

Laboratory Evaluation

PurpleAir PA-II PM Sensor



Background

Three **PurpleAir PA-II** sensors that were previously evaluated for their performance in the field (deployment period: 12/08/2016 to 01/26/2017) under ambient environmental conditions, have now been evaluated in the South Coast AQMD Chemistry Laboratory under controlled artificial aerosol concentration/size range, temperature, and relative humidity.

PurpleAir PA-II (3 nodes tested):

- Particle sensors (**optical; non-FEM**) (model PMS 5003; *two identical sensors per node*)
- Each sensor reports: PM_1 , $PM_{2.5}$, PM_{10} mass concentration ($\mu\text{g}/\text{m}^3$)
- Time resolution: 35-sec
- **Unit cost: ~\$200**
- Units IDs: Node #1 (8464a, 8464b); Node #2 (cc53a, cc53b); Node #3 (d688a, d688b)

GRIMM (ref. method for PM_1 and $PM_{2.5}$ mass):

- Optical particle counter
- **FEM $PM_{2.5}$**
- Uses proprietary algorithms to calculate PM_{10} , $PM_{2.5}$, and PM_1 mass conc. from particle number measurements
- **Cost: ~\$25,000**

TSI APS 3321 (ref. method for PM_{10} mass):

- Aerodynamic particle sizer
- Measures particles from 0.5 to 20 μm
- Uses a patented, double-crest optical system for unmatched sizing accuracy
- **Cost: ~\$50,000**

Evaluation results guideline

- PurpleAir PA-II vs GRIMM PM₁ mass concentration
- PurpleAir PA-II vs GRIMM PM_{2.5} mass concentration
- PurpleAir PA-II vs APS vs GRIMM PM₁₀ mass concentration

