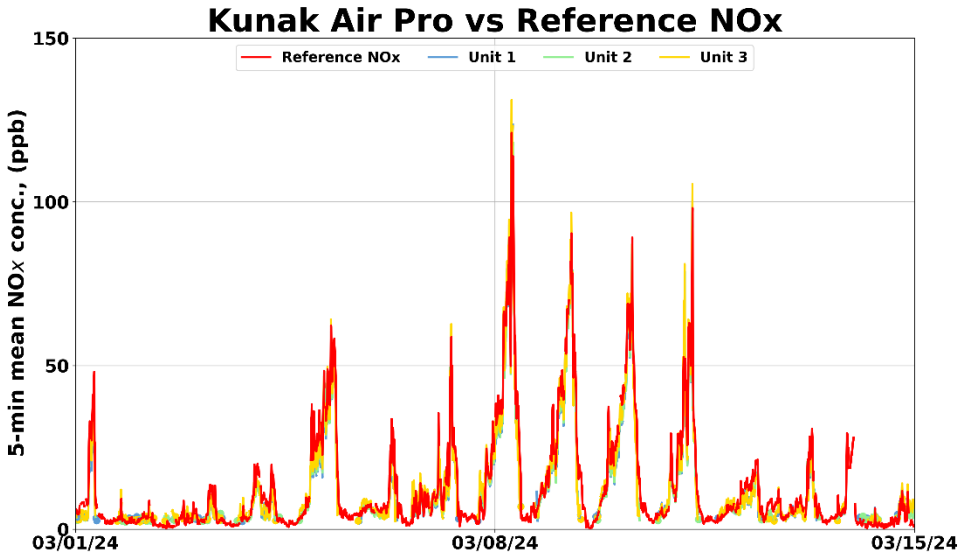
(calculated as the standard deviation of the three sensor means)

- Relative intra-model variability was ~2.28% for the NO_x measurements

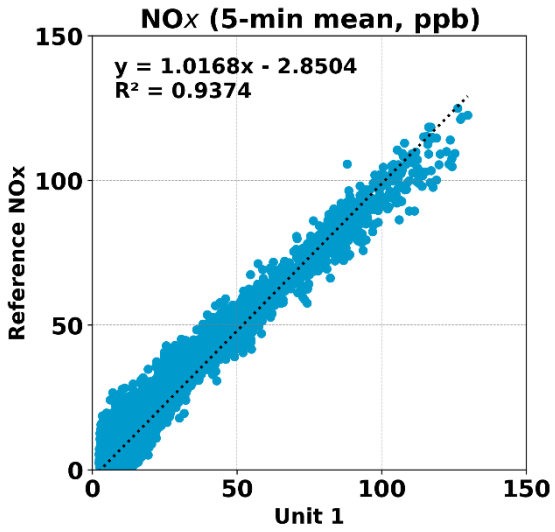
(calculated as the absolute intra-model variability relative to the mean of the three sensor means)

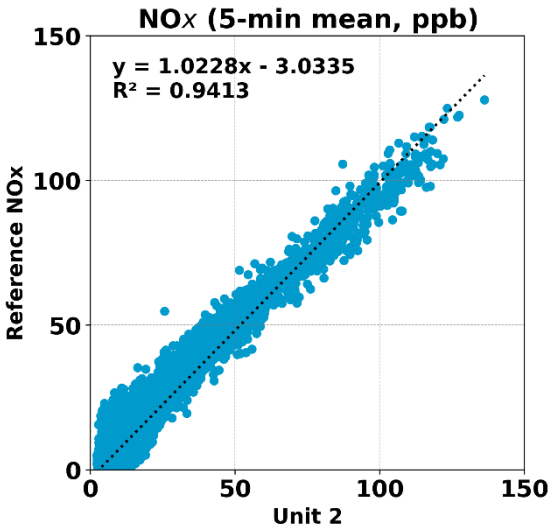


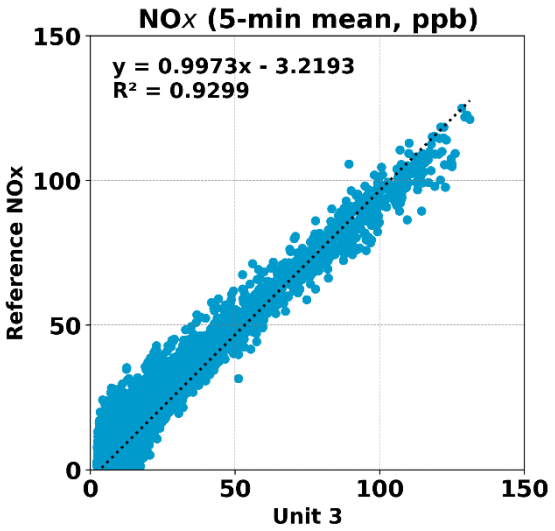
Kunak Air Pro vs Reference NO_x (5-min mean)



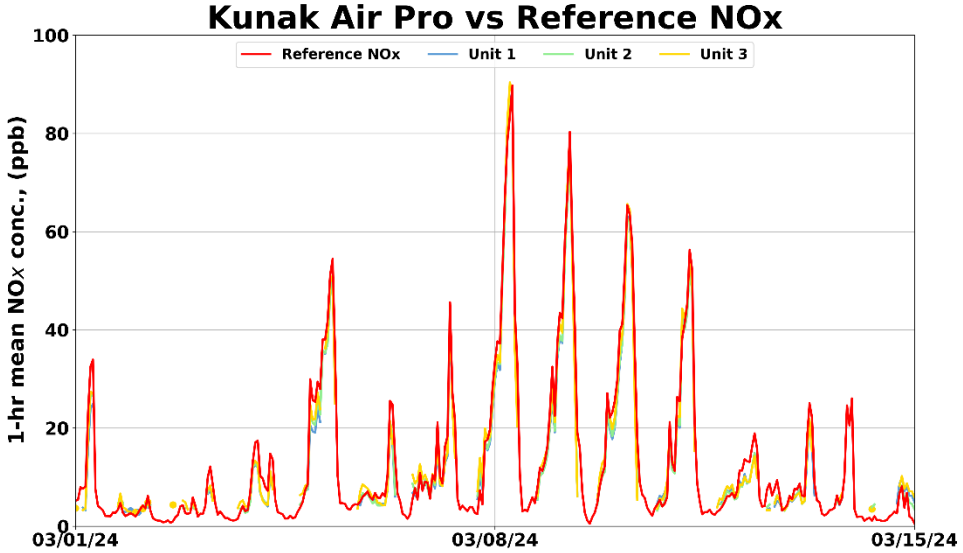
- The Kunak Air Pro sensors showed very strong correlations with the corresponding reference NO_x data ($0.92 < R^2 < 0.95$)
- Overall, the Kunak Air Pro sensors overestimated the NO_x concentration as measured by the reference instrument
- The Kunak Air Pro sensors seemed to track the diurnal NO_x variations as recorded by the reference instrument



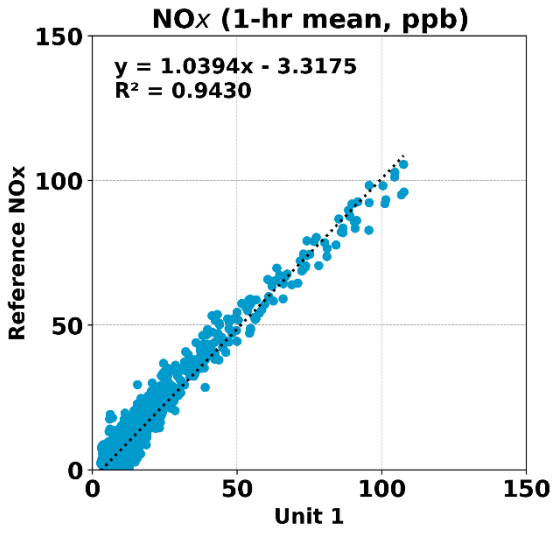


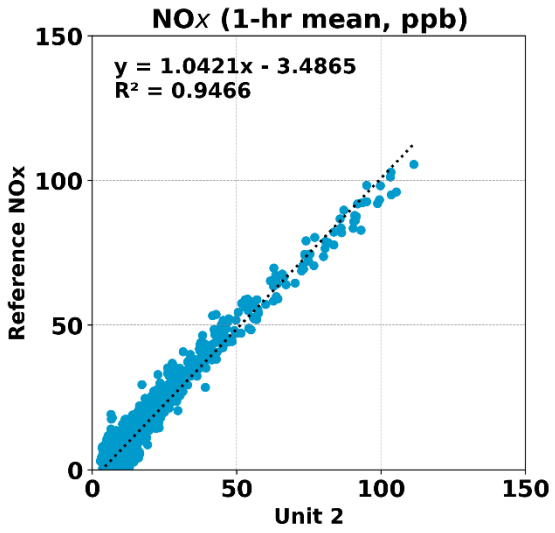


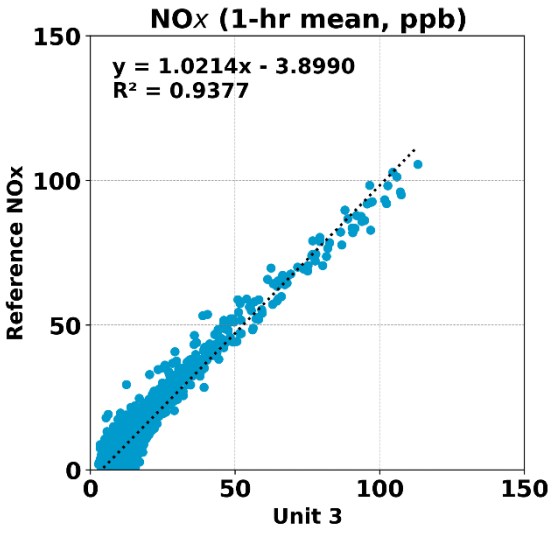
Kunak Air Pro vs Reference NO_x (1-hr mean)



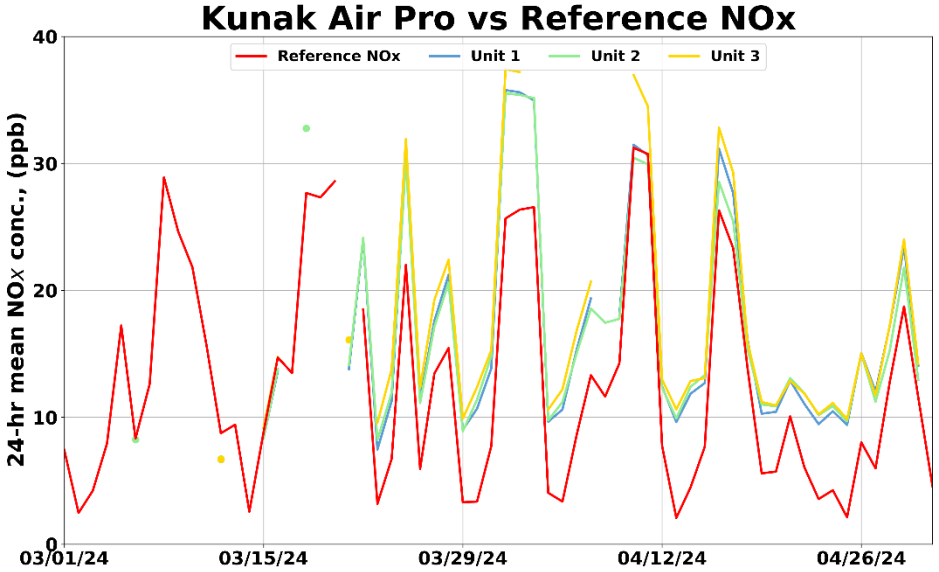
- The Kunak Air Pro sensors showed very strong correlations with the corresponding reference NO_x data ($0.93 < R^2 < 0.95$)
- Overall, the Kunak Air Pro sensors overestimated the NO_x concentration as measured by reference instrument
- The Kunak Air Pro sensors seemed to track the diurnal NO_x variations as recorded by reference instrument



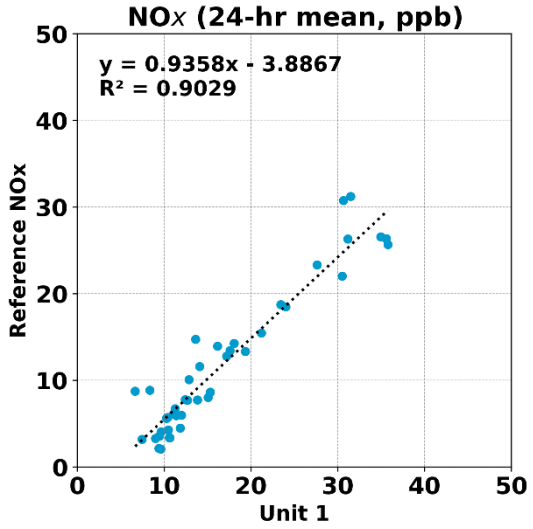


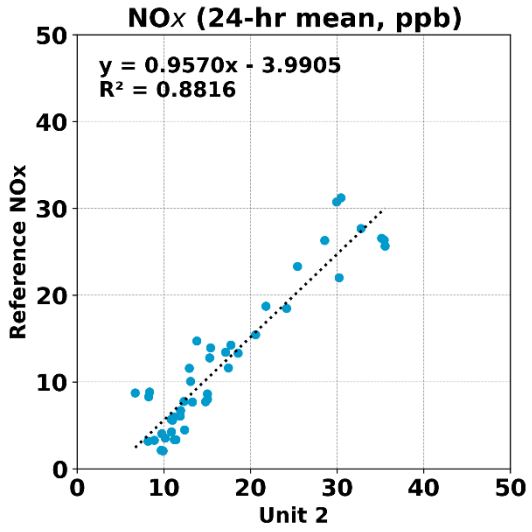


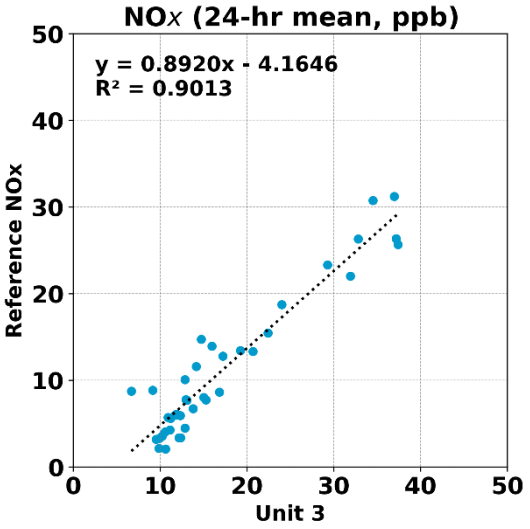
Kunak Air Pro vs Reference NO_x (24-hr mean)



