# Field Evaluation
# Magnasci SRL uRADMonitor INDUSTRIAL (version HW103) Sensor



South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

# Background

- From 11/02/2018 to 01/08/2019, three **Magnasci SRL uRADMonitor INDUSTRIAL version HW103 (hereinafter abbreviated as uRADMonitor INDUSTRIAL)** sensors were deployed at a South Coast AQMD stationary ambient monitoring site in Rubidoux and were run side-by-side with three reference instruments measuring the same pollutants

- uRADMonitor INDUSTRIAL (*3 units tested*):
  - PM sensor: Winsen ZH03A (optical; non-FEM)
  - Gas sensor: Ozone (Winsen ZE03-$O_3$), carbon monoxide (Winsen ZE03-CO), sulfur dioxide (Winsen ZE03-$SO_2$), nitrogen dioxide (Winsen ZE03-$NO_2$)
  - Each unit reports: $PM_{1.0}$, $PM_{2.5}$ and $PM_{10}$ ($\mu g/m^3$), Carbon monoxide (ppm), Ozone (ppm), $SO_2$ (ppm), $NO_2$(ppm)
  - Unit cost: ~$1300
  - Time resolution: 1- 5 min
  - Units IDs: 001D, 001E, 001F


- **South Coast AQMD Reference instruments:**
  - MetOne BAM (FEM $PM_{2.5}$ & $PM_{10}$), cost: ~$20,000
    - Time resolution: 1-hr
  - GRIMM (FEM $PM_{2.5}$), cost: ~$25,000 and up
    - Time resolution: 1-min
  - 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
  - $SO_2$ instrument; FEM, cost: ~$11,000
    - Time resolution: 1-min
  - Met station (T, RH, P, WS, WD), cost: ~$5,000
    - Time resolution: 1-min

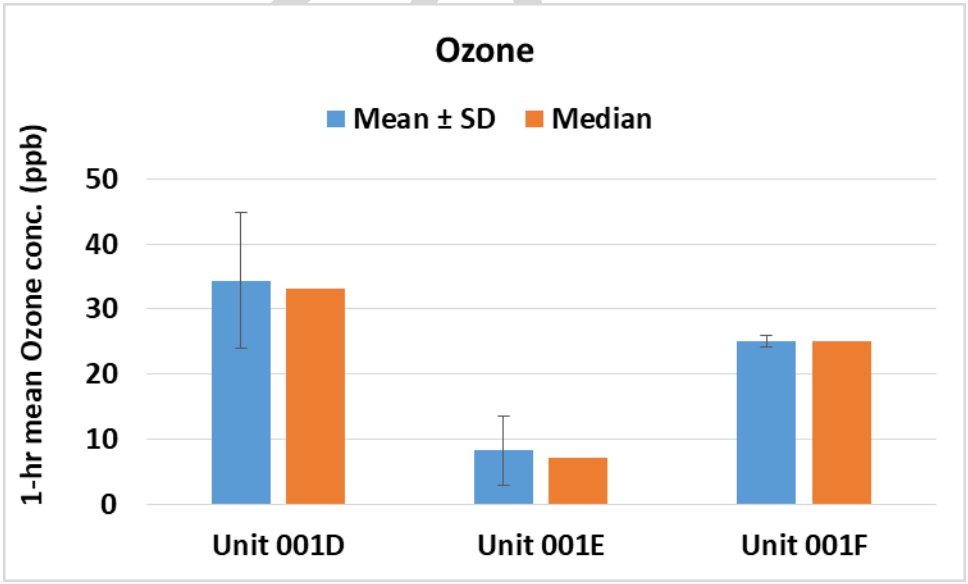
# Ozone ($O_3$) in uRADMonitor INDUSTRIAL

# Data validation & recovery

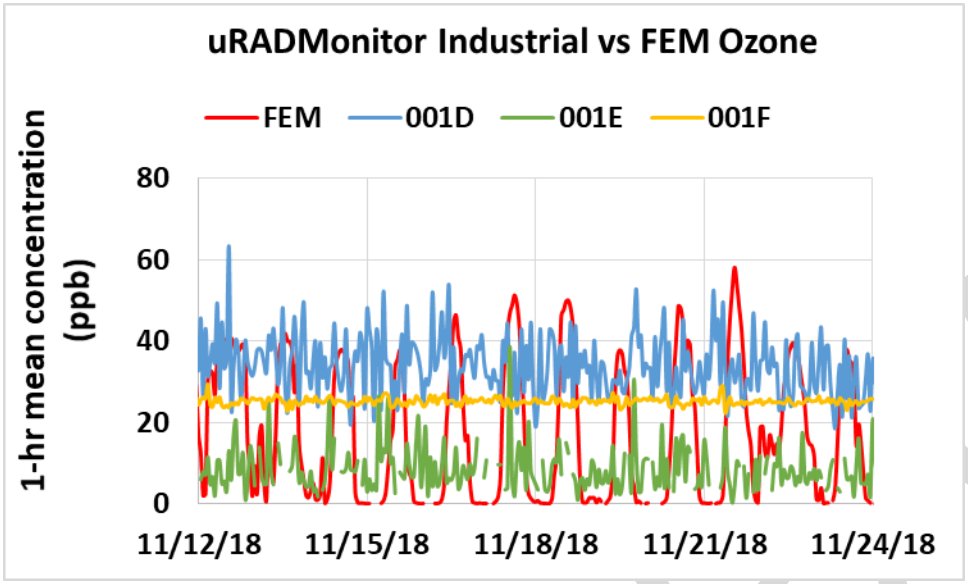
- Basic QA/QC procedures were used to validate the collected data (i.e. obvious outliers, negative values and invalid data-points were eliminated from the data-set)
- Data recovery from units 001D, 001E, and 001F is 99.9%, 84.5% and 99.9%, respectively. Data recovery is calculated based on the one hour averages due to the fact that the sensors have inconsistent time stamp, limiting comparisons at higher time resolution

# uRADMonitor INDUSTRIAL; intra-model variability

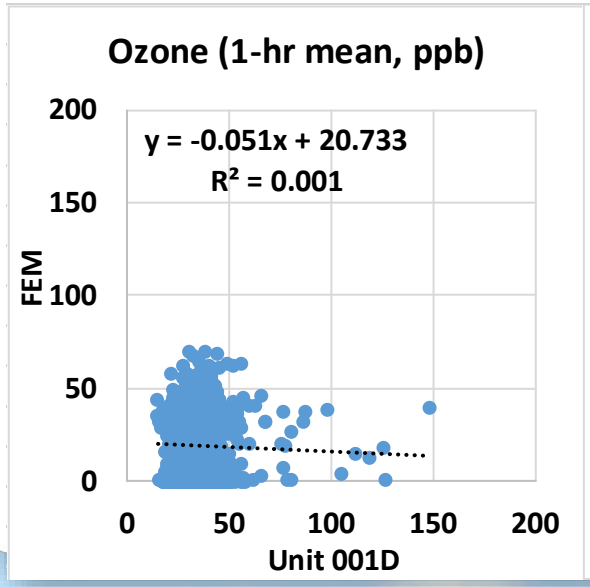
- High measurement variability (115%) was observed between the three uRADMonitor INDUSTRIAL units for ozone measurements.

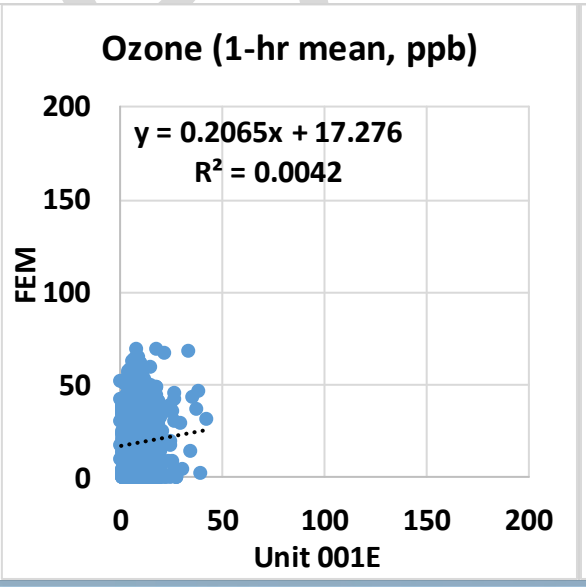


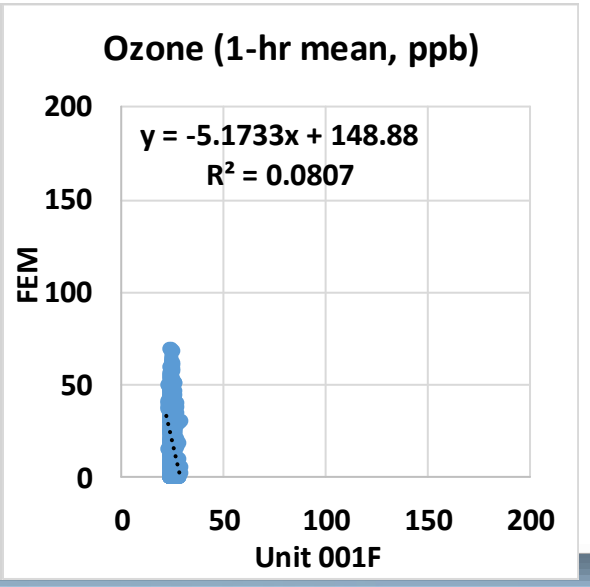
# uRADMonitor INDUSTRIAL vs FEM (Ozone; 1-hr mean)




- uRADMonitor INDUSTRIAL sensors do not correlate with the corresponding FEM ozone data ($R^2$ ~ 0.03)
- Overall, the uRADMonitor INDUSTRIAL sensors (unit 001E and 001F) underestimate while unit 001D overestimates ozone concentration as measured by the FEM instrument
- The uRADMonitor INDUSTRIAL sensors do not track the ozone diurnal variations as recorded by the FEM instrument



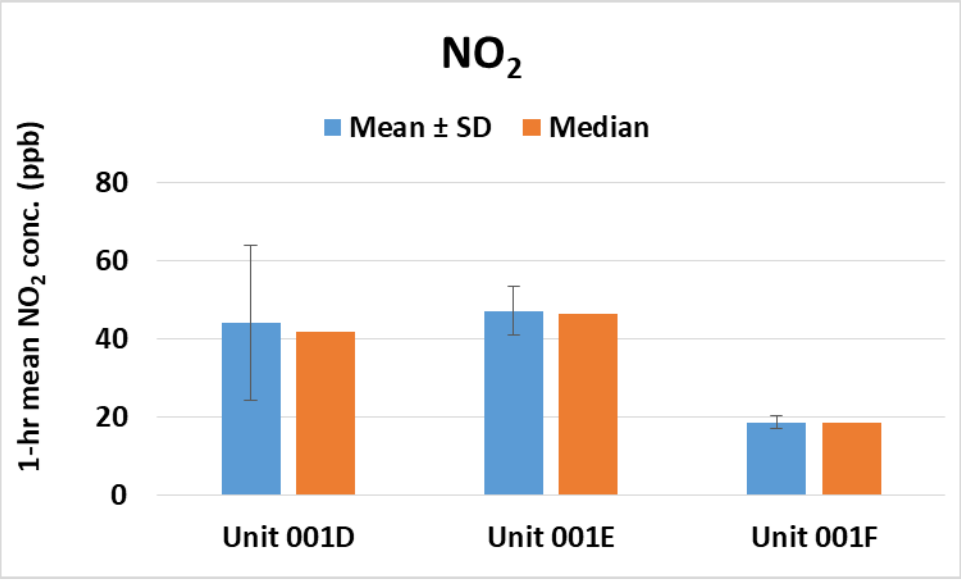
# Nitrogen dioxide ($NO_2$) in uRADMonitor INDUSTRIAL

# Data validation & recovery

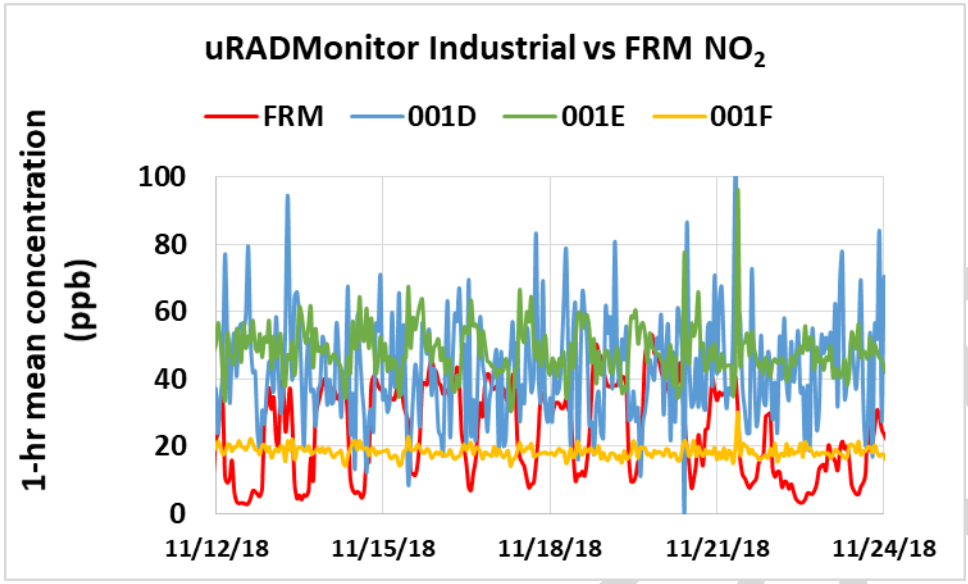
- Basic QA/QC procedures were used to validate the collected data (i.e. obvious outliers, negative values and invalid data-points were eliminated from the data-set)
- Data recovery from units 001D, 001E, and 001F is 99.8%, 99.9% and 99.9%, respectively. Data recovery is calculated based on the one hour averages due to the fact that the sensors have inconsistent time stamp, limiting comparisons at higher time resolution

# uRADMonitor INDUSTRIAL; intra-model variability

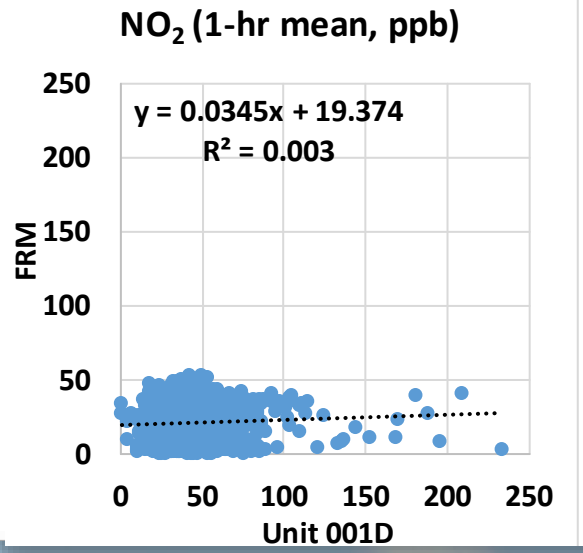
- High measurement variability (78%) was observed between the three uRADMonitor INDUSTRIAL units for $NO_2$ measurements