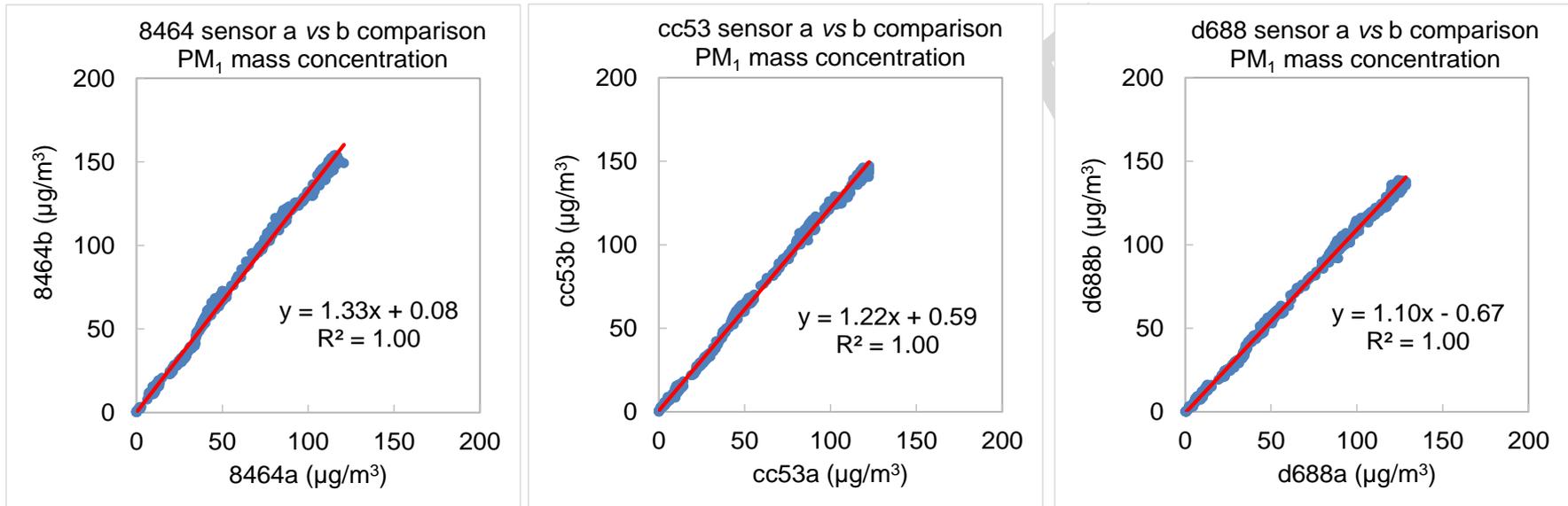


**Evaluation results for
PurpleAir PA-II PM₁ mass concentration**

PurpleAir PA-II vs GRIMM

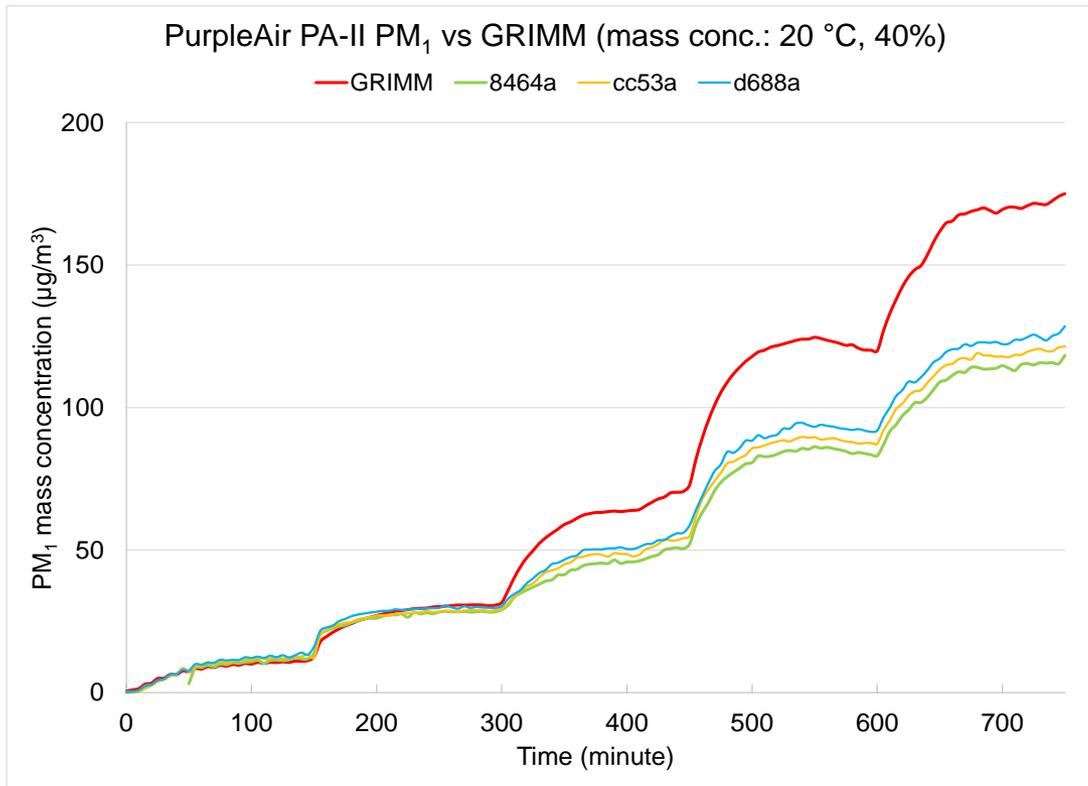
DRAFT

sensor a vs b comparison



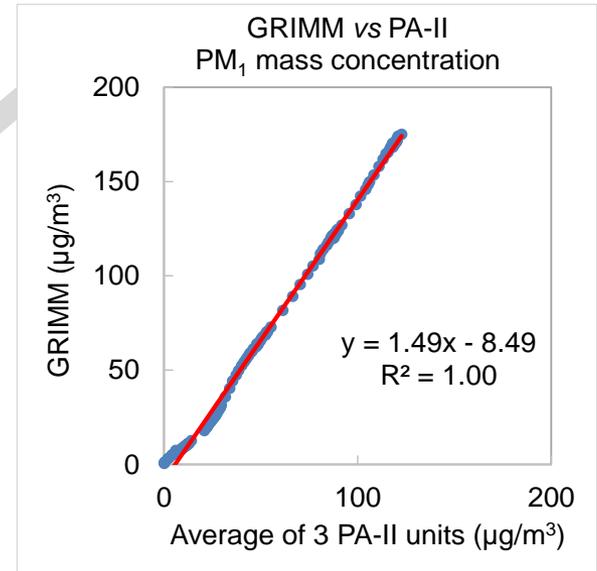
- Each PurpleAir PA-II nodes contains two identical raw sensors, denoted *a* and *b*. For a PM concentration ramping experiment, sensor *a* and sensor *b* had excellent coefficient of determination with $R^2 > 0.99$.
- However, sensor *b* reported 10-33% higher PM₁ mass concentration than sensor *a* did.
- In order to strictly follow the AQ-SPEC laboratory evaluation protocol, only data from the three *a* sensors is considered in determining evaluation parameters.

PA-II vs GRIMM (PM₁ mass; 5-min mean)



- Over the full PM₁ concentration range tested (0-175 $\mu\text{g}/\text{m}^3$), the three PA-II sensors tracked well with the concentration variation recorded by GRIMM.

Coefficient of Determination



- PA-II sensors showed very strong correlations with GRIMM PM₁ mass conc. ($R^2 > 0.99$) between 0-175 $\mu\text{g}/\text{m}^3$.
- PA-II sensors underestimated the GRIMM PM₁ mass conc.

PM₁ Accuracy: PA-II vs GRIMM

- Accuracy (20 °C and 40% RH)

Steady State (#)	Sensor mean (µg/m ³)	GRIMM (µg/m ³)	Accuracy (%)
1	12.6	11.0	85.2
2	29.0	30.7	94.5
3	53.0	69.8	76.0
4	87.9	120.8	72.7
5	120.5	172.6	69.8

- The PurpleAir PA-II sensors showed good accuracy compared to GRIMM PM₁ over the concentration range of 0-175 µg/m³ at 20 °C and 40% RH. PA-II sensors had better accuracy (85-95%) at lower PM₁ concentration (10-30 µg/m³). PurpleAir PA-II sensors' accuracy decreased to ~70% when PM₁ mass conc. was between 70-175 µg/m³.

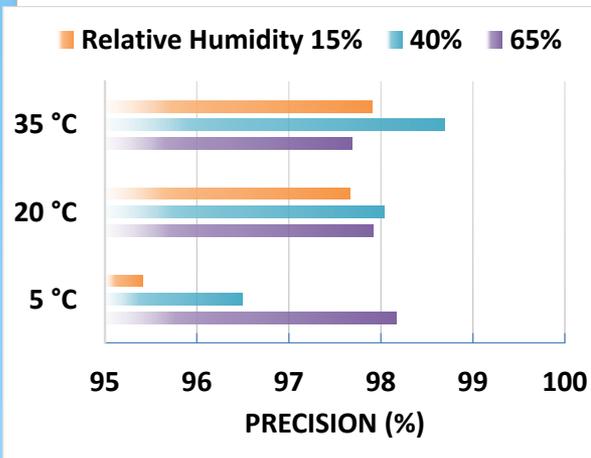
PA-II Data Recovery and Intra-model variability

- Data recovery for PM₁ mass concentration from 8464a, cc53a, and b688a were 95.9%, 96.6%, and 96.7%.
- Low PM₁ measurement variations were observed among the three PA-II units.

