# Field Evaluation
# IQAir - AirVisual Outdoor

DRAFT

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

# Background

- From 10/27/2022 to 12/27/2022, three **IQAir – AirVisual Outdoor** 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

- IQAir AirVisual Outdoor (*3 units tested*):
  - Particle sensor: optical; non-FEM
  - Each unit reports: $PM_{1.0}$, $PM_{2.5}$ and $PM_{10}$ (μg/m$^3$), T (°F), RH (%)
  - Also measures: $CO_2$ (ppm)
  - Unit cost: $289
  - Time resolution: 1-min
  - Units IDs: ZFW8, JM83, Y5EF

- GRIMM EDM180 (*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 $PM_{1.0}$, $PM_{2.5}$ and $PM_{10}$ (μg/m$^3$)
  - Cost: ~$21,000
  - Time resolution: 1-min

- Met Station (T, RH, P, WS, WD):
  - Cost: ~$5,000
  - Time resolution: 1-min

FEM GRIMM

FEM T640

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# 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 all units was ~100%, ~98% and ~100% respectively for $PM_{1.0}$, $PM_{2.5}$ and $PM_{10}$, respectively

# IQAir AirVisual Outdoor; intra-model variability

- Absolute intra-model variability was ~0.24, ~0.39 and ~0.34 µg/m$^3$ for $PM_{1.0}$, $PM_{2.5}$ and $PM_{10}$, respectively (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was ~4.4%, ~4.0% and ~0.9% 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)

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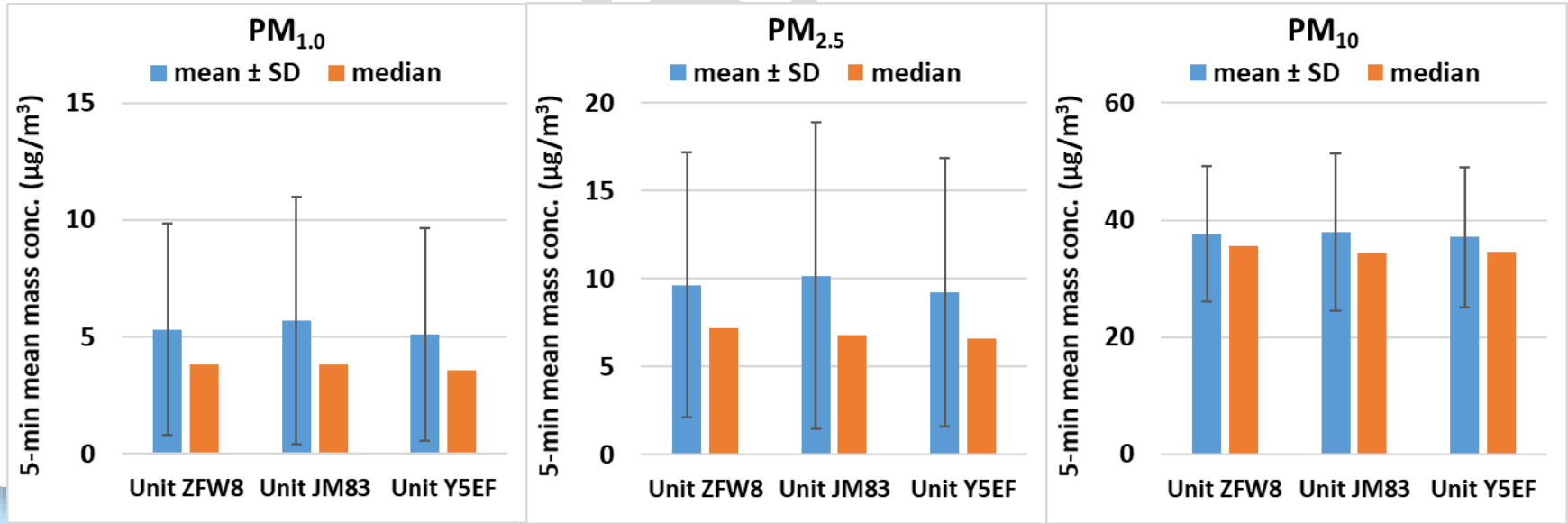
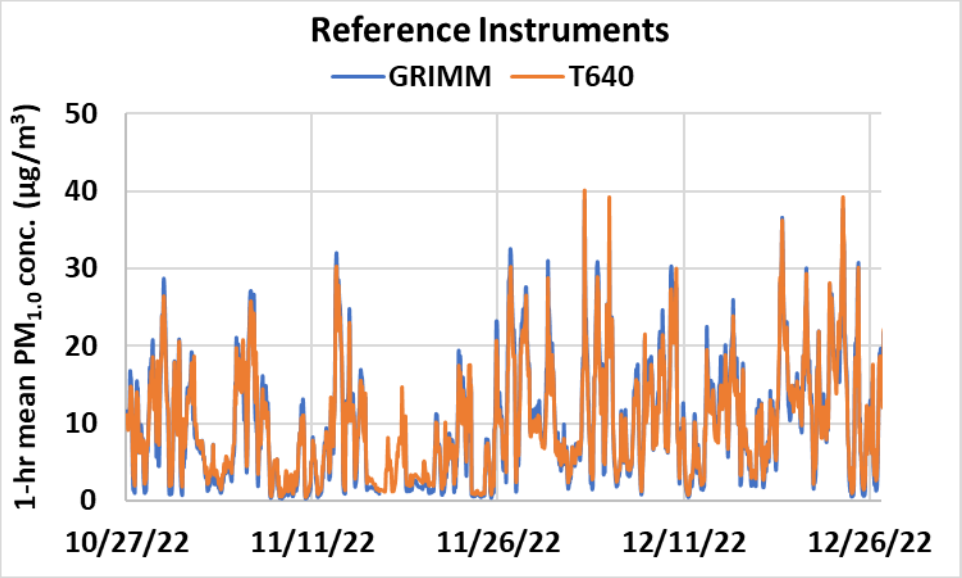
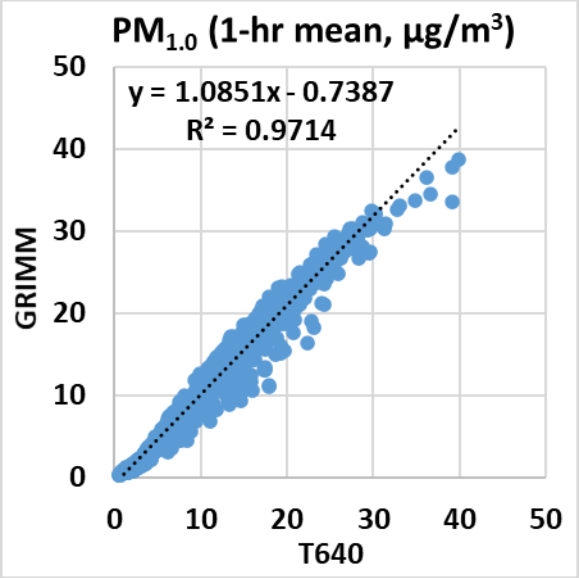


# Reference Instruments: $PM_{1.0}$ GRIMM and T640

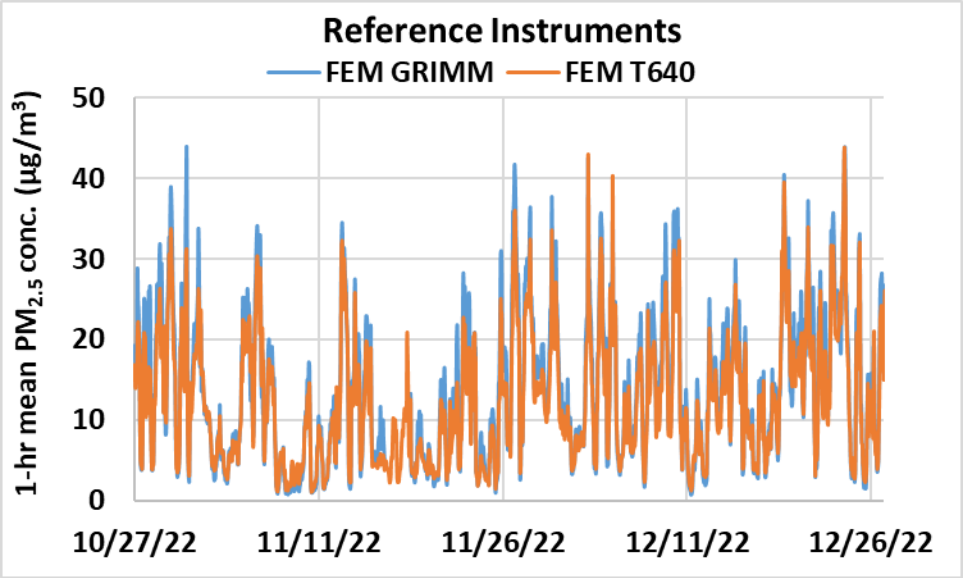
- Data recovery for $PM_{1.0}$ from GRIMM and T640 was ~96.7% and ~100%, respectively.
- Very strong correlations between the reference instruments for $PM_{1.0}$ measurements ($R^2$ ~0.97) were observed.

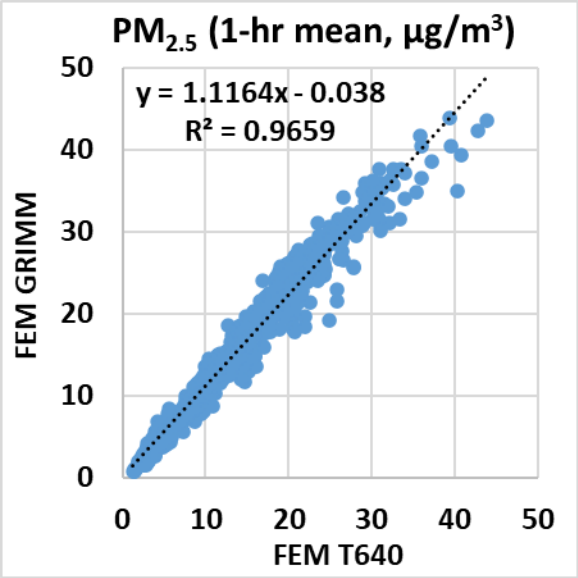


# Reference Instruments: $PM_{2.5}$ FEM GRIMM and FEM T640

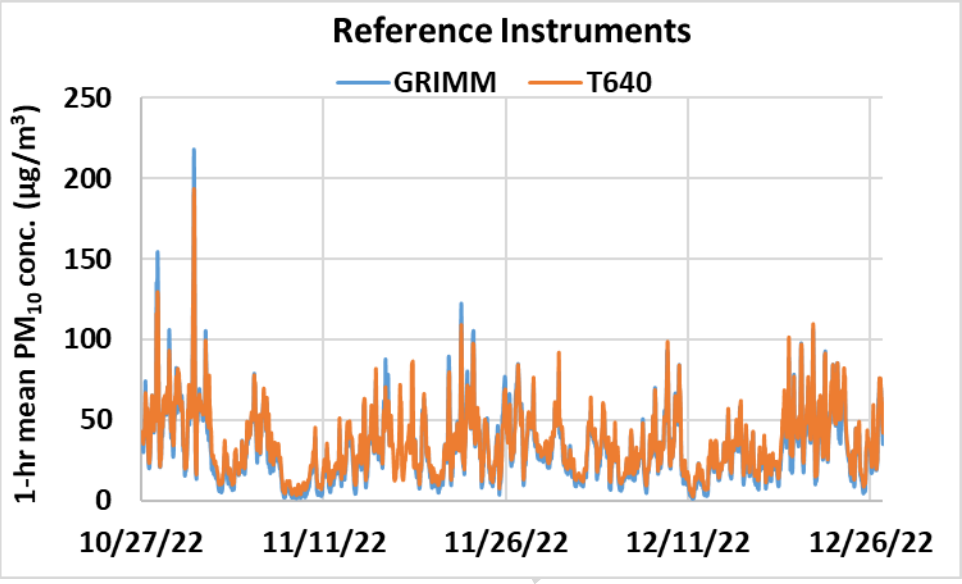
- Data recovery for $PM_{2.5}$ from FEM GRIMM and FEM T640 was ~96.7% and ~100%, respectively.
- Very strong correlations between the reference instruments for $PM_{2.5}$ measurements ($R^2$ ~0.97) were observed.

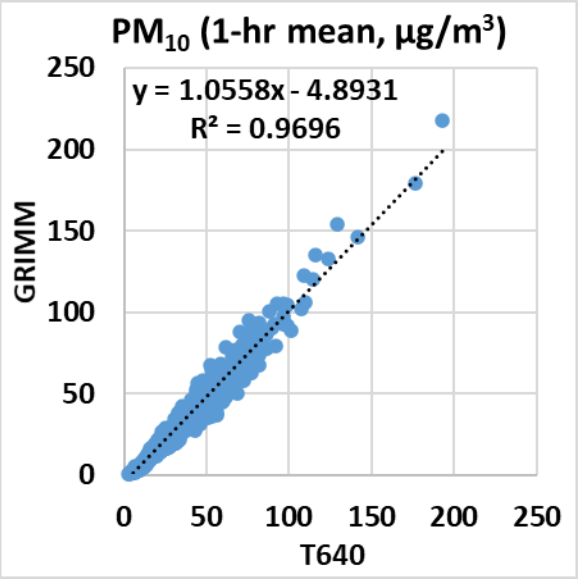


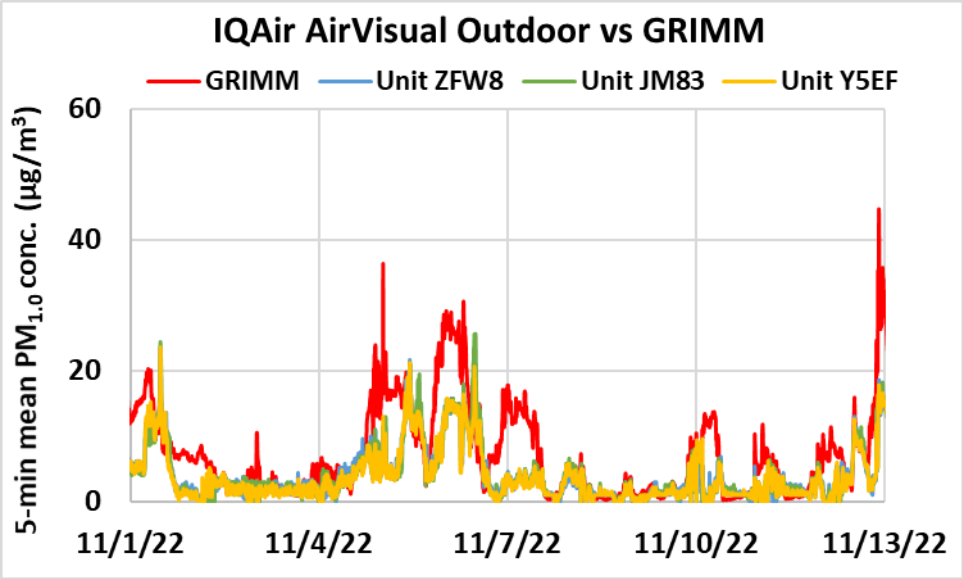
# Reference Instruments: $PM_{10}$ GRIMM and T640

- Data recovery for $PM_{10}$ from GRIMM and T640 was ~96.7% and ~100%, respectively.
- Very strong correlations between the reference instruments for $PM_{10}$ measurements ($R^2$ ~0.97) were observed.

