Air Quality CONSULTANTS

Response to AQEG Request for Rapid Evidence on COVID-19 & UK Air Quality

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Experts in air quality management & assessment

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1 Introduction

1.1 This note summarises some of the analysis carried out by Air Quality Consultants ltd. into the effects of the COVID-19 social and travel restrictions on UK air quality. It has been prepared in response to the Air Quality Expert Group call for evidence on: *"estimates for how emissions and ambient concentrations of NOx, NO_2, PM, O_3, VOC, NH_3 etc may have changed since the COVID outbreak"*.

1.2 The analysis has used Boosted Regression Trees (BRT)[1] to construct models of the dependence on meteorology of NOx, NO_2, and O_3 concentrations at 205 UK monitoring sites[2]. The models have been built using openair[3] from >5 years of hourly-mean measurements[4] covering the period 1st Jan 2015 to 9th Apr 2020. These models have then been used to nominally remove the effects of meteorological and temporal factors from the measurements[5]. The residual variation in concentrations at each site is that which cannot be explained by the BRT models solely in terms of predictable responses to weather and routine cyclical patterns. Recent measurements are unratified and so still subject to change; however, confidence is added to the overall findings of this note by the inclusion of a relatively large number of monitoring sites.

1.3 This note focuses on observed changes in ambient concentrations. Lockdown is taken to run from 23rd March, although more limited restrictions on travel started from around 11th March. It has not, at this time, been possible to link the changes in concentrations with robust activity data or emissions estimates.

2 NOx and NO_2

2.1 Figure 1 shows an example of the observed and BRT-adjusted results; focusing on daily mean NOx at four sites. While the raw measured concentrations (dashed lines in Figure 1) vary considerably over time, the models are able to account for almost all of this variability up until mid-march, resulting in little apparent variation in the BRT-adjusted concentrations (bold lines in Figure 1). The step change seen just before the 'lockdown' at these four sites is typical of that at many of the road-influenced sites. The precise timing of the main 'step' varies between sites, but is often followed by a second, smaller, step immediately after the lockdown. Results for all 205 sites are shown in a more concise format in Appendix 1, with time-series averaged across all sites, grouped by site type, in Appendix 2.

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1 Carslaw, DC & Taylor, PJ 2009, 'Analysis of air pollution data at a mixed source location using boosted regression trees', *Atmos Env* 43, no. 22-23, pp. 3563-3570.

2 All sites on the UK Automatic Urban and Rural Network (AURN), Scottish Air Quality Network (SAQN), Welsh Air Quality Network (WAQN) and Air Quality England (AQE) network, which achieved a data capture rate of at least 80% between 1st Jan 2015 and 29th Feb 2020 and at least 90% between 1st Mar and 9th Apr 2020.

3 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.

4 Pairing each air quality monitor with the nearest suitable meteorological monitoring site. The same data capture thresholds were applied to meteorological data as to air quality data.

5 The parameters which have been controlled for are: wind speed, wind direction, air temperature, relative humidity, hour of day, day of week, and week of year.

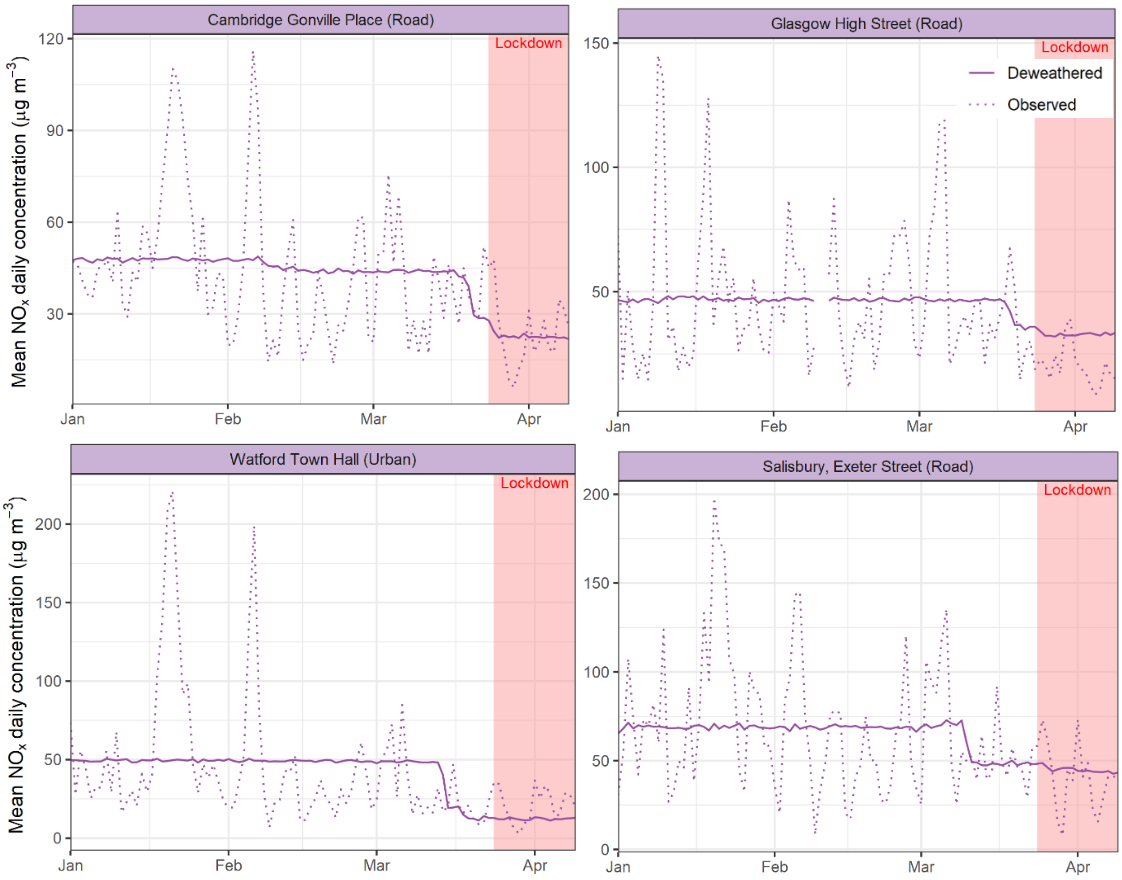


Figure 1: Measured and BRT-adjusted Daily-mean NOx at Four Sites 1st Jan to 9th April 2020

