Field Evaluation
Kunak Air A10

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

- From 04/28/2019 to 07/11/2019, three **Kunak Air A10** (hereinafter **Kunak**) 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 (*3 units tested*):
  - Particle sensor: AS OPC N3 (optical; non-FEM)
  - Gas sensors: AS B4 series (electrochemical; non-FEM)
  - Each unit reports: $PM_{1.0}$, $PM_{2.5}$ and PM_{10} ($\mu g/m^3$), Ozone (ppb), CO (ppb), NO, NO_2, NO_x (ppb), temperature (°C), RH (%), pressure, [1]Wind Speed (km/h), [1]Wind Direction (degree)
  - [2]Unit cost: ~$7,900 (PM + Gas); $3,000 (PM only) and $5,000 (4 gases, temp/RH, anemometer and solar panel)
  - Time resolution: 5-min
  - Units IDs: 0000, 0001, 0002

[1]Only available in Unit 0002
[2]4G LTE, 9w solar panel, includes 1-yr cell connectivity, tech support, cloud data access for configuration, calibration, firmware upgrade, alarms, data validation, reporting, advanced analytics, APIrest.

- **South Coast AQMD Reference instruments:**
  - MetOne BAM (FEM $PM_{2.5}$ & PM_{10}), cost: ~$20,000
    - Time resolution: 1-hr
  - Teledyne T640 (FEM $PM_{2.5}$), cost: ~$21,000
    - Time resolution: 1-min
  - CO instrument; FRM, cost: ~$10,000
    - Time resolution: 1-min
  - NOx instrument; FRM, cost: ~$11,000
    - Time resolution: 1-min
  - O_3 instrument; FEM, cost: ~$7,000
    - Time resolution: 1-min
  - Met station (T, RH, P, WS, WD), cost: ~$5,000
    - Time resolution: 1-min

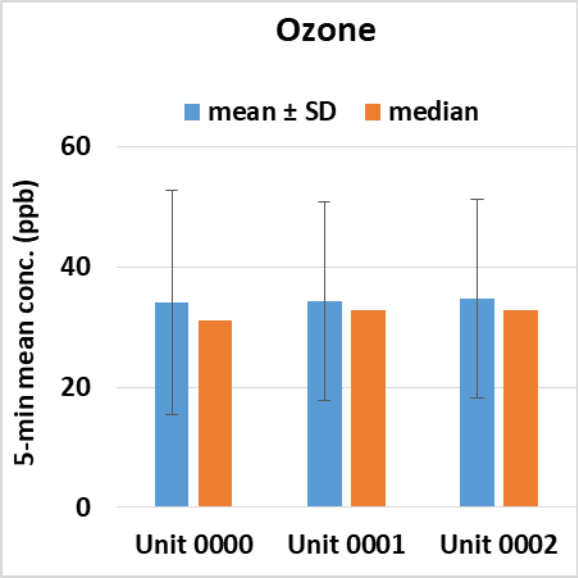
Ozone (O_3) in Kunak

Data validation & recovery

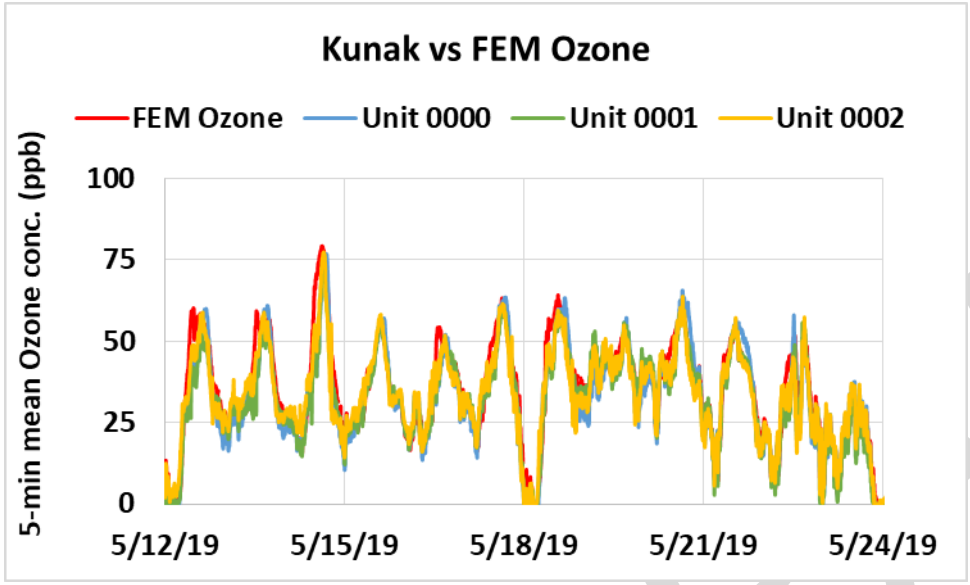
- Basic QA/QC procedures were used to validate the collected data (i.e. obvious outliers, negative values and invalid data-points were eliminated from the data-set)
- Data recovery from units 0000, 0001, 0002 was ~ 98% for ozone measurements

Kunak; intra-model variability

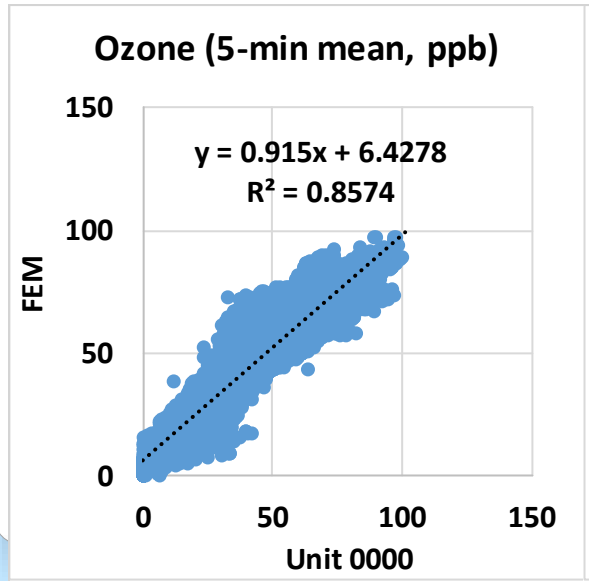
- Absolute intra-model variability was ~ 0.32 ppb
  (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was ~ 0.94%
  (calculated as the absolute intra-model variability relative to the mean of the three sensor means)

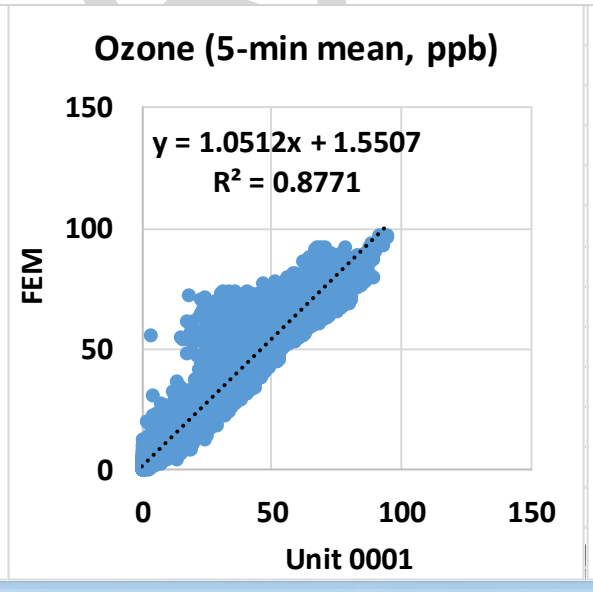


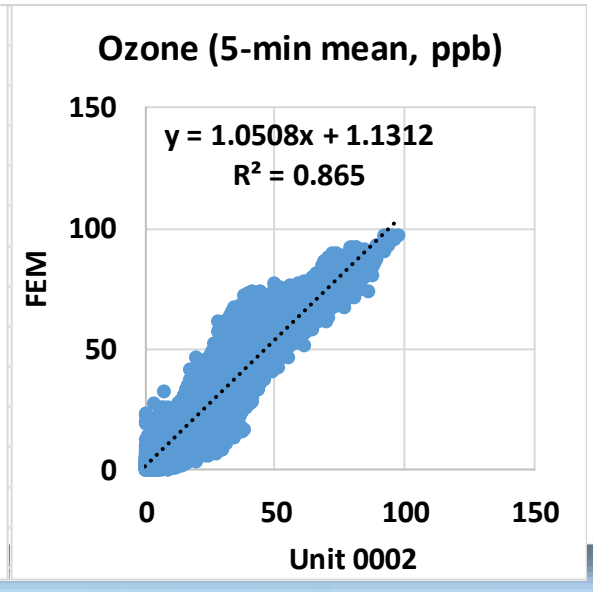
Kunak vs FEM (Ozone; 5-min mean)



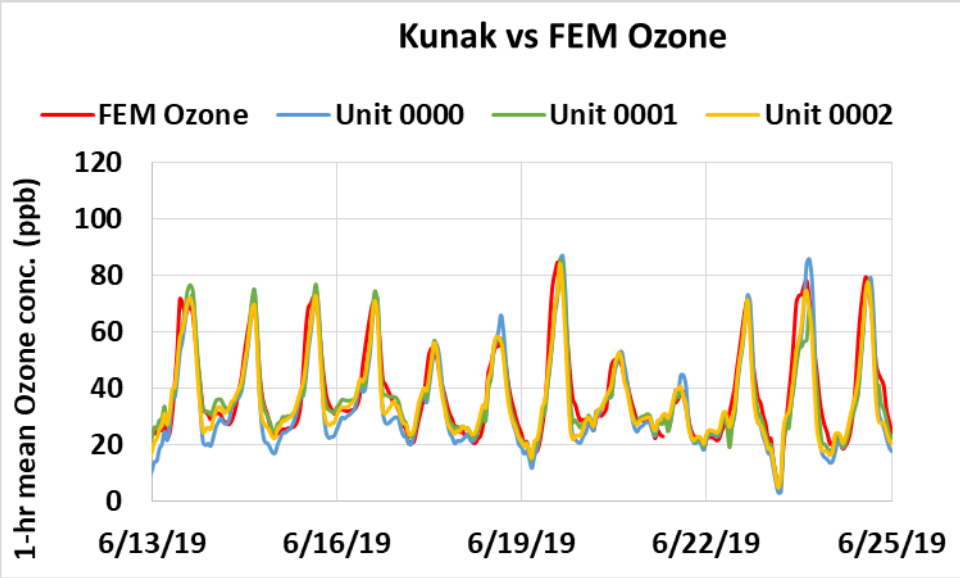
- Kunak sensors showed strong correlations with the corresponding FEM ozone data (R^2 ~ 0.87)
- Overall, the Kunak sensors underestimated the ozone concentrations as measured by the FEM instrument
- The Kunak sensors seemed to track the ozone diurnal variations as recorded by the FEM instrument



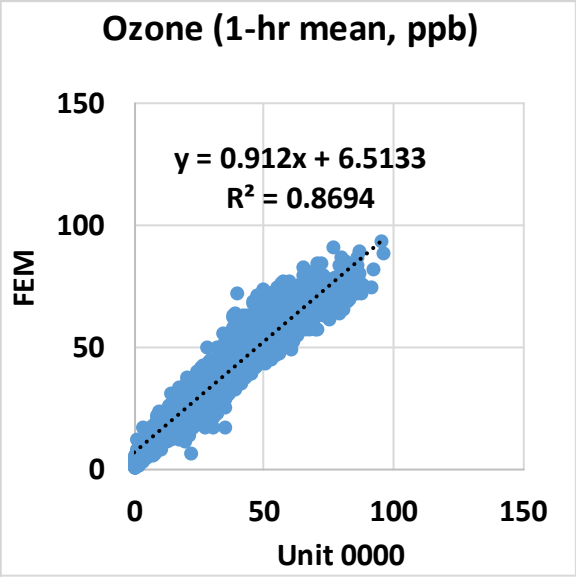


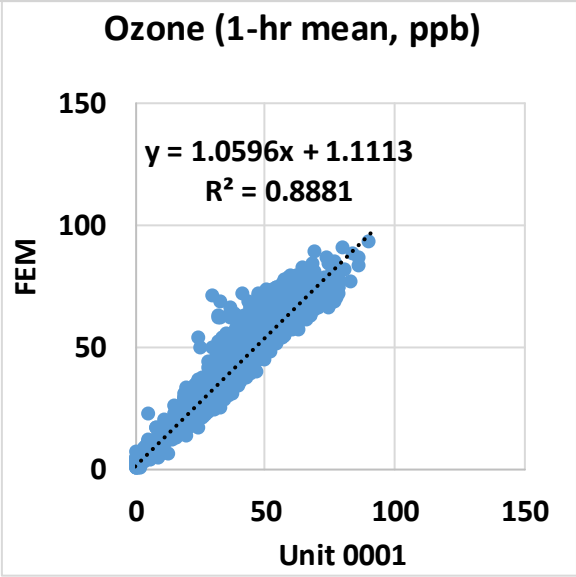


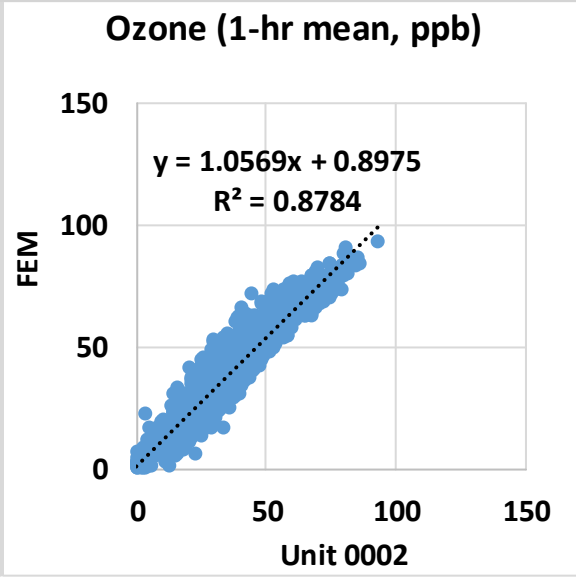
Kunak vs FEM (Ozone; 1-hr mean)



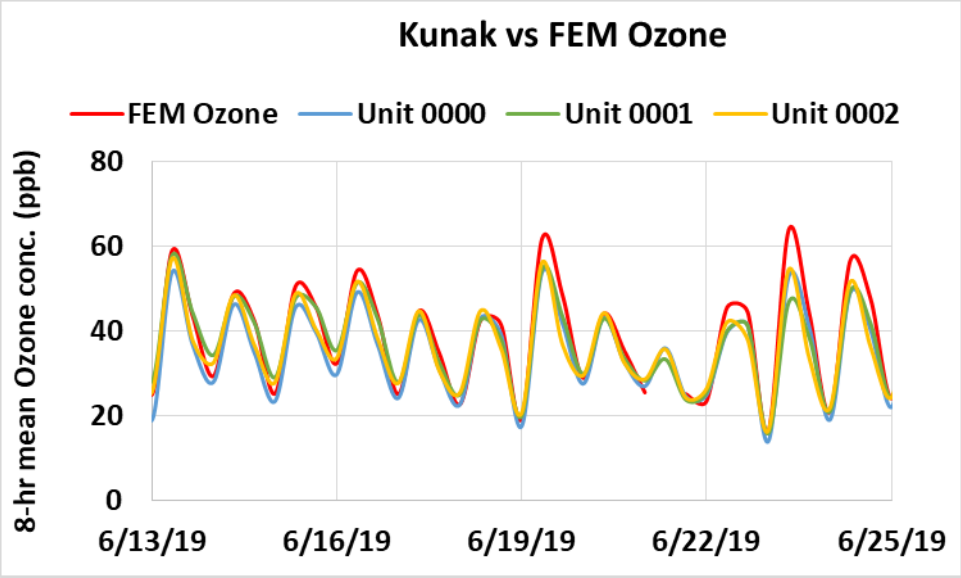
- Kunak sensors showed strong correlations with the corresponding FEM ozone data (R^2 ~ 0.88)
- Overall, the Kunak sensors underestimated the ozone concentrations as measured by the FEM instrument
- The Kunak sensors seemed to track the ozone diurnal variations as recorded by the FEM instrument



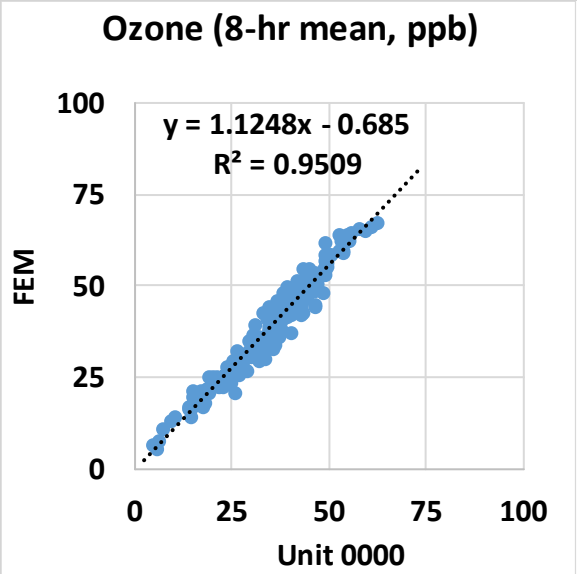


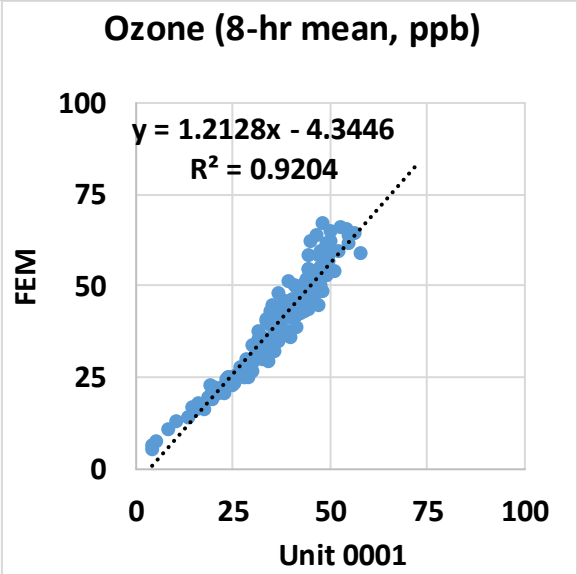


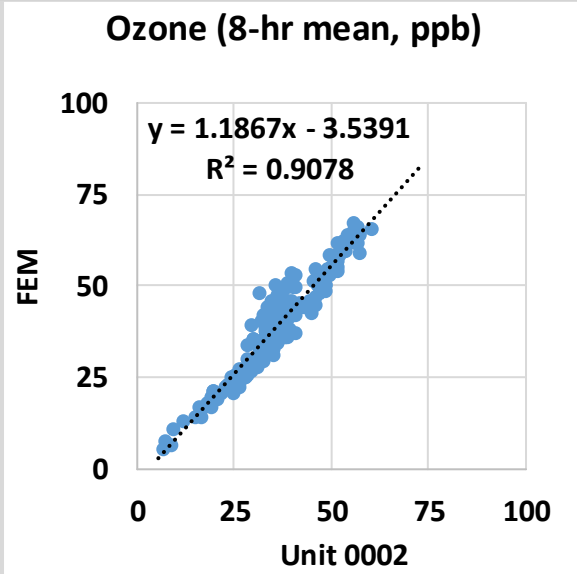
Kunak vs FEM (Ozone; 8-hr mean)



- Kunak sensors showed very strong correlations with the corresponding FEM ozone data (R^2 ~ 0.93)
- Overall, the Kunak sensors underestimated the ozone concentrations as measured by the FEM instrument
- The Kunak sensors seemed to track the ozone diurnal variations as recorded by the FEM instrument







