Field Evaluation
HabitatMap AirBeam2 Sensor

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

- From 07/20/2018 to 09/19/2018, three **HabitatMap AirBeam2** (hereinafter AirBeam2) sensors were deployed at a SCAQMD stationary ambient monitoring site in Rubidoux and were run side-by-side with three reference instruments measuring the same pollutants

- AirBeam2 (*3 units tested*):
  - Particle sensor (optical; non-FEM)
  - PM sensor: Plantower PMS7003
  - Each unit measures: $PM_{1.0}$, $PM_{2.5}$ and PM_{10} (µg/m^3) Temperature (°F), Relative Humidity (%) (measures T and RH inside of sensor)
  - Unit cost: ~$250
  - Time resolution: 1-min
  - Units IDs: F4F1, 6FE0, 63CC
  - Differences from 1st Generation:
    - Different hardware (temp/RH sensor, PM sensor) and design
    - Firmware: 3.19.18 AirBeam2
    - Wi-Fi and cellular capabilities
    - Different microcontroller
    - Measures $PM_{1.0}$, $PM_{2.5}$ and PM_{10} mass conc. only

- MetOne BAM (*reference instrument*):
  - Beta-attenuation monitor (FEM $PM_{2.5}$ & PM_{10})
  - Measures $PM_{2.5}$ & PM_{10} (µg/m^3)
  - Unit cost: ~$20,000
  - Time resolution: 1-hr

- GRIMM (*reference instrument*):
  - Optical particle counter (FEM $PM_{2.5}$)
  - Measures $PM_{1.0}$, $PM_{2.5}$, and PM_{10} (µg/m^3)
  - Cost: ~$25,000 and up
  - Time resolution: 1-min

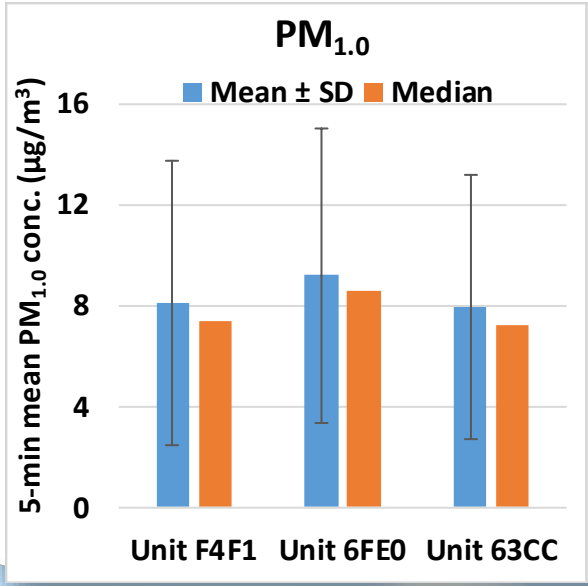
- Teledyne API T640 (*reference instrument*):
  - Optical particle counter (FEM $PM_{2.5}$)
  - Measures $PM_{2.5}$ & PM_{10} (µg/m^3)
  - Unit cost: ~$21,000
  - Time resolution: 1-min

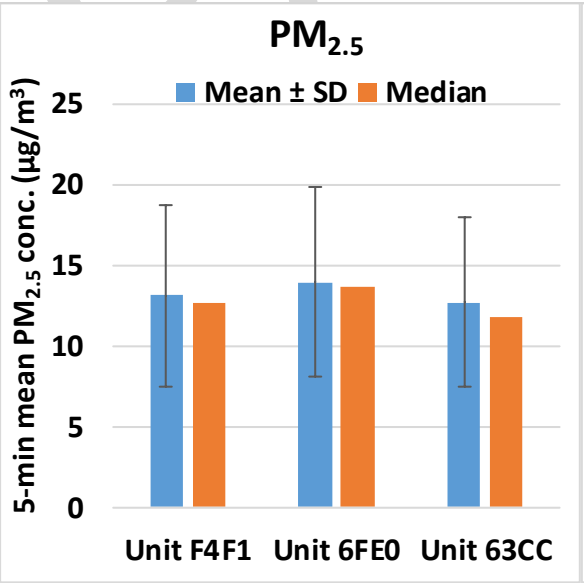
Data validation & recovery

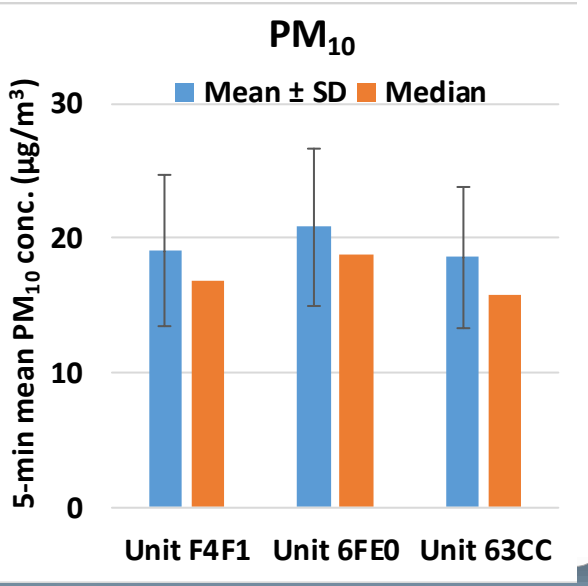
- Basic QA/QC procedures were used to validate the collected data (i.e. obvious outliers, negative values and invalid data-points were eliminated from the data-set)
- Data recovery for $PM_{1.0}$, $PM_{2.5}$ and PM_{10} from all units is ~ 74.5%, 77.8% and 77.9%, respectively. During this evaluation, HabitatMap discovered an issue with the AirBeam2 firmware that prevented the AirBeam2 from reestablishing a WiFi connection if the connection was temporarily disrupted. After discovering this issue, HabitatMap updated the firmware running on the AirBeam2 and it successfully resolved this issue.

AirBeam2; intra-model variability

- Low measurement variability (9.5-14.8%) was observed between the three AirBeam2 units for $PM_{1.0}$, $PM_{2.5}$ and PM_{10}

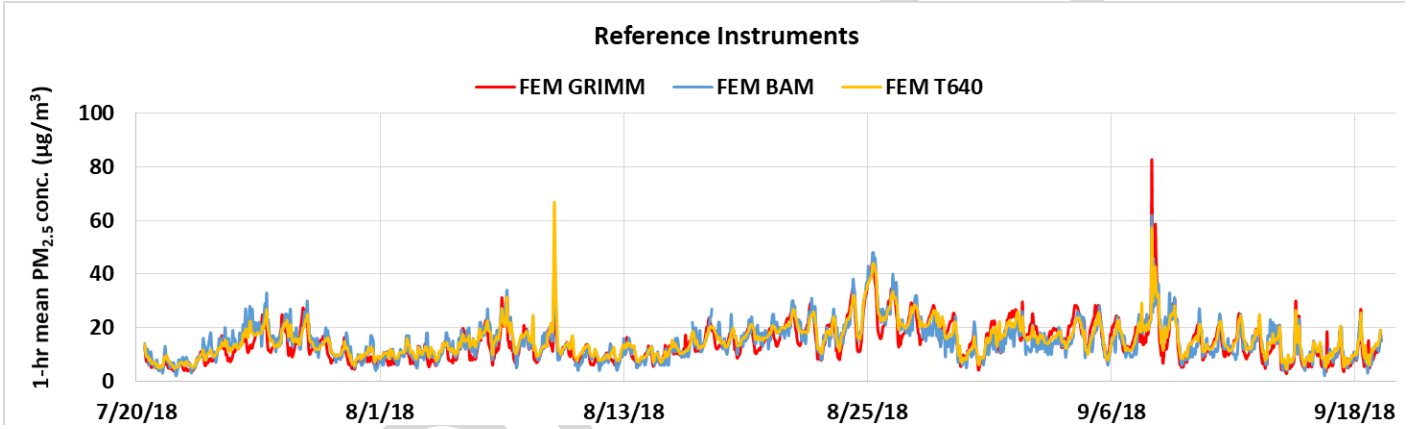


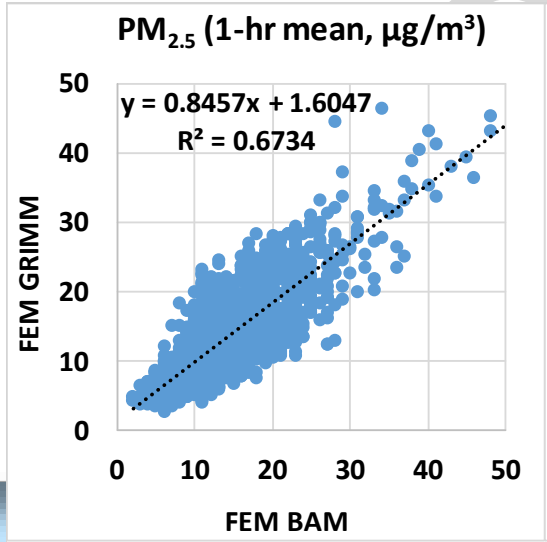


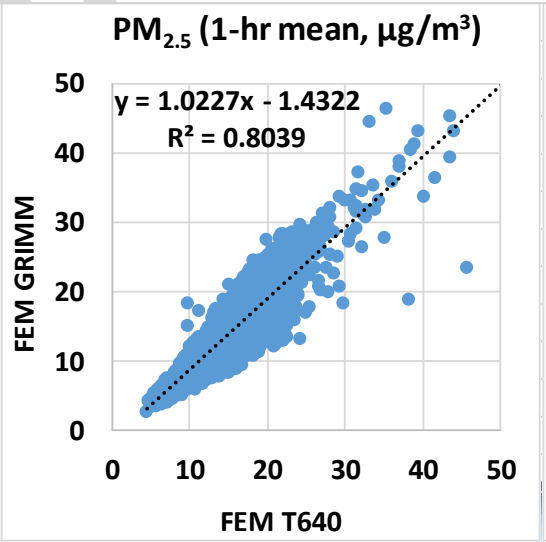


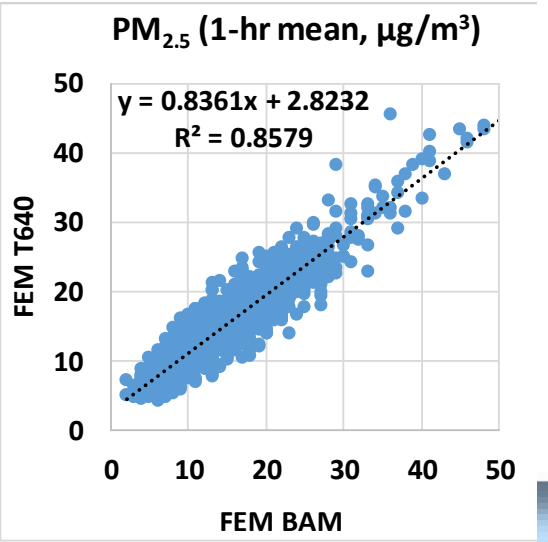
Reference Instruments: $PM_{2.5}$ GRIMM, BAM & T640

- 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 $PM_{2.5}$ from FEM GRIMM, FEM BAM and FEM T640 is 100 %, 94.2 % and 99.9 %, respectively
- Good correlations between the three reference instruments for $PM_{2.5}$ measurements ($0.67 < R^2 < 0.86$)



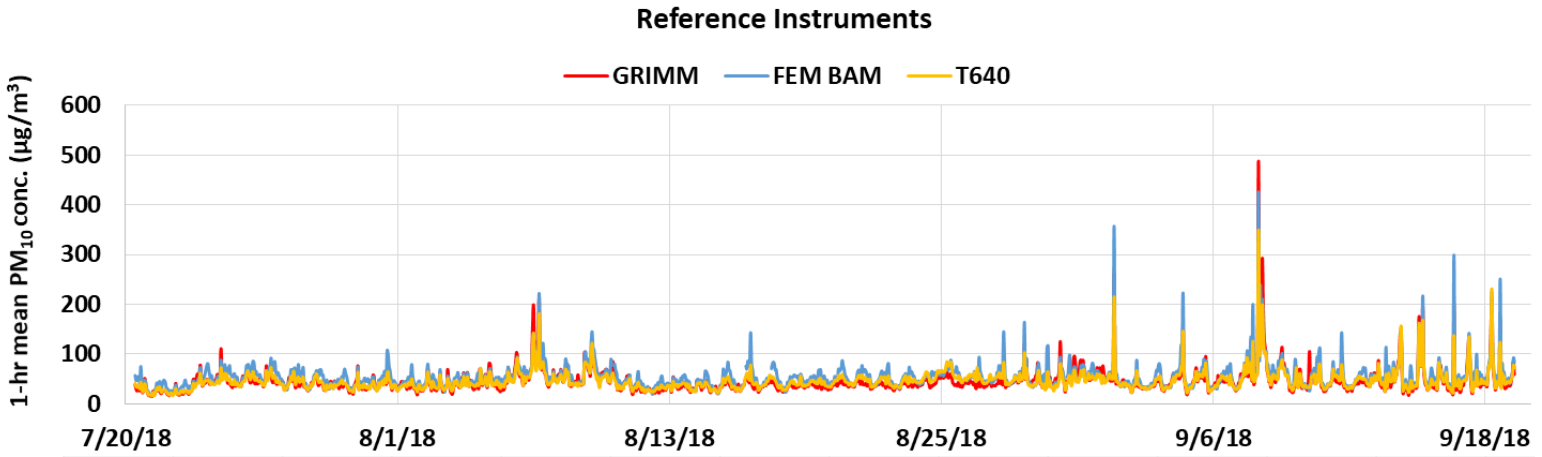


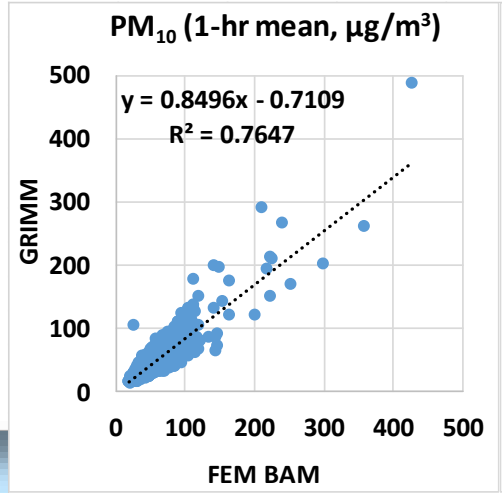


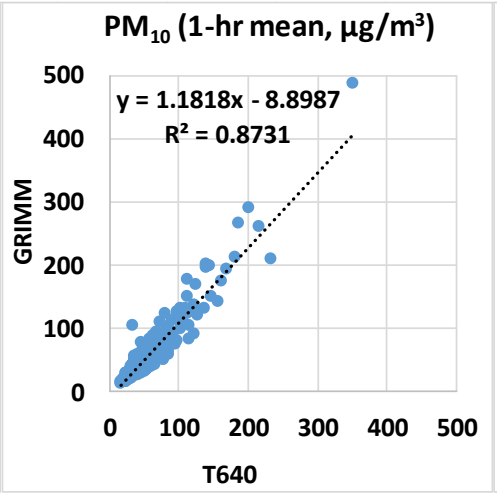


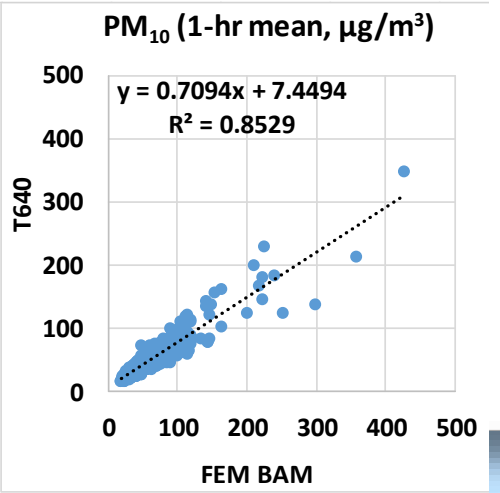
Reference Instruments: PM_{10} GRIMM, BAM & T640

- 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 PM_{10} from GRIMM, FEM BAM and T640 is 100 %, 99.1 % and 99.9 %, respectively
- Good correlations between the three reference instruments for PM_{10} measurements ($0.76 < R^2 < 0.88$)