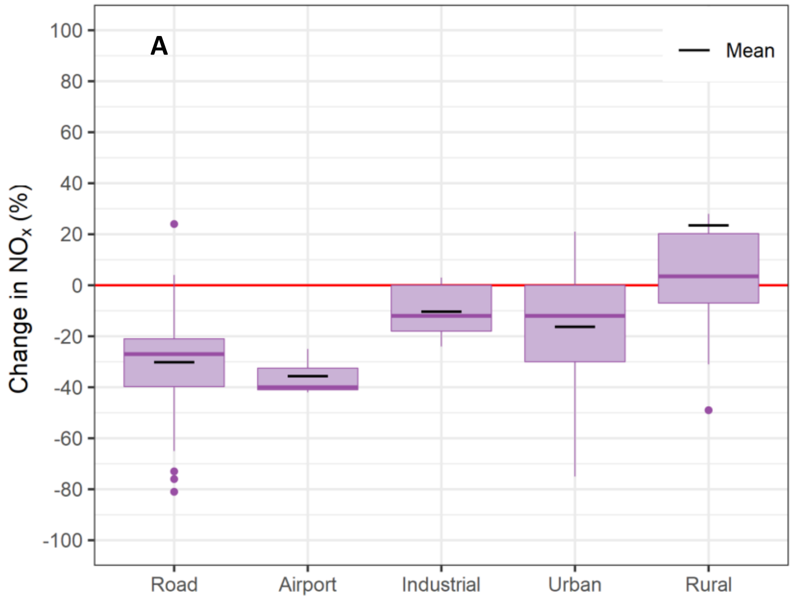
2.2 The relative changes in BRT-adjusted NOx concentrations, comparing a period before the travel disruptions (1st Jan to 14th Mar 2020) with the period between the lockdown and Easter (24th Mar to 9th Apr 2020) are summarised in Figure 2, and shown for each site in Appendix 3. More than half of the roadside sites (68 out of 122) recorded BRT-adjusted reductions in NOx of between 20 and 40%. The average reduction in NOx across 122 roadside sites was 30%, although there was considerable variation from site to site (see Appendix 3). Appendix 4 shows the geographical distribution of these changes, revealing no obvious spatial patterns.

2.3 NOx concentrations at the airport and industrial sites shown in Figure 2 are thought to be heavily influenced by road traffic and no attempt has been made to disentangle different drivers, although the significant reduction at the airport sites is to be expected given the known reductions in flight movements[6]. BRT-adjusted NOx and NO_2 concentrations at many rural sites have been higher since the lockdown; with these sites spread across much of the UK[7]. It is considered unlikely that this regional episode was caused by the COVID-19 restrictions, but it will have offset the improvements seen at roadside sites (noting that large relative changes at rural sites are typically small in absolute

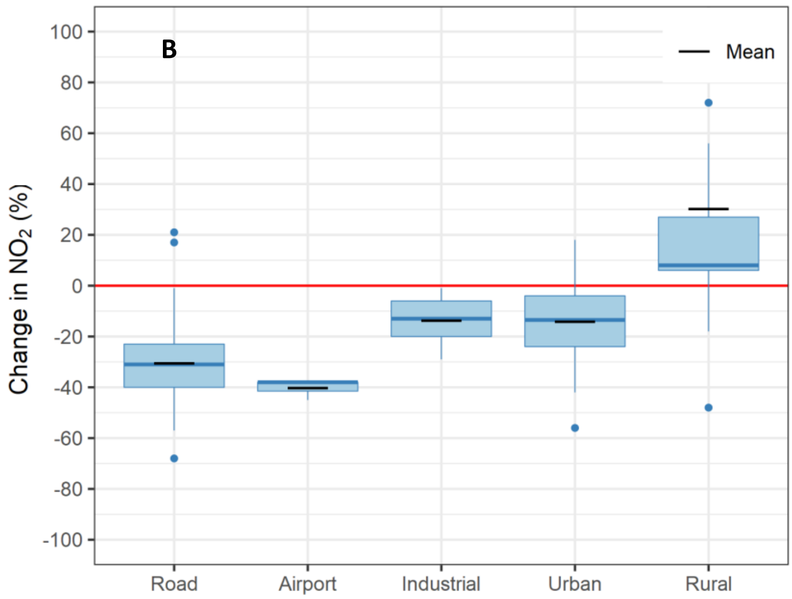
6 It should be noted that all three airport sites are associated with a single airport (Heathrow).

7 Building meteorology-based BRT models to describe concentrations at rural sites is considered less robust than at roadside sites, owing to the importance of regional patterns and the smaller concentration range (which is either rounded or truncated in the data archives) against which to train the models. This is borne out by tests of model fit, which are not presented here. The regional episode at rural sites nevertheless appears to be genuine.

terms). Most urban background sites experienced improvements; albeit smaller than those seen at roadside sites. Some urban background sites saw increases in both NOx and NO_2, which may reflect the influence of the rural episode.



	Road	Airport	Industrial	Urban	Rural
No. Sites	122	3	9	57	14
Mean	-30%	-36%	-10%	-16%	23%



	Road	Airport	Industrial	Urban	Rural
No. Sites	123	3	9	56	13
Mean	-31%	-40%	-14%	-14%	15%

Figure 2: Relative Change in BRT-adjusted [A] NOx and [B] NO_2 Concentrations at 205 UK Sites (comparing mean of period 24th Mar to 9th Apr 2020 with period 1st Jan to 14th Mar 2020) (Boxes show Q1 and Q3 ranges, vertical lines extend to points no further than 1.5 times interquartile range from Q1 and Q3, dots show remaining points. Outliers at 195% (NOx) and 242% (NO_2) are not shown)[8].

[8] Mean NO_2 measured at Eskdalemuir prior to March is currently reported as negative. This site has been removed from Plot B.

2.4 While the period-average reductions of BRT-adjusted NOx and NO_2 at roadside sites are similar, the detailed patterns show increases in NO_2 as the lockdown period proceeds, while the NOx concentrations remained steady (Appendix 2). This is likely to be a response to the higher photochemical activity during this period affecting O_3 concentrations and to some extent the higher rural NO_2, which may be due to an influx of air from continental Europe (see Section 3). O_3 has not, at this time, been included as a BRT model parameter in the NO_2 analysis.

2.5 Figure 3 shows the relationship between the reduction in BRT-adjusted NOx and the total, pre-restrictions, BRT-adjusted concentration measured at each road site. There is general pattern of larger relative improvements at the more polluted sites, which is likely to reflect the greater relative importance of road traffic at these sites when compared with other sources. A similar relationship exists for NO_2 but is not shown here.

