

Laboratory Evaluation

Aeroqual – AQY-R



Outline

1. Background
2. O_3
3. NO_2
4. $PM_{2.5}$

DRAFT

Background

Three **Aeroqual AQY-R** sensors (unit IDs: 0193, 0194, 0195) were field-tested at the South Coast AQMD Rubidoux fixed ambient monitoring station (04/14/2022 to 06/12/2022) 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.

Aeroqual AQY-R (3 units tested):

- Gas Sensors: Ozone – **Gas Sensitive Semiconductor (Aeroqual; MOx/GSS)**; NO₂ – **Gas Sensitive Electrochemical (Aeroqual NO₂/MA-2, non-FEM/non-FRM)**
- PM_{2.5} – **Laser Particle Counter (LPC) (Nova Fitness SDS011, non-FEM)**
- Each unit measures: O₃ (ppb), NO₂ (ppb), PM_{2.5} (µg/m³), T (°C), RH (%)
- **Unit cost: \$5,000 for the unit, and \$1000 to \$2000/year for cloud data and services**
- Time resolution: 1-min
- Unit IDs: 0193, 0194, and 0195

Aeroqual
AQY-R



Reference instruments:

- O₃ instrument (**Teledyne T400, hereinafter FEM T400**); **cost: ~\$9,000**
- Time resolution; 1-min
- NO/NO₂ instrument (**Teledyne T200, hereinafter FRM T200**); **cost: ~\$13,000**
- Time resolution: 1-min
- PM_{2.5} instrument (**Teledyne T640x, hereinafter FEM T640x**); **cost: ~\$37,000**
- Time resolution: 1-min



FEM T640



FEM T400



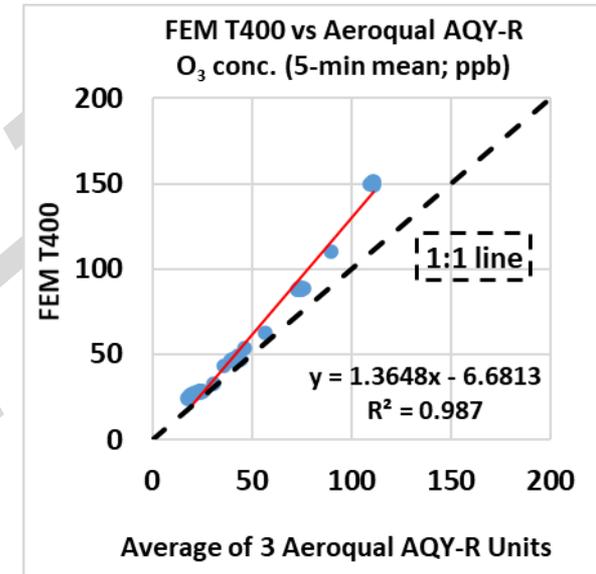
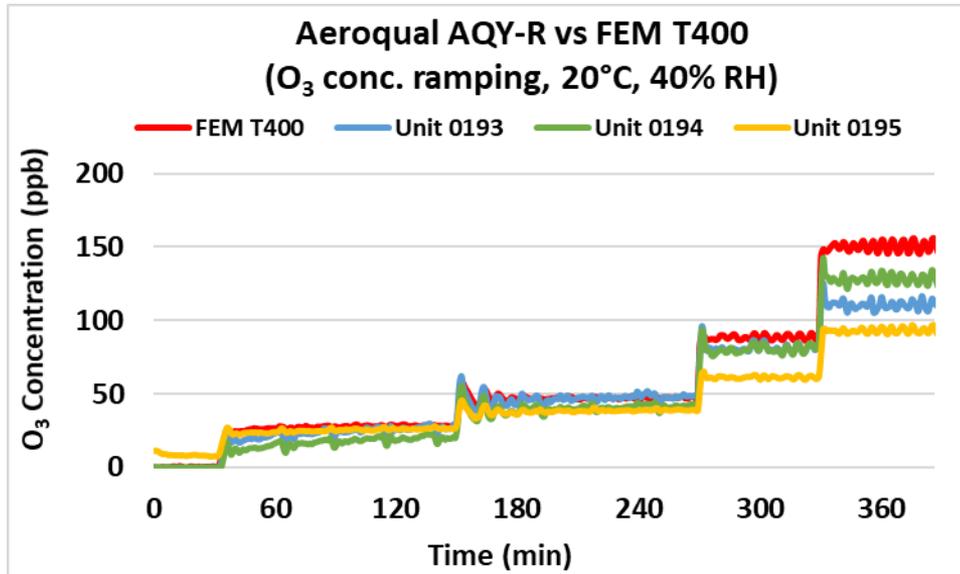
FRM T200



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

Aeroqual AQY-R vs FEM T400 (O₃)

Coefficient of Determination



- The three Aeroqual AQY-R sensors tracked the O₃ concentration variations recorded by FEM T400 instrument from ~30 to 150 ppb
- The Aeroqual AQY-R sensors underestimated the O₃ concentration as recorded by the FEM T400 instrument
- The Aeroqual AQY-R sensors showed very strong correlations with the corresponding FEM T400 O₃ conc. ($R^2 \sim 0.99$)

Accuracy: Aeroqual AQY-R vs FEM T400 (O₃)

- Accuracy (20°C and 40% RH)

| Steady State (#) | Sensor Mean (ppb) | FEM T400 (ppb) | Accuracy (%) |
|------------------|-------------------|----------------|--------------|
| 1 | 24.8 | 28.5 | 86.8 |
| 2 | 42.7 | 47.5 | 89.8 |
| 3 | 74.3 | 88.6 | 83.8 |
| 4 | 110.9 | 150.6 | 73.7 |

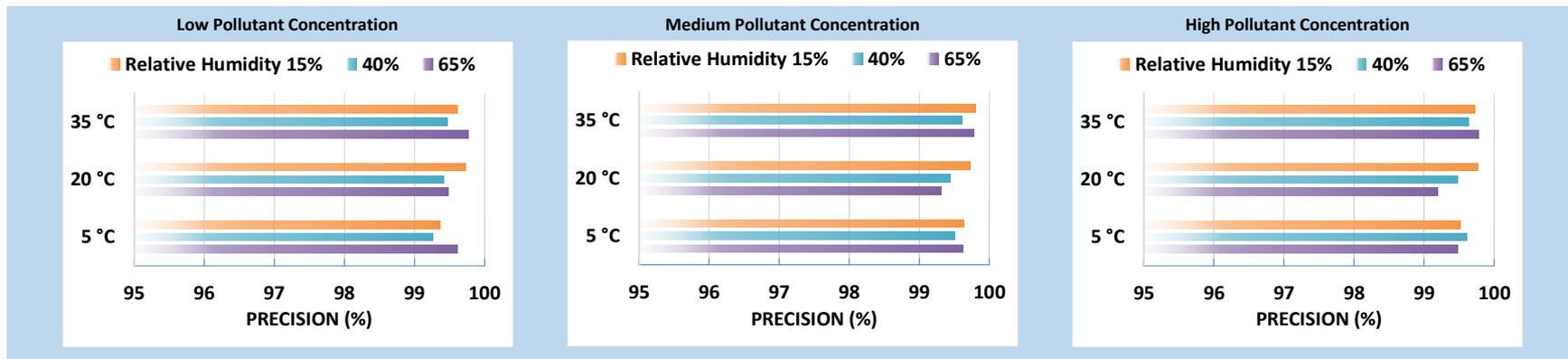
- Accuracy of the three Aeroqual AQY-R sensors ranged from 73.7% to 89.8%. The sensors underestimated the FEM T400 measurements at all O₃ concentrations at 20°C and 40% RH.

Aeroqual AQY-R Data Recovery and Intra-model Variability

- Data recovery for ozone measurements was 91.5%, 91.3%, and 100% for Units 0193, 0194, and 0195, respectively.
- Moderate O₃ concentration variations were observed between the three units at 20°C and 40% RH at low, medium and high O₃ concentrations as measured by the FEM T400.