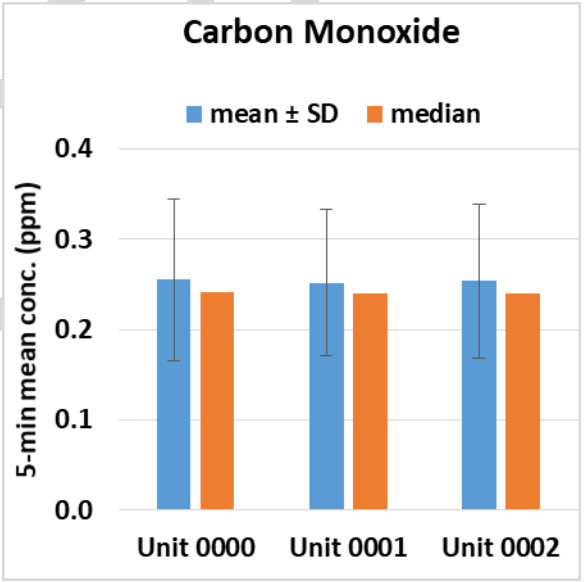
Carbon Monoxide (CO) in Kunak

Data validation & recovery

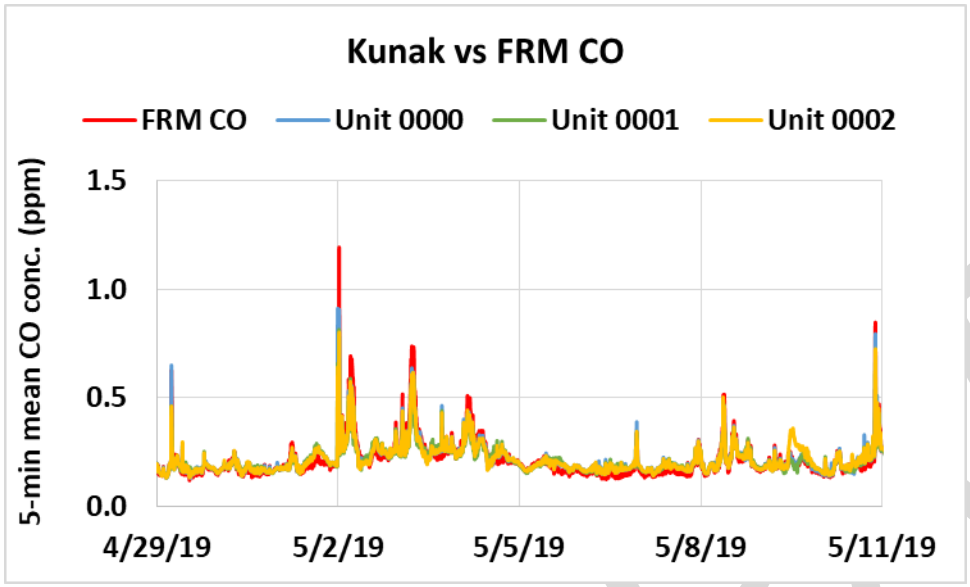
- Basic QA/QC procedures were used to validate the collected data (i.e. obvious outliers, negative values and invalid data-points were eliminated from the data-set)
- Data recovery from units 0000, 0001, 0002 was ~100% for CO measurements

Kunak; intra-model variability

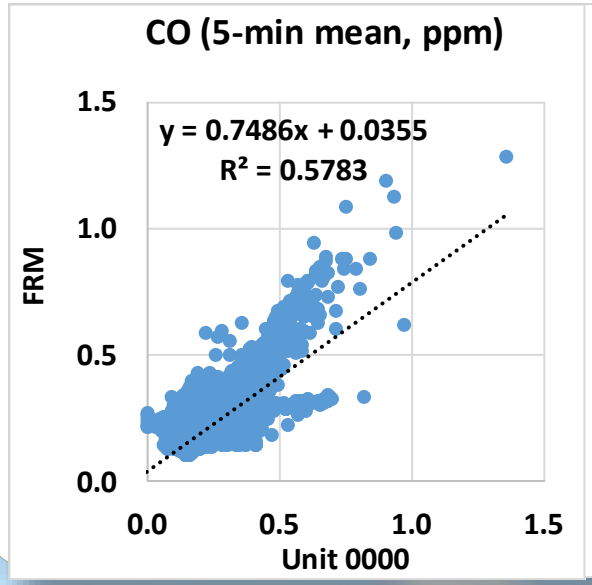
- Absolute intra-model variability was ~ 0.002 ppm
  (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was ~ 0.66%
  (calculated as the absolute intra-model variability relative to the mean of the three sensor means)

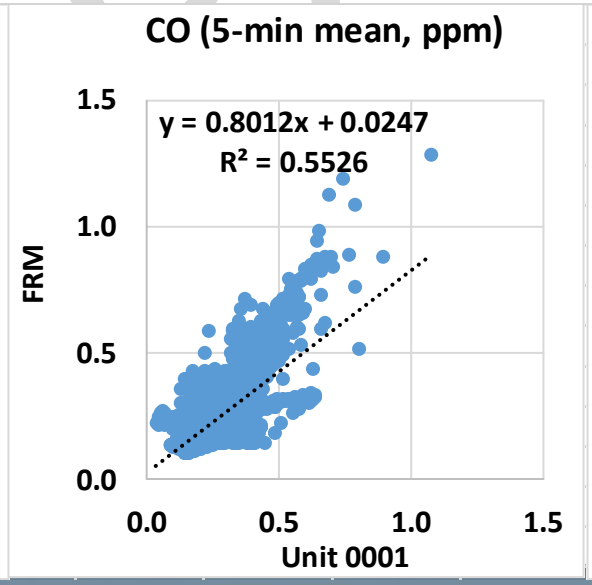


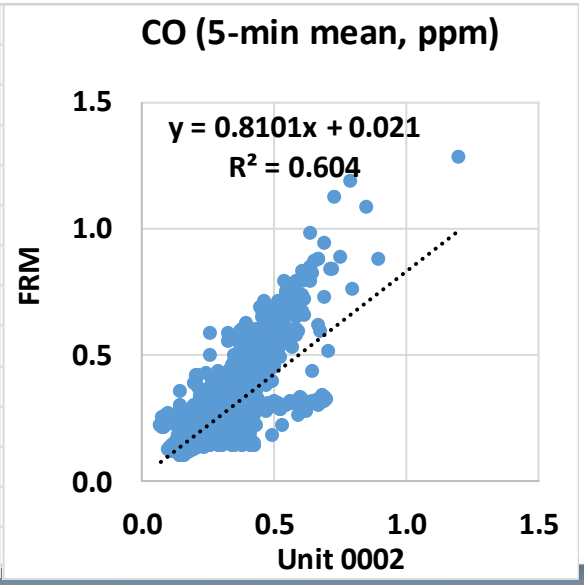
Kunak vs FRM (CO; 5-min mean)



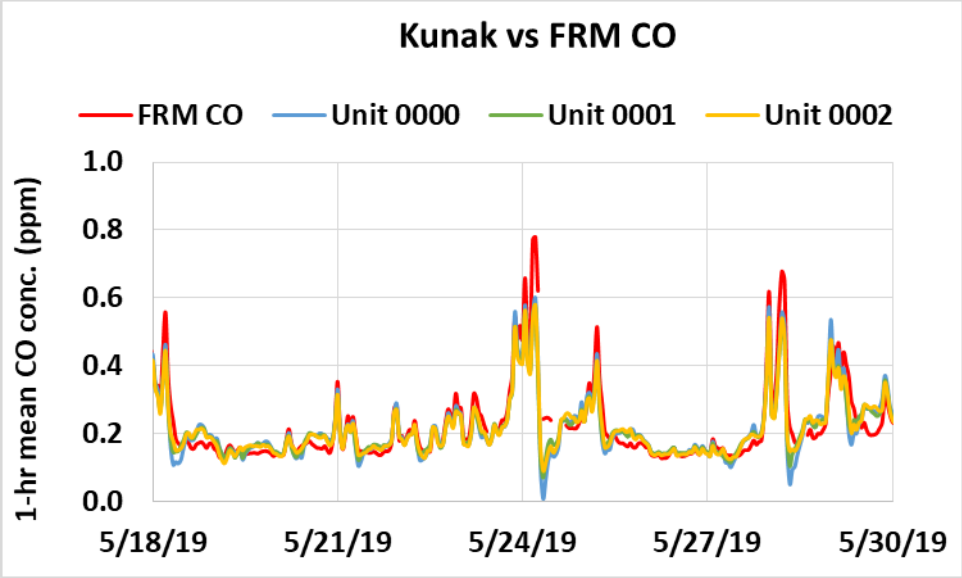
- Kunak sensors showed moderate correlations with the corresponding FRM CO data (R^2 ~ 0.58)
- Overall, the Kunak sensors overestimated the CO concentrations as measured by the FRM instrument
- The Kunak sensors seemed to track the CO diurnal variations as recorded by the FRM instrument



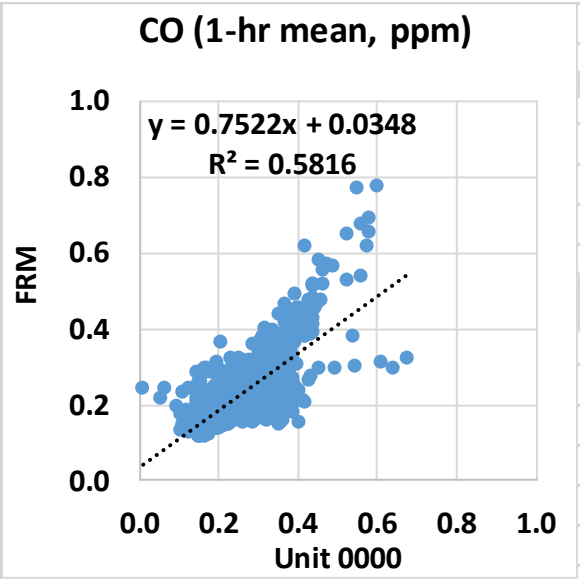


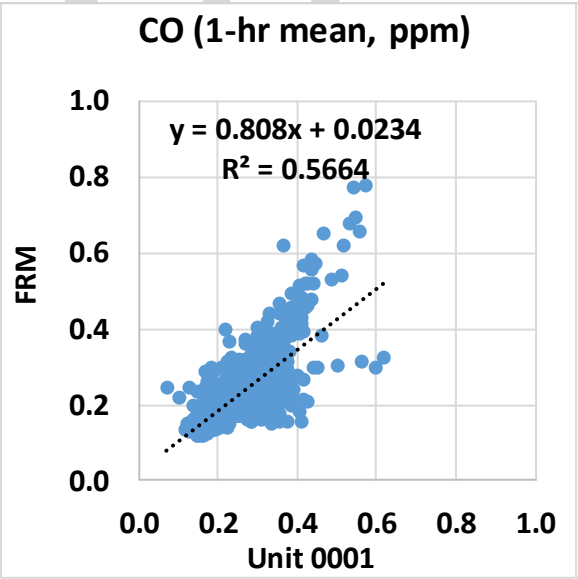


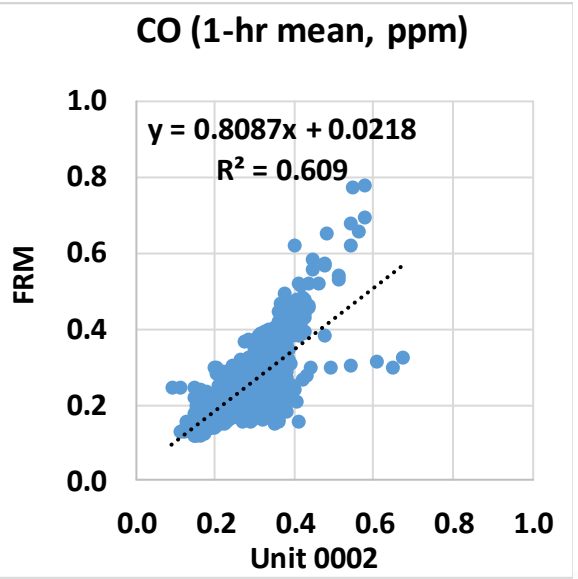
Kunak vs FRM (CO; 1-hr mean)



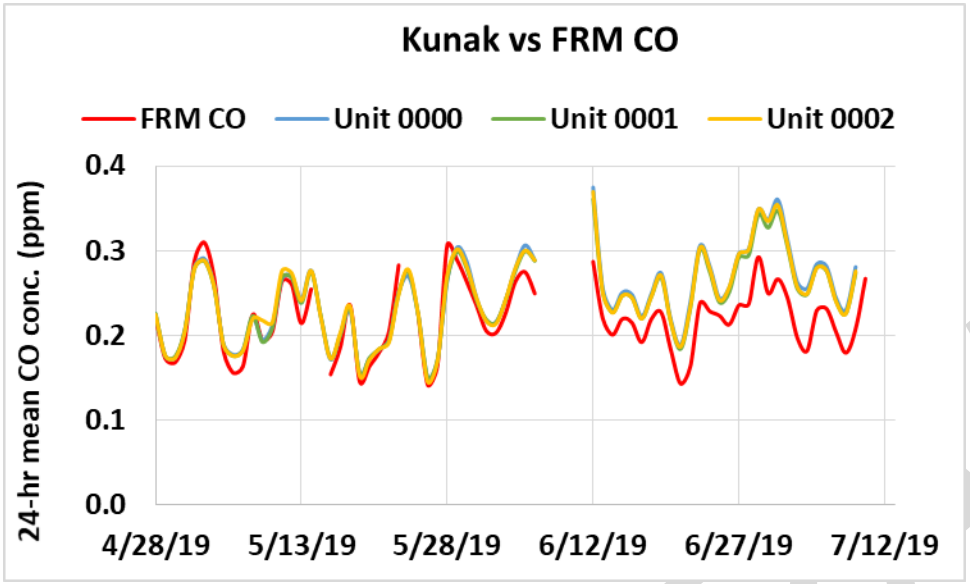
- Kunak sensors showed moderate correlations with the corresponding FRM CO data (R^2 ~ 0.59)
- Overall, the Kunak sensors overestimated the CO concentrations as measured by the FRM instrument
- The Kunak sensors seemed to track the CO diurnal variations as recorded by the FRM instrument





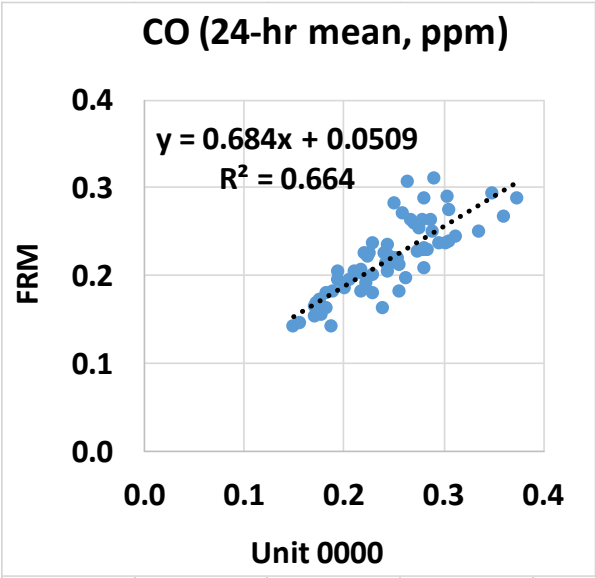


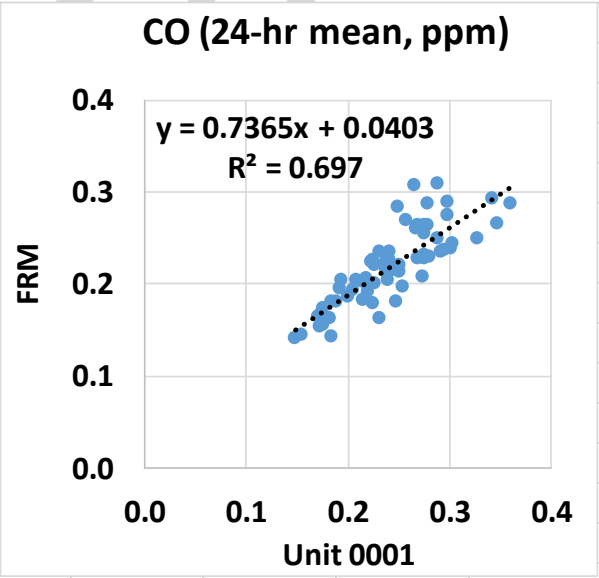
Kunak vs FRM (CO; 24-hr mean)

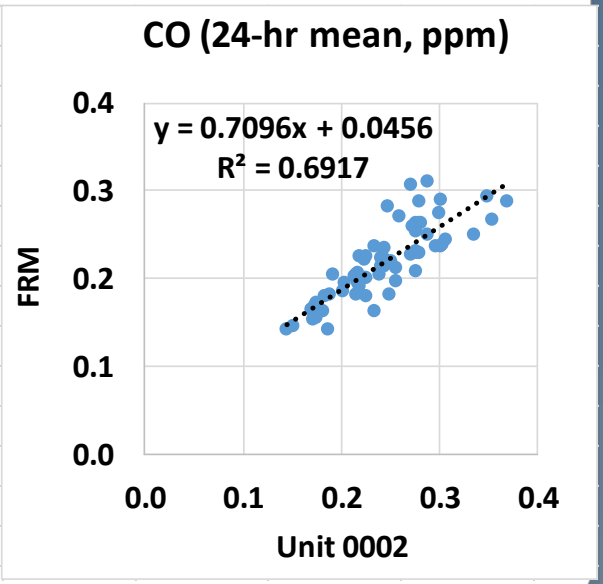


- Kunak sensors showed moderate correlations with the corresponding FRM CO data (R^2 ~ 0.68)
- Overall, the Kunak sensors overestimated the CO concentrations as measured by the FRM instrument
- The Kunak sensors seemed to track the CO diurnal variations as recorded by the FRM instrument

Note: The FRM instrument was down between 6/7/19-6/11/19, both FRM and sensor CO data were excluded from the data set during this period.







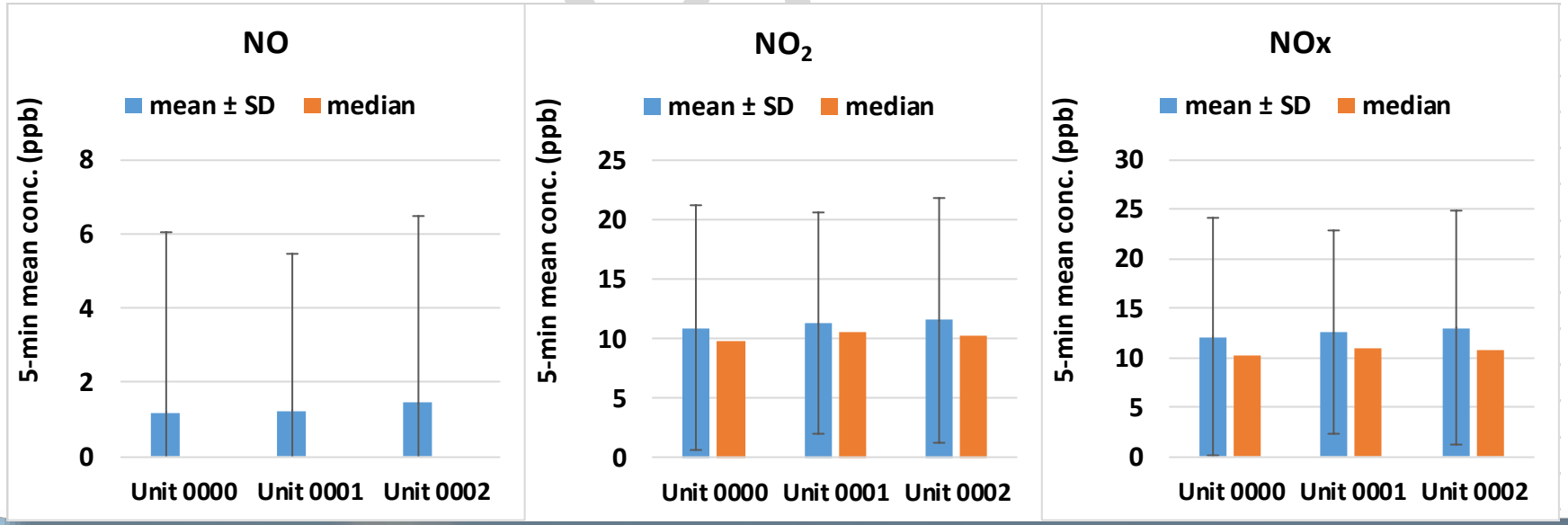
Nitrogen Oxides in Kunak

Data validation & recovery

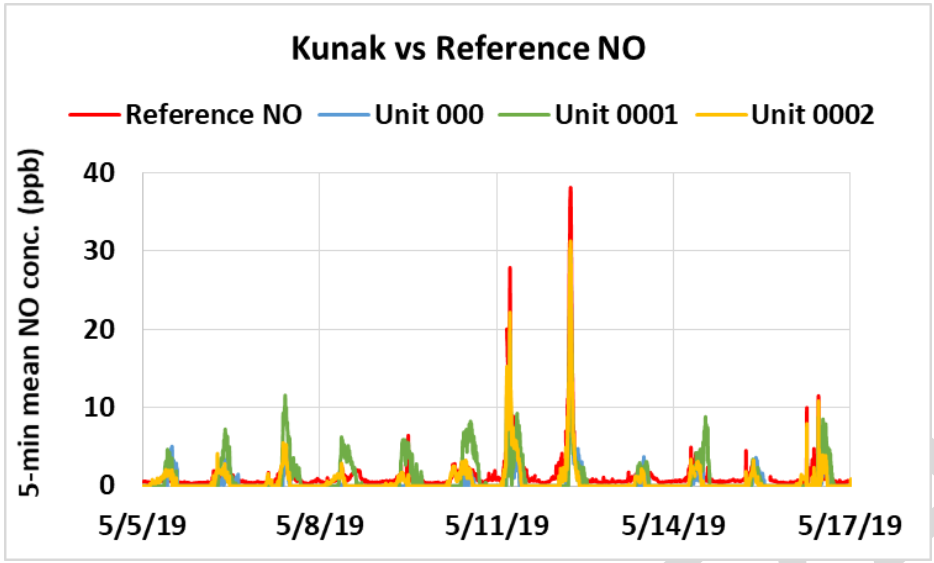
- Basic QA/QC procedures were used to validate the collected data (i.e. obvious outliers, negative values and invalid data-points were eliminated from the data-set)
- Average Data recovery from all units was 94%, 96% and 92% for NO, NO_2 and NO_x measurements, respectively.