- The Kunak Air Pro sensors showed strong to very strong correlations with the corresponding reference NO_x data ($0.88 < R^2 < 0.91$)
- Overall, the Kunak Air Pro sensors overestimated the NO_x concentration as measured by the reference NO_x instrument
- The Kunak Air Pro sensors seemed to track the daily NO_x variations as recorded by the reference NO_x instrument







Summary: NO_x

	Average of 3 Sensors, NOx		Kunak Air Pro vs Reference NOx						Reference NOx (ppb)		
	Average (ppb)	SD (ppb)	R^2	Slope	Intercept	MBE[1] (ppb)	MAE[2] (ppb)	RMSE[3] (ppb)	Reference Average	Reference SD	Range during the field evaluation
5-min	17.7	18.0	0.93 to 0.94	1.0 to 1.02	-3.2 to -2.9	2.6 to 3.3	4.5 to 5.0	5.4 to 6.1	12.6	17.9	0.1 to 127.8
1-hr	18.0	17.6	0.94 to 0.95	1.02 to 1.04	-3.9 to -3.3	2.6 to 3.5	4.4 to 4.9	5.2 to 5.9	12.9	17.4	0.4 to 105.6
24-hr	16.9	8.5	0.88 to 0.90	0.89 to 0.96	-4.2 to -3.9	4.7 to 6.0	4.9 to 6.1	5.5 to 6.6	12.8	8.8	2.1 to 31.2

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

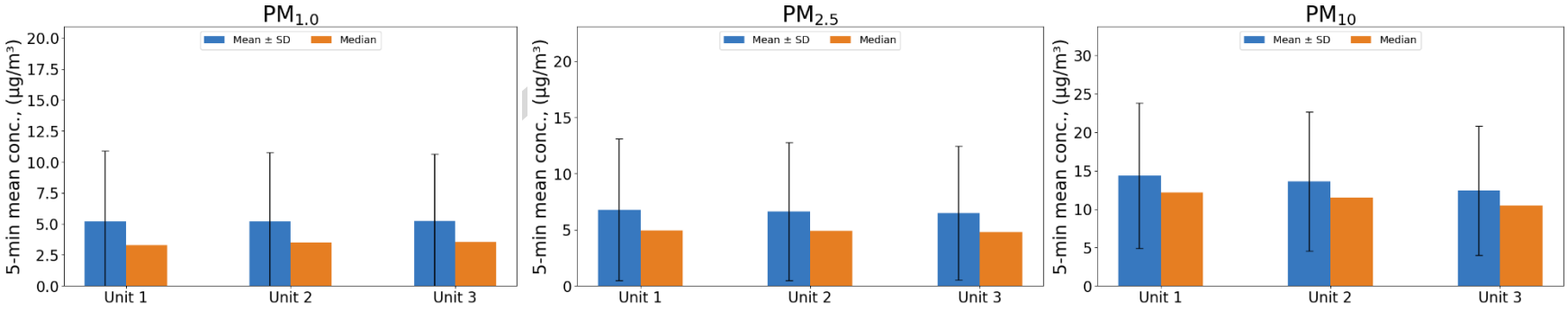
Particulate Matter (PM) in Kunak Air Pro

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 Unit 1, Unit 2 and Unit 3 was ~95.9% for all PM measurements
- Values below manufacturer stated limit of detection were excluded from further analysis but do not count against data recovery

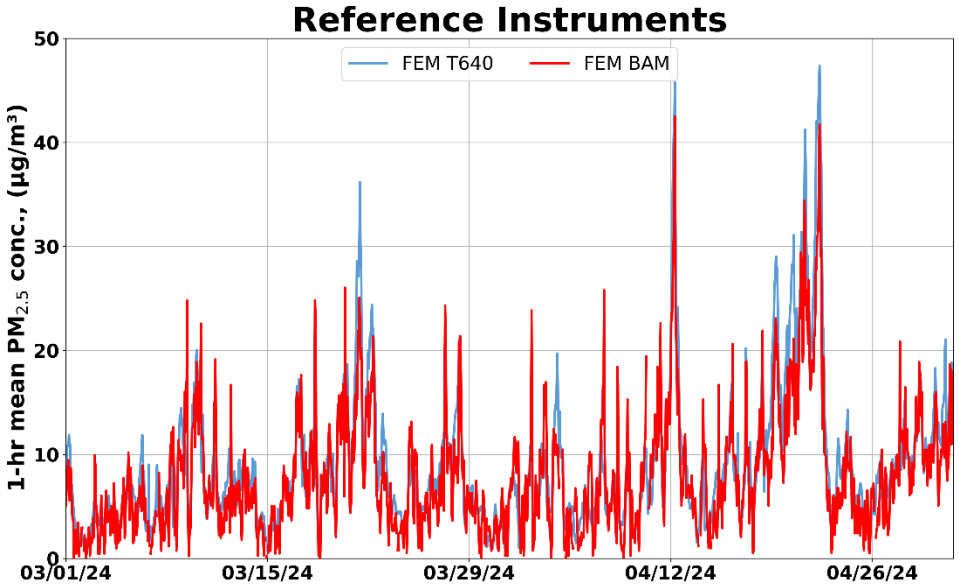
Kunak Air Pro; intra-model variability

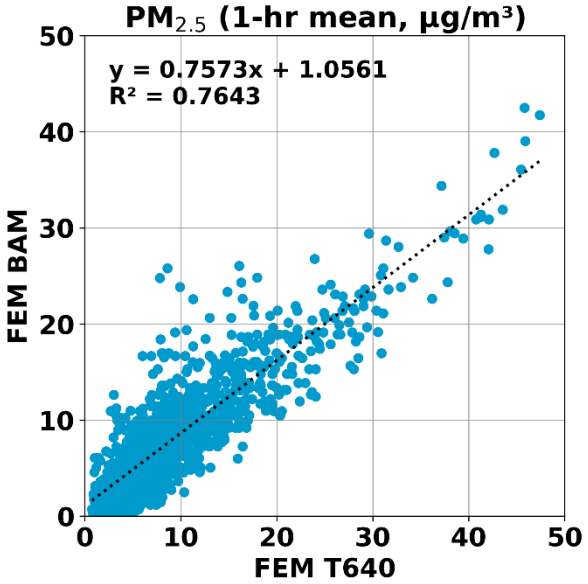
- Absolute intra-model variability was ~0.02, ~0.16 and ~0.99 µg/m3 for $PM_{1.0}$, $PM_{2.5}$ and PM_{10}, respectively (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was ~0.38%, ~2.41% and ~7.36% for $PM_{1.0}$, $PM_{2.5}$ and PM_{10}, respectively (calculated as the absolute intra-model variability relative to the mean of the three sensor means)



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

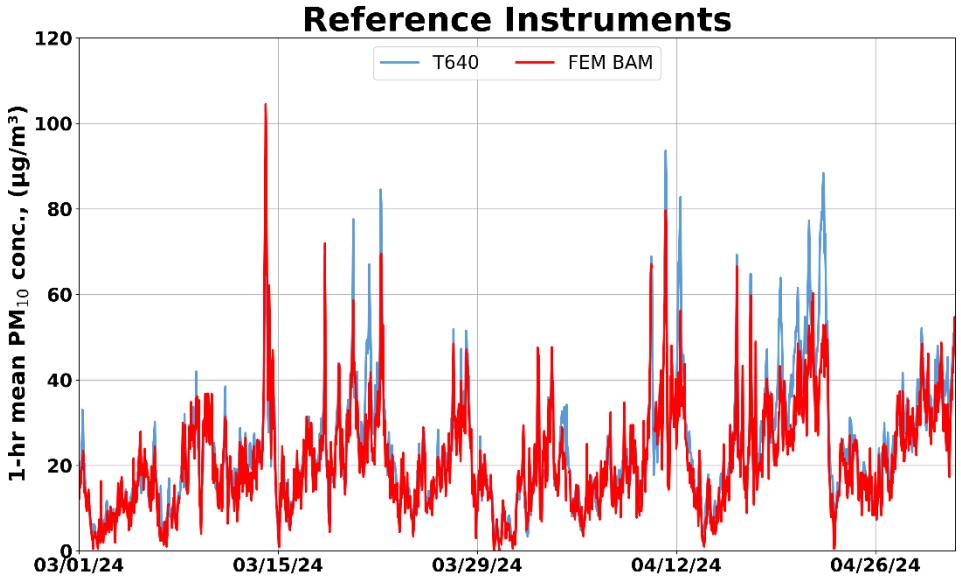
- Data recovery for $PM_{2.5}$ from FEM BAM and FEM T640 was ~97.1 % and 99.9%, respectively.
- Strong correlations between the reference instruments for $PM_{2.5}$ measurements (R^2 ~ 0.76) were observed.

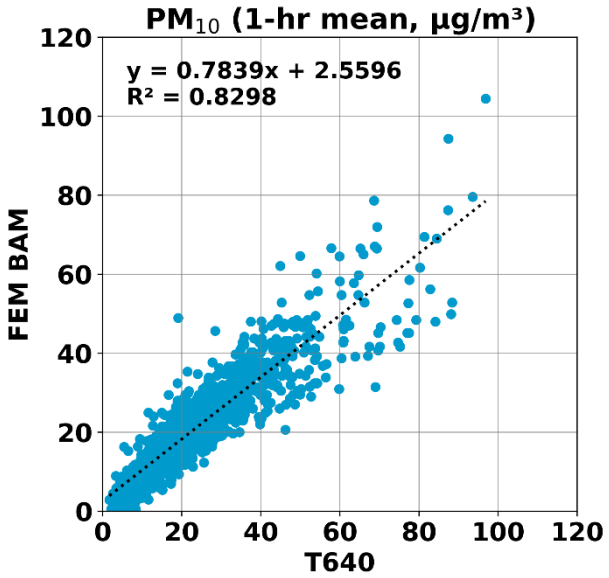




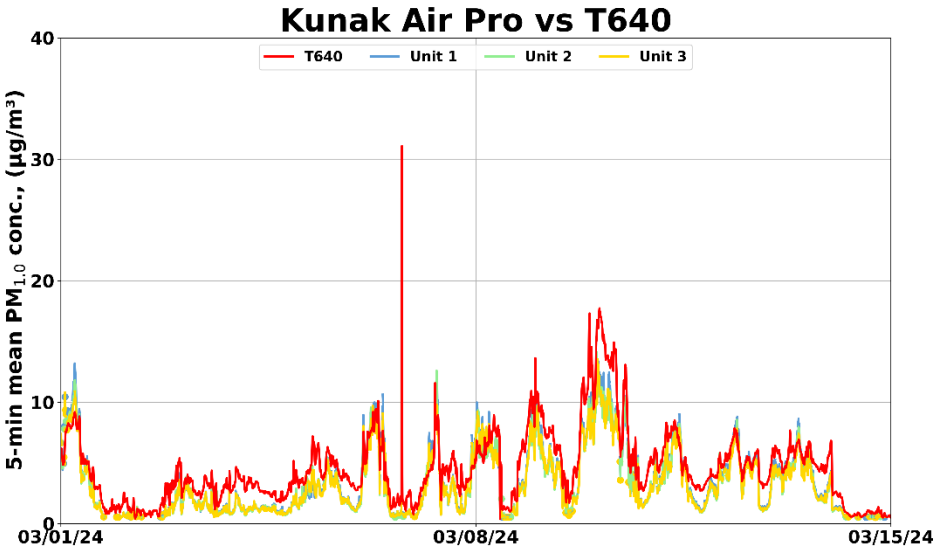
Reference Instruments: PM_{10} FEM BAM and T640

- Data recovery for PM_{10} from FEM BAM and T640 was ~98.9% and 99.9%, respectively.
- Strong correlations between the reference instruments for PM_{10} measurements (R^2 ~ 0.83) were observed.

