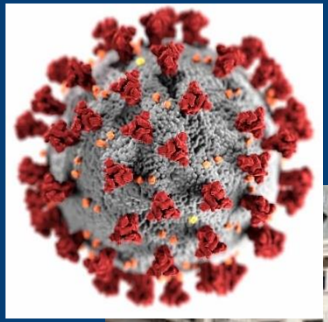
Quantifying the Impact of COVID-19 Restrictions on Emissions using Inverse Modelling and Measurements



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21st International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes

27-30 September 2022,

Aveiro, Portugal

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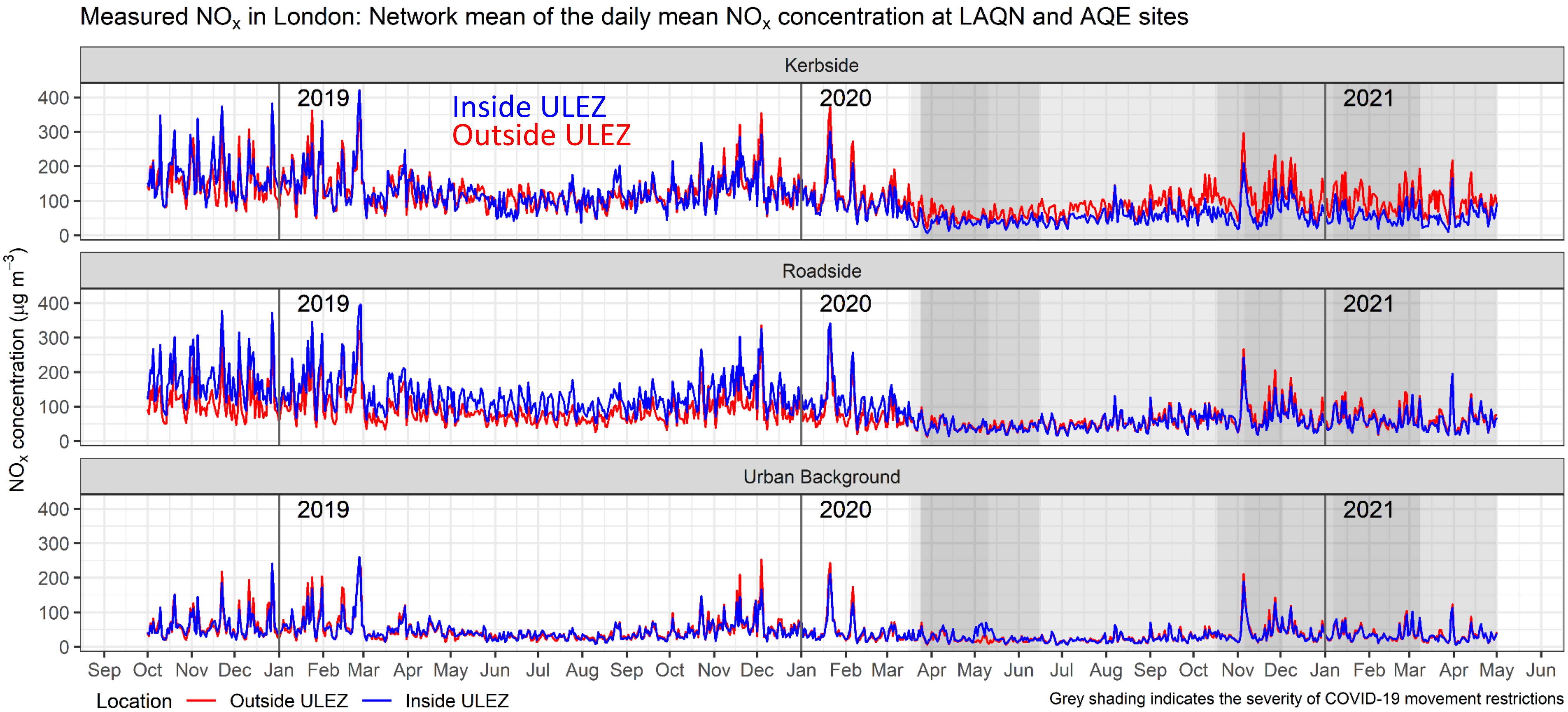
Motivation

- Unprecedented change in transport activity caused by the March 2020 lockdown
- Potential for massive discrepancies in emissions compared with established emissions inventories
- Vital that we try to understand the changes – some effects could be long-lasting or even permanent (e.g. increased home-working)
- Emissions inventories take time to collate – we need to understand the impacts on emissions sooner – e.g. air quality forecasting
- <u>Plus</u> this is a once-in-a-generation chance to analyse and understand the effects of a step-change in transport activity on this scale
- The work presented here focuses on London, through our work on the Breathe London Pilot project

What do air quality measurements in London tell us?



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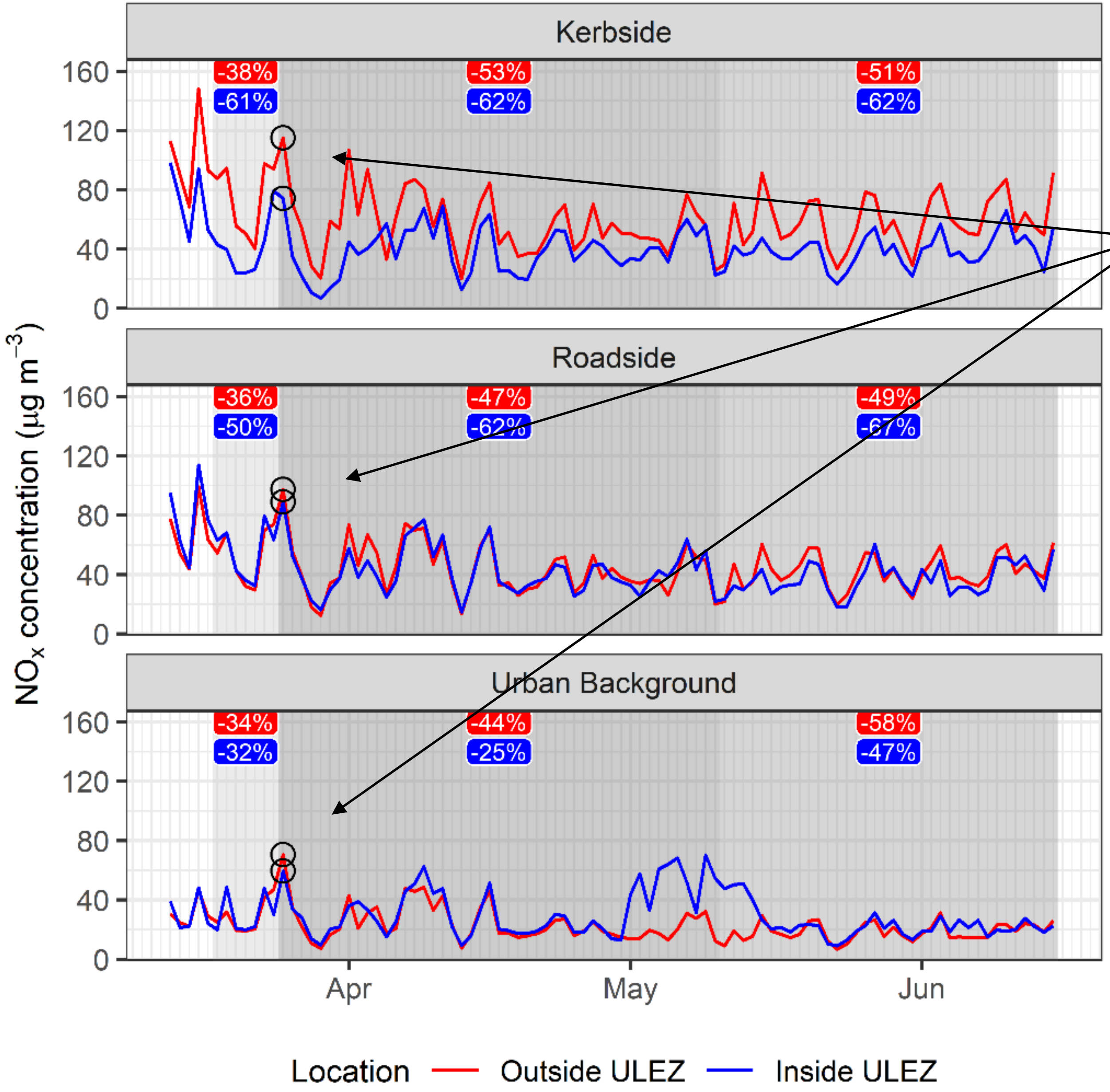
What was the impact of the March 2020 restrictions?



