

# Laboratory Evaluation

## Ecomesure - EcomSmart



# Outline

1. Background
2. O<sub>3</sub>
3. NO<sub>2</sub>
4. CO
5. PM

DRAFT

# Background

Three **Ecomesure EcomSmart** (hereinafter **EcomSmart**) multi-sensor units (units IDs: 0531, 0532, 0533) were field-tested at the South Coast AQMD Rubidoux fixed ambient monitoring station (03/10/2022 to 05/10/2022) under ambient environmental conditions. Following field testing, the units were subjected to further laboratory testing in the South Coast AQMD Sensor Environmental Test Chamber 2 (SENTEC-2) under controlled pollutant concentration, temperature, and relative humidity conditions. Note that Unit 0531 did not transmit data during the laboratory evaluation except for certain experiments during the CO evaluation.

## EcomSmart (3 units tested):

- Gas Sensors: **Electrochemical (Alphasense, non-FEM)**
- PM<sub>2.5</sub> – **Optical (Tera Sensors NextPM, non-FEM)**
- Each unit measures: O<sub>3</sub> (ppb), NO<sub>2</sub> (ppb), CO (ppb), PM<sub>1.0</sub> (µg/m<sup>3</sup>), PM<sub>2.5</sub> (µg/m<sup>3</sup>), PM<sub>10</sub> (µg/m<sup>3</sup>), T (°C), RH (%)
- **Unit cost: \$4,550 as-tested + \$480/year platform subscription fee**
- Time resolution: 1-min
- Units IDs: 0531, 0532, and 0533



Ecomesure EcomSmart

## Reference instruments:

- O<sub>3</sub> instrument (**FEM, T400, Teledyne, San Diego, CA**); cost: **~\$9,000**
  - Time resolution: 1-min
- NO<sub>x</sub> instrument (**FRM, T200, Teledyne, San Diego, CA**); cost: **~\$13,000**
  - Time resolution: 1-min
- CO instrument (**FRM, T300U, Teledyne, San Diego, CA**); cost: **~\$15,000**
  - Time resolution: 1-min
- PM<sub>2.5</sub> instrument (**Teledyne T640x, San Diego, CA; hereinafter FEM T640x**); cost: **~\$37,000**
  - Time resolution: 1-min



FEM T400



FRM T300U



FRM T200

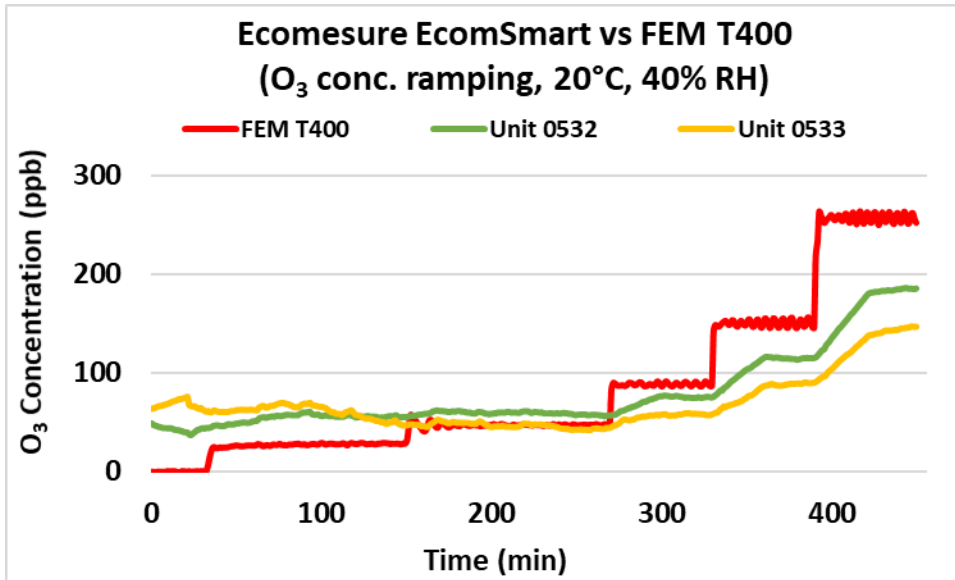


FEM T640x

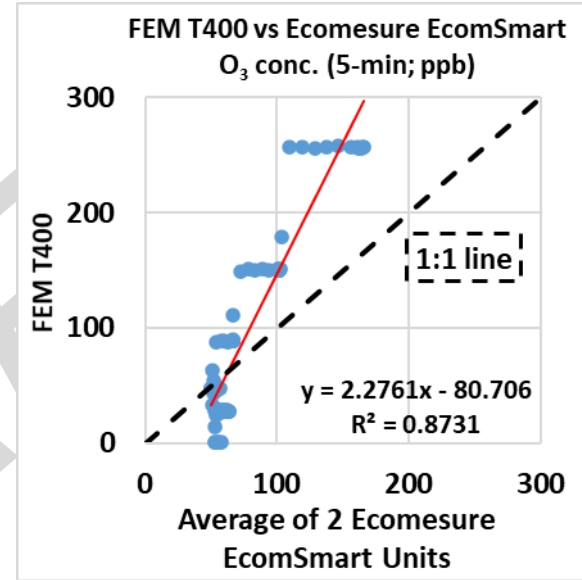


1. **FEM T400 vs Ecomesure EcomSmart**
2. **Accuracy, data recovery and intra-model variability**
3. **Precision**
4. **Climate susceptibility**
5. **Interferents**
6. **Discussion**

# EcomSmart vs FEM T400 (O<sub>3</sub>)



## Coefficient of Determination



- The EcomSmart sensors tracked the O<sub>3</sub> concentration variations recorded by FEM T400 instrument from ~50 to 250 ppb
- The EcomSmart sensors overestimated the O<sub>3</sub> concentration as recorded by the FEM T400 instrument at low O<sub>3</sub> concentrations (< 50 ppb) and underestimated the O<sub>3</sub> concentrations at high ozone levels
- The EcomSmart sensors showed strong correlations with the corresponding FEM T400 O<sub>3</sub> conc. ( $R^2 \sim 0.87$ )

## Accuracy: EcomSmart vs FEM T400 (O<sub>3</sub>)

- Accuracy (20°C and 40% RH)

| Steady State (#) | Sensor Mean (ppb) | FEM T400 (ppb) | Accuracy (%) |
|------------------|-------------------|----------------|--------------|
| 1                | 52.9              | 28.5           | 14.6         |
| 2                | 50.4              | 47.5           | 93.9         |
| 3                | 66.8              | 88.6           | 75.4         |
| 4                | 102.2             | 150.6          | 67.9         |
| 5                | 164.7             | 257.0          | 64.1         |

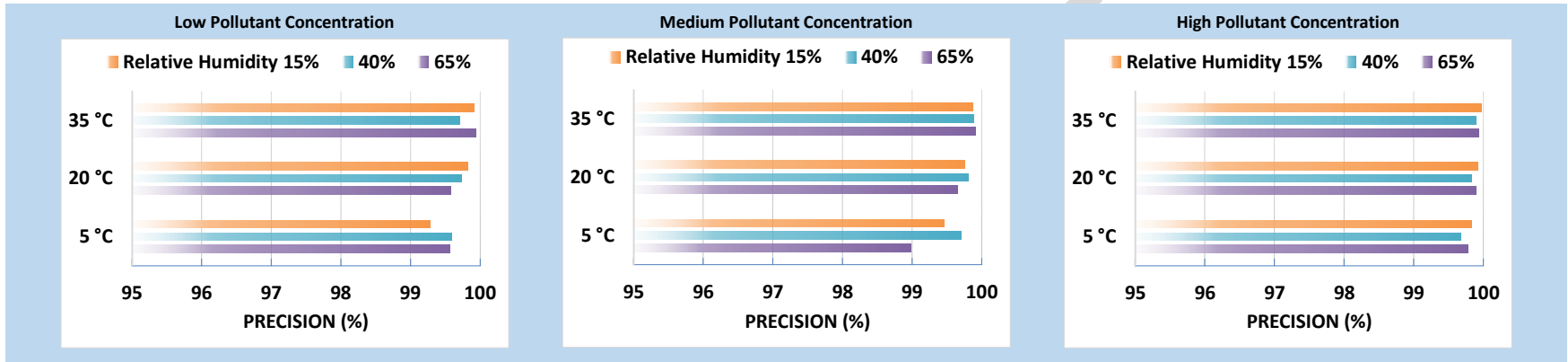
- Accuracy of the two EcomSmart sensors ranged from 14.6% to 93.9%. The accuracy decreased as O<sub>3</sub> concentrations increased, except at the first steady state. Overall, the sensors overestimated the FEM T400 O<sub>3</sub> measurements at low O<sub>3</sub> concentrations and underestimated at high O<sub>3</sub> concentrations at 20°C and 40% RH.

## EcomSmart Data Recovery and Intra-model Variability

- Data recovery for ozone measurements was 100%, and 97.6% for Units 0532 and 0533, respectively. Unit 0531 did not transmit data, therefore all results presented here were from Units 0532 and 0533.
- Moderate O<sub>3</sub> concentration variations were observed between the two units at 20°C and 40% RH at low, medium and high O<sub>3</sub> concentrations as measured by the FEM T400.

# Precision: EcomSmart vs FEM T400 (O<sub>3</sub>)

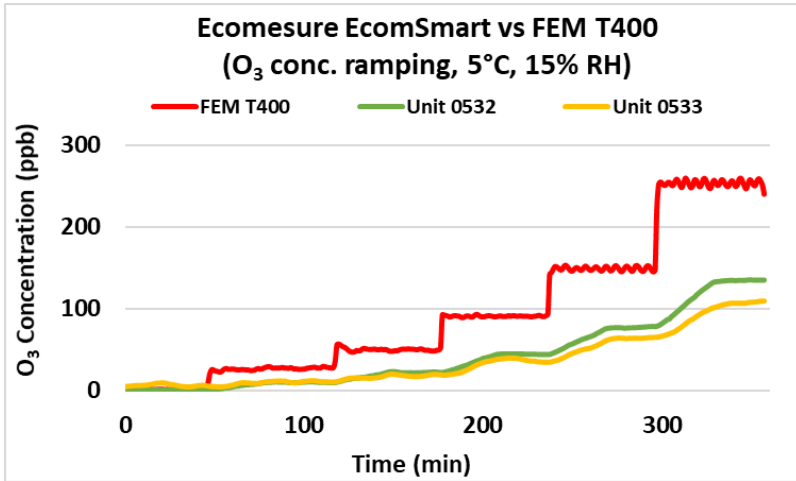
- Precision (Effect of O<sub>3</sub> conc., temperature and relative humidity)



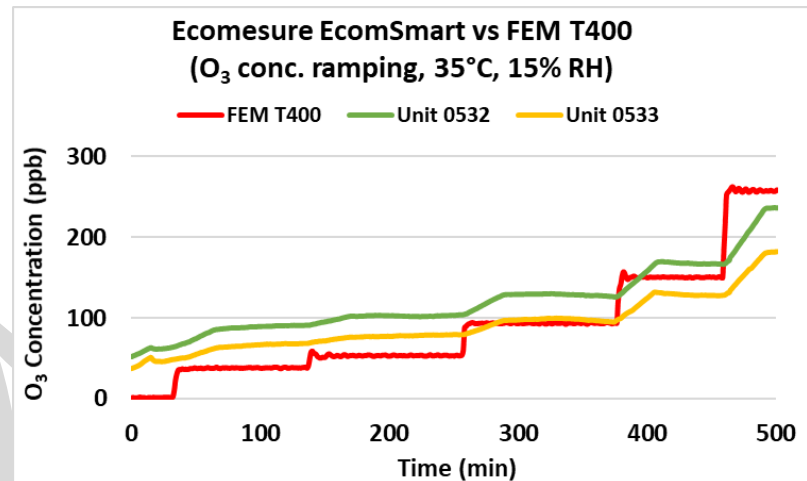
- Overall, the two EcomSmart sensors showed high precision for all combinations of low, medium, and high O<sub>3</sub> conc., T, and RH.