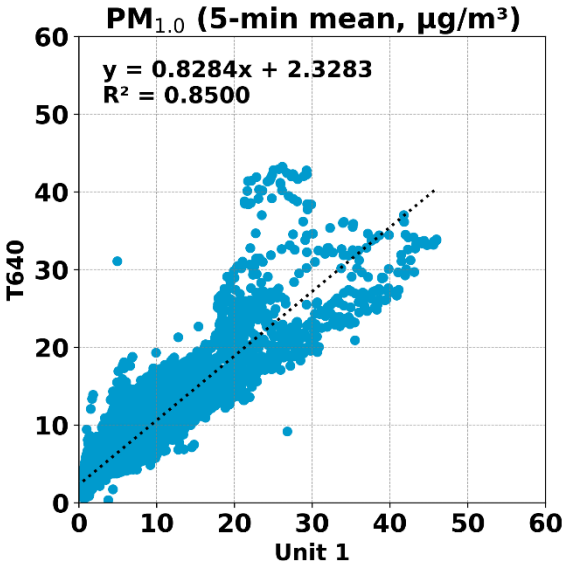


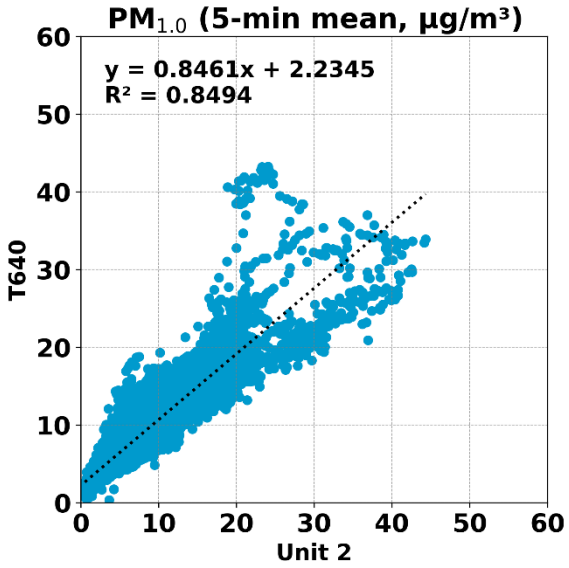


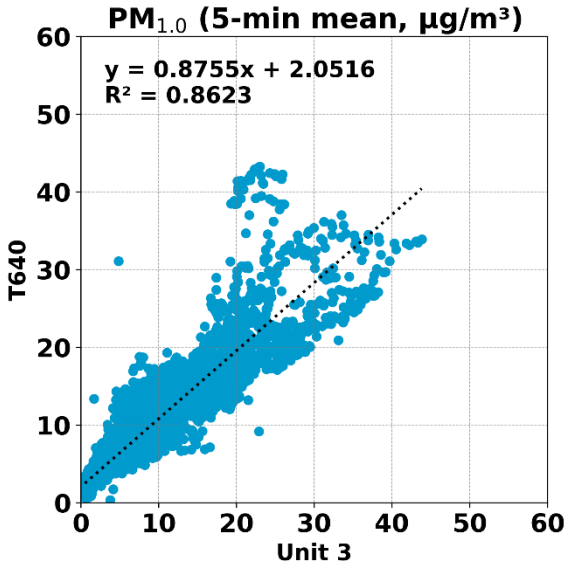
Kunak Air Pro vs T640 ($PM_{1.0}$; 5-min mean)



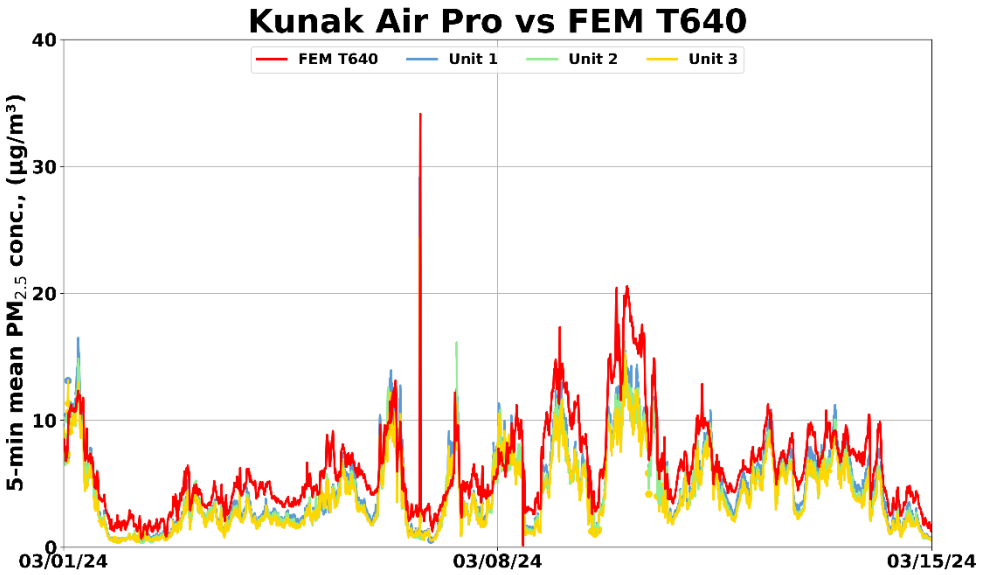
- The Kunak Air Pro sensors showed strong correlations with the corresponding T640 data ($0.84 < R^2 < 0.87$)
- Overall, the Kunak Air Pro sensors underestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The Kunak Air Pro sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by T640



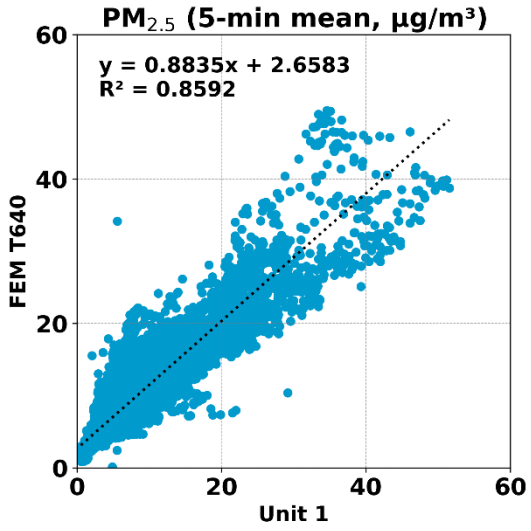


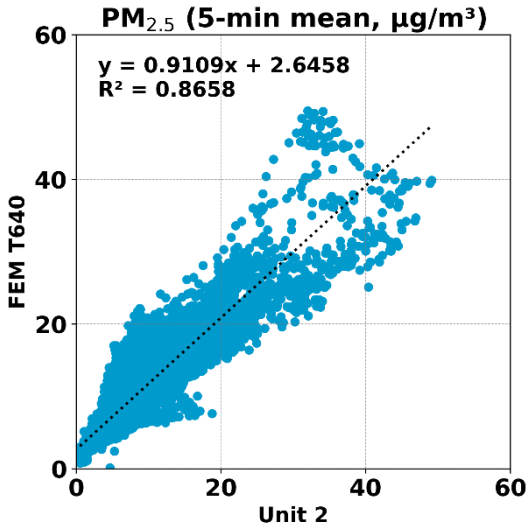


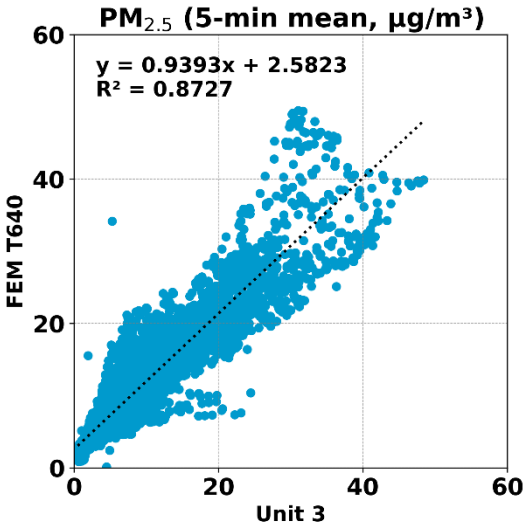
Kunak Air Pro vs FEM T640 ($PM_{2.5}$; 5-min mean)



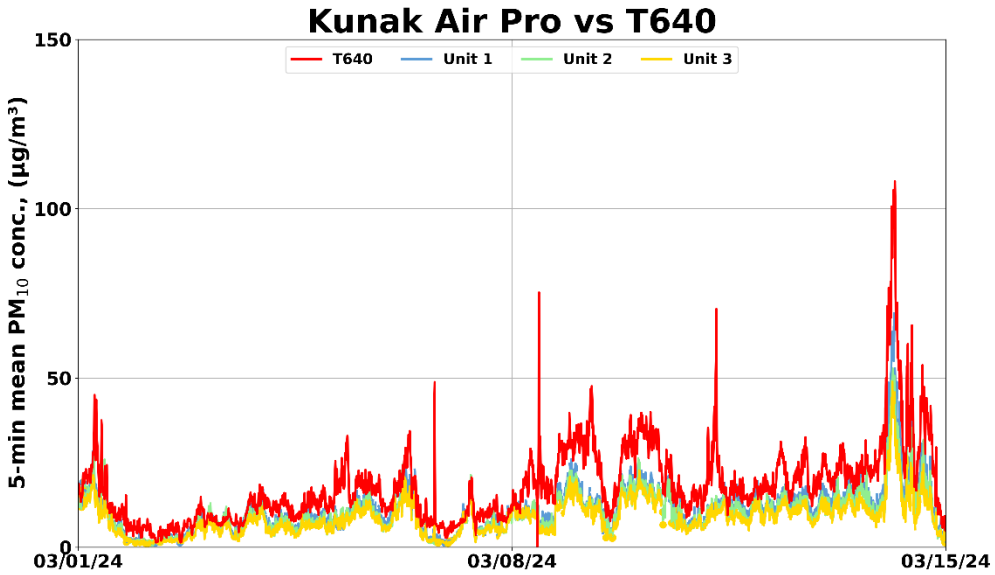
- The Kunak Air Pro sensors showed strong correlations with the corresponding FEM T640 data ($0.85 < R^2 < 0.88$)
- Overall, the Kunak Air Pro sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The Kunak Air Pro sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



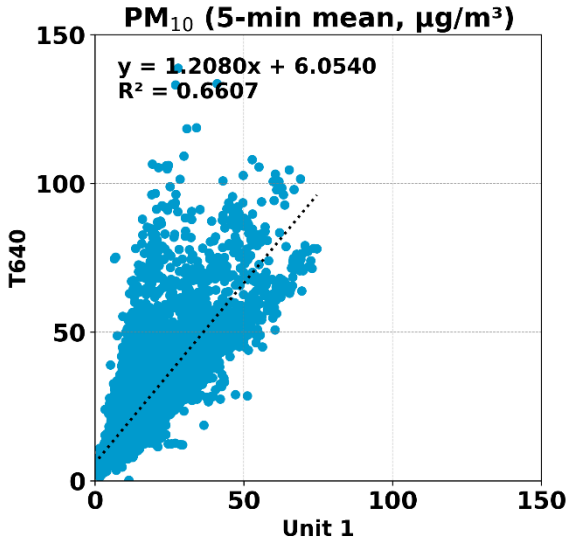


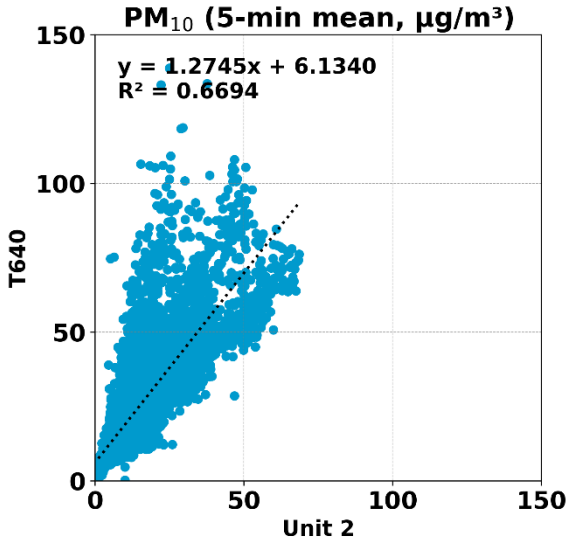


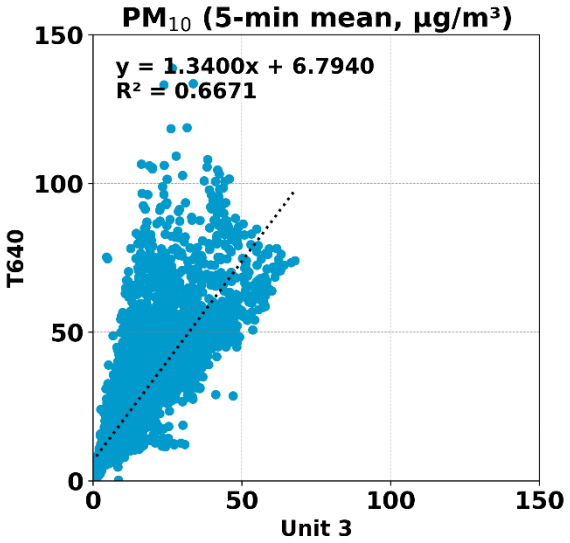
Kunak Air Pro vs T640 (PM_{10}; 5-min mean)