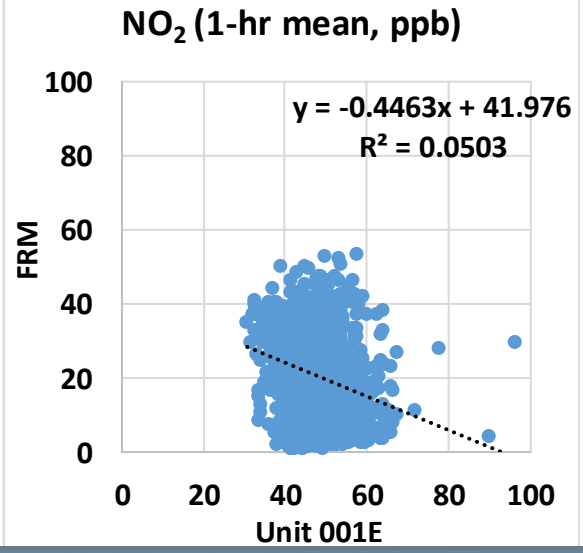


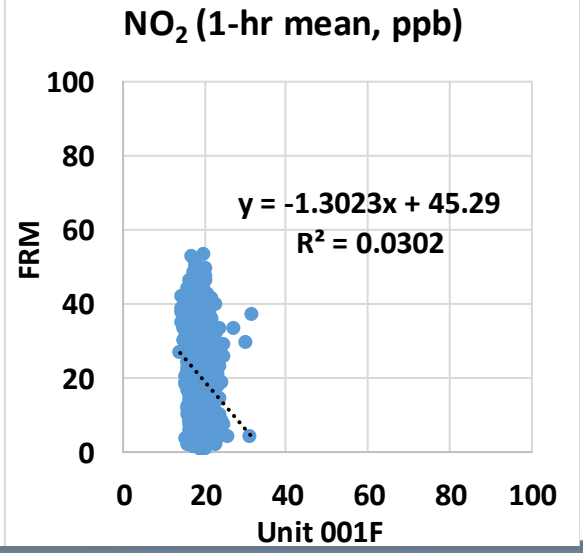
# uRADMonitor INDUSTRIAL vs FRM ($NO_2$; 1-hr mean)




- uRADMonitor INDUSTRIAL sensors do not correlate with the corresponding FRM $NO_2$ data ($R^2$ ~ 0.03)
- Overall, the uRADMonitor INDUSTRIAL sensors (units 001D and 001E) overestimate while unit 001F underestimates $NO_2$ concentration as measured by the FRM instrument
- The uRADMonitor INDUSTRIAL sensors do not track the $NO_2$ diurnal variations as recorded by the FRM instrument



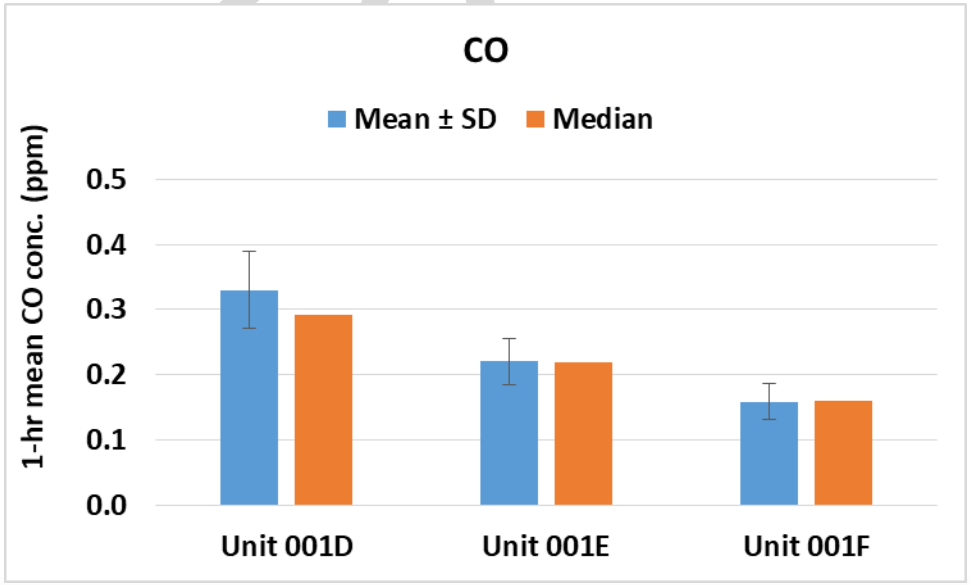
# Carbon Monoxide (CO) in uRADMonitor INDUSTRIAL

# Data validation & recovery

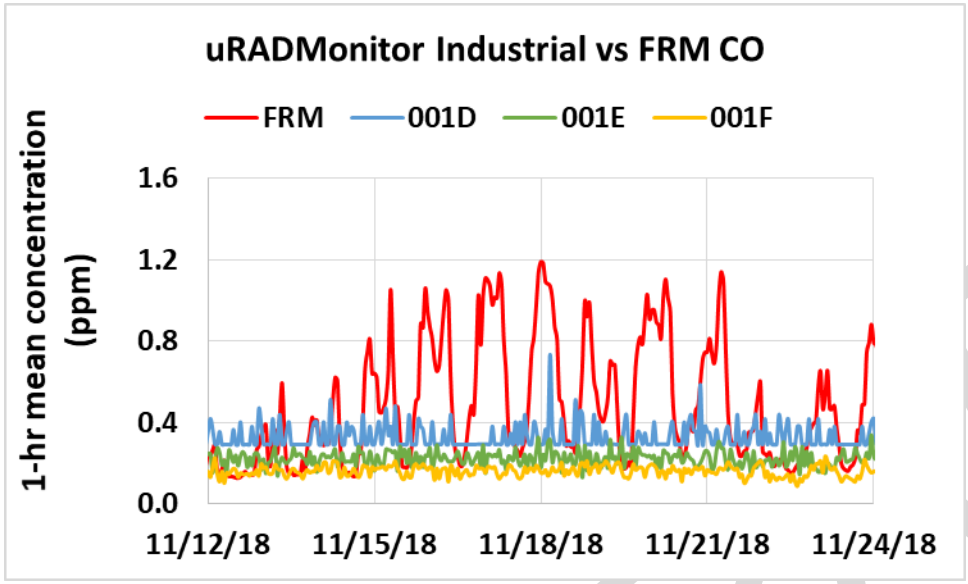
- Basic QA/QC procedures were used to validate the collected data (i.e. obvious outliers, negative values and invalid data-points were eliminated from the data-set)
- Data recovery from units 001D, 001E, and 001F is 99.9%, 99.9% and 99.9%, respectively. Data recovery is calculated based on the one hour averages due to the fact that the sensors have inconsistent time stamp, limiting comparisons at higher time resolution

# uRADMonitor INDUSTRIAL; intra-model variability

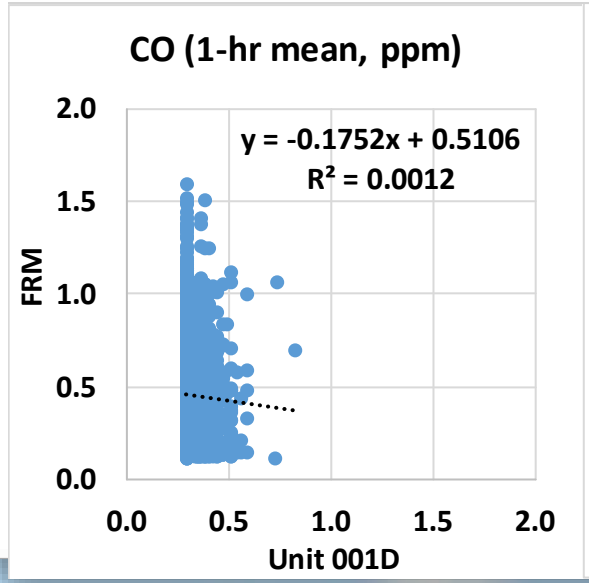
- High measurement variability (73%) was observed between the three uRADMonitor INDUSTRIAL units for CO measurements

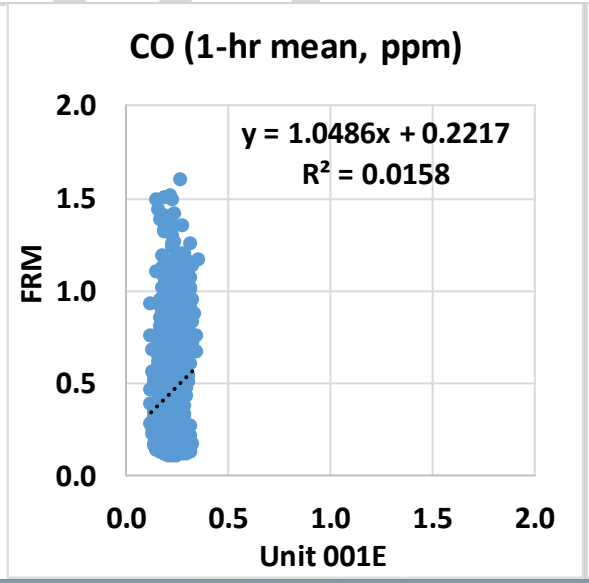


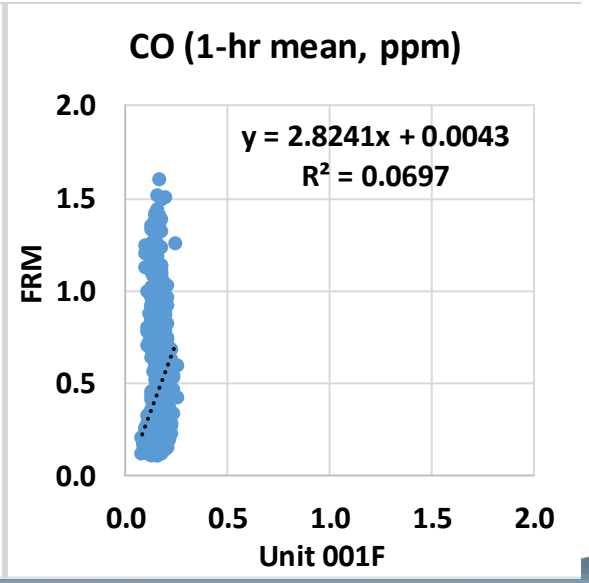
# uRADMonitor INDUSTRIAL vs FRM (CO; 1-hr mean)




- uRADMonitor INDUSTRIAL sensors do not correlate with the corresponding FRM CO data ($R^2$ ~ 0.03)
- Overall, the uRADMonitor INDUSTRIAL sensors underestimates CO concentration as measured by the FRM instrument
- The uRADMonitor INDUSTRIAL sensors do not track the CO diurnal variations as recorded by the FRM instrument



# PM ($PM_{1.0}$, $PM_{2.5}$, $PM_{10}$) in uRADMonitor INDUSTRIAL

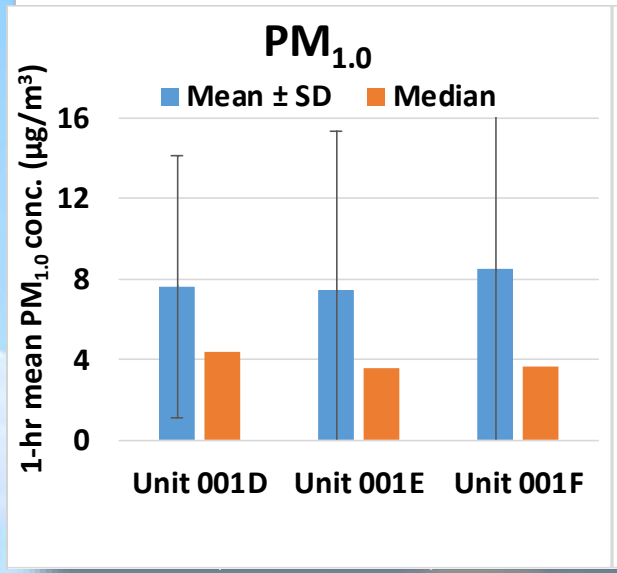
# Data validation & recovery

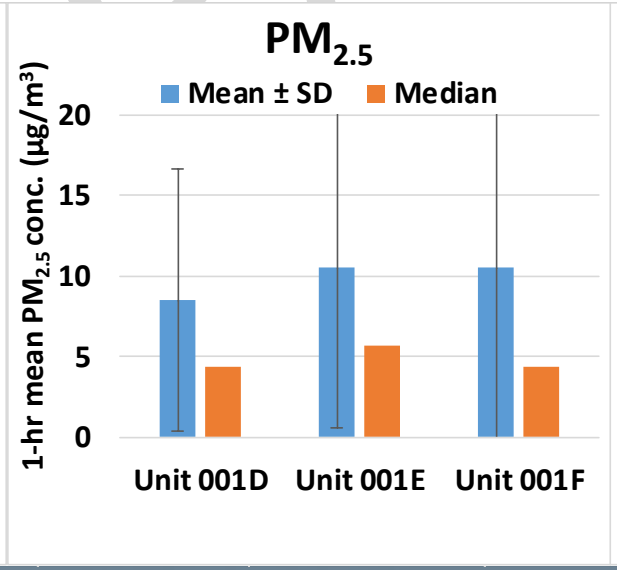
- Basic QA/QC procedures were used to validate the collected data (i.e. obvious outliers, negative values and invalid data-points were eliminated from the data-set)
- Data recovery from units 001D, 001E, and 001F is 99.9%, for all PM fractions. Data recovery is calculated based on the one hour averages due to the fact that the sensors have inconsistent time stamp, limiting comparisons at higher time resolution

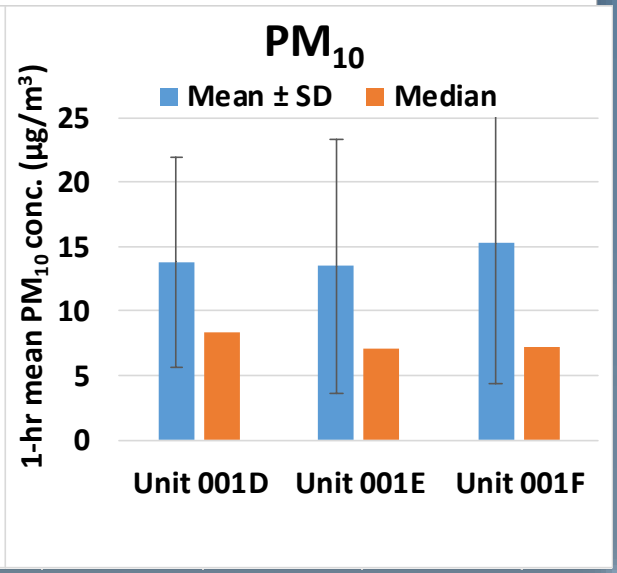
# uRADMonitor INDUSTRIAL; intra-model variability

- Moderate measurement variability (12-20%) was observed between the three uRADMonitor INDUSTRIAL units for $PM_{1.0}$, $PM_{2.5}$ and $PM_{10}$