Precision: Aeroqual AQY-R vs FEM T400 (O₃)

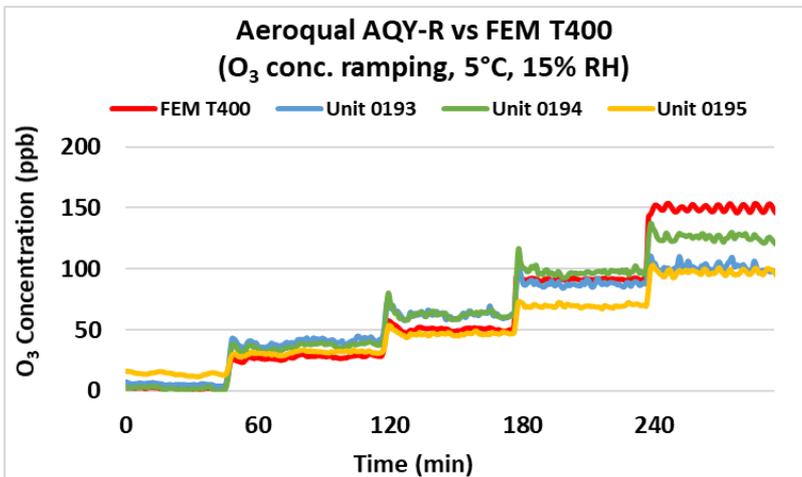
- Precision (Effect of O₃ conc., temperature and relative humidity)



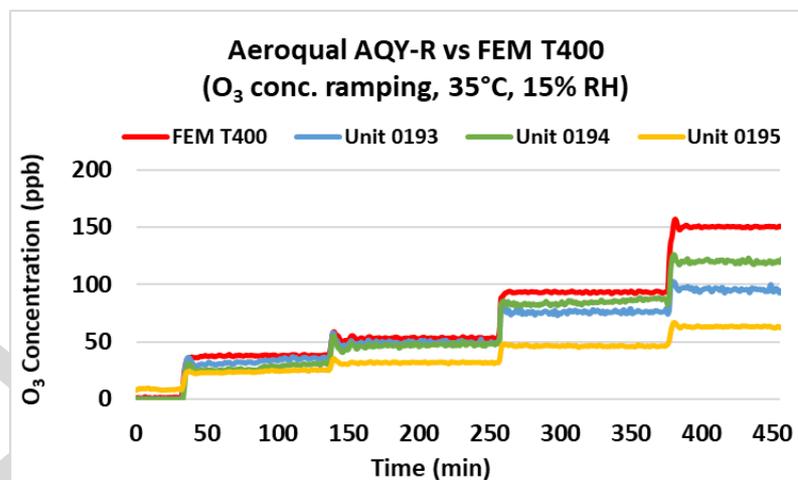
- Overall, the three Aeroqual AQY-R sensors showed high precision for all combinations of low, medium and high O₃ conc., T, and RH.

Climate Susceptibility: Aeroqual AQY-R (O₃)