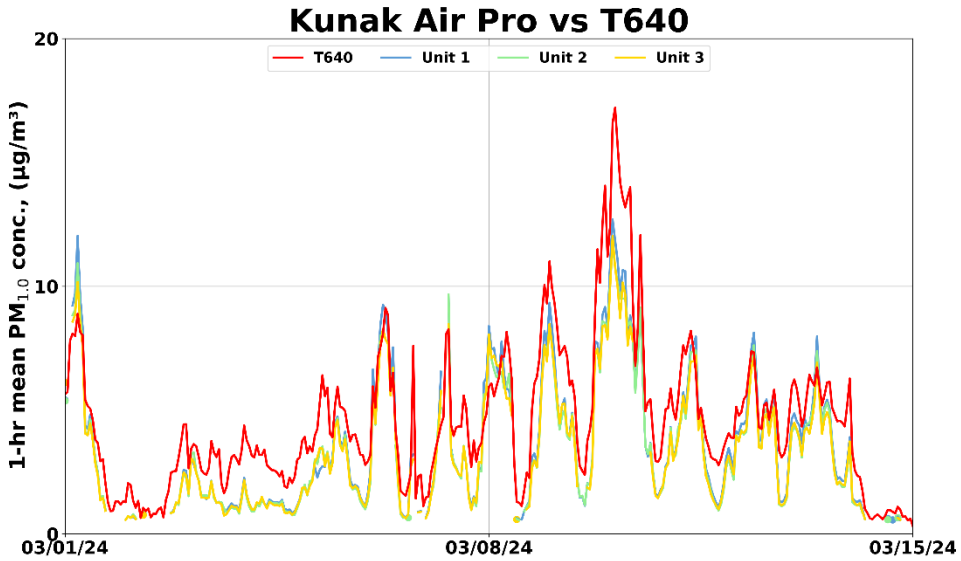
- The Kunak Air Pro sensors showed moderate correlations with the corresponding T640 data ($0.66 < R^2 < 0.67$)
- Overall, the Kunak Air Pro sensors underestimated the PM_{10} mass concentrations as measured by T640
- The Kunak Air Pro sensors seemed to track the PM_{10} diurnal variations as recorded by T640



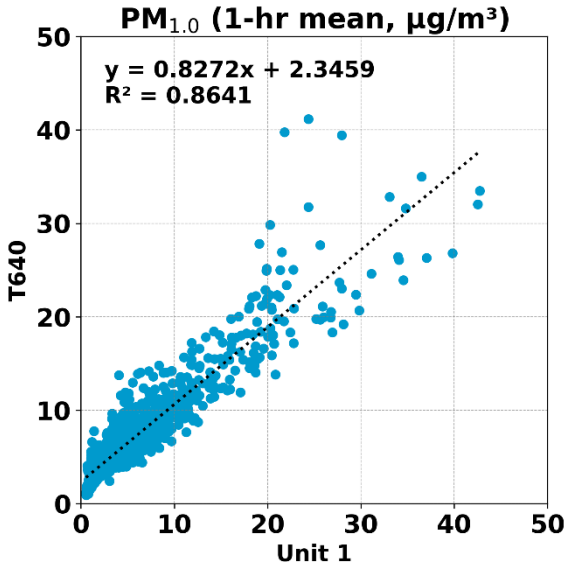


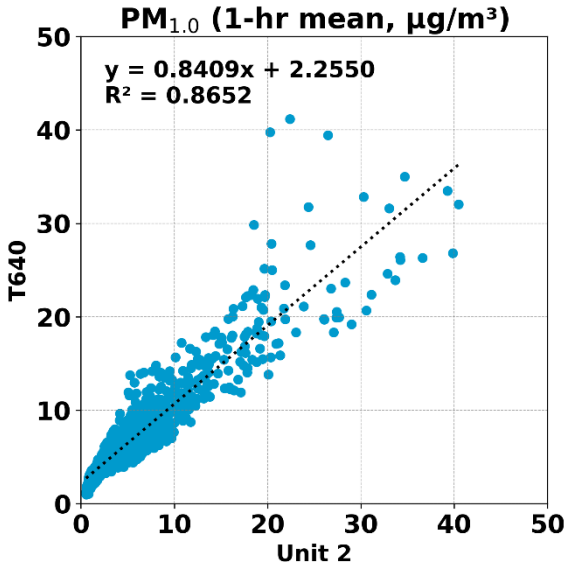


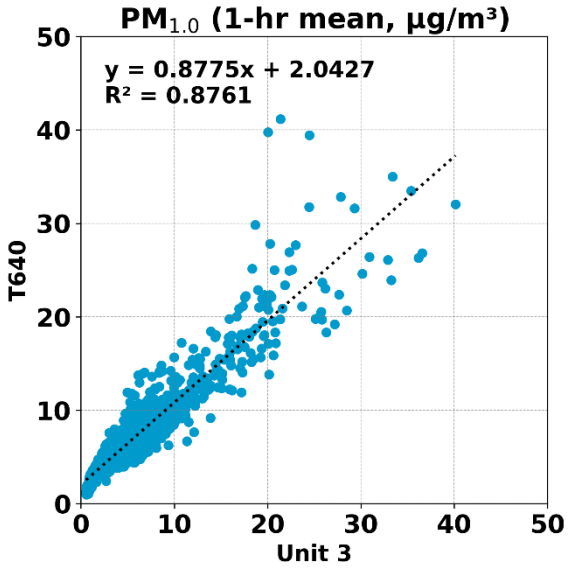
Kunak Air Pro vs T640 ($PM_{1.0}$; 1-hr mean)



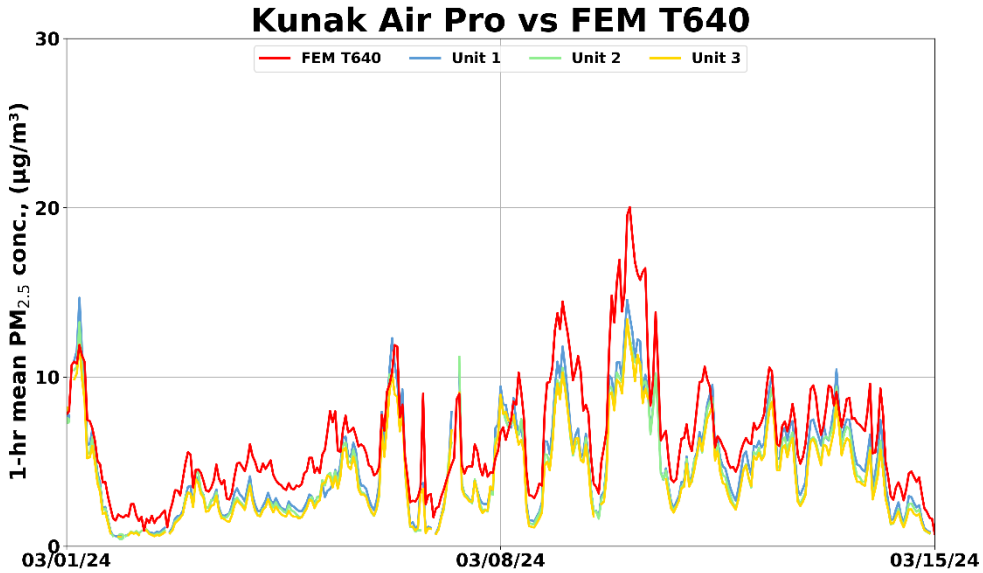
- The Kunak Air Pro sensors showed strong correlations with the corresponding T640 data ($0.86 < R^2 < 0.88$)
- Overall, the Kunak Air Pro sensors underestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The Kunak Air Pro sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by T640



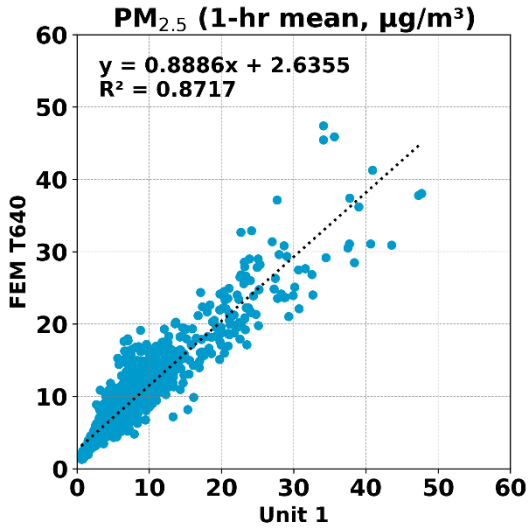


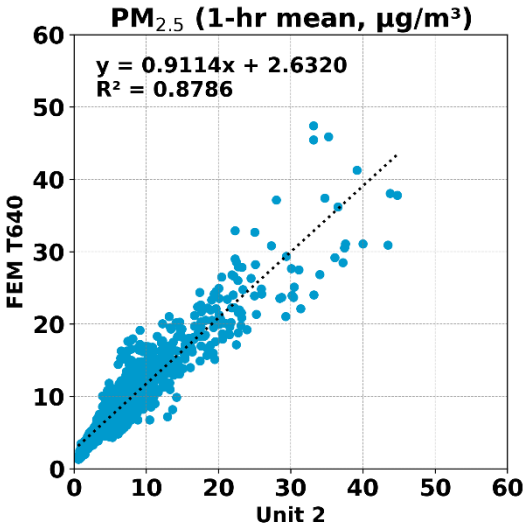


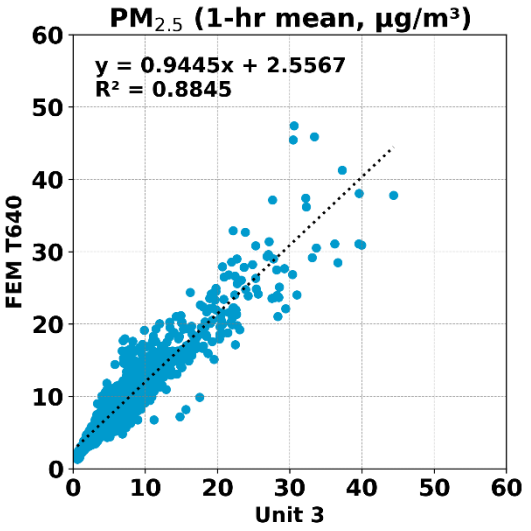
Kunak Air Pro vs FEM T640 ($PM_{2.5}$; 1-hr mean)



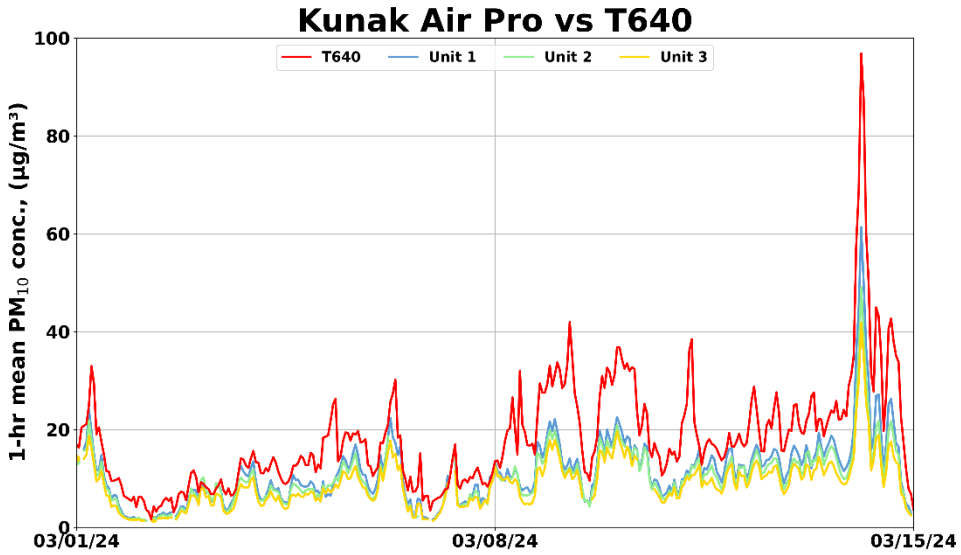
- The Kunak Air Pro sensors showed strong correlations with the corresponding FEM T640 data ($0.87 < R^2 < 0.89$)
- Overall, the Kunak Air Pro sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The Kunak Air Pro sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



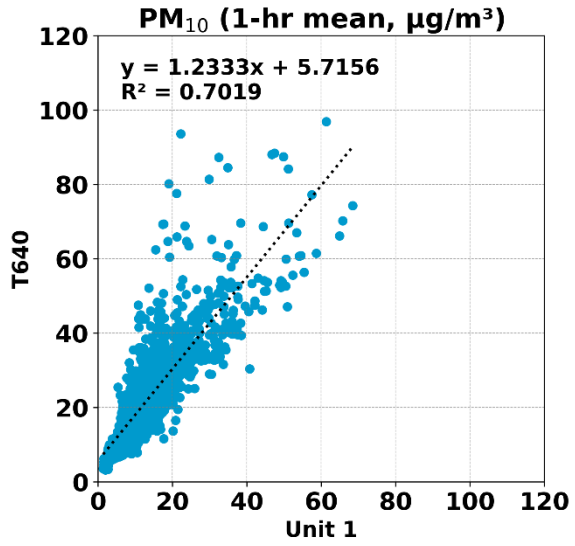


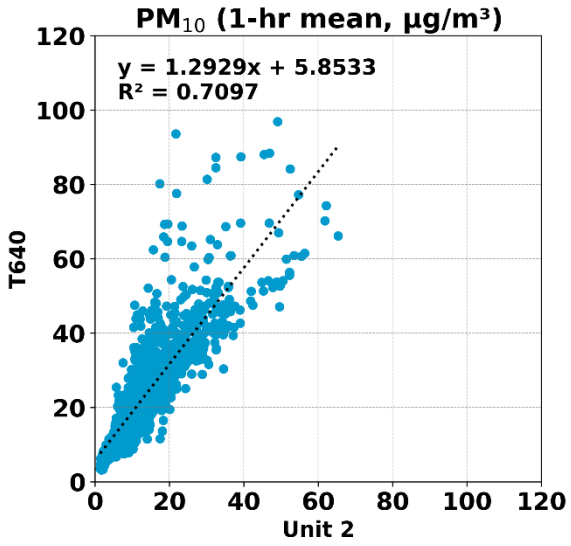


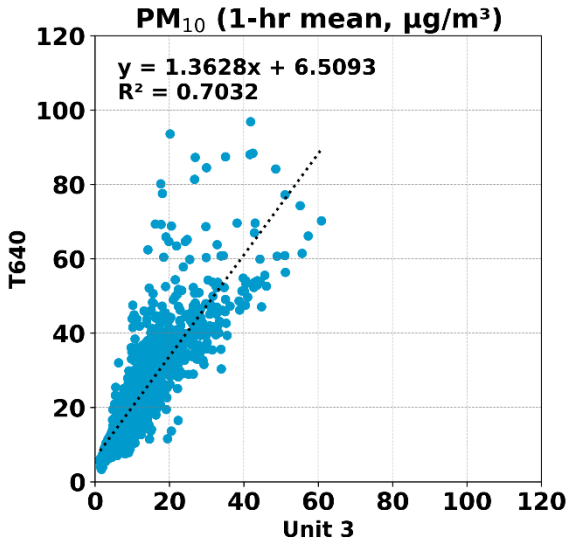
Kunak Air Pro vs T640 (PM_{10}; 1-hr mean)