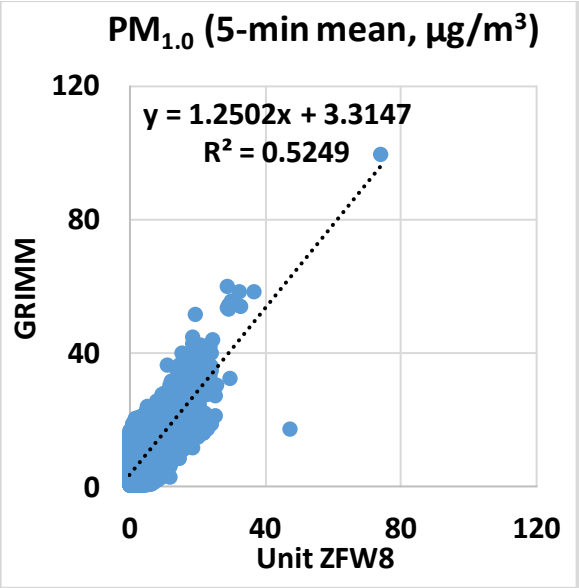


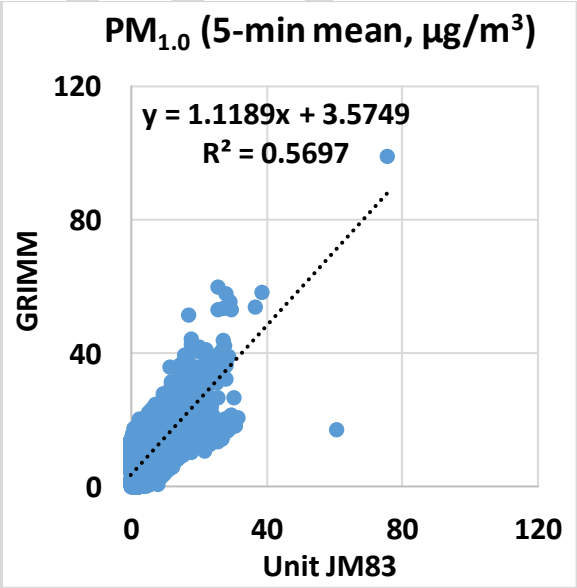



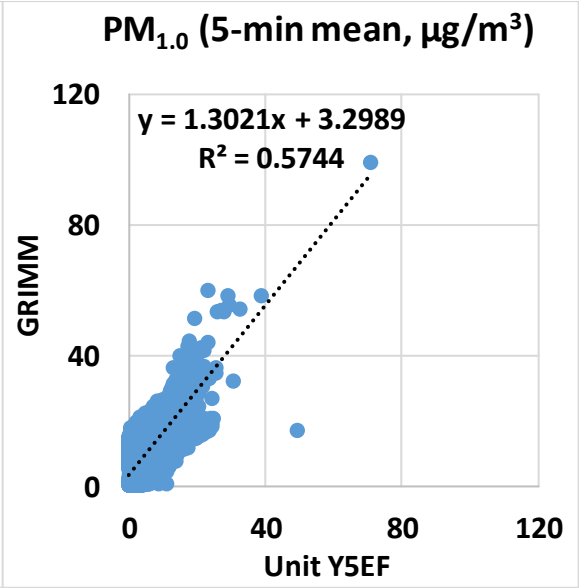
# IQAir AirVisual Outdoor vs GRIMM ($PM_{1.0}$; 5-min mean)



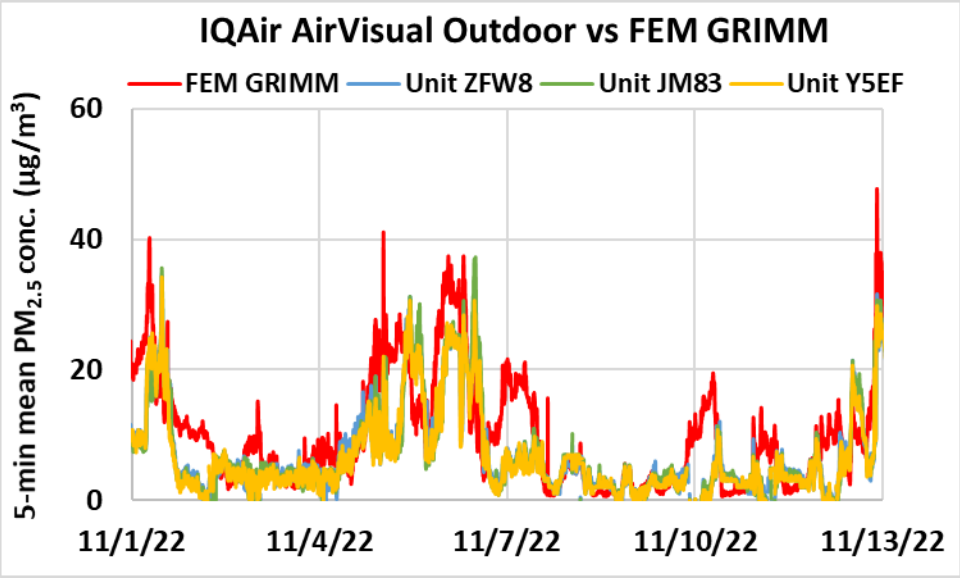

- The IQAir AirVisual Outdoor sensors showed moderate correlations with the corresponding GRIMM data ($0.52 < R^2 < 0.58$)
- Overall, the IQAir AirVisual Outdoor sensors underestimated the $PM_{1.0}$ mass concentrations as measured by GRIMM
- The IQAir AirVisual Outdoor sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by GRIMM



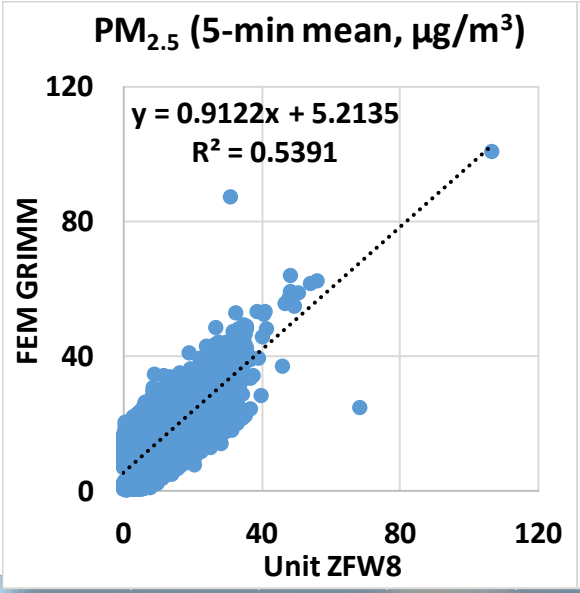



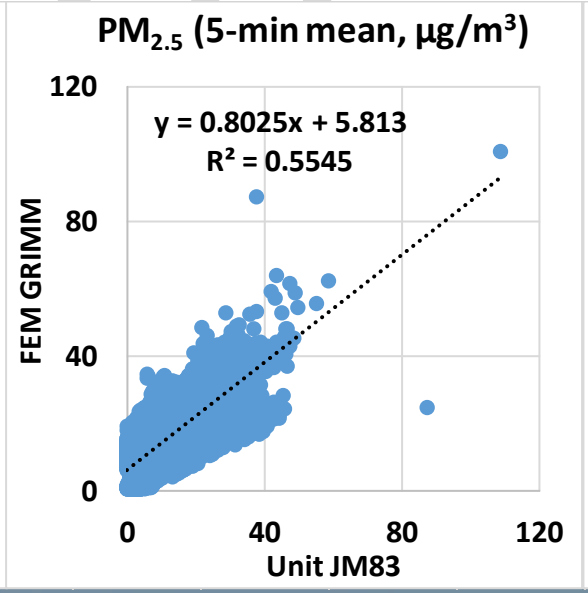



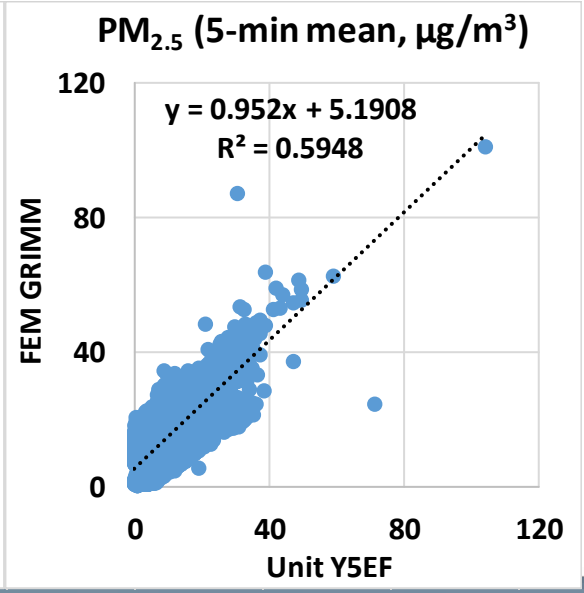
# IQAir AirVisual Outdoor vs FEM GRIMM ($PM_{2.5}$; 5-min mean)



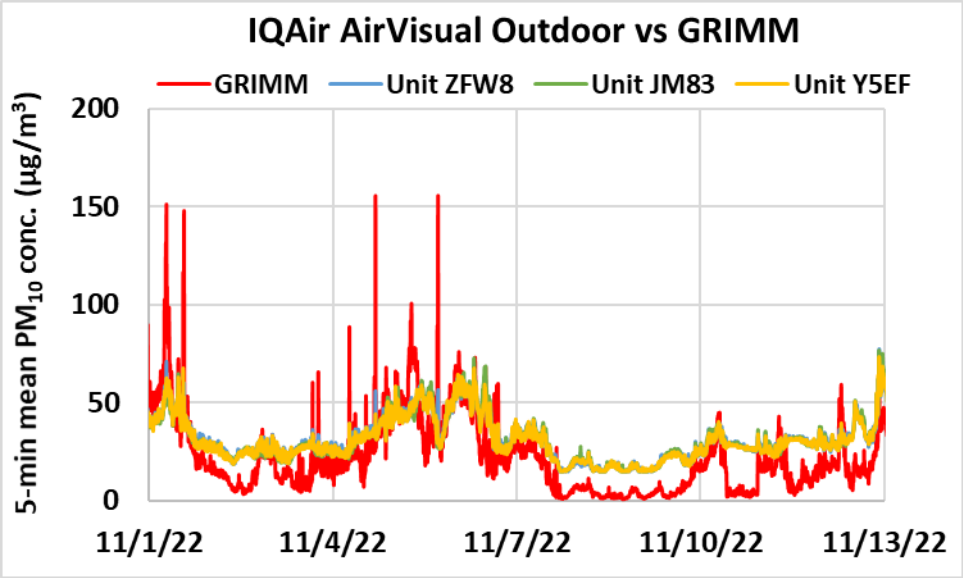

- The IQAir AirVisual Outdoor sensors showed moderate correlations with the corresponding FEM GRIMM data ($0.53 < R^2 < 0.60$)
- Overall, the IQAir AirVisual Outdoor sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM GRIMM
- The IQAir AirVisual Outdoor sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM GRIMM



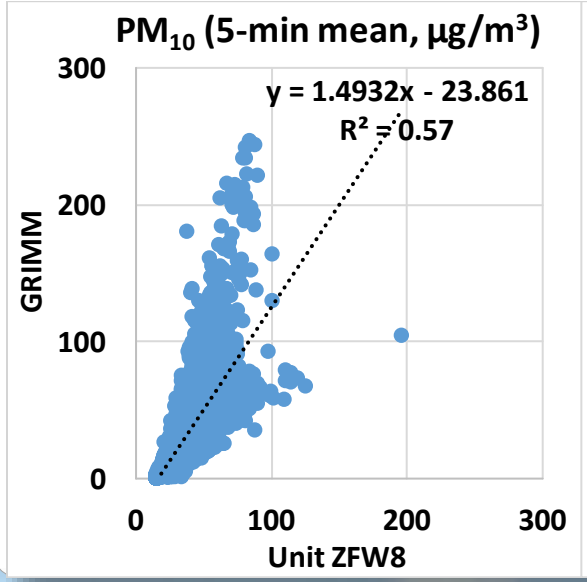



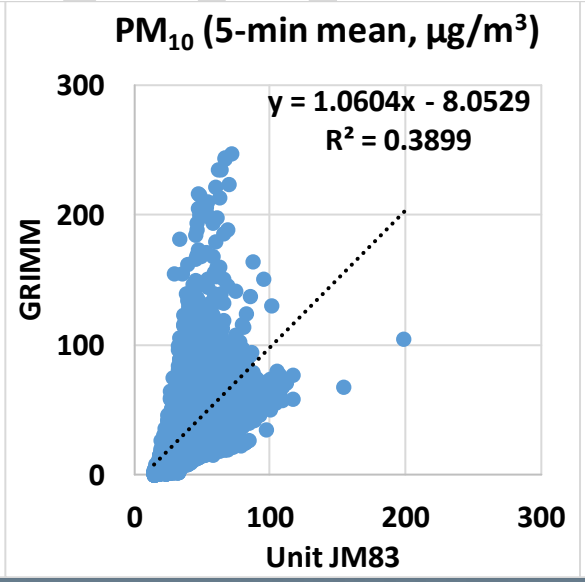



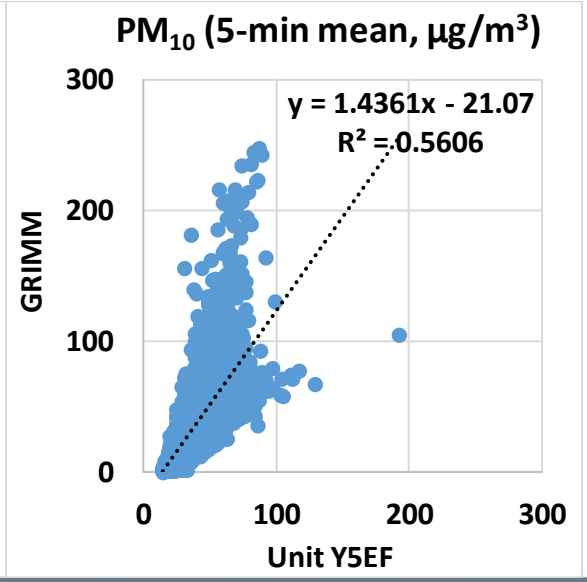
# IQAir AirVisual Outdoor vs GRIMM ($PM_{10}$; 5-min mean)



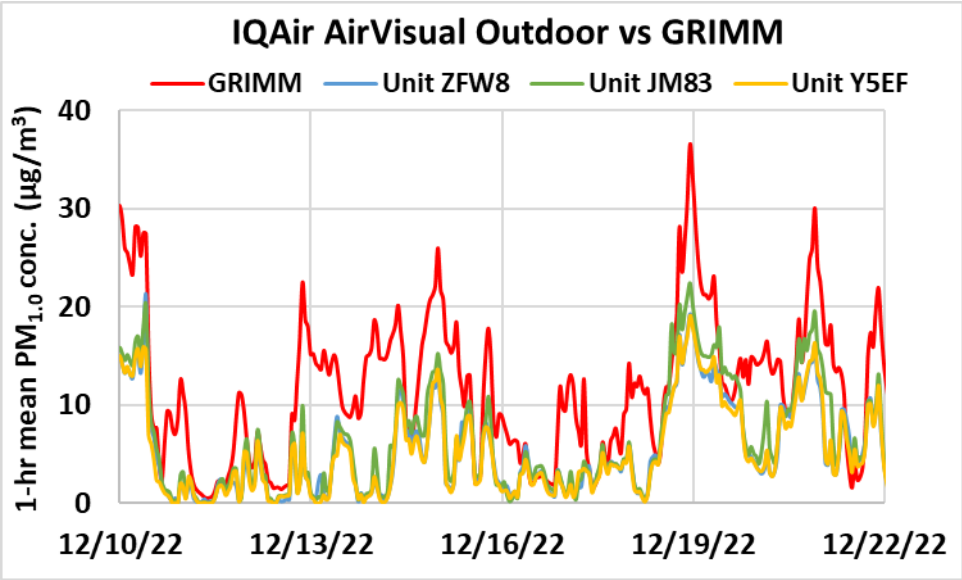

- The IQAir AirVisual Outdoor sensors showed weak to moderate correlations with the corresponding GRIMM data ($0.38 < R^2 < 0.58$)
- Overall, the IQAir AirVisual Outdoor sensors overestimated the $PM_{10}$ mass concentrations as measured by GRIMM
- The IQAir AirVisual Outdoor sensors sometimes seemed to track the $PM_{10}$ diurnal variations as recorded by GRIMM



