Field Evaluation
Smart Citizen Kit v2.1

DRAFT

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

- From 09/19/2019 to 11/19/2019, three **Smart Citizen Kit v2.1** (hereinafter **SCK 2.1**) sensors were deployed at the South Coast AQMD stationary ambient monitoring site in Rubidoux and were run side-by-side with Federal Equivalent Method (FEM) instruments measuring the same pollutants

- SCK 2.1 (*3 units tested*):
  - Particle sensor: optical; non-FEM (model PMS 5003, Plantower)
  - Each unit reports: $PM_{1.0}$, $PM_{2.5}$ and PM_{10} ($\mu g/m^3$), temperature (°C), RH (%), pressure (Pa), noise level (dBA) and ambient light (Lux), VOC (ppb), equivalent carbon dioxide (ppm)
  - Unit cost: $119 (Smart Citizen Starter Kit)
 - Time resolution: 1-min
  - Units IDs: 7FD1, 3423, 4E34

- MetOne BAM (*reference instrument*):
  - Beta-attenuation monitor (FEM $PM_{2.5}$ & PM_{10})
  - Measures $PM_{2.5}$ & PM_{10} ($\mu g/m^3$)
  - 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} ($\mu g/m^3$)
  - 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} ($\mu g/m^3$)
  - Unit cost: ~$21,000
  - Time resolution: 1-min

- Met station (T, RH, P, WS, WD), cost: ~$5,000
  - 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 from units 7FD1, 3423, 4E34 was ~100% for all PM measurements

SCK 2.1; intra-model variability

- Absolute intra-model variability was ~ 0.35, 0.44 and 1.13 $\mu g/m^3$ 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 ~ 3.2%, 2.5% and 6.0 % 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)
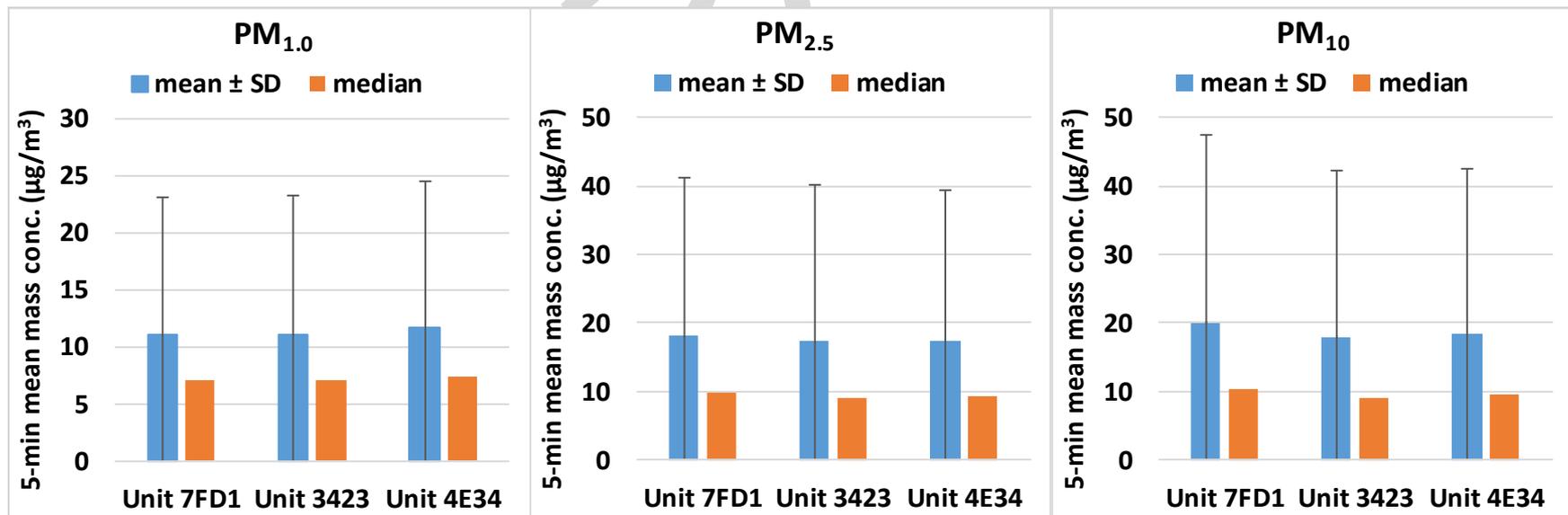
Reference Instruments: $PM_{2.5}$
GRIMM, BAM & T640

- Data recovery for $PM_{2.5}$ from FEM GRIMM, FEM BAM and FEM T640 was ~ 98%, 99% and 100%, respectively.
- Very strong correlations between the reference instruments for $PM_{2.5}$ measurements (R^2 ~ 0.90) were observed.

Note: GRIMM data were not available between 9/19/19 and 10/9/19 due to maintenance.

4
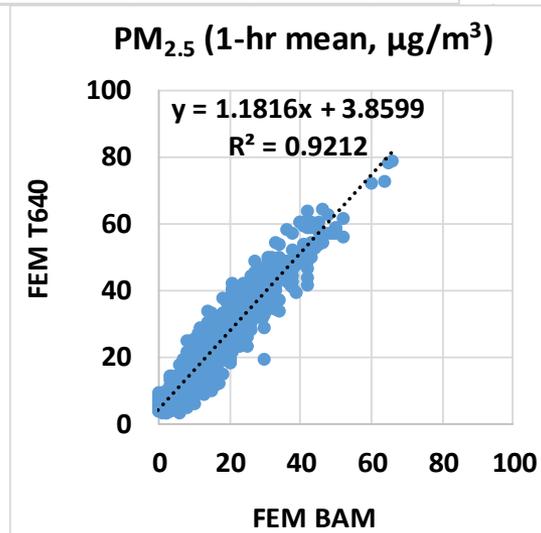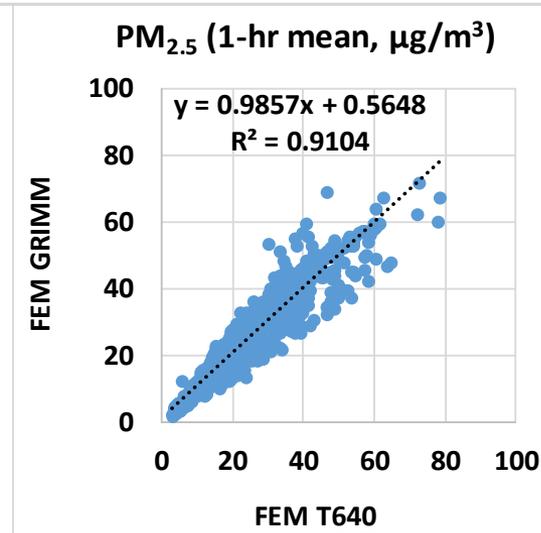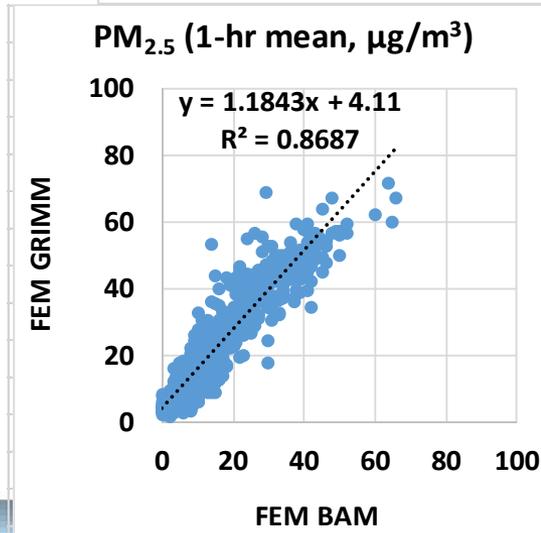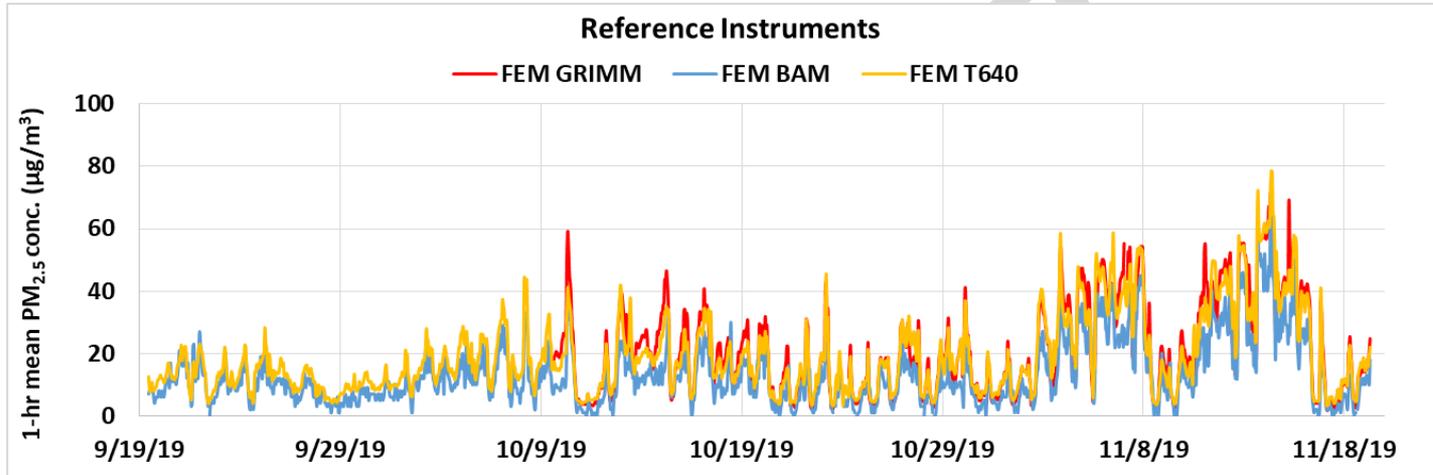
Reference Instruments: PM$_{10}$
GRIMM, BAM & T640

- Data recovery for PM$_{10}$ from GRIMM, FEM BAM and T640 was ~97%, 99% and 100%, respectively.
- Strong correlations between the reference instruments for PM$_{10}$ measurements ($R^2 \sim 0.88$) were observed.

Note: GRIMM data were not available between 9/19/19 and 10/9/19 due to maintenance.

Reference Instruments
— GRIMM — FEM BAM — T640

PM$_{10}$ (1-hr mean, µg/m^3)

$y = 0.8888x + 13.939$
$R^2 = 0.8325$

(GRIMM vs FEM BAM)

PM$_{10}$ (1-hr mean, µg/m^3)

$y = 1.0216x + 1.6189$
$R^2 = 0.8879$

(GRIMM vs T640)

PM$_{10}$ (1-hr mean, µg/m^3)

$y = 0.8635x + 12.484$
$R^2 = 0.9224$

(T640 vs FEM BAM)
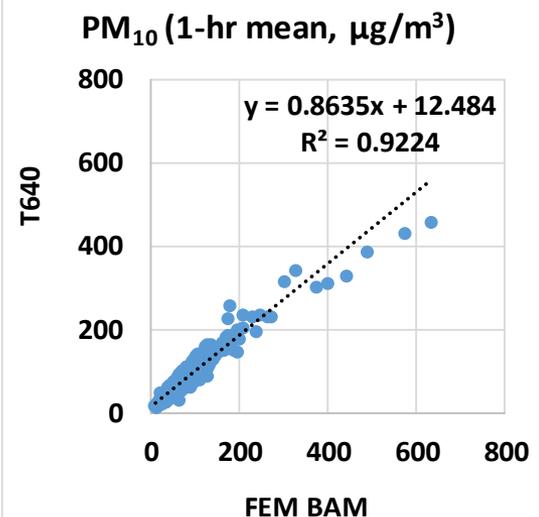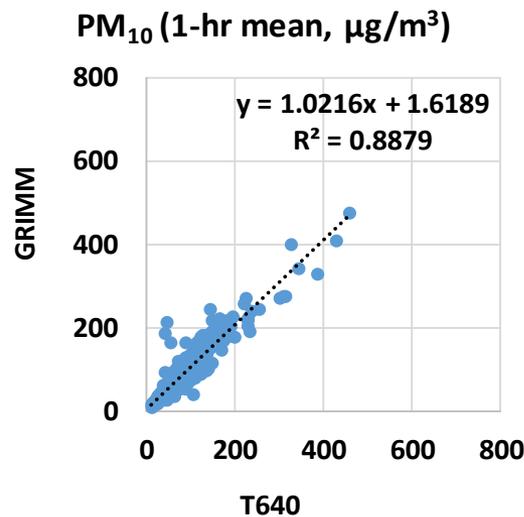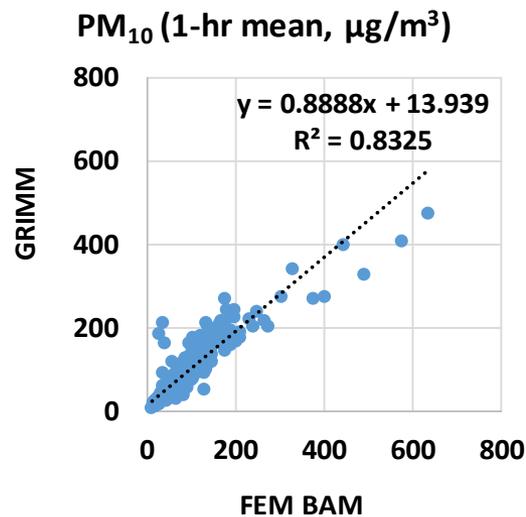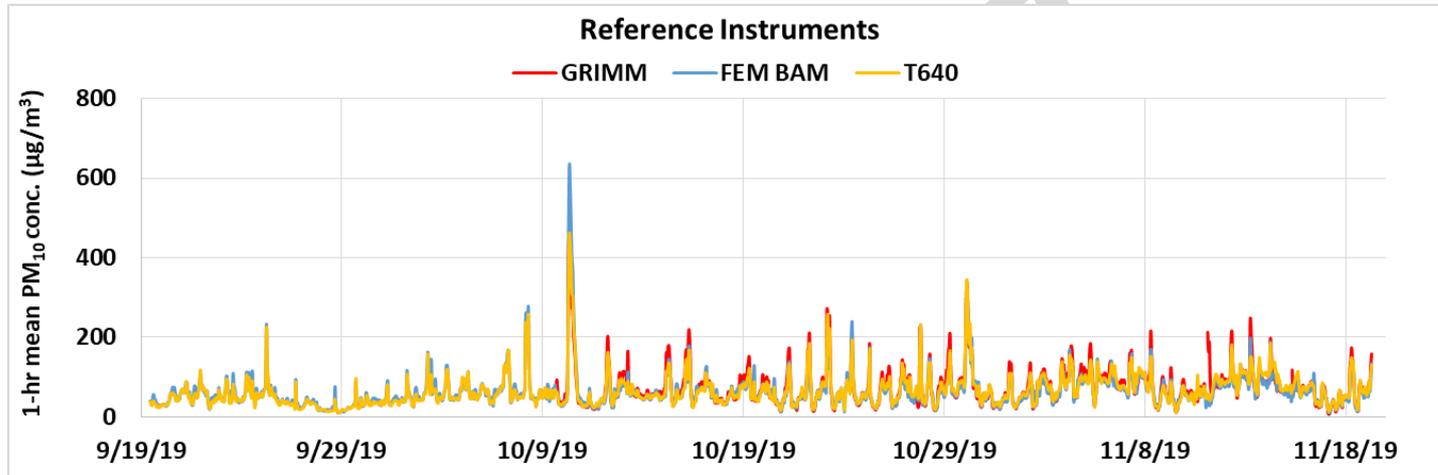
SCK 2.1 vs GRIMM (PM$_{1.0}$; 5-min mean)
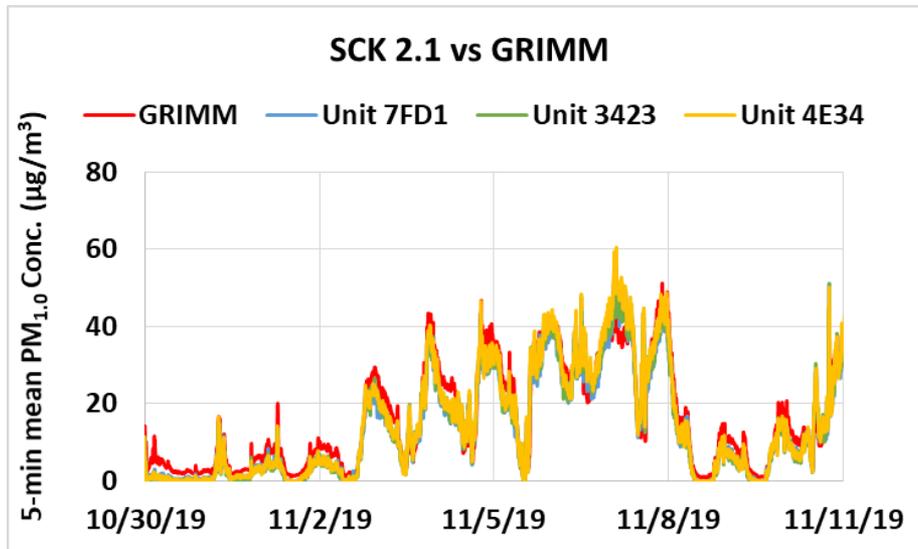
- SCK 2.1 sensors showed very strong correlations with the corresponding GRIMM data (R^2 ~ 0.94)
- Overall, the SCK 2.1 sensors underestimated the PM$_{1.0}$ mass concentrations when PM$_{1.0}$ mass concentrations were lower than 30 µg/m^3 and overestimated the PM$_{1.0}$ mass concentrations when PM$_{1.0}$ mass concentrations were higher than 30 µg/m^3 as measured by GRIMM
- The SCK 2.1 sensors seemed to track the PM$_{1.0}$ diurnal variations as recorded by GRIMM
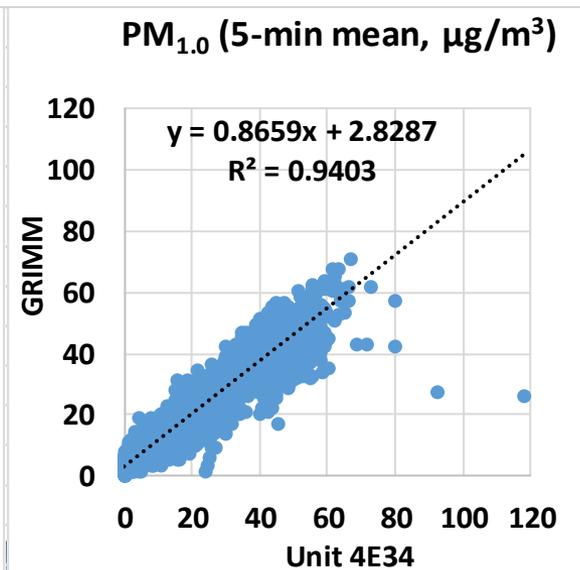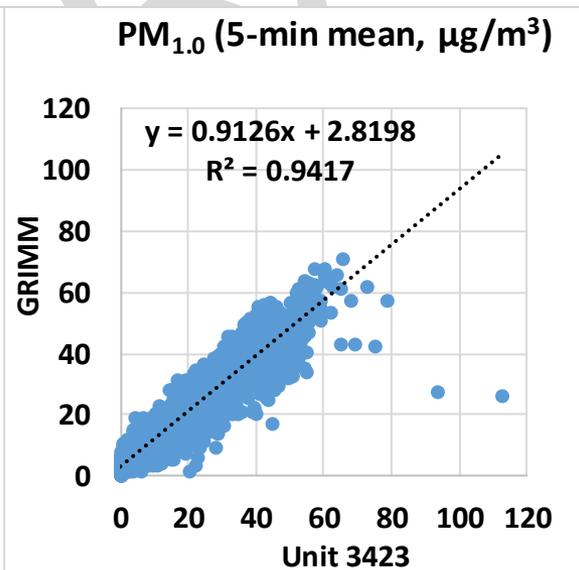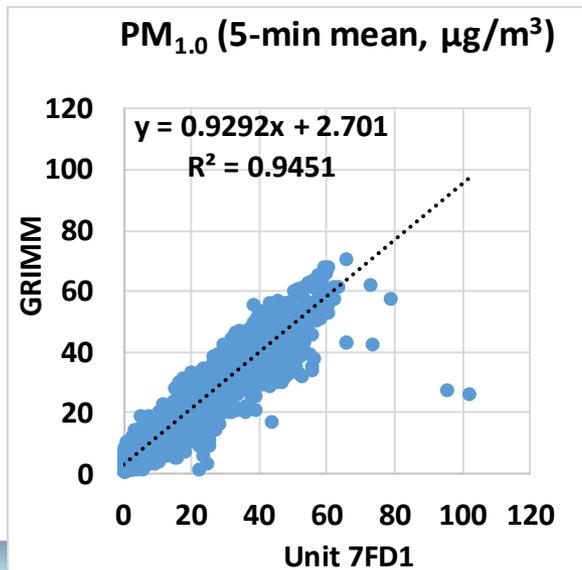
SCK 2.1 vs FEM GRIMM (PM$_{2.5}$; 5-min mean)