- Look closer at the initial lockdown period
- Concentrations are high on the second day of lockdown (25 March)
- Concentrations were lower **after** the restrictions began to be lifted from 10 May than when London was under the most severe restrictions (24 March to 9 May)
- We need to tease apart the effects of meteorology from the effects of the lockdown itself…

Breathe London Pilot

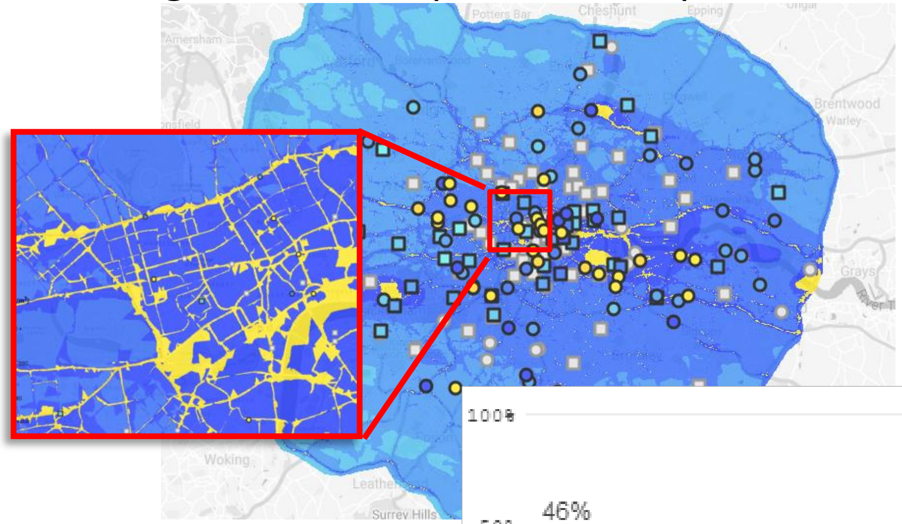
BreatheLondonPilot.org

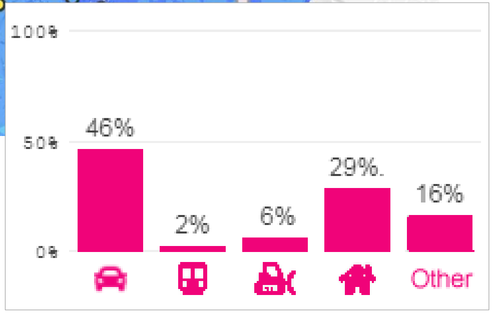
BREATHE LONDON

A project combining **modelling** with **measurements** from small low cost sensors and mobile monitors to give insight into London's air pollution

MODELLING

High resolution pollution maps

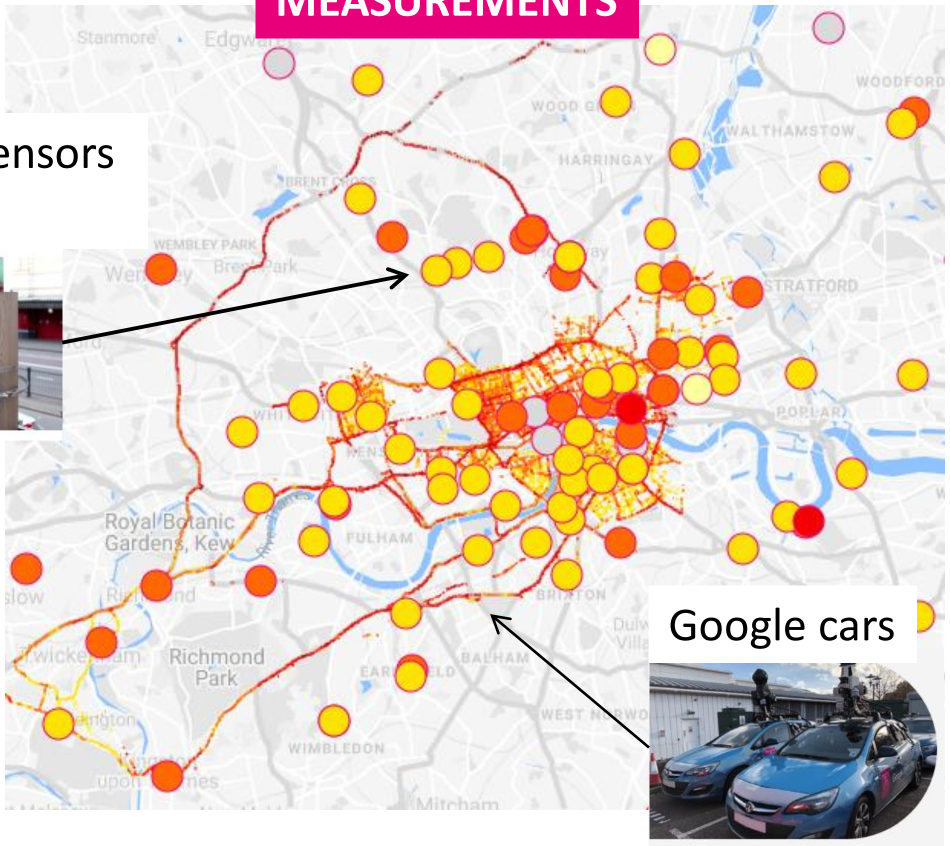




Source apportionment

MEASUREMENTS

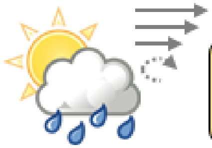
100 lower cost sensors
(~ £5000)



Google cars

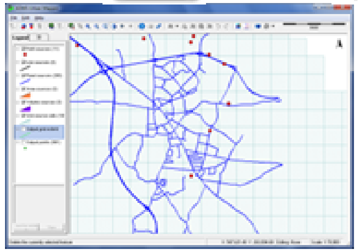
EDF Environmental Defense Fund — Finding the ways that work
AirMonitors.co.uk — Quality · Service · Innovation
University of Cambridge
CERC
Google Earth Outreach
NPL National Physical Laboratory
King's College London
Greater London Authority
C40 Cities
Children's Investment Fund Foundation

ADMS-Urban: Atmospheric Dispersion Modelling System



meteorological data

emissions / activity data (including traffic flows)



source data

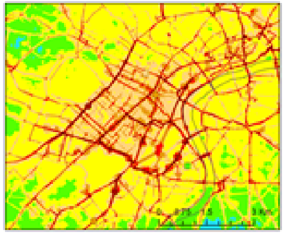
background concentrations

time-varying emission profiles

ADMS-Urban

- dispersion
- met. pre-processor
- regional model link
- chemistry
- deposition
- street canyons
- urban canopy
- tunnels
- elevated roads
- buildings
- complex terrain

high resolution pollution maps



annual averages, exceedences, percentiles, hourly means

comparison with monitoring data

comparison with air quality standards

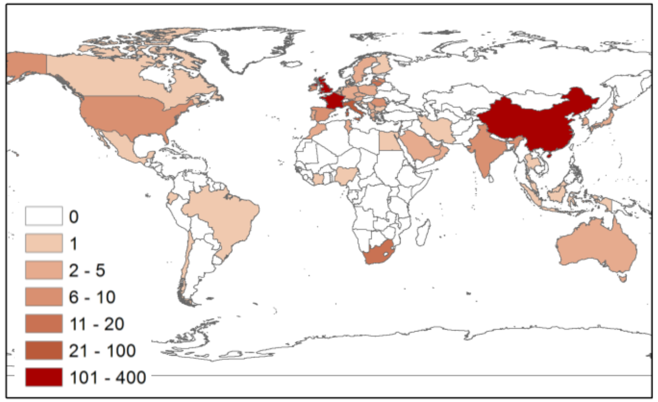
source apportionment, footprints

future scenarios

traffic management

Hundreds of ADMS licences worldwide

Organisations using ADMS per country

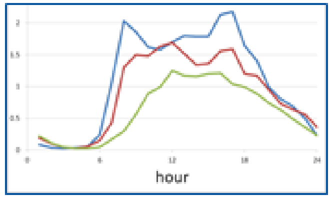


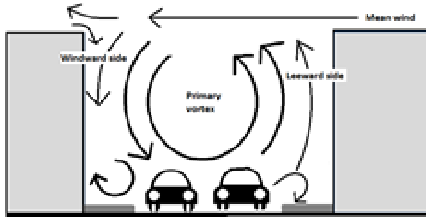
Widely used by…

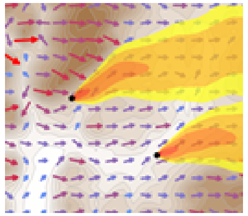
- Companies
- Regulatory bodies
- Local government
- National government
- Research organisations