# Climate Susceptibility: EcomSmart (O<sub>3</sub>)

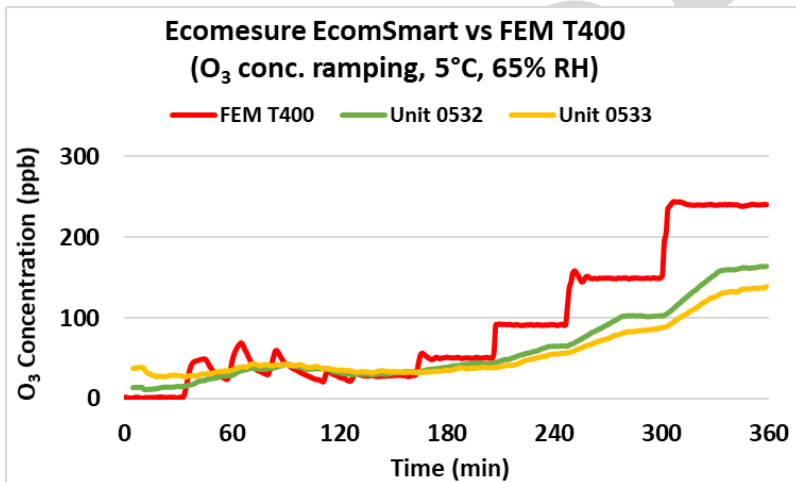
## Low Temp-Low RH



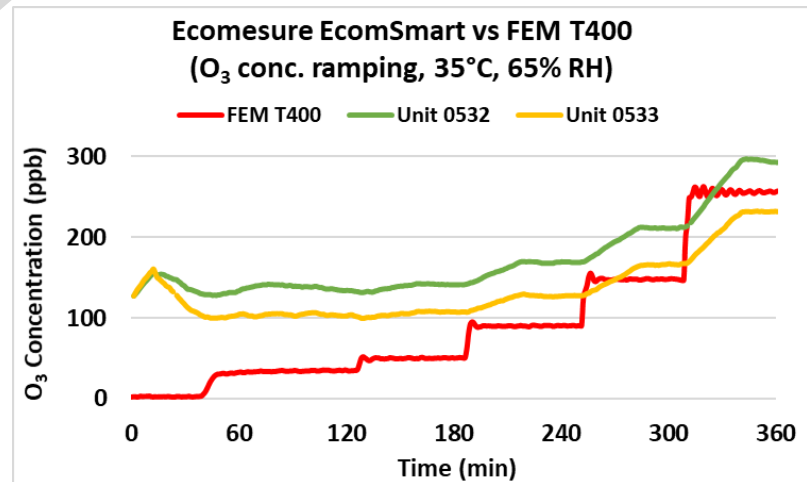
## High Temp-Low RH



## Low Temp-High RH

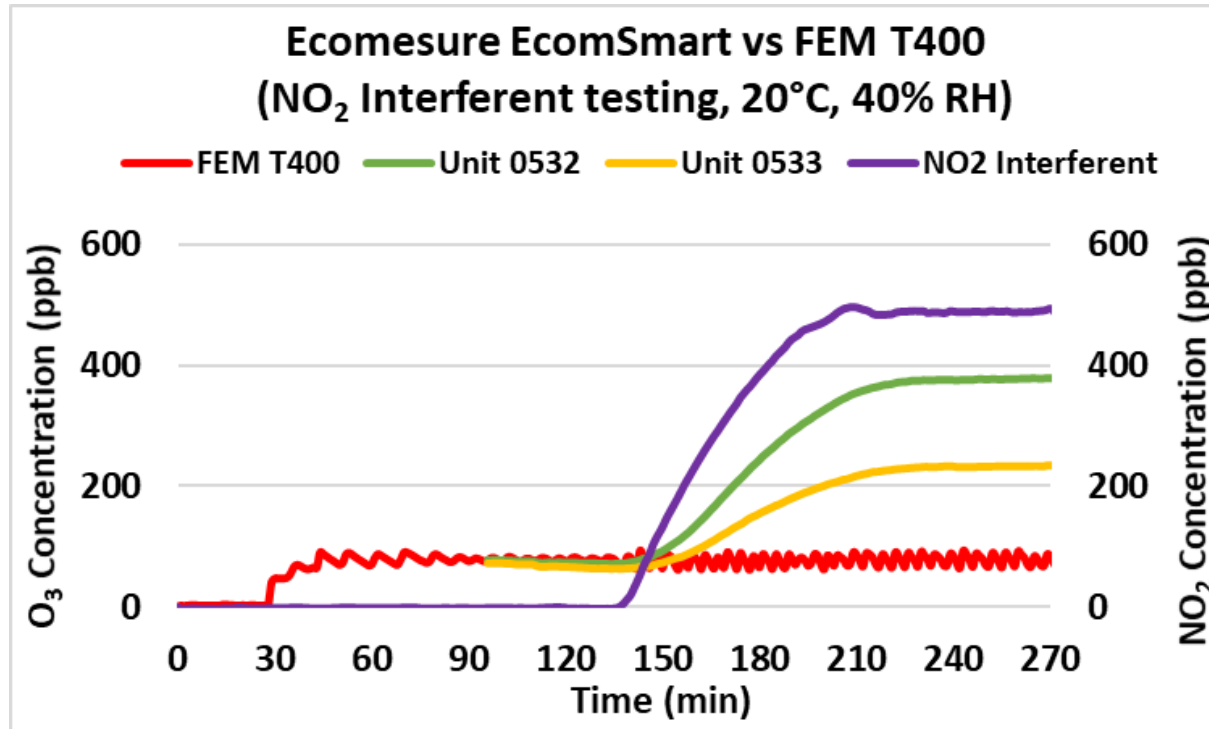


## High Temp-High RH



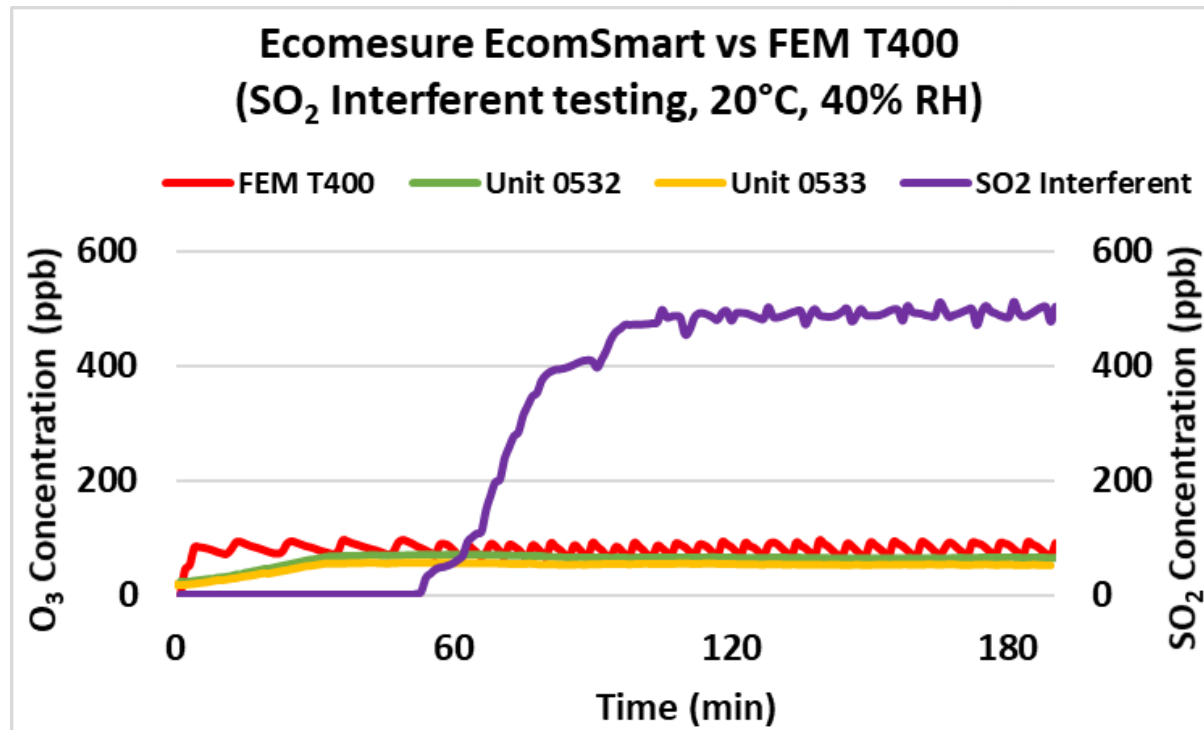


# NO<sub>2</sub> Interferent: EcomSmart vs FEM T400 (O<sub>3</sub>)



In the laboratory, the effect of NO<sub>2</sub> interferent is evaluated by exposing sensors to 500 ppb of NO<sub>2</sub> at 20°C and 40% RH while holding O<sub>3</sub> concentrations at 80 ppb. As shown in the figure, the FEM T400 was not affected by NO<sub>2</sub> while the sensors' ozone readings increased with increasing NO<sub>2</sub>.

# SO<sub>2</sub> Interferent: EcomSmart vs FEM T400 (O<sub>3</sub>)



In the laboratory, the effect of SO<sub>2</sub> interferent is evaluated by exposing the sensors to 500 ppb of SO<sub>2</sub> at 20°C and 40% RH while holding O<sub>3</sub> concentrations at 80 ppb. As shown in the figure, both the FEM T400 and sensors' O<sub>3</sub> measurements were not affected by SO<sub>2</sub>.

# Discussion: O<sub>3</sub>

- **Accuracy:** The two EcomSmart sensors showed accuracy ranged from 14.6% to 93.9%. The accuracy decreased as O<sub>3</sub> concentrations increased, except at the first steady state. Overall, the sensors overestimated the FEM T400 O<sub>3</sub> measurements at low O<sub>3</sub> concentrations (< 50 ppb) and underestimated at high O<sub>3</sub> concentrations at 20°C and 40% RH.
- **Precision:** The two EcomSmart sensors exhibited high precision for all combinations of O<sub>3</sub>, T and RH conditions.
- **Intra-model variability:** moderate O<sub>3</sub> measurement variations were observed among the two EcomSmart sensors at 20°C and 40% RH.
- **Data recovery:** Data recovery for O<sub>3</sub> measurements was 100%, and 97.6% for Units 0532 and 0533, respectively.
- **Baseline:** At all conditions, FEM T400 O<sub>3</sub> instrument baseline was ranging from 0.5 to 2.4 ppb, while the sensors' baseline varied from 0.4 to 137 ppb, the sensors' baseline was higher at high temperatures and high RH values.
- **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 and the max gas flow of 20 LPM, it was not possible to reach a high pollutant concentration within a short time.
- **Linear Correlation:** The two EcomSmart sensors showed strong to very strong correlation/linear response with the corresponding FEM T400 O<sub>3</sub> measurement data ( $R^2 \sim 0.87$ ).
- **Interferent (NO<sub>2</sub>):** The two EcomSmart sensors' ozone measurements increased with increasing NO<sub>2</sub> concentrations at 20°C and 40% RH.
- **Interferent (SO<sub>2</sub>):** The two EcomSmart sensors were inert to SO<sub>2</sub> at 20°C and 40% RH. When SO<sub>2</sub> was increased to 500 ppb, the sensors maintained similar readings compared to those before the SO<sub>2</sub> injection.

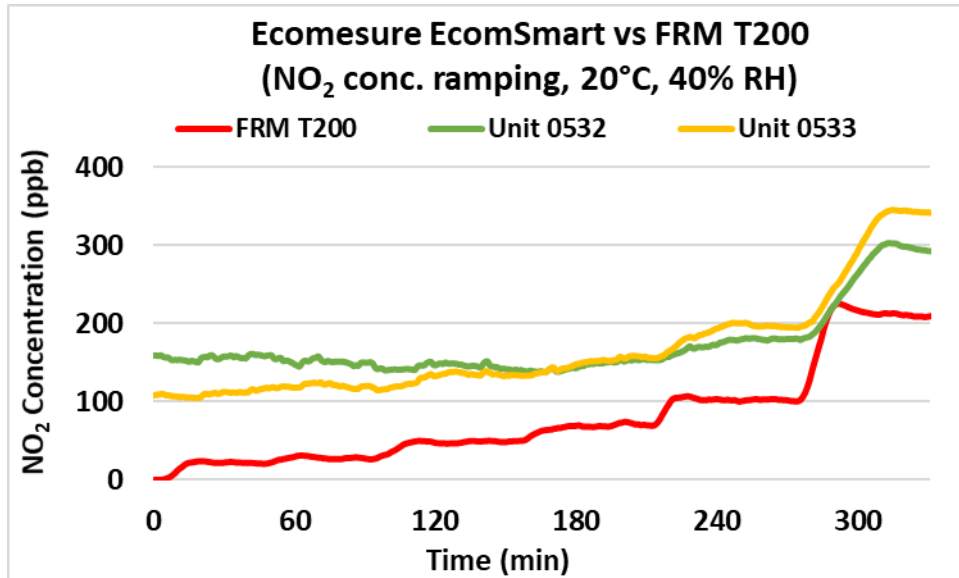
# Discussion: O<sub>3</sub>

- **Measurement duration:** EcomSmart sensors report 1-min averaged values for the duration of all experiments.
- **Measurement frequency:** EcomSmart sensors report 1-min 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 T400.
- **Sensor contamination and expiration:** Prior to the laboratory evaluation, the EcomSmart sensors were tested in the field for two months. The O<sub>3</sub> laboratory studies lasted for about 17 days with intermittent non-operating periods and a storage period of ~10 months. For O<sub>3</sub> measurements, the two EcomSmart sensors maintained their functionalities and operated normally throughout the duration of the testing.
- **Concentration range:** 0-5 ppm O<sub>3</sub> concentration as suggested by the manufacturer. During the laboratory evaluation, the EcomSmart sensors were challenged with O<sub>3</sub> concentrations up to 250 ppb.
- **Climate susceptibility:** During the lab studies, temperature and relative humidity generally had little effect on the precision of O<sub>3</sub> concentrations as recorded by the EcomSmart sensors. The sensors reported higher baseline values at high temperatures at all RH values.
- **Response to loss of power:** The EcomSmart sensors were powered through the entirety of the lab tests.