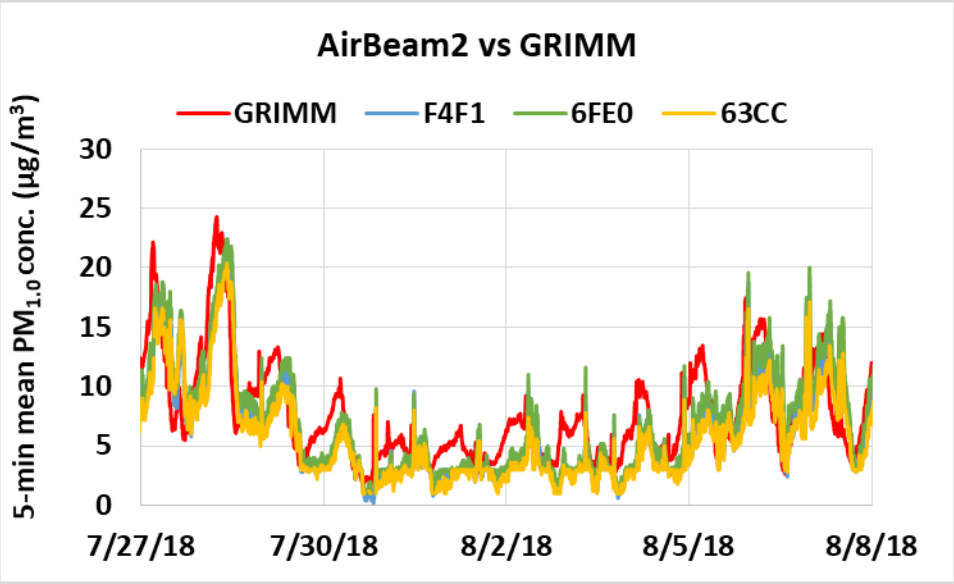




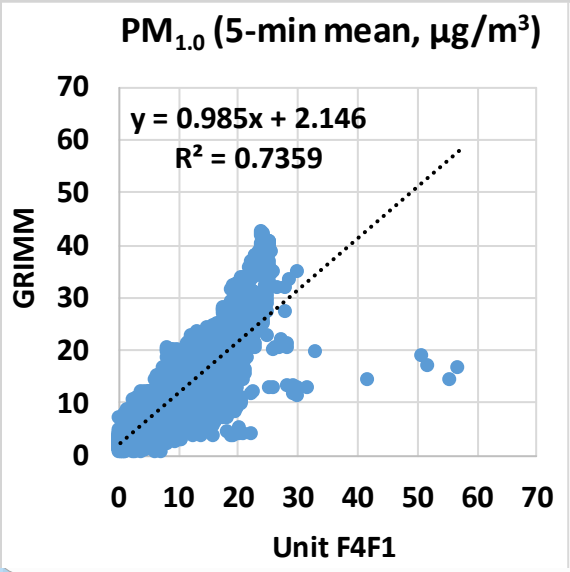


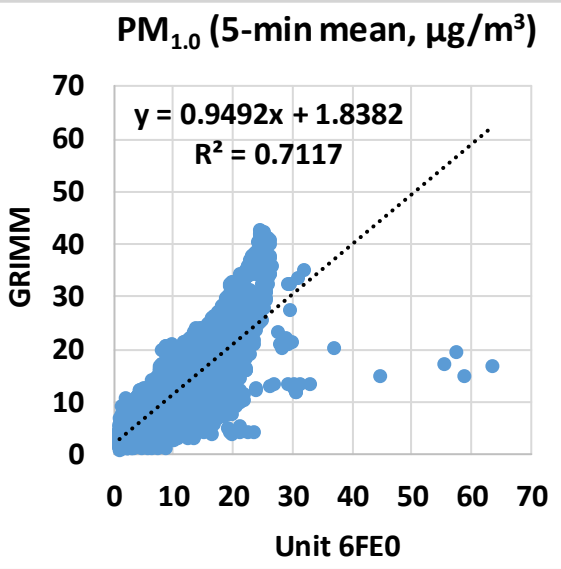


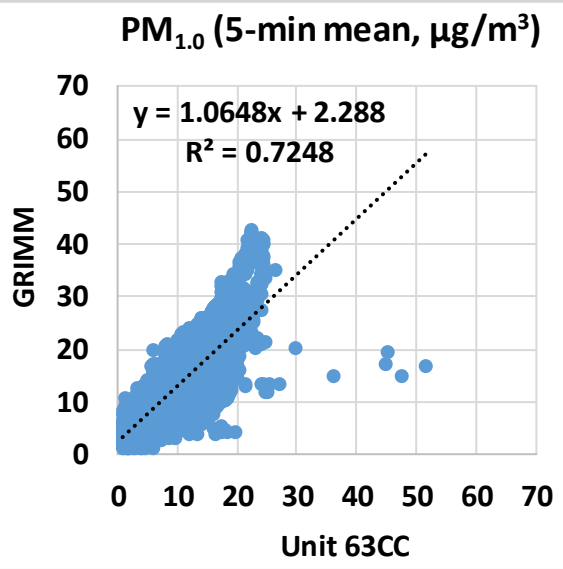
AirBeam2 vs GRIMM ($PM_{1.0}$; 5-min mean)



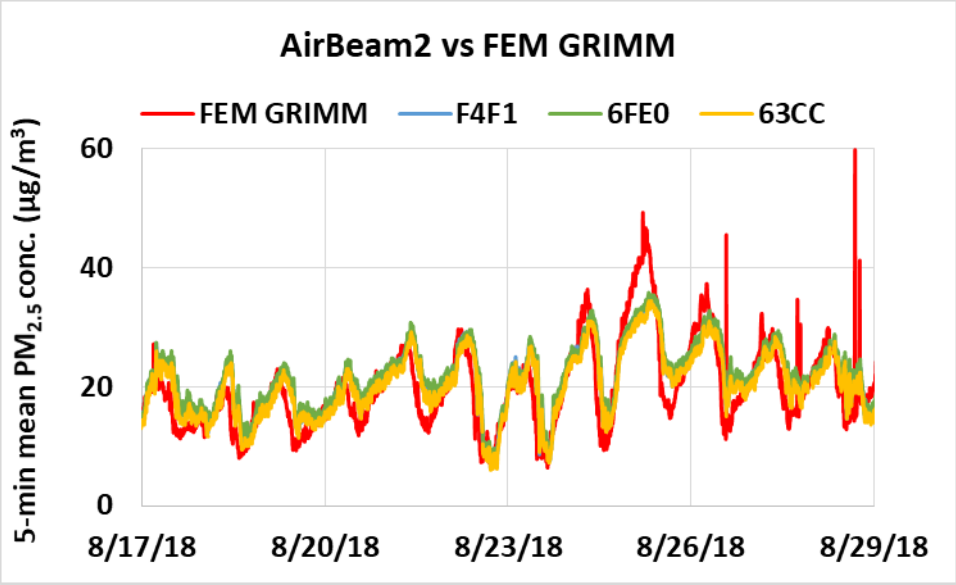
- The AirBeam2 sensors show good correlations with the corresponding GRIMM data (R^2 ~ 0.72)
- Overall, the AirBeam 2 sensors underestimate $PM_{1.0}$ mass concentrations as measured by GRIMMM
- The AirBeam2 sensors seem to track well the $PM_{1.0}$ diurnal variations as recorded by GRIMM



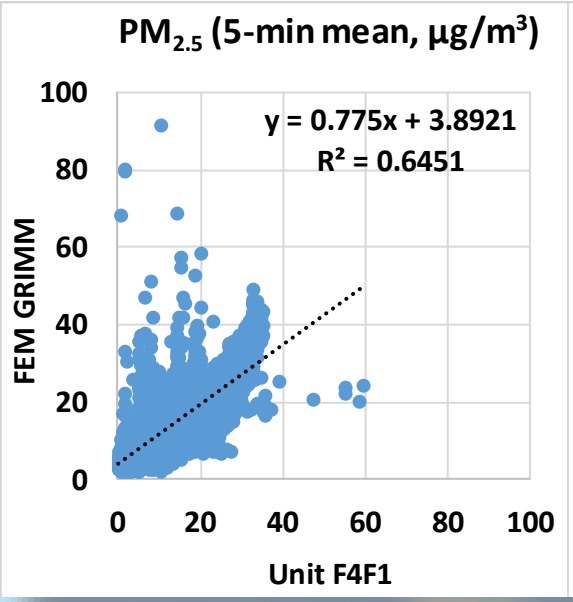


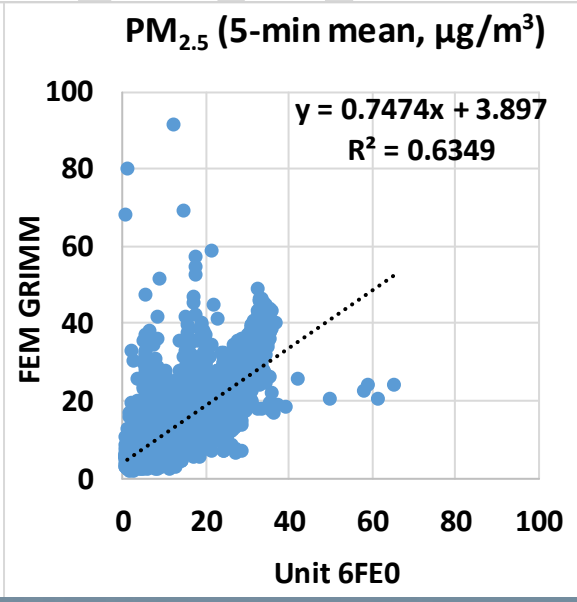


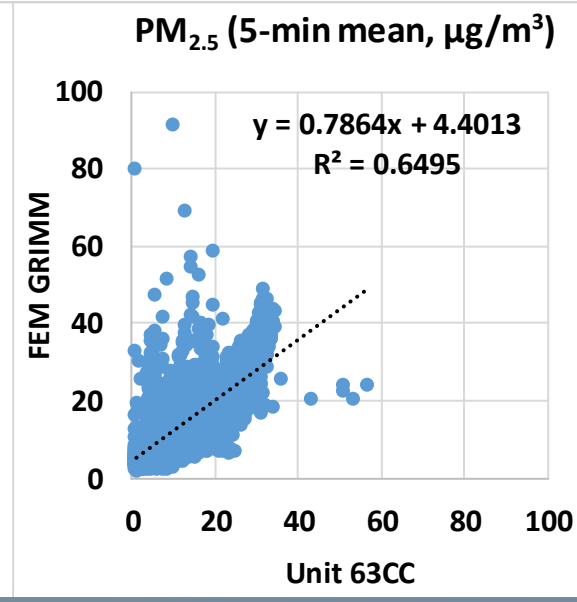
AirBeam2 vs FEM GRIMM ($PM_{2.5}$; 5-min mean)



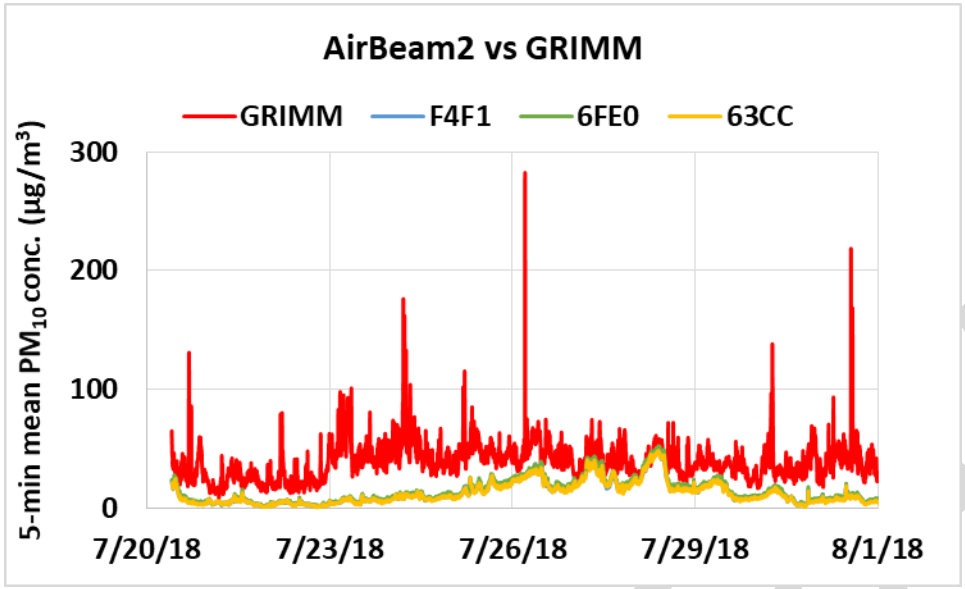
- The AirBeam2 sensors show moderate correlations with the corresponding FEM GRIMM data (R^2 ~ 0.64)
- Overall, the AirBeam2 sensors underestimate the $PM_{2.5}$ mass concentrations measured by FEM GRIMM
- The AirBeam2 sensors seem to track well the $PM_{2.5}$ diurnal variations as recorded by FEM GRIMM



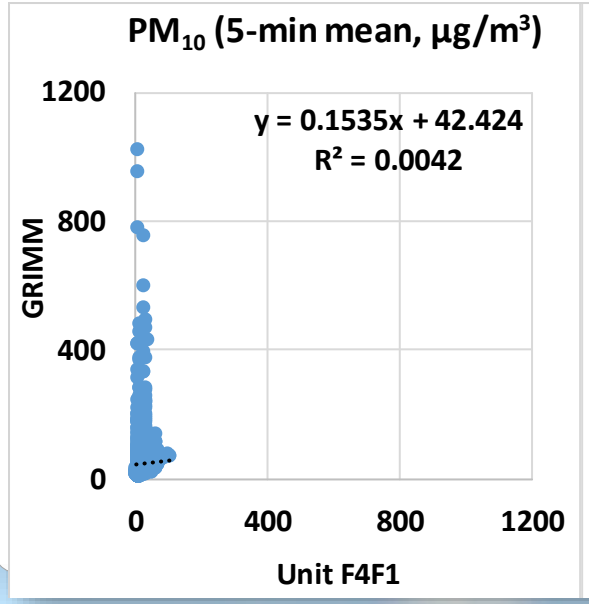


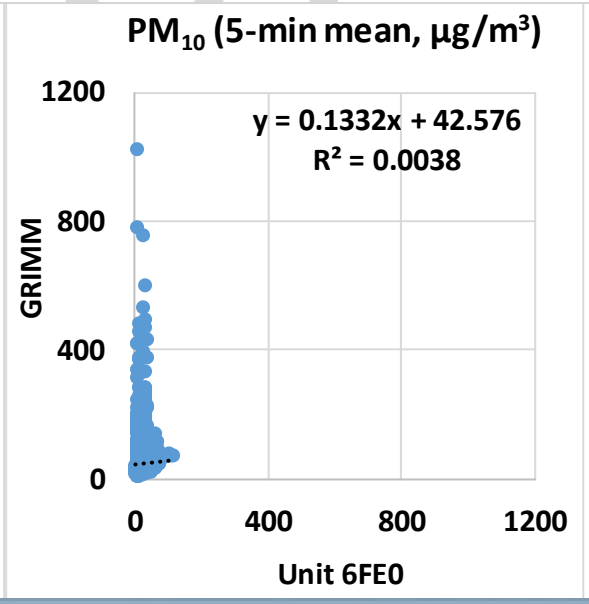


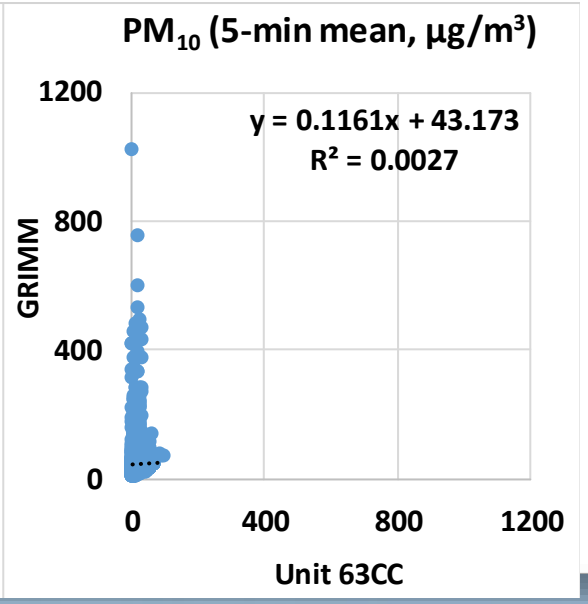
AirBeam2 vs GRIMM (PM_{10}; 5-min mean)