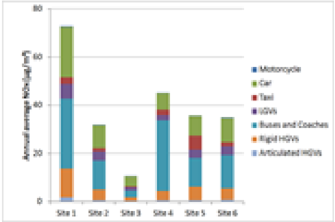
Provided with…

- Professional Helpdesk Service
- Training (online available)
- Detailed user documentation







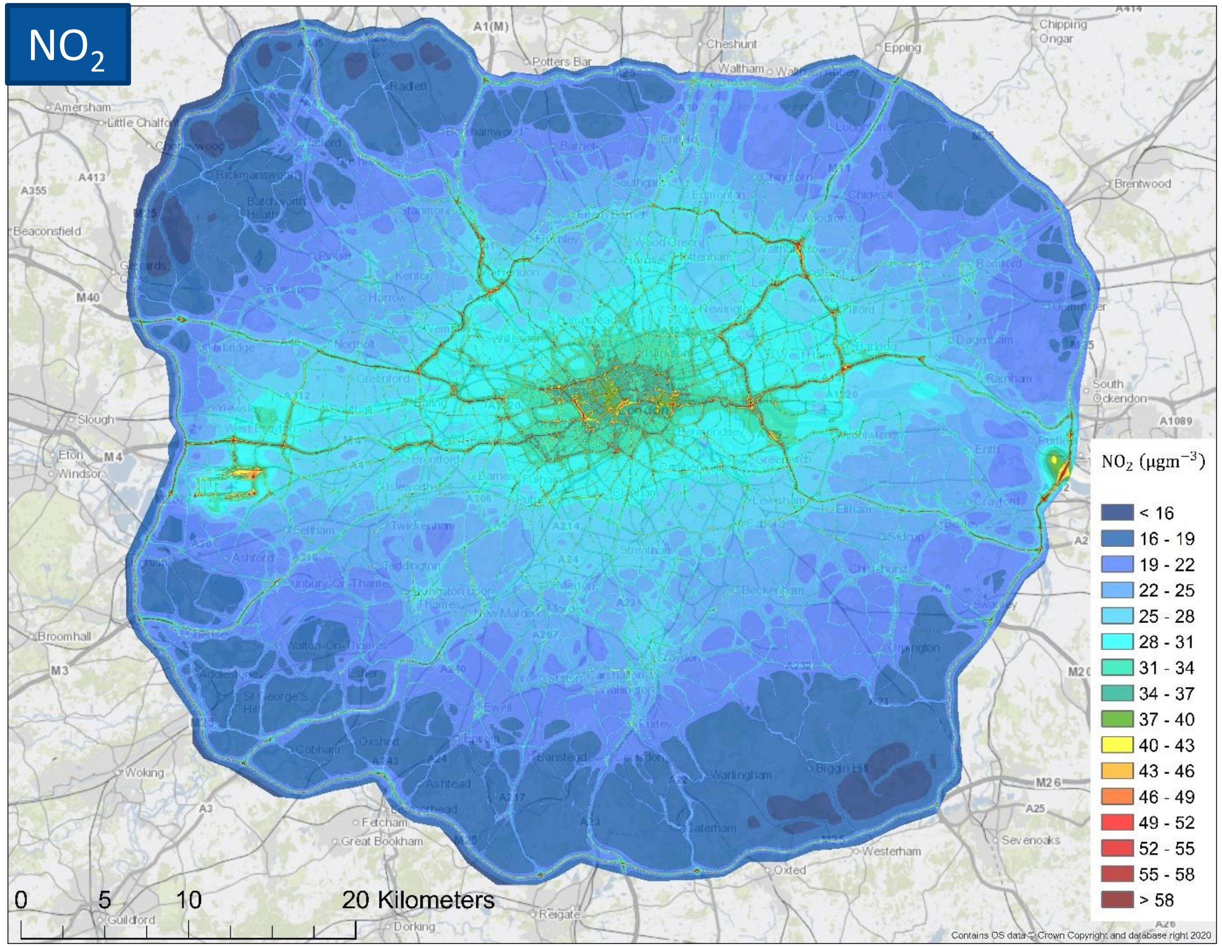


CERC

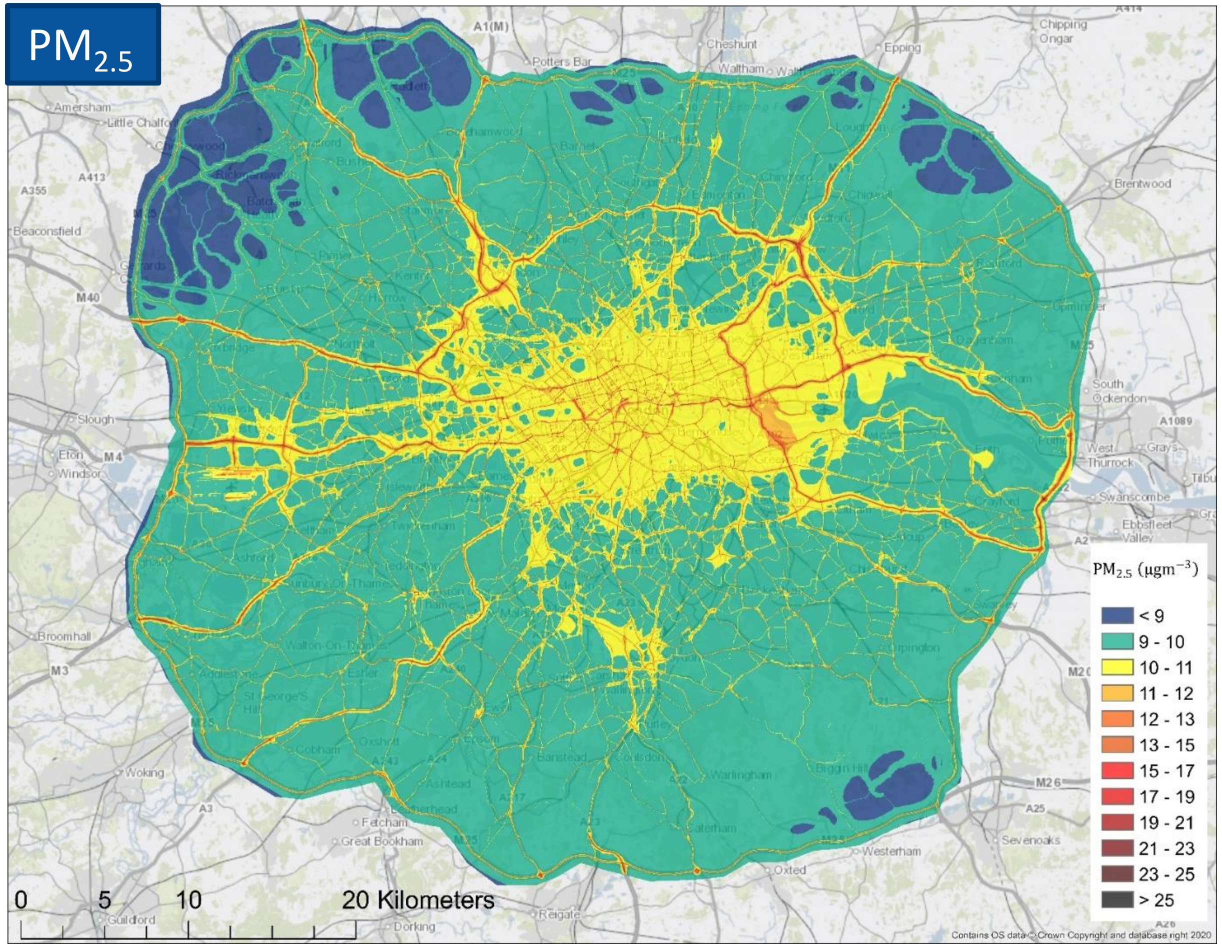
www.cerc.co.uk/ADMS-Urban

Understand the problem: Model gives air pollution levels everywhere, all the time

Modelled air pollution in London in 2019 with a resolution of 10 metres



Area coloured yellow, orange and red exceeds UK annual objective of 40 μg/m³ for NO_2



Area coloured yellow, orange and red exceeds WHO guideline of 10 μg/m³ for $PM_{2.5}$

Understand the problem: Model gives air pollution levels everywhere, all the time