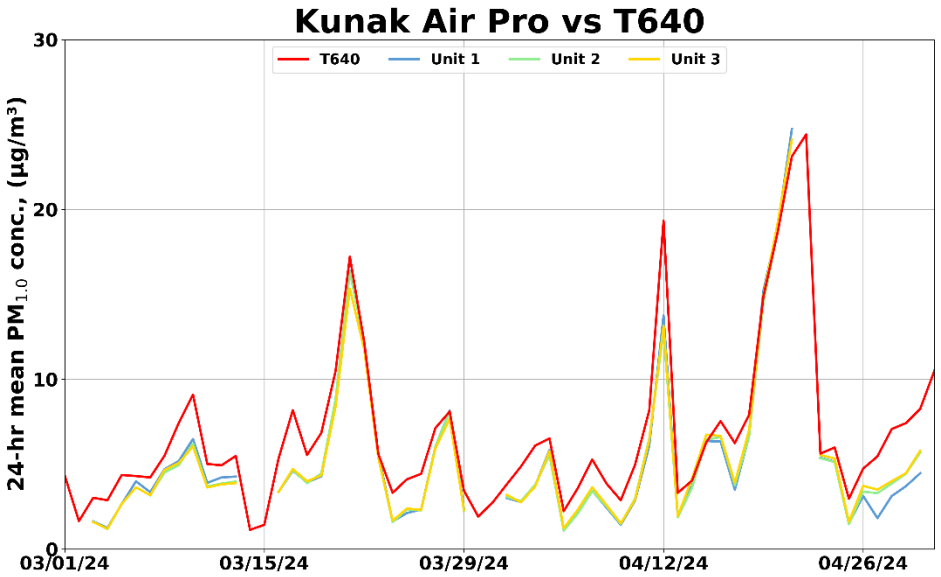
- The Kunak Air Pro sensors showed strong correlations with the corresponding T640 data ($0.70 < R^2 < 0.71$)
- Overall, the Kunak Air Pro sensors underestimated the PM_{10} mass concentrations as measured by T640
- The Kunak Air Pro sensors seemed to track the PM_{10} diurnal variations as recorded by T640



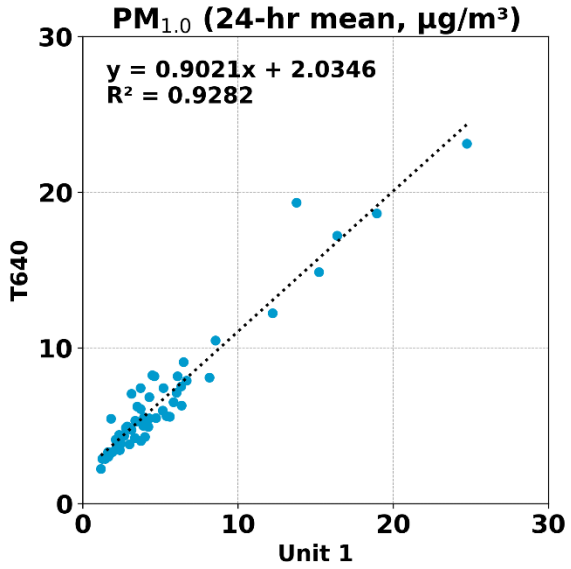


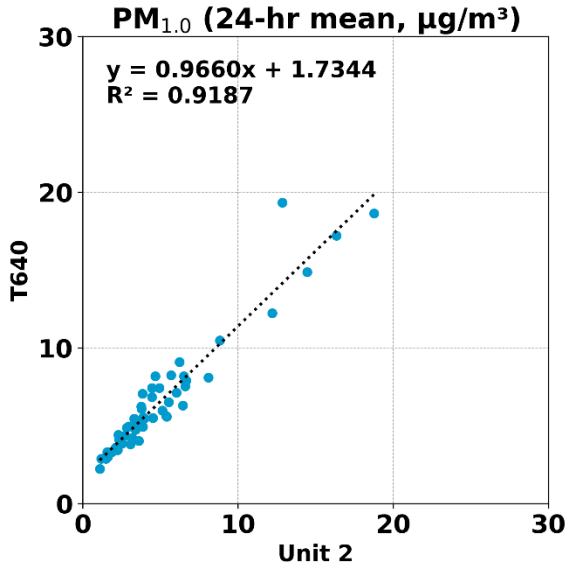


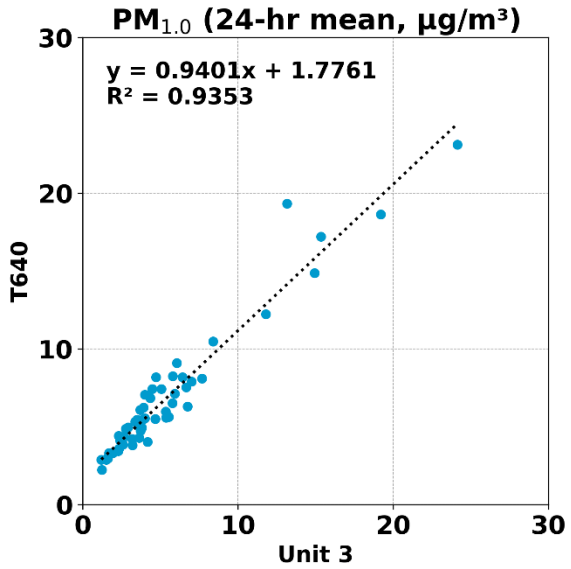
Kunak Air Pro vs T640 ($PM_{1.0}$; 24-hr mean)



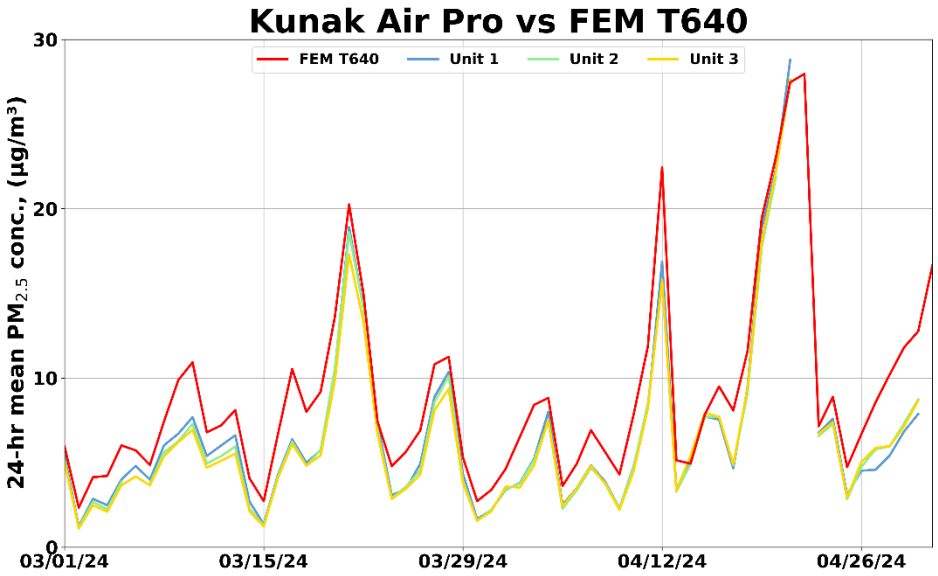
- The Kunak Air Pro sensors showed very strong correlations with the corresponding T640 data ($0.91 < R^2 < 0.94$)
- Overall, the Kunak Air Pro sensors underestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The Kunak Air Pro sensors seemed to track the $PM_{1.0}$ daily variations as recorded by T640



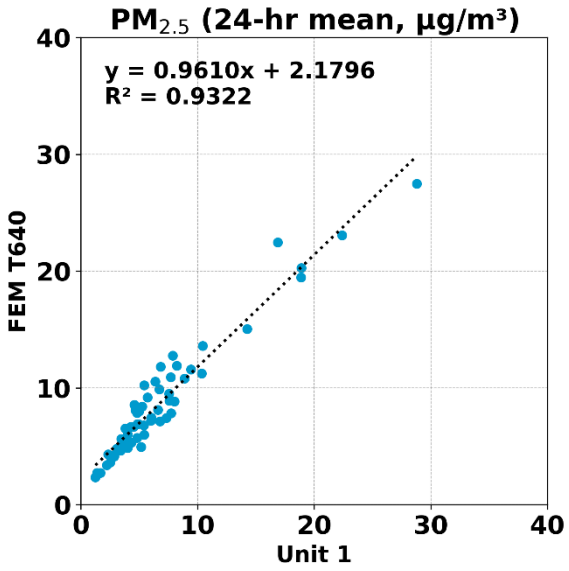


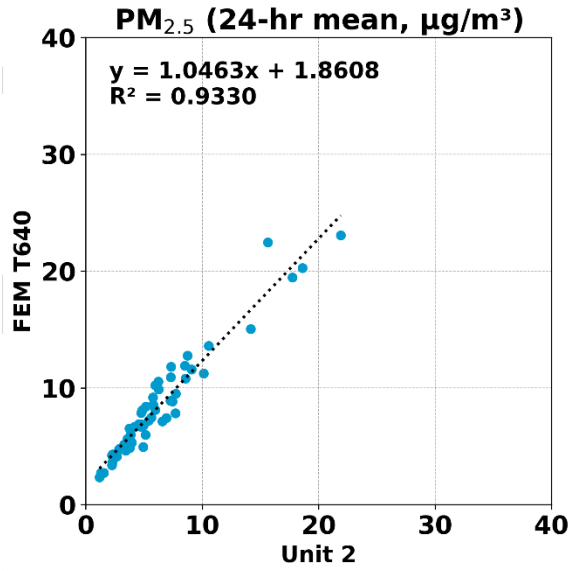


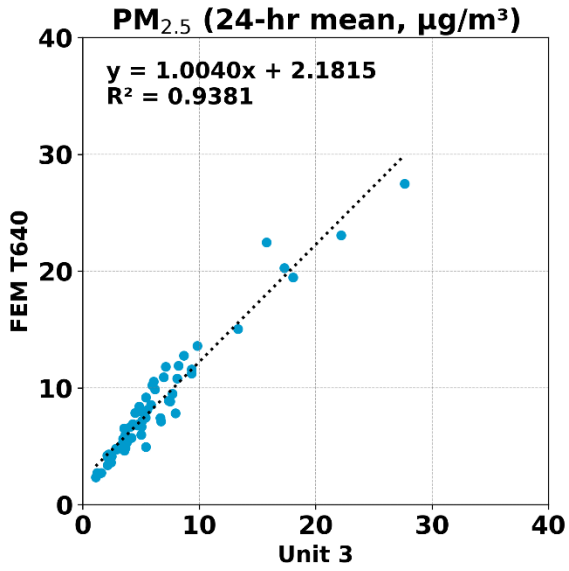
Kunak Air Pro vs FEM T640 ($PM_{2.5}$; 24-hr mean)



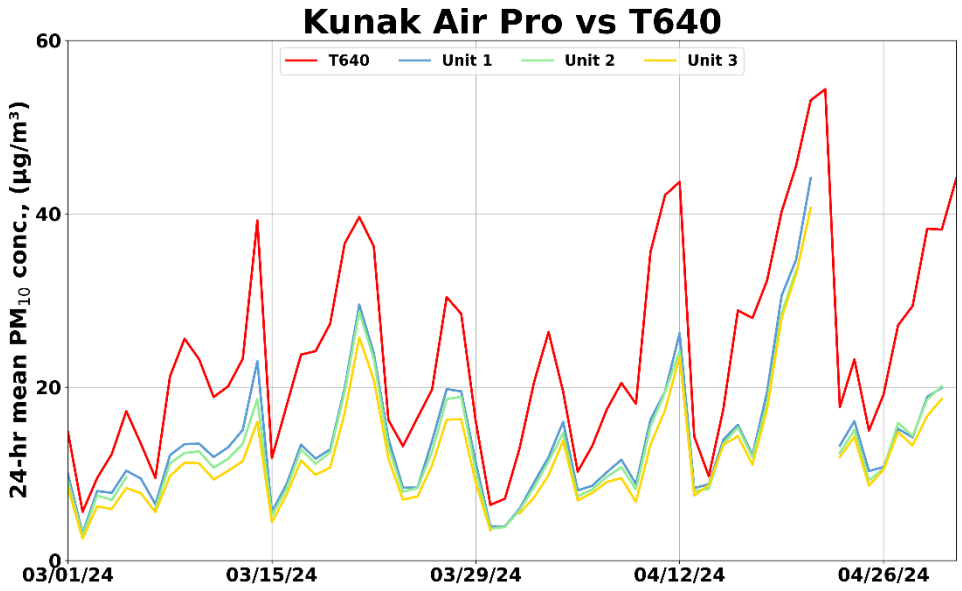
- The Kunak Air Pro sensors showed very strong correlations with the corresponding FEM T640 data ($0.93 < R^2 < 0.94$)
- Overall, the Kunak Air Pro sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The Kunak Air Pro sensors seemed to track the $PM_{2.5}$ daily variations as recorded by FEM T640



