The Effect of COVID-19 Social and Travel Restrictions on UK Air Quality – 06 April Update

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Experts in air quality
management & assessment

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1 Introduction

1.1 There is widespread reporting of reductions in nitrogen oxides (NOx)[1] and nitrogen dioxide (NO_2) concentrations as a result of the COVID-19 pandemic. However, much of the evidence has focused on direct comparisons between air quality measurements made before and after social and travel restrictions were in place. Such comparisons can often be misleading. This is because the social and travel restrictions are not the only factors affecting the measured concentrations; indeed, they may not even be the main factor.

1.2 Air quality conditions typically change significantly over short periods simply because of changes to the weather. Put simply, as the wind blows from different directions, then pollution levels will be affected by different emissions sources. Simplistic comparisons which focus on relatively short periods 'before' and 'after' the UK public was instructed to "*lock down*" are thus mostly a comparison of the weather during those two periods. Expanding analyses to include longer-term averages goes some way to addressing this, but it has already been demonstrated that NOx concentrations measured alongside many roads have been falling appreciably year-on-year irrespective of the COVID-19 pandemic[2]. Thus, simple comparisons of measurements made at different times may be misleading.

1.3 To avoid these problems, the current analysis has used statistical models to identify the influence of key meteorological and temporal variables on the ambient measurements. These statistical models, which have been built from time series of air quality and meteorological measurements, allow the effects of meteorology and temporal factors to be nominally removed. This then allows identification of the changes in concentrations which would, in theory, have been recorded if meteorological conditions and temporal influences had remained constant.

1.4 As well as concentrations of NOx and NO_2, this analysis has also considered concentrations of ground level ozone (O_3)[3]. NOx emissions are formed by combustion, including from heating and road transport, so reducing these activities will reduce NOx emissions. Ground-level O_3 is not emitted directly; it is formed in the atmosphere by reaction of NOx with Volatile Organic Compounds (VOCs). However, O_3 also reacts with nitric oxide (NO) to form NO_2 and this means that ground-level O_3 concentrations at the roadside, and in urban areas, are typically depressed when compared with rural values. Reducing NOx emissions thus simultaneously provides a driver for reducing ground level O_3 and increasing it; albeit over different timescales and in different locations. NO_2 and O_3 have both been linked with negative health effects[4], and so while reductions in NO_2 concentrations are welcome, increases in ground-level O_3 concentrations are not.

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1 NOx is the sum of nitric oxide (NO) and NO_2. NO reacts with ozone (O_3) in the air to form NO_2.

2 Gellatly, R. and Marner, B. (2020) *Nitrogen Oxides Trends in the UK 2013 to 2019*, Available: https://www.aqconsultants.co.uk/CMSPages/GetFile.aspx?guid=af089039-6a2f-49b5-9533-fe31205f3134

3 Ground level ozone is distinct from stratospheric ozone. While the latter forms a protective layer from ultraviolet rays, the former can harm both humans and plants.

4 It is not within the scope of this current report to comment on the likely effects of changes in concentrations on human health or hospital admissions.

1.5 The changes to air quality which have, no doubt, been brought about by the COVID-19 pandemic are challenging to interpret. One reason is that they affect the whole of the country, making it currently impossible to measure the concentrations at a ‘control’ site which isn’t affected. In any event, different locations are affected by different factors irrespective of the current pandemic, so it would be unreasonable to expect changes at one site to precisely mirror those at another site. The current pandemic is also likely to have affected different emissions sources in different ways. For example, most observers have noted a reduction in overall traffic volumes on UK roads, but trips made by food delivery vans have increased. There is then anecdotal evidence of an increase in the use of domestic wood combustion[5]. It is also very difficult to identify a specific point in time when the pandemic affected these activities; even within the UK, instructions from Central Government evolved over time, and many people changed their activity patterns independently of direct instruction to do so.

1.6 The main mechanism which is expected to have reduced NOx and NO_2 concentrations is a reduction in road traffic associated with COVID-19 social and travel restrictions. It is thus clearly helpful to examine whether change in concentrations have coincided with changes in traffic volumes. At the current time it is not possible to carry out a detailed analysis of this, but generalised trends in UK-average traffic volumes have been compared with the measured ambient concentrations.

1.7 This current report differs from the previous 27th March 2020 update in that it now includes a much larger number of UK sites and includes data through to 29th March.

[5] which in urban areas in the UK is often used for ‘entertainment’ rather than heat.

2 Methodology

2.1 Openair software[6] has been used to download all measured NOx, NO_2, and O_3 data recorded between 1st Jan 2015 and 29th March 2020 from the UK Automatic Urban and Rural Network (AURN), Scottish Air Quality Network (SAQN), Welsh Air Quality Network (WAQN) and Air Quality England network. It should be noted that recent measurements are unratified and so still subject to change, however, since this analysis includes a large number of sites, any changes would be extremely unlikely to affect the overall findings.

2.2 Duplicate sites (for example those that exist in more than one of the networks) have been removed, as have all sites which did not meet the following data capture requirements. The data capture requirement has been 75% between 1st Jan 2015 and 29th Feb 2020, while for March 2020 it has been 90%. Each monitoring station has been linked with the closest meteorological observation site which satisfied these same data capture criteria.

2.3 The sites have been grouped into the following categories:

- Road: which groups together kerbside and roadside sites; ·
- Urban: which groups together urban centre, urban background suburban sites;
- Rural: i.e. all sites away from urban and road traffic sources;
- Airport[7]; and
- Industrial.

2.4 For each grouping, the hourly-mean concentrations have been averaged to give daily mean concentrations for use when generating figures.

2.5 Meteorological effects have then been removed by building statistical models to account for their influences on pollutant concentrations; this process has used the raw hourly mean concentration data. Traffic flows typically exhibit strong diurnal, weekly and, to a lesser extent, annual profiles; statistical models have, therefore, also been built to remove the predicted effects of hour of day, day of week, and week of year.

2.6 Hourly measurements of wind speed, wind direction, temperature, relative humidity, and atmospheric pressure (where available) have been paired with concurrent hourly measurements of NOx, NO_2, and O_3 concentrations. A boosted regression tree approach[8] has then been used to build statistical models of the input measured data that take account of the many complex interactions between variables, as well as non-linear relationships between the variables. These allow the identification of the relationship between the pollutant concentrations and the covariates used in the

[6] Carslaw, D.C. and Ropkins, K. (2012) 'openair - An R package for air quality data analysis', *Environmental Modelling & Software,* vol. 27-28, pp. 52-61.

[7] Three out of the four valid airport monitoring sites are close to Heathrow. Ozone is only measured at Birmingham Airport.

[8] Carslaw, D.C. and P.J. Taylor (2009). Analysis of air pollution data at a mixed source location using boosted regression trees. Atmospheric Environment. Vol. 43, pp. 3563–3570.

model while holding the value of other covariates at their mean level. This has then allowed the meteorological and temporal effects to be nominally removed from the time series of measurements, leaving only the trend caused by changes in factors such as local emissions (other than hour of the day, day of the week and week of the year patterns in local emissions). All of these calculations have been performed within the 'deweather' package of the openair software[6].

2.7 The statistical models have been built from the full five plus years of measured air quality and meteorology data (including the period to 29th March 2020). These models have been used to predict concentrations during 2020 in the absence of the identified meteorological and temporal influences. These predicted concentrations have then been grouped in the same way as the raw concentrations data (see Paragraph 2.3), and averaged to give daily-mean concentrations.

3 Results

Trends in Traffic Volumes

3.1 At the present time, it has not been possible to examine how traffic volumes on different roads, or for different vehicle types, have changed over time. Figure 1 presents a summary of recent changes in overall transport use published by the Cabinet Office. While the precise nature of the data in Figure 1 is not yet known, including how many monitoring sites it represents and what "pre-outbreak" period it refers to, it suggests that road traffic volumes did not fall appreciably until around the 16th of March, after which volumes fell significantly. Traffic volumes also appear to have roughly levelled out in the last few days of the month, at around a third of previous levels. In a simplistic way, emissions from road traffic would be expected to have declined by two thirds of previous levels.

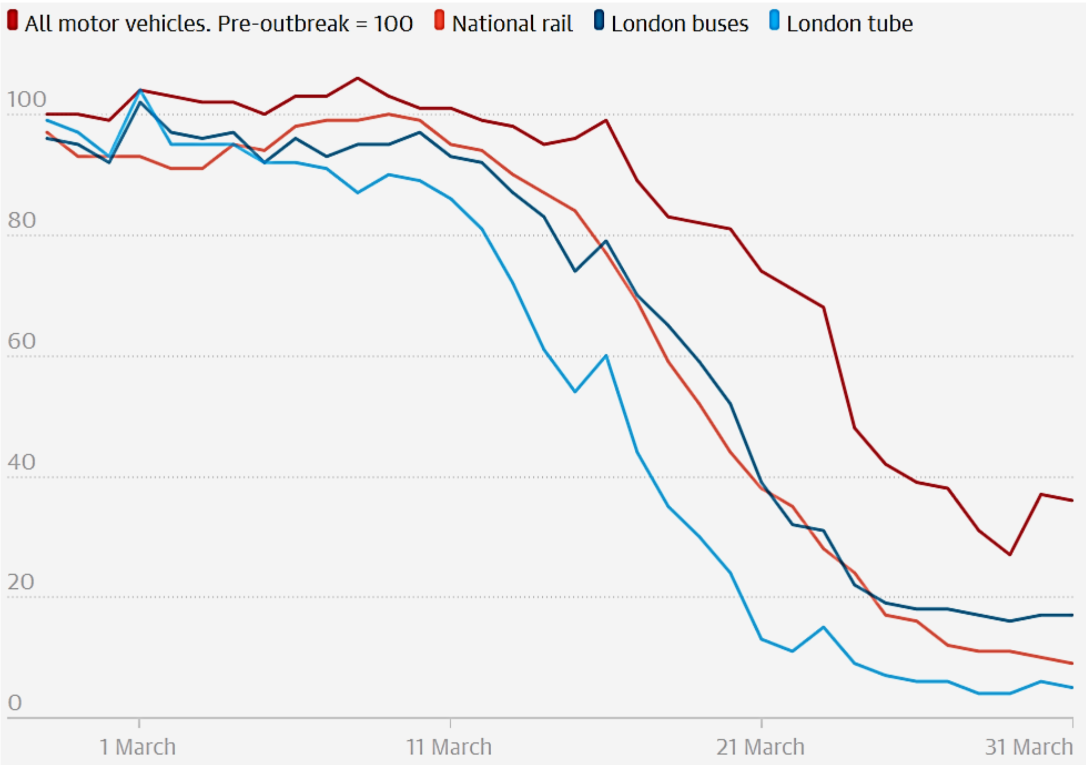

Figure 1: Relative Change in Transport Use (% of Pre-outbreak Mean) (data source: cabinet office, image source, the Guardian)

