The Pittsburgh RAMP network: Development, deployment, results, and lessons learned

Albert Presto
November 20, 2019
Acknowledgments

Postdocs

Collaborators

PhD students

Funding Sources

This research is funded by U.S. EPA - Science to Achieve Results (STAR) Program. Grant #
Three main points

• Low-cost sensors can meet EPA metrics for supplemental and exposure monitoring

• Citywide networks can be used to separate local emissions from regional climatology impacts and to evaluate environmental justice, but cannot capture all spatial variations

• Low-cost monitors are good candidates for monitoring in case of extreme or unexpected events
The trend: Hyper-local air quality

BC ($\mu g/m^3$)
- High
- Low

Tan et al, 2016
The trend: Hyper-local air quality + social media
Many low-cost sensors are commercially available

<table>
<thead>
<tr>
<th>PM Sensors</th>
<th>Gaseous Sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sensor</strong></td>
<td><strong>Make (Model)</strong></td>
</tr>
<tr>
<td><strong>Aeroqual</strong> (AQY) Ver. 0.5</td>
<td>$3,000</td>
</tr>
<tr>
<td>Actlabs (microAeth)</td>
<td>$6,500</td>
</tr>
<tr>
<td>Air Quality Egg (2018 Model)</td>
<td>$249</td>
</tr>
<tr>
<td>Air Quality Egg (Version 1)</td>
<td>$200</td>
</tr>
<tr>
<td>Air Quality Egg (Version 2)</td>
<td>$1000</td>
</tr>
<tr>
<td>AirThinx (IAQ)</td>
<td>$150</td>
</tr>
<tr>
<td>Airviz Inc. (Speck)</td>
<td>$310</td>
</tr>
</tbody>
</table>

| **Sensor** | **Make (Model)** | **Est. Cost (USD)** | **Type** | **Meas.** | **Field R²** | **Lab R²** | **Summary Report** |
| **2B Technologies (POM)** | $4,500 | UV absorption (FEM Method) | O$_3$ | 1.00 | 0.99 | PDF (1,295 KB) |
| **Aeroqual** (AQY) Ver. 0.5 | $3,000 | Electrochem | NO$_2$ | 0.77 | 0.98 | PDF (1,158 KB) |
| **Aeroqual** (S-500) | $500 | Metal Oxide | O$_3$ | 0.85 | 0.99 | PDF (1,197 KB) |
| **Air Quality Egg** Ver. 1 | $200 | Metal Oxide | CO | 0.0 | 0.0 | NO$_2$ | 0.40 |
| **Air Quality Egg** Ver. 2 | $240 | Electrochem | CO | 0.0 | 0.0 | NO$_2$ | 0.0 |
| **Air Quality Egg** Ver. 3 | $240 | Electrochem | O$_3$ | 0.0 to 0.20 | 0.0 | SO$_2$ | n/a |
# AQ-SPEC

**Air Quality Sensor Performance Evaluation Center**

## PM Sensors

<table>
<thead>
<tr>
<th>Sensor Image</th>
<th>Make (Model)</th>
<th>Est. Cost (USD)</th>
<th>Pollutant(s)</th>
<th>Field $R^2$</th>
<th>Lab $R^2$</th>
<th>Summary Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aeroqual (AQY)</td>
<td>Aeroqual (AQY)</td>
<td>$3,000</td>
<td>PM$_{2.5}$</td>
<td>0.84 to 0.87</td>
<td>0.99</td>
<td>PDF (1,178 KB)</td>
</tr>
<tr>
<td>Ver. 0.5</td>
<td>AechLabs (microAeth)</td>
<td>$6,500</td>
<td>BC (Black Carbon)</td>
<td>0.79 to 0.94</td>
<td>0.99</td>
<td>PDF (771 KB)</td>
</tr>
<tr>
<td>Air Quality Egg</td>
<td>Air Quality Egg (2018 Model)</td>
<td>$249</td>
<td>PM$_{1.0}$</td>
<td>0.86 to 0.88</td>
<td>0.99</td>
<td>PDF (771 KB)</td>
</tr>
<tr>
<td>(Version 1)</td>
<td>Air Quality Egg (Version 2)</td>
<td>$200</td>
<td>PM</td>
<td>$\sim$ 0.0</td>
<td>0.99</td>
<td>PDF (771 KB)</td>
</tr>
<tr>
<td>AirThinx (IAQ)</td>
<td>$1000</td>
<td>PM$_{1.0}$</td>
<td>0.68 to 0.70</td>
<td>0.99</td>
<td>PDF (1,178 KB)</td>
<td></td>
</tr>
<tr>
<td>Airviz Inc. (Speck)</td>
<td>$150</td>
<td>PM$_{2.5}$</td>
<td>0.32</td>
<td>0.99</td>
<td>PDF (1,178 KB)</td>
<td></td>
</tr>
<tr>
<td>Alphasense (OPC-N2)</td>
<td>$310</td>
<td>PM$_{1.0}$</td>
<td>0.63 to 0.82</td>
<td>0.99</td>
<td>PDF (1,178 KB)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>PM$_{2.5}$</td>
<td>0.65 to 0.80</td>
<td>0.99</td>
<td>PDF (1,178 KB)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>PM$_{10}$</td>
<td>0.45 to 0.57</td>
<td>0.99</td>
<td>PDF (1,178 KB)</td>
<td></td>
</tr>
</tbody>
</table>

