Evaluation of Small Sensor Technology for Criteria Pollutants at Ground-based Sites and a Citizen Science Network

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U.S. Environmental Protection Agency

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Outline

• Background information
  – Next Generation Air Monitoring
  – DISCOVER-AQ Study
• Houston, TX deployment (CairClip Sensors)
  – Citizen science-based sensor network
  – Educational Outreach
  – Results from sensor network
• EPA RTP, NC AIRS (AQMesh Sensor)
• Current and future work
Next Generation Air Monitoring

- Small sensors are a rapidly emerging technology for measuring air pollutants
- Growing interest in understanding the capability of sensors to accurately measure criteria pollutants in ambient air
- Potential to use these devices for various applications
DISCOVER-AQ (Deriving Information on Surface Conditions from Column and VERtically Resolved Observations Relevant to Air Quality)

- NASA earth science suborbital venture mission
- Science Question:
  - Under what conditions can ambient air quality be reliably informed using satellite remote sensing?
- Multi-Year Mission
  - Baltimore, MD – Washington, DC (June-July 2011)
  - San Joaquin Valley, CA (January-February 2013)
  - **Houston, TX (September 2013)**
  - Denver, CO (July-August 2014)
DISCOVER-AQ
Observational Components

**NASA King Air (Remote sensing)**
Continuous mapping of aerosols with HSRL and trace gas columns with ACAM

**NASA P-3B (in situ measurements)**
In situ profiling of aerosols and trace gases over surface measurement sites.

**Ground Sites**
- Ambient trace gases and aerosols (based on EPA FRM/FEM)
- Remote sensing of trace gas and aerosol columns
- Aerosol and Ozone profiles
EPA Collaboration with DISCOVER-AQ

- Conducting research in Federal Reference and Equivalent methods (FRM/FEM) used for NAAQS compliance
  - Direct measurement methods for nitrogen dioxide (NO$_2$) and oxides of nitrogen (NOx)
  - New ozone (O$_3$) FRM
- Changing the paradigm of air pollution monitoring
  - Remote sensing technology
  - Small sensor technology
EPA Federal Reference and Equivalent Methods Program

• **Federal Reference Methods (FRM)**
  - Method, sampler, or analyzer that utilizes measurement principles and calibration procedure specified in 40 CFR* Part 50

• **Federal Equivalent Methods (FEM)**
  - Method that has been tested under 40 CFR Part 53 and designated by EPA as an FEM under Part 53

• **FRM/FEM** provide a specified, definitive method for measuring criteria pollutants for comparison to the National Ambient Air Quality Standards (NAAQS)

* CFR = Code of Federal Regulations
DISCOVER-AQ Houston
September 4-28, 2013
Field measurements were located at 4 sites. A small sensor network was deployed at local schools.

**Ground sites/measurements**
- *In situ (ambient) trace gases and aerosols*
- *Remote sensing of trace gas and aerosol columns*
- *Aerosol & Ozone profile observations*
- *Compact sensors of trace gas*
8 schools participated (elementary, junior high, and high school)

Teachers trained on how to operate sensors

Teachers/students collected data and incorporated activities into lesson plans

EPA scientists visited schools and conducted educational outreach activities
CairClip Sensor

• Electrochemical sensor
  – Measures current between working electrode and counter electrode
  – Gas reacts at working electrode and generates a measurable difference in electrical potential between electrodes
  – Difference proportional to target gas concentration

• Contains micro fan to allow for dynamic air sampling

• Includes air filter to remove particles from sample

• Sensor components enclosed in aluminum-based casing cylinder (32 X 62mm)
CairClip Sensor