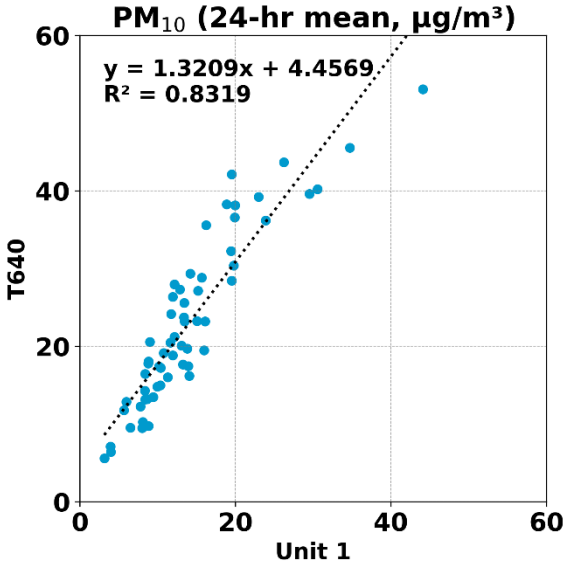


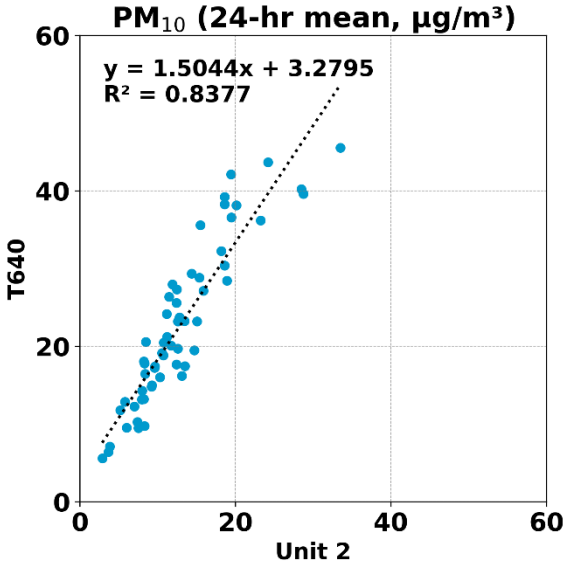


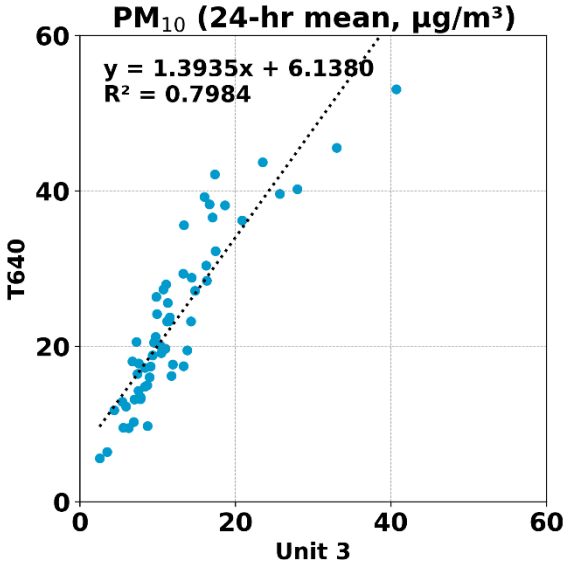
Kunak Air Pro vs T640 (PM_{10}; 24-hr mean)



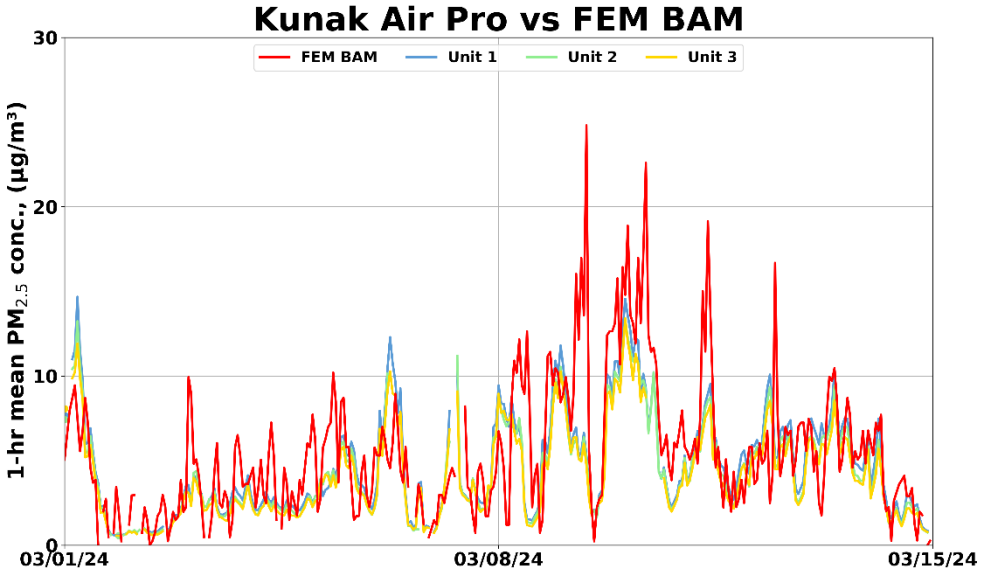
- The Kunak Air Pro sensors showed strong correlations with the corresponding T640 data ($0.79 < R^2 < 0.84$)
- Overall, the Kunak Air Pro sensors underestimated the PM_{10} mass concentrations as measured by T640
- The Kunak Air Pro sensors seemed to track the PM_{10} daily variations as recorded by T640



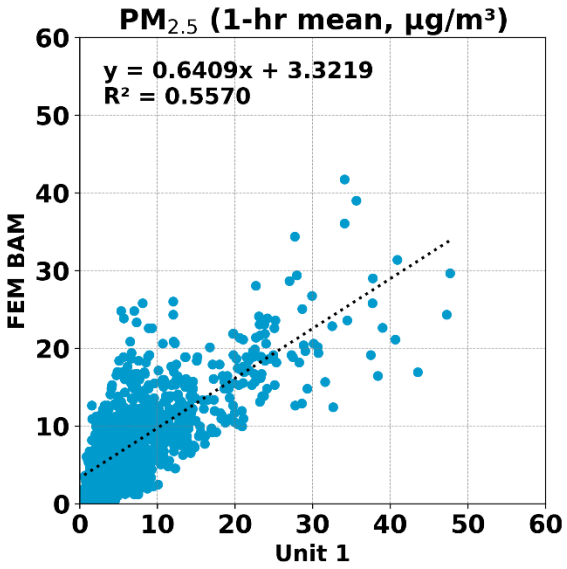


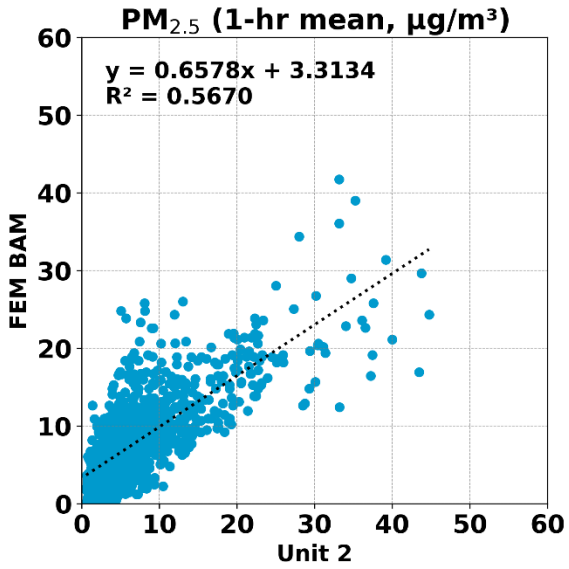


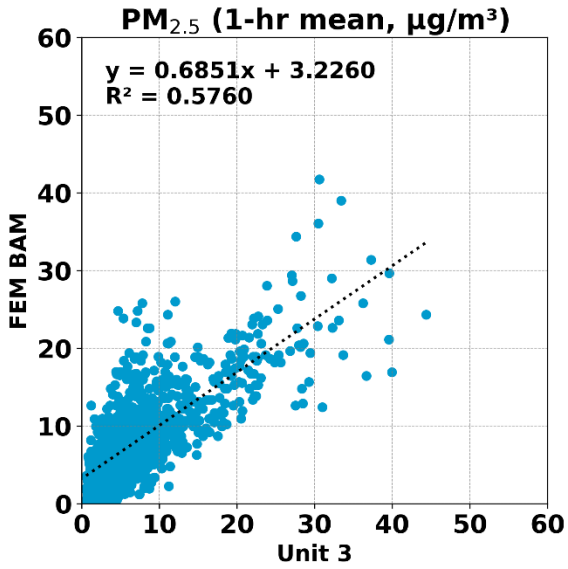
Kunak Air Pro vs FEM BAM ($PM_{2.5}$; 1-hr mean)



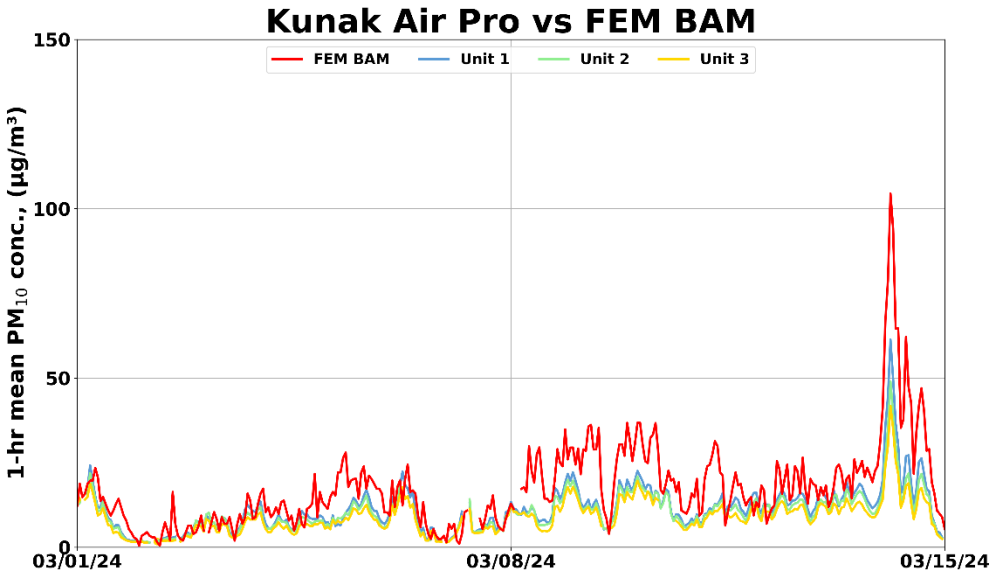
- The Kunak Air Pro sensors showed moderate correlations with the corresponding FEM BAM data ($0.55 < R^2 < 0.58$)
- Overall, the Kunak Air Pro sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM BAM
- The Kunak Air Pro sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM BAM



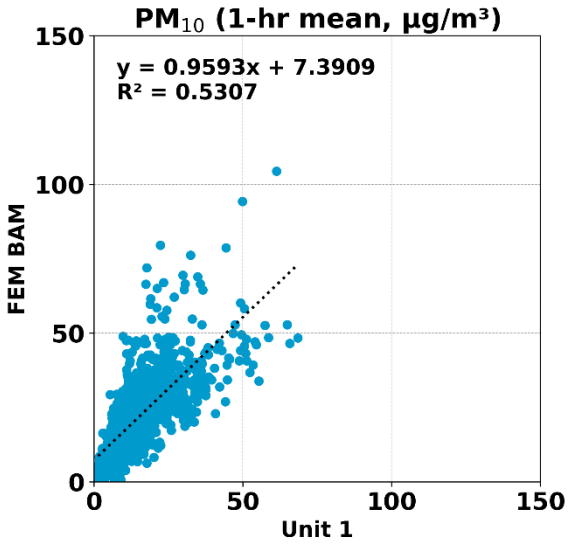


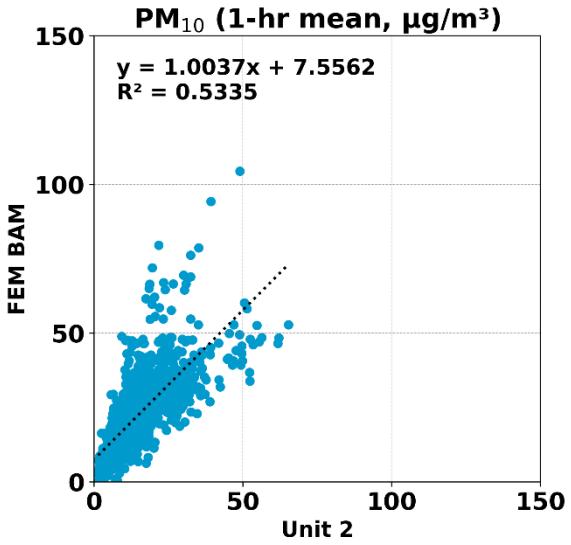


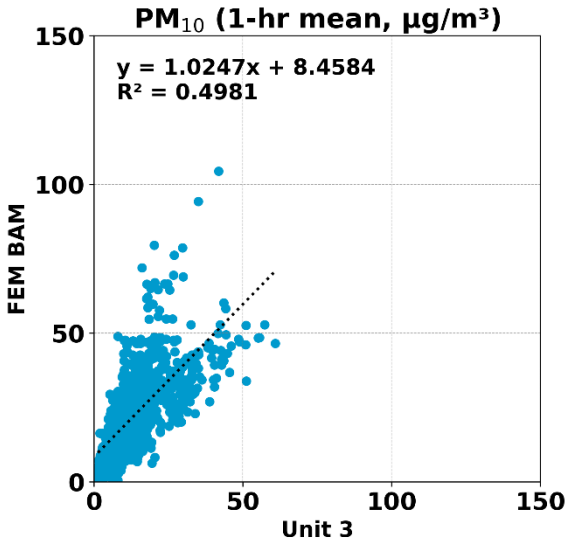
Kunak Air Pro vs FEM BAM (PM_{10}; 1-hr mean)