Kunak; intra-model variability

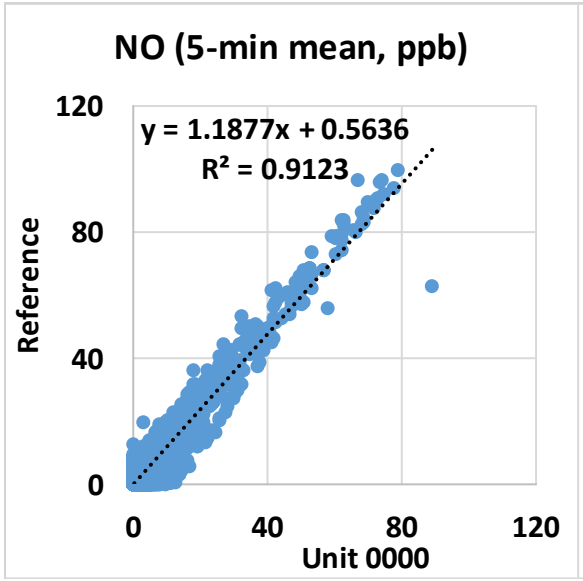
- Absolute intra-model variability was ~ 0.15, 0.33 and 0.47 ppb for NO, NO_2 and NO_x, respectively (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was ~ 11.4%, 2.9% and 3.7% for NO, NO_2 and NO_x, respectively (calculated as the absolute intra-model variability relative to the mean of the three sensor means)

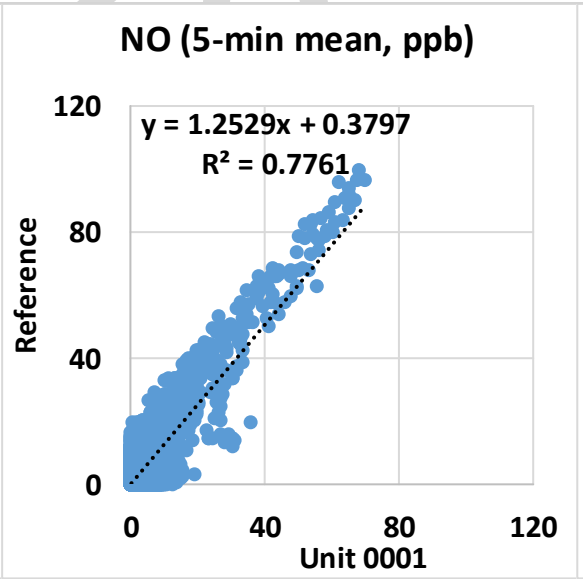


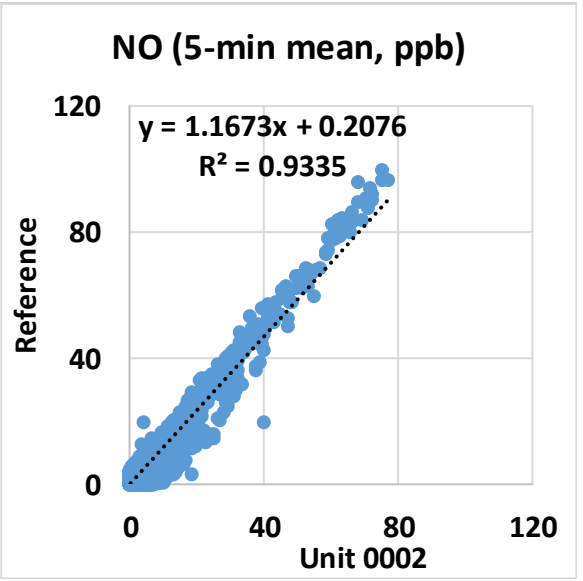
Kunak vs Reference (NO; 5-min mean)



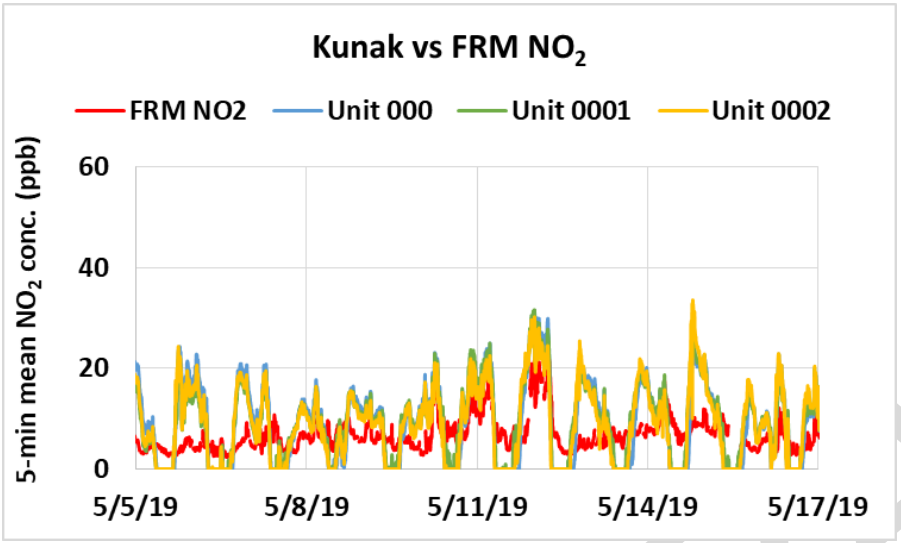
- Kunak sensors showed strong correlations with the corresponding reference NO data (R^2 ~ 0.87)
- Overall, the Kunak sensors underestimated the NO concentrations as measured by the reference instrument
- The Kunak sensors seemed to track the NO diurnal variations as recorded by the reference instrument



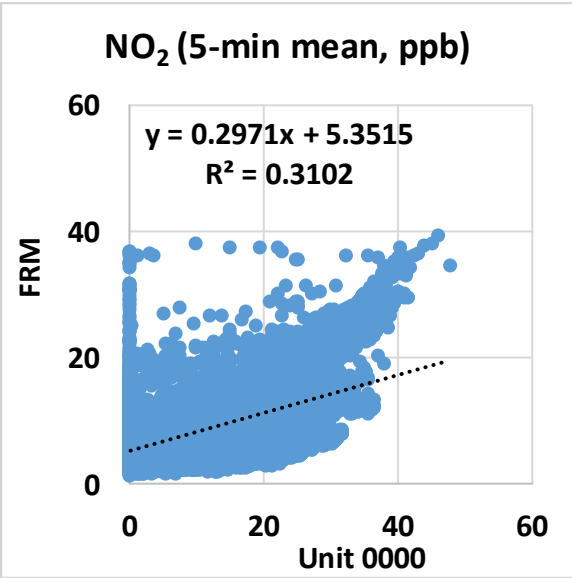


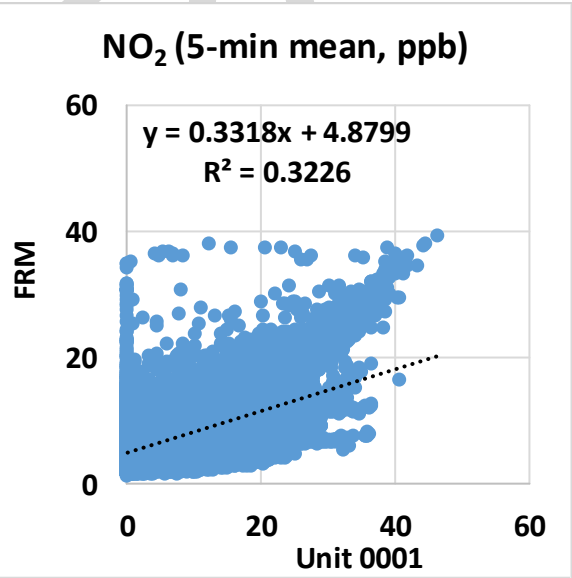


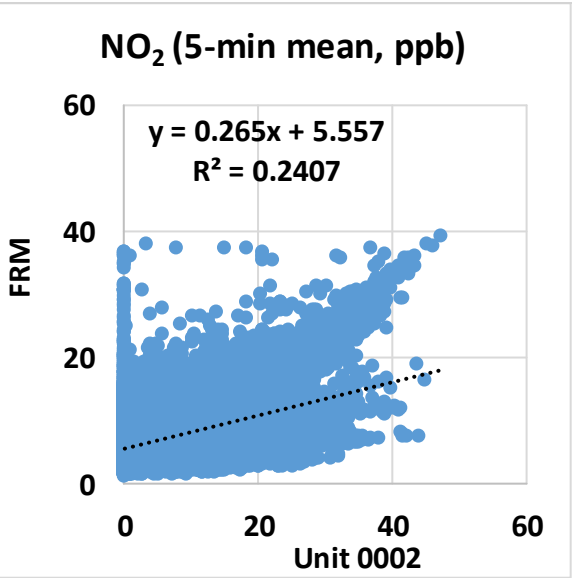
Kunak vs FRM (NO_2; 5-min mean)



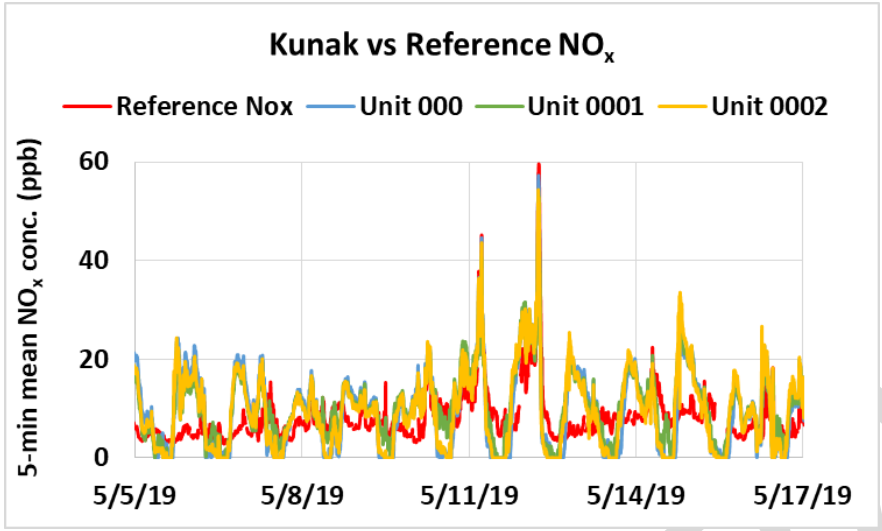
- Kunak sensors showed very weak correlations with the corresponding FRM NO_2 data (R^2 ~ 0.29)
- Overall, the Kunak sensors overestimated the NO_2 concentrations as measured by the FRM instrument
- The Kunak sensors did not seem to track the NO_2 diurnal variations as recorded by the FRM instrument



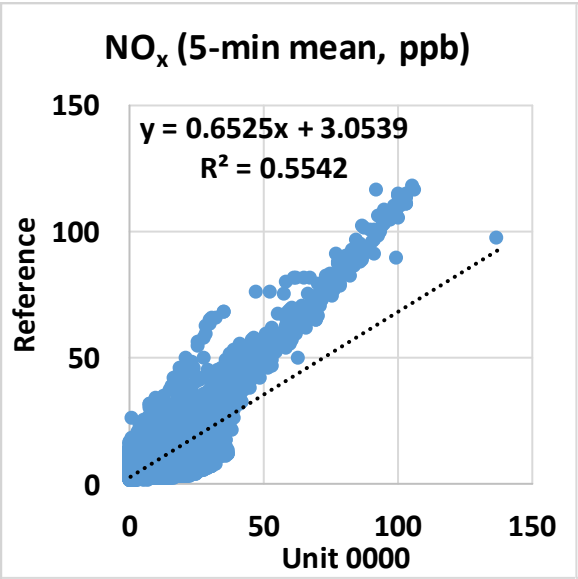


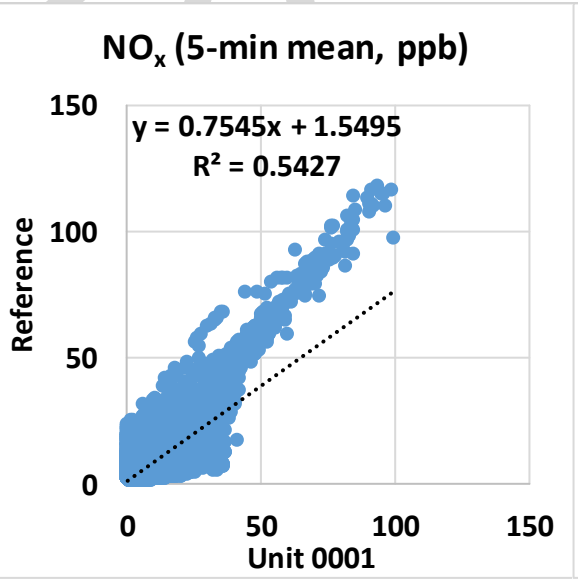


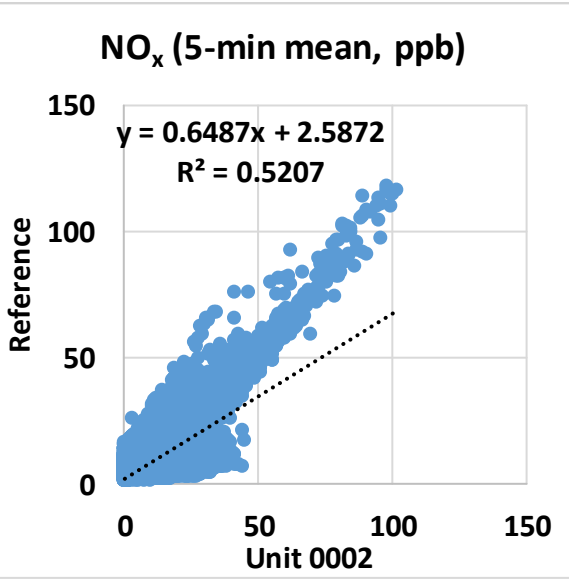
Kunak vs Reference (NO_x; 5-min mean)



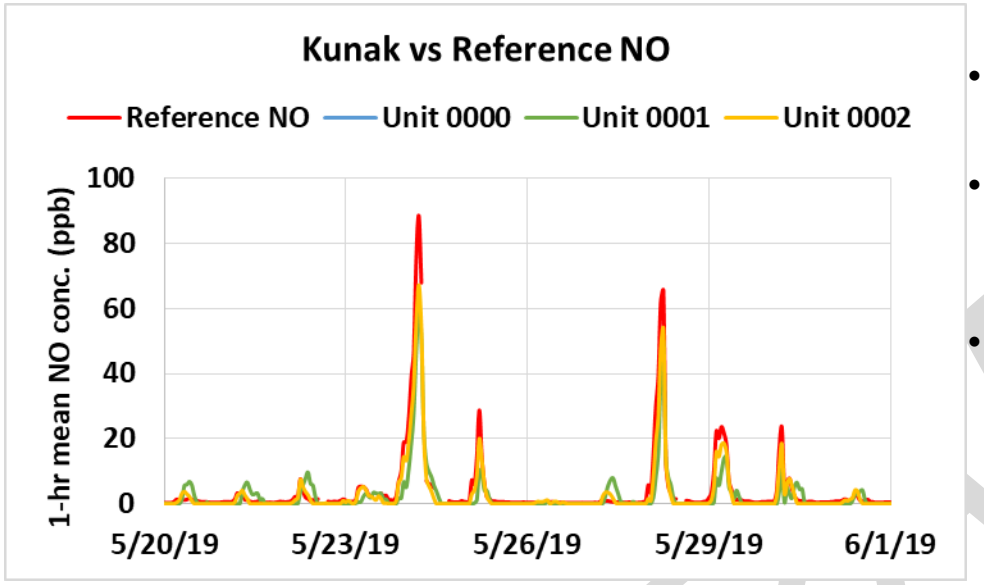
- Kunak sensors showed moderate correlations with the corresponding reference NO_x data (R^2 ~ 0.54)
- Overall, the Kunak sensors overestimated the NO_x concentrations as measured by the reference instrument
- The Kunak sensors seemed to track the NO_x diurnal variations as recorded by the reference instrument



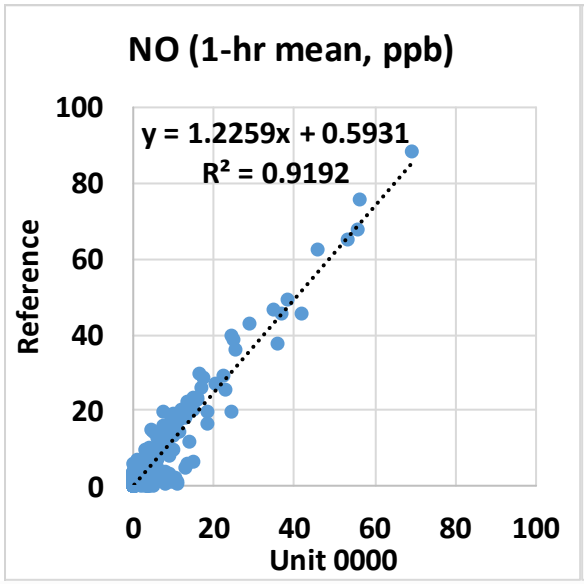


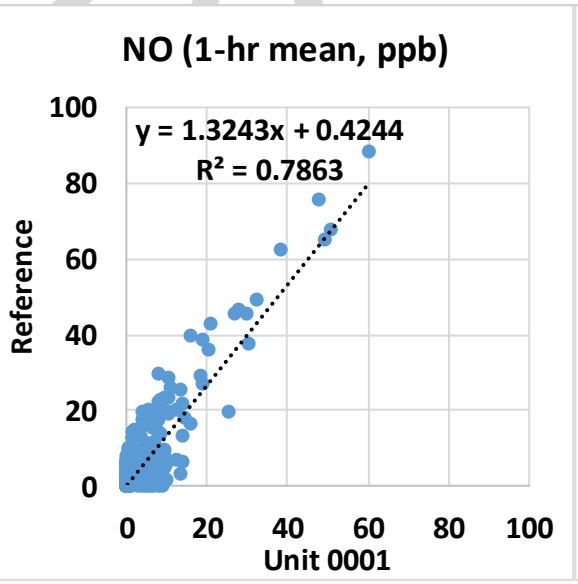


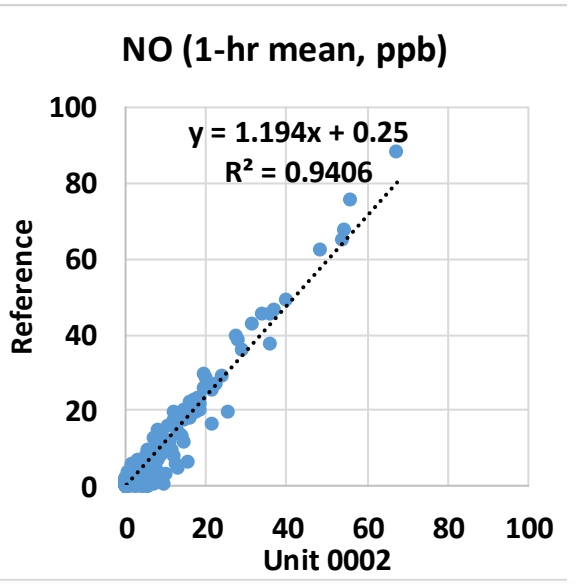
Kunak vs Reference (NO; 1-hr mean)



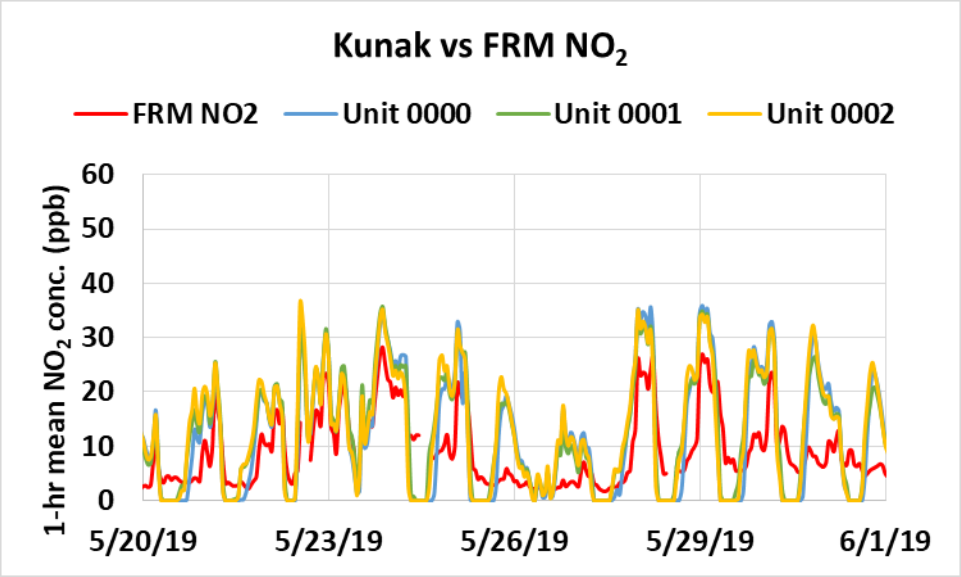
- Kunak sensors showed strong correlations with the corresponding reference NO data (R^2 ~ 0.88)
- Overall, the Kunak sensors underestimated the NO concentrations as measured by the reference instrument
- The Kunak sensors seemed to track the NO diurnal variations as recorded by the reference instrument



