Results and Lessons Learned from Using Low-Cost PM Sensors to Detect Ambient PM$_{2.5}$ and PM$_{10}$

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for
PQAO Meeting
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Outline

• Background on air sensors
• Studies
  – PM\textsubscript{10} coal dust
  – PM\textsubscript{2.5} winter PM conditions
  – PM\textsubscript{10} windblown dust
  – PM\textsubscript{2.5} wood smoke
• Lessons learned
Startups (2014)

- AirBase
- Sensaris
- Cairpol
- Airboxlab
- Libelium
- Esensors
- CubeSensor
- Canary
- Lapka
- Sensordrone
Startups (now)
Key Issues

- New technology
- Data logging
- Communications
- Data management
- Cost
- Scale
Evaluation Efforts

- EPA evaluating sensor technology
  - Laboratory and infield evaluations
  - Ozone, NO$_2$, PM, and VOCs

- Joint Research Center (EU)
  - Evaluation for last 4 years

- SCAQMD
  - Air Quality Sensor Performance Evaluation Center (AQ-SPEC)
  - Field and laboratory evaluations
  - Ozone, PM, NO$_x$, CO, VOCs, H$_2$S
Results

• Evaluations
  – Compare to FEM reference

• Results
  – VOCs: Needs more work
  – Gases: Some promise for ozone, CO, NO
  – PM: Good results from some sensors

PM$_{2.5}$
5-min average
$r^2 = 0.78$

PM$_{10}$
1-hr average
$r^2 = 0.81$
Path Forward

- How Good? Evaluations
- How Useful? Field Projects
- How Sustainable? Businesses

- In progress
- ?

Background
1. Study – Coal Dust ($PM_{10}$)

- **Objectives**
  - Determine whether sensors can detect and quantify fugitive $PM_{10}$ from coal piles
  - Identify sensor limitations and technical challenges

- **Study**
  - 2-month study in warm climate
  - Weather station

### Equipment

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Instrument</td>
<td>MetOne BAM-1020 $PM_{10}$</td>
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<tr>
<td></td>
<td>Thermo PDR-1500</td>
</tr>
<tr>
<td>Sensors</td>
<td>Dylos</td>
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<td>AirBeam</td>
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</tbody>
</table>

Sponsor: Electric Power Research Institute (EPRI)
1. Results – Coal Dust (PM$_{10}$)

- 17 events were identified
  - Short in duration (a few minutes)
  - Concentrations were 2–5 times higher than background
- 37 of 1,392 hours (2.7%) were impacted by windblown dust events

Sponsor: Electric Power Research Institute (EPRI)
1. Results – Coal Dust (PM$_{10}$)

Dylos had good correlation with the BAM for events; weak correlation for all data
2. Study – Winter (PM$_{2.5}$)

- **Objectives**
  - Examine the use of low-cost PM sensors for answering questions about Tribal air quality
  - Conduct intercomparison study and mobile sampling

- **Study**
  - 8-month study in northern Minnesota (Oct-June)
  - Outdoor exposure

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<tr>
<td></td>
<td>FRM – PM$_{2.5}$ (1-in-6 day)</td>
<td>AirBeam MicroPEM</td>
</tr>
</tbody>
</table>

Sponsor: U.S. EPA and Leech Lake Band of Ojibwe
2. Results – Winter (PM$_{2.5}$)

- The MicroPEM and AirBeam B are well correlated during most time periods between calibration/zeroing.
- The MicroPEM was difficult to zero properly and exhibited significant baseline shifts between calibration/zeroing.

