Laboratory Evaluation

Aeroqual AQY (v0.5)

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Outline

1. Background
2. Ozone
3. NO_2 / NO_2 (V2)
4. $PM_{2.5}$

Background

Three **Aeroqual AQY (Version 0.5)** multi-sensor units (IDs: 130, 131, and 132), previously field-tested at the South Coast AQMD Rubidoux fixed ambient monitoring station (12/22/2017 to 03/27/2018) under ambient environmental conditions, have now been evaluated in the South Coast AQMD Chemistry Laboratory under controlled artificial aerosol concentration/size range, gas concentrations, temperature, and relative humidity.

Aeroqual AQY (*3 units tested*):

- Sensors: Ozone – Gas Sensitive Semiconductor (GSS); NO_2 - Gas Sensitive Electrochemical (GSE) (non-FEM/non-FRM); $PM_{2.5}$ – Laser Particle Counter (LPC) (non-FEM), (Model SDS011 by Nova Fitness)
- Each unit measures O_3 (ppb), NO_2 (ppb), $PM_{2.5}$ ($\mu g/m^3$), T (°C), RH (%)
- Unit cost: ~$3000 (includes 2-yr tech support + cloud data software license)
- Time resolution: 1-min
- Units IDs: AQY 130, AQY 131, AQY 132

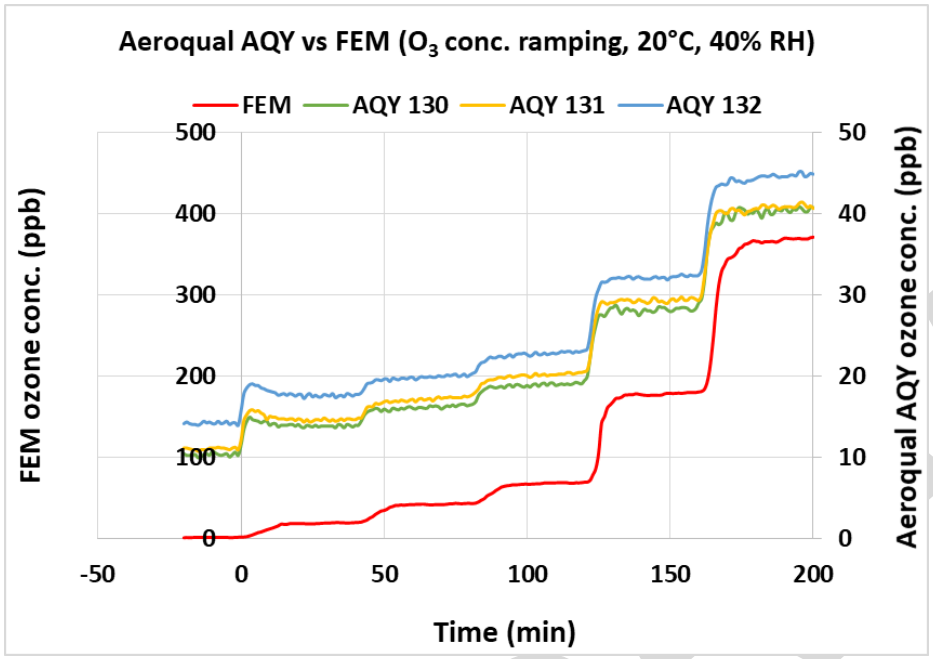
***Reference instruments*:**

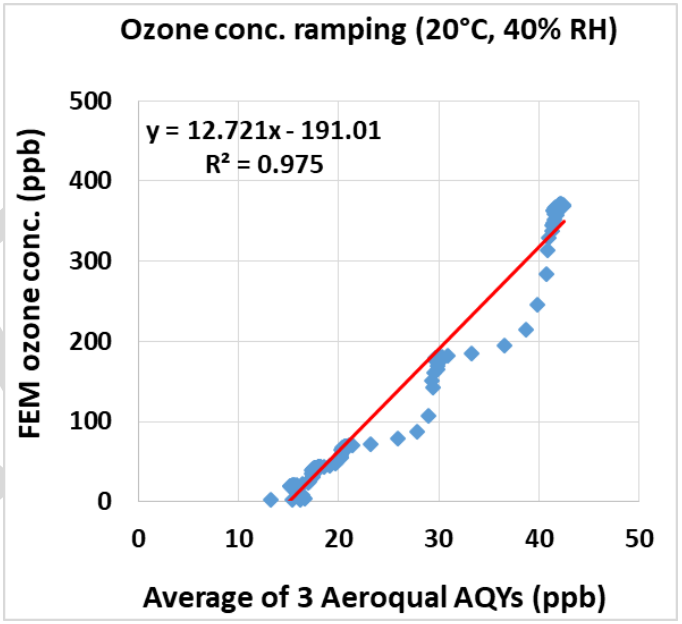
- O_3 instrument (FEM, Serinus 10, American Ecotech, Providence, RI); cost: ~$7,000
  - Time resolution: 1-min
- NO_x instrument (FRM, Serinus 40, American Ecotech, Providence, RI); cost: ~$11,000
  - Time resolution: 1-min
- GRIMM (FEM $PM_{2.5}$) ; cost: ~$25,000
  - Time resolution: 1-min

Ozone

1. FEM O_3 vs Aeroqual AQY O_3
2. Accuracy, data recovery & Intra-model variability
3. Precision
4. Climate susceptibility
5. NO_2 Interferent
6. Discussion

Aeroqual AQY vs FEM (Ozone; 1-min mean)





- The FEM instrument reported a baseline of ~ 2 ppb and the Aeroqual AQY sensors reported baseline values between ~ 10 – 14 ppb
- The three Aeroqual AQY sensors tracked well the ozone concentration variations recorded by FEM instrument
- The Aeroqual AQY sensors underestimated the ozone concentration as recorded by the FEM instrument

** Note the scale of the x and y axis is different*

- The Aeroqual AQY sensors showed very strong correlations with the corresponding FEM ozone conc. (R^2 > 0.97)

Aeroqual AQY Accuracy (O_3, 1-min mean)

- Accuracy (20 °C and 40% RH)

Steady State (#)	Sensor mean (ppb)	FEM (ppb)	Accuracy (%)
1	15.4	19.5	79.0
2	17.9	42.9	41.7
3	20.8	68.8	30.2
4	30.0	178.8	16.8
5	42.0	368.3	11.4

- Accuracy of the three Aeroqual AQY sensors decreased as concentration increased, with accuracy ranging from 11.4% at the highest concentration to 79% at the lowest concentration. The sensors underestimated the ozone concentrations as measured by the FEM instrument at 20 °C and 40% RH.

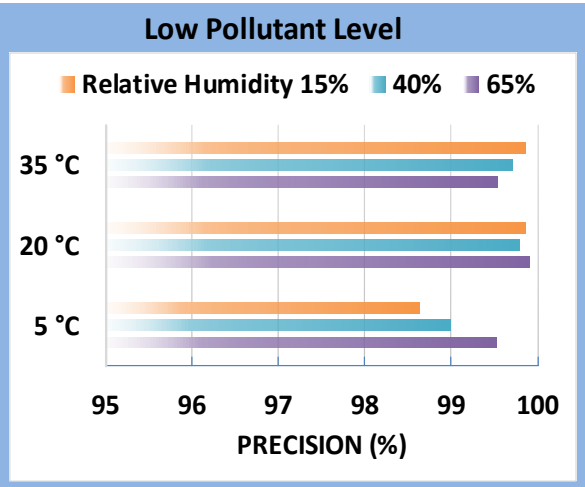
Aeroqual AQY Data Recovery & Intra-model Variability

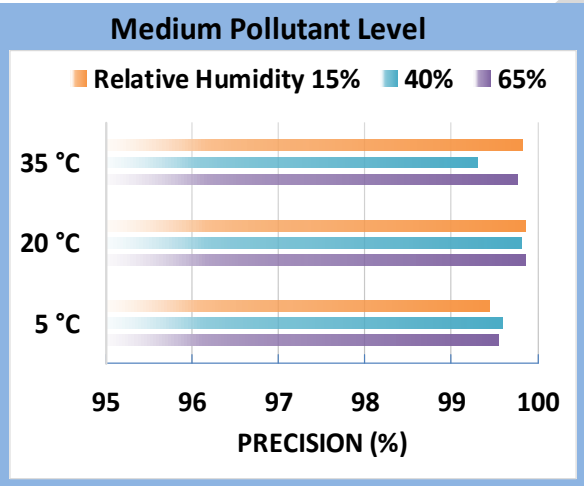
- Data recovery for all three Aeroqual AQY units was 100%.

