Laboratory Evaluation
PurpleAir PA-II PM Sensor
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 ($\mu$g/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 $\mu$m
- Uses a patented, double-crest optical system for unmatched sizing accuracy
- Cost: ~$50,000
Evaluation results guideline

- PurpleAir PA-II vs GRIMM PM$_1$ mass concentration
- PurpleAir PA-II vs GRIMM PM$_{2.5}$ mass concentration
- PurpleAir PA-II vs APS vs GRIMM PM$_{10}$ mass concentration
Evaluation results for PurpleAir PA-II PM$_1$ mass concentration

PurpleAir PA-II vs GRIMM
• Each PurpleAir PA-II node 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 PM\(_1\) 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 (PM$_1$ mass; 5-min mean)

- Over the full PM$_1$ concentration range tested (0-175 µg/m$^3$), the three PA-II sensors tracked well with the concentration variation recorded by GRIMM.

- PA-II sensors showed very strong correlations with GRIMM PM$_1$ mass conc. ($R^2 > 0.99$) between 0-175 µg/m$^3$.

- PA-II sensors underestimated the GRIMM PM$_1$ mass conc.

Coefficient of Determination

$y = 1.49x - 8.49$

$R^2 = 1.00$
PM$_1$ Accuracy: PA-II vs GRIMM

- Accuracy (20 °C and 40% RH)

<table>
<thead>
<tr>
<th>Steady State (#)</th>
<th>Sensor mean (µg/m$^3$)</th>
<th>GRIMM (µg/m$^3$)</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.6</td>
<td>11.0</td>
<td>85.2</td>
</tr>
<tr>
<td>2</td>
<td>29.0</td>
<td>30.7</td>
<td>94.5</td>
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<tr>
<td>3</td>
<td>53.0</td>
<td>69.8</td>
<td>76.0</td>
</tr>
<tr>
<td>4</td>
<td>87.9</td>
<td>120.8</td>
<td>72.7</td>
</tr>
<tr>
<td>5</td>
<td>120.5</td>
<td>172.6</td>
<td>69.8</td>
</tr>
</tbody>
</table>

- The PurpleAir PA-II sensors showed good accuracy compared to GRIMM PM$_1$ over the concentration range of 0-175 µg/m$^3$ at 20 °C and 40% RH. PA-II sensors had better accuracy (85-95%) at lower PM$_1$ concentration (10-30 µg/m$^3$). PurpleAir PA-II sensors’ accuracy decreased to ~70% when PM$_1$ mass conc. was between 70-175 µg/m$^3$.

PA-II Data Recovery and Intra-model variability

- Data recovery for PM$_1$ mass concentration from 8464a, cc53a, and b688a were 95.9%, 96.6%, and 96.7%.
- Low PM$_1$ measurement variations were observed among the three PA-II units.
PM\textsubscript{1} Precision: PurpleAir PA-II

- Precision (Effect of PM\textsubscript{1} conc., Temperature and Relative Humidity)

- Overall, the three PA-II sensors showed high precision for most of the combinations of low, medium and high PM\textsubscript{1} conc., T, and RH.

- At low PM\textsubscript{1} mass conc. and 5 °C/15% RH, precision was lower for both the sensors and the GRIMM.
PurpleAir PA-II Climate Susceptibility

PurpleAir PA-II vs GRIMM
(5 °C RH ramping, med PM, mass conc.)

- GRIMM
- 8464a
- cc53a
- d688a

From 15 to 40% RH
To 65% RH

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 μg/m$^3$), the three PA-II sensors tracked well with the concentration variation recorded by FEM GRIMM.