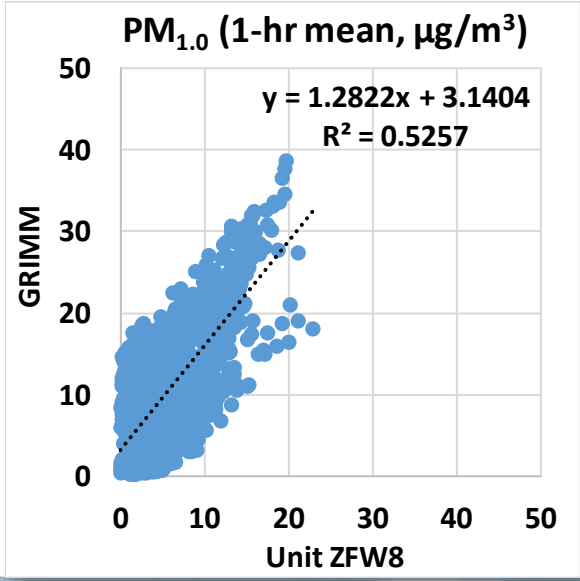



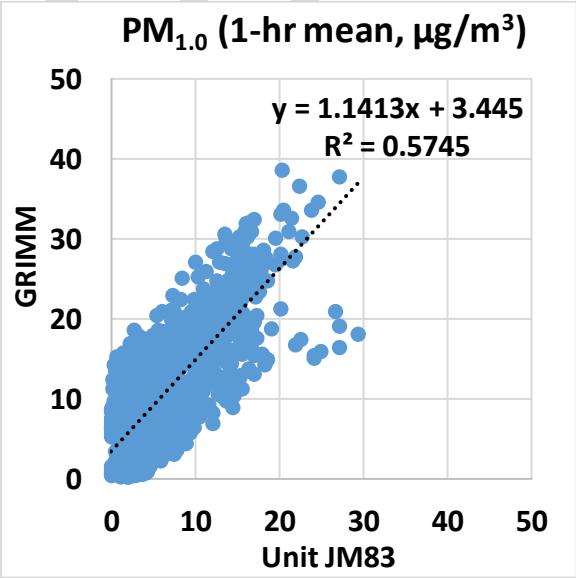



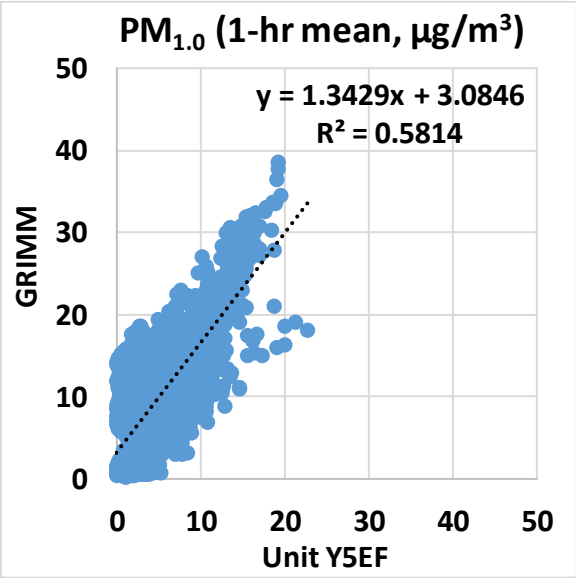
# IQAir AirVisual Outdoor vs GRIMM ($PM_{1.0}$; 1-hr mean)



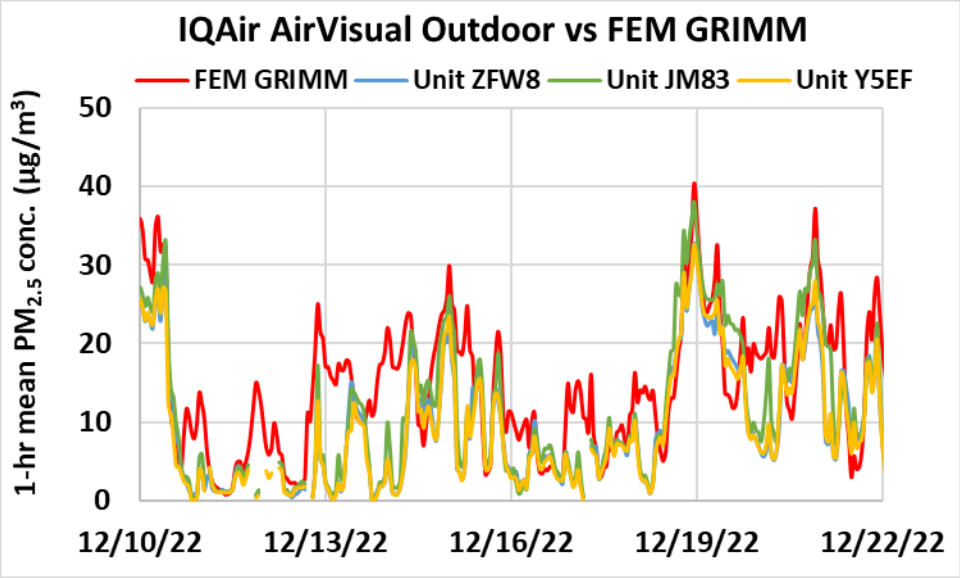

- The IQAir AirVisual Outdoor sensors showed moderate correlations with the corresponding GRIMM data ($0.52 < R^2 < 0.59$)
- Overall, the IQAir AirVisual Outdoor sensors underestimated the $PM_{1.0}$ mass concentrations as measured by GRIMM
- The IQAir AirVisual Outdoor sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by GRIMM



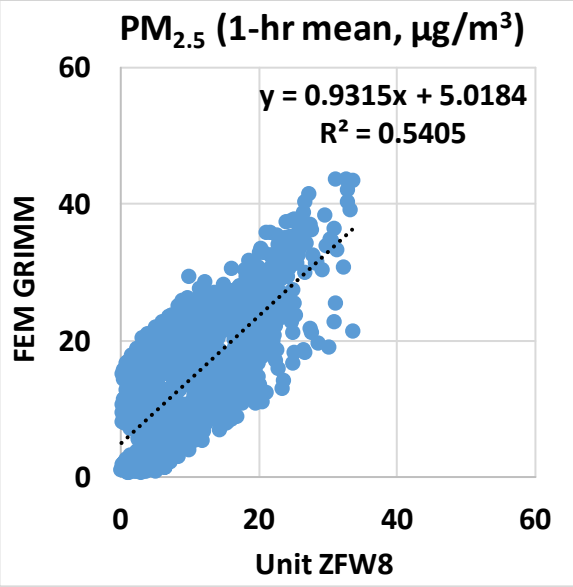



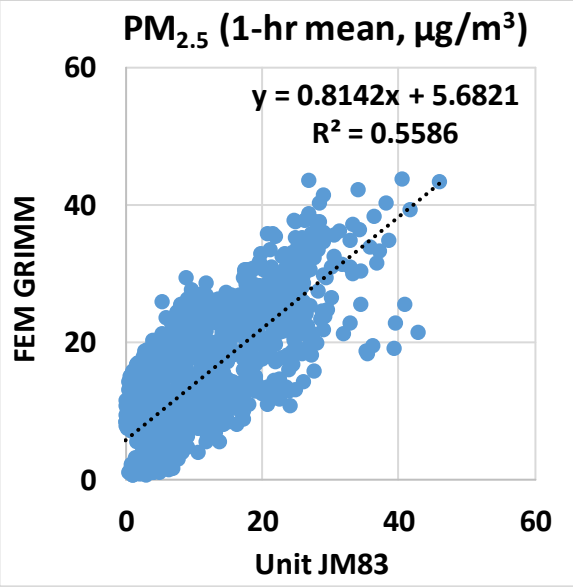



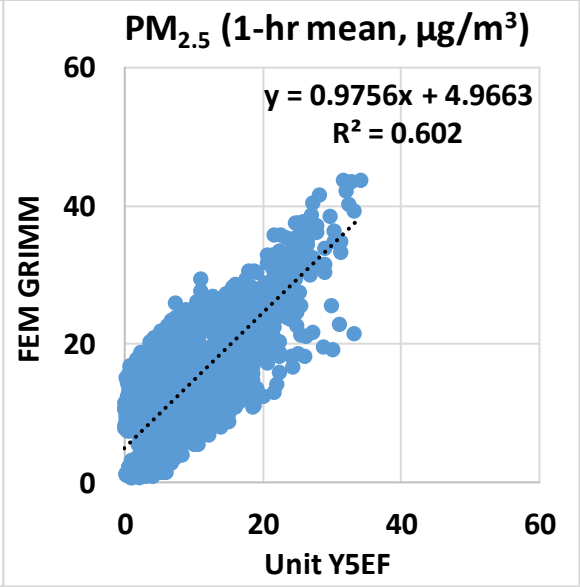
# IQAir AirVisual Outdoor vs FEM GRIMM ($PM_{2.5}$; 1-hr mean)



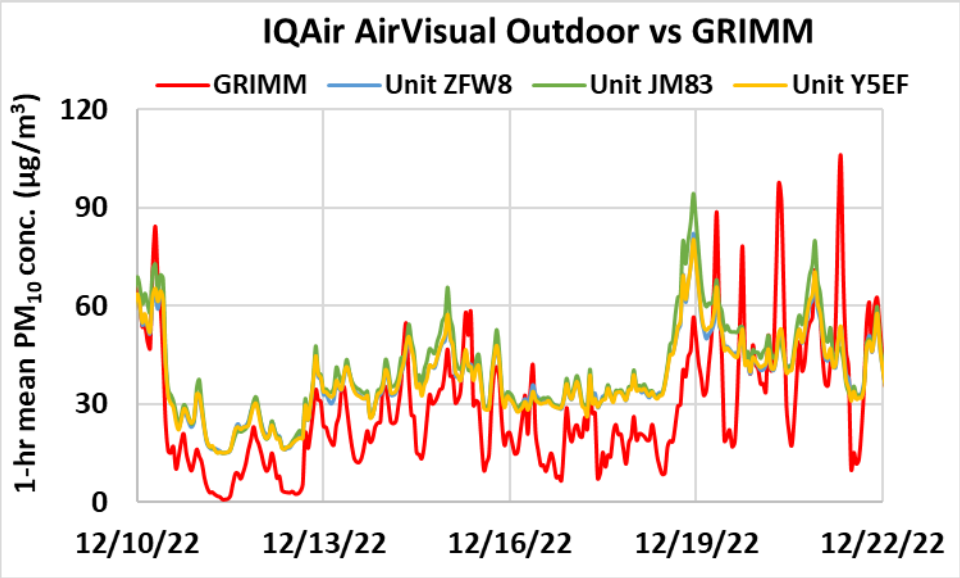

- The IQAir AirVisual Outdoor sensors showed moderate correlations with the corresponding FEM GRIMM data ($0.54 < R^2 < 0.61$)
- Overall, the IQAir AirVisual Outdoor sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM GRIMM
- The IQAir AirVisual Outdoor sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM GRIMM



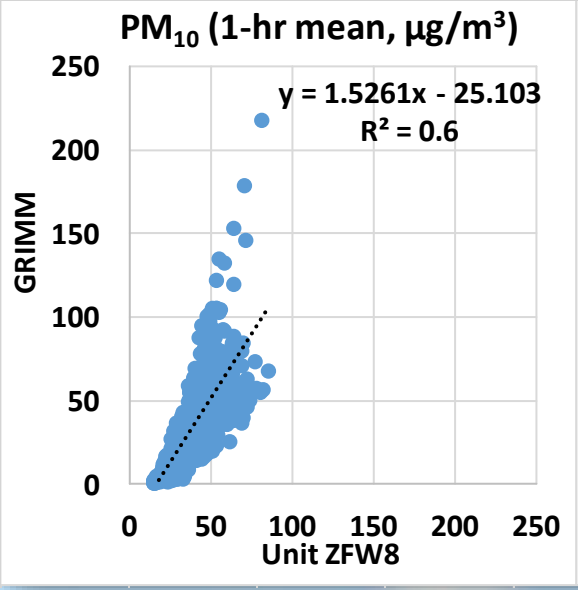



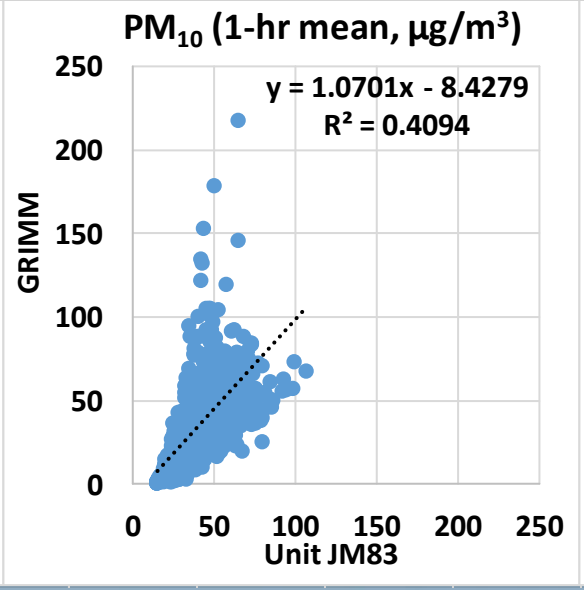



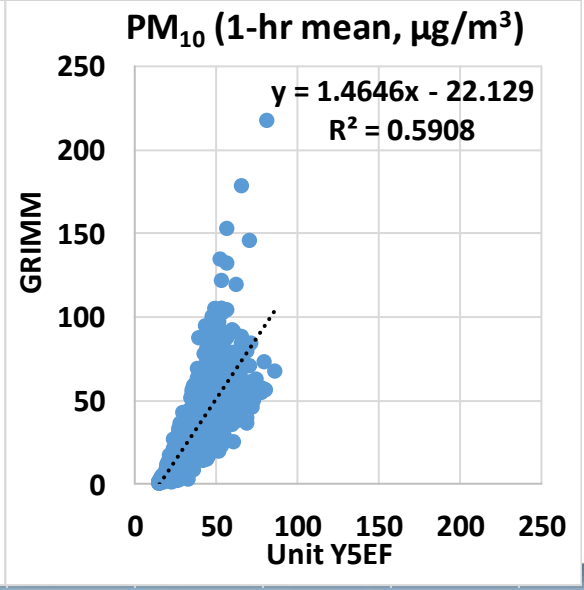
# IQAir AirVisual Outdoor vs GRIMM ($PM_{10}$; 1-hr mean)



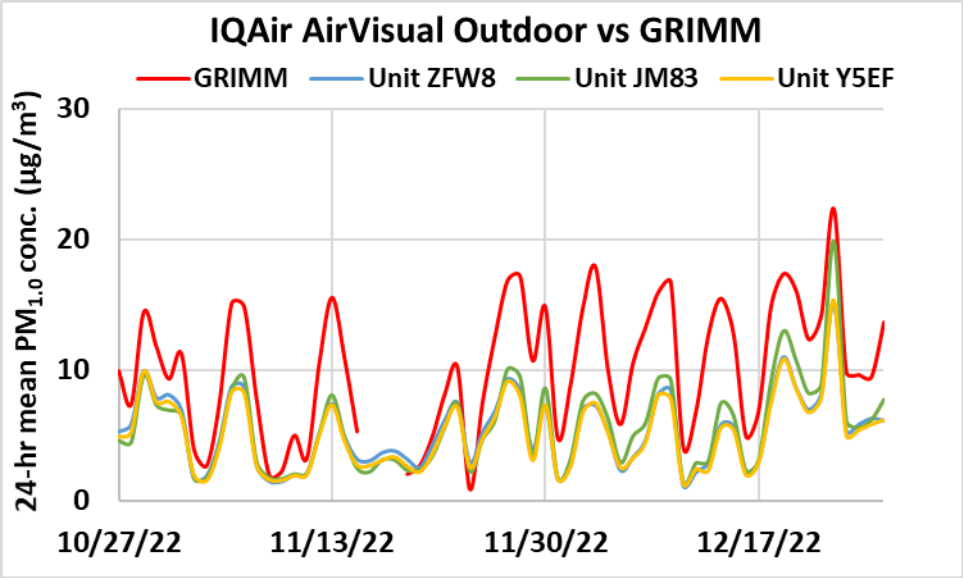

- The IQAir AirVisual Outdoor sensors showed weak to moderate correlations with the corresponding GRIMM data ($0.40 < R^2 < 0.61$)
- Overall, the IQAir AirVisual Outdoor sensors overestimated the $PM_{10}$ mass concentrations as measured by GRIMM
- The IQAir AirVisual Outdoor sensors sometimes seemed to track the $PM_{10}$ diurnal variations as recorded by GRIMM