## Gaseous Sensors

<table>
<thead>
<tr>
<th>Sensor Image</th>
<th>Make (Model)</th>
<th>Est. Cost (USD)</th>
<th>Type</th>
<th>Meas.</th>
<th>Field $R^2$</th>
<th>Lab $R^2$</th>
<th>Summary Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>2B Technologies (POM)</td>
<td>2B Technologies (POM)</td>
<td>$4,500</td>
<td>UV absorption (FEM Method)</td>
<td>O$_3$</td>
<td>1.00</td>
<td>0.99</td>
<td>PDF (1,295 KB)</td>
</tr>
<tr>
<td>Aeroqual (AQY)</td>
<td>Aeroqual (AQY)</td>
<td>$3,000</td>
<td>Metal Oxide</td>
<td>O$_3$</td>
<td>0.77</td>
<td>0.98</td>
<td>PDF (1,158 KB)</td>
</tr>
<tr>
<td>Ver. 0.5</td>
<td>Air Quality Egg (S-500)</td>
<td>$500</td>
<td>Metal Oxide</td>
<td>O$_3$</td>
<td>0.95</td>
<td>0.98</td>
<td>PDF (1,163 KB)</td>
</tr>
<tr>
<td>Air Quality Egg</td>
<td>Air Quality Egg (S-500)</td>
<td>$200</td>
<td>Metal Oxide</td>
<td>CO</td>
<td>0.0</td>
<td>0.99</td>
<td>PDF (1,197 KB)</td>
</tr>
<tr>
<td>Egg</td>
<td>Air Quality Egg (S-500)</td>
<td>$240</td>
<td>Electrochem</td>
<td>NO$_2$</td>
<td>0.40</td>
<td>0.99</td>
<td>PDF (1,197 KB)</td>
</tr>
<tr>
<td>Ver. 1</td>
<td>Air Quality Egg (S-500)</td>
<td>$240</td>
<td>Electrochem</td>
<td>O$_3$</td>
<td>0.85</td>
<td>0.99</td>
<td>PDF (1,197 KB)</td>
</tr>
<tr>
<td>Air Quality Egg</td>
<td>Air Quality Egg (S-500)</td>
<td>$240</td>
<td>Electrochem</td>
<td>CO</td>
<td>0.0</td>
<td>0.99</td>
<td>PDF (1,197 KB)</td>
</tr>
<tr>
<td>Egg</td>
<td>Air Quality Egg (S-500)</td>
<td>$240</td>
<td>Electrochem</td>
<td>NO$_2$</td>
<td>0.0</td>
<td>0.99</td>
<td>PDF (1,197 KB)</td>
</tr>
</tbody>
</table>
Real-time Affordable Multi-Pollutant (RAMP) monitor

- **Pollutants measured:**
  - CO, O\textsubscript{3}, NO\textsubscript{2}, SO\textsubscript{2}, PM\textsubscript{2.5}
  - GSM communication
  - Deployed for 1+ year
RAMPs use electrochemical gas sensors and optical PM$_{2.5}$ measurement


Zimmerman et al, AMT, 2018
We developed machine learning calibration algorithms for electrochemical gas sensors

![Scatter plot showing the relationship between O₃ (ppb) values from Calibrated RAMP and ACHD Ref. Monitor. The plot includes a best-fit line with a slope of 0.75, an intercept of 3.2 ppb, and an R² value of 0.92.](image_url)
Machine learning cals give performance close to EPA standards for reference monitoring.
Machine learning calcs give performance close to EPA standards for reference monitoring.