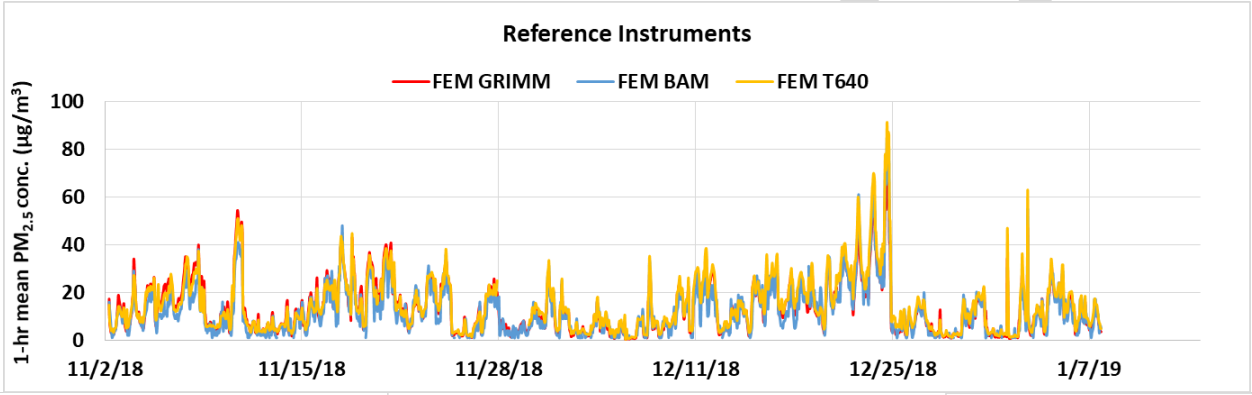


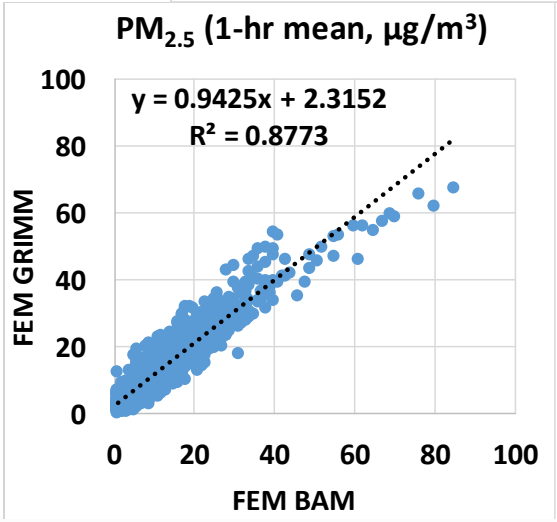



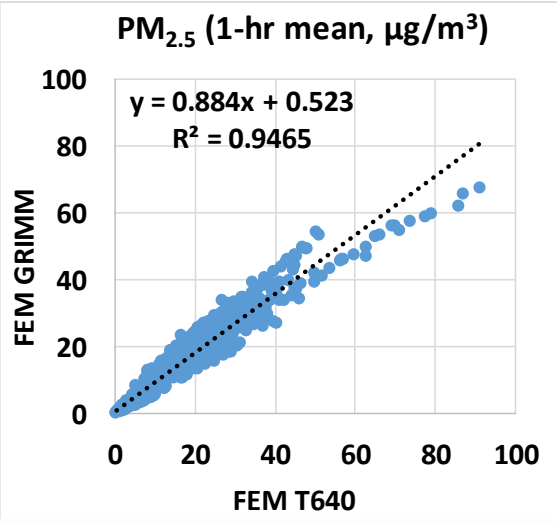



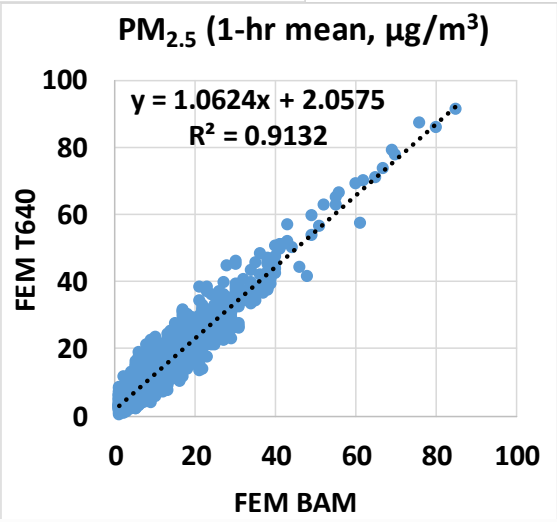
# Reference Instruments: $PM_{2.5}$ GRIMM, BAM & T640

- 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 99.9%, 90.5 % and 96.6 %, respectively
- Strong to very strong correlations between the three reference instruments for $PM_{2.5}$ measurements ($0.87 < R^2 < 0.95$)



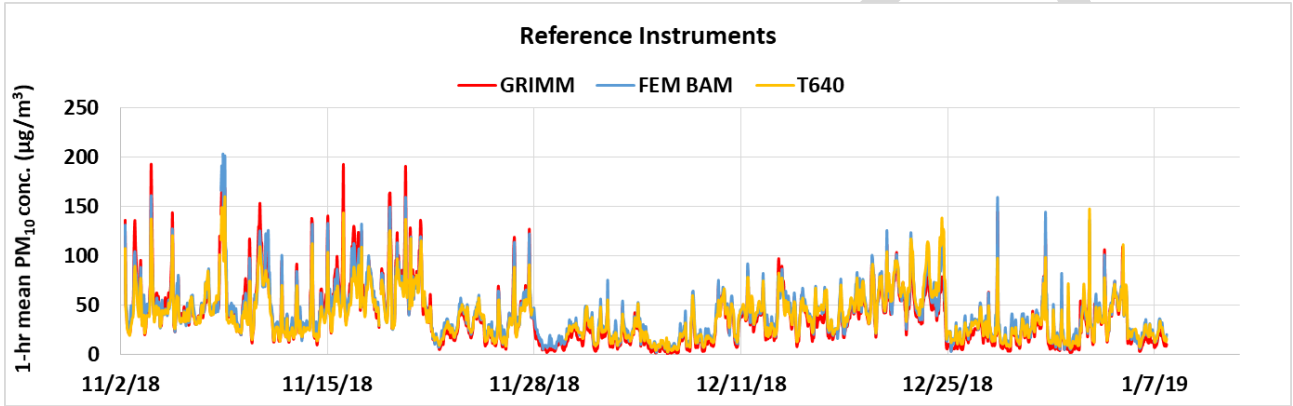



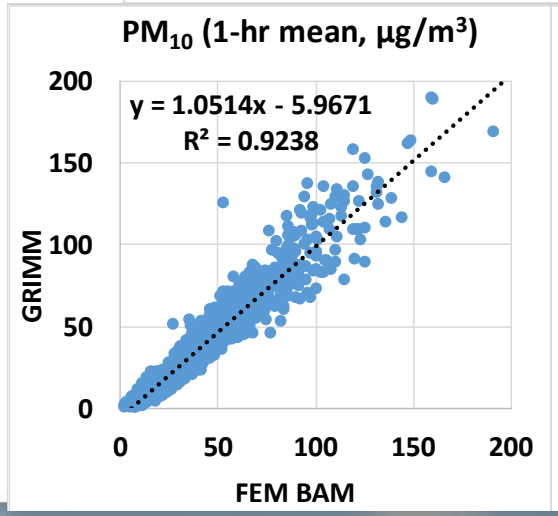



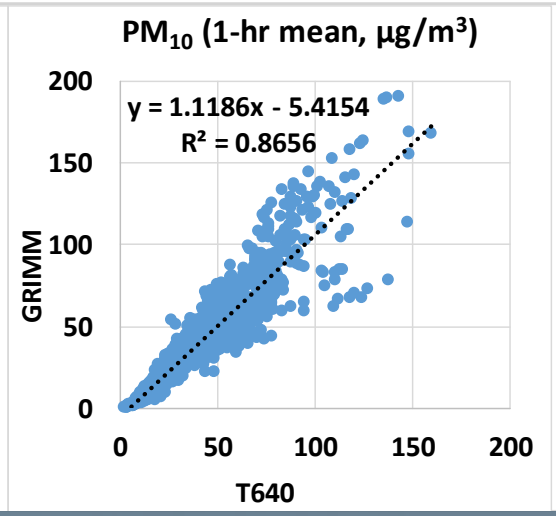



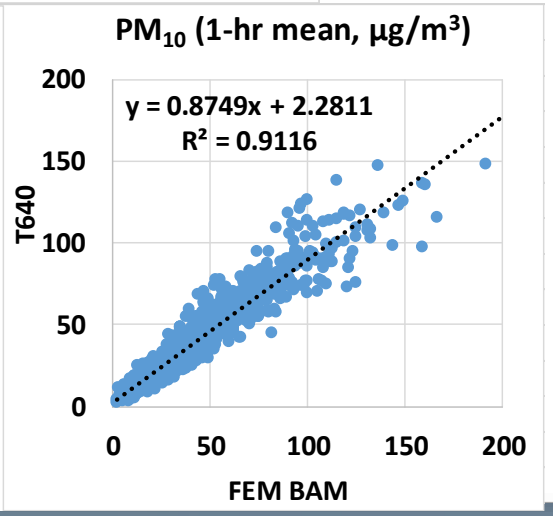
# Reference Instruments: $PM_{10}$ GRIMM, BAM & T640

- 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 99.7 %, 99.2 % and 96.4 %, respectively
- Strong to very strong correlations between the three reference instruments for $PM_{10}$ measurements ($0.86 < R^2 < 0.92$)

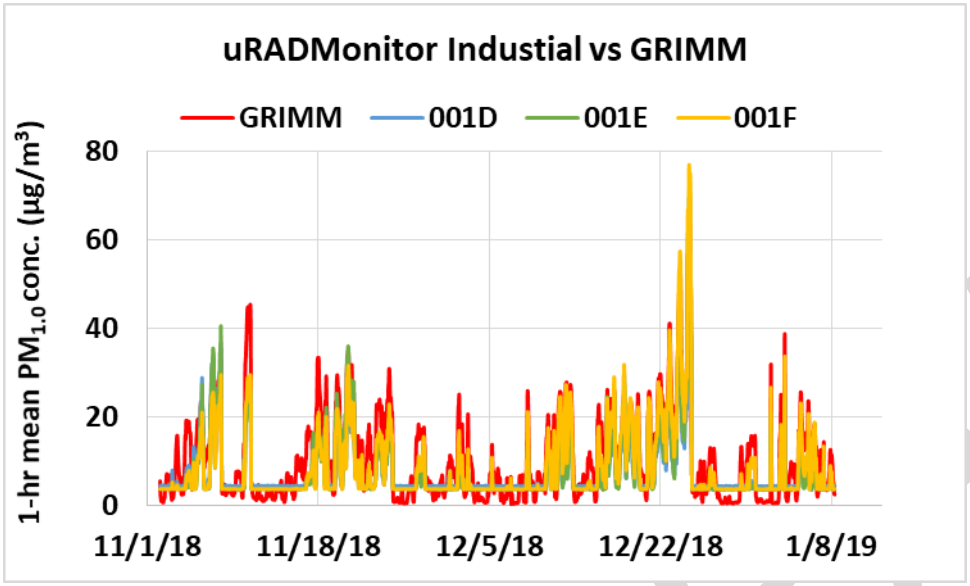


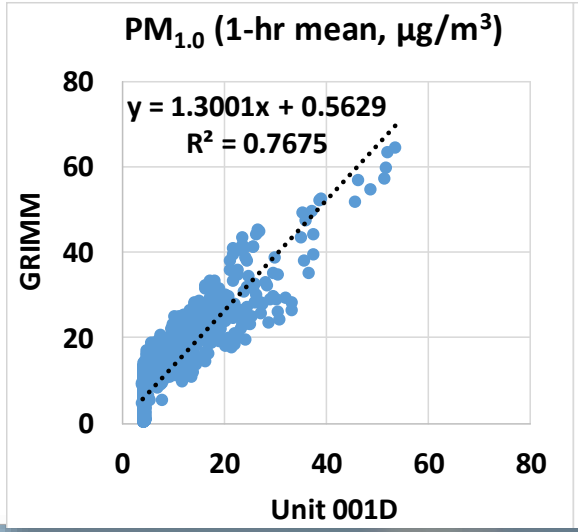



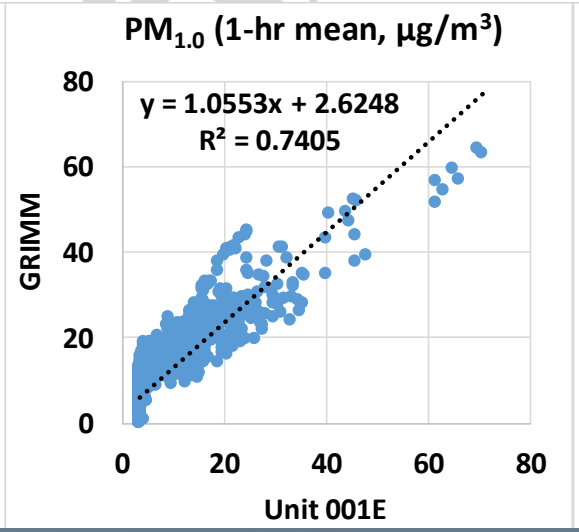



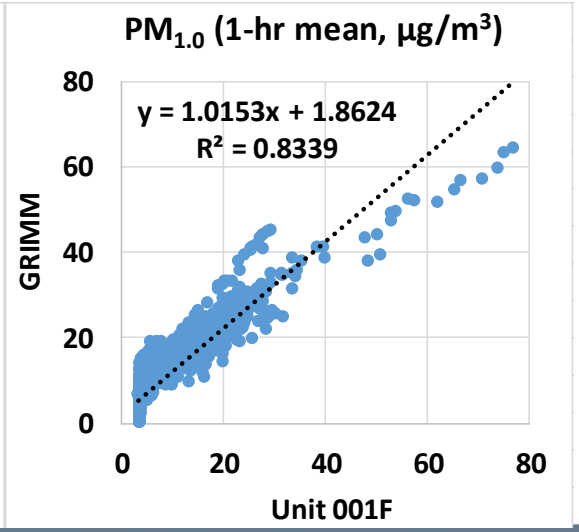
# uRADMonitor INDUSTRIAL vs GRIMM ($PM_{1.0}$; 1-hr mean)



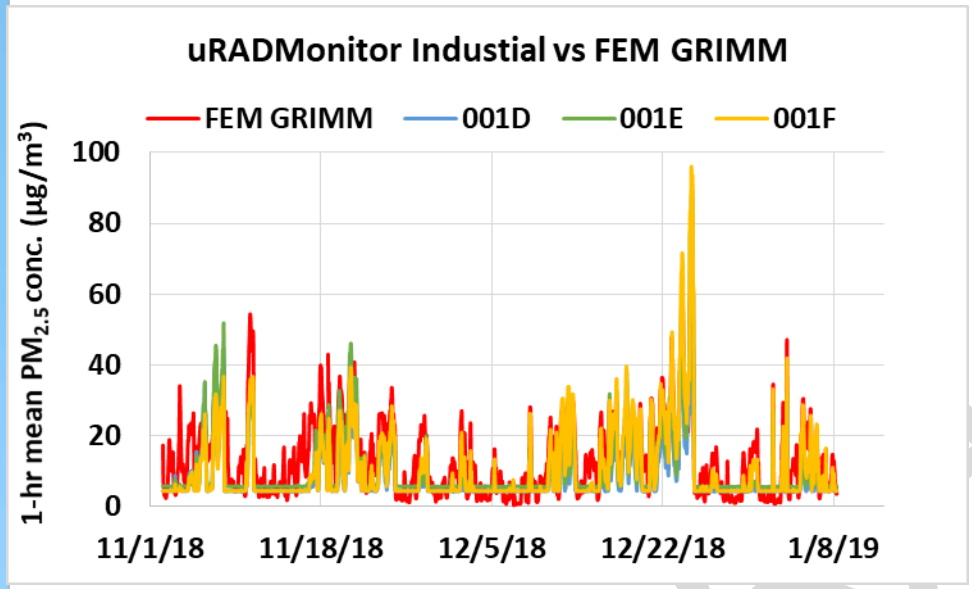

- uRADMonitor INDUSTRIAL sensors show strong correlations with the corresponding GRIMM data ($R^2$ ~ 0.78) when $PM_{1.0}$ mass concentration is > ~10 µg/m$^3$ as recorded by GRIMM
- Overall, the uRADMonitor INDUSTRIAL sensors underestimate $PM_{1.0}$ mass concentration as measured by GRIMM
- The uRADMonitor INDUSTRIAL sensors seem to track well the $PM_{1.0}$ diurnal variations when $PM_{1.0}$ mass concentration is > 10 µg/m$^3$ and report constant values of ~ 2.4 – 3.2 µg/m$^3$ when $PM_{1.0}$ mass concentration is < ~10 µg/m$^3$ as recorded by GRIMM.



