Maximizing insights from air quality sensor networks through continuous performance evaluation

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Dan Peters
Senior Air Quality Data Analyst
Environmental Defense Fund
dpeters@edf.org
What I’m going to talk about

Project background
What we learned
Conclusions

Evaluating uncertainty in sensor networks for urban air pollution insights

Daniel R. Peters¹, Olalekan A. M. Popoola², Roderic L. Jones², Nicholas A. Martin³, Jim Mills²,
Elizabeth R. Fonseca⁴, Amy Stidworthy⁴, Ella Forsyth⁴, David Carruthers⁶, Megan Dupuy-Todd⁴, Felicia Douglas⁵,
Katie Moore¹, Rishabh U. Shah¹, Lauren E. Padilla¹, and Ramón A. Alvarez¹
Project background
The Breathe London pilot project (BL)

Additional activities

Sensor network

Mobile monitoring

Air quality modeling

Wearables study

www.breathelondon.org/pilot
How reliably can a large network of sensors characterize local air pollution?
A data-rich context for validation

- Extensive network of reference-grade monitors
- ~100 sensor-reference collocations

![Image of Greater London map showing reference and BL sensor locations](image)

![Image of BL sensor pod](image)

![Image of London Air Quality Network (LAQN) monitor](image)

![Image of AQMesh reference monitor](image)

![Image of graph showing performance metrics](image)
Ongoing sensor evaluation with “test” sensors that remained at reference sites

I hope to convince you to install a subset of sensors alongside reference monitor(s) for the full duration of any sensor network deployment.
## Context for comparing BL and reference networks

<table>
<thead>
<tr>
<th></th>
<th>Breathe London pilot project (BL)</th>
<th>London reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Device</strong></td>
<td>AQMesh small sensor air quality monitoring system</td>
<td>Reference monitors from multiple UK networks: London Air Quality Network (LAQN), Air Quality England (AQE) network, and Automatic Urban and Rural Network (AURN)</td>
</tr>
<tr>
<td><strong>NO₂ method</strong></td>
<td>Electrochemical sensor</td>
<td>Chemiluminescent analyzer</td>
</tr>
<tr>
<td><strong>Total number</strong></td>
<td>100</td>
<td>105</td>
</tr>
<tr>
<td><strong>Site types</strong></td>
<td>Kerbside (n=36), Roadside (n=36), and Urban Background (n=40)</td>
<td>Kerbside (n=12), Roadside (n=62), and Urban Background (n=31)</td>
</tr>
<tr>
<td><strong>Modeled annual mean NO₂ (2019)</strong></td>
<td>36 µg m⁻³</td>
<td>41 µg m⁻³</td>
</tr>
</tbody>
</table>

Based on modeling, average NO₂ pollution at reference sites is expected to be $5 \text{ µg m}^{-3}$ higher than at BL sites.
NO$_2$ methodology

- **QA/QC**
  - Automated procedures (e.g., flag redaction and high/low limits)
  - Weekly manual inspection

- **Calibration**
  - Physical collocation
  - Remote network calibration

- **Ozone cross-interference correction**

- **Uncertainty evaluation**
  - Average hourly uncertainty (RMSE) of ± 35% compared to reference measurements

See detailed methods in our [paper](#) and in the [BL QA/QC Procedures document](#)
What we learned
Long-term network trends
Long-term network trends

![Graph showing NO₂ levels over time](image-url)
Long-term network trends
Weekday diurnal patterns at near-road and urban background sites
Weekday diurnal patterns at near-road and urban background sites

![Graph showing diurnal patterns of NO₂ at near-road and urban background sites. The graph indicates higher NO₂ levels at 8:00 and 18:00 for both Near-road (Kerb/Roadside) and Urban Background sites. The Breathe London site shows distinct peaks compared to the Reference site.](image-url)
Local hotspots

BL sensor pod

![Graph showing NO2 concentrations over time for BL Network and Holloway Bus Garage. The graph displays peaks in NO2 concentrations during specific hours.](image-url)
Can we rely on these numbers?

"The sensor situation" part 2

Guess I’ll have to look at my “test” sensors to find out
“Test” sensors as indicators for sensor network performance

Bias and error of “test” sensors varied seasonally and peaked during the summer.
Case study 1: Interpreting a short-term episode with elevated NO2 sensor measurements (July 2019)

Network mean concentrations

![Graph showing network mean concentrations with R² = 0.69]

**Is a real pollution event causing elevated BL network measurements?**

**Are the “test” sensors performing well?**

**“Test” sensor measurements are much higher than collocated reference**

**We can infer that the BL network spike was caused by sensor error**

“Test” sensor timeseries compared to collocated reference monitor

![Graphs showing NO2 levels from different units and dates]
Case study 2: Interpreting a short-term episode with elevated NO2 sensor measurements (December 2019)

Network mean concentrations

<table>
<thead>
<tr>
<th>NO2 (µg m⁻³)</th>
<th>Date (2019)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>Dec 01</td>
</tr>
<tr>
<td>50</td>
<td>Dec 02</td>
</tr>
<tr>
<td>75</td>
<td>Dec 03</td>
</tr>
<tr>
<td>100</td>
<td>Dec 04</td>
</tr>
<tr>
<td>25</td>
<td>Dec 05</td>
</tr>
<tr>
<td>50</td>
<td>Dec 06</td>
</tr>
<tr>
<td>75</td>
<td>Dec 07</td>
</tr>
</tbody>
</table>

R² = 0.96

“Test” sensor timeseries compared to collocated reference monitor

Is a real pollution event causing elevated BL network measurements?

Are the “test” sensors performing well?

“Test” sensor measurements closely track collocated reference

We can infer that BL network spike was really caused by elevated pollution levels
Conclusions
Differentiating robust air pollution patterns from measurement artifacts

- The BL network effectively characterized NO$_2$ pollution patterns, with some irregularities
  - We validated sensor network results using comparisons to London’s reference network
- In a place without an extensive reference network, you are left without the dashed line to compare against
  - How do you tell if measured events (like the ones below) are real?
Differentiating robust air pollution patterns from measurement artifacts

- We demonstrated the use of representative “test” sensors that were continuously stationed at reference sites as an indicator for network performance.

- Projects should use at least one reference monitor or another source of reliable measurements to track sensor performance on an ongoing basis.
In the future?

“Using sensors is so much easier now that technology, calibration, and QA/QC has improved, and my sensors meet certain performance standards.”

“The sensor situation” part 3
Thanks for listening!

Contact

Dan Peters
Senior Air Quality Data Analyst
Environmental Defense Fund
dpeters@edf.org

EDF’s Global Clean Air team
Extra slides
Case study 3: Correction for seasonal sensor bias

Bias (and RMSE) of “test” sensors varies seasonally, peaks during the summer

Application of monthly bias correction derived from “test” sensor collocations corrects irregularities in network mean timeseries
Comparison of modeled and measured NO2 at individual monitoring sites
Diurnal (hour-of-day) and day-of-week network patterns
Sensor bias vs. temperature during “test” collocations