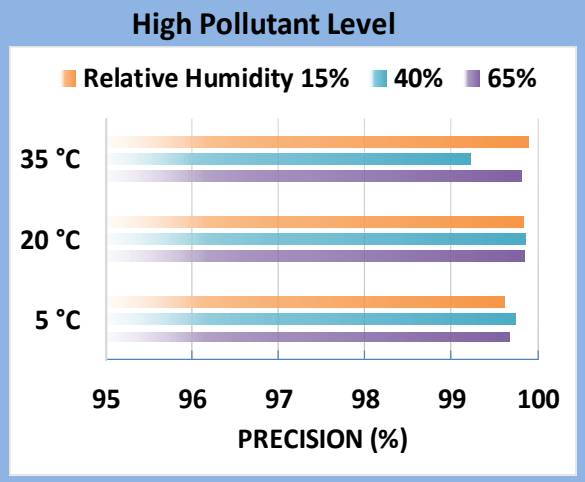
- Low to moderate ozone measurement variations are observed for the three Aeroqual AQY units at 20 °C and 40% RH

Aeroqual AQY Precision (Ozone; 1-min mean)

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

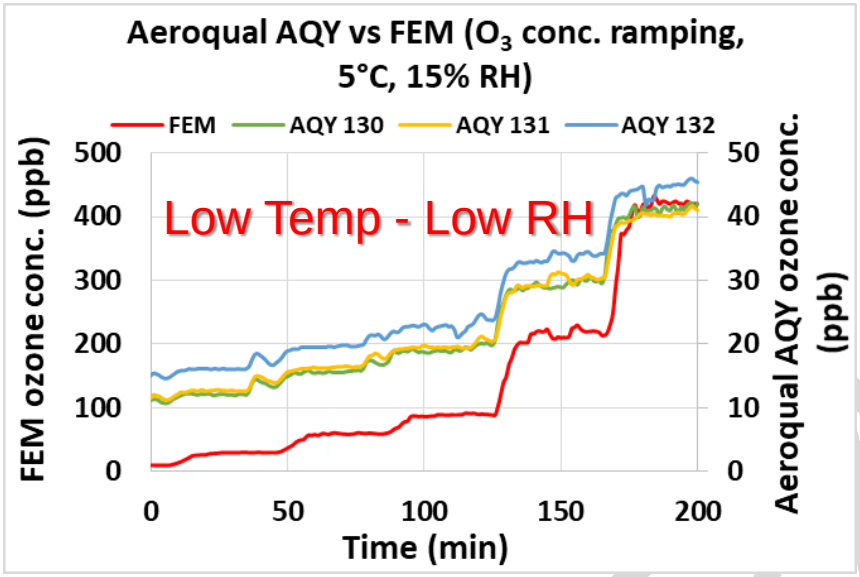


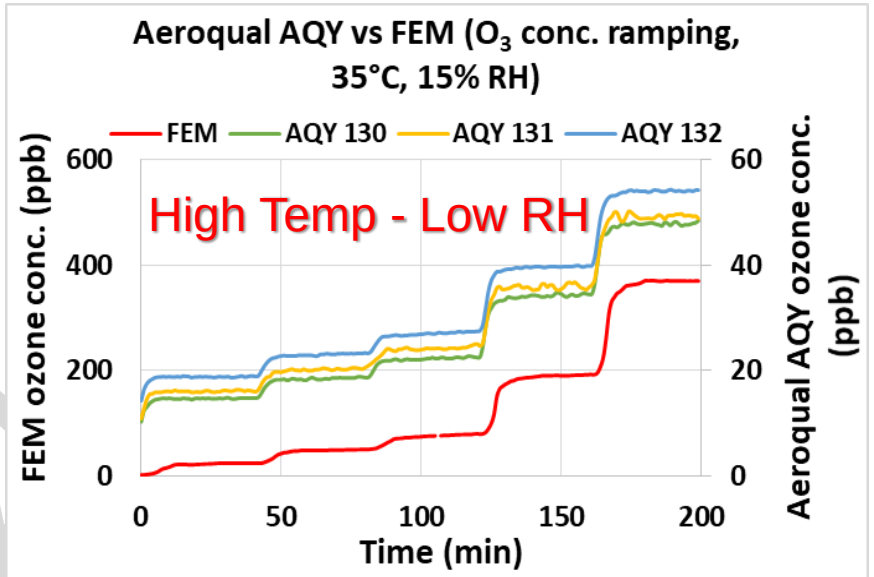


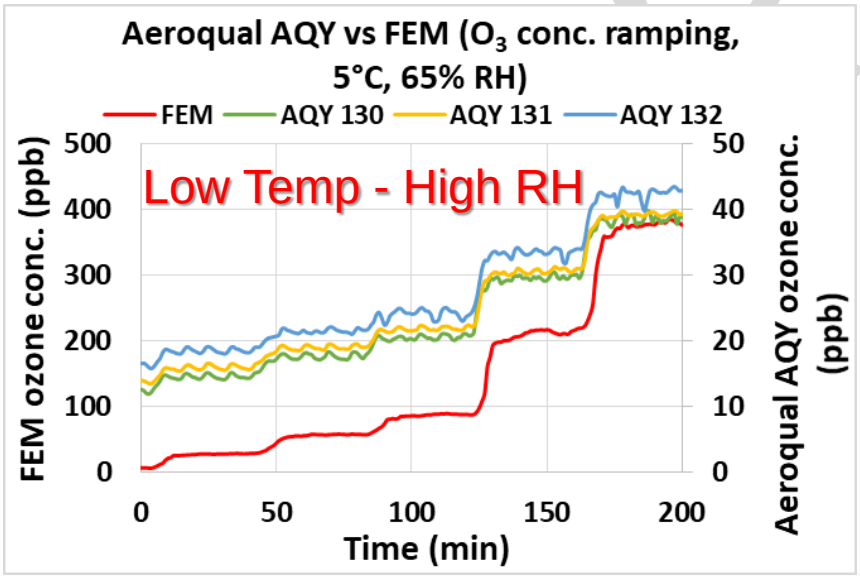


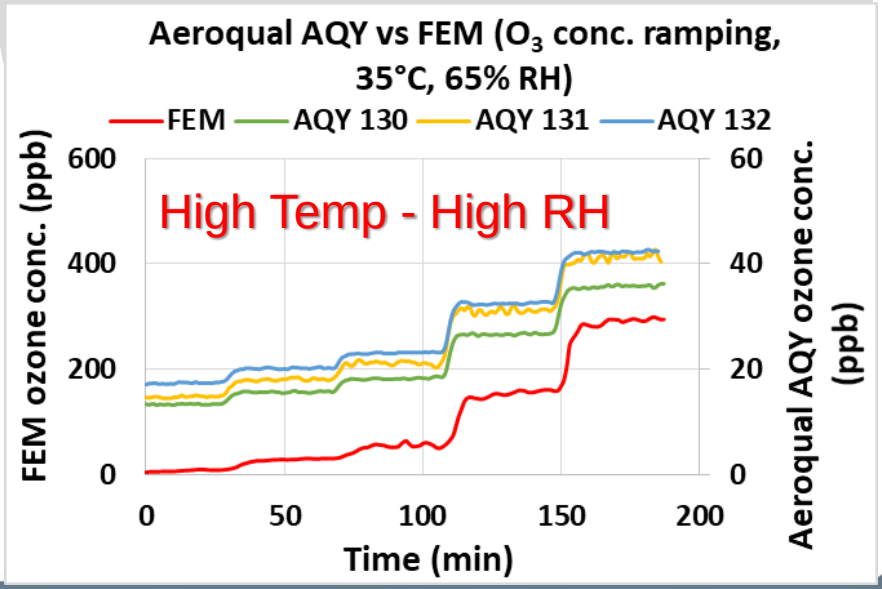
- Overall, the three Aeroqual AQY sensors showed high precision for all combinations of low, medium and high ozone conc., T, and RH.
- FEM's precision was also high across all conditions

Aeroqual AQY Climate Susceptibility

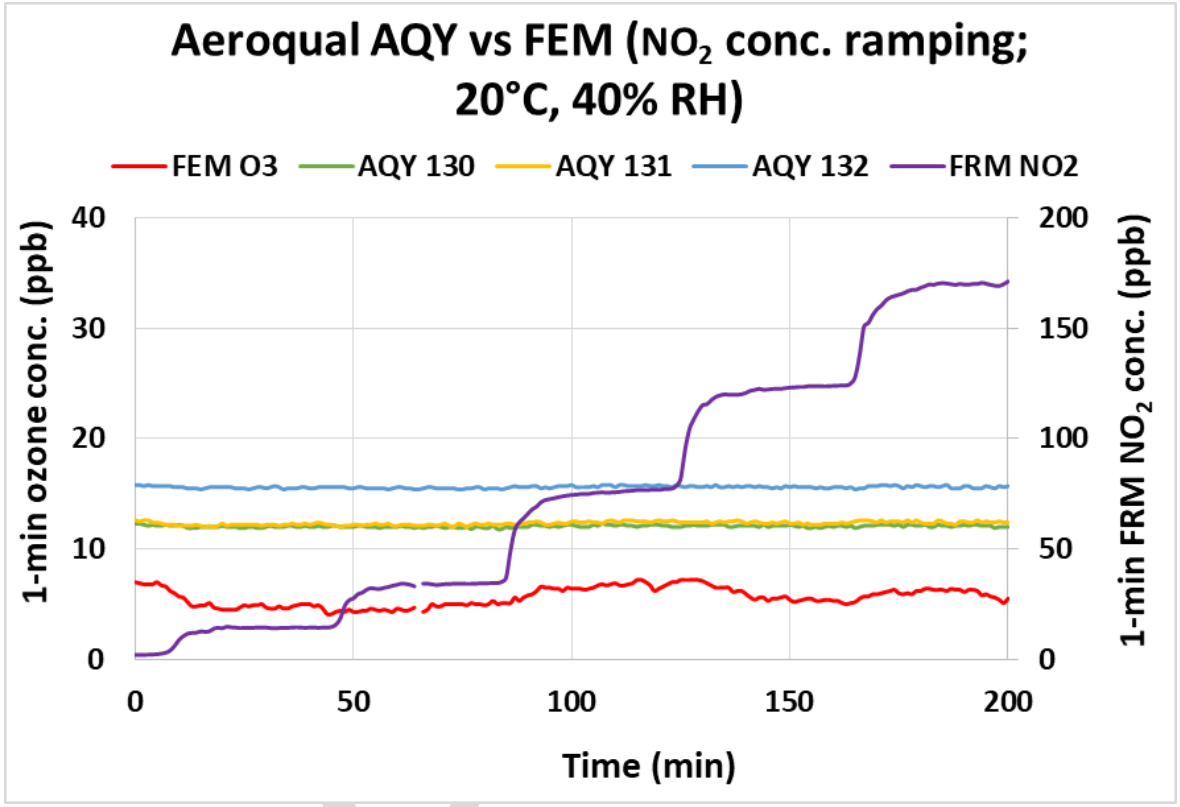








NO_2 Interferent (1-min mean)



In the laboratory, the effect of NO_2 interferent was evaluated by exposing sensors to increasing concentrations of NO_2 at 20 °C and 40% RH. As shown in the figure, both the FEM and Aeroqual AQY O_3 measurements were not affected by the NO_2 interferent and maintained their baseline readings throughout the NO_2 concentration ramping from 0 to ~ 150 ppb.

