Field Evaluation
Kunak Air Lite

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

- From 03/01/2024 to 05/01/2024, three **Kunak Air Lite** 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 Lite (*3 units tested*):
  - Gas Sensors: Electrochemical (Alphasense, non-FEM)
  - PM – Optical (Plantower PMS5003, non-FEM)
  - Each unit measures: O_3 (ppb), NO_2 (ppb), $PM_{1.0}$ ($\mu g/m^3$), $PM_{2.5}$ ($\mu g/m^3$), PM_{10}($\mu g/m^3$), T (°C), RH (%)
  - Unit cost: $5,033 as-tested ($5,960 with cloud service)
  - Time resolution: 1-min
  - Units IDs: 144, 145, and 146

- South Coast AQMD Reference instruments:
  - O_3 instrument (Teledyne T400, hereinafter FEM T400); cost: ~$7,000
    - Time resolution; 1-min
  - NO/NO_2 instrument (Teledyne T200, hereinafter FRM T200); cost: ~$11,000
    - Time resolution: 1-min
  - PM instrument (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} ($\mu g/m^3$)
  - PM Instrument (MetOne BAM; FEM $PM_{2.5}$ and PM_{10}, hereinafter FEM BAM); cost: $25,000 and up
    - Time resolution: 1-hr
    - Measures $PM_{2.5}$, PM_{10} ($\mu g/m^3$)
  - Met station (T, RH, P, WS, WD); cost: ~$5,000
    - Time resolution: 1-min

Data Handling

- The Kunak Air Lite 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

Ozone (O_3) in Kunak Air Lite

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 144, Unit 145 and Unit 146 was ~98.9%, ~99.1% and ~99.1%, respectively
- Values below manufacturer stated limit of detection were excluded from further analysis but do not count against data recovery

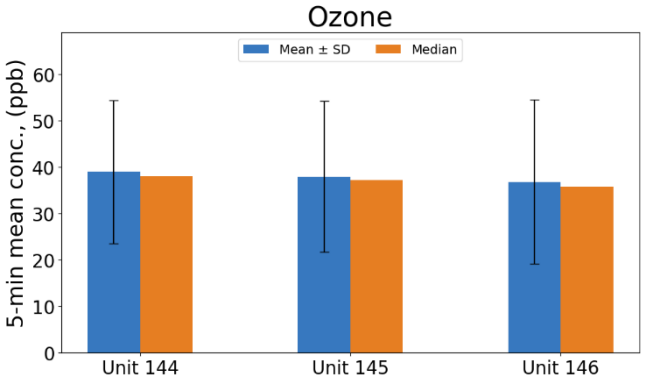
Kunak Air Lite; Intra-model variability

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

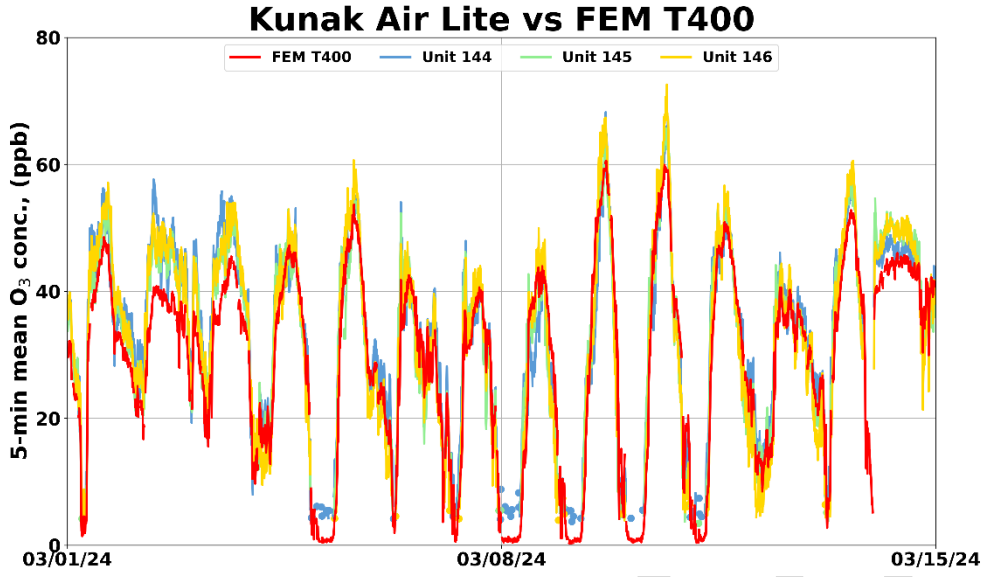
(calculated as the standard deviation of the three sensor means)

- Relative intra-model variability was ~2.86% for the ozone measurements

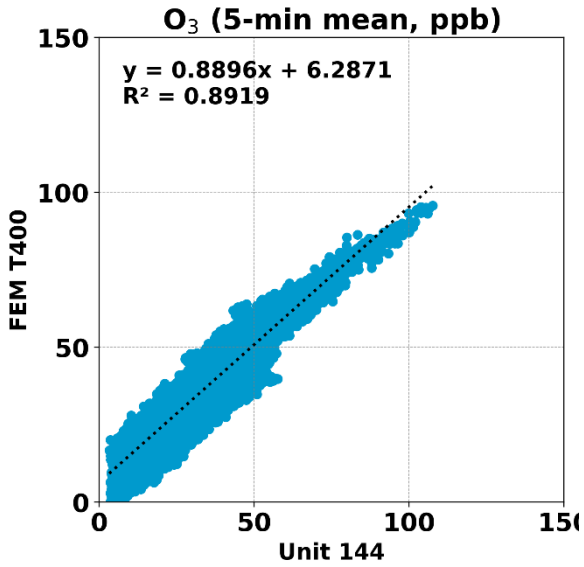
(calculated as the absolute intra-model variability relative to the mean of the three sensor means)

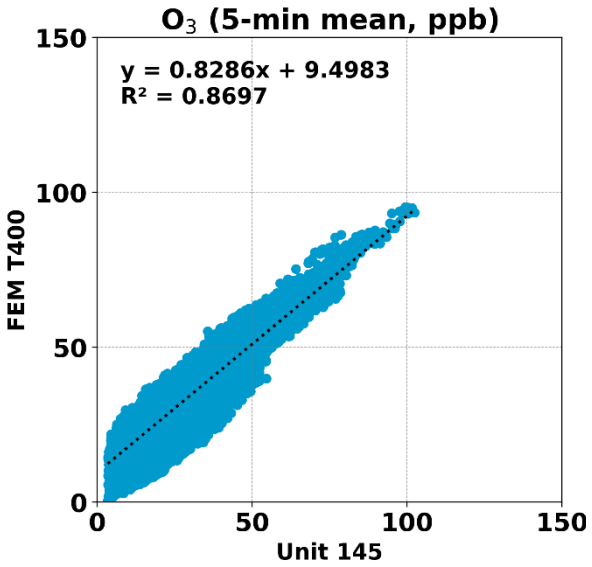


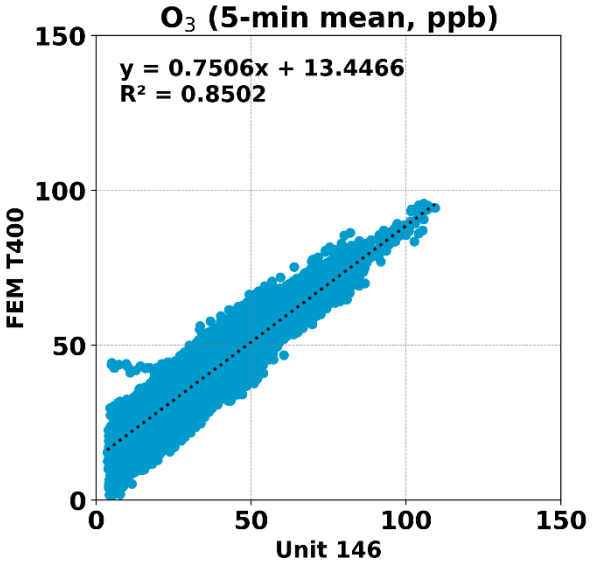
Kunak Air Lite vs FEM T400 (Ozone; 5-min mean)



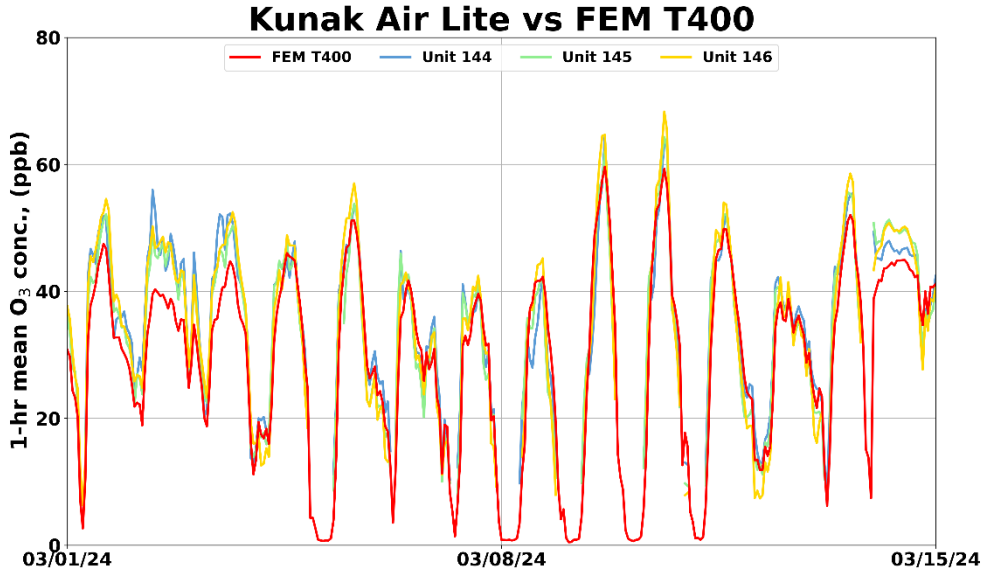
- The Kunak Air Lite sensors showed strong correlation with the corresponding FEM T400 ozone data ($0.85 < R^2 < 0.90$)
- Overall, the Kunak Air Lite sensors underestimated the ozone concentration as measured by the FEM T400 ozone instrument
- The Kunak Air Lite sensors seemed to track the diurnal ozone variations as recorded by the FEM T400 instrument



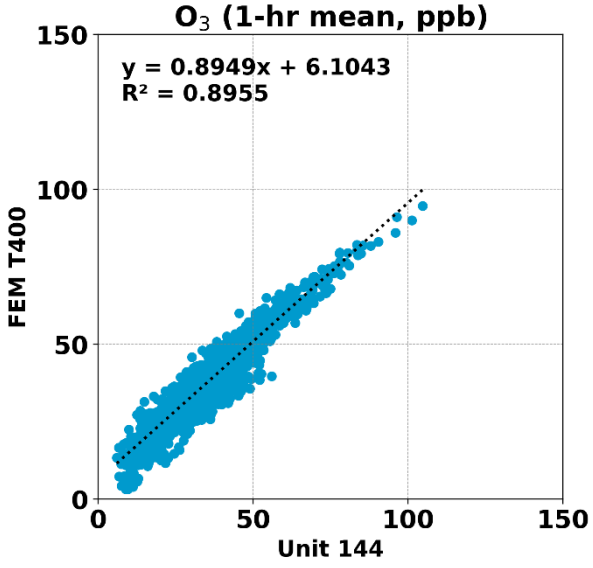


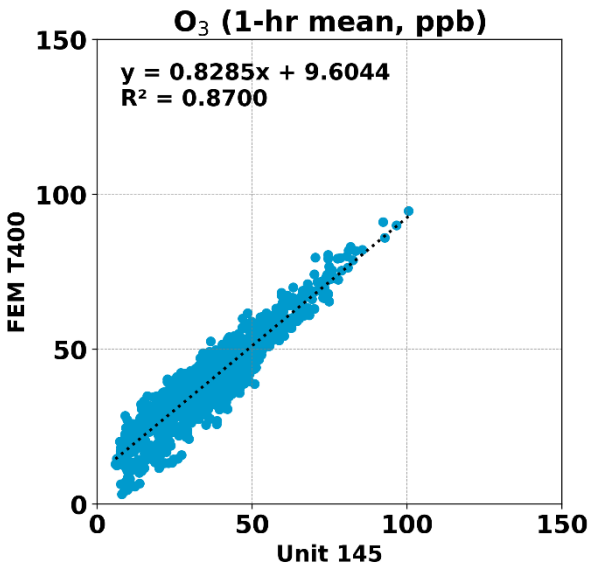


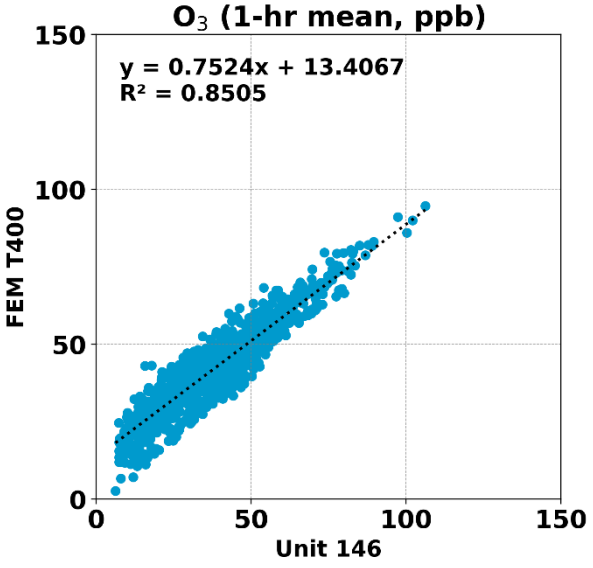
Kunak Air Lite vs FEM T400 (Ozone; 1-hr mean)



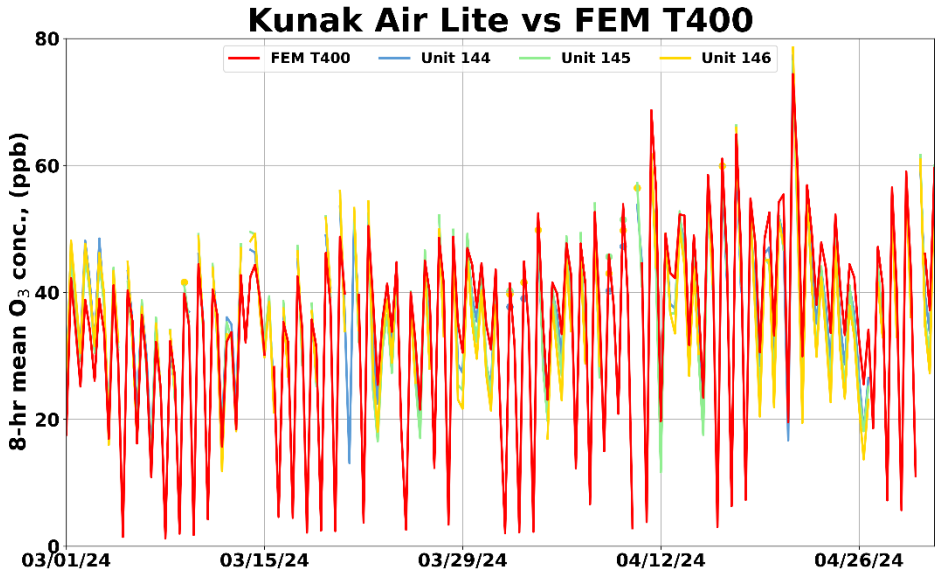
- The Kunak Air Lite sensors showed strong correlation with the corresponding FEM T400 ozone data ($0.85 < R^2 < 0.90$)
- Overall, the Kunak Air Lite sensors underestimated the ozone concentration as measured by the FEM T400 ozone instrument
- The Kunak Air Lite sensors seemed to track the diurnal ozone variations as recorded by the FEM T400 instrument