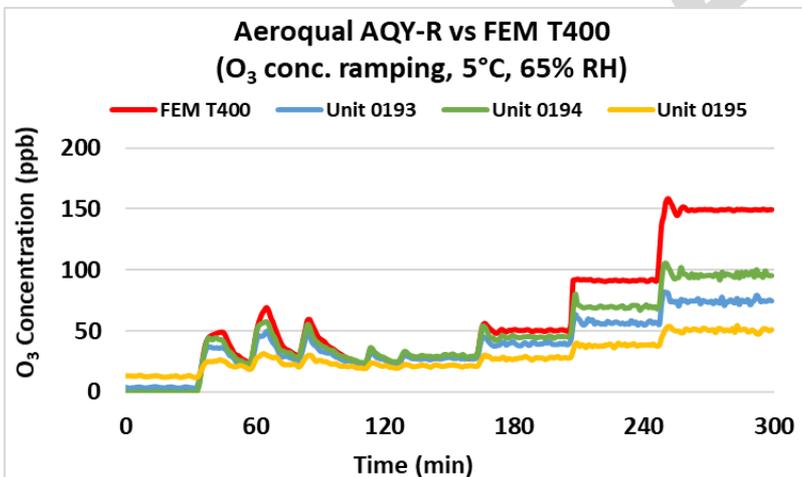
Low Temp-Low RH



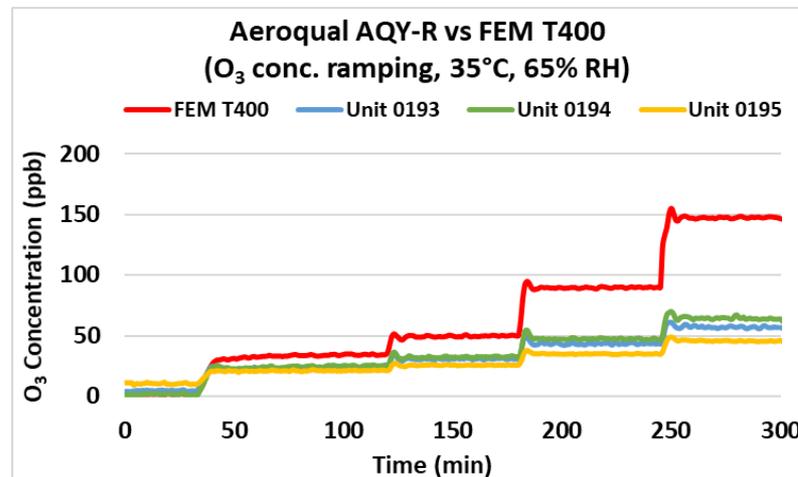
High Temp-Low RH



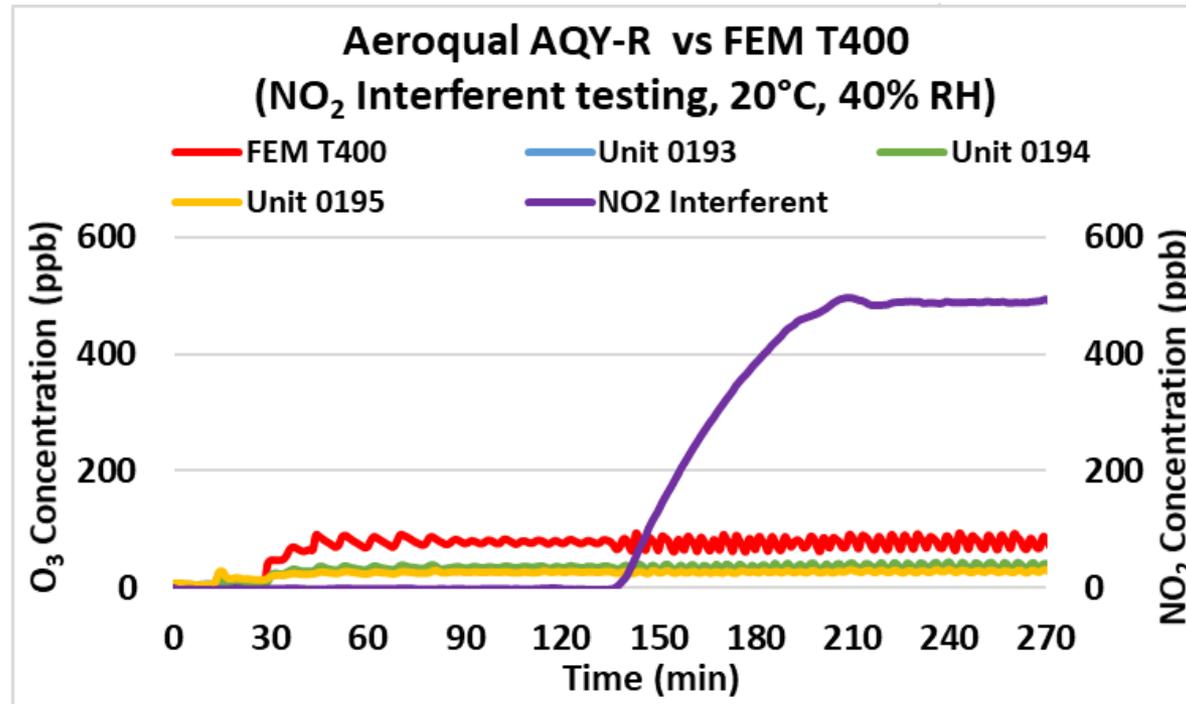
Low Temp-High RH



High Temp-High RH

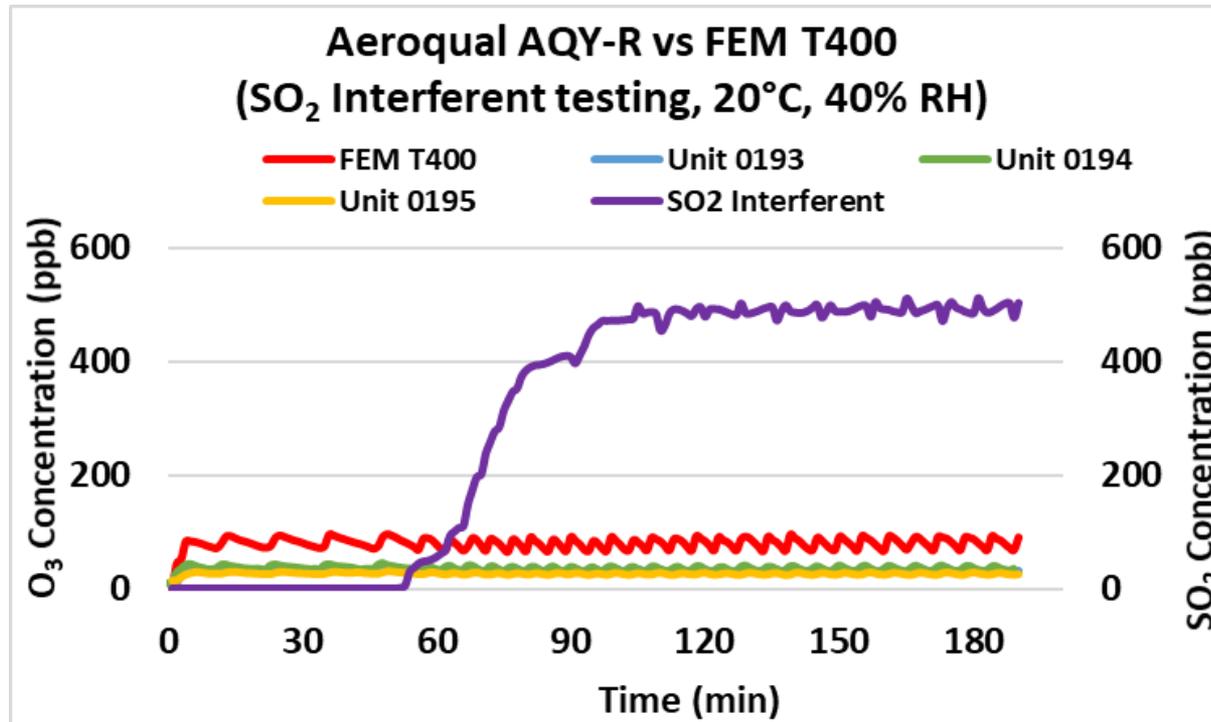


NO₂ Interferent: Aeroqual AQY-R vs FEM T400 (O₃)



In the laboratory, the effect of NO₂ interferent is evaluated by exposing sensors to 500 ppb of NO₂ at 20°C and 40% RH while holding O₃ concentrations at 80 ppb. As shown in the figure, the FEM T400 and the sensors' O₃ measurements were not affected by NO₂.

SO₂ Interferent: Aeroqual AQY-R vs FEM T400 (O₃)



In the laboratory, the effect of SO₂ interferent is evaluated by exposing the sensors to 500 ppb of SO₂ at 20°C and 40% RH while holding O₃ concentrations at 80 ppb. As shown in the figure, both the FEM T400 and sensors' O₃ measurements were not affected by SO₂.

Discussion: O₃

- **Accuracy:** The three Aeroqual AQY-R sensors showed accuracy ranged from 73.7% to 89.8%.
- **Precision:** The three Aeroqual AQY-R sensors exhibited high precision for all combinations of O₃, T and RH conditions.
- **Intra-model variability:** Moderate O₃ measurement variations were observed among the three Aeroqual AQY-R sensors at 20°C and 40% RH.
- **Data recovery:** Data recovery for ozone measurements was 91.5%, 91.3%, and 100% for Units 0193, 0194, and 0195, respectively.
- **Baseline:** At all conditions, FEM T400 O₃ instrument baseline was ranging from 0.5 to 2.4 ppb, while the sensors' baseline was ranging from 0.4 to 13.1 ppb. Unit 0195 generally showed higher baseline compared to Units 0193 and 0194.
- **Response time:** Response time could not be studied due to the system design of the chamber system. With a 1.6 m³ 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 three Aeroqual AQY-R sensors showed very strong correlation/linear response with the corresponding FEM T400 O₃ measurement data ($R^2 \sim 0.99$).
- **Interferent (NO₂):** The three Aeroqual AQY-R sensors were inert to NO₂ at 20°C and 40% RH. When NO₂ was increased to 500 ppb, the sensors maintained their readings at ~ 30 ppb.
- **Interferent (SO₂):** The three Aeroqual AQY-R sensors were inert to SO₂ at 20°C and 40% RH. When SO₂ was increased to 500 ppb, the sensors maintained their readings at ~ 30 ppb.

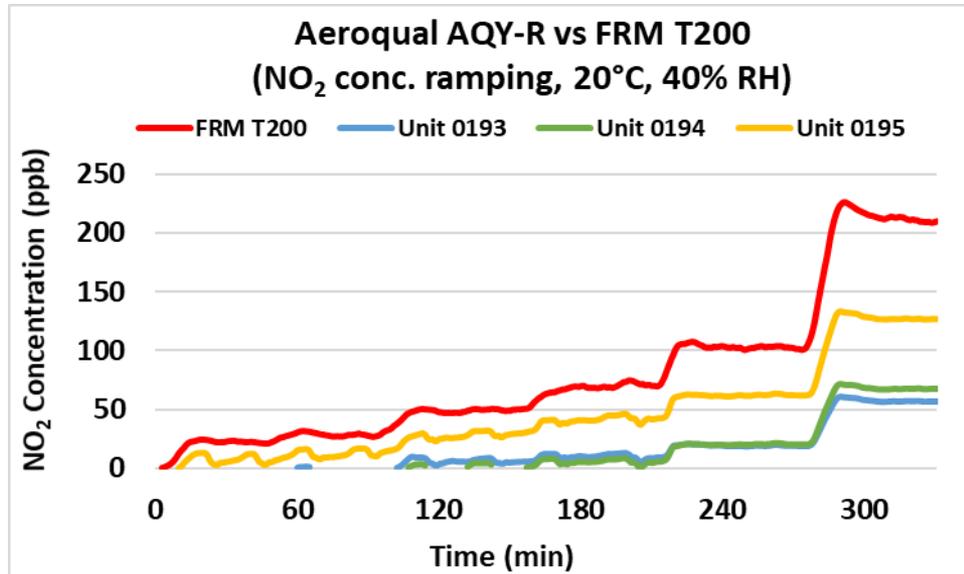
Discussion: O₃

- **Measurement duration:** Aeroqual AQY-R sensors report 1-min averaged values.
- **Measurement frequency:** Aeroqual AQY-R 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 Aeroqual AQY-R sensors were tested in the field for two months. The O₃ laboratory studies lasted for about 17 days with intermittent non-operating periods and a storage period of ~ 10 months. For O₃ measurements, all three Aeroqual AQY-R sensors maintained their functionalities and operated normally throughout the duration of the testing.
- **Concentration range:** 0-200 ppb O₃ concentration as suggested by the manufacturer. During the laboratory evaluation, the Aeroqual AQY-R sensors were challenged with O₃ concentrations up to 150 ppb.
- **Climate susceptibility:** During the lab studies, temperature and relative humidity generally had little effect on the precision of O₃ concentrations as recorded by the Aeroqual AQY-R sensors.
- **Response to loss of power:** Aeroqual AQY-R sensors were powered through the entirety of the lab tests.

NO₂

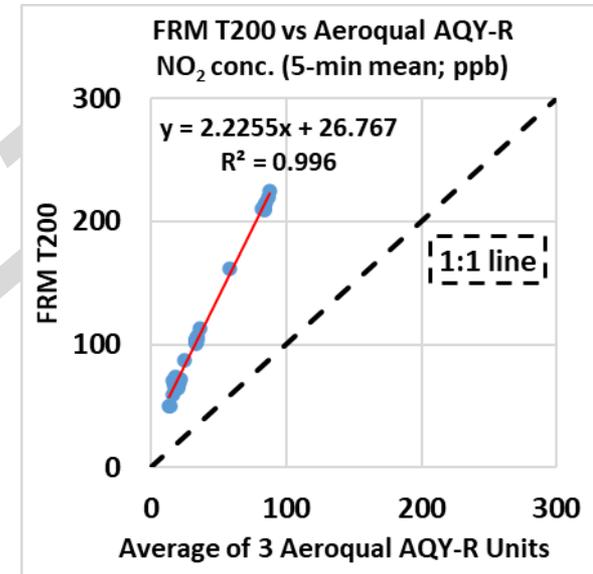
1. **FRM T200 vs Aeroqual AQY-R**
2. **Accuracy, data recovery and intra-model variability**
3. **Precision**
4. **Climate susceptibility**
5. **Interferents**
6. **Discussion**

Aeroqual AQY-R vs FRM T200 (NO₂)