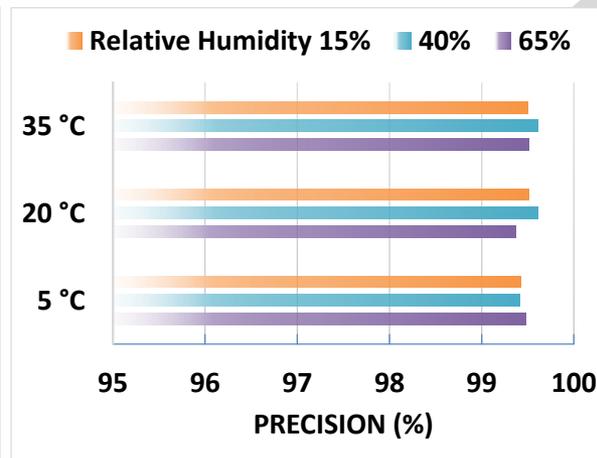
PM₁ Precision: PurpleAir PA-II

- Precision (Effect of PM₁ conc., Temperature and Relative Humidity)

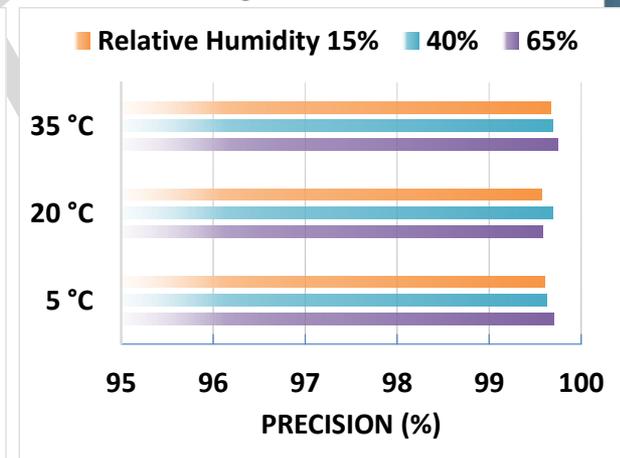
Low conc.



Medium conc.

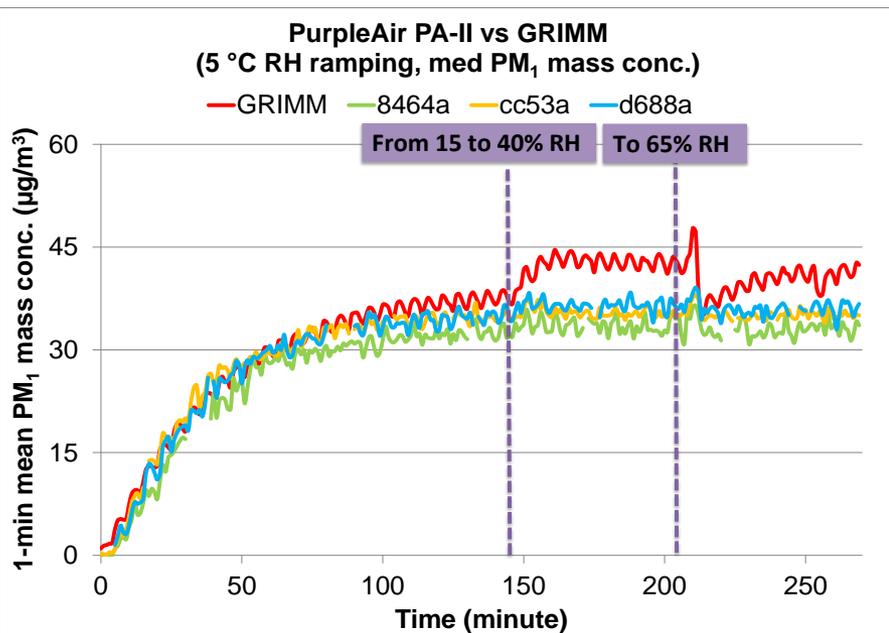


High conc.

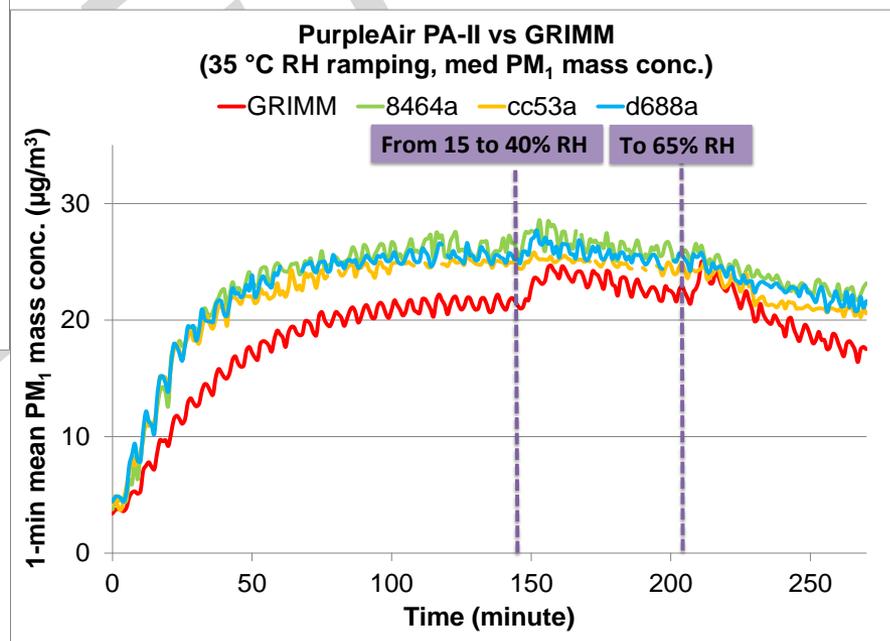


- Overall, the three PA-II sensors showed high precision for most of the combinations of low, medium and high PM₁ conc., T, and RH.
- At low PM₁ mass conc. and 5 °C/15% RH, precision was lower for both the sensors and the GRIMM.

