Breathe-London submission to the AQEG/Defra Covid-19 call.

This document was prepared by the BL partners (Air Monitors/ACOEM, Cambridge Environmental Research Consultants, Environmental Defense Fund, National Physical Laboratory and the University of Cambridge).

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The Breathe London (BL) project is a Clean Air Fund (CAF) funded initiative to investigate air quality across London. The three measurement components of BL are a network of around 100 low cost AQMesh air quality sensors (pods) which have run from October 2018 to the present, two Google Street view cars fitted with reference standard air quality instrumentation which ran for 14 months from September 2018, and a study using wearable air quality sensors. Data and details of the partners involved with BL can be found at https://www.breathelondon.org. This document uses data from the AQMesh air quality network measurements and includes associated air quality modelling. High resolution versions of figures are available in the Appendix.

1) *Observed changes in air quality associated with the Covid-19 traffic reductions*

Nitrogen dioxide (NO_2) and NOx

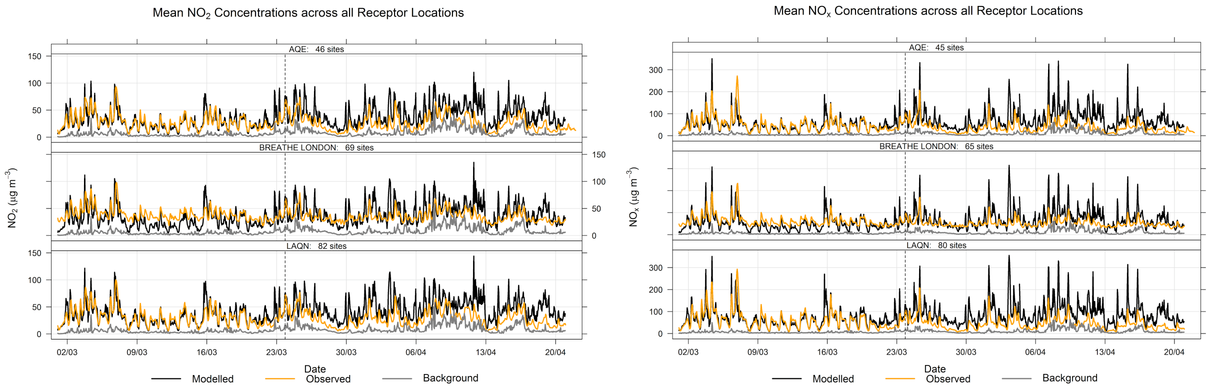


Figure 1.1 Modelled (black) and observed (yellow) AQE, LAQN and BL network hourly average time series for NO2 and NOx for March 2020 onwards. Modelled data were calculated using the ADMS-Urban dispersion model. The dotted line marks 8.30pm on 23 March, when the lockdown was announced.

Figure 1.1 shows hourly averaged time series for March 2020 onwards for NO_2 and NOx, both measured by the Air Quality England (AQE), BL and London Air Quality Network (LAQN) networks and modelled using the air quality model ADMS-Urban. Similar features are observed in all three networks, although as network sites differ, some differences are to be expected.

The BL network shows the same patterns as seen in the reference networks, though a small positive bias is evident. Diagnostic work has shown that this appears to be largely due to an increasing O_3 cross interference as the NO_2 sensors age. A correction algorithm to account for this is in the final stages of development, but has not been applied to the data shown in this document.

The ADMS model calculations, which in these figures assume no change in traffic characteristics following lockdown, show generally good consistency prior to the 23rd March, but a significant overestimation following, consistent with a reduction in emissions from traffic in the observations. This is discussed further in section 2. Observations from all three networks (and model results) also show significant variability, including periods of elevated pollution levels associated with more stagnant meteorological conditions.

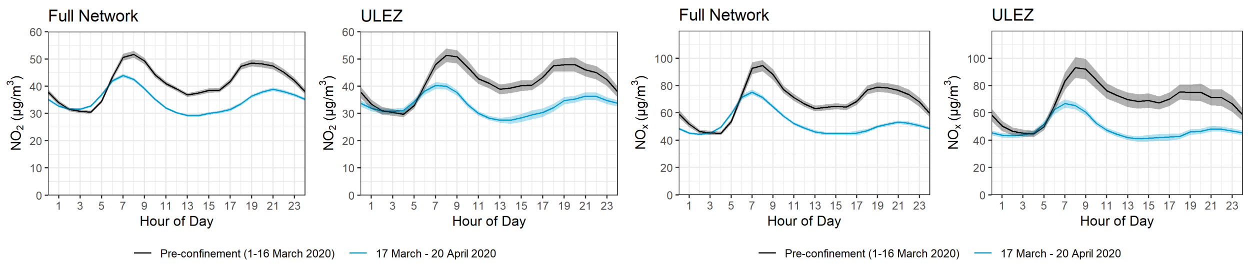


Figure 1.2 Differences in the diurnal patterns of NO_2 and NOx for the pre- and post-lockdown periods for the full BL network and for the BL sites inside the ULEZ. The shading shows the 95% confidence limits of the network averages.

Figure 1.2 shows diurnal patterns of NO_2 and NOx pre- and post-lockdown (1st - 16th March, 17th March - 20th April respectively). Key conclusions from figure 1.2 are that the BL network shows that there have been statistically significant reductions in both NO_2 and NOx during the covid-19 lockdown period across the BL network (15% and 23% respectively). They also show that the effects are greater within the ULEZ (20% and 29% respectively), but that the reductions are much reduced and in many cases are statistically insignificant during the night-time where traffic contributions to NO_2 and NOx are expected to be much lower.