SCK 2.1 vs FEM GRIMM
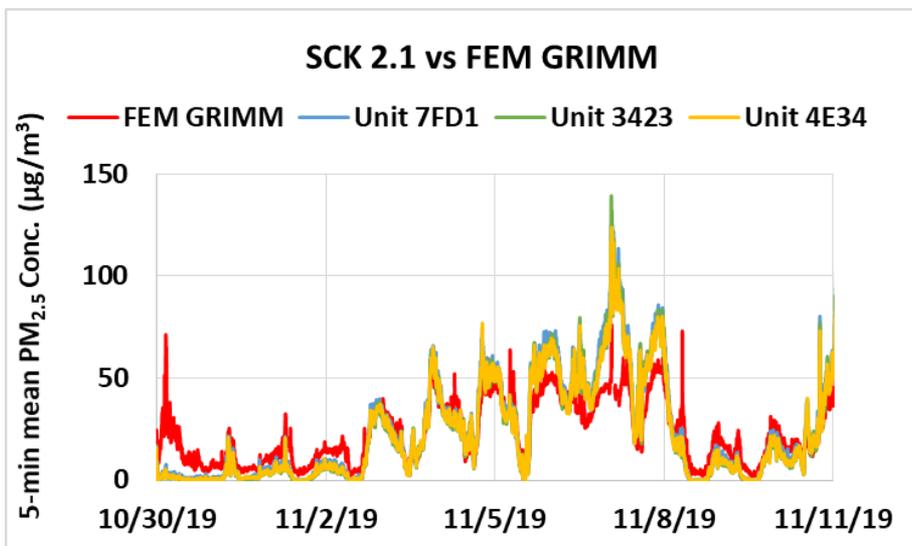
- SCK 2.1 sensors showed strong correlations with the corresponding FEM GRIMM data ($R^2 \sim 0.77$)

- Overall, the SCK 2.1 sensors underestimated the PM$_{2.5}$ mass concentrations when PM$_{2.5}$ mass concentrations were lower than 20 µg/m^3 and overestimated the PM$_{2.5}$ mass concentrations when PM$_{2.5}$ mass concentrations were higher than 20 µg/m^3 as measured by FEM GRIMM

- The SCK 2.1 sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM GRIMM

PM$_{2.5}$ (5-min mean, µg/m^3)

$y = 0.4938x + 10.761$
$R^2 = 0.7719$

PM$_{2.5}$ (5-min mean, µg/m^3)

$y = 0.4954x + 11.257$
$R^2 = 0.759$

PM$_{2.5}$ (5-min mean, µg/m^3)

$y = 0.5173x + 10.861$
$R^2 = 0.7695$

SCK 2.1 vs GRIMM (PM_{10}; 5-min mean)

SCK 2.1 vs GRIMM

Legend: GRIMM, Unit 7FD1, Unit 3423, Unit 4E34

Y-axis: 5-min mean PM_{10} Conc. ($\mu g/m^3$)

X-axis dates: 10/30/19, 11/2/19, 11/5/19, 11/8/19, 11/11/19
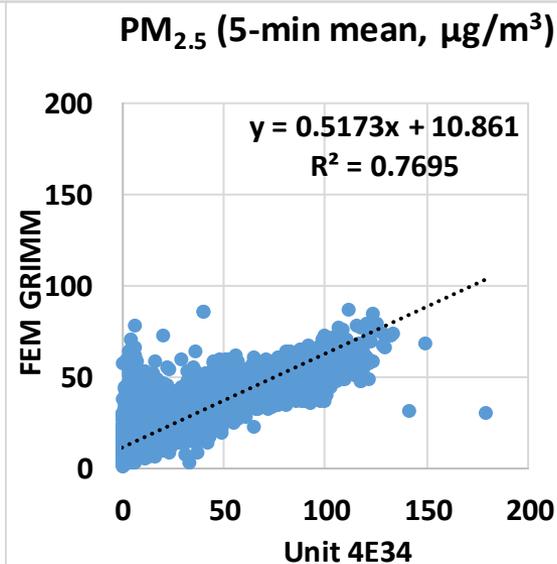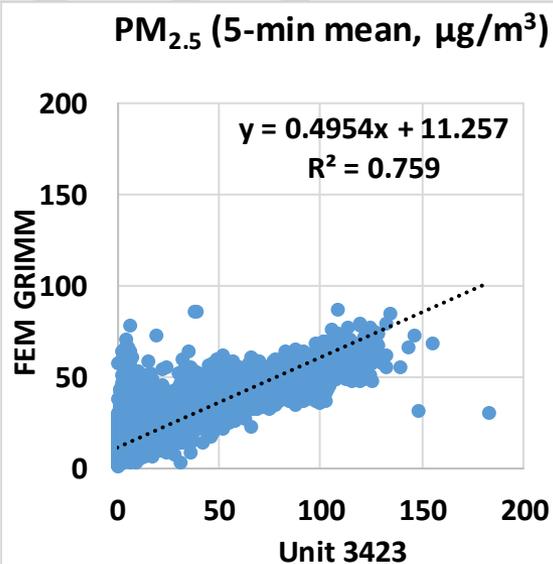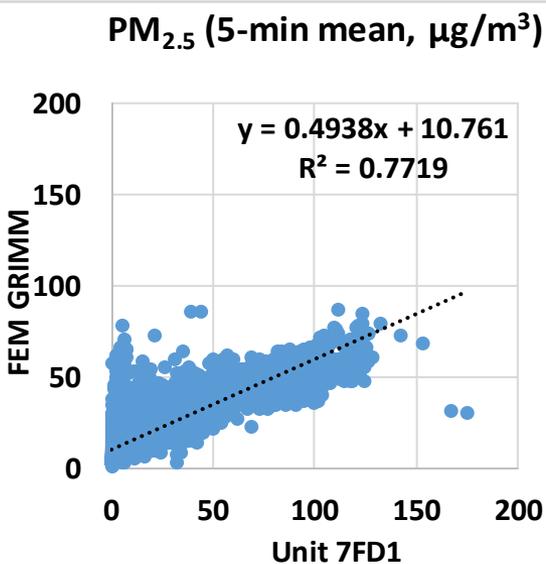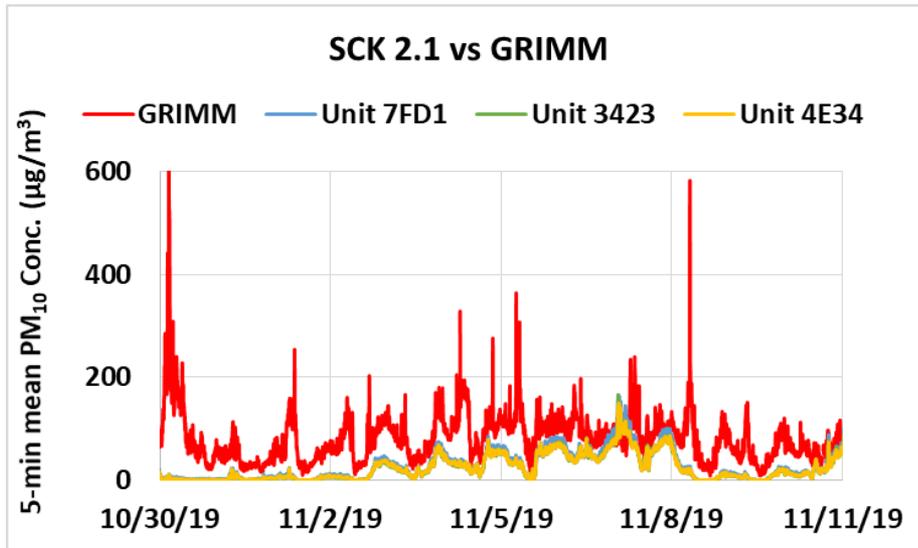
- SCK 2.1 sensors did not correlate with the corresponding GRIMM data ($R^2 \sim 0.06$)

- Overall, the SCK 2.1 sensors underestimated the PM_{10} mass concentrations measured by GRIMM

- The SCK 2.1 sensors did not seem to track the PM_{10} diurnal variations as recorded by GRIMM

PM_{10} (5-min mean, $\mu g/m^3$)

$y = 0.4179x + 66.093$
$R^2 = 0.0592$

Y-axis: GRIMM; X-axis: Unit 7FD1

PM_{10} (5-min mean, $\mu g/m^3$)

$y = 0.4621x + 66.436$
$R^2 = 0.0569$

Y-axis: GRIMM; X-axis: Unit 3423

PM_{10} (5-min mean, $\mu g/m^3$)

$y = 0.4784x + 65.917$
$R^2 = 0.0602$

Y-axis: GRIMM; X-axis: Unit 4E34
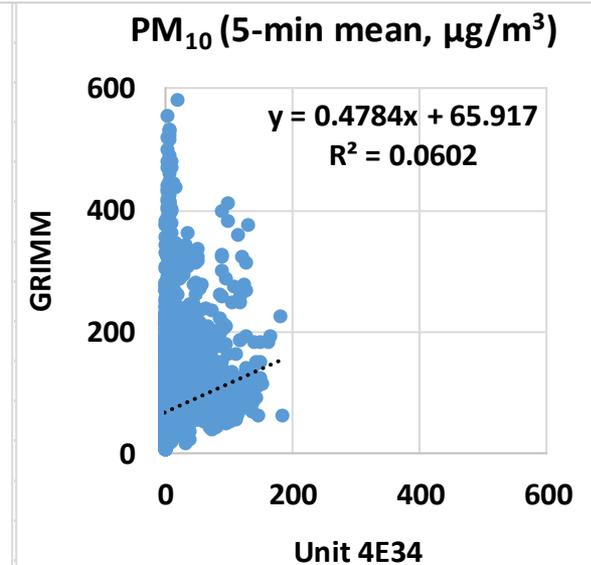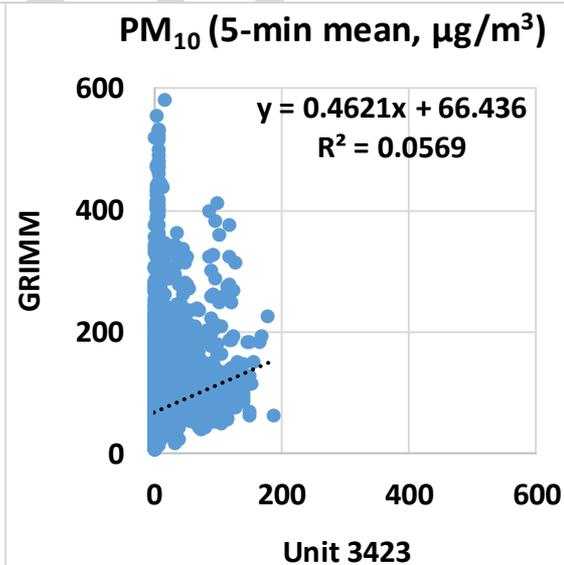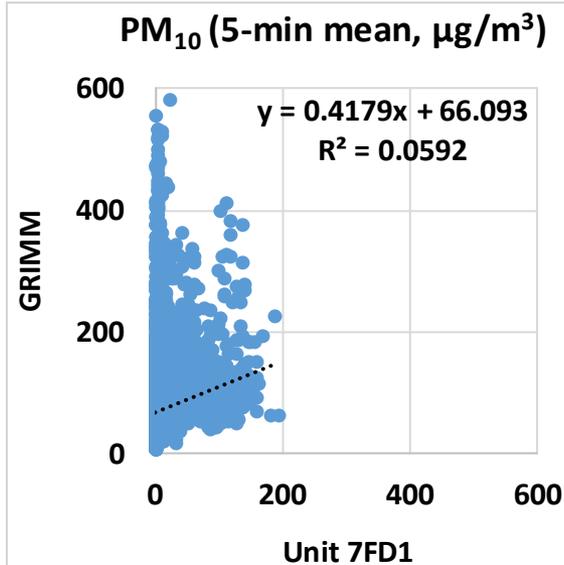
SCK 2.1 vs GRIMM (PM$_{1.0}$; 1-hr mean)
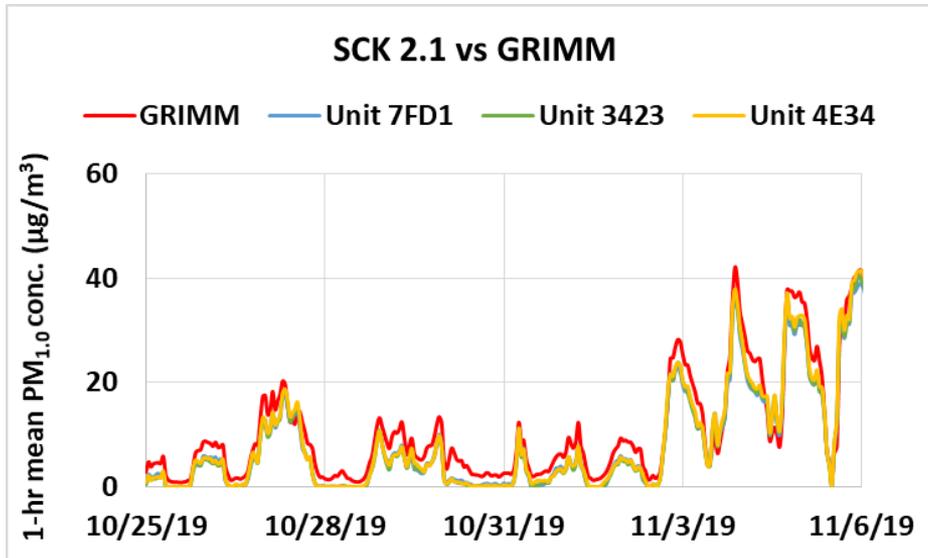
- SCK 2.1 sensors showed very strong correlations with the corresponding GRIMM data (R$^2 \sim$ 0.96)