PurpleAir PA-II Climate Susceptibility



Low Temp - RH ramping
(medium conc.)

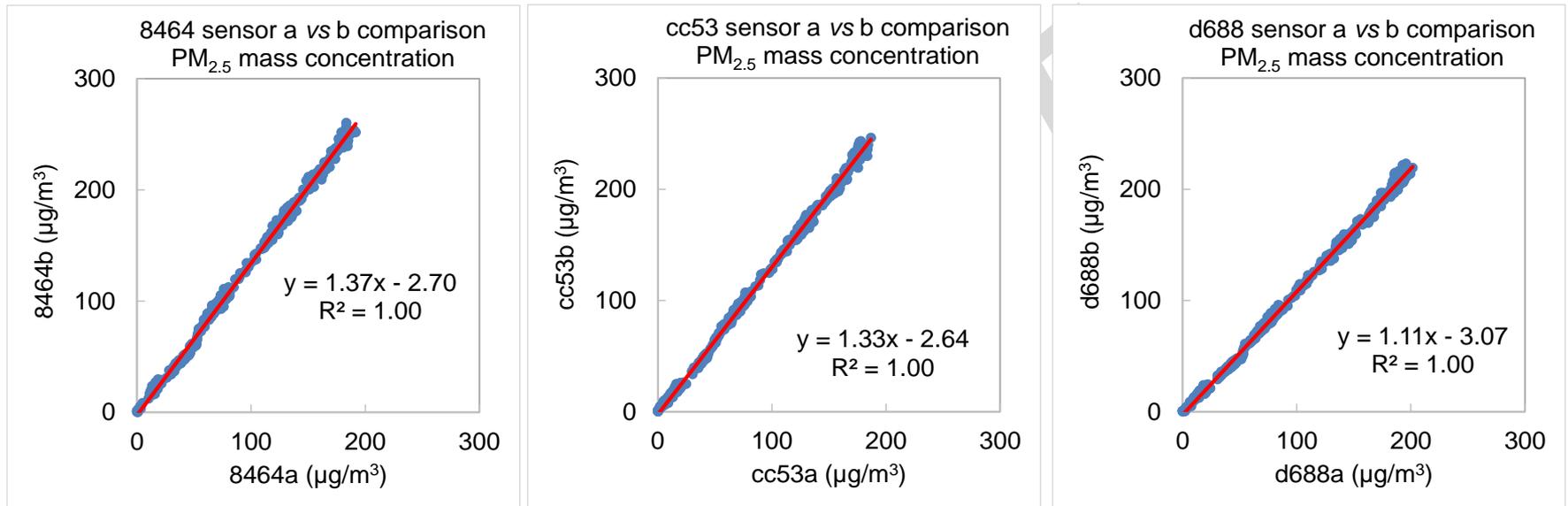


High Temp - RH ramping
(medium conc.)