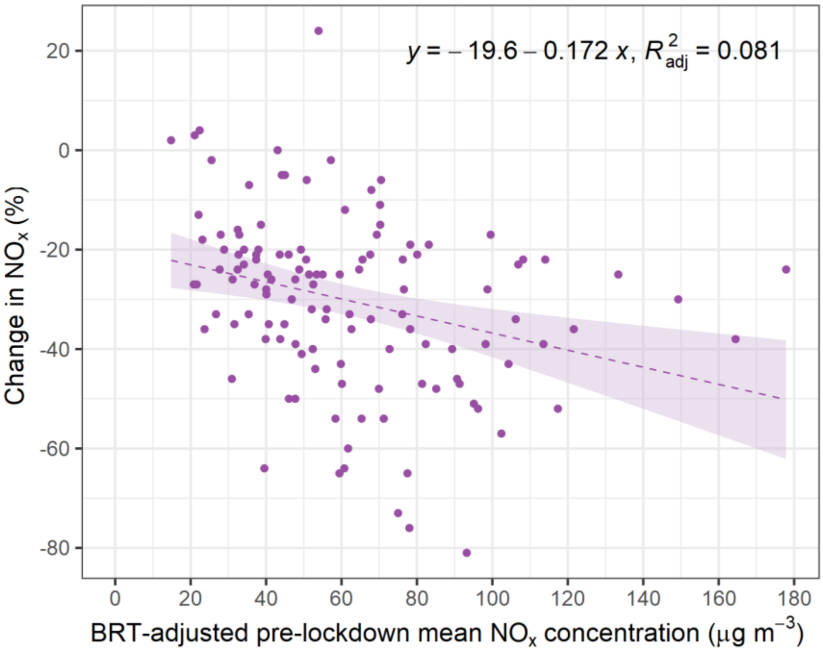
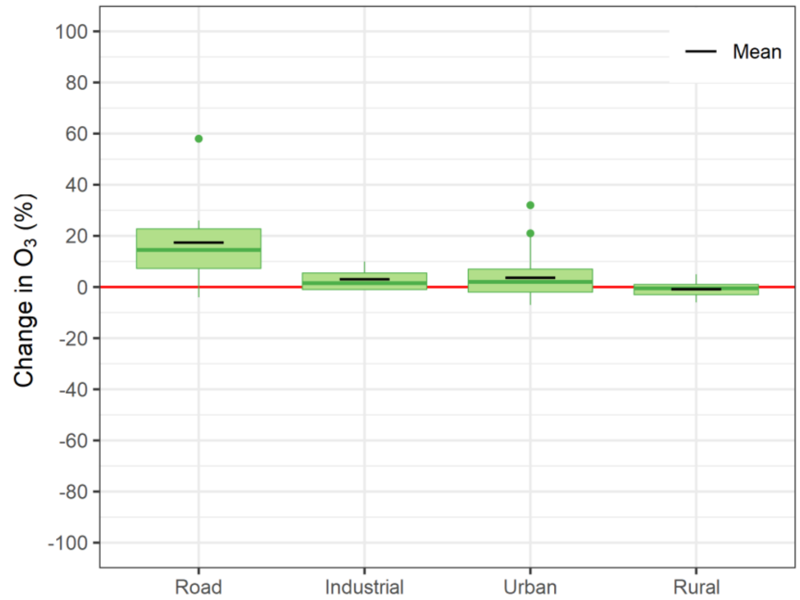


Figure 3: Relative Change in BRT-adjusted NOx at 122 Road sites (comparing mean of period 24th Mar to 9th Apr 2020 with period 1st Jan to 14th Mar 2020) vs BRT-adjusted Mean NOx for period 1st Jan to 14th Mar 2020. Shading shows 95% confidence interval.

3 Ozone

3.1 Appendix 1 summarises the measured and BRT-adjusted daily-mean O_3 concentrations at 74 UK sites. The relative changes, grouped by site type, are summarised in Figure 4 and shown in detail in Appendix 2. Higher daily-mean O_3 concentrations have been recorded at most rural sites since late March, but the BRT models appear able to accurately predict these events; meaning that BRT-adjusted O_3 concentrations during 2020 are relatively constant (Figure 5). At road sites, lower NOx emissions appear to have caused locally-elevated O_3 concentrations in late March, although there is some evidence that O_3 concentrations at the roadside have reverted toward their pre-COVID-19 mean levels (Figure 5) in early April. The current analysis ends on 9th April (immediately before Easter) and so the apparent downward trend for roadside O_3 in April (Figure 5) may be misleading.



	Road	Industrial	Urban	Rural
No. Sites	10	4	40	20
Mean	17%	3%	4%	-1%

Figure 4: Relative Change in BRT-adjusted O_3 Concentrations at 74 UK Sites (comparing mean of period 24th Mar to 9th Apr 2020 with period 1st Jan to 14th Mar 2020) (Boxes show Q1 and Q3 ranges, vertical lines extend to points no further than 1.5 times interquartile range from Q1 and Q3, dots show remaining points)

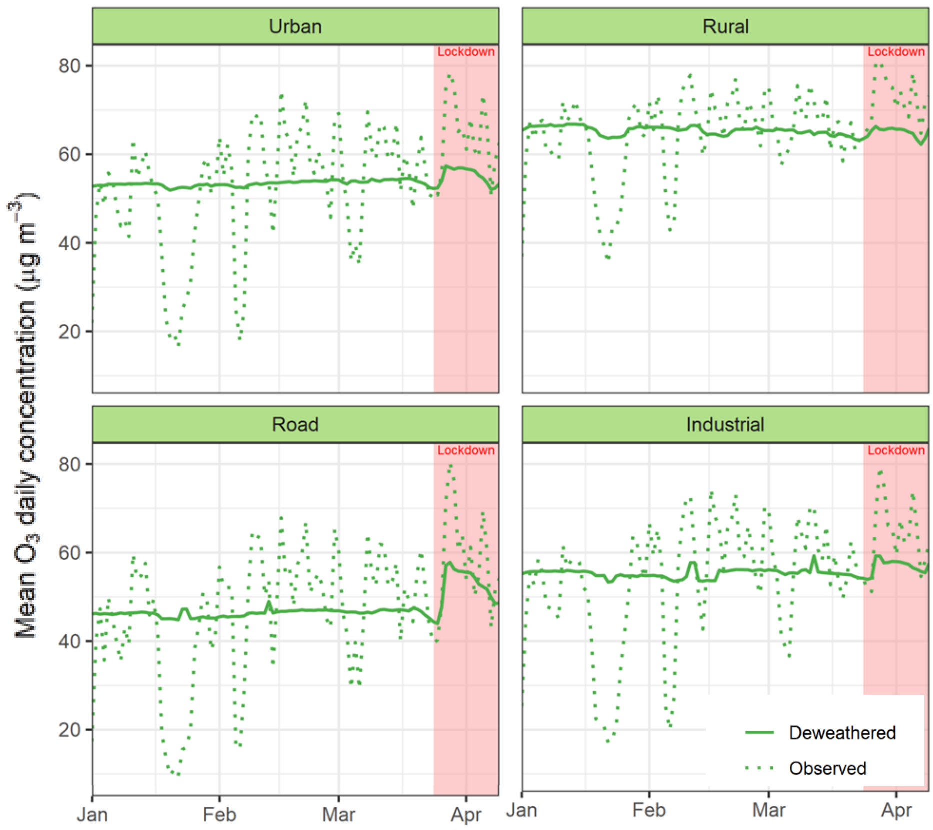


Figure 5: Average Daily-mean O_3 at Different Site Types (Average of site-specific daily-mean values)

3.2 Figure 6 shows the relationship between the reduction in BRT-adjusted O_3 and the total, pre-restriction BRT-adjusted concentration at each road site. It suggests that the largest increases were at the sites where O_3 is typically most effectively titrated.