Zimmerman et al, *AMT*, 2018
Machine learning calcs give performance close to EPA standards for reference monitoring.

Zimmerman et al, AMT, 2018
Calibrations allow us to resolve differences between sites

Zimmerman et al, AAQR, 2019
RAMPs use electrochemical gas sensors and optical PM$_{2.5}$ measurement

http://www.cas.manchester.ac.uk/restools/instruments/aerosol/opc/cavity/index.html
Raw Purple Air output shows humidity bias

MAE = 4.2 $\mu$g/m$^3$

bias = 1.9 $\mu$g/m$^3$

$r = 0.76$
Humidity correction removes the bias; hourly data are still scattered.
1 hr: 3 – 4 μg m⁻³

1 day: 2 – 2.5 μg m⁻³

1 week: 1.5 μg m⁻³

6 month: 1 μg m⁻³
Pittsburgh RAMP network (2017)

N = 48
Pittsburgh RAMP network (2017)

N = 48
PM$_{2.5}$ spatial variability is largely driven by emissions spikes
PM$_{2.5}$ spatial variability is largely driven by emissions spikes
PM$_{2.5}$ spatial variability is largely driven by emissions spikes.

Downtown/High traffic | Urban Background | Industrial

Tanzer et al, *IJERPH*, 2019
PM$_{2.5}$ spatial variability is largely driven by emissions spikes

Tanzer et al, IJERPH, 2019
PM$_{2.5}$ spatial variability is largely driven by emissions spikes.
Some source-impacted sites are never “background”

- Highway
- Downtown
- Downwind Industrial

Tanzer et al, *IJERPH*, 2019
Some source-impacted sites are never “background” – but it depends on the pollutant.
The network provides information on how exposure patterns change throughout the day.
Application to extreme events
Air Quality in Puerto Rico in the Aftermath of Hurricane Maria: A Case Study on the Use of Lower Cost Air Quality Monitors

R. Subramanian,*,† Aja Ellis,†,∞ Elvis Torres-Delgado,‡ Rebecca Tanzer,† Carl Malings,† Felipe Rivera,§ Maité Morales,∥ Darrel Baumgardner,‖ Albert Presto,*,∞ and Olga L. Mayol-Bracero*
Crews respond to fire at Coke plant

Thankfully, no one has been injured in the fire at a Coke plant in Pittsburgh.

During a press conference on December 24, the Pittsburgh Fire Department said the fire was caused by an electrical issue in one of the Coke production buildings. The fire, which started just after 2 p.m., has been contained and there are no reports of injuries.

The fire has caused a temporary halt of production at the plant, and the company is currently investigating the cause. The fire department said they will work to ensure that the plant is safe before production can resume.

The Pittsburgh Post-Gazette report that the fire was first reported on Twitter, where a user posted a photo of the fire and the words "#HotIdle." The hashtag "#HotIdle" is often used to express frustration or anger.

The event has sparked a conversation on social media, with many users expressing concern for the safety of the workers and the environment.

The Pittsburgh Post-Gazette also reports that the fire department was able to quickly respond to the incident, thanks to the efforts of the local fire department and the community.

The fire is currently under investigation, and the Pittsburgh Post-Gazette will continue to report on the situation as more information becomes available.

DON HOPEY
Pittsburgh Post-Gazette
chopey@post-gazette.com

JAN 22, 2019 7:24 PM
The RAMP network captures upset events at Clairton
The RAMP network captures upset events at Clairton
RAMP data are publicly available
We provide RAMP reports to hosts
Three main points

• Low-cost sensors can meet EPA metrics for supplemental and exposure monitoring

• Citywide networks can be used to separate local emissions from regional climatology impacts and to evaluate environmental justice, but cannot capture all spatial variations

• Low-cost monitors are good candidates for monitoring in case of extreme or unexpected events
Was it worth the effort?

• 50-node networks of low-cost sensors might not be ‘low cost’
  • Even reliable sensors break down
  • Should this be repeated at scale in multiple cities?

• Dense network is good at capturing:
  • Broad spatial gradients
  • PM plumes and other episodic events
The policy focus has traditionally been on regional improvements.

Data: Allegheny County Health Dept.

1.25 MM residents
Generalized calibrations perform nearly as well as individual ones

CO: Individual

Malings et al, AMT, 2019