Particulate matter ($PM_{2.5}$)

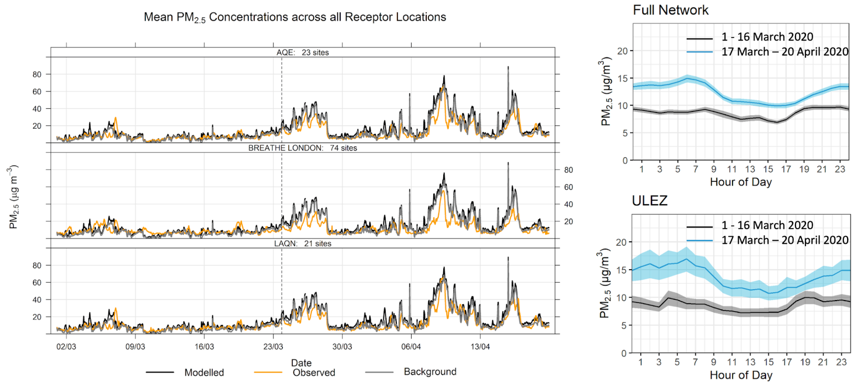


Figure 1.3 Left: Modelled (black) and observed (yellow) AQE, LAQN and BL network hourly average time series for $PM_{2.5}$ for March 2020 onwards. Right: Differences in the diurnal patterns of $PM_{2.5}$ for the pre- and post-lockdown periods for the full BL network (upper) and for the BL sites inside the ULEZ (lower). The shading shows 95% confidence limits of the network averages.

Modelled and observed hourly averaged time series for March 2020 onwards are shown for $PM_{2.5}$ in figure 1.3 for the AQE, BL and LAQN networks. Similar changes are again observed in all three networks. Unlike for NO_2 and NOx, however, in this case there is no obvious suggestion of model overestimation during the lockdown period, and observations and model show a series of elevated PM episodes post lockdown likely associated with long range transport of secondary PM. Reflecting this, BL PM measurements show increases across the network and in the ULEZ (43% and 59% respectively).

Covid-19 conclusions:

- The BL network suggests that NO_2 and NOx levels in London have reduced post lockdown, with the reductions greater within the ULEZ (15 - 23% *vs* 20 - 29%).
- Implementation of the O_3 cross interference correction algorithm and other ratifications will lead to a refinement of these numbers.
- $PM_{2.5}$ concentrations from the BL network have shown increases directly post the covid-19 lockdown. However, this appears to be associated in significant part with meteorological effects and is not necessarily a reflection of changes in local emissions. This requires further analysis.

2) Assimilation of air quality measurements into models to improve emission inventories

CERC have developed a data assimilation scheme that applies a Bayesian inversion technique to a high resolution (street-level) atmospheric dispersion model to modify pollution emission rates based on local measurements (Carruthers *et al.*, 2020). Results for NOx for the Covid-19 period using ADMS-Urban are presented below in figures 2.1 to 2.3. In this experiment, assumed *a priori* uncertainties were 100%, 20%, 10% and 30% for road traffic emissions, other emission types, LAQN and AQE measurements and AQMesh measurements respectively. While agreement between modelled and measured NOx concentrations in London was generally good during the early part of March, most sites in both the BL and reference networks show marked reductions in measured and *modified* model NOx (i.e. results from model integrations into which observations had been assimilated) from mid-March onwards. This general behaviour is reflected in the increased visibility of the red lines (un-modified model) in the individual panels post lockdown in figures 2.1 and 2.2.

Figure 2.3 shows how measured concentrations and road traffic emissions derived by data assimilation have changed since the Government first issued social distancing advice. The derived emissions first show a marked drop over the weekend of 21st/22nd March, which coincides with the announcement on the evening of Friday 20th March that bars and restaurants should close.

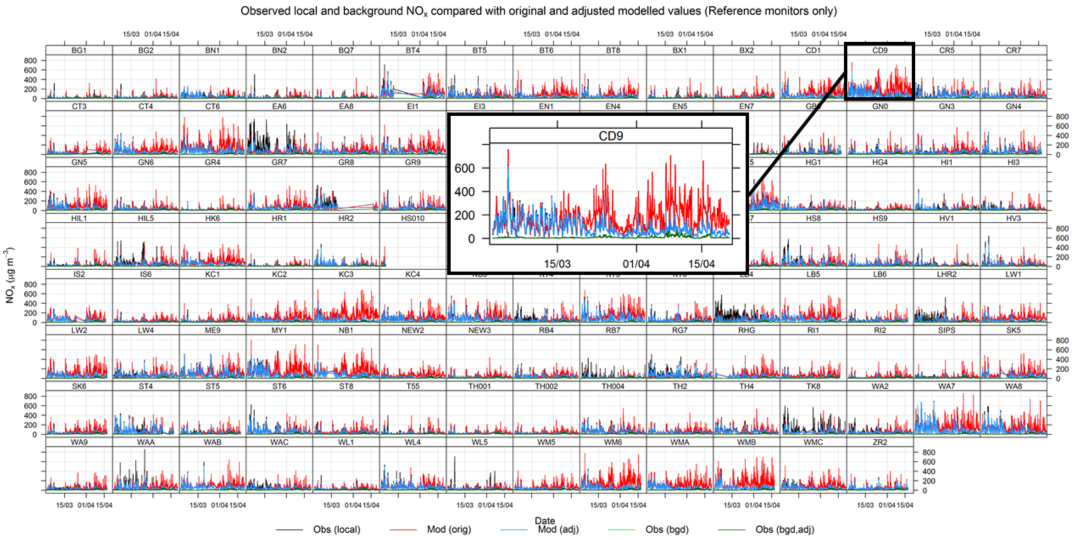


Figure 2.1: Time series of hourly ADMS-Urban modelled (red) and observed (black) NOx (ug/m3) at the LAQN and AQE sites in London from 1 March to 20 April 2020. The 'adjusted' modelled concentration (blue) is calculated using road traffic emissions derived by assimilating local measured data with modelled concentrations. One site (CD9) has been highlighted for clarity (see text for further discussion).