# NO<sub>2</sub>

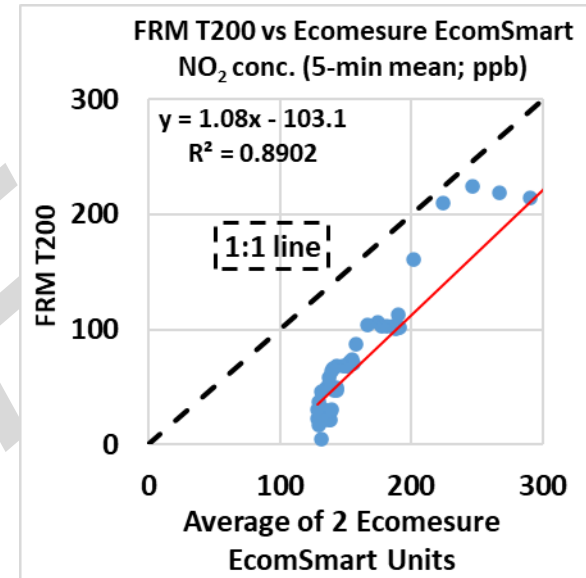
1. **FRM T200 vs Ecomesure EcomSmart**
2. **Accuracy, data recovery and intra-model variability**
3. **Precision**
4. **Climate susceptibility**
5. **Interferents**
6. **Discussion**

# EcomSmart vs FRM T200 (NO<sub>2</sub>)



- The sensors tracked the NO<sub>2</sub> concentration variations recorded by FRM T200 instrument
- Overall, the sensors overestimated the NO<sub>2</sub> concentration as recorded by the FRM T200 instrument

## Coefficient of Determination



- The EcomSmart sensors showed strong correlations with the corresponding FRM T200 NO<sub>2</sub> conc. ( $R^2 \sim 0.89$ )

# Accuracy: EcomSmart vs FRM T200 (NO<sub>2</sub>)

- Accuracy (20 °C and 40% RH)

| Steady State (#) | Sensor Mean (ppb) | FRM T200 (ppb) | Accuracy (%) |
|------------------|-------------------|----------------|--------------|
| 1                | 135.1             | 27.6           | -290.0       |
| 2                | 139.6             | 49.6           | -81.5        |
| 3                | 154.3             | 71.3           | -16.4        |
| 4                | 187.9             | 102.6          | 16.9         |
| 5                | 320.6             | 210.9          | 48.0         |

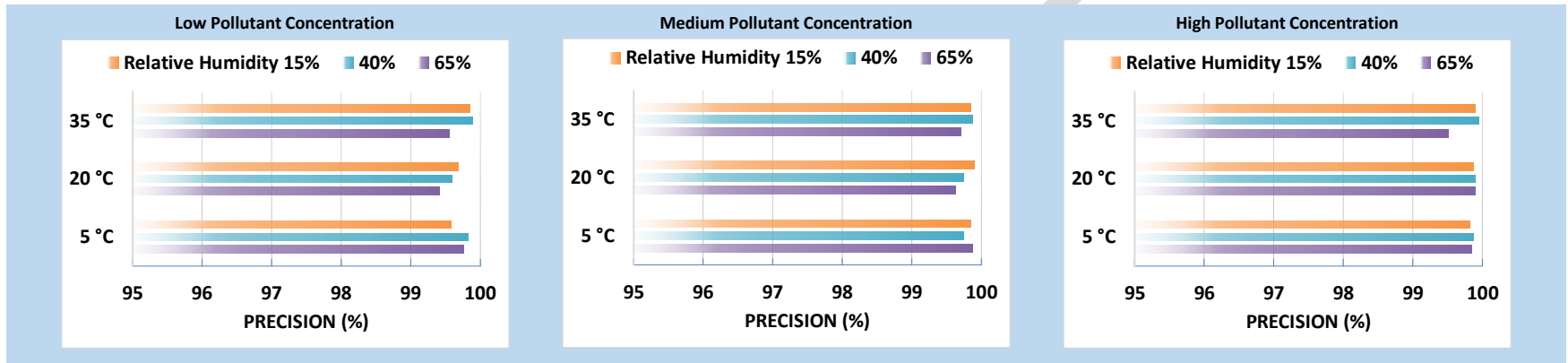
- Accuracy of the two EcomSmart sensors ranged from -290.0% to 48%. Overall, the sensors overestimated the FRM T200 measurements at all NO<sub>2</sub> concentrations at 20°C and 40% RH.

## EcomSmart Data Recovery and Intra-model Variability

- Data recovery for NO<sub>2</sub> measurements was 100% and 97.6% for Units 0532 and 0533, respectively. Unit 0531 did not transmit data, therefore all results presented here were from Units 0532 and 0533.
- Low NO<sub>2</sub> concentration variations were observed between the two units at 20°C and 40% RH at low, medium and high NO<sub>2</sub> concentrations as measured by the FRM T200.

# Precision: EcomSmart vs FRM T200 (NO<sub>2</sub>)

- Precision (Effect of NO<sub>2</sub> conc., temperature and relative humidity)

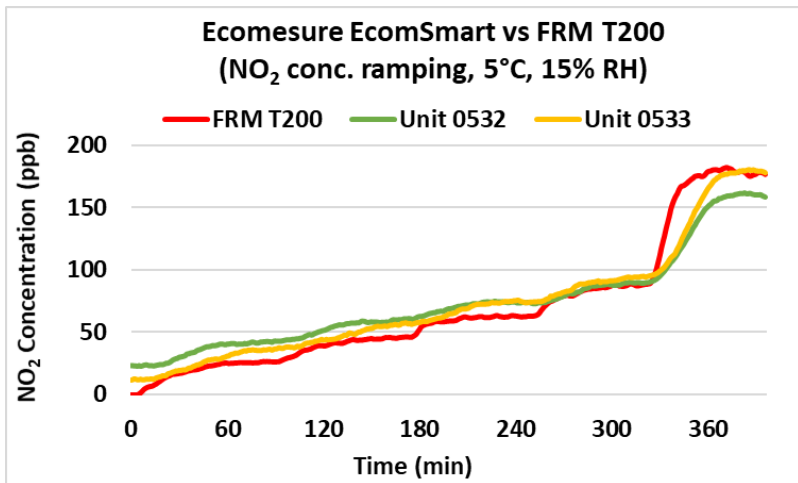


- Overall, the two EcomSmart sensors showed high precision for all combinations of NO<sub>2</sub> conc., T, and RH.

