

# Laboratory Evaluation

## MetOne ES-405



# Outline

1. Background
2.  $PM_{2.5}$
3.  $PM_{10}$

DRAFT

# Background

Three **MetOne ES-405 Particulate Profiler** (hereinafter **MetOne ES-405**) sensors were field-tested at the South Coast AQMD Rubidoux fixed ambient monitoring station (12/24/2020 to 2/24/2021) under ambient environmental conditions. Following field-testing, the same three units were evaluated in the South Coast AQMD Sensor Environmental Testing Chamber 2 (SENTEC-2) under controlled artificial aerosol concentration/size range, temperature, and relative humidity.

## MetOne ES-405 (3 units tested):

- Particle sensor: **optical; non-FEM (right angle laser scattering)**
- Each unit reports:  $PM_{1.0}$ ,  $PM_{2.5}$ , and  $PM_{10}$  ( $\mu\text{g}/\text{m}^3$ )
- **Unit cost: ~\$5,200**
- Time resolution: 1-min
- Unit IDs: 1744, 1745, 1746



## Reference instruments:

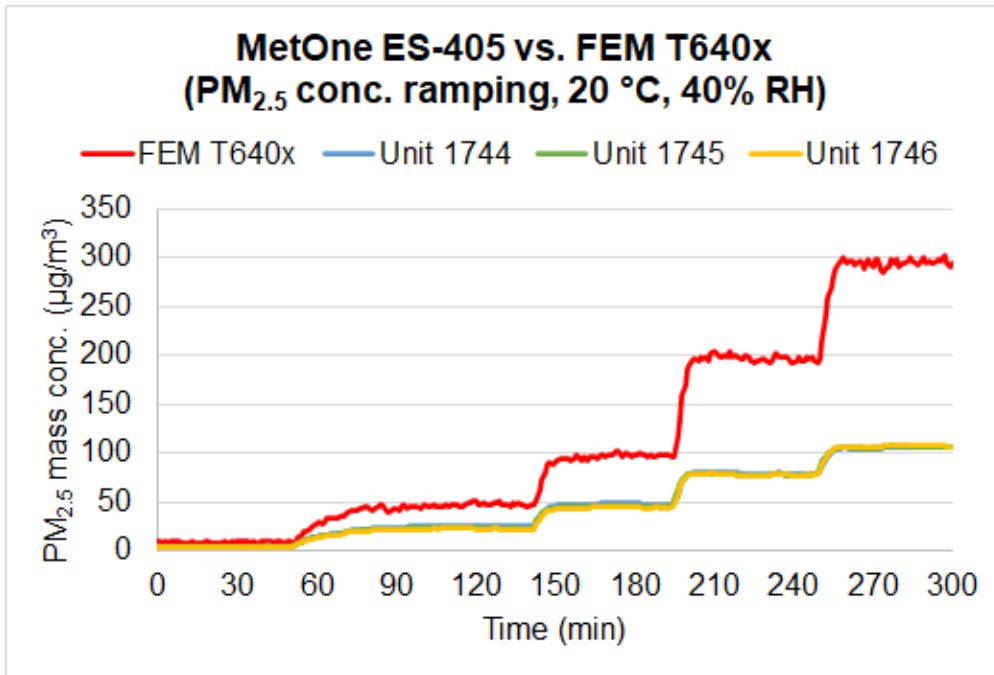
- $PM_{2.5/10}$  instrument (**FEM, T640x, Teledyne, San Diego, CA**); **cost: ~\$37,000**
  - Time resolution: 1-min
- $PM_{10}$  instrument (**non-FEM, APS, TSI, Shoreview, MN**); **cost: ~\$55,000**
  - Time resolution: 1-min