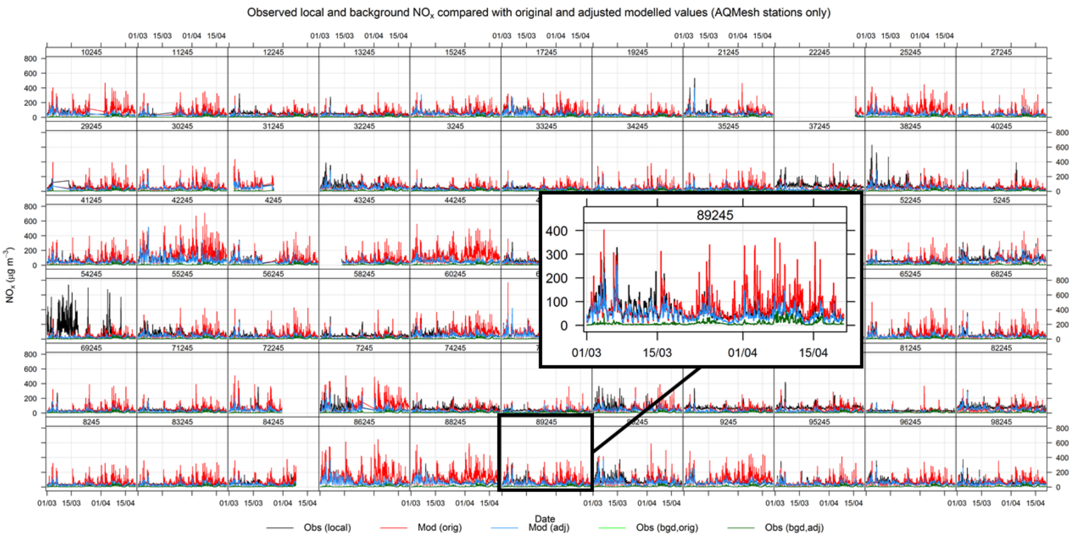


Figure 2.2: As figure 2.1 except for the BL network. In this case pod 89245 has been highlighted (see text).

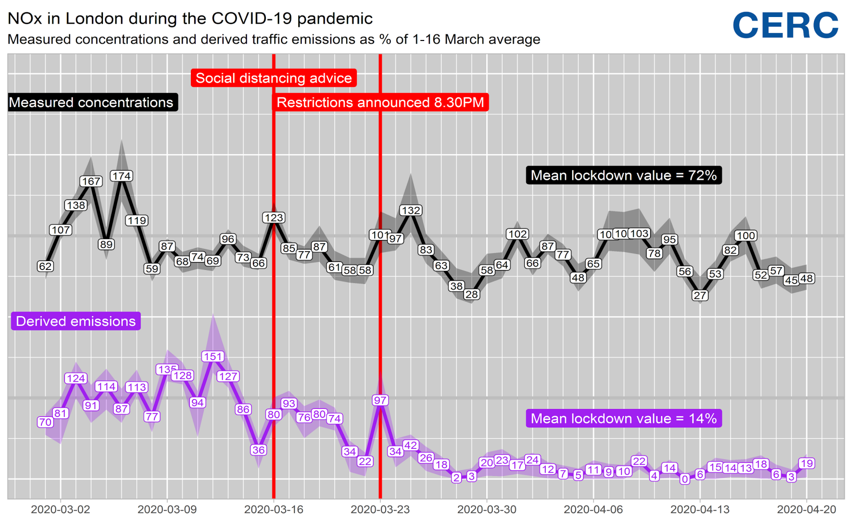


Figure 2.3: London measured concentrations (black) and derived road traffic emissions (purple), both as a percentage of the average over the 1-16 March pre-lockdown period. Measured concentrations are from all available sites in the LAQN, AQE and BL networks (184 sites in total); traffic emissions have been calculated by assimilating measurements using the ADMS-Urban model. The numbers indicate the median value; the shaded areas give the inter-quartile range. Key dates are shown by the red lines, as are the mean lockdown values (24th March onwards).

Monday 23rd March saw a widely-reported rush hour in London; this can be seen in both the measured concentrations and the derived emissions. The impact of the restrictions announced in the evening of 23rd March can be seen in the derived emissions in the following days, even though measured concentrations continued to rise through Wednesday 25th March, due to the sunny and still weather conditions. The lowest derived emissions are seen on the weekend of 28th/29th March, averaging 2-3% of pre-restriction levels. Weekday derived road traffic emissions of consistently around 14% of pre-restriction levels contrast with a second peak in measured concentrations on 1st April, again caused by still weather conditions. During April, road traffic emissions derived by data assimilation have remained very low, with the lowest levels at weekends, even when measured concentrations suggest little overall change if compared with only the first two weeks of March (e.g. 7-9th April).
The derived road traffic emissions depend on the assumed uncertainties input to the data assimilation scheme, but by directly linking measurements, including those from BL, with modelling these results provide quantifiable evidence that NOx emissions from road traffic in London have reduced dramatically during the lockdown.

Covid-19 conclusions:

- Assimilation of air quality observations into the ADMS model allows direct quantification of changes in NOx emissions associated with the Covid-19 lockdown; initial results suggest a reduction in road traffic NOx emissions to around 10-20% of pre-lockdown levels.
- The next step is to apply the data assimilation scheme to $PM_{2.5}$ over the same period.
- While the impact of the assimilation methodology is clear, further work is required to assess more fully the implications of the *a priori* assumptions made.

3) Future directions

Direct determination of emission indices (EIs)

The inclusion of measurements of CO_2 in all BL pods allows emissions indices (EIs - pollutant to CO_2 ratios) to be derived directly from the BL measurements (see e.g. Popoola et al., 2018).

