Local modelling of Fluxes and Footprints

David Carruthers, Martin Seaton, Kate Johnson, Amy Stidworthy, Jenny Stocker

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Estonia

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Local modelling

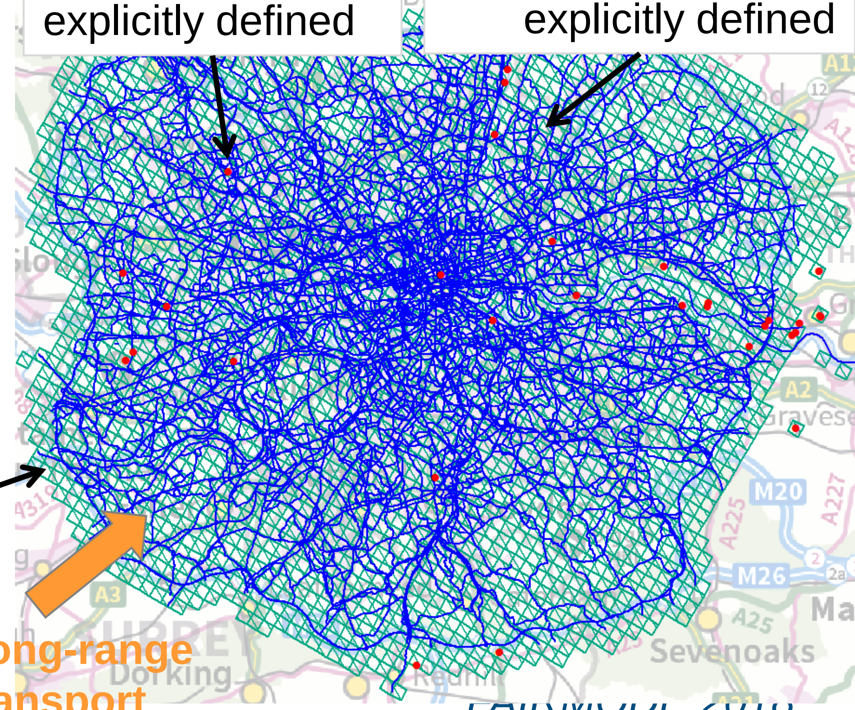
ADMS-Urban models dispersion from a wide range of urban sources:

- Gaussian type model with point, line area, road and grid sources; non-Gaussian vertical profile of concentration in convective conditions
- Concentrations calculated at street-scale resolution (<10m)
- Includes meteorological pre-processor
- Options for different chemical mechanisms
- Considers effects of complex terrain: surface elevation and roughness
- Allows for the effects of buildings; fully integrated street canyon model;
- Integration with Geographical Information Systems (GIS) and an Emissions Inventory Database (EMIT)

Example ADMS-Urban emissions inventory

Point sources explicitly defined

Major road sources explicitly defined



Minor road, commercial and domestic sources etc defined at lower resolution (1 km grid)

Long-range transport

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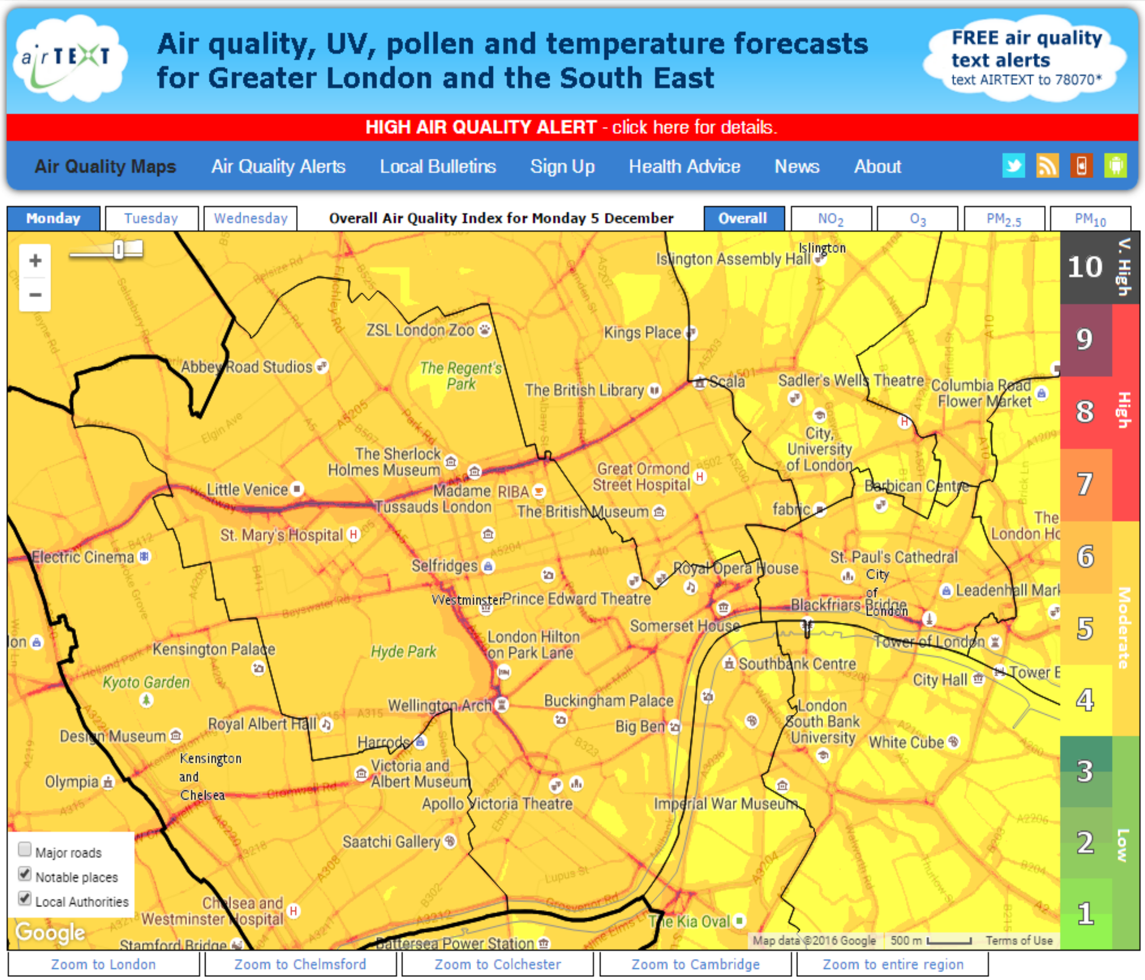
Local modelling

…but what else can we do with the model?