# PM<sub>2.5</sub>

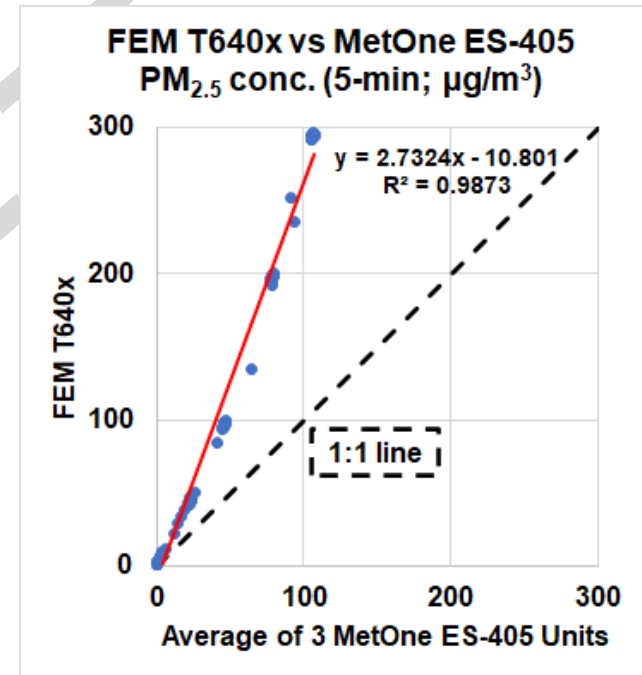
1. **FEM T640x vs MetOne ES-405**
2. **Accuracy, data recovery, and intra-model variability**
3. **Precision**
4. **Climate susceptibility**
5. **Discussion**

# MetOne ES-405 vs FEM T640x (PM<sub>2.5</sub>)



- The MetOne ES-405 sensors tracked well with the concentration variation but underestimated PM<sub>2.5</sub> concentration values compared to the FEM T640x in the concentration range of 0 - 300 µg/m<sup>3</sup>.

## Coefficient of Determination



- The MetOne ES-405 sensors showed very strong correlations with the FEM T640x PM<sub>2.5</sub> mass conc. ( $R^2 > 0.98$ )

# MetOne ES-405 vs FEM T640x PM<sub>2.5</sub> Accuracy

- Accuracy (20°C and 40% RH)

Steady state #	Sensor Mean (µg/m <sup>3</sup> )	FEM T640x (µg/m <sup>3</sup> )	Accuracy (%)
1	4.19	9.05	46.3%
2	23.34	47.50	49.1%
3	45.93	97.71	47.0%
4	78.22	196.31	39.8%
5	106.34	296.41	35.9%

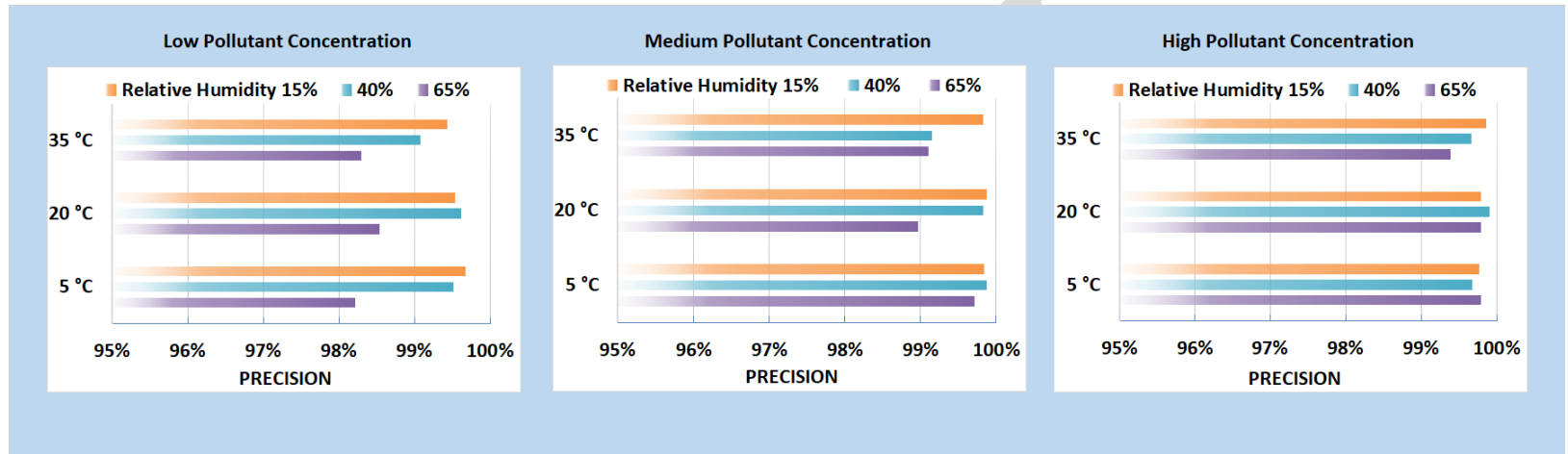
- The MetOne ES-405 sensors underestimated the measured concentration compared to the FEM T640x PM<sub>2.5</sub> mass concentration at 20 °C and 40% RH. The MetOne ES-405 sensors showed low to moderate accuracy (35.9% to 49.1%) for all tested PM<sub>2.5</sub> concentrations compared to the reference FEM T640x for the entirety of test.

