Maximizing insights from air quality sensor networks through continuous performance evaluation

Air Sensors International Conference (ASIC) 2022

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What I'm going to talk about

Project background

What we learned

Conclusions

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Atmospheric Measurement Techniques
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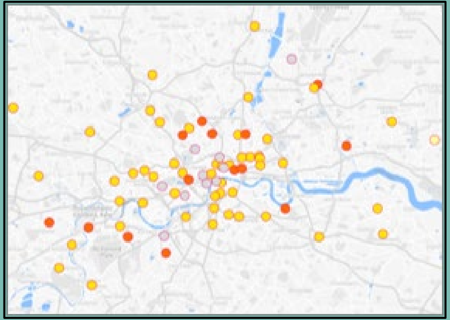
Evaluating uncertainty in sensor networks for urban air pollution insights

Daniel R. Peters[1], Olalekan A. M. Popoola[2], Roderic L. Jones[2], Nicholas A. Martin[3], Jim Mills[4], Elizabeth R. Fonseca[5], Amy Stidworthy[6], Ella Forsyth[6], David Carruthers[6], Megan Dupuy-Todd[1,a], Felicia Douglas[5], Katie Moore[1,b], Rishabh U. Shah[1], Lauren E. Padilla[1], and Ramón A. Alvarez[1]

Project background

The Breathe London pilot project (BL)

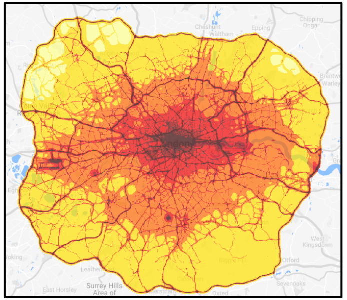
Sensor network



Additional activities

Mobile monitoring

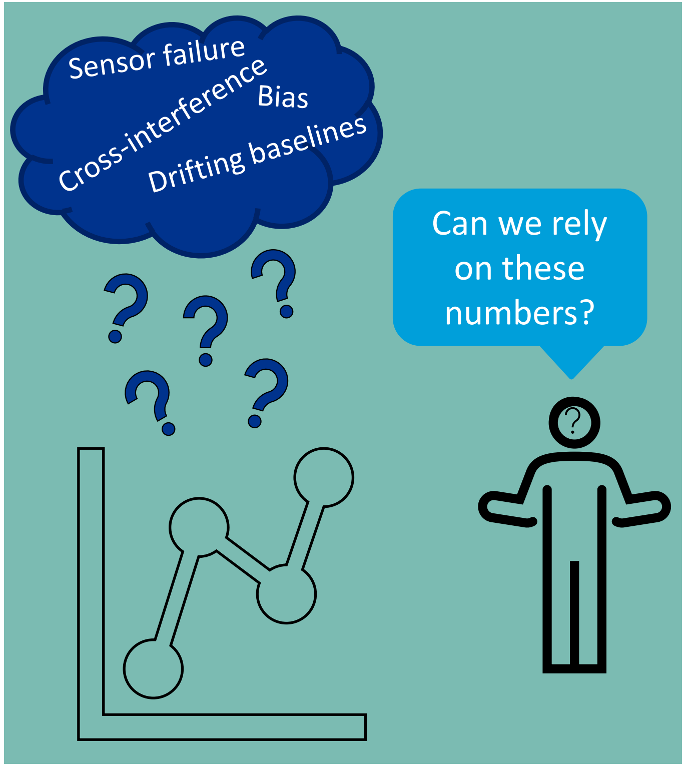
Air quality modeling



Wearables study

www.breathelondon.org/pilot

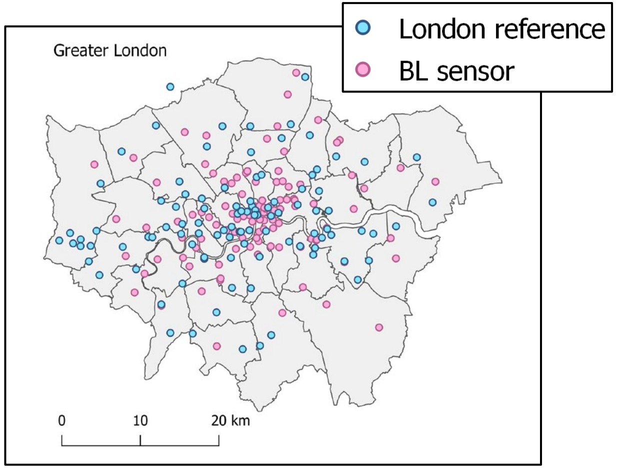
How reliably can a large network of sensors characterize local air pollution?