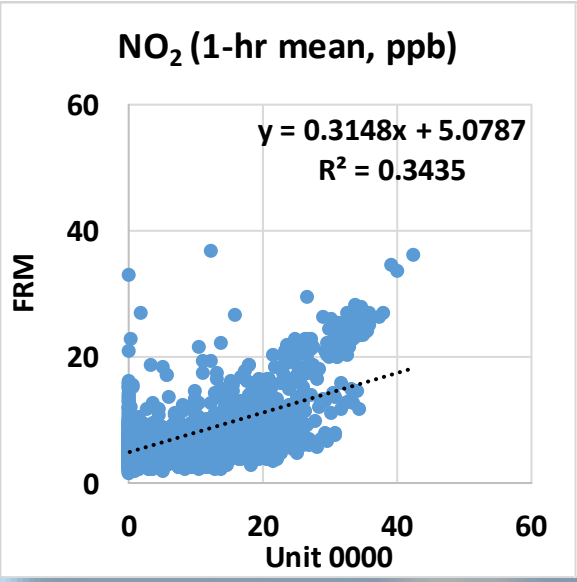


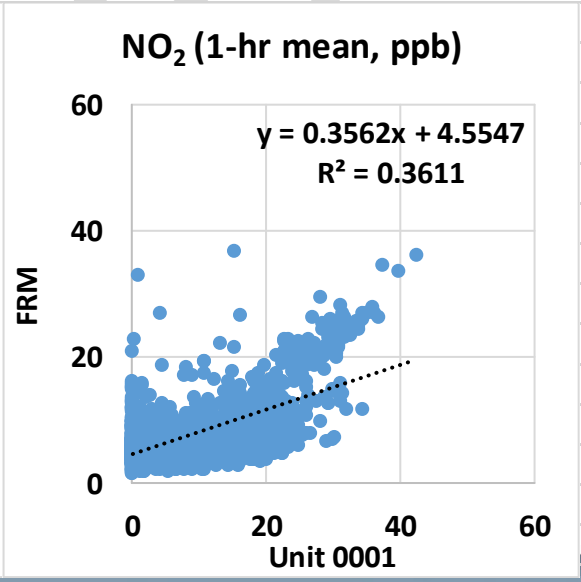


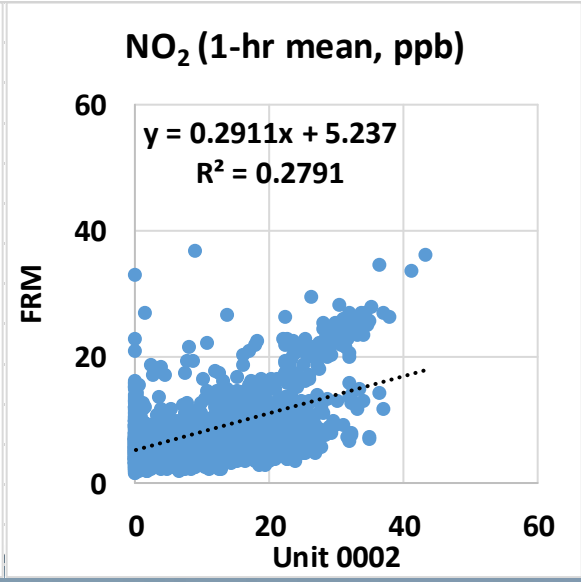
Kunak vs FRM (NO_2; 1-hr mean)



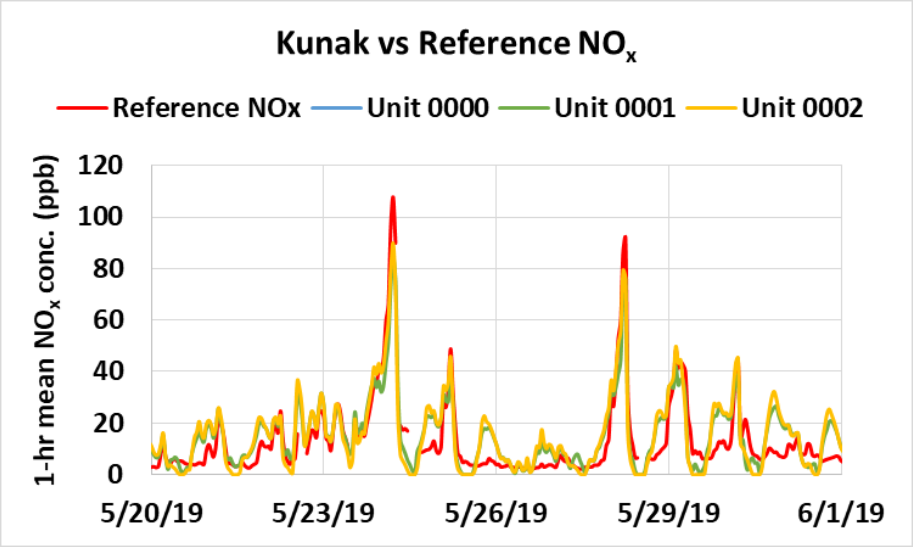
- Kunak sensors showed weak correlations with the corresponding FRM NO_2 data (R^2 ~ 0.33)
- Overall, the Kunak sensors overestimated the NO_2 concentrations as measured by the FRM instrument
- The Kunak sensors seemed to track the NO_2 diurnal variations as recorded by the FRM instrument



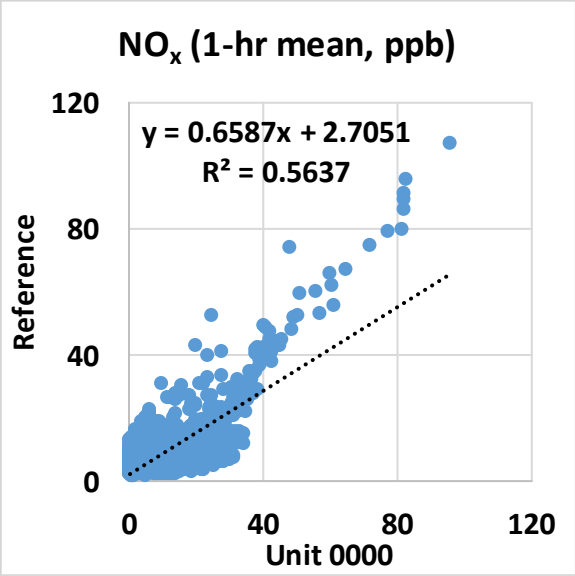


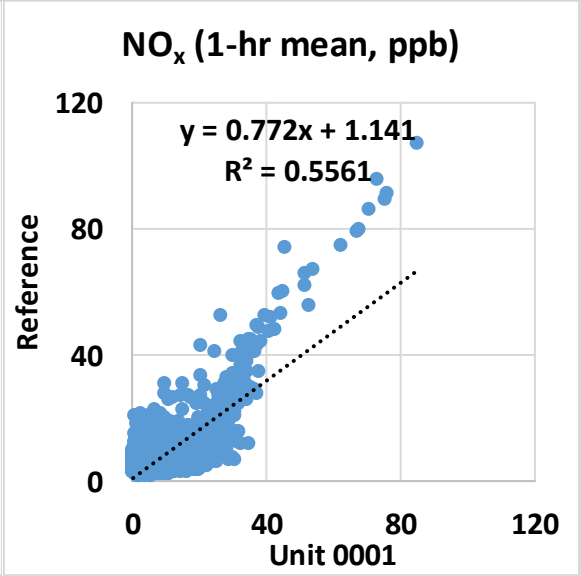


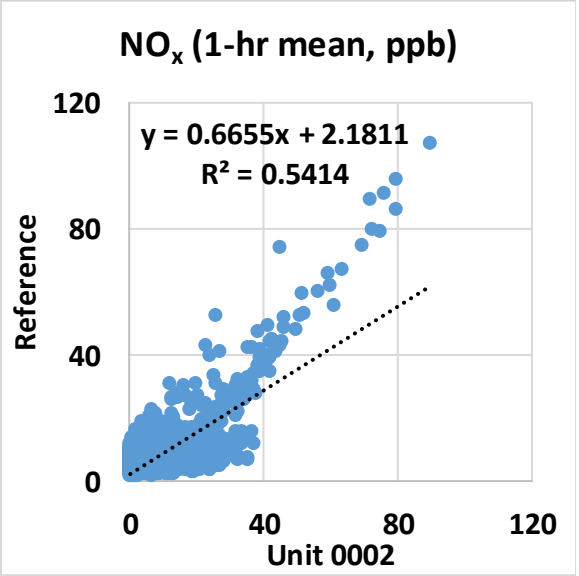
Kunak vs Reference (NO_x; 1-hr mean)



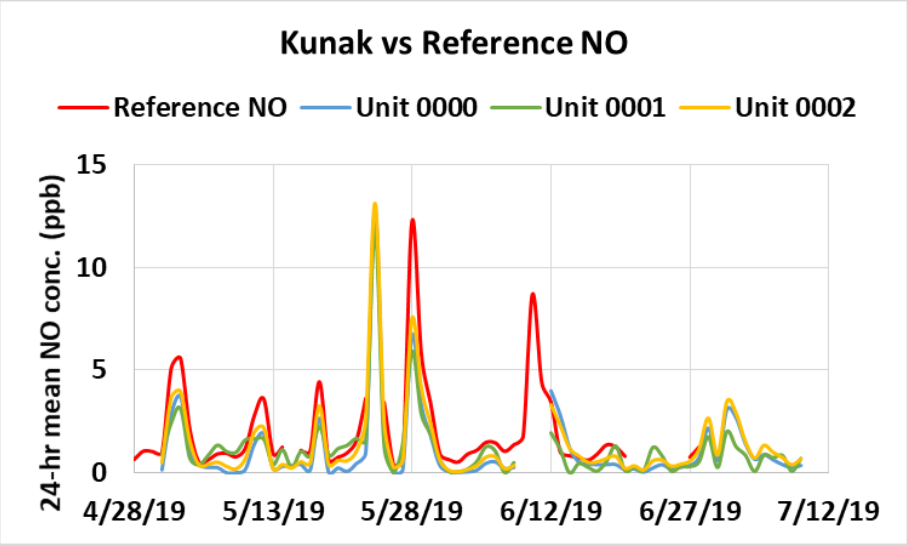
- Kunak sensors showed moderate correlations with the corresponding reference NO_x data (R^2 ~ 0.55)
- Overall, the Kunak sensors overestimated the NO_x concentrations as measured by the reference instrument
- The Kunak sensors seemed to track the NO_x diurnal variations as recorded by the reference instrument



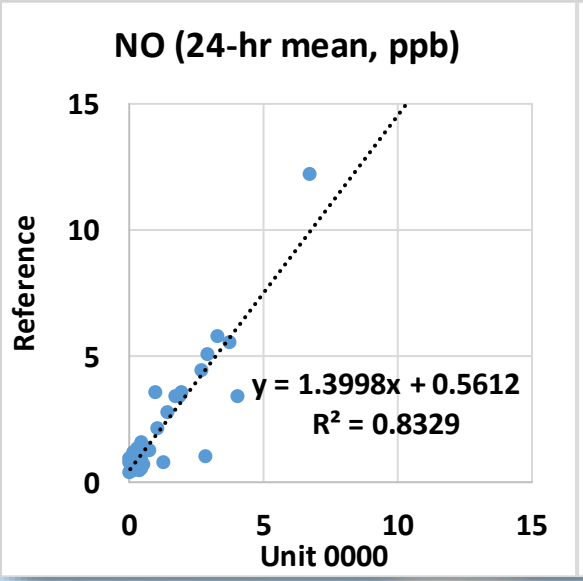


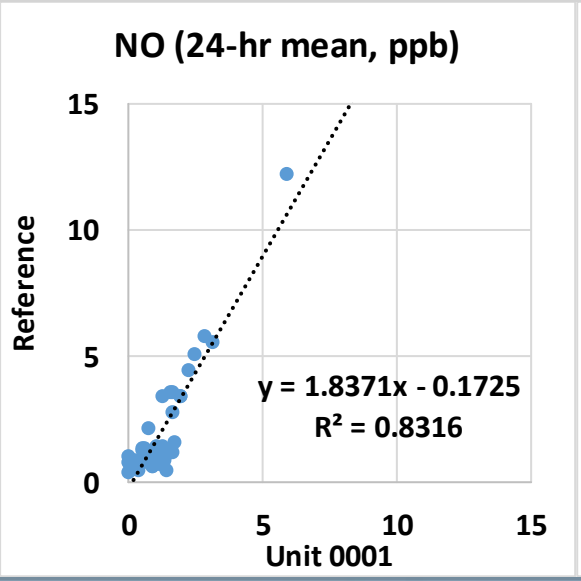


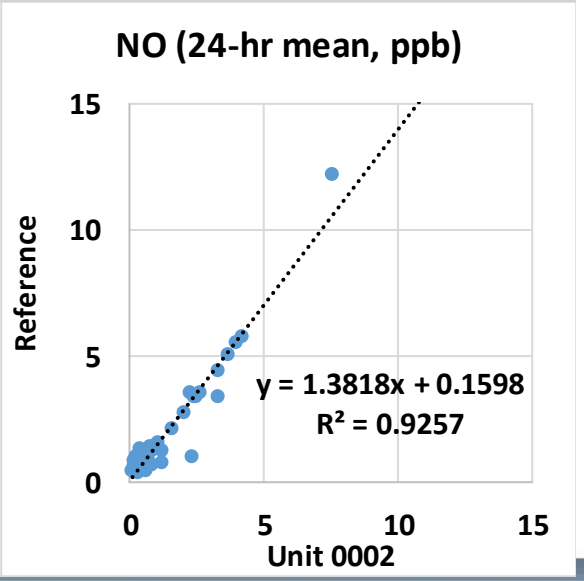
Kunak vs Reference (NO; 24-hr mean)



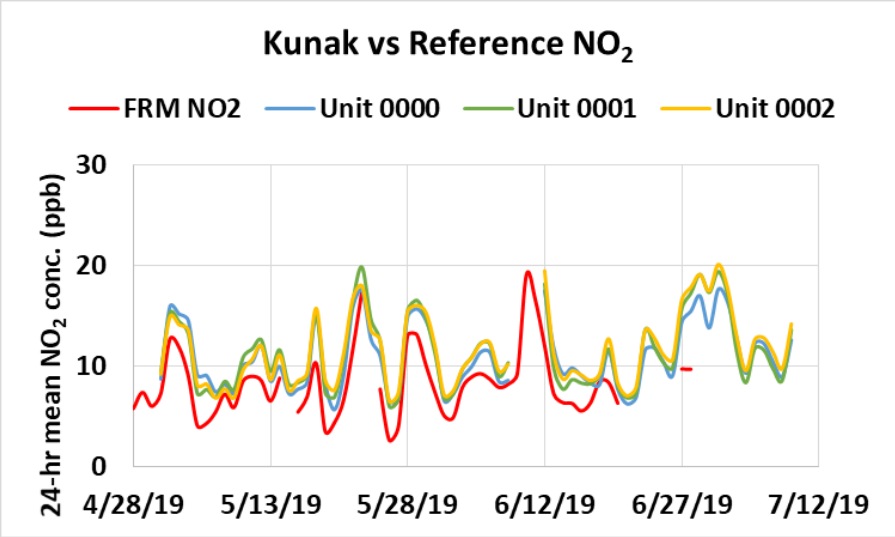
- Kunak sensors showed strong correlations with the corresponding reference NO data (R^2 ~ 0.86)
- Overall, the Kunak sensors underestimated the NO concentrations as measured by the reference instrument
- The Kunak sensors seemed to track the NO diurnal variations as recorded by the reference instrument



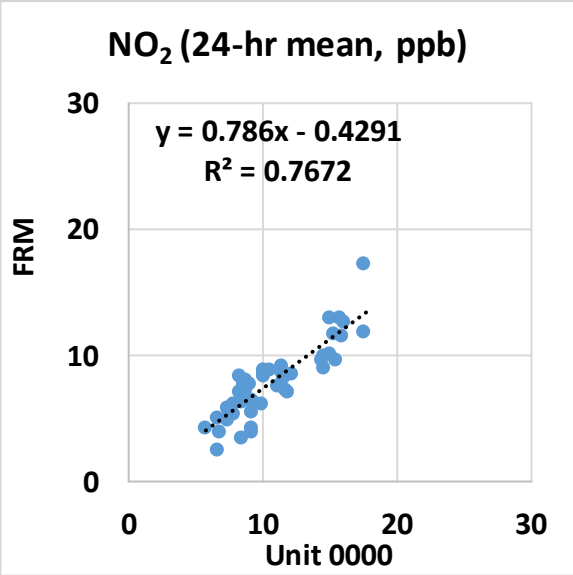


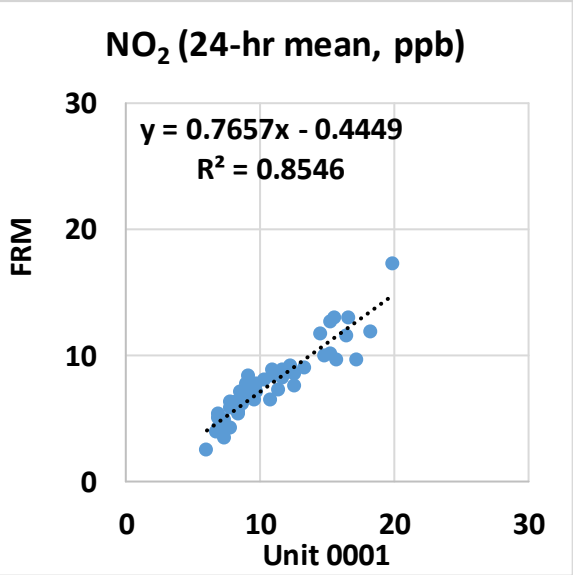


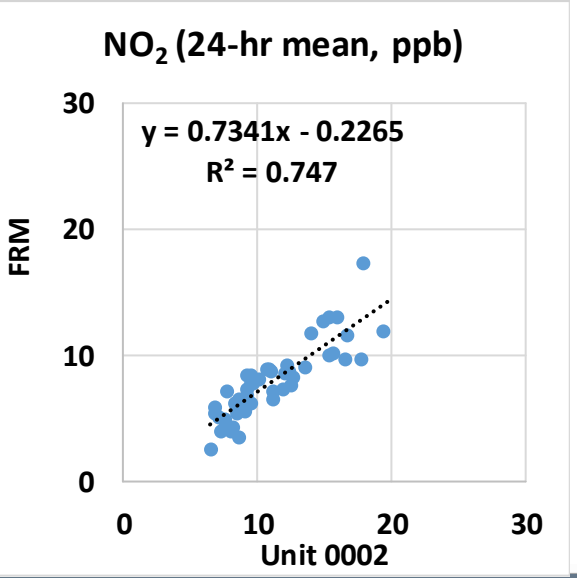
Kunak vs FRM (NO_2; 24-hr mean)



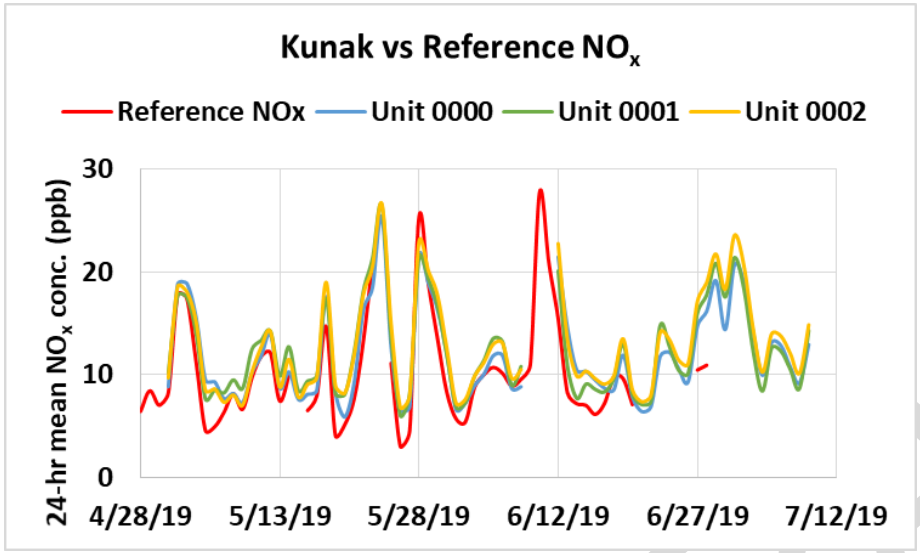
- Kunak sensors showed strong correlations with the corresponding FRM NO_2 data (R^2 ~ 0.79)
- Overall, the Kunak sensors overestimated the NO_2 concentrations as measured by the FRM instrument
- The Kunak sensors seemed to track the NO_2 diurnal variations as recorded by the FRM instrument