Trends in Raw Measured Concentrations

3.1 Figure 2 to Figure 4 show the daily mean NOx, NO_2 and O_3 concentrations, respectively, averaged across all UK sites. Figures A1.1 to A1.5 in Appendix 1 show the temporal variation in measured concentrations at individual sites. There are clearly some patterns evident in these data, with some peaks of higher NOx and NO_2 concentrations occurring in late January and early February, with commensurately lower O_3 concentrations. There do also appear to be some signs of generally lower roadside NOx and NO_2 concentrations during March, with higher O_3 concentrations: particularly toward the end of this time series. It is also clear, however, that the average measured NOx and NO_2 concentrations recorded at all site types since 16th March are mostly within the range of values recorded earlier in the year. These presentations of the raw data do not demonstrate a clear effect of the reduction in traffic in the second half of March.

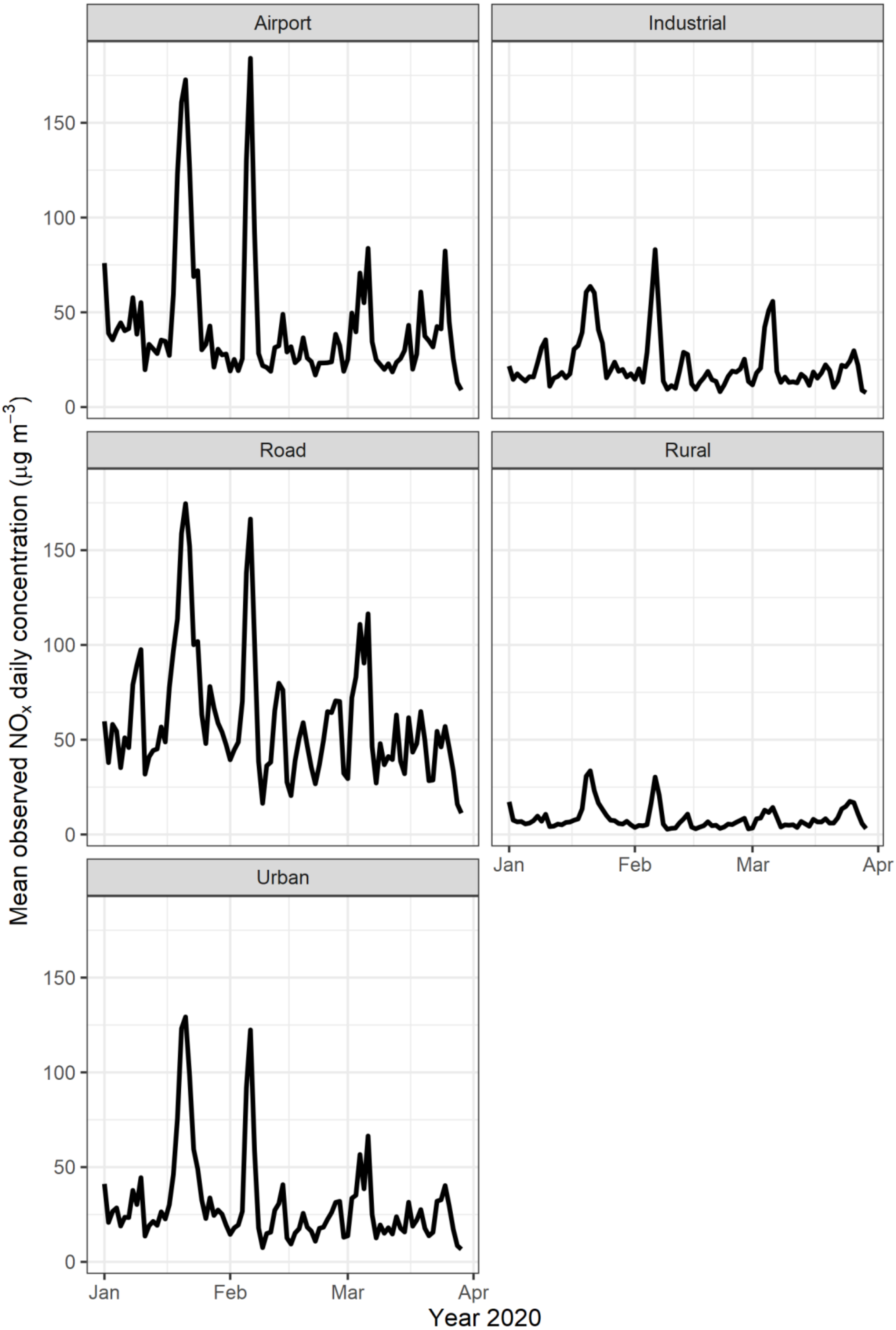

Figure 2: Averaged Daily Mean NOx at all UK Sites – 1st Jan to 29th March 2020. Averaged across: Airport – 4 sites, Industrial – 13 sites, Road – 147 sites, Rural – 13 sites, and Urban – 70 sites.

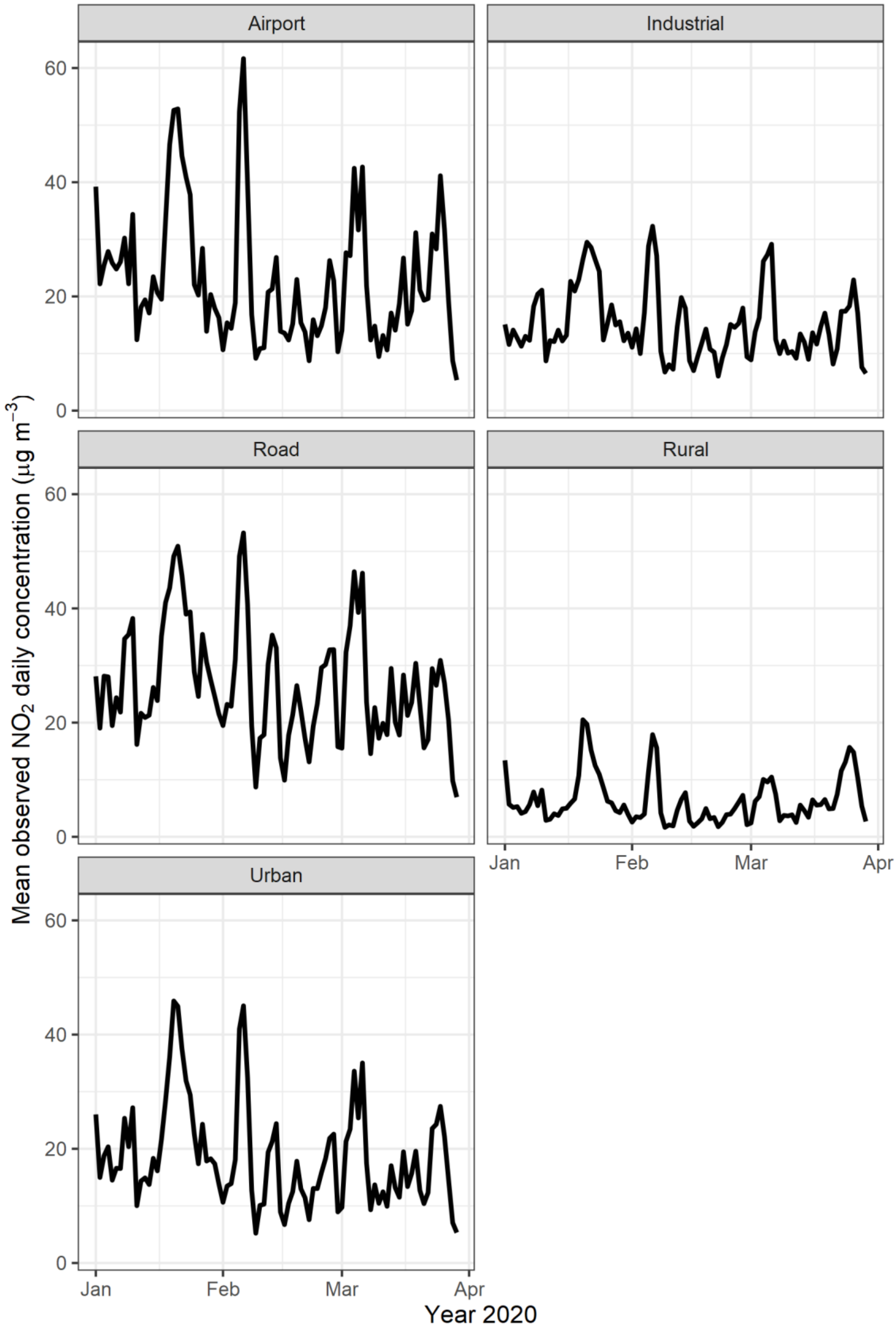

Figure 3: Averaged Daily Mean NO_2 at all UK Sites – 1st Jan to 29th March 2020 Averaged across: Airport – 4 sites, Industrial – 13 sites, Road – 147 sites, Rural – 13 sites, and Urban – 70 sites.

