Laboratory Evaluation
Kunak Air A10 - PM
Background

Three Kunak Air A10 (Hereinafter Kunak) sensors (units IDs: 0000, 0001 and 0002) were field-tested at the South Coast AQMD Rubidoux fixed ambient monitoring station (04/28/2019 to 07/11/2019) 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 Kunak units were tested both in the field (1\textsuperscript{st} stage of testing) and in the laboratory (2\textsuperscript{nd} stage of testing).

- **Kunak (3 units tested):**
  - Particle sensor: AlphaSense OPC N3 (optical; non-FEM)
  - Gas sensors: AlphaSense B4 series (electrochemical; non-FEM)
  - Each unit reports: PM\textsubscript{1.0}, PM\textsubscript{2.5} and PM\textsubscript{10} (\textmu g/m\textsuperscript{3})\textsuperscript{1}, Ozone (ppb), CO (ppb), NO, NO\textsubscript{2}, NO\textsubscript{x} (ppb), temperature (°C), RH (%), pressure, Wind Speed (km/h), Wind Direction (degree)
  - Unit cost: ~$7,900 (PM + Gas); $3,000 (PM only) and $5,000 (4 gases, temp/RH, anemometer and solar panel)
  - Time resolution: 5-min
  - Units IDs: 0000, 0001, 0002

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

- **TSI APS 3321 (reference method for PM\textsubscript{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

Note: all results presented here are 5-min averages due to the 5-min time resolution of the Kunak sensors.

\textsuperscript{1}Parameters tested in this laboratory evaluation
\textsuperscript{2}Only available in Unit 0002
\textsuperscript{3}4G LTE, 9w solar panel, includes 1-yr cell connectivity, tech support, cloud data access for configuration, calibration, firmware upgrade, alarms, data validation, reporting, advanced analytics, APIrest.
Evaluation results guideline

- Kunak Air A10 vs GRIMM PM$_{1.0}$ mass concentration
- Kunak Air A10 vs FEM GRIMM PM$_{2.5}$ mass concentration
- Kunak Air A10 vs GRIMM vs APS PM$_{10}$ mass concentration
Evaluation results for PM$_{1.0}$ mass concentration

Kunak vs GRIMM
The Kunak 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 Kunak sensors showed very strong correlations with the GRIMM PM$_{1.0}$ mass conc. (R$^2 > 0.99$).

Coefficient of Determination

GRIMM vs Kunak Air A10
PM$_{1.0}$ mass conc. (5-min; µg/m$^3$)

y = 1.3898x + 2.4336
R$^2 = 0.9978$
Kunak vs GRIMM PM$_{1.0}$: Accuracy

- Accuracy (20 °C and 40% RH)

<table>
<thead>
<tr>
<th>Steady state #</th>
<th>Sensor Mean ($\mu$g/m$^3$)</th>
<th>GRIMM ($\mu$g/m$^3$)</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.9</td>
<td>5.5</td>
<td>52.7</td>
</tr>
<tr>
<td>2</td>
<td>5.0</td>
<td>10.0</td>
<td>50.1</td>
</tr>
<tr>
<td>3</td>
<td>13.0</td>
<td>29.9</td>
<td>43.4</td>
</tr>
<tr>
<td>4</td>
<td>33.3</td>
<td>83.4</td>
<td>39.9</td>
</tr>
<tr>
<td>5</td>
<td>54.1</td>
<td>141.1</td>
<td>38.3</td>
</tr>
<tr>
<td>6</td>
<td>80.8</td>
<td>215.0</td>
<td>37.6</td>
</tr>
</tbody>
</table>

- The Kunak sensors underestimated GRIMM PM$_{1.0}$ mass concentration. The accuracy of the Kunak sensors decreased as PM$_{1.0}$ mass concentrations increased.

Kunak: Data Recovery and Intra-model Variability

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

- Overall, the Kunak sensors showed high precision for all of the combinations of low, medium and high PM$_{1.0}$ conc., T and RH except at medium and high PM$_{1.0}$ conc. under 5 °C/65% RH.
Kunak PM$_{1.0}$: Climate Susceptibility

Low Temp – RH ramping (medium conc.)

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

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

The Kunak sensors showed very strong correlations with the FEM GRIMM PM₂.₅ mass conc. (R² > 0.99)
**Kunak vs FEM GRIMM PM$_{2.5}$ Accuracy**

- Accuracy (20 °C and 40% RH)

<table>
<thead>
<tr>
<th>Steady state #</th>
<th>Sensor Mean (µg/m$^3$)</th>
<th>FEM GRIMM (µg/m$^3$)</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.4</td>
<td>6.6</td>
<td>66.7</td>
</tr>
<tr>
<td>2</td>
<td>7.7</td>
<td>11.5</td>
<td>66.6</td>
</tr>
<tr>
<td>3</td>
<td>24.0</td>
<td>36.3</td>
<td>66.2</td>
</tr>
<tr>
<td>4</td>
<td>72.9</td>
<td>109.8</td>
<td>66.3</td>
</tr>
<tr>
<td>5</td>
<td>131.4</td>
<td>193.4</td>
<td>67.9</td>
</tr>
<tr>
<td>6</td>
<td>218.2</td>
<td>301.7</td>
<td>72.3</td>
</tr>
</tbody>
</table>

- The Kunak sensors underestimated FEM GRIMM PM$_{2.5}$ mass concentration at 20 °C and 40% RH. The accuracy of the Kunak sensors was fairly constant (66% to 72%) for the PM$_{2.5}$ mass concentration range tested.