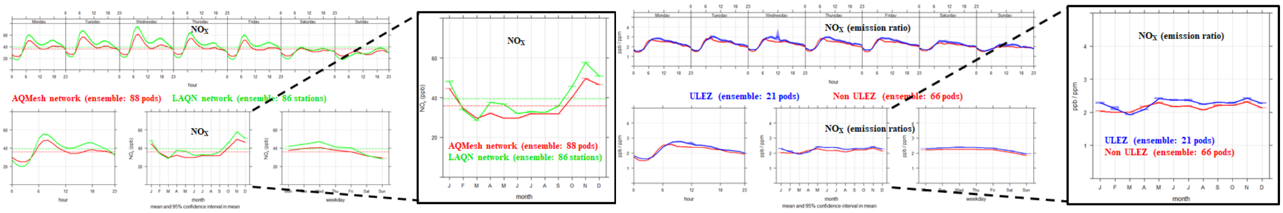


Figure 3.1. Diurnal statistics derived from the London networks. Left: comparison of the LAQN and BL networks. Right: emission indices from the BL network split by ULEZ and non-ULEZ.

This provides an important additional diagnostic of traffic (emission source) mix, but also removes the confounding effects of meteorology in assessing the effectiveness of interventions (in this case the seasonal increase in NOx apparent in the BL and LAQN networks, but not in the derived EIs - see figure 3.1).

Covid-19 conclusions:

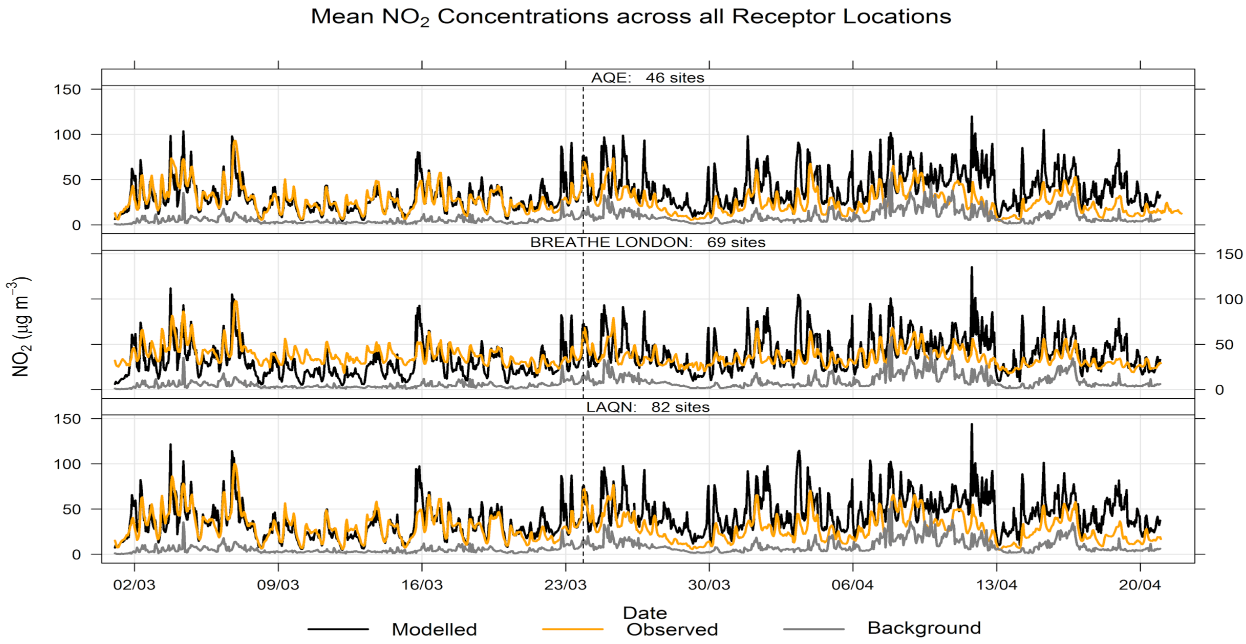
- Future work including analysis of EIs for the Covid-19 lockdown period and development of the assimilation methodology to incorporate these observationally determined EIs will provide additional insights into the impacts of the Covid-19 lockdown.

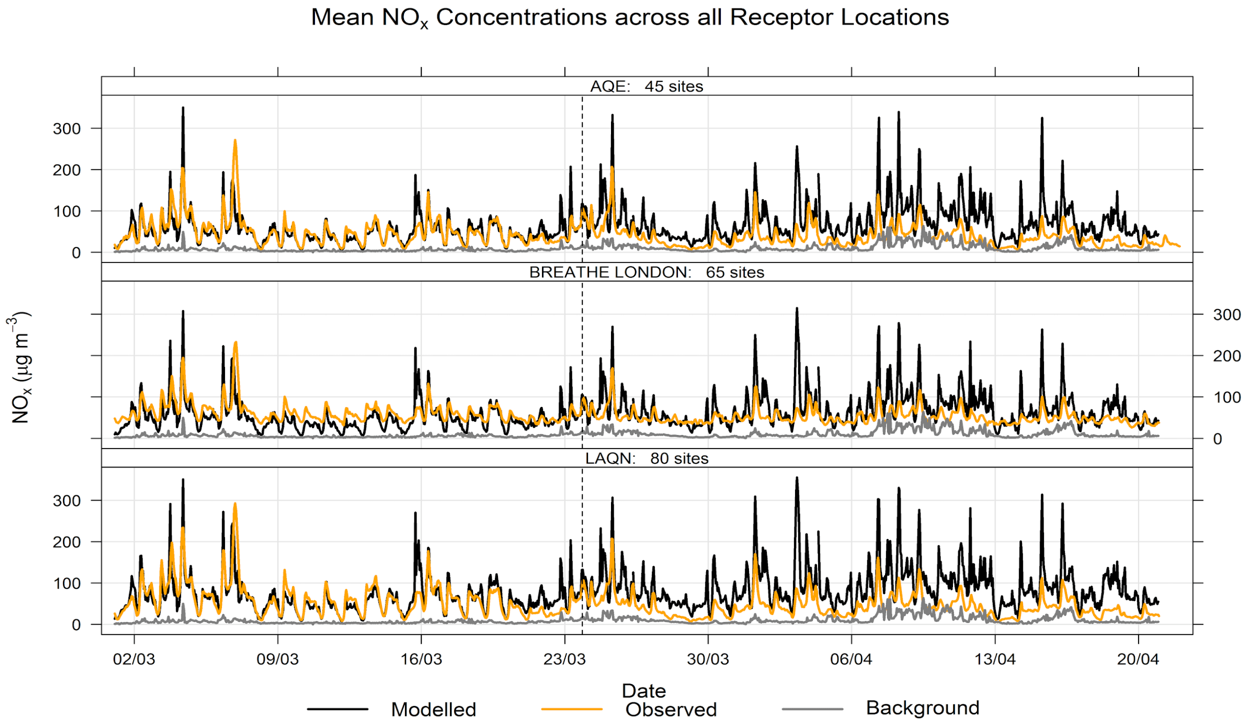
Relevant references:

Carruthers D, Stidworthy A, Clarke D, Dicks J, Jones R, Leslie I, Popoola OAM and Seaton M, 2020: *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 Available online

Popoola OAM , Carruthers D, Lad C, Bright VB, Mead MI, Stettler MEJ, Saffell JR and Jones RL, 2018: *Use of networks of low cost air quality sensors to quantify air quality in urban settings.* Atmospheric Environment 194 (2018) 58–70, doi.org/10.1016/j.atmosenv.2018.09.03

Appendix





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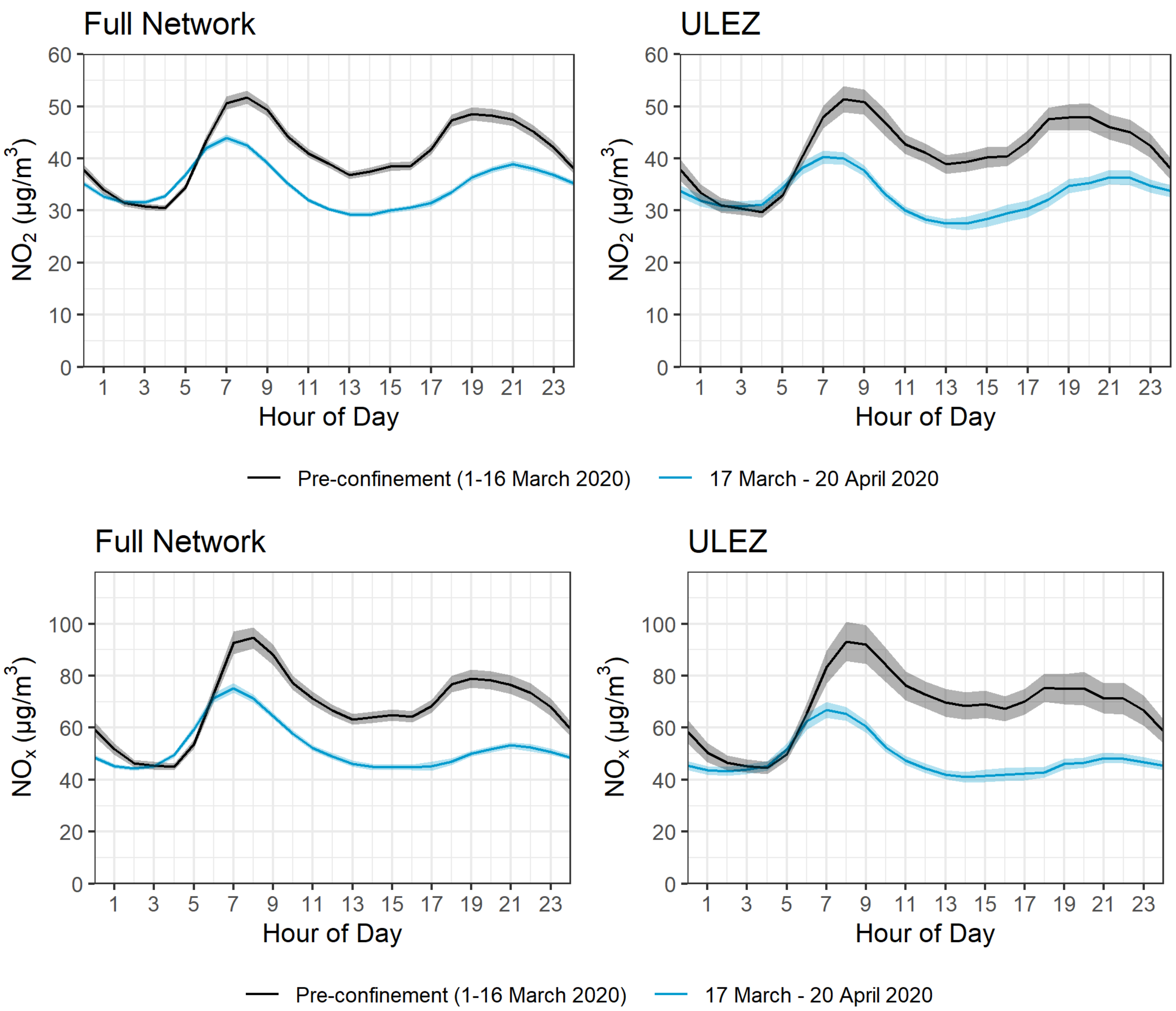