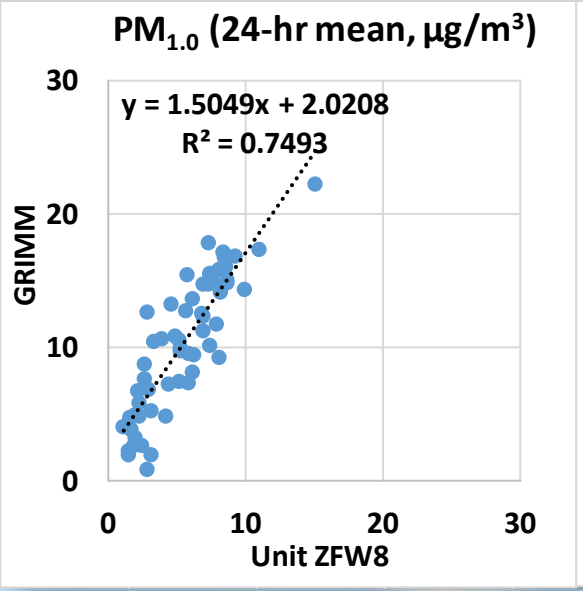



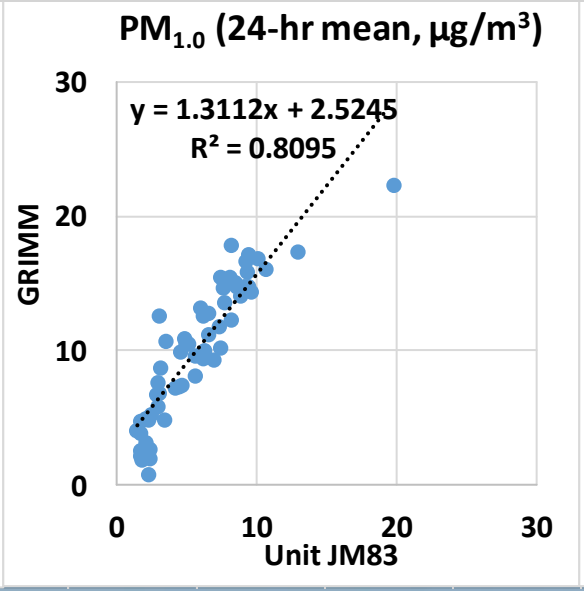



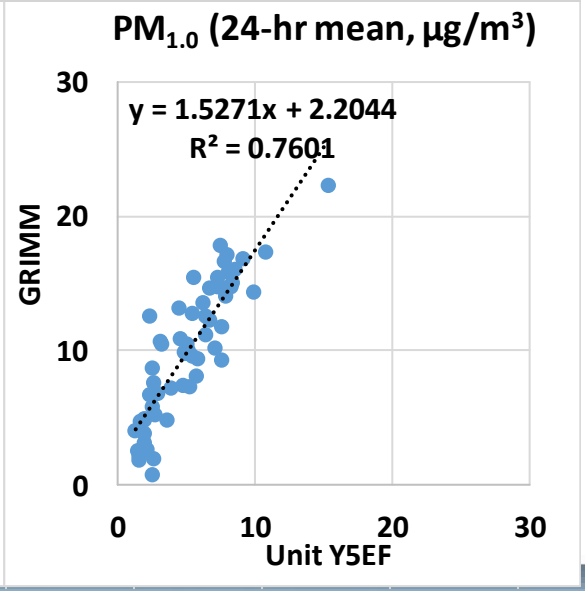
# IQAir AirVisual Outdoor vs GRIMM ($PM_{1.0}$; 24-hr mean)



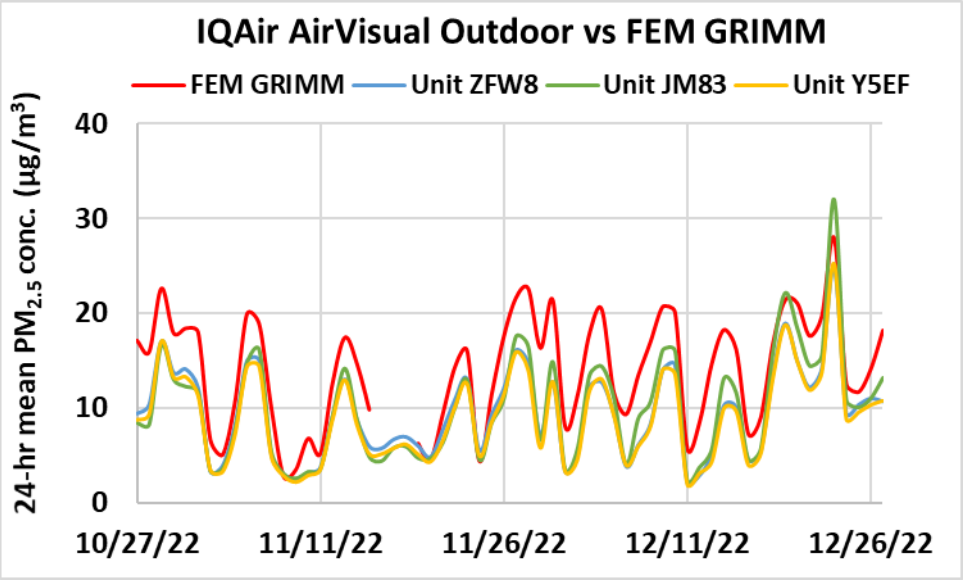

- The IQAir AirVisual Outdoor sensors showed strong correlations with the corresponding GRIMM data ($0.74 < R^2 < 0.81$)
- Overall, the IQAir AirVisual Outdoor sensors underestimated the $PM_{1.0}$ mass concentrations as measured by GRIMM
- The IQAir AirVisual Outdoor sensors seemed to track the $PM_{1.0}$ daily variations as recorded by GRIMM



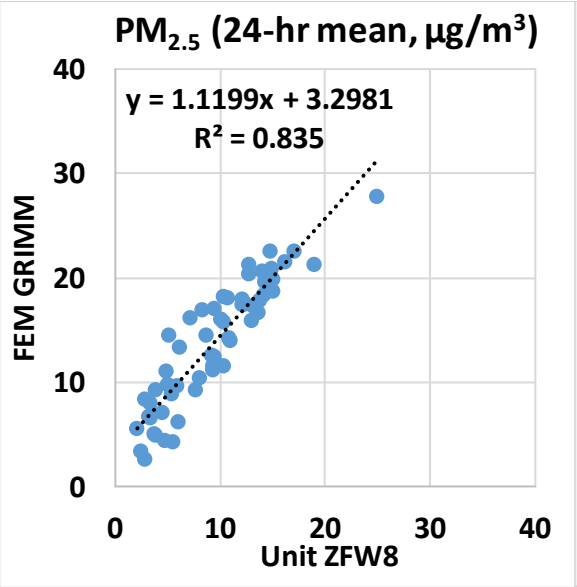



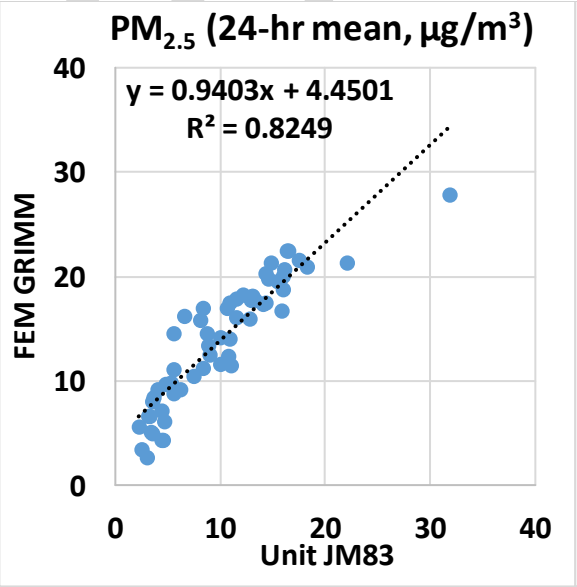



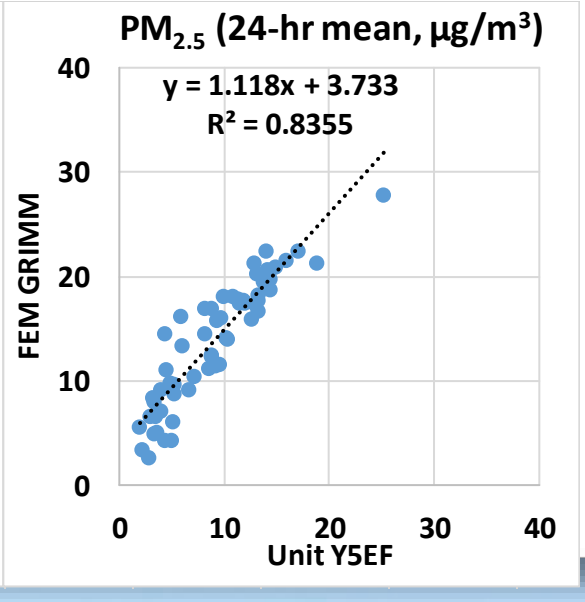
# IQAir AirVisual Outdoor vs FEM GRIMM ($PM_{2.5}$; 24-hr mean)



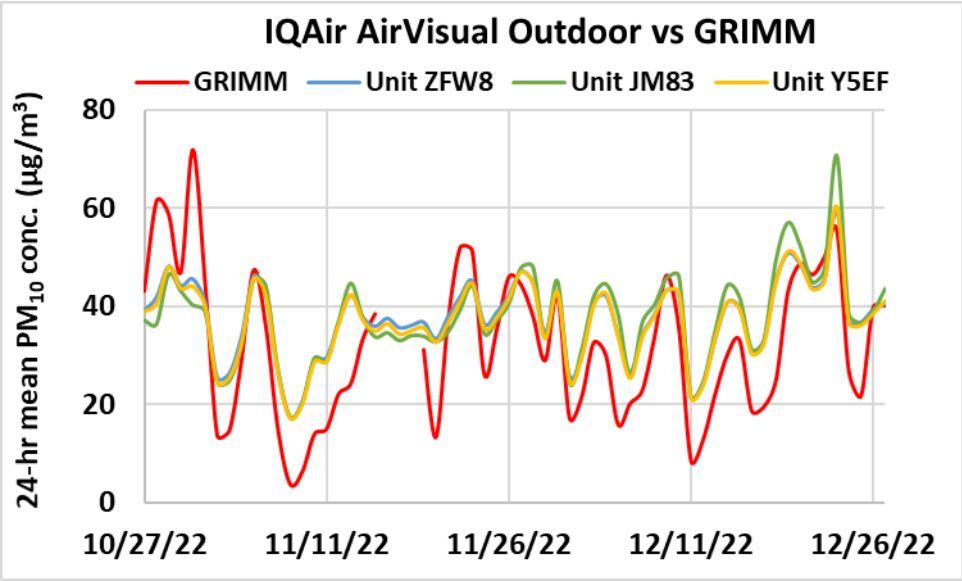

- The IQAir AirVisual Outdoor sensors showed strong correlations with the corresponding FEM GRIMM data ($0.82 < R^2 < 0.84$)
- Overall, the IQAir AirVisual Outdoor sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM GRIMM
- The IQAir AirVisual Outdoor sensors seemed to track the $PM_{2.5}$ daily variations as recorded by FEM GRIMM



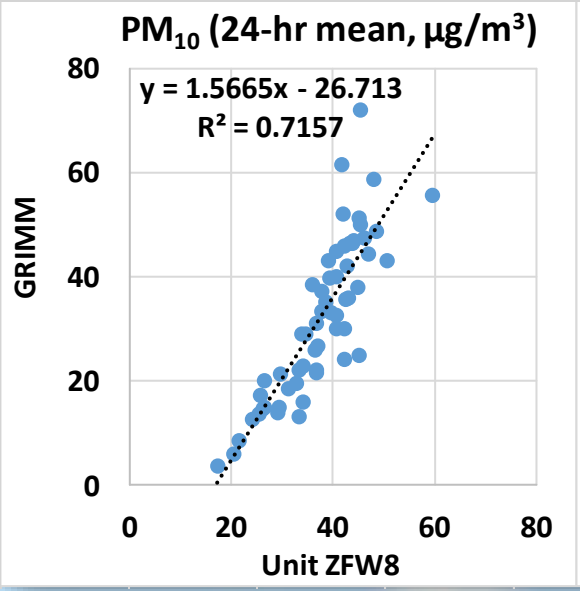



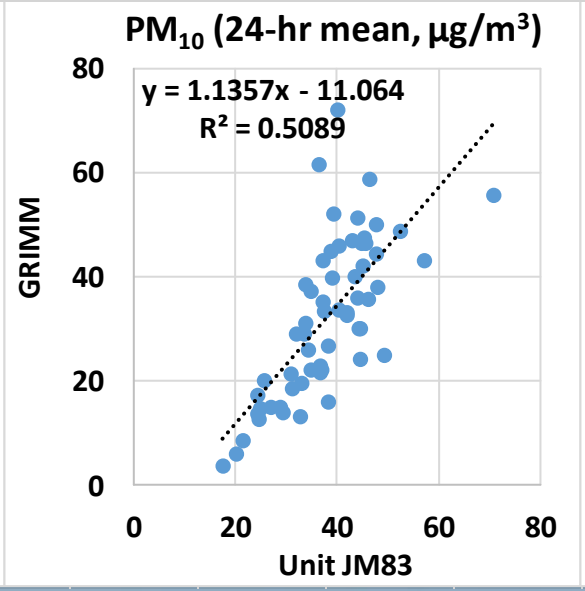



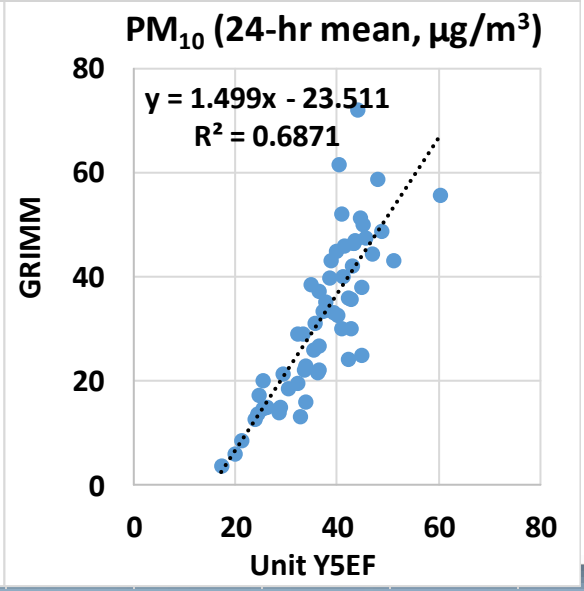
# IQAir AirVisual Outdoor vs GRIMM ($PM_{10}$; 24-hr mean)



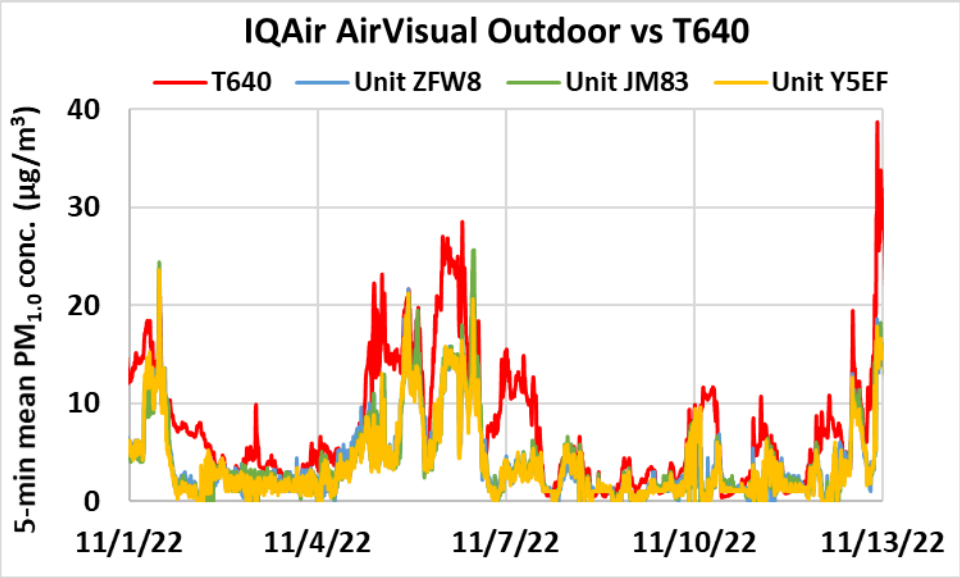

- The IQAir AirVisual Outdoor sensors showed moderate to strong correlations with the corresponding GRIMM data ($0.50 < R^2 < 0.72$)
- Overall, the IQAir AirVisual Outdoor sensors overestimated the $PM_{10}$ mass concentrations as measured by GRIMM
- The IQAir AirVisual Outdoor sensors sometimes seemed to track the $PM_{10}$ daily variations as recorded by GRIMM