“The sensor situation” part 1

A data-rich context for validation

- Extensive network of reference-grade monitors



BL sensor pod

London Air Quality Network (LAQN) monitor

- ~100 sensor-reference collocations

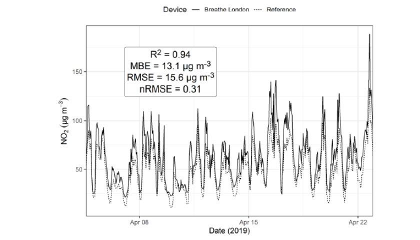
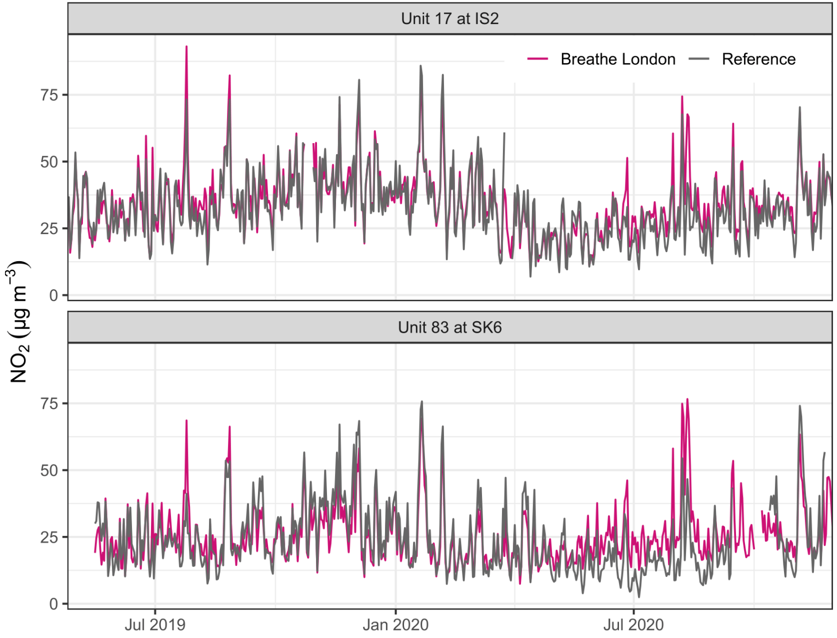


Figure S5: Example April 2019 reference collocation analysis result for BL sensor 2046150 at Camden, Swiss Cottage (CD1) reference site.

Ongoing sensor evaluation with “test” sensors that remained at reference sites

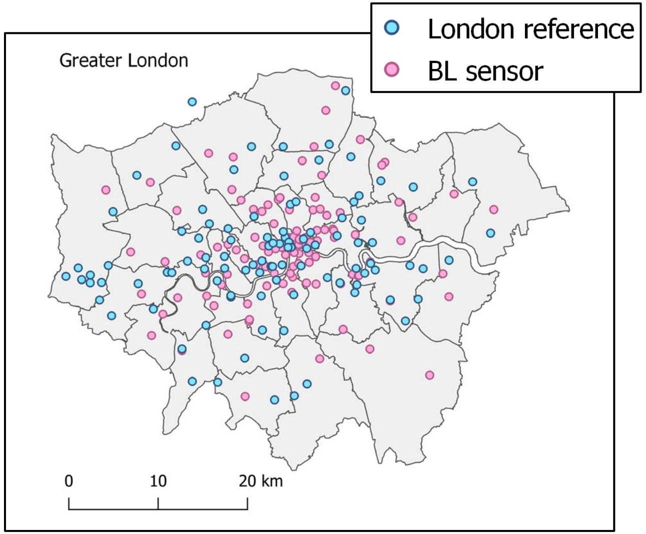


SPOILER ALERT

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

	Breathe London pilot project (BL)	London reference
Device	AQMesh small sensor air quality monitoring system	Reference monitors from multiple UK networks: London Air Quality Network (LAQN), Air Quality England (AQE) network, and Automatic Urban and Rural Network (AURN)
NO_2 method	Electrochemical sensor	Chemiluminescent analyzer
Total number	100	105
Site types	Kerbside (n=36), Roadside (n=36), and Urban Background (n=40)	Kerbside (n=12), Roadside (n=62), and Urban Background (n=31)
Modeled annual mean NO_2 (2019)	36 $\mu g\ m^{-3}$	41 $\mu g\ m^{-3}$



Based on modeling, average NO_2 pollution at reference sites is expected to be **5 $\mu g\ m^{-3}$ higher** than at BL sites

NO_2 methodology

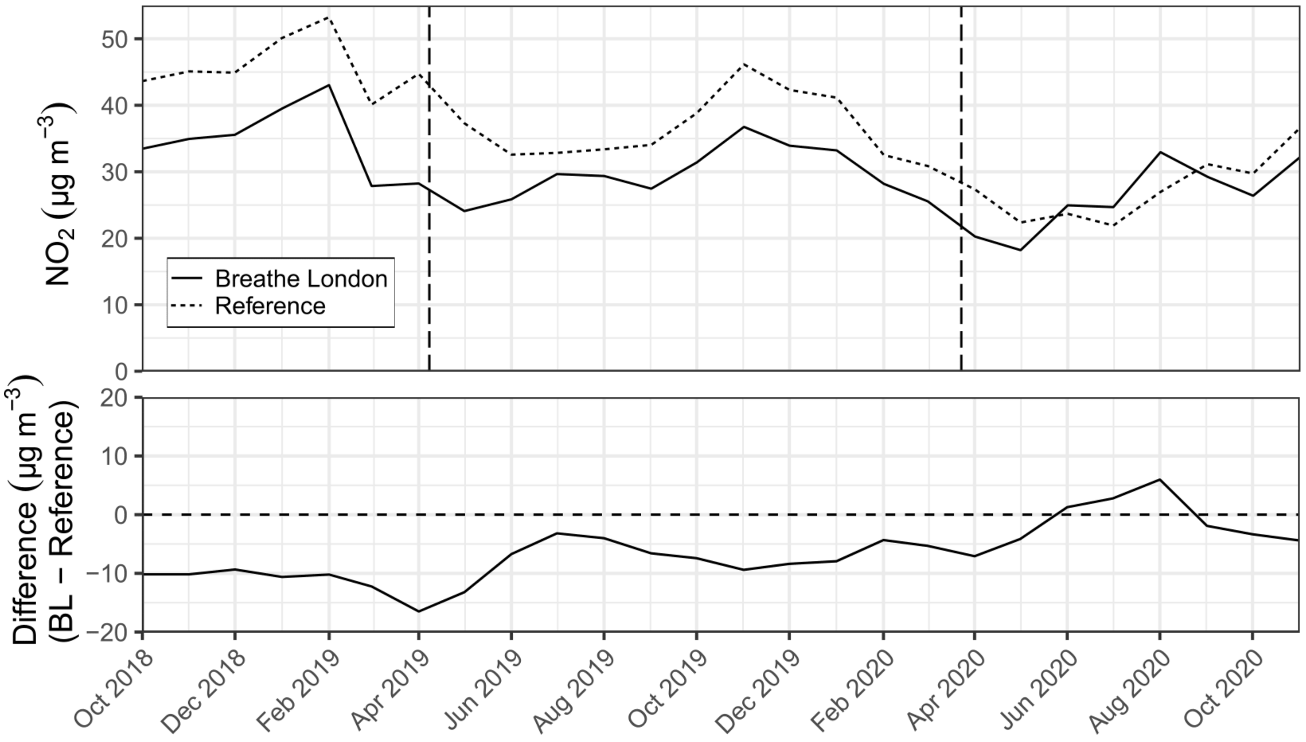
The paper and results presented here focus exclusively on nitrogen dioxide (NO_2) measurements