Example application: *air*TEXT: **local air quality forecasts**

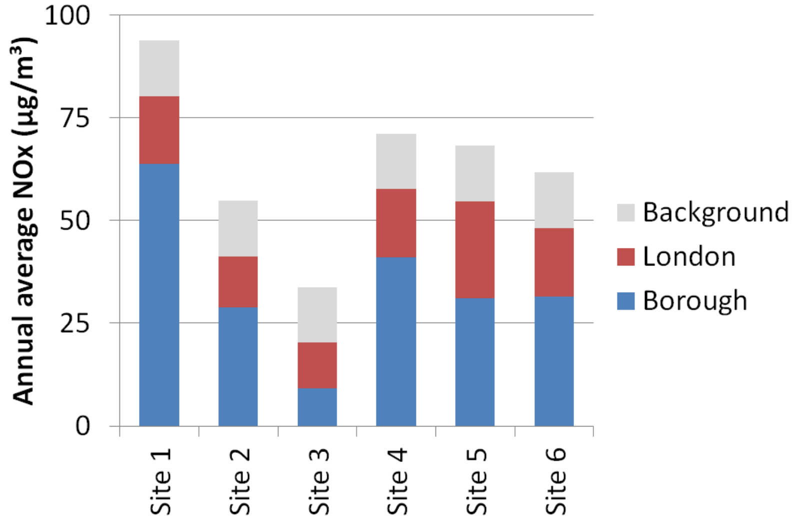


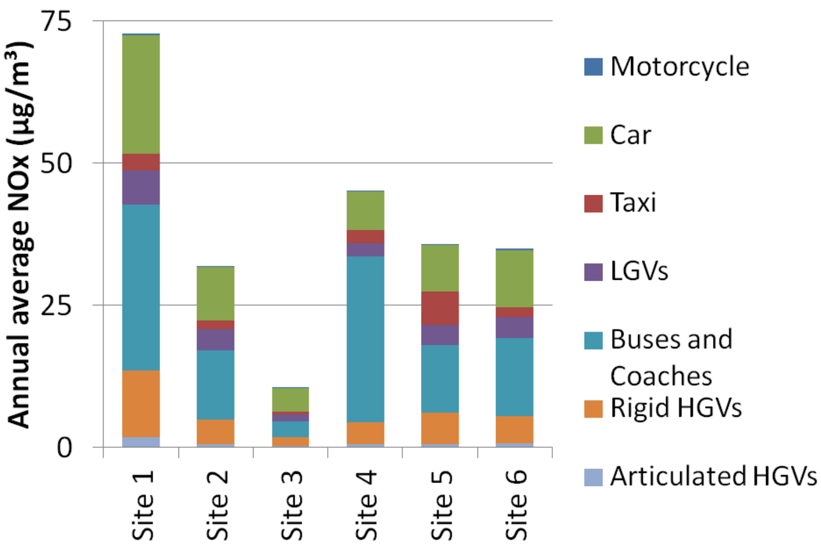
Dispersion of emissions is modelled on a source-by-source basis, so *where chemistry & deposition can be neglected:*

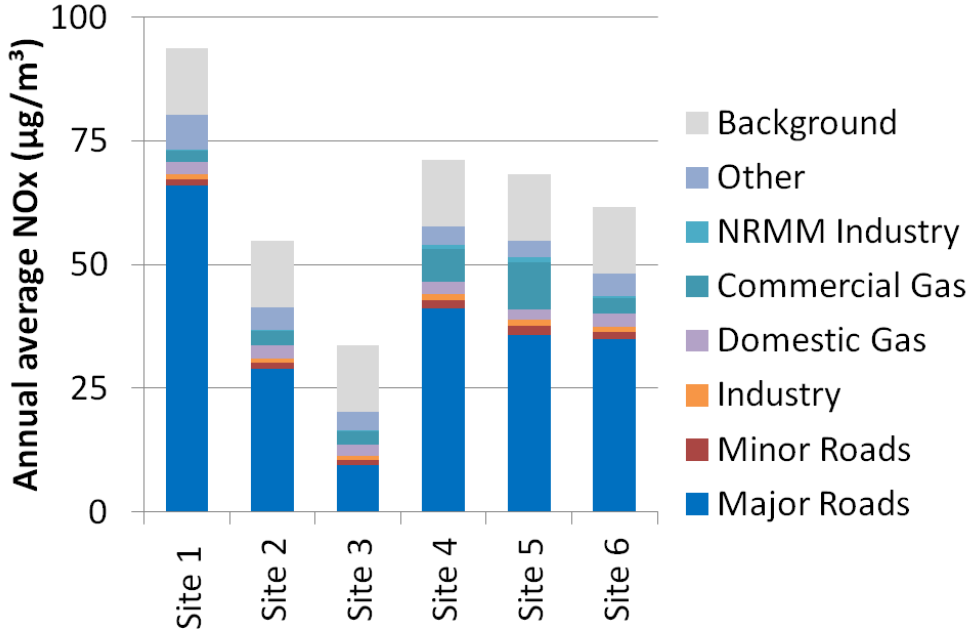
- Detailed **source apportionment** & **'footprint modelling'** is straightforward.
- Analytical expressions for the flux due to each source can be derived allowing detailed **flux & 'flux footprint'** calculations

Source apportionment – standard approach

- For many years the model has been used to perform SA of NO_x and PM at monitor locations, where model results have been validated against the absolute magnitude of measured concentrations:
  - SA can be performed at other sites, away from the monitors e.g. schools
  - Using a combination of features in the dispersion model and emissions tools, SA by vehicle type and/or emissions type can be performed
  - SA according to spatial location can be performed







Source apportionment – streamlined approach

- The model has now been developed to output ‘concentration per source’ or ‘concentration per grid cell’
- Leads to a range of useful high-resolution, spatial source apportionment outputs