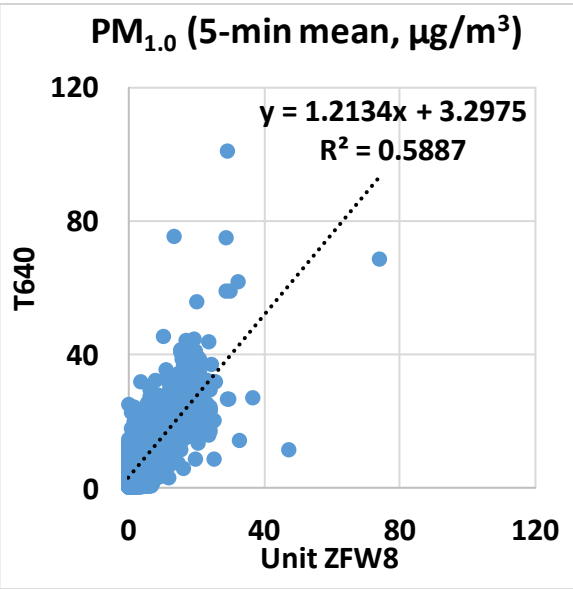



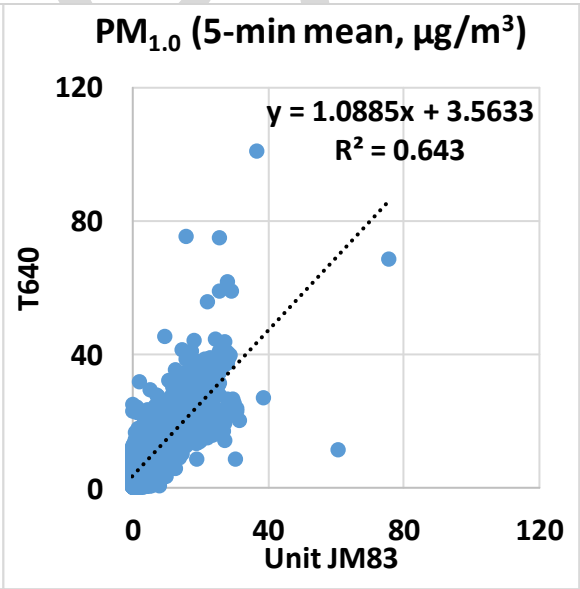



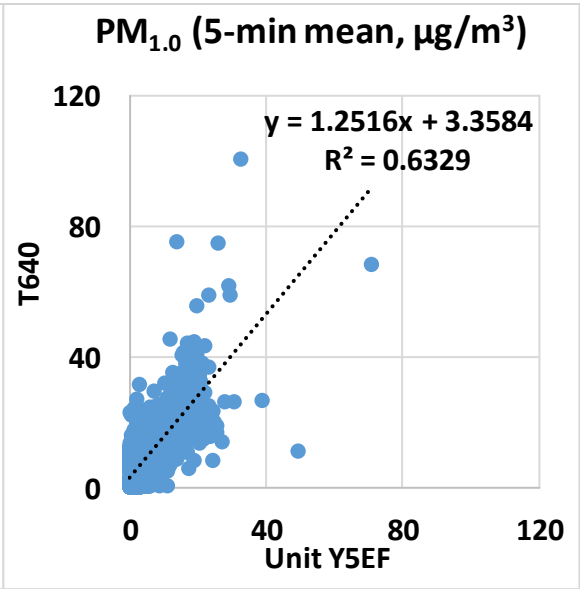
# IQAir AirVisual Outdoor vs T640 ($PM_{1.0}$; 5-min mean)



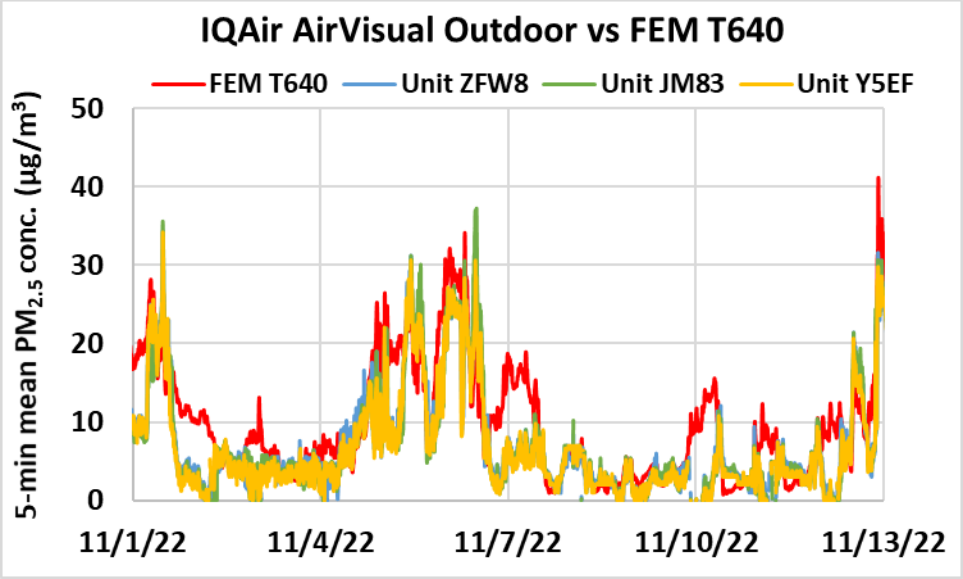

- The IQAir AirVisual Outdoor sensors showed moderate correlations with the corresponding T640 data ($0.58 < R^2 < 0.65$)
- Overall, the IQAir AirVisual Outdoor sensors underestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The IQAir AirVisual Outdoor sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by T640



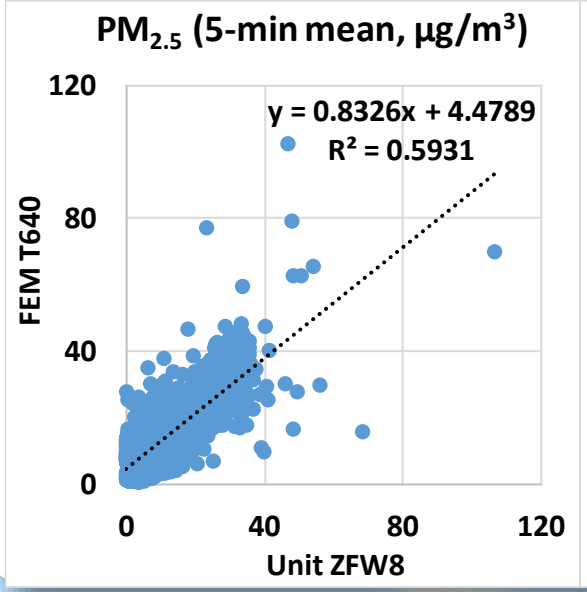



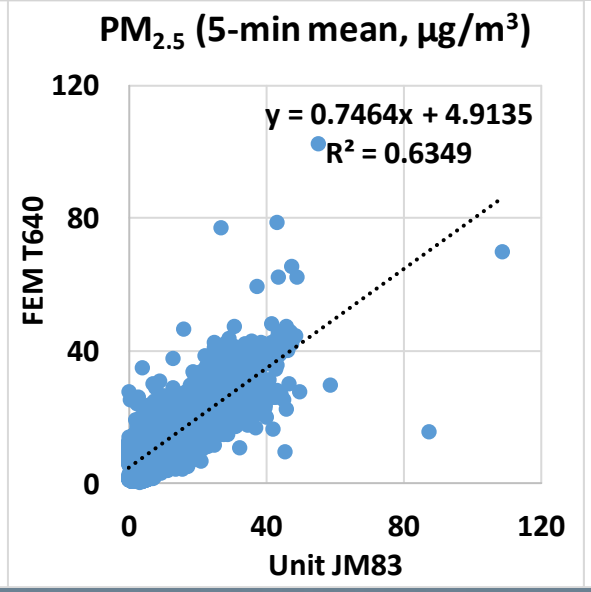



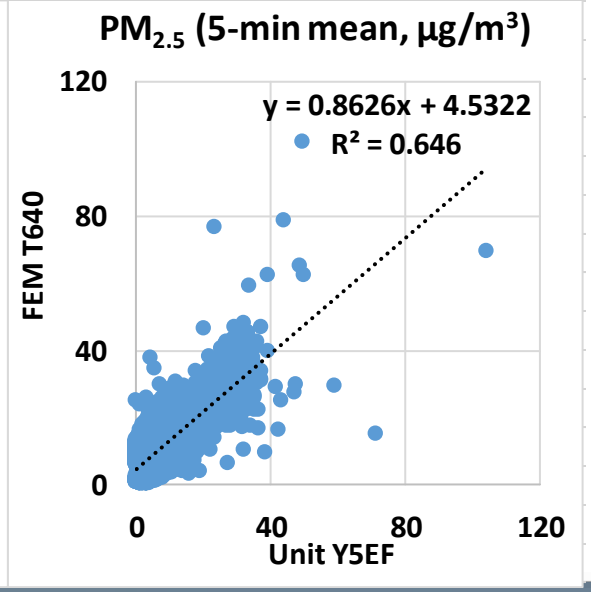
# IQAir AirVisual Outdoor vs FEM T640 ($PM_{2.5}$; 5-min mean)



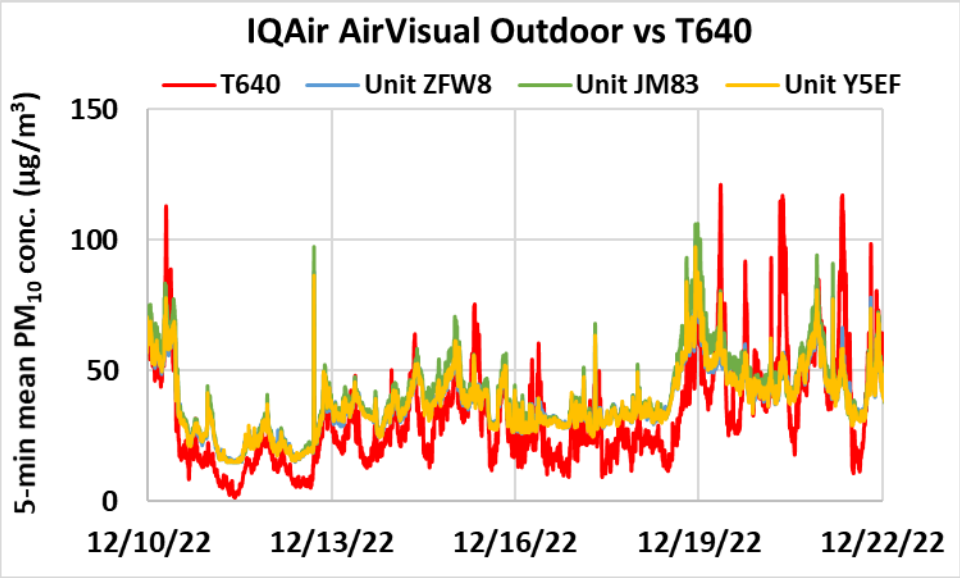

- The IQAir AirVisual Outdoor sensors showed moderate correlations with the corresponding FEM T640 data ($0.59 < R^2 < 0.65$)
- Overall, the IQAir AirVisual Outdoor sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The IQAir AirVisual Outdoor sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



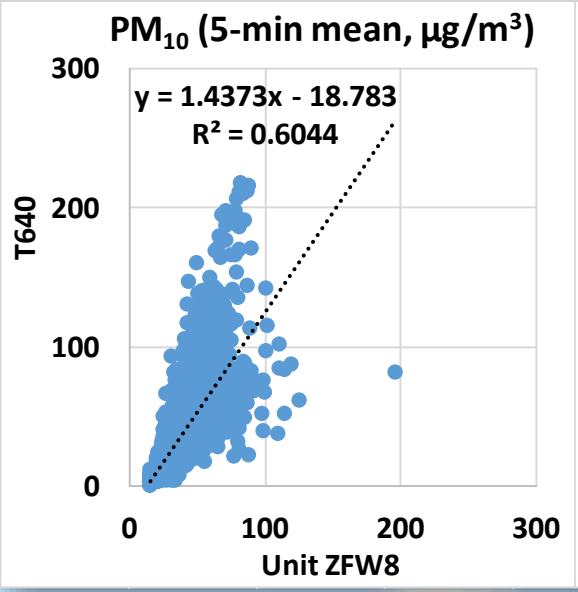



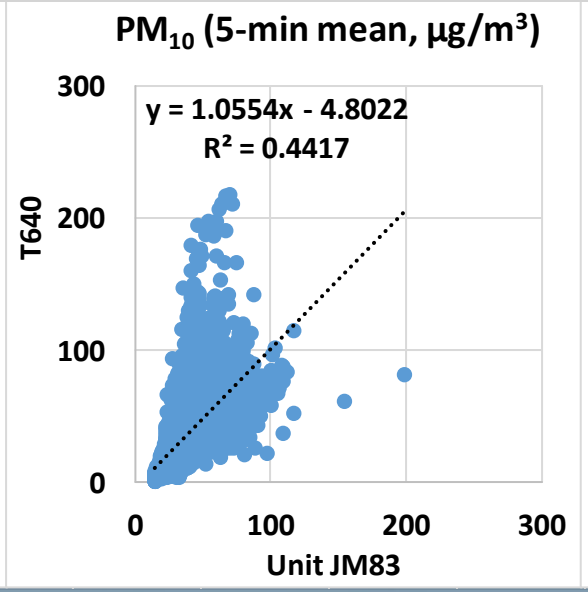



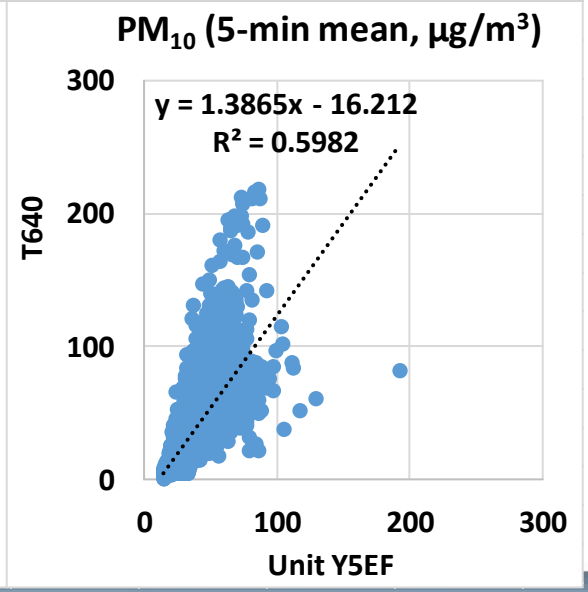
# IQAir AirVisual Outdoor vs T640 ($PM_{10}$; 5-min mean)



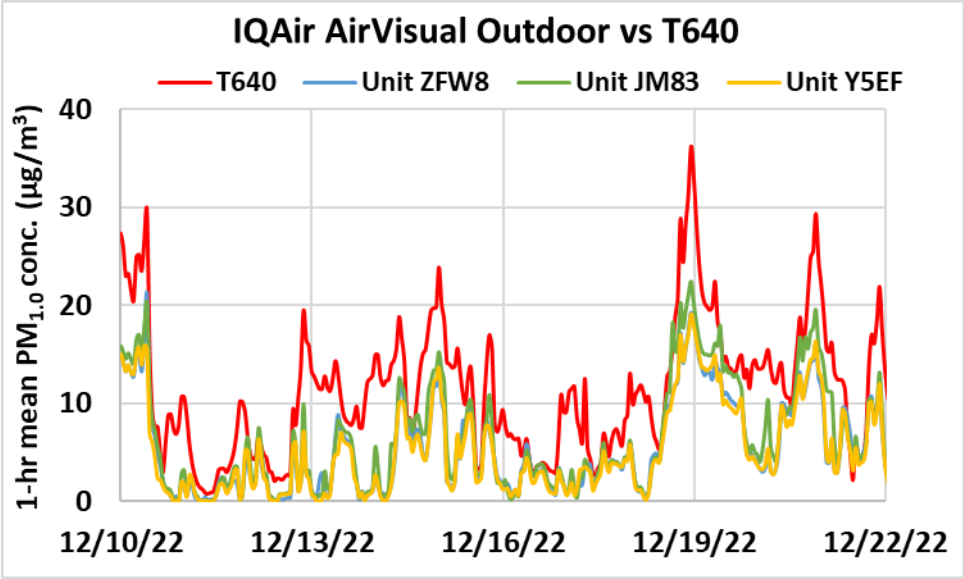

- The IQAir AirVisual Outdoor sensors showed weak to moderate correlations with the corresponding T640 data ($0.44 < R^2 < 0.61$)
- Overall, the IQAir AirVisual Outdoor sensors overestimated the $PM_{10}$ mass concentrations as measured by T640
- The IQAir AirVisual Outdoor sensors seemed to track the $PM_{10}$ diurnal variations as recorded by T640