**Evaluation results for
PurpleAir PA-II PM_{2.5} mass concentration**

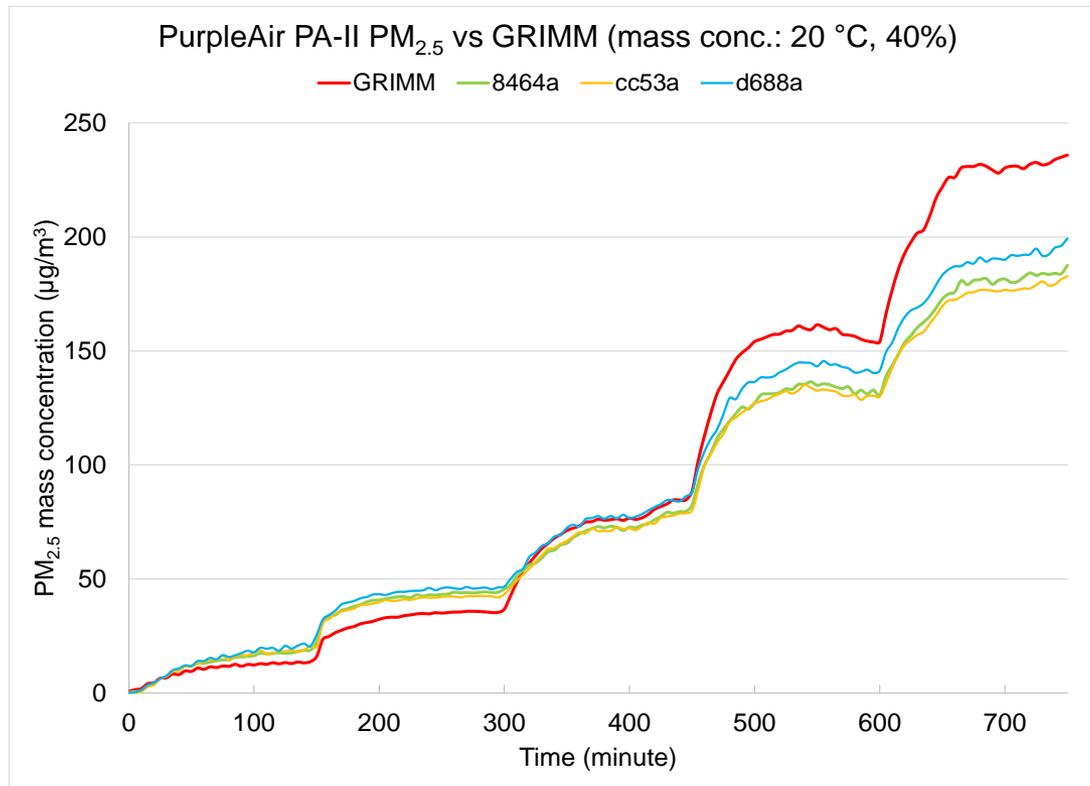
PurpleAir PA-II vs FEM GRIMM

sensor a vs b comparison



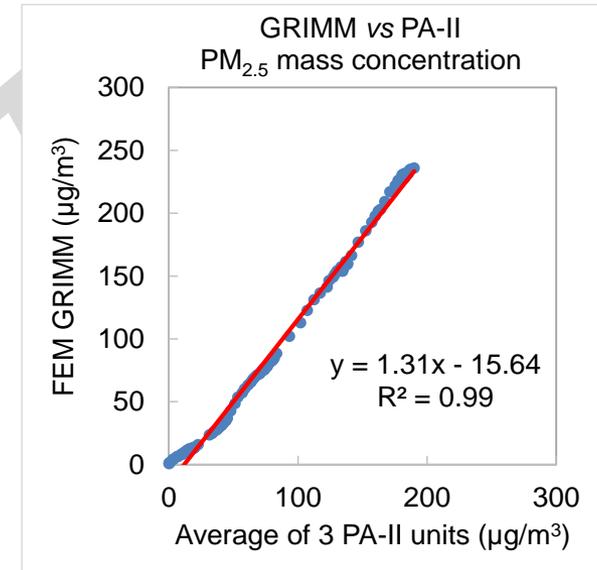
- PurpleAir PA-II contains two raw sensors in each unit, denoted *a* and *b*. For a PM concentration ramping experiment, sensor *a* and sensor *b* had excellent coefficient of determination with $R^2 > 0.99$.
- However, sensor *b* reported 11-37% higher PM_{2.5} mass concentration than sensor *a* did.
- In order to strictly follow the AQ-SPEC laboratory evaluation protocol, only data from the three *a* sensors is considered in determining evaluation parameters.

PA-II vs FEM GRIMM (PM_{2.5} mass; 5-min mean)



- Over the full PM_{2.5} concentration range tested (0-250 $\mu\text{g}/\text{m}^3$), the three PA-II sensors tracked well with the concentration variation recorded by FEM GRIMM.

Coefficient of Determination



- Three PA-II sensors showed very strong correlations with GRIMM PM_{2.5} mass conc. ($R^2 > 0.99$) between 0-250 $\mu\text{g}/\text{m}^3$.
- PA-II sensor underestimated the GRIMM PM_{2.5} mass conc.

PM_{2.5} Accuracy: PA-II vs FEM GRIMM

- Accuracy (20 °C and 40% RH)

Steady State (#)	Sensor mean (µg/m ³)	GRIMM (µg/m ³)	Accuracy (%)
1	19.7	13.5	54.3
2	44.3	35.7	75.7
3	80.8	84.1	96.1
4	134.7	155.1	86.8
5	186.3	233.5	79.8

- The three PA-II sensors showed moderate to good accuracy (54.3-96.1%) compared to FEM GRIMM PM_{2.5} over the concentration range tested (0-250 µg/m³).

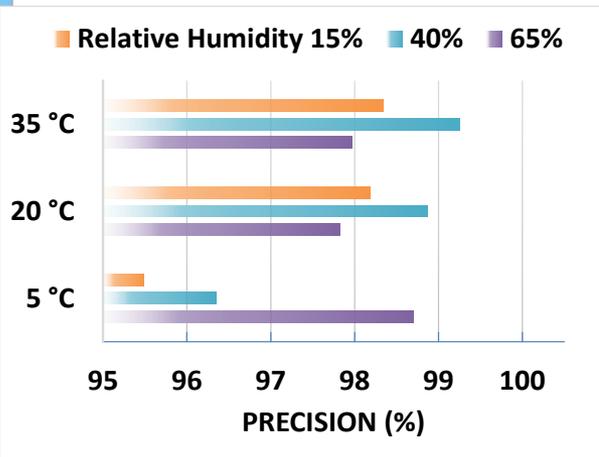
PA-II Data Recovery and Intra-model variability

- Data recovery for PM_{2.5} mass concentration from 8464a, cc53a, and b688a were 96.1%, 96.6%, and 96.1%.
- Low PM_{2.5} measurement variations were observed among the three PA-II sensors.

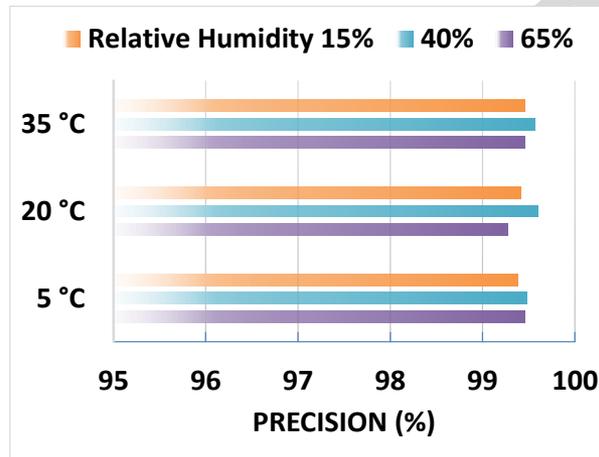
PM_{2.5} Precision: PurpleAir PA-II

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

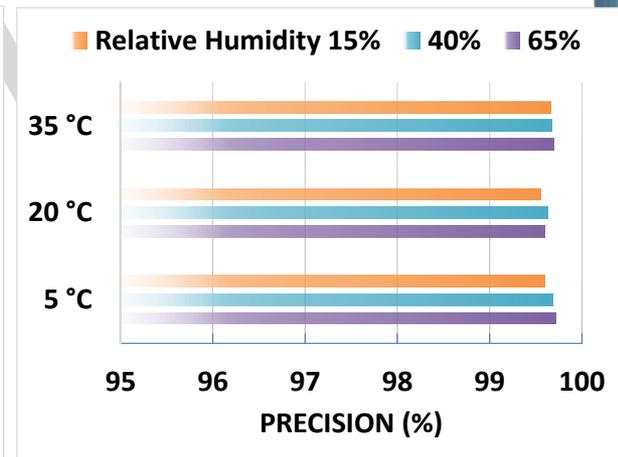
Low conc.