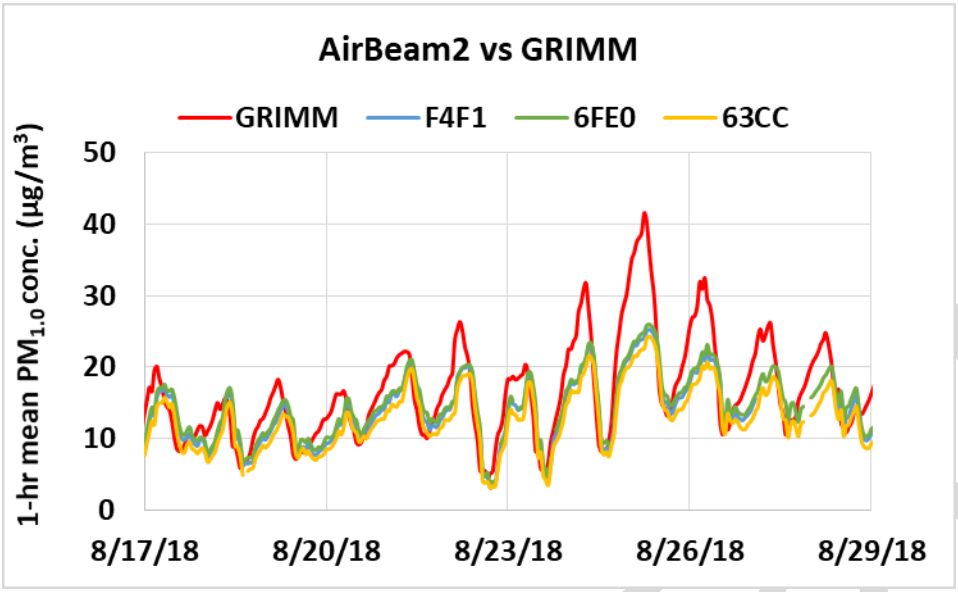
- The AirBeam2 sensors do not correlate with the corresponding GRIMM data (R^2 ~ 0)
- Overall, the AirBeam2 sensors largely underestimate the PM_{10} mass concentrations measured by GRIMM
- The AirBeam2 sensors seem to modestly track the PM_{10} diurnal variations as recorded by GRIMM



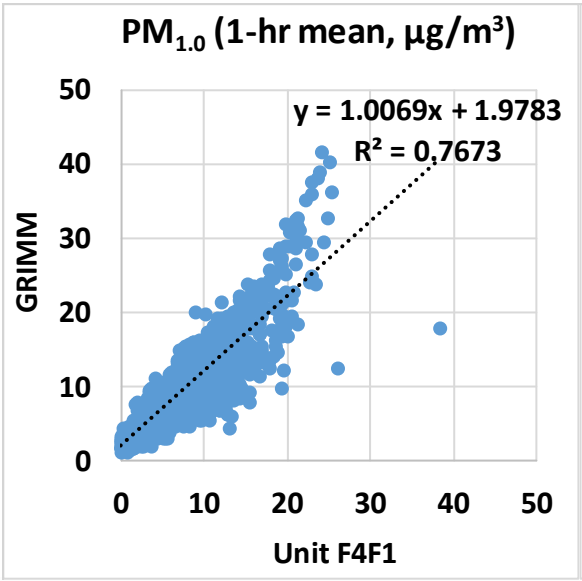


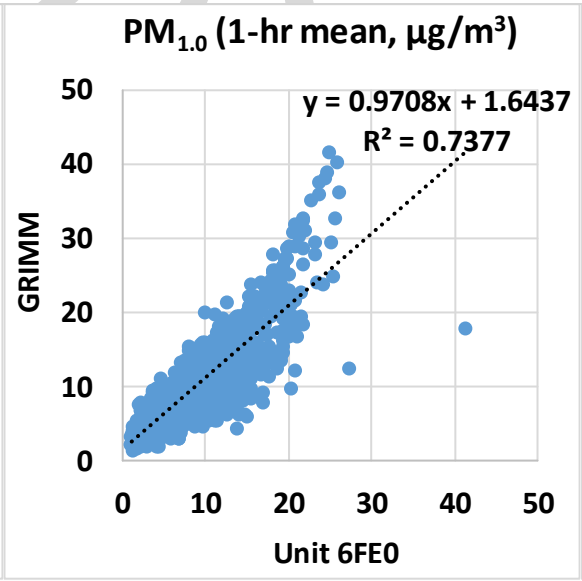


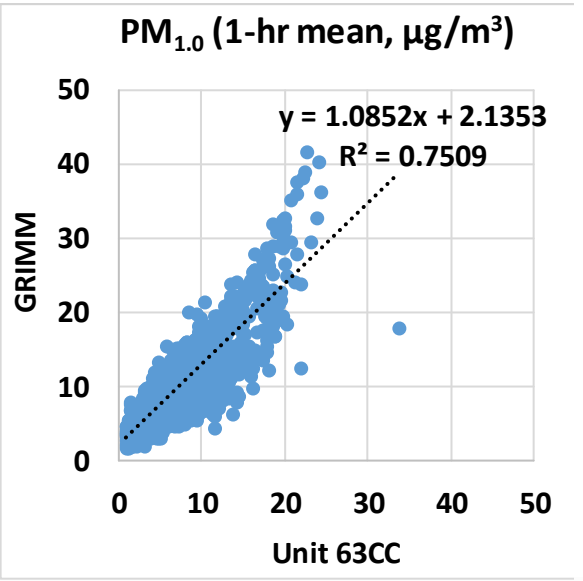
AirBeam2 vs GRIMM ($PM_{1.0}$; 1-hr mean)



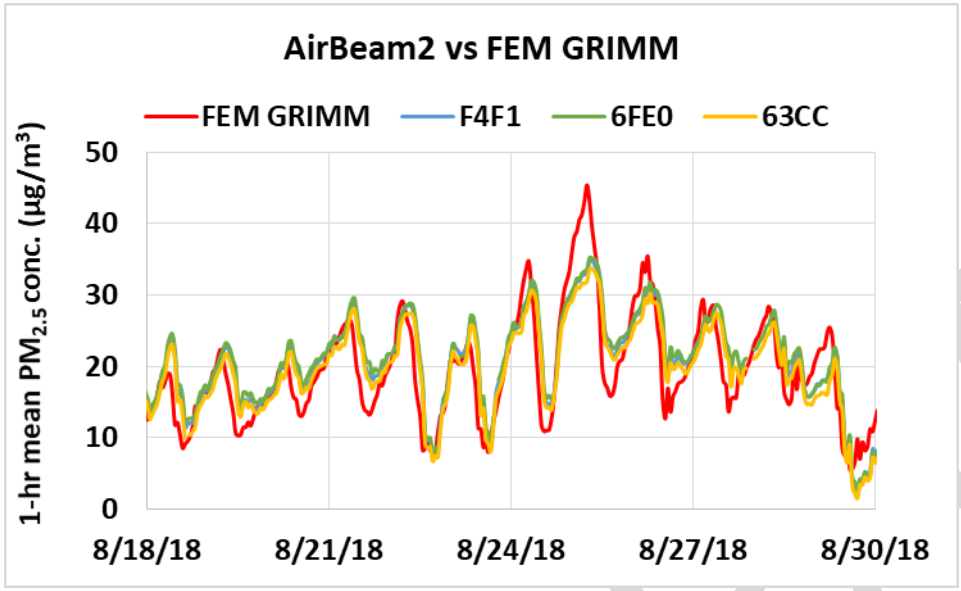
- AirBeam2 sensors show good correlations with the corresponding GRIMM data (R^2 ~ 0.75)
- Overall, the AirBeam2 sensors underestimate $PM_{1.0}$ mass concentration as measured by GRIMM
- The AirBeam2 sensors seem to track well the $PM_{1.0}$ diurnal variations as recorded by GRIMM



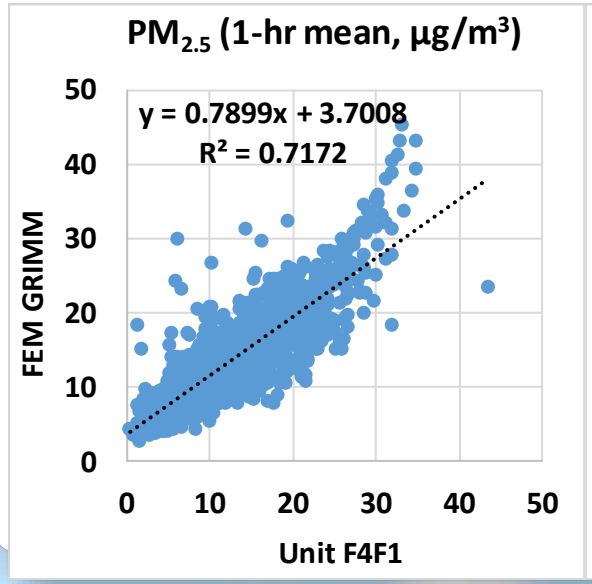


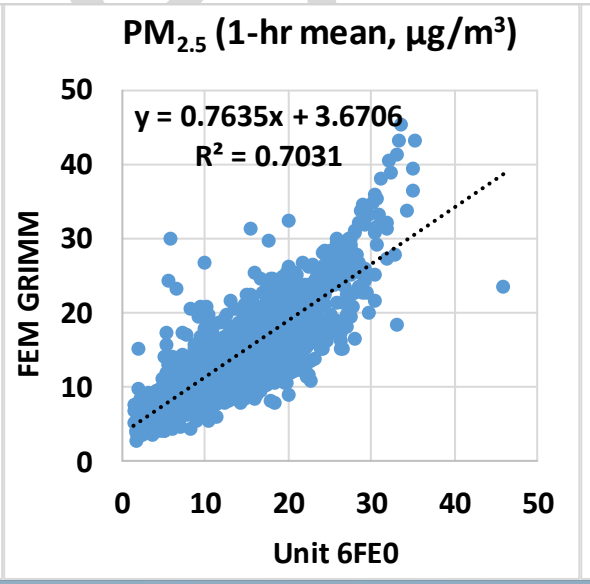


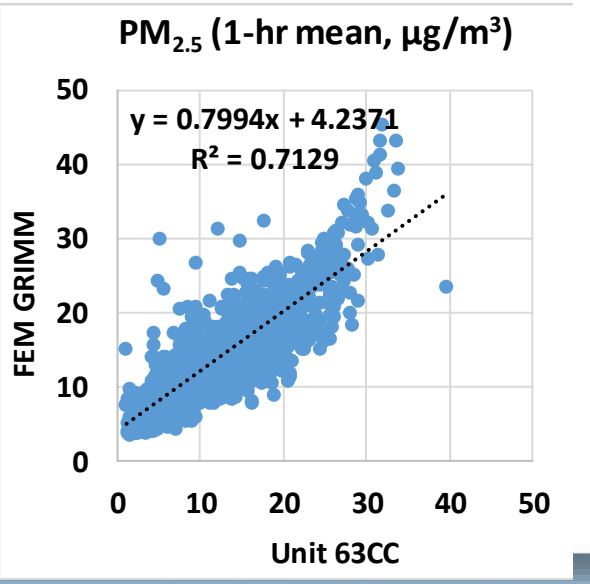
AirBeam2 vs FEM GRIMM ($PM_{2.5}$; 1-hr mean)



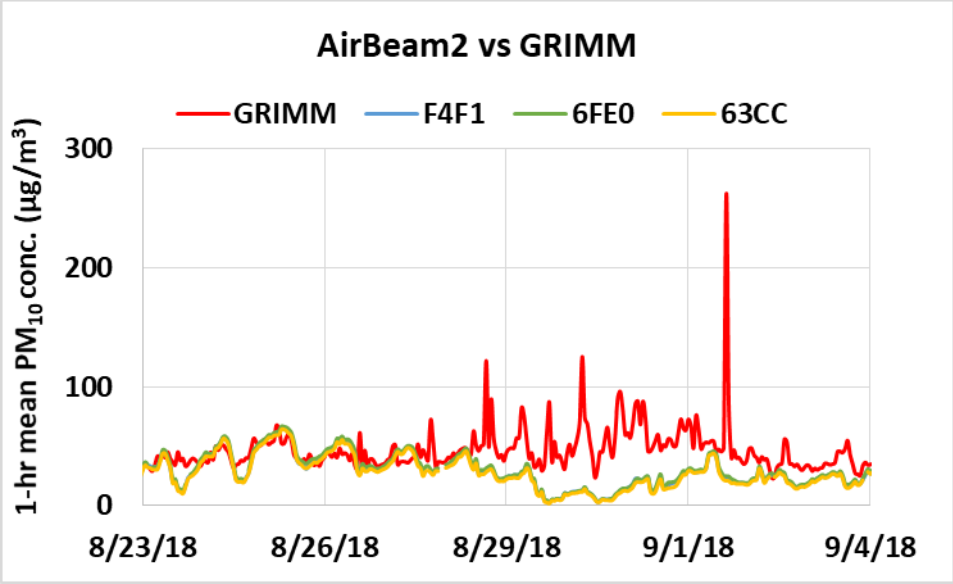
- AirBeam2 sensors show good correlations with the corresponding FEM GRIMM data (R^2 ~ 0.71)
- Overall, the AirBeam2 sensors underestimate the $PM_{2.5}$ mass concentrations measured by FEM GRIMM
- The AirBeam2 seem to track well the $PM_{2.5}$ diurnal variations as recorded by FEM GRIMM



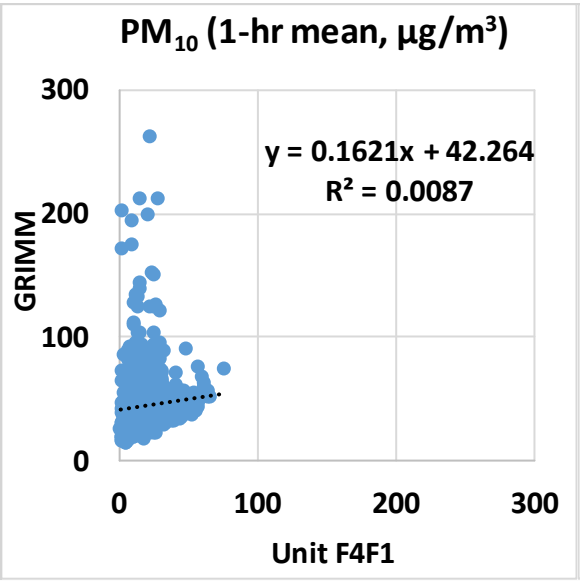


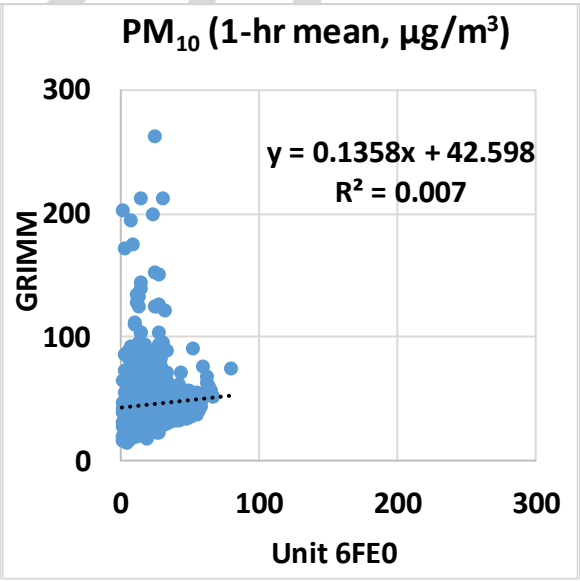


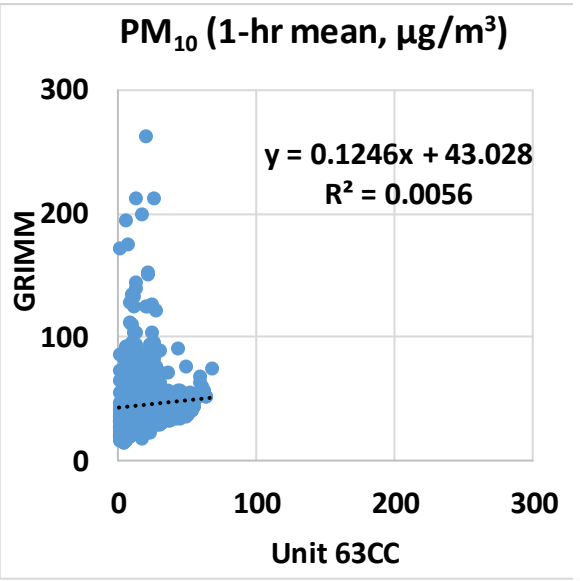
AirBeam2 vs GRIMM (PM_{10}; 1-hr mean)



