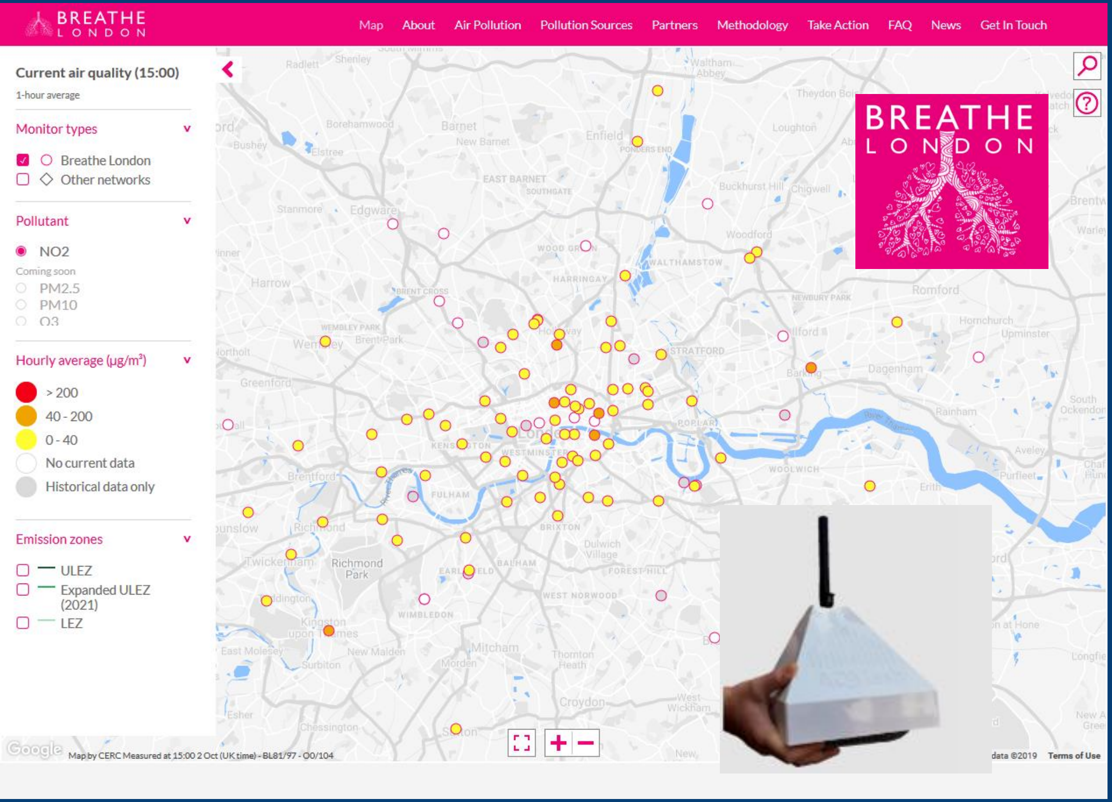
Deployment of a sensor network in London: outcomes and lessons learnt