- The FRM T200 instrument reported a baseline of ~ 0 ppb and units 0193 and 0194 reported negative values for baseline and the first two steps of the concentration ramping.
- The sensors tracked the NO₂ concentration variations recorded by FRM T200 instrument
- Overall, the sensors underestimated the NO₂ concentration as recorded by the FRM T200 instrument

Coefficient of Determination



- The Aeroqual AQY-R sensors showed very strong correlations with the corresponding FRM T200 NO₂ conc. ($R^2 > 0.99$)

Accuracy: Aeroqual AQY-R vs FRM T200 (NO₂)

- Accuracy (20°C and 40% RH)

| Steady State (#) | Sensor Mean (ppb) | FRM T200 (ppb) | Accuracy (%) |
|------------------|-------------------|----------------|--------------|
| 1 | - | 27.6 | - |
| 2 | 15.6 | 49.6 | 31.4 |
| 3 | 19.2 | 71.3 | 26.9 |
| 4 | 34.0 | 102.6 | 33.1 |
| 5 | 83.9 | 210.9 | 39.8 |

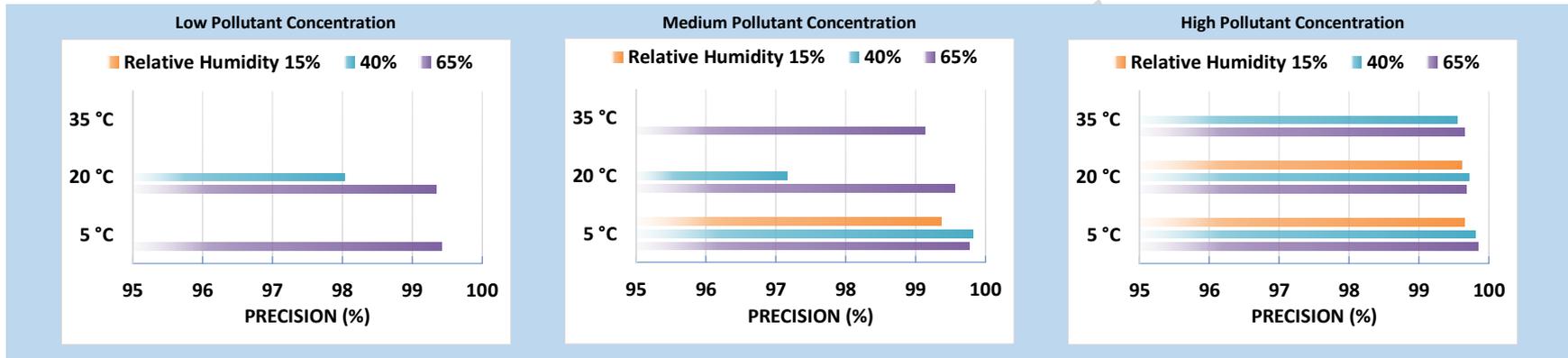
- Accuracy of the three Aeroqual AQY-R sensors ranged from 26.9% to 39.8%. Overall, the sensors underestimated the FRM T200 measurements at all NO₂ concentrations at 20°C and 40% RH. Please note that accuracy were not calculated for the first steady state because Units 0193 and 0194 reported negative values.

Aeroqual AQY-R Data Recovery and Intra-model Variability

- Data recovery for NO₂ measurements was 81.9%, 67.8%, and 97.0% for Units 0193, 0194, and 0195, respectively.
- Very high NO₂ concentration variations were observed between the three units at 20°C and 40% RH at low, medium and high NO₂ concentrations as measured by the FRM T200.

Precision: Aeroqual AQY-R vs FRM T200 (NO₂)

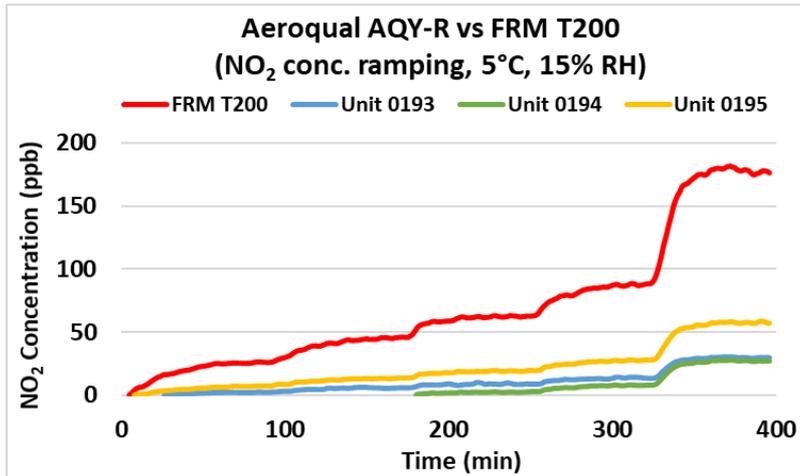
- Precision (Effect of NO₂ conc., temperature and relative humidity)



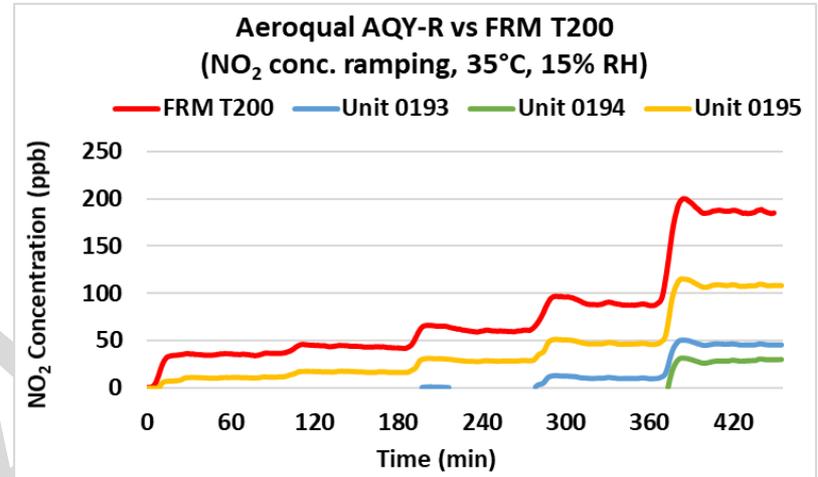
- Overall, the three Aeroqual AQY-R sensors showed high precision for low, medium and high combinations of NO₂ conc., T, and RH.
- The missing bars indicate that precision cannot be calculated for that condition because one or more sensors reported negative values.

Climate Susceptibility: Aeroqual AQY-R (NO₂)