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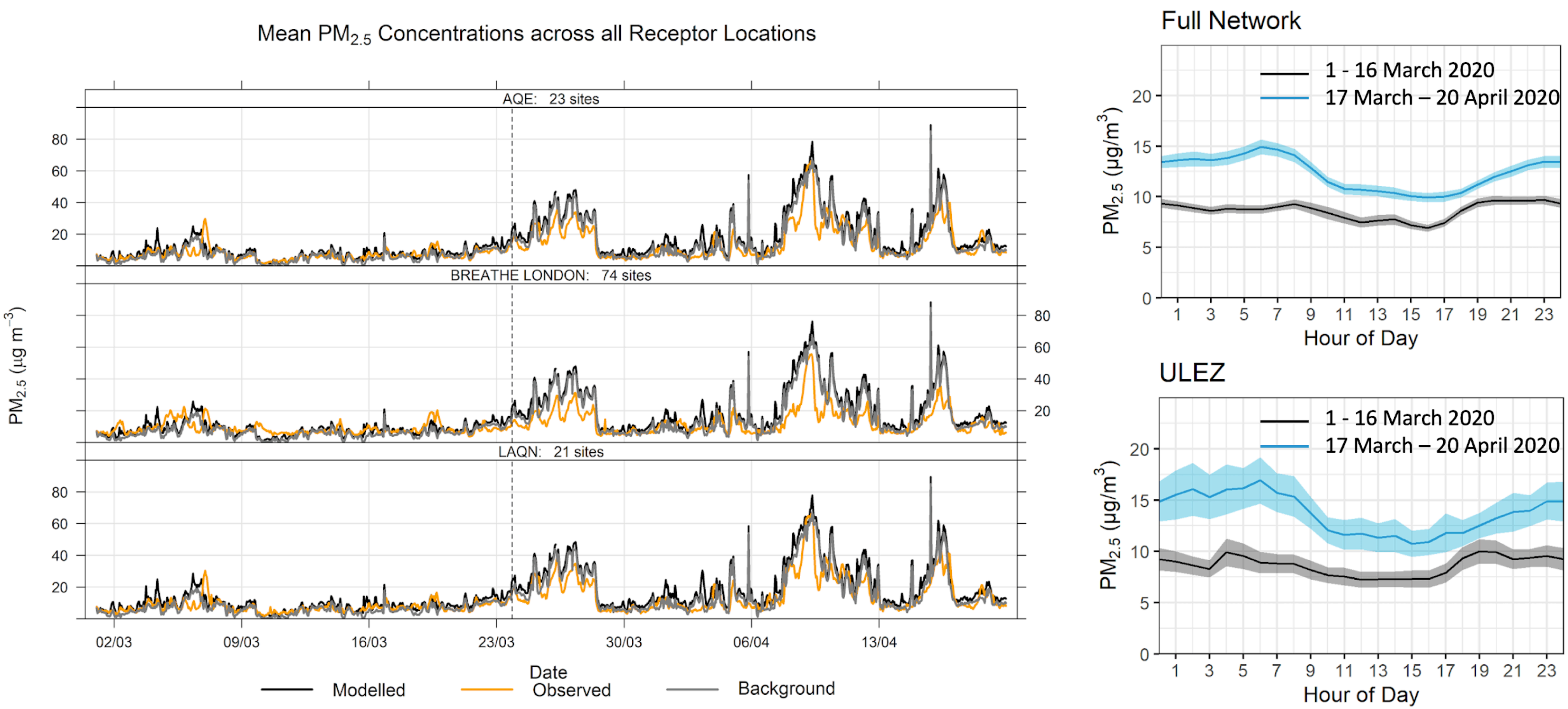

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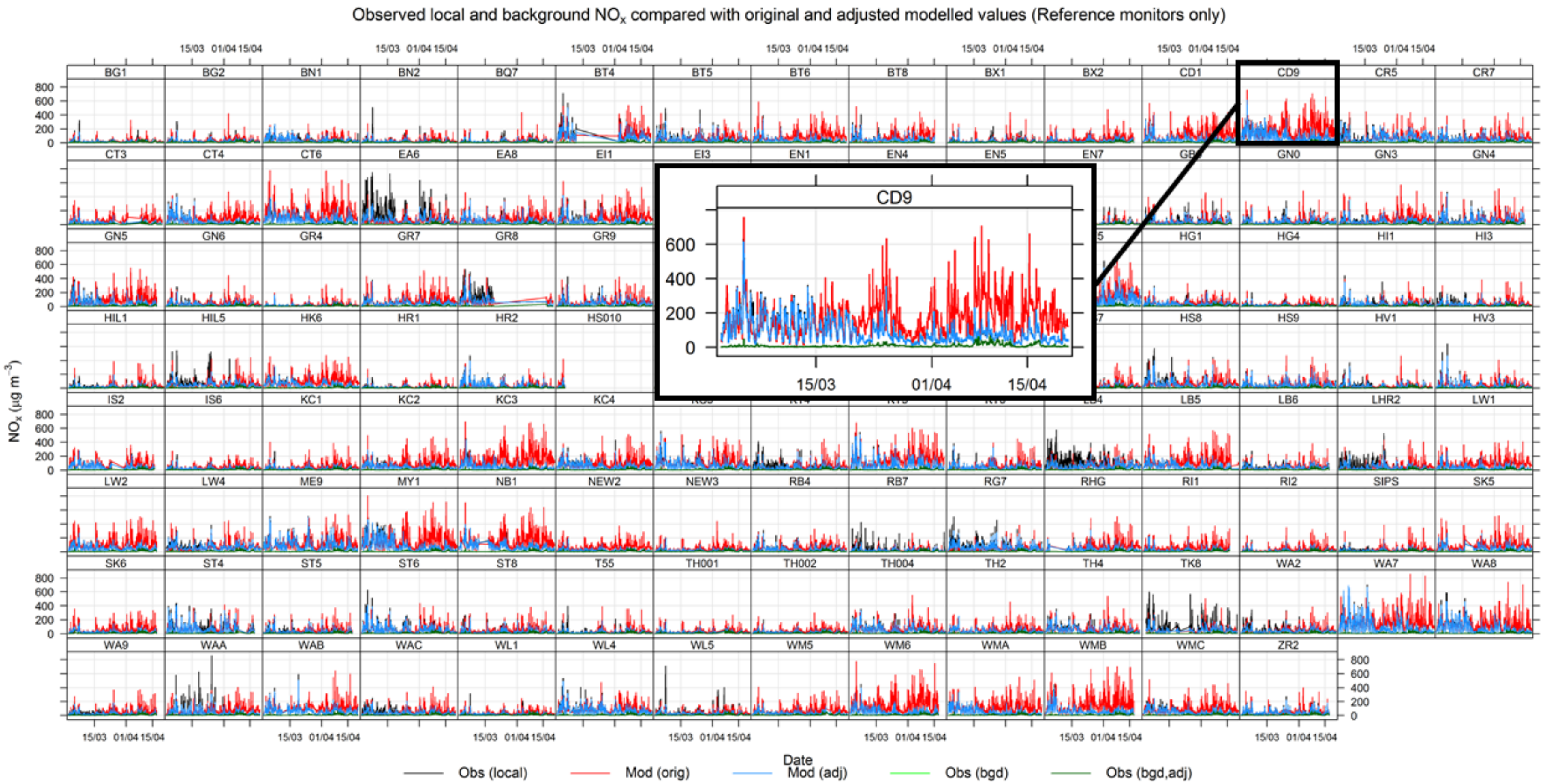