Amy Stidworthy, David Carruthers, Mark Jackson & Jenny Stocker

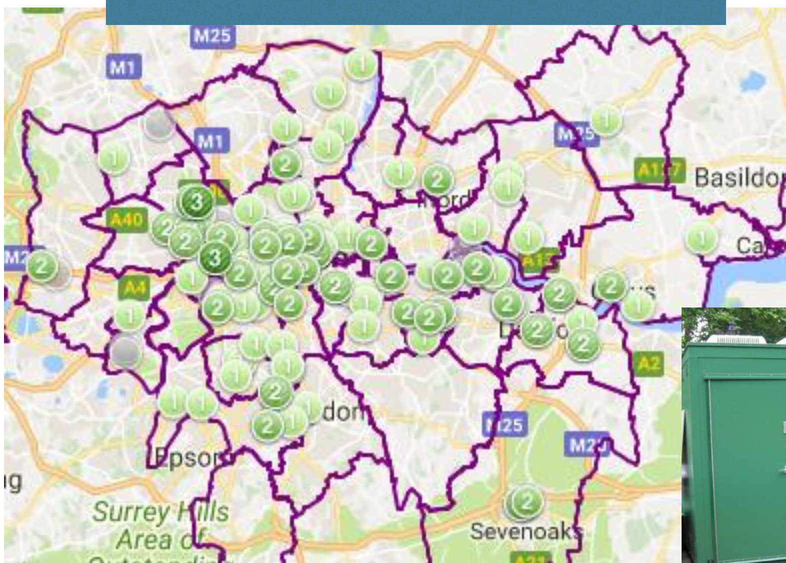
FAIRMODE

October 2019

CIEMAT-Madrid

Motivation for sensor deployment

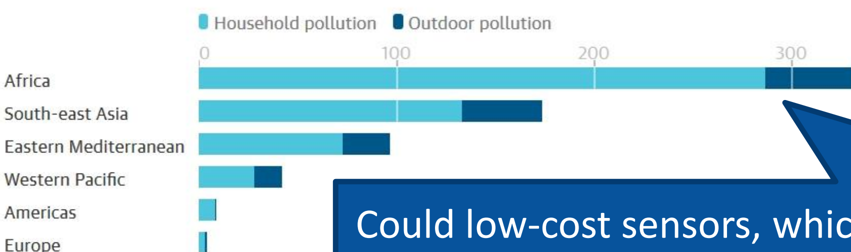
London Air



Traditional reference-standard air quality monitoring networks are high quality, but difficult to site and expensive to maintain, so the number of monitors is limited.

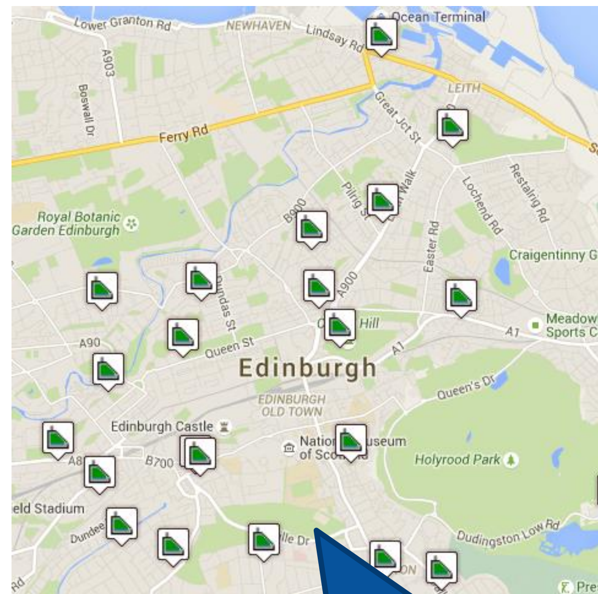
Air pollution is linked to diseases and infections that kill around 600,000 children under five each year

Under-five deaths linked to air pollution, 000s



Guardian graphic | Source: WHO, 2012

Could low-cost sensors, which are less accurate but easier to site and cheaper to buy and maintain, take reliable measurements where there are few or no reference monitors?



CITI-SENSE

Could low-cost sensors be used to improve modelling? Sensors can provide AQ datasets with high spatial and temporal resolution

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Breathe London

BreatheLondon.org

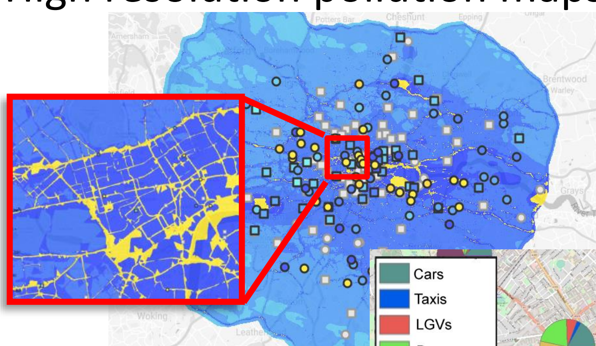
BREATHE LONDON

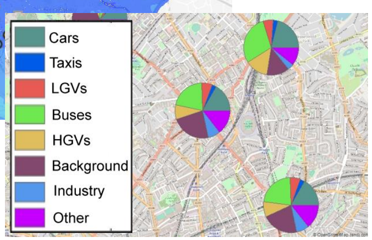
- A current 12-month project combining **modelling** with **measurements** from small low cost sensors and mobile monitors to provide new insight into London's air pollution problems