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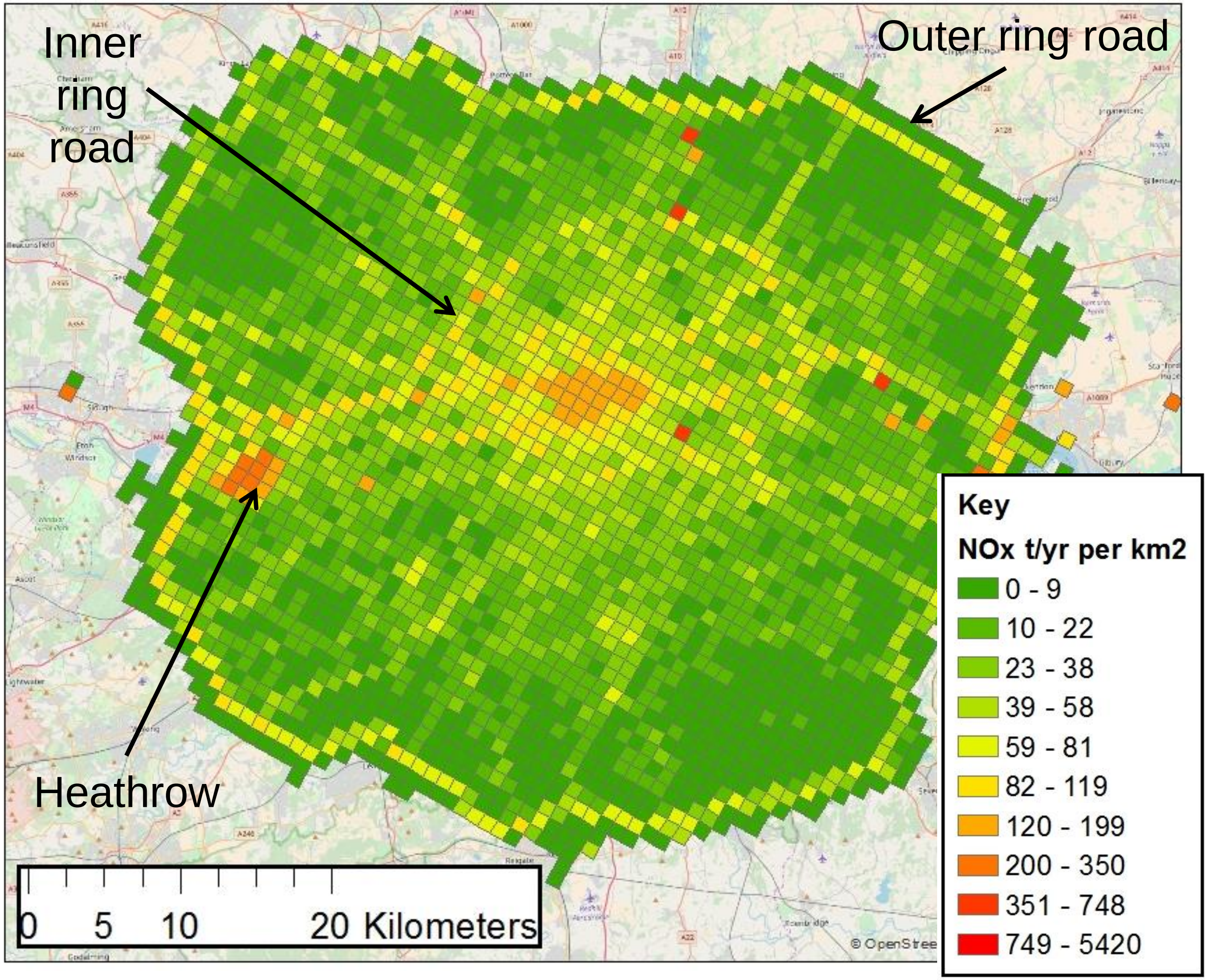
Gridded NOx emissions (t/yr per km2)

- Starting with gridded emissions of NOx at 1km x 1 km resolution
- Data from the London Atmospheric Emissions Inventory
- Road traffic NOx adjusted in line with real-world emissions measurements



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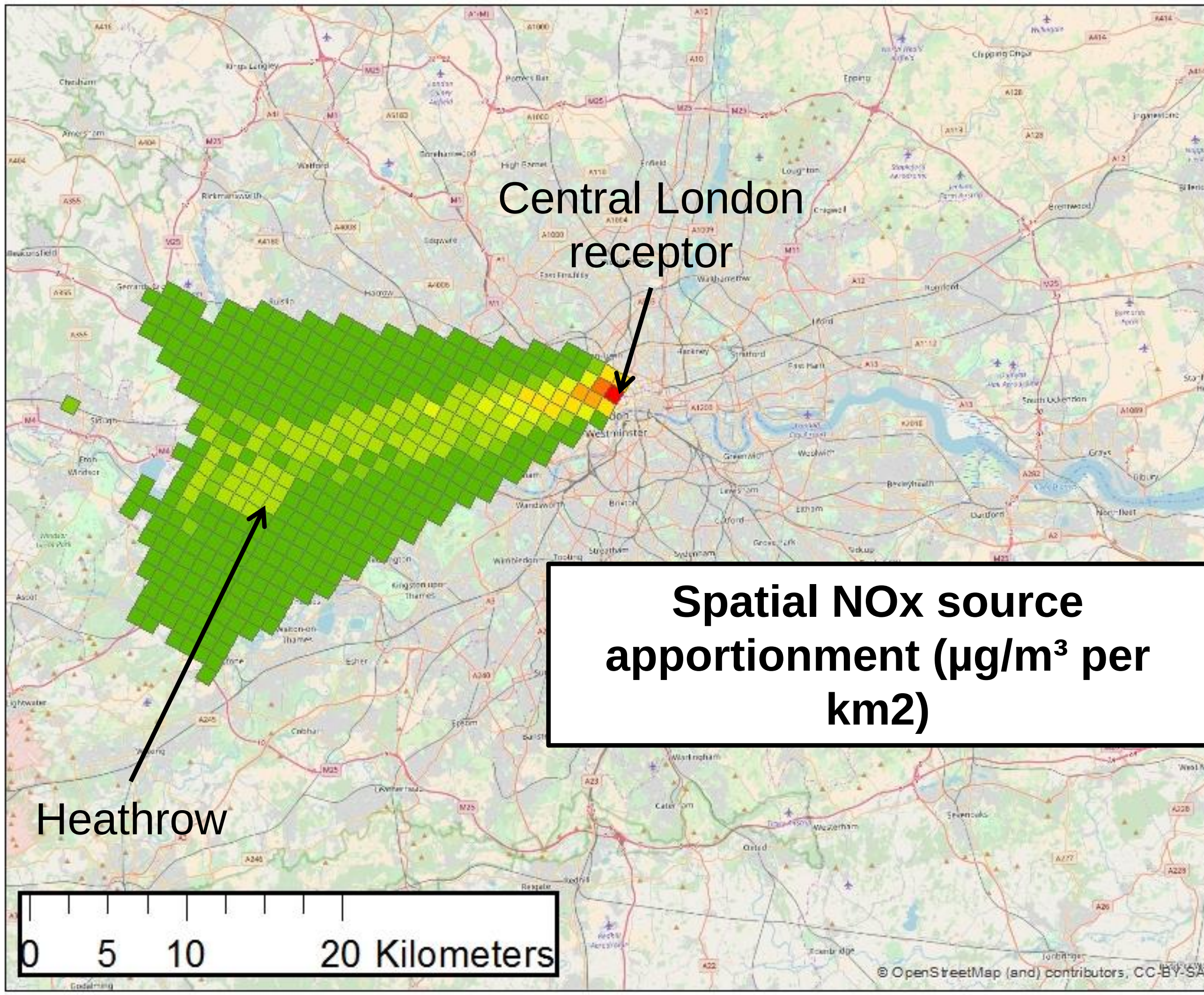
Source apportionment – streamlined approach