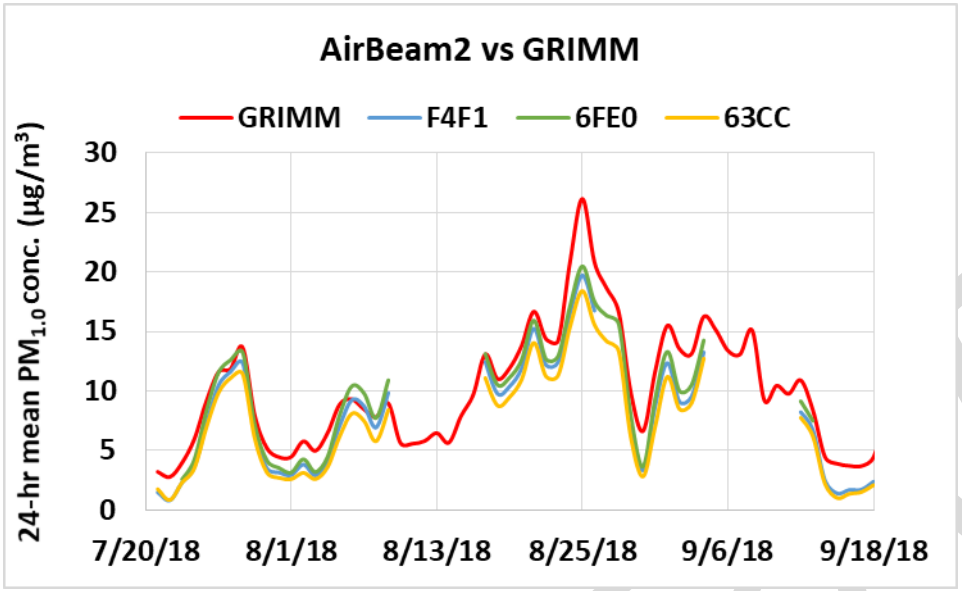
- AirBeam2 sensors do not correlate with the corresponding GRIMM data ($R^2 \sim 0$)
- Overall, the AirBeam2 sensors underestimate the PM_{10} mass concentrations measured by GRIMM
- The AirBeam2 sensors seem to modestly track the PM_{10} diurnal variations as recorded by GRIMM



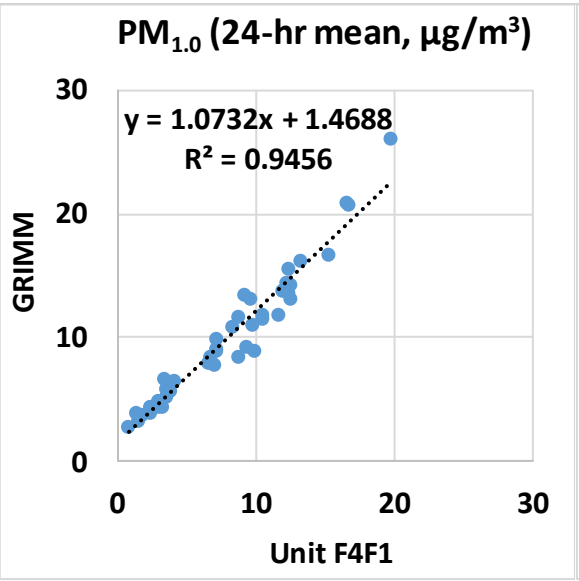


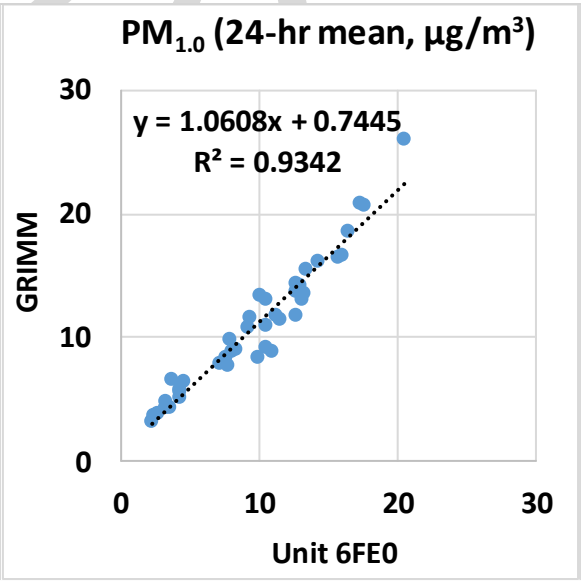


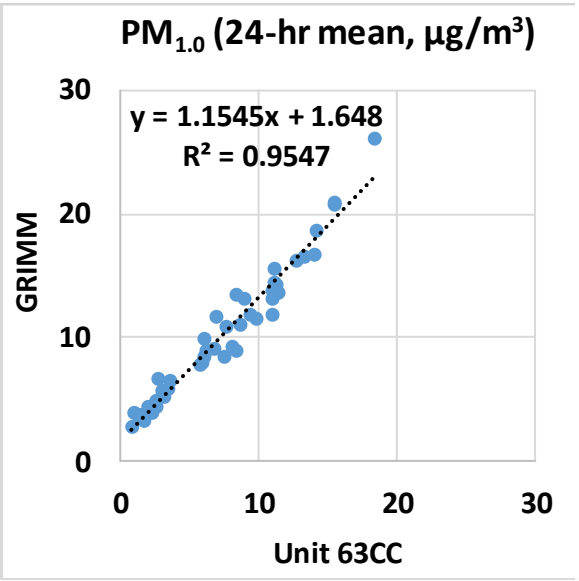
AirBeam2 vs GRIMM ($PM_{1.0}$; 24-hr mean)



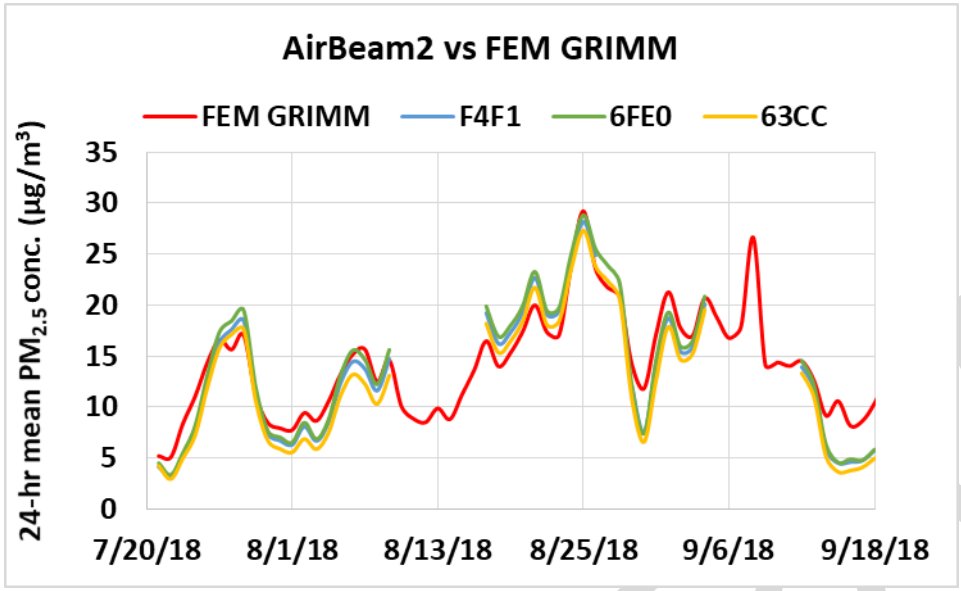
- AirBeam2 sensors correlate well with the corresponding GRIMM data (R^2 ~ 0.94)
- Overall, the AirBeam2 sensors underestimate $PM_{1.0}$ mass concentration as measured by GRIMM
- The AirBeam2 seem to track well the $PM_{1.0}$ concentration variations as recorded by GRIMM



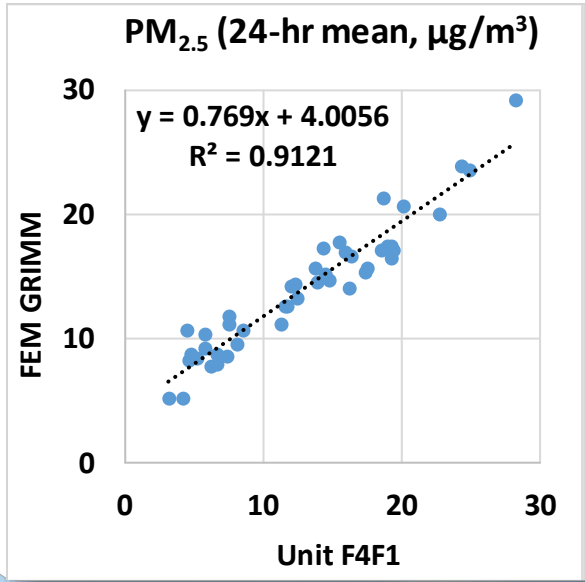


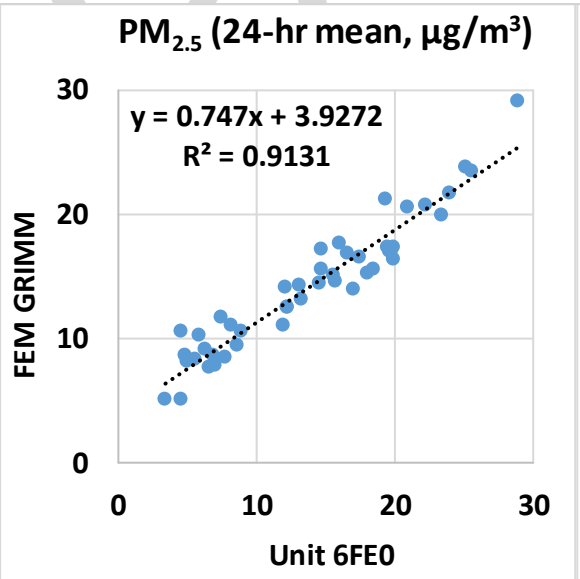


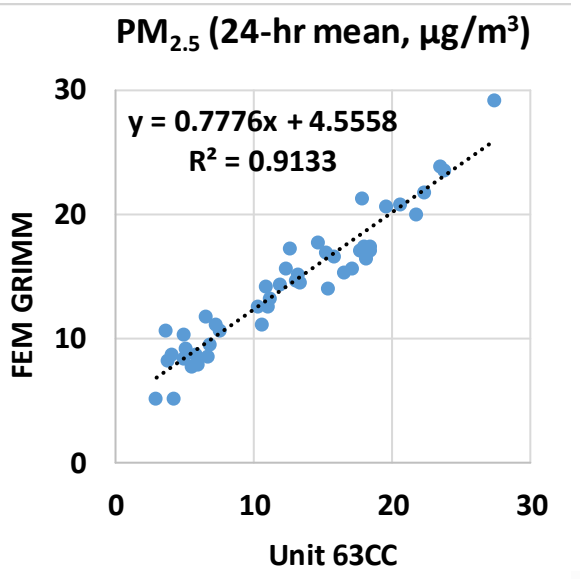
AirBeam2 vs FEM GRIMM ($PM_{2.5}$; 24-hr mean)



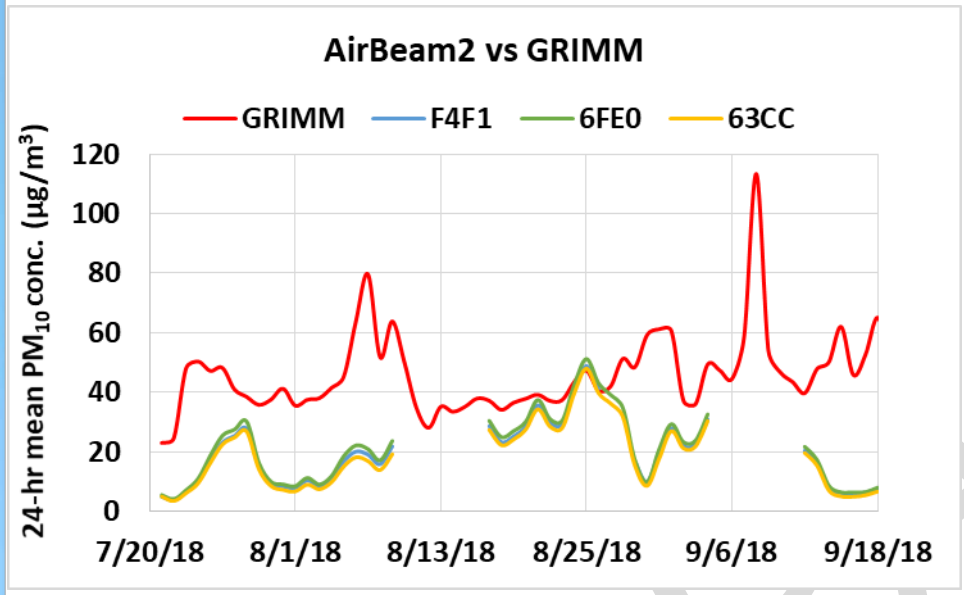
- AirBeam2 sensors correlate well with the corresponding FEM GRIMM data (R^2 ~ 0.91)
- Overall, the AirBeam2 sensors seem to be quite accurate
- The AirBeam2 seem to track well the $PM_{2.5}$ concentration variations as recorded by FEM GRIMM



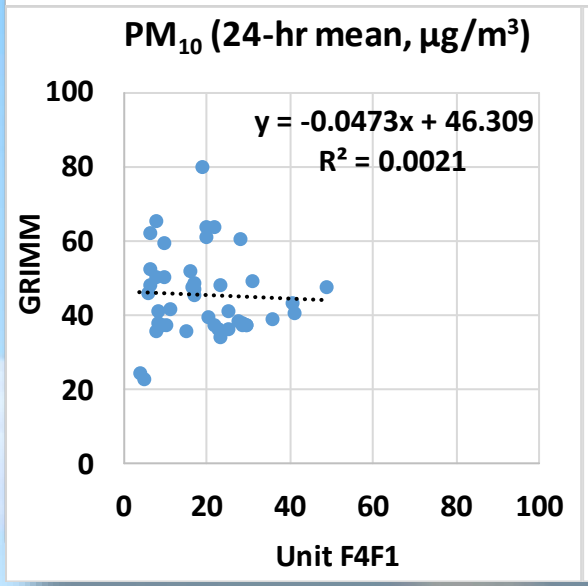


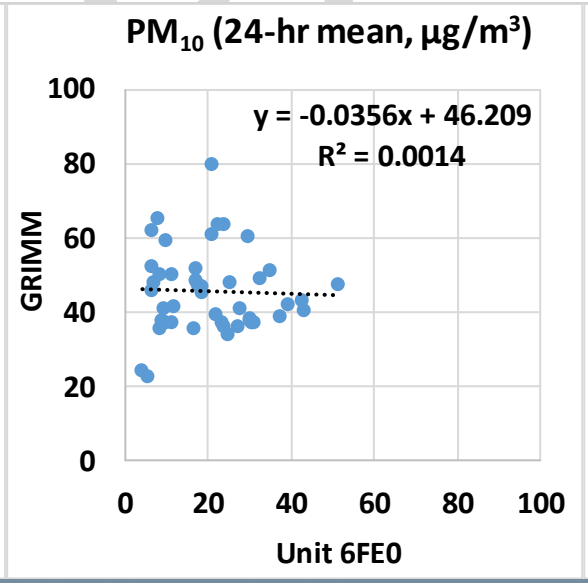


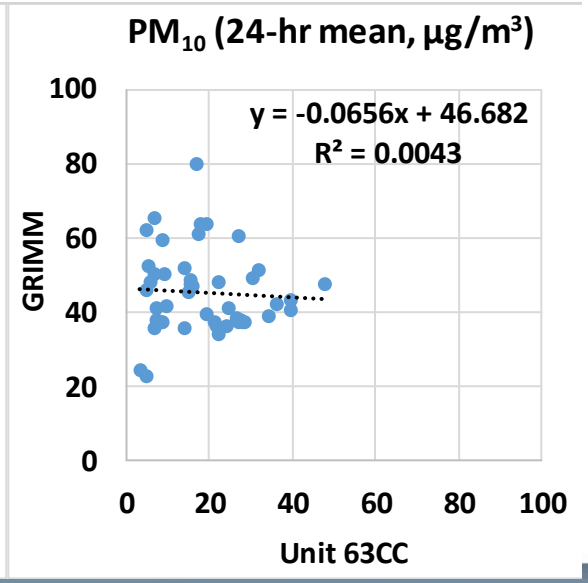
AirBeam2 vs GRIMM (PM_{10}; 24-hr mean)