EDF ENVIRONMENTAL DEFENSE FUND Finding the ways that work | AirMonitors.co.uk | UNIVERSITY OF CAMBRIDGE | CERC | Google Earth Outreach | NPL National Physical Laboratory | KING'S College LONDON | GREATER LONDON AUTHORITY | C40 CITIES | CHILDREN'S INVESTMENT FUND FOUNDATION

MODELLING

High resolution pollution maps





Source apportionment

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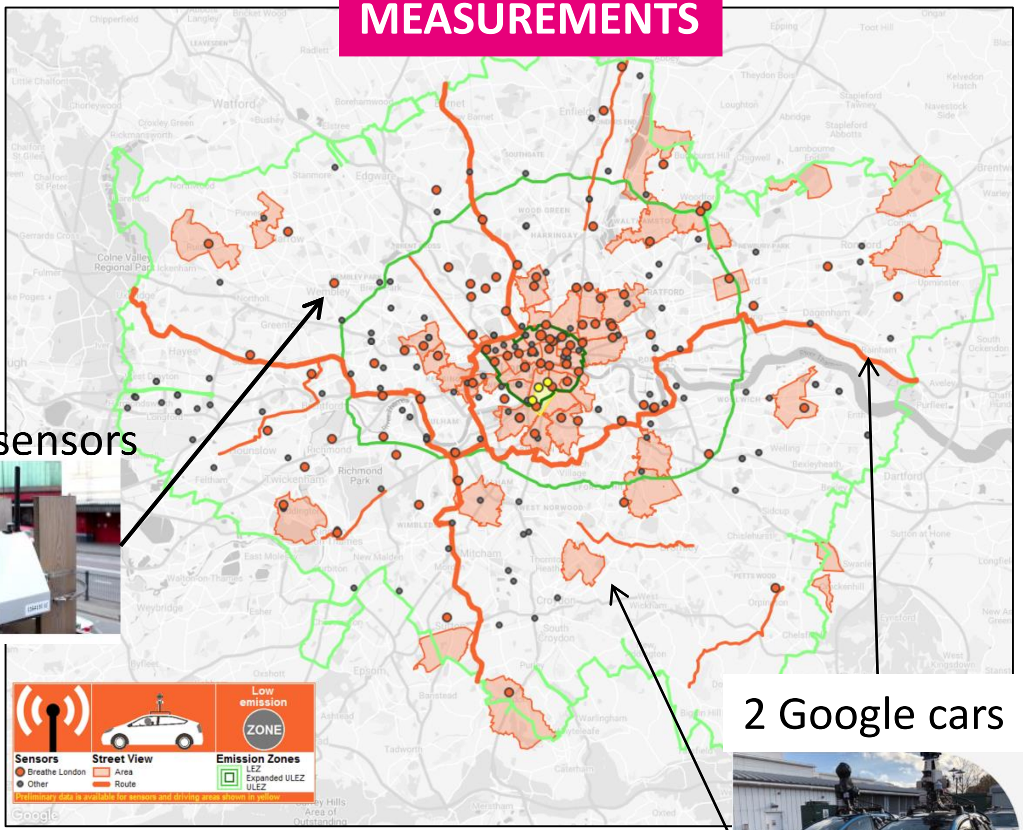
MEASUREMENTS

100 low cost sensors



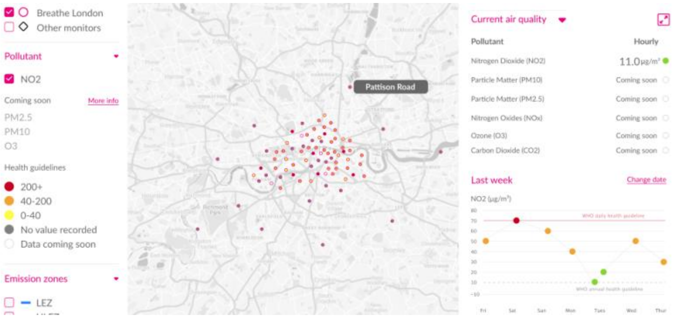
2 Google cars

CERC role in Breathe London (1)