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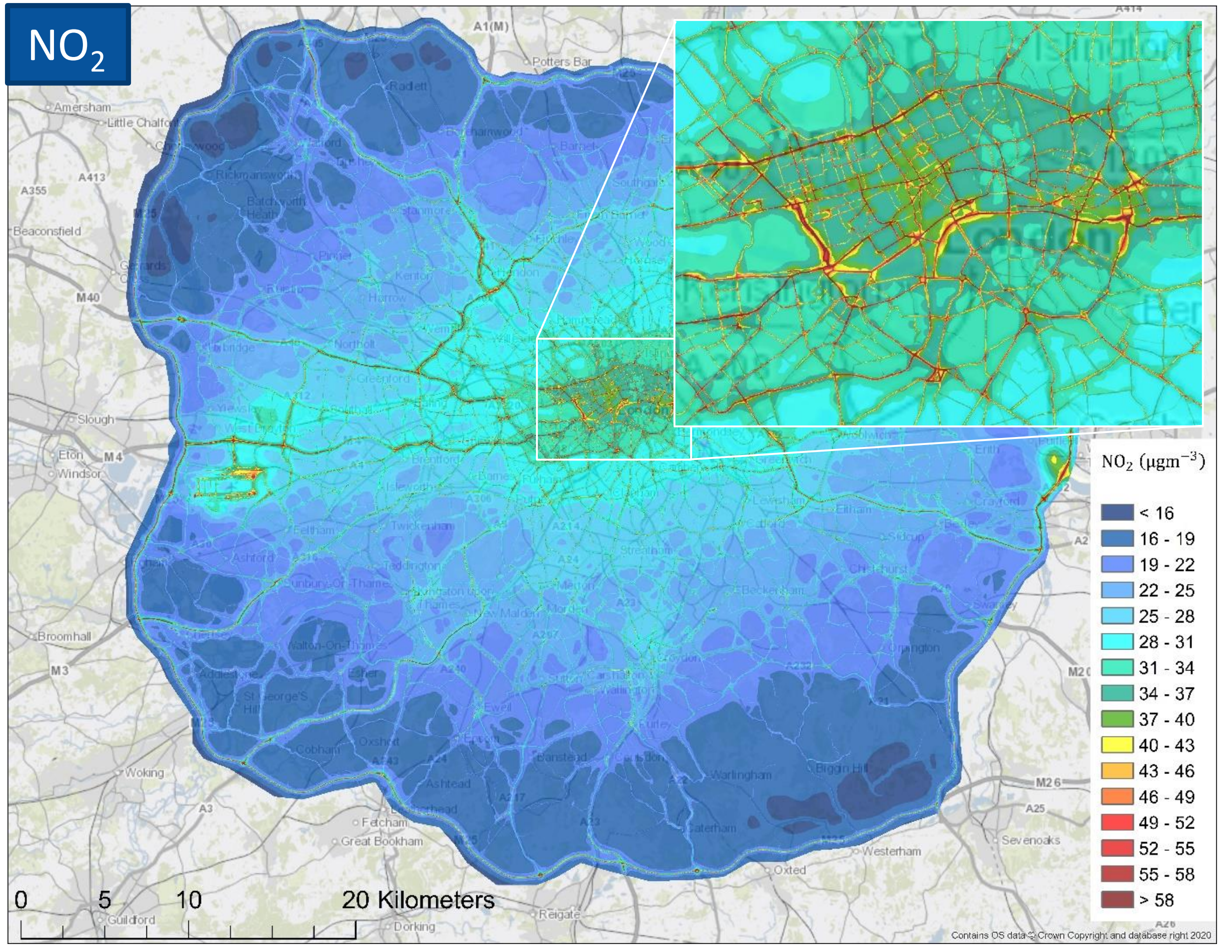

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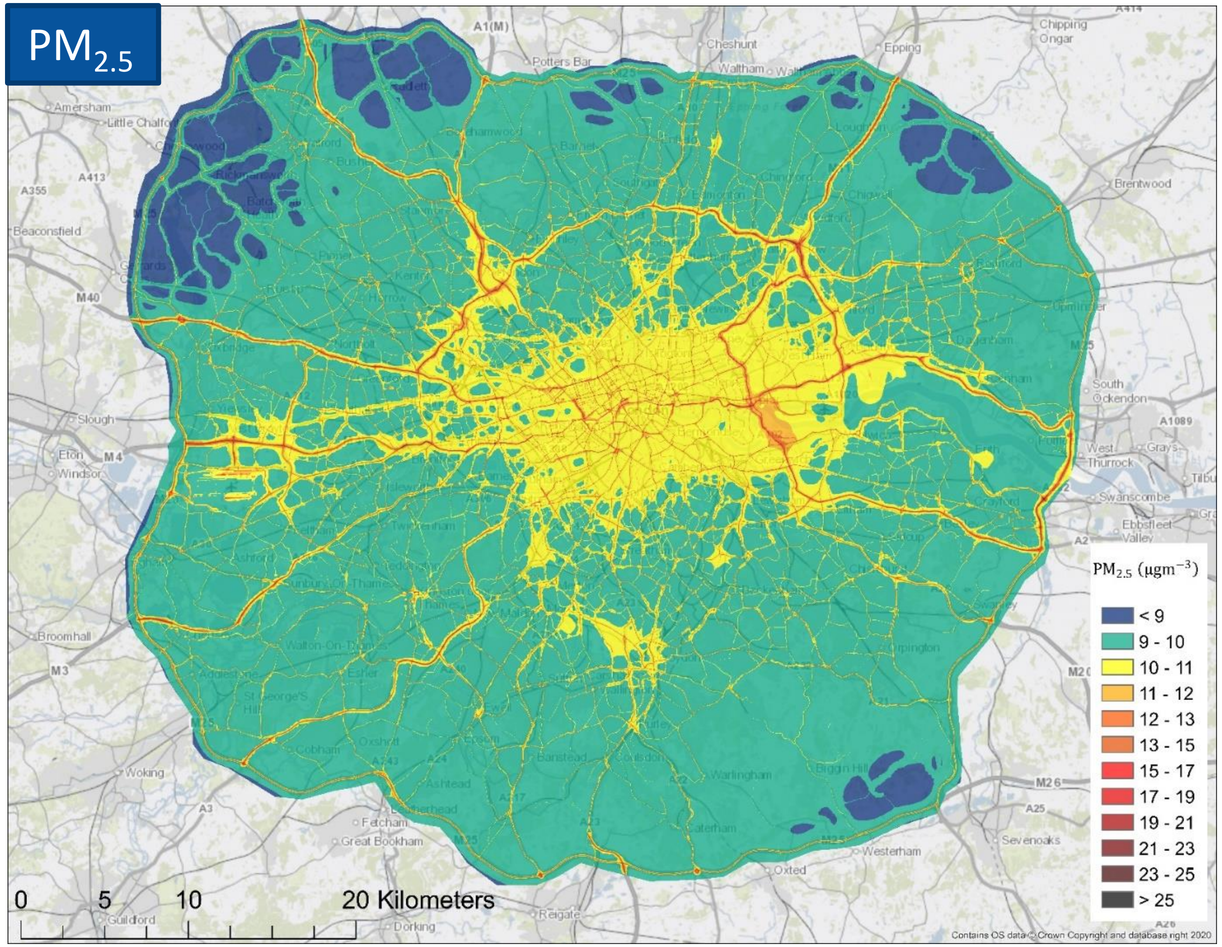


Area coloured yellow, orange and red exceeds WHO guideline of 10 µg/m^3 for $PM_{2.5}$

Inversion scheme: Cost function

Cost function **J** minimised using a non-negative least squares solver to obtain **x**, a vector of adjusted emissions.

$$J(\mathbf{x}) = \underbrace{(\mathbf{Mx}-\mathbf{y})^T \mathbf{R}^{-1}(\mathbf{Mx}-\mathbf{y})}_{\text{Modelled concentration error}} + \underbrace{(\mathbf{x}-\mathbf{e})^T \mathbf{B}^{-1}(\mathbf{x}-\mathbf{e})}_{\text{Emissions error}}$$

Quantity	Definition	Dimensions
x	Vector of *a posteriori* 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 *a priori* emissions	n
B	Error covariance matrix for the emissions	n by n

Run **ADMS-Urban** with unit emission rates to **calculate** the normalised contribution from each source to each receptor