- The model has now been developed to output ‘concentration per source’ or ‘concentration per grid cell’
- Contributing grid sources for an example morning rush hour in January

Key

Source apportionment NOx ug/m3

- 0.0
- 0.010 - 0.050
- 0.051 - 0.10
- 0.11 - 0.50
- 0.51 - 1.0
- 1.1 - 5.0
- 5.1 - 10
- 11 - 15
- 16 - 20
- 21 - 25



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Source apportionment – streamlined approach

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- Contributing grid sources for an example morning rush hour in June

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Source apportionment

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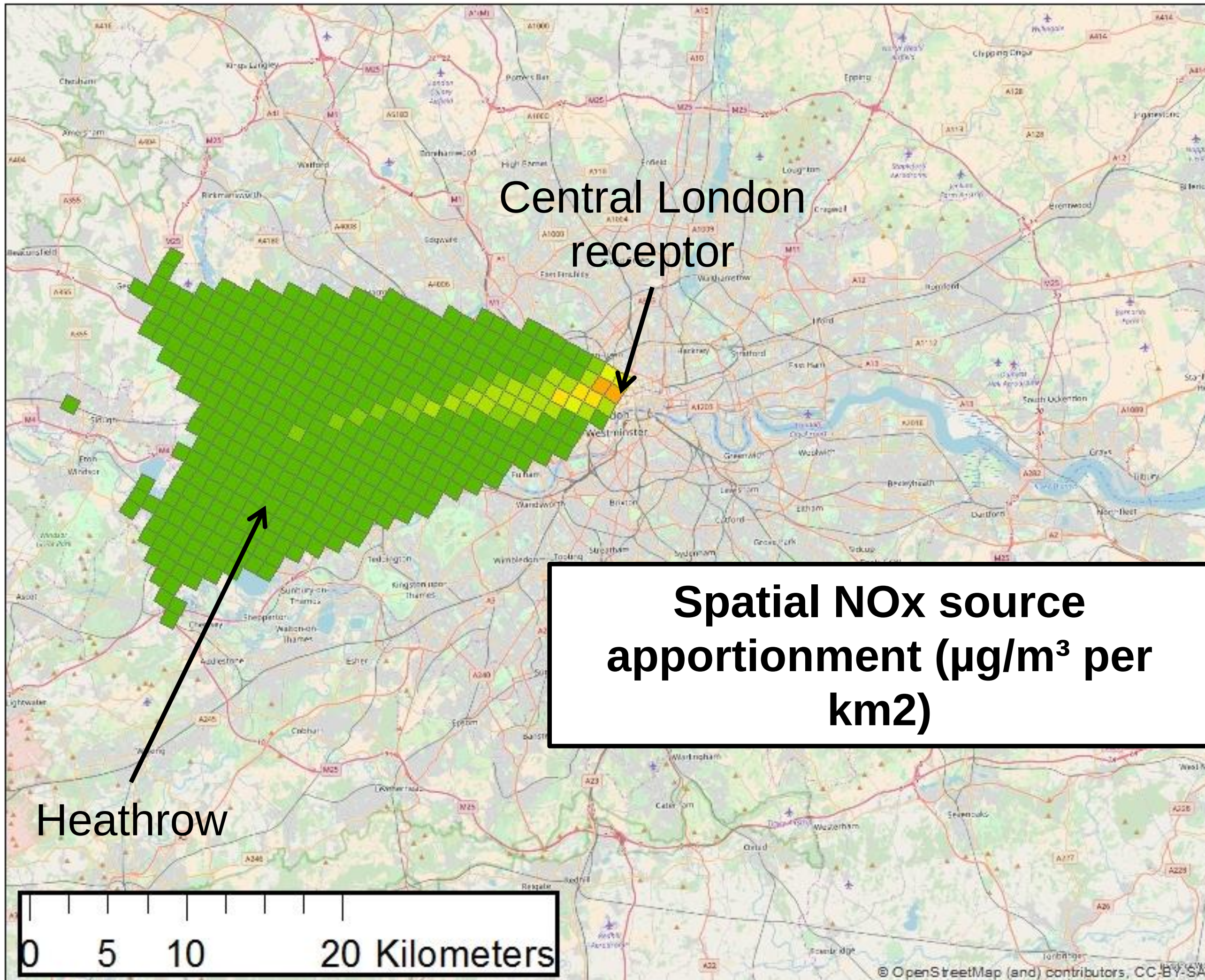