- 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

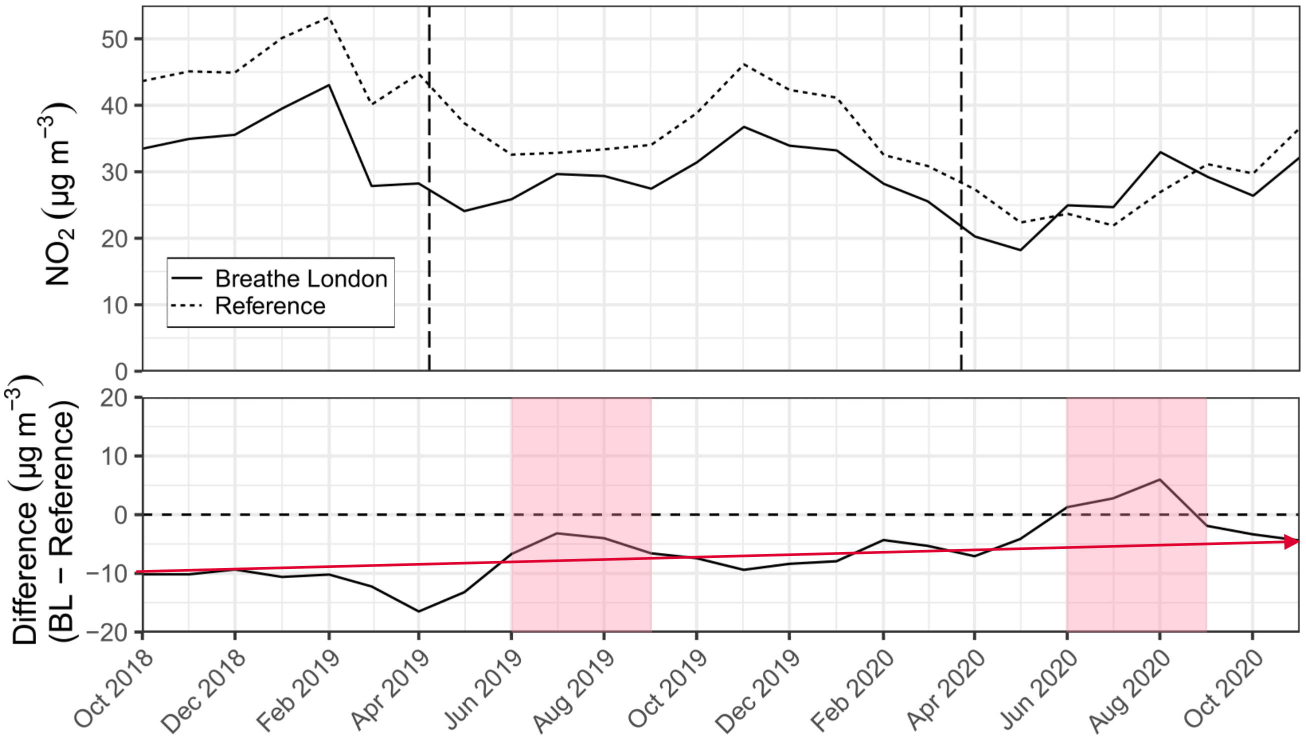
What we learned

Long-term network trends

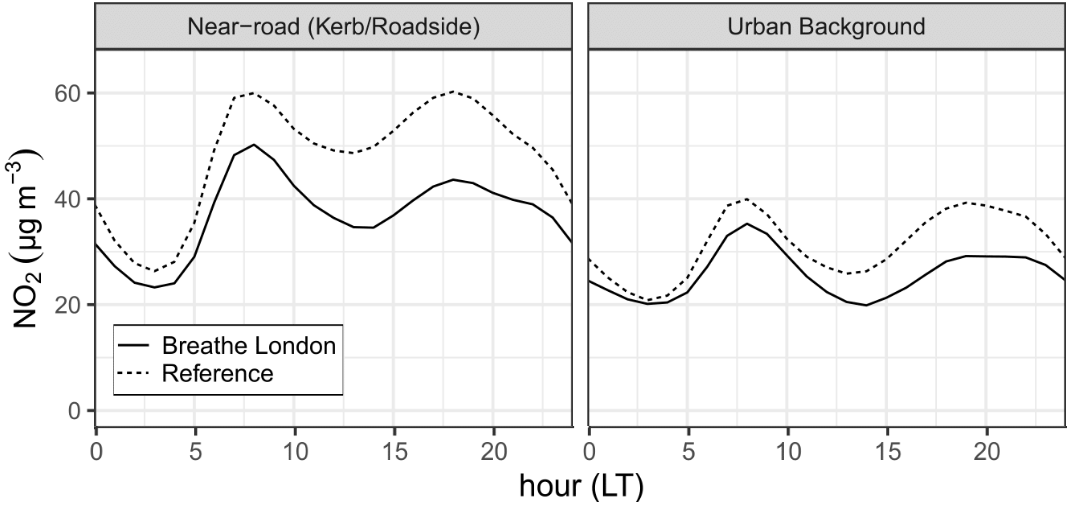


Long-term network trends

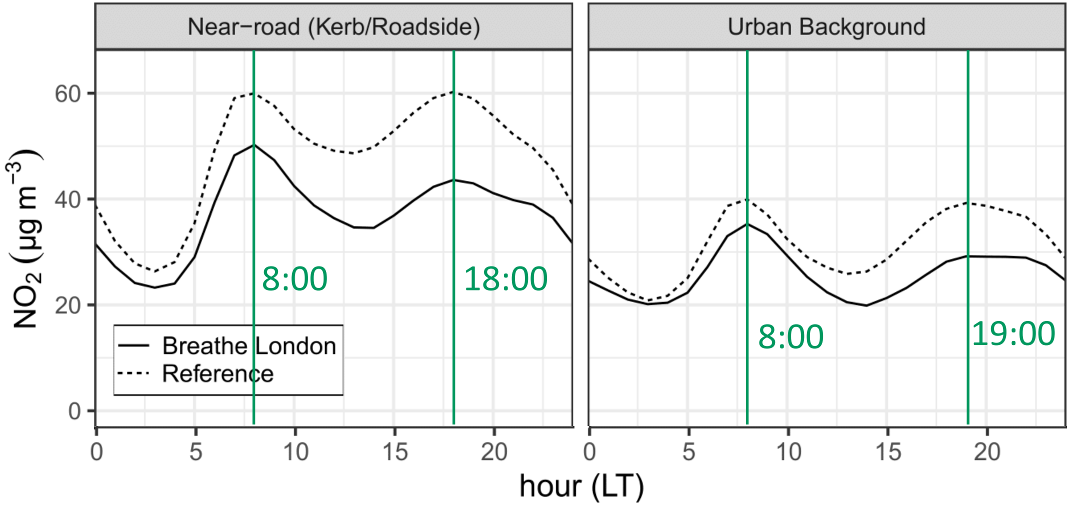