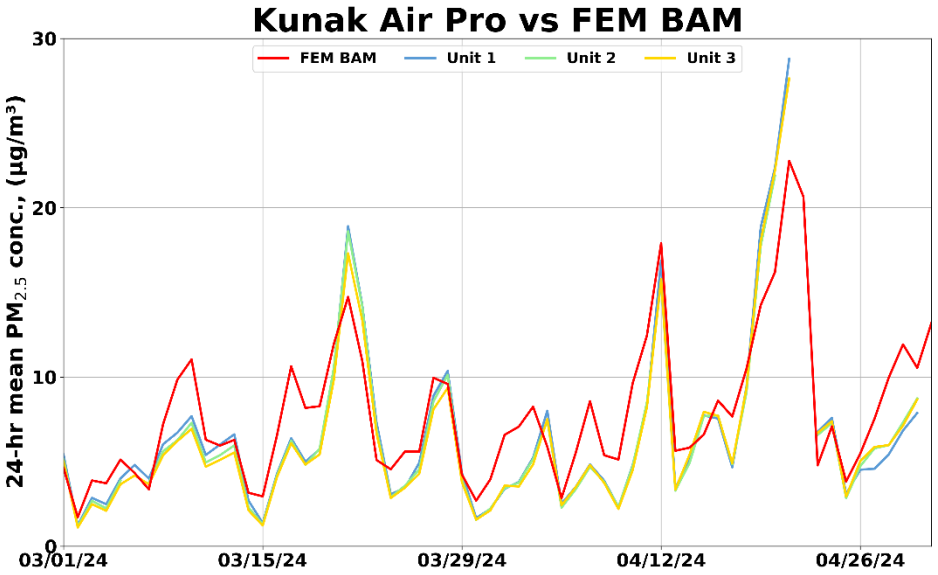
- The Kunak Air Pro sensors showed weak to moderate correlations with the corresponding FEM BAM data ($0.49 < R^2 < 0.54$)
- Overall, the Kunak Air Pro sensors underestimated the PM_{10} mass concentrations as measured by FEM BAM
- The Kunak Air Pro sensors seemed to track the PM_{10} diurnal variations as recorded by FEM BAM



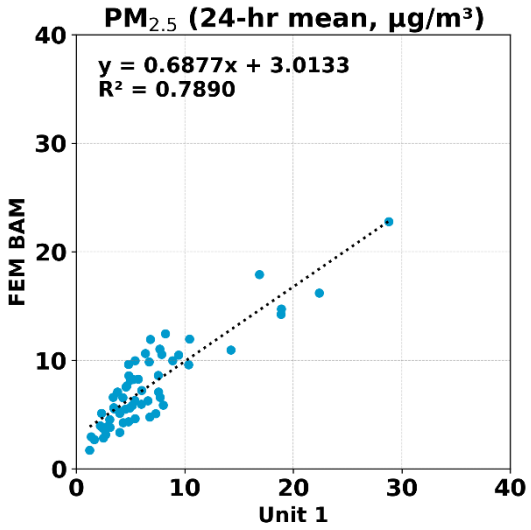


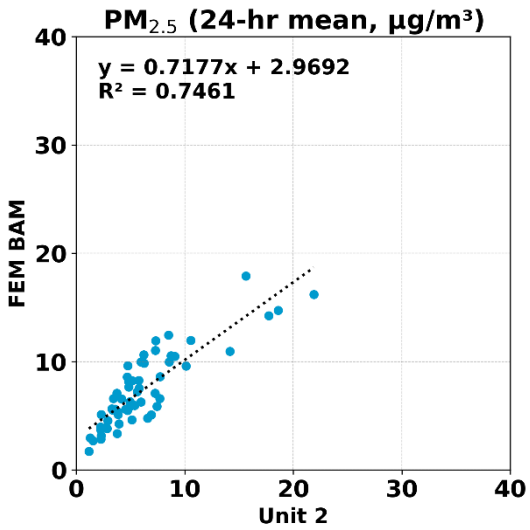


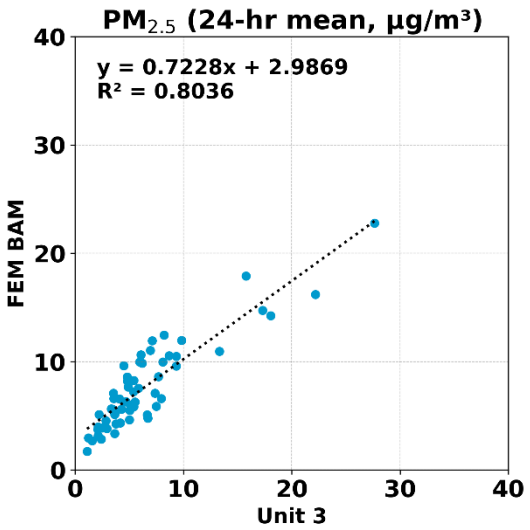
Kunak Air Pro vs FEM BAM ($PM_{2.5}$; 24-hr mean)



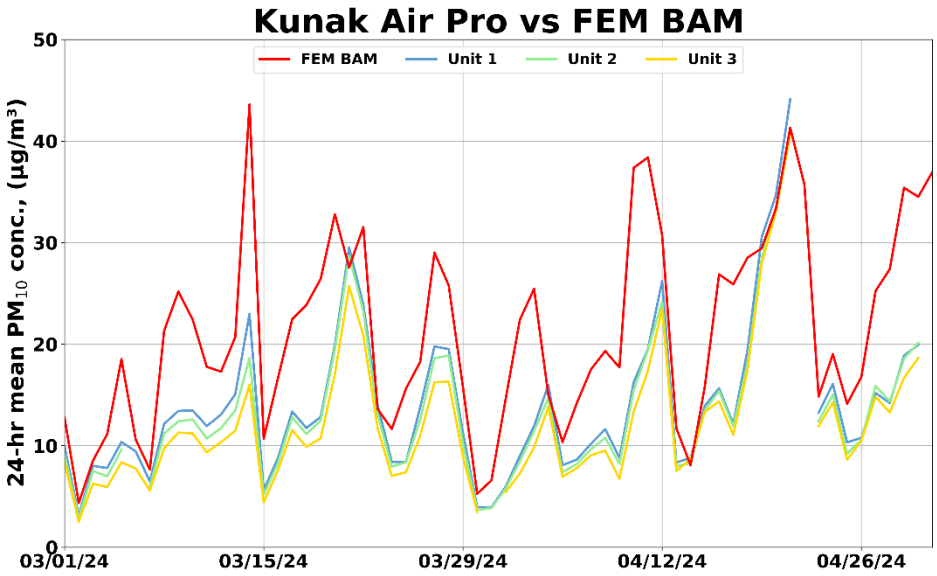
- The Kunak Air Pro sensors showed strong correlations with the corresponding FEM BAM data ($0.74 < R^2 < 0.81$)
- Overall, the Kunak Air Pro sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM BAM
- The Kunak Air Pro sensors seemed to track the $PM_{2.5}$ daily variations as recorded by FEM BAM



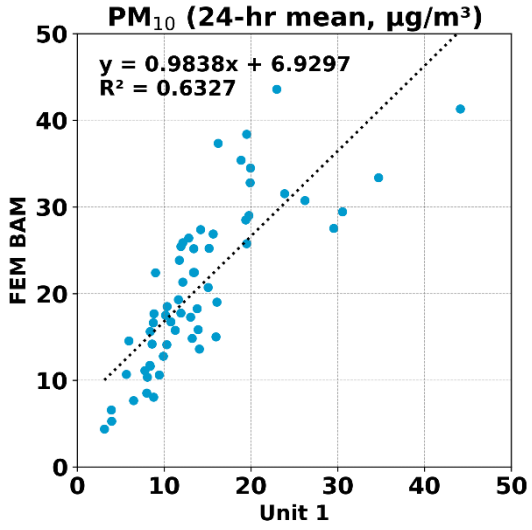


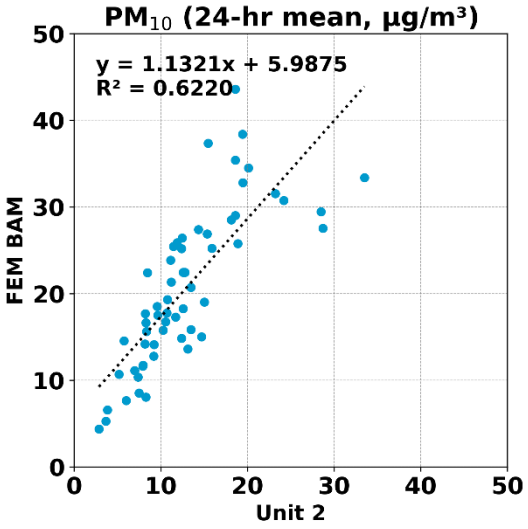


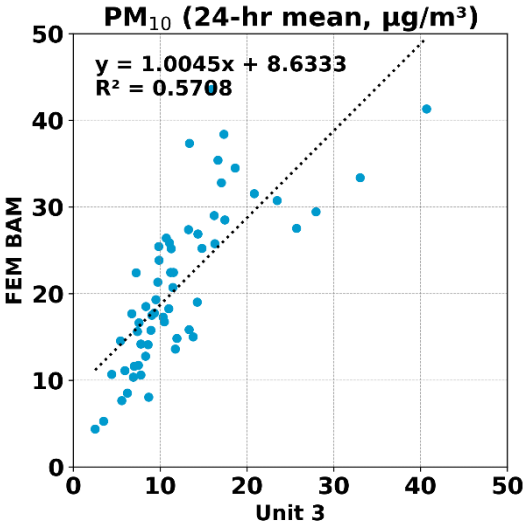
Kunak Air Pro vs FEM BAM (PM_{10}; 24-hr mean)



- The Kunak Air Pro sensors showed moderate correlations with the corresponding FEM BAM data ($0.57 < R^2 < 0.64$)
- Overall, the Kunak Air Pro sensors underestimated the PM_{10} mass concentrations as measured by FEM BAM
- The Kunak Air Pro sensors seemed to track the PM_{10} daily variations as recorded by FEM BAM