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Roads near receptor

ug_m5

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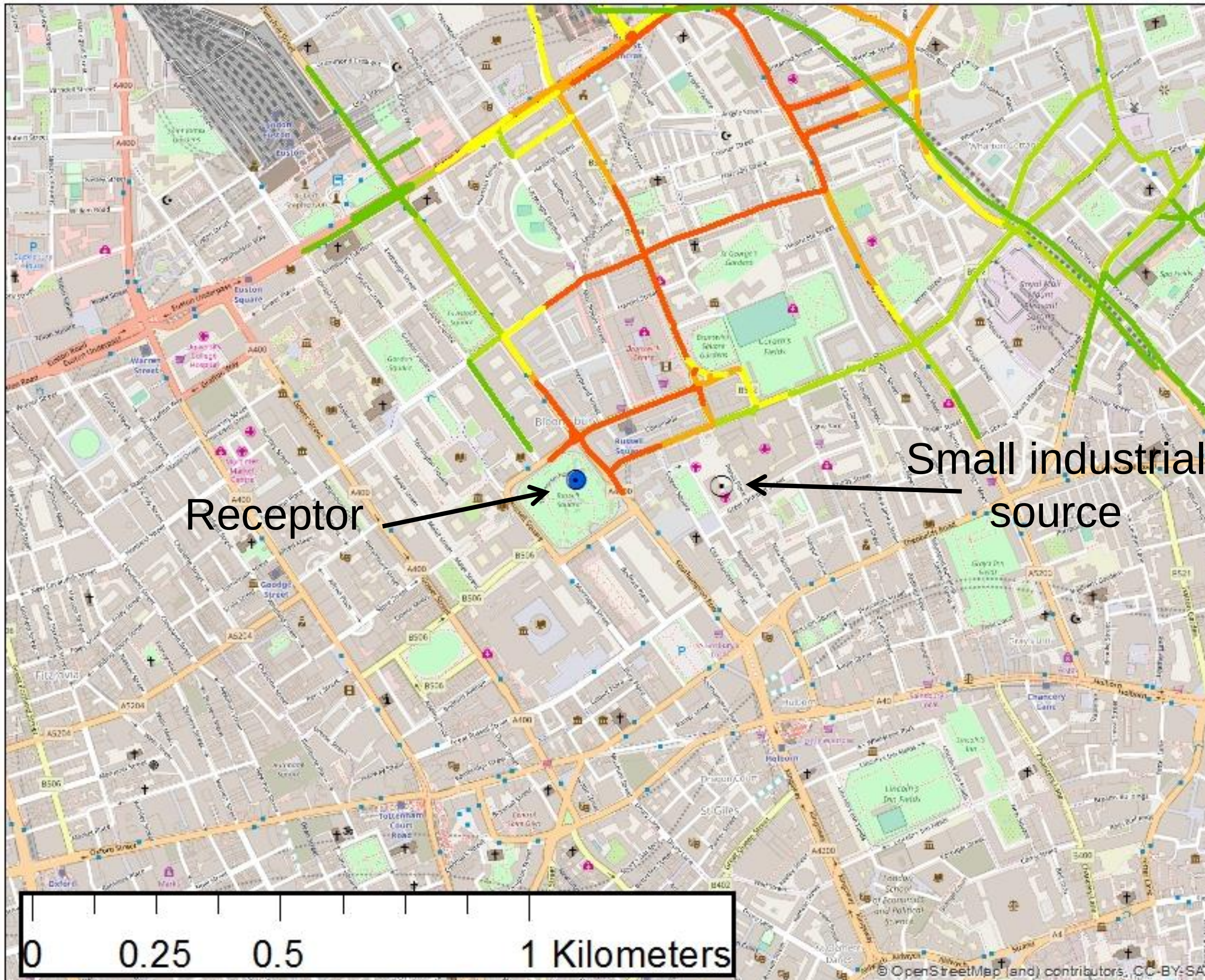

Wind

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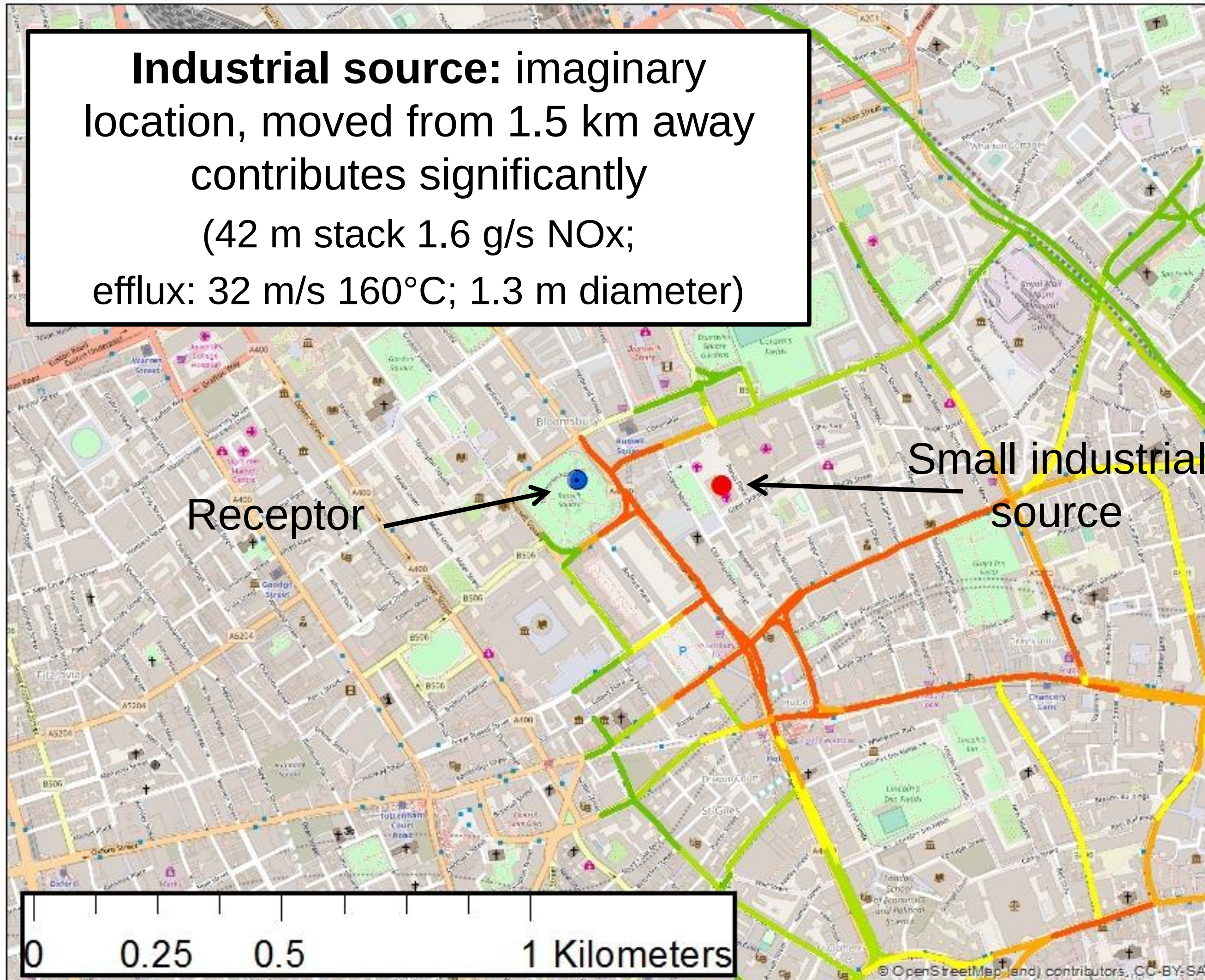