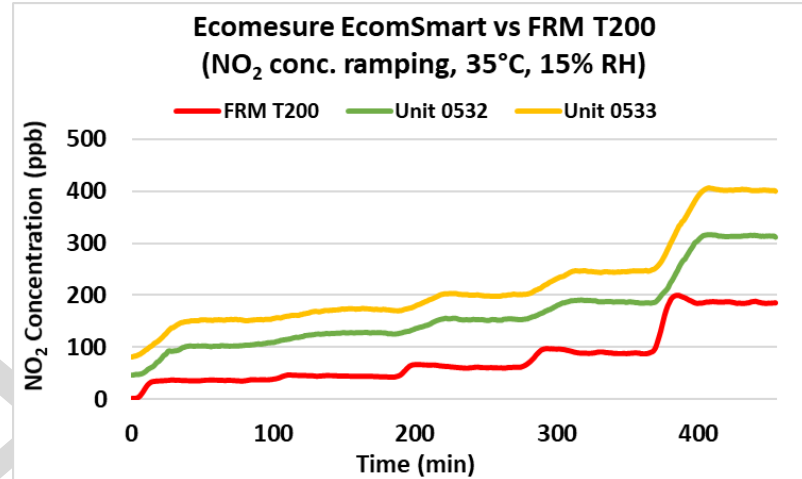


# Climate Susceptibility: EcomSmart (NO<sub>2</sub>)

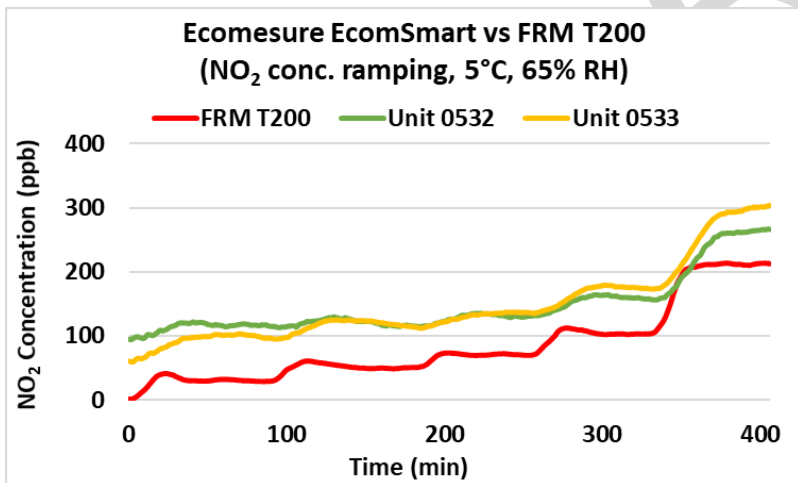
## Low Temp-Low RH



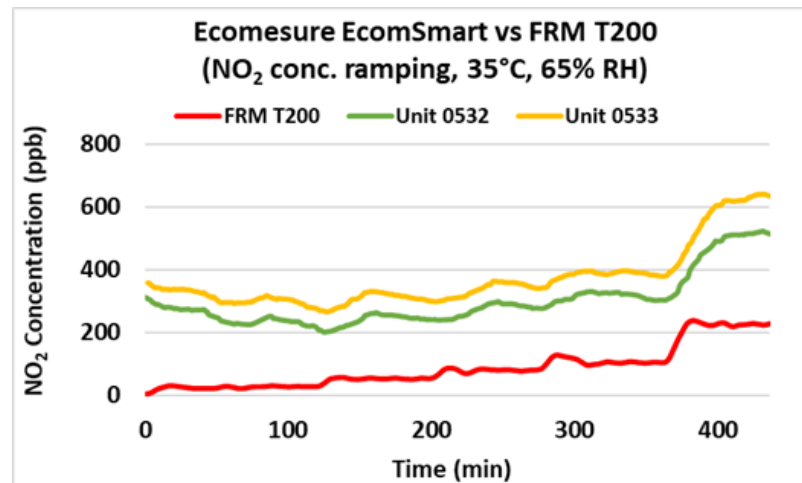
## High Temp-Low RH



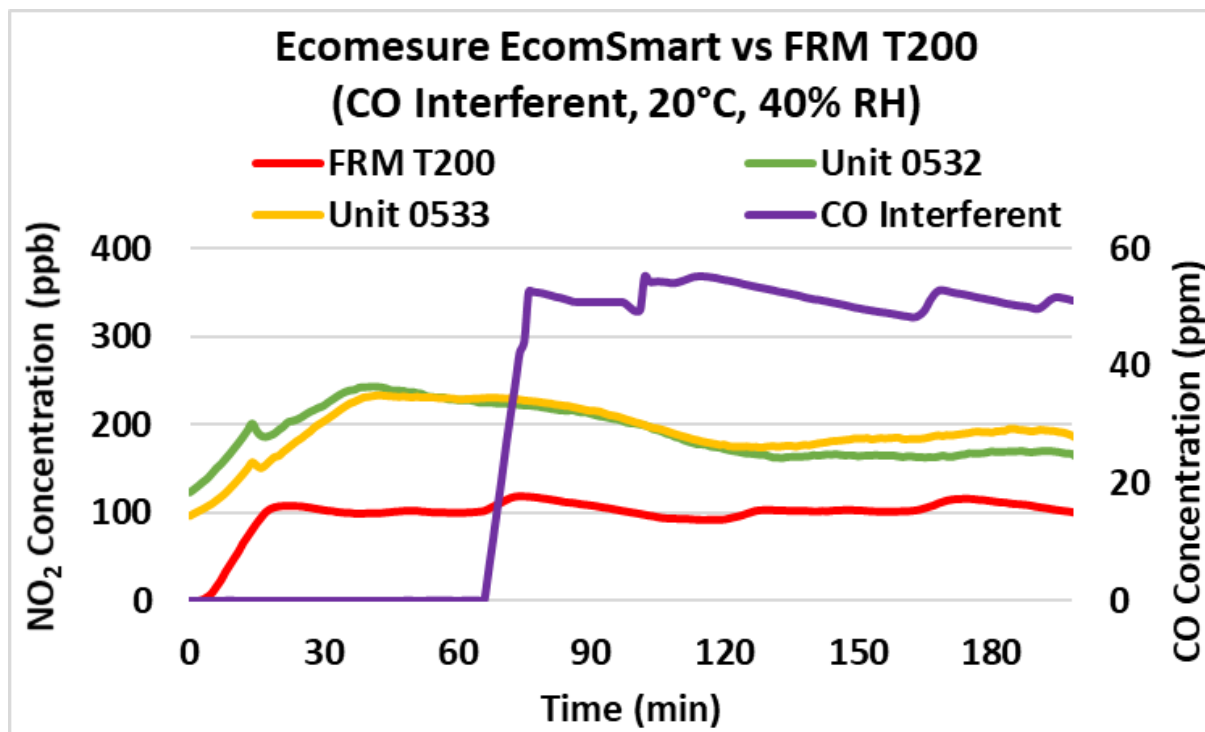
## Low Temp-High RH



## High Temp-High RH

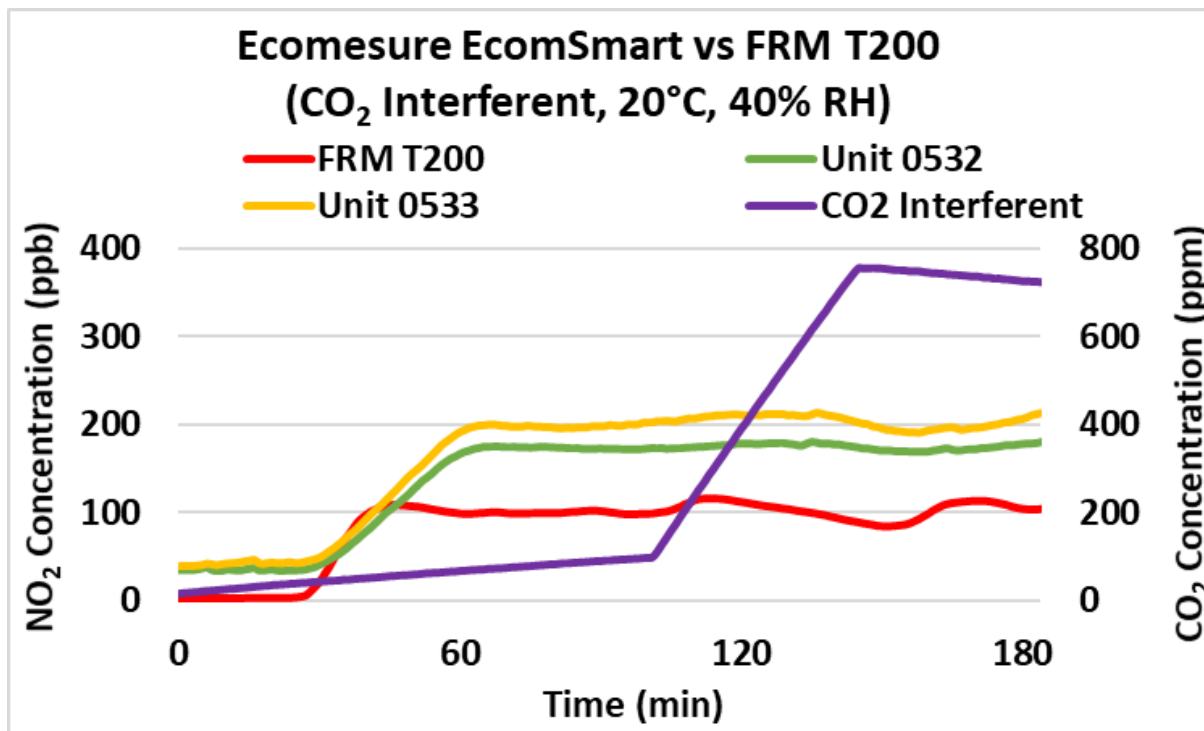


## CO Interferent: EcomSmart vs FRM T200 (NO<sub>2</sub>)



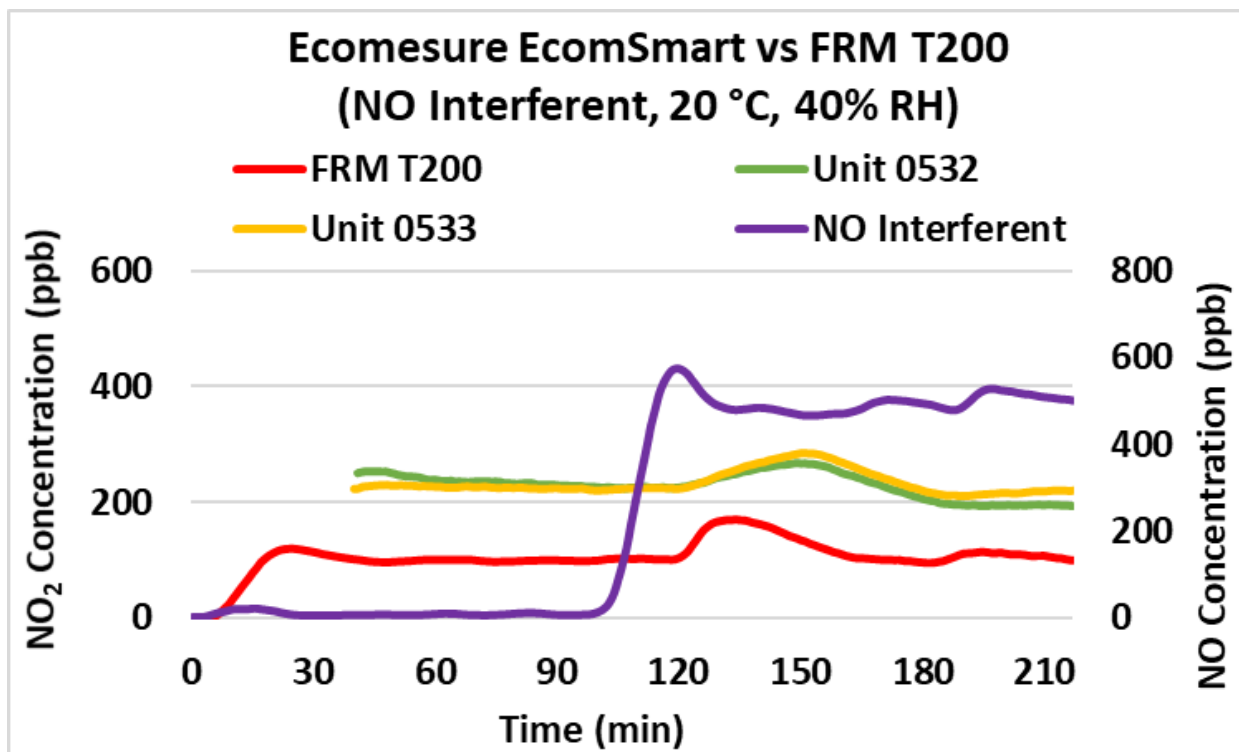
In the laboratory, the effect of CO interferent is evaluated by exposing sensors to 50 ppm of CO at 20 °C and 40% RH while holding the NO<sub>2</sub> concentrations at 100 ppb. As shown in the figure, the FRM T200 and the sensors maintained their readings as the CO concentration increased to 50 ppm.

## CO<sub>2</sub> Interferent: EcomSmart vs FRM T200 (NO<sub>2</sub>)



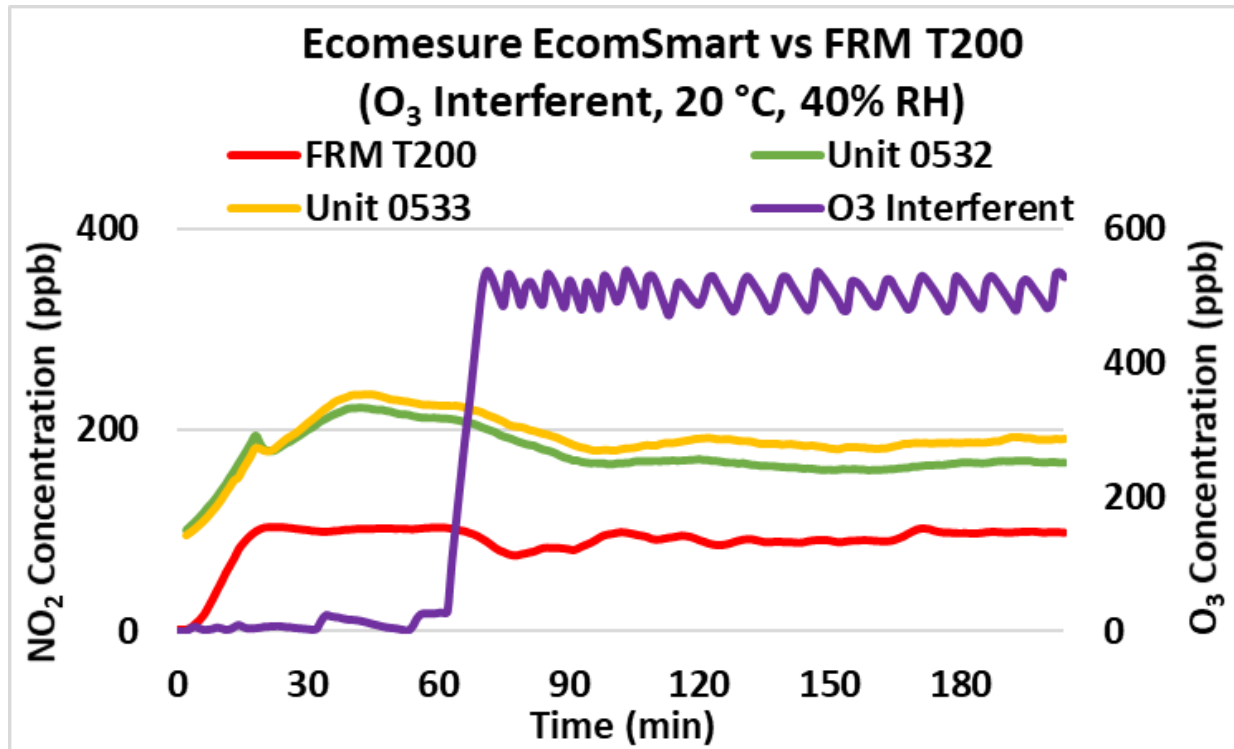
In the laboratory, the effect of CO<sub>2</sub> interferent is evaluated by exposing sensors to 750 ppm of CO<sub>2</sub> at 20°C and 40% RH while holding the NO<sub>2</sub> concentrations at 100 ppb. As shown in the figure, the FRM T200 and the sensors maintained their readings as the CO<sub>2</sub> concentration increased to 750 ppm.

## NO Interferent: EcomSmart vs FRM T200 (NO<sub>2</sub>)



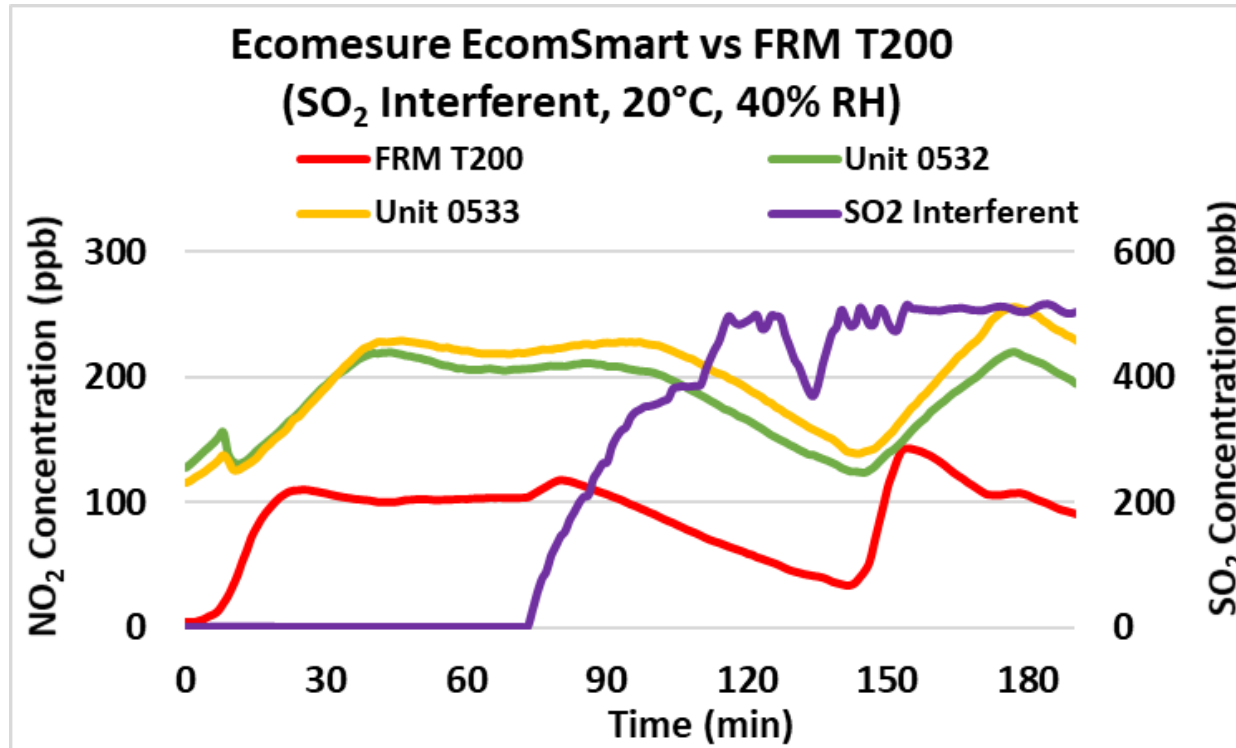
In the laboratory, the effect of NO interferent is evaluated by exposing sensors to 500 ppb of NO at 20°C and 40% RH while holding the NO<sub>2</sub> concentrations at 100 ppb. As shown in the figure, the FRM T200 and the sensors maintained their readings as the NO concentration increased to 500 ppb.