- Overall, the SCK 2.1 sensors underestimated the PM$_{1.0}$ mass concentrations when PM$_{1.0}$ mass concentrations were lower than 30 μg/m^3 and overestimated the PM$_{1.0}$ mass concentrations when PM$_{1.0}$ mass concentrations were higher than 30 μg/m^3 as measured by GRIMM

- The SCK 2.1 sensors seemed to track the PM$_{1.0}$ diurnal variations as recorded by GRIMM
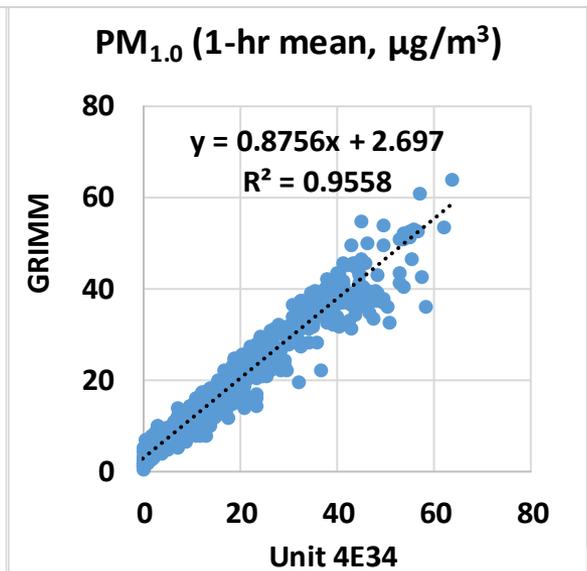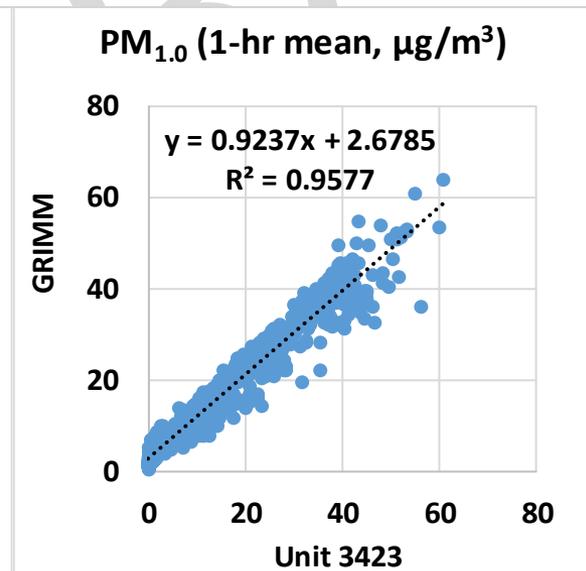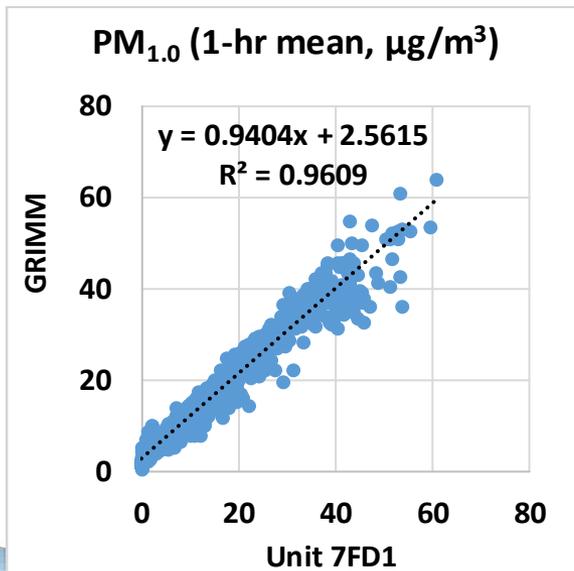
# SCK 2.1 vs FEM GRIMM (PM$_{2.5}$; 1-hr mean)
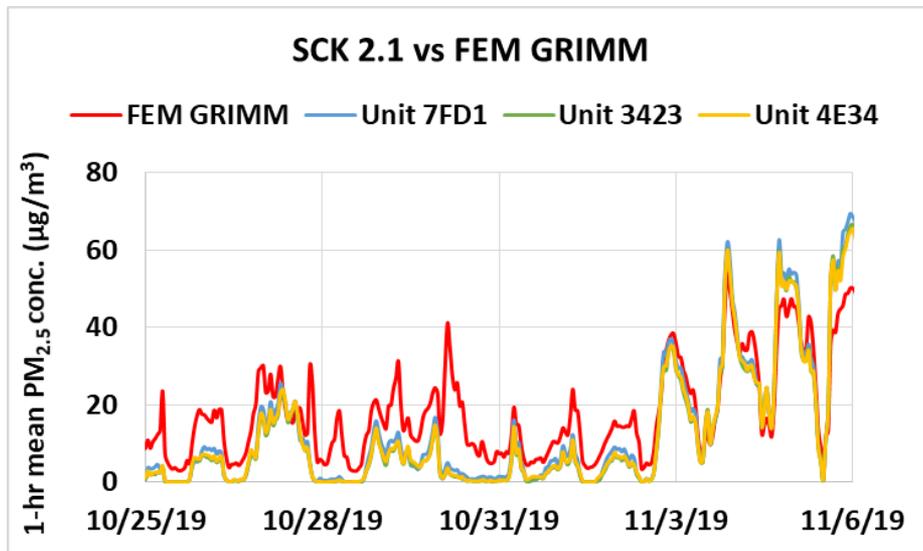
- SCK 2.1 sensors showed strong correlations with the corresponding FEM GRIMM data (R^2 ~ 0.79)

- Overall, the SCK 2.1 sensors underestimated the PM$_{2.5}$ mass concentrations when PM$_{2.5}$ mass concentrations were lower than 20 µg/m^3 and overestimated the PM$_{2.5}$ mass concentrations when PM$_{2.5}$ mass concentrations were higher than 20 µg/m^3 as measured by FEM GRIMM

- The SCK 2.1 sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM GRIMM
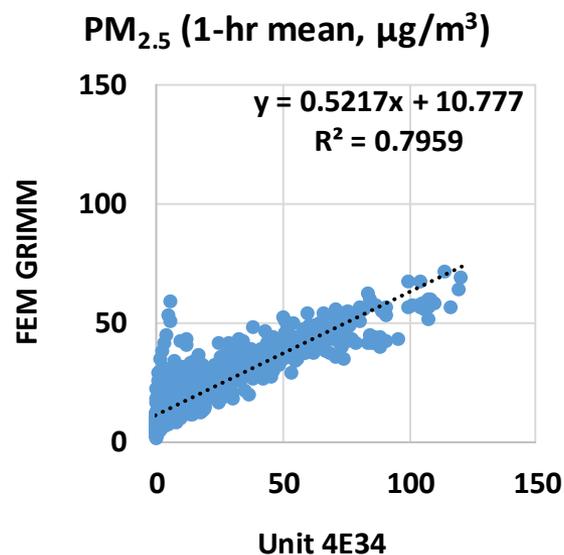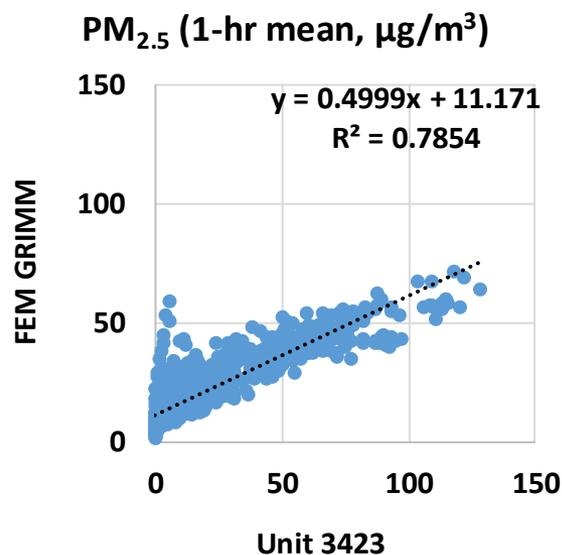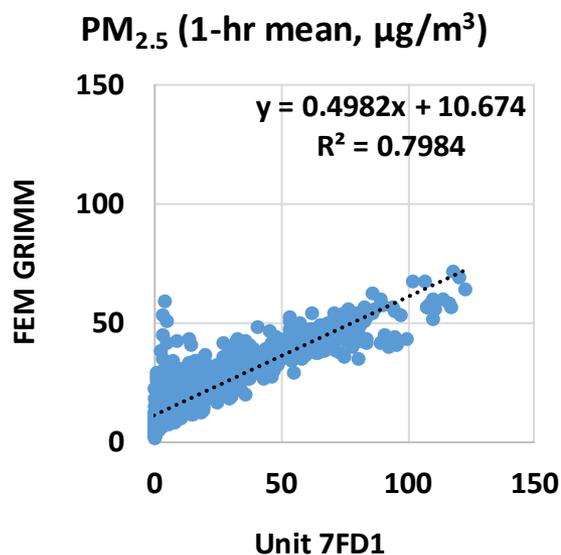
SCK 2.1 vs GRIMM (PM$_{10}$; 1-hr mean)
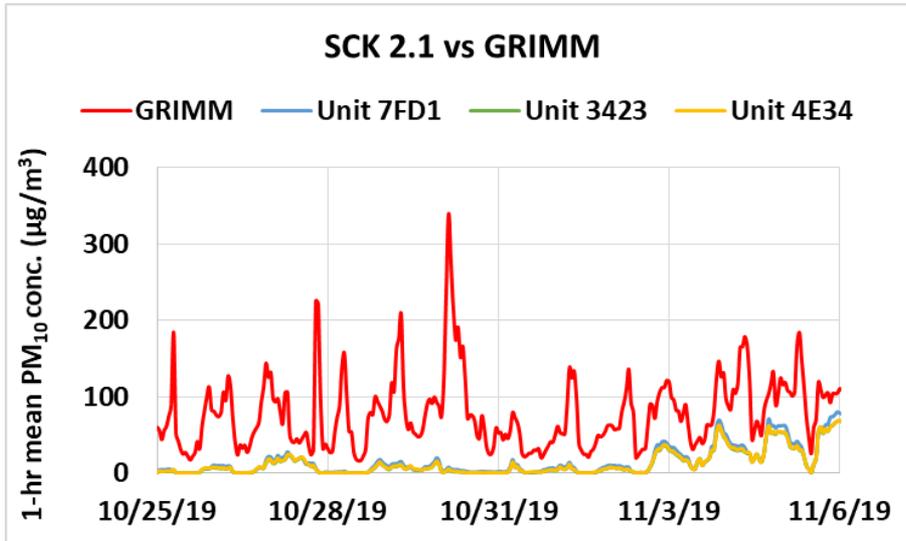
- SCK 2.1 sensors did not correlate with the corresponding GRIMM data (R^2 ~ 0.07)
- Overall, the SCK 2.1 sensors underestimated the PM$_{10}$ mass concentrations measured by GRIMM
- The SCK 2.1 sensors did not seem to track the PM$_{10}$ diurnal variations as recorded by GRIMM
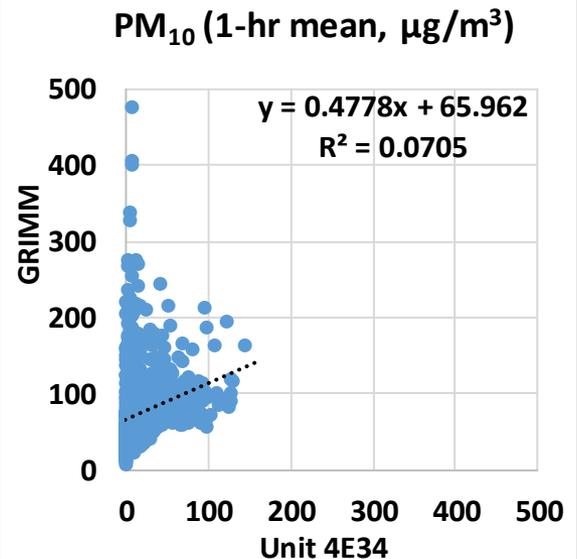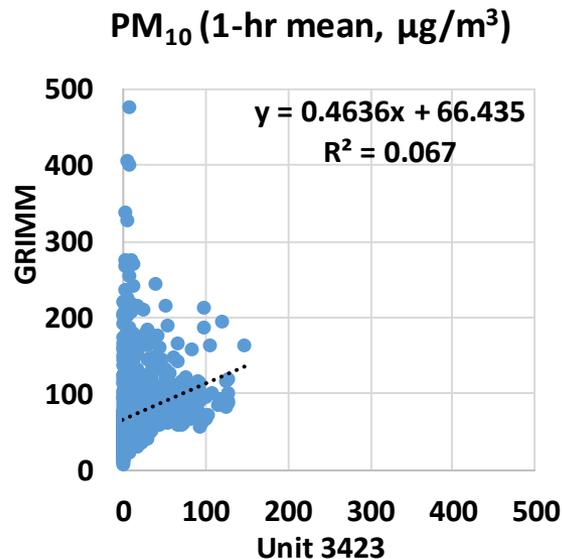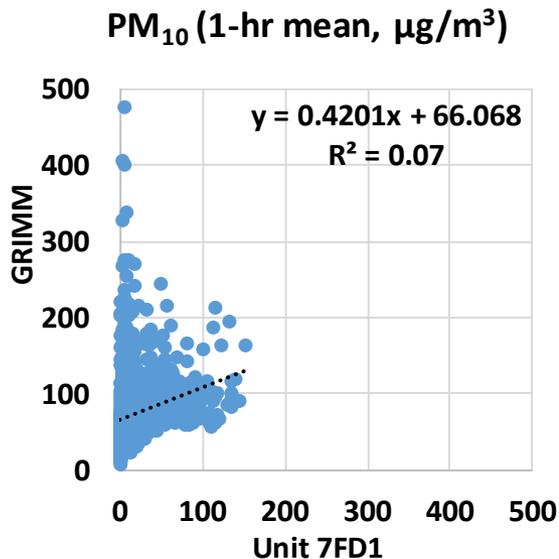
SCK 2.1 vs GRIMM (PM$_{1.0}$; 24-hr mean)
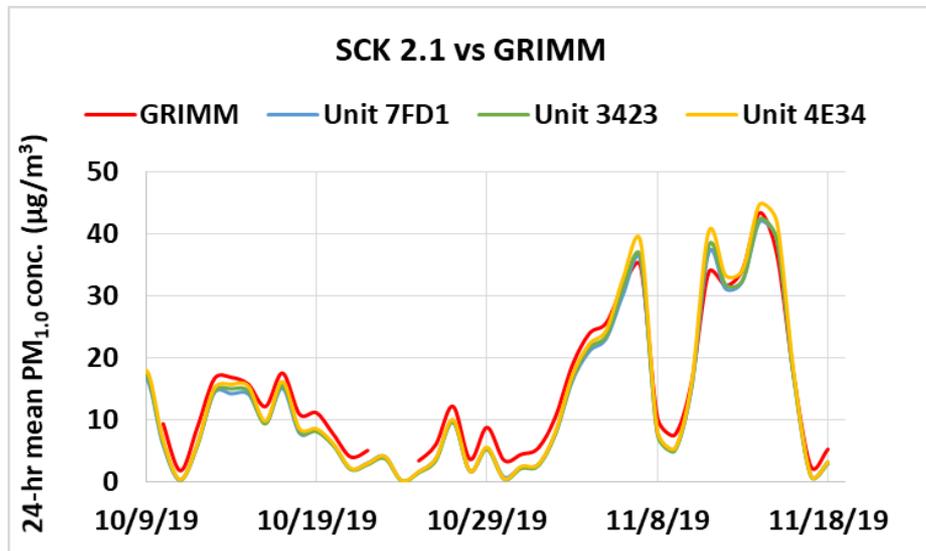
- SCK 2.1 sensors showed very strong correlations with the corresponding GRIMM data (R^2 ~ 0.99)