## MetOne ES-405 Data Recovery and Intra-model Variability

- Data recovery for PM<sub>2.5</sub> measurements was 100% for all units.
- Low to moderate PM<sub>2.5</sub> concentration variations were observed between the three units at 20° C and 40% RH, at 10, 50, and 150 µg/m<sup>3</sup> PM<sub>2.5</sub> as measured by the FEM T640x.

# Precision: MetOne ES-405 (PM<sub>2.5</sub>)

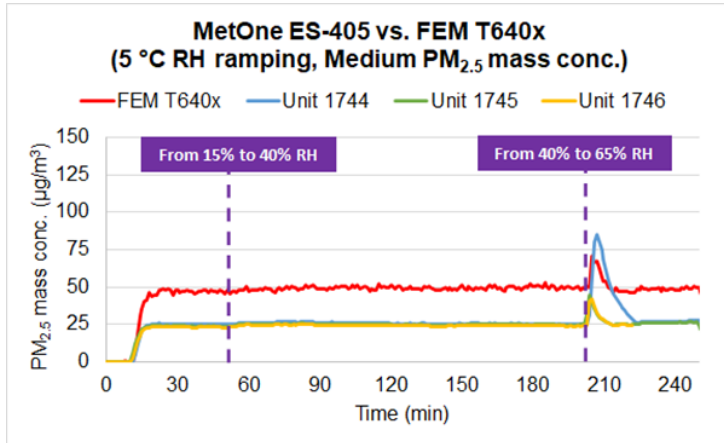
- Precision (Effect of PM<sub>2.5</sub> conc., temperature and relative humidity)



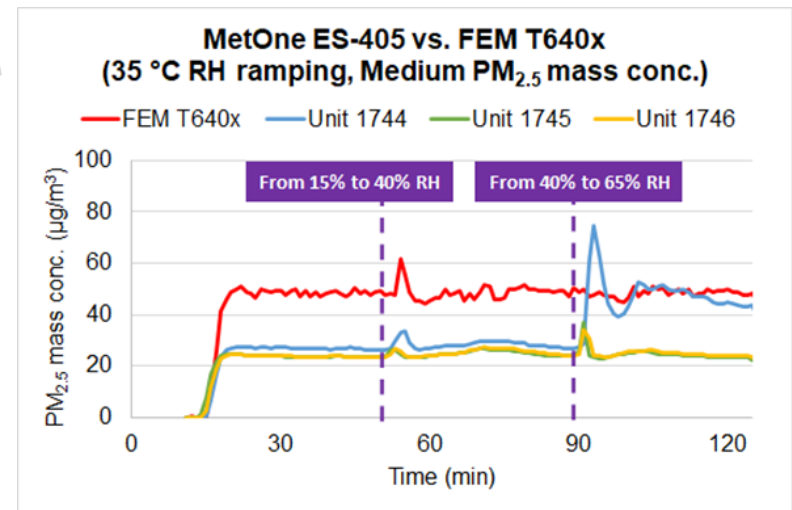
- Overall, the three MetOne ES-405 sensors showed high precision for all combinations of PM<sub>2.5</sub> conc., T, and RH.