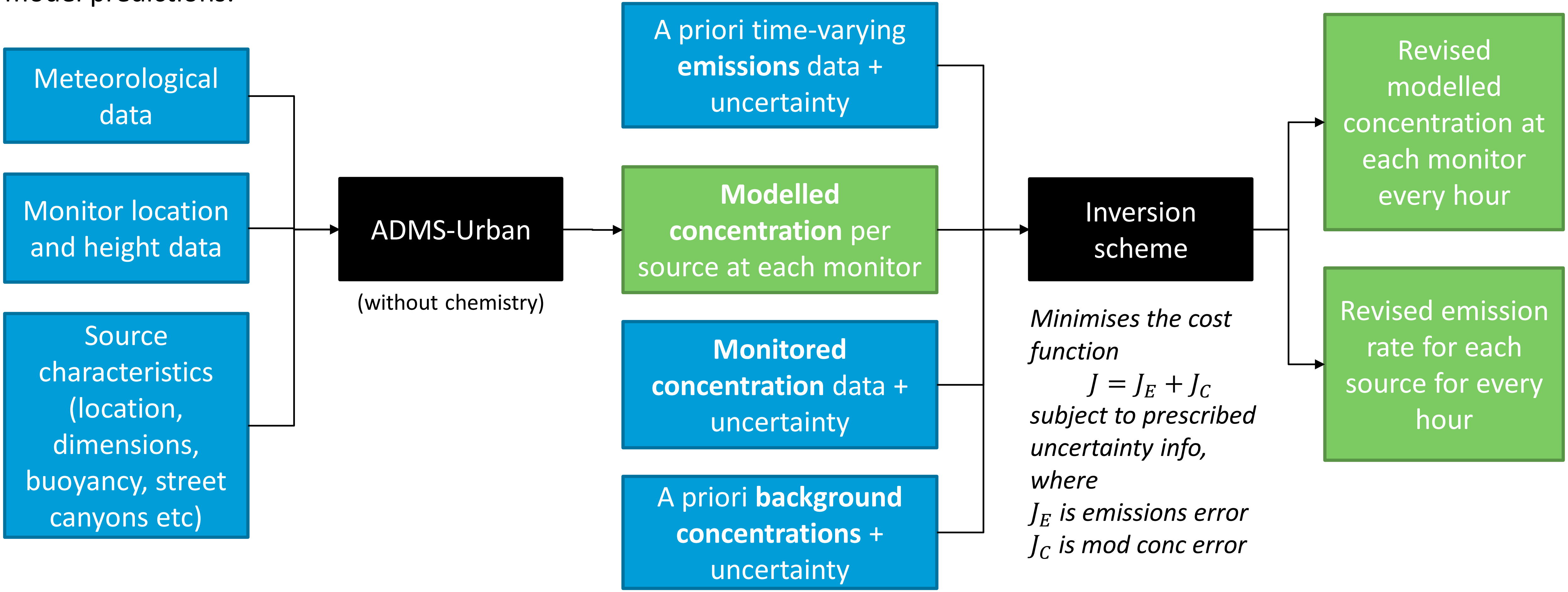
Estimated measurement error and error co-variance between monitors or sensors

Estimated emissions error and error co-variance between sources

The background concentration each hour is treated as a source that contributes equally to every receptor

CERC Inversion Scheme

The inversion scheme uses monitoring data from a network of monitors/sensors to adjust emissions to reduce error in the model predictions:



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. 66, issue 4, pp. 252-266

Inversion scheme inputs for London COVID-19 NO_X impact analysis

Hourly meteorological data from Heathrow Airport

NO_X emissions and traffic flows for London for 2019 from the GLA's London Atmospheric Emissions Inventory (LAEI)

Upwind hourly background concentrations from 4 rural AURN sites around London

LAQN and AQE hourly monitored NO_X data at 115 sites across London

Breathe London AQMesh hourly monitored NO_X data at 80 sites across London

ADMS-Urban modelled hourly concentrations at each monitoring site for each source

Analysis period: 1 January 2020 – 30 April 2021

Inversion scheme uncertainties and error covariances

Uncertainties

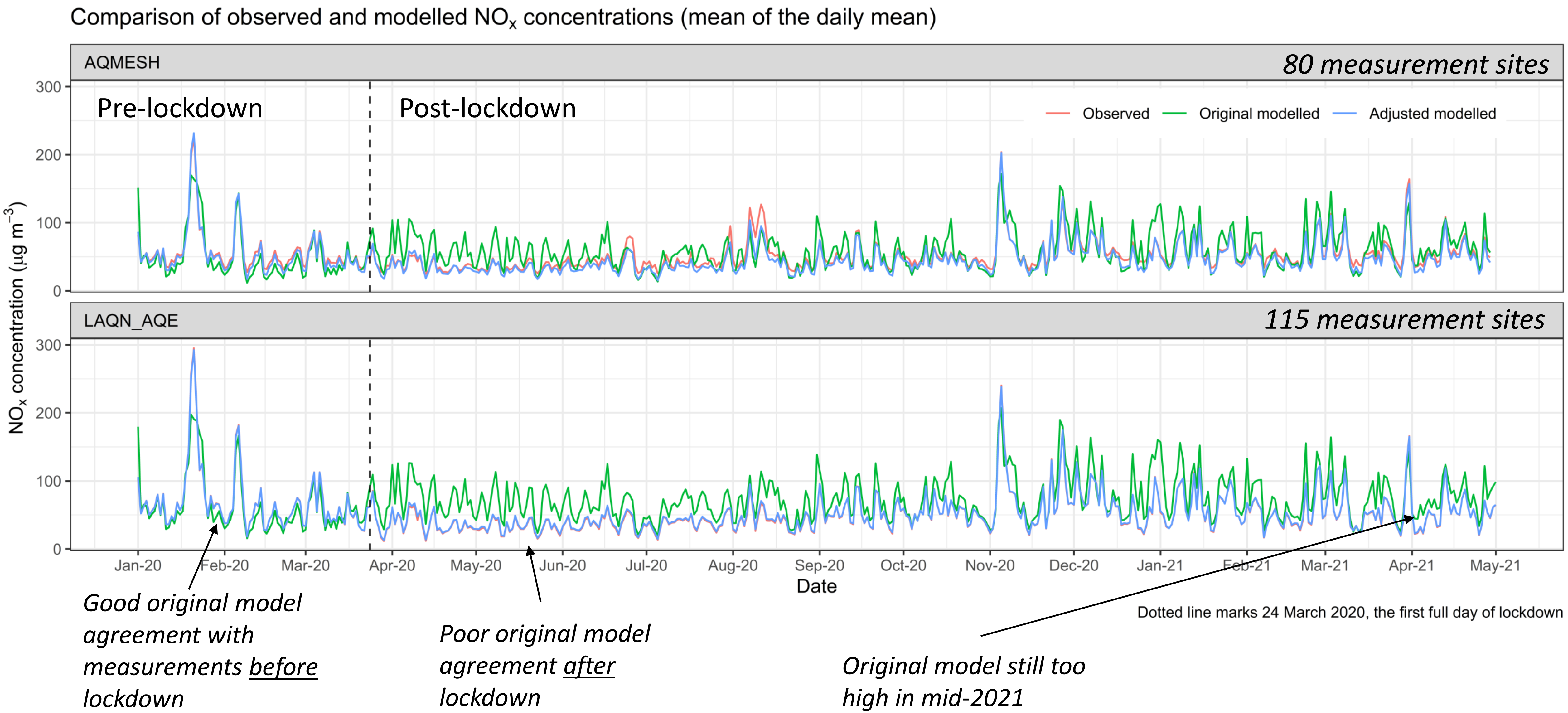
- Measurements:
  - AQMesh 12 µg m^{-3}
  - LAQN/AQE 4 µg m^{-3}
- Emissions (% of emission rate): roads 100%, fuels 50%, other 20%
- *Background (% of conc): 0.1% (i.e. background unchanged)*

Error covariances

(as a percentage of uncertainty)

