Laboratory Evaluation

Sensirion Nubo

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center
Background

Three **Sensirion Nubo** sensors (units IDs: 2A3E, 1743, 051E) were field-tested at the South Coast AQMD Rubidoux fixed ambient monitoring station (12/27/2019 to 02/27/2020) under ambient environmental conditions and have been evaluated in the South Coast AQMD Chemistry Laboratory under controlled artificial aerosol concentration/size range, temperature, and relative humidity. The same three Sensirion Nubo units were tested both in the field (1\textsuperscript{st} stage of testing) and in the laboratory (2\textsuperscript{nd} stage of testing).

- **Sensirion Nubo (3 units tested):**
  - Particle sensor: optical; non-FEM (model: SPS30, Sensirion)
  - Each unit reports: PM\textsubscript{1.0} and PM\textsubscript{2.5} (μg/m\textsuperscript{3}), temperature (°C), RH (%), dew point (°C)
  - PM\textsubscript{10} algorithm measurement is currently under development by the manufacturer
  - Unit cost: $2000 per unit with a yearly SaaS at $500
  - Time resolution: 1-min
  - Units IDs: 2A3E, 1743, 051E

- **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: ~$25,000
  - Time resolution: 1-min
Evaluation results for PM$_{1.0}$ mass concentration

Sensirion Nubo vs GRIMM
The Sensirion Nubo 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 Sensirion Nubo sensors showed very strong correlations with the GRIMM PM$_{1.0}$ mass conc. (R$^2 > 0.99$).
Sensirion Nubo 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>6.6</td>
<td>7.2</td>
<td>92.3</td>
</tr>
<tr>
<td>2</td>
<td>10.7</td>
<td>12.0</td>
<td>89.4</td>
</tr>
<tr>
<td>3</td>
<td>34.6</td>
<td>37.8</td>
<td>91.4</td>
</tr>
<tr>
<td>4</td>
<td>90.6</td>
<td>92.1</td>
<td>98.4</td>
</tr>
<tr>
<td>5</td>
<td>219.8</td>
<td>193.5</td>
<td>86.4</td>
</tr>
</tbody>
</table>

- Overall, the Sensirion Nubo sensors overestimated GRIMM PM$_{1.0}$ measurements when PM$_{1.0}$ mass concentrations were > 100 µg/m$^3$. The accuracy of the Sensirion Nubo sensors fairly constant (86% to 98%) over the range of PM$_{1.0}$ mass concentration tested.

Sensirion Nubo: 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 Sensirion Nubo sensors
• Precision (Effect of PM$_{1.0}$ conc., Temperature and Relative Humidity)

Overall, the Sensirion Nubo sensors showed high precision for all of the combinations of low, medium and high PM$_{1.0}$ conc., T, and RH.

• Precision was relatively higher at higher PM$_{1.0}$ mass concentrations.
Sensirion Nubo 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

Sensirion Nubo vs FEM GRIMM
The Sensirion Nubo sensors tracked well with the concentration variation as recorded by the FEM GRIMM in the concentration range of 0 - ~250 μg/m³.

The Sensirion Nubo sensors showed very strong correlations with the FEM GRIMM PM$_{2.5}$ mass conc. (R$^2 > 0.99$).
Sensirion Nubo vs FEM GRIMM PM$_{2.5}$ Accuracy

- Accuracy$^*$ (20 °C and 40% RH)

<table>
<thead>
<tr>
<th>Steady state #</th>
<th>Sensor Mean ($\mu g/m^3$)</th>
<th>FEM GRIMM ($\mu g/m^3$)</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.9</td>
<td>8.4</td>
<td>93.9</td>
</tr>
<tr>
<td>2</td>
<td>16.4</td>
<td>13.7</td>
<td>80.9</td>
</tr>
<tr>
<td>3</td>
<td>52.3</td>
<td>45.3</td>
<td>84.5</td>
</tr>
<tr>
<td>4</td>
<td>131.5</td>
<td>117.7</td>
<td>88.3</td>
</tr>
<tr>
<td>5</td>
<td>308.5</td>
<td>261.5</td>
<td>82.0</td>
</tr>
</tbody>
</table>

- The Sensirion Nubo sensors overestimated FEM GRIMM PM$_{2.5}$ mass concentration at 20 °C and 40% RH. The accuracy of the Sensirion Nubo sensors was fairly constant (81% to 94%) for the PM$_{2.5}$ mass concentration range tested.

Sensirion Nubo: Data Recovery and Intra-model Variability

- Data recovery for PM$_{2.5}$ mass concentration from all units was 100%
- Low PM$_{2.5}$ measurement variations were observed between the Sensirion Nubo sensors
Sensirion Nubo PM2.5: Precision

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

Overall, the Sensirion Nubo sensors showed high precision for all of the combinations of low, medium and high PM$_{2.5}$ conc., T, and RH.

• Precision was relatively higher at higher PM$_{2.5}$ mass concentrations.
Sensirion Nubo PM$_{2.5}$: Climate Susceptibility

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

**High Temp – RH ramping (medium conc.)**
Discussion

➢ **Accuracy**: Overall, the accuracy of the Sensirion Nubo sensors fairly constant (86% to 98% and 81% to 94%) over the range of PM$_{1.0}$ and PM$_{2.5}$ mass concentration tested, respectively. Overall, the Sensirion Nubo sensors overestimated PM$_{1.0}$ measurements when PM$_{1.0}$ mass concentrations were > 100 μg/m$^3$ and overestimated PM$_{2.5}$ measurements from GRIMM in the laboratory experiments at 20 °C and 40% RH.

➢ **Precision**: The Sensirion Nubo 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 Sensirion Nubo sensors.

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

➢ **Coefficient of Determination**: The Sensirion Nubo 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 Sensirion Nubo’s precision. At the set-points of RH changes, the Sensirion Nubo sensors reported spiked changes in concentrations for all PM levels at 5 °C.