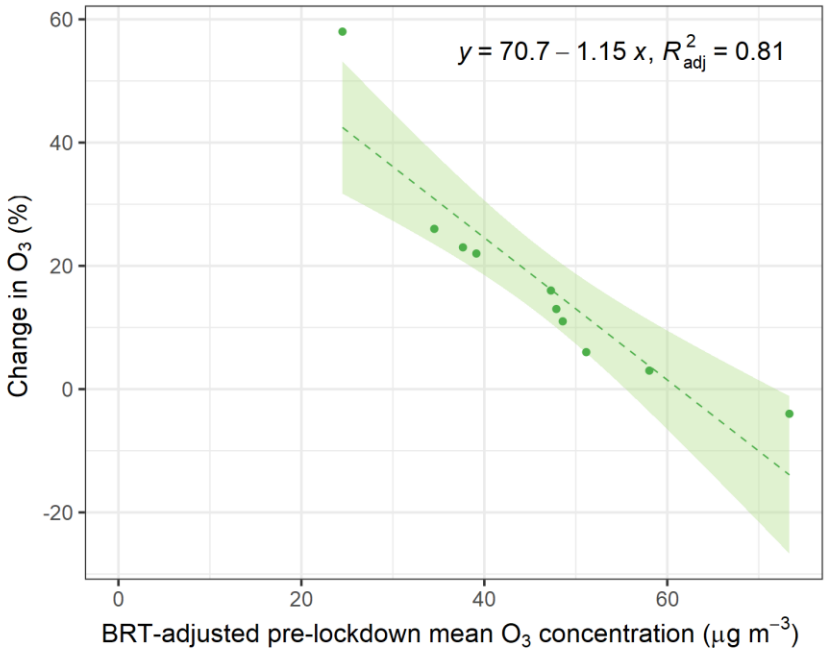


Figure 6: Relative Change in BRT-adjusted O_3 at 10 Road sites (comparing mean of period 24th Mar to 9th Apr 2020 with period 1st Jan to 14th Mar 2020) vs BRT-adjusted Mean O_3 for period 1st Jan to 14th Mar 2020. Shading shows 95% confidence interval.

Appendix 1 Relative Changes in NOx, NO_2, and O_3 at 205 Sites

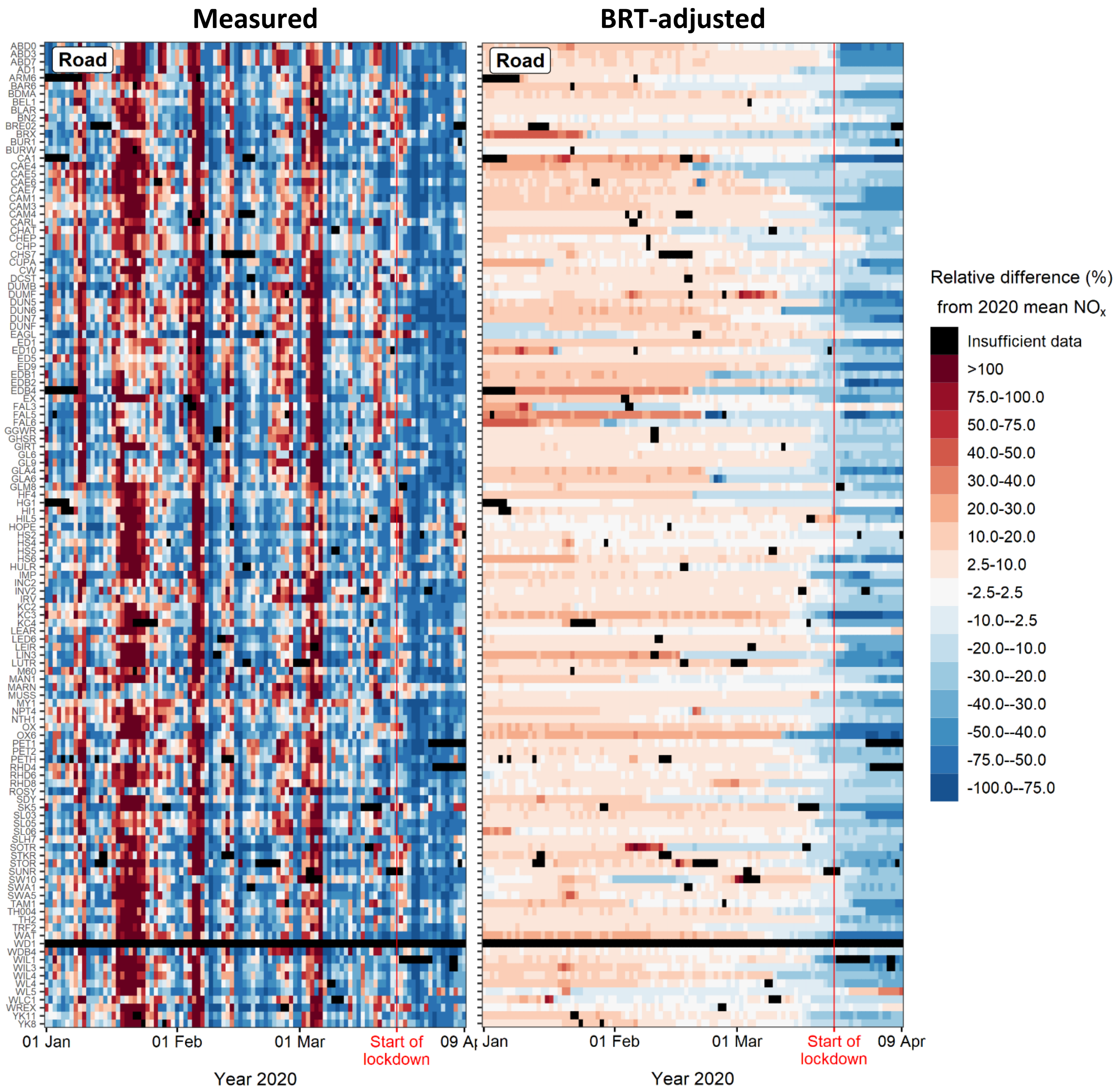


Figure A1.1: Relative Change in Raw Measured and BRT-adjusted Daily-mean NOx Concentrations at UK Roadside Sites – 1st Jan to 9th April 2020. Each row of pixels represents a single site, with the site code given on the y-axis.