Medium conc.

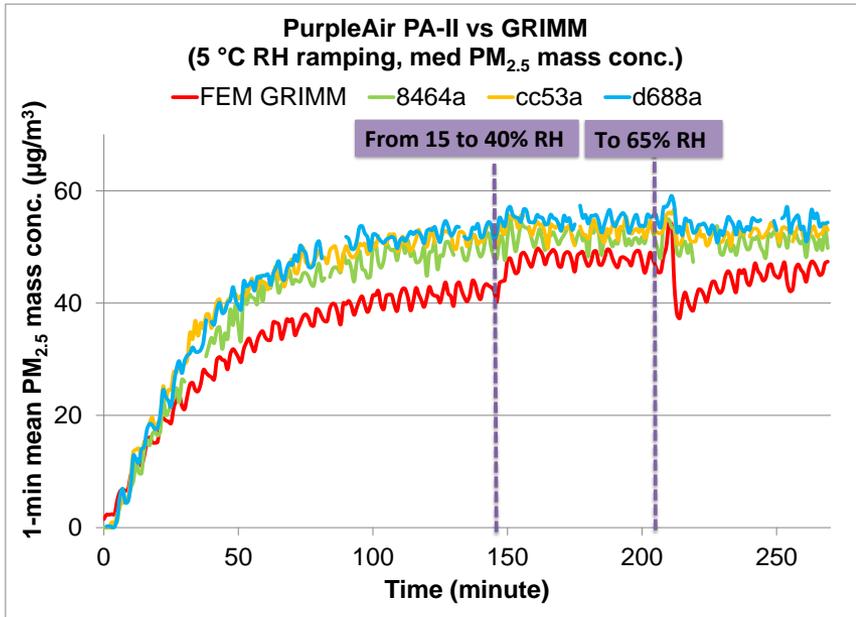


High conc.

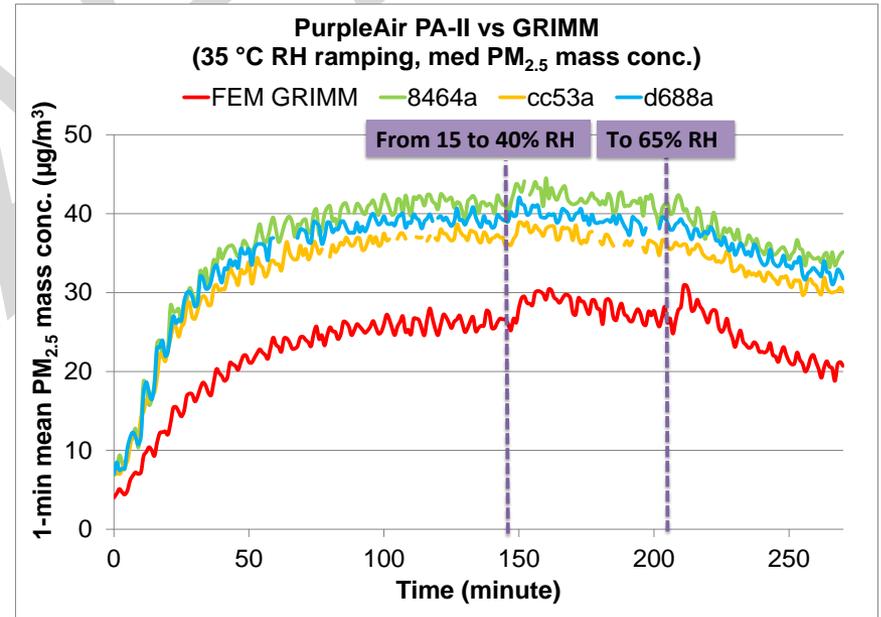


- Overall, the three PA-II sensors showed high precision for most of the combinations of low, medium and high PM_{2.5} conc., T, and RH.
- At 5 °C/15% RH, 5 °C/40% and low PM_{2.5} mass conc., precision was lower for both the sensors and the GRIMM.

PurpleAir PA-II Climate Susceptibility



Low Temp - RH ramping
(medium conc.)



High Temp - RH ramping
(medium conc.)

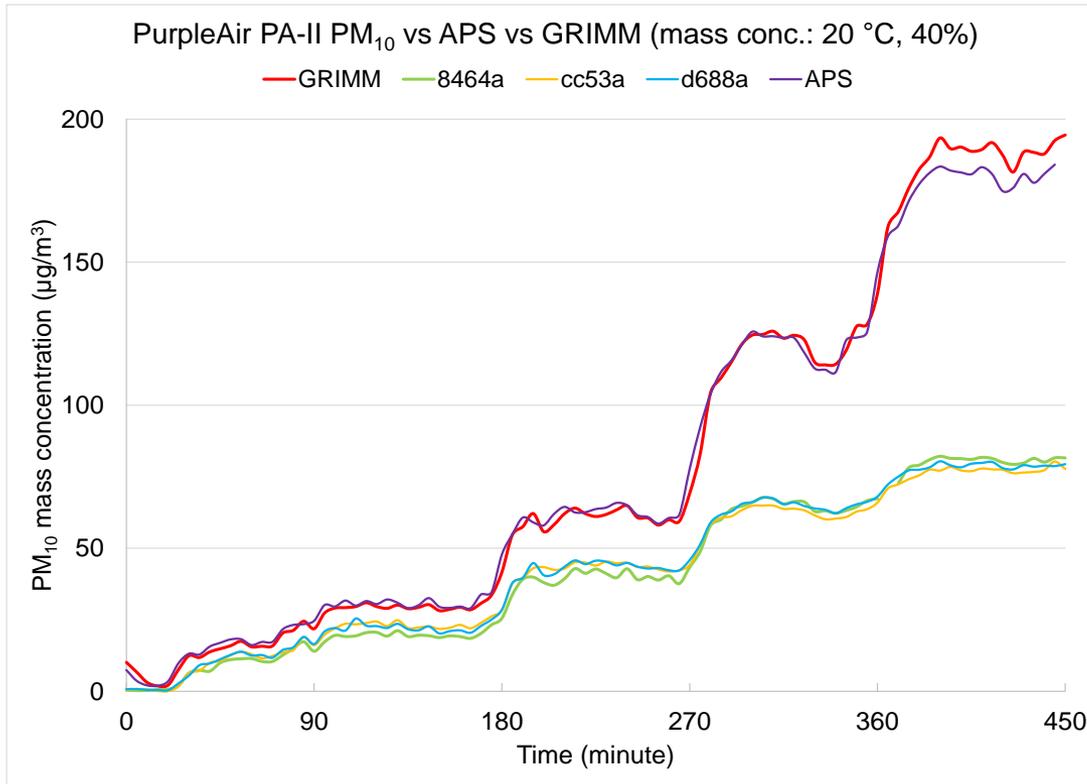
Discussion (PM₁ and PM_{2.5})