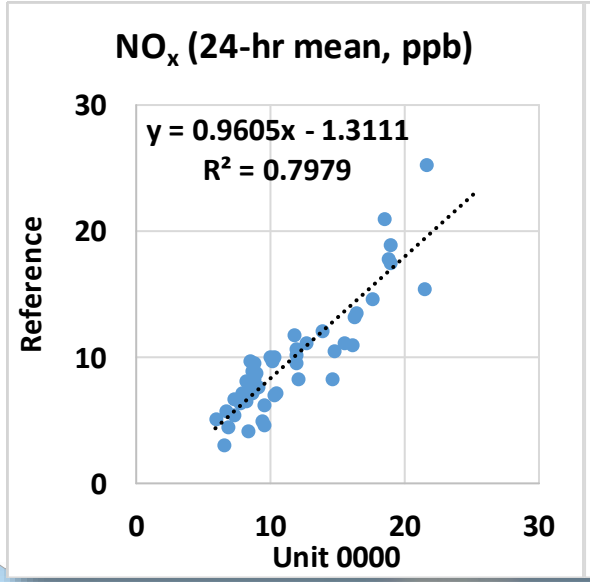


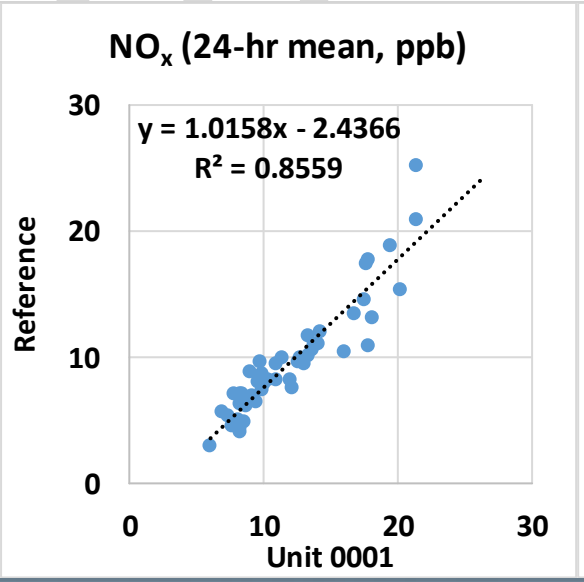


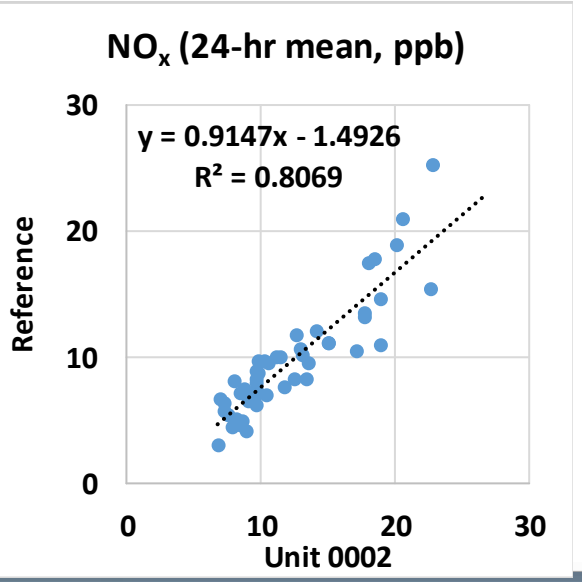
Kunak vs Reference (NO_x; 24-hr mean)



- Kunak sensors showed moderate correlations with the corresponding reference NO_x data (R^2 ~ 0.82)
- Overall, the Kunak sensors overestimated the NO_x concentrations as measured by the reference instrument
- The Kunak sensors seemed to track the NO_x diurnal variations as recorded by the reference instrument







Discussion

- The three **Kunak** sensors' data recovery from all units was ~ 98%, ~ 96% and ~ 100% for ozone, NO_2 and CO measurements, respectively
- The three sensors showed an absolute intra-model variability of 0.32 ppb, 0.33 ppb and 0.002 ppm for ozone, NO_2 and CO measurements, respectively.
- During the field deployment testing period:
  - Ozone sensors showed strong correlations (R^2 ~0.87, 5-min mean) with the FEM instrument and underestimated the corresponding FEM Ozone measurements
  - Nitric Oxide (NO) sensors showed strong correlations (R^2 ~0.87, 5-min mean) with the reference instrument
  - Nitrogen Dioxide (NO_2) sensors showed weak correlations (R^2 ~0.29, 5-min mean) with the reference instrument and overestimated the corresponding FRM NO_2 data
  - Nitrogen Oxides (NO_x) sensors showed moderate correlations (R^2 ~0.54, 5-min mean) with the reference instrument
  - CO sensors showed moderate correlations (R^2 ~0.58, 5-min mean) with the FRM instrument and underestimated the corresponding FRM CO data
- No sensor calibration was performed by South Coast AQMD Staff prior to the beginning of this test
- Laboratory chamber testing is necessary to fully evaluate the performance of these sensors under known aerosol concentrations and controlled temperature and relative humidity conditions
- All results are still preliminary

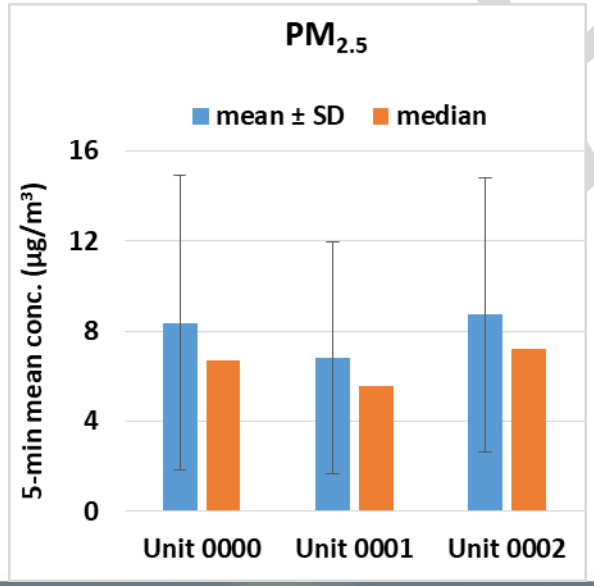
PM in Kunak

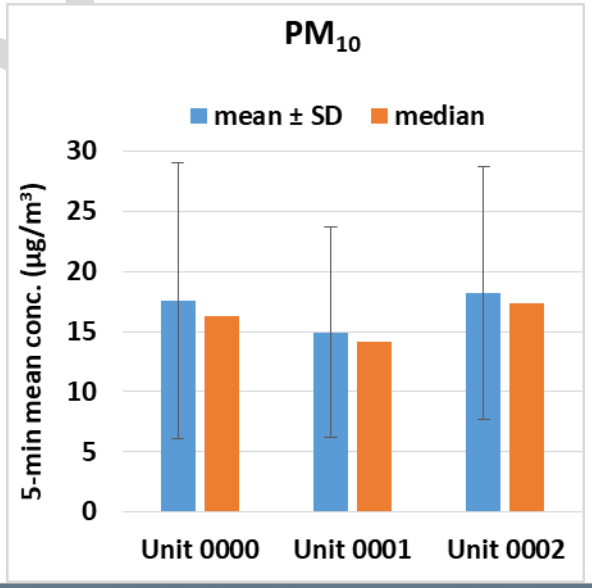
Data validation & recovery

- 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 units 0000, 0001, 0002 was ~100% for all PM measurements

Kunak; intra-model variability

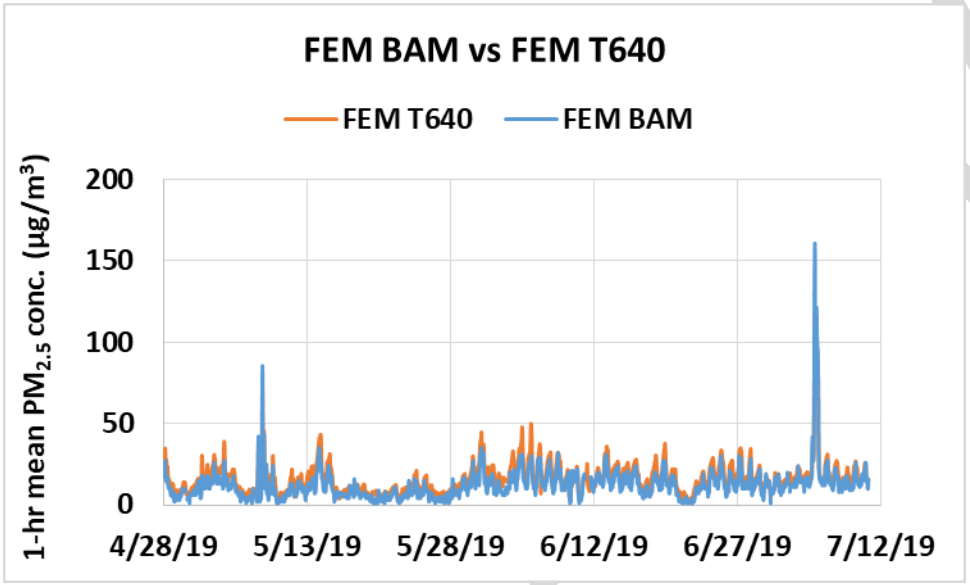
- Absolute intra-model variability was ~ 1.02 and 1.73 µg/m^3 for $PM_{2.5}$ and $PM_{10,}$ respectively (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was ~ 13 and 10 % for $PM_{2.5}$ and $PM_{10,}$ respectively (calculated as the absolute intra-model variability relative to the mean of the three sensor means)

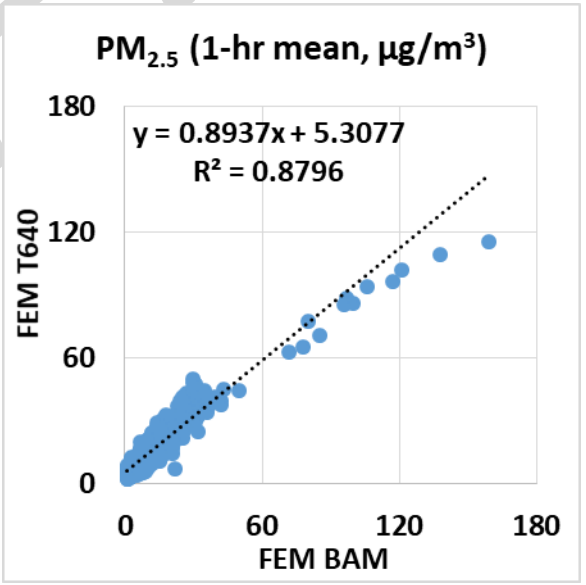




Reference Instruments: $PM_{2.5}$ BAM & T640

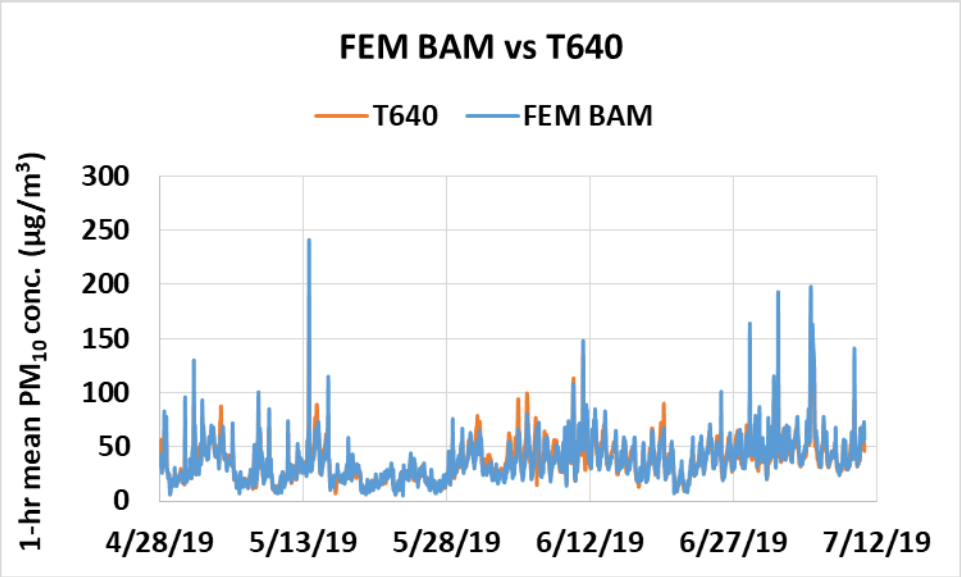
- Data recovery for $PM_{2.5}$ from FEM BAM and FEM T640 was 98 % and 99.7%, respectively.
- Strong correlations between the reference instruments for $PM_{2.5}$ measurements (R^2 ~ 0.88) were observed.

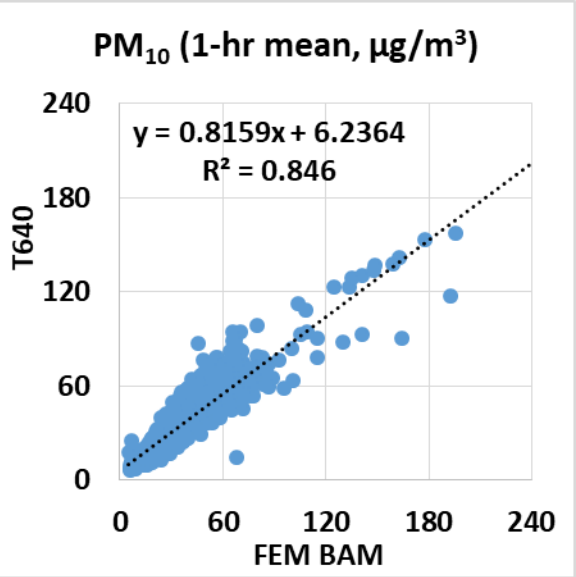




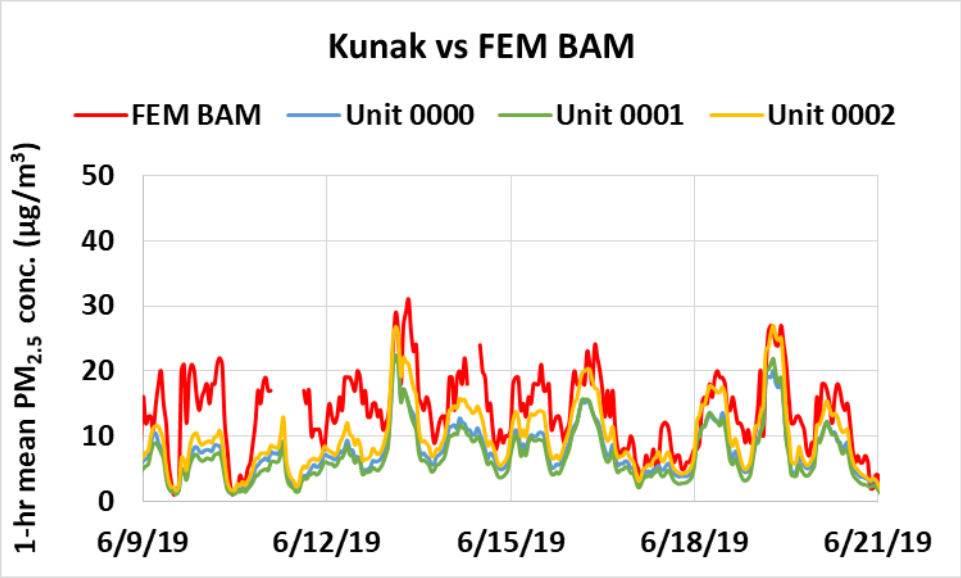
Reference Instruments: PM_{10} BAM & T640

- Data recovery for PM_{10} from FEM BAM and T640 was 98.9 % and 99.7 %, respectively.
- Strong correlations between the reference instruments for PM_{10} measurements (R^2 ~ 0.85) were observed.

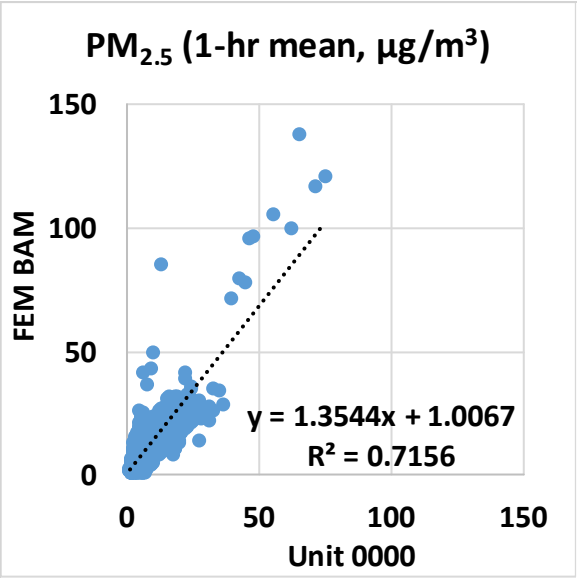


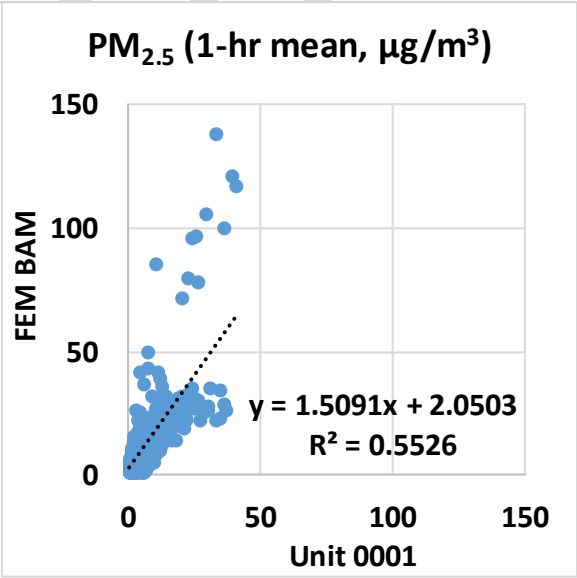


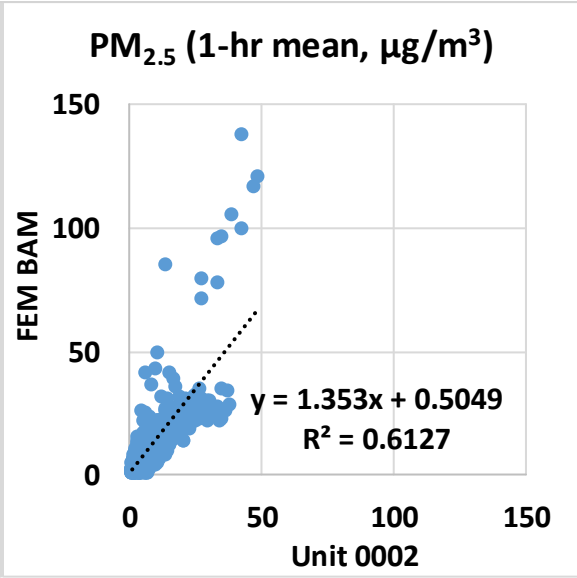
Kunak vs FEM BAM ($PM_{2.5}$; 1-hr mean)



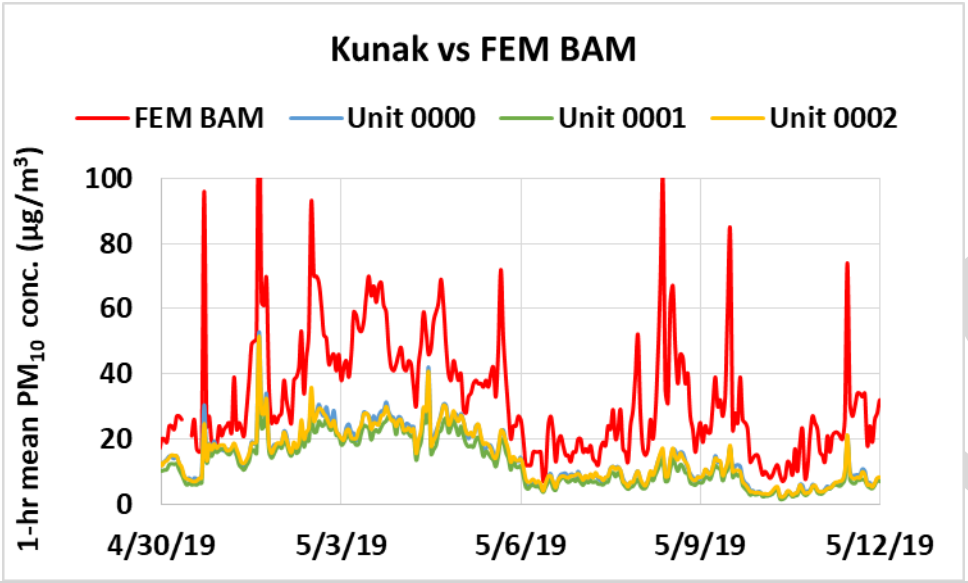
- Kunak sensors showed moderate correlations with the corresponding FEM BAM data (R^2 ~ 0.63)
- Overall, the Kunak sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM BAM
- The Kunak sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM BAM