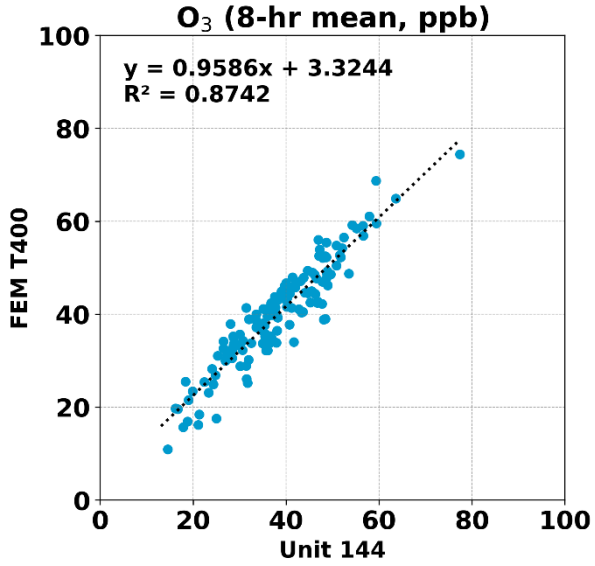


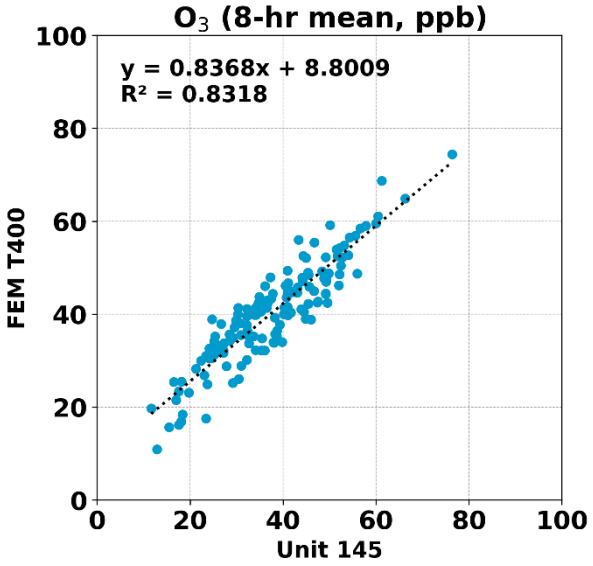


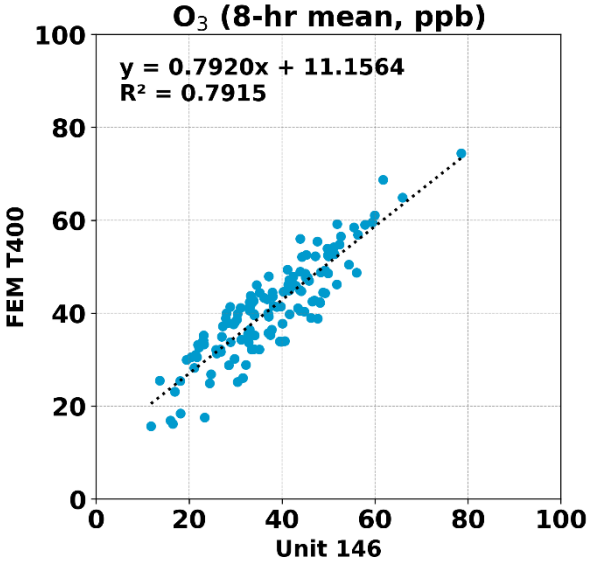
Kunak Air Lite vs FEM T400 (Ozone; 8-hr mean)



- The Kunak Air Lite sensors showed strong correlation with the corresponding FEM T400 ozone data ($0.79 < R^2 < 0.88$)
- Overall, the Kunak Air Lite sensors underestimated the ozone concentration as measured by the FEM T400 ozone instrument
- The Kunak Air Lite sensors seemed to track the diurnal ozone variations as recorded by the FEM T400 instrument







Summary: Ozone

	Average of 3 Sensors, Ozone		Kunak Air Lite 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	37.0	17.1	0.85 to 0.89	0.75 to 0.89	6.3 to 13.4	-4.1 to -2.1	4.7 to 6.8	5.8 to 8.2	35.0	19.2	0.1 to 95.7
1-hr	37.5	16.5	0.85 to 0.90	0.75 to 0.89	6.1 to 13.4	-4.2 to -2.1	4.5 to 6.7	5.5 to 8.0	33.9	19.2	0.5 to 94.6
8-hr	38.1	11.7	0.79 to 0.87	0.79 to 0.96	3.3 to 11.2	-3.4 to -1.7	3.6 to 5.3	4.3 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 Lite

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 144, Unit 145 and Unit 146 was ~99.0%, ~99.1% and ~99.2%, respectively
- Values below manufacturer stated limit of detection were excluded from further analysis but do not count against data recovery

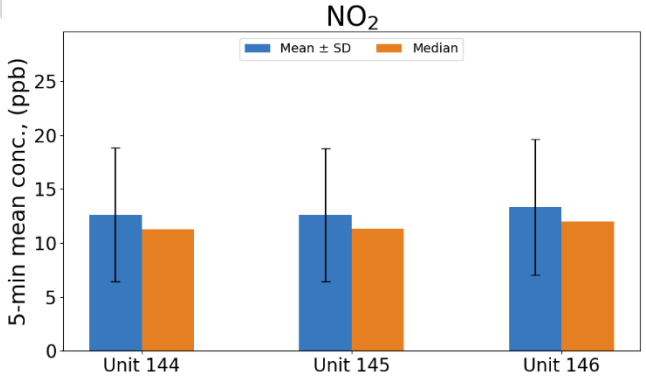
Kunak Air Lite; Intra-model variability

- Absolute intra-model variability was ~0.41 ppb for the NO_2 measurements

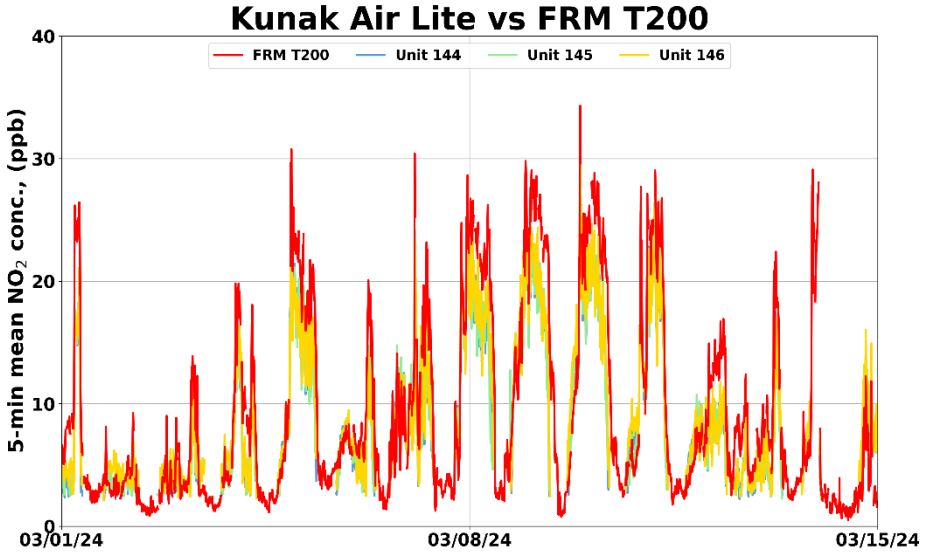
(calculated as the standard deviation of the three sensor means)

- Relative intra-model variability was ~3.21% for the NO_2 measurements

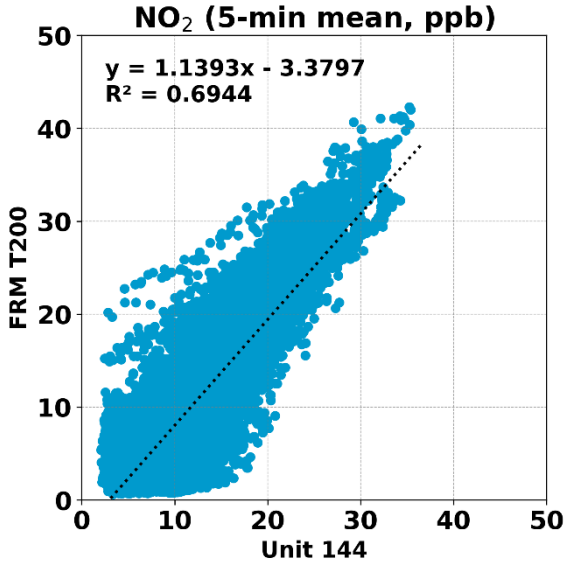
(calculated as the absolute intra-model variability relative to the mean of the three sensor means)

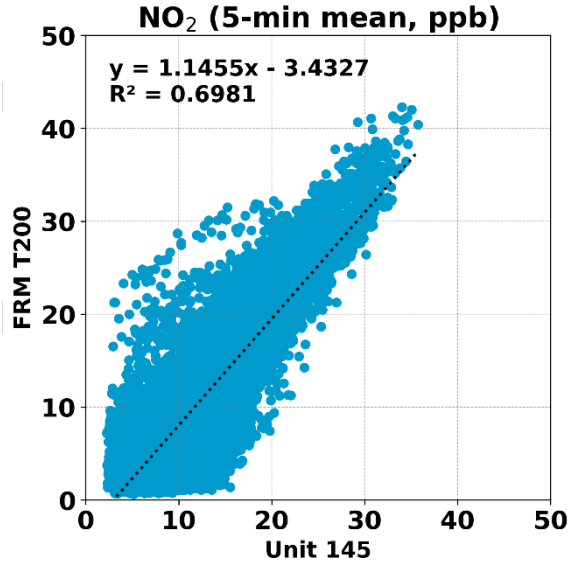


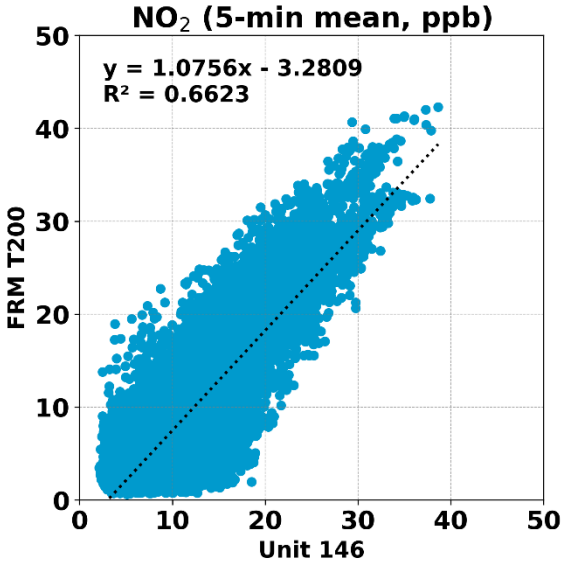
Kunak Air Lite vs FRM T200 (NO_2; 5-min mean)



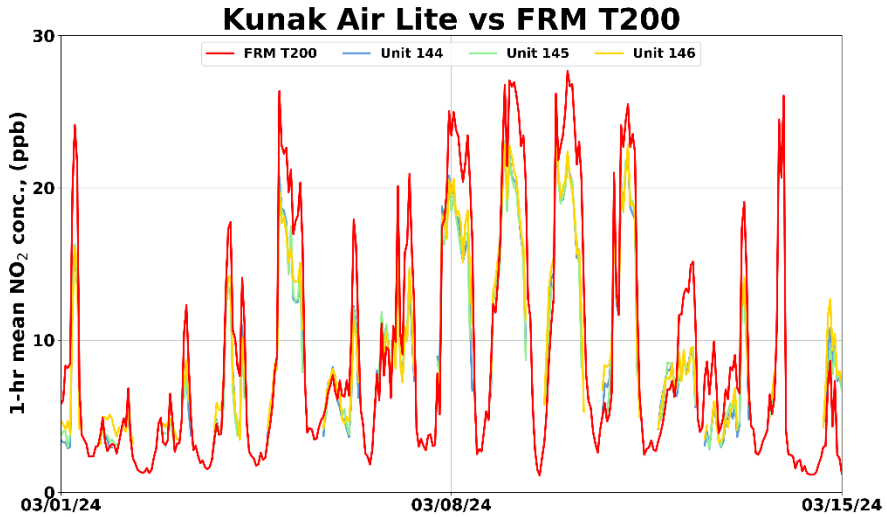
- The Kunak Air Lite sensors showed moderate correlations with the corresponding FRM T200 NO_2 data ($0.66 < R^2 < 0.70$)
- Overall, the Kunak Air Lite sensors overestimated the NO_2 concentration as measured by the FRM T200 instrument
- The Kunak Air Lite sensors seemed to track the diurnal NO_2 variations as recorded by the FRM T200 instrument



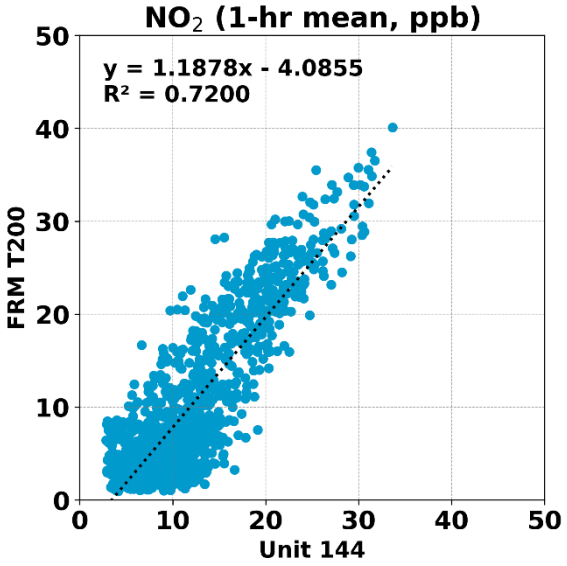


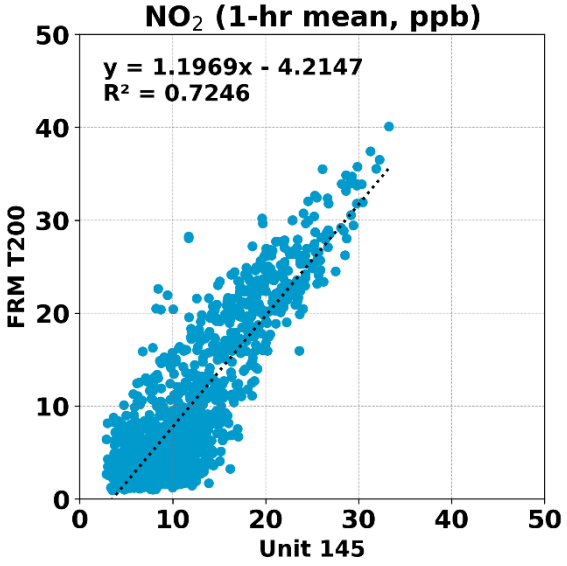


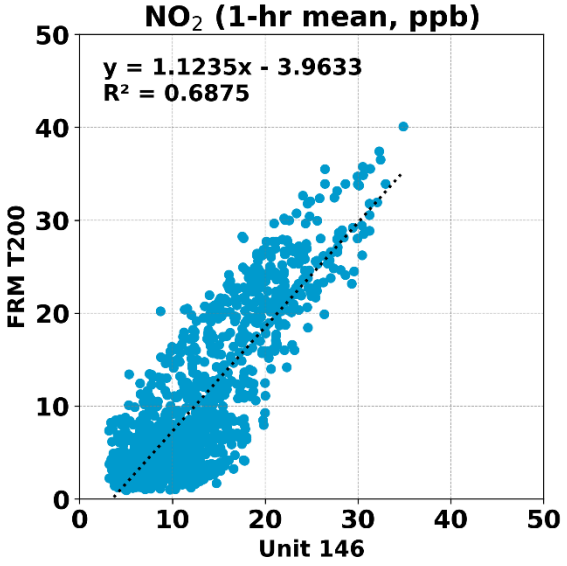
Kunak Air Lite vs FRM T200 (NO_2; 1-hr mean)