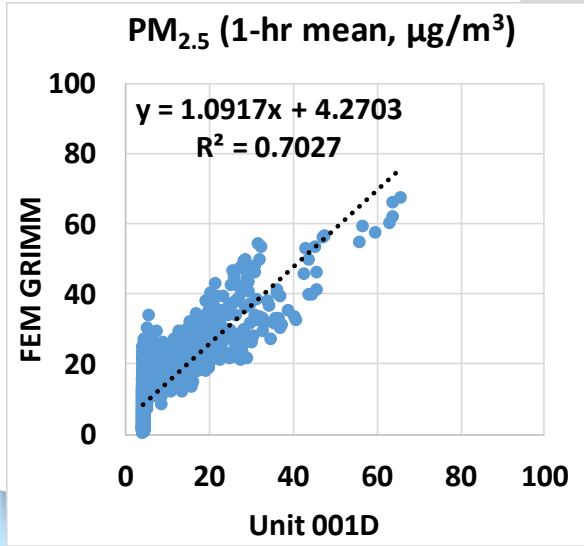



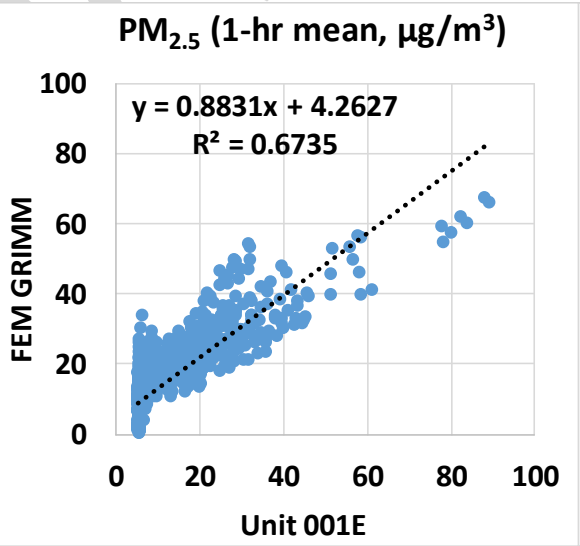



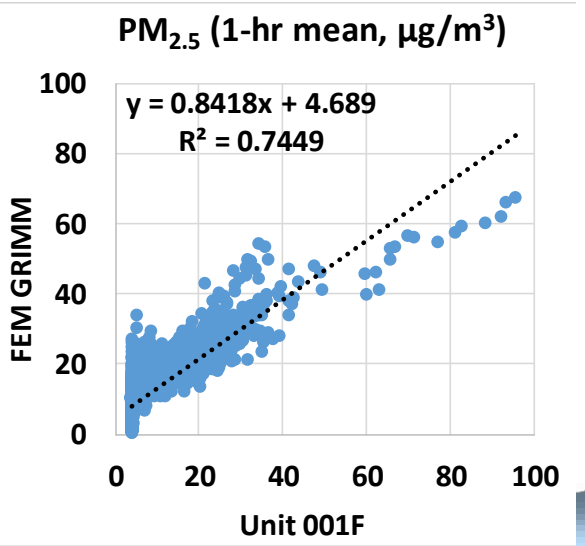
# uRADMonitor INDUSTRIAL vs FEM GRIMM ($PM_{2.5}$; 1-hr mean)



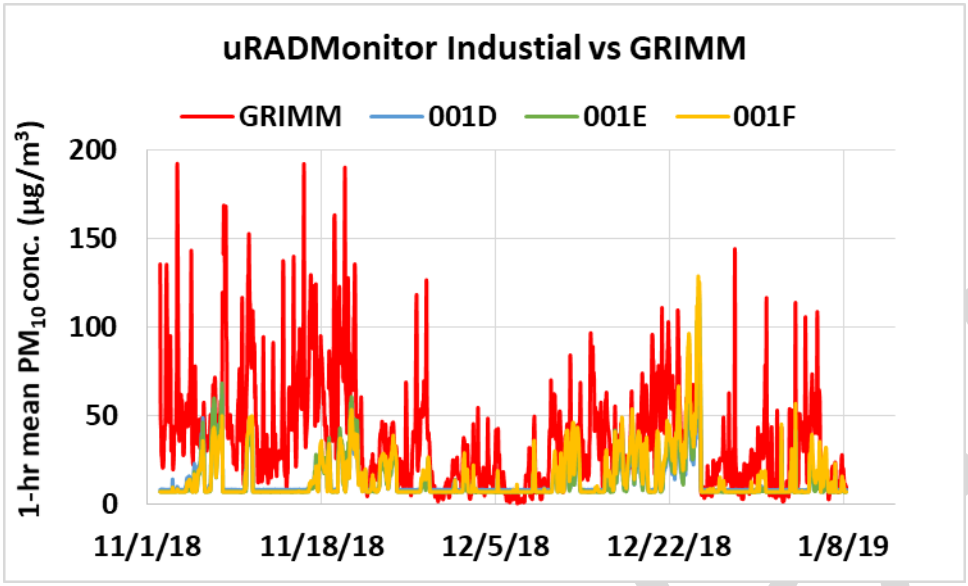

- uRADMonitor INDUSTRIAL sensors show strong correlations with the corresponding FEM GRIMM data ($R^2$ ~ 0.71) when $PM_{2.5}$ mass concentration is > ~15 µg/m$^3$
- Overall, the uRADMonitor INDUSTRIAL sensors underestimate the $PM_{2.5}$ mass concentrations measured by FEM GRIMM
- The uRADMonitor INDUSTRIAL seem to track the $PM_{2.5}$ diurnal variations when $PM_{2.5}$ mass concentration is > 15 µg/m$^3$ and report constant values of ~ 4.2 – 5.7 µg/m$^3$ when $PM_{1.0}$ mass concentration is < ~15 µg/m$^3$ as recorded by FEM GRIMM.



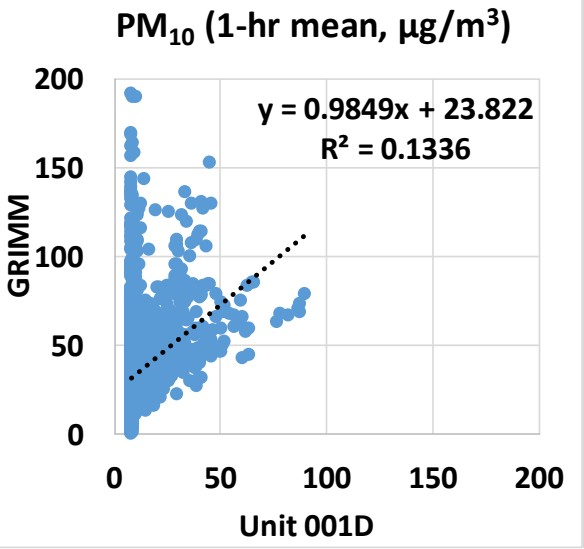



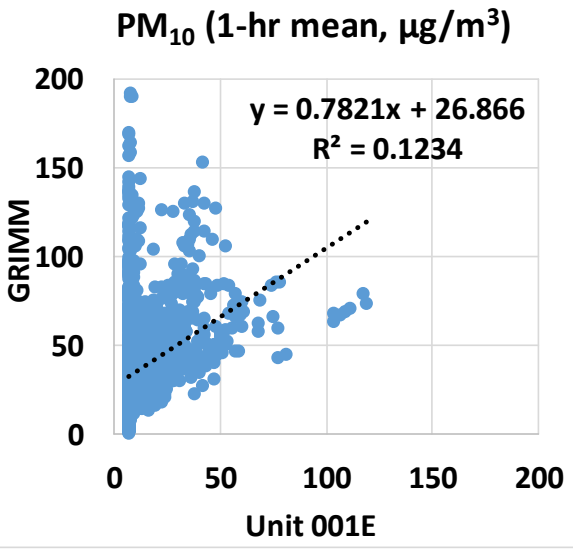



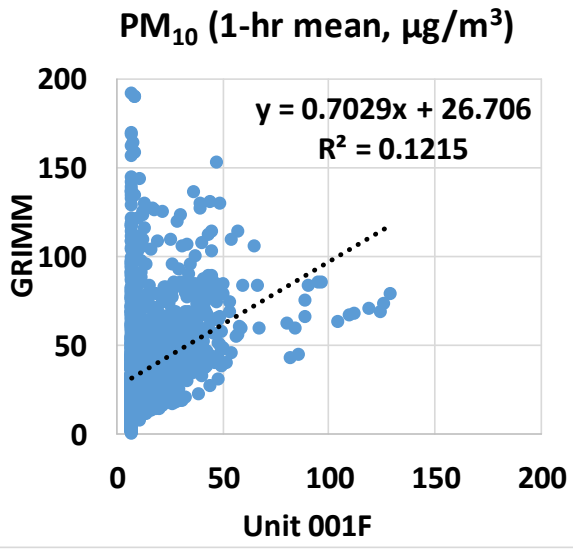
# uRADMonitor INDUSTRIAL vs GRIMM ($PM_{10}$; 1-hr mean)



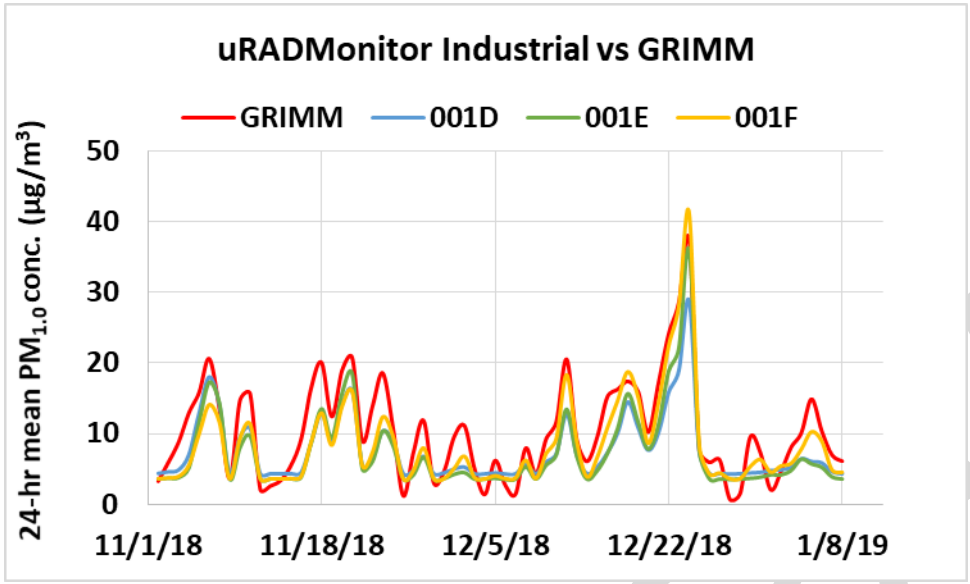

- uRADMonitor INDUSTRIAL sensors show very weak correlations with the corresponding GRIMM data ($R^2$ ~ 0.13)
- Overall, the uRADMonitor INDUSTRIAL sensors underestimate the $PM_{10}$ mass concentrations measured by GRIMM
- The uRADMonitor INDUSTRIAL sensors do not seem to track the $PM_{10}$ diurnal variations when reporting constant values of ~ 6.9 – 8.4 µg/m$^3$ during the field deployment period



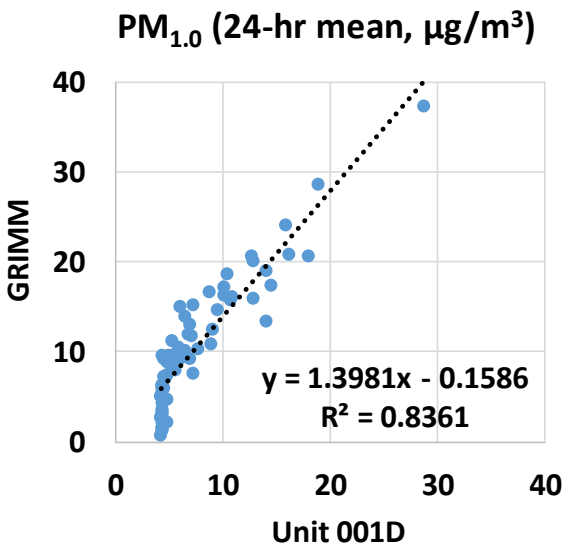



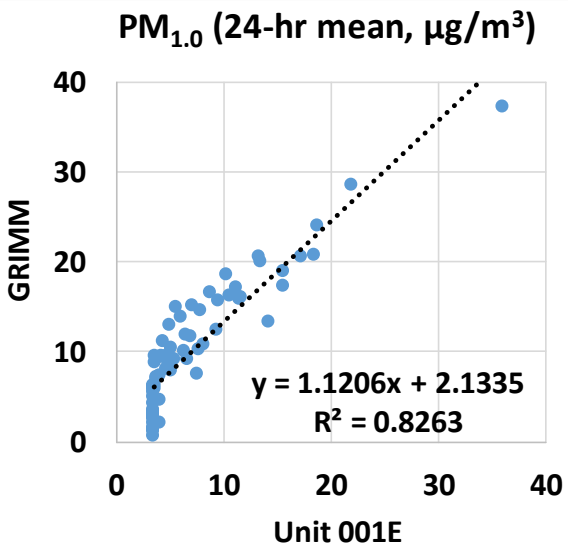



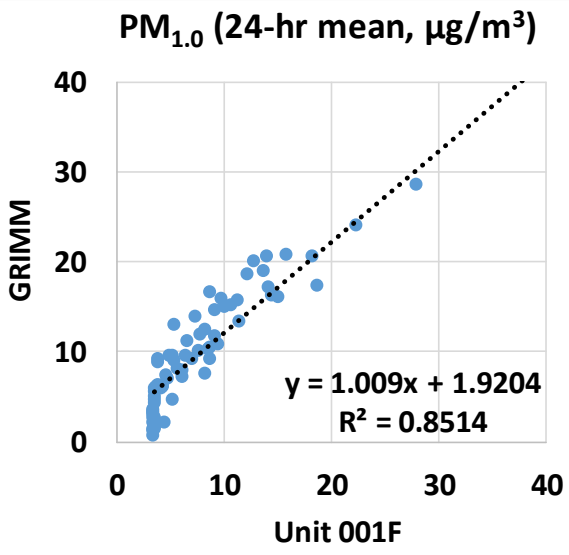
# uRADMonitor INDUSTRIAL vs GRIMM ($PM_{1.0}$; 24-hr mean)