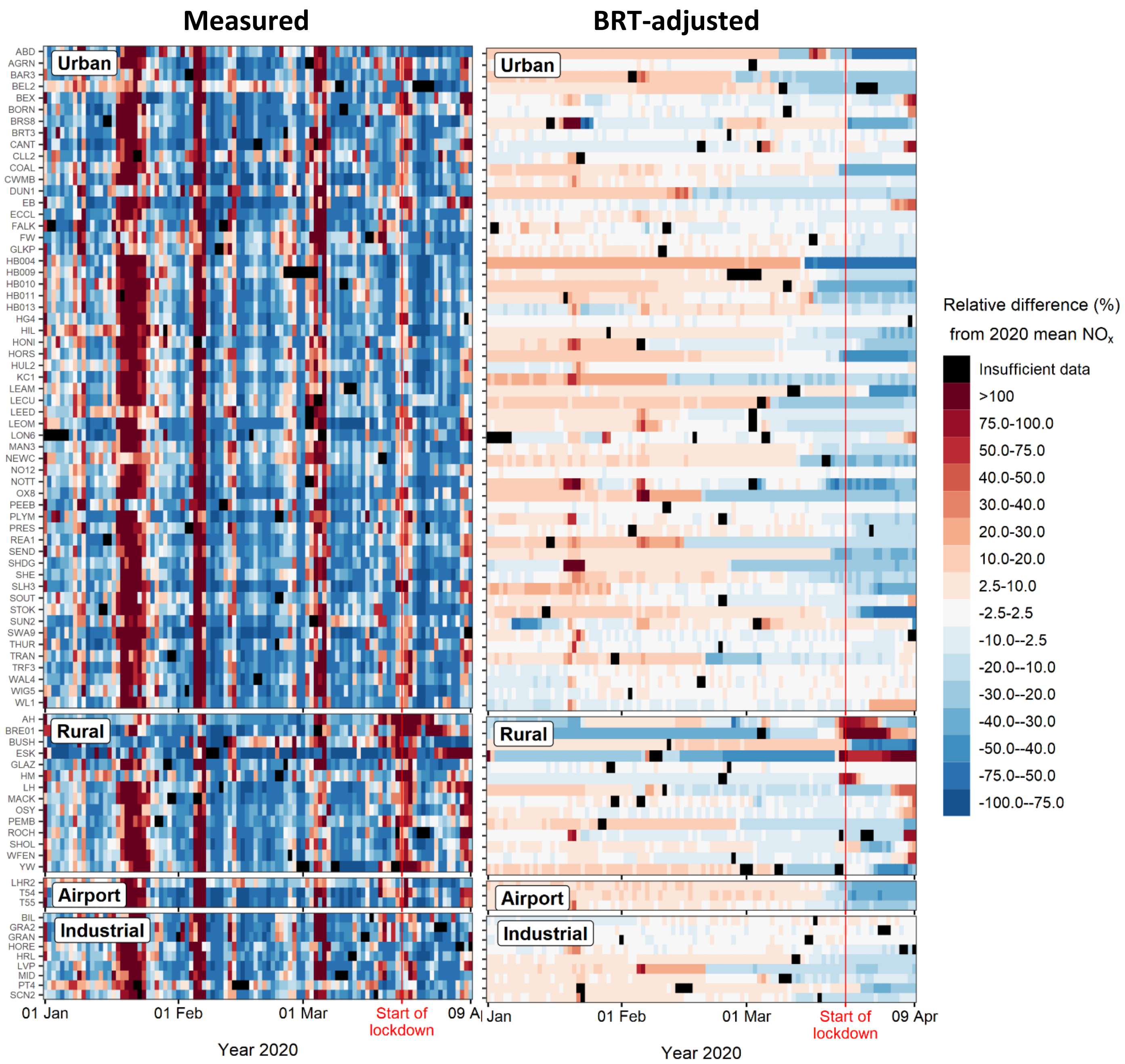


Figure A1.2: Relative Change in Raw Measured and BRT-adjusted Daily-mean NOx Concentrations at UK Non-roadside Sites – 1st Jan to 9th April 2020. Each row of pixels represents a single site, with the site code given on the y-axis.

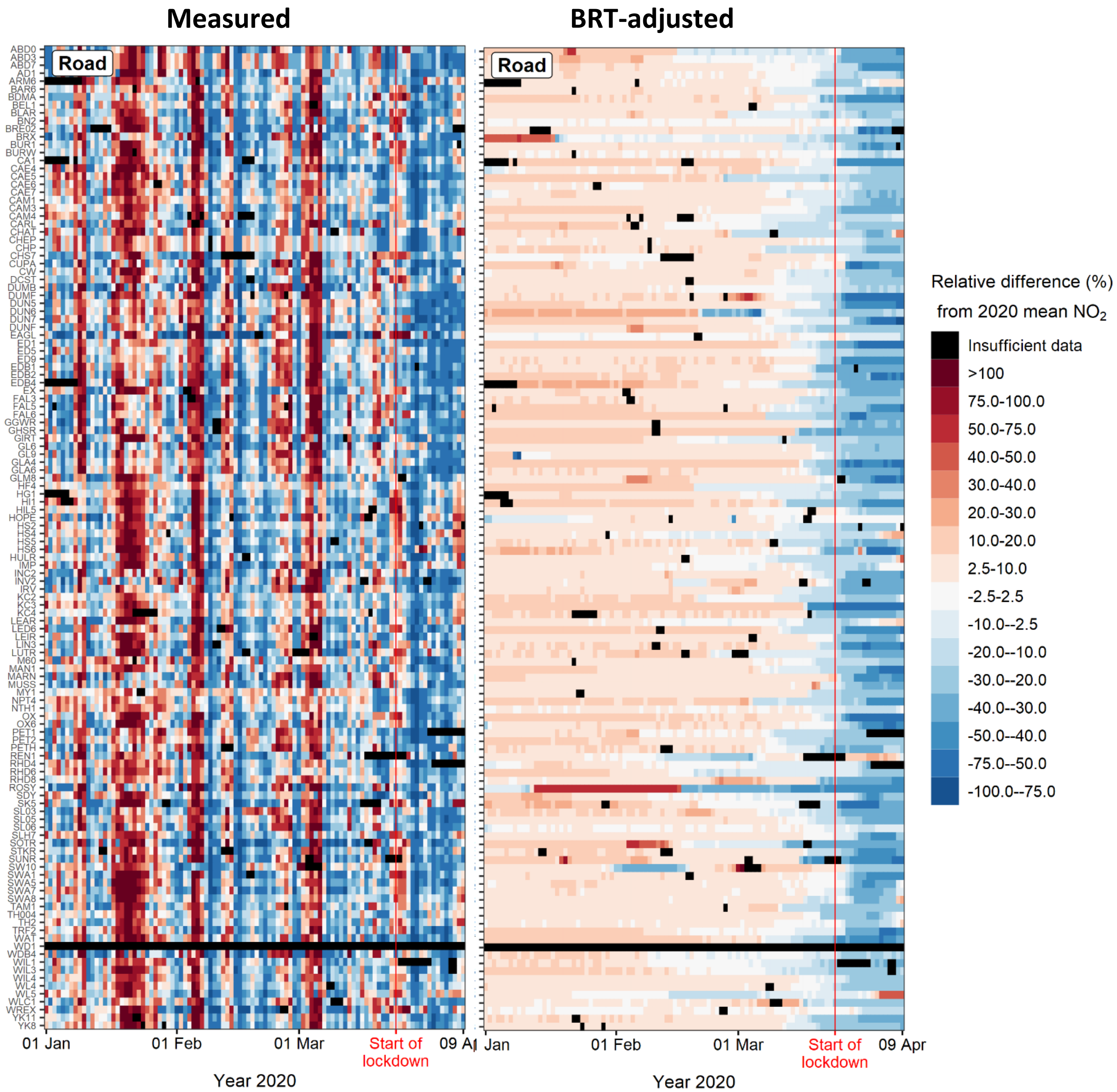


Figure A1.3: Relative Change in Raw Measured and BRT-adjusted Daily-mean NO_2 Concentrations at UK Roadside Sites – 1st Jan to 9th April 2020. Each row of pixels represents a single site, with the site code given on the y-axis.