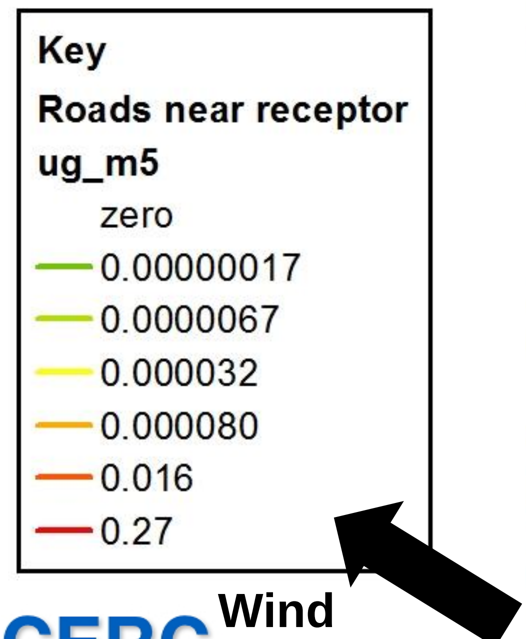

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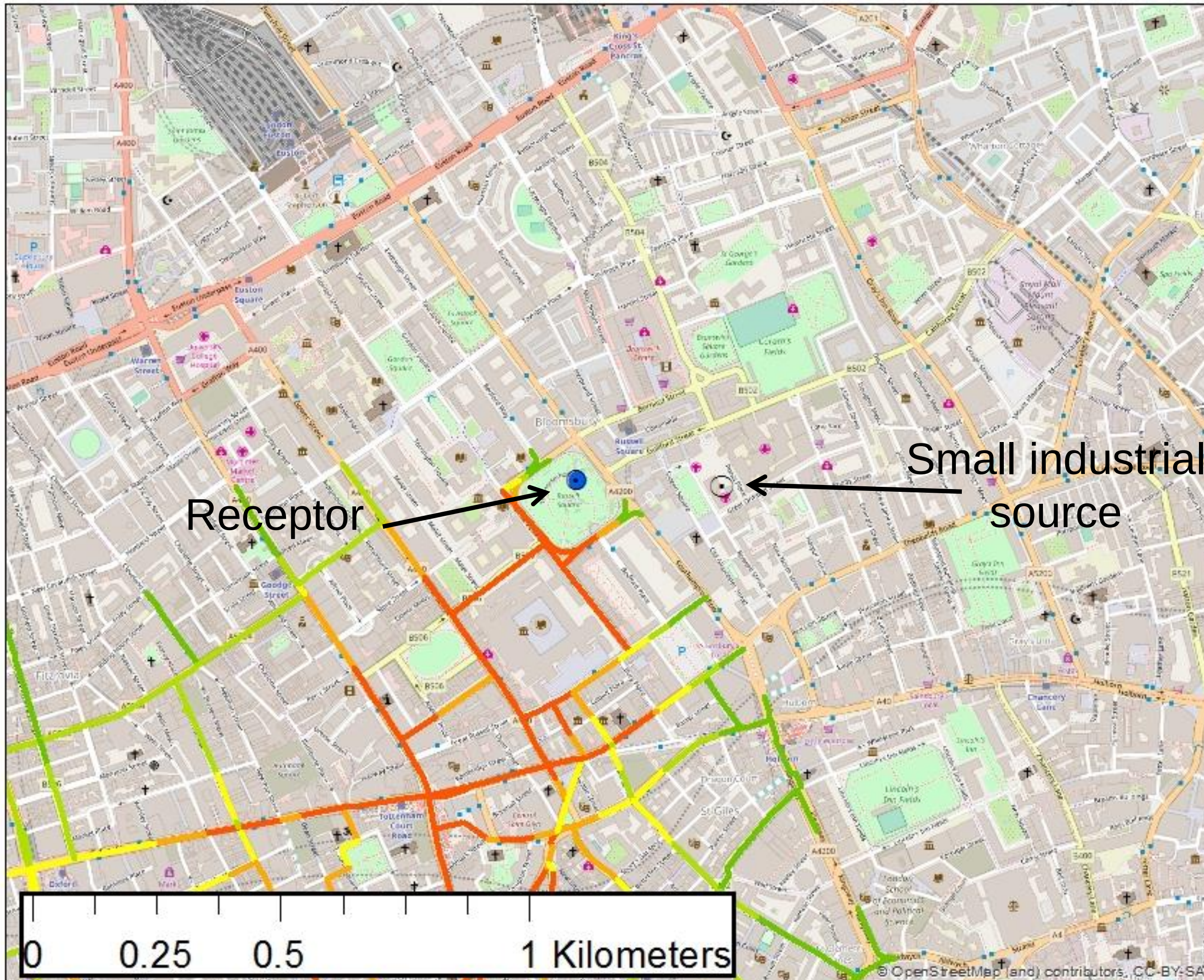