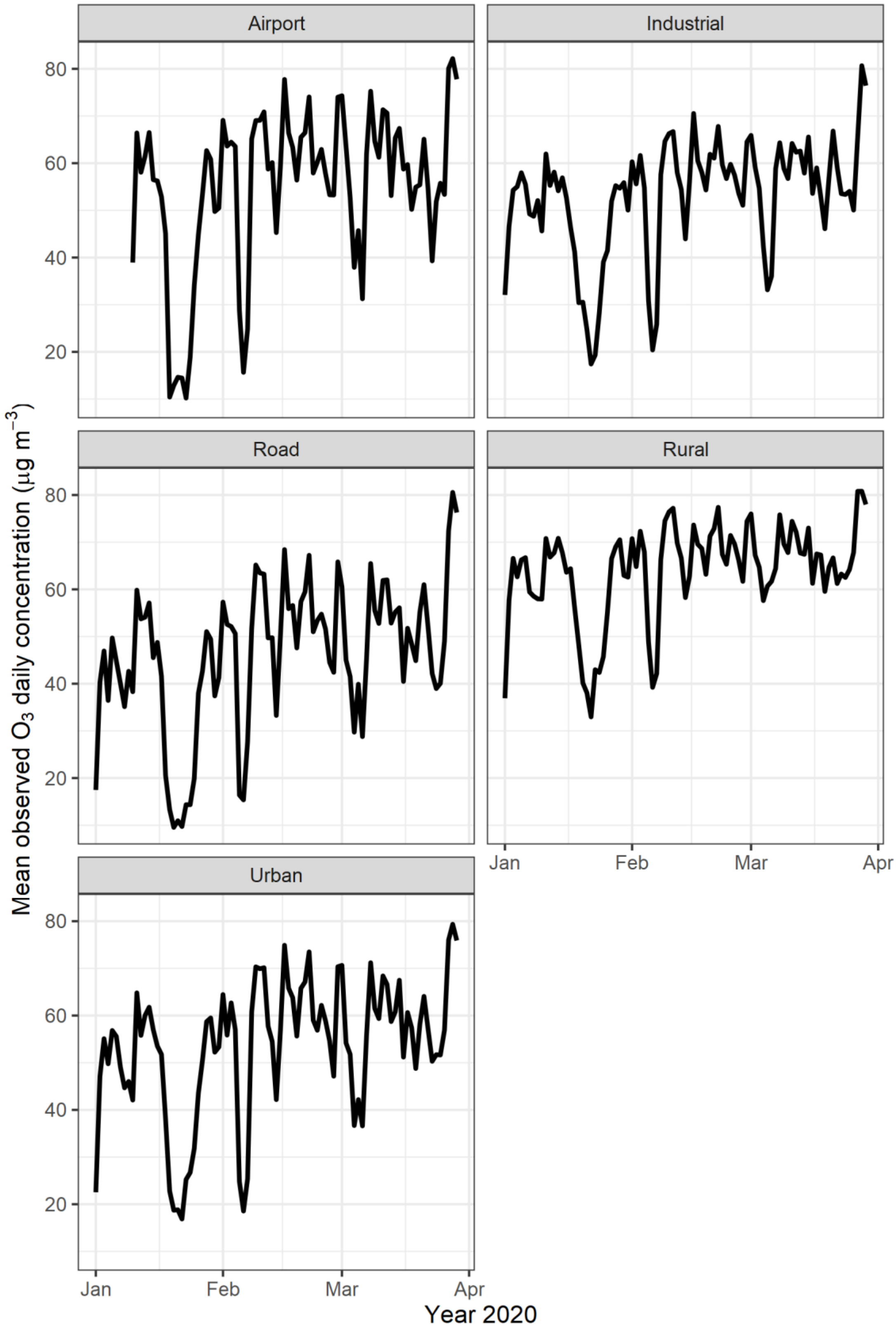

Figure 4: Averaged Daily Mean O_3 at all UK Sites – 1st Jan to 29th March 2020 Averaged across: Airport – 1 site, Industrial – 6 sites, Road – 11 sites, Rural – 19 sites, and Urban – 45 sites.

Trends in 'Deweathered' Concentrations

3.2 Figure 5 to Figure 7 show the same data as Figure 2 to Figure 4, but with the effects of meteorology and other temporal variability nominally removed as described in Paragraph 2.6. Figures A1.6 to A1.10 in Appendix 1 show the temporal variation in adjusted-measured concentrations at individual sites (the values show the relative change around the adjusted-measured mean for 2020). The reduction in NOx and NO_2 concentrations seen at roadside sites is particularly striking. When comparing this trend with that for traffic volumes in Figure 1, it should be noted that the two plots cover different time periods. Nevertheless, the largest reductions in both traffic volumes and adjusted measured roadside NOx concentrations have been observed since around 16th March. The small 'up-ticks' at the end of March for both roadside NOx and traffic volumes may not be causally-linked. Similarly, because lines for 'airport' in Figure 5 and Figure 6 represent the average for just four sites, the different patterns shown for NOx compared with NO_2 may not be significant.

3.3 Many (but not all) of the rural sites showed an episode of increased NOx and NO_2 concentrations in late March, but it is not possible to say whether this relates to changes in activity caused by the current pandemic, or to some regional changes not picked up in the model. The higher rural concentrations over this period do, however, suggest that the reduction in roadside concentrations would have been even greater if not offset by this regional background episode.

3.4 The patterns for O_3 shown in Figure 7 are, to a large extent, to be expected given those seen for NOx. The removal of fresh NOx at roadside sites has halted the usual titration (removal) of O_3. Thus, concentrations measured at roadside and urban sites have increased to be closer to those recorded in rural locations. Whilst it is possible that the higher rural O_3 concentrations shown at the end of March relate to changes in emissions patterns, it is perhaps more likely that the statistical modelling has not adequately accounted for what might simply be a typical, regional-scale weather-related, O_3 episode.

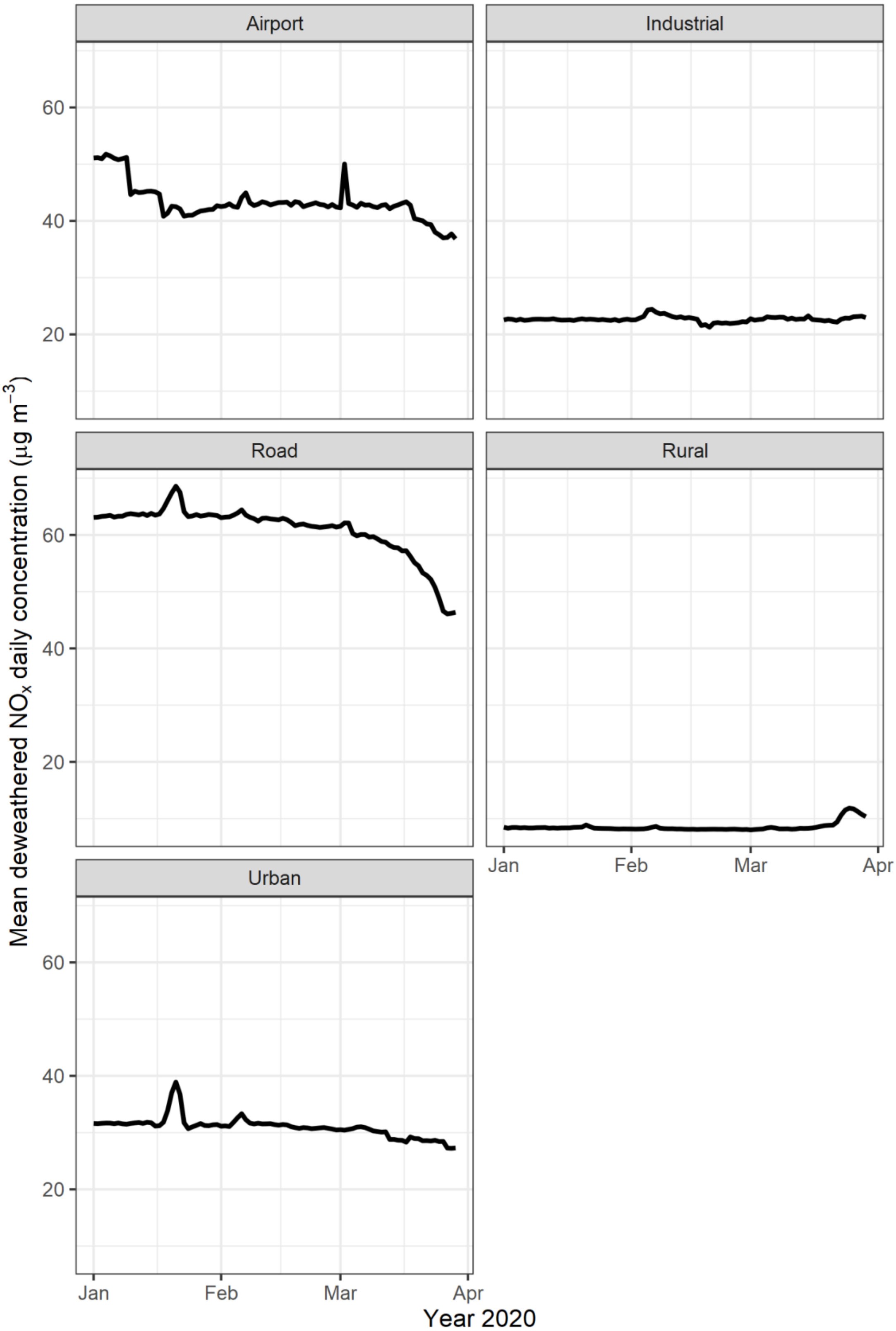

Figure 5: Averaged 'Deweathered' Daily Mean NOx at all UK Sites – 1st Jan to 29th March 2020 Averaged across: Airport – 4 sites, Industrial – 13 sites, Road – 147 sites, Rural – 13 sites, and Urban – 70 sites.