Discussion: Ozone

- **Accuracy**: The three Aeroqual AQYs showed low to high accuracy compared to the FEM at 20 °C and 40% RH. Accuracy ranges from 11.4% to 79.0%. (refer to slide 6).
- **Precision**: The three Aeroqual AQY sensors exhibited high precision during all tested conditions (ozone concentration, T and RH). (refer to slide 7)
- **Intra-model variability**: Low to moderate ozone measurement variations were observed among the three Aeroqual AQY sensors at 20 °C and 40% RH. (refer to slide 6)
- **Data recovery**: Data recovery for ozone measurements was 100% for all units. (refer to slide 6)
- **Baseline:** Under various T/RH conditions, the FEM ozone instrument baseline was close to zero, while the sensors' baseline was around 9 -14 ppb.
- **Coefficient of Determination**: The Aeroqual AQY sensors showed very strong correlation/linear response with the corresponding the FEM ozone measurement data (R^2 ~ 0.97) (refer to slide 5)
- **Interferent:** The Aeroqual AQY sensors were inert to NO_2 at 20 °C and 40% RH. When NO_2 was increased from 0 to 150 ppb, the sensors maintained their baseline readings.
- **Climate susceptibility**: During the lab studies, temperature and relative humidity had little effect on ozone concentrations as recorded by the Aeroqual AQY sensors.

NO_2

1. FRM NO_2 vs Aeroqual AQY NO_2
2. Accuracy, data recovery & Intra-model variability
3. Precision
4. Climate susceptibility
5. O_3 Interferent
6. Discussion

NO_2 Data Handling

During the AQ-SPEC field evaluation, Aeroqual corrected and calculated NO_2 in all units, using two different approaches:

1st approach (in this report, pollutant referred to as NO_2):

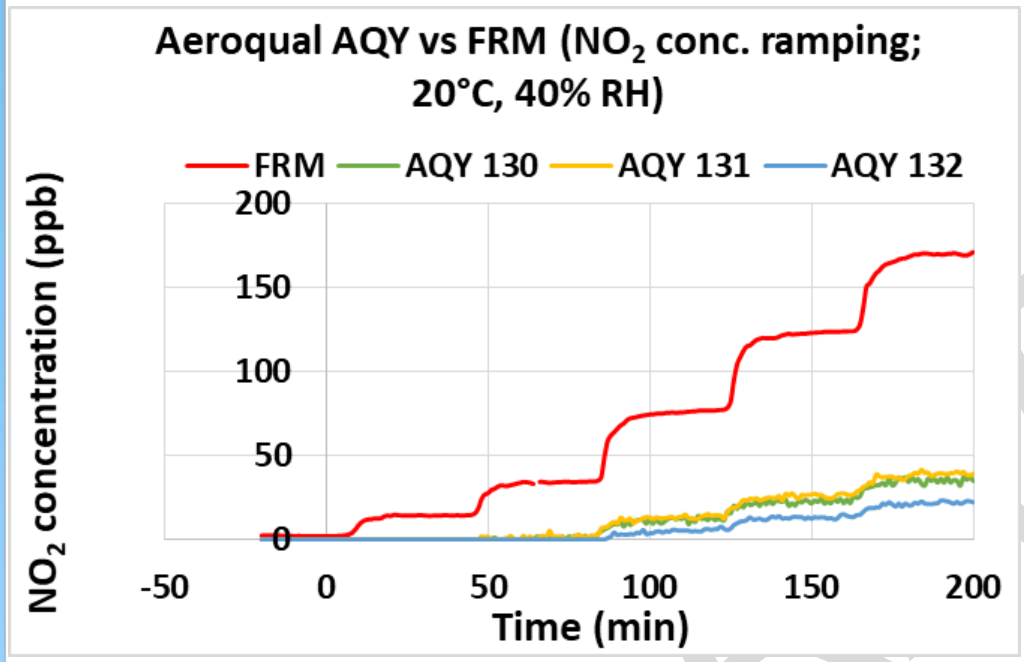
- Correction based on AQY Ozone data in real-time
- Calculation by Aeroqual algorithm

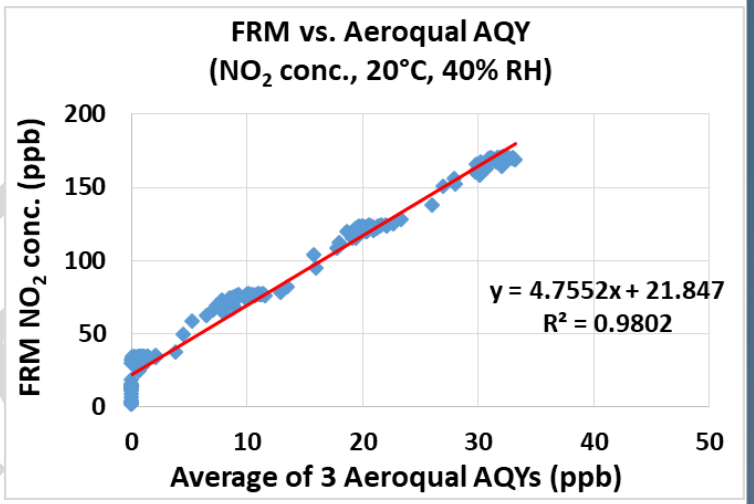
2nd approach (in this report, pollutant referred to as NO_2 V2)

- Correction based on AQY Ozone and AQY RH data in real-time
- Calculation by new Aeroqual algorithm

- To better assist in understanding the procedures mentioned above, Aeroqual has shared all relevant proprietary information with AQ-SPEC
- The same data handling procedures were used during the lab evaluation

Aeroqual AQY vs FRM (NO_2; 1-min mean)





** Note the scale of the x and y axis is different*

- The FRM instrument reported baseline values of ~ 2 ppb and the Aeroqual AQY sensors reported baseline values of 0 ppb as the FRM measurement increased from 0-30 ppb
- The three Aeroqual AQY sensors tracked the concentration variations recorded by the FRM instrument at higher NO_2 concentration but did not tack concentration change below 30 ppb
- Aeroqual AQY sensors underestimated the NO_2 concentration as recorded by the FRM instrument

- The Aeroqual AQY sensors showed very strong correlations with the FRM NO_2 conc. (R^2 > 0.98)

Aeroqual AQY Accuracy: (NO_2; 1-min mean)

- Accuracy (20 °C and 40% RH)

Steady State (#)	Sensor mean (ppb)	FRM (ppb)	Accuracy (%)
1	N/A	14.4	N/A
2	0.9	34.1	2.6
3	10.2	75.9	13.4
4	20.6	123.0	16.7
5	32.2	170.0	18.9

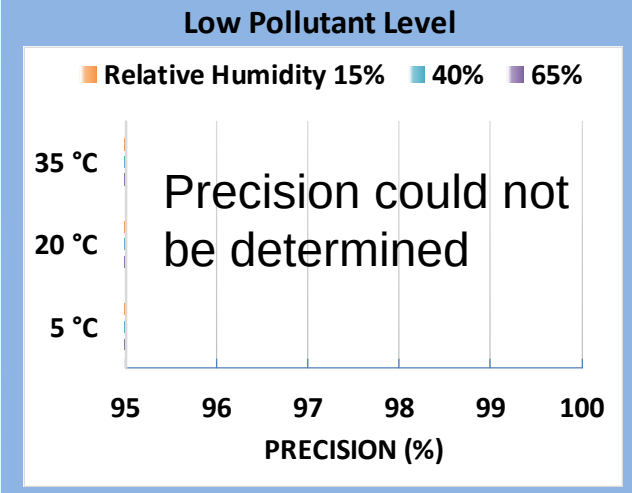
- The three Aeroqual AQY units showed low accuracy compared to the FRM at 20 °C and 40% RH. Accuracy ranged from 2.6 to 19% with increasing NO_2 concentration.