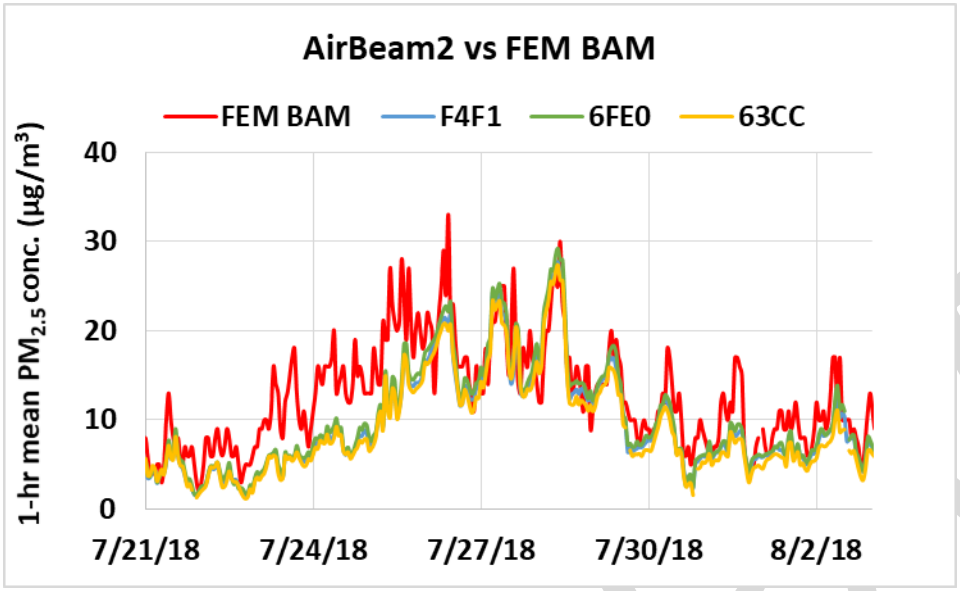
- AirBeam2 sensors do not correlate with the corresponding GRIMM data ($R^2 \sim 0$)
- Overall, the AirBeam2 sensors underestimate the PM_{10} mass concentrations measured by GRIMM
- The AirBeam2 sensors seem to modestly track the PM_{10} concentration variations as recorded by GRIMM



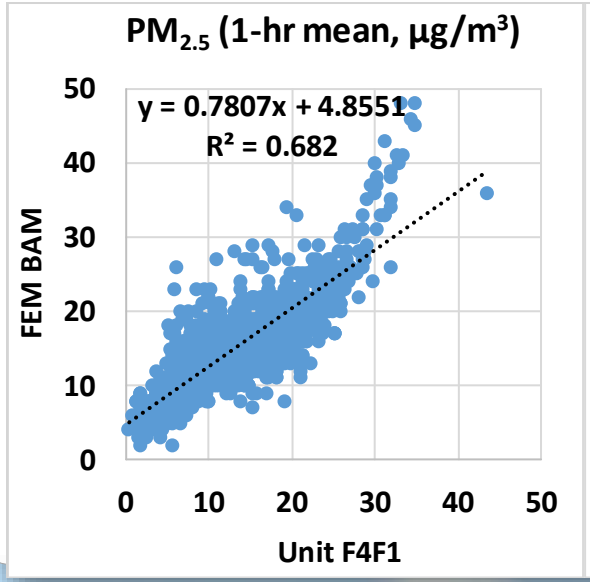


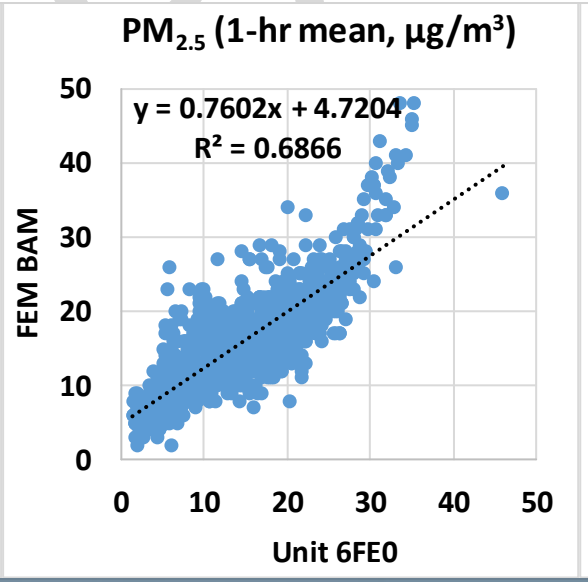


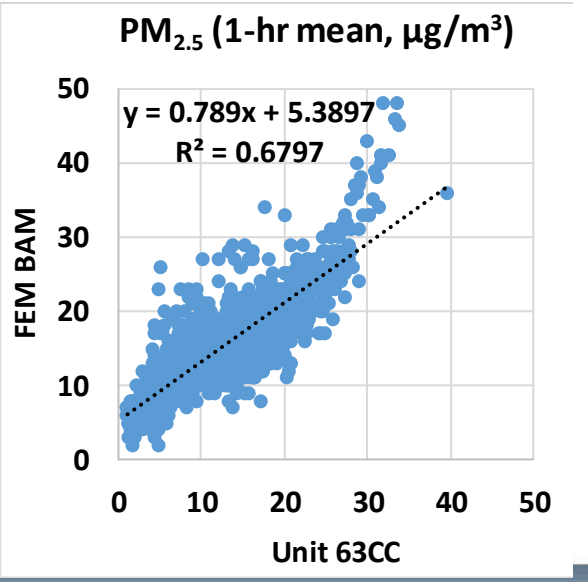
AirBeam2 vs FEM BAM ($PM_{2.5}$; 1-hr mean)



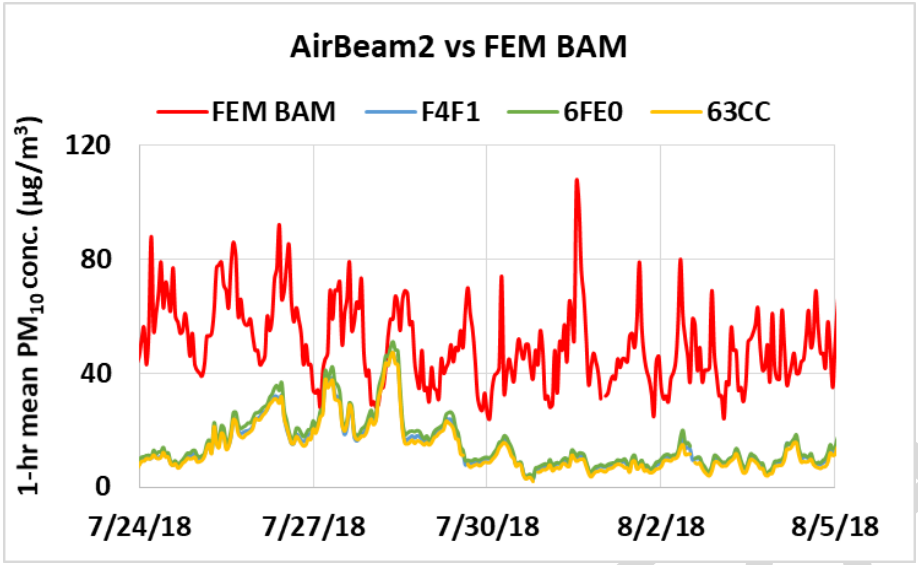
- AirBeam2 sensors show moderate correlations with the corresponding FEM BAM data (R^2 ~ 0.68)
- Overall, the AirBeam2 sensors underestimate the $PM_{2.5}$ mass concentrations measured by FEM BAM
- The AirBeam2 seem to track the $PM_{2.5}$ diurnal variations as recorded by FEM BAM



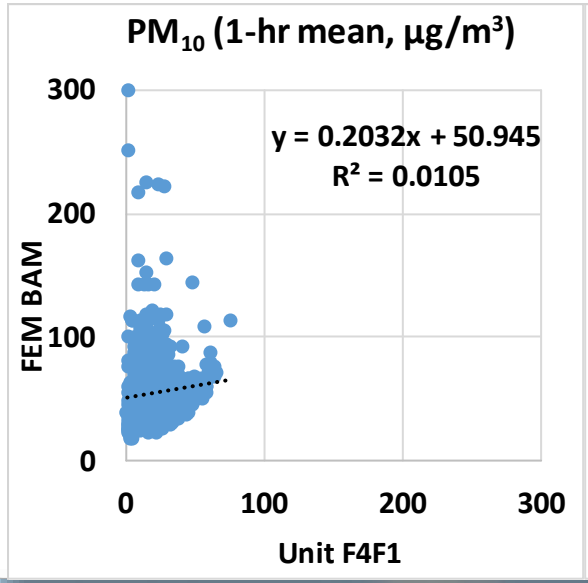


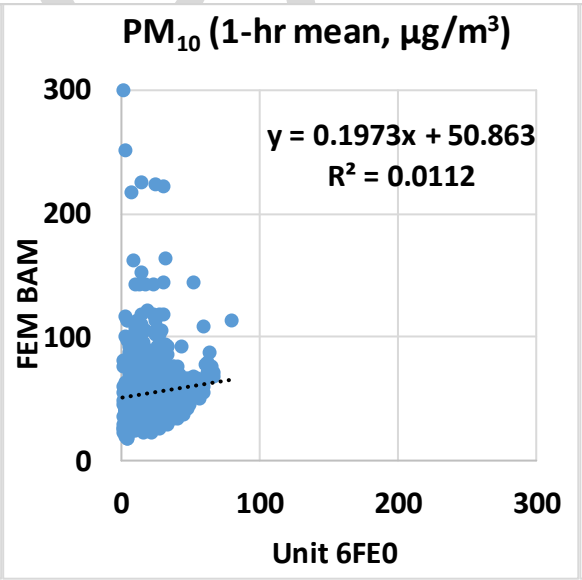


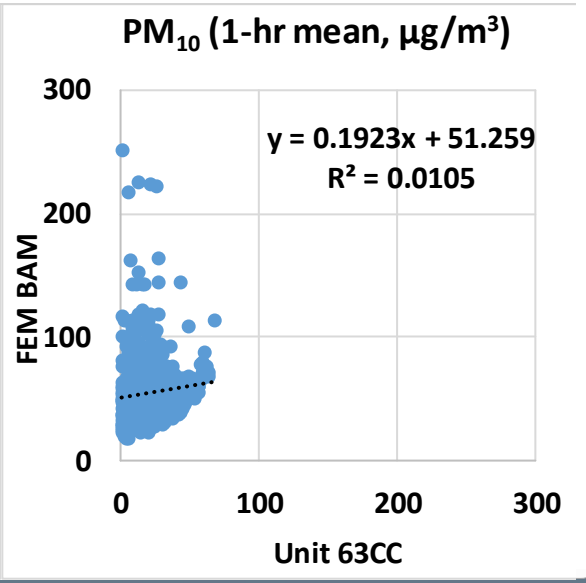
AirBeam2 vs FEM BAM (PM_{10}; 1-hr mean)



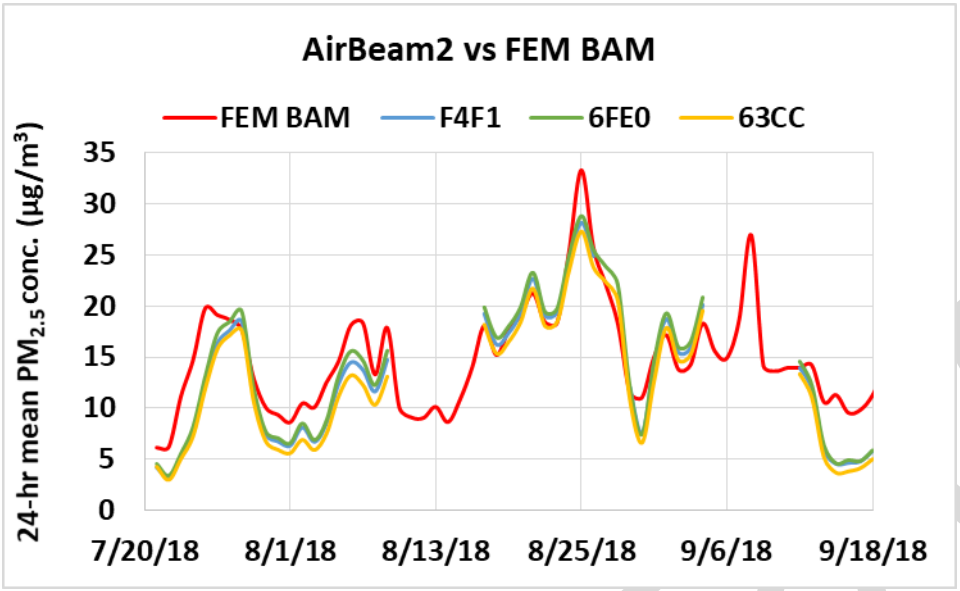
- AirBeam2 sensors do not correlate with the corresponding FEM BAM data (R^2 ~ 0.01)
- Overall, the AirBeam2 sensors underestimate the PM_{10} mass concentrations measured by FEM BAM
- The AirBeam2 sensors do not track the PM_{10} diurnal variations as recorded by FEM BAM



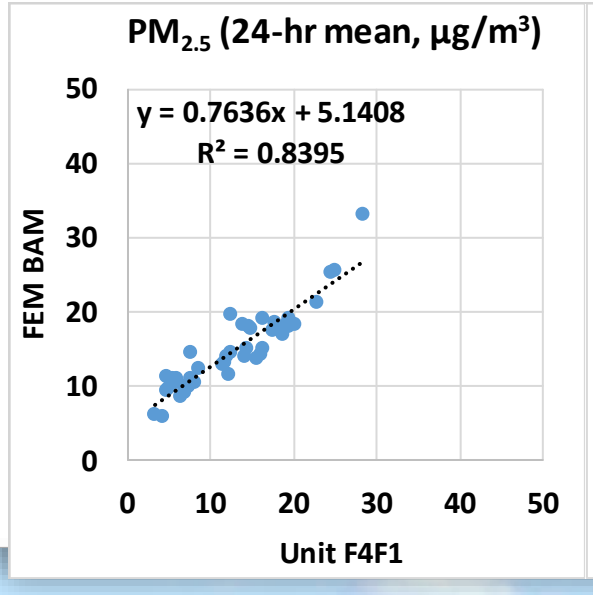


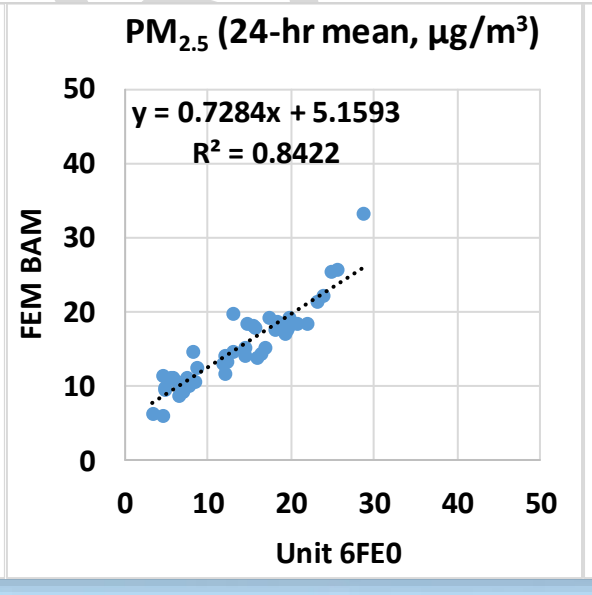


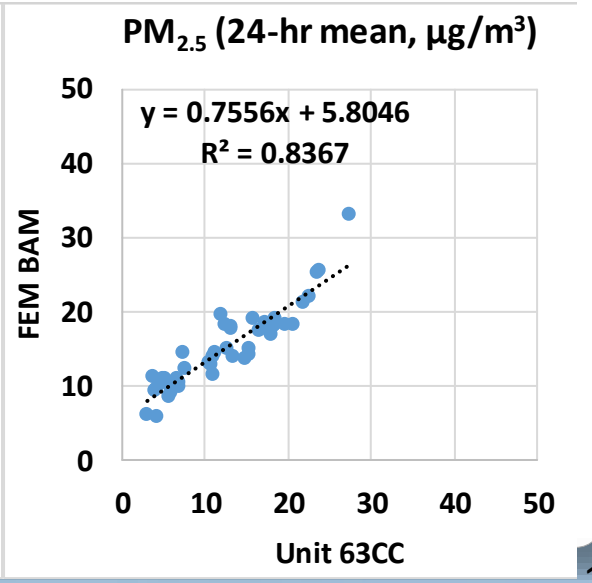
AirBeam2 vs FEM BAM ($PM_{2.5}$; 24-hr mean)