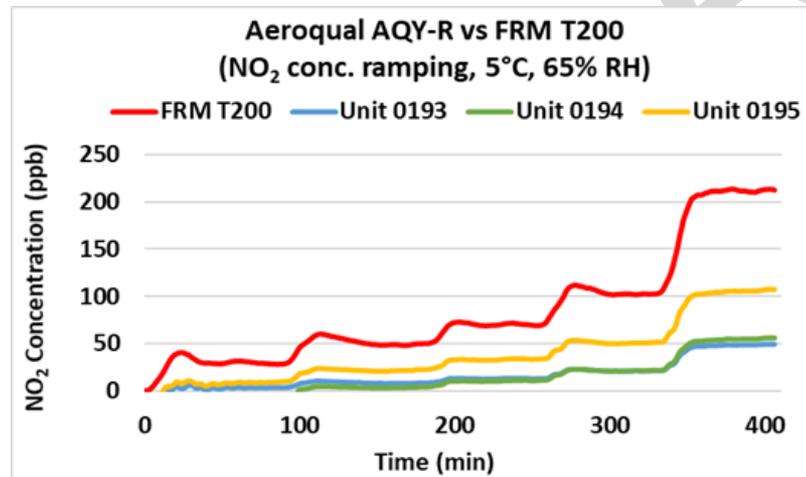
Low Temp-Low RH



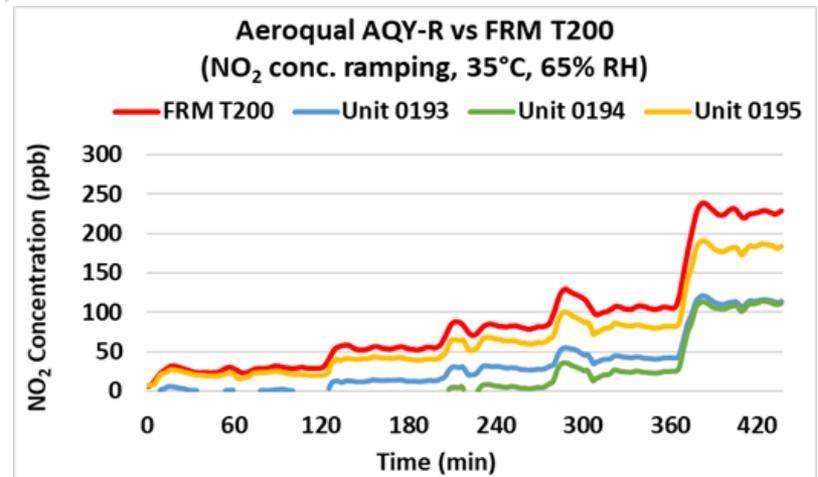
High Temp-Low RH



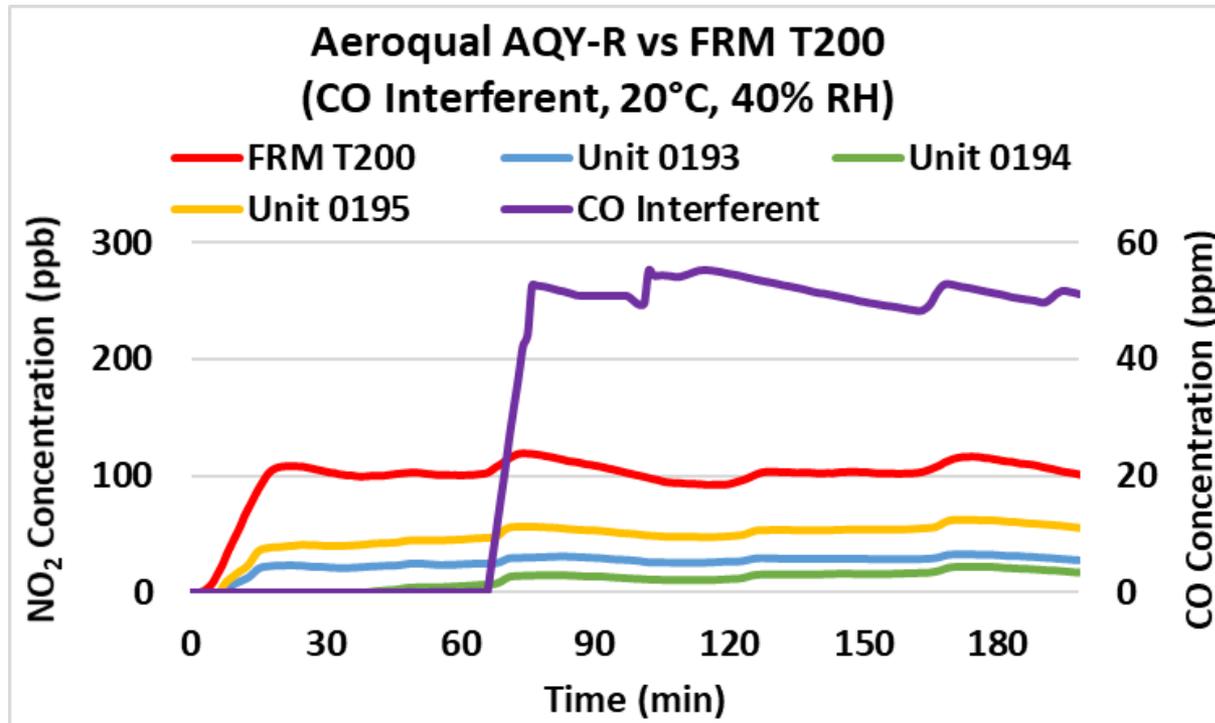
Low Temp-High RH



High Temp-High RH

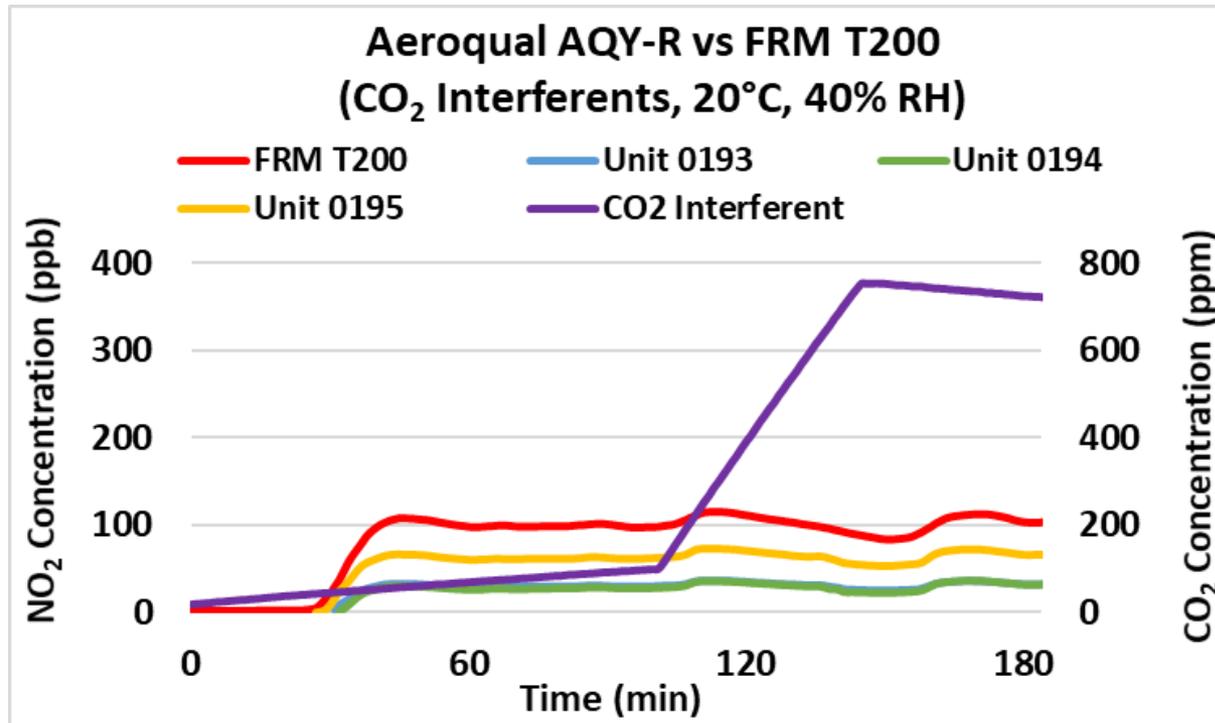


CO Interferent: Aeroqual AQY-R vs FRM T200 (NO₂)



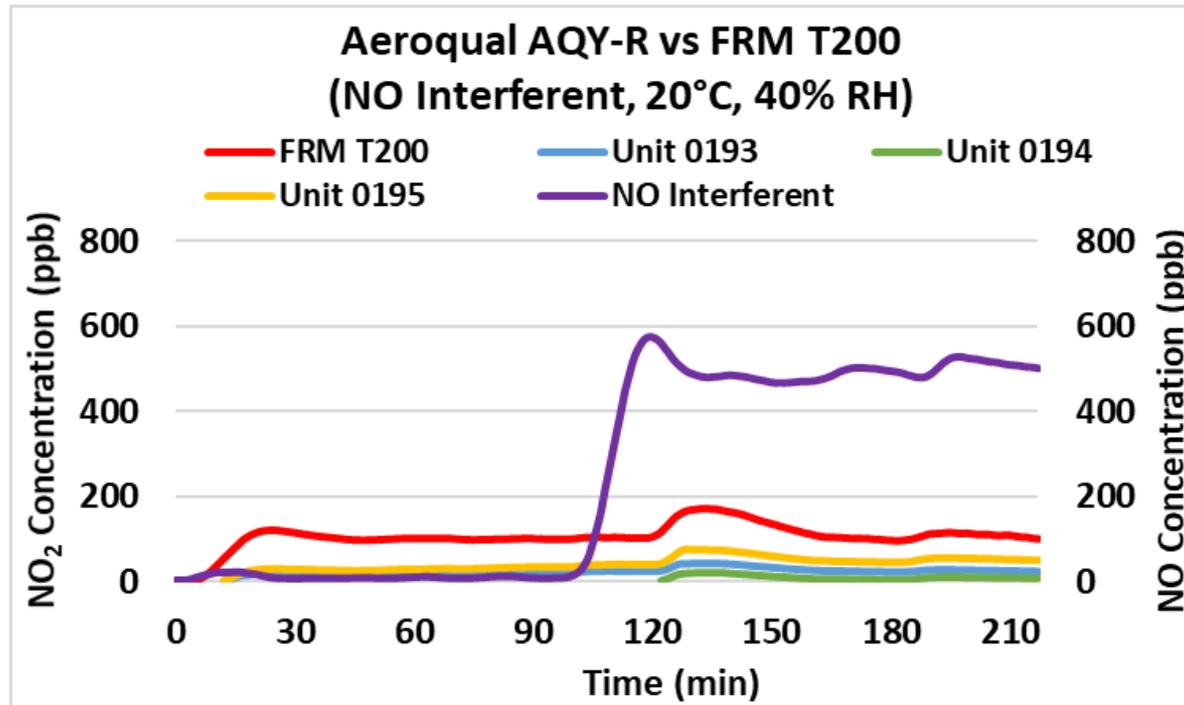
In the laboratory, the effect of CO interferent is evaluated by exposing sensors to 50 ppm of CO at 20°C and 40% RH while holding the NO₂ concentrations at 100 ppb. As shown in the figure, the FRM T200 and the sensors maintained their readings as the CO concentration increased to 50 ppm.