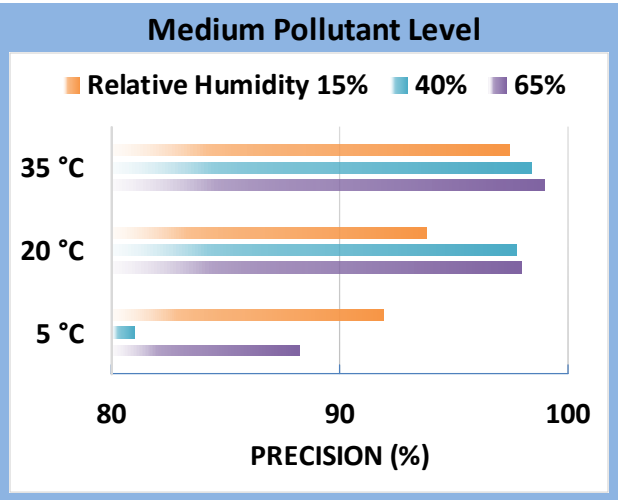
Aeroqual AQY Data Recovery & Intra-model Variability

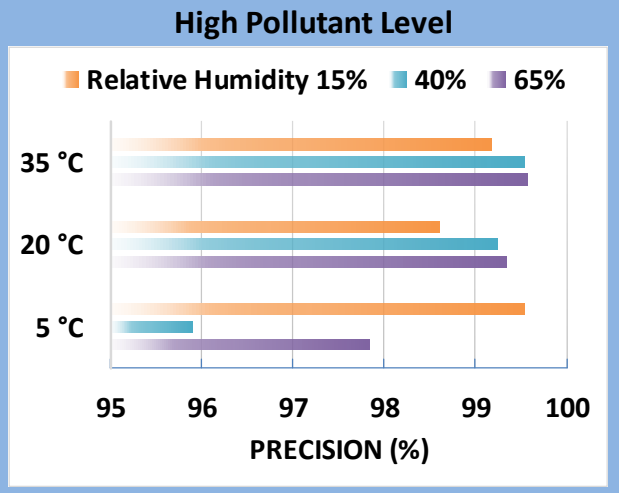
- Data recovery for all three Aeroqual AQY units was 100%.
- High NO_2 measurement variations among the Aeroqual AQY sensors at 20 °C and 40% RH at medium and high. Intra-model variability could not be determined at low NO_2 concentrations

Precision: Aeroqual AQY (NO_2; 1-min mean)

- Precision (Effect of NO_2 conc., temperature and relative humidity)

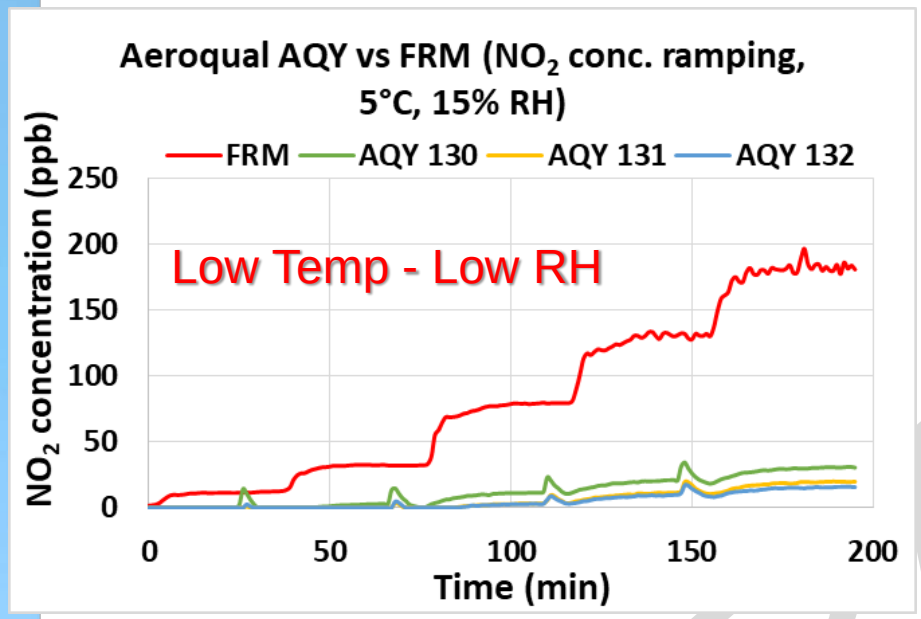


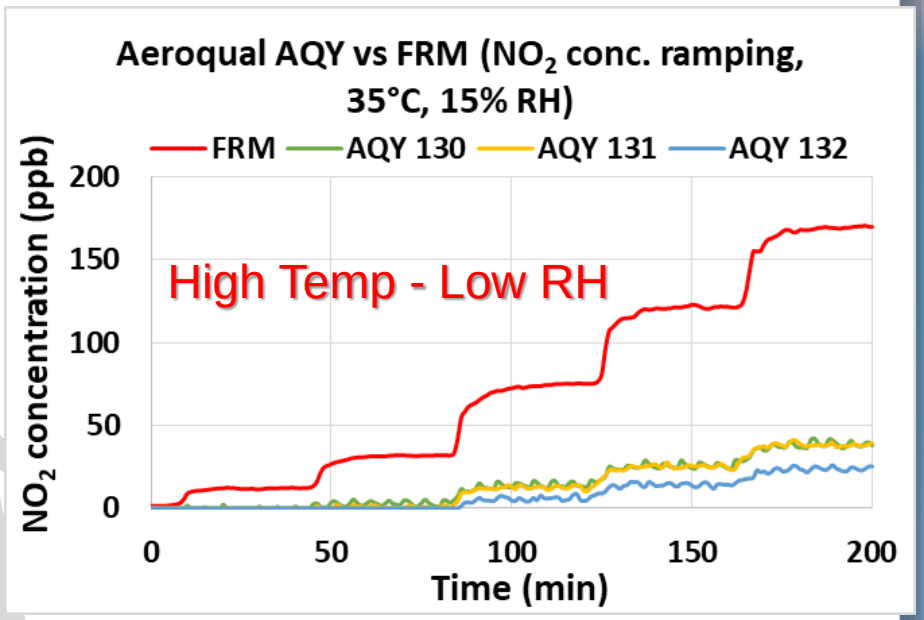


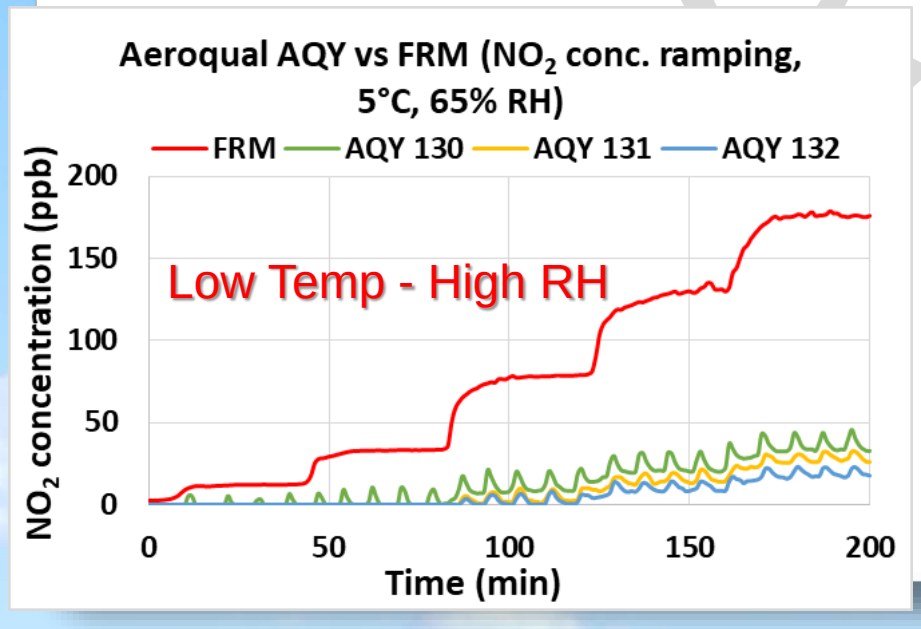


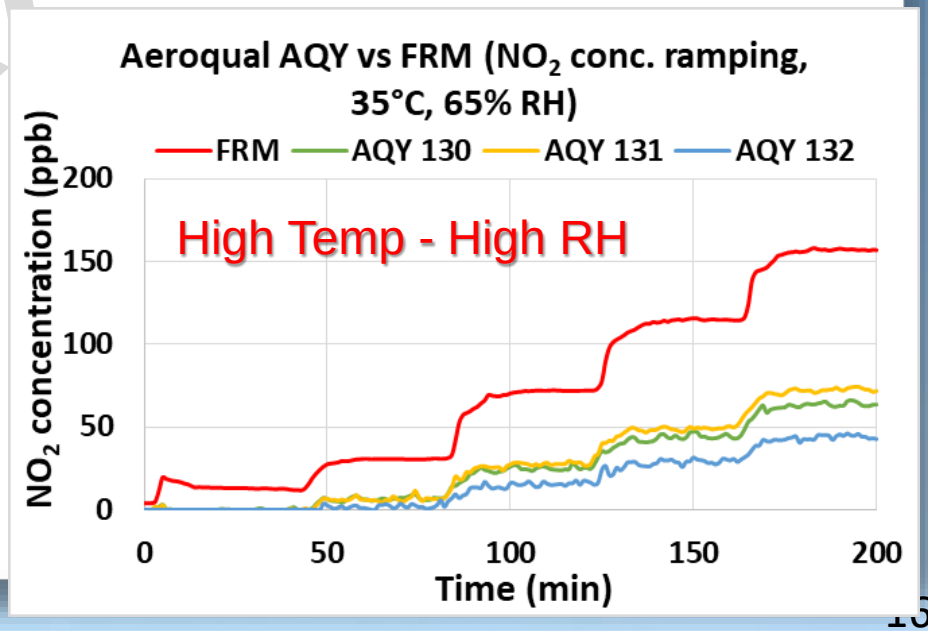
- Overall, precision of the three Aeroqual AQY units at low NO_2 concentrations for all conditions could not be determined due to the sensors consistently reporting 0 ppb values
- Moderate to high precisions were observed for all combinations of medium and high NO_2 conc., T, and RH.
- FRM's precision was also high across all conditions.