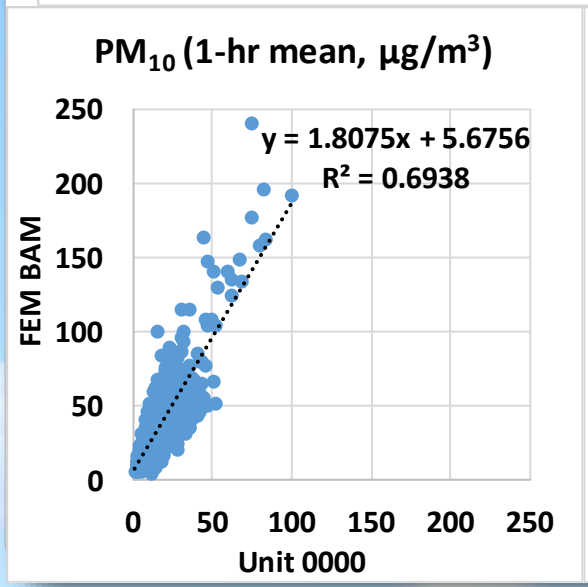


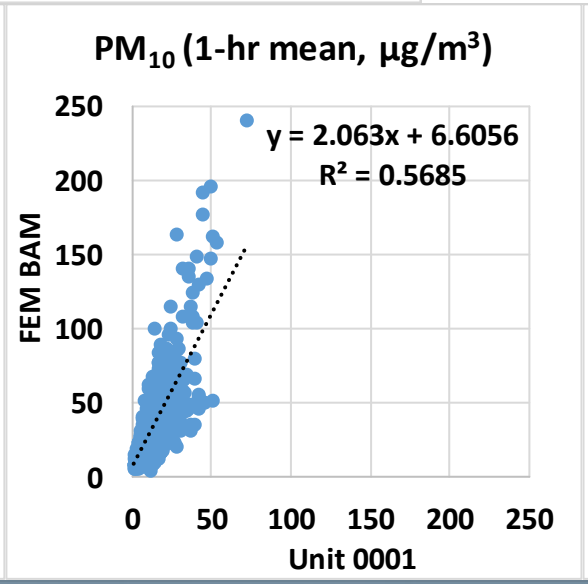


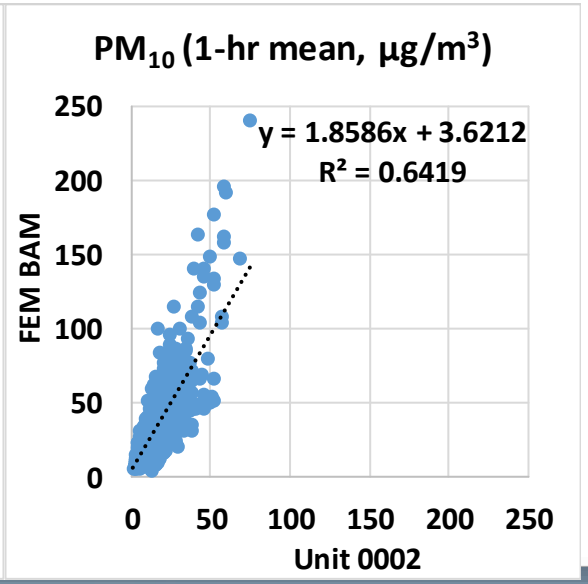
Kunak vs FEM BAM (PM_{10}; 1-hr mean)



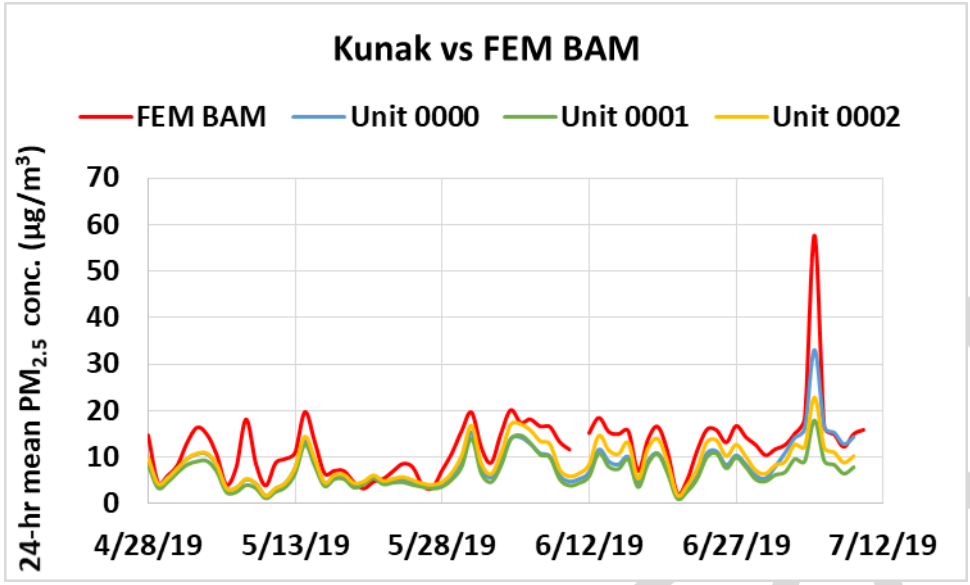
- Kunak sensors showed moderate correlations with the corresponding FEM BAM data (R^2 ~ 0.63)
- Overall, the Kunak sensors underestimated the PM_{10} mass concentrations measured by FEM BAM
- The Kunak sensors seemed to track the PM_{10} diurnal variations as recorded by FEM BAM



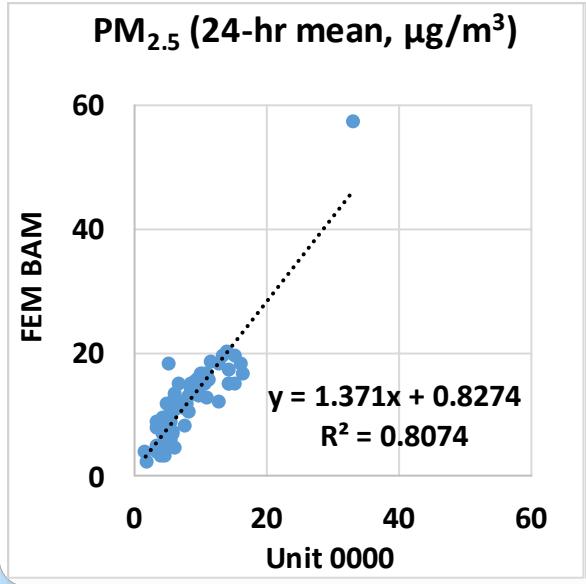


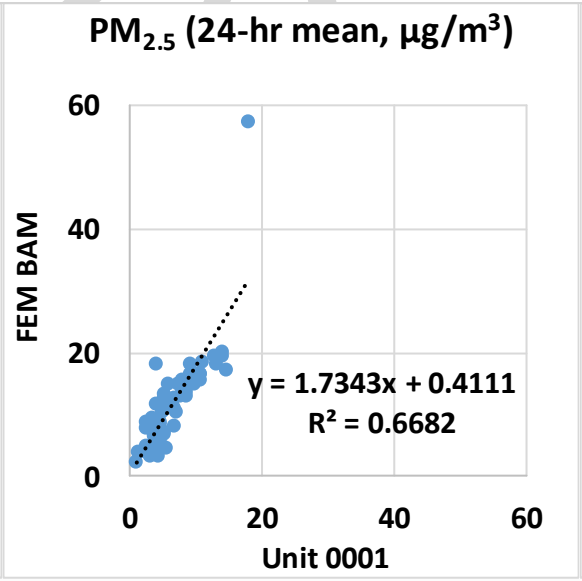


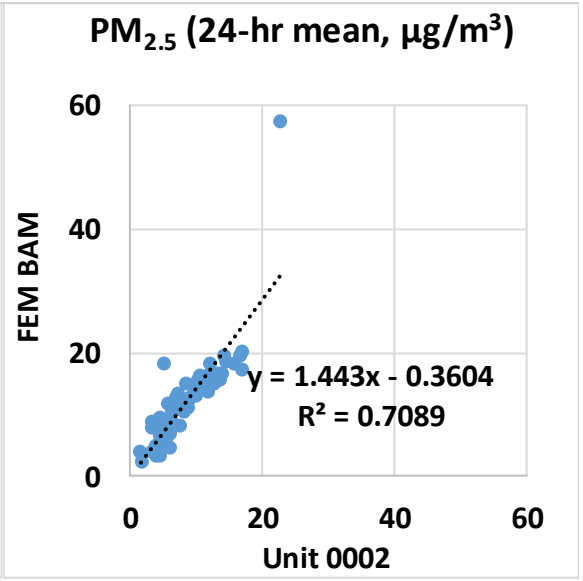
Kunak vs FEM BAM ($PM_{2.5}$; 24-hr mean)



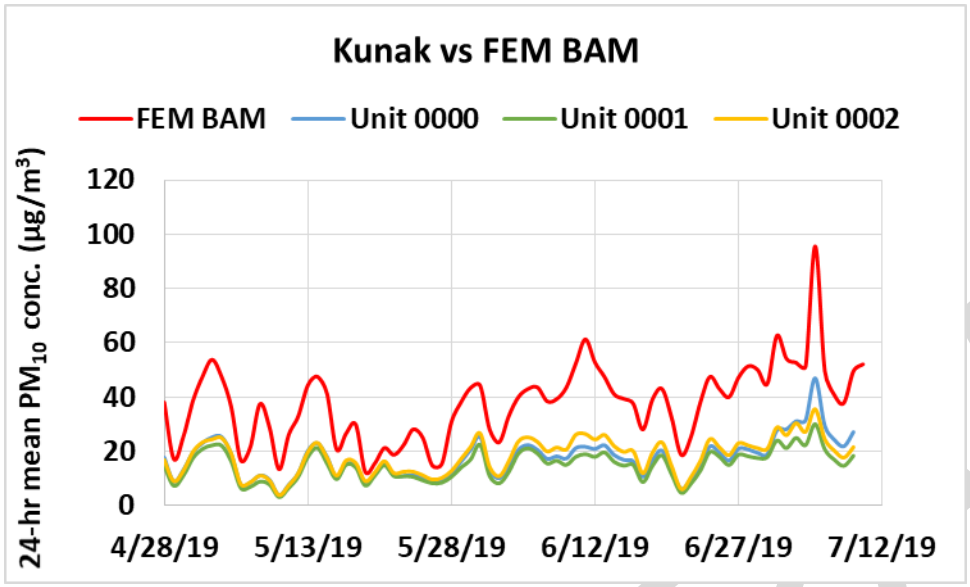
- Kunak sensors showed strong correlations with the corresponding FEM BAM data (R^2 ~ 0.73)
- Overall, the Kunak sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM BAM
- The Kunak sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM BAM



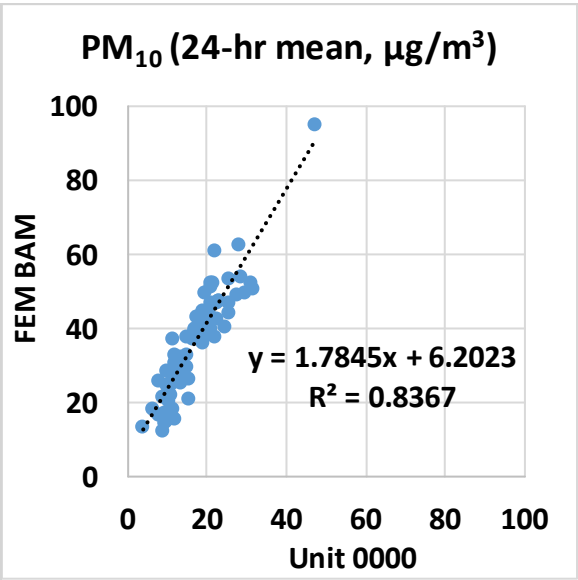


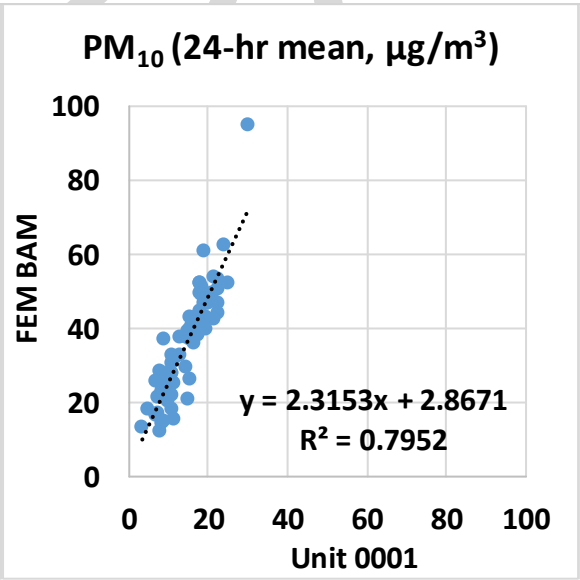


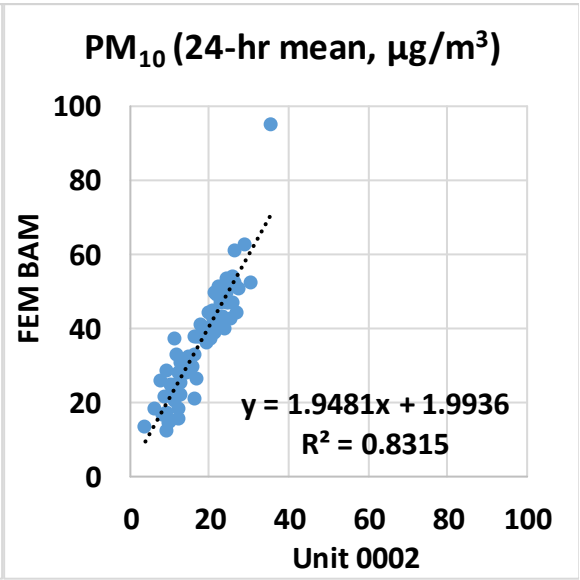
Kunak vs FEM BAM (PM_{10}; 24-hr mean)



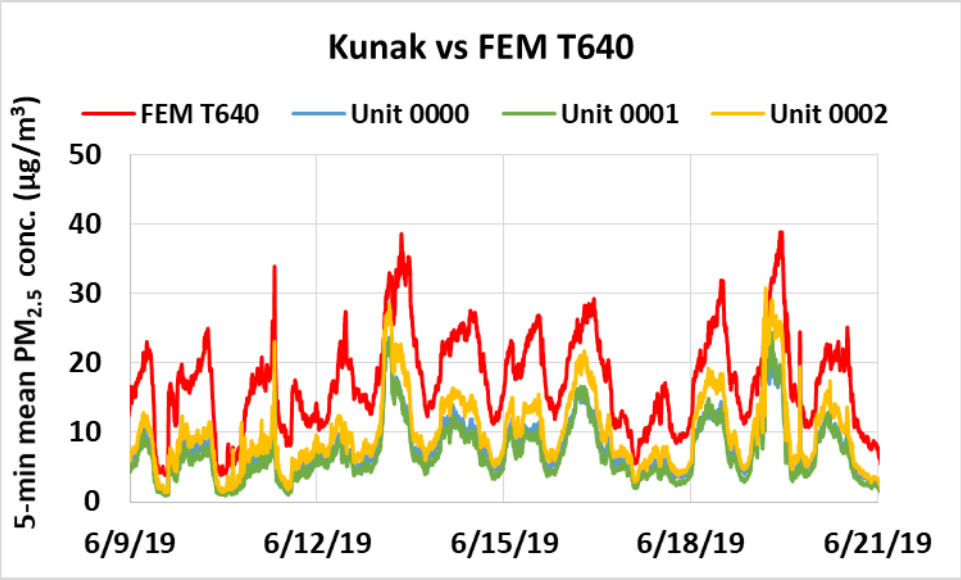
- Kunak sensors showed strong correlations with the corresponding FEM BAM data (R^2 ~ 0.82)
- Overall, the Kunak sensors underestimated the PM_{10} mass concentrations measured by FEM BAM
- The Kunak sensors seemed to track the PM_{10} diurnal variations as recorded by FEM BAM



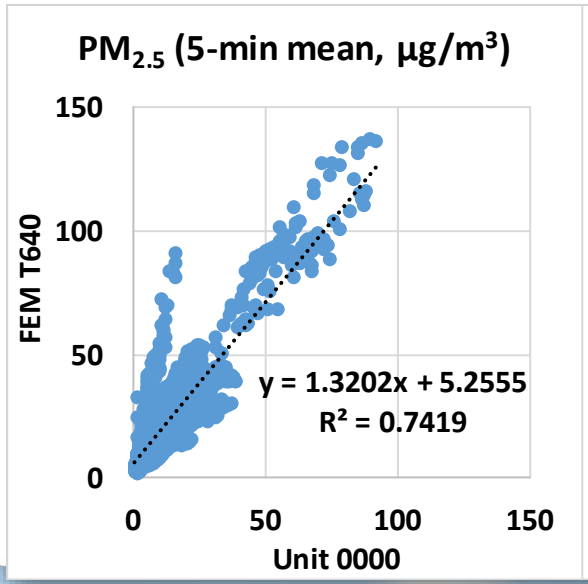


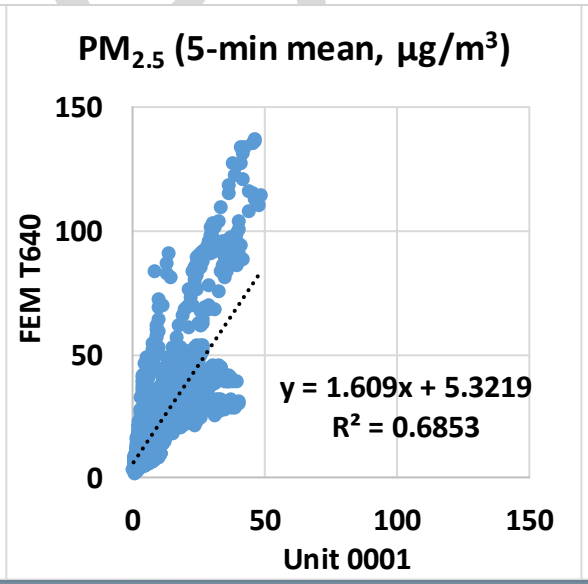


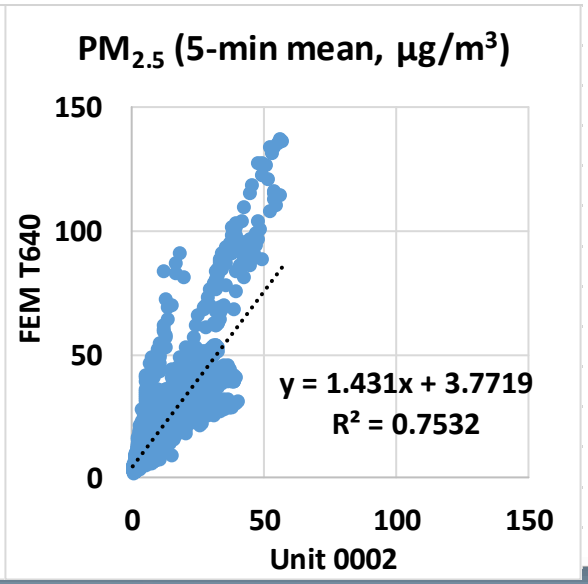
Kunak vs FEM T640 ($PM_{2.5}$; 5-min mean)



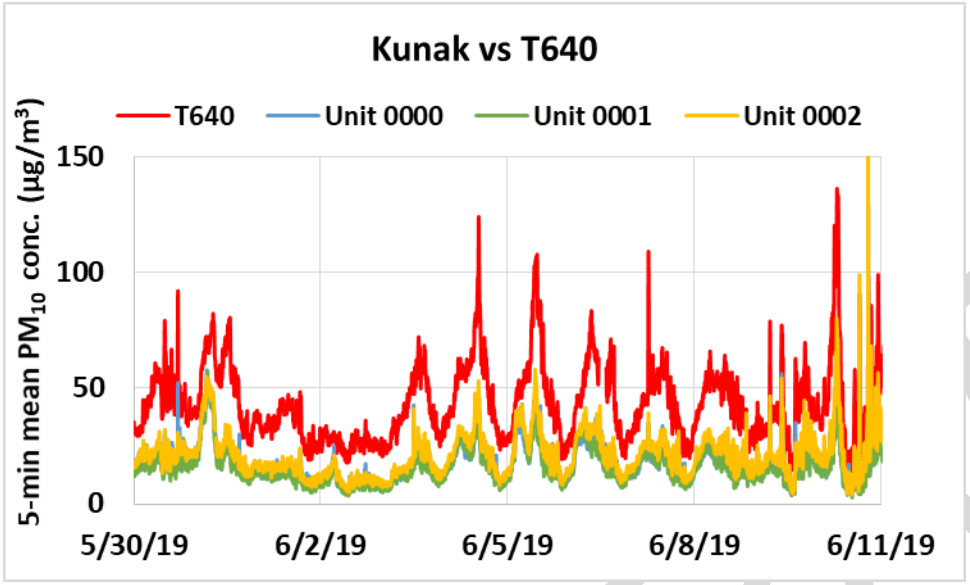
- Kunak sensors showed strong correlations with the corresponding FEM T640 data (R^2 ~ 0.73)
- Overall, the Kunak sensors underestimated the $PM_{2.5}$ mass concentrations measured by FEM T640
- The Kunak sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