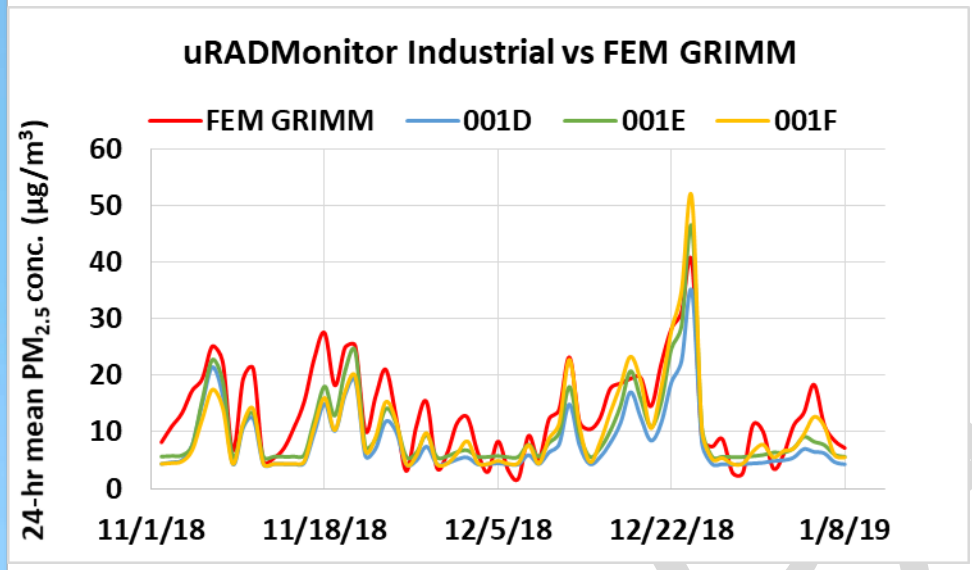

- uRADMonitor INDUSTRIAL sensors show strong correlations with the corresponding GRIMM data ($R^2$ ~ 0.84) when $PM_{1.0}$ mass concentration is > 10 µg/m³
- Overall, the uRADMonitor INDUSTRIAL sensors underestimate $PM_{1.0}$ mass concentration as measured by GRIMM
- The uRADMonitor INDUSTRIAL seem to track well the $PM_{1.0}$ concentration variations when $PM_{1.0}$ mass concentration is > 10 µg/m³ as recorded by GRIMM



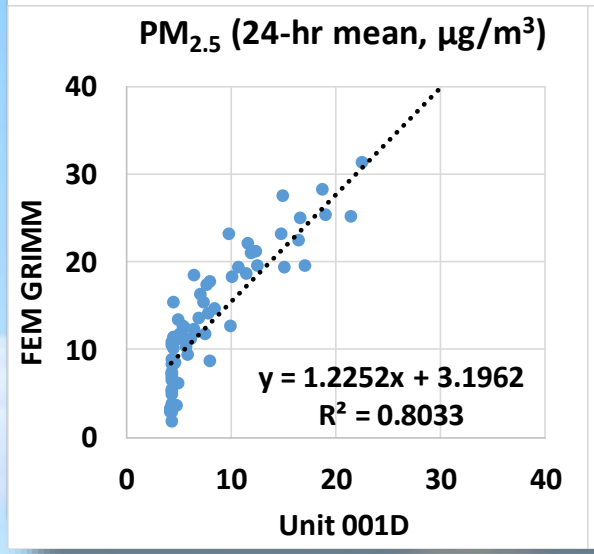



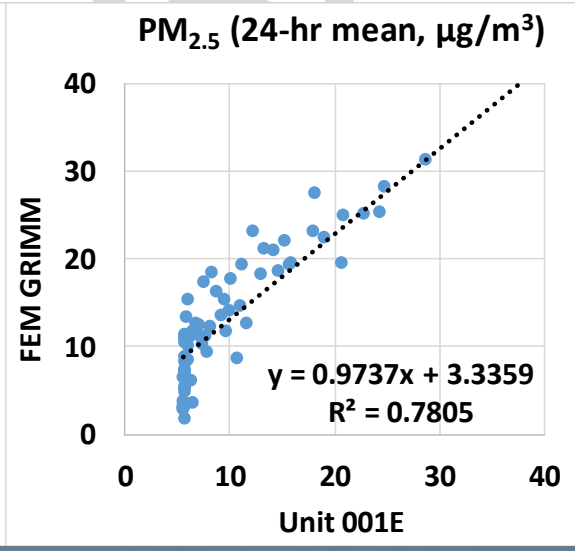



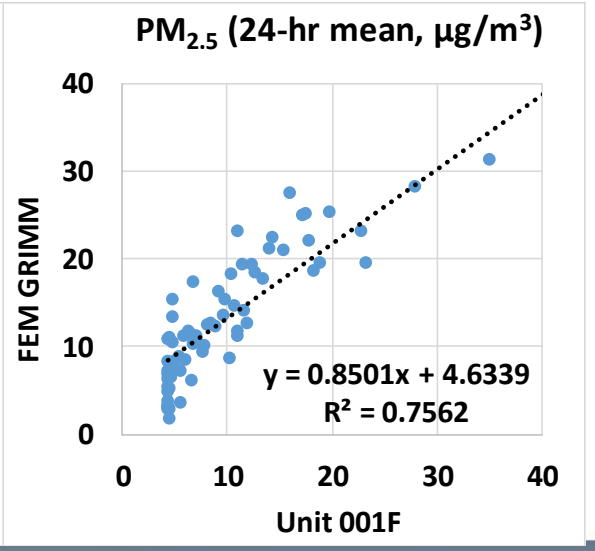
# uRADMonitor INDUSTRIAL vs FEM GRIMM ($PM_{2.5}$; 24-hr mean)



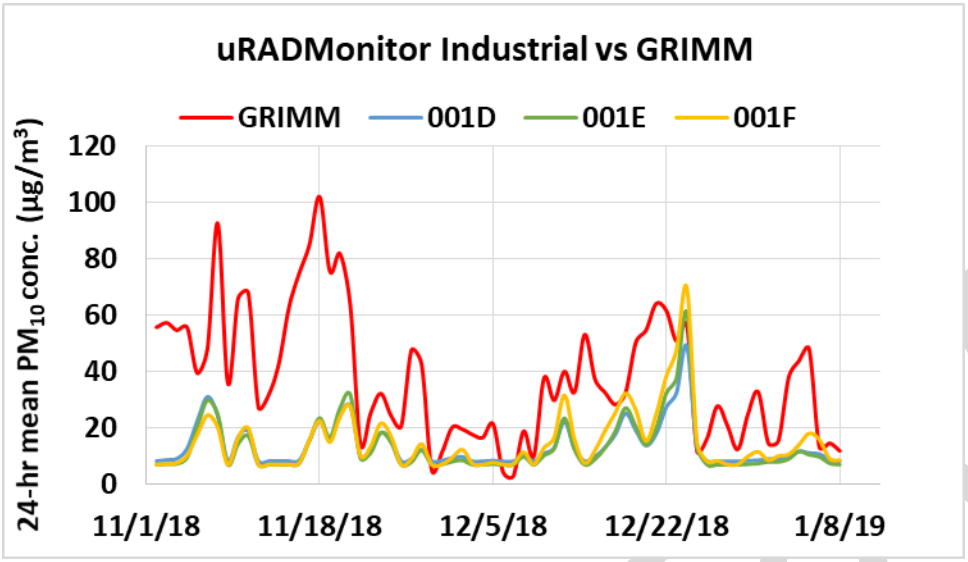

- uRADMonitor INDUSTRIAL sensors show strong correlations with the corresponding FEM GRIMM data ($R^2$ ~ 0.78)
- Overall, the uRADMonitor INDUSTRIAL sensors underestimate $PM_{2.5}$ mass concentration as measured by FEM GRIMM
- The uRADMonitor INDUSTRIAL seem to track well the $PM_{2.5}$ concentration variations when $PM_{2.5}$ mass concentration is > 10 µg/m$^3$ as recorded by FEM GRIMM



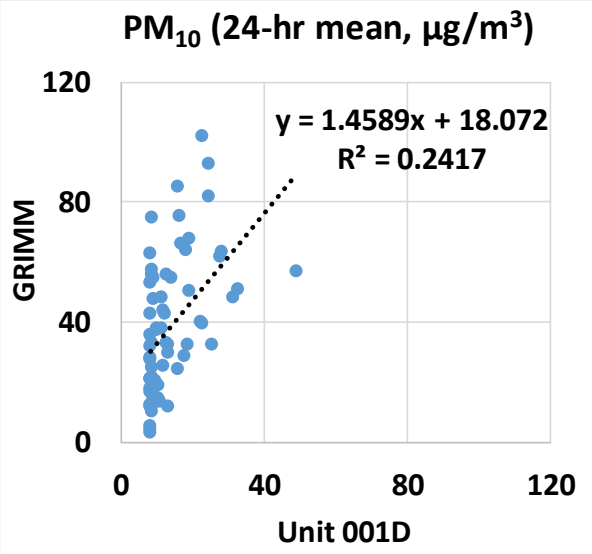



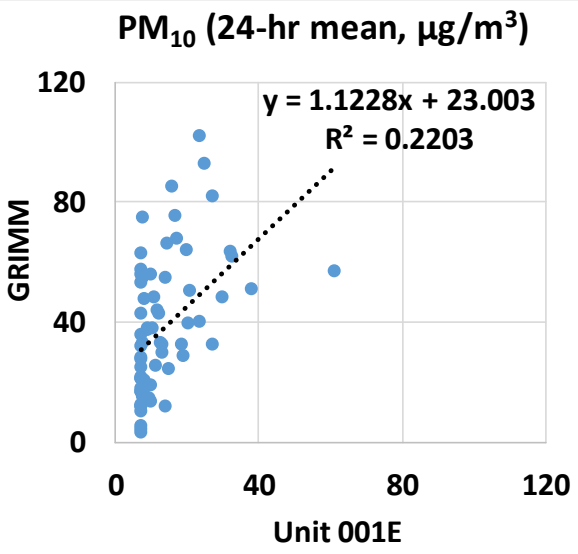



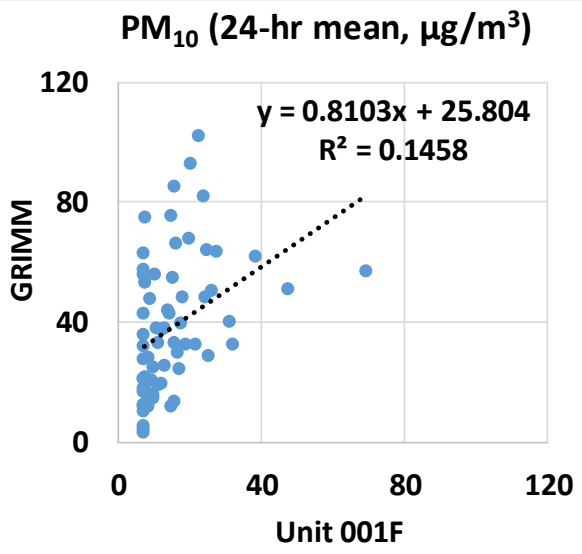
# uRADMonitor INDUSTRIAL vs GRIMM ($PM_{10}$; 24-hr mean)



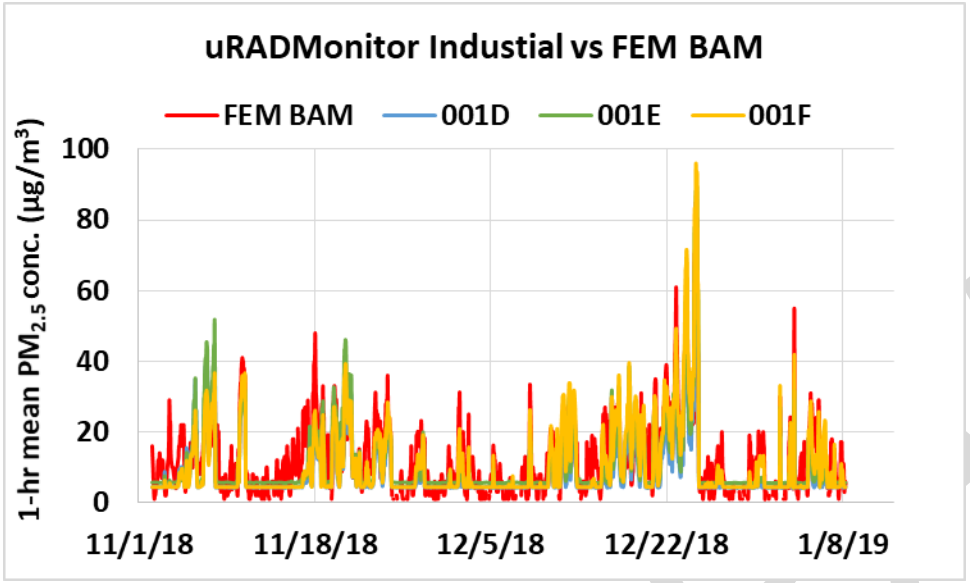

- uRADMonitor INDUSTRIAL sensors show very weak correlations with the corresponding GRIMM data ($R^2$ ~ 0.20)
- Overall, the uRADMonitor INDUSTRIAL sensors underestimate the $PM_{10}$ mass concentrations measured by GRIMM
- The uRADMonitor INDUSTRIAL sensors do not seem to track the $PM_{10}$ concentration variations when reporting constant values of ~ 6.9 – 8.4 µg/m$^3$ during the field deployment period