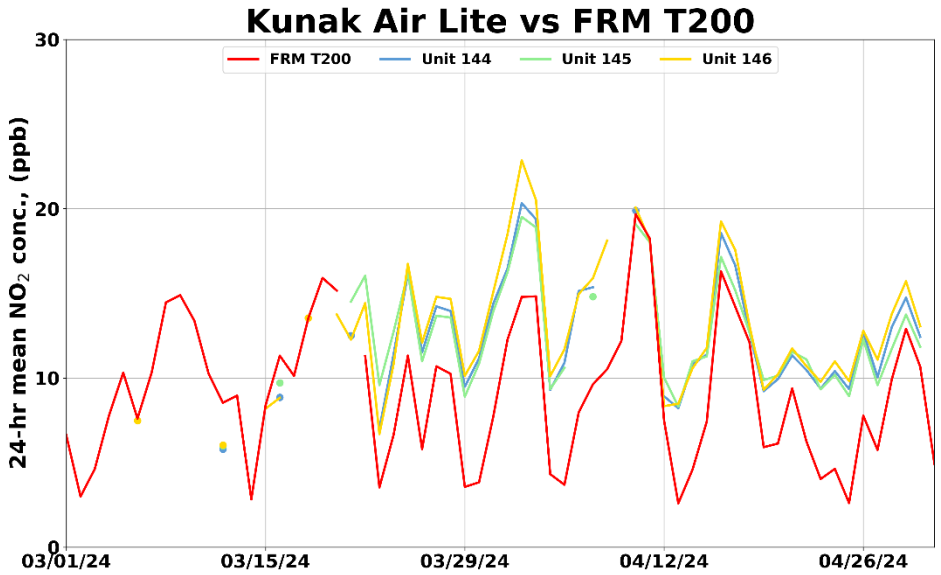
- The Kunak Air Lite sensors showed moderate to strong correlations with the corresponding FRM T200 NO_2 data ($0.68 < R^2 < 0.73$)
- Overall, the Kunak Air Lite sensors overestimated the NO_2 concentration as measured by the FRM T200 instrument
- The Kunak Air Lite sensors seemed to track the diurnal NO_2 variations as recorded by the FRM T200 instrument



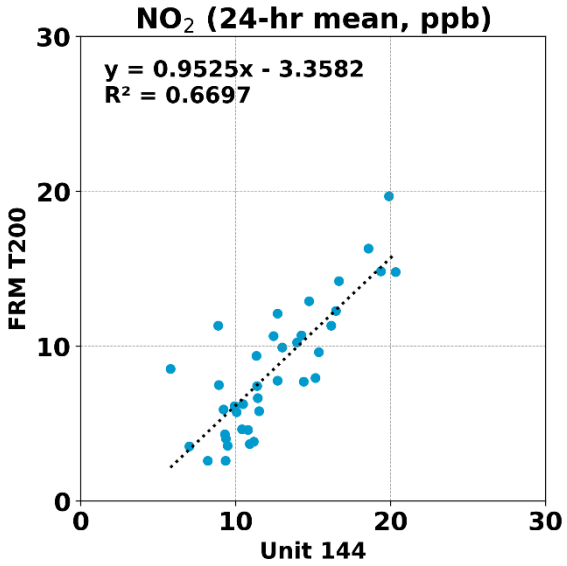


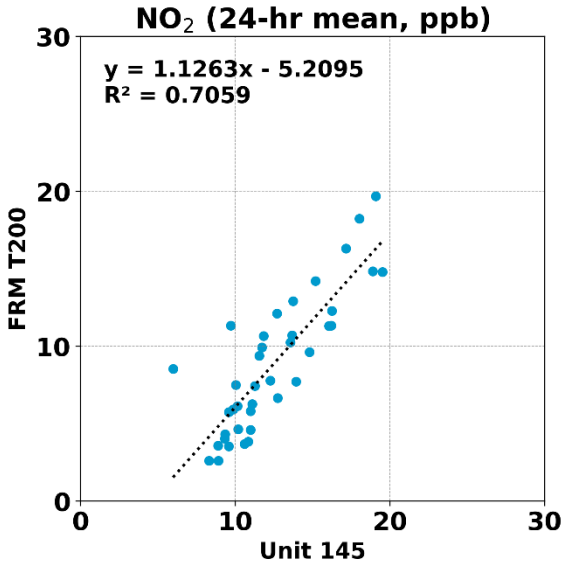


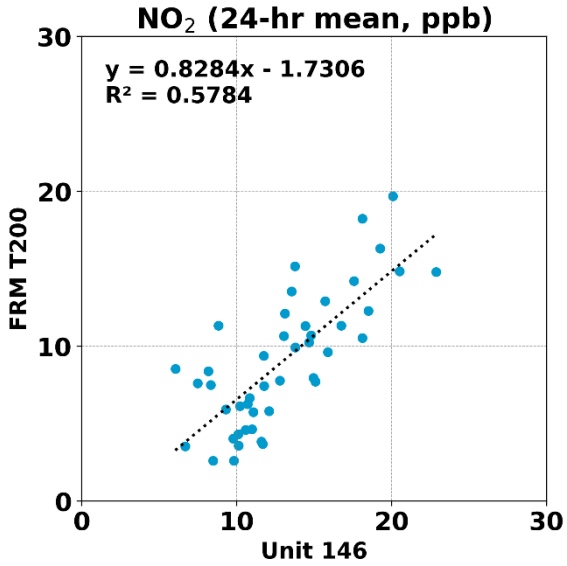
Kunak Air Lite vs FRM T200 (NO_2; 24-hr mean)



- The Kunak Air Lite sensors showed moderate to strong correlations with the corresponding FRM T200 NO_2 data ($0.57 < R^2 < 0.71$)
- Overall, the Kunak Air Lite sensors overestimated the NO_2 concentration as measured by the FRM T200 instrument
- The Kunak Air Lite 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 Lite 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	6.3	0.66 to 0.70	1.08 to 1.15	-3.4 to -3.3	1.7 to 2.3	4.2 to 4.5	5.0 to 5.4	9.1	8.1	0.5 to 42.3
1-hr	12.6	6.1	0.69 to 0.72	1.12 to 1.20	-4.2 to -4.0	1.7 to 2.4	4.1 to 4.4	4.9 to 5.3	9.4	8.1	1.0 to 40.1
24-hr	12.6	3.6	0.58 to 0.71	0.83 to 1.13	-5.2 to -1.7	3.6 to 4.0	3.9 to 4.3	4.4 to 4.9	9.1	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.

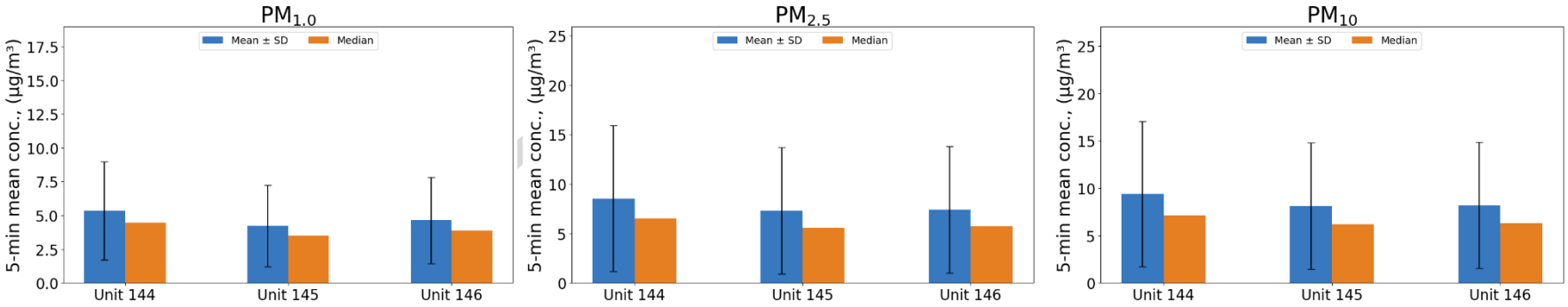
Particulate Matter (PM) in Kunak Air Lite

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 144, Unit 145 and Unit 146 was ~99.5%, ~99.8% and ~99.9%, respectively for all PM measurements
- Values below manufacturer stated limit of detection were excluded from further analysis but do not count against data recovery

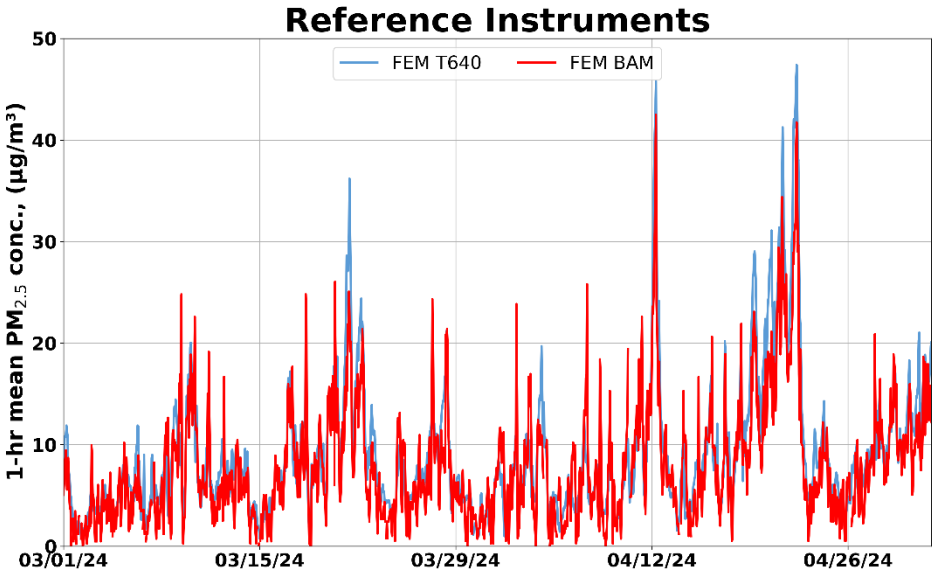
Kunak Air Lite; intra-model variability

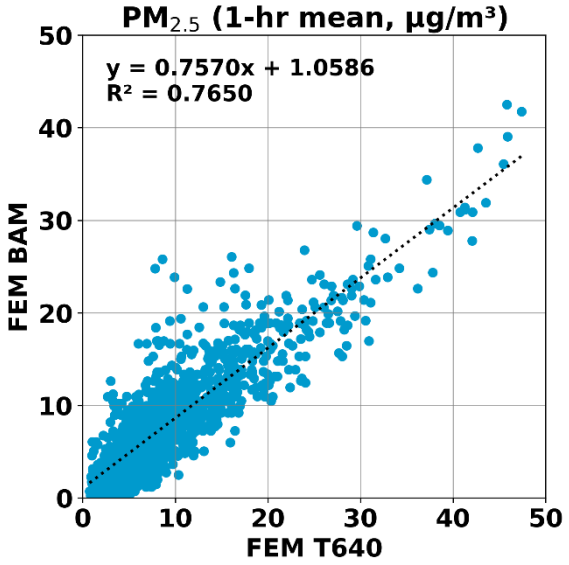
- Absolute intra-model variability was ~0.57, ~0.68 and ~0.72 µg/m^3 for $PM_{1.0}$, $PM_{2.5}$ and $PM_{10,}$ respectively (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was ~12.09%, ~8.75% and ~8.37% for $PM_{1.0}$, $PM_{2.5}$ and $PM_{10,}$ respectively (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

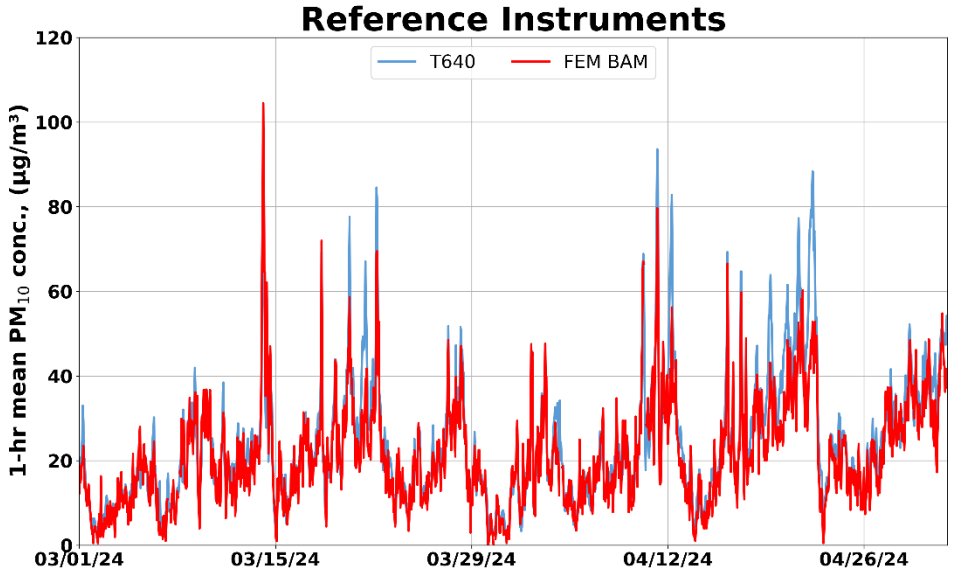
- Data recovery for $PM_{2.5}$ from FEM BAM and FEM T640 was ~ 99.1% and 99.9%, respectively.
- Strong correlations between the reference instruments for $PM_{2.5}$ measurements (R^2 ~0.77) were observed.

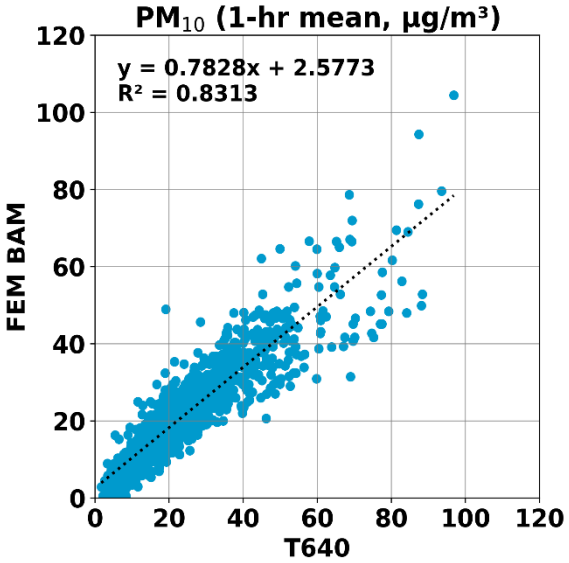




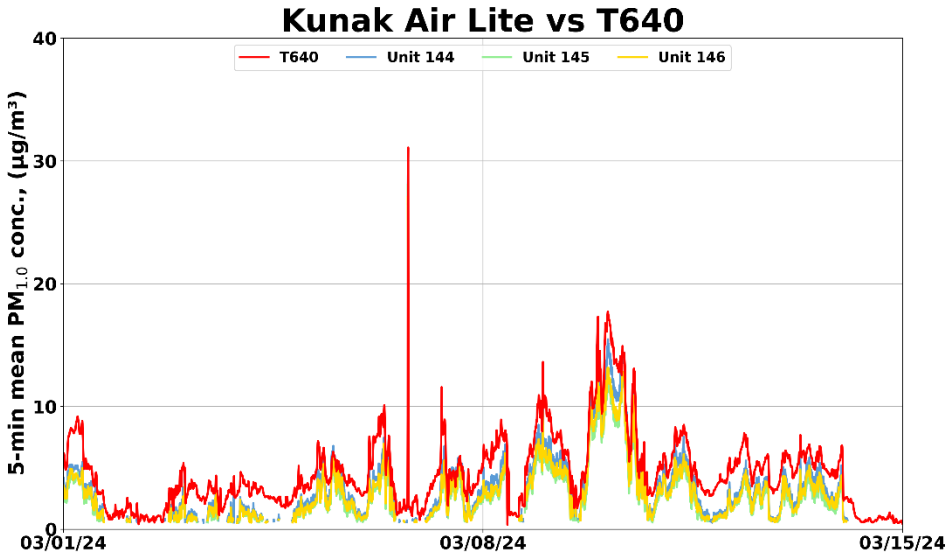
Reference Instruments: PM_{10} FEM BAM and T640

- 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.