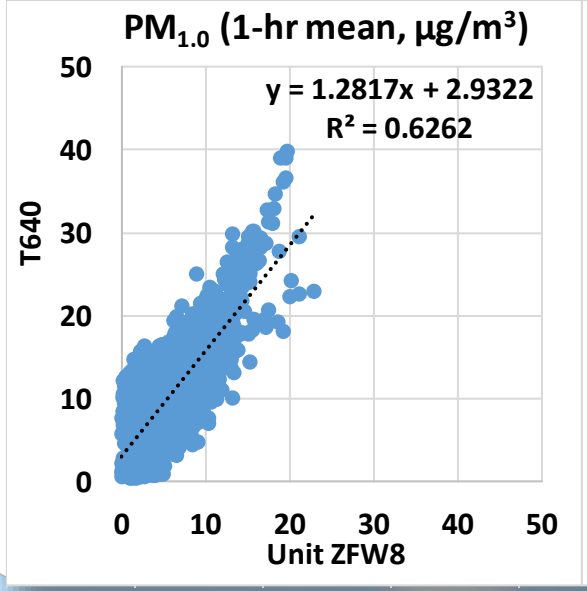



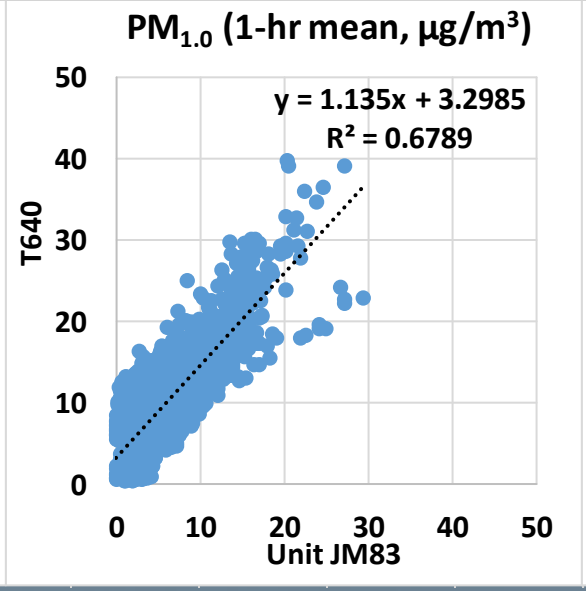



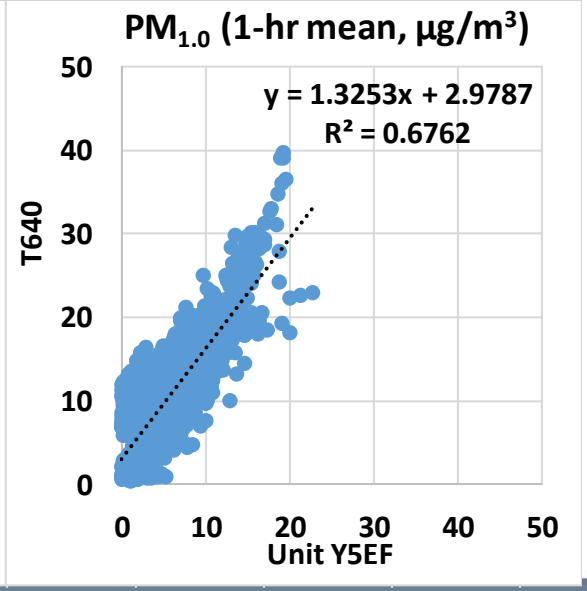
# IQAir AirVisual Outdoor vs T640 ($PM_{1.0}$; 1-hr mean)



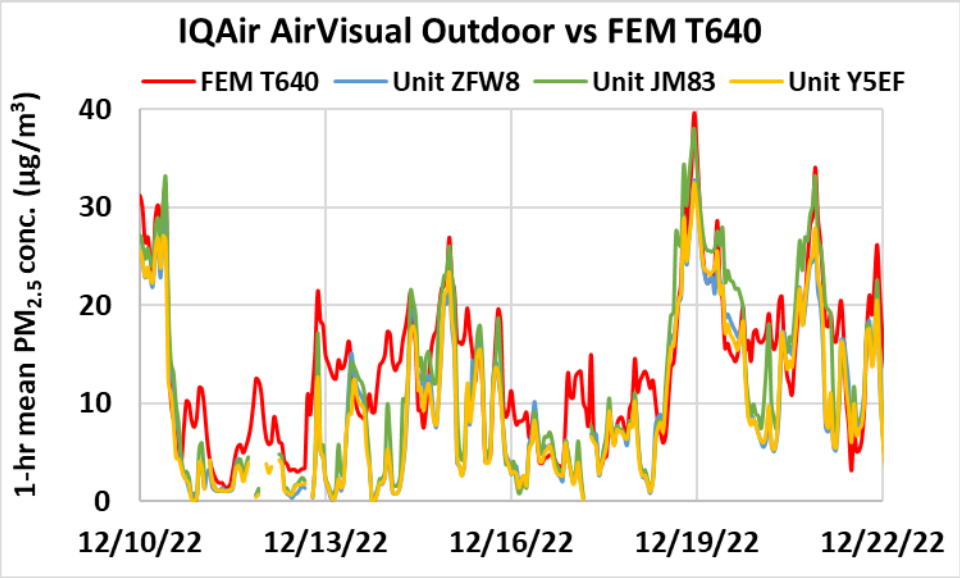

- The IQAir AirVisual Outdoor sensors showed moderate correlations with the corresponding T640 data ($0.62 < R^2 < 0.68$)
- Overall, the IQAir AirVisual Outdoor sensors underestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The IQAir AirVisual Outdoor sensors seemed to track the $PM_{1.0}$ diurnal variations as recorded by T640



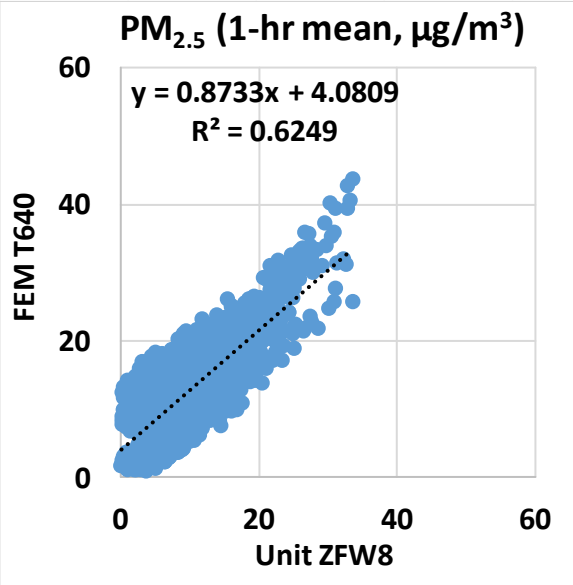



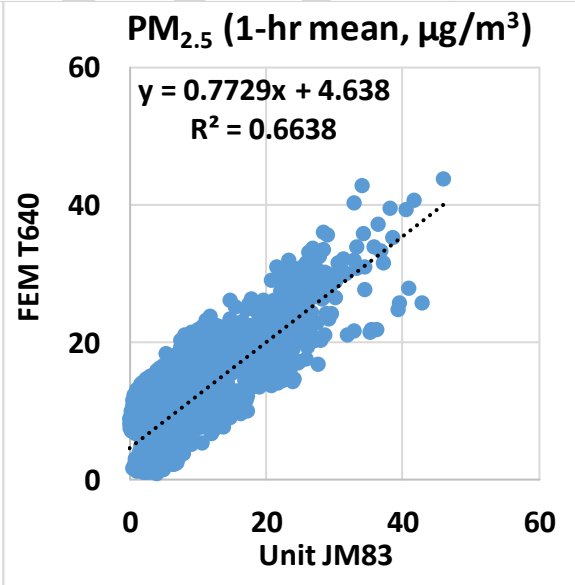



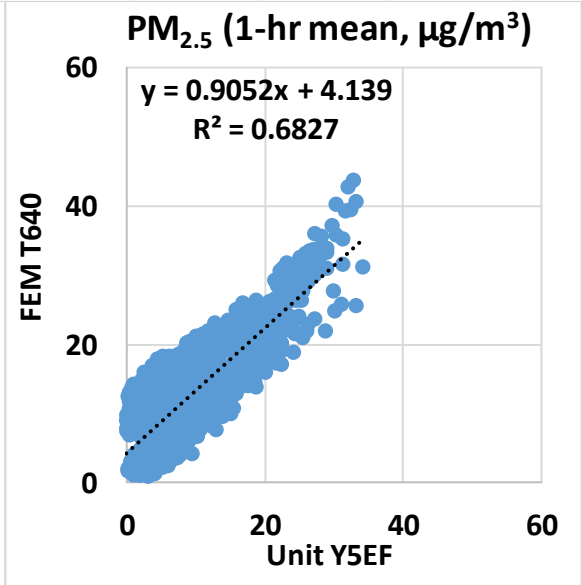
# IQAir AirVisual Outdoor vs FEM T640 ($PM_{2.5}$; 1-hr mean)



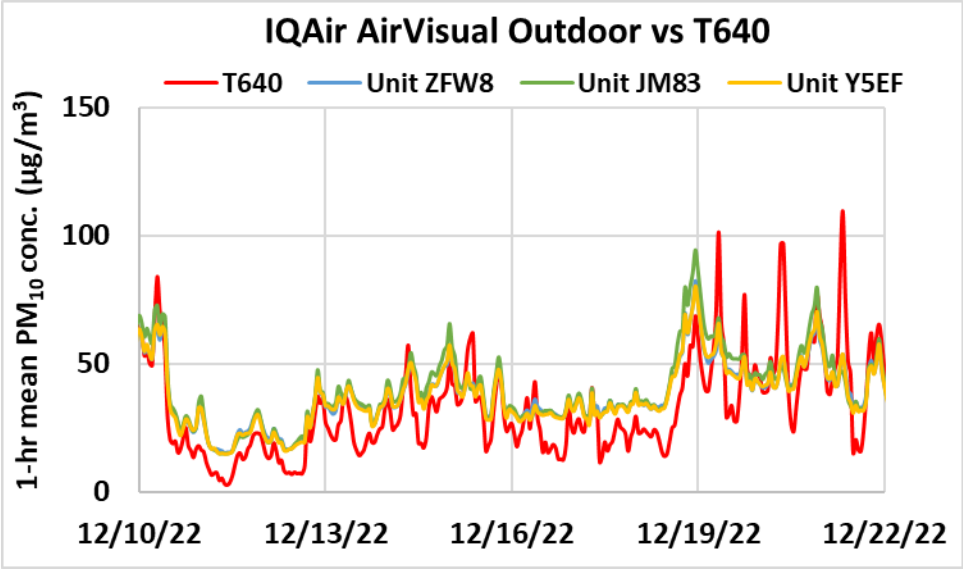

- The IQAir AirVisual Outdoor sensors showed moderate correlations with the corresponding FEM T640 data ($0.62 < R^2 < 0.69$)
- Overall, the IQAir AirVisual Outdoor sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The IQAir AirVisual Outdoor sensors seemed to track the $PM_{2.5}$ diurnal variations as recorded by FEM T640



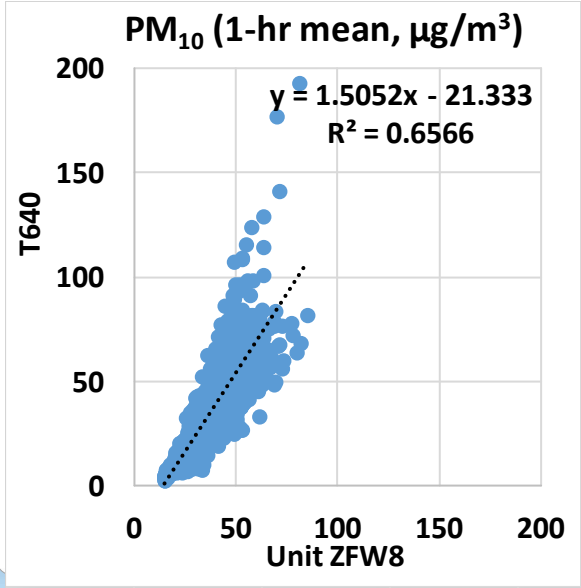



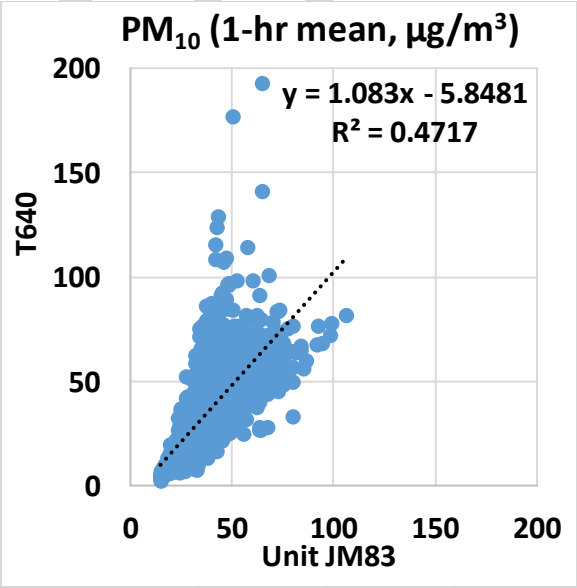



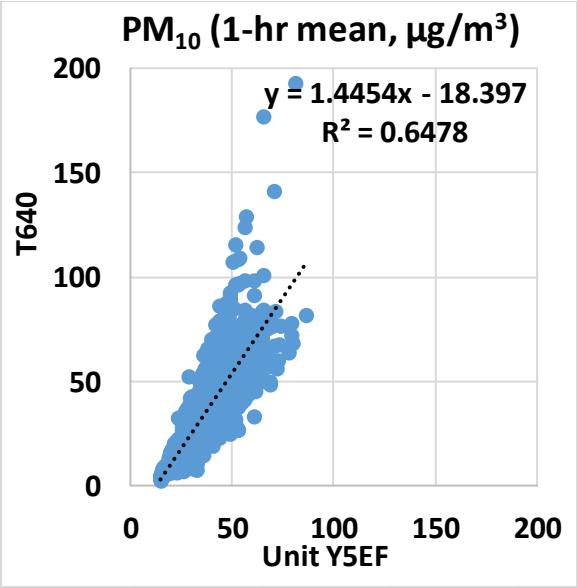
# IQAir AirVisual Outdoor vs T640 ($PM_{10}$; 1-hr mean)



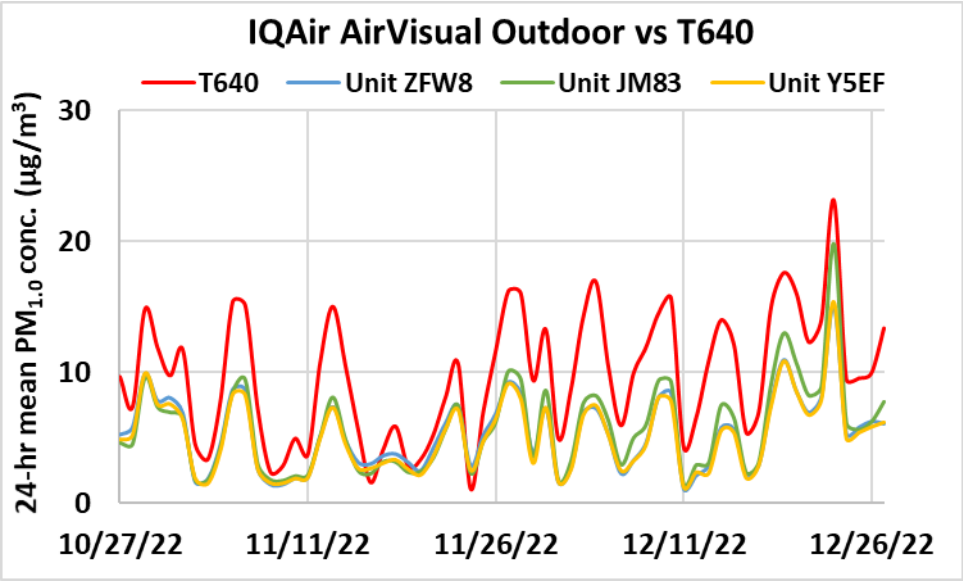

- The IQAir AirVisual Outdoor sensors showed weak to moderate correlations with the corresponding T640 data ($0.47 < R^2 < 0.66$)
- Overall, the IQAir AirVisual Outdoor sensors overestimated the $PM_{10}$ mass concentrations as measured by T640
- The IQAir AirVisual Outdoor sensors seemed to track the $PM_{10}$ diurnal variations as recorded by T640