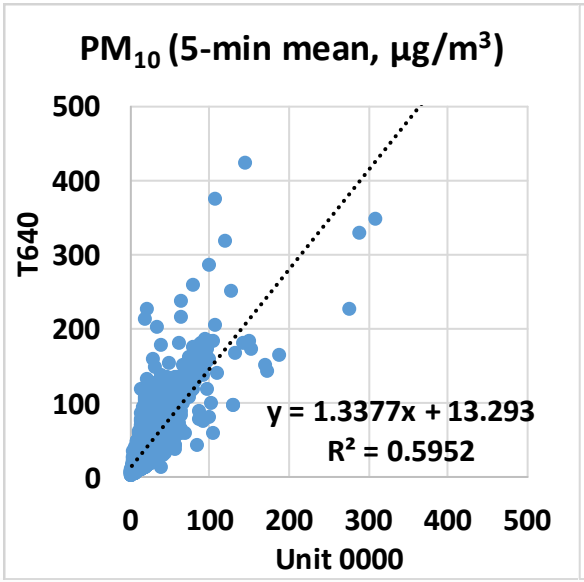


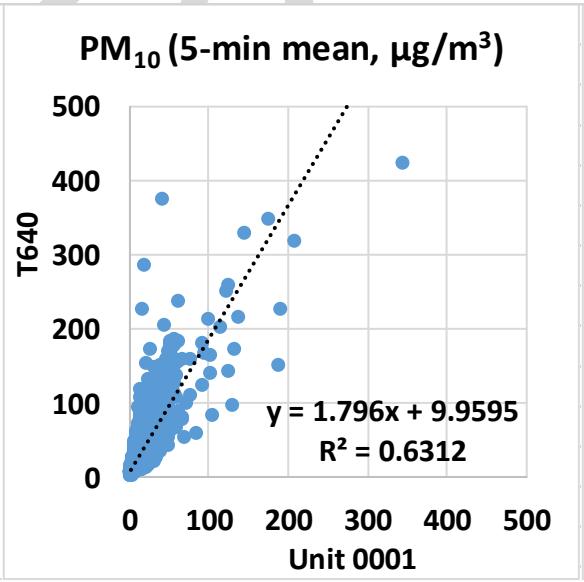


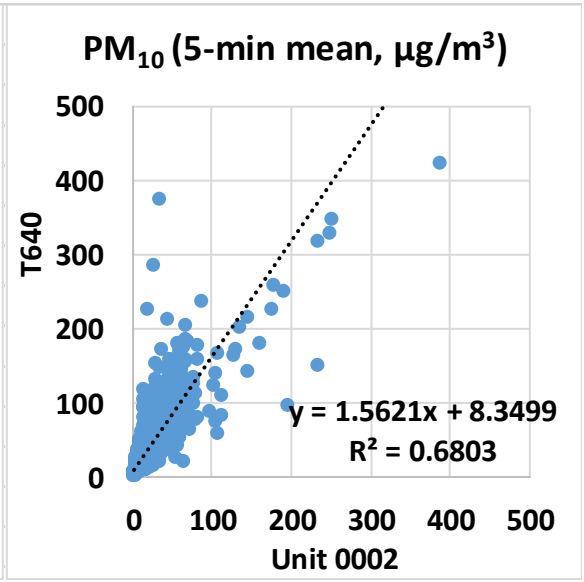
Kunak vs T640 (PM_{10}; 5-min mean)



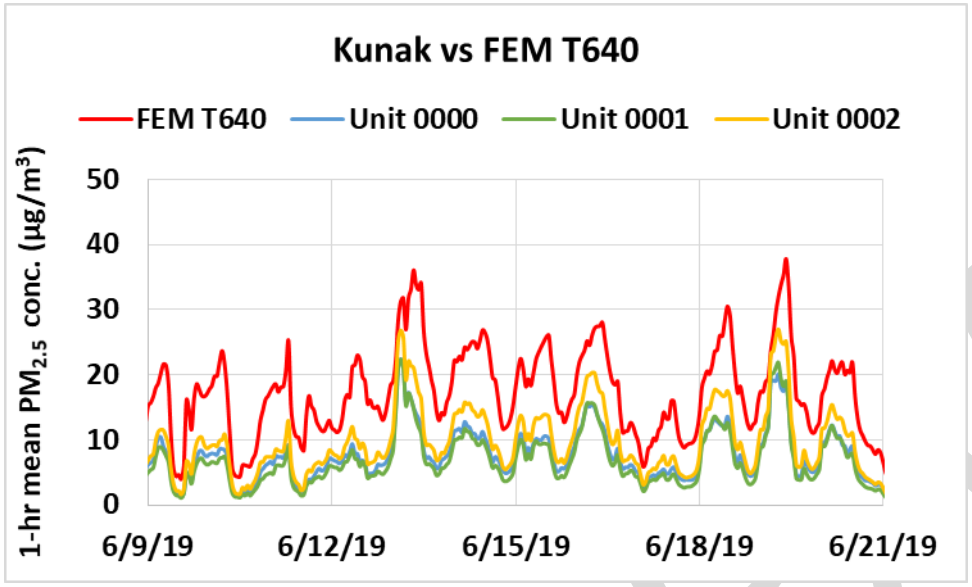
- Kunak sensors showed moderate correlations with the corresponding T640 data (R^2 ~ 0.64)
- Overall, the Kunak sensors underestimated the PM_{10} mass concentrations measured by T640
- The Kunak sensors seemed to track the PM_{10} diurnal variations as recorded by T640



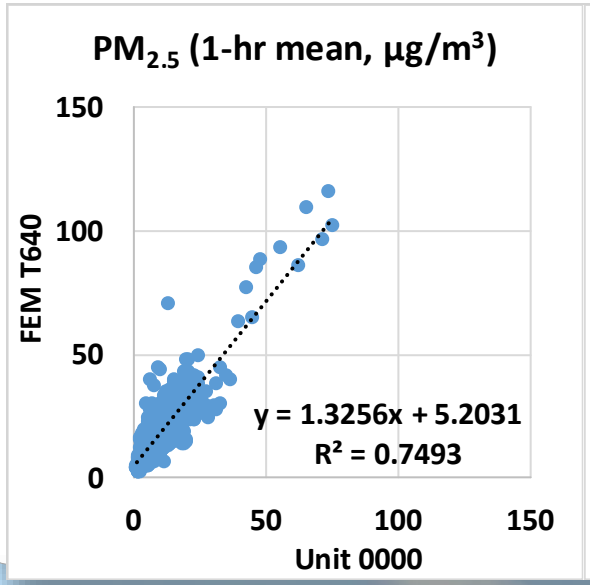


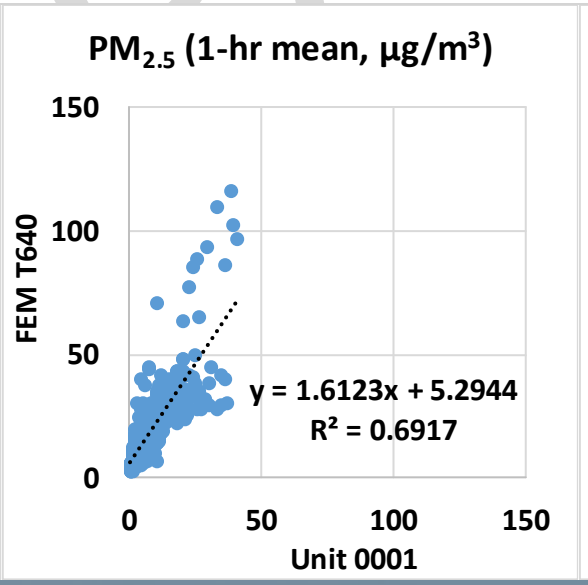


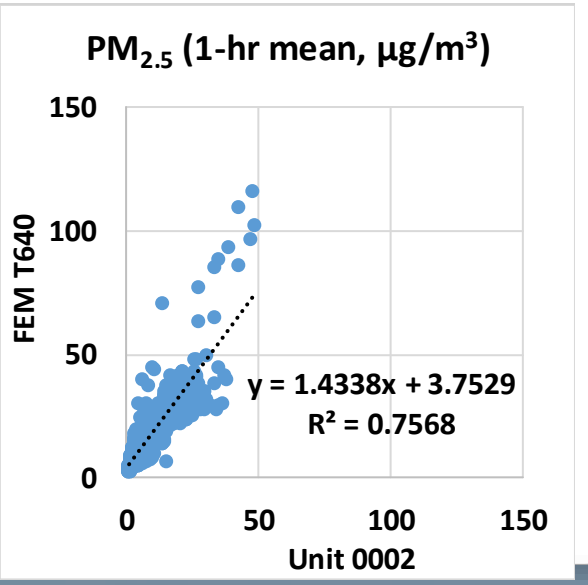
Kunak vs FEM T640 ($PM_{2.5}$; 1-hr mean)



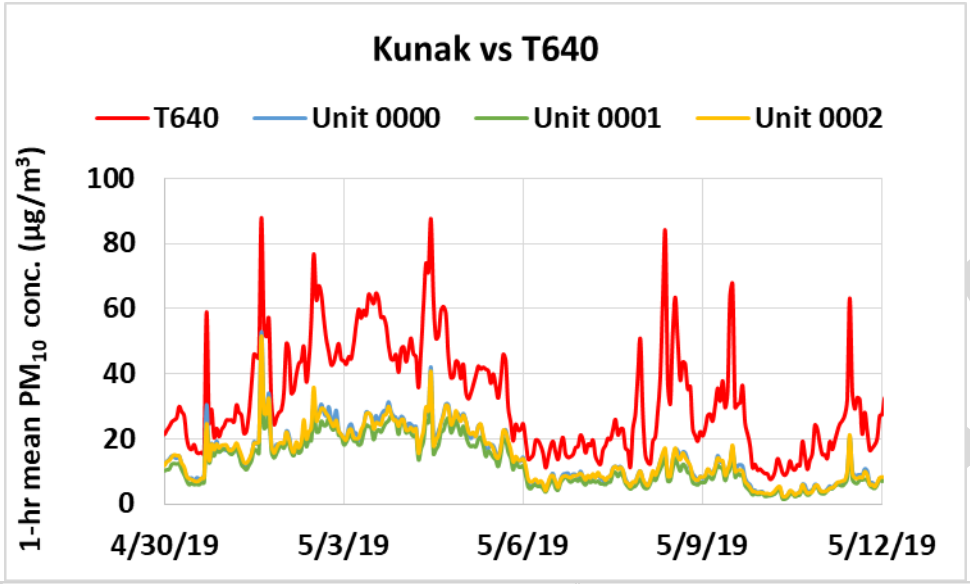
- Kunak sensors showed strong correlations with the corresponding FEM T640 data (R^2 ~ 0.73)
- Overall, the Kunak sensors underestimated the $PM_{2.5}$ mass concentrations measured by FEM T640
- The Kunak sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



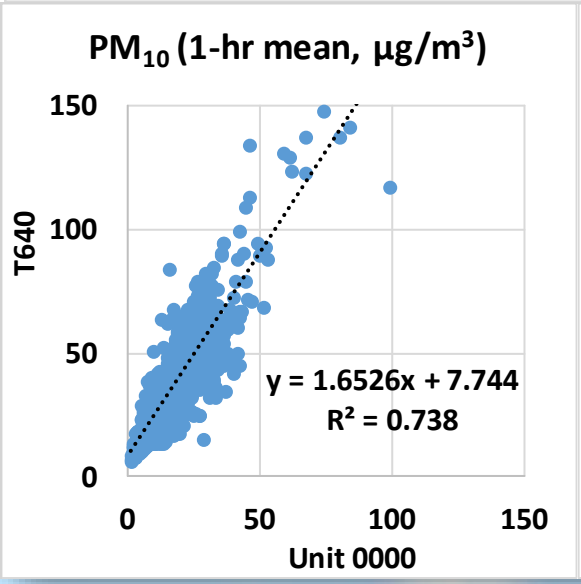


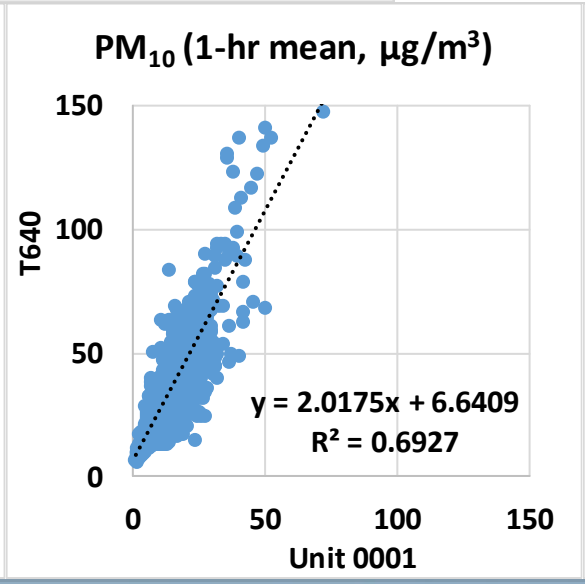


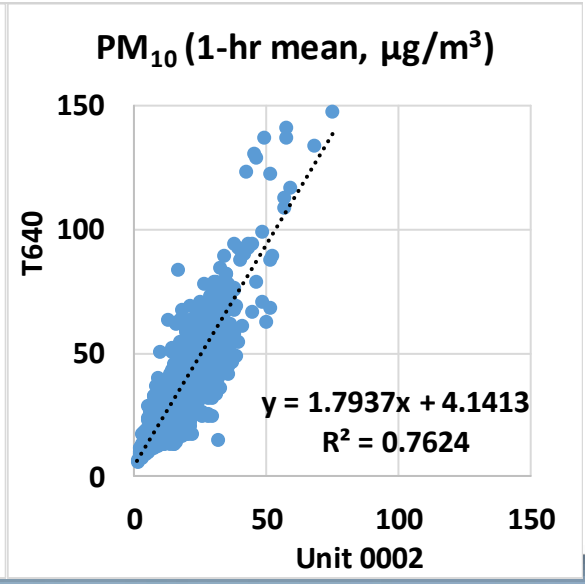
Kunak vs T640 (PM_{10}; 1-hr mean)



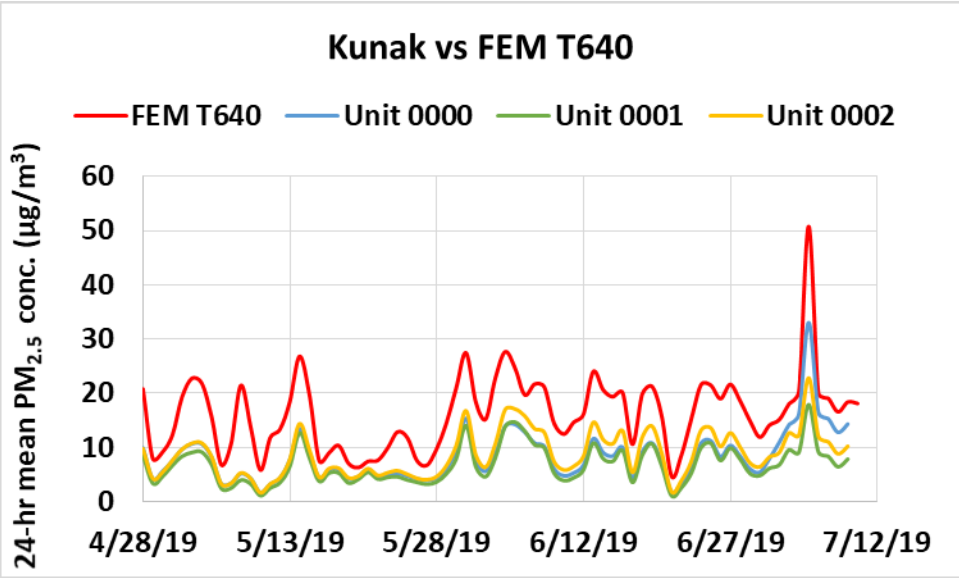
- Kunak sensors showed strong correlations with the corresponding T640 data (R^2 ~ 0.73)
- Overall, the Kunak sensors underestimated the PM_{10} mass concentrations measured by T640
- The Kunak sensors seemed to track the PM_{10} diurnal variations as recorded by T640



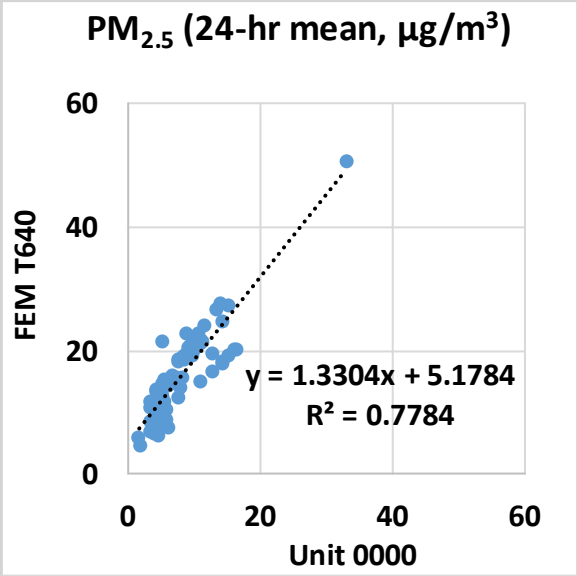


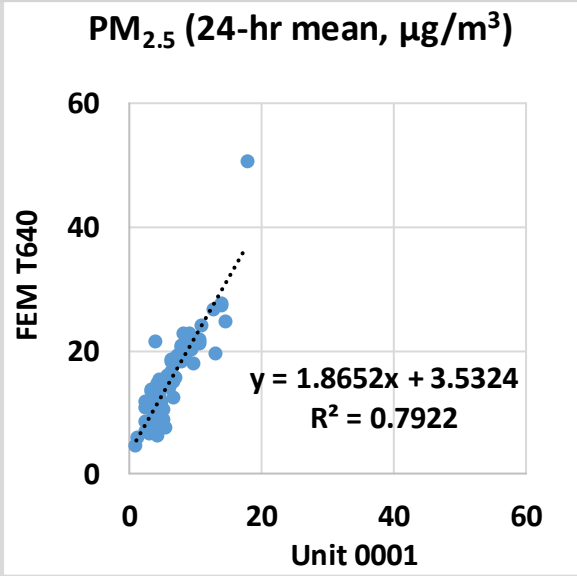


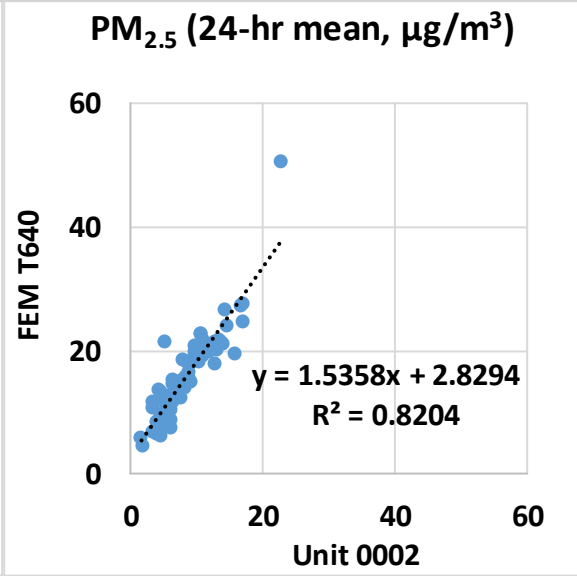
Kunak vs FEM T640 ($PM_{2.5}$; 24-hr mean)



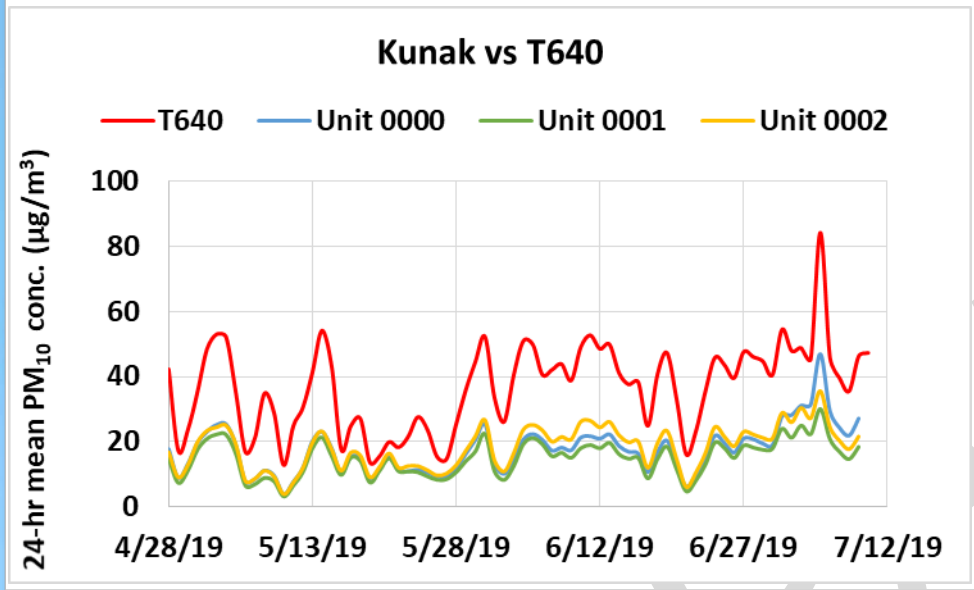
- Kunak sensors showed strong correlations with the corresponding FEM T640 data (R^2 ~ 0.80)
- Overall, the Kunak sensors underestimated the $PM_{2.5}$ mass concentrations measured by FEM T640
- The Kunak sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