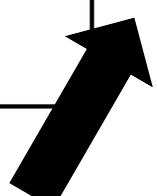

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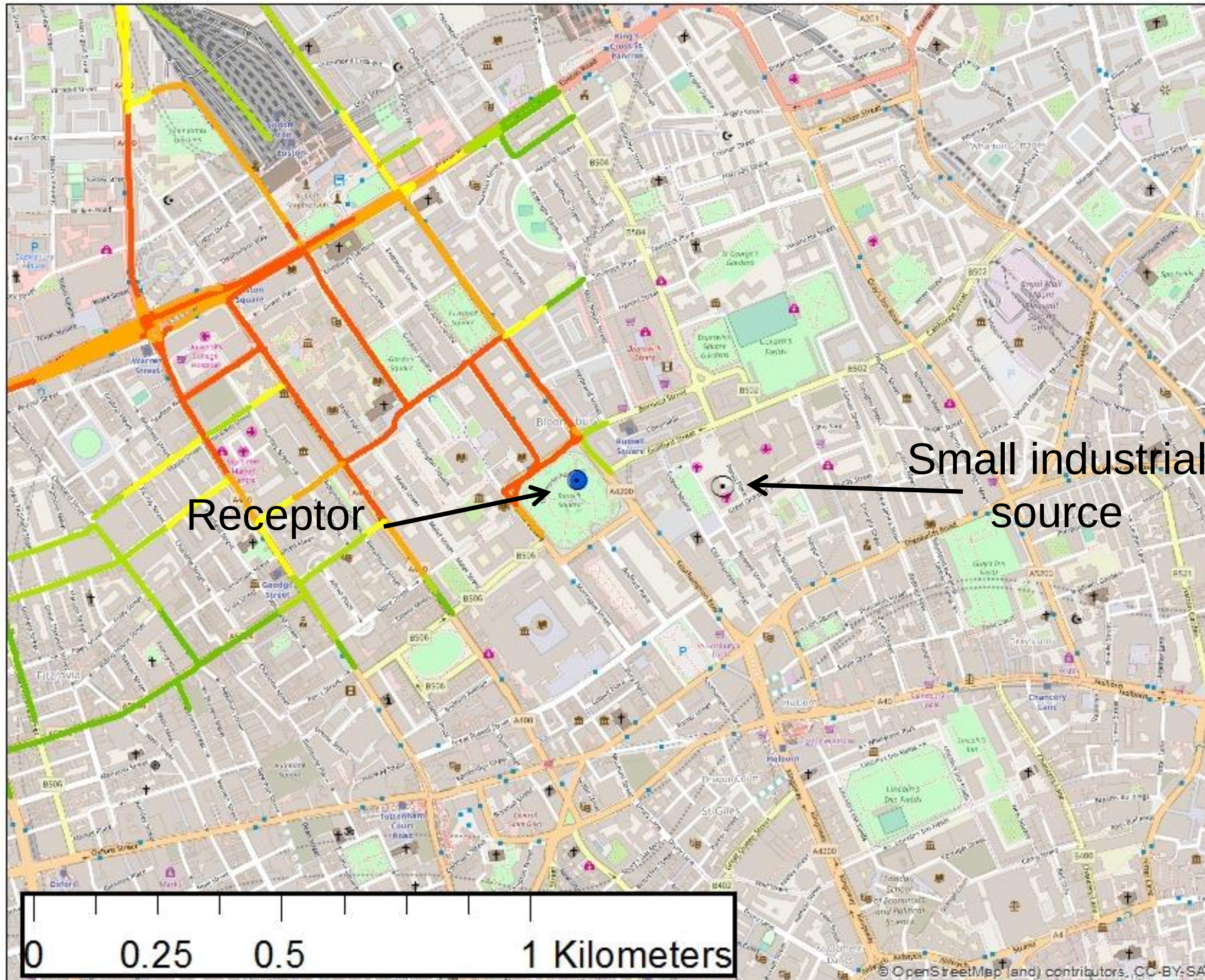

Wind

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Other uses of ‘concentration per source’

- The ‘concentration per source’ output can be used within an air dispersion model optimisation technique that uses output from low-cost sensor networks

www.aqmesh.com/

Define a cost function J(x) with two terms: one that describes the error in the modelled concentration (left-hand term) and one that describes the error in the emissions (right-hand term)

$$J(\mathbf{x}) = (\mathbf{Mx} - \mathbf{y})^T \mathbf{R}^{-1} (\mathbf{Mx} - \mathbf{y}) + (\mathbf{x} - \mathbf{e})^T \mathbf{B}^{-1} (\mathbf{x} - \mathbf{e})$$

The aim is to minimise J to obtain x, a vector of adjusted emissions.

Quantity	Definition	Dimensions
x	Vector of emissions (result)	n
M	Transport matrix relating the source term to the observations	n by k
y	Vector of observations	k
R	Error covariance matrix for the observations	k by k
e	Vector of first guess emissions	n
B	Error covariance matrix for the first guess emissions	n by n

More info: www.slideshare.net/ies-uk/amy-stidworthy-optimising-local-air-quality-models-with-sensor-data/

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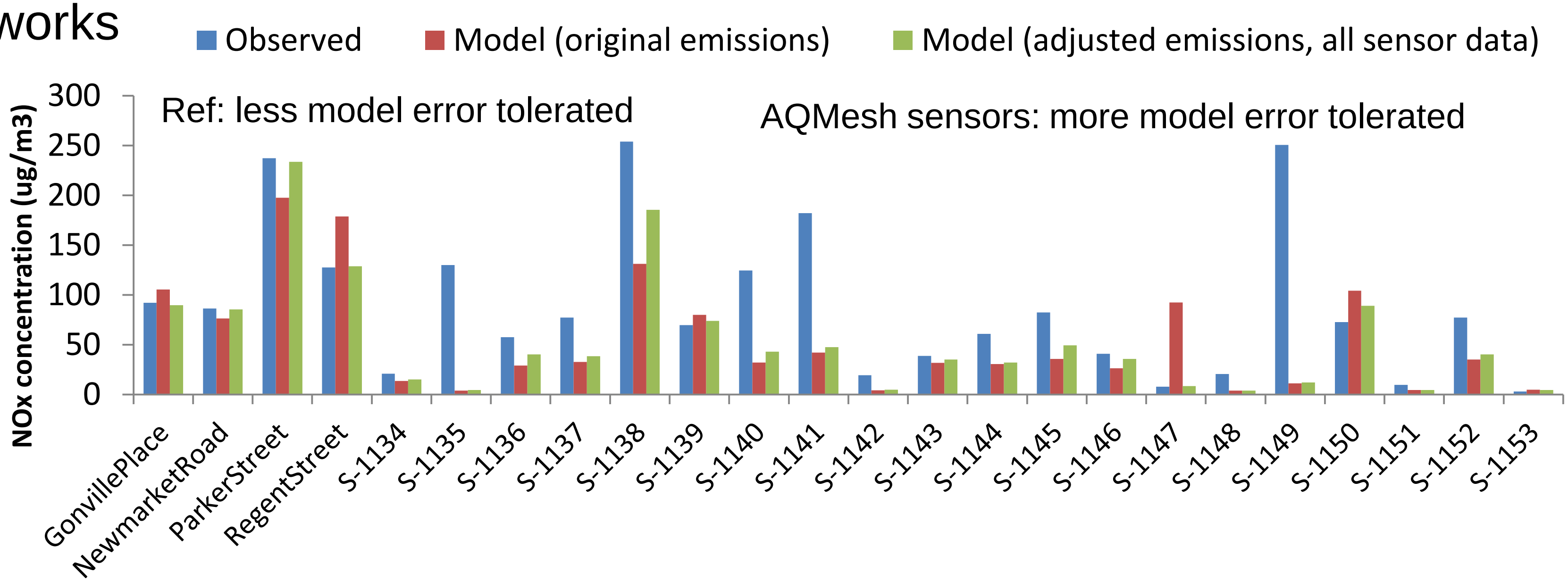