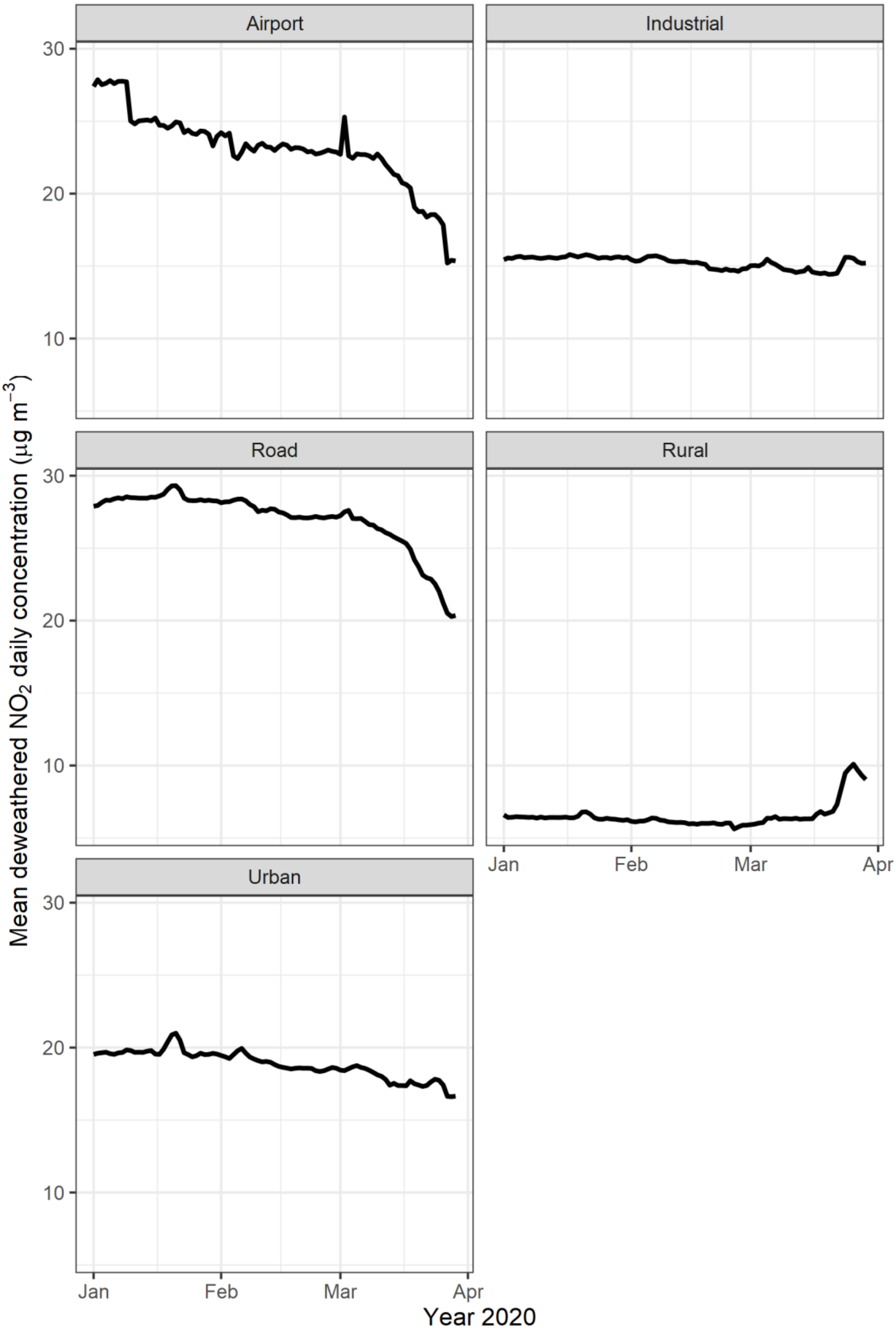

Figure 6: Averaged 'Deweathered' Daily Mean NO_2 at all UK Sites – 1st Jan to 29th March 2020 Averaged across: Airport – 4 sites, Industrial – 13 sites, Road – 147 sites, Rural – 13 sites, and Urban – 70 sites.

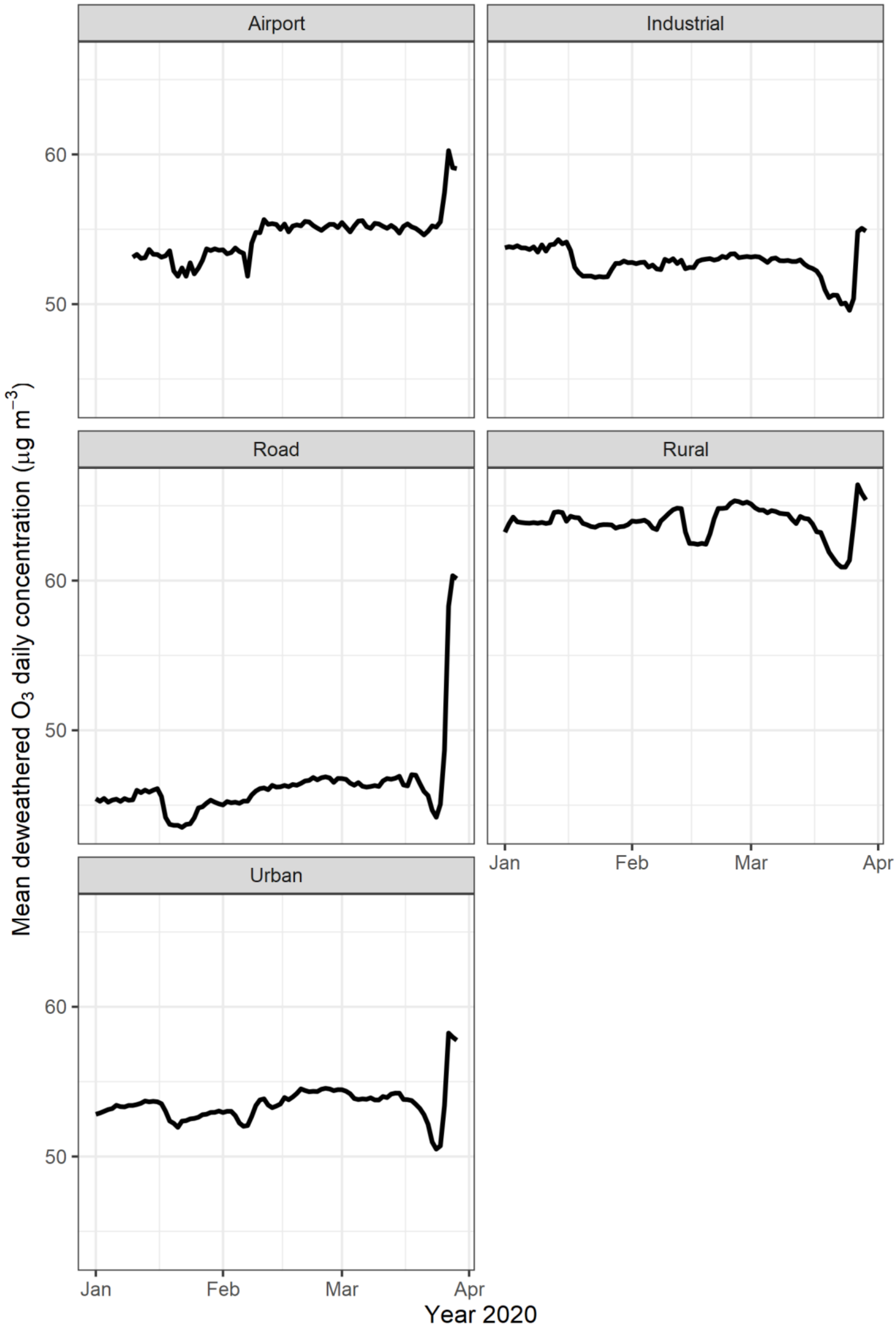

Figure 7: Averaged 'Deweathered' Daily Mean O_3 at all UK Sites – 1st Jan to 29th March 2020 Averaged across: Airport – 1 site, Industrial – 6 sites, Road – 11 sites, Rural – 19 sites, and Urban – 45 sites.

Changes to Exposure

3.5 It is important to acknowledge that the same behavioural changes that have reduced NOx emissions and concentrations are also likely to have changed the way in which most people are exposed to air pollution. Many people are likely to have reduced the amount of time that they spend breathing roadside air, instead spending more time in their homes. Whether this provides a net benefit or net disbenefit in terms of exposure to pollutants is outside of the scope of this report.

4 Conclusions

4.1 Analysis of changes in raw NOx, NO_2 and O_3 concentrations in 2020 to date has shown no very obvious influence of the social and travel restrictions implemented in the UK in response to the COVID-19 pandemic. However, isolating and removing meteorological and temporal effects has revealed clear reductions in NOx and NO_2 concentrations at a very large number of monitoring sites across the UK in the second half of March.

4.2 Reductions in adjusted-measured NOx and NO_2 concentrations at roadside monitors appear to be substantial; with these reductions apparently coinciding with reductions in traffic volumes on UK roads. As roadside NOx concentrations have fallen, roadside O_3 concentrations have increased to be closer to those recorded at rural sites. This is a predictable response to the removal of fresh NOx emissions, which typically depress roadside O_3.

