Laboratory Evaluation
AirBeam PM$_{2.5}$ Sensor
Background

- Three **AirBeam** PM Sensors that were previously field-tested at the South Coast AQMD Rubidoux fixed air monitoring station (deployment period: 04/30/2015 to 06/19/2015) under ambient weather conditions, have now been evaluated in the South Coast AQMD Chemistry Laboratory under controlled PM concentration, temperature and relative humidity.

- **AirBeam Sensor (3 units tested):**
  - Particle sensors (optical; non-FEM)
  - Each unit measures: PM$_{2.5}$ mass (µg/m$^3$) and PM$_{2.5}$ count (hundred particles/ft$^3$)
  - Unit cost: ~$200
  - Time resolution: 1-min
  - Firmware: March 2015 AirBeam firmware
  - Units IDs: D42, CC7, CA9

- **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: ~$25,000
  - Time resolution: 1 min
AirBeam vs FEM GRIMM (PM$_{2.5}$ mass; 5-min mean)

- When GRIMM PM$_{2.5}$ concentration was less than 50 µg/m$^3$, the AirBeam sensors tracked well with PM$_{2.5}$ (µg/m$^3$) variations (concentration ramping) recorded by the GRIMM.

- The AirBeam sensors reached their maximum PM$_{2.5}$ reading of about 300 µg/m$^3$ when GRIMM PM$_{2.5}$ exceeded 50 µg/m$^3$.

- The GRIMM showed very low measurement variability at low PM$_{2.5}$ concentration compared to the AirBeam sensors.

- AirBeam sensors showed strong correlation with GRIMM PM$_{2.5}$ measurement data ($R^2$~0.87) when GRIMM PM$_{2.5}$ was lower than 50 µg/m$^3$. However, the AirBeam sensors largely overestimated (> 5 times) the GRIMM PM$_{2.5}$ (slope = 0.16 and intercept = -8.51).

\[
y = 0.16x - 8.52
\]

\[
R^2 = 0.87
\]
AirBeam vs FEM GRIMM (PM$_{2.5}$ count; 5-min mean)

- AirBeam sensors showed strong correlation with GRIMM PM$_{2.5}$ measurement data ($R^2 \approx 0.76$) when GRIMM PM$_{2.5}$ count was lower than $2.0 \times 10^6$ #/L. However, the AirBeam sensors significantly underestimated (about 80% less) the GRIMM PM$_{2.5}$ (slope = 5.66 and intercept = $-3.8 \times 10^6$).

- When GRIMM PM$_{2.5}$ count was less than $2.0 \times 10^6$ #/L, the AirBeam sensors tracked well with PM$_{2.5}$ (#/L) diurnal variations (concentration ramping) recorded by the GRIMM.

- The Airbeam sensors reached their maximum PM$_{2.5}$ reading of about $6.5 \times 10^4$ (x100/ft$^3$) when GRIMM PM$_{2.5}$ exceeded $1.0 \times 10^6$ #/L.

- The GRIMM showed very low measurement variability at low PM$_{2.5}$ count compared to the AirBeam sensors.

\[ y = 5.66x - 3.8E+06 \]
\[ R^2 = 0.77 \]
AirBeam PM\textsubscript{2.5} mass 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>147.9</td>
<td>11.5</td>
<td>-1086</td>
</tr>
<tr>
<td>2</td>
<td>243</td>
<td>25.4</td>
<td>-757</td>
</tr>
<tr>
<td>3</td>
<td>296.2</td>
<td>48.7</td>
<td>-408</td>
</tr>
</tbody>
</table>

• Overall, the three AirBeam sensors showed very low accuracy compared to FEM GRIMM at 20 °C and 40% RH, when varying PM\textsubscript{2.5} mass concentration from 10 to 50 µg/m\textsuperscript{3}. The AirBeam significantly overestimated the FEM GRIMM readings. According to the method of calculating accuracy, the %accuracy for the sensors were all negative. When PM\textsubscript{2.5} mass conc. was over 50 µg/m\textsuperscript{3}, AirBeam sensors reached a plateau of 315 µg/m\textsuperscript{3}.