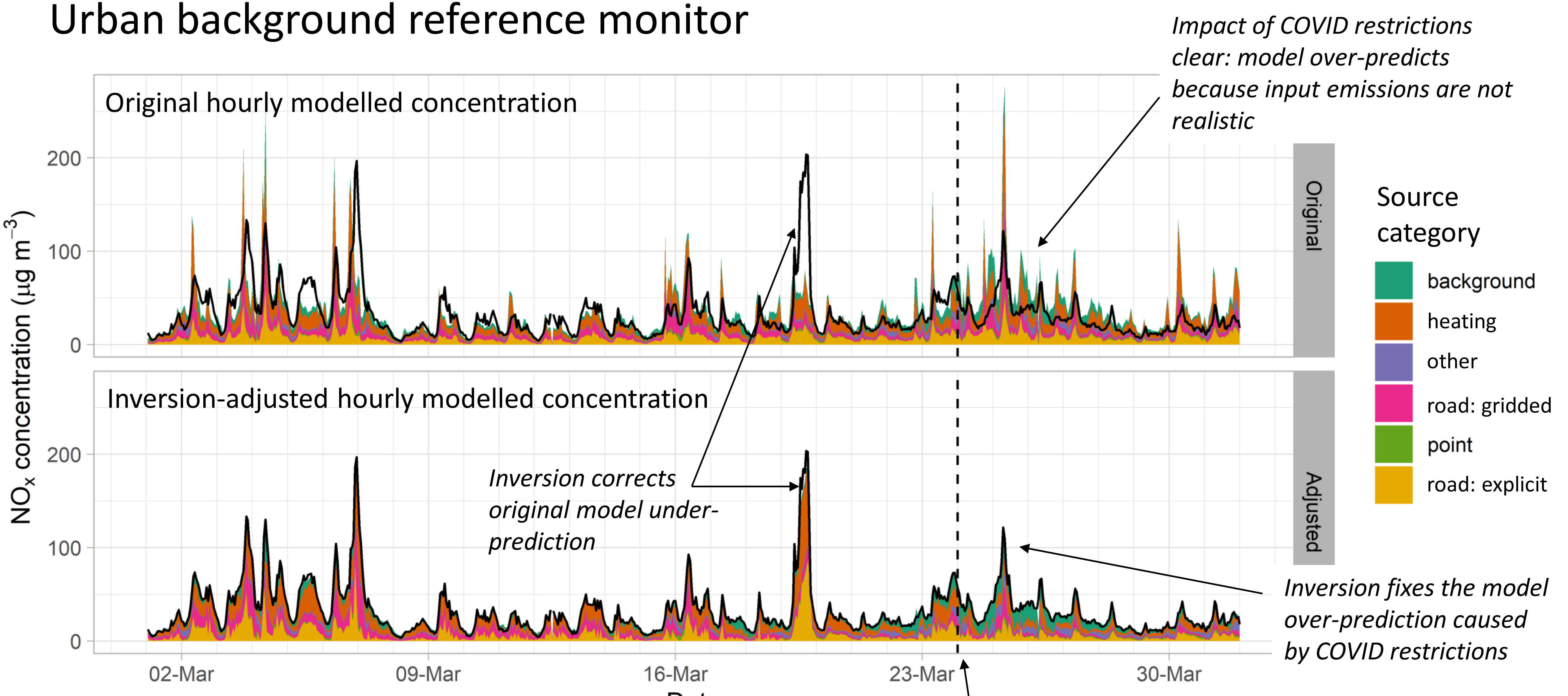
- AQMesh-AQMesh and LAQN/AQE-LAQN/AQE : 5%
- Zero error covariance between AQMesh and LAQN/AQE
- Roads-Roads 40% (common emission factors)
- Fuels-Fuels 20% (commercial and domestic oil and gas)
- Other-Other 20%

Results – NO_x concentrations



Results – NO_x concentrations – individual sites

Urban background reference monitor

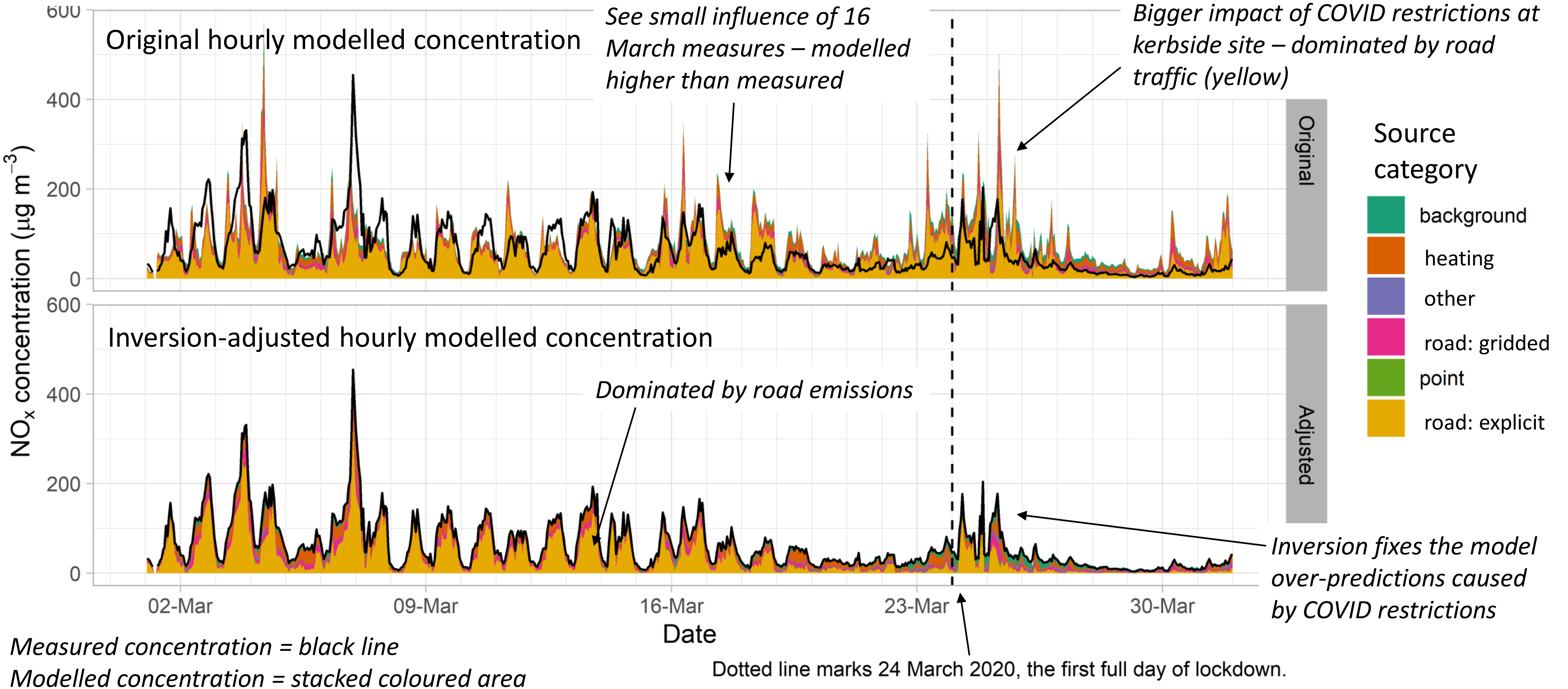


Measured concentration = black line
Modelled concentration = stacked coloured area

Dotted line marks 24 March 2020, the first full day of lockdown.

Results – NO_x concentrations – individual sites

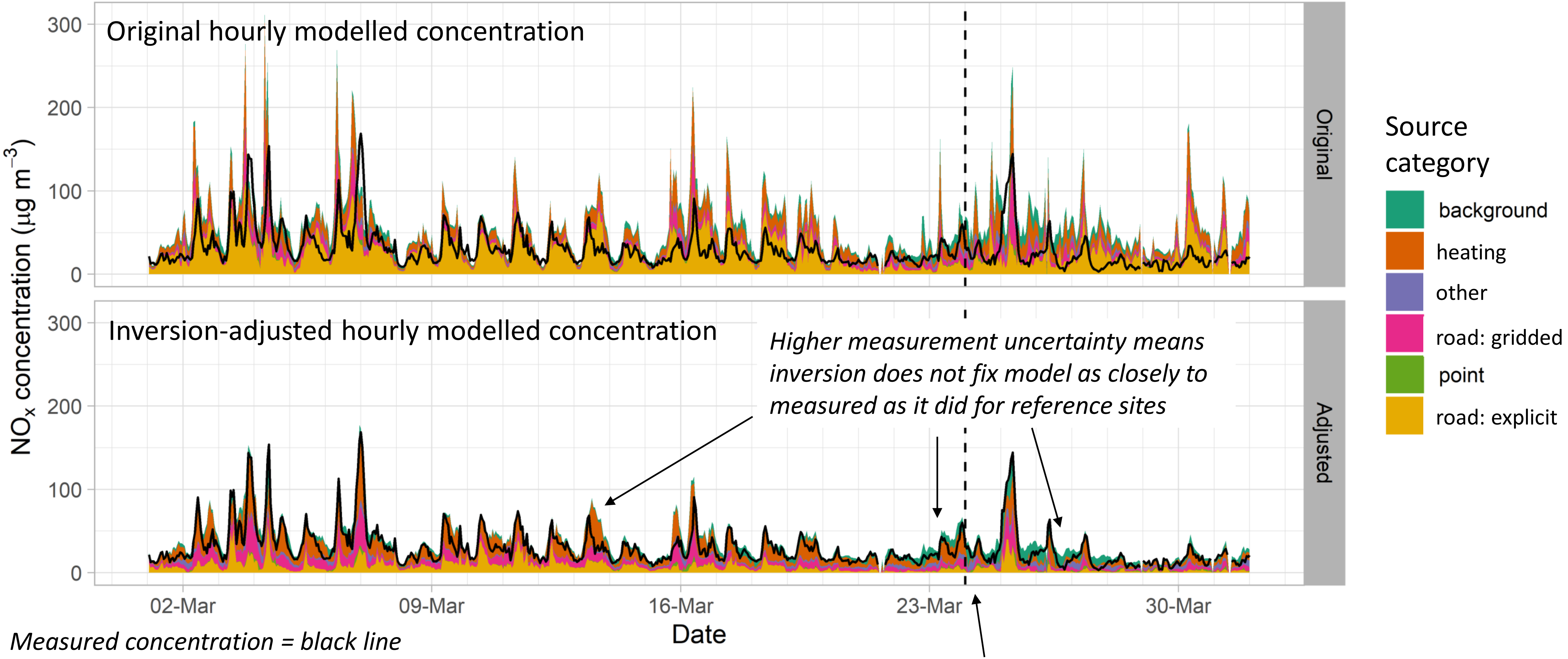
Kerbside reference monitor



Measured concentration = black line
Modelled concentration = stacked coloured area