- **Accuracy:** Overall, the three PA-II sensors have moderate to good accuracy, compared to GRIMM PM₁ and PM_{2.5} in the range of 0 to 250 µg/m³.
- **Precision:** The three PA-II sensors have high precision for most of the test combinations (PM concentrations, T and RH).
- **Intra-model variability:** Low intra-model variability was observed among the three PA-II sensors.
- **Data Recovery:** Data recovery for PM₁ mass concentration from 8464a, cc53a, and b688a was 95.9%, 96.6%, and 96.7%. Data recovery for PM_{2.5} mass concentration from 8464a, cc53a, and b688a was 96.1%, 96.6%, and 96.6%.
- **Coefficient of Determination:** The three PA-II sensors showed very strong correlation/linear response with the corresponding GRIMM PM₁ and PM_{2.5} measurement data ($R^2 > 0.99$) for mass concentration range between 0 and 250 µg/m³.
- **Climate susceptibility:** For most of the temperature and relative humidity combinations, the climate condition had minimal effect on the PA-II's precision. At the set-points of RH changes at low PM concentrations, PA-II sensors had some spikes.

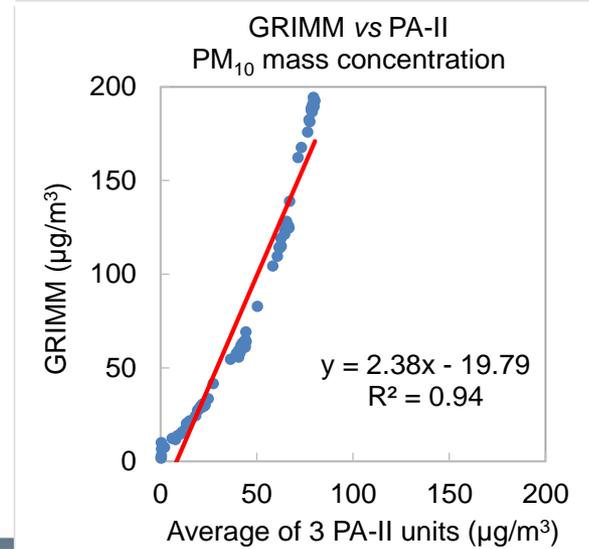
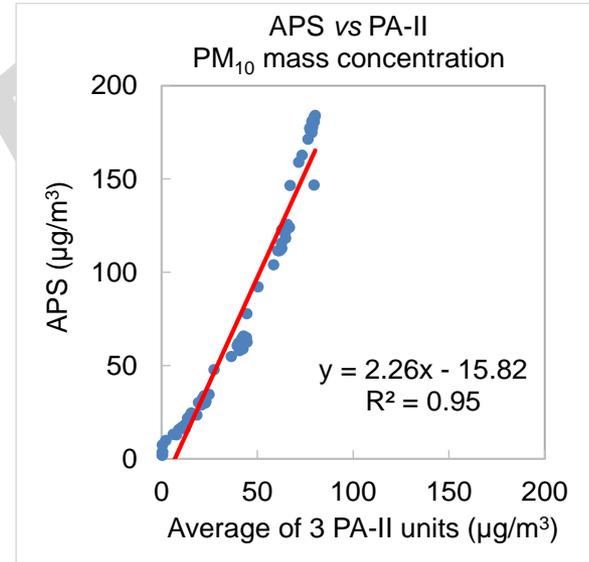
**Evaluation results for
PurpleAir PA-II PM₁₀ mass concentration**

PurpleAir PA-II vs GRIMM vs APS

PA-II vs APS vs GRIMM (PM₁₀ mass; 5-min mean) Concentration ramping at 20 °C, 40% RH



- Over the full PM₁₀ concentration range tested (0-200 µg/m³ as measured by APS using 2.6 g/cm³), the three PA-II sensors tracked well the conc. variation as recorded by the APS and GRIMM.
- The PA-II sensors underestimated the PM₁₀ mass concentration measured by APS and GRIMM, especially at higher concentration.