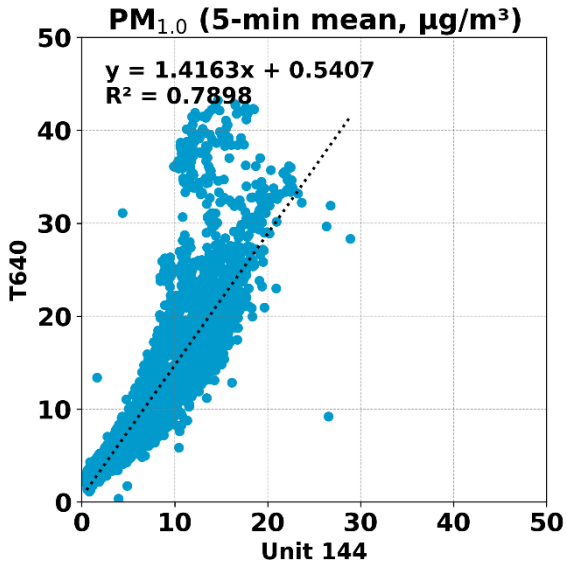


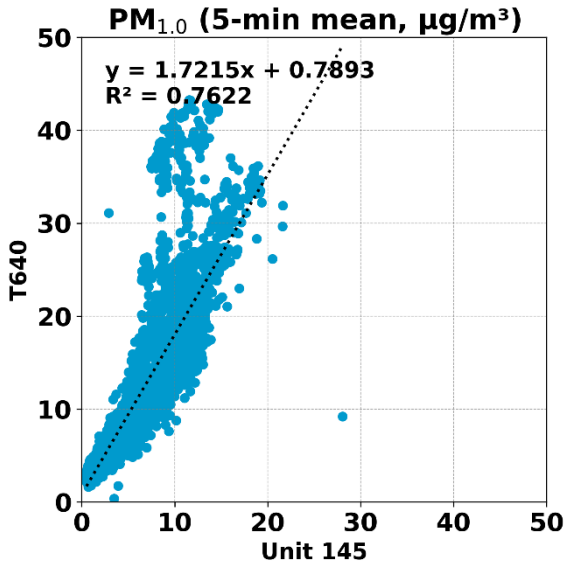


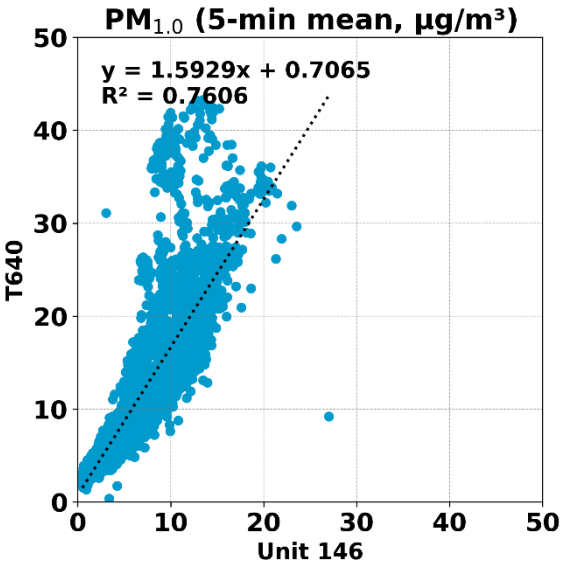
Kunak Air Lite vs T640 ($PM_{1.0}$; 5-min mean)



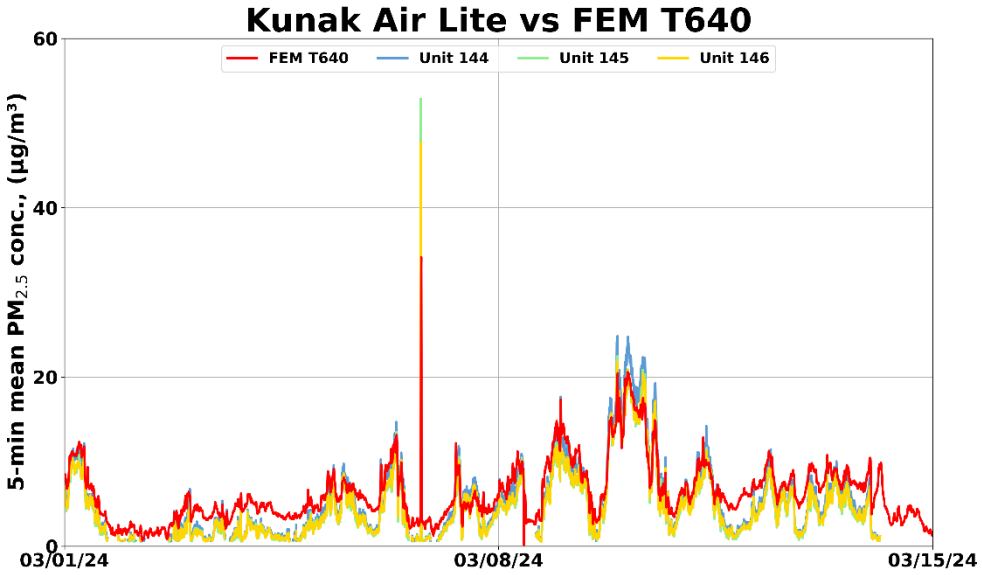
- The Kunak Air Lite sensors showed strong correlations with the corresponding T640 data ($0.76 < R^2 < 0.79$)
- Overall, the Kunak Air Lite sensors underestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The Kunak Air Lite sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by T640



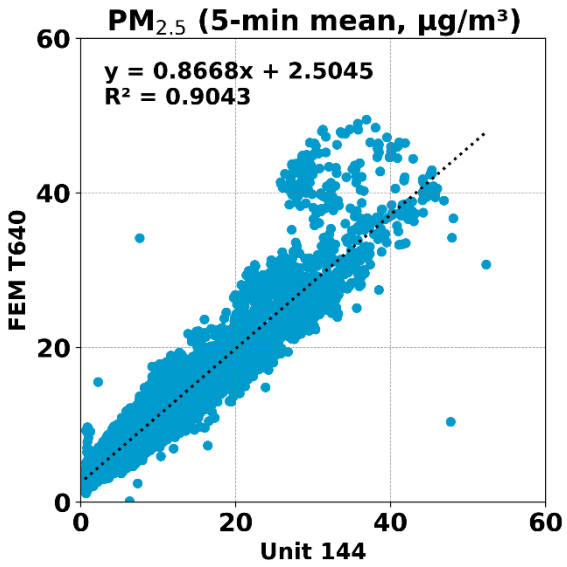


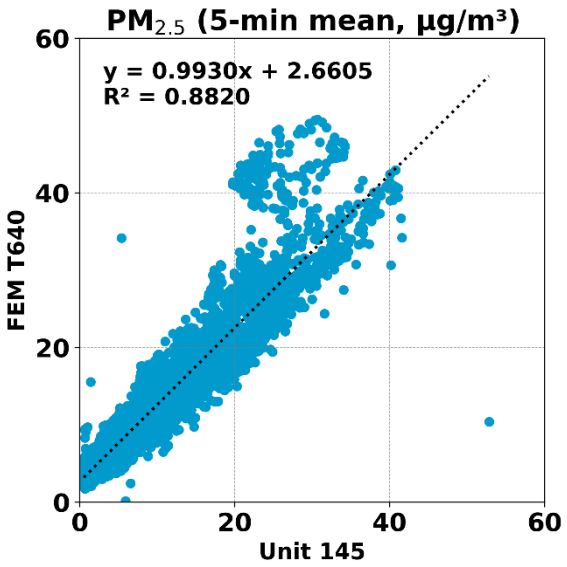


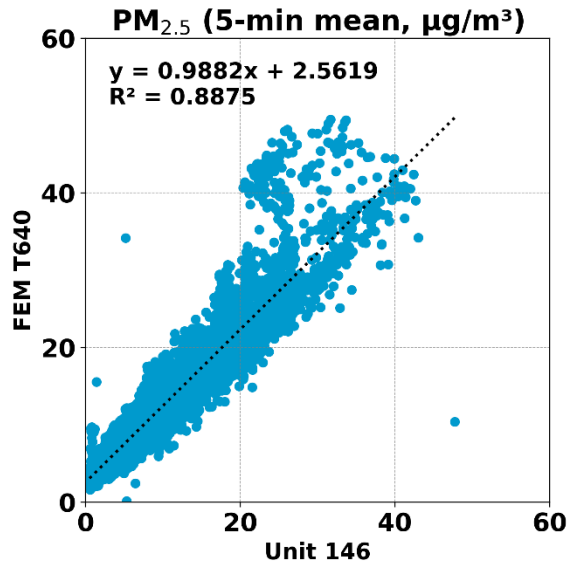
Kunak Air Lite vs FEM T640 ($PM_{2.5}$; 5-min mean)



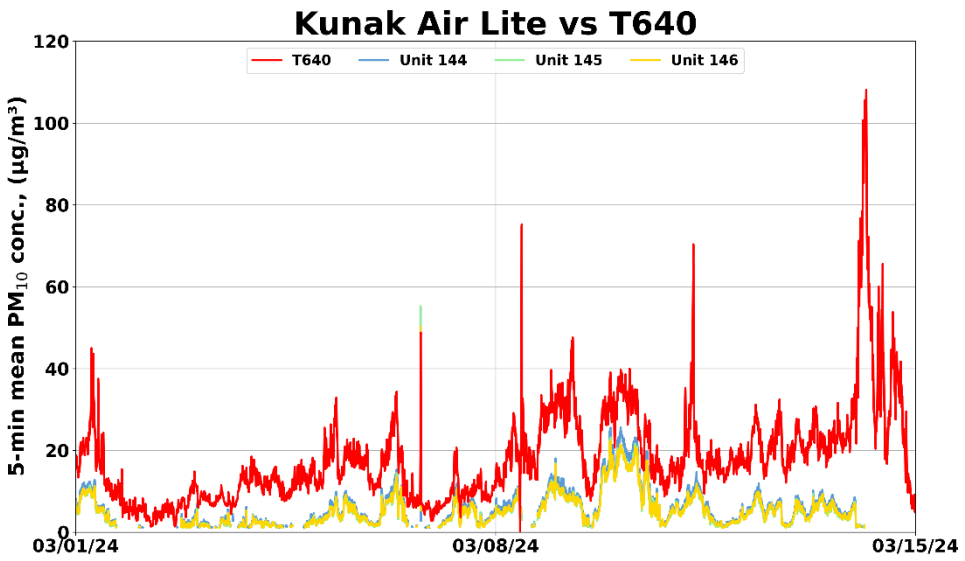
- The Kunak Air Lite sensors showed strong to very strong correlations with the corresponding FEM T640 data ($0.88 < R^2 < 0.91$)
- Overall, the Kunak Air Lite sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The Kunak Air Lite sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



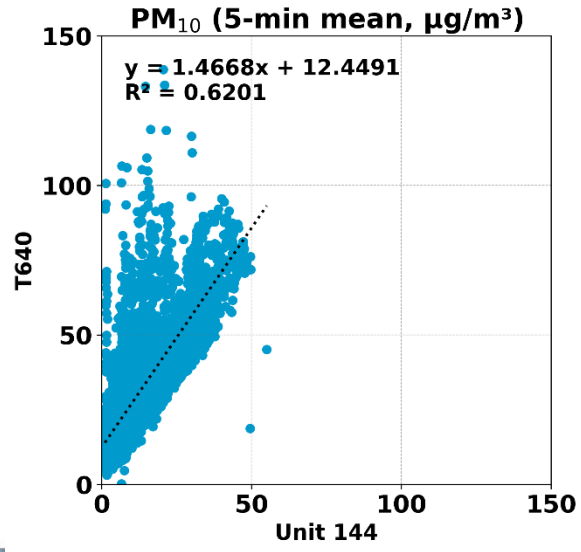


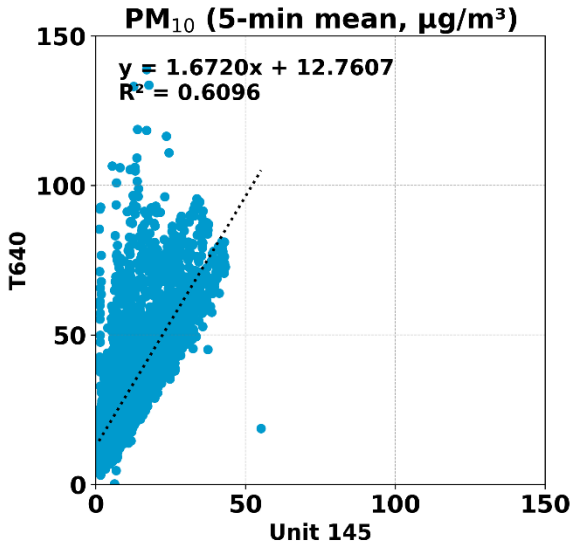


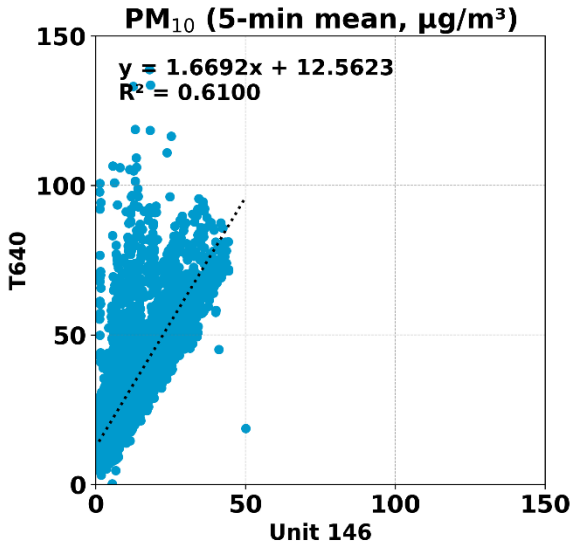
Kunak Air Lite vs T640 (PM_{10}; 5-min mean)



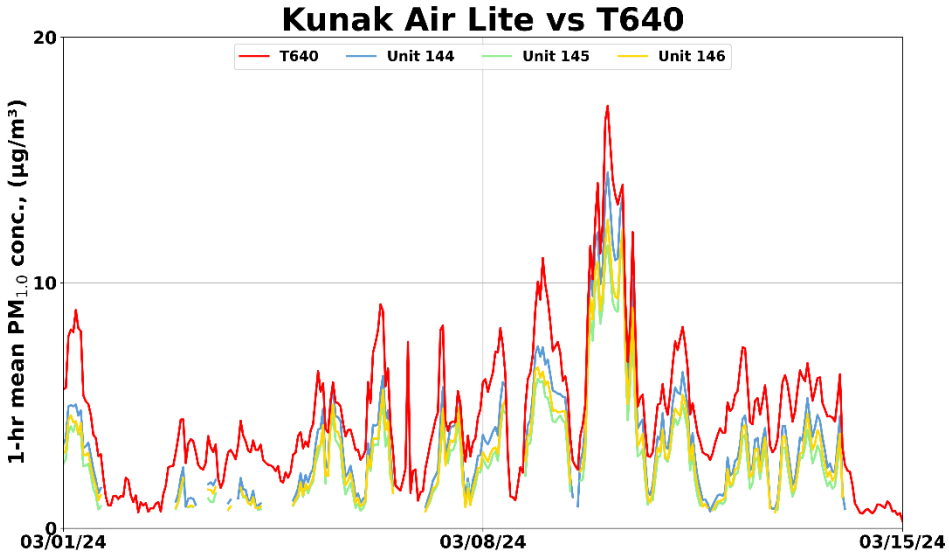
- The Kunak Air Lite sensors showed moderate correlations with the corresponding T640 data ($0.60 < R^2 < 0.63$)
- Overall, the Kunak Air Lite sensors underestimated the PM_{10} mass concentrations as measured by T640
- The Kunak Air Lite sensors seemed to track the PM_{10} diurnal variations as recorded by T640