- Overall, the SCK 2.1 sensors underestimated the PM$_{1.0}$ mass concentrations when PM$_{1.0}$ mass concentrations were lower than 30 µg/m^3 and overestimated the PM$_{1.0}$ mass concentrations when PM$_{1.0}$ mass concentrations were higher than 30 µg/m^3 as measured by GRIMM

- The SCK 2.1 sensors seemed to track the PM$_{1.0}$ diurnal variations as recorded by GRIMM
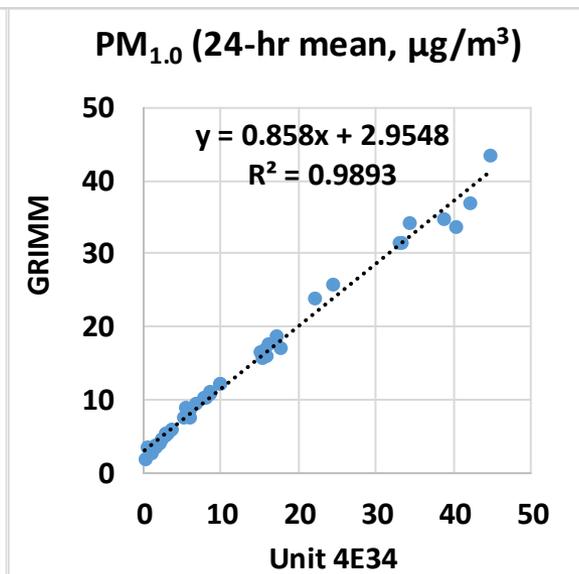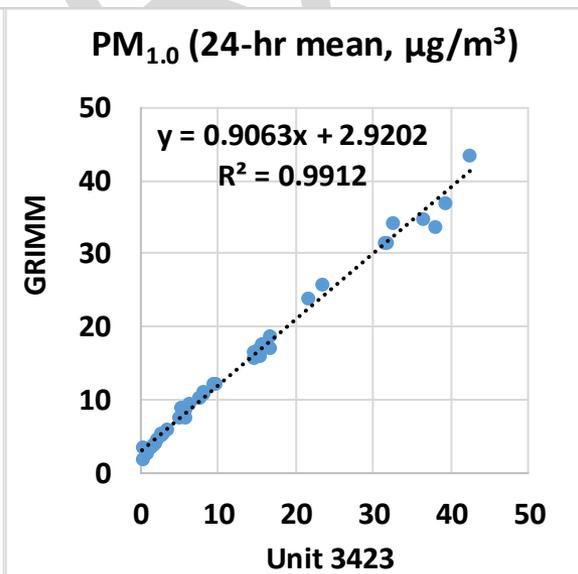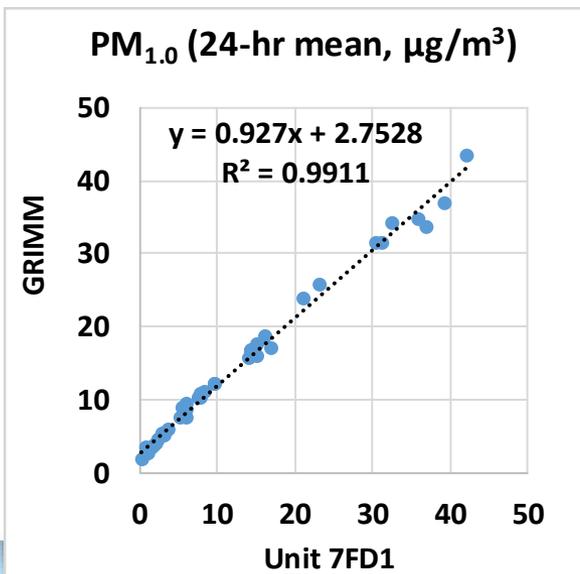
SCK 2.1 vs FEM GRIMM (PM$_{2.5}$; 24-hr mean)
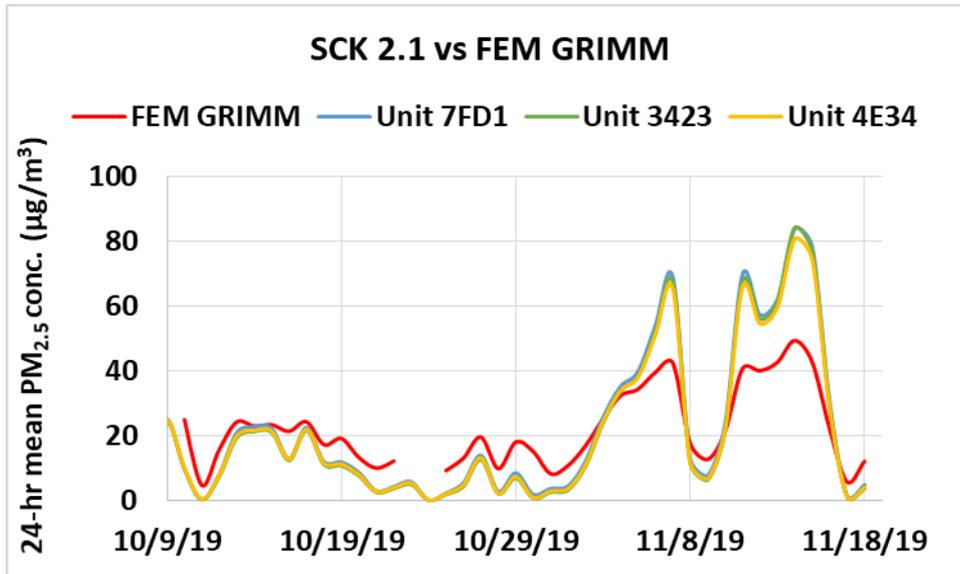
- SCK 2.1 sensors showed very strong correlations with the corresponding FEM GRIMM data (R^2 ~ 0.92)

- Overall, the SCK 2.1 sensors underestimated the PM$_{2.5}$ mass concentrations when PM$_{2.5}$ mass concentrations were lower than 20 µg/m^3 and overestimated the PM$_{2.5}$ mass concentrations when PM$_{2.5}$ mass concentrations were higher than 20 µg/m^3 as measured by FEM GRIMM

- The SCK 2.1 sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM GRIMM

SCK 2.1 vs GRIMM (PM$_{10}$; 24-hr mean)

SCK 2.1 vs GRIMM

- GRIMM — Unit 7FD1 — Unit 3423 — Unit 4E34

24-hr mean PM$_{10}$ conc. ($\mu g/m^3$)
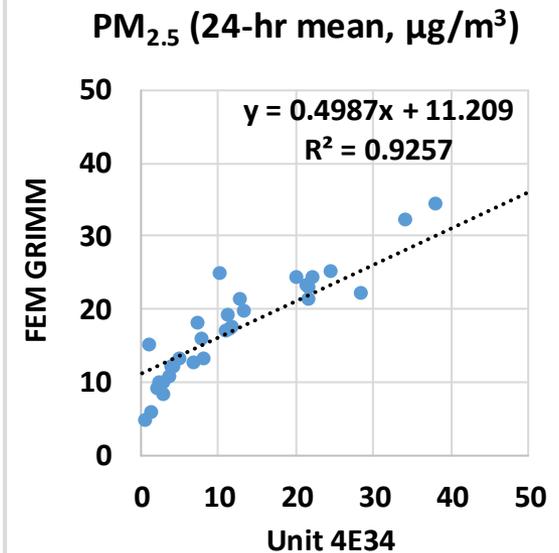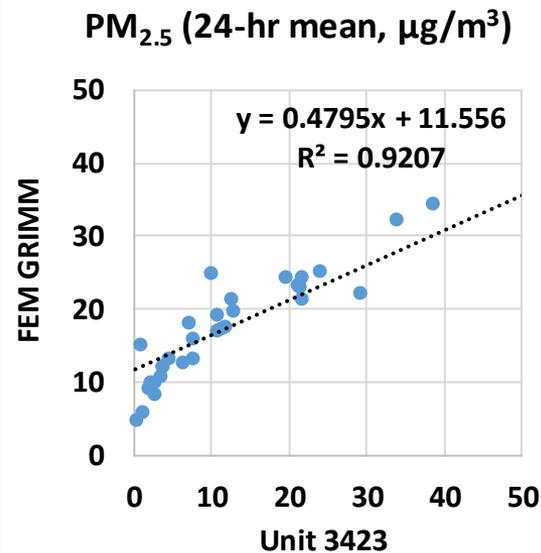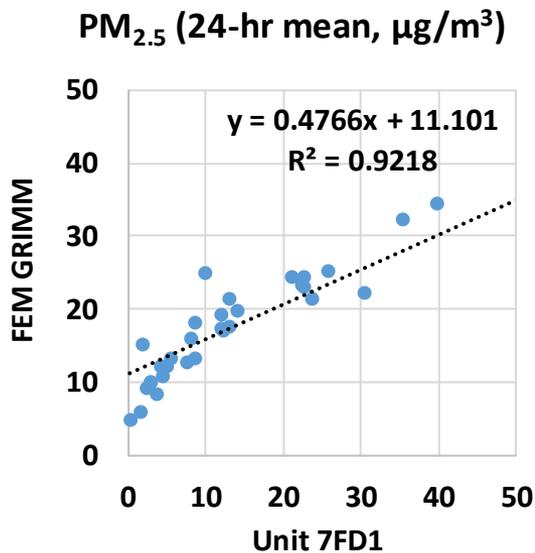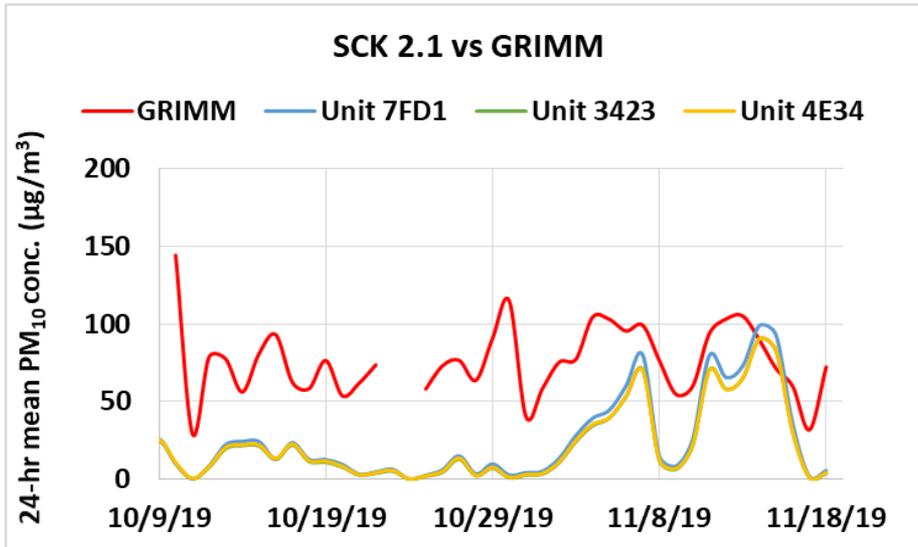
- SCK 2.1 sensors showed very weak correlations with the corresponding GRIMM data (R^2 ~ 0.17)

- Overall, the SCK 2.1 sensors underestimated the PM$_{10}$ mass concentrations measured by GRIMM

- The SCK 2.1 sensors did not seem to track the PM$_{10}$ diurnal variations as recorded by GRIMM

PM$_{10}$ (24-hr mean, $\mu g/m^3$)

$y = 0.3394x + 67.409$
$R^2 = 0.167$

GRIMM

Unit 7FD1

PM$_{10}$ (24-hr mean, $\mu g/m^3$)

$y = 0.3795x + 67.599$
$R^2 = 0.1693$

GRIMM

Unit 3423

PM$_{10}$ (24-hr mean, $\mu g/m^3$)

$y = 0.3828x + 67.383$
$R^2 = 0.1705$

GRIMM

Unit 4E34

14
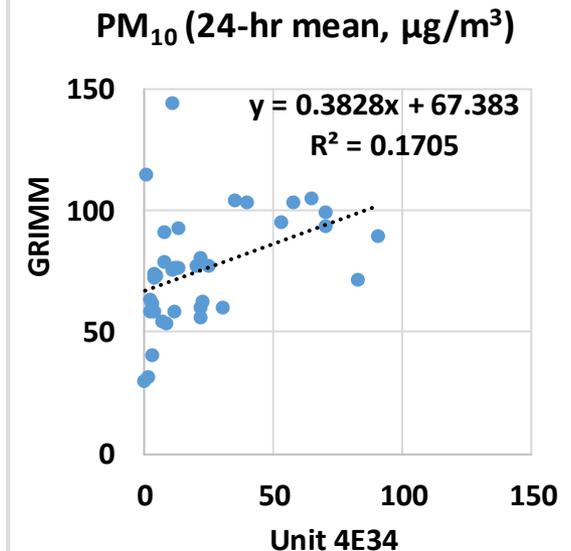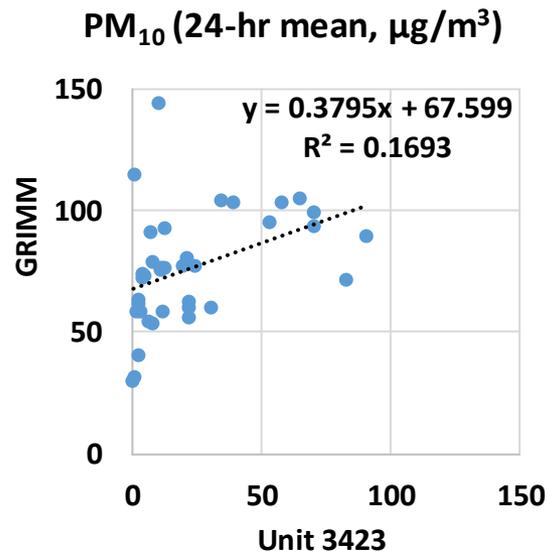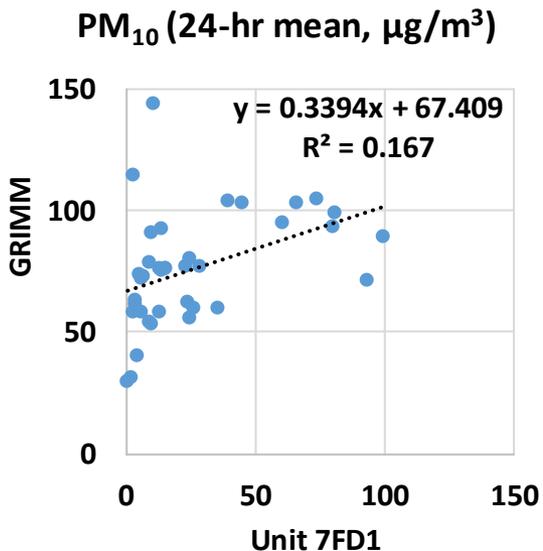
SCK 2.1 vs FEM BAM (PM$_{2.5}$; 1-hr mean)