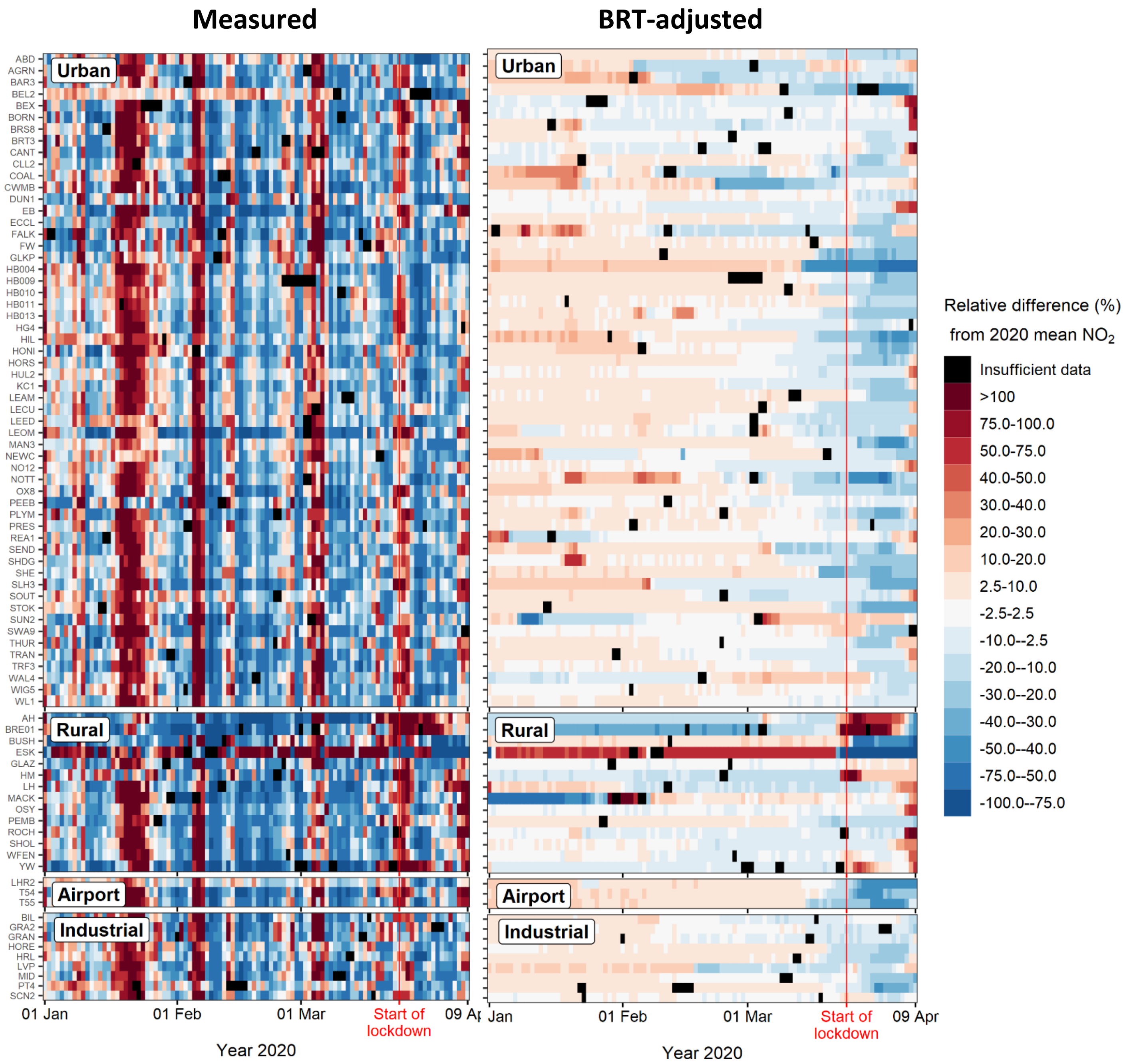


Figure A1.4: Relative Change in Raw Measured and BRT-adjusted Daily-mean NO_2 Concentrations at UK Non-roadside Sites – 1st Jan to 9th April 2020. Each row of pixels represents a single site, with the site code given on the y-axis.