Online platform

- Open access to measurements, modelling and analysis
- Street-by-street maps of pollution hotspots and forecasts
- Near-real-time hyperlocal maps of current air quality
- Replicable and scalable
- www.breathelondon.org

First version launched July 2019 - includes open online access to AQMesh NO_2 sensor data and maps and graphs of latest measurements



Maps and graphs of measurements

Maps of hotspots from mobile data

Maps of forecasts

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CERC role in Breathe London (2)

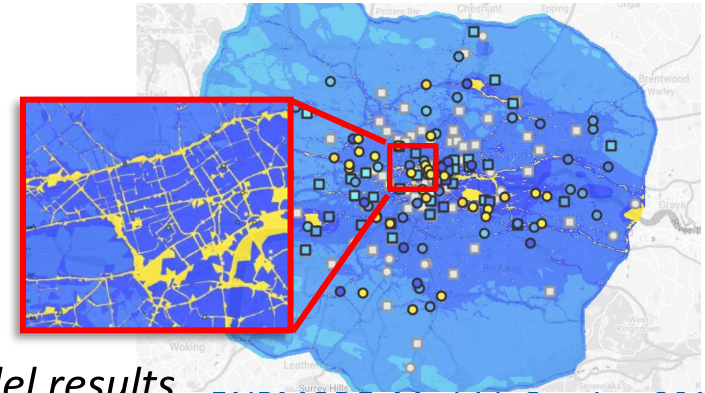
Modelling and analysis

- **Assist with the analyses relating to the calibration of the sensor data**
- Analyse measurements to identify hotspots and improve emission factors using ratios of toxic pollutants to CO2
- Modelling with ADMS-Urban to predict air quality everywhere
- Source apportionment to understand causes of pollution
- **Optimize emissions inventory**
- All this improves modelling of impacts of future policy measures

Mobile sensor

ADMS model

Source apportionment



ADMS model results

Lessons learned about sensors in Breathe London

Sensors are located within 'pods'

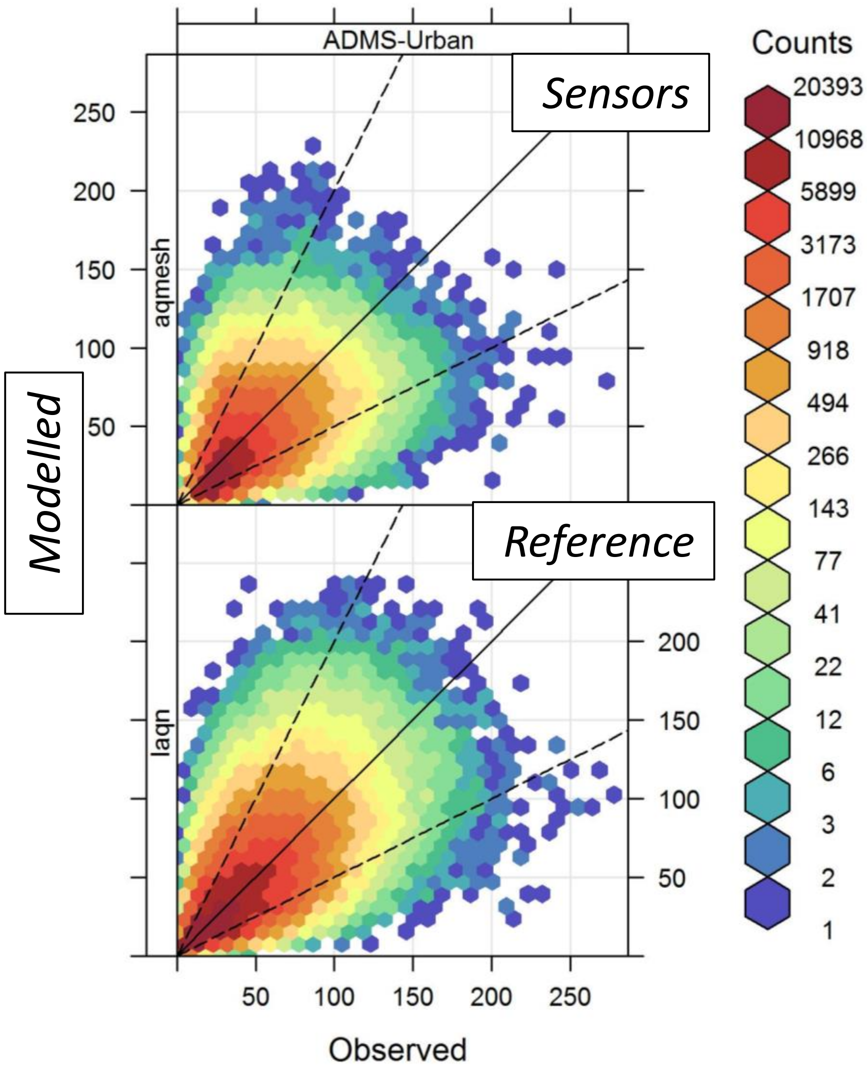
- Allow sufficient time to obtain permissions to locate pods
- Challenges associated with sensor calibration:
  - Step changes in concentrations recorded by sensors before and after calibration
  - Different calibration approaches work best for different pollutants
  - Calibration methods are being developed as the project progresses
- Instruments require maintenance to ensure best performance:
  - Sensors may be sensitive to high humidity
  - Pods could be affected by other issues e.g. vandalism
- Once calibrated, sensor measurements **can be** reliable if maintained