- In these inversion calculations:
  - Reference monitor uncertainty set to 10%
  - AQMesh sensor uncertainty set to 30%
  - Covariance between Reference monitors (systematic error) set to 5%
  - Covariance between AQMesh sensors (systematic error) set to 10%
  - No covariance between Reference monitors and AQMesh sensors

Example hour: 7am on 5th July

More info: www.slideshare.net/ies-uk/amy-stidworthy-optimising-local-air-quality-models-with-sensor-data/

Concentration flux modelling

- Various AQ measurement campaigns record concentration fluxes (e.g. ClearFlo* in London, AIRPRO** in Beijing)
- These measurements are elevated
- Why measure concentration flux?:
  - Fluxes are much less dependent on long-range pollutant transport compared to absolute concentrations
  - Fluxes are relatively insensitive to the spatial distribution of ground-level sources

so fluxes are a good way to quantify aggregated urban emissions, if wind speeds are non-negligible.

*www.clearflo.ac.uk/ **http://aphh.org.uk/project/index/airpro

Concentration flux modelling

- Definition of vertical concentration flux (***per source plume***):

$$\boxed{F_z} = -\boxed{K_z}\boxed{\frac{\partial C}{\partial z}} + \boxed{wC}$$

Concentration flux
μg/m²/s

Eddy diffusivity m²/s

$$K_z = \frac{1}{2}\left(\frac{d(\sigma_z^2)}{dt}\right)$$

where σ_z is vertical plume spread

Vertical concentration gradient
μg/m⁴

Bulk transport by mean vertical velocity
μg/m²/s

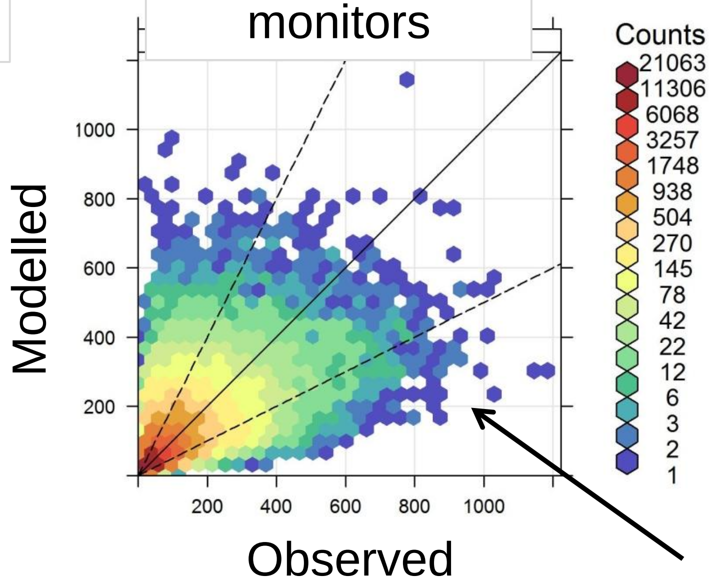
- Eddy diffusivity and concentration gradient can be derived from plume dispersion expressions

Concentration flux modelling

Preliminary results

How well does the model predict NOx concentrations – ground level & elevated?

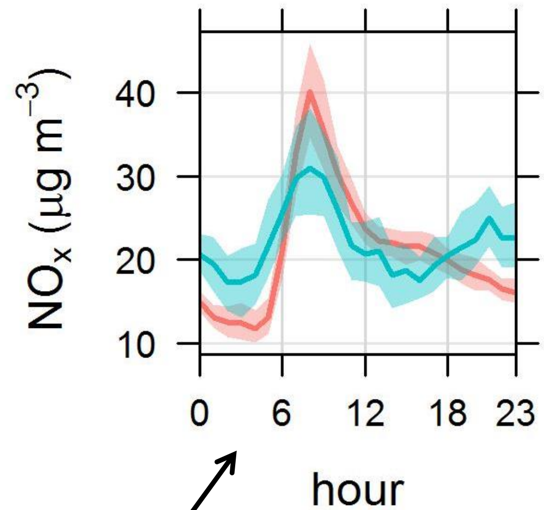
All ground level monitors



Frequency scatter plot

Concentrations

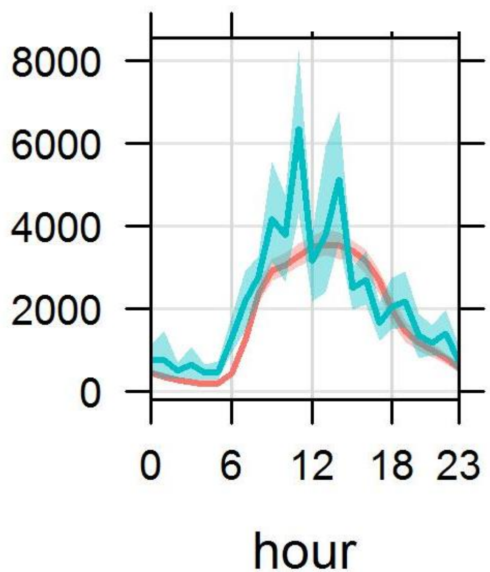
BT Tower



Fluxes

NOx flux

ng/m²/s



BT Tower: average diurnal profiles

How well does the model predict NOx fluxes?

Observed

Modelled

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Summary

Concentrations

- Local-scale dispersion models can perform detailed source apportionment calculations on a source-by source basis (e.g. road sources, industrial sources, grid cells)
- Concentrations can be apportioned at high resolution in terms of:
  - Source of emissions (e.g. vehicle types)
  - Spatial extent

  allowing targeted air pollution mitigation plans to be assessed
- 'Concentration per source' output has other uses e.g. model optimisation using AQ sensor networks

Concentration fluxes

- Calculating concentration fluxes on a source-by-source basis allows:
  - Validation of flux measurements
  - Evaluation of emissions inventories
  - Greenhouse gas assessments

For both concentrations and concentration fluxes, it is important to evaluate against measurements where possible