Summary: PM

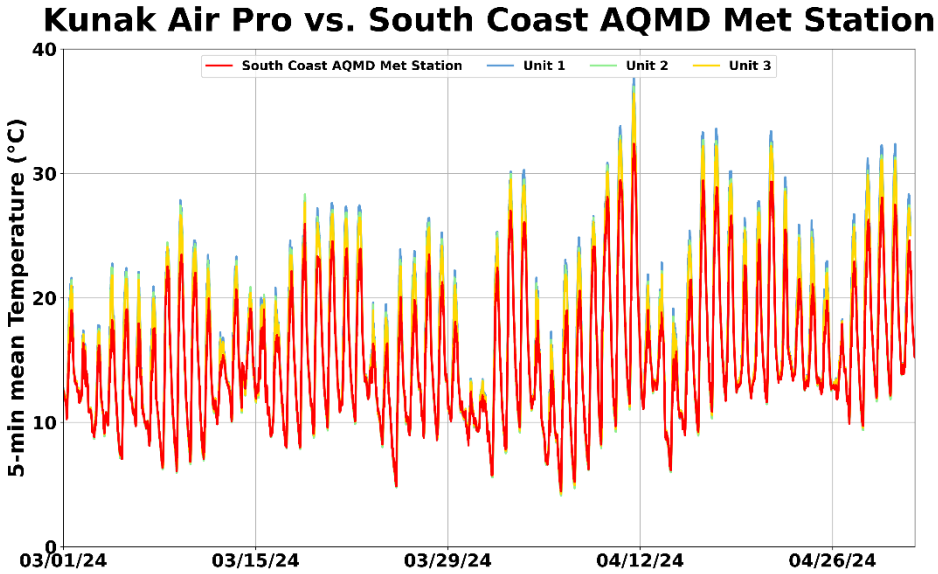
	Average of 3 Sensors, $PM_{1.0}$		Kunak Air Pro vs T640, $PM_{1.0}$						T640 ($PM_{1.0}$, $\mu g/m^3$)		
	Average ($\mu g/m^3$)	SD ($\mu g/m^3$)	R^2	Slope	Intercept	MBE[1] ($\mu g/m^3$)	MAE[2] ($\mu g/m^3$)	RMSE[3] ($\mu g/m^3$)	Ref. Average	Ref. SD	Range during the field evaluation
5-min	5.3	5.6	0.85 to 0.86	0.83 to 0.88	2.1 to 2.3	-1.4 to -1.4	1.9 to 2.0	2.5 to 2.7	6.7	5.9	0.2 to 43.2
1-hr	5.3	5.6	0.86 to 0.88	0.83 to 0.88	2.0 to 2.3	-1.4	1.9 to 2.0	2.4 to 2.6	6.7	5.9	0.3 to 42.0
24-hr	5.2	4.3	0.92 to 0.94	0.90 to 0.97	1.7 to 2.0	-1.6 to -1.5	1.5 to 1.6	1.8 to 2.0	6.7	4.9	1.1 to 24.4
	Average of 3 Sensors, $PM_{2.5}$		Kunak Air Pro vs FEM BAM & FEM T640, $PM_{2.5}$						FEM BAM & FEM T640 ($PM_{2.5}$, $\mu g/m^3$)		
	Average ($\mu g/m^3$)	SD ($\mu g/m^3$)	R^2	Slope	Intercept	MBE[1] ($\mu g/m^3$)	MAE[2] ($\mu g/m^3$)	RMSE[3] ($\mu g/m^3$)	Ref. Average	Ref. SD	Range during the field evaluation
5-min	6.7	6.3	0.86 to 0.87	0.88 to 0.94	2.6 to 2.7	-2.2 to -1.9	2.4 to 2.5	3.1	9.0	6.8	0.1 to 49.5
1-hr	6.7	6.2	0.56 to 0.88	0.64 to 0.94	2.6 to 3.3	-2.2 to -0.8	2.3 to 3.1	3.0 to 4.4	8.0 to 9.0	5.9 to 6.8	0.0 to 47.4
24-hr	6.4	4.8	0.75 to 0.94	0.69 to 1.05	1.9 to 3.0	-2.2 to -0.9	2.0 to 2.2	2.3 to 2.6	7.8 to 8.9	4.3 to 5.7	1.7 to 28.0
	Average of 3 Sensors, PM_{10}		Kunak Air Pro vs FEM BAM & T640, PM_{10}						FEM BAM & T640 (PM_{10}, $\mu g/m^3$)		
	Average ($\mu g/m^3$)	SD ($\mu g/m^3$)	R^2	Slope	Intercept	MBE[1] ($\mu g/m^3$)	MAE[2] ($\mu g/m^3$)	RMSE[3] ($\mu g/m^3$)	Ref. Average	Ref. SD	Range during the field evaluation
5-min	13.5	9.2	0.66 to 0.67	1.21 to 1.34	6.1 to 6.8	-11.1 to -9.0	9.2 to 11.1	12.4 to 14.1	23.7	15.0	0.2 to 138.8
1-hr	13.6	9.0	0.5 to 0.71	0.96 to 1.36	5.7 to 8.5	-11.1 to -6.8	8.0 to 11.1	10.9 to 13.8	21.2 to 23.7	12.6 to 14.6	0.0 to 104.5
24-hr	13.1	6.9	0.57 to 0.84	0.98 to 1.50	3.3 to 8.6	-11.0 to -6.7	7.0 to 11.0	8.8 to 12.3	21.0 to 23.6	9.5 to 11.6	4.4 to 54.4

[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).

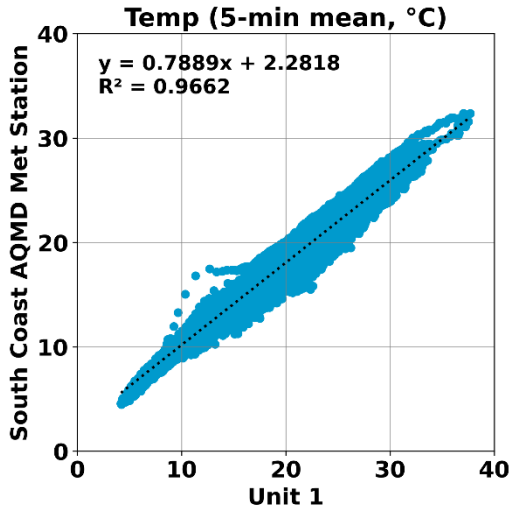
[2] Mean Absolute Error (MAE): the absolute difference between the sensors and the reference instruments. The larger MAE values, the higher measurement errors as compared to the reference instruments.

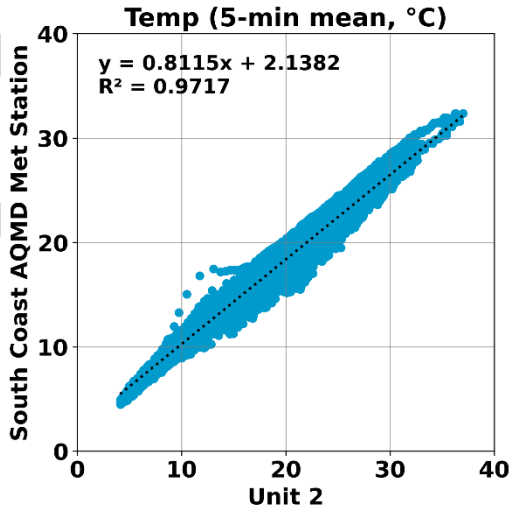
[3] Root Mean Square Error (RMSE): another metric to calculate measurement errors.

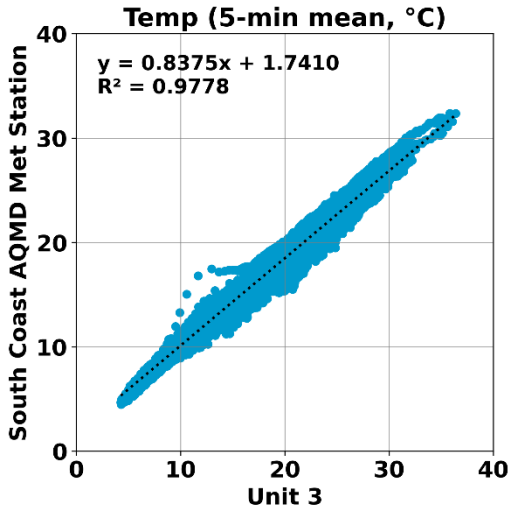
Kunak Air Pro vs South Coast AQMD Met Station (Temp; 5-min mean)



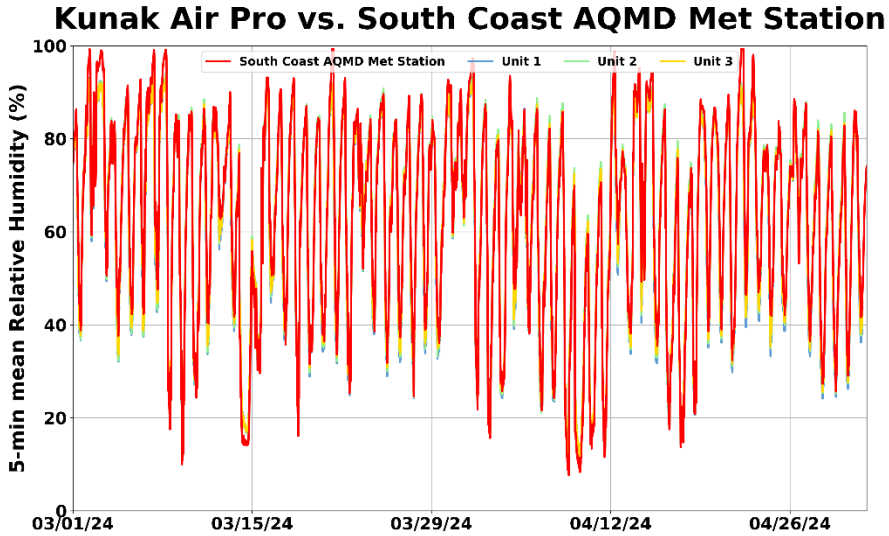
- The Kunak Air Pro sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($0.96 < R^2 < 0.98$)
- Overall, the Kunak Air Pro sensors overestimated the temperature measurement as recorded by South Coast AQMD Met Station
- The Kunak Air Pro sensors seemed to track the diurnal temperature variations as recorded by South Coast AQMD Met Station



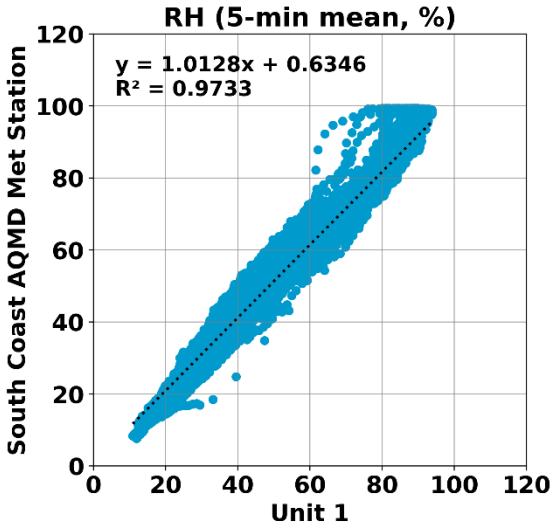


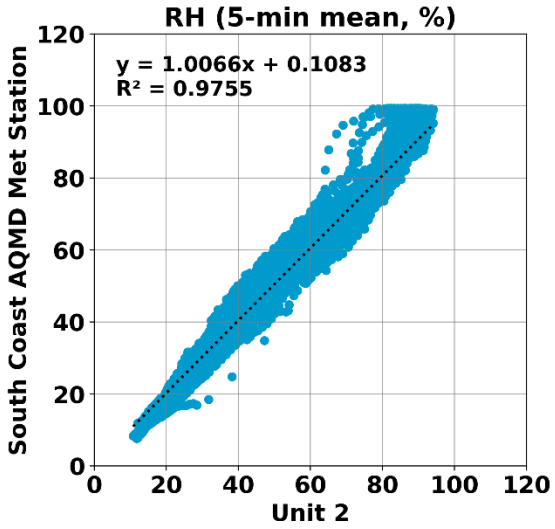


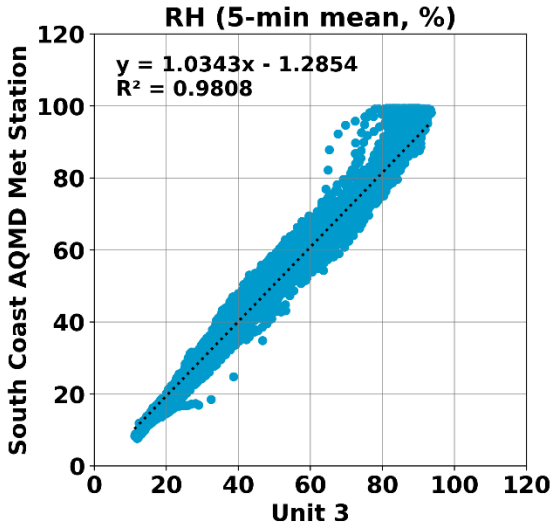
Kunak Air Pro vs South Coast AQMD Met Station (RH; 5-min mean)



- Kunak Air Pro sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($0.97 < R^2 < 0.99$)
- Overall, the Kunak Air Pro sensors underestimated the RH measurement as recorded by South Coast AQMD Met Station
- The Kunak Air Pro sensors seemed to track the diurnal RH variations as recorded by South Coast AQMD Met Station







Discussion

- The three **Kunak Air Pro** sensors' data recovery for CO, O_3, NO_2, NO_x, NO, and all PM fractions was ~97.7%, ~97.2%, ~97.2%, ~97.2%, ~97.7%, and 95.9%, respectively.
- The absolute intra-model variability for CO, O_3, NO_2, NO_x, NO was ~ 3.64 ppb, ~ 1.09 ppb, 0.45 ppb, 0.42 ppb, 0.27 ppb respectively. Absolute intra-model variability was ~ 0.02, ~ 0.16 and ~ 0.99 µg/m^3 for $PM_{1.0}$, $PM_{2.5}$ and PM_{10}, respectively
- Reference instruments: strong correlations between FEM BAM and FEM T640 for $PM_{2.5}$ (R^2 ~ 0.76, 1-hr mean) and strong correlations between FEM BAM and T640 for PM_{10} (R^2 ~ 0.83, 1-hr mean) mass concentration measurements
- During the entire field deployment testing period:
  - CO sensors showed strong correlation with the FRM Horiba instrument (0.83 < R2 < 0.86, 5-min mean) and generally overestimated the corresponding FRM Horiba data
  - Ozone sensors showed strong correlation with the FEM T400 instrument (0.84 < R2 < 0.89, 5-min mean) and generally underestimated the corresponding FEM T400 data
  - NO_2 sensors showed moderate to strong correlations with the FRM T200 instrument (0.69 < R2 < 0.75, 5-min mean) and overestimated the corresponding FRM T200 data
  - NO_x sensors showed very strong correlation with the Reference NOx instrument (0.92 < R2 < 0.95, 5-min mean) and generally overestimated the corresponding Reference NOx data
  - NO sensors showed very strong correlation with the Reference NO instrument (0.98 < R2 < 0.99, 5-min mean) and generally overestimated the corresponding Reference NO data
  - The Kunak Air Pro sensors showed strong correlations with the corresponding T640 $PM_{1.0}$ data (0.86 < R^2 < 0.88, 1-hr mean), moderate to strong correlations with the corresponding FEM BAM and FEM T640 $PM_{2.5}$ data (0.55 < R^2 < 0.89, 1-hr mean) and weak to strong correlations with the corresponding FEM BAM and T640 reference PM_{10} data (0.49 < R^2 < 0.71; 1-hr mean). The sensors underestimated $PM_{1.0}$, $PM_{2.5}$ and PM_{10} mass concentrations as measured by the reference instruments
  - Temperature and relative humidity sensors showed very strong correlations with the South Coast AQMD Met Station T and RH data, respectively (R^2 ~ 0.97 for T and R^2 ~ 0.98 for RH) and overestimated the T and underestimated the 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