## O<sub>3</sub> Interferent: EcomSmart vs FRM T200 (NO<sub>2</sub>)



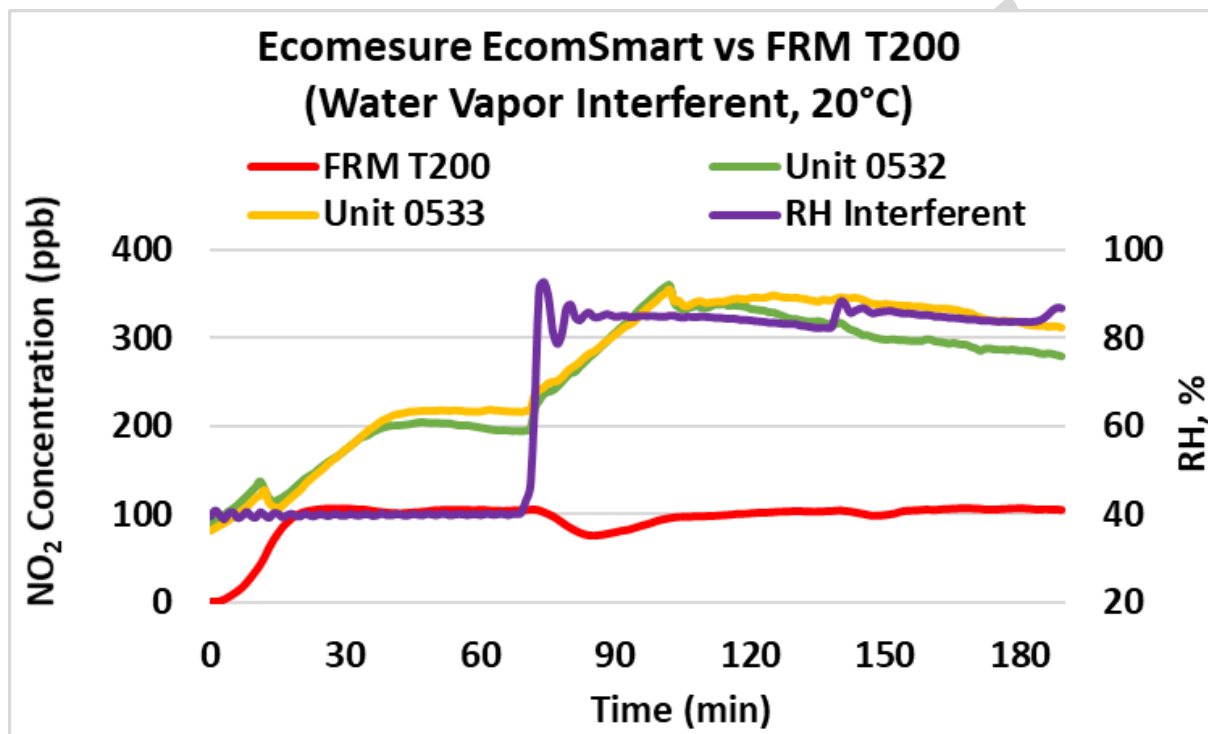
In the laboratory, the effect of O<sub>3</sub> interferent is evaluated by exposing sensors to 500 ppb of O<sub>3</sub> at 20°C and 40% RH while holding the NO<sub>2</sub> concentrations at 100 ppb. As shown in the figure, the FRM T200 and the sensors maintained their readings as the O<sub>3</sub> concentration increased to 500 ppb.

## SO<sub>2</sub> Interferent: EcomSmart vs FRM T200 (NO<sub>2</sub>)



In the laboratory, the effect of SO<sub>2</sub> interferent is evaluated by exposing sensors to 500 ppb of SO<sub>2</sub> at 20°C and 40% RH while holding the NO<sub>2</sub> concentrations at 100 ppb. As shown in the figure, the FRM T200 and the sensors maintained their readings relative to the FRM T200 as the SO<sub>2</sub> concentration increased to 500 ppb.

# Water Vapor Interferent: EcomSmart vs FRM T200 (NO<sub>2</sub>)



In the laboratory, the effect of water vapor interferent is evaluated by exposing sensors to 20,000 ppm of water vapor, which is corresponding to the water content at 20°C and 85% RH, while holding the NO<sub>2</sub> concentrations at 100 ppb. As shown in the figure, the FRM T200 maintained its NO<sub>2</sub> readings at 100 ppb as RH increased from 40% to 85% while the sensors' NO<sub>2</sub> readings increased as RH increased.

# Discussion: NO<sub>2</sub>

- **Accuracy:** The two EcomSmart sensors showed accuracy ranged from -290.0% to 48%. Overall, the sensors overestimated the FRM T200 measurements at all NO<sub>2</sub> concentrations at 20°C and 40% RH.
- **Precision:** The two EcomSmart sensors exhibited high precision during all tested NO<sub>2</sub> conc., T, and RH conditions.
- **Intra-model variability:** Low NO<sub>2</sub> measurement variations were observed among the two EcomSmart sensors at 20°C and 40% RH.
- **Data recovery:** Data recovery for NO<sub>2</sub> measurements was 100% and 97.6% for Units 0532 and 0533, respectively.
- **Baseline:** At all conditions, FRM T200 NO<sub>2</sub> instrument baseline was ranging from 0 to 5.4 ppb, while the sensors' baseline was ranging from 10.2 to 387 ppb; high sensor baselines were observed at 35°C and high RH levels.
- **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 and the max gas flow of 20 LPM, it was not possible to reach a high pollutant concentration within a short time.
- **Linear Correlation:** The two EcomSmart sensors showed strong correlation/linear response with the corresponding FRM T200 NO<sub>2</sub> measurement data ( $R^2 \sim 0.89$ ).
- **Interferents:** The two EcomSmart sensors were inert to most interferents (i.e. CO, CO<sub>2</sub>, NO, O<sub>3</sub>, and SO<sub>2</sub>) at 20°C and 40% RH. The sensors' NO<sub>2</sub> readings increased as RH increased from 40% to 85%.



# Discussion: NO<sub>2</sub>

- **Measurement duration:** EcomSmart sensors report 1-min averaged values for the duration of all experiments.
- **Measurement frequency:** EcomSmart sensors report 1-min 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 FRM T200.
- **Sensor contamination and expiration:** Prior to the laboratory evaluation, the EcomSmart sensors were tested in the field for two months. The NO<sub>2</sub> laboratory studies lasted for about 24 days with intermittent non-operating periods and a storage period of ~10 months. For NO<sub>2</sub> measurements, the two EcomSmart sensors maintained their functionalities and operated normally throughout the duration of the testing.
- **Concentration range:** 0-5 ppm NO<sub>2</sub> concentration as suggested by the manufacturer. During the laboratory evaluation, the EcomSmart sensors were challenged with NO<sub>2</sub> concentrations up to 200 ppb.
- **Climate susceptibility:** During the lab studies, temperature and relative humidity generally had little effect on the precision of NO<sub>2</sub> concentrations as recorded by the EcomSmart sensors. The sensors' NO<sub>2</sub> readings increased as RH increased; the sensors' overestimation increased as RH and T increased.
- **Response to loss of power:** The EcomSmart sensors were powered through the entirety of the lab tests.

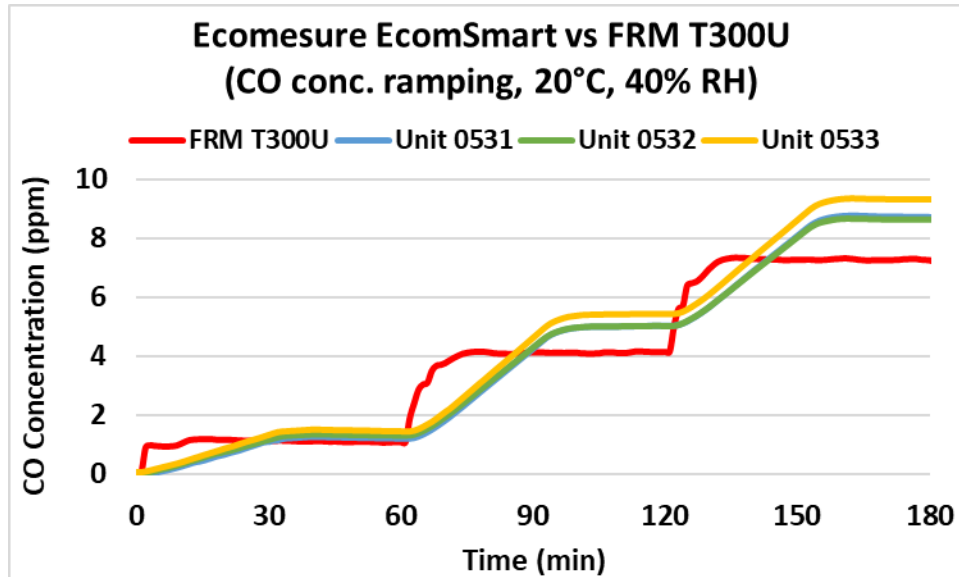
# CO

- 1. FRM T300U vs Ecomesure EcomSmart**
- 2. Accuracy, data recovery and intra-model variability**
- 3. Precision**
- 4. Climate susceptibility**
- 5. Interferents**
- 6. Discussion**

*Note #1: the Ecomesure Ecomsmart's user manual states the CO range is 0-8 ppm, and therefore the CO sensor's lab evaluation only considers the first three CO concentration steps.*

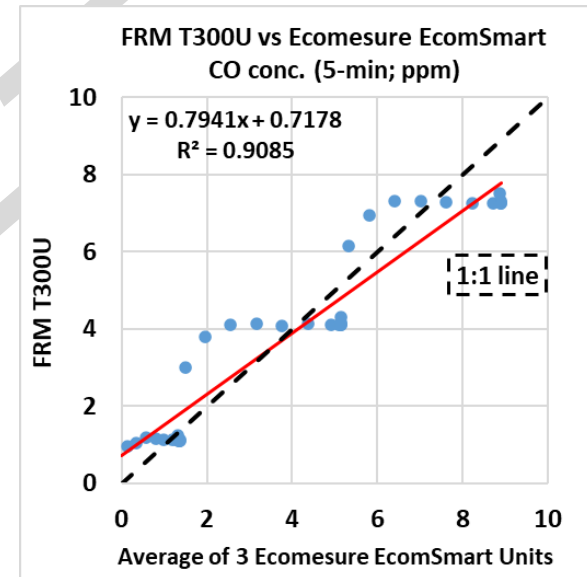
*Note #2: Unit 0531 did not transmit data during the laboratory evaluation except for certain experiments during the CO evaluation.*

# EcomSmart vs FRM T300U (CO)



- The sensors tracked the CO concentration variations recorded by FRM T300U instrument
- Overall, the sensors generally overestimated the CO concentration as recorded by the FRM T300U instrument

## Coefficient of Determination



- The EcomSmart sensors showed very strong correlations with the corresponding FRM T300U CO conc. ( $R^2 \sim 0.91$ )

# Accuracy: EcomSmart vs FRM T300U (CO)

- Accuracy (20°C and 40% RH)

| Steady State (#) | Sensor Mean (ppm) | FRM T300U (ppm) | Accuracy (%) |
|------------------|-------------------|-----------------|--------------|
| 1                | 1.3               | 1.1             | 77.5         |
| 2                | 5.1               | 4.1             | 75.4         |
| 3                | 8.9               | 7.3             | 77.7         |

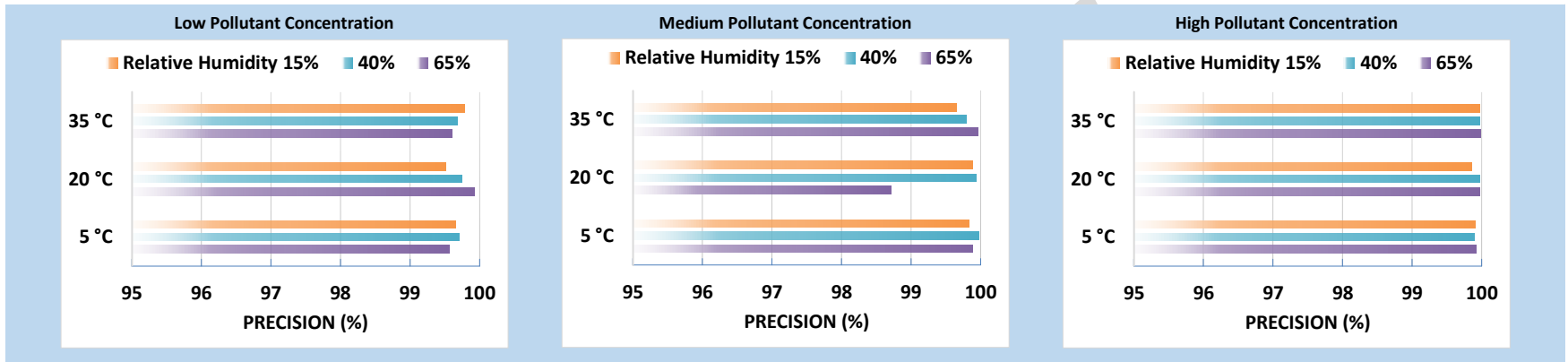
- Accuracy of the three EcomSmart sensors ranged from 75.4% to 77.7%. Overall, the sensors overestimated the FRM T300U measurements at all CO concentrations at 20°C and 40% RH.