# Climate Susceptibility: MetOne ES-405 (PM<sub>2.5</sub>)

Low Temp - RH ramping  
(medium conc.)



High Temp - RH ramping  
(medium conc.)





# Discussion: PM<sub>2.5</sub>

- **Accuracy:** The three MetOne ES-405 sensors showed accuracy ranged from 35.9% to 49.1%. (refer to slide 6)
- **Precision:** The three MetOne ES-405 sensors exhibited high precision during all tested PM<sub>2.5</sub> conc., T, and RH conditions. (refer to slide 7)
- **Intra-model variability:** Low to moderate PM<sub>2.5</sub> measurement variations were observed among the three MetOne ES-405 sensors at 20 °C and 40% RH. (refer to slide 6)
- **Data Recovery:** Data recovery for PM<sub>2.5</sub> measurements was 100% for all units. (refer to slide 6)
- **Bias:** N/A
- **Detection limit:** The detection limit cannot be estimated due to limitations in the chamber system design.
- **Response time:** Response time could not be studied due to the system design of the chamber system. With a 1.6 m<sup>3</sup> chamber volume, it was not possible to reach a high pollutant concentration within a short time.
- **Linear Correlation:** The three MetOne ES-405 sensors showed very strong correlation/linear response with the corresponding FEM T640x PM<sub>2.5</sub> measurement data ( $R^2 > 0.98$ ). (refer to slide 5)
- **Selectivity:** N/A for PM sensors test
- **Interferences:** N/A for PM sensors test
- **Note about PM<sub>1.0</sub>:** The field evaluation compared the PM<sub>1.0</sub> values reported from the MetOne ES-405 sensors against the field GRIMM and T640 that reported PM<sub>1.0</sub>. However, PM<sub>1.0</sub> was not compared in this lab evaluation because at the time of lab testing (before March 2022) the lab T640x firmware upgrade to report PM<sub>1.0</sub> was not finalized yet.