Long-term network trends



Weekday diurnal patterns at near-road and urban background sites

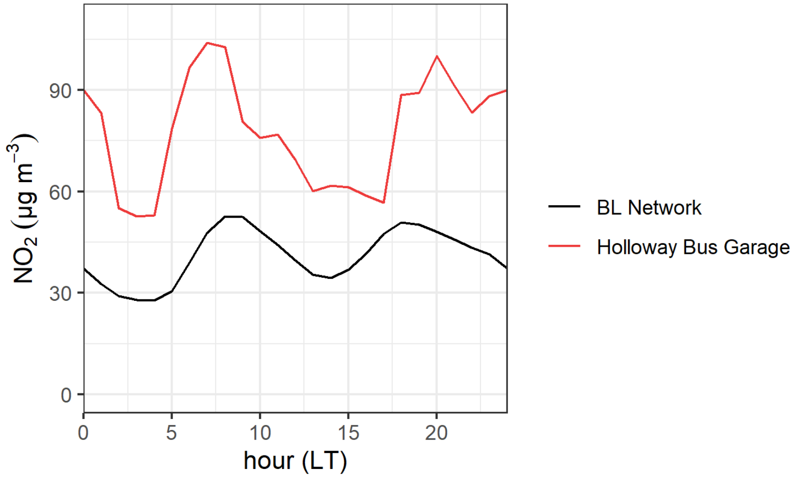


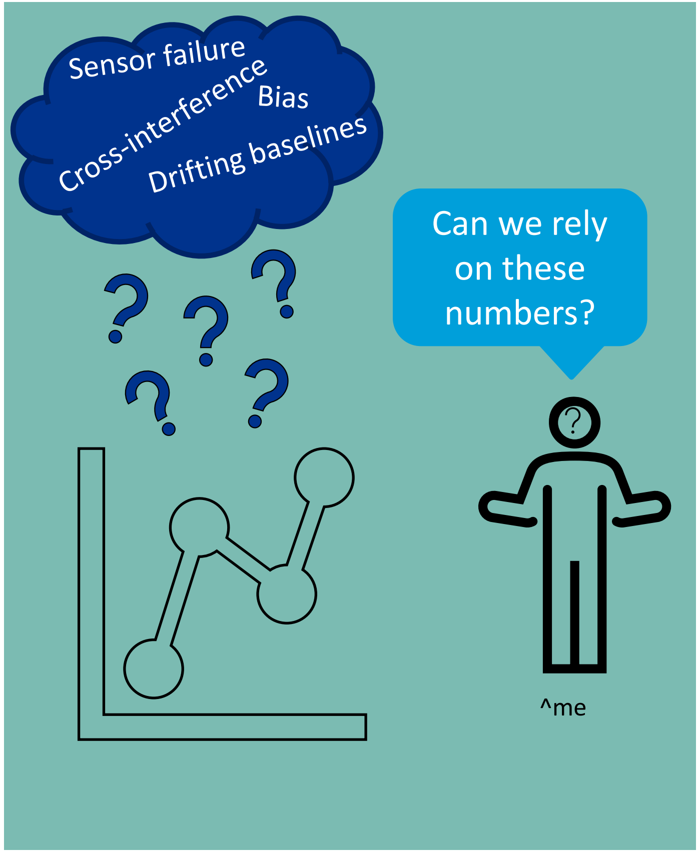
Weekday diurnal patterns at near-road and urban background sites