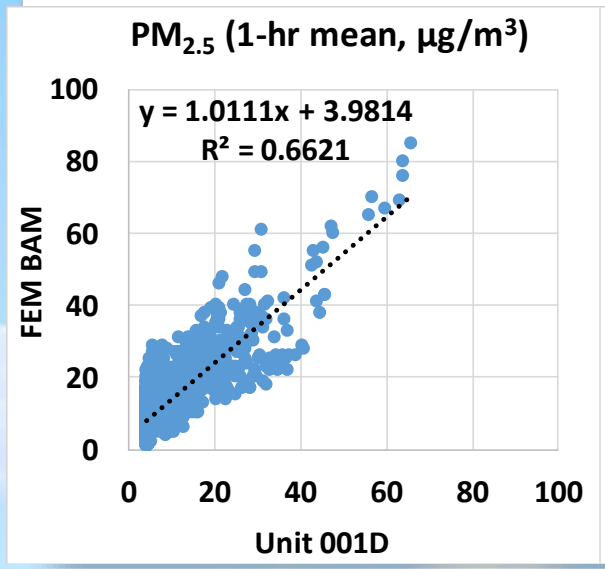



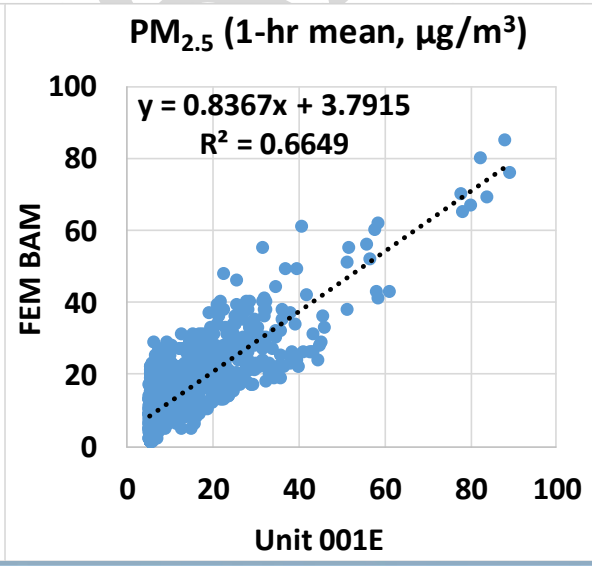



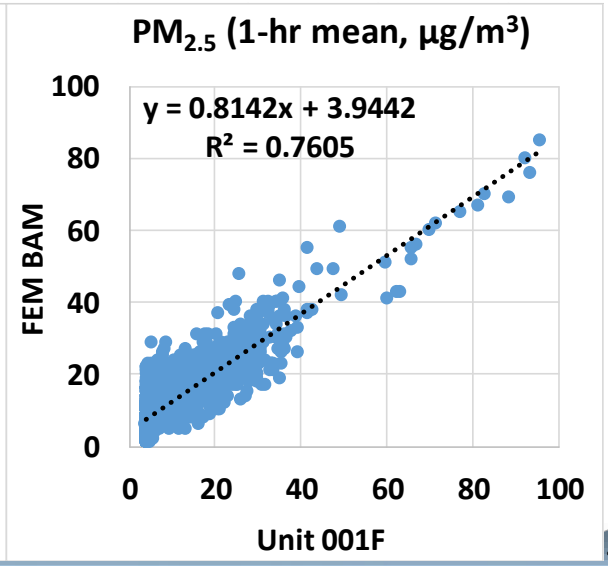
# uRADMonitor INDUSTRIAL vs FEM BAM ($PM_{2.5}$; 1-hr mean)



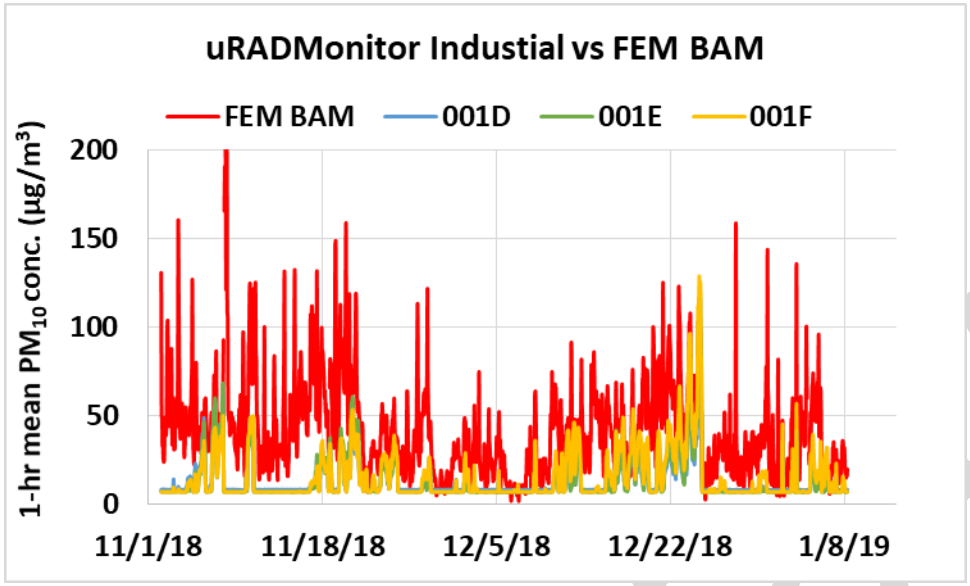

- uRADMonitor INDUSTRIAL sensors show moderate to strong correlations with the corresponding FEM BAM data ($R^2$ ~ 0.70) when $PM_{2.5}$ mass concentration is > ~10 µg/m$^3$
- Overall, the uRADMonitor INDUSTRIAL sensors underestimate the $PM_{2.5}$ mass concentrations measured by FEM BAM
- The uRADMonitor INDUSTRIAL seem to track the $PM_{2.5}$ diurnal variations when $PM_{2.5}$ mass concentration is > ~10 µg/m$^3$ and report constant values of ~ 2.4 – 3.2 µg/m$^3$ when $PM_{2.5}$ mass concentration is < ~10 µg/m$^3$



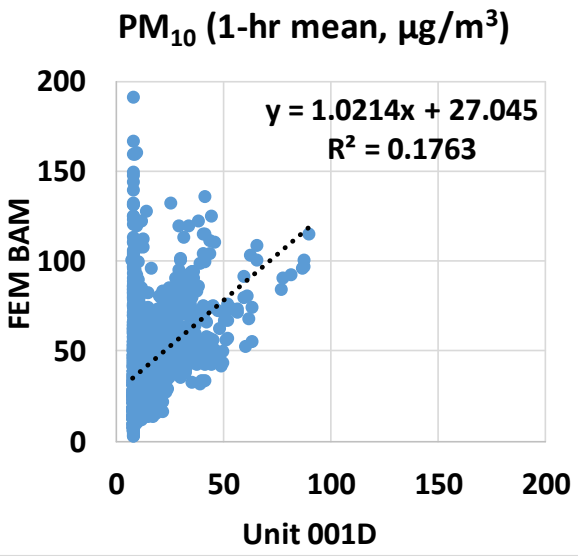



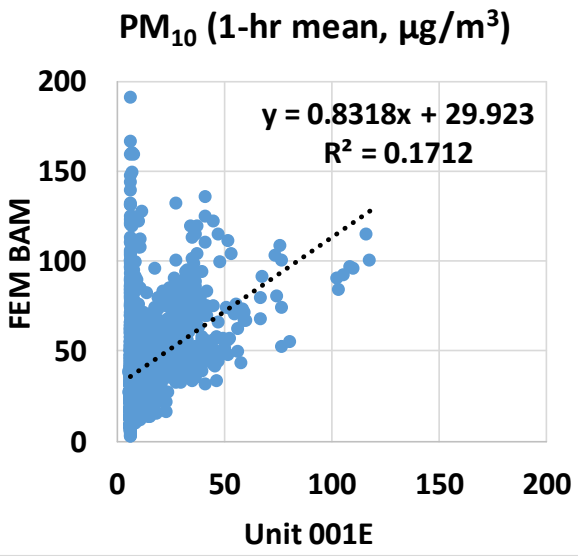



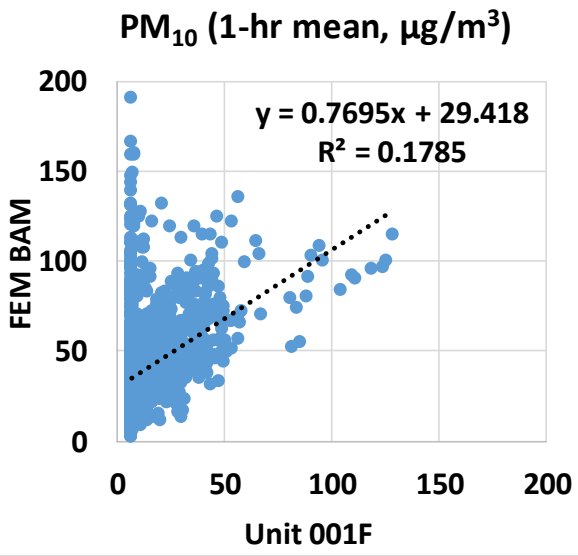
# uRADMonitor INDUSTRIAL vs FEM BAM ($PM_{10}$; 1-hr mean)



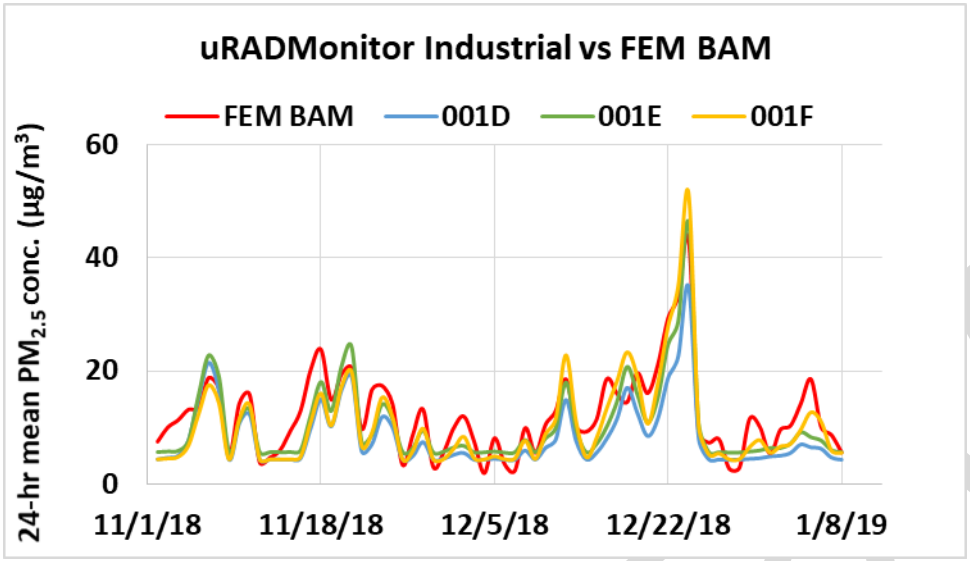

- uRADMonitor INDUSTRIAL sensors show very weak correlations with the corresponding FEM BAM data ($R^2$ ~ 0.17)
- Overall, the uRADMonitor INDUSTRIAL sensors underestimate the $PM_{10}$ mass concentrations measured by FEM BAM
- The uRADMonitor INDUSTRIAL sensors do not seem to track the $PM_{10}$ diurnal variations when reporting constant values of ~ 6.9 – 8.4 µg/m$^3$ during the field deployment period



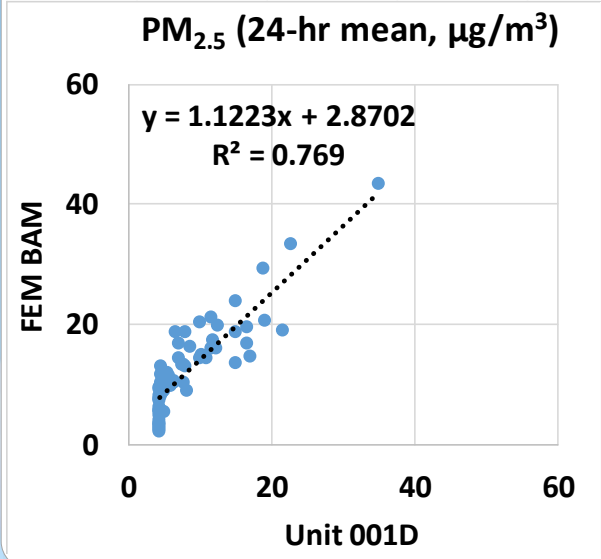



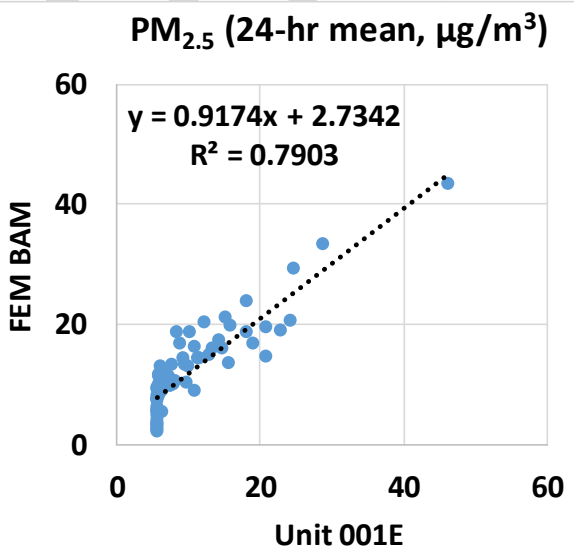



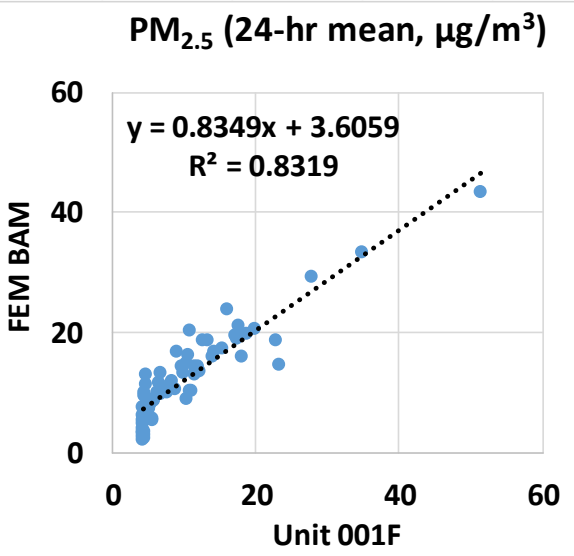
# uRADMonitor INDUSTRIAL vs FEM BAM ($PM_{2.5}$; 24-hr mean)