SCK 2.1 vs FEM BAM
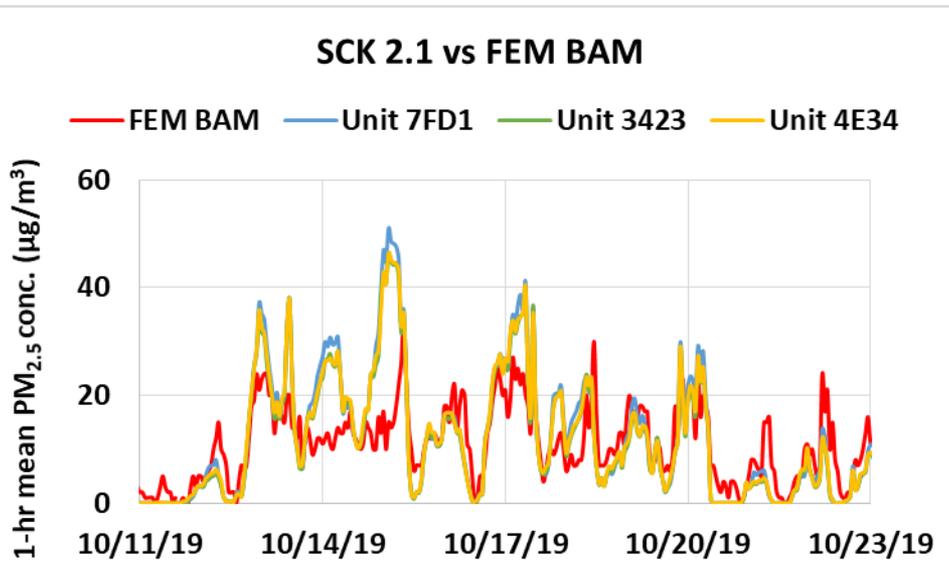
- SCK 2.1 sensors showed strong correlations with the corresponding FEM BAM data (R^2 ~ 0.71)

- Overall, the SCK 2.1 sensors underestimated the PM$_{2.5}$ mass concentrations when PM$_{2.5}$ mass concentrations were lower than 10 µg/m^3 and overestimated the PM$_{2.5}$ mass concentrations when PM$_{2.5}$ mass concentrations were higher than 10 µg/m^3 as measured by FEM BAM

- The SCK 2.1 sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM BAM

PM$_{2.5}$ (1-hr mean, µg/m^3)

$y = 0.3759x + 6.5441$
$R^2 = 0.7127$

PM$_{2.5}$ (1-hr mean, µg/m^3)

$y = 0.3814x + 6.7399$
$R^2 = 0.7105$

PM$_{2.5}$ (1-hr mean, µg/m^3)

$y = 0.3975x + 6.4348$
$R^2 = 0.719$
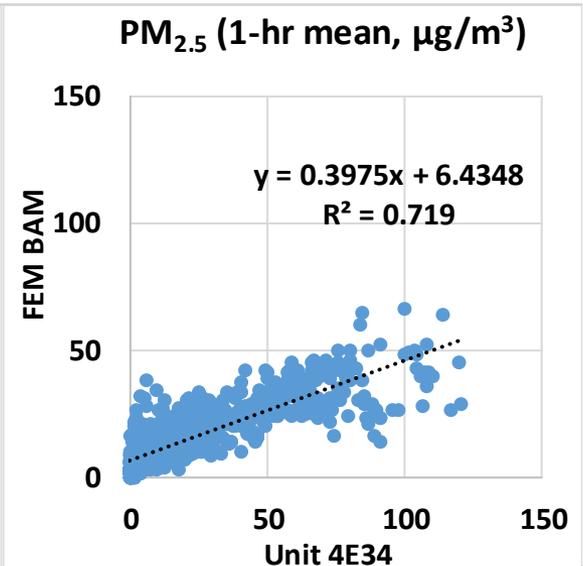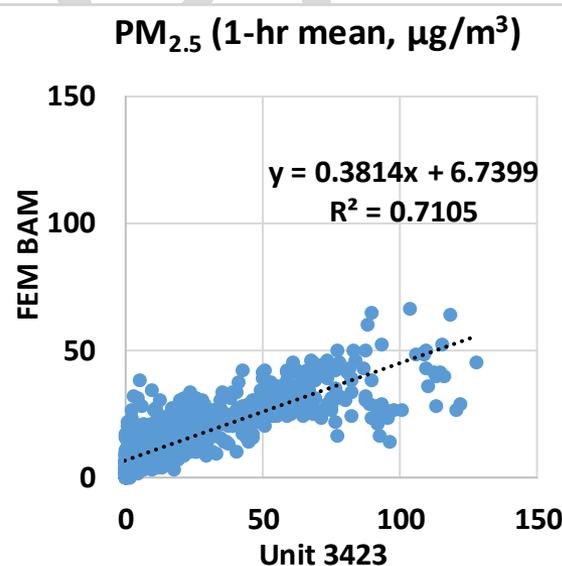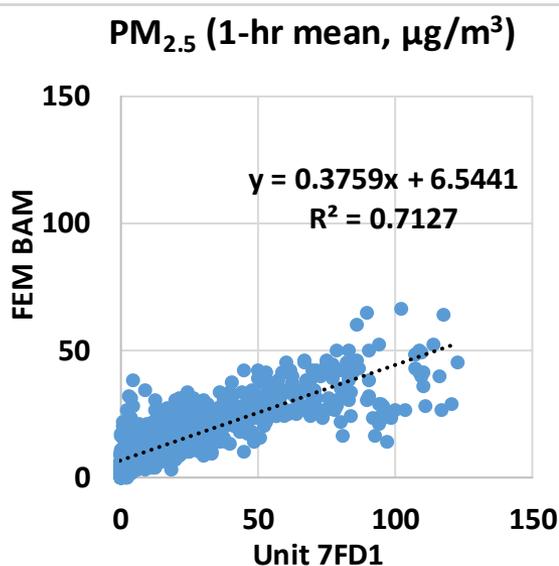
SCK 2.1 vs FEM BAM (PM$_{10}$; 1-hr mean)
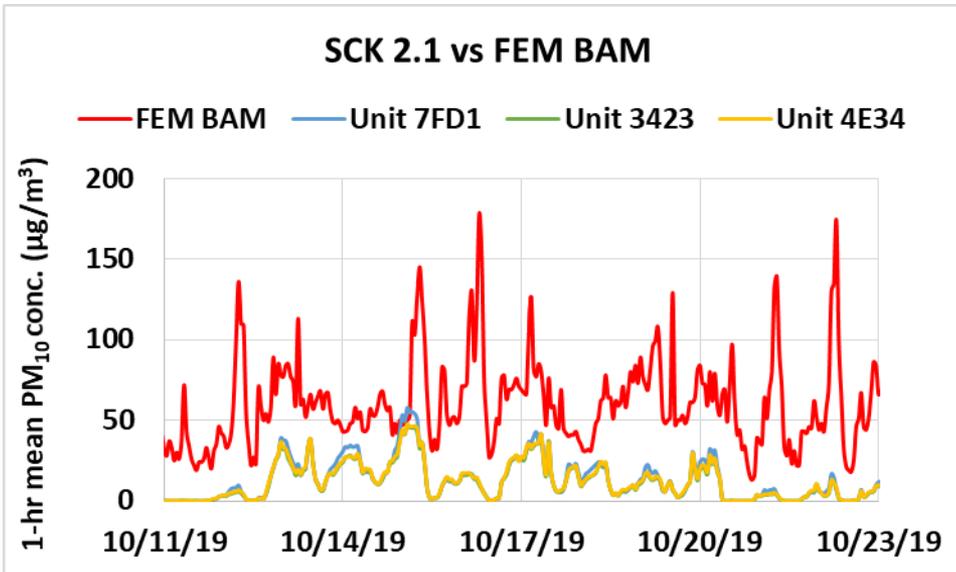
- SCK 2.1 sensors did not correlate with the corresponding FEM BAM data ($R^2 \sim 0.04$)
- Overall, the SCK 2.1 sensors underestimated the PM$_{10}$ mass concentrations measured by FEM BAM
- The SCK 2.1 sensors did not seem to track the PM$_{10}$ diurnal variations as recorded by FEM BAM
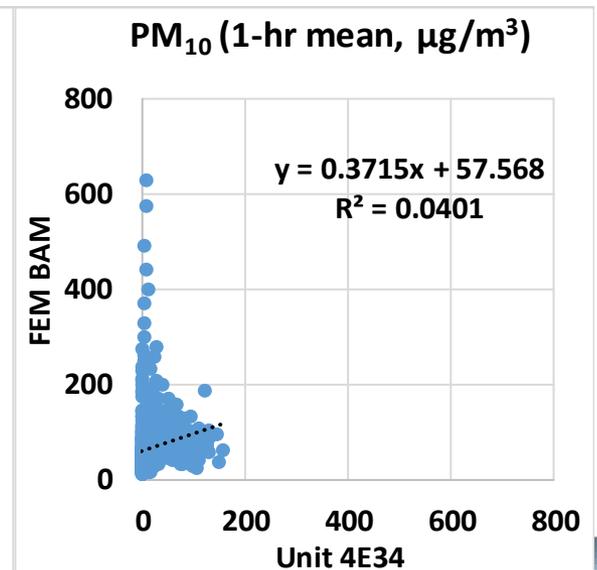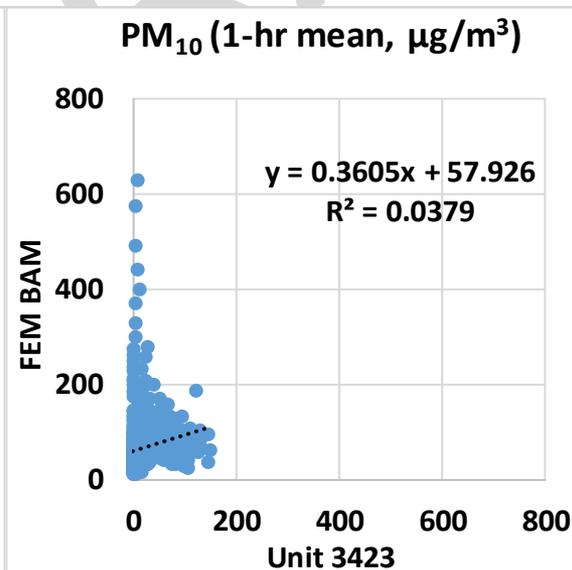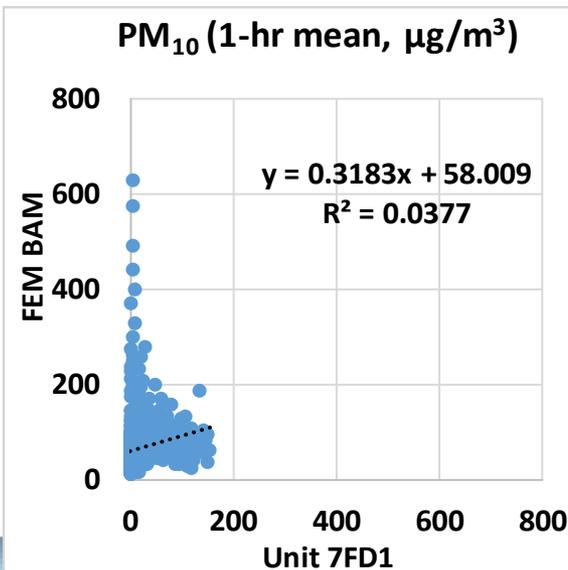
# SCK 2.1 vs FEM BAM (PM$_{2.5}$; 24-hr mean)
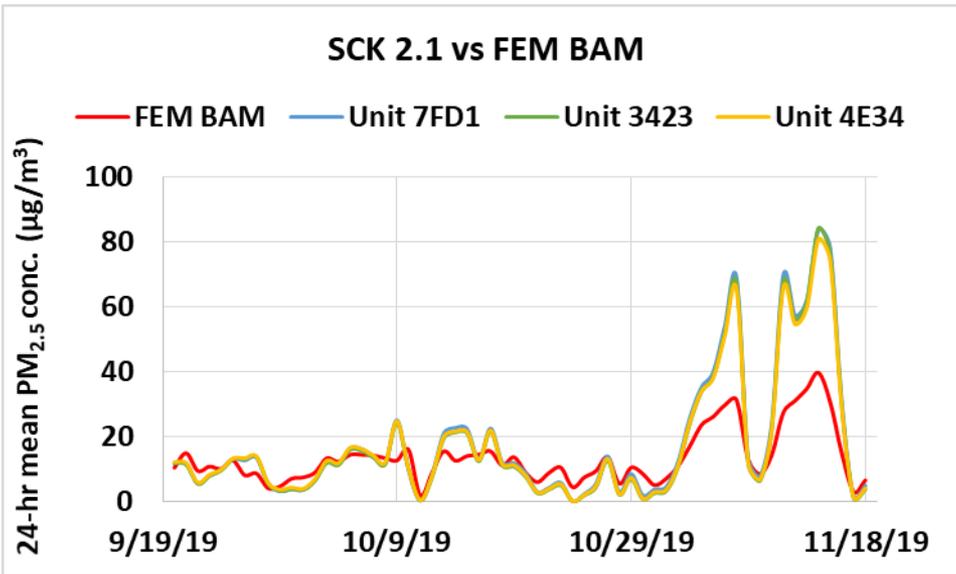
- SCK 2.1 sensors showed very strong correlations with the corresponding FEM BAM data (R$^2 \sim$ 0.90)

- Overall, the SCK 2.1 sensors underestimated the PM$_{2.5}$ mass concentrations when PM$_{2.5}$ mass concentrations were lower than 10 µg/m^3 and overestimated the PM$_{2.5}$ mass concentrations when PM$_{2.5}$ mass concentrations were higher than 10 µg/m^3 as measured by FEM BAM