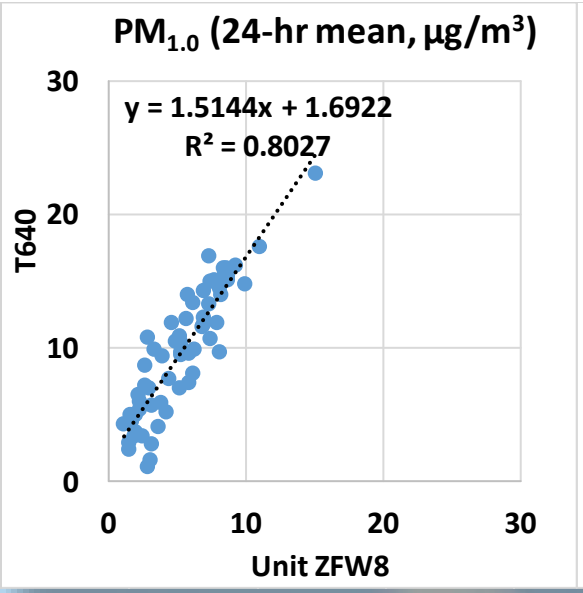



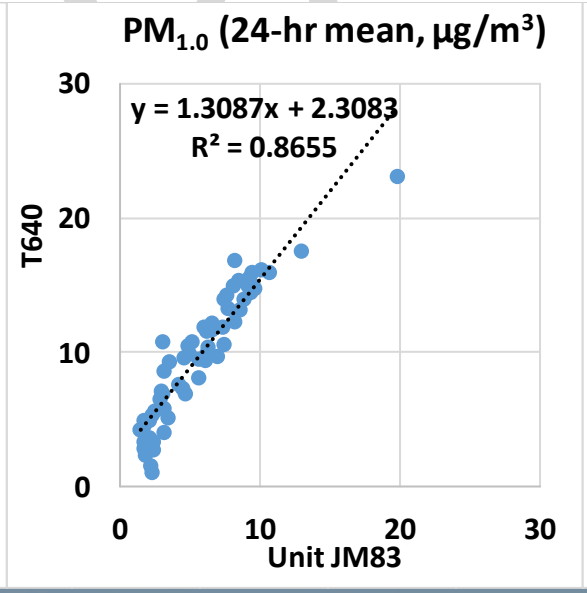



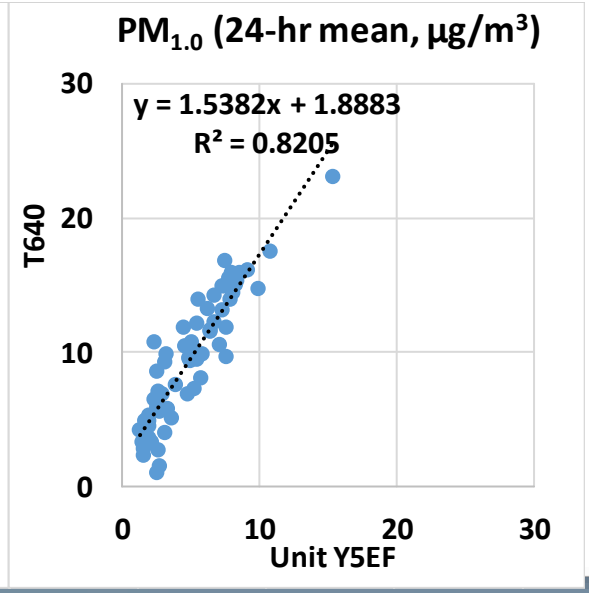
# IQAir AirVisual Outdoor vs T640 ($PM_{1.0}$; 24-hr mean)



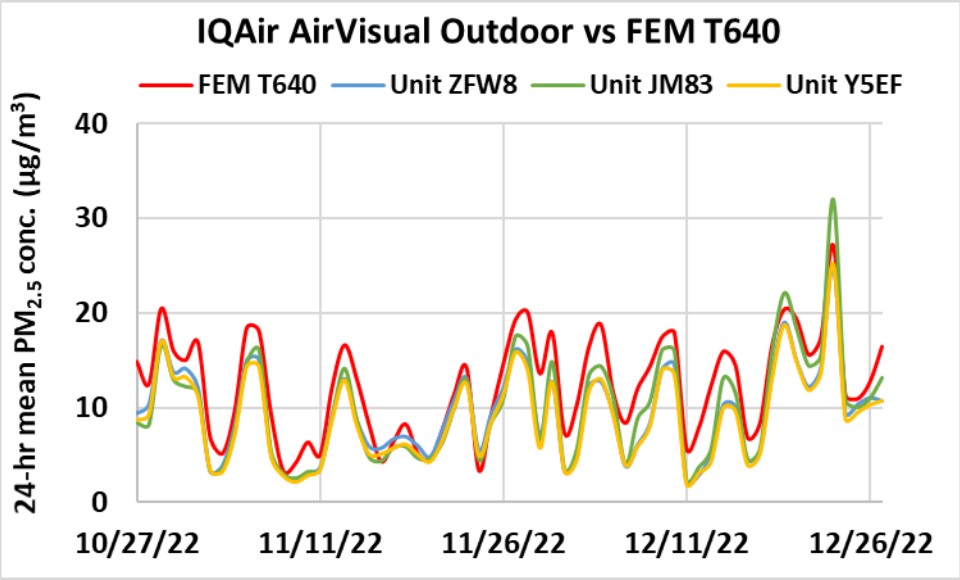

- The IQAir AirVisual Outdoor sensors showed strong correlations with the corresponding T640 data ($0.80 < R^2 < 0.87$)
- Overall, the IQAir AirVisual Outdoor sensors underestimated the $PM_{1.0}$ mass concentrations as measured by T640
- The IQAir AirVisual Outdoor sensors seemed to track the $PM_{1.0}$ daily variations as recorded by T640



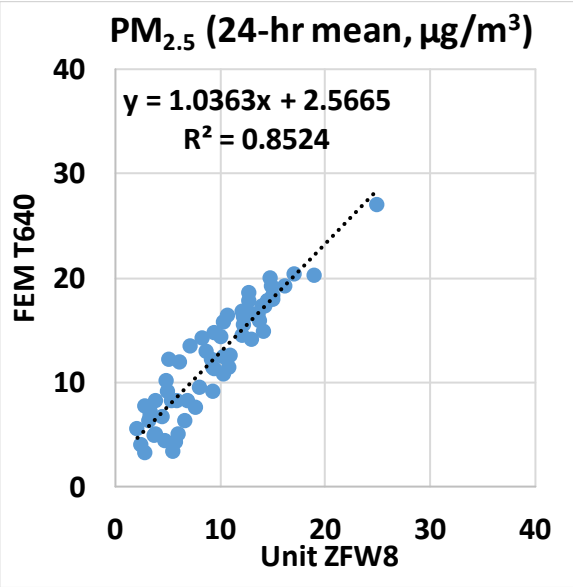



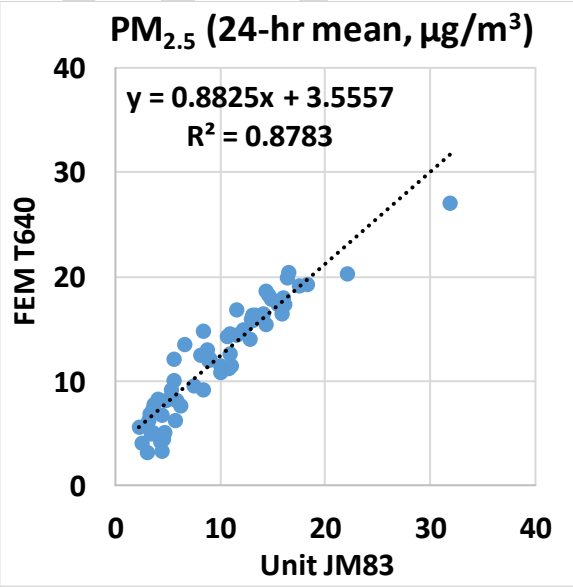



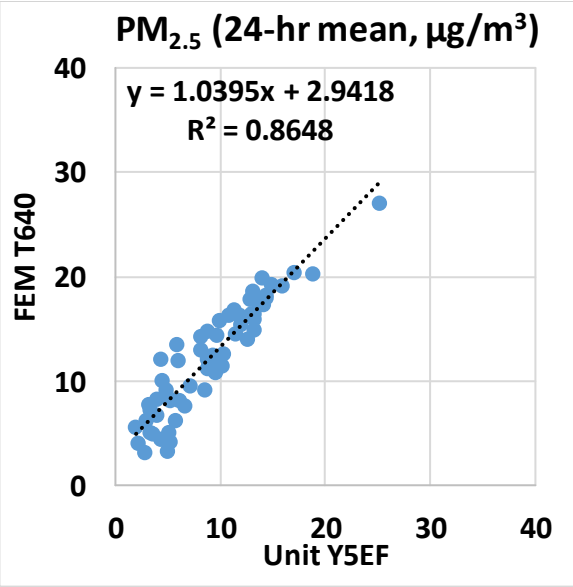
# IQAir AirVisual Outdoor vs FEM T640 ($PM_{2.5}$; 24-hr mean)



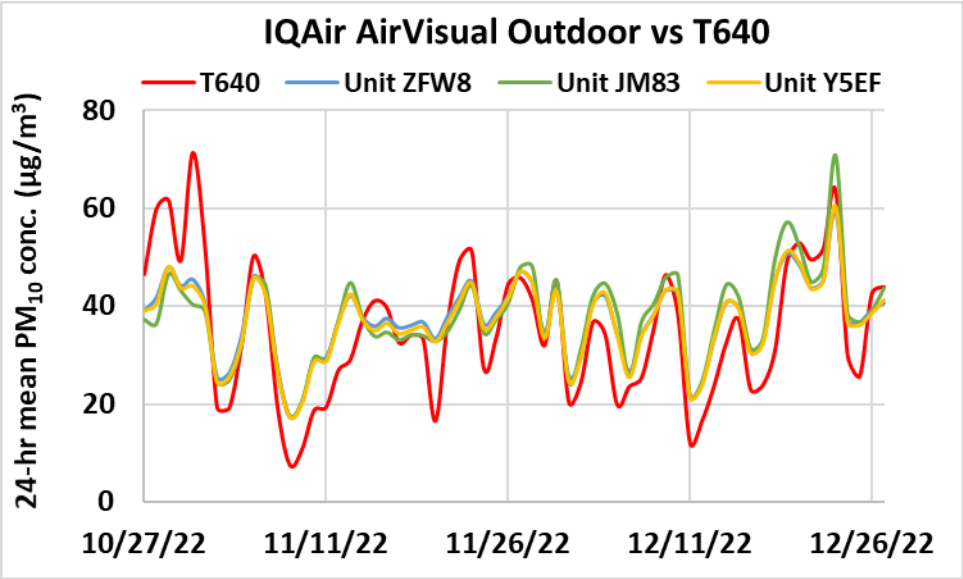

- The IQAir AirVisual Outdoor sensors showed strong correlations with the corresponding FEM T640 data ($0.85 < R^2 < 0.88$)
- Overall, the IQAir AirVisual Outdoor sensors underestimated the $PM_{2.5}$ mass concentrations as measured by FEM T640
- The IQAir AirVisual Outdoor sensors seemed to track the $PM_{2.5}$ daily variations as recorded by FEM T640



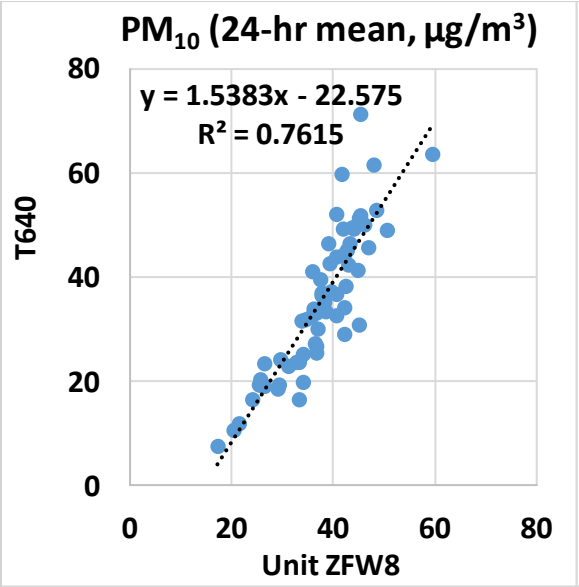



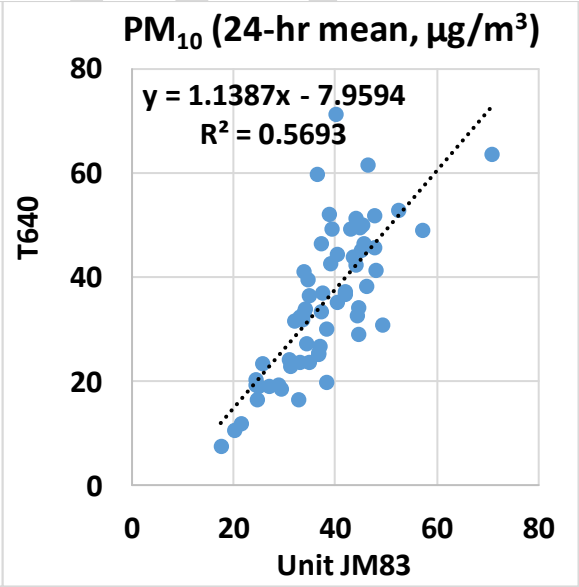



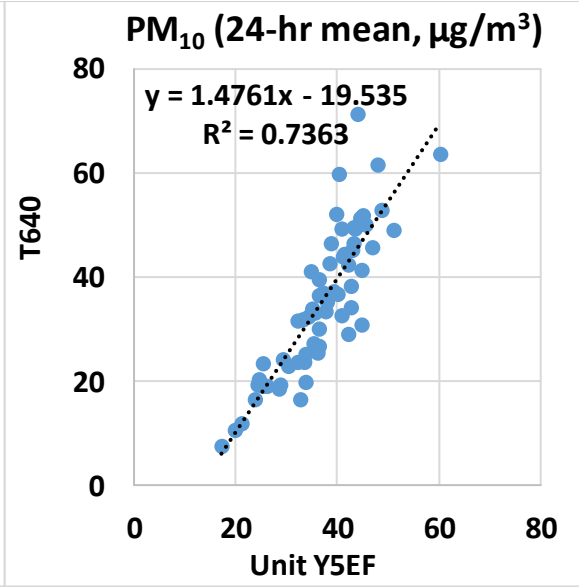
# IQAir AirVisual Outdoor vs T640 ($PM_{10}$; 24-hr mean)