Aeroqual AQY Climate Susceptibility

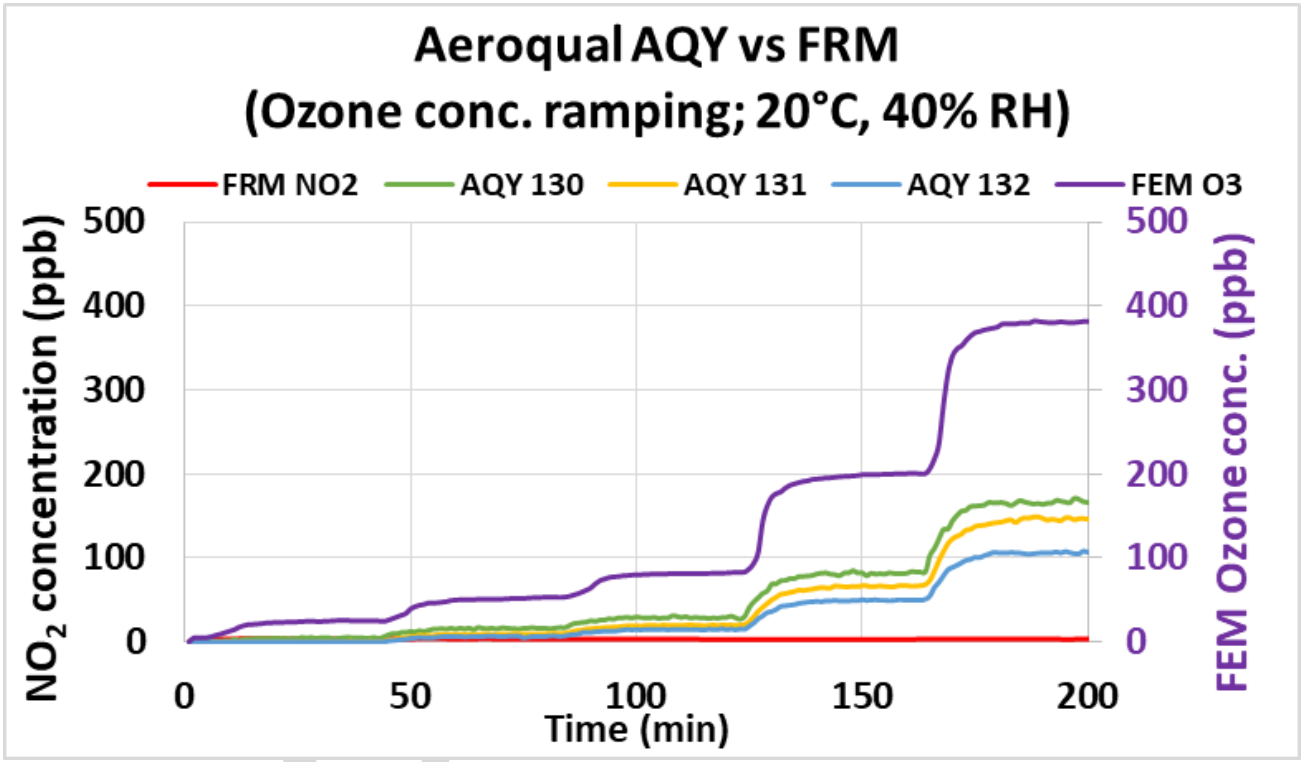








O_3 Interferent (NO_2;1-min mean)



In the laboratory, the effect of O_3 interferent was evaluated by exposing sensors to increasing O_3 concentrations at 20 °C and 40% RH. As shown in the figure, the FRM NO_2 measurements maintained their baseline readings throughout the O_3 concentration ramping from 0 to ~ 400 ppb while the Aeroqual AQY sensors showed increasing NO_2 concentrations as O_3 interferent concentration increased from 0 to ~ 400 ppb.

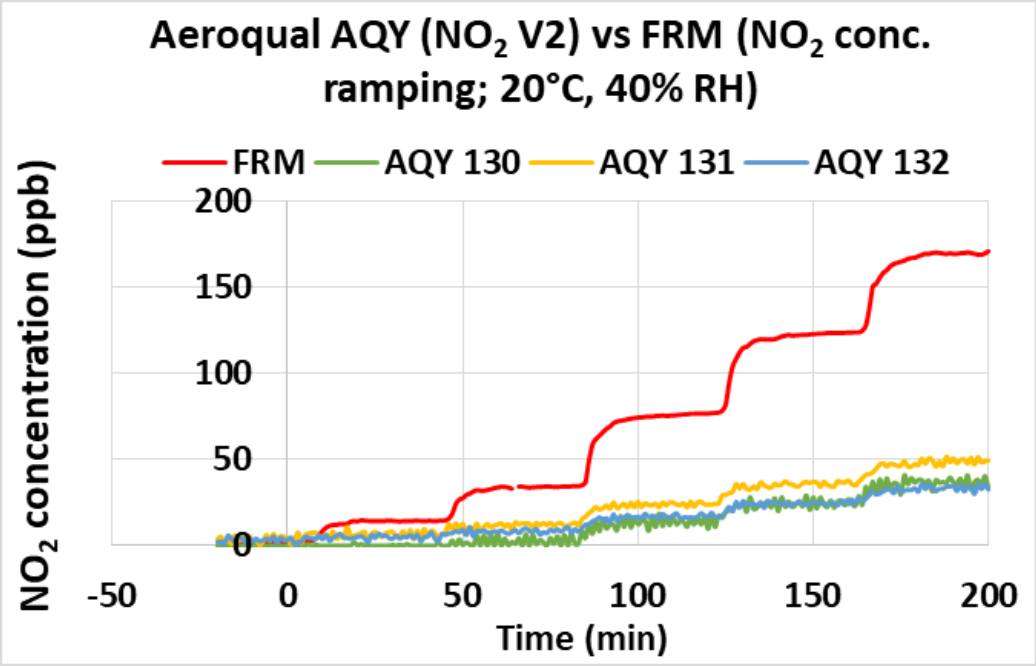
Discussion: NO_2

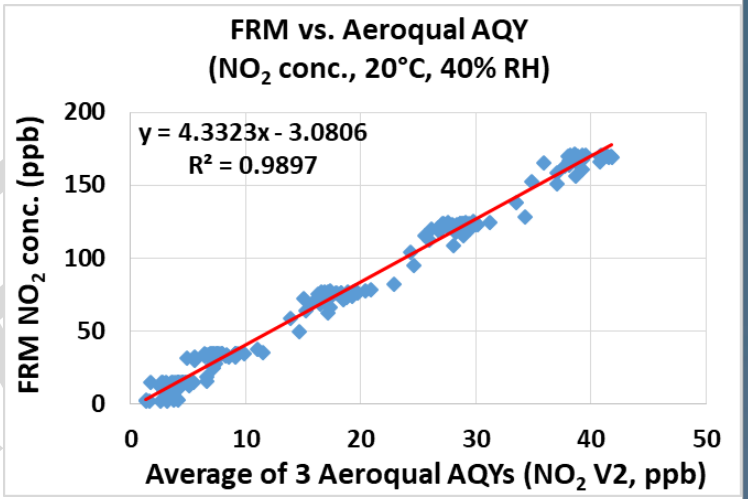
- **Accuracy**: The three Aeroqual AQYs showed low accuracy compared to the FRM at 20 °C and 40% RH. Accuracy ranged from 2.6 % to 19%. (refer to slide 14).
- **Precision**: The precision of the three Aeroqual AQY sensors could not be determined for all RH and T conditions at low concentrations. Moderate to high precisions were observed for all RH and T conditions at medium and high concentrations (refer to slide 15)
- **Intra-model variability**: High NO_2 measurement variations among the Aeroqual AQY sensors at 20 °C and 40% RH at medium and high. Intra-model variability could not be determined at low NO_2 concentrations (refer to slide 14)
- **Data recovery**: Data recovery for NO_2 measurements was 100% for all units. (refer to slide 14)
- **Coefficient of Determination**: Aeroqual AQY sensors showed very strong correlation/linear response with the corresponding FRM NO_2 measurement data at 20 °C and 40% RH ($R^2 > 0.98$) (refer to slide 13)
- **Interferent:** Ozone had shown to interfere with the NO_2 measurements recorded by the Aeroqual AQY sensors at 20 °C and 40% RH. The NO_2 concentration measured by the sensors increased as the ozone concentrations increased from 0 to ~400 ppb. (refer to slide 17)
- **Climate susceptibility**: During the lab studies, the Aeroqual AQY sensors showed cyclic peaks at low temperature at all relative humidity. (refer to slide 16)

NO_2 (V2)

1. FRM NO_2 vs Aeroqual AQY NO_2
2. Accuracy, data recovery & Intra-model variability
3. Precision
4. Climate susceptibility
5. O_3 Interferent
6. Discussion

Aeroqual AQY vs FRM (NO_2 V2; 1-min mean)





** Note the scale of the x and y axis is different*

- The FRM instrument reported baseline values of ~ 2 ppb and the Aeroqual AQY130 sensor reported baseline values ~ 0 ppb and AQY 131 and AQY 132 reported baseline values ranging between 0 - 7 ppb
- The Aeroqual AQY sensors tracked the concentration variations recorded by the FRM instrument.
- The Aeroqual AQY sensors underestimated the NO_2 concentrations as recorded by the FRM instrument

- Three Aeroqual AQY sensors showed very strong correlations with the FRM NO_2 conc. (R^2 > 0.98)

Aeroqual AQY Accuracy: (NO_2 V2, 1-min mean)

- Accuracy (20 °C and 40% RH)

Steady State (#)	Sensor mean (ppb)	FRM (ppb)	Accuracy (%)
1	4.0	14.4	27.5
2	7.7	34.1	22.7
3	18.3	75.9	24.1
4	28.5	123.0	23.1
5	39.8	170.0	23.4

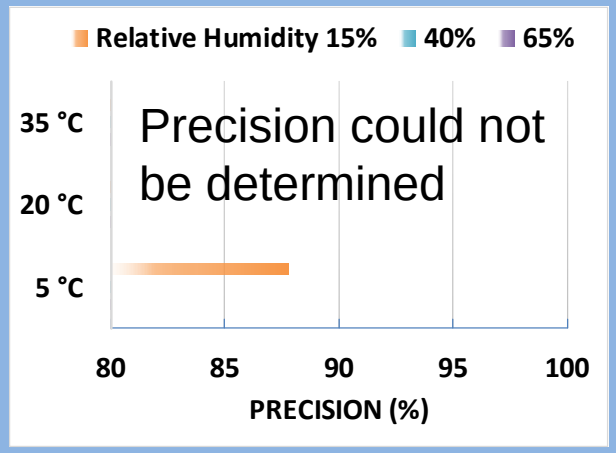
- The three Aeroqual AQY sensors showed low accuracy compared to the FRM at 20 °C and 40% RH. Accuracy ranged from 22 to 27%.