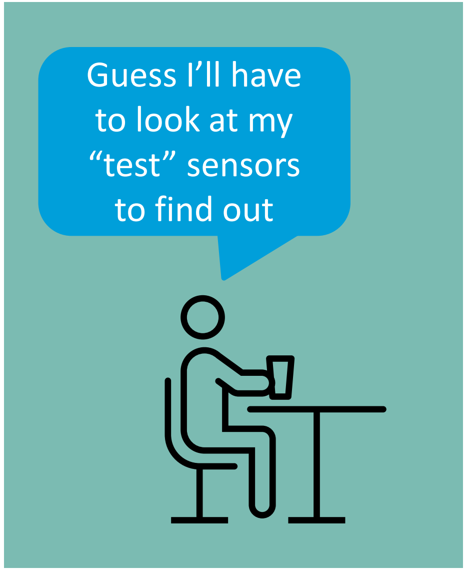


Local hotspots

BL sensor pod



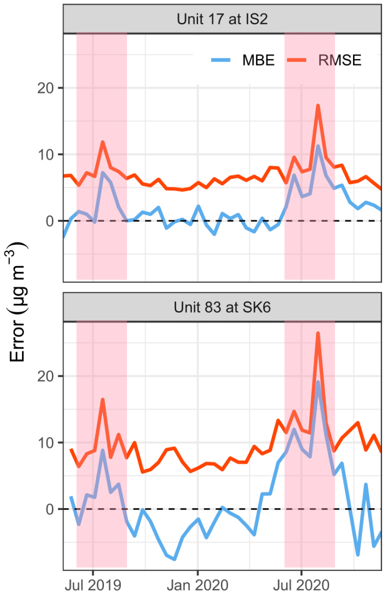




"The sensor situation" part 2

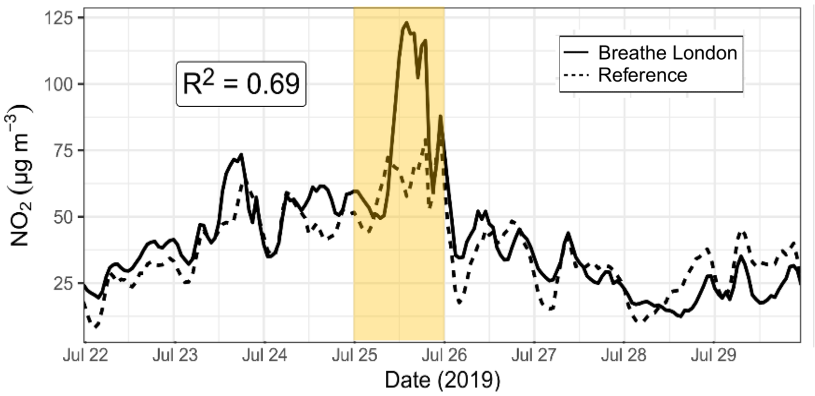
“Test” sensors as indicators for sensor network performance

Bias and error of “test” sensors varied seasonally and peaked during the summer

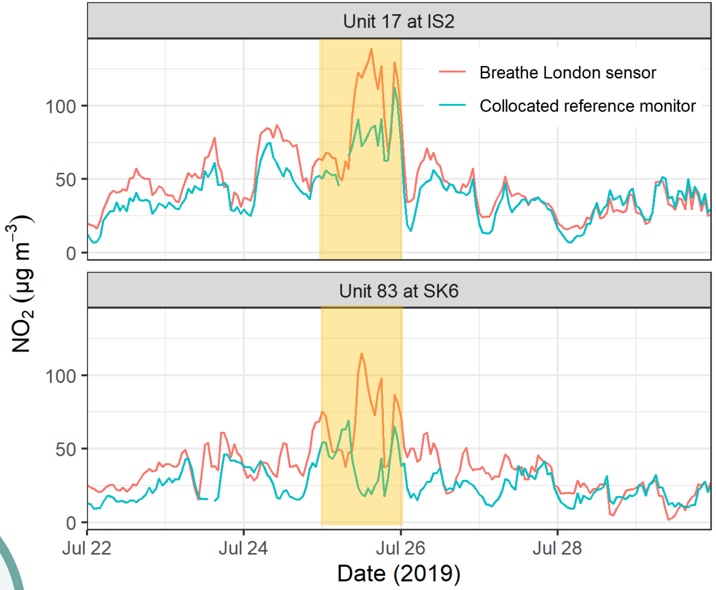


Case study 1: Interpreting a short-term episode with elevated NO2 sensor measurements (July 2019)

Network mean concentrations



"Test" sensor timeseries compared to collocated reference monitor



Is a real pollution event causing elevated BL network measurements?