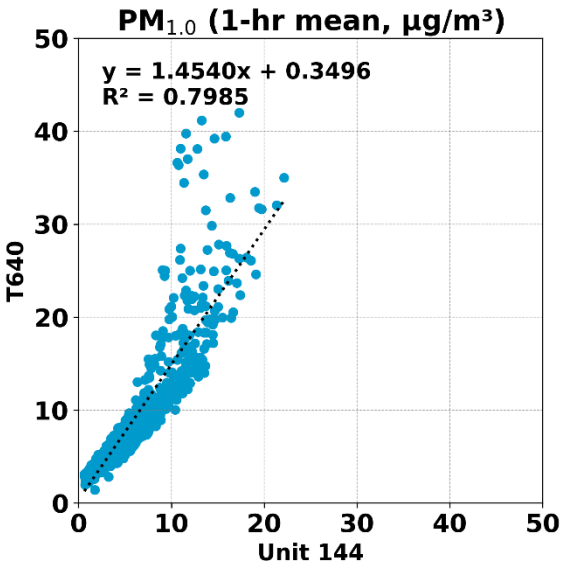


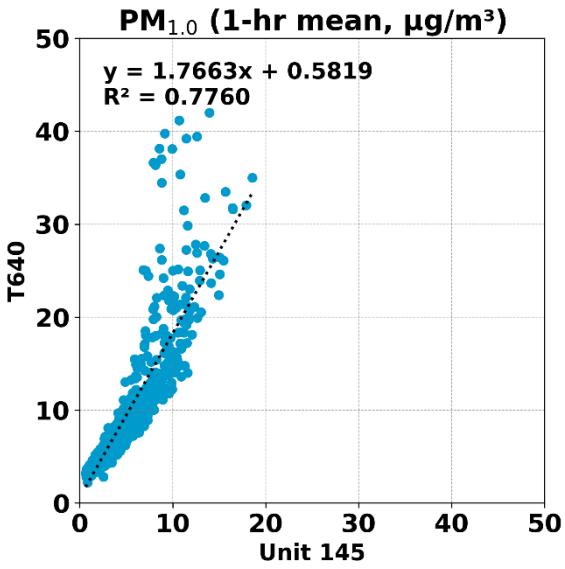


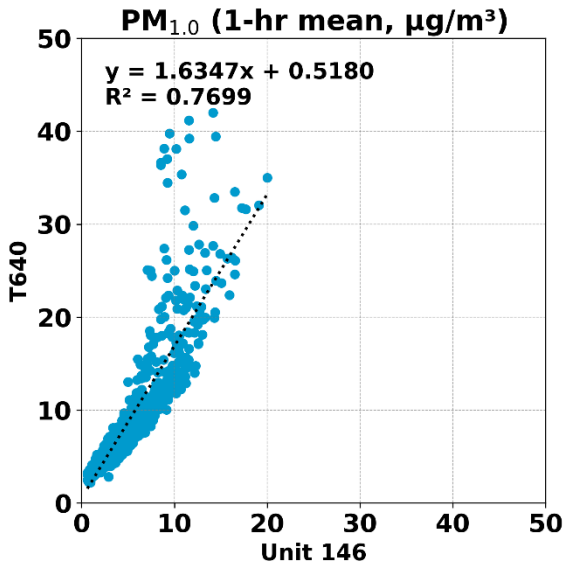
Kunak Air Lite vs T640 ($PM_{1.0}$; 1-hr mean)



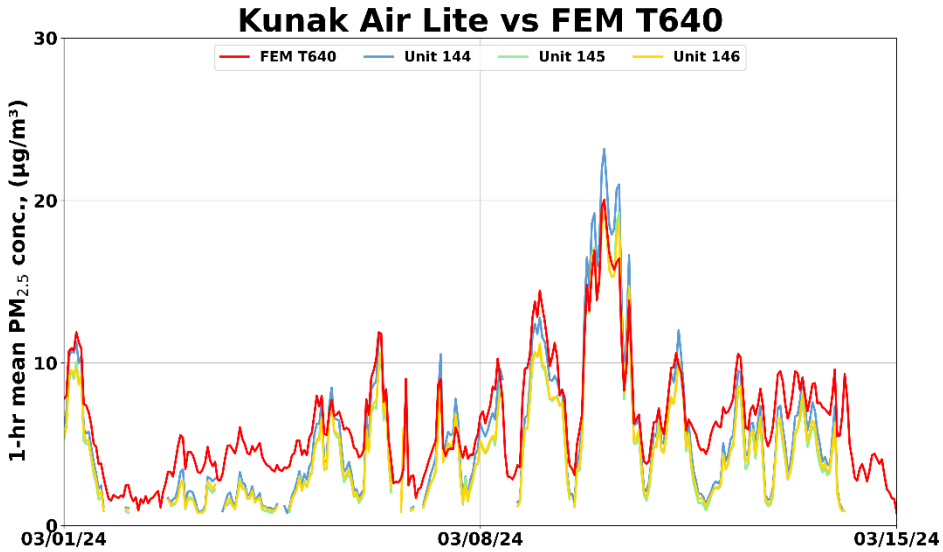
- The Kunak Air Lite sensors showed strong correlations with the corresponding T640 data ($0.77 < R^2 < 0.80$)
- Overall, the Kunak Air Lite sensors underestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The Kunak Air Lite sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by T640



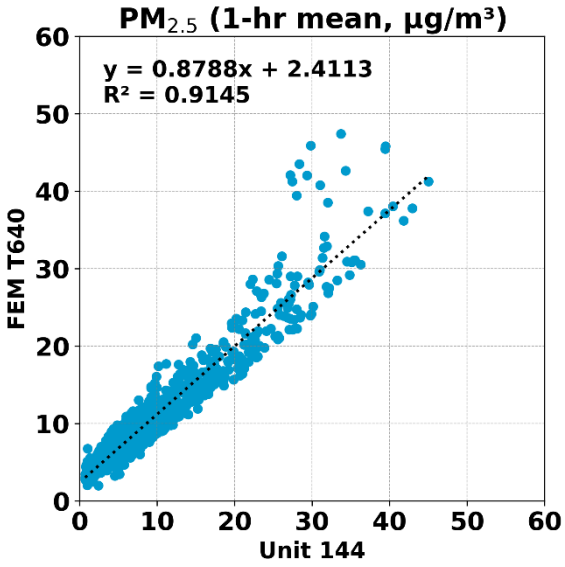


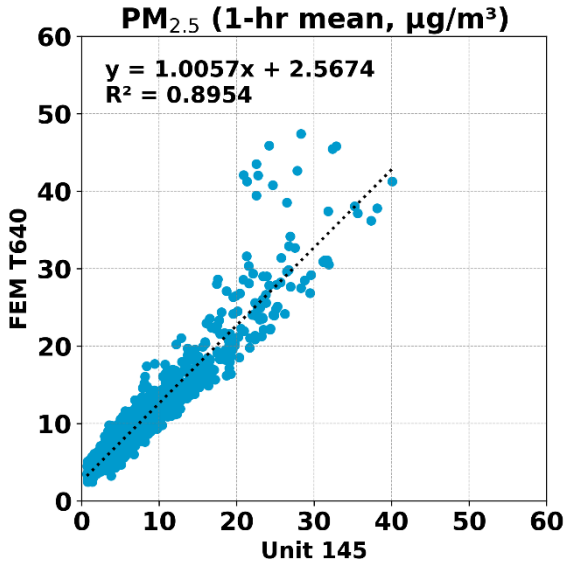


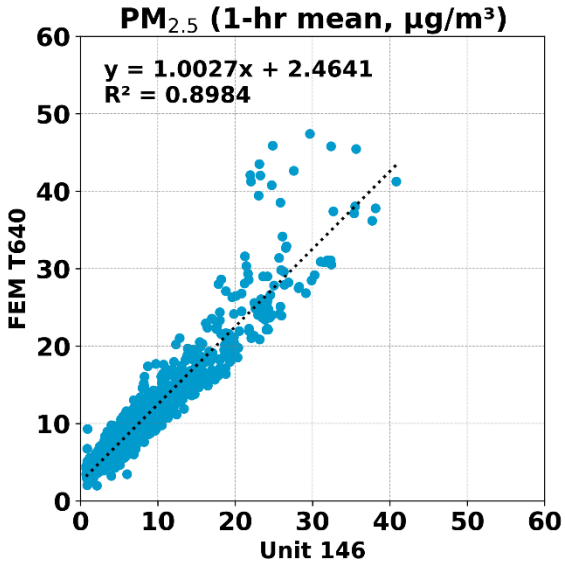
Kunak Air Lite vs FEM T640 ($PM_{2.5}$; 1-hr mean)



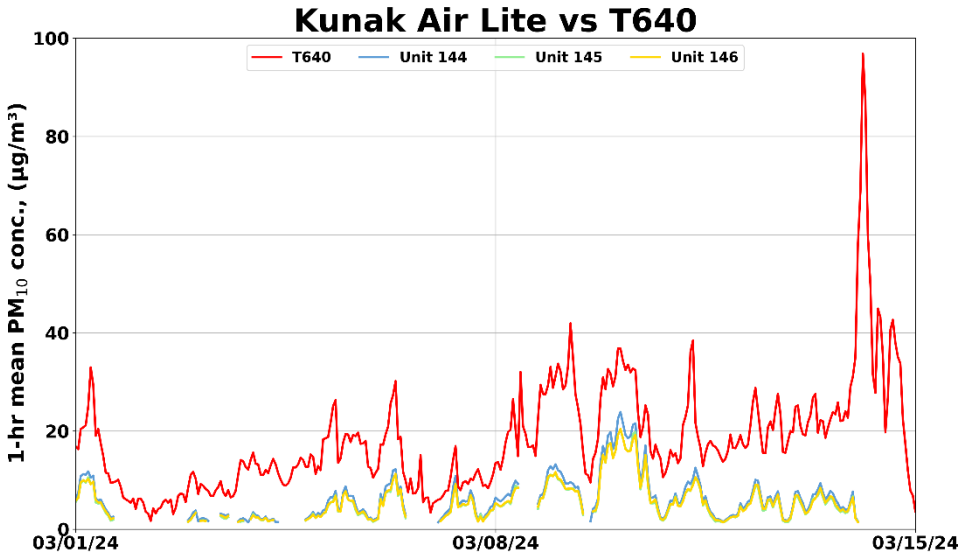
- The Kunak Air Lite sensors showed strong to very strong correlations with the corresponding FEM T640 data ($0.89 < R^2 < 0.92$)
- Overall, the Kunak Air Lite sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The Kunak Air Lite sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



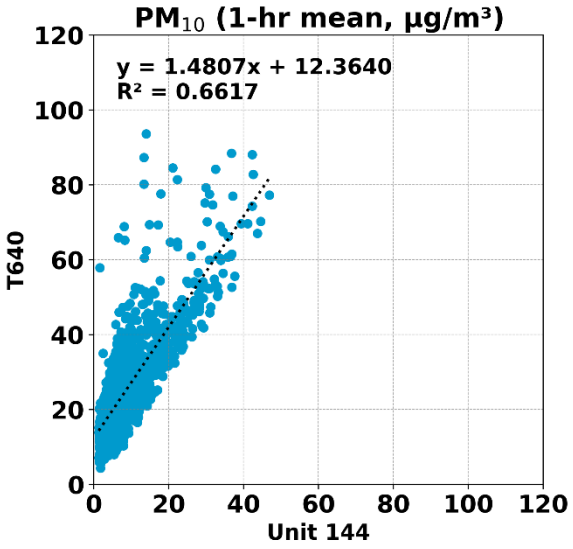


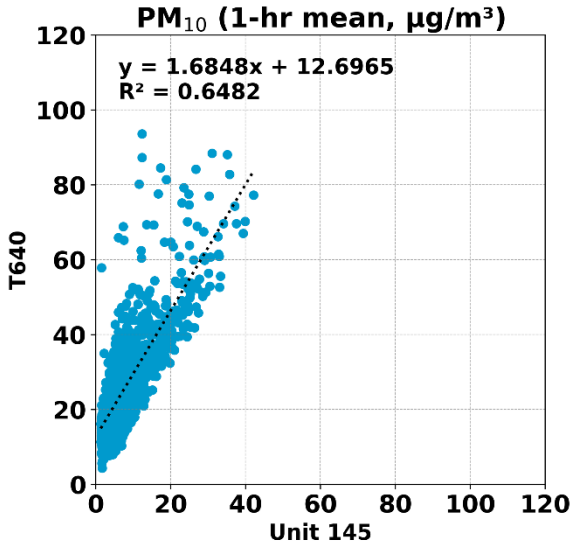


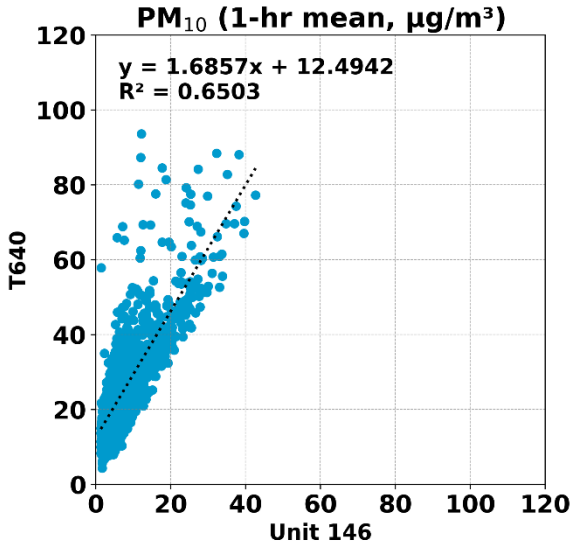
Kunak Air Lite vs T640 (PM_{10}; 1-hr mean)



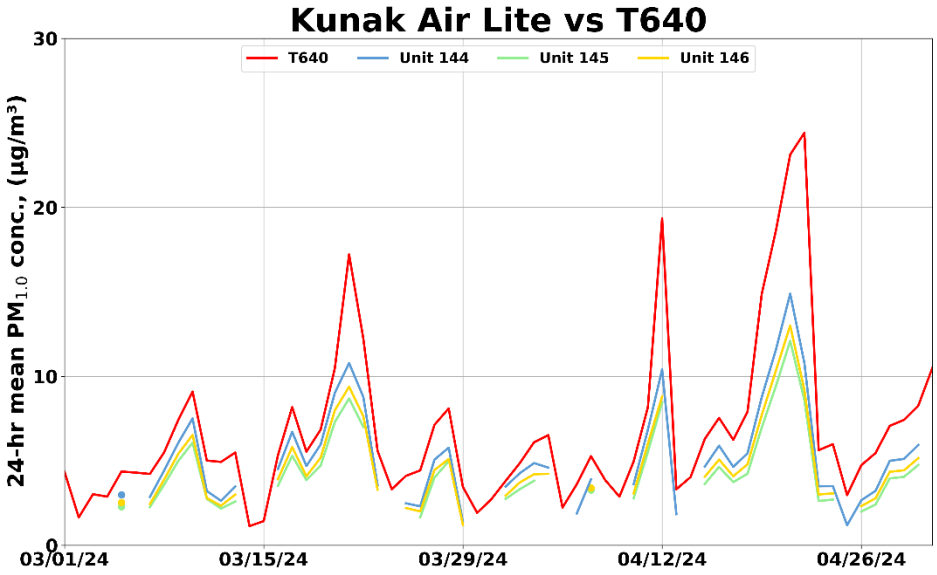
- The Kunak Air Lite sensors showed moderate correlations with the corresponding T640 data ($0.64 < R^2 < 0.67$)
- Overall, the Kunak Air Lite sensors underestimated the PM_{10} mass concentrations as measured by T640
- The Kunak Air Lite sensors seemed to track the PM_{10} diurnal variations as recorded by T640