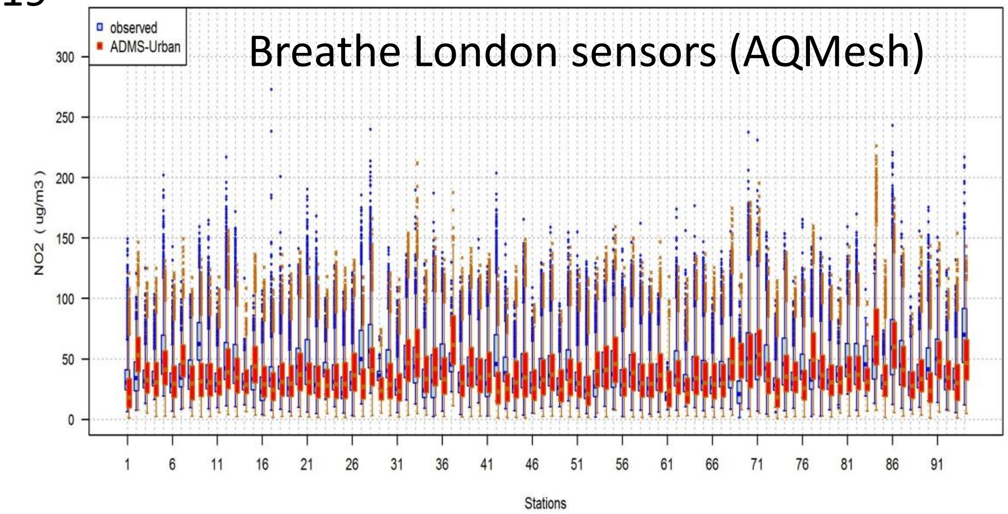
Calibration approaches

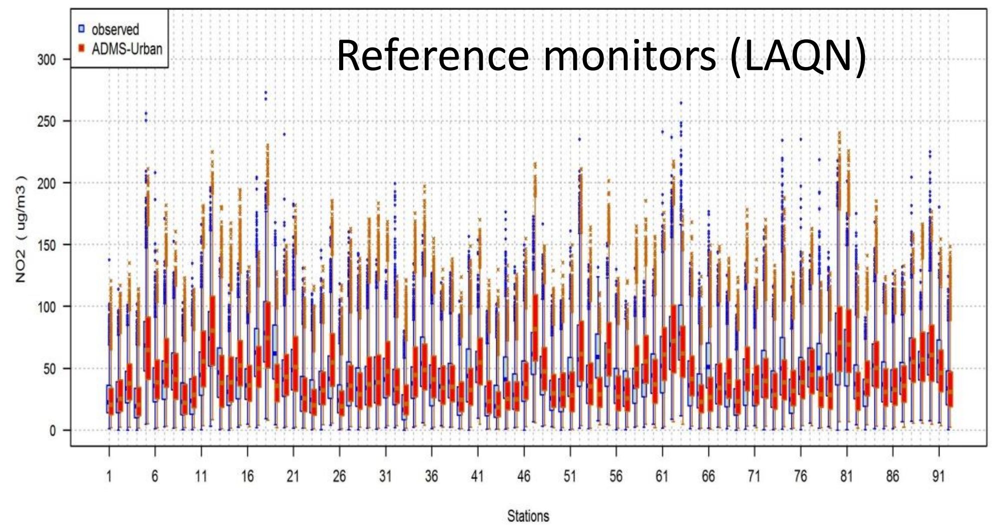
1. Co-locate pods with reference monitors, and then deploy the pod at a different location
2. Introduce gold pods: small number of pods that had a longer period of co-location with the reference monitor, then move the gold pods round the different pod locations
3. Network-based calibration: use an algorithm that derives a baseline across the whole network (University of Cambridge)

Comparison of modelled data with measurements

Model validation for NO_2 Oct 2018 – May 2019







Comparison of AQMesh data with ADMS-Urban model data has helped in the QA/QC of the AQMesh dataset

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Modelling (Inversion techniques)

Refer to:

- *'Using low-cost sensor networks to refine emissions for use in air quality modelling' presentation – FAIRMODE 2017*
- *Carruthers DJ, Stidworthy AL, Clarke D, Dicks KJ, Jones RL, Leslie I, Popoola OAM, Billingsley A and Seaton M, 2018: Urban emission inventory optimisation using sensor data, an urban air quality model and inversion techniques. International Journal of Environment and Pollution, vol. 64*

- Emissions errors account for a significant proportion of dispersion model error
- Traditionally, dispersion models such as ADMS-Urban are validated against data from reference monitors:
  - Modellers either use the validation to improve model setup; or
  - Calculate and apply a model adjustment factor to model results
- Sensor accuracy and reliability is typically lower than reference monitors, but larger spatial coverage is possible
- **How can sensor data be best used in dispersion modelling?**

Inversion techniques: Introduction

- The aim was to develop an inversion technique to use monitoring data from a network of sensors to automatically adjust emissions to improve model predictions
- Basic idea:
  - Run ADMS-Urban to obtain modelled concentrations at monitor locations in the normal way
  - Take these modelled concentrations and their associated emissions as a 'first guess', together with
    a) monitored concentration data at the same locations
    b) information about the error in the monitored data and the proportion of that error that co-varies across all monitors
    c) Information about the error in the emissions data and the proportion of that error that co-varies between sources
  - Use an inversion technique to calculate an adjusted set of emissions that reduces error in the modelled concentrations
- Full description of methodology in this paper (in press):