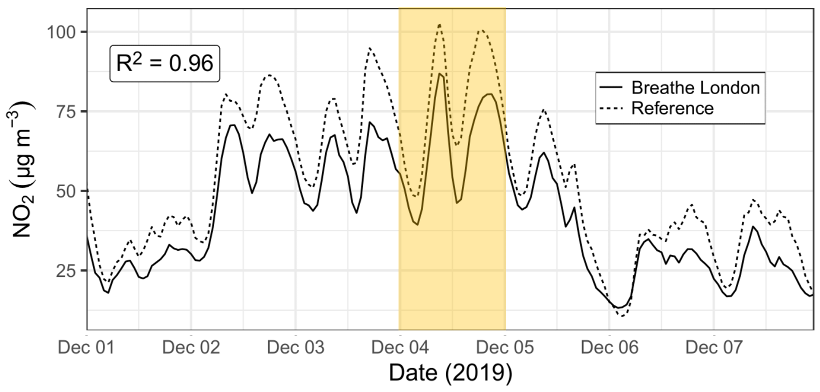
Are the "test" sensors performing well?

"Test" sensor measurements are much higher than collocated reference

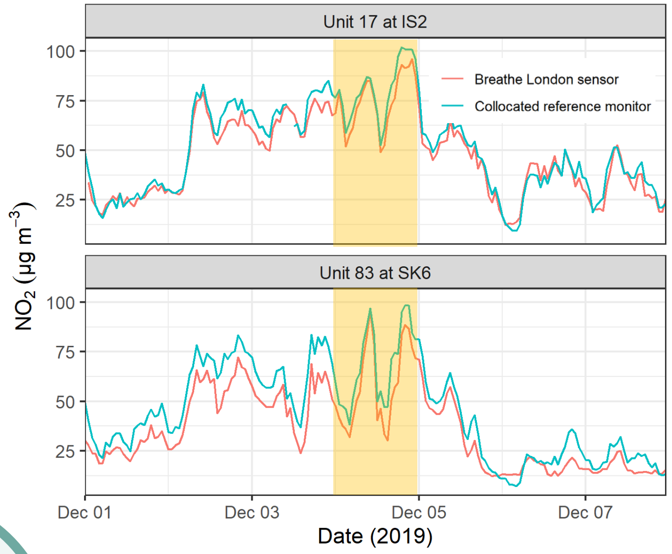
We can infer that the BL network spike was caused by sensor error

Case study 2: Interpreting a short-term episode with elevated NO2 sensor measurements (December 2019)

Network mean concentrations



"Test" sensor timeseries compared to collocated reference monitor



Is a real pollution event causing elevated BL network measurements?

Are the "test" sensors performing well?

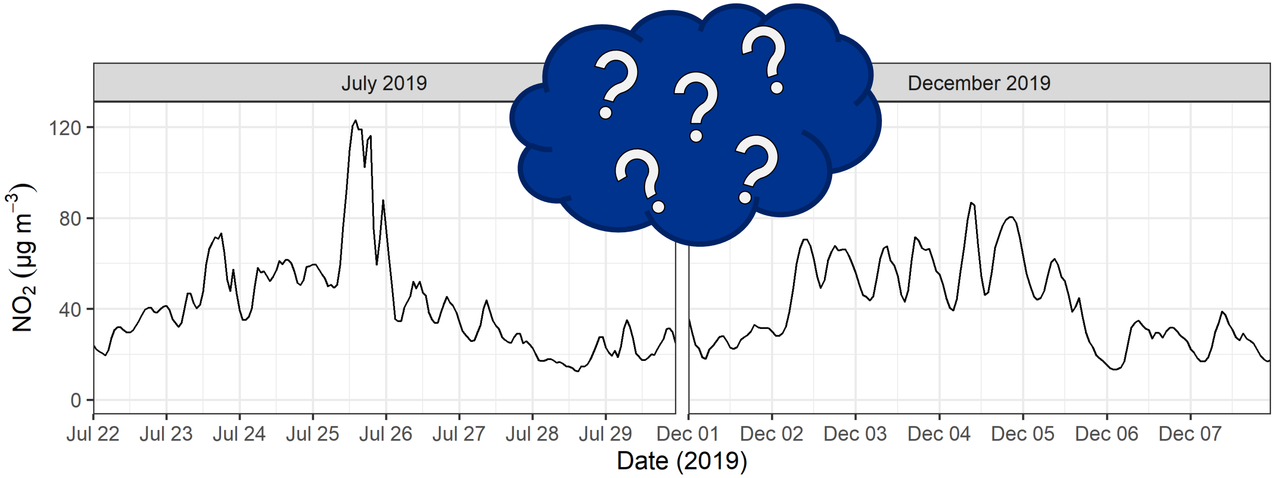
"Test" sensor measurements closely track collocated reference

We can infer that BL network spike was really caused by elevated pollution levels

Conclusions

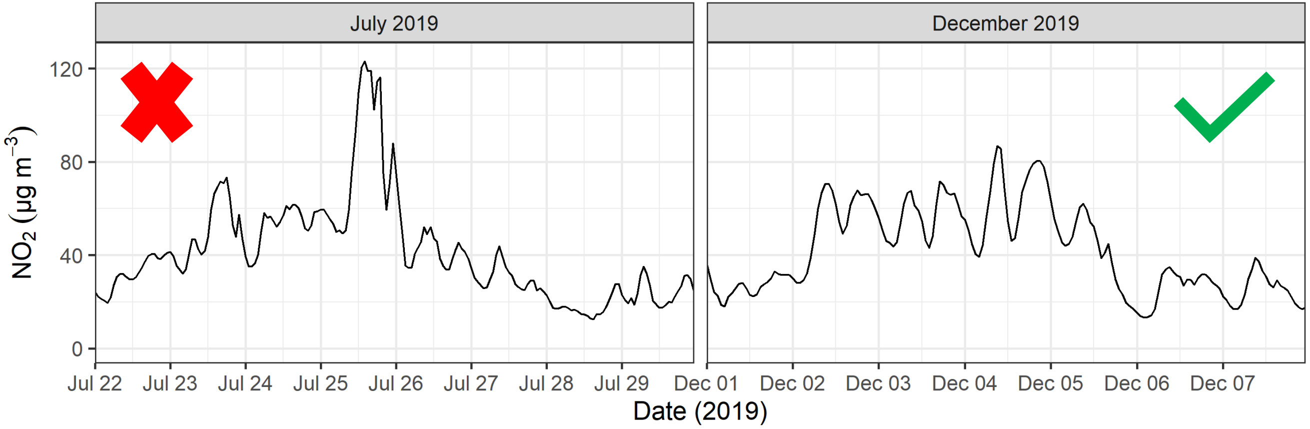
Differentiating robust air pollution patterns from measurement artifacts

- 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?