CO₂ Interferent: Aeroqual AQY-R vs FRM T200 (NO₂)



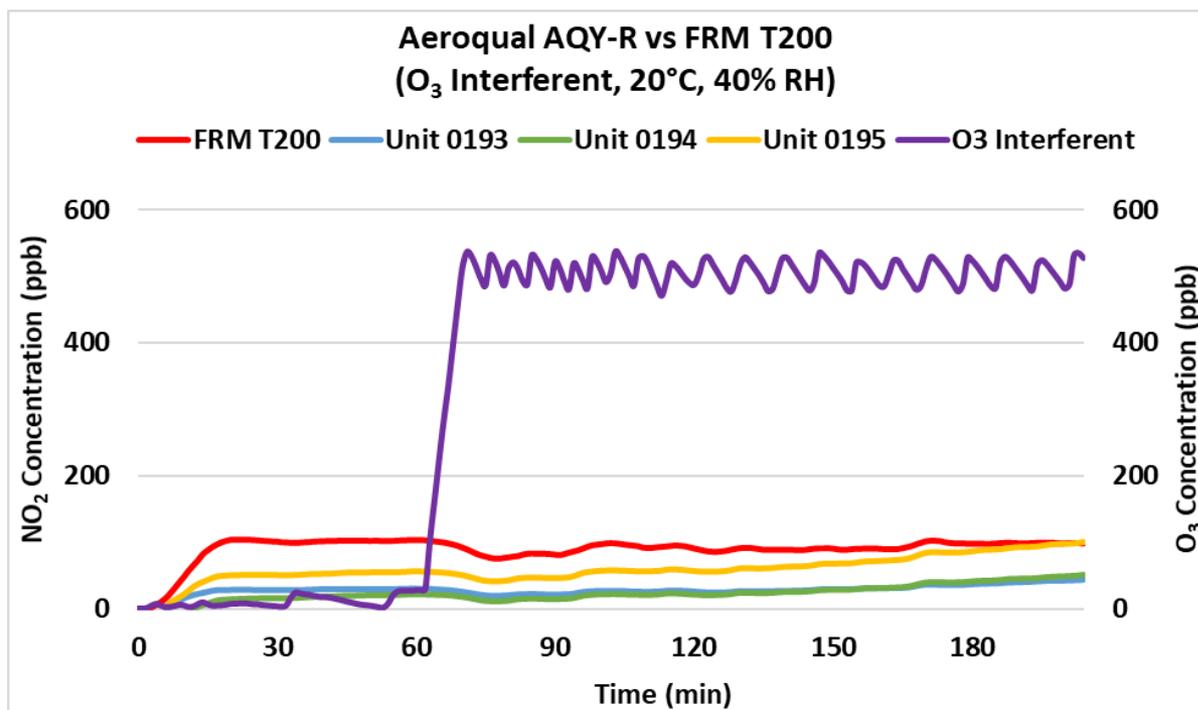
In the laboratory, the effect of CO₂ interferent is evaluated by exposing sensors to 750 ppm of CO₂ at 20°C and 40% RH while holding the NO₂ concentrations at 100 ppb. As shown in the figure, the FRM T200 and the sensors maintained their readings as the CO₂ concentration increased to 750 ppm.

NO Interferent: Aeroqual AQY-R vs FRM T200 (NO₂)



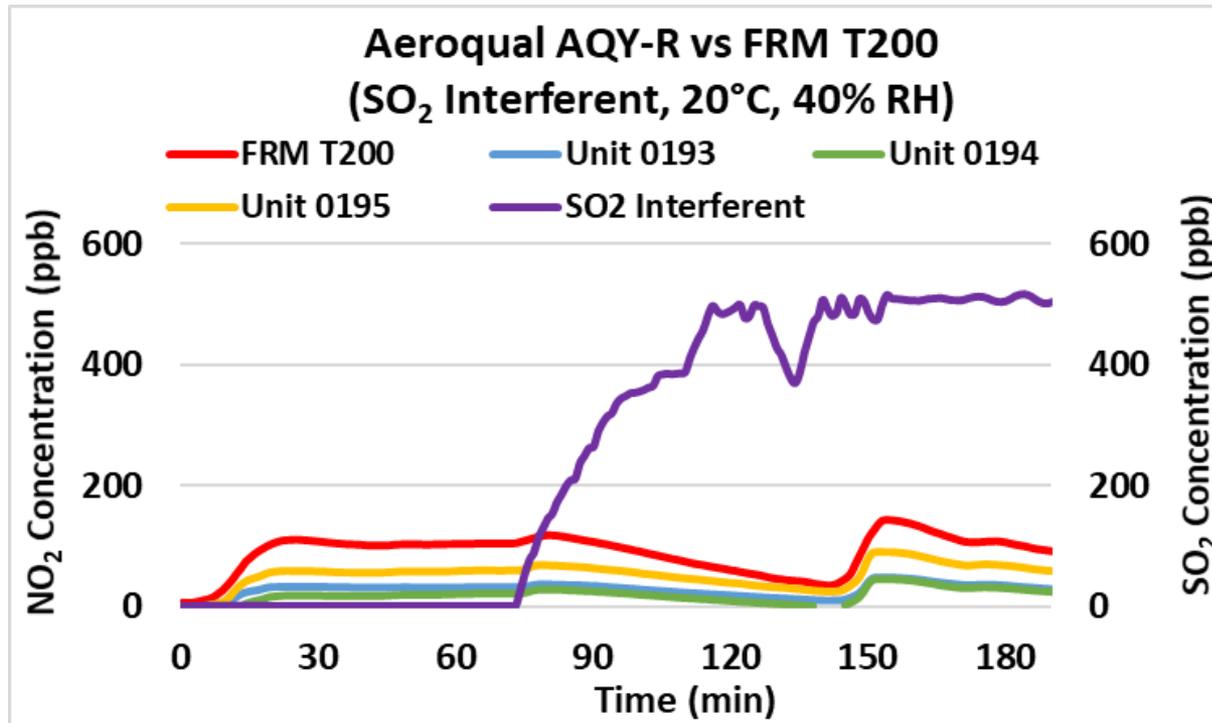
In the laboratory, the effect of NO interferent is evaluated by exposing sensors to 500 ppb of NO at 20°C and 40% RH while holding the NO₂ concentrations at 100 ppb. As shown in the figure, the FRM T200 and the sensors maintained their readings as the NO concentration increased to 500 ppb.