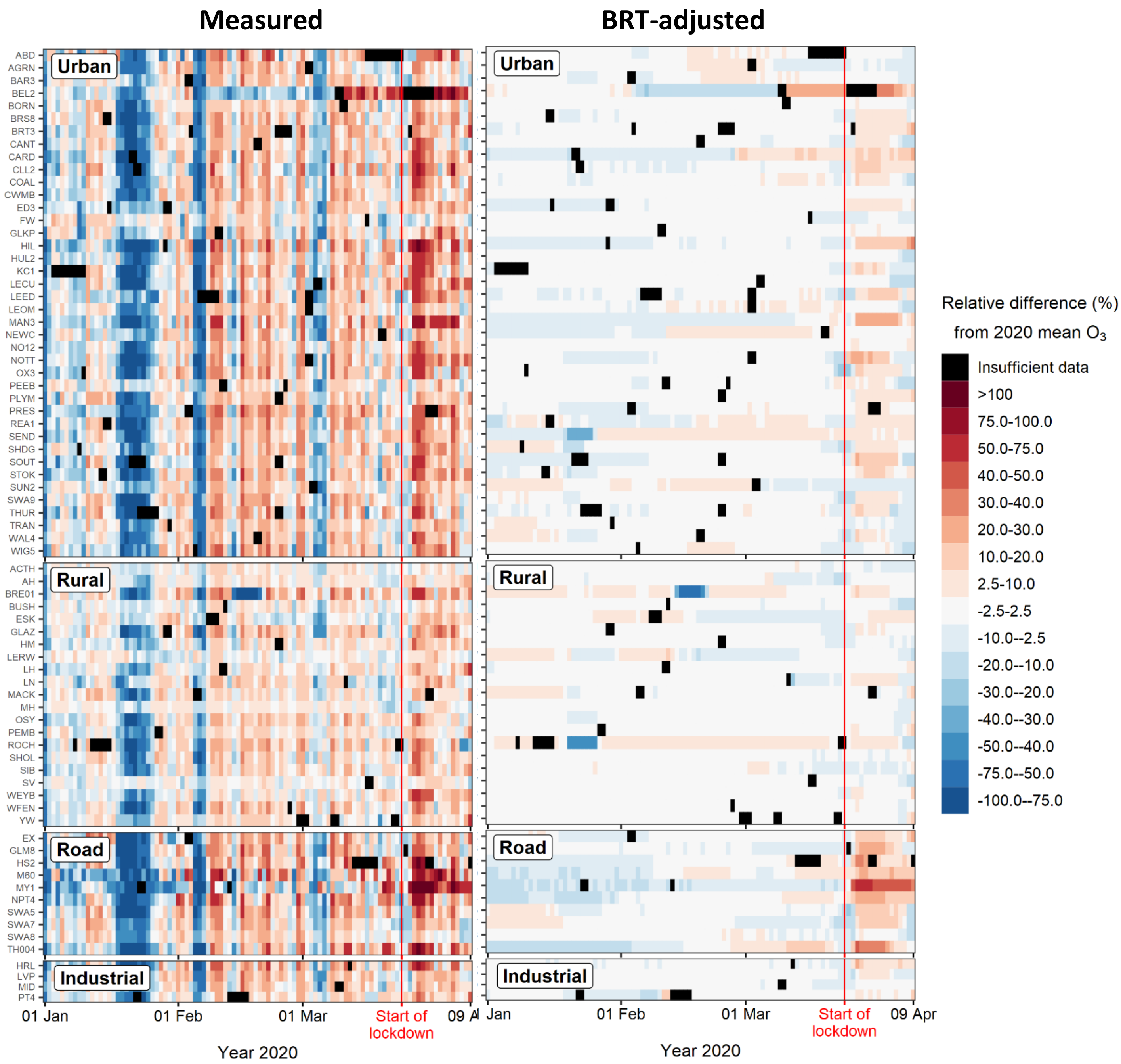


Figure A1.5: Relative Change in Raw Measured and BRT-adjusted Daily-mean O_3 All UK Sites – 1st Jan to 9th April 2020. Each row of pixels represents a single site, with the site code given on the y-axis.

Appendix 2 Aggregated Time-series for NOx and NO_2

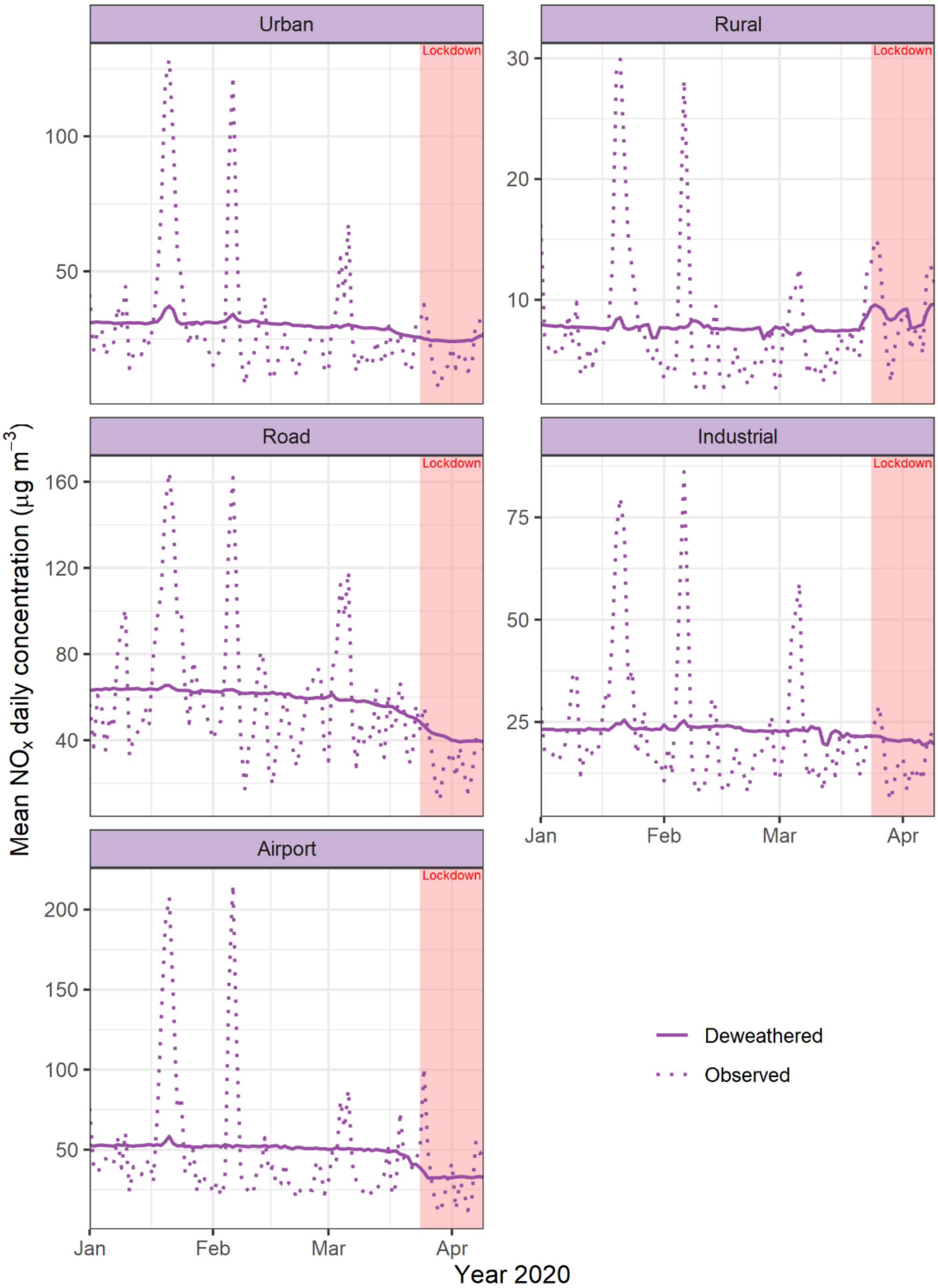


Figure A2.1: Average Daily-mean NOx at Different Site Types (Average of site-specific daily-mean values)