**Kunak : Data Recovery and Intra-model Variability**

- Data recovery for PM$_{2.5}$ mass concentration from all units was 100%
- High PM$_{2.5}$ measurement variations were observed between the Kunak sensors
Kunak PM$_{2.5}$: Precision

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

<table>
<thead>
<tr>
<th>Relative Humidity</th>
<th>15%</th>
<th>40%</th>
<th>65%</th>
</tr>
</thead>
<tbody>
<tr>
<td>35 °C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 °C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 °C</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Overall, the Kunak sensors showed high precision for all of the combinations of low, medium and high PM$_{2.5}$ conc., T and RH except at 5 °C/65% RH for all PM$_{2.5}$ levels
Kunak 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 Kunak decreased as PM$_{1.0}$ mass concentrations increased and was fairly constant (66% to 72%) for the PM$_{2.5}$ mass concentration range tested. The Kunak sensors underestimated PM$_{1.0}$ and PM$_{2.5}$ measurements from GRIMM in the laboratory experiments at 20 °C and 40% RH.

- **Precision**: The Kunak sensors showed high precision for all test combinations (PM concentrations, T and RH) for both PM$_{1.0}$ and PM$_{2.5}$ mass concentrations except at 5 °C/65% RH.

- **Intra-model variability**: high intra-model variability was observed among the Kunak sensors.

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

- **Coefficient of Determination**: The Kunak 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 Kunak’s precision. The Kunak sensors showed some small spikes at the RH set-points and showed significant variation in concentration at 5 °C/65% RH; this could be due to the RH transient effect produced when abrupt change in RH occurs (e.g. RH change exceeding ±10% RH per hour), as explained in the Kunak Manual.
Evaluation results for $PM_{10}$ mass concentration

Kunak vs GRIMM vs APS
The Kunak sensors tracked well with the concentration variation as recorded by the APS and GRIMM in the concentration range of 0 - ~200 μg/m³.

The Kunak sensors showed very strong correlations with the corresponding GRIMM and APS PM_{10} mass conc. (R² > 0.99).
Kunak 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>9.0</td>
<td>10.1</td>
<td>88.8</td>
<td>1</td>
<td>9.0</td>
<td>8.0</td>
<td>87.3</td>
</tr>
<tr>
<td>2</td>
<td>17.2</td>
<td>22.1</td>
<td>77.9</td>
<td>2</td>
<td>17.2</td>
<td>17.6</td>
<td>97.7</td>
</tr>
<tr>
<td>3</td>
<td>39.8</td>
<td>51.9</td>
<td>76.7</td>
<td>3</td>
<td>39.8</td>
<td>42.8</td>
<td>93.0</td>
</tr>
<tr>
<td>4</td>
<td>89.6</td>
<td>115.4</td>
<td>77.7</td>
<td>4</td>
<td>89.6</td>
<td>95.5</td>
<td>93.9</td>
</tr>
<tr>
<td>5</td>
<td>153.5</td>
<td>199.1</td>
<td>77.1</td>
<td>5</td>
<td>153.5</td>
<td>166.5</td>
<td>92.2</td>
</tr>
</tbody>
</table>

- The Kunak sensors underestimated GRIMM and APS PM\textsubscript{10} mass concentration at 20 °C and 40% RH. The accuracy of the Kunak sensors was fairly constant (77% to 88% for GRIMM and 87% to 98% for APS) over the PM\textsubscript{10} mass concentration range tested. The accuracy is higher when compared to APS than to GRIMM.

Kunak: Data Recovery and intra-model variability

- Data recovery for PM\textsubscript{10} mass concentration from all units was 100%
- High PM\textsubscript{10} measurement variations were observed between the Kunak sensors
Kunak PM$_{10}$: Climate Susceptibility

Low Temp – RH ramping (medium conc.)

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

- **Accuracy**: Overall, the accuracy of the Kunak sensors was fairly constant (77% to 88% for GRIMM and 87% to 98% for APS) over the entire range of PM$_{10}$ mass concentrations tested. The accuracy is higher when compared to APS than to GRIMM. The Kunak 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**: High intra-model variability was observed among the Kunak sensors.

- **Data Recovery**: Data recovery for PM$_{10}$ mass concentration from all units was 100%.

- **Coefficient of Determination**: The Kunak sensors showed very strong correlation/linear response with the corresponding GRIMM PM$_{10}$ and APS PM$_{10}$ ($R^2 > 0.99$).

- **Climate susceptibility**: For most of the temperature and relative humidity combinations, the climate condition had minimal effect on the Kunak sensors. The Kunak sensors recorded out-of-range PM$_{10}$ mass concentrations at 5 °C/65% RH; this could be due to the RH transient effect produced when abrupt change in RH occurs (e.g. RH change exceeding ±10% RH per hour), as explained in the Kunak Manual.