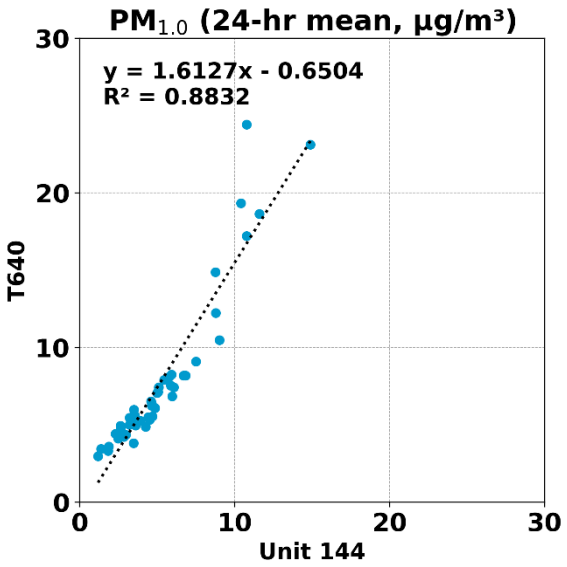


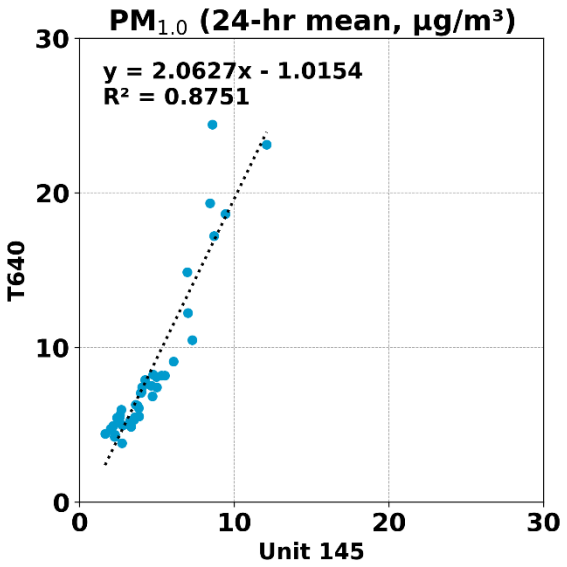


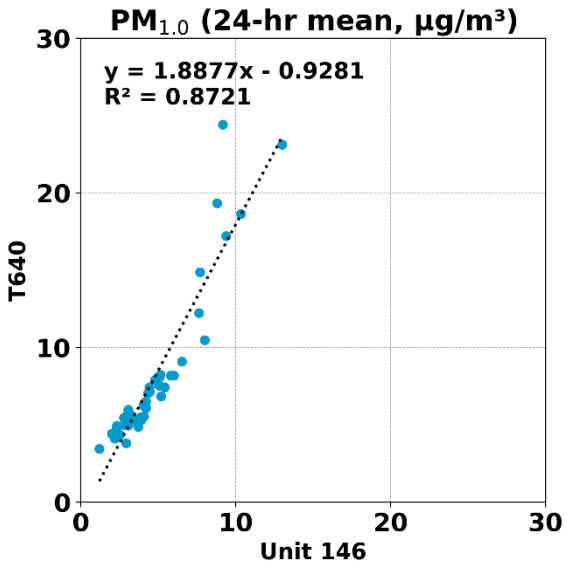
Kunak Air Lite vs T640 ($PM_{1.0}$; 24-hr mean)



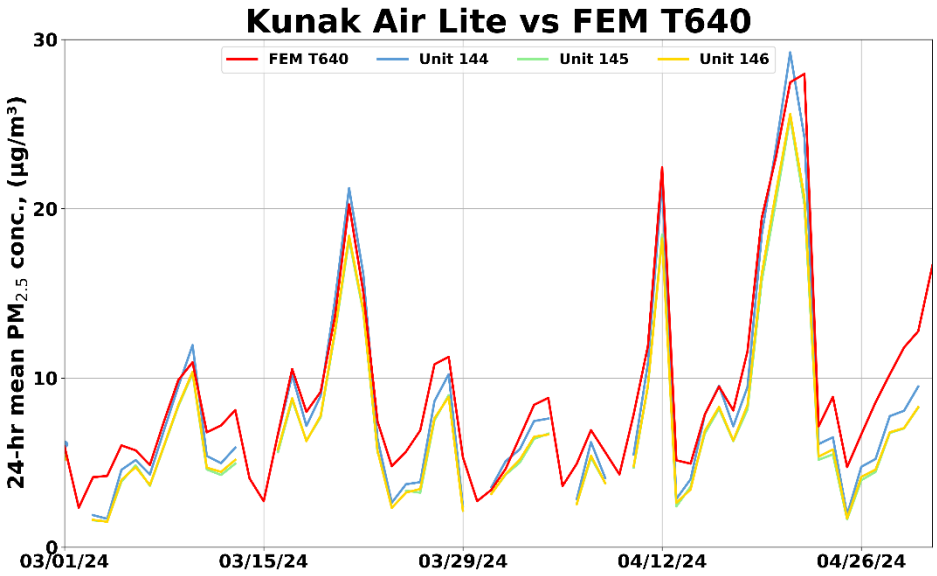
- The Kunak Air Lite sensors showed strong correlations with the corresponding T640 data ($0.87 < R^2 < 0.89$)
- Overall, the Kunak Air Lite sensors underestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The Kunak Air Lite sensors seemed to track the $PM_{1.0}$ daily variations as recorded by T640



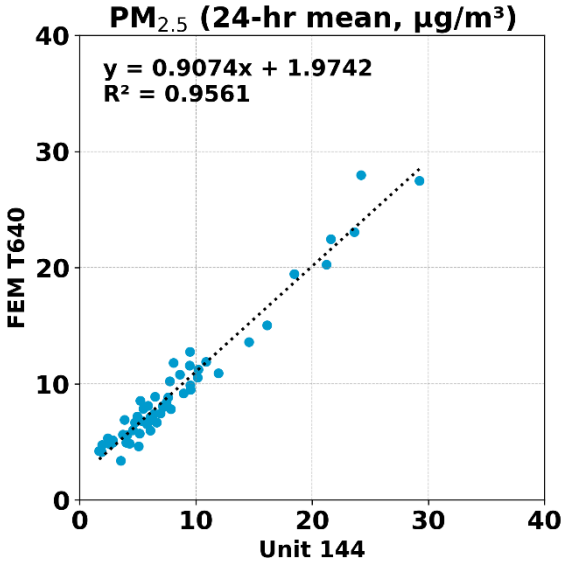


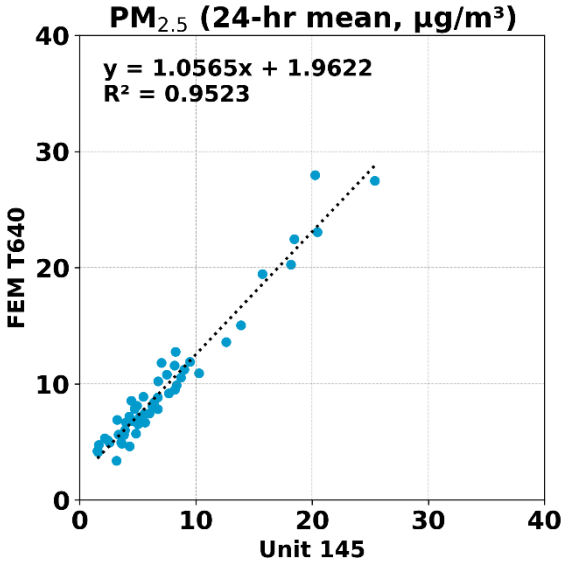


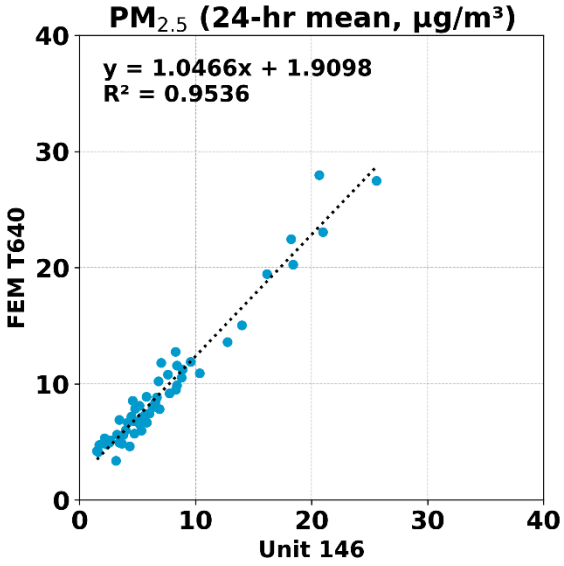
Kunak Air Lite vs FEM T640 ($PM_{2.5}$; 24-hr mean)



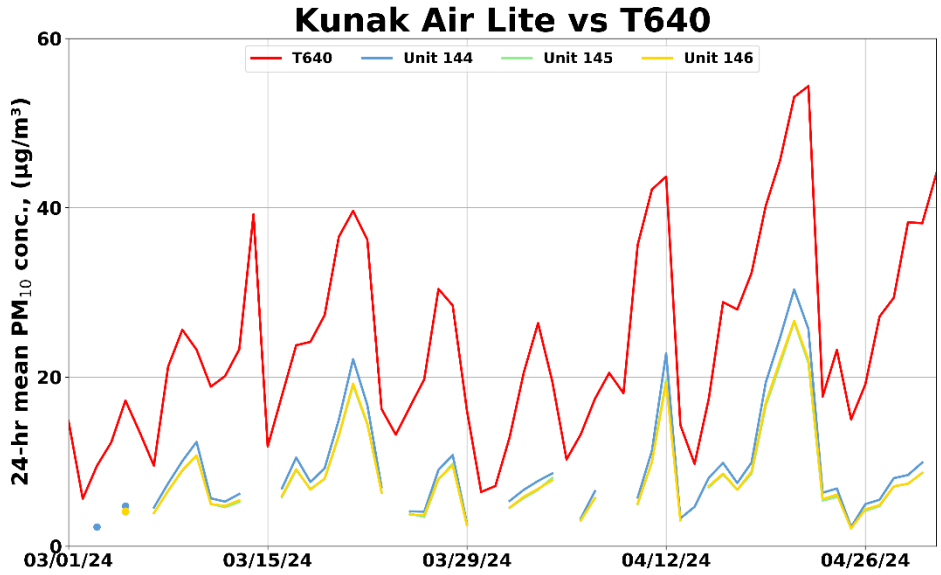
- The Kunak Air Lite sensors showed very strong correlations with the corresponding FEM T640 data ($0.95 < R^2 < 0.96$)
- Overall, the Kunak Air Lite sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The Kunak Air Lite sensors seemed to track the $PM_{2.5}$ daily variations as recorded by FEM T640



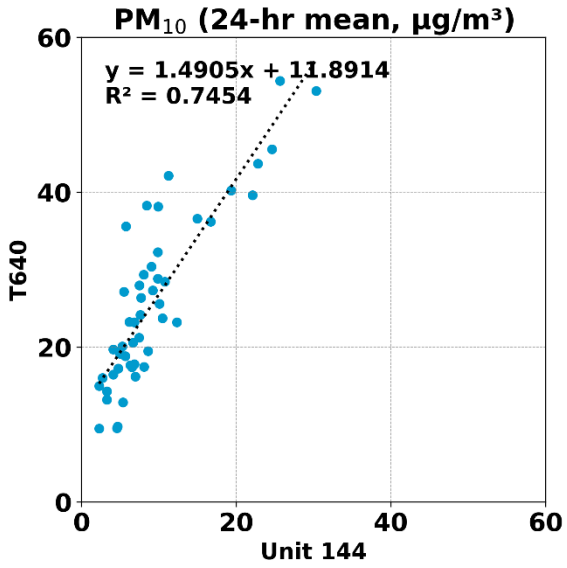


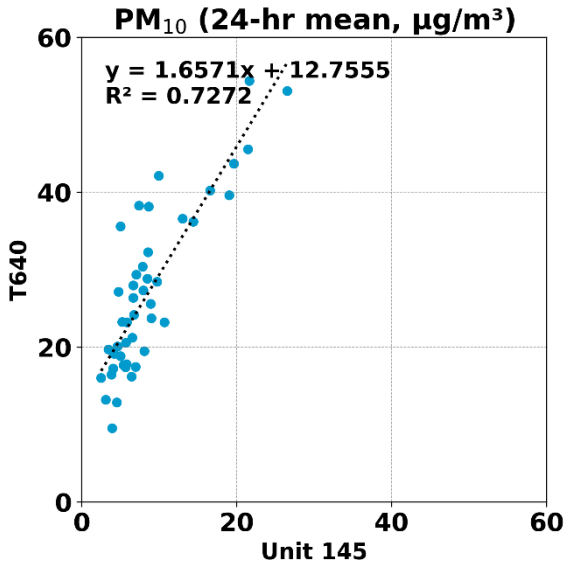


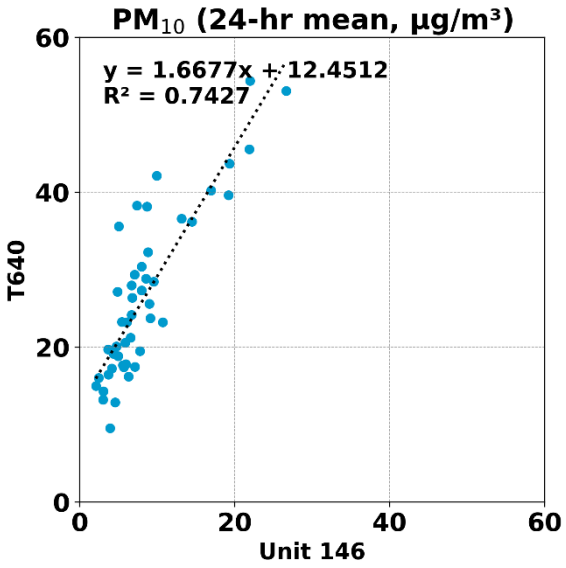
Kunak Air Lite vs T640 (PM_{10}; 24-hr mean)



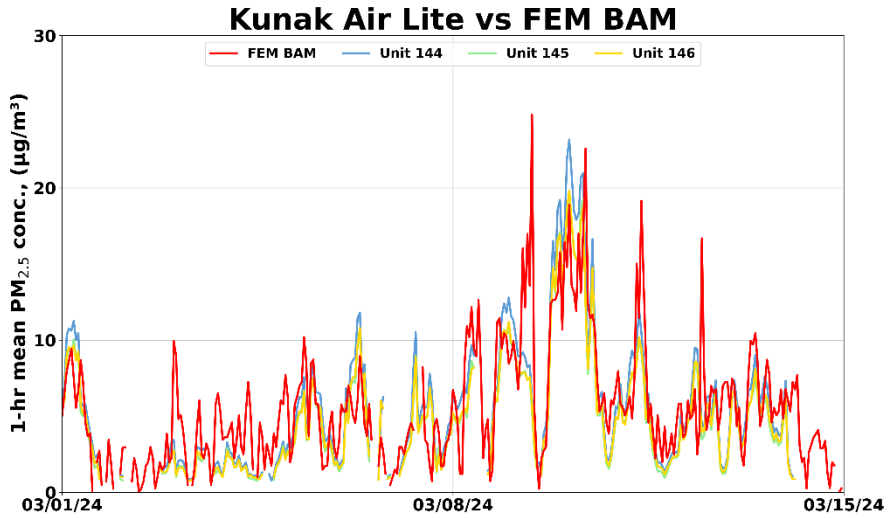
- The Kunak Air Lite sensors showed strong correlations with the corresponding T640 data ($0.72 < R^2 < 0.75$)
- Overall, the Kunak Air Lite sensors underestimated the PM_{10} mass concentrations as measured by T640
- The Kunak Air Lite sensors seemed to track the PM_{10} daily variations as recorded by T640