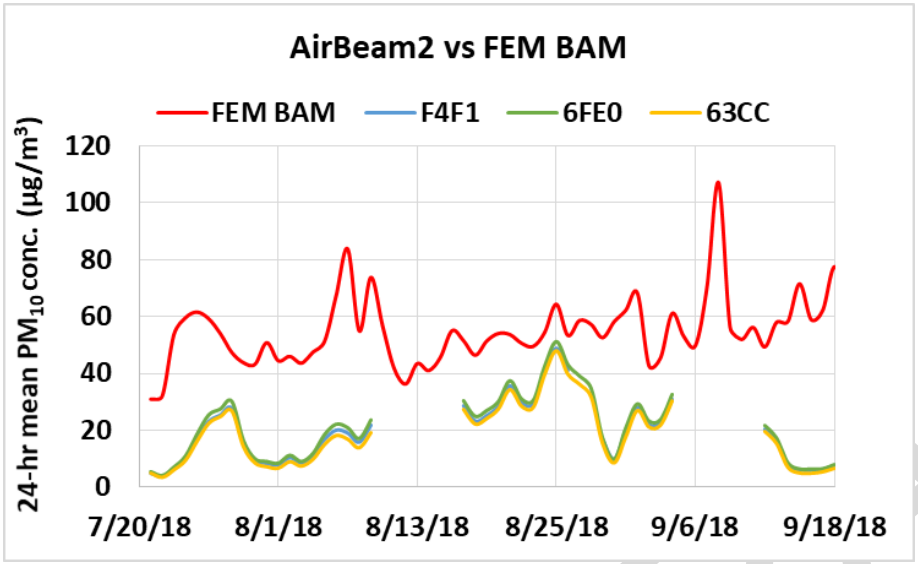
- AirBeam2 sensors show good correlations with the corresponding FEM BAM data (R^2 ~ 0.84)
- Overall, the AirBeam2 sensors underestimate the $PM_{2.5}$ mass concentrations measured by FEM BAM
- The AirBeam2 seem to track well the $PM_{2.5}$ concentration variations as recorded by FEM BAM



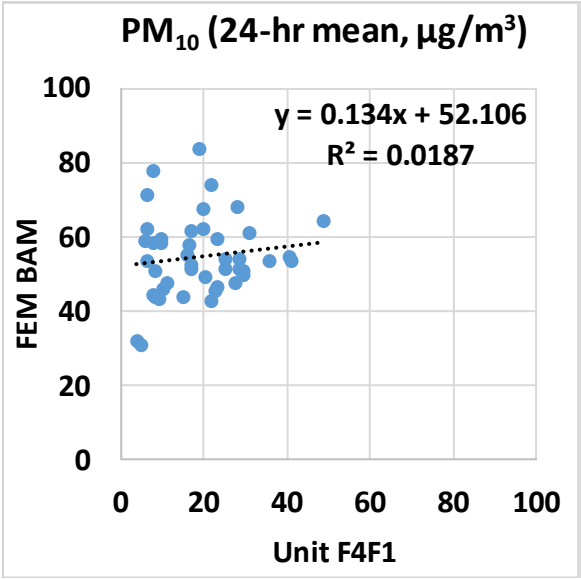


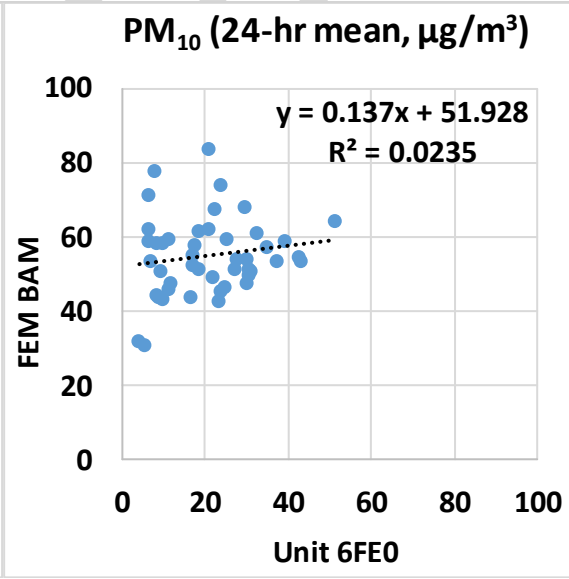


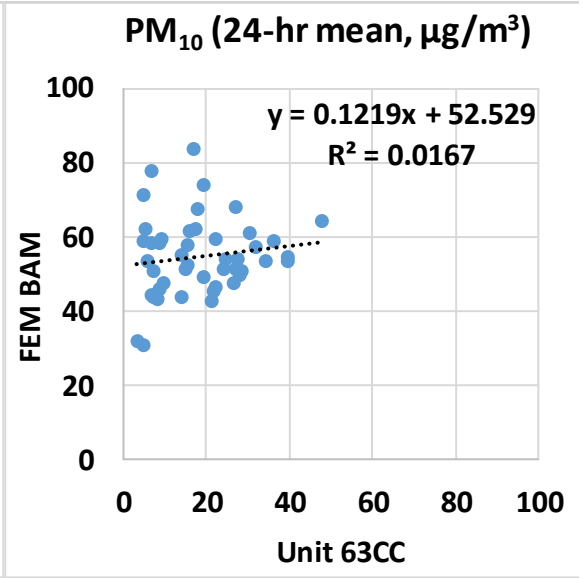
AirBeam2 vs FEM BAM (PM_{10}; 24-hr mean)



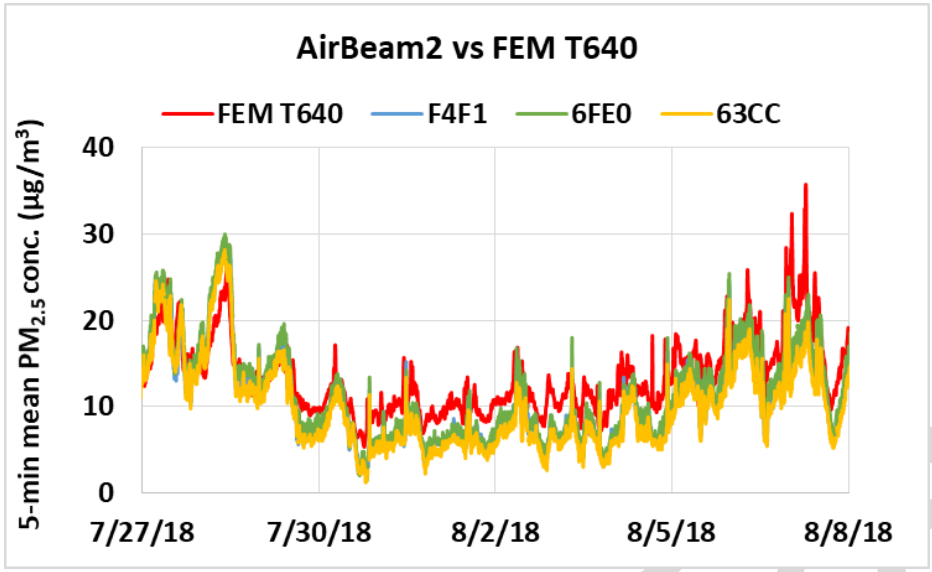
- AirBeam2 sensors do not correlate with the corresponding FEM BAM data (R^2 ~ 0.02)
- Overall, the AirBeam2 sensors underestimate the PM_{10} mass concentrations measured by FEM BAM
- The AirBeam2 sensors seem to track the PM_{10} concentration variations as recorded by FEM BAM



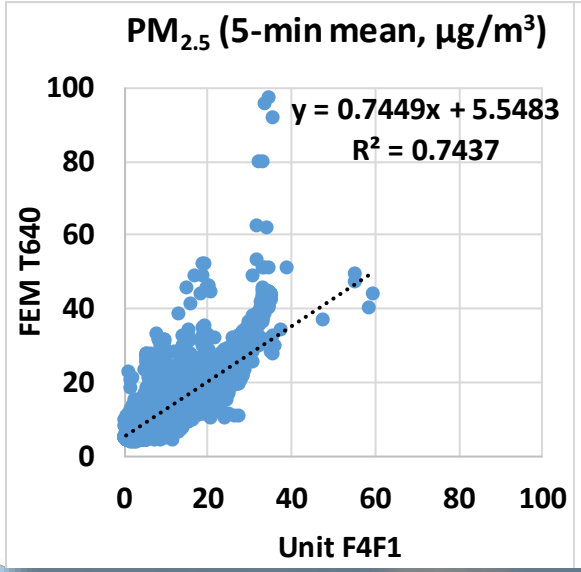


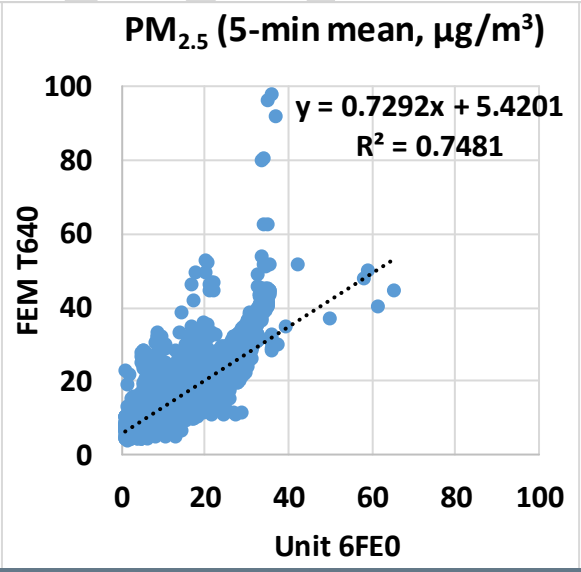


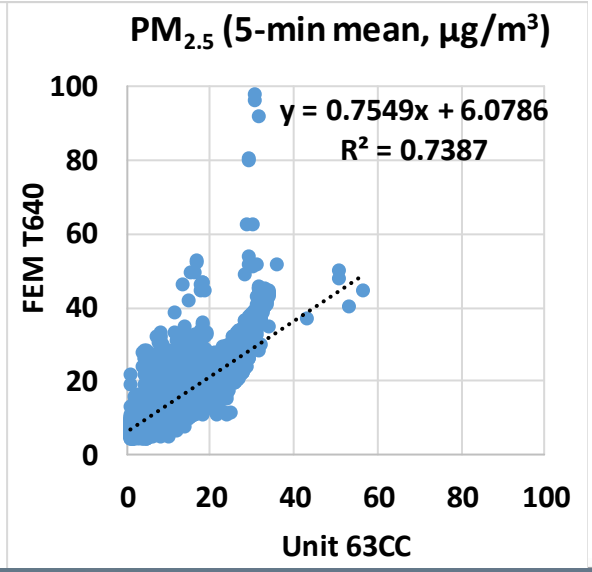
AirBeam2 vs FEM T640 ($PM_{2.5}$; 5-min mean)



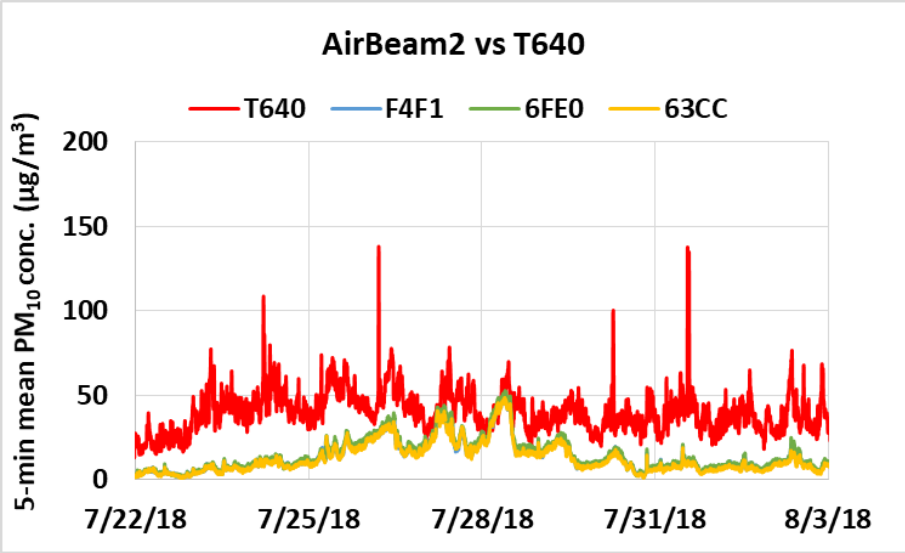
- AirBeam2 sensors show good correlations with the corresponding FEM T640 data (R^2 ~ 0.74)
- Overall, the AirBeam2 sensors underestimate the $PM_{2.5}$ mass concentrations measured by FEM T640
- The AirBeam2 sensors seem to track well the $PM_{2.5}$ diurnal variations as recorded by FEM T640



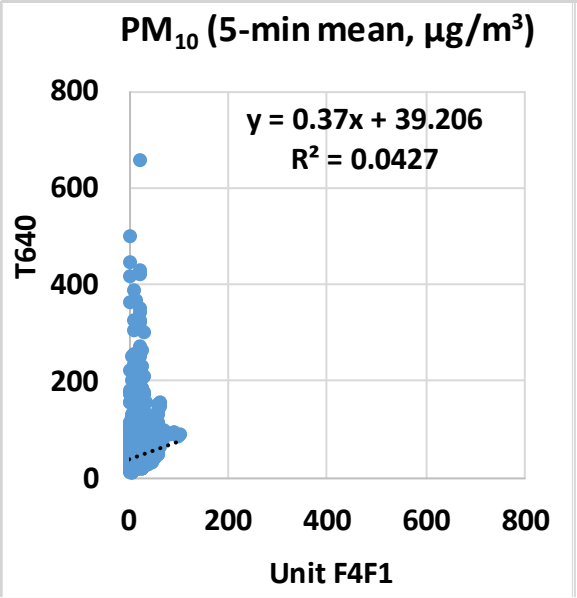


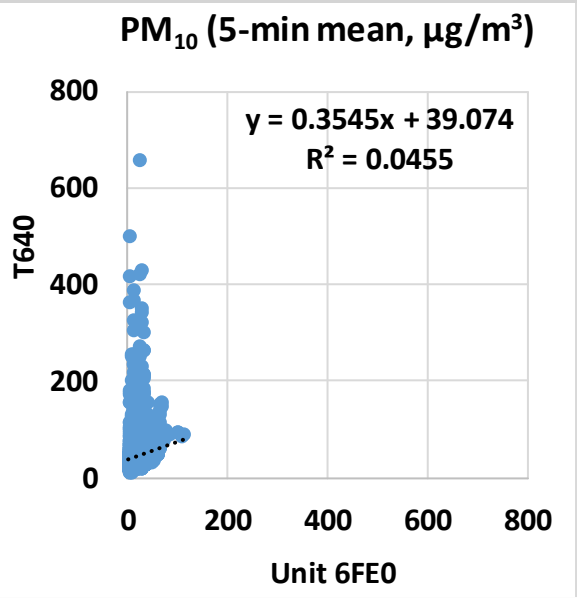


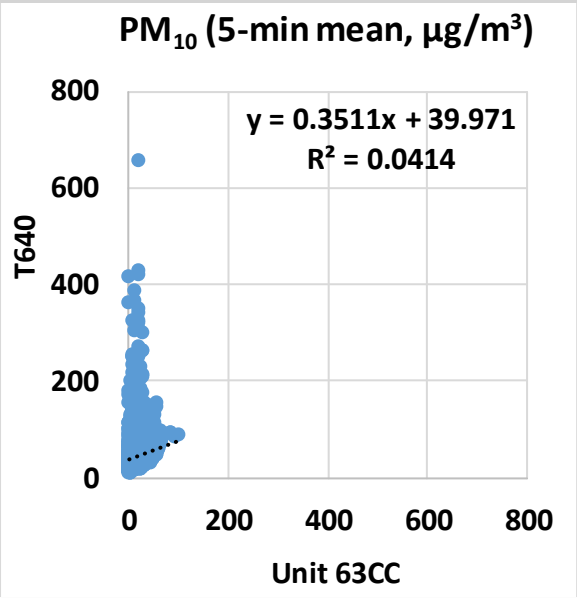
AirBeam2 vs T640 (PM_{10}; 5-min mean)