O₃ Interferent: Aeroqual AQY-R vs FRM T200 (NO₂)



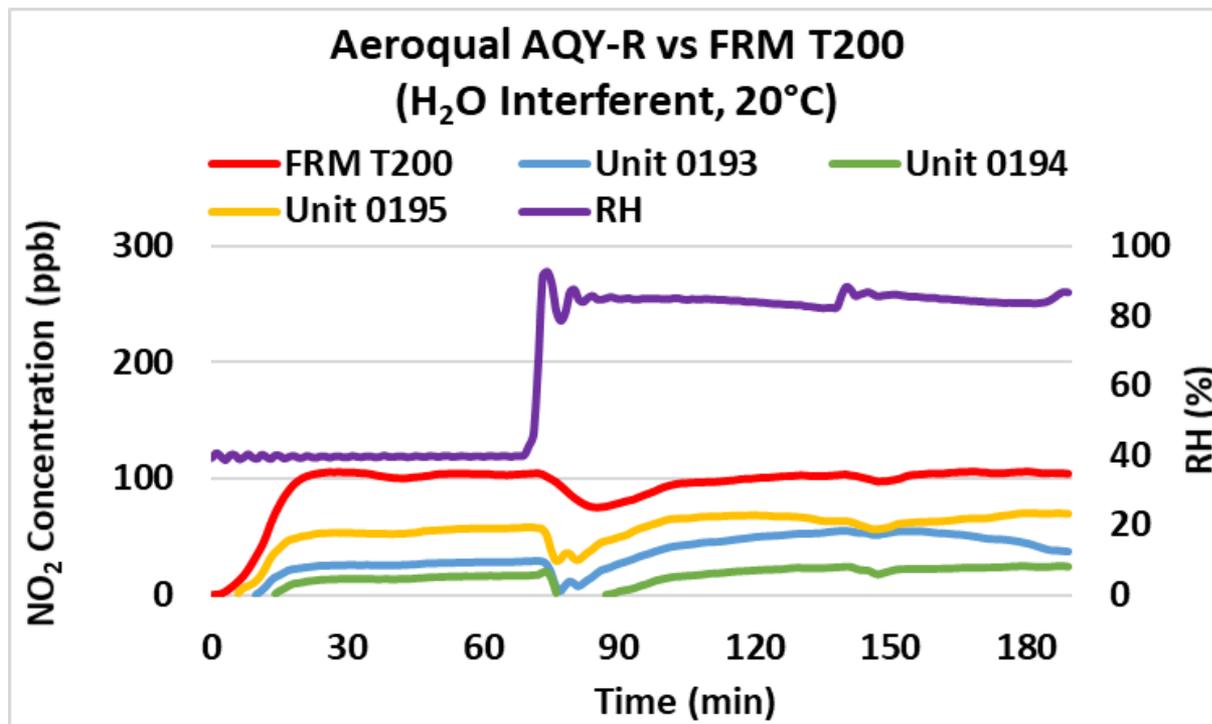
In the laboratory, the effect of O₃ interferent is evaluated by exposing sensors to 500 ppb of O₃ at 20°C and 40% RH while holding the NO₂ concentrations at 100 ppb. As shown in the figure, the FRM T200 and the sensors maintained their readings as the O₃ concentration increased to 500 ppb.

SO₂ Interferent: Aeroqual AQY-R vs FRM T200 (NO₂)



In the laboratory, the effect of SO₂ interferent is evaluated by exposing sensors to 500 ppb of SO₂ at 20°C and 40% RH while holding the NO₂ concentrations at 100 ppb. As shown in the figure, the FRM T200 and the sensors maintained their readings as the SO₂ concentration increased to 500 ppb.

Water Vapor Interferent: Aeroqual AQY-R vs FRM T200 (NO₂)



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 NO₂ concentrations at 100 ppb. As shown in the figure, the FRM T200 and the sensors maintained their NO₂ readings at 100 ppb as RH increased from 40% to 85%.

Discussion: NO₂

- **Accuracy:** The three Aeroqual AQY-R sensors showed accuracy ranged from 26.9% to 39.8%. Overall, the sensors underestimated the FRM T200 measurements at all NO₂ concentrations at 20°C and 40% RH.
- **Precision:** The three Aeroqual AQY-R sensors exhibited high precision during most tested NO₂ conc., T, and RH conditions. Precision cannot be calculated if one or more sensors reported negative values for the respective concentration steps.
- **Intra-model variability:** Very high NO₂ measurement variations were observed among the three Aeroqual AQY-R sensors at 20°C and 40% RH. Unit 0195 showed higher NO₂ readings than Units 0193 and 0194.
- **Data recovery:** Data recovery for NO₂ measurements was 81.9%, 67.8%, and 97.0% for Units 0193, 0194, and 0195, respectively at 20°C and 40% RH.
- **Baseline:** At all conditions, FEM T200 NO₂ instrument baseline was ranging from 0 to 5.4 ppb, while the sensors' baseline cannot be determined because the sensors reported negative values
- **Response time:** Response time could not be studied due to the system design of the chamber system. With a 1.6 m³ 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 three Aeroqual AQY-R sensors showed very strong correlation/linear response with the corresponding FRM T200 NO₂ measurement data ($R^2 > 0.99$)
- **Interferents:** The three Aeroqual AQY-R sensors were inert to all interferents tested (i.e. CO , CO₂, NO, O₃, SO₂ and water vapor) at 20°C and 40% RH.

Discussion: NO₂

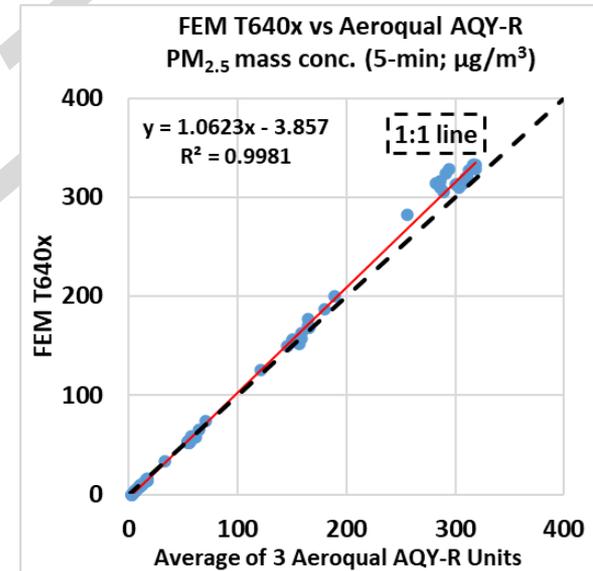
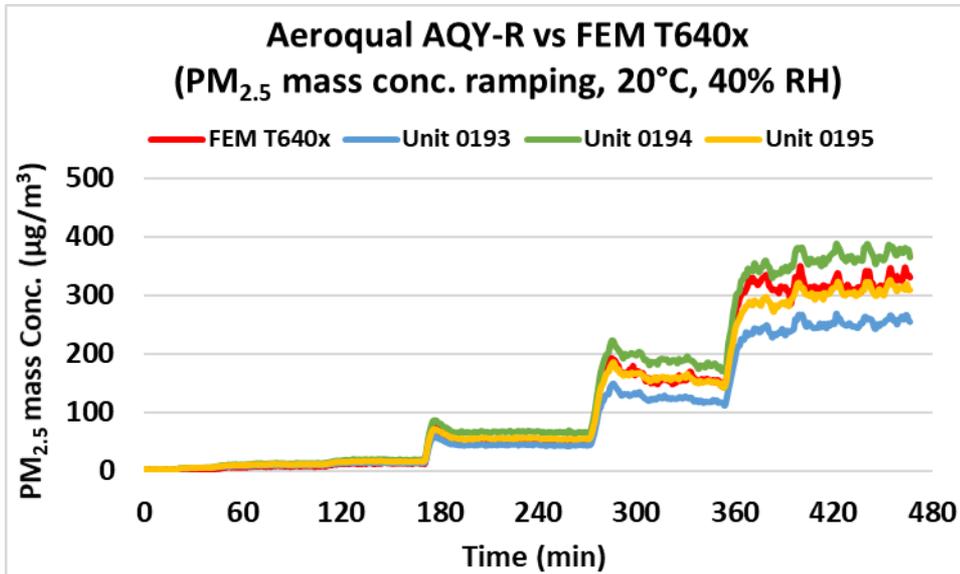
- **Measurement duration:** Aeroqual AQY-R sensors report 1-min averaged values.
- **Measurement frequency:** Aeroqual AQY-R sensors report 1-min averaged values. The obtained data was used as-is for calculation of statistics (e.g. data recovery, intra-model variability, mean, accuracy, precision), but condensed into 5-minute averages for linear correlation studies against the FRM T200.
- **Sensor contamination and expiration:** Prior to the laboratory evaluation, the Aeroqual AQY-R sensors were tested in the field for two months. The NO₂ laboratory studies lasted for about 24 days with intermittent non-operating periods and a storage period of ~ 10 months. For NO₂ measurements, all three Aeroqual AQY-R sensors maintained their functionalities and operated normally throughout the duration of the testing.
- **Concentration range:** 0-500 ppb NO₂ concentration as suggested by the manufacturer. During the laboratory evaluation, the Aeroqual AQY-R sensors were challenged with NO₂ concentrations up to 200 ppb.
- **Climate susceptibility:** During the lab studies, temperature and relative humidity generally had little effect on the precision of NO₂ concentrations as recorded by the Aeroqual AQY-R sensors.
- **Response to loss of power:** Aeroqual AQY-R sensors were powered through the entirety of the lab tests.