- The SCK 2.1 sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM BAM
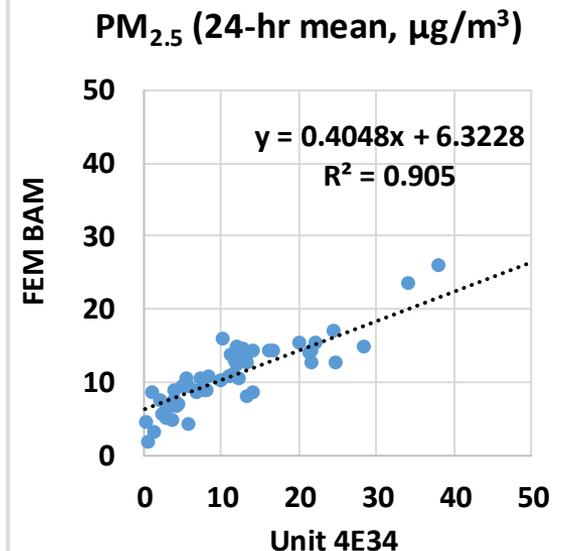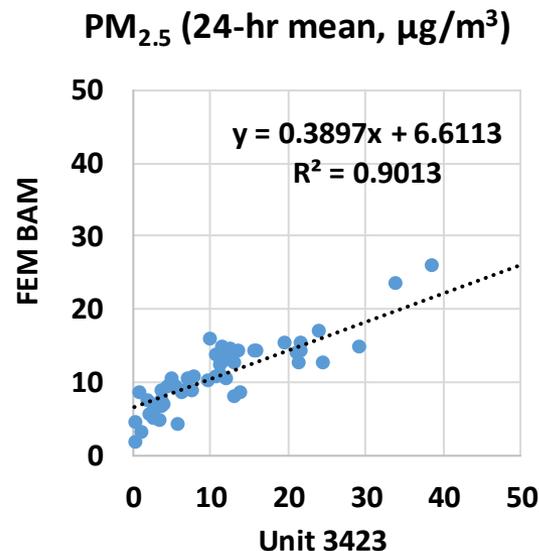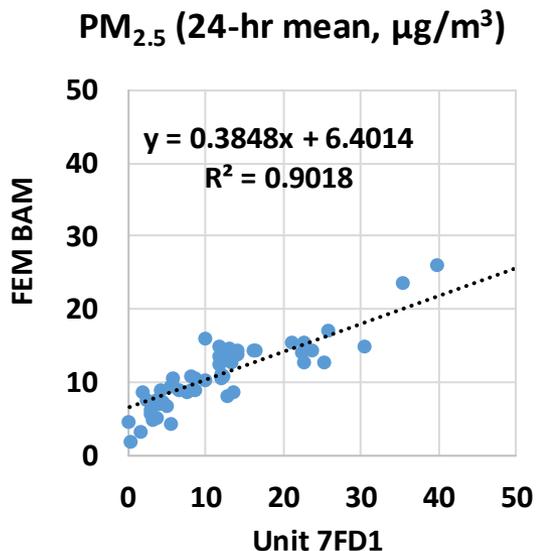
SCK 2.1 vs FEM BAM (PM$_{10}$; 24-hr mean)
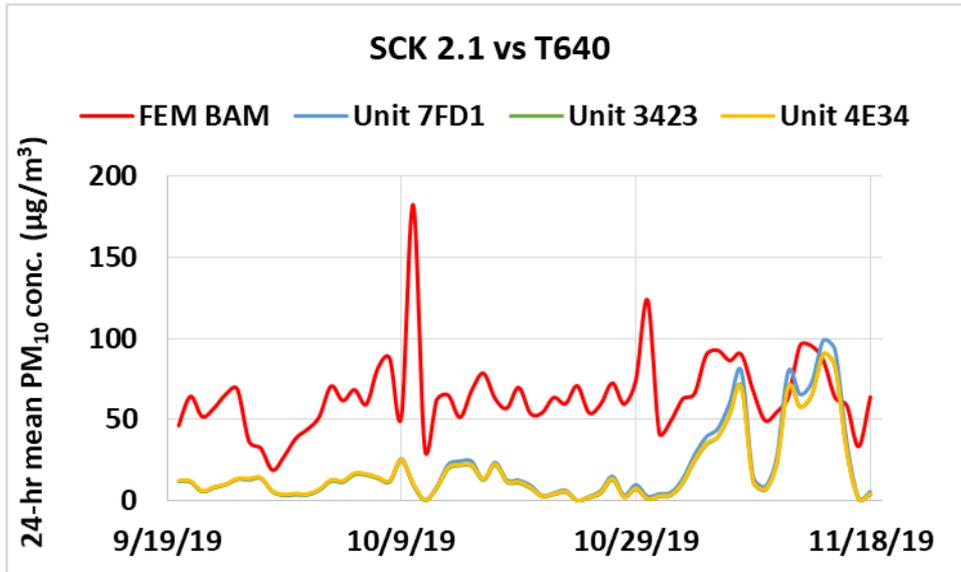
- SCK 2.1 sensors showed very weak correlations with the corresponding FEM BAM data (R^2 ~ 0.10)
- Overall, the SCK 2.1 sensors underestimated the PM$_{10}$ mass concentrations measured by FEM BAM
- The SCK 2.1 sensors did not seem to track the PM$_{10}$ diurnal variations as recorded by FEM BAM
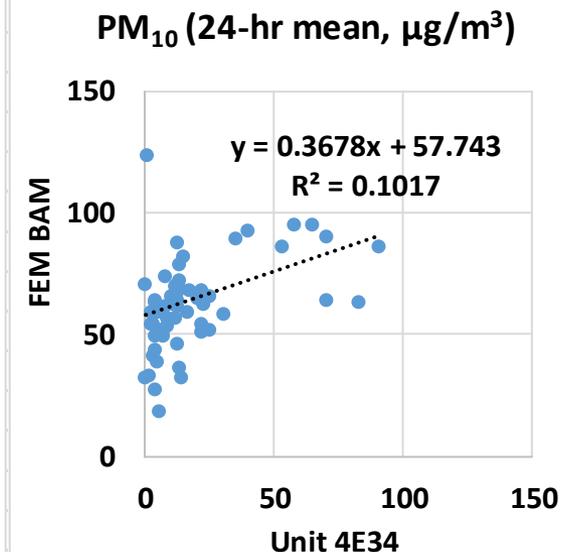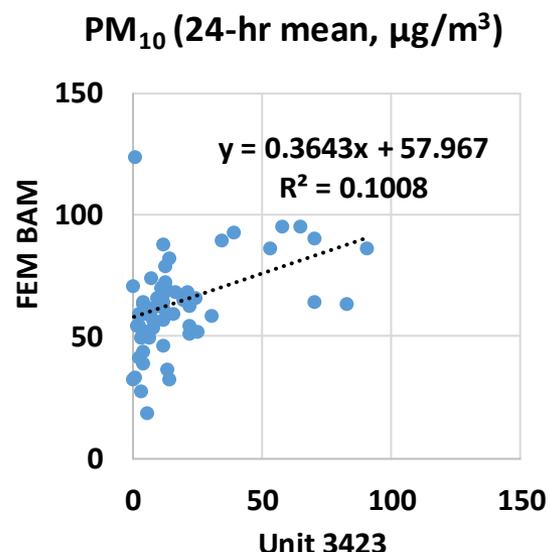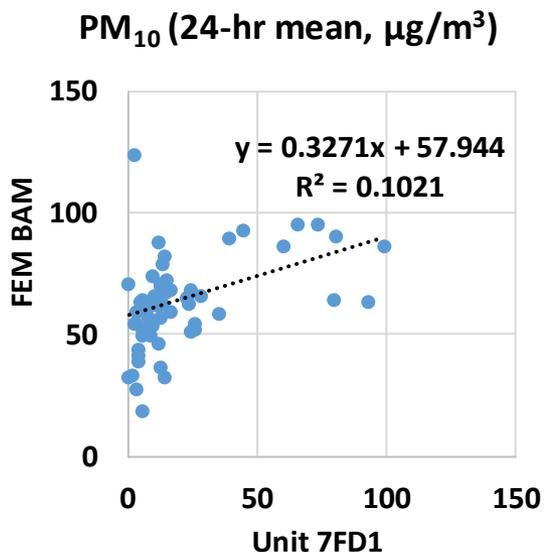
SCK 2.1 vs FEM T640 (PM$_{2.5}$; 5-min mean)
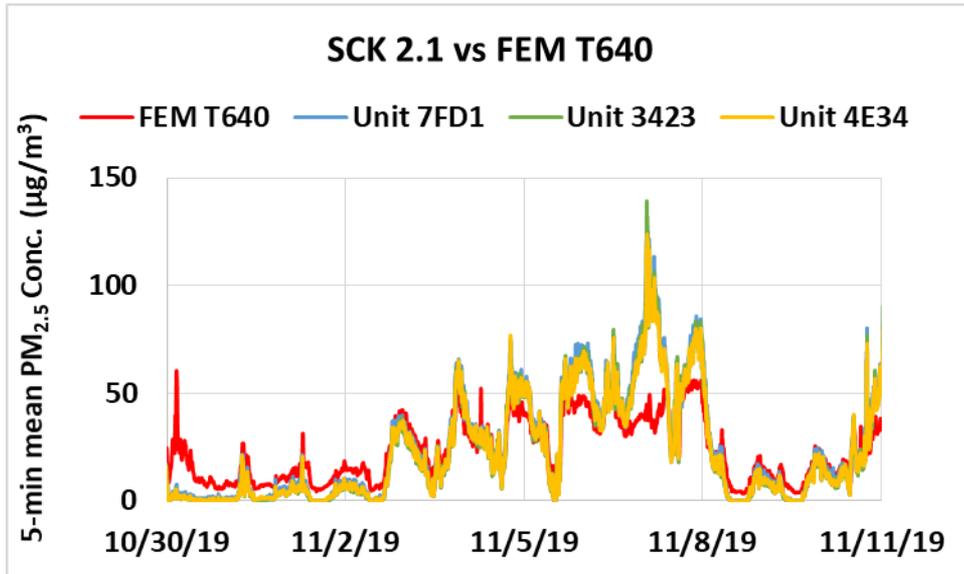
- SCK 2.1 sensors showed strong correlations with the corresponding FEM T640 data (R^2 ~ 0.77)

- Overall, the SCK 2.1 sensors underestimated the PM$_{2.5}$ mass concentrations when PM$_{2.5}$ mass concentrations were lower than 20 µg/m^3 and overestimated the PM$_{2.5}$ mass concentrations when PM$_{2.5}$ mass concentrations were higher than 20 µg/m^3 as measured by FEM T640

- The SCK 2.1 sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM T640
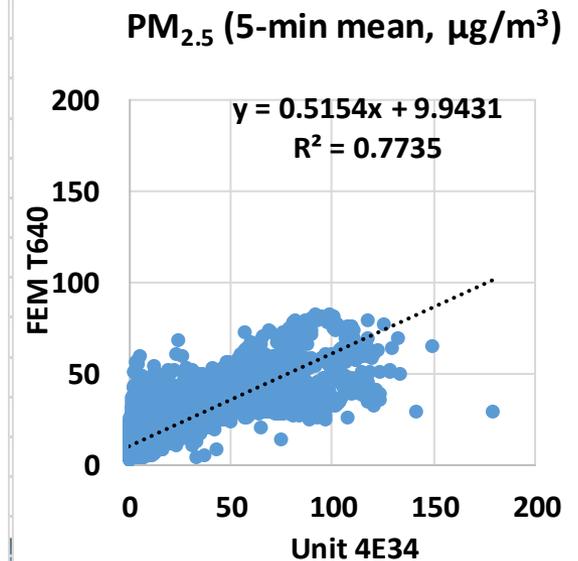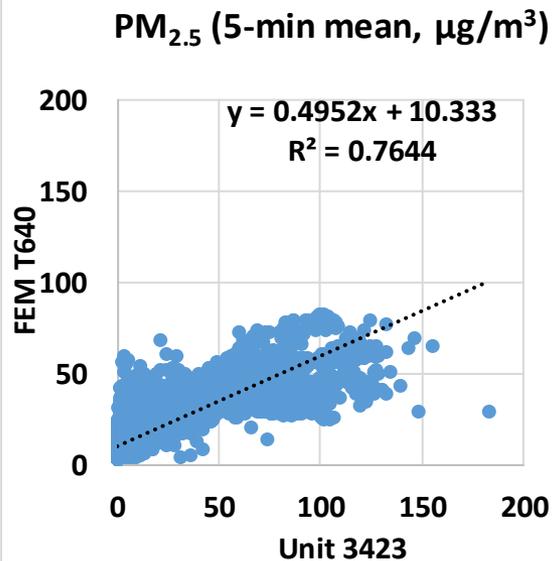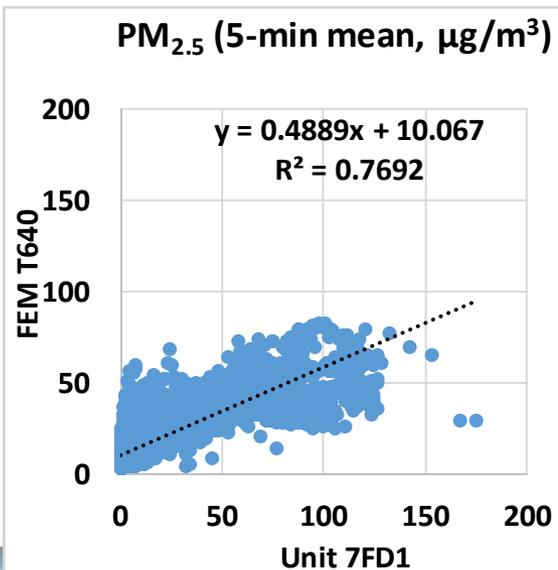
SCK 2.1 vs T640 (PM$_{10}$; 5-min mean)
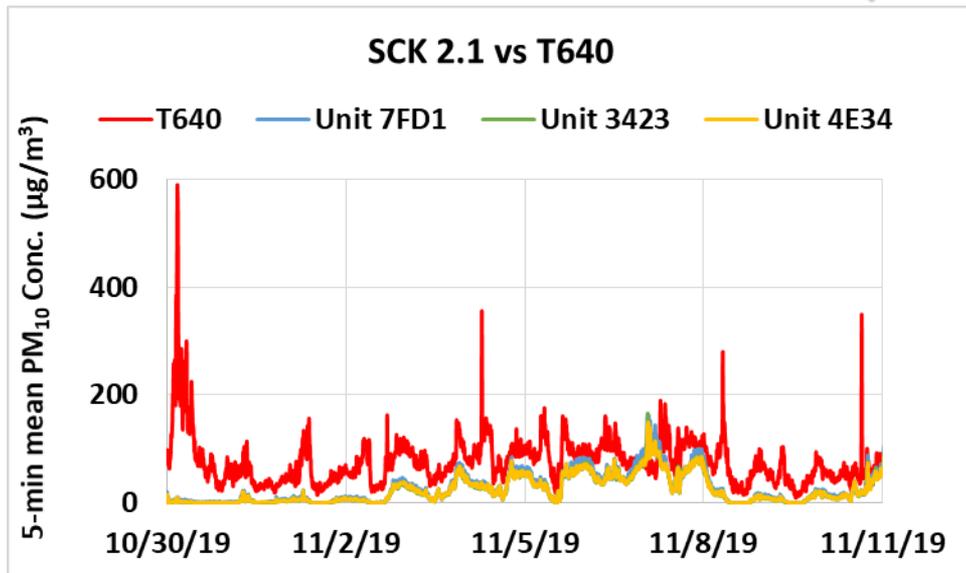
- SCK 2.1 sensors did not correlate with the corresponding T640 data ($R^2 \sim 0.086$)
- Overall, the SCK 2.1 sensors underestimated the PM$_{10}$ mass concentrations measured by T640
- The SCK 2.1 sensors did not seem to track the PM$_{10}$ diurnal variations as recorded by T640

PM$_{10}$ (5-min mean, μg/m³)
Unit 7FD1
$y = 0.4716x + 56.041$
$R^2 = 0.0855$

PM$_{10}$ (5-min mean, μg/m³)
Unit 3423
$y = 0.5315x + 55.959$
$R^2 = 0.0853$

PM$_{10}$ (5-min mean, μg/m³)
Unit 4E34
$y = 0.5417x + 55.52$
$R^2 = 0.0881$
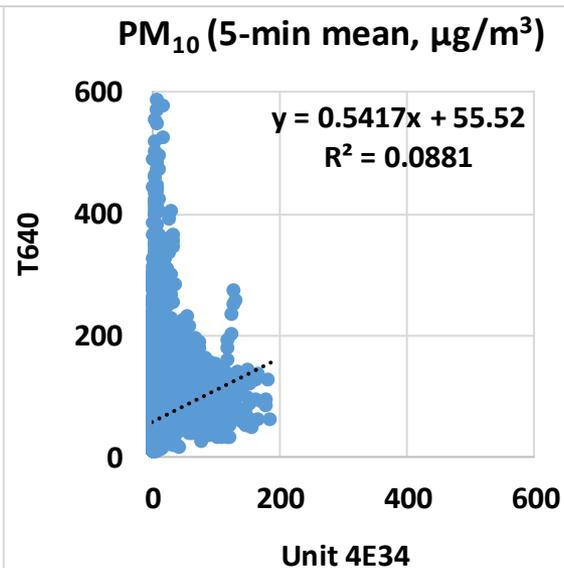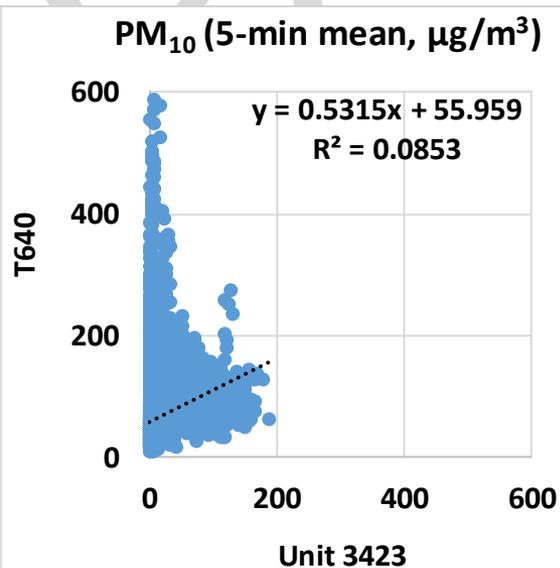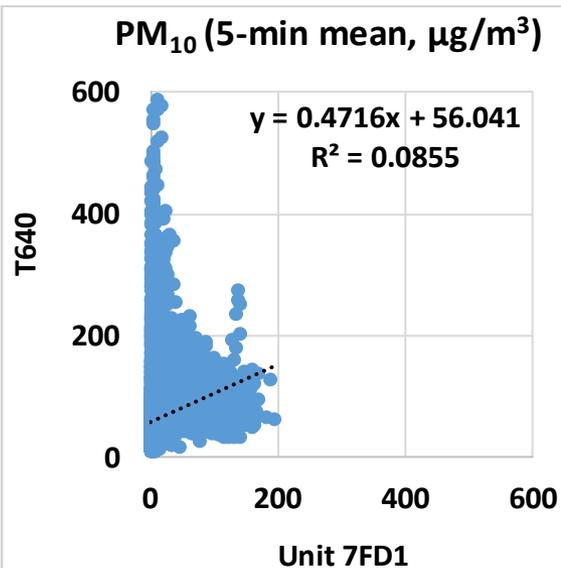
SCK 2.1 vs FEM T640 (PM$_{2.5}$; 1-hr mean)