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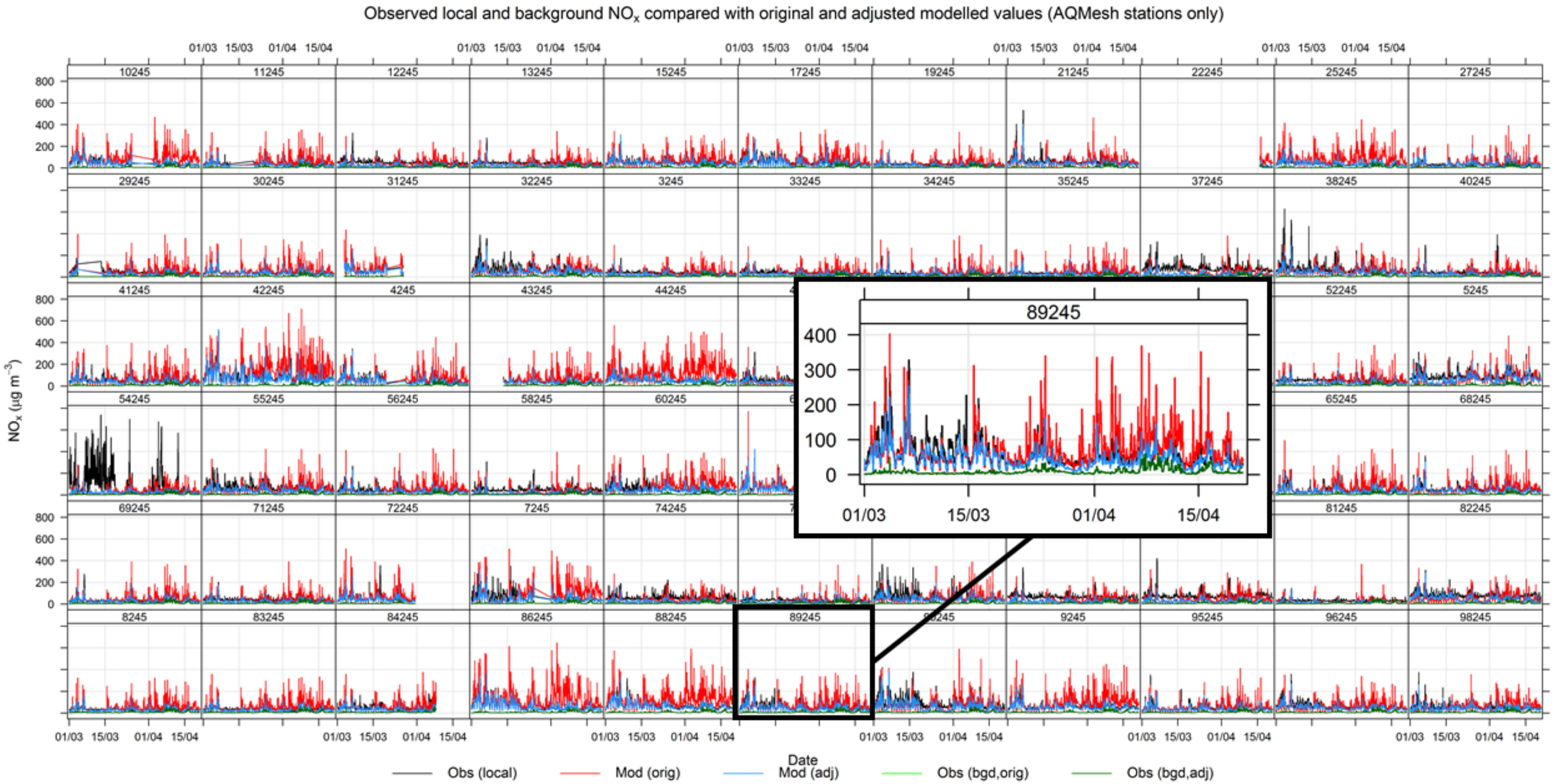