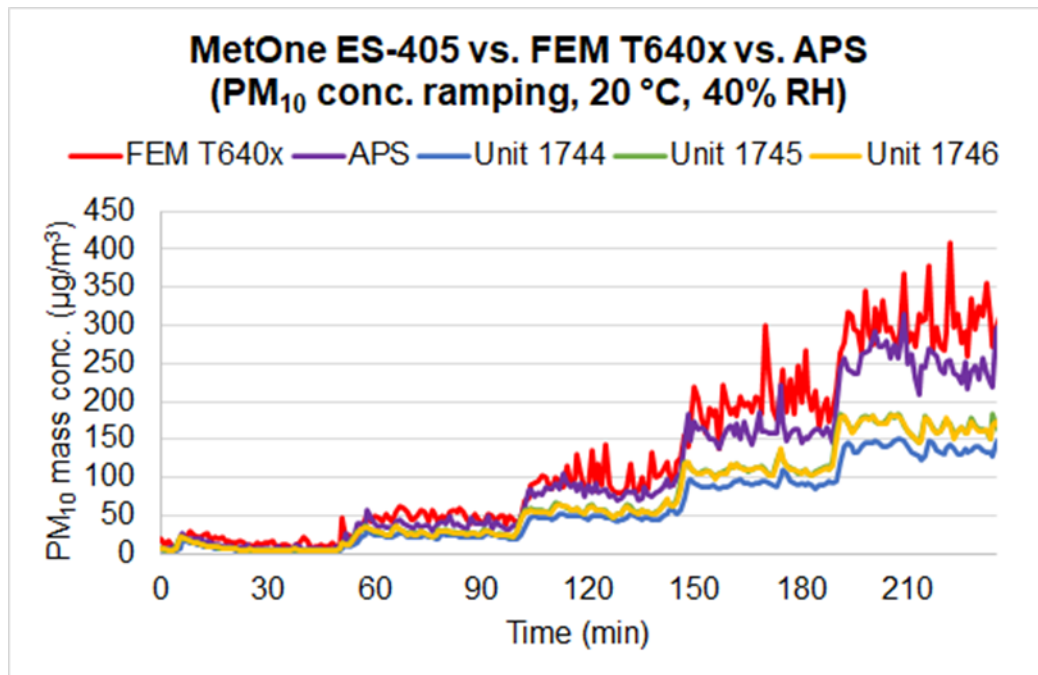
# Discussion: PM<sub>2.5</sub>

- **Measurement duration:** MetOne ES-405 sensors report 1-minute averaged values.
- **Measurement frequency:** MetOne ES-405 sensors report 1-minute averaged values. The obtained data was used as-is for calculation of statistics (e.g. data recovery, intra-model variability, mean, accuracy, precision), but condensed into 5-minute averages for linear correlation studies against the FEM T640x.
- **Sensor contamination and expiration:** Prior to the laboratory evaluation, the MetOne ES-405 sensors were tested in the field for two months. The PM<sub>2.5</sub> laboratory studies lasted for about 9 days with intermittent non-operating periods and a storage period of ~ 10 months. For PM<sub>2.5</sub> measurements, all of the MetOne ES-405 sensors maintained their functionalities and operated normally throughout the duration of the testing.
- **Concentration range:** Up to 2,000 µg/m<sup>3</sup> PM<sub>2.5</sub> concentration as suggested by the manufacturer. During the laboratory evaluation, the MetOne ES-405 sensors were challenged with PM<sub>2.5</sub> concentrations up to 300 µg/m<sup>3</sup>. (refer to slide 5)
- **Drift:** N/A
- **Climate susceptibility:** During the lab studies, temperature and relative humidity generally had little effect on the precision of PM<sub>2.5</sub> concentrations as recorded by the MetOne ES-405 sensors. However, Unit 1746 showed especially pronounced overestimation of PM<sub>2.5</sub> concentrations at higher relative humidity. (refer to slides 7 and 8)
- **Response to loss of power:** MetOne ES-405 sensors were powered through the entirety of the lab tests.

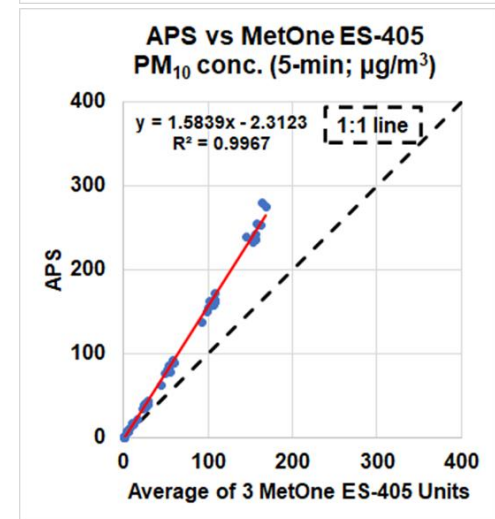
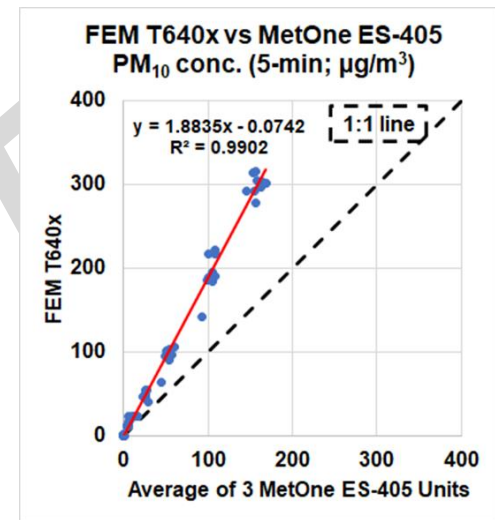
# PM<sub>10</sub>

1. **FEM T640x vs APS vs MetOne ES-405**
2. **Accuracy, data recovery, and intra-model variability**
3. **Climate susceptibility**
4. **Discussion**

# MetOne ES-405 vs FEM T640x vs APS (PM<sub>10</sub>)



- The MetOne ES-405 sensors tracked well with the PM<sub>10</sub> concentration variations as recorded by the FEM T640x and APS in the concentration range of 0 - 300 µg/m<sup>3</sup>.
- The MetOne ES-405 sensors showed very strong correlations with both FEM T640x and APS PM10 measurement data ( $R^2 > 0.99$ ).