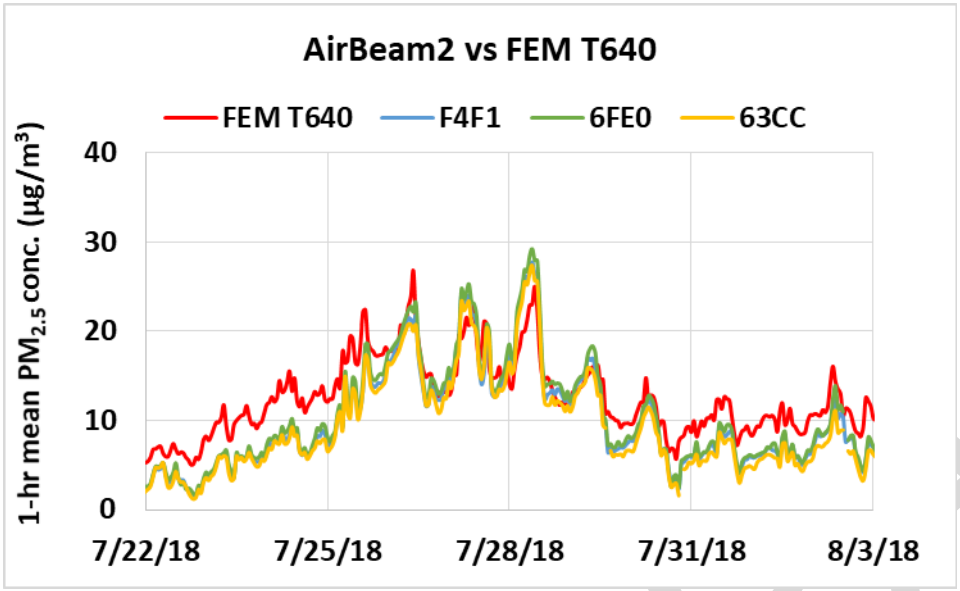
- AirBeam2 sensors do not correlate with the corresponding T640 data (R^2 ~ 0.04)
- Overall, the AirBeam2 sensors underestimate the PM_{10} mass concentrations measured by T640
- The AirBeam2 sensors seem to modestly track the PM_{10} diurnal variations as recorded by T640



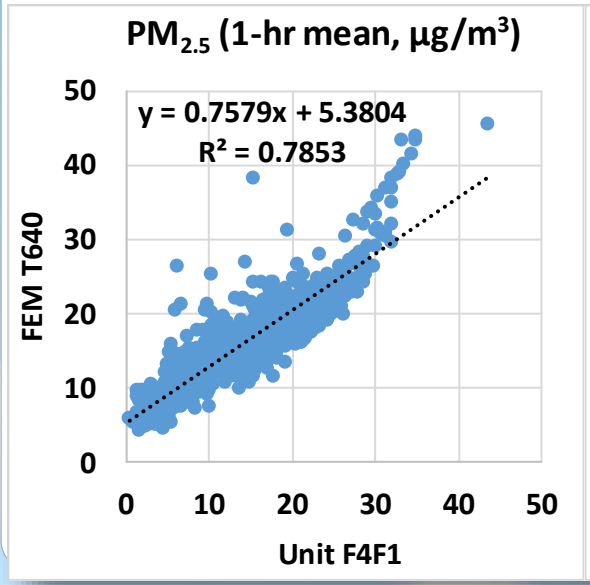


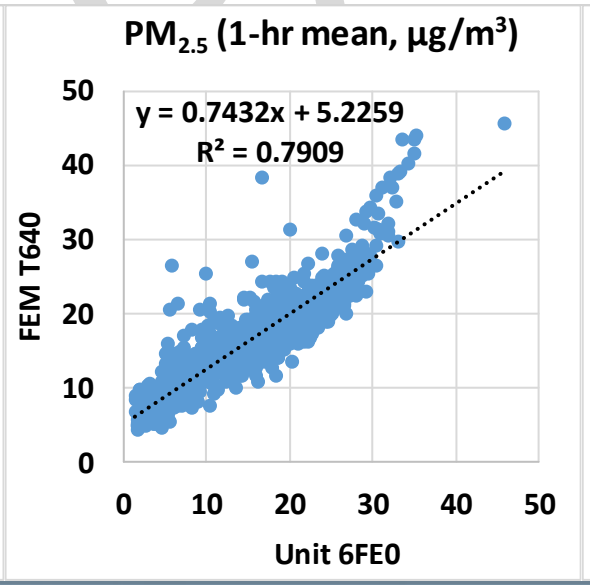


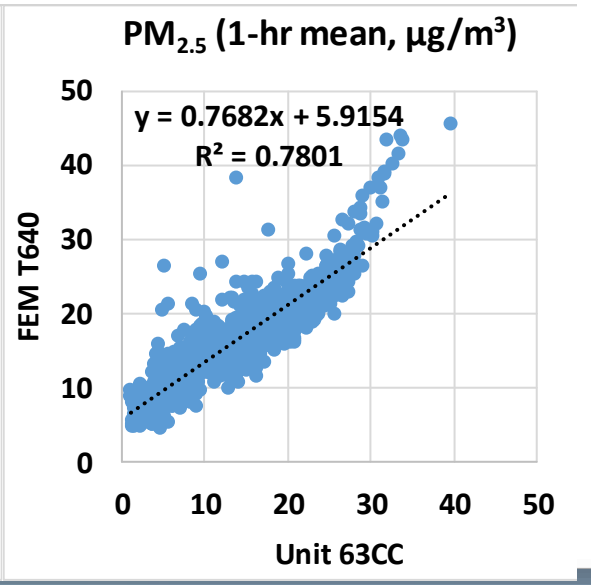
AirBeam2 vs FEM T640 ($PM_{2.5}$; 1-hr mean)



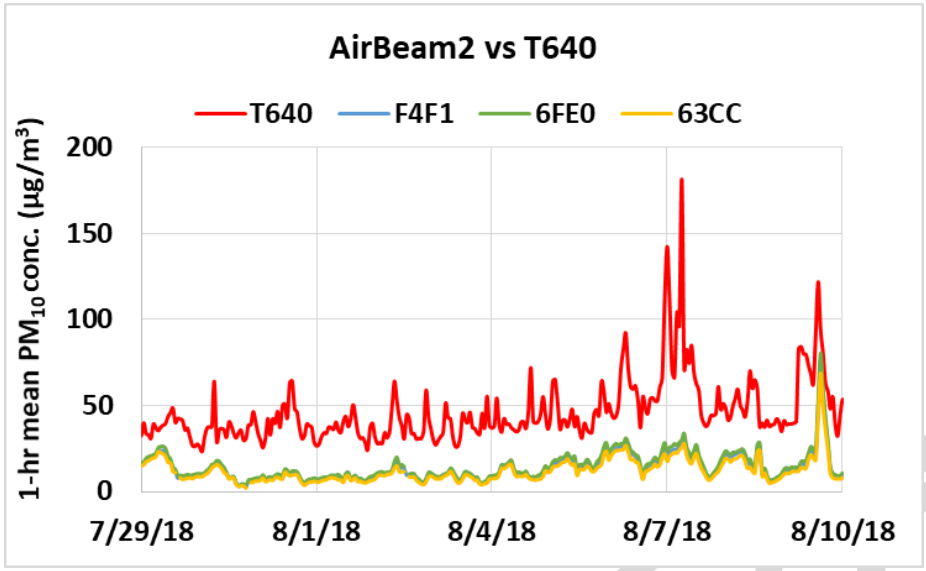
- AirBeam2 sensors show good correlations with the corresponding FEM T640 data (R^2 ~ 0.78)
- Overall, the AirBeam2 sensors underestimate the $PM_{2.5}$ mass concentrations measured by FEM T640
- The AirBeam2 sensors seem to track well the $PM_{2.5}$ diurnal variations as recorded by FEM T640



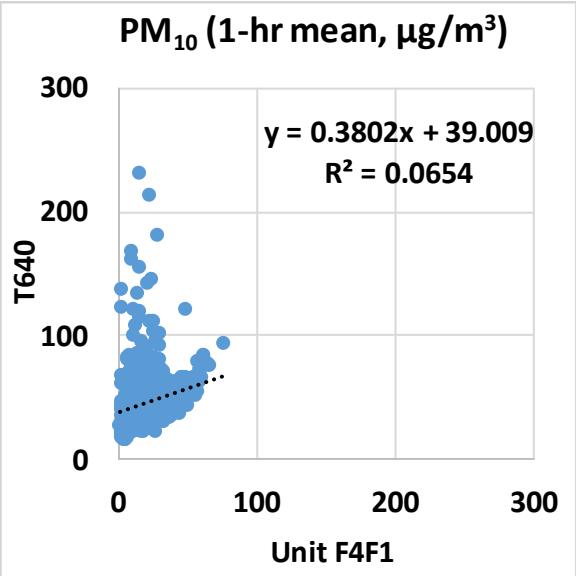


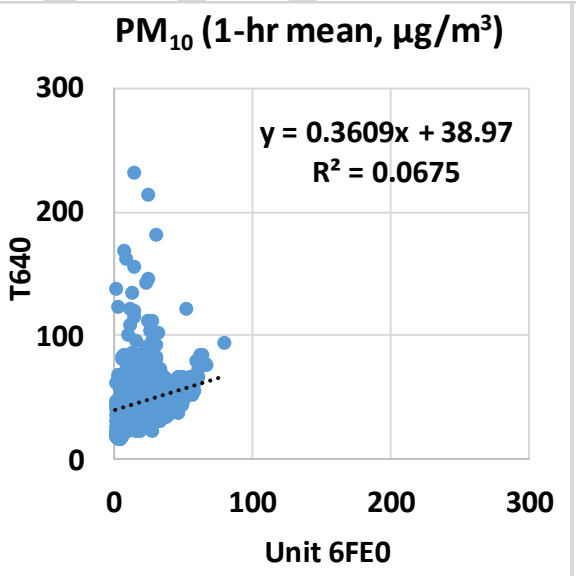


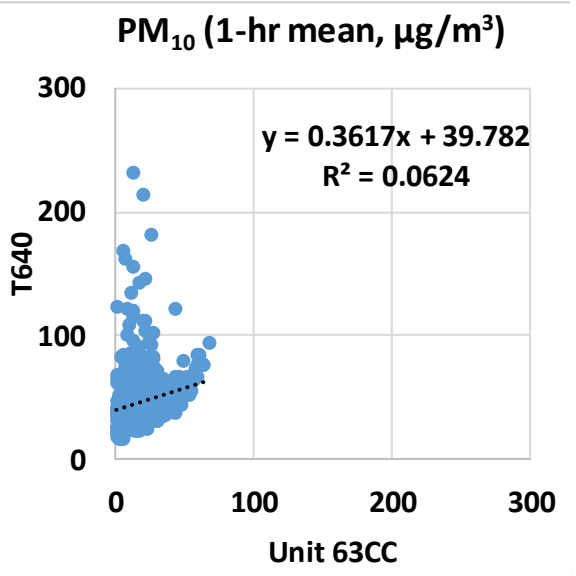
AirBeam2 vs T640 (PM_{10}; 1-hr mean)



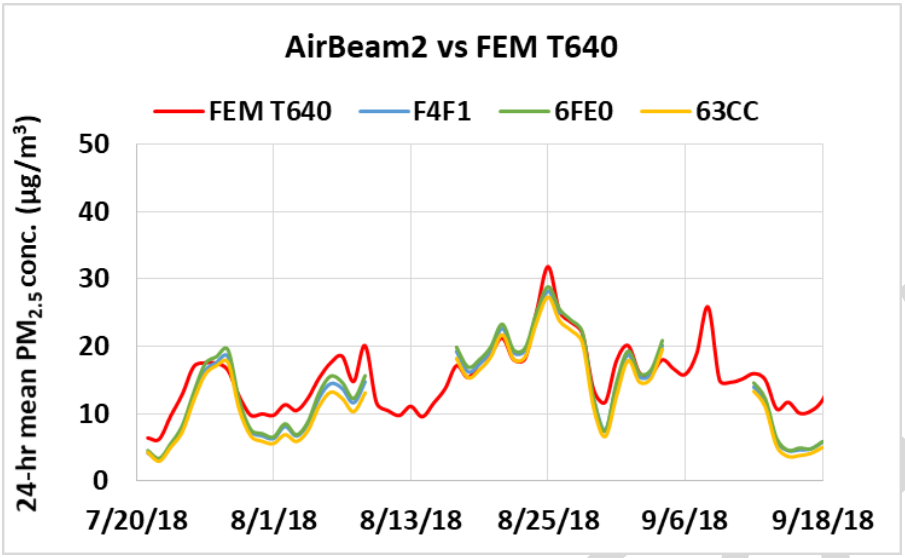
- AirBeam2 sensors do not correlate with the corresponding T640 data (R^2 ~ 0.06)
- Overall, the AirBeam2 sensors underestimate the PM_{10} mass concentrations measured by T640
- The AirBeam2 sensors seem to modestly track the PM_{10} diurnal variations as recorded by T640



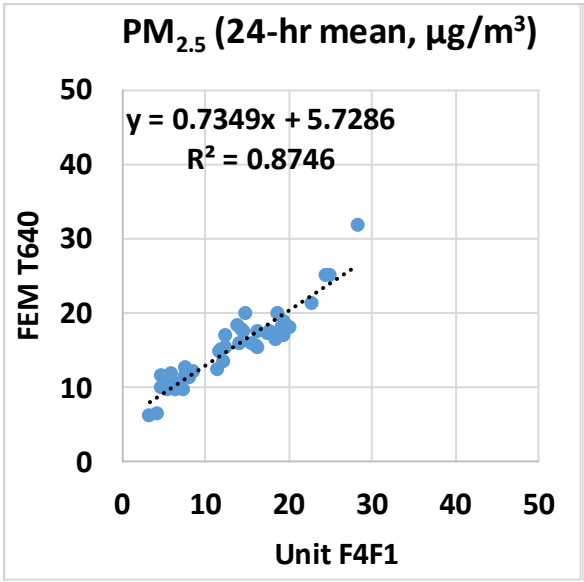


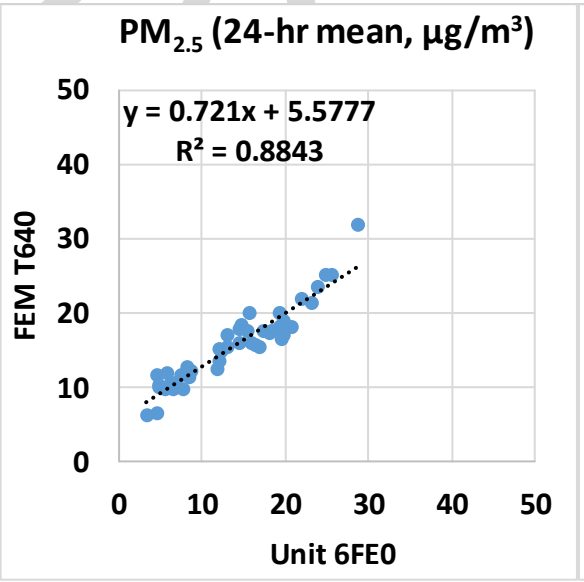


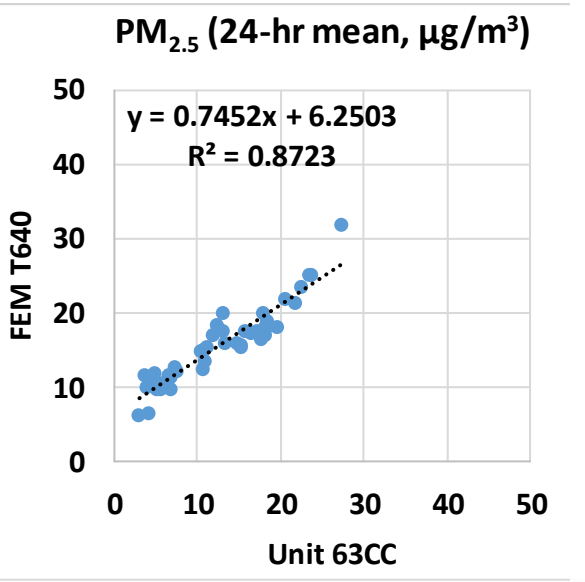
AirBeam2 vs FEM T640 ($PM_{2.5}$; 24-hr mean)



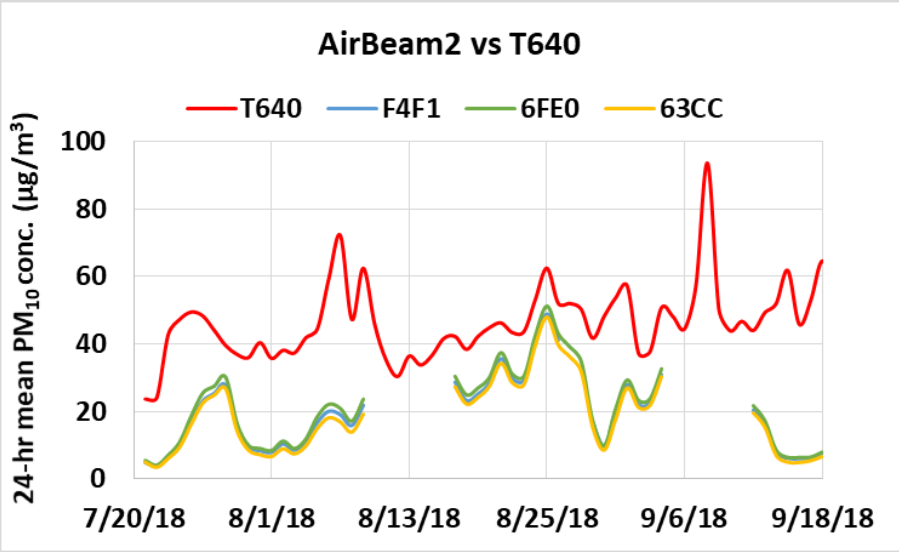
- AirBeam2 sensors show good correlations with the corresponding FEM T640 data (R^2 ~ 0.88)
- Overall, the AirBeam2 sensors underestimate the $PM_{2.5}$ mass concentrations measured by FEM T640
- The AirBeam2 sensors seem to track well the $PM_{2.5}$ concentration variations as recorded by FEM T640