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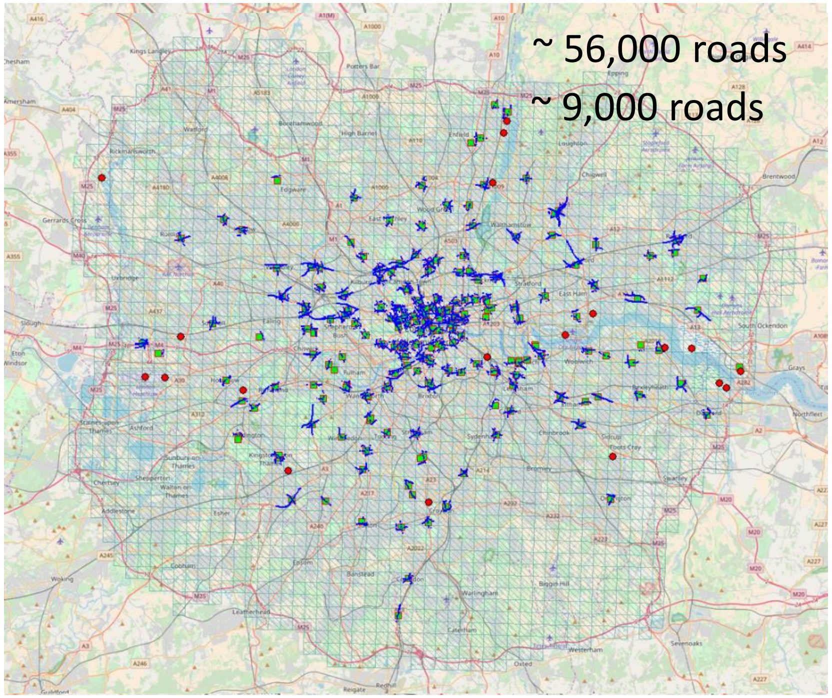
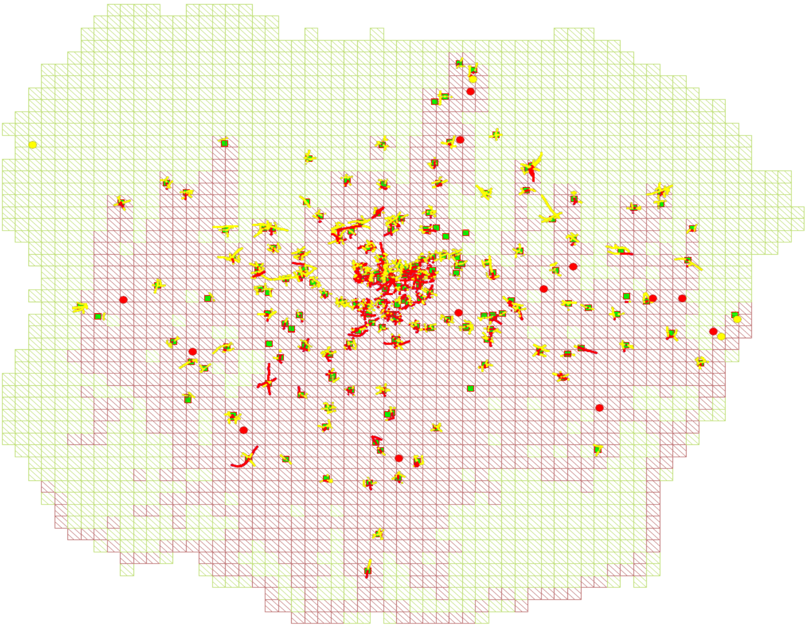
Testing the inversion scheme in London

What can we learn about emissions, commonly-used emissions factors and diurnal emissions profiles by combining modelling with monitored data?

- Challenging to apply inversion scheme to London (11306 road, grid and point sources)
- Only use only LAQN NO_X measurements to start with – will include Breathe London AQMesh dataset in future tests
- Remove lowest contributing sources each hour to reduce number of sources included in the inversion by ~70%