Appendix 1 Results for Individual Monitoring Sites

Raw Measurements

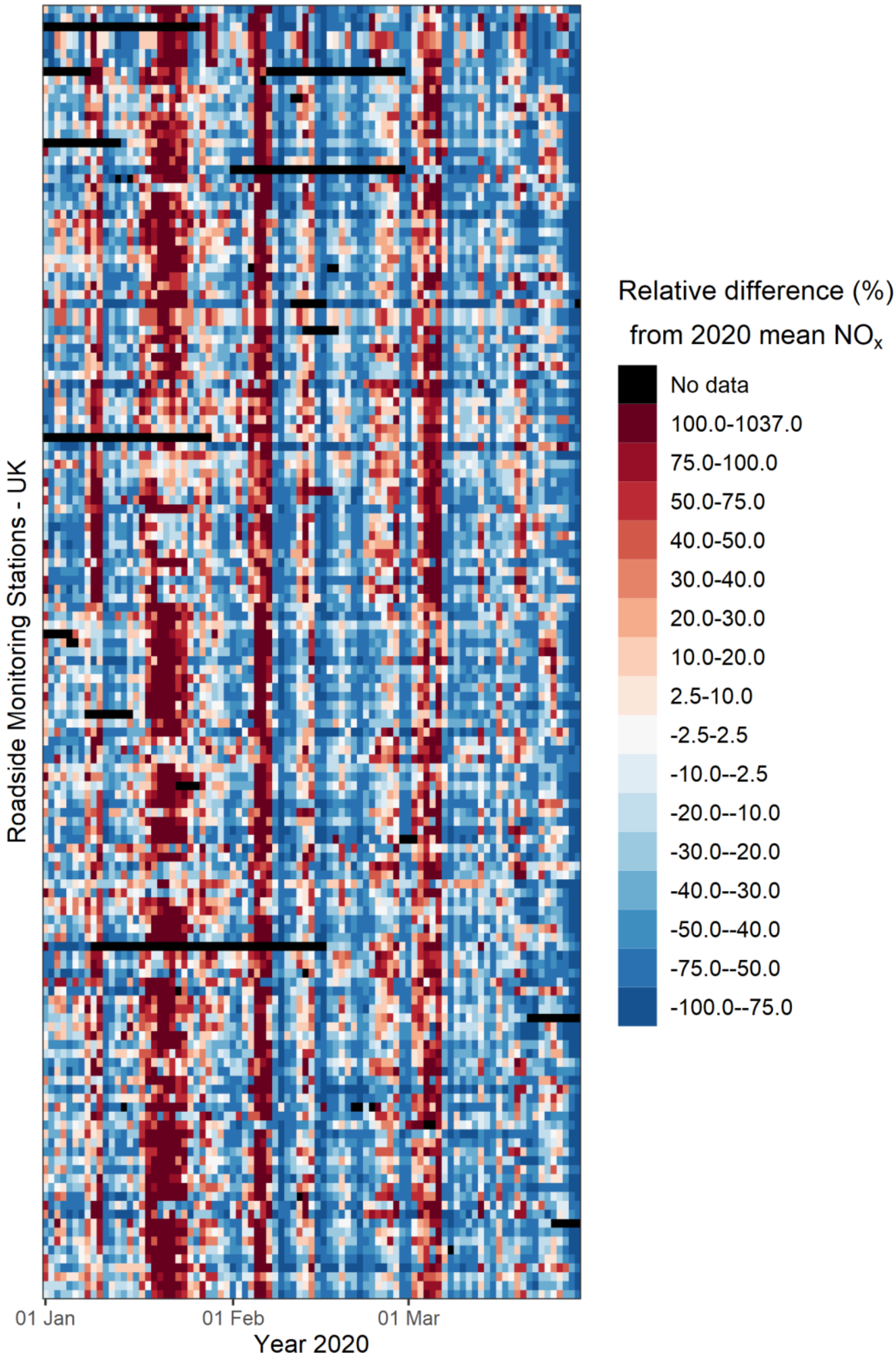

Figure A1.1: Relative Change in Raw Measured Daily Mean NOx Concentrations at UK Roadside Sites – 1st Jan to 29th March 2020. Each row of pixels represents a single site.

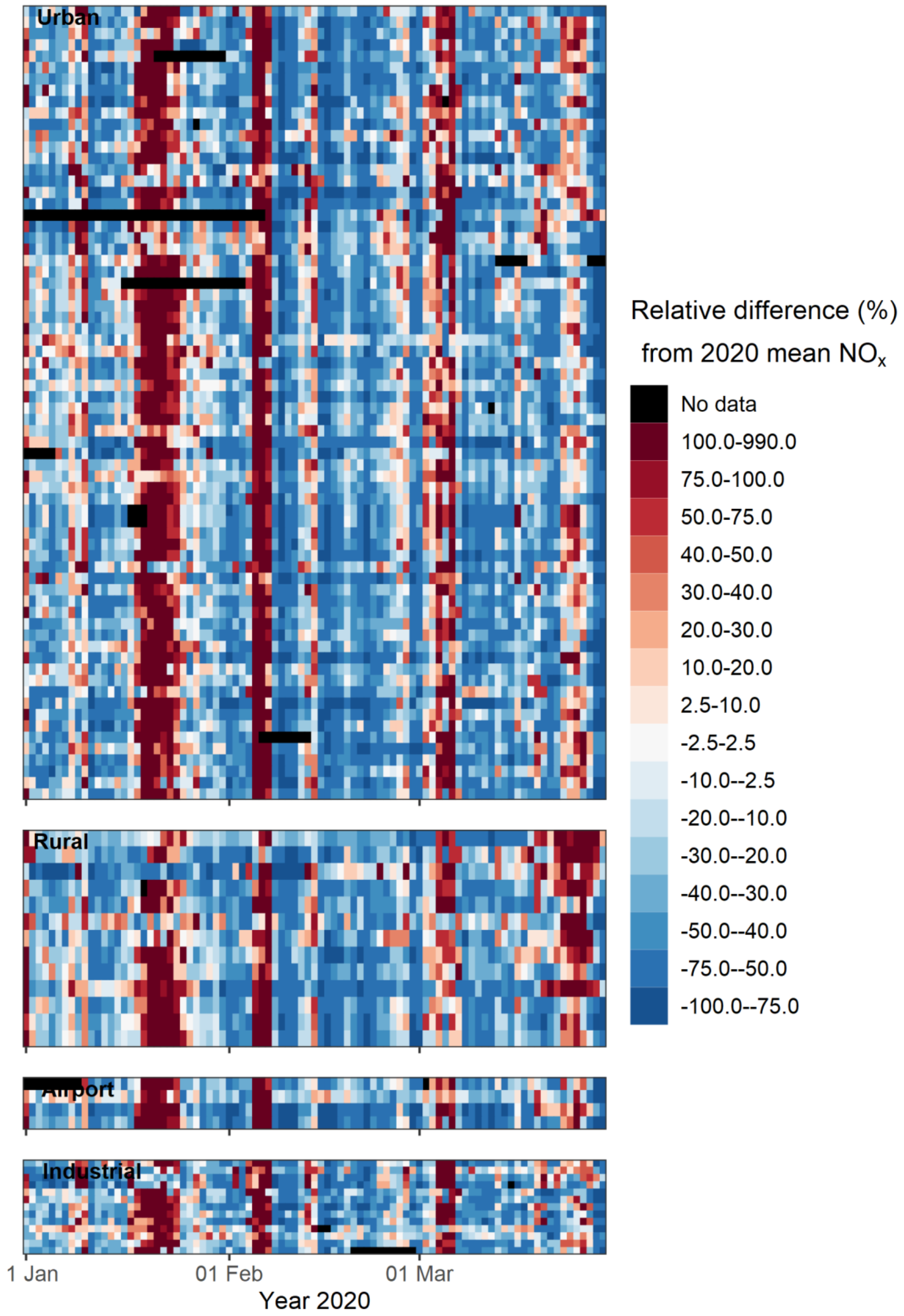

Figure A1.2: Relative Change in Raw Measured Daily Mean NOx Concentrations at UK Urban, Rural, Airport and Industrial Sites – 1st Jan to 29th March 2020. Each row of pixels represents a single site.