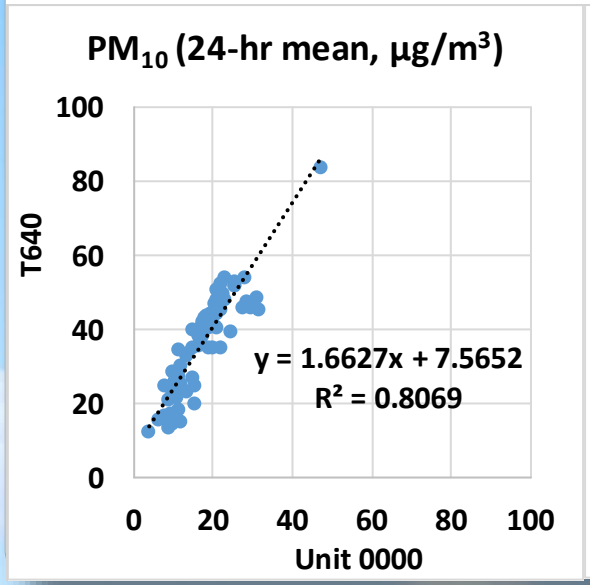


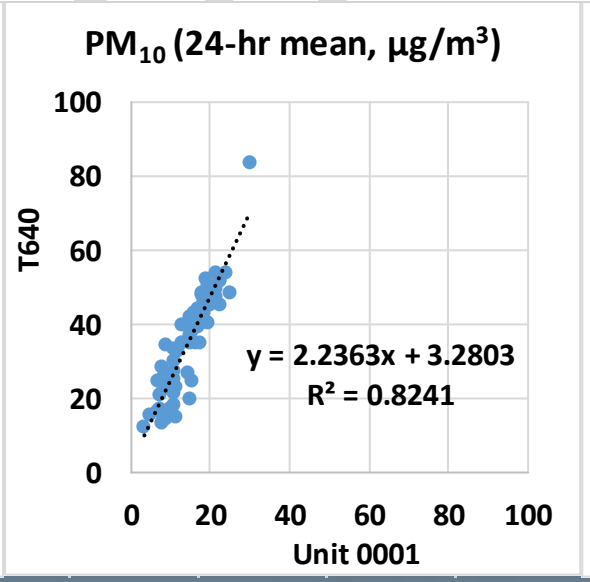


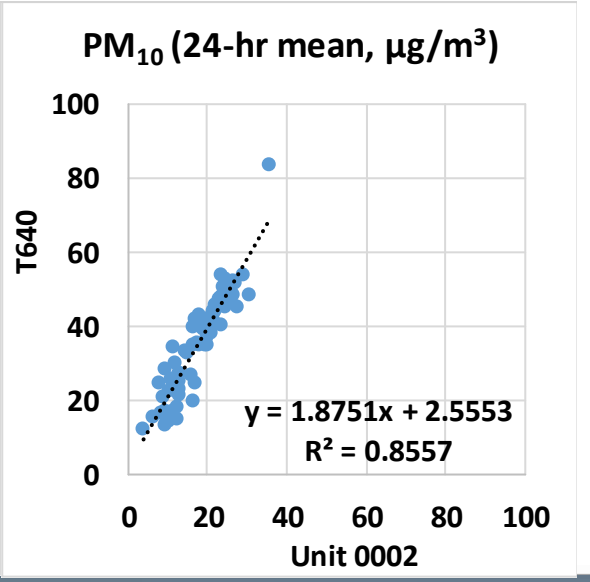
Kunak vs T640 (PM_{10}; 24-hr mean)



- Kunak sensors showed strong correlations with the corresponding T640 data (R^2 ~ 0.83)
- Overall, the Kunak sensors underestimated the PM_{10} mass concentrations measured by T640
- The Kunak sensors seemed to track the PM_{10} diurnal variations as recorded by T640

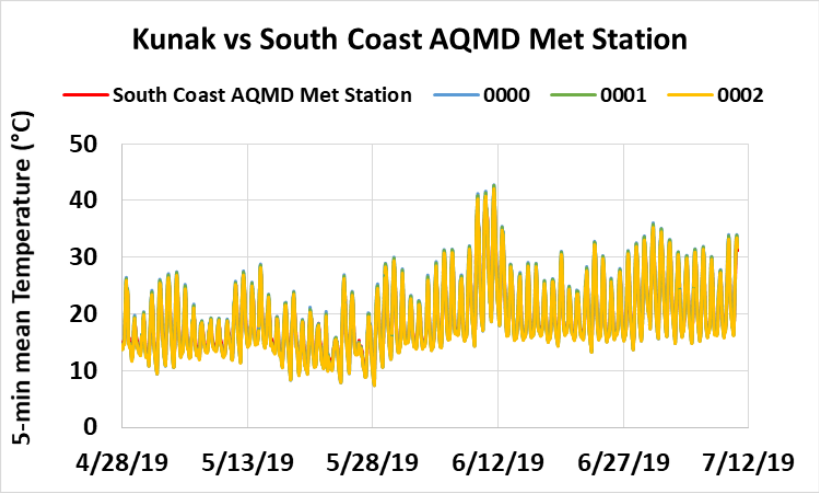




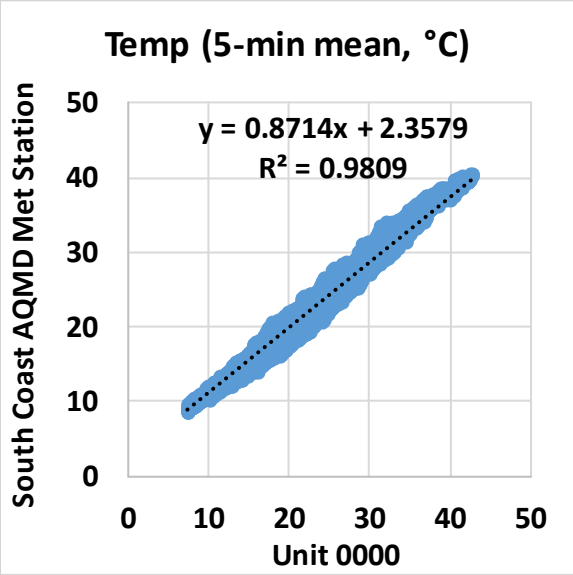


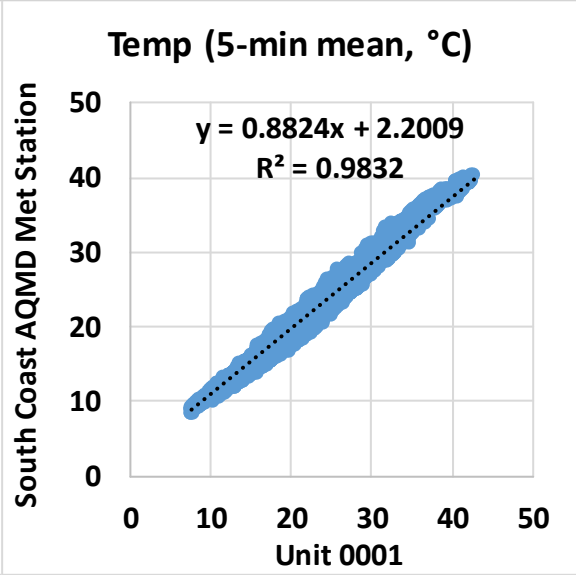
Meteorological data in Kunak

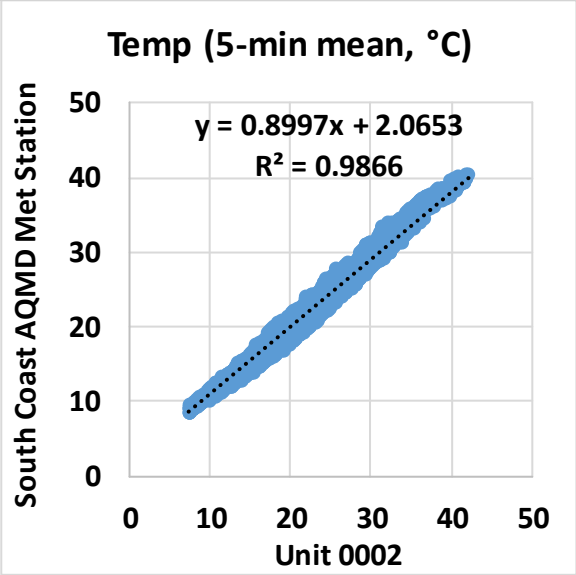
Kunak vs South Coast AQMD Met Station (Temp; 5-min mean)



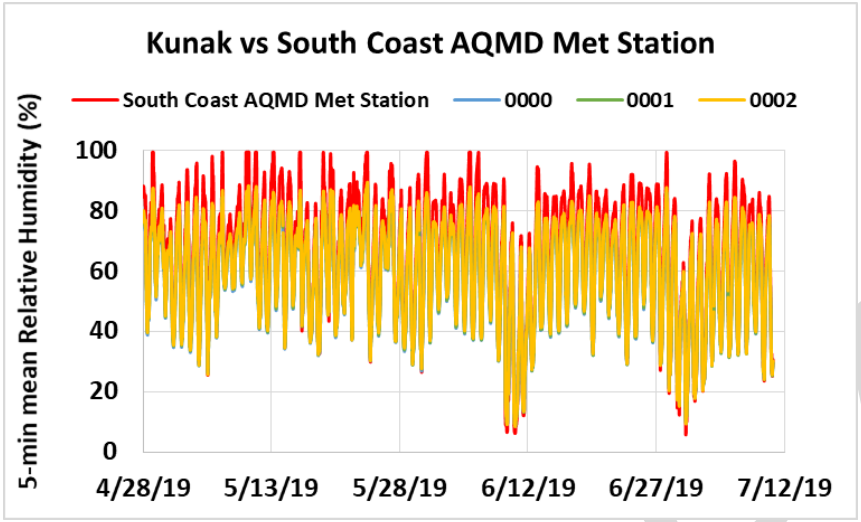
- Kunak temperature measurements showed very strong correlations with the corresponding South Coast AQMD Met Station data (R^2 ~ 0.98)
- Overall, the Kunak temperature measurements overestimated the corresponding South Coast AQMD Met Station data
- The Kunak sensors seemed to track well the temperature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



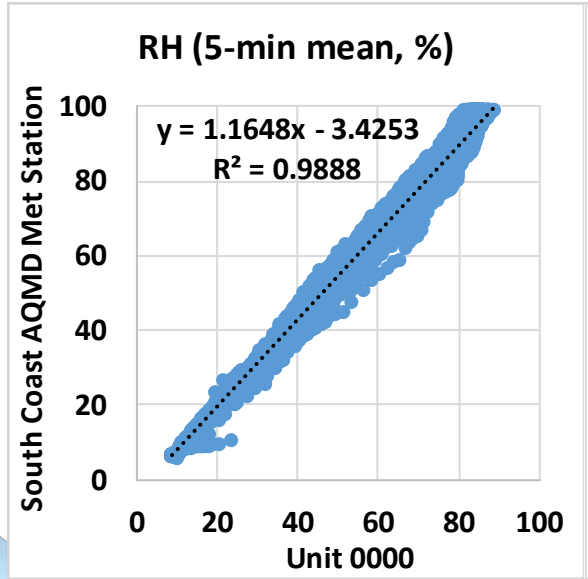


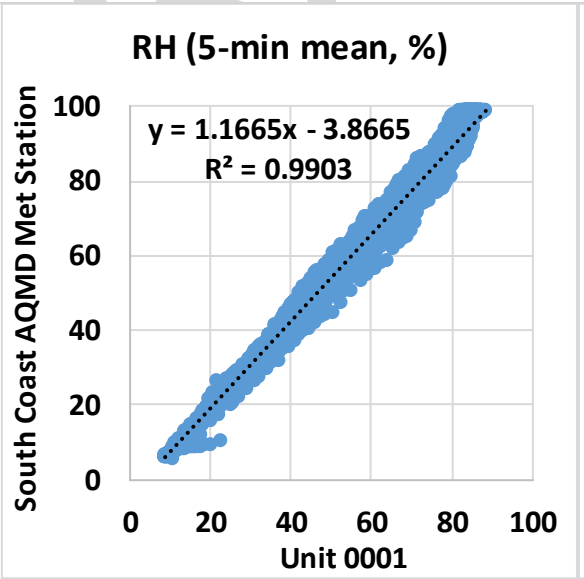


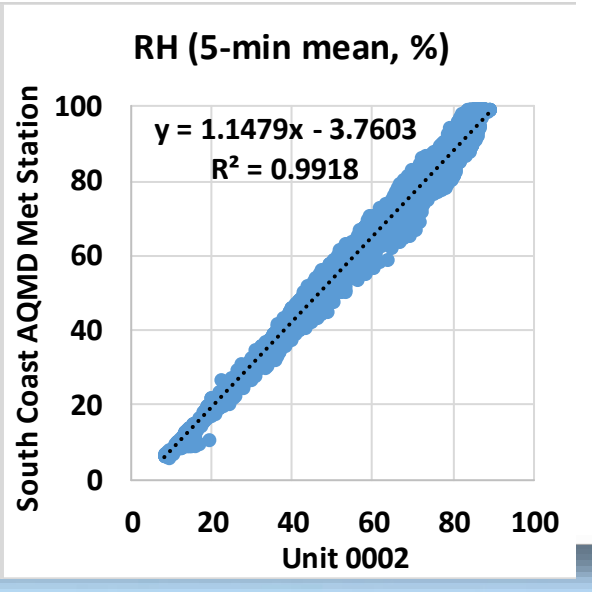
Kunak vs South Coast AQMD Met Station (RH; 5-min mean)



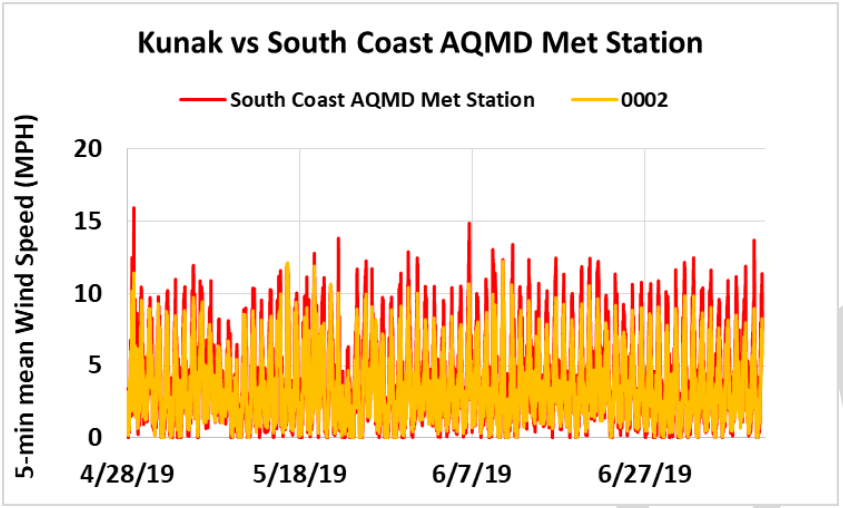
- Kunak RH measurements showed very strong correlations with the corresponding South Coast AQMD Met Station data (R^2 ~ 0.99)
- Overall, the Kunak RH measurements underestimated the corresponding South Coast AQMD Met Station data
- The Kunak sensors seemed to track well the RH diurnal variations as recorded by South Coast AQMD Met Station





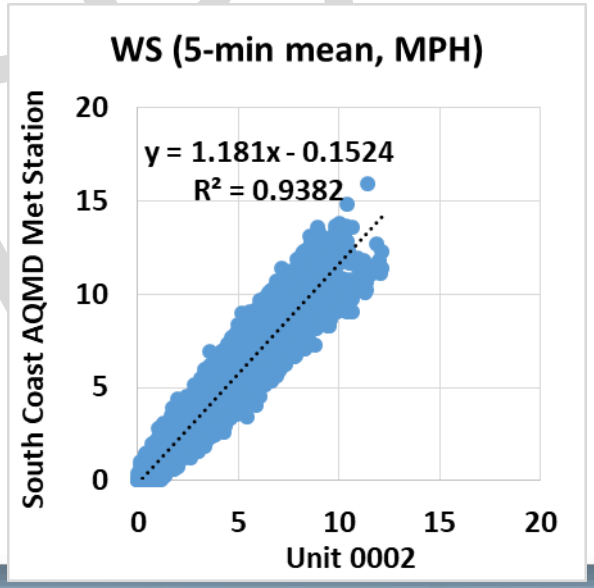


Kunak vs South Coast AQMD Met Station (WS; 5-min mean)

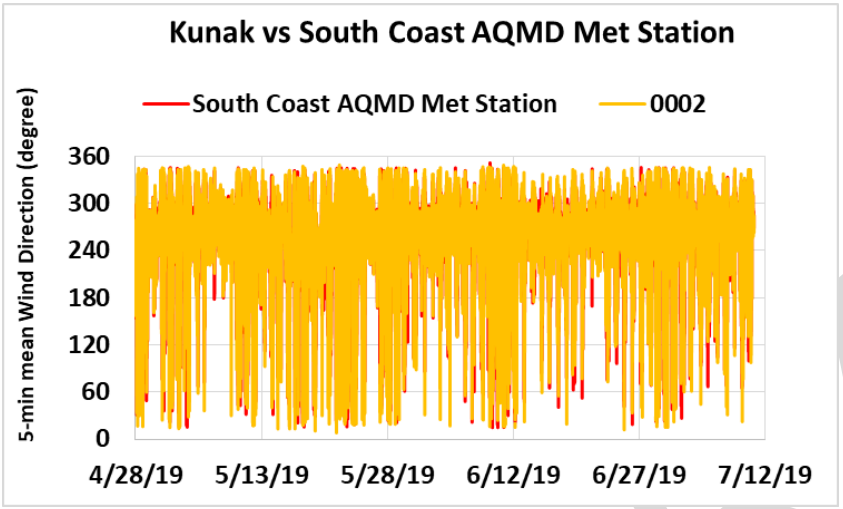


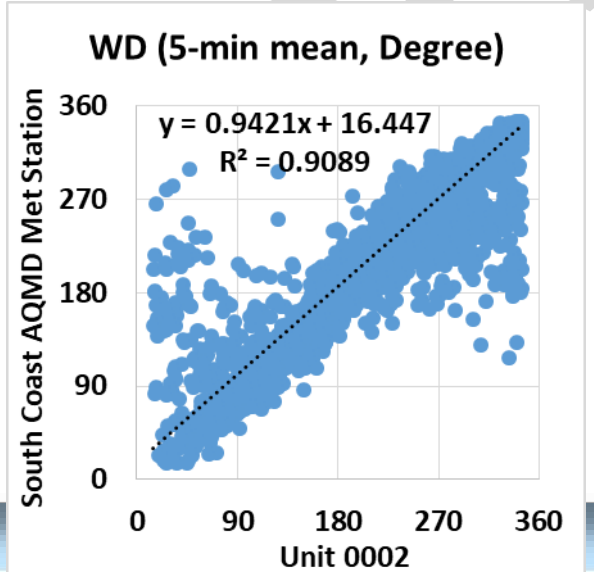
- Kunak wind speed (WS) measurements showed very strong correlations with the corresponding South Coast AQMD Met Station data (R^2 ~ 0.94)
- Overall, the Kunak WS measurements underestimated the corresponding South Coast AQMD Met Station data
- The Kunak sensors seemed to track well the WS diurnal variations as recorded by South Coast AQMD Met Station

Note: Only Unit 0002 reports wind speed (WS).



Kunak vs South Coast AQMD Met Station (WD; 5-min mean)





- Kunak wind direction (WD) measurements showed very strong correlations with the corresponding South Coast AQMD Met Station data (R^2 ~ 0.91)
- Overall, the Kunak WD measurements underestimated the corresponding South Coast AQMD Met Station data
- The Kunak sensors seemed to track the WD diurnal variations as recorded by South Coast AQMD Met Station

Note: Only Unit 0002 reports wind direction (WD). Only valid wind direction data were included (at wind speed higher than 0.5 m/s). To avoid confusion in WD comparison, values lower than 15 degrees and higher than 345 degrees have been omitted from the data set.

Discussion

- The three **Kunak** sensors' data recovery from all units was ~ 100% for all PM measurements
- The absolute intra-model variability was ~ 1.02 and 1.73 µg/m^3 for $PM_{2.5}$ and $PM_{10,}$ respectively
- The reference instruments (BAM and T640) showed strong correlations with each other for both $PM_{2.5}$ (R^2 ~ 0.88) and PM_{10} (R^2 ~ 0.85) mass concentration measurements (1-hr mean)
- $PM_{2.5}$ mass concentration measurements measured by Kunak sensors showed moderate to strong correlations with the corresponding FEM BAM and FEM T640 data (R^2 ~ 0.63 and 0.73, respectively, 1-hr mean). The sensors underestimated $PM_{2.5}$ mass concentrations measured by FEM BAM and FEM T640
- PM_{10} mass concentration measurements measured by Kunak sensors showed moderate to strong correlations with the corresponding FEM BAM and T640 data (R^2 ~ 0.63 and 0.73, respectively; 1-hr mean) and underestimated PM_{10} mass concentrations measured by FEM BAM and T640
- No sensor calibration was performed by South Coast AQMD Staff prior to the beginning of this test
- Laboratory chamber testing is necessary to fully evaluate the performance of these sensors under known aerosol concentrations and controlled temperature and relative humidity conditions
- All results are still preliminary