## EcomSmart Data Recovery and Intra-model Variability

- Data recovery for CO measurements was 97.8%, 100% and 97.3% for Units 0531, 0532 and 0533, respectively. Note that Unit 0531 did not transmit data for all experiments carried out at 35°C and the interferent tests.
- Low CO concentration variations were observed between the three units at 20°C and 40% RH at low, medium and high CO concentrations as measured by the FRM T300U.

# Precision: EcomSmart vs FRM T300U (CO)

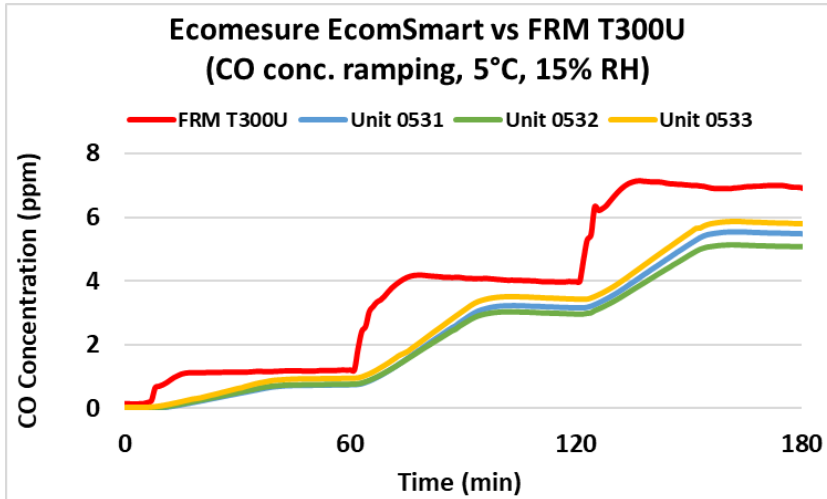
- Precision (Effect of CO conc., temperature and relative humidity)



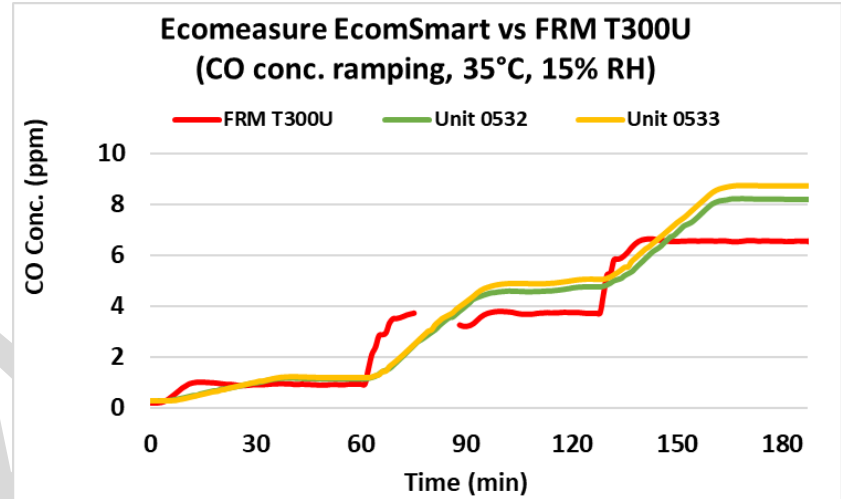
- Overall, the three EcomSmart sensors showed high precision for all combinations of CO conc., T, and RH.

# Climate Susceptibility: EcomSmart (CO)

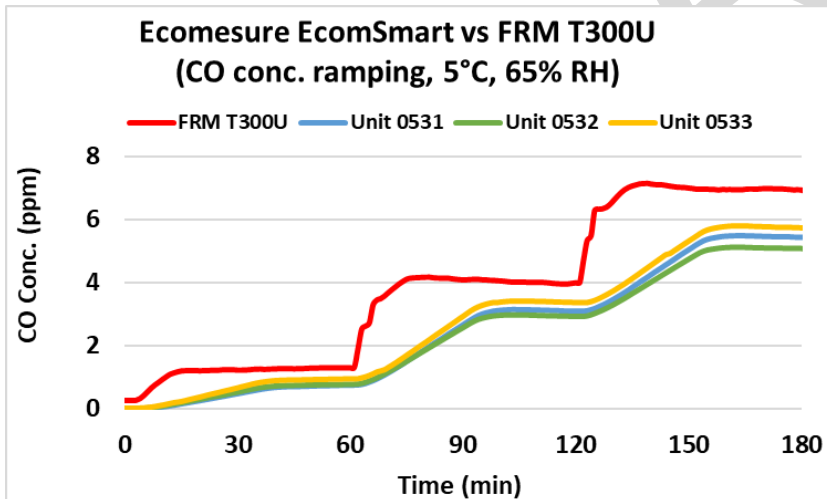
## Low Temp-Low RH



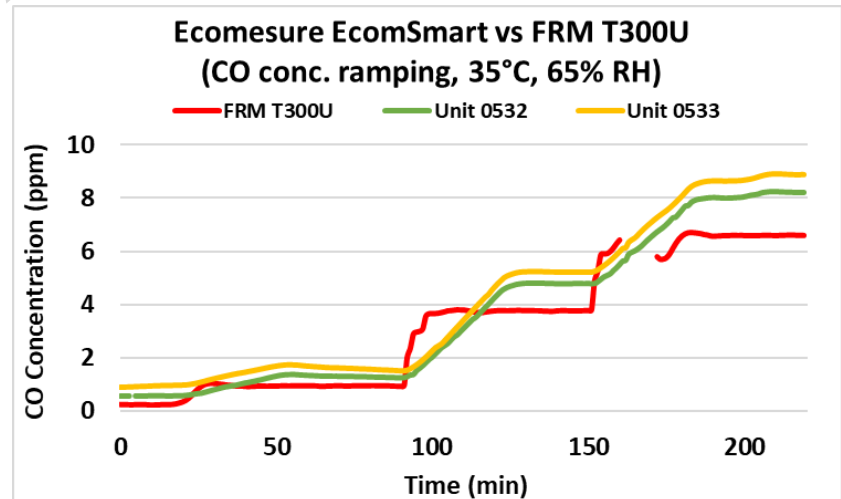
## High Temp-Low RH



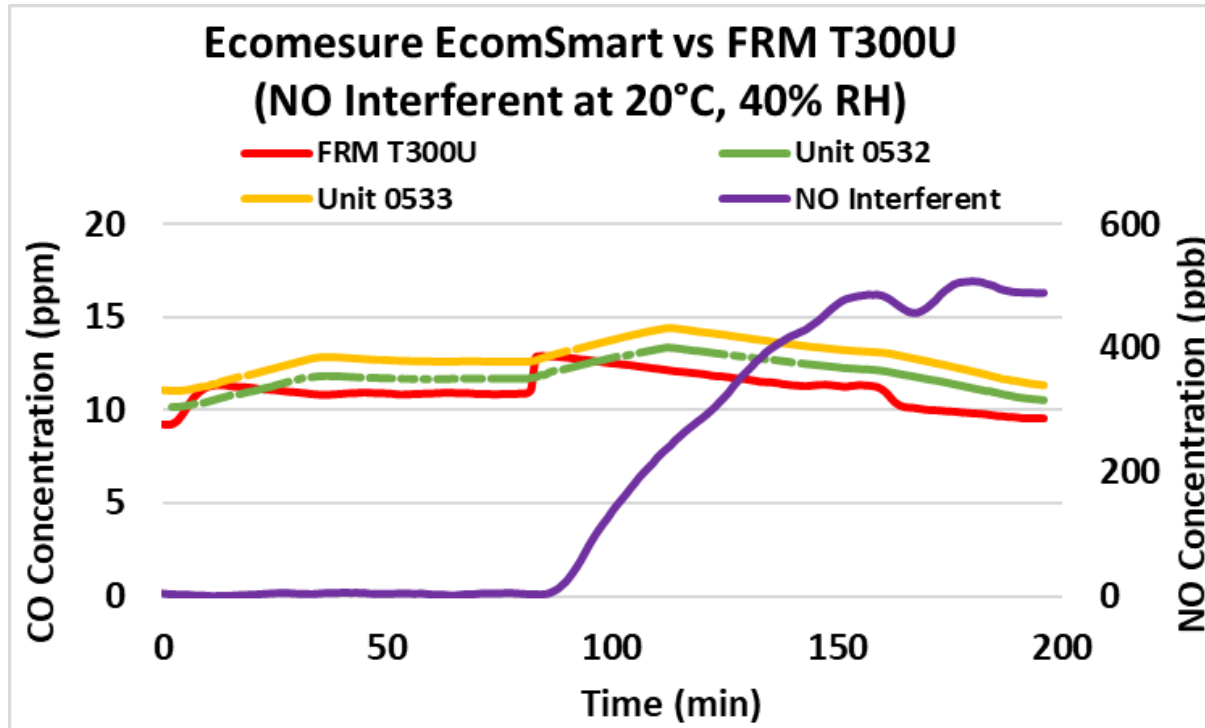
## Low Temp-High RH



## High Temp-High RH

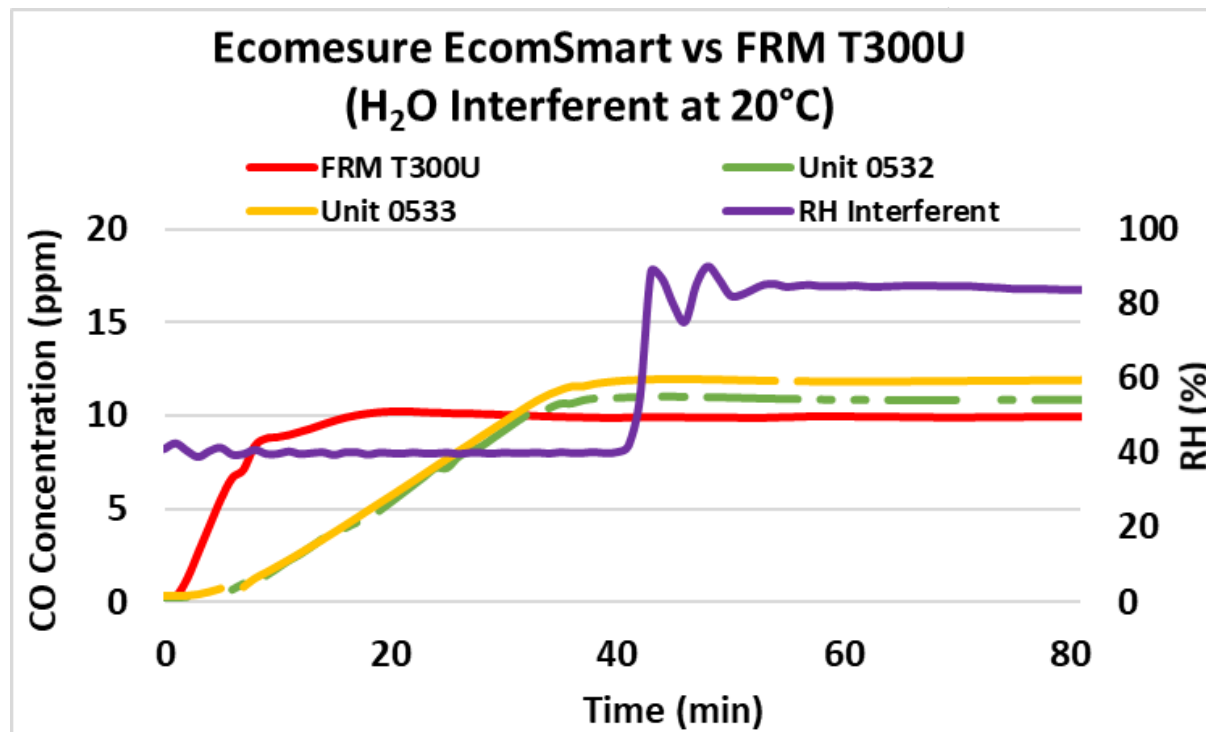


# NO Interferent: EcomSmart vs FRM T300U (CO)



In the laboratory, the effect of NO interferent is evaluated by exposing sensors to 500 ppb of NO at 20°C and 40% RH while holding the CO concentrations at 10 ppm. As shown in the figure, the FRM T300U and the sensors maintained their readings as the NO concentration increased to 500 ppb.

## Water Vapor Interferent: EcomSmart vs FRM T300U (CO)



In the laboratory, the effect of water vapor interferent is evaluated by exposing sensors to 20,000 ppm of water vapor, which is corresponding to the water content at 20°C and 85% RH, while holding the CO concentrations at 10 ppm. As shown in the figure, the FRM T300U and the sensors maintained their CO readings as RH increased from 40% to 85%.