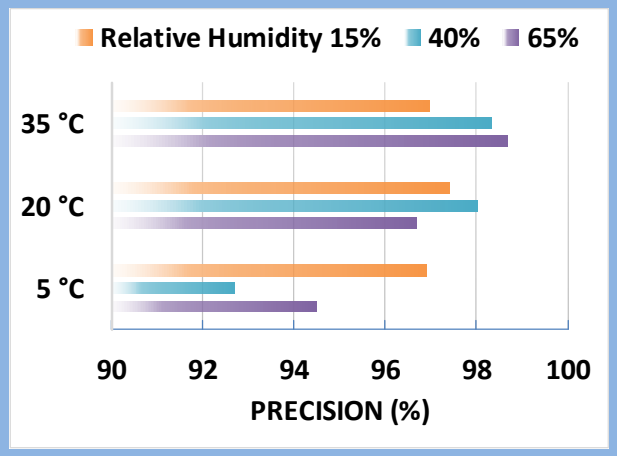
Aeroqual AQY Data Recovery & Intra-model Variability

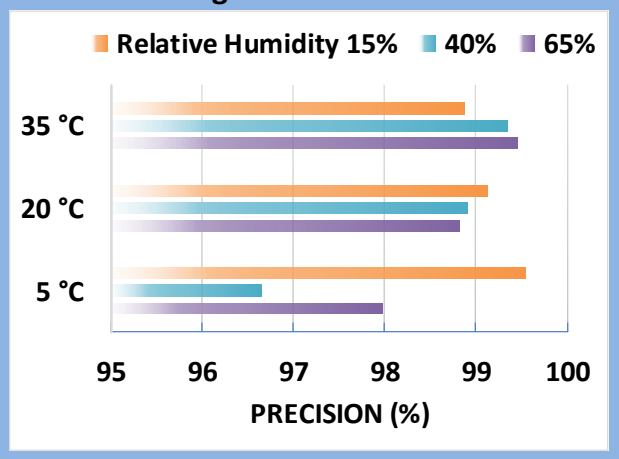
- Data recovery for all three Aeroqual AQY units was 100%.
- High NO_2 measurement variations among the Aeroqual AQY sensors at 20 °C and 40% RH at medium and high. Intra-model variability could not be determined at low NO_2 concentrations

Precision: Aeroqual vs FRM (NO_2 V2; 1-min mean)

- Precision* (Effect of NO_2 conc.,temperature and relative humidity)

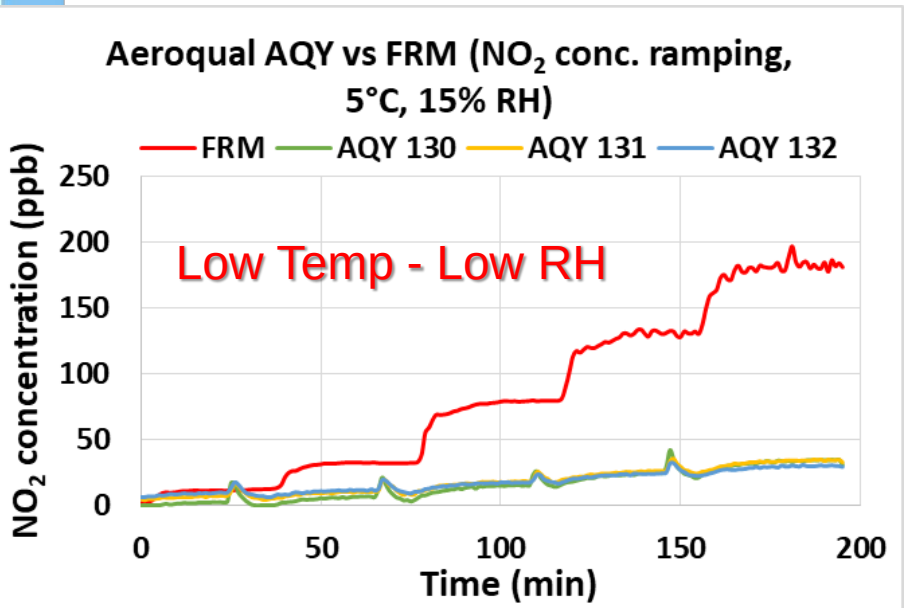


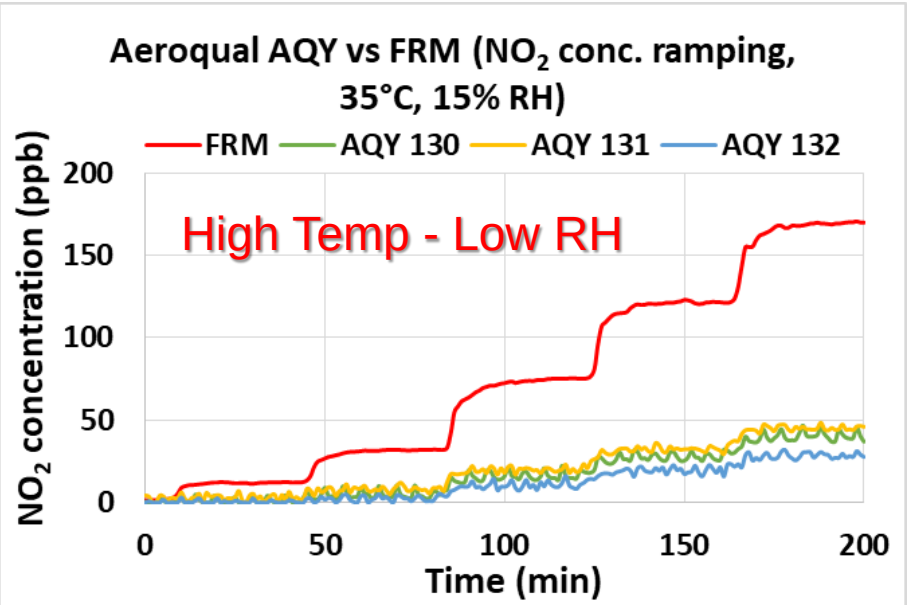


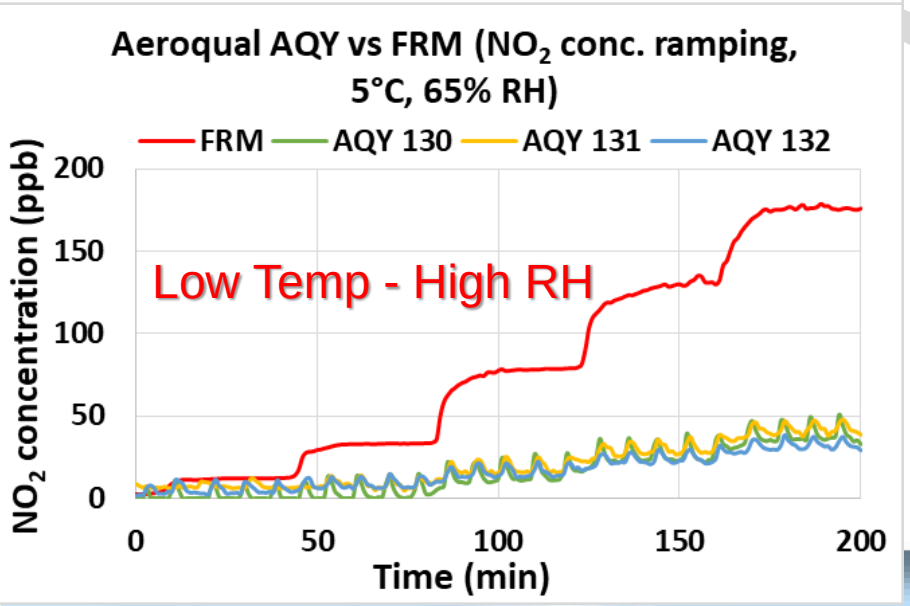


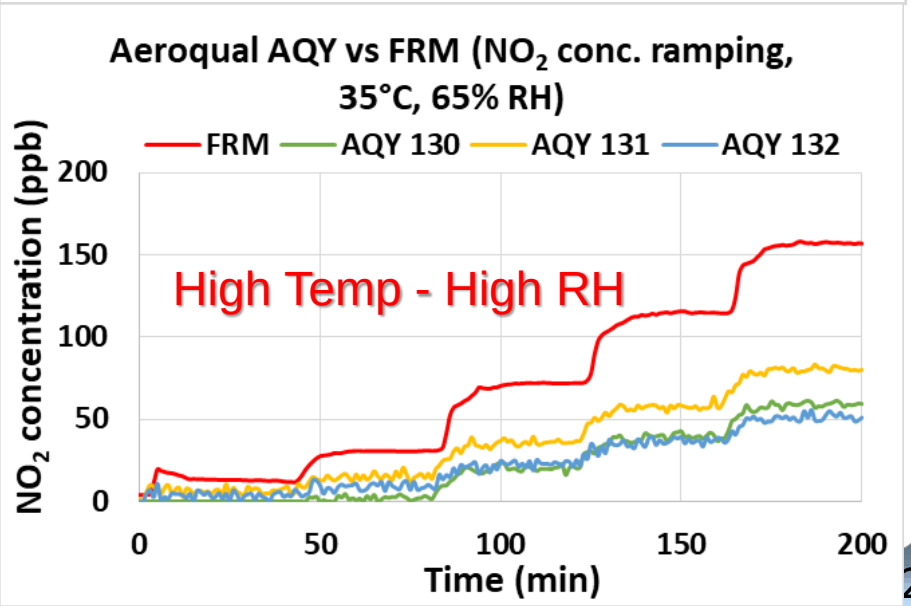
- Overall, precision of the three Aeroqual AQY sensors at low NO_2 V2 concentrations for all conditions could not be determined due to AQY 130 consistently reporting 0 ppb values
- High precisions are observed for all combinations of medium and high NO_2 conc., T, and RH.
- FRM's precision was also high across all conditions.