- 2 versions: NO$_2$ and combined O$_3$+NO$_2$
- Detection Range: 0-250 ppb
- Weight: 55 grams (0.12 pounds)
- Dimensions: 32 mm wide, 63 mm long
- Battery life: ≥ 24 hours
- Recharging battery: 4-6 hours to charge
- Data storage: 28,800 data points (20 days of 1 minute averaged data)
- Data retrieval: Cairsoft software
<table>
<thead>
<tr>
<th>School</th>
<th>Sensor Type</th>
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<tbody>
<tr>
<td></td>
<td>AQMesh*</td>
<td>CairClip NO₂</td>
<td>CairClip O₃+NO₂</td>
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<tr>
<td>Lomax Junior High</td>
<td>X</td>
<td>X</td>
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<tr>
<td>College Park Elementary</td>
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<tr>
<td>Heritage Elementary</td>
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<tr>
<td>Deer Park High South</td>
<td>X</td>
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<tr>
<td>Deer Park High North</td>
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<td>X</td>
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<tr>
<td>Deer Park Elementary</td>
<td>X</td>
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<tr>
<td>JP Dabbs Elementary</td>
<td>X</td>
<td>X</td>
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<tr>
<td>DeZavela Elementary</td>
<td>X</td>
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<td>X</td>
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<tr>
<td>LaPorte Airport (Ground site)</td>
<td>X</td>
<td>X</td>
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* Sensor deployed by NASA; measures NO₂, NO, O₃, SO₂, and CO
Sensor Network Results

Sensor data will be shown for these schools only.
• CairClip sensors collocated with O$_3$ and NO$_2$/NOx FRM/FEM measurements
• Missed approach site for NASA-P3B Aircraft
La Porte Airport (La Porte, TX)
EPA Ground-Based Site

- Very good agreement between CairClip and FRM measurements
- Ozone NAAQS (75 ppb, 8hrs) exceeded on September 25, 2013
La Porte Airport (La Porte, TX)
EPA Ground-Based Site

• CairClip reported much higher NO$_2$ measurements
• Ozone NAAQS exceedance day on September 25, 2013
  • Good agreement between Cairclip O$_3$+NO$_2$ and FRM
Identified secure areas at each school to place sensors
  - Flag poles or sturdy columns
Avoided placing sensors near high pollution spots
  - Bus lanes
  - Student drop off/pick up
Teachers/students deployed sensors in morning and collected them at the end of the day
Teachers/students able to track flight days and asked to deploy sensors on flight days
  - 10-12 flight days total
Lomax Junior High (La Porte, TX)  
~ 1 mile from La Porte Airport

CairClip Sensor

AQMesh Sensor
Lomax Junior High (La Porte, TX)  
~ 1 mile from La Porte Airport

- Sensors normally deployed on NASA P-3B flight days
- CairClip $O_3$+NO$_2$ sensor performed well
Heritage Elementary (La Porte, TX)
~ 2 miles from La Porte Airport

AQMesh Sensor

CairClip Sensor
• CairClip $O_3+NO_2$ sensor performed well
College Park Elementary (La Porte, TX)  
~ 3 miles from La Porte Airport

- Low cost sensor performed well
Deer Park High South (Deer Park, TX) ~ 4.5 miles from La Porte Airport
• CairClip $O_3 + NO_2$ sensor performed well
Deer Park High North (Deer Park, TX) ~ 6 miles from La Porte Airport

- Low cost sensor performed well
EPA Scientists gave presentations at 4 schools, ranging in grades from Kindergarten to 12th Grade, for a total of 650 students!

About 250 students (7th and 8th Grade) visited EPA’s ground site at La Porte Airport.
“The students and I have loved being involved in this project, and I know they have a better understanding of air quality, the effects of pollution, the science processes, and what being a scientist entails in general.” Katy Jordan, 5th Grade Science Teacher, Heritage Elementary School

“Thank you for including us in this study!” Kristen Knoedler, Science Department, Deer Park High School South

“There is no way for us to express our gratitude to the EPA and NASA for the experience given to the Dabbs students. Everyone’s willingness to contribute in all the ways they have has been unbelievable. We have enjoyed the chatting, the question and answer session, and the field trip (which I am so sorry I couldn’t attend). These opportunities provided our children experiences they will never forget, have motivated many, and has peaked their interest in science. Thank you again for allowing Dabbs to participate in the research study and we look forward to hearing from you!” Becky Turner, Amy Etchberger 5th Grade Science Teachers, JP Dabbs Elementary School