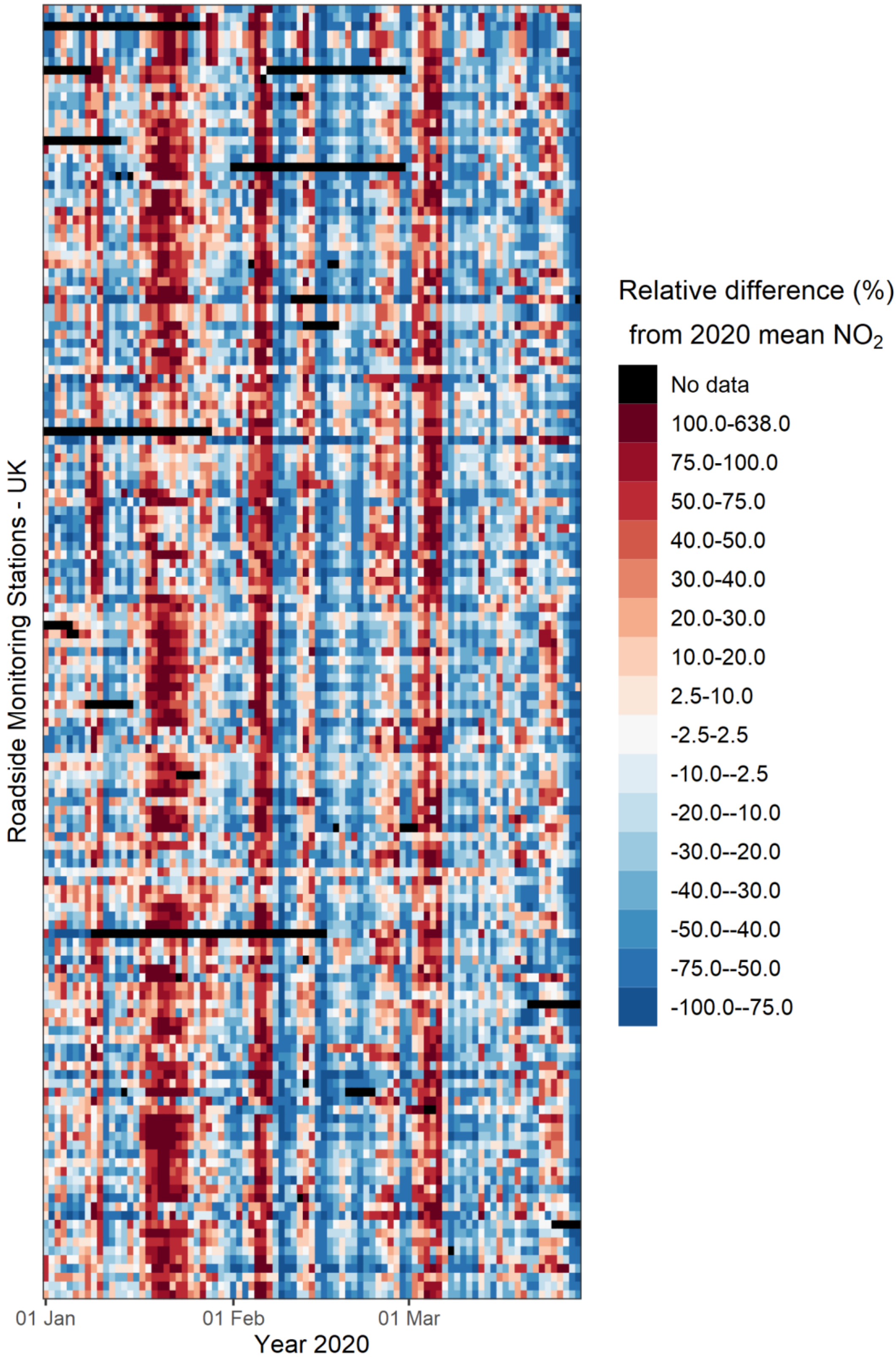

Figure A1.3: Relative Change in Raw Measured Daily Mean NO_2 Concentrations at UK Roadside Sites – 1st Jan to 29th March 2020. Each row of pixels represents a single site.

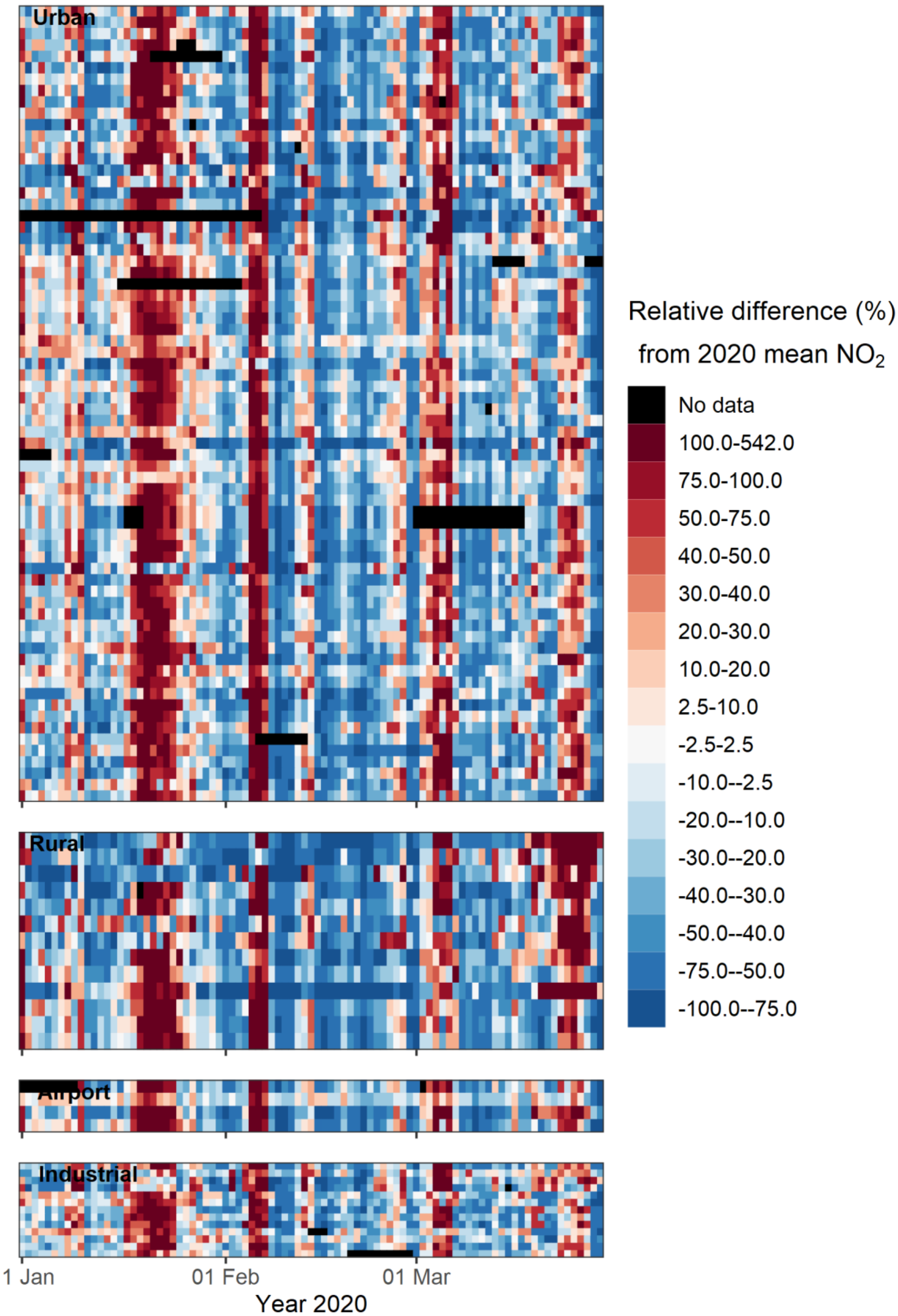

Figure A1.4: Relative Change in Raw Measured Daily Mean NO_2 Concentrations at UK Urban, Rural, Airport and Industrial Sites – 1st Jan to 29th March 2020. Each row of pixels represents a single site.

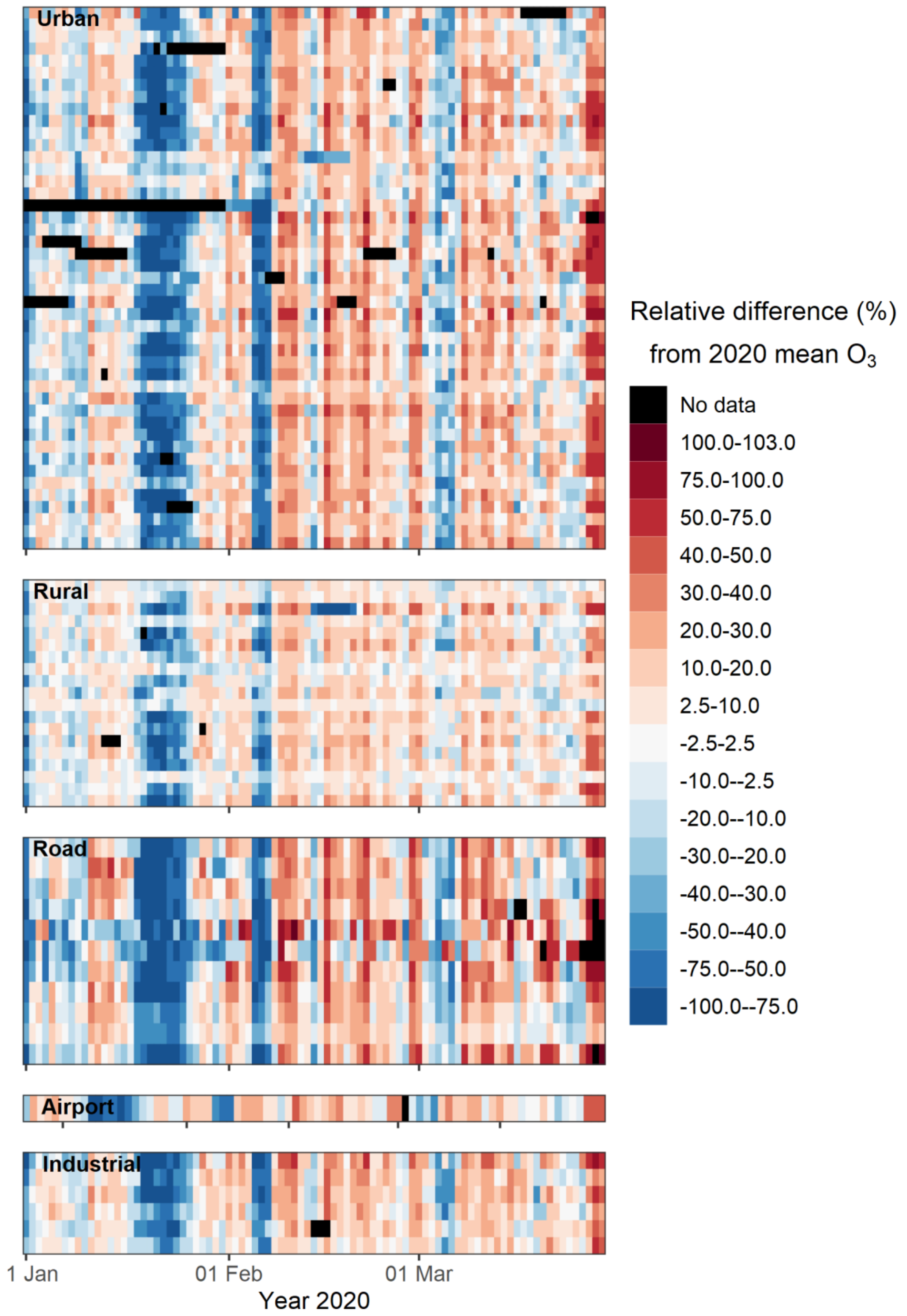

Figure A1.5: Relative Change in Raw Measured Daily Mean O_3 Concentrations at all UK Urban Sites – 1st Jan to 29th March 2020. Each row of pixels represents a single site.