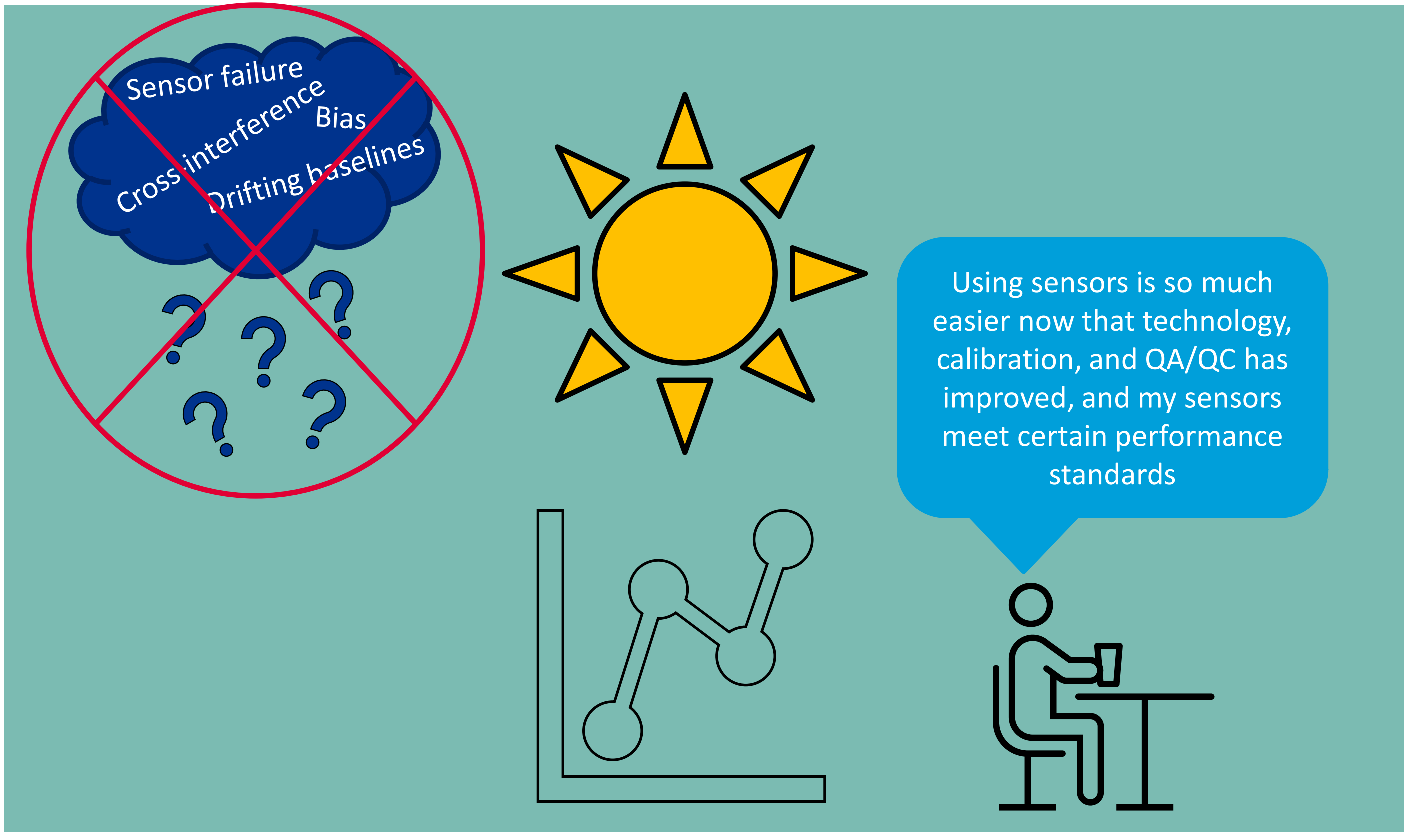


Differentiating robust air pollution patterns from measurement artifacts

- 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?



“The sensor situation” part 3

Thanks for listening!