# MetOne ES-405 vs FEM T640x vs APS PM<sub>10</sub> Accuracy

- Accuracy (20°C and 40% RH)

Steady state #	Sensor Mean (µg/m <sup>3</sup> )	FEM T640x (µg/m <sup>3</sup> )	Accuracy (%)
1	4.89	11.95	40.9%
2	25.41	48.26	52.7%
3	54.07	98.26	55.0%
4	105.90	210.17	50.4%
5	155.90	306.70	50.8%

Steady state #	Sensor Mean (µg/m <sup>3</sup> )	APS (µg/m <sup>3</sup> )	Accuracy (%)
1	4.89	6.81	71.8%
2	25.41	38.54	65.9%
3	54.07	80.60	67.1%
4	105.90	161.67	65.5%
5	155.90	241.91	64.4%

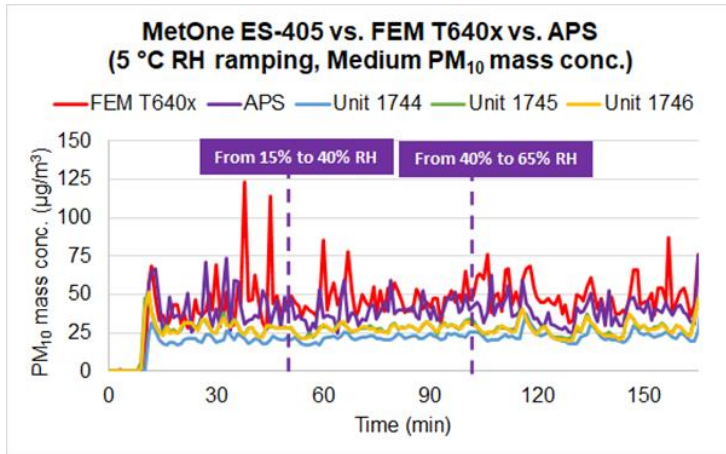
- The MetOne ES-405 sensors underestimated the measured PM<sub>10</sub> concentration compared to the FEM T640x and APS at 20 °C and 40% RH. The MetOne ES-405 sensors showed moderate accuracy for all tested PM<sub>10</sub> concentrations compared to the reference FEM T640x (40.9% to 55.0%) and APS (64.4% to 71.8%) for the entirety of test.

## MetOne ES-405 Data Recovery and Intra-model Variability

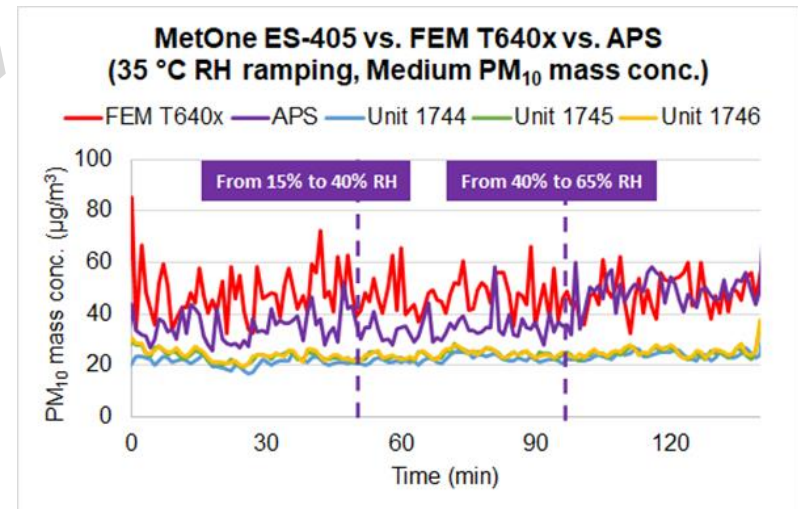
- Data recovery was 100% for PM<sub>10</sub> mass concentration values for all units.
- Moderate PM<sub>10</sub> concentration variations were observed between the three units at 20° C and 40% RH, at 10, 50, and 100 µg/m<sup>3</sup> PM<sub>10</sub> as measured by the FEM T640x.