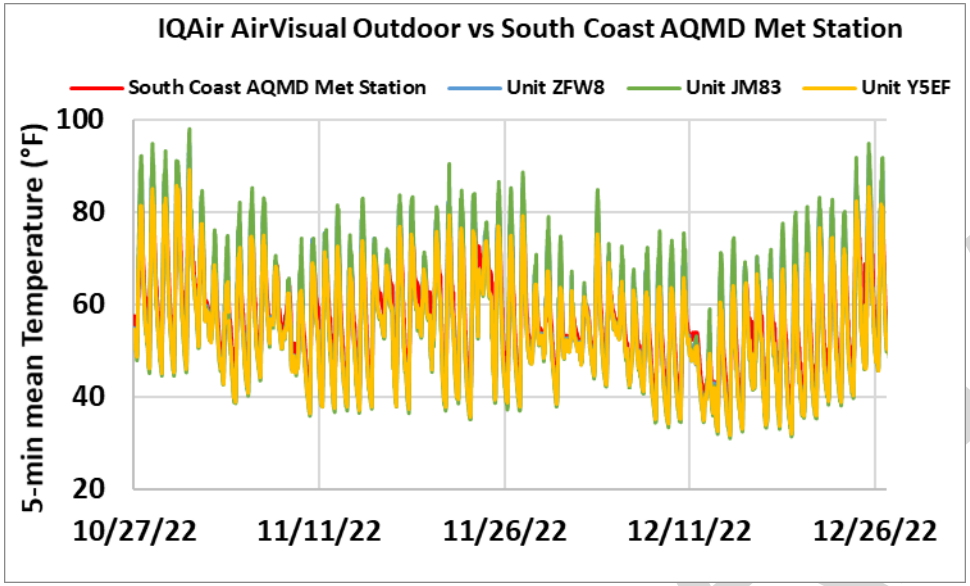

- The IQAir AirVisual Outdoor sensors showed moderate to strong correlations with the corresponding T640 data ($0.56 < R^2 < 0.77$)
- Overall, the IQAir AirVisual Outdoor sensors overestimated the $PM_{10}$ mass concentrations as measured by T640
- The IQAir AirVisual Outdoor sensors seemed to track the $PM_{10}$ daily variations as recorded by T640



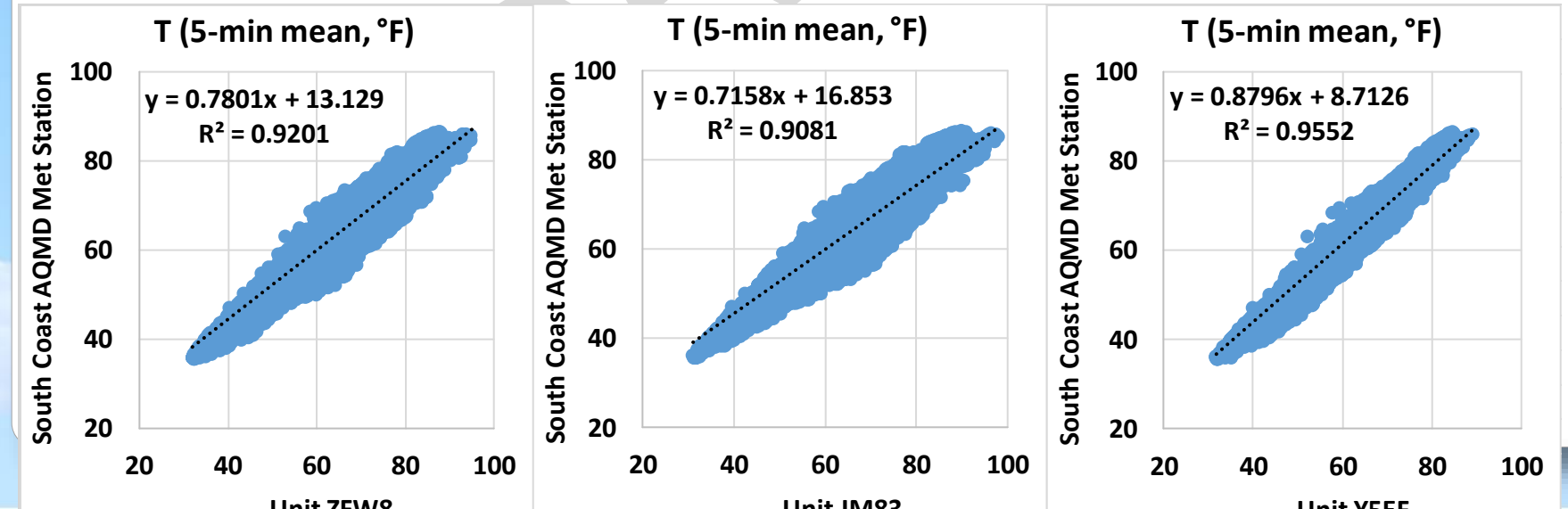



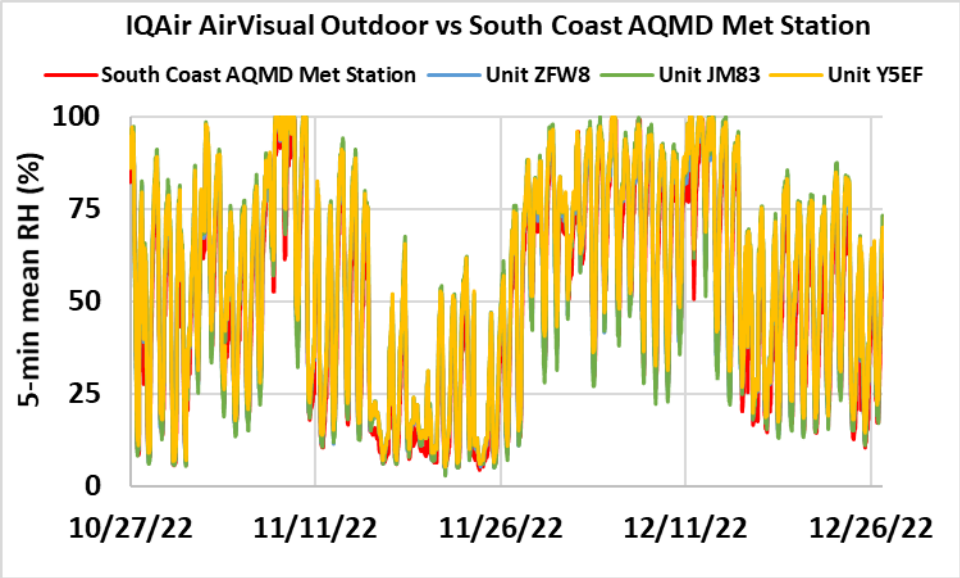
# IQAir AirVisual Outdoor vs South Coast AQMD Met Station (Temp; 5-min mean)



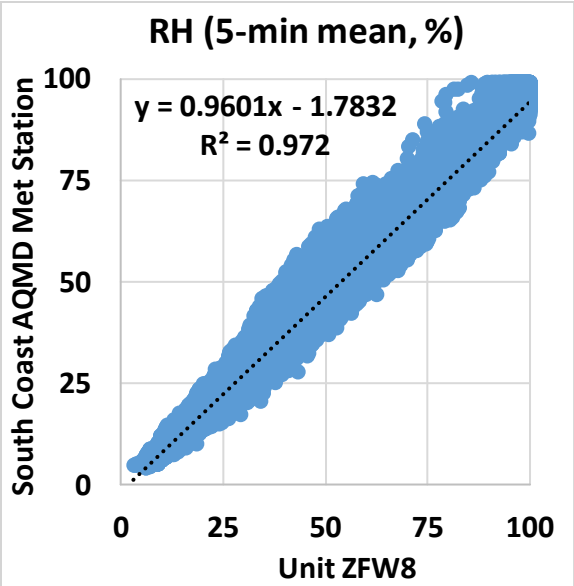

- The IQAir AirVisual Outdoor sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($0.90 < R^2 < 0.96$)
- Overall, the IQAir AirVisual Outdoor sensors underestimated the temperature measurement as recorded by South Coast AQMD Met Station
- The IQAir AirVisual Outdoor sensors seemed to track the diurnal temperature variations as recorded by South Coast AQMD Met Station

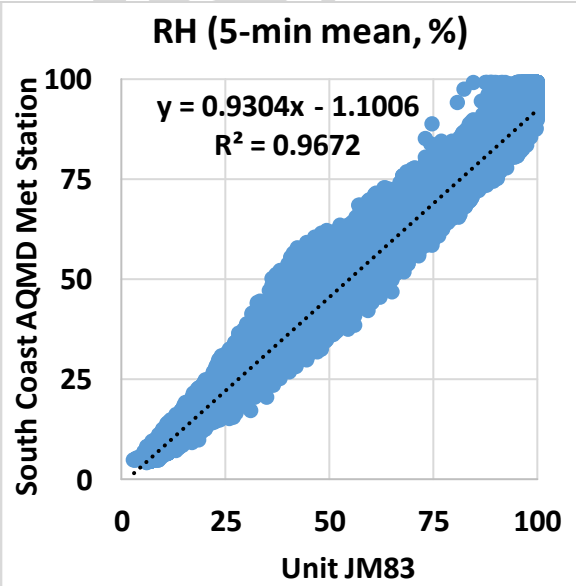


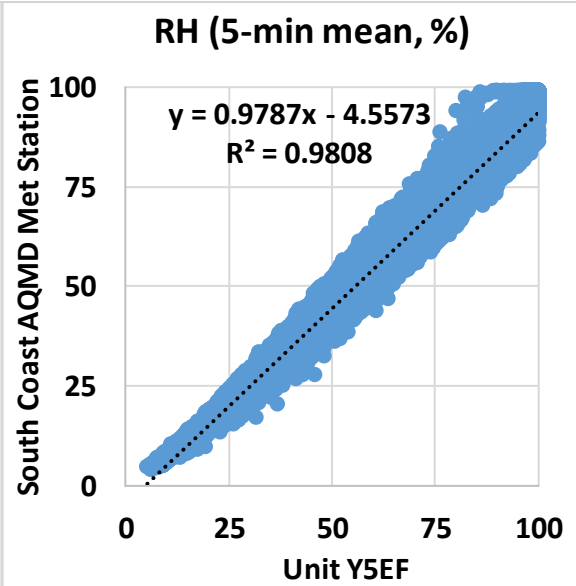
# IQAir AirVisual Outdoor vs South Coast AQMD Met Station (RH; 5-min mean)




- The IQAir AirVisual Outdoor sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($0.96 < R^2 < 0.99$)
- Overall, the IQAir AirVisual Outdoor sensors overestimated the RH measurement as recorded by South Coast AQMD Met Station
- The IQAir AirVisual Outdoor sensors seemed to track the diurnal RH variations as recorded by South Coast AQMD Met Station



# Summary

| | Average of 3 Sensors, $PM_{1.0}$ | | IQAir AirVisual Outdoor vs GRIMM & T640, $PM_{1.0}$ | | | | | | GRIMM & T640 ($PM_{1.0}$, $\mu g/m^3$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average ($\mu g/m^3$) | SD ($\mu g/m^3$) | $R^2$ | Slope | Intercept | MBE[1] ($\mu g/m^3$) | MAE[2] ($\mu g/m^3$) | RMSE[3] ($\mu g/m^3$) | Ref. Average | Ref. SD | Range during the field evaluation |
| **5-min** | 5.4 | 4.8 | 0.52 to 0.64 | 1.09 to 1.30 | 3.3 to 3.6 | -4.9 to -4.1 | 4.5 to 5.6 | 5.9 to 7.3 | 9.8 to 10.1 | 7.2 to 7.9 | 0.2 to 101.2 |
| **1-hr** | 5.4 | 4.6 | 0.53 to 0.68 | 1.14 to 1.34 | 2.9 to 3.4 | -4.9 to -4.1 | 4.4 to 5.5 | 5.7 to 7.2 | 9.8 to 10.1 | 7.0 to 7.7 | 0.3 to 39.9 |
| **24-hr** | 5.4 | 3.0 | 0.75 to 0.87 | 1.31 to 1.54 | 1.7 to 2.5 | -5.0 to -4.1 | 4.1 to 5.0 | 4.5 to 5.7 | 9.8 to 10.2 | 4.8 to 5.0 | 0.9 to 23.1 |
| | Average of 3 Sensors, $PM_{2.5}$ | | IQAir AirVisual Outdoor vs FEM GRIMM & FEM T640, $PM_{2.5}$ | | | | | | FEM GRIMM & FEM T640 ($PM_{2.5}$, $\mu g/m^3$) | | |
| | Average ($\mu g/m^3$) | SD ($\mu g/m^3$) | $R^2$ | Slope | Intercept | MBE[1] ($\mu g/m^3$) | MAE[2] ($\mu g/m^3$) | RMSE[3] ($\mu g/m^3$) | Ref. Average | Ref. SD | Range during the field evaluation |
| **5-min** | 9.6 | 7.9 | 0.54 to 0.65 | 0.75 to 0.95 | 4.5 to 5.8 | -4.7 to -2.4 | 4.4 to 6.0 | 5.9 to 7.8 | 12.3 to 13.9 | 8.1 to 9.4 | 0.4 to 102.7 |
| **1-hr** | 9.6 | 7.6 | 0.54 to 0.68 | 0.77 to 0.98 | 4.1 to 5.7 | -4.7 to -2.3 | 4.2 to 6.0 | 5.5 to 7.6 | 12.3 to 13.9 | 7.9 to 9.1 | 0.7 to 43.9 |
| **24-hr** | 9.5 | 5.0 | 0.82 to 0.88 | 0.88 to 1.12 | 2.6 to 4.5 | -4.8 to -2.4 | 2.6 to 4.8 | 3.1 to 5.4 | 12.3 to 14.0 | 5.3 to 5.9 | 2.7 to 27.9 |
| | Average of 3 Sensors, $PM_{10}$ | | IQAir AirVisual Outdoor vs GRIMM & T640, $PM_{10}$ | | | | | | GRIMM & T640 ($PM_{10}$, $\mu g/m^3$) | | |
| | Average ($\mu g/m^3$) | SD ($\mu g/m^3$) | $R^2$ | Slope | Intercept | MBE[1] ($\mu g/m^3$) | MAE[2] ($\mu g/m^3$) | RMSE[3] ($\mu g/m^3$) | Ref. Average | Ref. SD | Range during the field evaluation |
| **5-min** | 37.5 | 12.3 | 0.39 to 0.60 | 1.06 to 1.49 | -23.9 to -4.8 | 1.9 to 5.8 | 10.5 to 14.4 | 14.4 to 19.0 | 32.3 to 35.2 | 21.3 to 23.1 | 0.5 to 247.7 |
| **1-hr** | 37.5 | 11.8 | 0.41 to 0.66 | 1.07 to 1.53 | -25.1 to -5.8 | 1.9 to 5.8 | 9.9 to 13.8 | 13.3 to 17.9 | 32.3 to 35.2 | 20.5 to 22.0 | 0.9 to 217.9 |
| **24-hr** | 37.5 | 8.4 | 0.51 to 0.76 | 1.14 to 1.57 | -26.7 to -8.0 | 1.9 to 5.9 | 6.6 to 10.1 | 8.3 to 12.1 | 32.2 to 35.2 | 13.9 to 14.9 | 3.7 to 72.0 |

[1] Mean Bias Error (MBE): the difference between the sensors and the reference instruments. MBE indicates the tendency of the sensors to underestimate (negative MBE values) or overestimate (positive MBE values).

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

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

# Discussion

- The three **IQAir AirVisual Outdoor** sensors' data recovery from all units was ~100%, ~98% and ~100% respectively for $PM_{1.0}$, $PM_{2.5}$ and $PM_{10,}$ respectively
- The absolute intra-model variability was ~0.24, ~0.39 and ~0.34 µg/m$^3$ for $PM_{1.0}$, $PM_{2.5}$ and $PM_{10,}$ respectively
- Reference instruments: very strong correlations between GRIMM and T640 for $PM_{1.0}$ ($R^2$ ~0.97, 1-hr mean); very strong correlations between FEM GRIMM and FEM T640 for $PM_{2.5}$ ($R^2$ ~0.97, 1-hr mean) and very strong correlations between GRIMM and T640 for $PM_{10}$ ($R^2$ ~0.97, 1-hr mean) mass concentration measurements
- $PM_{1.0}$ mass concentrations measured by the IQAir AirVisual Outdoor sensors showed moderate correlations with the corresponding GRIMM and T640 data ($0.52 < R^2 < 0.68$, 1-hr mean). The sensors underestimated $PM_{1.0}$ mass concentrations as measured by GRIMM and T640
- $PM_{2.5}$ mass concentrations measured by the IQAir AirVisual Outdoor sensors showed moderate correlations with the corresponding FEM GRIMM and FEM T640 data ($0.54 < R^2 < 0.69$, 1-hr mean). The sensors underestimated $PM_{2.5}$ mass concentrations as measured by FEM GRIMM and FEM T640
- $PM_{10}$ mass concentrations measured by the IQAir AirVisual Outdoor sensors showed weak to moderate correlations with the corresponding GRIMM and T640 data ($0.40 < R^2 < 0.66$; 1-hr mean). The sensors overestimated $PM_{10}$ mass concentrations as measured by GRIMM and T640
- No sensor calibration was performed by South Coast AQMD Staff for this evaluation
- Laboratory chamber testing is necessary to fully evaluate the performance of these sensors under known aerosol concentrations and controlled temperature and relative humidity conditions

- All results are still preliminary

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