# Discussion: CO

- **Accuracy:** The three EcomSmart sensors showed accuracy ranged from 75.4% to 77.7%. Overall, the sensors overestimated the FRM T300U measurements at all CO concentrations at 20°C and 40% RH.
- **Precision:** The EcomSmart sensors exhibited high precision during all tested CO conc., T, and RH conditions.
- **Intra-model variability:** Low CO measurement variations were observed among the three EcomSmart sensors at 20°C and 40% RH.
- **Data recovery:** Data recovery for CO measurements was 97.8%, 100% and 97.3% for Units 0531, 0532 and 0533, respectively, in the 20°C/40% RH CO ramp. Note that Unit 0531 did not transmit data for all experiments carried out at 35°C and the interferent tests.
- **Baseline:** At all conditions, FRM T300U CO instrument baseline was ranging from 0.02 to 0.30 ppm, while the sensors' baseline was ranging from 0 to 0.74 ppm.
- **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 and the max gas flow of 20 LPM, it was not possible to reach a high pollutant concentration within a short time.
- **Linear Correlation:** The EcomSmart sensors showed very strong correlation/linear response with the corresponding FRM T300U CO measurement data ( $R^2 \sim 0.91$ ).
- **Interferents:** The EcomSmart sensors were inert to both NO and water vapor interferents. The sensors' remained their CO readings as interferent concentrations increased.

# Discussion: CO

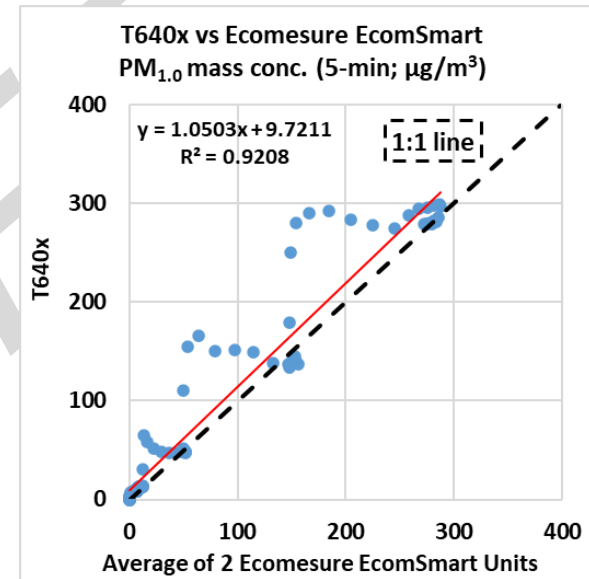
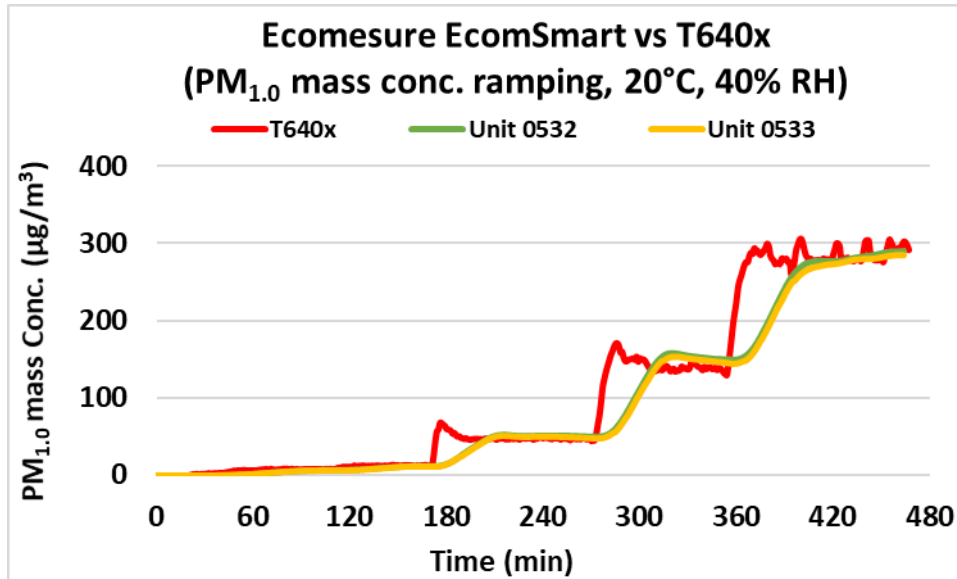
- **Measurement duration:** EcomSmart sensors report 1-min averaged values for the duration of all experiments.
- **Measurement frequency:** EcomSmart sensors report 1-min averaged values. The obtained data was used as-is for calculation of statistics (e.g. data recovery, intra-model variability, mean, accuracy, precision), but condensed into 5-minute averages for linear correlation studies against the FRM T300U.
- **Sensor contamination and expiration:** Prior to the laboratory evaluation, the EcomSmart sensors were tested in the field for two months. The CO laboratory studies lasted for about four weeks with intermittent non-operating periods and a storage period of ~ 10 months. For CO measurements, all EcomSmart sensors maintained their functionalities and operated normally throughout the duration of the testing.
- **Concentration range:** 0-8 ppm CO concentration as suggested by the manufacturer. During the laboratory evaluation, the EcomSmart sensors were challenged with CO concentrations up to ~7 ppm.
- **Climate susceptibility:** During the lab studies, temperature and relative humidity generally had little effect on the precision of CO concentrations as recorded by the EcomSmart sensors.
- **Response to loss of power:** EcomSmart sensors were powered through the entirety of the lab tests.

# PM<sub>1.0</sub>

1. **T640x vs Ecomesure EcomSmart**
2. **Accuracy, data recovery and intra-model variability**
3. **Precision**
4. **Climate susceptibility**
5. **Discussion**

# EcomSmart vs T640x (PM<sub>1.0</sub>)

## Coefficient of Determination



- The EcomSmart sensors tracked well with the concentration variation but generally underestimated PM<sub>1.0</sub>, compared to the T640x in the concentration range of 0 - 300 µg/m<sup>3</sup>, except at third and fourth concentration steps.
- The EcomSmart sensors showed very strong correlations with the T640x PM<sub>1.0</sub> mass conc. ( $R^2 \sim 0.92$ )

# EcomSmart vs T640x PM<sub>1.0</sub> Accuracy

- Accuracy (20°C and 40% RH)

| Steady State # | Sensor Mean (µg/m <sup>3</sup> ) | T640x (µg/m <sup>3</sup> ) | Accuracy (%) |
|----------------|----------------------------------|----------------------------|--------------|
| 1              | 6.9                              | 8.4                        | 81.2         |
| 2              | 12.0                             | 13.1                       | 91.2         |
| 3              | 50.1                             | 47.5                       | 94.4         |
| 4              | 149.9                            | 138.0                      | 91.4         |
| 5              | 286.3                            | 293.3                      | 97.6         |

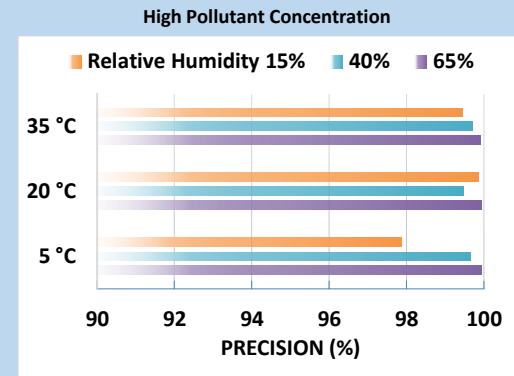
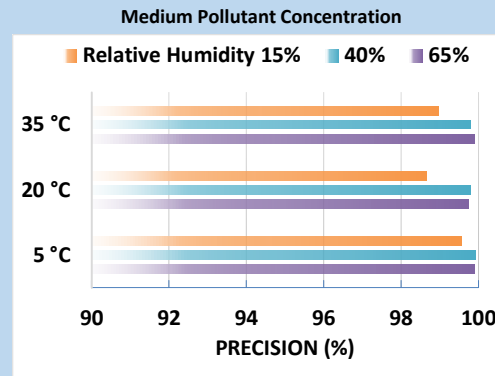
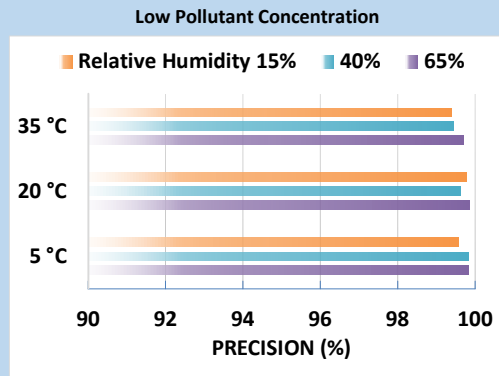
- Overall, the EcomSmart sensors generally underestimated PM<sub>1.0</sub> concentrations compared to the T640x at 20°C and 40% RH, except at third and fourth concentration steps. The EcomSmart sensors' accuracy ranged from 81.2% to 97.6% in the concentrations ranged from 10 to 300 µg/m<sup>3</sup>.

## EcomSmart Data Recovery and Intra-model Variability

- Data recovery for PM<sub>1.0</sub> measurements was 99.4% and 95.1% for Units 0532 and 0533; Unit 0531 did not report data for the entire PM laboratory evaluation.
- Low PM<sub>1.0</sub> concentration variations were observed between the two units at 20°C and 40% RH at low, medium and high PM<sub>1.0</sub> concentrations as measured by the T640x.

# EcomSmart vs T640x (PM<sub>1.0</sub>)

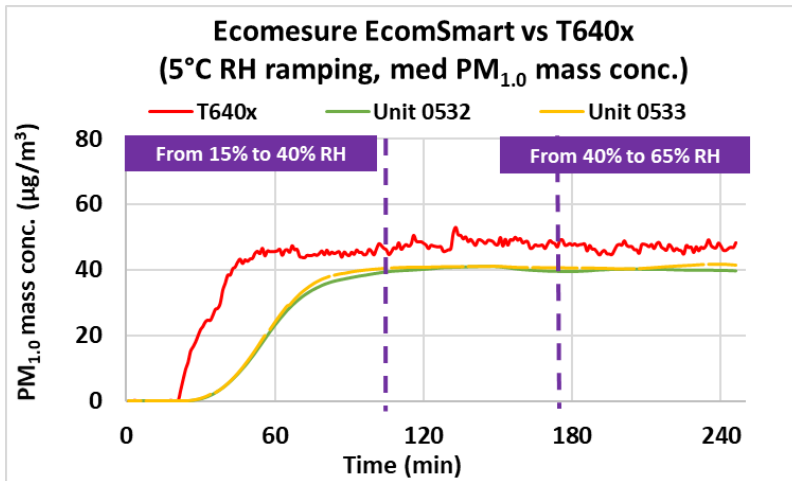
- Precision (effect of PM<sub>1.0</sub> conc., temperature and relative humidity)



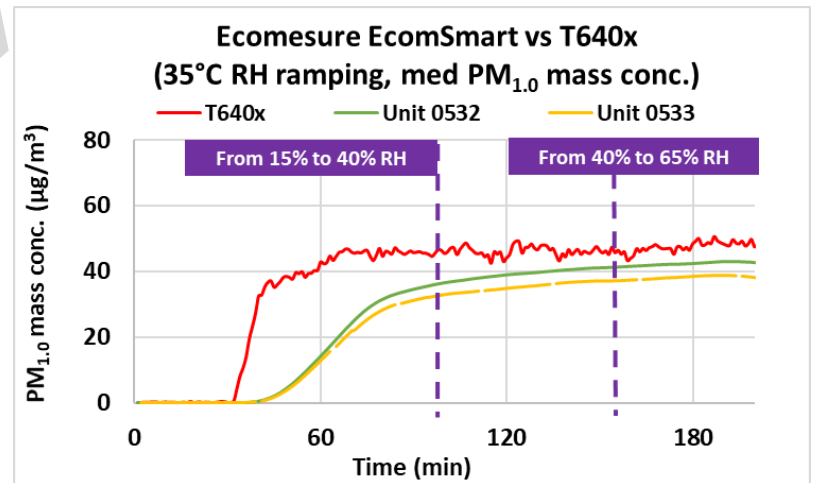
- Overall, EcomSmart sensors showed high precision for all the combinations of low, medium, and high PM<sub>1.0</sub> conc., T, and RH.

# Climate Susceptibility: EcomSmart (PM<sub>1.0</sub>)

Low Temp - RH ramping  
(medium conc.)



High Temp - RH ramping  
(medium conc.)