# Climate Susceptibility: MetOne ES-405 (PM<sub>10</sub>)

Low Temp - RH ramping  
(medium conc.)



High Temp – RH ramping  
(medium conc.)



# Discussion: PM<sub>10</sub>

- **Accuracy:** The MetOne ES-405 sensors underestimated the measured PM<sub>10</sub> concentration compared to the FEM T640x and APS at 20 °C and 40% RH. The MetOne ES-405 sensors showed moderate accuracy for all tested PM<sub>10</sub> concentrations compared to the reference FEM T640x (40.9% to 55.0%) and APS (64.4% to 71.8%) for the entirety of test. (refer to slide 13)
- **Precision:** Due to the nature of Arizona Test Dust dispersion, the aerosol concentration showed some variability, therefore, the precision cannot be fairly estimated.
- **Intra-model variability:** Moderate PM<sub>10</sub> measurement variations were observed among the three MetOne ES-405 sensors at 20 °C and 40% RH. (refer to slide 13)
- **Data Recovery:** Data recovery for PM<sub>10</sub> measurements was 100% for all units. (refer to slide 13)
- **Bias:** N/A
- **Detection limit:** The detection limit cannot be estimated due to limitations in the chamber system design.
- **Response time:** Response time could not be studied due to the system design of the chamber system. With a 1.6 m<sup>3</sup> chamber volume, it was not possible to reach a high pollutant concentration within a short time.
- **Linear Correlation:** The three MetOne ES-405 sensors showed very strong correlation/linear response with the corresponding FEM T640x and APS PM<sub>10</sub> measurement data ( $R^2 > 0.99$ ). (refer to slide 12)
- **Selectivity:** N/A for PM sensors test
- **Interferences:** N/A for PM sensors test
- **Note about PM<sub>1.0</sub>:** The field evaluation compared the PM<sub>1.0</sub> values reported from the MetOne ES-405 sensors against the field GRIMM and T640 that reported PM<sub>1.0</sub>. However, PM<sub>1.0</sub> was not compared in this lab evaluation because at the time of lab testing (before March 2022) the lab T640x firmware upgrade to report PM<sub>1.0</sub> was not finalized yet.

# Discussion: PM<sub>10</sub>

- **Measurement duration:** MetOne ES-405 sensors report 1-minute averaged values.
- **Measurement frequency:** MetOne ES-405 sensors report 1-minute averaged values. The obtained data was used as-is for calculation of statistics (e.g. data recovery, intra-model variability, mean, accuracy, precision), but condensed into 5-minute averages for linear correlation studies against the FEM T640x and APS.
- **Sensor contamination and expiration:** Prior to the laboratory evaluation, the MetOne ES-405 sensors were tested in the field for two months. The PM<sub>10</sub> laboratory studies lasted for about 8 days with intermittent non-operating periods and a storage period of ~ 11 months. For PM<sub>10</sub> measurements, all MetOne ES-405 sensors maintained their functionalities and operated normally throughout the duration of the testing.
- **Concentration range:** Up to 10,000 µg/m<sup>3</sup> PM<sub>10</sub> concentration as suggested by the manufacturer. During the laboratory evaluation, the MetOne ES-405 sensors were challenged with PM<sub>10</sub> concentrations up to 300 µg/m<sup>3</sup>. (refer to slide 12)
- **Drift:** N/A
- **Climate susceptibility:** During the lab studies, relative humidity generally had little effect on the stability of PM<sub>10</sub> as recorded by the MetOne ES-405 sensors. (refer to slide 14)
- **Response to loss of power:** MetOne ES-405 sensors were powered through the entirety of the lab tests.