SCK 2.1 vs FEM T640

Legend: FEM T640 — Unit 7FD1 — Unit 3423 — Unit 4E34

- SCK 2.1 sensors showed strong correlations with the corresponding FEM T640 data (R^2 ~ 0.79)

- Overall, the SCK 2.1 sensors underestimated the PM$_{2.5}$ mass concentrations when PM$_{2.5}$ mass concentrations were lower than 20 µg/m^3 and overestimated the PM$_{2.5}$ mass concentrations when PM$_{2.5}$ mass concentrations were higher than 20 µg/m^3 as measured by FEM T640

- The SCK 2.1 sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM T640

PM$_{2.5}$ (1-hr mean, µg/m^3)

$y = 0.4934x + 9.9858$
$R^2 = 0.7899$

Unit 7FD1

PM$_{2.5}$ (1-hr mean, µg/m^3)

$y = 0.4999x + 10.252$
$R^2 = 0.7853$

Unit 3423

PM$_{2.5}$ (1-hr mean, µg/m^3)

$y = 0.5209x + 9.8559$
$R^2 = 0.7949$

Unit 4E34
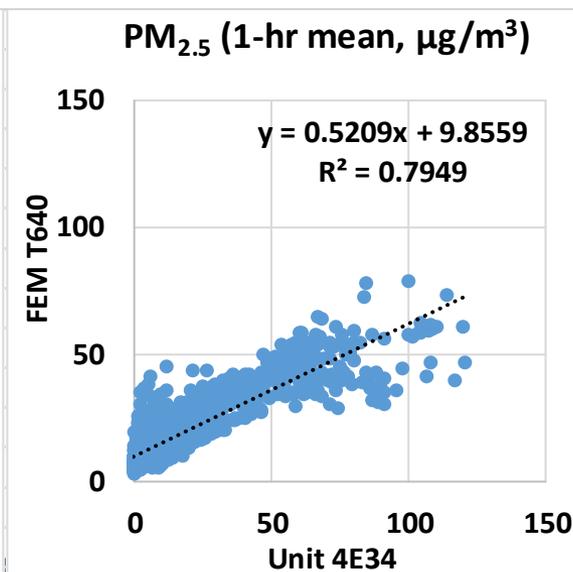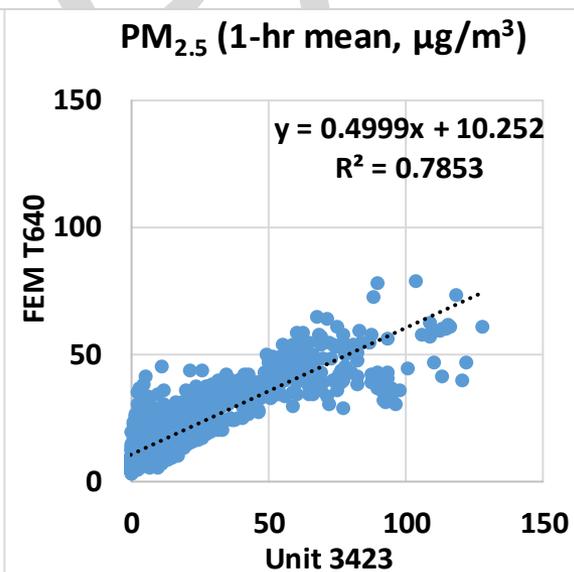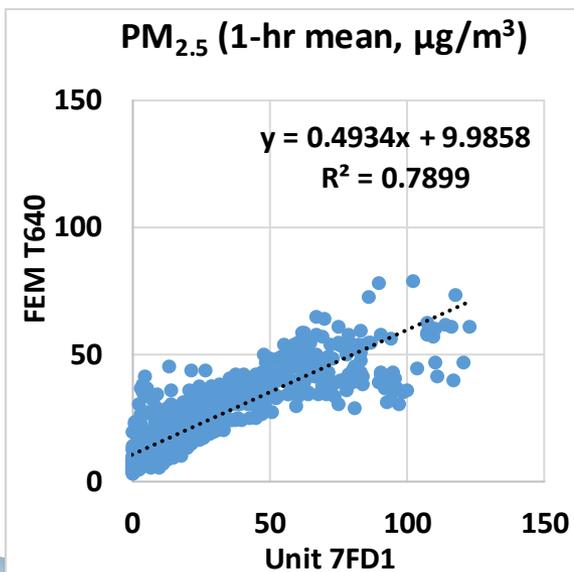
SCK 2.1 vs T640 (PM$_{10}$; 1-hr mean)
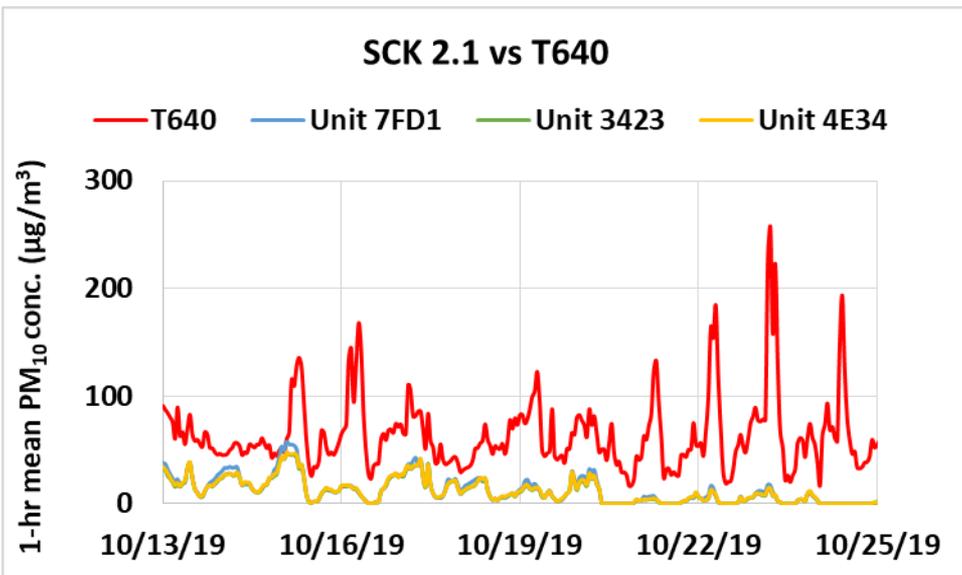
- SCK 2.1 sensors did not correlate with the corresponding T640 data ($R^2 \sim 0.097$)
- Overall, the SCK 2.1 sensors underestimated the PM$_{10}$ mass concentrations measured by T640
- The SCK 2.1 sensors did not seem to track the PM$_{10}$ diurnal variations as recorded by T640
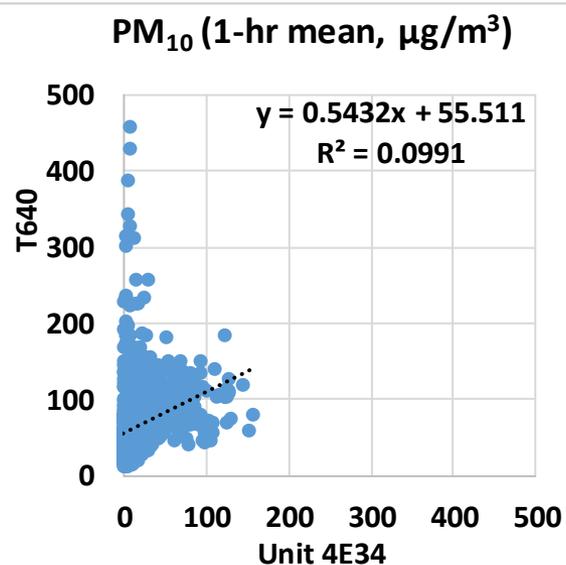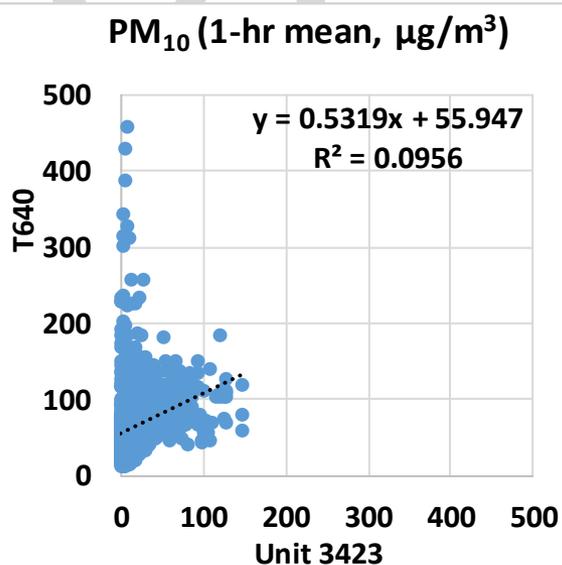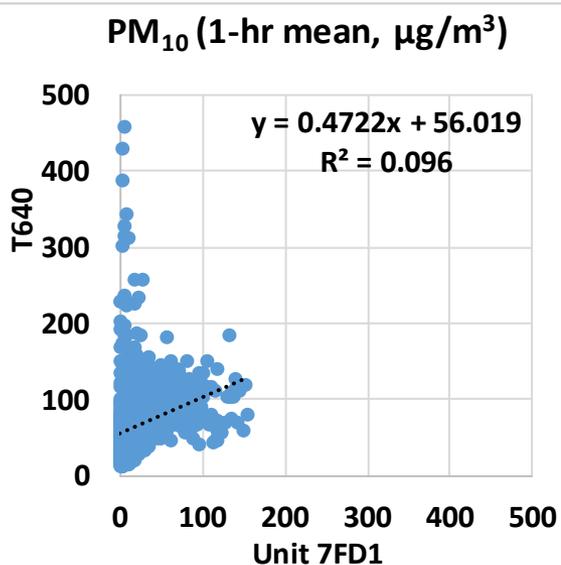
SCK 2.1 vs FEM T640 (PM$_{2.5}$; 24-hr mean)
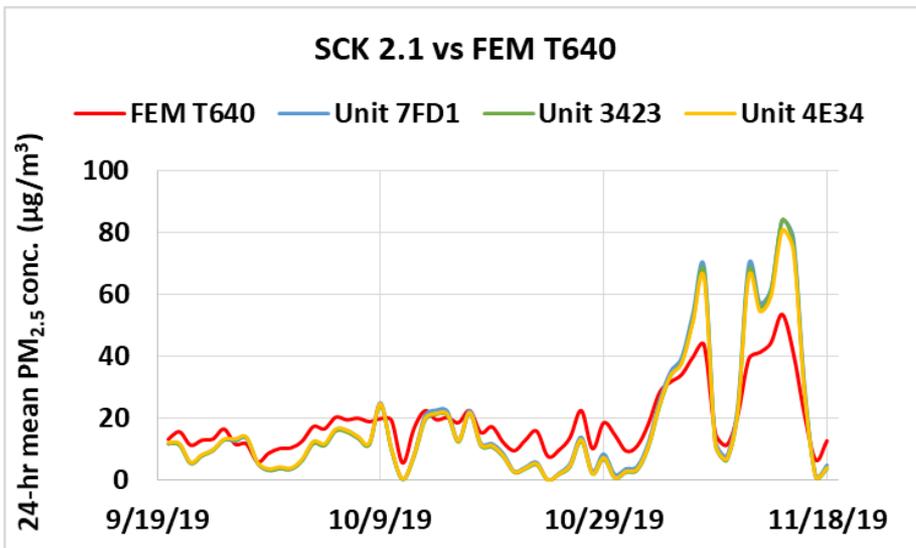
- SCK 2.1 sensors showed strong correlations with the corresponding FEM T640 data (R^2 ~ 0.91)

- Overall, the SCK 2.1 sensors underestimated the PM$_{2.5}$ mass concentrations when PM$_{2.5}$ mass concentrations were lower than 20 µg/m^3 and overestimated the PM$_{2.5}$ mass concentrations when PM$_{2.5}$ mass concentrations were higher than 20 µg/m^3 as measured by FEM T640