# Discussion: PM<sub>1.0</sub>

- **Accuracy:** Overall, the EcomSmart sensors generally underestimated PM<sub>1.0</sub> concentrations compared to the T640x at 20°C and 40% RH, except at third and fourth concentration steps. The EcomSmart sensors' accuracy ranged from 81.2% to 97.6% in the concentrations ranged from 10 to 300 µg/m<sup>3</sup>.
- **Precision:** The two EcomSmart sensors exhibited high precision during all tested PM<sub>1.0</sub> conc., T, and RH conditions.
- **Intra-model variability:** Low PM<sub>1.0</sub> measurement variations were observed among the two EcomSmart sensors at 20°C and 40% RH.
- **Data Recovery:** Data recovery for PM<sub>1.0</sub> measurements was 99.4% and 95.1% for Units 0532 and 0533; Unit 0531 did not report data for the entire laboratory evaluation.
- **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 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 two EcomSmart sensors showed very strong correlation/linear response with the corresponding T640x PM<sub>1.0</sub> measurement data ( $R^2 \sim 0.92$ ).
- **Selectivity:** N/A for PM sensors test
- **Interferences:** N/A for PM sensors test



# Discussion: PM<sub>1.0</sub>

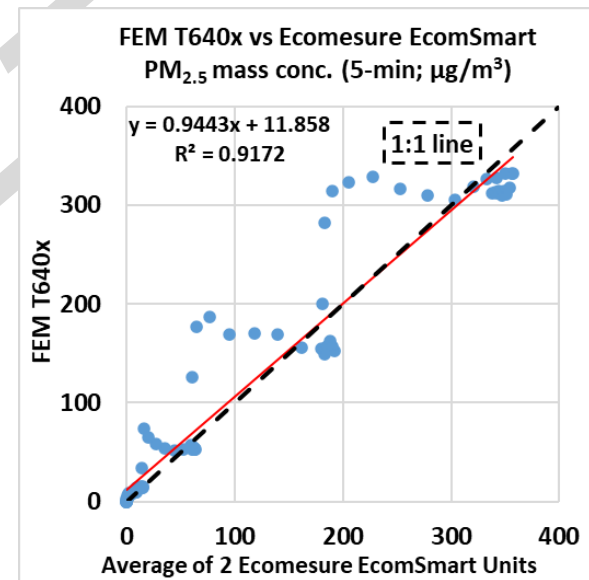
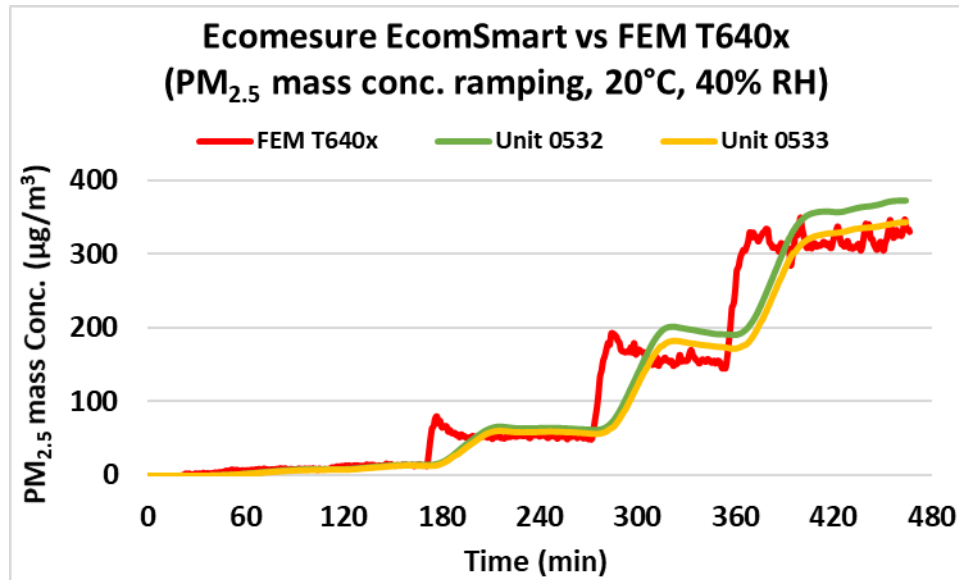
- **Measurement duration:** EcomSmart sensors report 1-min averaged values.
- **Measurement frequency:** EcomSmart sensors report 1-min averaged values. The obtained data was used for calculation of statistics (e.g. data recovery, intra-model variability, mean, accuracy, precision), and condensed to 5-minute averages for linear correlation studies against the T640x.
- **Sensor contamination and expiration:** Prior to the laboratory evaluation, the EcomSmart sensors were tested in the field for two months. The PM<sub>1.0</sub> laboratory studies lasted for about three weeks with intermittent non-operating periods and a storage period of ~ 10 months.
- **Concentration range:** Up to 1000 µg/m<sup>3</sup> as suggested by the manufacturer. During the laboratory evaluation, the EcomSmart sensors were challenged with PM<sub>1.0</sub> concentrations up to 300 µg/m<sup>3</sup>.
- **Drift:** N/A
- **Climate susceptibility:** During the lab studies, climate did not significantly impact the sensors' precision.
- **Response to loss of power:** EcomSmart sensors were powered through the entirety of the lab tests.

# PM<sub>2.5</sub>

1. **T640x vs Ecomesure EcomSmart**
2. **Accuracy, data recovery and intra-model variability**
3. **Precision**
4. **Climate susceptibility**
5. **Discussion**

# EcomSmart vs FEM T640x (PM<sub>2.5</sub>)

## Coefficient of Determination



- The EcomSmart sensors tracked well with the concentration variation and generally overestimated PM<sub>2.5</sub>, compared to the FEM T640x in the concentration range of 0 - 300  $\mu\text{g}/\text{m}^3$ .

- The EcomSmart sensors showed very strong correlations with the FEM T640x PM<sub>2.5</sub> mass conc. ( $R^2 \sim 0.92$ )

# EcomSmart 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              | 8.4                              | 9.3                            | 90.1         |
| 2              | 14.4                             | 14.3                           | 99.9         |
| 3              | 60.9                             | 52.6                           | 84.1         |
| 4              | 184.5                            | 154.1                          | 80.3         |
| 5              | 355.6                            | 327.1                          | 91.3         |

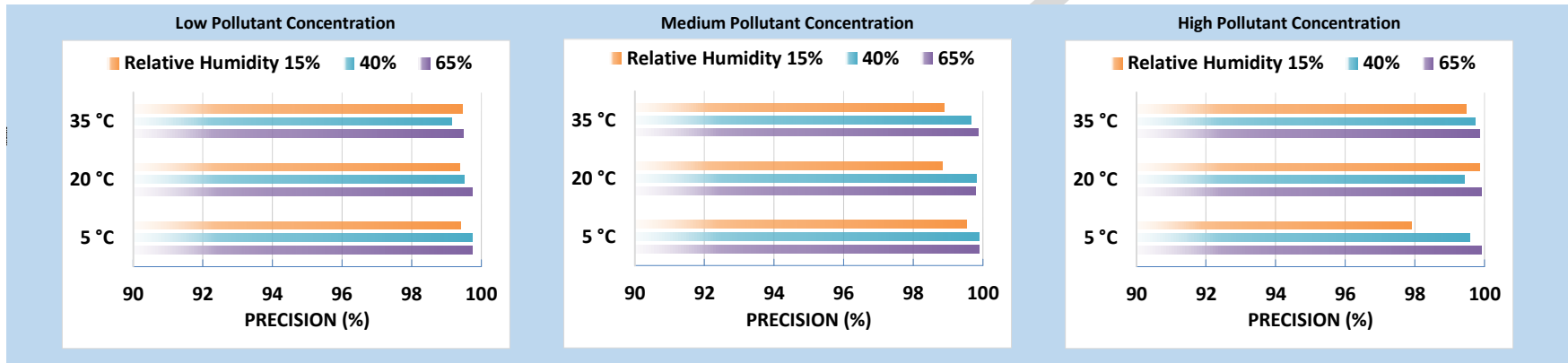
- Overall, the EcomSmart sensors overestimated PM<sub>2.5</sub> concentration values compared to the FEM T640x PM<sub>2.5</sub> mass concentration at 20°C and 40% RH. The EcomSmart sensors' accuracy ranged from 80.3% to 99.9% in the concentrations ranged from 10 to 300 µg/m<sup>3</sup>.

## EcomSmart Data Recovery and Intra-model Variability

- Data recovery for PM<sub>2.5</sub> measurements was 99.4% and 95.1% for Units 0532 and 0533; Unit 0531 did not report data for the entire laboratory evaluation.
- Low PM<sub>2.5</sub> concentration variations were observed between the two units at 20°C and 40% RH at low, medium and high PM<sub>2.5</sub> concentrations as measured by the T640x.

# EcomSmart vs FEM T640x (PM<sub>2.5</sub>)

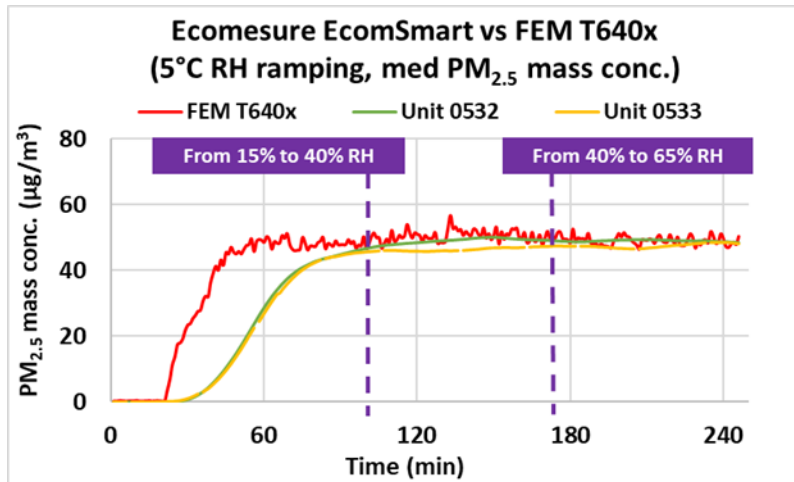
- Precision (effect of PM<sub>2.5</sub> conc., temperature and relative humidity)



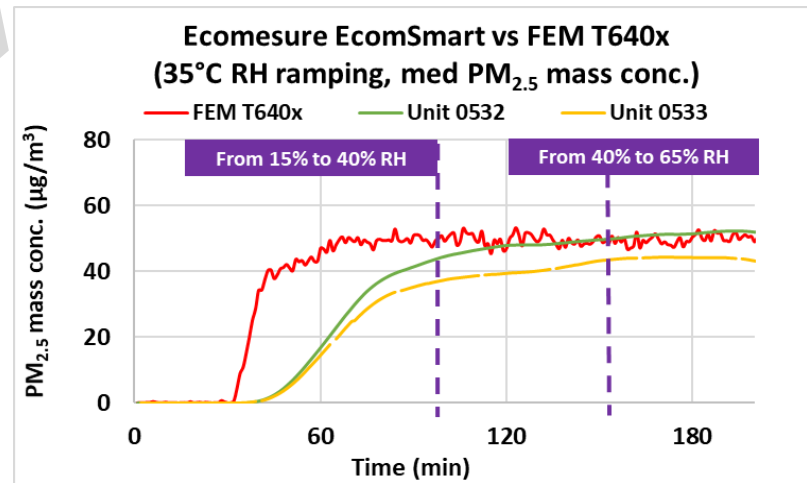
- Overall, EcomSmart sensors showed high precision for all the combinations of low, medium, and high PM<sub>2.5</sub> conc., T, and RH.

# Climate Susceptibility: EcomSmart (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 EcomSmart sensors overestimated PM<sub>2.5</sub> concentration values compared to the FEM T640x PM<sub>2.5</sub> mass concentration at 20°C and 40% RH. The EcomSmart sensors' accuracy ranged from 80.3% to 99.9% in the concentrations ranged from 10 to 300 µg/m<sup>3</sup> as compared to the reference FEM T640x.
- **Precision:** The two EcomSmart sensors exhibited high precision during all tested PM<sub>2.5</sub> conc., T, and RH conditions.
- **Intra-model variability:** Low PM<sub>2.5</sub> measurement variations were observed among the two EcomSmart sensors at 20°C and 40% RH.
- **Data Recovery:** Data recovery for PM<sub>2.5</sub> measurements was 99.4% and 95.1% for Units 0532 and 0533; Unit 0531 did not report data for the entire laboratory evaluation.
- **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 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 two EcomSmart sensors showed very strong correlation/linear response with the corresponding FEM T640x PM<sub>2.5</sub> measurement data ( $R^2 \sim 0.92$ ).
- **Selectivity:** N/A for PM sensors test
- **Interferences:** N/A for PM sensors test

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

- **Measurement duration:** EcomSmart sensors report 1-min averaged values.
- **Measurement frequency:** EcomSmart sensors report 1-min averaged values. The obtained data was used for calculation of statistics (e.g. data recovery, intra-model variability, mean, accuracy, precision), and condensed to 5-minute averages for linear correlation studies against the FEM T640x.
- **Sensor contamination and expiration:** Prior to the laboratory evaluation, the EcomSmart sensors were tested in the field for two months. The PM<sub>2.5</sub> laboratory studies lasted for about three weeks with intermittent non-operating periods and a storage period of ~ 10 months.
- **Concentration range:** Up to 1000 µg/m<sup>3</sup> as suggested by the manufacturer. During the laboratory evaluation, the EcomSmart sensors were challenged with PM<sub>2.5</sub> concentrations up to 300 µg/m<sup>3</sup>.
- **Drift:** N/A
- **Climate susceptibility:** During the lab studies, climate did not significantly impact the sensors' precision.
- **Response to loss of power:** EcomSmart sensors were powered through the entirety of the lab tests.