- Three PA-II sensors showed very strong correlations with GRIMM PM$_{2.5}$ mass conc. ($R^2 > 0.99$) between 0-250 μg/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)

<table>
<thead>
<tr>
<th>Steady State (#)</th>
<th>Sensor mean (µg/m$^3$)</th>
<th>GRIMM (µg/m$^3$)</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>19.7</td>
<td>13.5</td>
<td>54.3</td>
</tr>
<tr>
<td>2</td>
<td>44.3</td>
<td>35.7</td>
<td>75.7</td>
</tr>
<tr>
<td>3</td>
<td>80.8</td>
<td>84.1</td>
<td>96.1</td>
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<tr>
<td>4</td>
<td>134.7</td>
<td>155.1</td>
<td>86.8</td>
</tr>
<tr>
<td>5</td>
<td>186.3</td>
<td>233.5</td>
<td>79.8</td>
</tr>
</tbody>
</table>

- 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/m$^3$).

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)

- 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 (PM$_1$ and PM$_{2.5}$)

- **Accuracy**: Overall, the three PA-II sensors have moderate to good accuracy, compared to GRIMM PM$_1$ and PM$_{2.5}$ in the range of 0 to 250 µg/m$^3$.

- **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 PM$_1$ 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 PM$_1$ and PM$_{2.5}$ measurement data ($R^2 > 0.99$) for mass concentration range between 0 and 250 µg/m$^3$.

- **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 PM$_{10}$ mass concentration

PurpleAir PA-II vs GRIMM vs APS
PA-II vs APS vs GRIMM (PM$_{10}$ mass; 5-min mean)
Concentration ramping at 20 °C, 40% RH

- Over the full PM$_{10}$ concentration range tested (0-200 μg/m$^3$ as measured by APS using 2.6 g/cm$^3$), the three PA-II sensors tracked well the conc. variation as recorded by the APS and GRIMM.
- The PA-II sensors underestimated the PM$_{10}$ mass concentration measured by APS and GRIMM, especially at higher concentration.
PM$_{10}$ Accuracy: PA-II vs APS vs GRIMM

- Accuracy (20 °C and 40% RH)

<table>
<thead>
<tr>
<th>Steady State (#)</th>
<th>Sensor mean (µg/m$^3$)</th>
<th>APS-2.6 (µg/m$^3$)</th>
<th>Accuracy (%)</th>
<th>Steady State (#)</th>
<th>Sensor mean (µg/m$^3$)</th>
<th>GRIMM (µg/m$^3$)</th>
<th>Accuracy (%)</th>
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<tbody>
<tr>
<td>1</td>
<td>13.8</td>
<td>21.4</td>
<td>64.5</td>
<td>1</td>
<td>13.8</td>
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<td>63.3</td>
<td>120.9</td>
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<td>63.3</td>
<td>120.3</td>
<td>52.7</td>
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<tr>
<td>5</td>
<td>78.8</td>
<td>178.7</td>
<td>44.1</td>
<td>5</td>
<td>78.8</td>
<td>188.0</td>
<td>41.9</td>
</tr>
</tbody>
</table>

- The three PA-II sensors had moderate accuracy (44%-73%) when compared to APS and GRIMM. As PM$_{10}$ concentration increased, sensors’ accuracy decreased. Sensors underestimated PM$_{10}$ concentration as measured by APS and GRIMM.

PA-II Data Recovery and Intra-model variability

- Data recovery for PM$_{10}$ mass concentration from 8464a, cc53a, and b688a were 94.4%, 93.2%, and 94.0%.
- Low PM$_{10}$ measurement variations were observed among the three PA-II sensors.
PurpleAir PA-II Climate Susceptibility

PurpleAir PA-II vs GRIMM
(5 °C RH ramping, med PM$_{10}$ mass conc.)

Low Temp - RH ramping
(medium conc.)

High Temp - RH ramping
(medium conc.)
Accuracy: The three PA-II sensors had moderate accuracy (44%-73%) when compared to APS and GRIMM. As PM$_{10}$ concentration increased, sensors' accuracy decreased. Sensors underestimated PM$_{10}$ 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 PM$_{10}$ 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 PM$_{10}$ ($R^2 = 0.95$) and GRIMM PM$_{10}$ ($R^2 = 0.94$).

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.