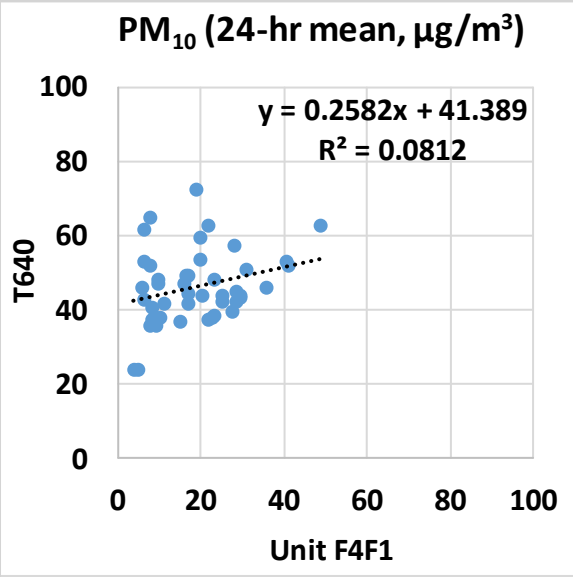


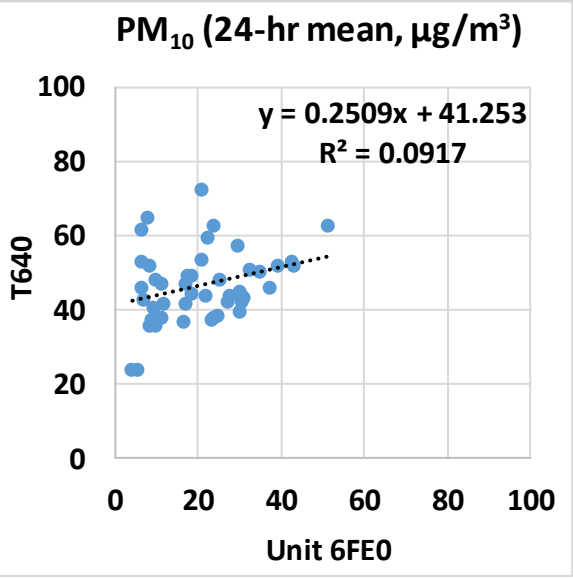


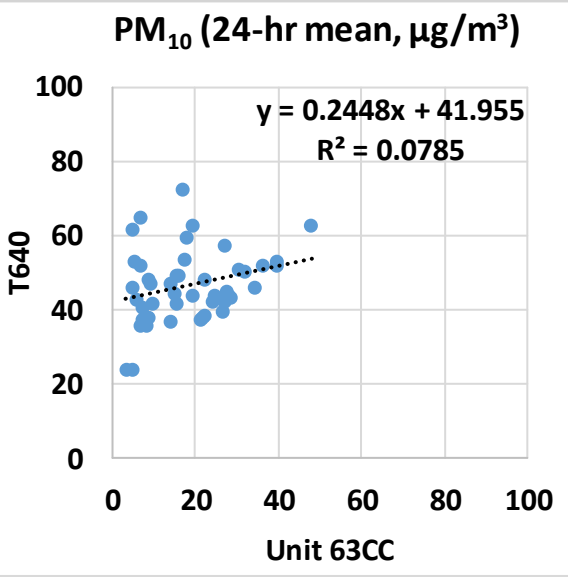
AirBeam2 vs T640 (PM_{10}; 24-hr mean)



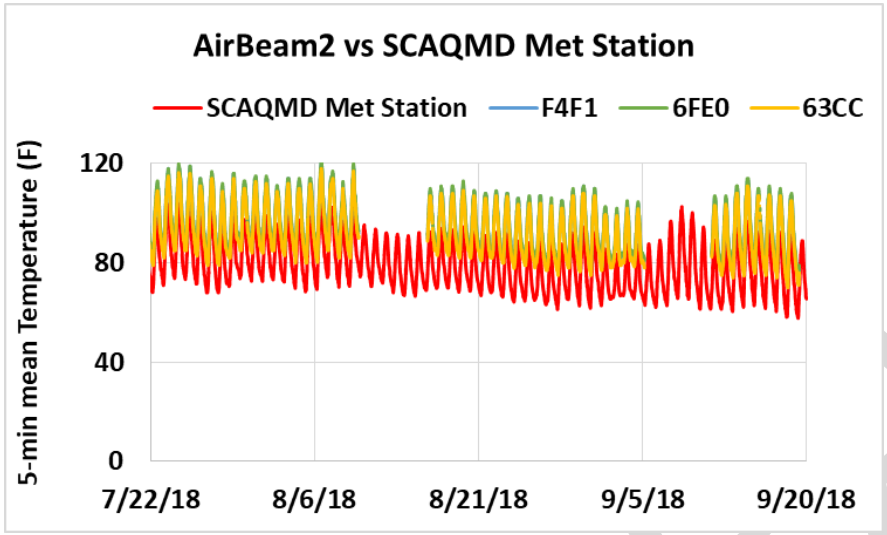
- AirBeam2 sensors do not correlate with the corresponding T640 data (R^2 ~ 0.08)
- Overall, the AirBeam2 sensors underestimate the PM_{10} mass concentrations measured by T640
- The AirBeam2 sensors seem to track the PM_{10} concentration variations as recorded by T640





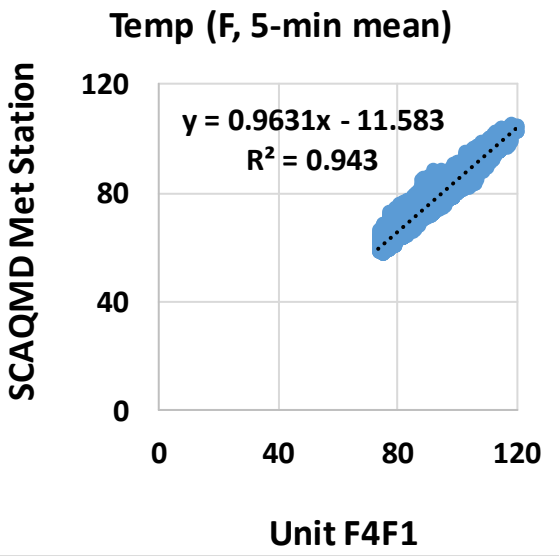


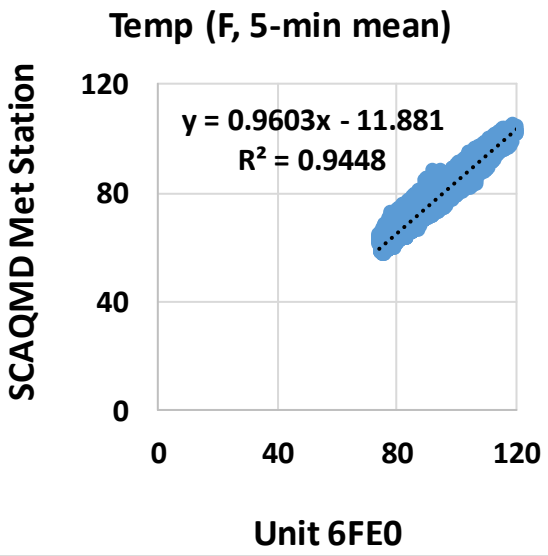
AirBeam2 vs SCAQMD Met Station (Temp; 5-min mean)

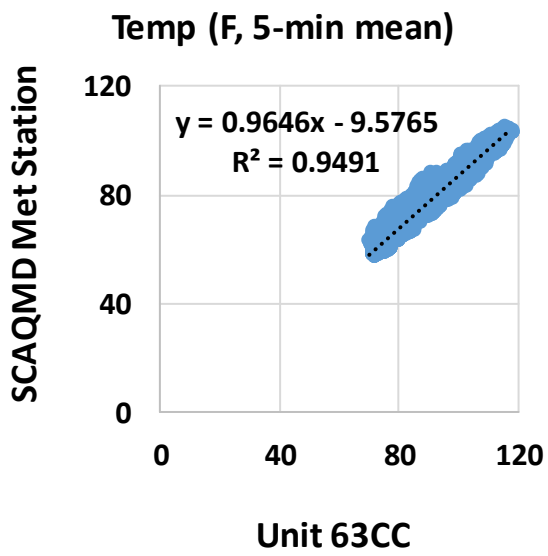


- AirBeam2 temperature measurements* correlate very well with the corresponding SCAQMD Met Station data (R^2 ~ 0.94)
- Overall, the AirBeam2 temperature measurements overestimate that as recorded by the SCAQMD Met Station
- The AirBeam2 sensors seem to track well the temperature diurnal variations as recorded by SCAQMD Met Station

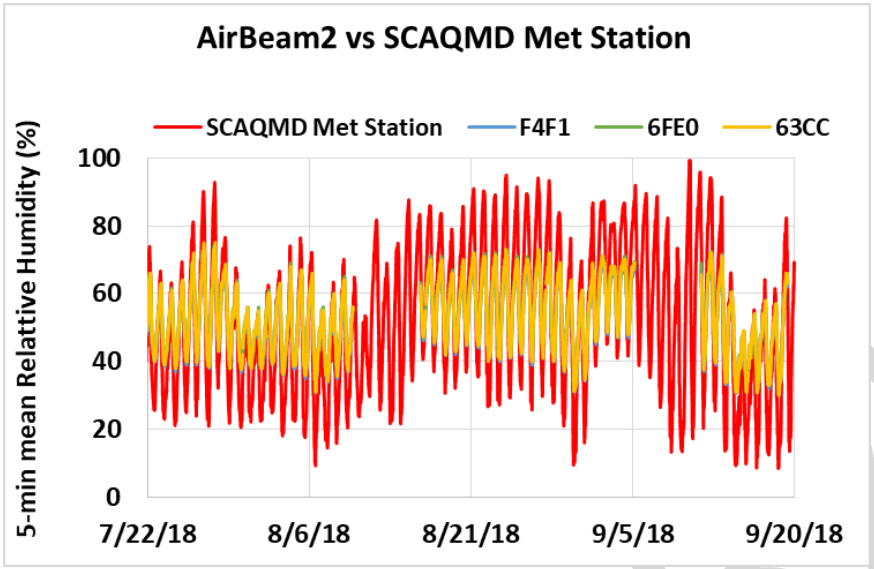
* Temperature recorded by the sensor is not representative of ambient temperature





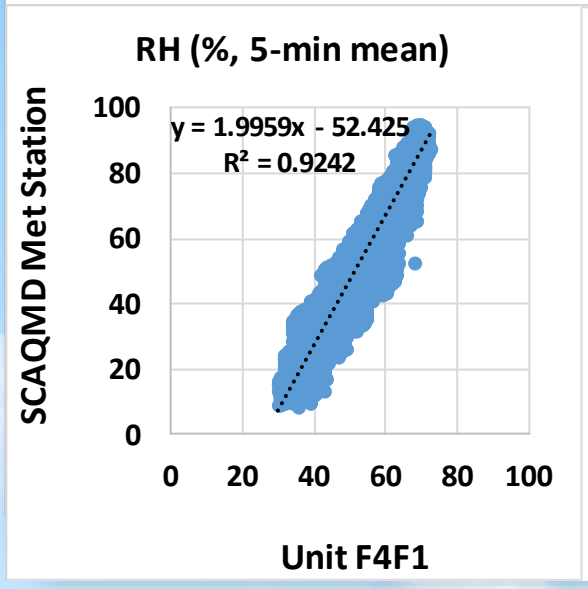


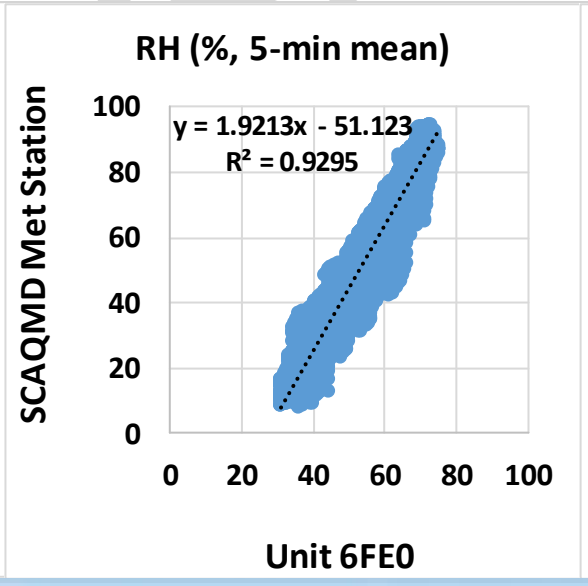
AirBeam2 vs SCAQMD Met Station (RH; 5-min mean)

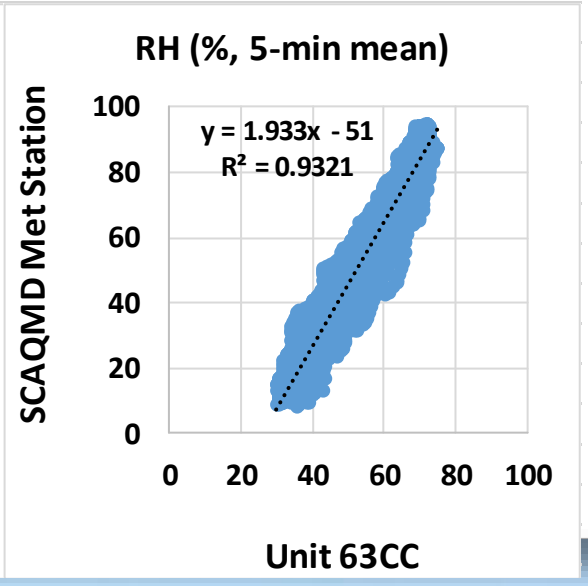


- The AirBeam2 RH measurements correlate very well with the corresponding SCAQMD Met Station data (R^2 ~ 0.98)
- Overall, the AirBeam2 RH measurements underestimate that as recorded by the SCAQMD Met Station
- The AirBeam2 sensors seem to track well the RH diurnal variations as recorded by SCAQMD Met Station

* RH recorded by the sensor is not representative of ambient RH







Discussion

- The three **AirBeam2** sensors' data recovery for $PM_{1.0}$, $PM_{2.5}$ and PM_{10} from all units was 74.5%, 77.8% and 77.9%, respectively. During this evaluation, HabitatMap discovered an issue with the AirBeam2 firmware that prevented the AirBeam2 from reestablishing a WiFi connection if the connection was temporarily disrupted. After discovering this issue, HabitatMap updated the firmware running on the AirBeam2 and it successfully resolved this issue.
- The three sensors showed low intra-model variability (9.5% to 14.8%)
- The reference instruments (GRIMM, BAM and T640) correlate well with each other for both $PM_{2.5}$ (R^2 ~ 0.78) and PM_{10} (R^2 ~ 0.83) mass concentration measurements (1-hr mean)
- PM_1 mass concentration measurements measured by AirBeam2 sensors correlate well with the corresponding GRIMM values (R^2 ~ 0.75, 1-hr mean) and underestimate $PM_{1.0}$ mass concentration measured by the GRIMM
- $PM_{2.5}$ mass concentration measurements measured by AirBeam2 sensors show good correlations with the corresponding FEM GRIMM, FEM BAM and FEM T640 (R^2 ~ 0.71, 0.68 and 0.78, respectively, 1-hr mean) and underestimate $PM_{2.5}$ mass concentration measured by the FEM GRIMM, FEM BAM and FEM T640
- PM_{10} mass concentration measurements measured by AirBeam2 sensors do not correlate with the corresponding GRIMM, FEM BAM and T640 (R^2 ~ 0.0 , 0.01 and 0.06, respectively, 1-hr mean) and underestimate PM_{10} mass concentration measured by the reference instruments
- AirBeam2 is different from AirBeam: 1) different hardware and design; 2) different firmware; 3) Wi-Fi and cellular capabilities; 4) different microcontroller; and 5) measures $PM_{1.0}$, $PM_{2.5}$, PM_{10} mass conc. only
- No sensor calibration was performed by SCAQMD 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