Sponsor: U.S. EPA and Leech Lake Band of Ojibwe
2. Results – Winter (PM$_{2.5}$)

Good correlations ($R^2$) between 24-hr sensor measurements on FRM sample days for AirBeam and bias-corrected MicroPEM

<table>
<thead>
<tr>
<th></th>
<th>FRM 1</th>
<th>FRM 2</th>
<th>MicroPEM</th>
<th>AirBeam A</th>
<th>AirBeam B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FRM 1</strong></td>
<td>1.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>FRM 2</strong></td>
<td>0.93</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>MicroPEM</strong></td>
<td>0.01$^{uc}$, 0.96$^{bc}$</td>
<td>0.01$^{uc}$, 0.89$^{bc}$</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
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<tr>
<td><strong>AirBeam A</strong></td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>-</td>
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<tr>
<td><strong>AirBeam B</strong></td>
<td>0.83</td>
<td>0.85</td>
<td>0.01$^{uc}$, 0.95$^{bc}$</td>
<td>NA</td>
<td>1.00</td>
</tr>
</tbody>
</table>

$^{uc}$ Uncorrected MicroPEM PM$_{2.5}$ data

$^{bc}$ Bias-corrected MicroPEM PM$_{2.5}$ is well correlated with the FRMs

Sponsor: U.S. EPA and Leech Lake Band of Ojibwe
3. Study – Windblown Dust ($PM_{10}$)

**Objectives**
- Can low-cost PM sensors detect dust events?
- How precise are the sensors?
- Are they reliable?
- Can they provide sufficient warning time?

**Study**
- 3-month springtime study
- School in eastern Santa Barbara County

**Equipment**

| Reference Instrument | MetOne BAM 1020 (FEM for $PM_{10}$)  
|                      | GRIMM 11-R (Particle counts)       
|                      | MetOne E-BAM ($PM_{10}$)           |
| Sensors              | AirBeam (3 units)                  
|                      | Alphasense OPC-N2 (3 units)        |

Sponsor: Santa Barbara County Air Pollution Control District
3. Results – Windblown Dust (PM$_{10}$)

Alphasense A vs. BAM
Hourly PM$_{10}$ measurements
$R^2 = 0.81$

Alphasense A vs. Alphasense B
Hourly PM$_{10}$ measurements
$R^2 = 0.81$
BAM = $1 \times x + 1.95$

Sponsor: Santa Barbara County Air Pollution Control District
3. Results – Windblown Dust (PM$_{10}$)

Early Detection
Alphasense A measures a peak at 21:21, for a lead time of 39 minutes over the FEM instrument.

Note: BAM reported at begin hour but not available until after the hour.
4. Study – Woodsmoke (PM$_{2.5}$)

• Objectives
  – Use low-cost sensors to provide spatial coverage and engage community
  – Assess the contribution of wood burning to air toxics in Sacramento

• Study
  – Sacramento Metropolitan AQMD project funded by EPA Grant
  – Two existing regulatory monitoring stations, 4 new temporary monitoring sites with FEMs, 9 new sites with low-cost monitors
  – Two-month wintertime study
  – Are certain communities in Sacramento County disproportionately impacted by wood smoke?

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<td>Aethalometer (BC)</td>
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Sponsor: SMAQMD
4. Study – Woodsmoke (PM$_{2.5}$)
4. Study – Woodsmoke (PM$_{2.5}$)
Early exploration of data to understand how well the sensors are doing and how they respond to relative humidity.

\[1.51 \times x - 1.24\]

\[R^2 = 0.72\]

\[n = 151\]
Key Challenges

• New technology
  – Rapid changes; versioning issues with firmware
  – Drift, calibration requirements, and “soiling” issues
  – Hardware issues
  – Unknown lifetime

• Data logging
  – Data acquisition systems don’t always handle sensors
  – Data formats and time standards

• Communications
  – Critical for high data availability
  – More challenging and costly
Key Challenges

- **Data management**
  - More challenging than FEM instrument (60 to 3600 times more data and more uncertainty)

- **Cost**
  - Projects cost much more than one sensor
  - Operations and data management are more intense

- **Scale**
  - 3 sensors vs. 10 sensors vs. 100 sensors
  - Scale affects everything (logistics, data management, reliability, costs)
Path Forward

How Good? Evaluations

How Useful? Field Projects

How Sustainable? Businesses

√ In progress

?
Contact

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