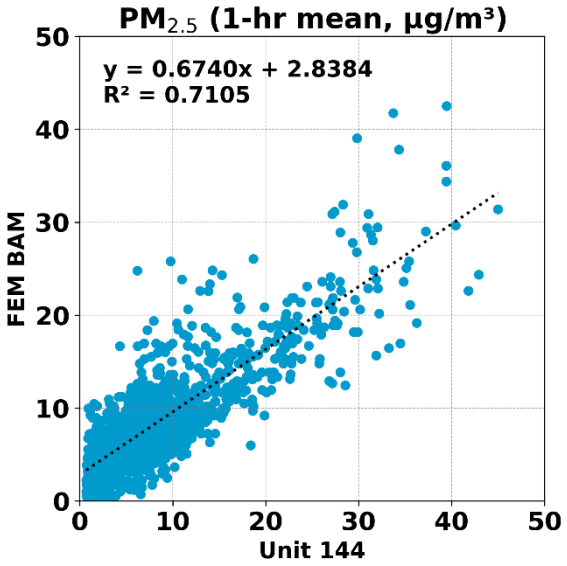


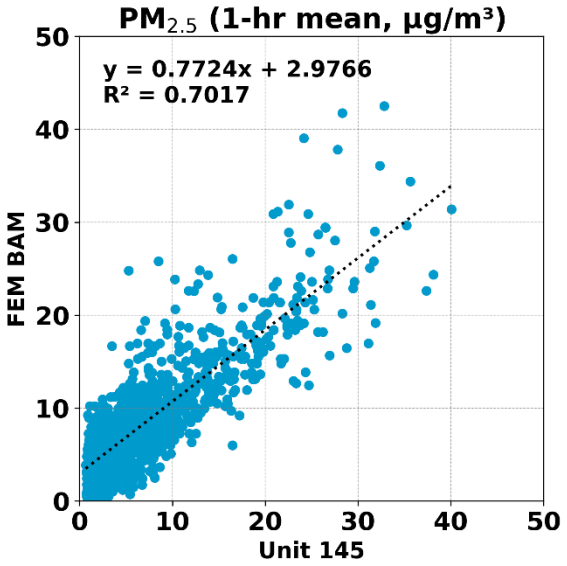


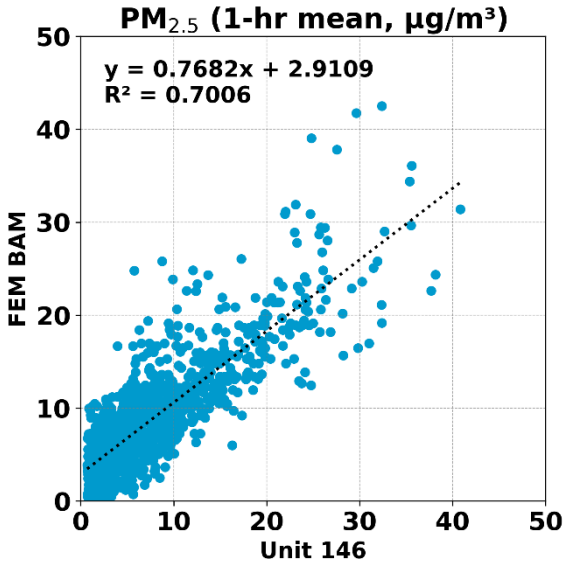
Kunak Air Lite vs FEM BAM ($PM_{2.5}$; 1-hr mean)



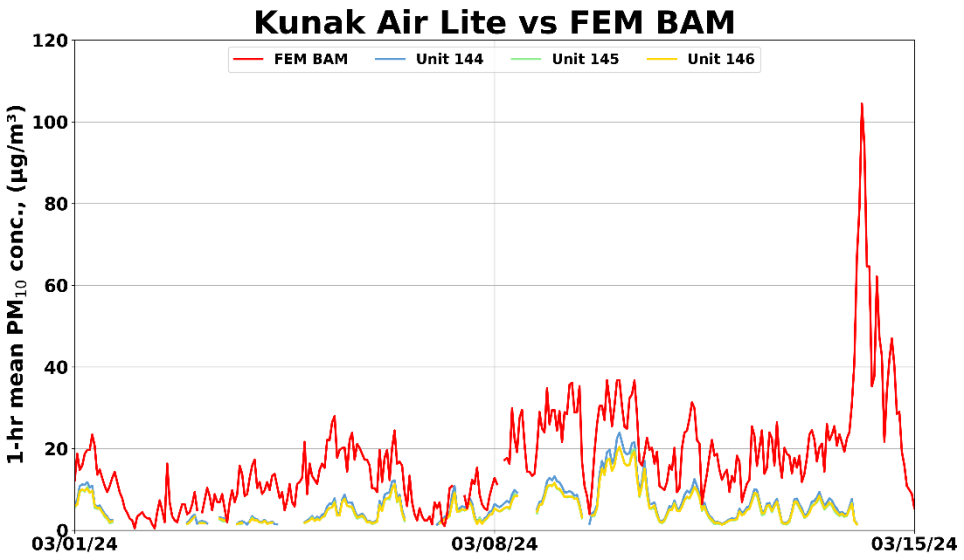
- The Kunak Air Lite sensors showed strong correlations with the corresponding FEM BAM data ($0.70 < R^2 < 0.72$)
- Overall, the Kunak Air Lite sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM BAM
- The Kunak Air Lite sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM BAM



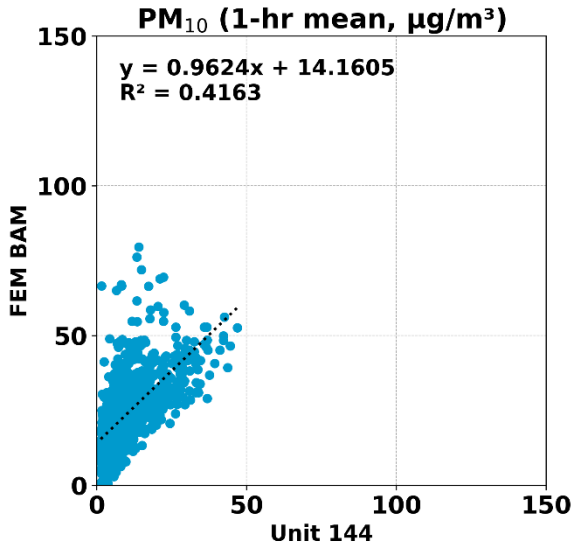


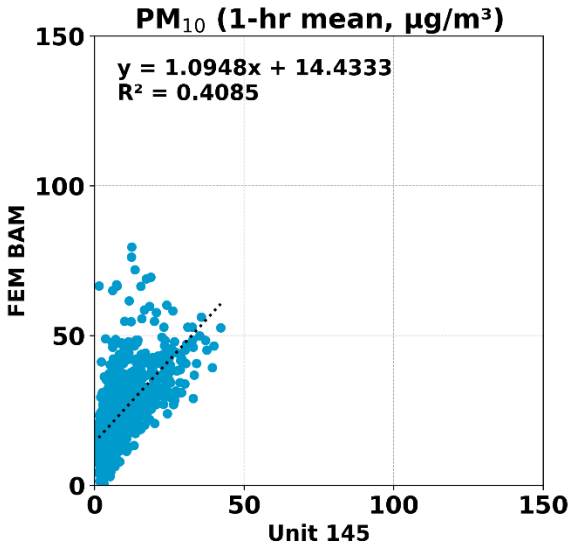


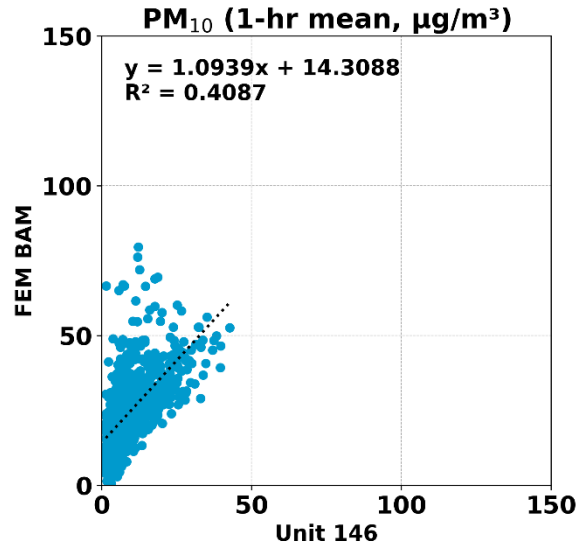
Kunak Air Lite vs FEM BAM (PM_{10}; 1-hr mean)



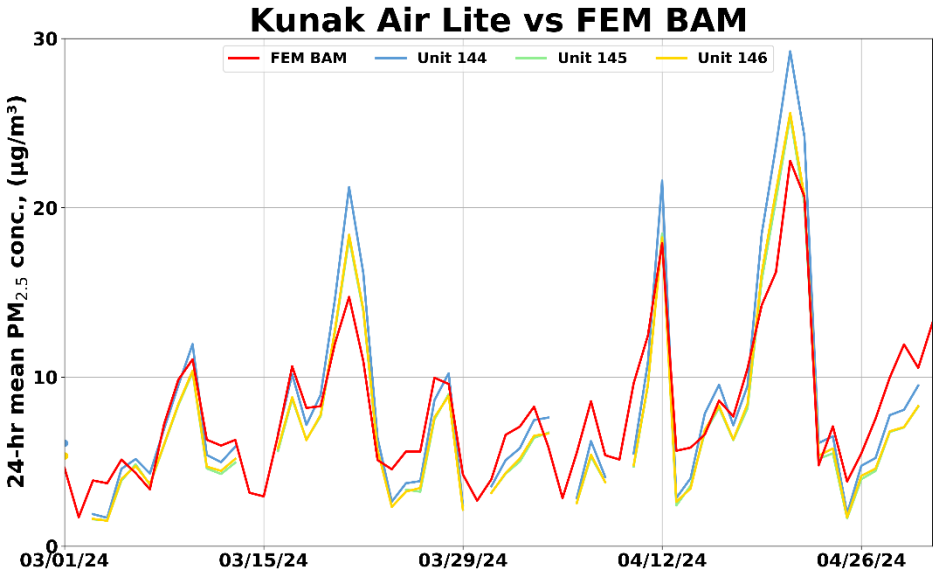
- The Kunak Air Lite sensors showed weak correlations with the corresponding FEM BAM data ($0.40 < R^2 < 0.42$)
- Overall, the Kunak Air Lite sensors underestimated the PM_{10} mass concentrations as measured by FEM BAM
- The Kunak Air Lite sensors seemed to track the PM_{10} diurnal variations as recorded by FEM BAM



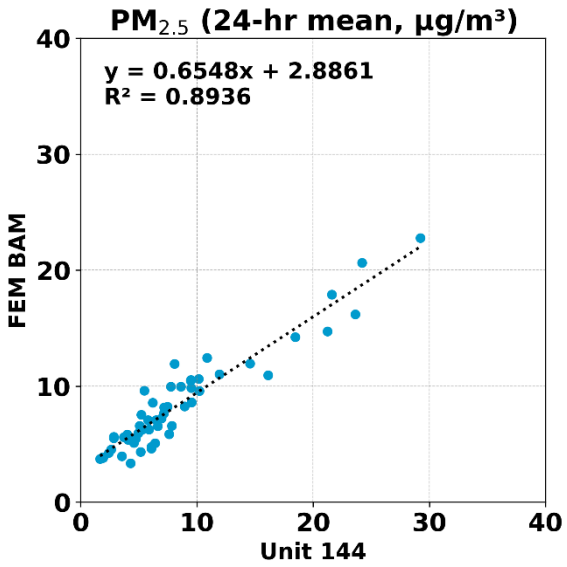


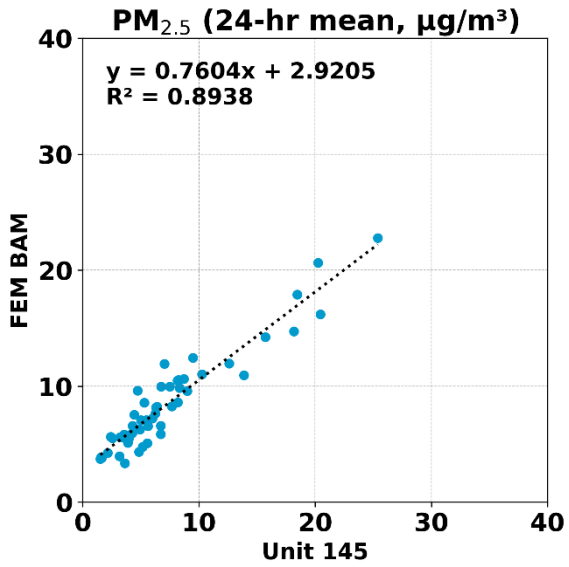


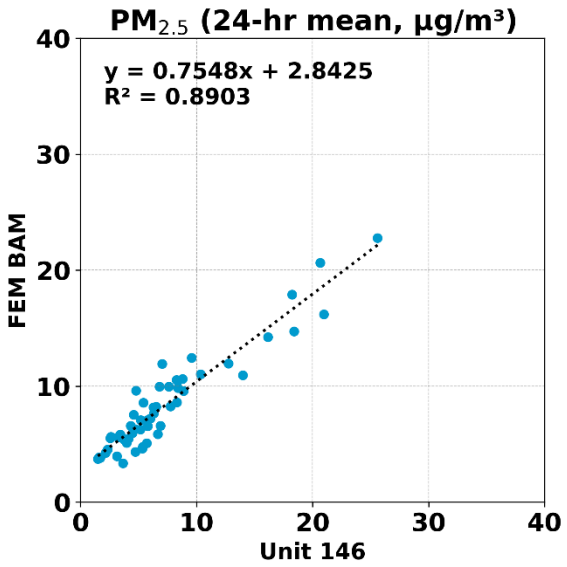
Kunak Air Lite vs FEM BAM ($PM_{2.5}$; 24-hr mean)



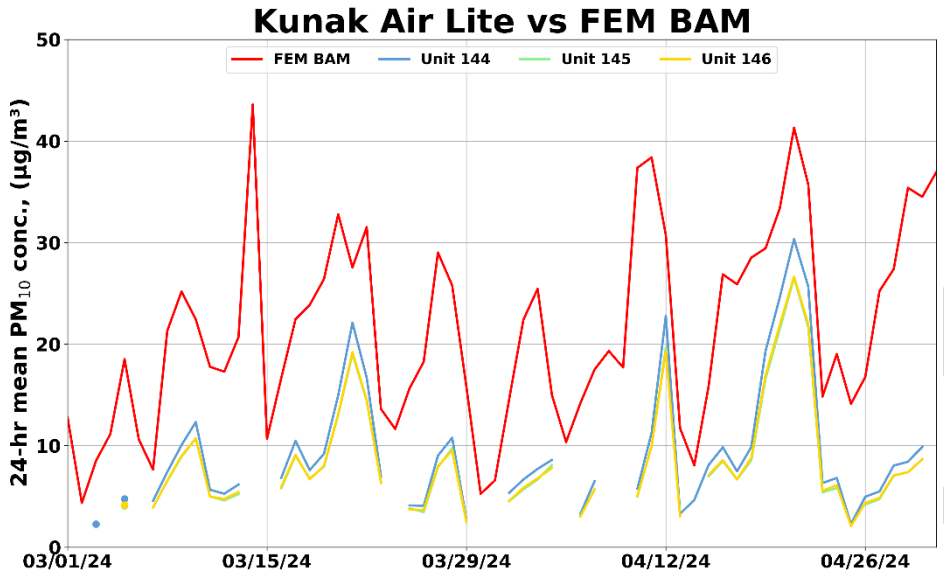
- The Kunak Air Lite sensors showed strong correlations with the corresponding FEM BAM data ($0.89 < R^2 < 0.90$)
- Overall, the Kunak Air Lite sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM BAM
- The Kunak Air Lite sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM BAM