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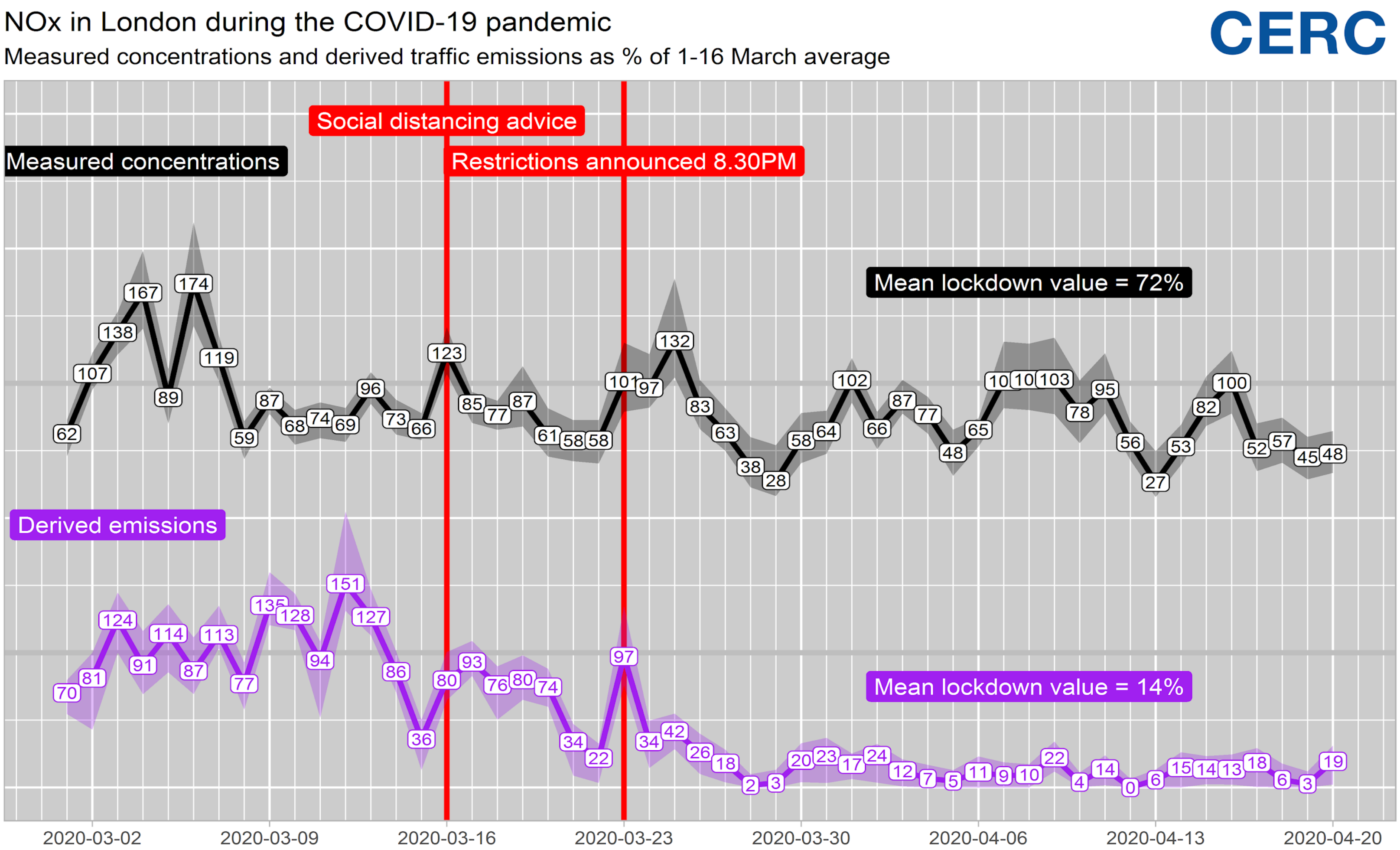

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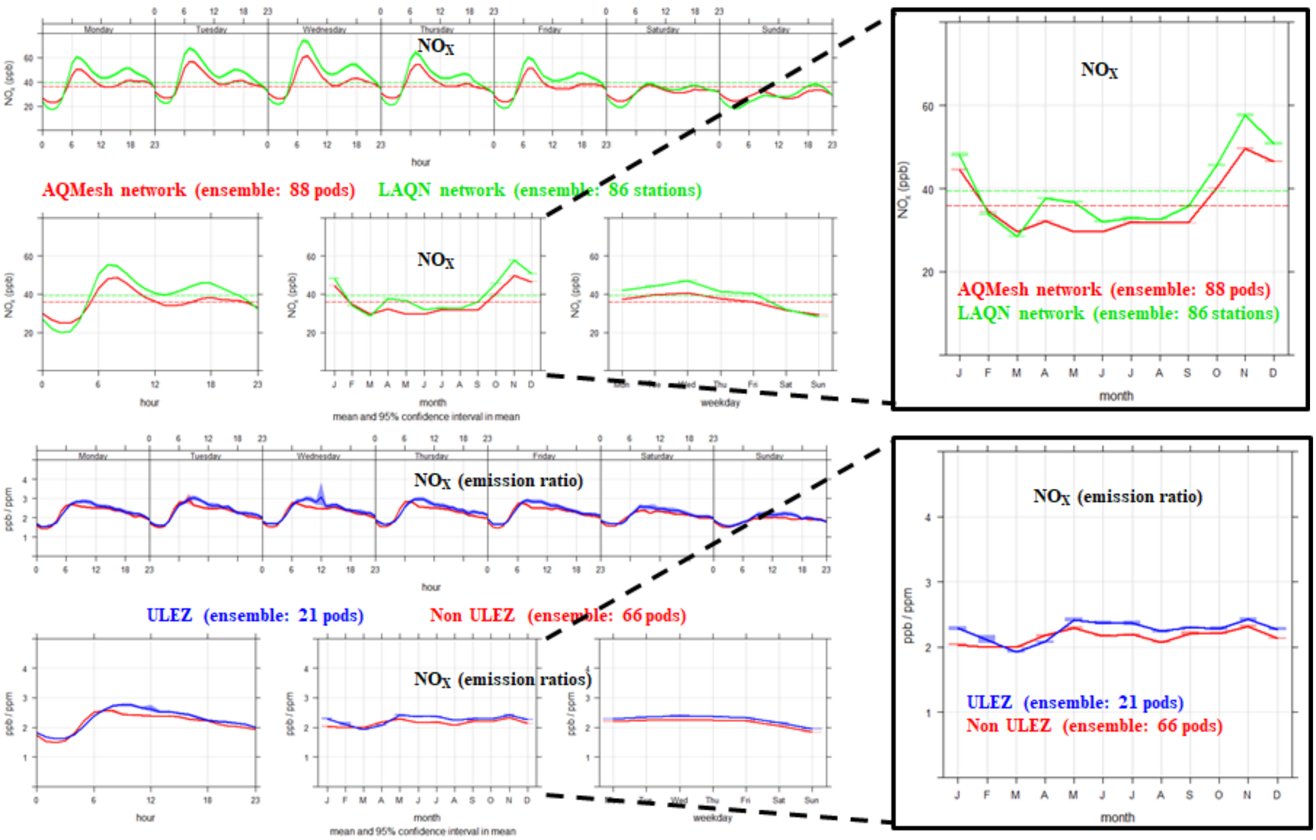

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