Aeroqual AQY Climate Susceptibility

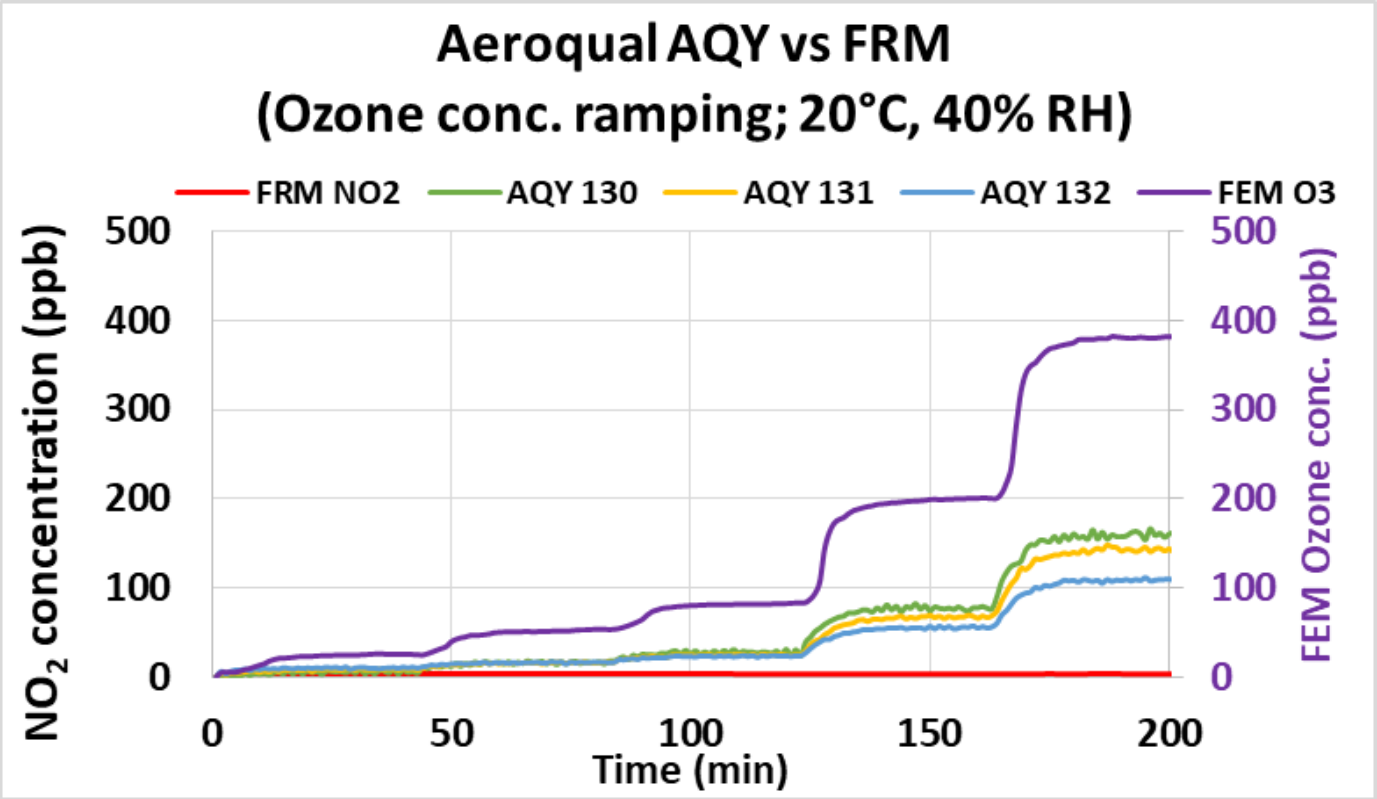








O_3 Interferent (NO_2 V2; 1-min mean)



In the laboratory, the effect of O_3 interferent was evaluated by exposing sensors to increasing concentrations of O_3 at 20 °C and 40% RH. As shown in the figure, the FRM NO_2 maintained their baseline readings throughout the O_3 concentration ramping from 0 to ~ 400 ppb while the Aeroqual AQY sensors showed increasing NO_2 concentrations as O_3 interferent concentration increased from 0 to ~ 400 ppb.

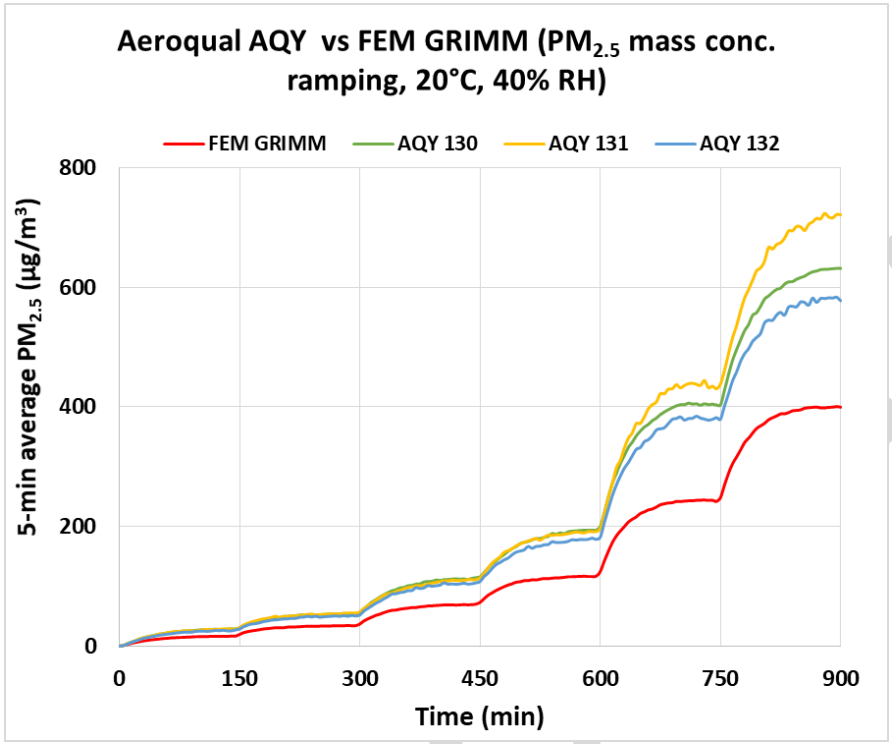
Discussion: NO_2 V2

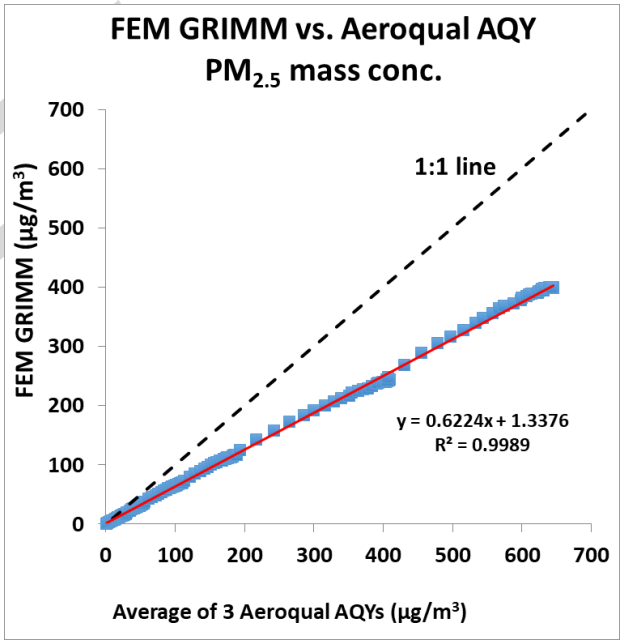
- **Accuracy**: The three Aeroqual AQYs showed low accuracy compared to the FRM at 20 °C and 40% RH. Accuracy ranged from 23 % to 27%. (refer to slide 21).
- **Precision**: Precision of the three Aeroqual AQY sensors at low NO_2 concentrations for all conditions could not be determined. The three Aeroqual AQY sensors exhibited high precision for all RH and T condition at medium and high concentrations (refer to slide 22)
- **Intra-model variability**: High NO_2 measurement variations were observed among the Aeroqual AQY sensors at 20 °C and 40% RH at medium and high. Intra-model variability could not be determined at low NO_2 concentrations (refer to slide 21)
- **Data recovery**: Data recovery for NO_2 measurements was 100% for all units. (refer to slide 21)
- **Coefficient of Determination**: Aeroqual AQY sensors showed very strong correlation/linear response with the corresponding FRM NO_2 measurement data ($R^2 > 0.98$) (refer to slide 20)
- **Interferent:** The ozone interferent interfered with the NO_2 measurements recorded by the Aeroqual AQY sensors at 20 °C and 40% RH and the NO_2 concentration measured by the sensors increased in the same manner as ozone as the ozone interferent concentration increased from 0 to ~400 ppb (refer to side 24)
- **Climate susceptibility**: During the lab studies, the Aeroqual AQY sensors showed cyclic peaks at low temperature at all relative humidity. (refer to slide 23)

