Laboratory Evaluation
PurpleAir PA-I Indoor
Background

Three PurpleAir PA-I Indoor (Hereinafter PA-I Indoor) sensors (units IDs: 29D1, A3CA and BB9F) were field-tested at the South Coast AQMD Rubidoux fixed ambient monitoring station (02/15/2018 to 04/25/2018) under ambient environmental conditions and have now been evaluated in the South Coast AQMD Chemistry Laboratory under controlled artificial aerosol concentration/size range, temperature, and relative humidity. The same three PA-I Indoor units were tested both in the field (1st stage of testing) and in the laboratory (2nd stage of testing).

- **PA-I Indoor (3 units tested):**
  - Particle sensor (optical; non-FEM)
  - PM sensor: Plantower PMS1003
  - Each unit measures: PM$_{1.0}$, PM$_{2.5}$ and PM$_{10}$ ($\mu$g/m$^3$) Temperature (°F)
  - Unit cost: ~$180
  - Time resolution: 2-min (during lab evaluation)
  - Units IDs: 29D1, A3CA and BB9F

- **GRIMM (reference method):**
  - Optical particle counter
  - FEM PM$_{2.5}$
  - Uses proprietary algorithms to calculate total PM, PM$_{2.5}$, and PM$_{1}$ mass conc. from particle number measurements
  - Cost: ~$25,000
  - Time resolution: 1-min

- **TSI APS 3321 (reference 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

- PurleAir PA-I Indoor vs GRIMM PM$_{1.0}$ mass concentration
- PurleAir PA-I Indoor vs FEM GRIMM PM$_{2.5}$ mass concentration
- PurleAir PA-I Indoor vs GRIMM vs APS PM$_{10}$ mass concentration
Evaluation results for PM$_{1.0}$ mass concentration

PurpleAir PA-I Indoor vs GRIMM
• The PA-I Indoor sensors tracked well with the PM$_{1.0}$ concentration variation as recorded by the GRIMM in the concentration range of 0 - ~200 μg/m$^3$.

• The PA-I Indoor sensors showed very strong correlations with the GRIMM PM$_{1.0}$ mass conc. (R$^2$ > 0.99).
PA-I Indoor vs GRIMM PM$_{1.0}$ Accuracy

- 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>12.8</td>
<td>9.5</td>
<td>65.1</td>
</tr>
<tr>
<td>2</td>
<td>18.8</td>
<td>14.2</td>
<td>67.5</td>
</tr>
<tr>
<td>3</td>
<td>44.5</td>
<td>52.1</td>
<td>85.3</td>
</tr>
<tr>
<td>4</td>
<td>109.5</td>
<td>123.1</td>
<td>89.0</td>
</tr>
<tr>
<td>5</td>
<td>183.3</td>
<td>199.1</td>
<td>92.1</td>
</tr>
</tbody>
</table>

- The PA-I Indoor sensors underestimated GRIMM PM$_{1.0}$ at mass concentrations > 50 µg/m$^3$, while they overestimated mass concentrations < 50 µg/m$^3$. The accuracy of the PA-I Indoor sensors increased as PM$_{1.0}$ mass concentrations increased.

**PA-I Indoor: Data Recovery and intra-model variability**

- Data recovery for PM$_{1.0}$ mass concentration from all units was 100%
- Low PM$_{1.0}$ measurement variations were observed between the PA-I Indoor sensors
Precision (Effect of PM$_{1.0}$ conc., Temperature and Relative Humidity)

Overall, the PA-I Indoor sensors showed high precision for all of the combinations of low, medium and high PM$_{1.0}$ conc., T and RH.
PA-I Indoor PM$_{1.0}$: Climate Susceptibility

Low Temp – RH ramping (medium conc.)

High Temp – RH ramping (medium conc.)
Evaluation results for PM$_{2.5}$ mass concentration

PurpleAir PA-I Indoor vs FEM GRIMM
• The PA-I Indoor sensors tracked well with the concentration variation as recorded by the FEM GRIMM in the concentration range of 0 - ~300 μg/m³.