“Thank you so much for including us. The students learned so much and had a blast while learning! We also really enjoyed the presentation Friday. All grade levels told me that they loved it!” Elaine Finnen, 5th Grade Science Teacher, College Park Elementary School
Summary of Sensor Network in Houston, TX

- Pilot sensor study proved to be successful
- CairClip O₃+NO₂ sensors performed very well throughout sensor network
  - Data compared well to FRM/FEM measurements
- NO₂ CairClip sensor data showed less agreement
  - NO₂ concentrations more localized
- Sensor technology capable of filling in spatial gaps along aircraft path
EPA-RTP AIRS Site
AQMMesh Evaluation
AQMesh Sensor

- Multi-pollutant Sensor (NO$_2$, NO, O$_3$, SO$_2$, CO) and met measurements (RH, temp, pressure)
- Electrochemical sensors
- Weight: < 4 lbs
- Size: 4.6 x 7.0 x 5.5 inches
- Battery powered (lifetime ~ 2 years*)
- Built in wireless GPRS communications
- Reading Intervals: 1 min, 15 min, 30 min

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Range Accuracy (ppb)</th>
<th>Lower Detectable Limit (ppb)</th>
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<tbody>
<tr>
<td>NO</td>
<td>0-20,000</td>
<td>&lt; 3 ppb</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>0-200</td>
<td>&lt; 5 ppb</td>
</tr>
<tr>
<td>O$_3$</td>
<td>0-200</td>
<td>&lt; 5 ppb</td>
</tr>
<tr>
<td>CO</td>
<td>0-50,000</td>
<td>&lt; 5 ppb</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>0-100,000</td>
<td>&lt; 5 ppb</td>
</tr>
</tbody>
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* Depends on reading interval
- AIRS site on EPA-RTP Campus
- 16 days of data
  - June 1-16, 2014
- AQMesh collocated with FRM/FEM measurements
- Focus: NO₂, NO, O₃, and SO₂
- 2 pods installed to evaluate precision and comparability to FRM/FEM measurements
15 Minute Averaged Data

- Fair agreement between AQMesh and FRM measurements
- AQMesh pods agree well with each other
- Moderate to fair agreement between AQMesh and FRM
Preliminary NO$_2$ and NO Data

- Poor agreement between AQMesh and FRM measurements
- AQMesh readings significantly higher
- Issues discovered with NO$_2$ sensors which required replacement
Preliminary SO₂ Data

- Poor agreement between AQMesh and FRM measurements
- AQMesh readings significantly higher
- Poor agreement between both pods

![Graph showing 15 Minute Averaged Data](image)

**Regression Analysis**

\[ y = 0.93x + 7.09 \]

\[ R^2 = 0.26 \]
Current Work

Final DISCOVER-AQ deployment in Denver, CO
July 16-Aug 11, 2014
DISCOVER-AQ Denver, CO

- Continuing to evaluate small sensor technology
  - Expanding network with new sensor technologies
  - Collocating sensors with FRM/FEM measurements
  - Understanding vertical distribution of pollutants (ground level to 300 meters)
- Citizen science and educational outreach
  - Citizens host sensors
  - Visiting local museums
TEMPO

- NASA’s first Earth Venture Instrument expected to launch in 2018
- Provides hourly daylight observations to capture rapidly varying emissions & chemistry important for air quality
- Potential to use small sensor technology at ground-based sites
Acknowledgements

- Alion Science and Technology
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- Citizen Scientists
  - Lomax Junior High, College Park Elementary, Heritage Elementary, Deer Park High South, Deer Park High North, DeZavela Elementary, JP Dabbs Elementary
- US EPA – Ron Williams, Nealsone Watkins
Thank You
Questions?

Disclaimer: Although this work was reviewed by EPA and approved for presentation, it may not necessarily reflect official Agency policy.