PM₁₀ Accuracy: PA-II vs APS vs GRIMM

- Accuracy (20 °C and 40% RH)

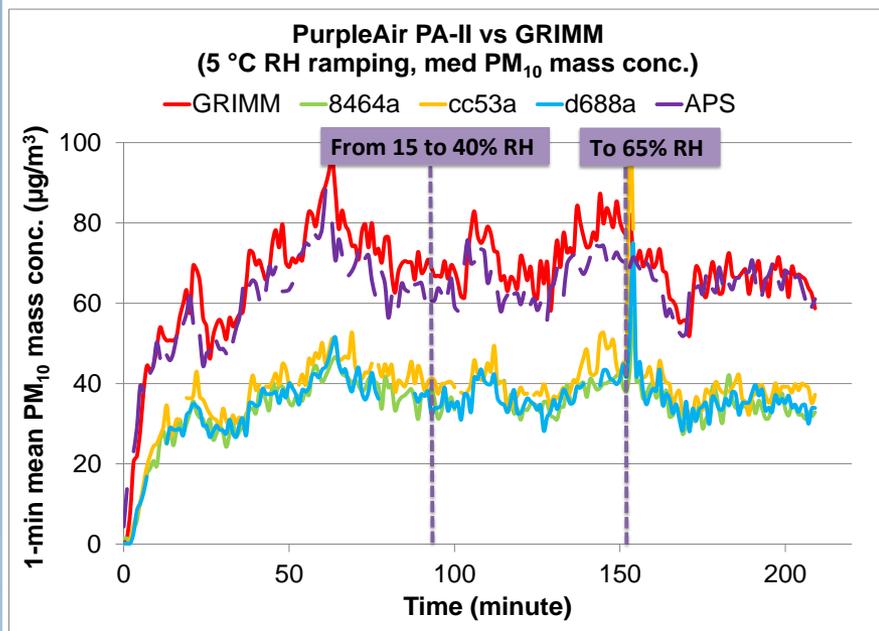
Steady State (#)	Sensor mean (µg/m ³)	APS-2.6 (µg/m ³)	Accuracy (%)	Steady State (#)	Sensor mean (µg/m ³)	GRIMM (µg/m ³)	Accuracy (%)
1	13.8	21.4	64.5	1	13.8	19.0	72.7
2	21.7	31.8	68.3	2	21.7	30.0	72.2
3	41.8	60.4	69.2	3	41.8	60.4	69.3
4	63.3	120.9	52.4	4	63.3	120.3	52.7
5	78.8	178.7	44.1	5	78.8	188.0	41.9

- The three PA-II sensors had moderate accuracy (44%-73%) when compared to APS and GRIMM. As PM₁₀ concentration increased, sensors' accuracy decreased. Sensors underestimated PM₁₀ concentration as measured by APS and GRIMM.

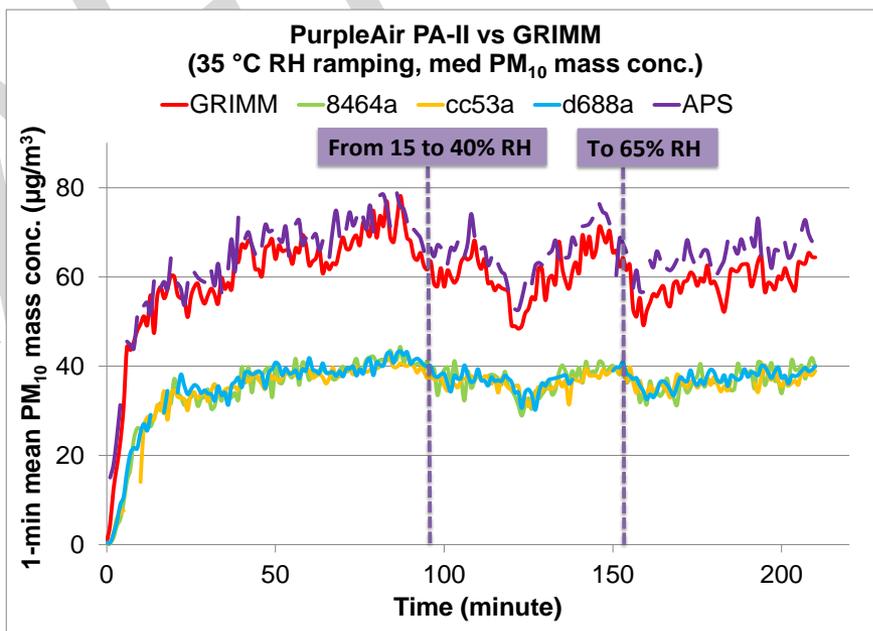
PA-II Data Recovery and Intra-model variability

- Data recovery for PM₁₀ mass concentration from 8464a, cc53a, and b688a were 94.4%, 93.2%, and 94.0%.
- Low PM₁₀ measurement variations were observed among the three PA-II sensors.

PurpleAir PA-II Climate Susceptibility



Low Temp - RH ramping
(medium conc.)



High Temp - RH ramping
(medium conc.)

Discussion (PM₁₀)

- **Accuracy:** The three PA-II sensors had moderate accuracy (44%-73%) when compared to APS and GRIMM. As PM₁₀ concentration increased, sensors' accuracy decreased. Sensors underestimated PM₁₀ concentration as measured by APS and GRIMM.
- **Precision:** Due to the nature of Arizona test dust, the aerosol concentration showed some variability, therefore, the precision cannot be fairly estimated. As observed in the climate susceptibility experiments, APS and GRIMM showed higher sensitivity to the aerosol concentration changes than the three PA-II sensors did.
- **Intra-model variability:** Low intra-model variability was observed among the PA-II sensors.
- **Data Recovery:** Data recovery for PM₁₀ mass concentration from 8464a, cc53a, and b688a were 94.4%, 93.2%, and 94.0%.
- **Coefficient of Determination:** PA-II sensors showed very strong correlation/linear response with the corresponding APS PM₁₀ ($R^2 = 0.95$) and GRIMM PM₁₀ ($R^2 = 0.94$).
- **Climate susceptibility:** From the laboratory studies, temperature and relative humidity had minimal effect on the PA-II sensors' performance. At the set-points of RH changes, units reported spiked changes in concentrations.