• The PA-I Indoor sensors showed very strong correlations with the FEM GRIMM PM$_{2.5}$ mass conc. (R$^2$ > 0.99)
PA-I Indoor vs FEM GRIMM PM\textsubscript{2.5} Accuracy

- Accuracy (20 °C and 40% RH)

<table>
<thead>
<tr>
<th>Steady state #</th>
<th>Sensor Mean (µg/m\textsuperscript{3})</th>
<th>FEM GRIMM (µg/m\textsuperscript{3})</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24.4</td>
<td>10.3</td>
<td>-37.1</td>
</tr>
<tr>
<td>2</td>
<td>33.9</td>
<td>15.3</td>
<td>-21.5</td>
</tr>
<tr>
<td>3</td>
<td>86.3</td>
<td>60.2</td>
<td>56.6</td>
</tr>
<tr>
<td>4</td>
<td>216.1</td>
<td>152.6</td>
<td>58.3</td>
</tr>
<tr>
<td>5</td>
<td>387.4</td>
<td>255.2</td>
<td>48.2</td>
</tr>
</tbody>
</table>

- The PA-I Indoor sensors overestimated FEM GRIMM PM\textsubscript{2.5} mass concentration at 20 °C and 40% RH. The accuracy of the PA-I Indoor sensors was negative at low PM\textsubscript{2.5} mass conc. and fairly constant (48% to 57%) for PM\textsubscript{2.5} mass concentrations > 50 µg/m\textsuperscript{3}.

PA-I Indoor: Data Recovery and intra-model variability

- Data recovery for PM\textsubscript{2.5} mass concentration from all units was 100%
- Low PM\textsubscript{2.5} measurement variations were observed between the PA-I Indoor sensors
**PM$_{2.5}$ Precision: PA-I Indoor**

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

<table>
<thead>
<tr>
<th>Low Pollutant Concentration</th>
<th>Medium Pollutant Concentration</th>
<th>High Pollutant Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Relative Humidity</strong></td>
<td><strong>Relative Humidity</strong></td>
<td><strong>Relative Humidity</strong></td>
</tr>
<tr>
<td>15%</td>
<td>15%</td>
<td>15%</td>
</tr>
<tr>
<td>40%</td>
<td>40%</td>
<td>40%</td>
</tr>
<tr>
<td>65%</td>
<td>65%</td>
<td>65%</td>
</tr>
</tbody>
</table>

- Overall, the PA-I Indoor sensors showed high precision for all of the combinations of low, medium and high PM$_{2.5}$ conc., T and RH.
PA-I Indoor PM$_{2.5}$: Climate Susceptibility

**Low Temp – RH ramping (medium conc.)**

**High Temp – RH ramping (medium conc.)**
Discussion (PM$_{1.0}$ and PM$_{2.5}$)

- **Accuracy:** Overall, the accuracy of the PA-I Indoor sensors increased with increasing PM$_{1.0}$ mass concentration. The accuracy of the PA-I Indoor sensors was negative at lower PM$_{2.5}$ mass conc. and fairly constant (48% to 57%) for PM$_{2.5}$ mass concentrations > 50 μg/m$^3$. The PA-I Indoor sensors underestimated PM$_{1.0}$ at PM$_{1.0}$ mass conc. > 50 μg/m$^3$, while they overestimate PM$_{1.0}$ mass conc. < 50 μg/m$^3$. The sensors overestimated all PM$_{2.5}$ measurements from GRIMM in the laboratory experiments at 20 °C and 40% RH.

- **Precision:** The PA-I Indoor sensors have high precision for all test combinations (PM concentrations, T and RH) for both PM$_{1.0}$ and PM$_{2.5}$ mass concentrations.

- **Intra-model variability:** Low intra-model variability was observed among the PA-I Indoor sensors.

- **Data Recovery:** Data recovery for PM$_{1.0}$ and PM$_{2.5}$ mass concentration from all units was 100%.

- **Coefficient of Determination:** The PA-I Indoor sensors showed very strong correlation/linear response with the corresponding GRIMM PM$_{1.0}$ and FEM GRIMM PM$_{2.5}$ measurement data (R$^2$ > 0.99).