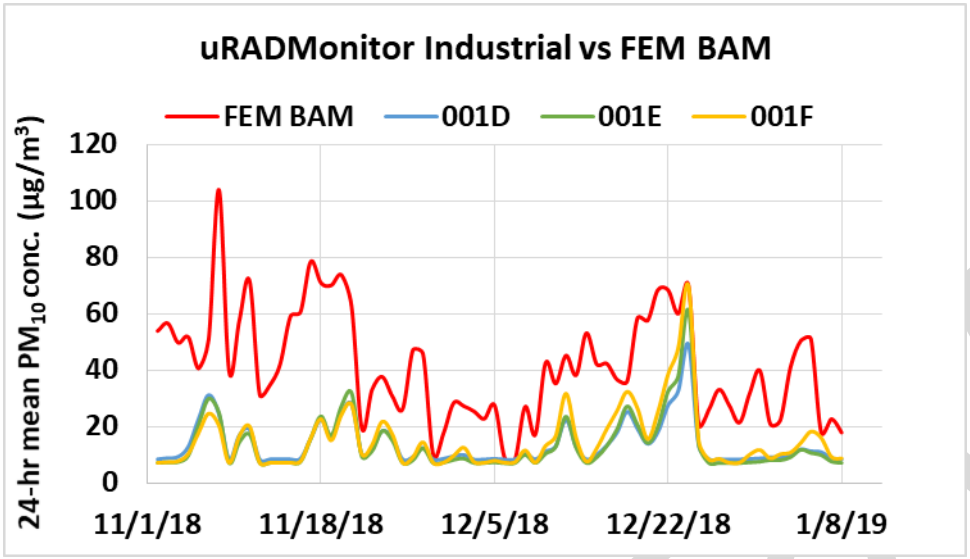

- uRADMonitor INDUSTRIAL sensors show strong correlations with the corresponding FEM BAM data ($R^2$ ~ 0.80) when $PM_{2.5}$ mass concentration is > ~10 µg/m³
- Overall, the uRADMonitor INDUSTRIAL sensors slightly underestimate the $PM_{2.5}$ mass concentrations measured by FEM BAM
- The uRADMonitor INDUSTRIAL seem to track the $PM_{2.5}$ concentration variations as recorded by FEM BAM when $PM_{2.5}$ mass concentration is > ~10 µg/m³



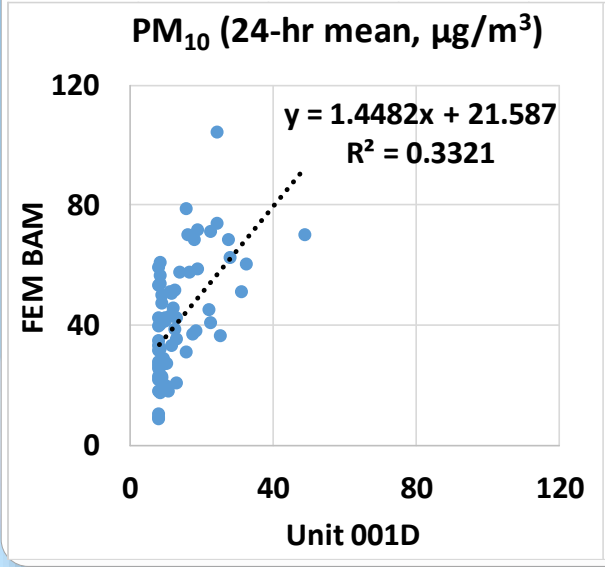



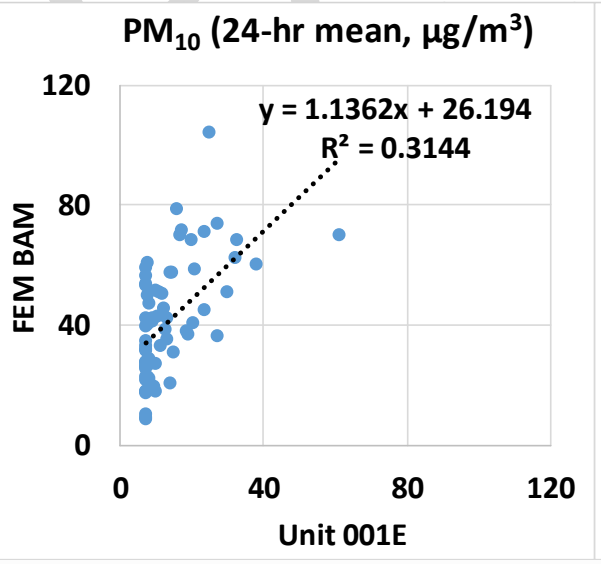



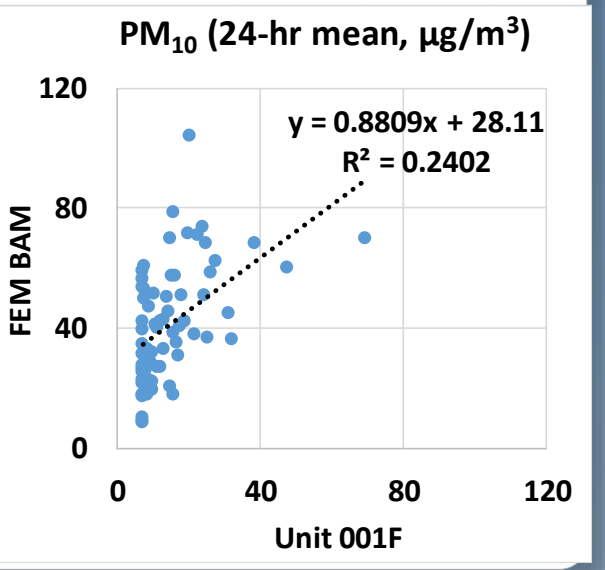
# uRADMonitor INDUSTRIAL vs FEM BAM ($PM_{10}$; 24-hr mean)



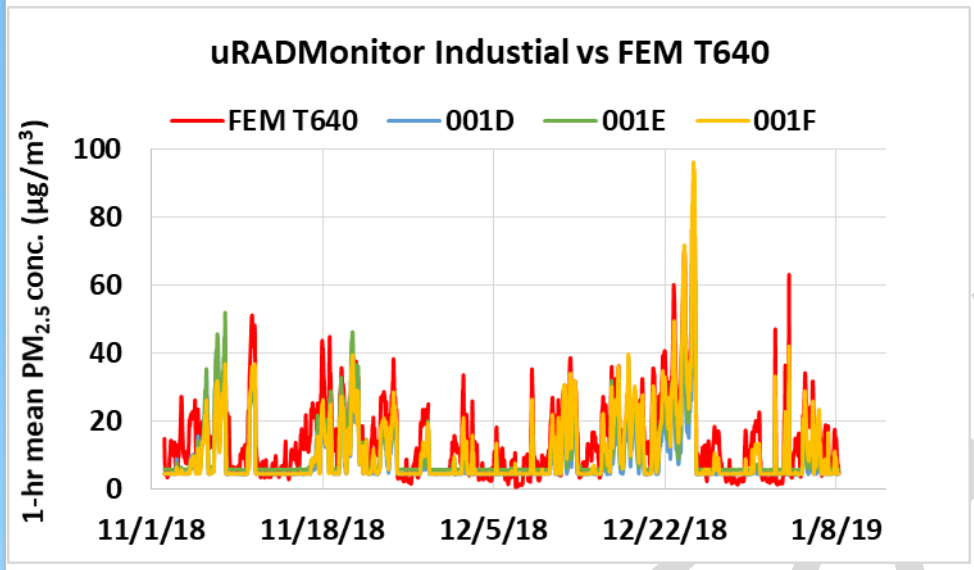

- uRADMonitor INDUSTRIAL sensors show weak correlations with the corresponding FEM BAM data ($R^2$ ~ 0.30)
- Overall, the uRADMonitor INDUSTRIAL sensors underestimate the $PM_{10}$ mass concentrations measured by FEM BAM
- The uRADMonitor INDUSTRIAL sensors do not seem to track the $PM_{10}$ concentration variations when reporting constant values of ~ 6.9 – 8.4 µg/m$^3$ during the field deployment period



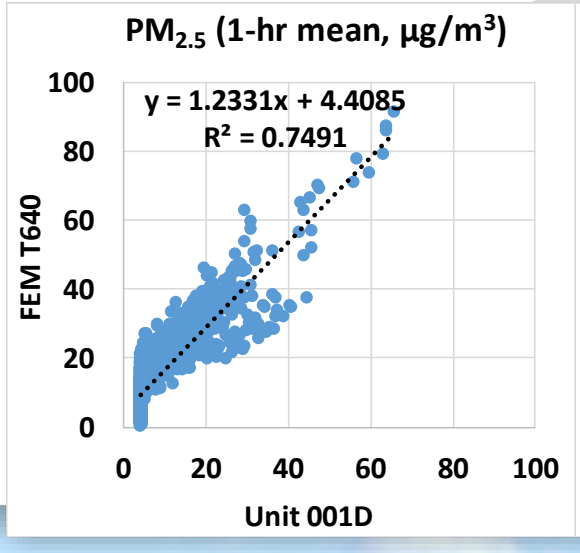



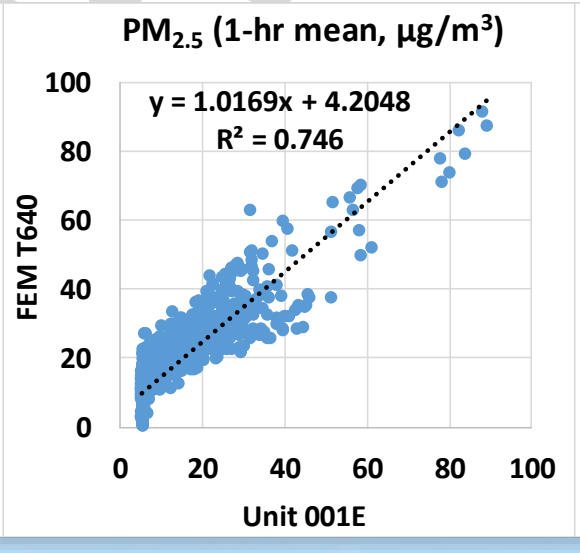



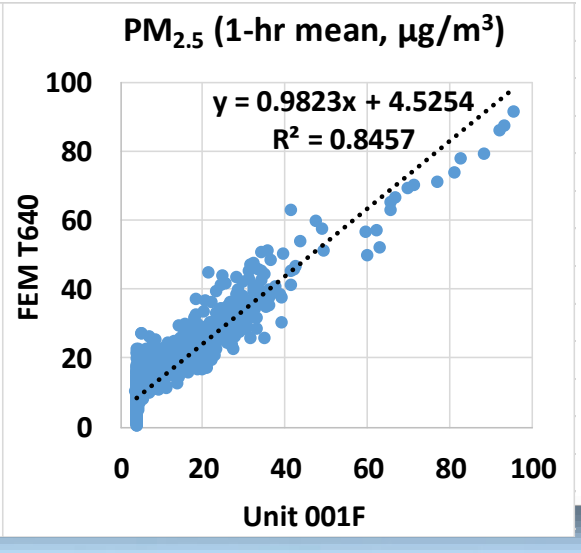
# uRADMonitor INDUSTRIAL vs FEM T640 ($PM_{2.5}$; 1-hr mean)



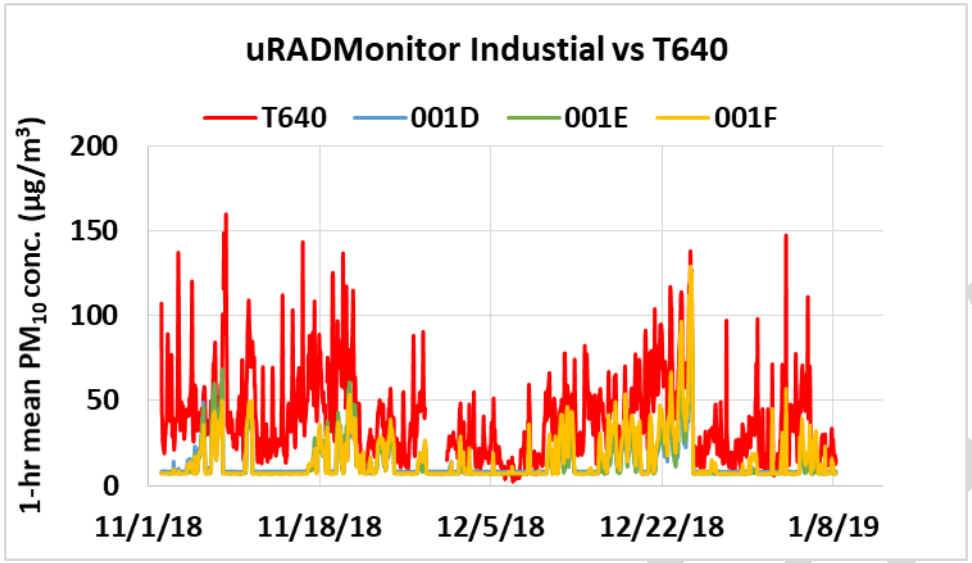

- uRADMonitor INDUSTRIAL sensors show strong correlations with the corresponding FEM T640 data ($R^2$ ~ 0.78) when $PM_{2.5}$ mass concentration is > 10 µg/m$^3$
- Overall, the uRADMonitor INDUSTRIAL sensors underestimate the $PM_{2.5}$ mass concentrations measured by FEM T640
- The uRADMonitor INDUSTRIAL sensors seem to track well the $PM_{2.5}$ diurnal variations when $PM_{2.5}$ mass concentration is > 10 µg/m$^3$ when $PM_{2.5}$ mass concentration is > ~10 µg/m$^3$ and report constant values of ~ 2.4 – 3.2 µg/m$^3$ when $PM_{2.5}$ mass concentration is < ~10 µg/m$^3$



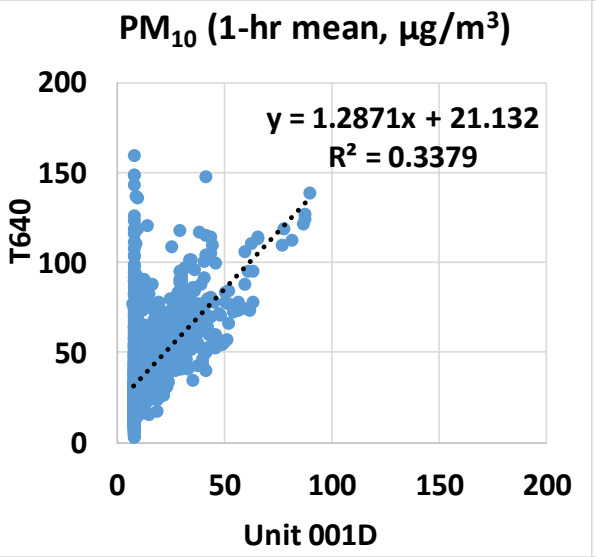



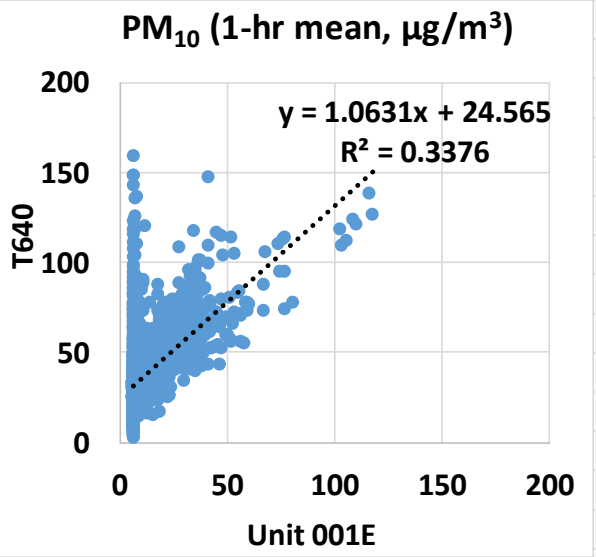



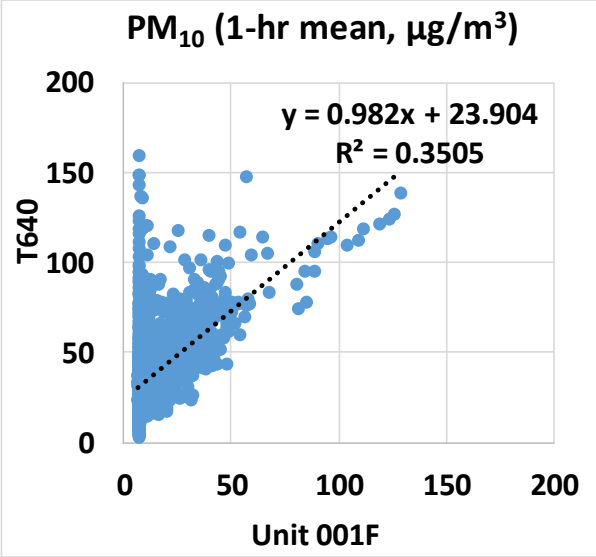
# uRADMonitor INDUSTRIAL vs T640 ($PM_{10}$; 1-hr mean)