'Deweathered' Measurements

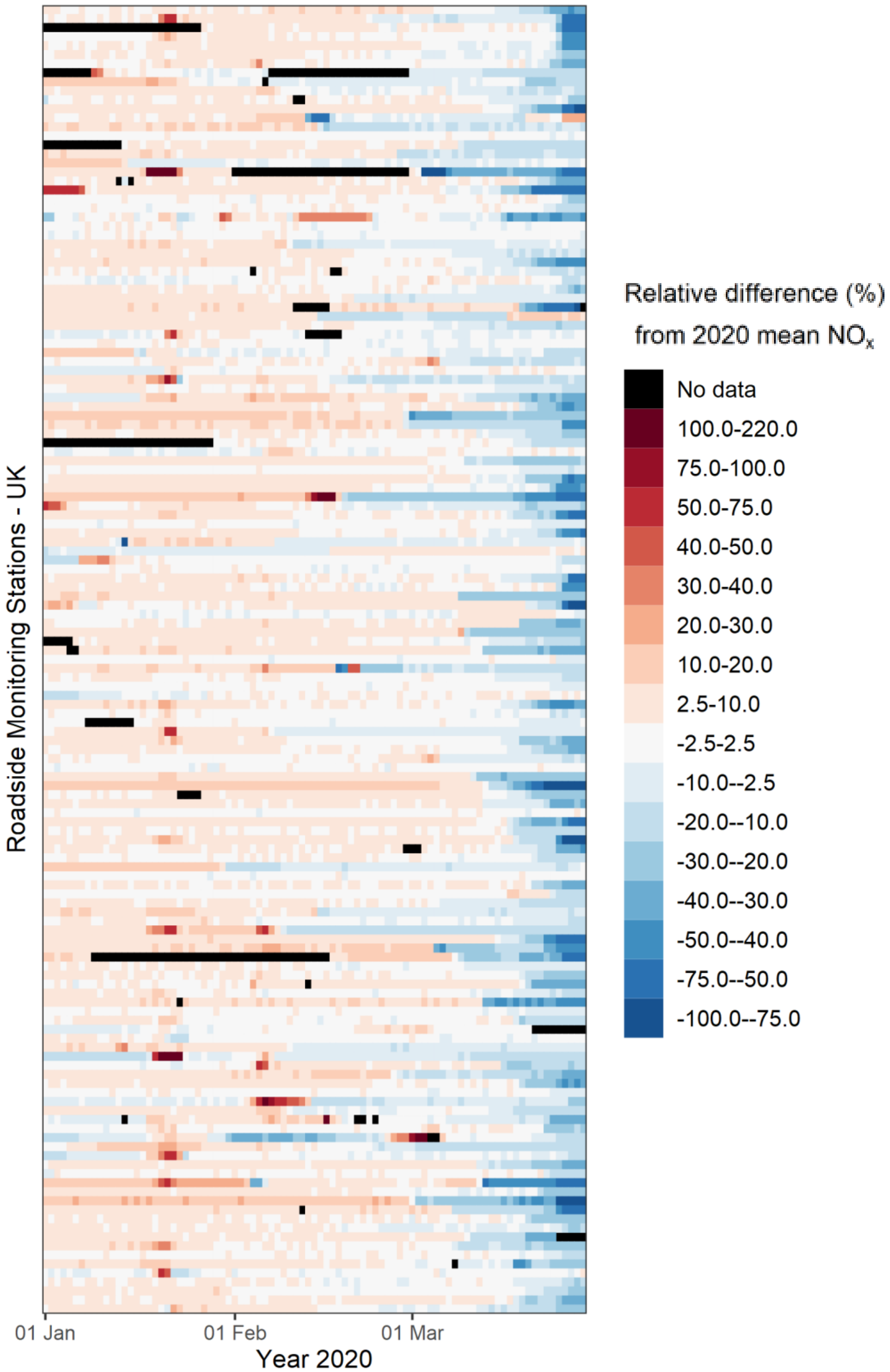

Figure A1.6: Relative Change in Deweathered Daily Mean NOx Concentrations at UK Roadside Sites – 1st Jan to 29th March 2020. Each row of pixels represents a single site.

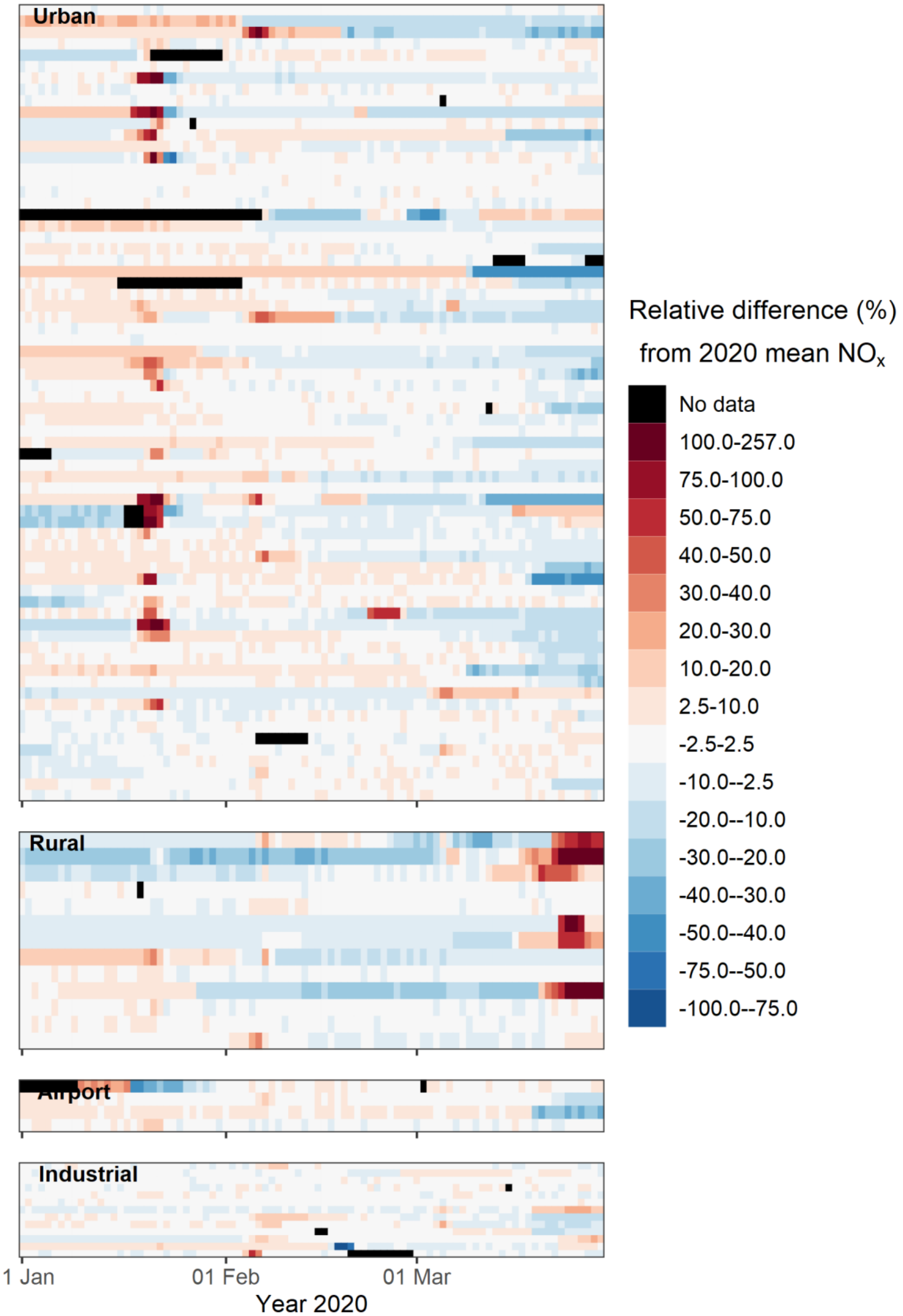

Figure A1.7: Relative Change in Deweathered Daily Mean NOx Concentrations at UK Urban, Rural, Airport and Industrial Sites – 1st Jan to 29th March 2020. Each row of pixels represents a single site.