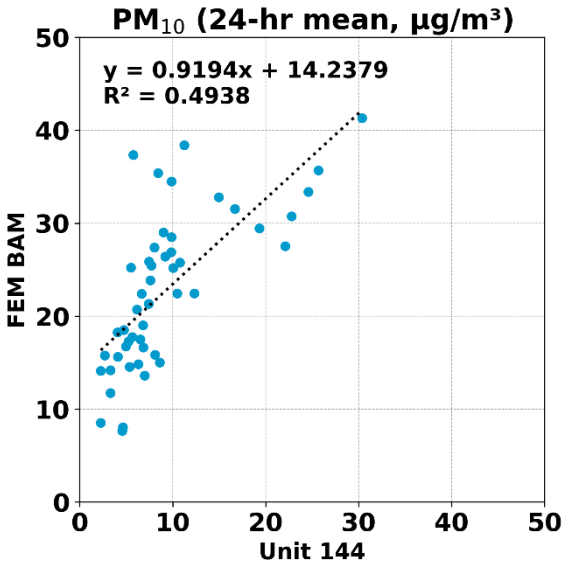


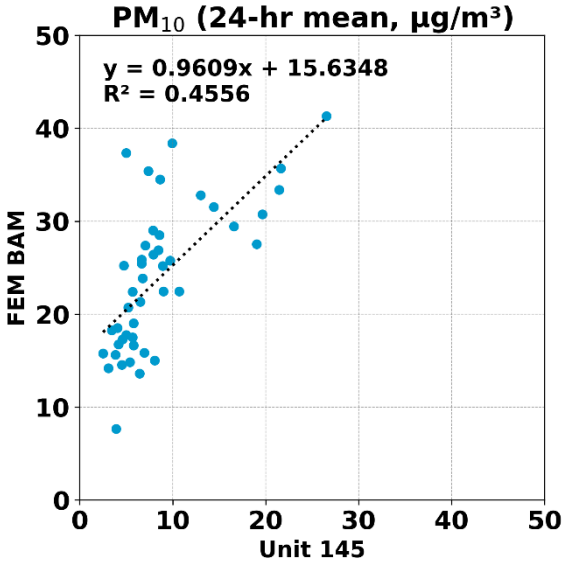


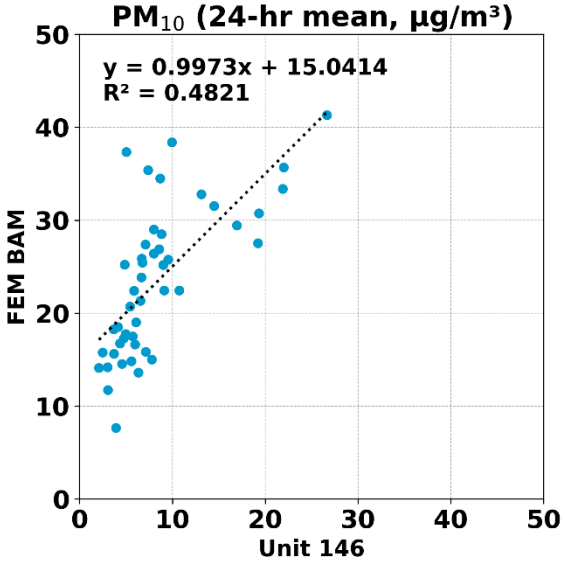
Kunak Air Lite vs FEM BAM (PM_{10}; 24-hr mean)



- The Kunak Air Lite sensors showed weak correlations with the corresponding FEM BAM data ($0.45 < R^2 < 0.50$)
- Overall, the Kunak Air Lite sensors underestimated the PM_{10} mass concentrations as measured by FEM BAM
- The Kunak Air Lite sensors seemed to track the PM_{10} diurnal variations as recorded by FEM BAM







Summary: PM

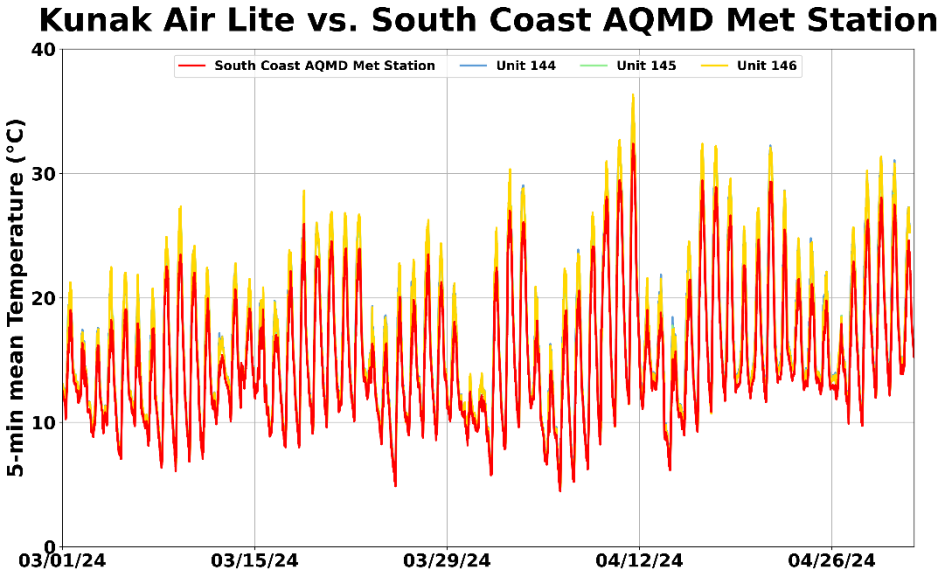
	Average of 3 Sensors, $PM_{1.0}$		Kunak Air Lite vs T640, $PM_{1.0}$						T640 ($PM_{1.0}$, $\mu g/m^3$)		
	Average ($\mu g/m^3$)	SD ($\mu g/m^3$)	R^2	Slope	Intercept	MBE[1] ($\mu g/m^3$)	MAE[2] ($\mu g/m^3$)	RMSE[3] ($\mu g/m^3$)	Ref. Average	Ref. SD	Range during the field evaluation
5-min	4.6	3.3	0.76 to 0.79	1.41 to 1.72	0.5 to 0.8	-3.8 to -2.6	2.6 to 3.8	4.1 to 5.3	6.7	5.9	0.2 to 43.2
1-hr	4.6	3.3	0.77 to 0.80	1.45 to 1.77	0.3 to 0.6	-3.9 to -2.7	2.7 to 3.9	4.1 to 5.3	6.7	5.9	0.3 to 42.0
24-hr	4.9	2.6	0.87 to 0.88	1.61 to 2.06	-1.0 to -0.7	-3.9 to -2.6	2.6 to 3.9	3.6 to 4.9	6.7	4.9	1.1 to 24.4
	Average of 3 Sensors, $PM_{2.5}$		Kunak Air Lite 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	7.6	6.8	0.88 to 0.90	0.87 to 0.99	2.5 to 2.7	-2.6 to -1.4	2.1 to 2.8	2.7 to 3.5	9.0	6.9	0.1 to 49.5
1-hr	7.7	6.7	0.70 to 0.91	0.67 to 1.01	2.4 to 3.0	-2.6 to -0.1	2.1 to 3.0	2.6 to 4.0	8.0 to 9.0	5.9 to 6.8	0.0 to 47.4
24-hr	7.6	5.5	0.89 to 0.96	0.65 to 1.06	1.9 to 2.9	-2.4 to -0.01	1.5 to 2.4	1.8 to 2.7	7.9 to 9.0	4.3 to 5.7	1.7 to 28.0
	Average of 3 Sensors, PM_{10}		Kunak Air Lite 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	8.4	7.1	0.61 to 0.62	1.47 to 1.67	12.4 to 12.8	-18.2 to -16.7	16.7 to 18.2	19.2 to 20.8	23.9	15.1	0.2 to 138.8
1-hr	8.5	7.0	0.41 to 0.66	0.96 to 1.69	12.4 to 14.4	-18.3 to -13.8	13.9 to 18.3	16.4 to 20.6	21.3 to 23.9	12.6 to 14.7	0.0 to 104.5
24-hr	8.8	5.9	0.46 to 0.75	0.92 to 1.67	11.9 to 15.6	-18.4 to -13.5	13.5 to 18.4	14.7 to 19.6	21.3 to 23.9	9.6 to 11.8	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).

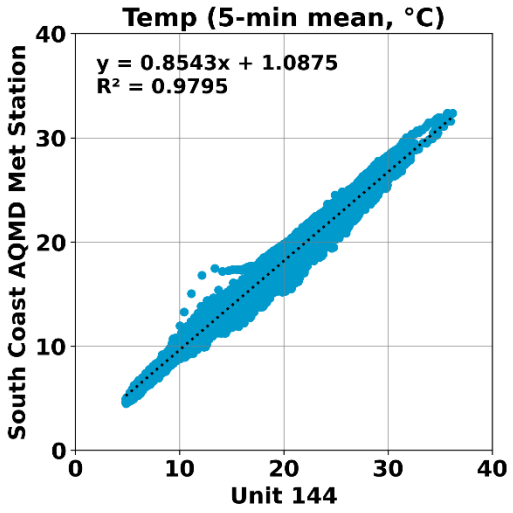
[2] Mean Absolute Error (MAE): the absolute difference between the sensors and the reference instruments. The larger MAE values, the higher measurement errors as compared to the reference instruments.

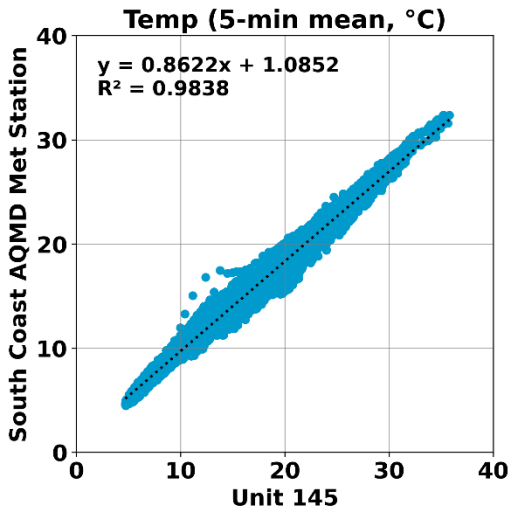
[3] Root Mean Square Error (RMSE): another metric to calculate measurement errors.

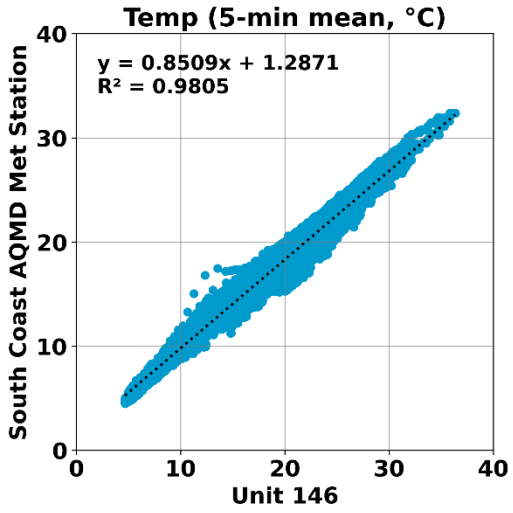
Kunak Air Lite vs South Coast AQMD Met Station (Temp; 5-min mean)



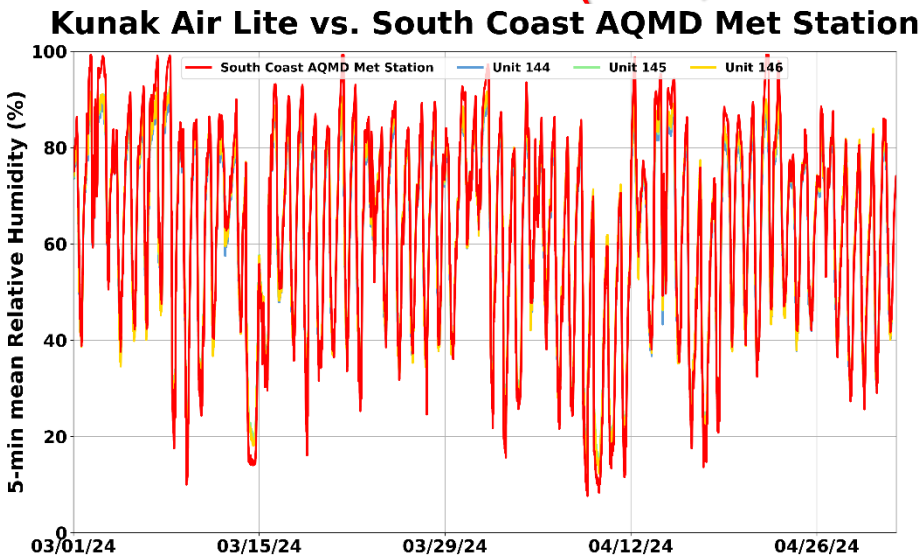
- The Kunak Air Lite sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($0.97 < R^2 < 0.99$)
- Overall, the Kunak Air Lite sensors overestimated the temperature measurement as recorded by South Coast AQMD Met Station
- The Kunak Air Lite sensors seemed to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



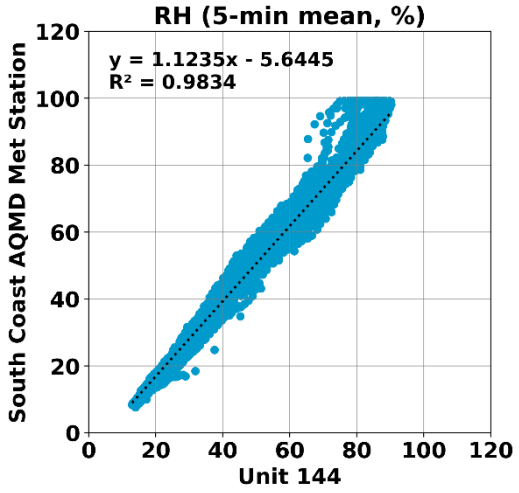


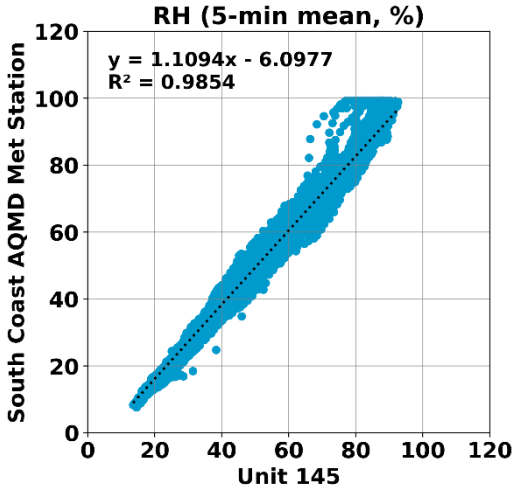


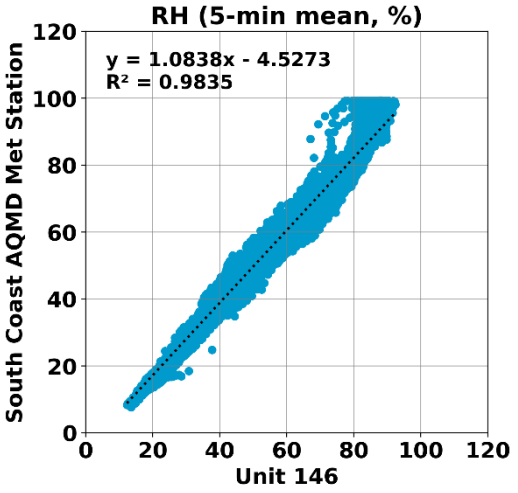
Kunak Air Lite vs South Coast AQMD Met Station (RH; 5-min mean)



- Kunak Air Lite sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($0.98 < R^2 < 0.99$)
- Overall, the Kunak Air Lite sensors underestimated the RH measurement as recorded by South Coast AQMD Met Station
- The Kunak Air Lite sensors seemed to track the diurnal RH variations as recorded by South Coast AQMD Met Station







Discussion

- The three **Kunak Air Lite** sensors' data recovery for O_3, NO_2 and all PM fractions was ~99.0%, 99.1% and 99.7%, respectively.
- The absolute intra-model variability for O_3 and NO_2 was ~1.09 ppb and ~0.41 ppb, respectively. Absolute intra-model variability was ~ 0.57, ~0.68 and ~0.72 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 ~ 0.77, 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:
  - Ozone sensors showed strong correlation with the FEM T400 instrument ($0.85 < R^2 < 0.90$, 5-min mean) and generally underestimated the corresponding FEM T400 data
  - NO_2 sensors showed moderate correlations with the FRM T200 instrument ($0.66 < R^2 < 0.70$, 5-min mean) and overestimated the corresponding FRM T200 data
  - The Kunak Air Lite sensors showed strong correlations with the corresponding reference $PM_{1.0}$ data ($0.77 < R^2 < 0.80$, 1-hr mean), strong to very strong correlations with the corresponding reference $PM_{2.5}$ data ($0.70 < R^2 < 0.92$, 1-hr mean) and weak to moderate correlations with the corresponding reference PM_{10} data ($0.4 < R^2 < 0.67$; 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 ~ 0.98 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