Results – NO_X concentrations – individual sites

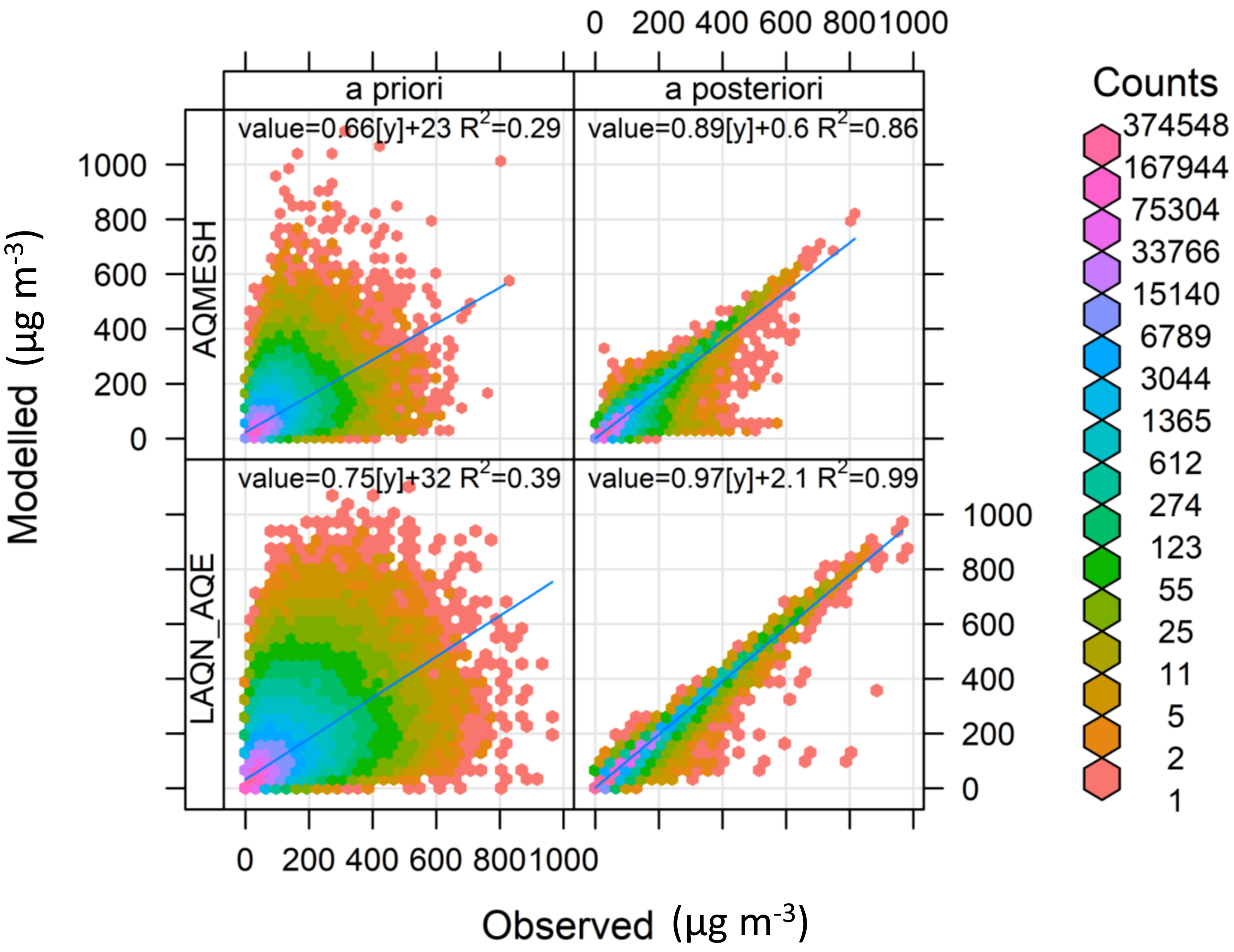
Roadside AQMesh Sensor



Measured concentration = black line
Modelled concentration = stacked coloured area

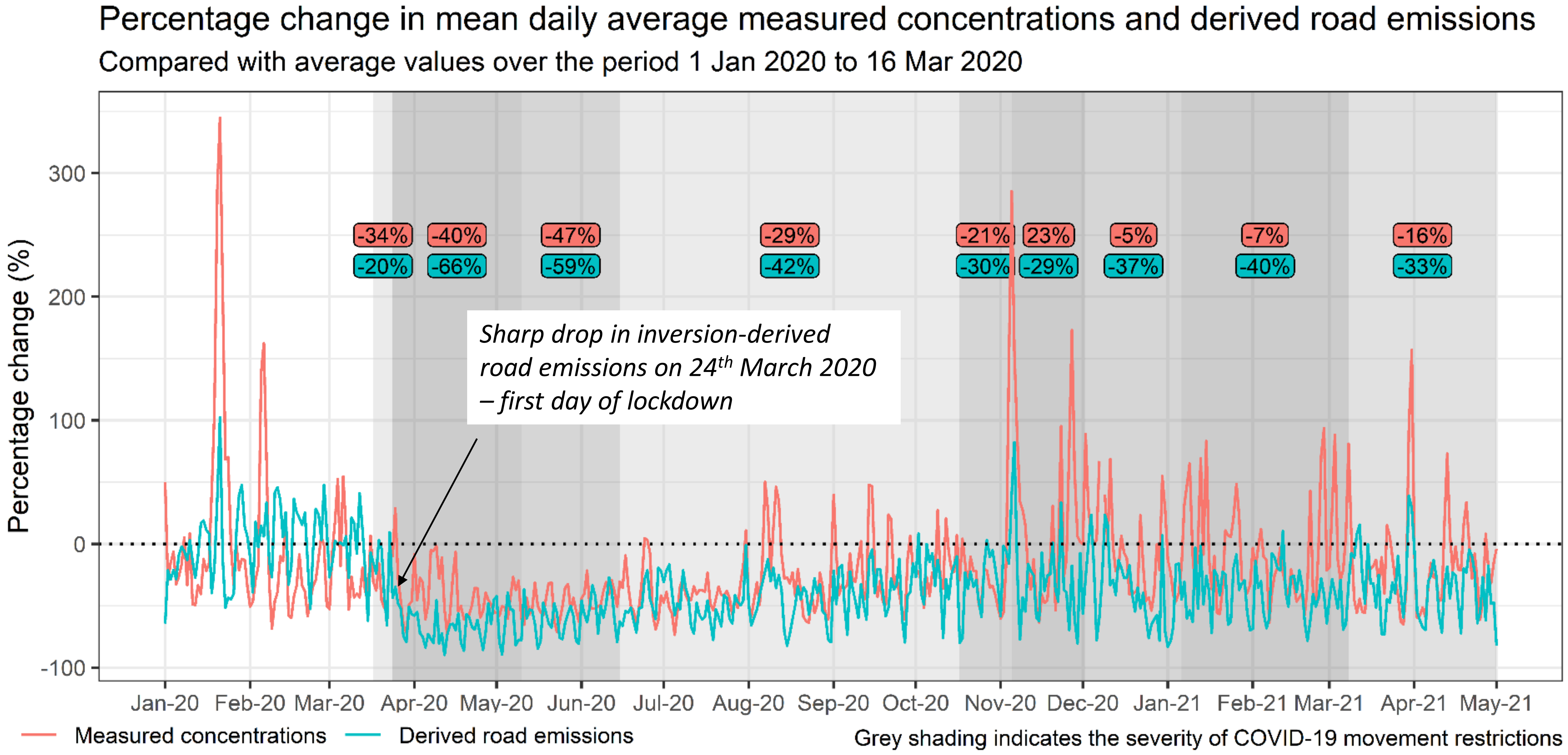
Dotted line marks 24 March 2020, the first full day of lockdown.