PM_{2.5}

1. **FEM T640x vs Aeroqual AQY-R**
2. **Accuracy, data recovery and intra-model variability**
3. **Precision**
4. **Climate susceptibility**
5. **Interferents**
6. **Discussion**

Aeroqual AQY-R vs FEM T640x (PM_{2.5})

Coefficient of Determination



- The Aeroqual AQY-R sensors tracked well with the concentration variation but underestimated PM_{2.5} mass concentrations compared to the FEM T640x in the concentration range of 0 - 300 µg/m³.
- The Aeroqual AQY-R sensors showed very strong correlations with the FEM T640x PM_{2.5} mass conc. ($R^2 > 0.99$)

Aeroqual AQY-R vs FEM T640x PM_{2.5} Accuracy

- Accuracy (20°C and 40% RH)

| Steady State # | Sensor Mean (µg/m ³) | FEM T640x (µg/m ³) | Accuracy (%) |
|----------------|----------------------------------|--------------------------------|--------------|
| 1 | 11.6 | 9.3 | 75.2 |
| 2 | 16.4 | 14.3 | 85.6 |
| 3 | 54.8 | 52.6 | 95.7 |
| 4 | 149.2 | 154.1 | 96.8 |
| 5 | 314.3 | 327.1 | 96.1 |

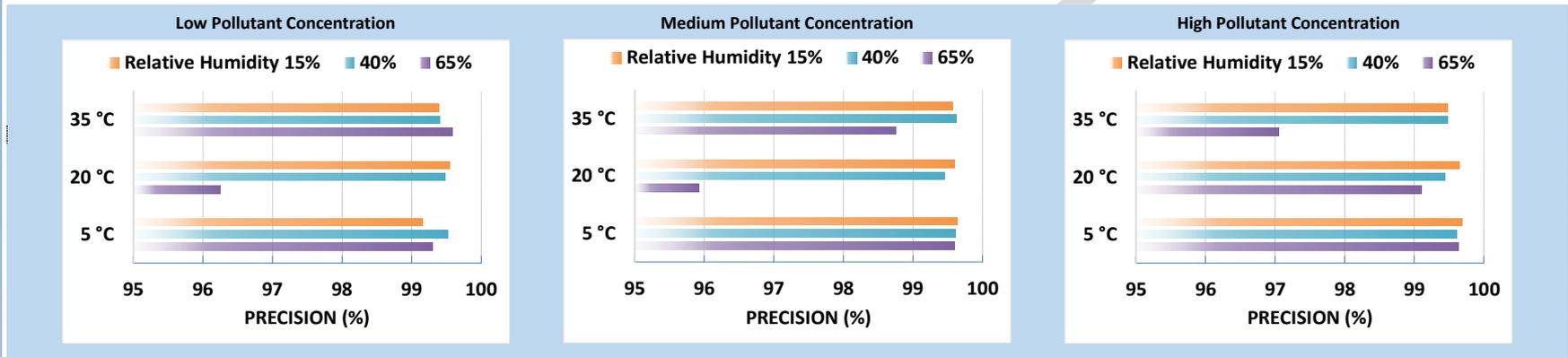
- Overall, the Aeroqual AQY-R sensors overestimated PM_{2.5} concentration values compared to the FEM T640x PM_{2.5} mass concentration at 20°C and 40% RH. The Aeroqual AQY-R sensors' accuracy ranged from 75.2% to 96.8% in the concentrations ranged from 10 to 300 µg/m³.

Aeroqual AQY-R Data Recovery and Intra-model Variability

- Data recovery for PM_{2.5} measurements was 100% for all units.
- Moderate PM_{2.5} concentration variations were observed between the three units at 20°C and 40% RH at low, medium and high NO₂ concentrations as measured by the FEM T640x.

Aeroqual AQY-R vs FEM T640x (PM_{2.5})

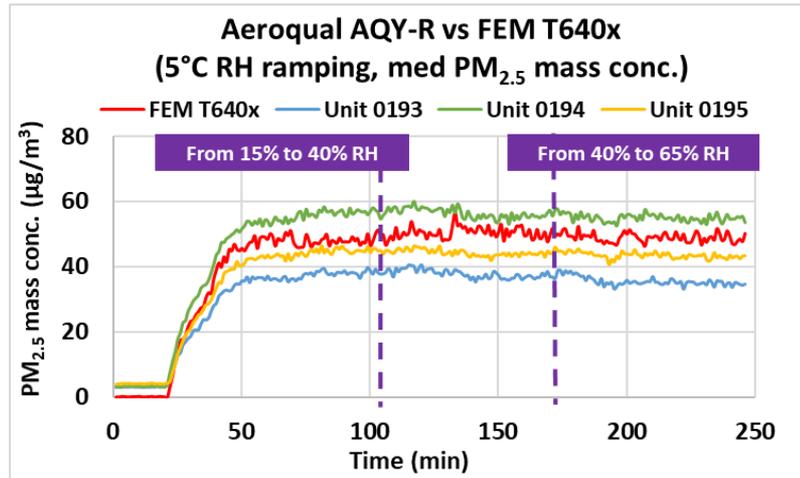
- Precision (effect of PM_{2.5} conc., temperature and relative humidity)



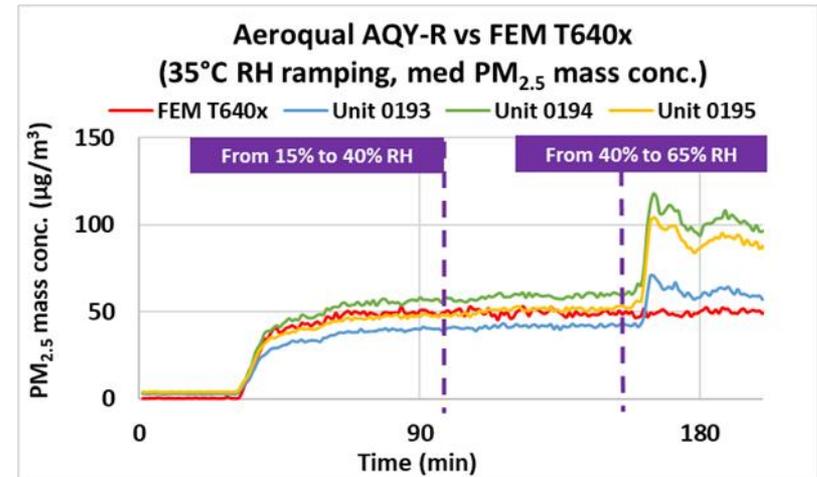
- Overall, Aeroqual AQY-R sensors showed high precision for all the combinations of low, medium, and high PM_{2.5} conc., T, and RH.

Climate Susceptibility: Aeroqual AQY-R (PM_{2.5})

Low Temp - RH ramping
(medium conc.)



High Temp - RH ramping
(medium conc.)



Discussion: PM_{2.5}

- **Accuracy:** the Aeroqual AQY-R sensors overestimated PM_{2.5} concentration values compared to the FEM T640x PM_{2.5} mass concentration at 20°C and 40% RH. The Aeroqual AQY-R sensors' accuracy ranged from 75.2% to 96.8% in the concentrations ranged from 10 to 300 µg/m³ as compared to the reference FEM T640x.
- **Precision:** The three Aeroqual AQY-R sensors exhibited high precision during all tested PM_{2.5} conc., T, and RH conditions.
- **Intra-model variability:** Moderate PM_{2.5} measurement variations were observed among the three Aeroqual AQY-R sensors at 20 °C and 40% RH.
- **Data Recovery:** Data recovery for PM_{2.5} measurements was 100% for all sensors.
- **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 m³ chamber volume, it was not possible to reach a high pollutant concentration within a short time.
- **Linear Correlation:** The three Aeroqual AQY-R sensors showed very strong correlation/linear response with the corresponding FEM T640x PM_{2.5} measurement data ($R^2 > 0.99$).
- **Selectivity:** N/A for PM sensors test
- **Interferences:** N/A for PM sensors test

Discussion: PM_{2.5}

- **Measurement duration:** Aeroqual AQY-R sensors report 1-min averaged values.
- **Measurement frequency:** Aeroqual AQY-R 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 Aeroqual AQY-R sensors were tested in the field for two months. The PM_{2.5} 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/m³ as suggested by the manufacturer. During the laboratory evaluation, the Aeroqual AQY-R sensors were challenged with PM_{2.5} concentrations up to 300 µg/m³.
- **Drift:** N/A
- **Climate susceptibility:** During the lab studies, climate did not significantly impact the sensor's precision. The sensors showed spiked concentration at the 65% RH change point at 20°C and 35°C.
- **Response to loss of power:** Aeroqual AQY-R sensors were powered through the entirety of the lab tests.