AirBeam data recovery & intra-model variability & LDL

• Data recovery for PM\textsubscript{2.5} from all three AirBeam units was 100%.

• Substantial intra-model variability (45%) was observed between the three AirBeam sensors at low PM\textsubscript{2.5} concentration (measured by GRIMM) at 20 °C and 40% RH. When the PM\textsubscript{2.5} concentration measured by the GRIMM exceeded 50 µg/m\textsuperscript{3}, the AirBeam sensors quickly reached their maximum of 300 µg/m\textsuperscript{3}, and they stopped responding to any further concentration increase. Thus, intra-model variability for medium and high PM\textsubscript{2.5} concentration could not be estimated.

• AirBeam sensors’ LDL were close to 0 µg/m\textsuperscript{3}. 
AirBeam vs FEM GRIMM (PM$_{2.5}$; 5-min mean)

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

  **Low PM$_{2.5}$ Concentration**

  Precision could not be estimated at medium to high PM$_{2.5}$ concentration; at least one of the three AirBeam sensors reached the maximum PM$_{2.5}$ it could measure.

- Overall, the three AirBeam sensors showed good precision for almost all combinations of T and RH at low PM$_{2.5}$ concentration.

- At medium to high GRIMM PM$_{2.5}$, sensors’ precision could not be estimated, because the sensors were only reporting their maximum measurement value of 300 µg/m$^3$.

- FEM GRIMM precision was very high across all conditions.
AirBeam PM$_{2.5}$ Climate Susceptibility

Low Temp – RH ramping (medium conc.)

High Temp – RH ramping (low conc.)

AirBeam vs FEM GRIMM (RH ramping, low PM mass and 5 °C)
- FEM GRIMM
- Unit CA9
- Unit CC7
- Unit D42

AirBeam vs FEM GRIMM (RH ramping, low PM mass and 35 °C)
- FEM GRIMM
- Unit CA9
- Unit CC7
- Unit D42

From 15 to 40% RH
To 65% RH
Discussion

- **Accuracy**: Overall, the three AirBeam sensors showed very low accuracy compared to FEM GRIMM at 20 °C and 40% RH, when varying PM$_{2.5}$ mass concentration from 10 to 50 µg/m$^3$. The AirBeam sensors significantly overestimated the FEM GRIMM readings. According to the method of calculating accuracy, the %accuracy for the sensors were all negative. When PM$_{2.5}$ mass conc. was over 50 µg/m$^3$, Airbeam sensors reached plateau of 315 µg/m$^3$. (refer to slides 3, 4, and 5)

- **Precision**: Overall, the three AirBeam sensors showed good precision for almost all combinations of T and RH at low PM$_{2.5}$ concentration. At moderate to high GRIMM PM$_{2.5}$, sensors’ precision could not be estimated, because the sensors were only reporting their maximum value of 300 µg/m$^3$. (refer to slide 6)

- **Data recovery**: Data recovery for PM$_{2.5}$ from all three AirBeam units was 100%.

- **Coefficient of Determination**: AirBeam sensors showed strong correlation/linear response with the corresponding FEM GRIMM PM$_{2.5}$ measurement data ($R^2 \sim 0.87$) for mass concentrations below 50 µg/m$^3$ (refer to slides 3 and 4)

- **Lower detection limit (LDL)**: AirBeam sensors’ LDL was close to 0 µg/m$^3$.

- **Climate susceptibility**: From the laboratory studies, temperature and relative humidity had little effect on the sensor performance at low GRIMM PM$_{2.5}$. However, at high PM$_{2.5}$ concentrations, sensors failed to respond to the diurnal variations and all reached their maximum output reading of about 300 µg/m$^3$, therefore, the effect under those conditions could not be studied. (refer to slide 7)