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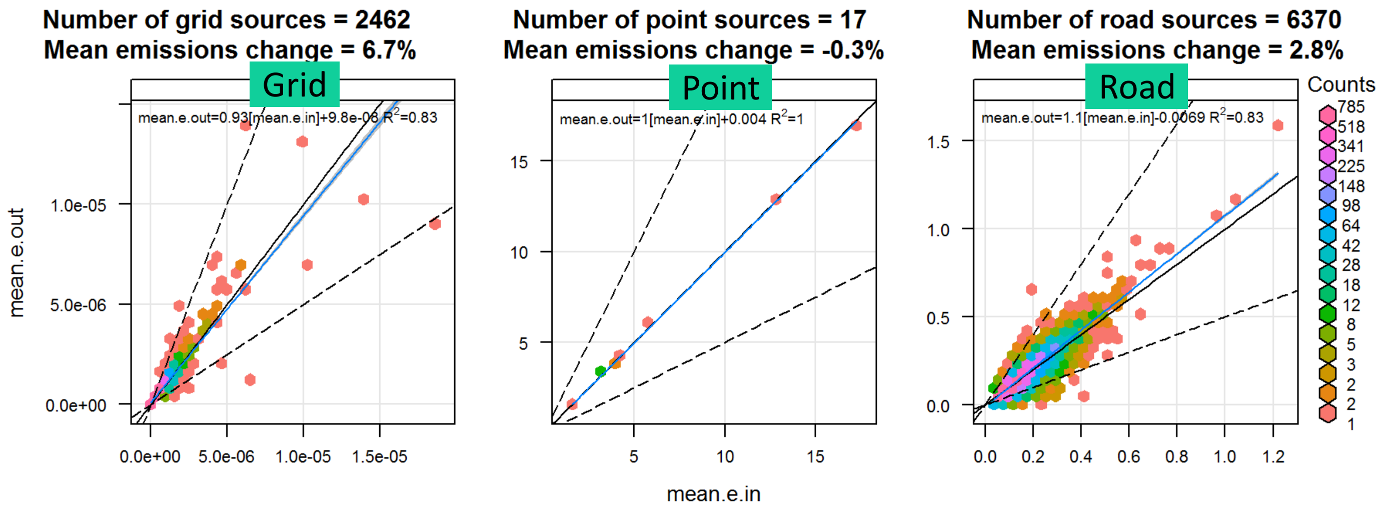
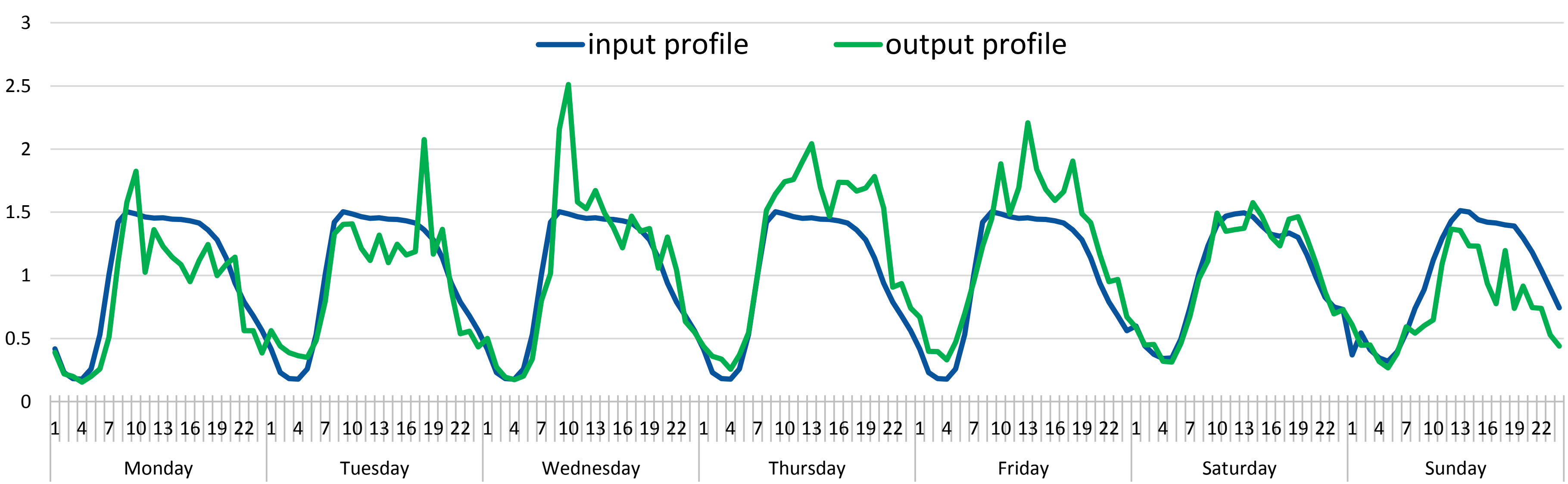
Testing the inversion scheme in London

- One month: Dec 2018
- LAQN measured data
- 9306 road sources
- 2483 grid source cells
- 17 point sources
- LAEI emissions, **not** adjusted for real-world emissions
- Error covariance between road and grid sources





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Summary

- Breathe London has demonstrated that sensor networks can generate air pollutant measurements that have accuracy close to that of reference monitors
- Sensor networks require maintenance and calibration – if calibration approaches can be made reliable / standardised, ‘low-cost’ sensor networks can be used in regions where reference monitoring is sparse
- Applying inversions techniques will provide insights into the uncertainties in the emission factors commonly used for dispersion modelling
- Optimised modelling will generate reliable source apportionment data that can be used to inform policy

Any questions?

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