- The SCK 2.1 sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM T640
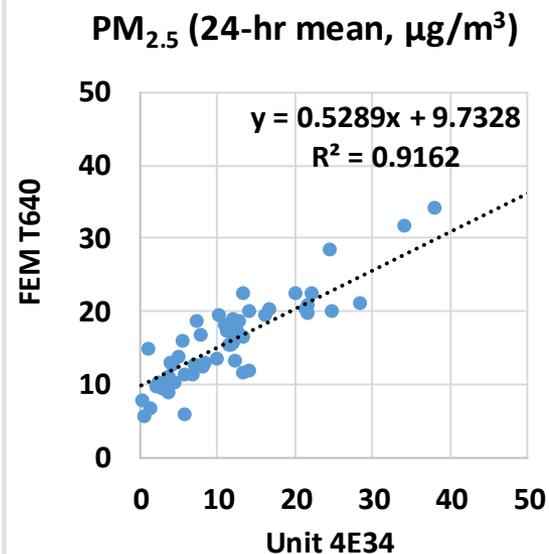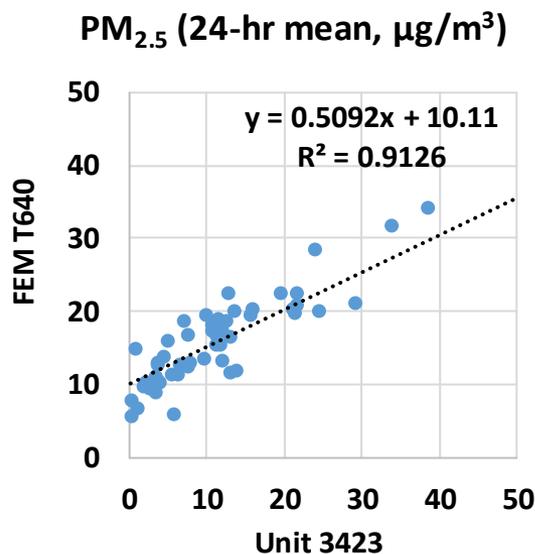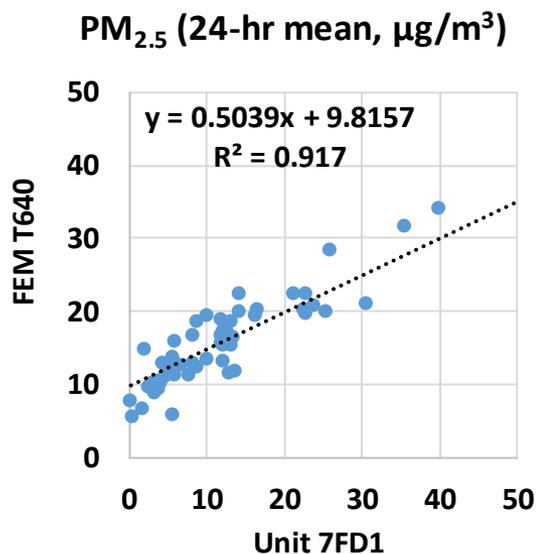
SCK 2.1 vs T640 (PM$_{10}$; 24-hr mean)
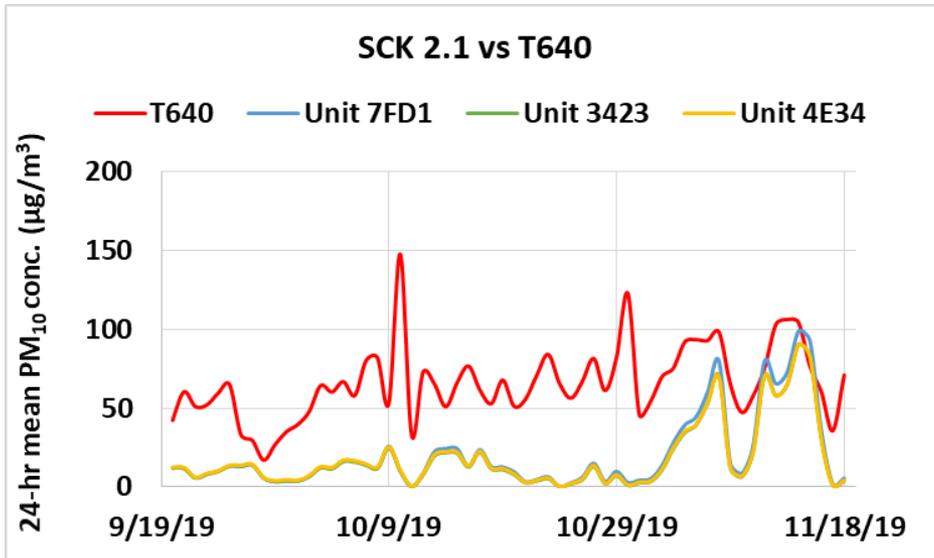
- SCK 2.1 sensors showed very weak correlations with the corresponding T640 data ($R^2 \sim 0.22$)
- Overall, the SCK 2.1 sensors underestimated the PM$_{10}$ mass concentrations measured by T640
- The SCK 2.1 sensors did not seem to track the PM$_{10}$ diurnal variations as recorded by T640
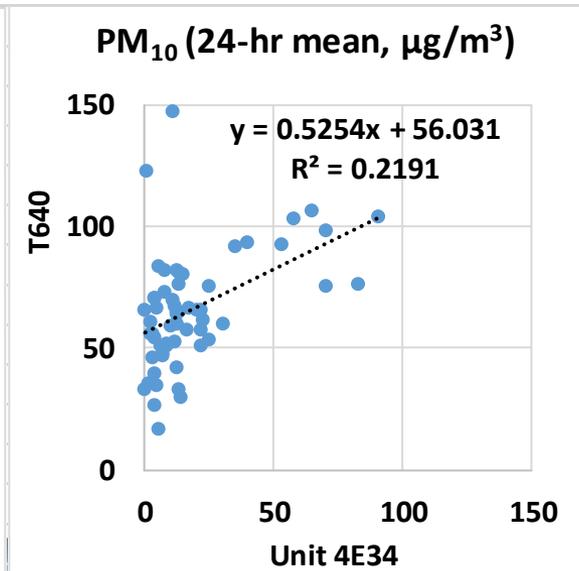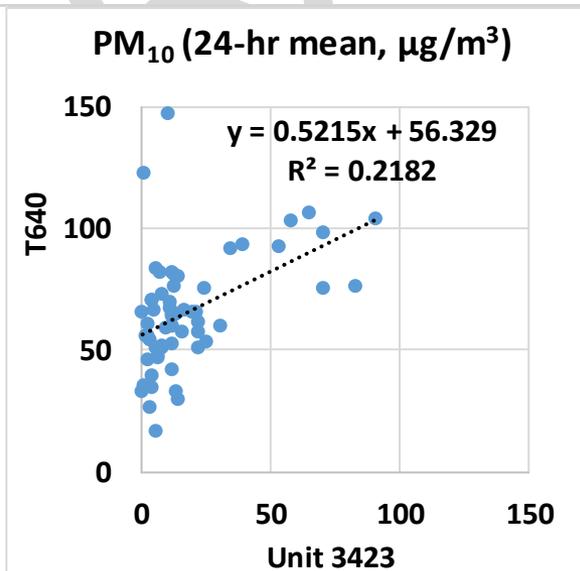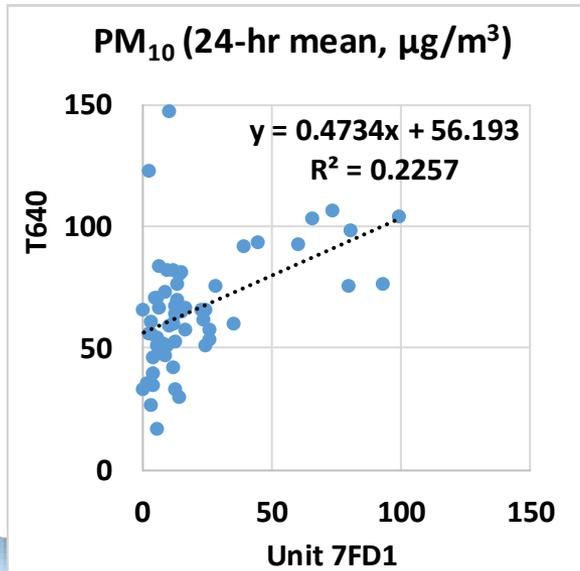
# SCK 2.1 vs South Coast AQMD Met Station (Temp; 5-min mean)
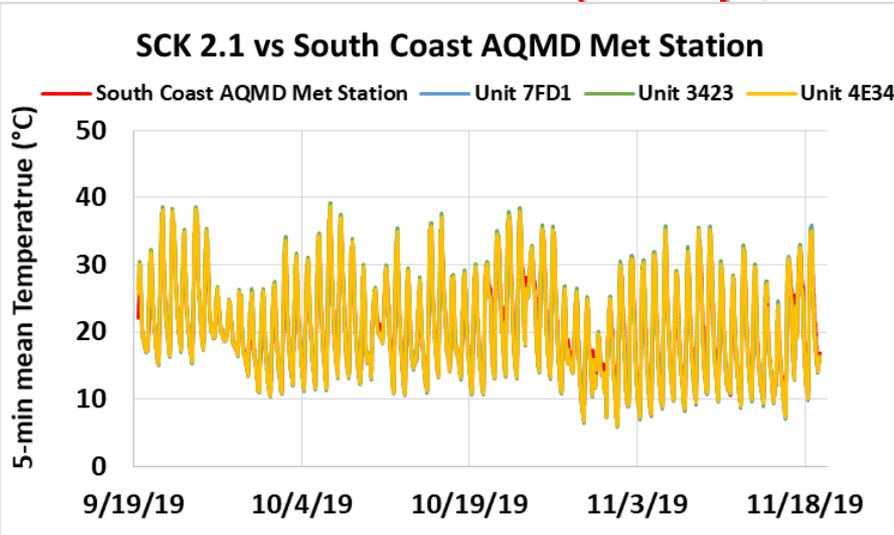
- SCK 2.1 temperature measurements showed very strong correlations with the corresponding South Coast AQMD Met Station data ($R^2 \sim 0.96$)

- Overall, the SCK 2.1 temperature measurements overestimated the corresponding South Coast AQMD Met Station data

- The SCK 2.1 sensors seemed to track well the temperature diurnal variations as recorded by South Coast AQMD Met Station
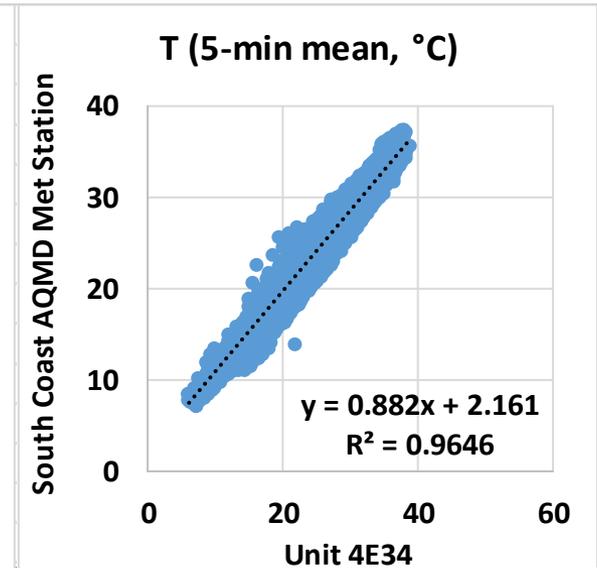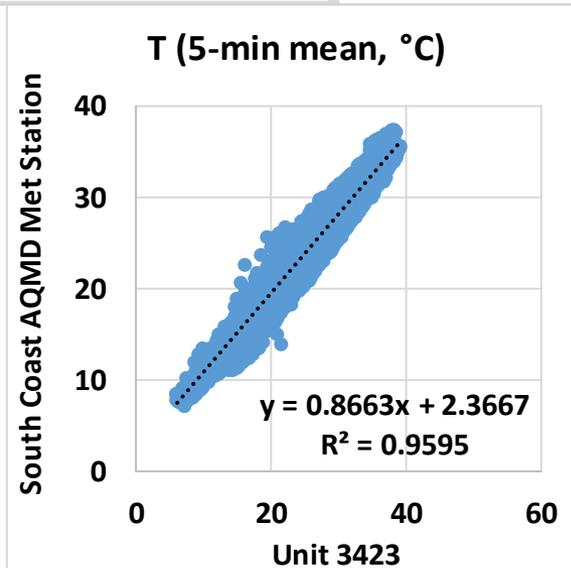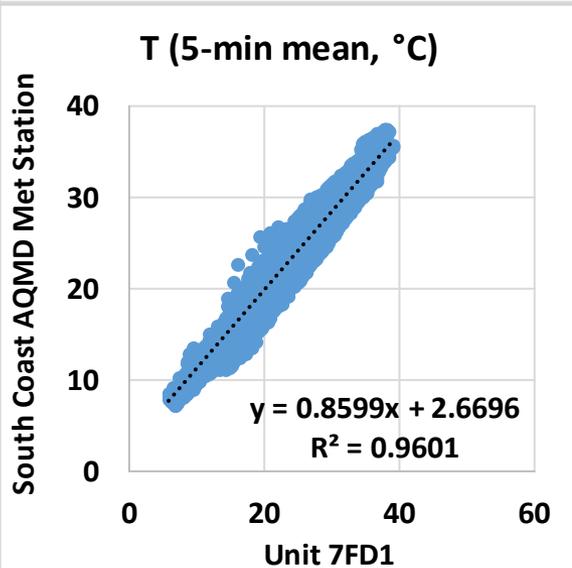
SCK 2.1 vs South Coast AQMD Met Station (RH; 5-min mean)
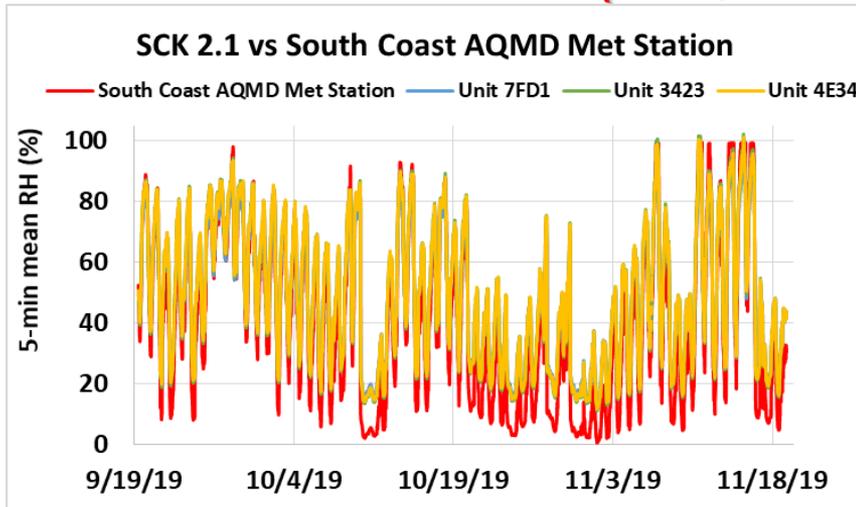
- SCK 2.1 RH measurements showed very strong correlations with the corresponding South Coast AQMD Met Station data ($R^2 \sim 0.98$)

- Overall, the SCK 2.1 RH measurements overestimated the corresponding South Coast AQMD Met Station data

- The SCK 2.1 sensors seemed to track well the RH diurnal variations as recorded by South Coast AQMD Met Station
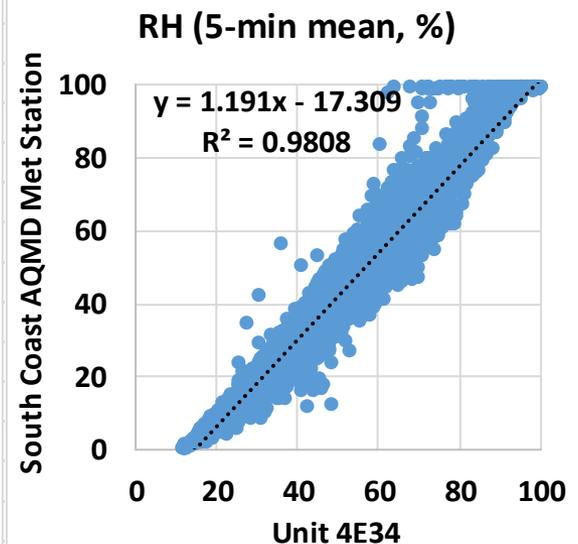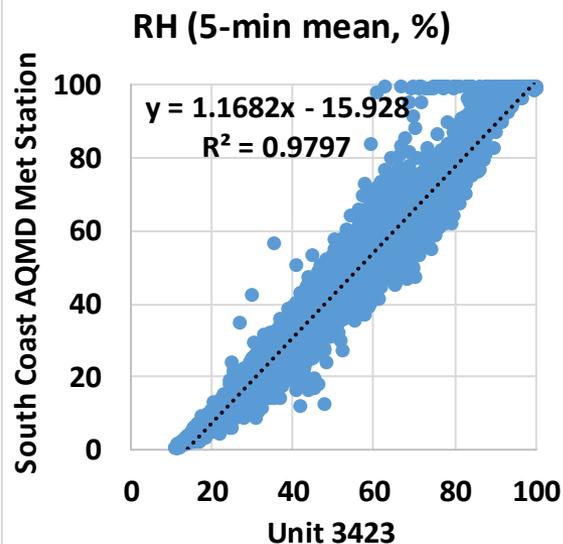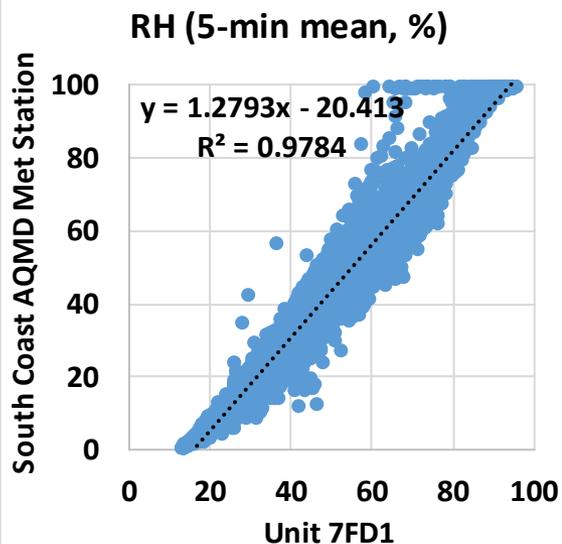
Discussion

- The three **SCK 2.1** sensors' data recovery from all units was ~ 100% for all PM measurements

- The absolute intra-model variability was ~ 0.35, 0.44 and 1.13 $\mu g/m^3$ for $PM_{1.0}$, $PM_{2.5}$ and PM_{10}, respectively

- The reference instruments (GRIMM, BAM and T640) showed strong to very strong correlations with each other for both $PM_{2.5}$ (R^2 ~ 0.90) and PM_{10} (R^2 ~ 0.88) mass concentration measurements (1-hr mean)

- $PM_{1.0}$ mass concentration measurements measured by SCK 2.1 sensors showed very strong correlations with the corresponding GRIMM data (R^2 ~ 0.96, 1-hr mean). The sensors underestimated $PM_{1.0}$ mass concentrations when $PM_{1.0}$ mass concentrations were lower than 30 $\mu g/m^3$ as measured by GRIMM

- $PM_{2.5}$ mass concentration measurements measured by SCK 2.1 sensors showed strong correlations with the corresponding FEM GRIMM, FEM BAM and FEM T640 data (R^2 ~ 0.79, 0.71 and 0.79, respectively, 1-hr mean). The sensors underestimated $PM_{2.5}$ mass concentrations when $PM_{2.5}$ mass concentrations were lower than 20, 10 and 20 $\mu g/m^3$ as measured by FEM GRIMM, FEM BAM and FEM T640, respectively; and overestimated $PM_{2.5}$ mass concentrations when $PM_{2.5}$ mass concentrations were higher than 20, 10 and 20 $\mu g/m^3$ as measured by FEM GRIMM, FEM BAM and FEM T640, respectively

- PM_{10} mass concentration measurements measured by SCK 2.1 sensors did not correlate with the corresponding GRIMM, FEM BAM and T640 data (R^2 ~ 0.07, 0.04 and 0.097, respectively; 1-hr mean) and underestimated PM_{10} mass concentrations measured by GRIMM, 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