- **Climate susceptibility:** For most of the temperature and relative humidity combination, the climate condition had minimal effect on the PA-I Indoor sensors except that the sensors showed some small spiked concentration changes at the 65% RH set-point at 5°C.
Evaluation results for $PM_{10}$ mass concentration

PurpleAir PA-I Indoor vs GRIMM vs APS
**PA-I Indoor vs GRIMM vs APS (PM$_{10}$ mass conc.)**

Concentration Ramping at 20 °C and 40% RH

- The PA-I Indoor sensors tracked well with the concentration variation as recorded by the APS and GRIMM in the concentration range of 0 - ~200 μg/m$^3$.

- The PA-I Indoor sensors showed very strong correlations with the corresponding GRIMM and APS PM$_{10}$ mass conc. ($R^2 > 0.96$).
PA-I Indoor vs GRIMM vs APS PM\textsubscript{10} Accuracy

• Accuracy (20 °C and 40% RH)

<table>
<thead>
<tr>
<th>Steady state #</th>
<th>Sensor Mean (µg/m\textsuperscript{3})</th>
<th>GRIMM (µg/m\textsuperscript{3})</th>
<th>Accuracy (%)</th>
<th>Steady state #</th>
<th>Sensor Mean (µg/m\textsuperscript{3})</th>
<th>APS (µg/m\textsuperscript{3})</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.1</td>
<td>10.1</td>
<td>70.3</td>
<td>1</td>
<td>7.1</td>
<td>7.9</td>
<td>89.8</td>
</tr>
<tr>
<td>2</td>
<td>15.2</td>
<td>21.8</td>
<td>69.7</td>
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<td>51.5</td>
<td>70.0</td>
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<td>36.0</td>
<td>42.5</td>
<td>84.7</td>
</tr>
<tr>
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<td>65.0</td>
<td>116.9</td>
<td>55.6</td>
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<td>65.0</td>
<td>96.4</td>
<td>67.4</td>
</tr>
<tr>
<td>5</td>
<td>90.3</td>
<td>198.5</td>
<td>45.5</td>
<td>5</td>
<td>90.3</td>
<td>166.7</td>
<td>54.2</td>
</tr>
</tbody>
</table>

• The PA-I Indoor sensors underestimated the corresponding GRIMM and APS PM\textsubscript{10} mass concentration at 20 °C and 40% RH. The accuracy of the PA-I Indoor sensors decreased as PM\textsubscript{10} mass concentration increased.

**PA-I Indoor : Data Recovery and intra-model variability**

• Data recovery for PM\textsubscript{10} mass concentration from all units was 100%
• Moderate PM\textsubscript{10} measurement variations were observed between the PA-I Indoor sensors
PA-I Indoor PM\textsubscript{10}: Climate Susceptibility

**Low Temp – RH ramping (medium conc.)**

**High Temp – RH ramping (medium conc.)**
**Discussion (PM$_{10}$)**

- **Accuracy:** Overall, the accuracy of the PA-I Indoor sensors decreased as PM$_{10}$ mass concentration increased. The PA-I Indoor sensors underestimated PM$_{10}$ mass concentrations as measured by GRIMM and APS in the laboratory experiments at 20 °C and 40% RH.

- **Precision:** Due to the nature of Arizona test dust, the aerosol concentration showed some variability, therefore, the precision cannot be fairly estimated.

- **Intra-model variability:** Moderate intra-model variability was observed among the PA-I Indoor sensors.

- **Data Recovery:** Data recovery for PM$_{10}$ mass concentration from all units was ~ 99%.

- **Coefficient of Determination:** The PA-I Indoor sensors showed very strong correlation/linear response with the corresponding GRIMM PM$_{10}$ ($R^2 = 0.97$) and APS PM$_{10}$ ($R^2 = 0.968$).

- **Climate susceptibility:** For most of the temperature and relative humidity combinations, the climate condition had minimal effect on the PA-I Indoor sensors except that the sensors showed spiked concentration changes at the 65% RH set-point at 5 °C.