Contact

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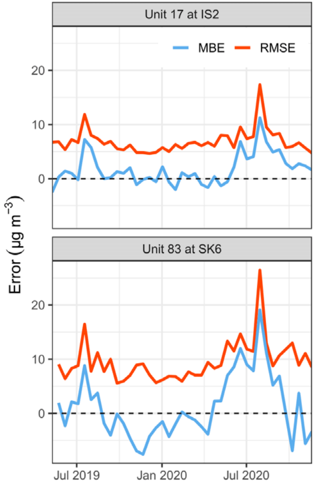
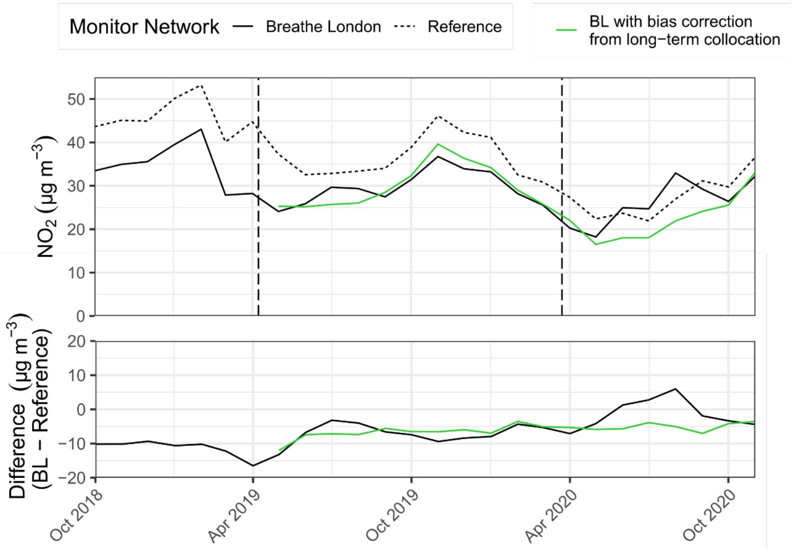
Extra slides

Case study 3: Correction for seasonal sensor bias

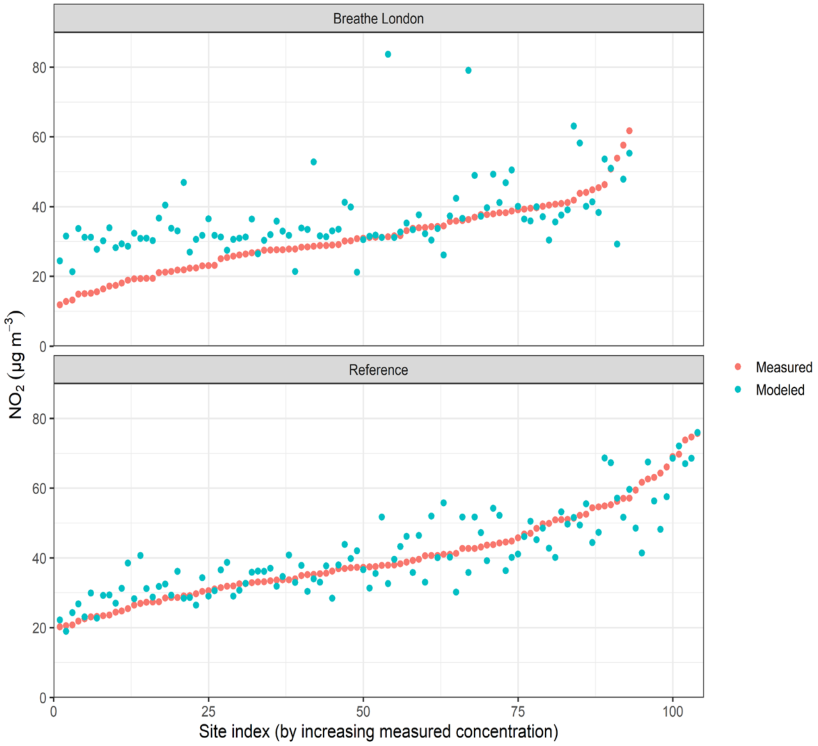
Bias (and RMSE) of "test" sensors varies seasonally, peaks during the summer



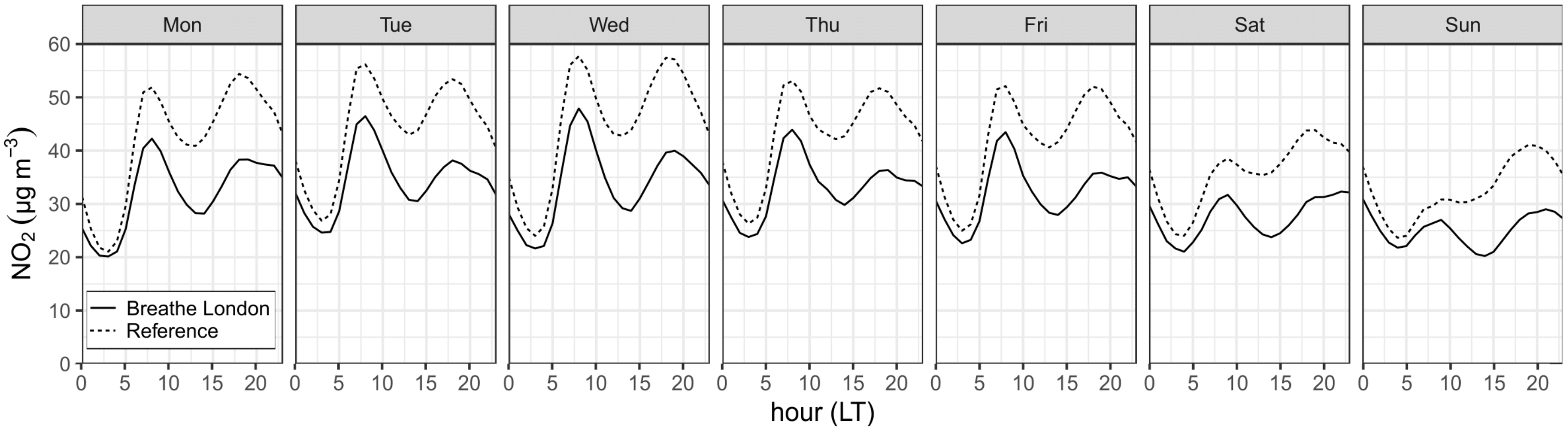
Application of monthly bias correction derived from "test" sensor collocations corrects irregularities in network mean timeseries



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