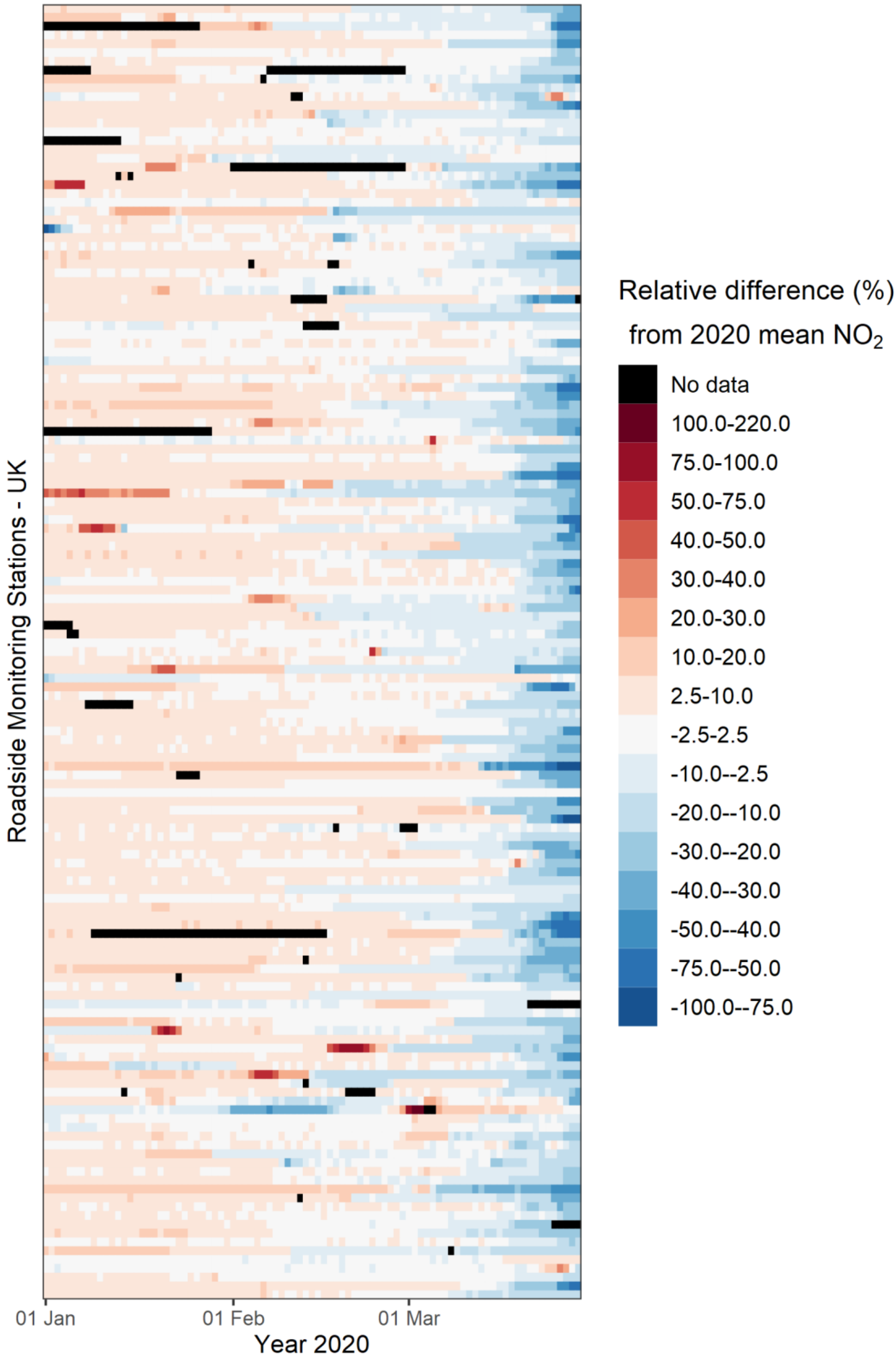

Figure A1.8: Relative Change in Deweathered Daily Mean NO_2 Concentrations at UK Roadside Sites – 1st Jan to 29th March 2020. Each row of pixels represents a single site.

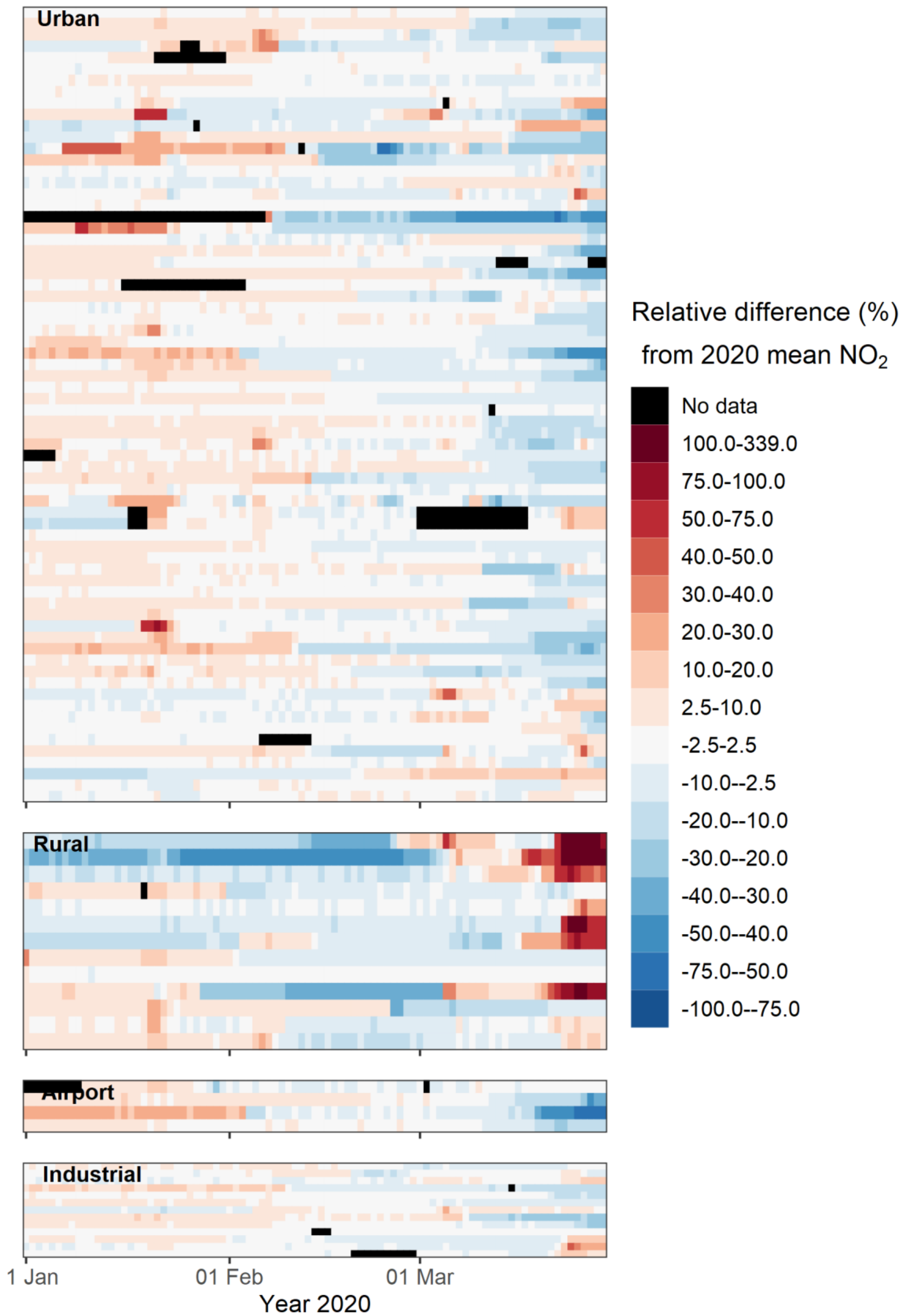

Figure A1.9: Relative Change in Deweathered Daily Mean NO_2 Concentrations at UK Urban, Rural, Airport and Industrial Sites – 1st Jan to 29th March 2020. Each row of pixels represents a single site.

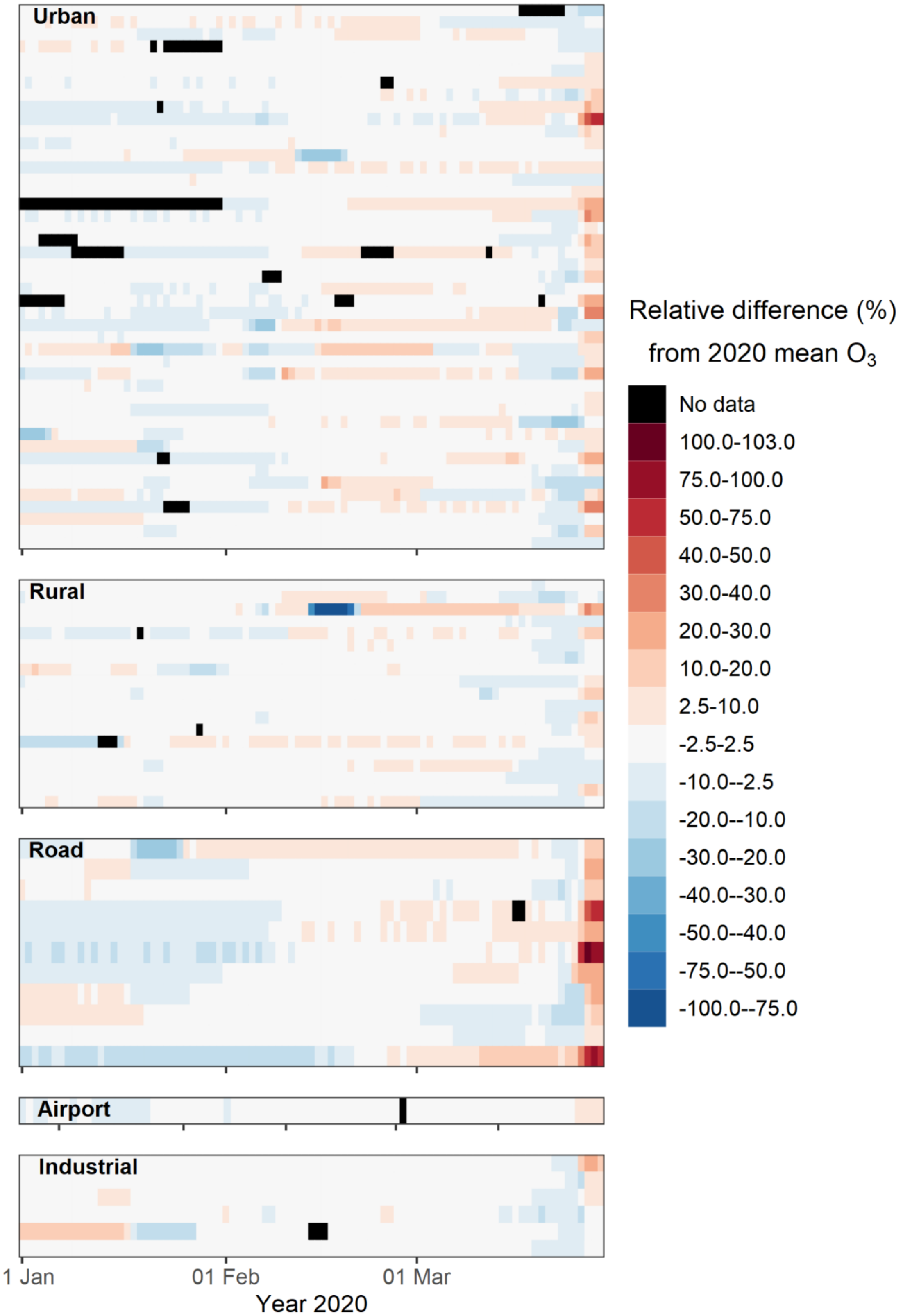

Figure A1.10: Relative Change in Deweathered Daily Mean O_3 Concentrations at all UK Urban Sites – 1st Jan to 29th March 2020. Each row of pixels represents a single site.