$PM_{2.5}$

1. FEM GRIMM $PM_{2.5}$ vs Aeroqual AQY $PM_{2.5}$
2. Accuracy, data recovery & Intra-model variability
3. Precision
4. Climate susceptibility
5. Discussion

Aeroqual AQY vs FEM GRIMM ($PM_{2.5}$ mass; 5-min mean)





- The three Aeroqual AQYsensors tracked well with the concentration variations recorded by FEM GRIMM
- Aeroqual AQY sensor overestimated the FEM GRIMM $PM_{2.5}$ mass concentrations

- Three Aeroqual AQY sensors showed very strong correlations with FEM GRIMM $PM_{2.5}$ mass conc. ($R^2 > 0.99$)

Accuracy: Aeroqual AQY vs FEM ($PM_{2.5}$; 1-min mean)

- Accuracy (20 °C and 40% RH)

Steady State (#)	Sensor Mean (µg/m³)	FEM GRIMM (µg/m³)	Accuracy (%)
1	28.2	17.0	34.6
2	50.1	34.7	55.6
3	109.6	69.8	42.9
4	188.0	117.0	39.4
5	407.0	244.0	33.2
6	581.4	366.5	41.4

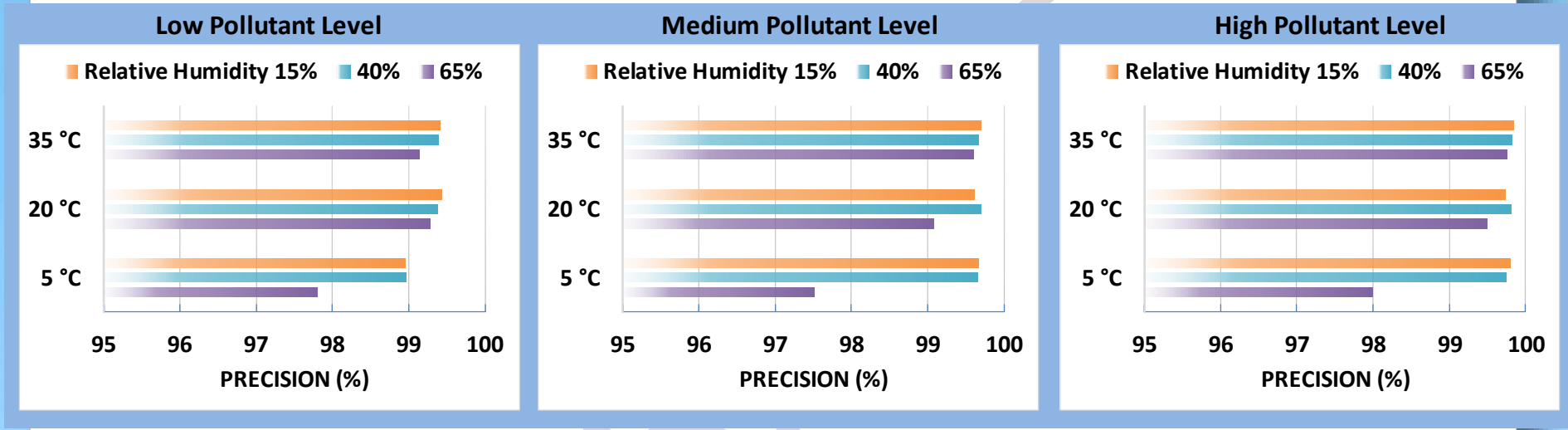
- The three Aeroqual AQY units showed low to moderate accuracy compared to the FEM at 20 °C and 40% RH. Accuracy ranged from 33 to 55%.

Aeroqual AQY Data Recovery & Intra-model Variability

- Data recovery for all three Aeroqual AQY units was 100%.
- Low $PM_{2.5}$ measurement variations among the Aeroqual AQY sensors at 20 °C and 40% RH

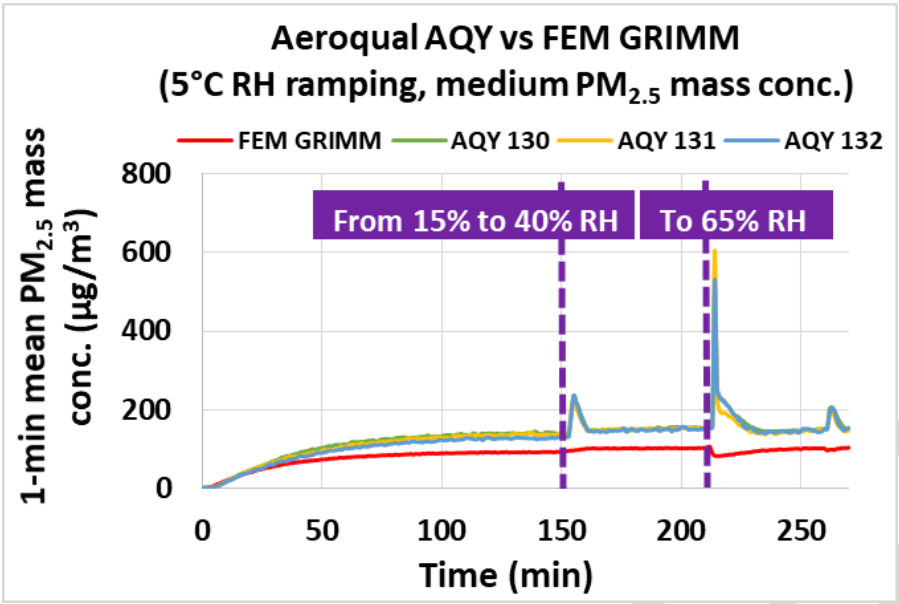
Aeroqual AQY vs FEM GRIMM ($PM_{2.5}$; 1-min mean)

- Precision (Effect of $PM_{2.5}$ conc.,Temperature and Relative Humidity)



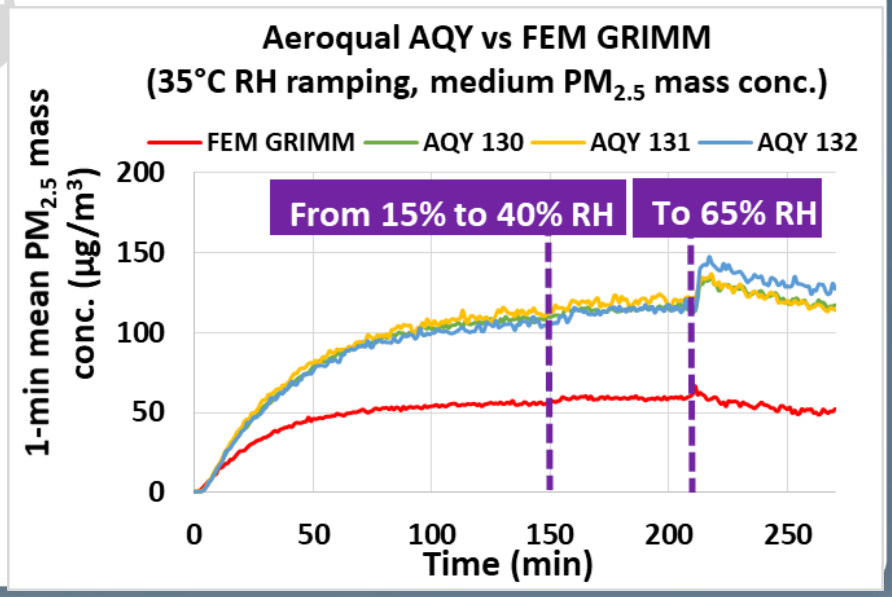
- Overall, the three Aeroqual AQY sensors showed high precision for all combinations of low, medium and high $PM_{2.5}$ conc., T, and RH.
- FEM GRIMM also showed high precisions at all combinations of low, medium and high high $PM_{2.5}$ conc., T, and RH.

Aeroqual AQY Climate Susceptibility



Low Temp – RH ramping
(medium conc.)

High Temp – RH ramping
(medium conc.)



Discussion $PM_{2.5}$

- **Accuracy**: Overall, the three Aeroqual AQY sensors have low to moderate accuracy, compared to FEM GRIMM $PM_{2.5}$ in the range of 0 to 400 µg/m^3. Aeroqual AQY sensors overestimate FEM GRIMM's reading in the laboratory experiments. (refer to slide 28)
- **Precision**: The Aeroqual AQY sensors showed high precision for almost all test combinations (PM concentrations, T and RH) (refer to slide 29)
- **Intra-model variability**: low intra-model variability was observed among the three Aeroqual AQY sensors. (refer to slide 28)
- **Data Recovery:** Data recovery for $PM_{2.5}$ mass concentration was 100% for all units tested. (refer to slide 28)
- **Coefficient of Determination**: The three Aeroqual AQY sensors showed very strong correlation/linear response with the corresponding FEM GRIMM $PM_{2.5}$ measurement data ($R^2 > 0.99$) for mass concentration range between 0 and 400 µg/m^3. (refer to slide 27)
- **Climate susceptibility**: For most of the temperature and relative humidity combinations, the climate condition had minimal effect on the Aeroqual AQY's precision. Aeroqual AQY sensors had some spikes at the set-points of RH changes at all PM concentrations (refer to slide 30)