Results – NO_X concentrations, modelled vs measured

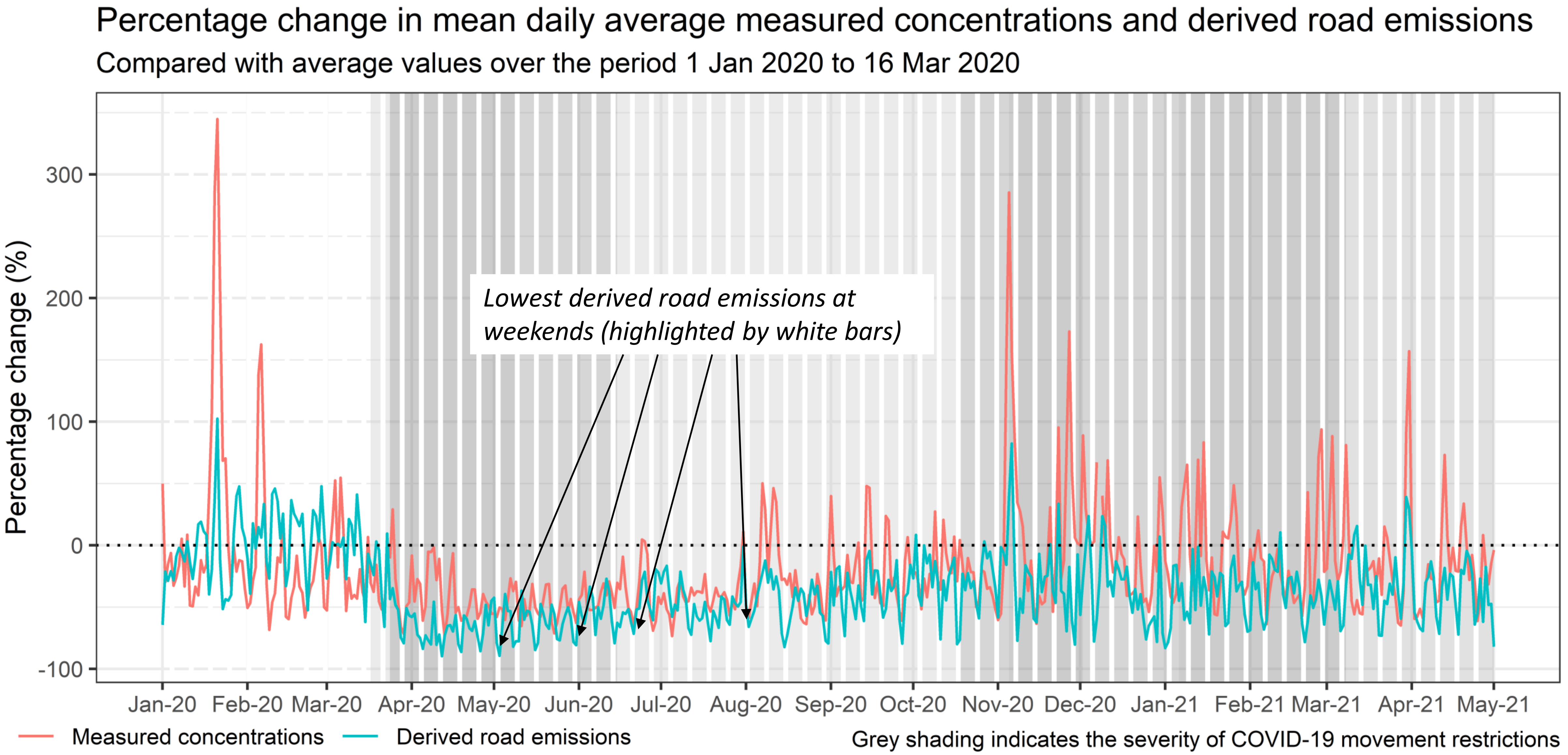


- Inversion Scheme is designed to adjust emissions to improve modelled concentrations
- As expected, agreement with observations greatly improved
- Correlation close to 1 for reference sites
- Agreement with reference monitors better than AQMesh sensors, as expected due to AQMesh sensors having higher input measurement uncertainty
- Inversion Scheme is behaving as expected – what does it say about emissions?

Results – Changes in derived NO_x road emissions

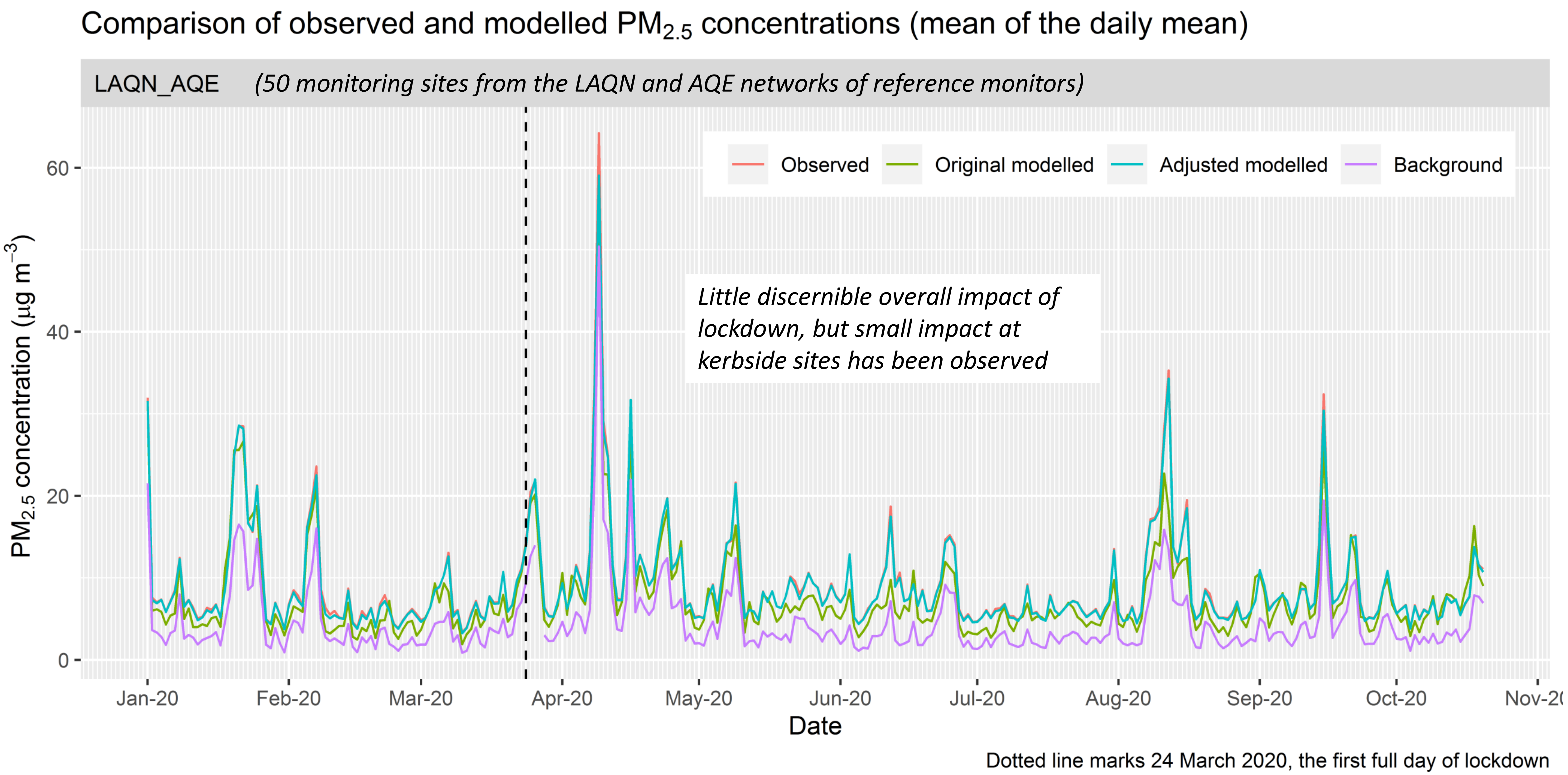


Results – Lowest NO_x road emissions at weekends



CERC

Results – $PM_{2.5}$ concentrations



Ongoing and future work

Other applications

CO_2 concentrations and emissions in London over the same period

Verifying the **CO_2** emissions inventory for Glasgow (COP26)

Industrial applications (e.g. quantifying H_2S emissions from landfill sites)

System developments

Introducing **time correlations**, to reduce sensitivity to missing data (currently each hour is treated independently), with break dates where changes are expected to break correlations (e.g. COVID-19 lockdowns, bank holidays etc)

Increasing **computational efficiency** to allow more sources to be included (currently low-contributing sources are removed)

This analysis was funded by a NERC COVID-19 emergency grant with the University of Cambridge and ACOEM – thanks to Rod Jones, Jim Mills and their teams, and of course CERC colleagues.

Thank you for listening!

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