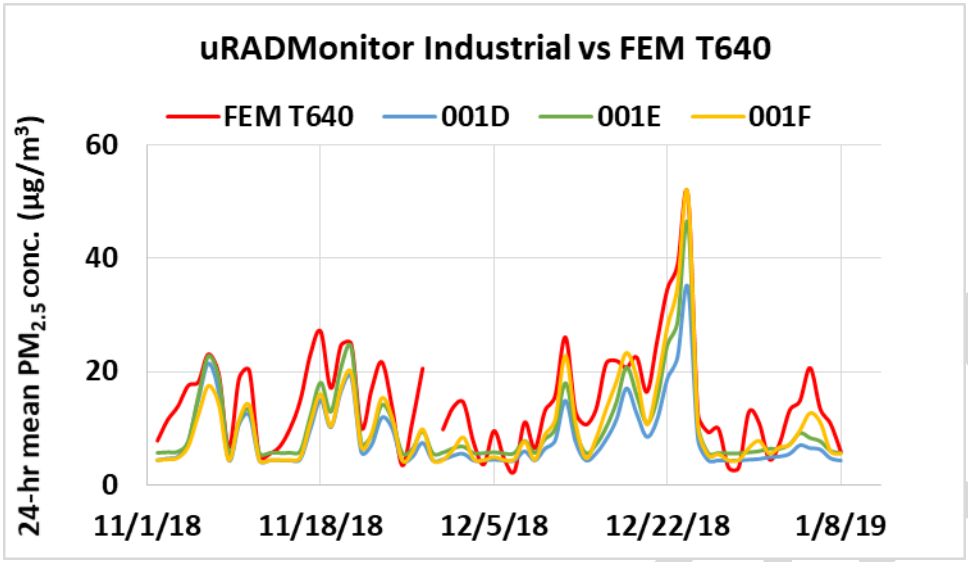

- uRADMonitor INDUSTRIAL sensors show weak correlations with the corresponding T640 data ($R^2$ ~ 0.34)
- Overall, the uRADMonitor INDUSTRIAL sensors underestimate the $PM_{10}$ mass concentrations measured by T640
- The uRADMonitor INDUSTRIAL sensors do not seem to track the $PM_{10}$ diurnal variations when reporting constant values of ~ 6.9 – 8.4 µg/m$^3$ during the field deployment period



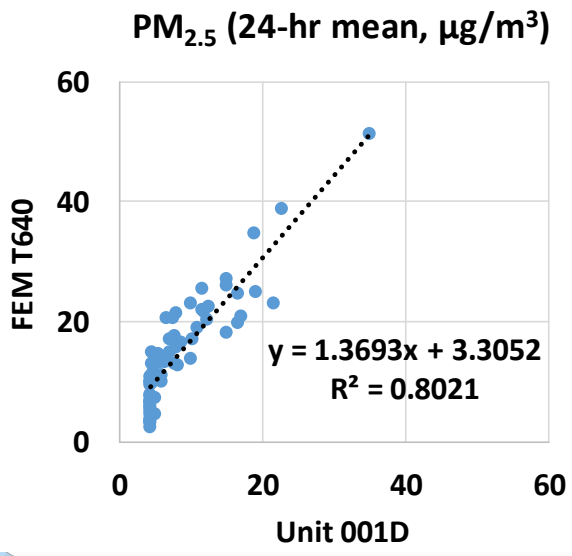



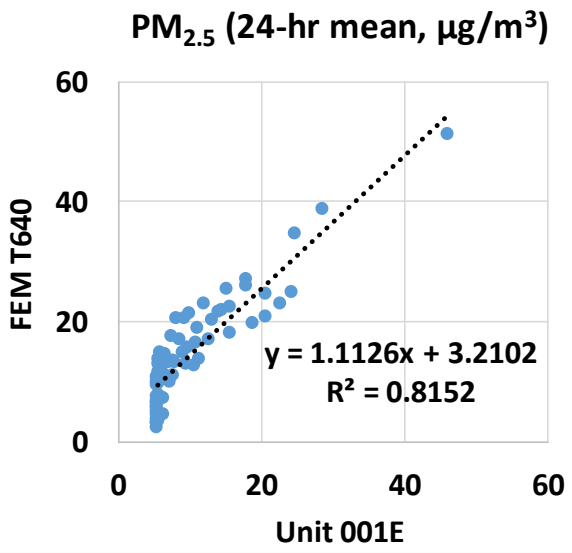



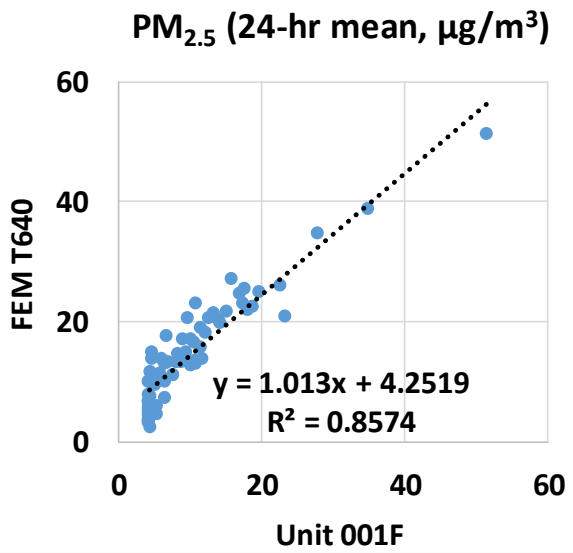
# uRADMonitor INDUSTRIAL vs FEM T640 ($PM_{2.5}$; 24-hr mean)



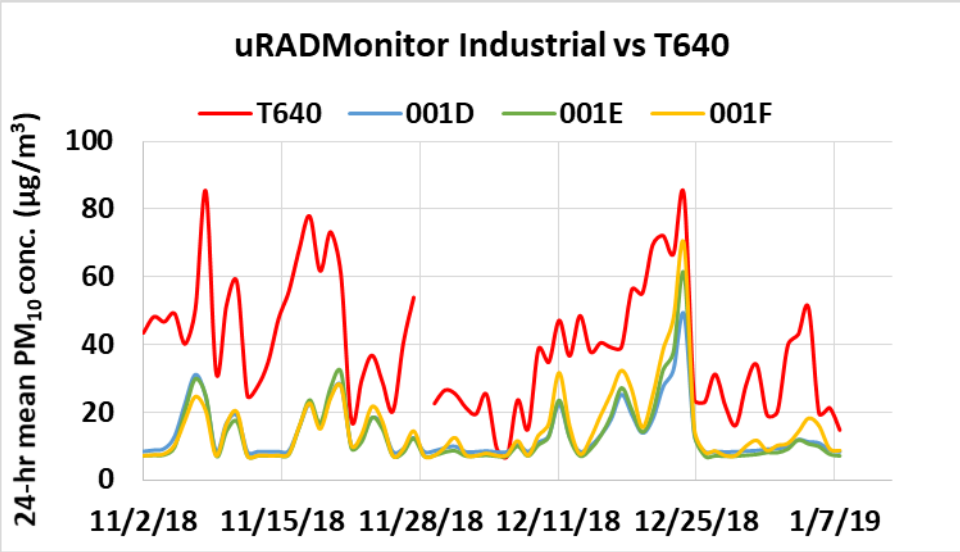

- uRADMonitor INDUSTRIAL sensors show strong correlations with the corresponding FEM T640 data ($R^2$ ~ 0.84) when $PM_{2.5}$ mass concentration is > 10 µg/m³
- Overall, the uRADMonitor INDUSTRIAL sensors underestimate the $PM_{2.5}$ mass concentrations measured by FEM T640
- The uRADMonitor INDUSTRIAL sensors seem to track the $PM_{2.5}$ concentration variations when $PM_{2.5}$ mass concentration is > ~10 µg/m³



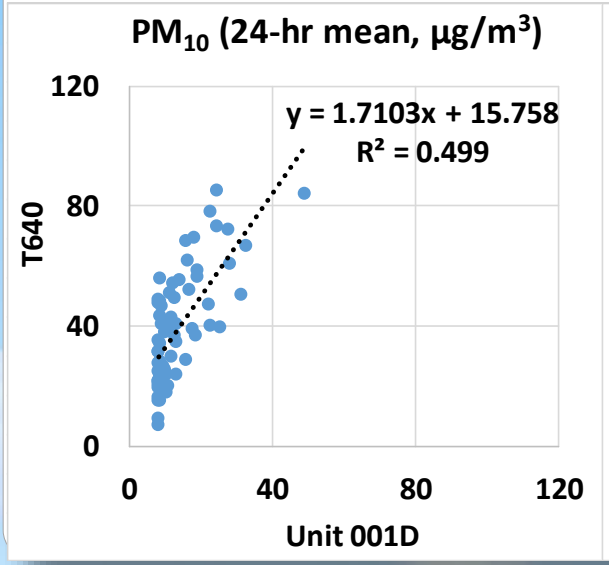



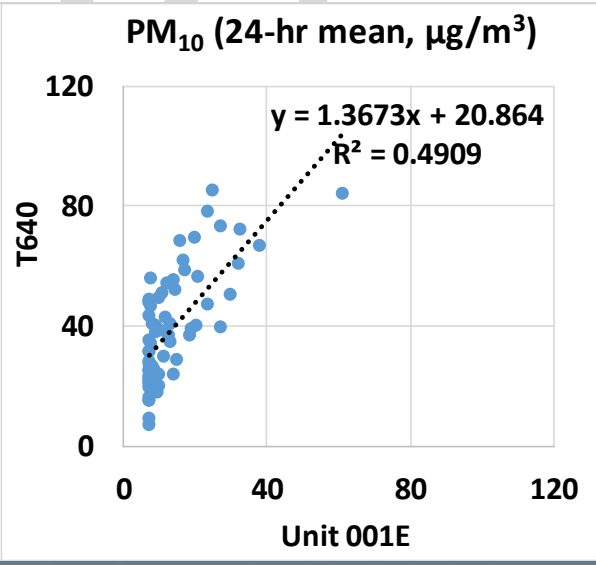



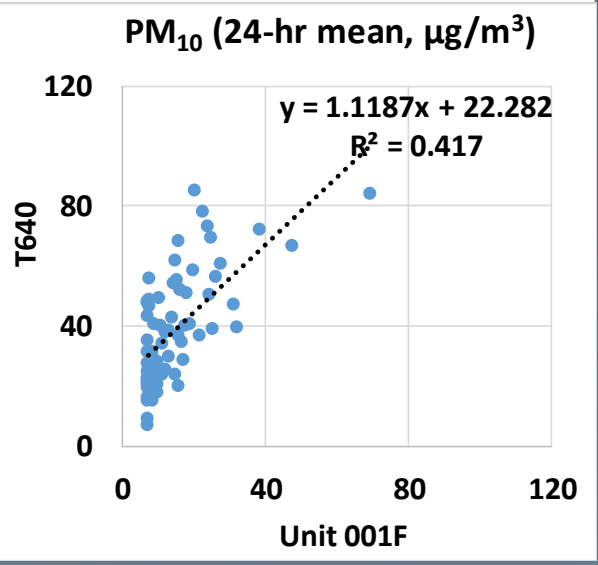
# uRADMonitor INDUSTRIAL vs T640 ($PM_{10}$; 24-hr mean)




- uRADMonitor INDUSTRIAL sensors show weak correlations with the corresponding T640 data ($R^2$ ~ 0.47)
- Overall, the uRADMonitor INDUSTRIAL sensors underestimate the $PM_{10}$ mass concentrations measured by T640
- The uRADMonitor INDUSTRIAL sensors do not seem to track the $PM_{10}$ concentration variations when reporting constant values of ~ 6.9 – 8.4 µg/m$^3$ during the field deployment period



# Discussion

- The three **uRADMonitor INDUSTRIAL** sensors' data recovery from each unit was ~99%, except for Ozone and $SO_2$ in unit 1E. Data recovery is calculated based on the one hour averages due to the fact that the sensors have inconsistent time stamp, limiting comparisons at higher time resolution
- The three sensors showed moderate intra-model variability (19% to 25%) for PM measurements and high intra-model variability for all gas measurements
- The reference instruments (GRIMM, BAM and T640) show very strong correlations with each other for both $PM_{2.5}$ ($R^2$ ~ 0.91) and $PM_{10}$ ($R^2$ ~ 0.90) mass concentration measurements (1-hr mean)
- $SO_2$ evaluation was not included in this report due to its concentrations during the field deployment period was too low to be reliably detected by the $SO_2$ FEM instrument
- During the field deployment testing period:
  - Ozone sensors did not correlate with the FEM instrument ($R^2$ ~0.03)
  - $NO_2$ sensors did not correlate with the FRM instrument ($R^2$ ~0.03)
  - CO sensors did not correlate with the FRM instrument ($R^2$ ~0.03)
  - $PM_{1.0}$ sensors show strong correlations with the corresponding GRIMM values ($R^2$ ~ 0.78, 1-hr mean) and underestimate $PM_{1.0}$ mass concentration measured by the GRIMM when $PM_{1.0}$ concentration is > ~ 10 µg/m$^3$
  - $PM_{2.5}$ sensors show strong correlations with the corresponding FEM GRIMM, FEM BAM and FEM T640 ($R^2$ ~ 0.71, 0.70 and 0.78, respectively, 1-hr mean) and underestimate $PM_{2.5}$ mass concentration measured by the FEM GRIMM, FEM BAM and FEM T640 when $PM_{1.0}$ concentration is > ~ 10 µg/m$^3$
  - $PM_{10}$ sensors show very weak correlations with the corresponding GRIMM and FEM BAM ($R^2$ ~ 0.13 and 0.17 respectively, 1-hr mean) and weak correlations with T640 ($R^2$ ~ 0.34 )and underestimate $PM_{10}$ mass concentration measured by the reference instruments
- 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