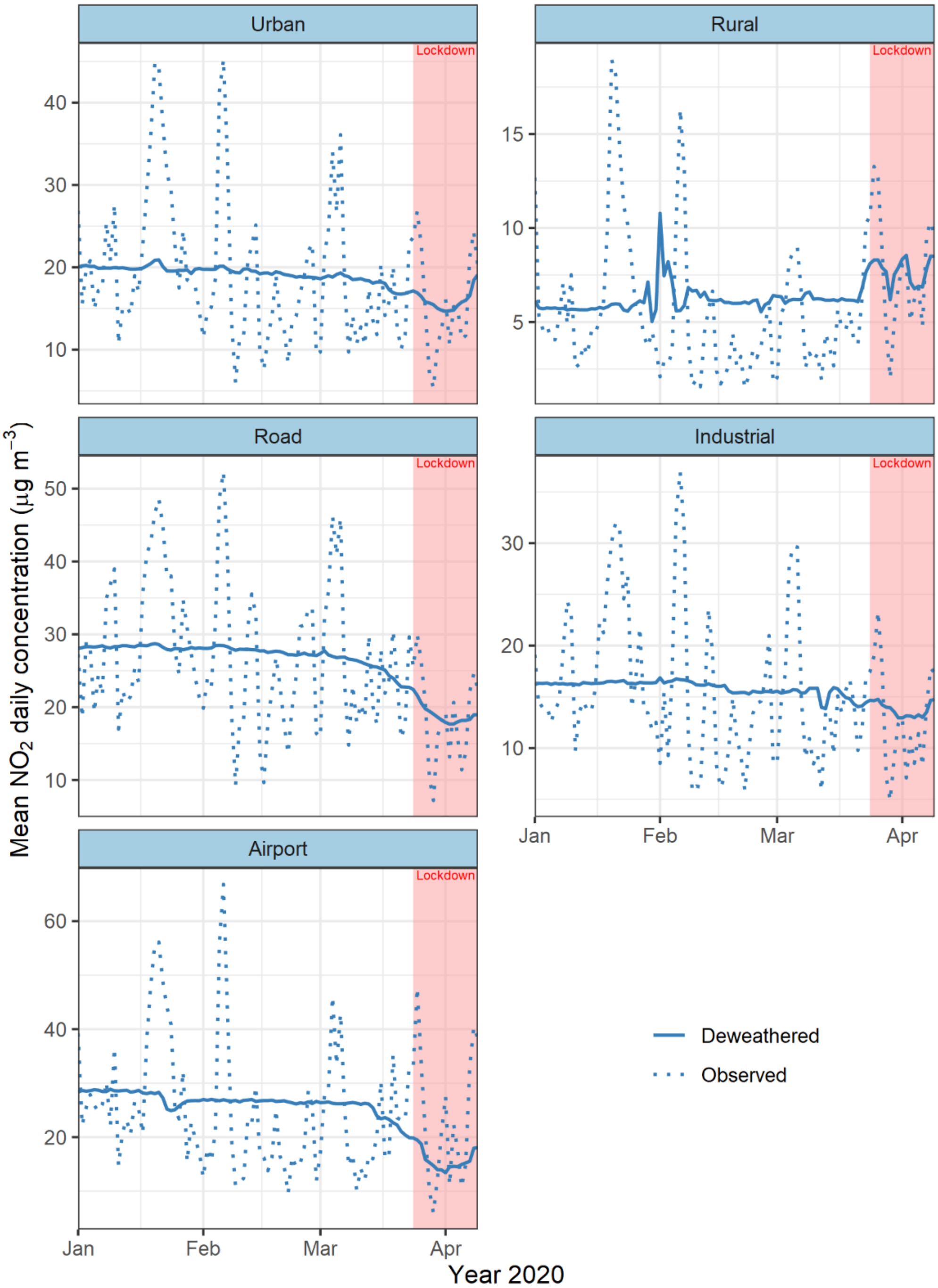


Figure A2.2: Average Daily-mean NO_2 at Different Site Types (Average of site-specific daily-mean values)

Appendix 3 Relative Changes at Each Site

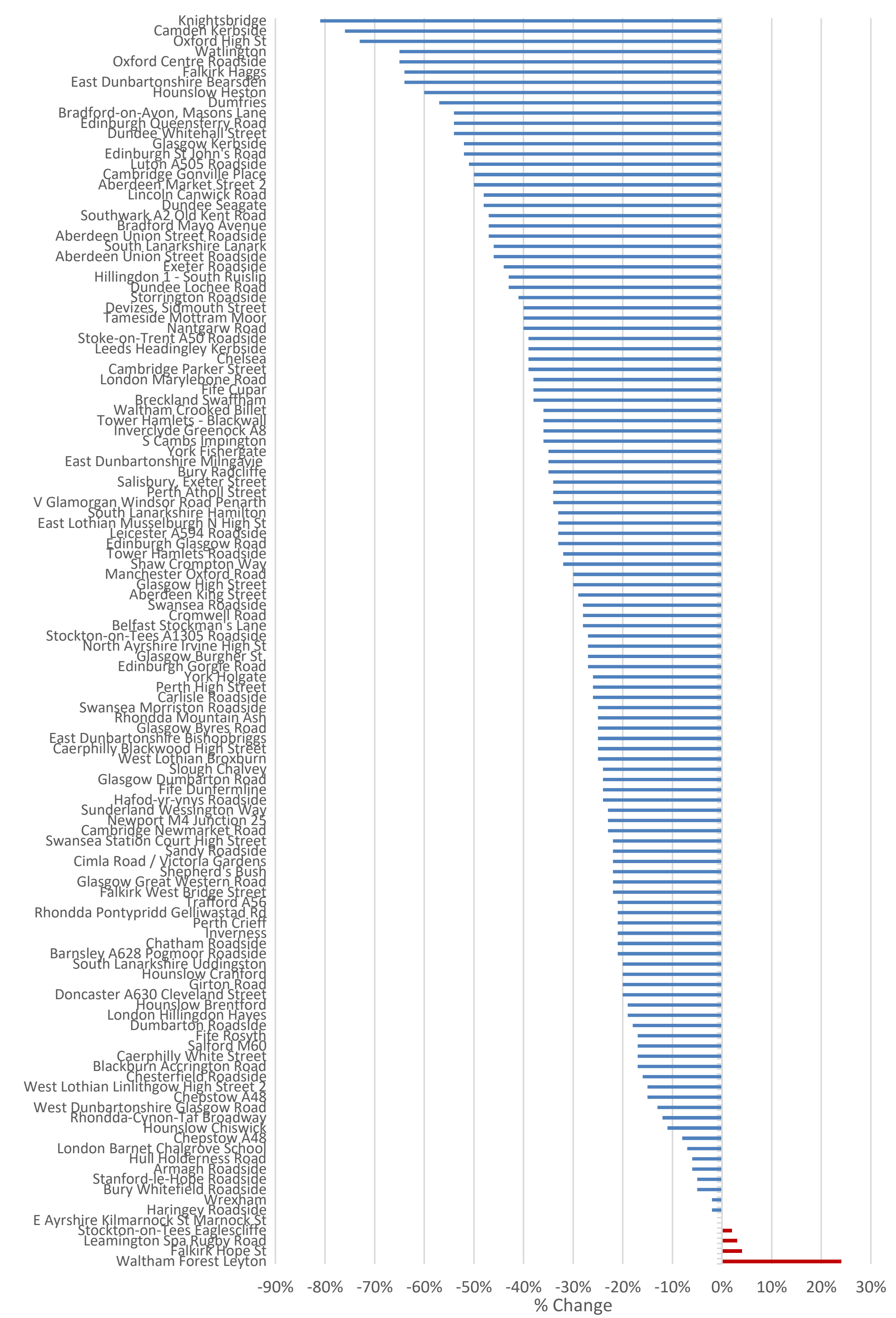


Figure A3.1: Relative Change in BRT-adjusted NOx at 122 Road Sites (comparing mean of period 24th Mar to 9th Apr 2020 with period 1st Jan to 14th Mar 2020)

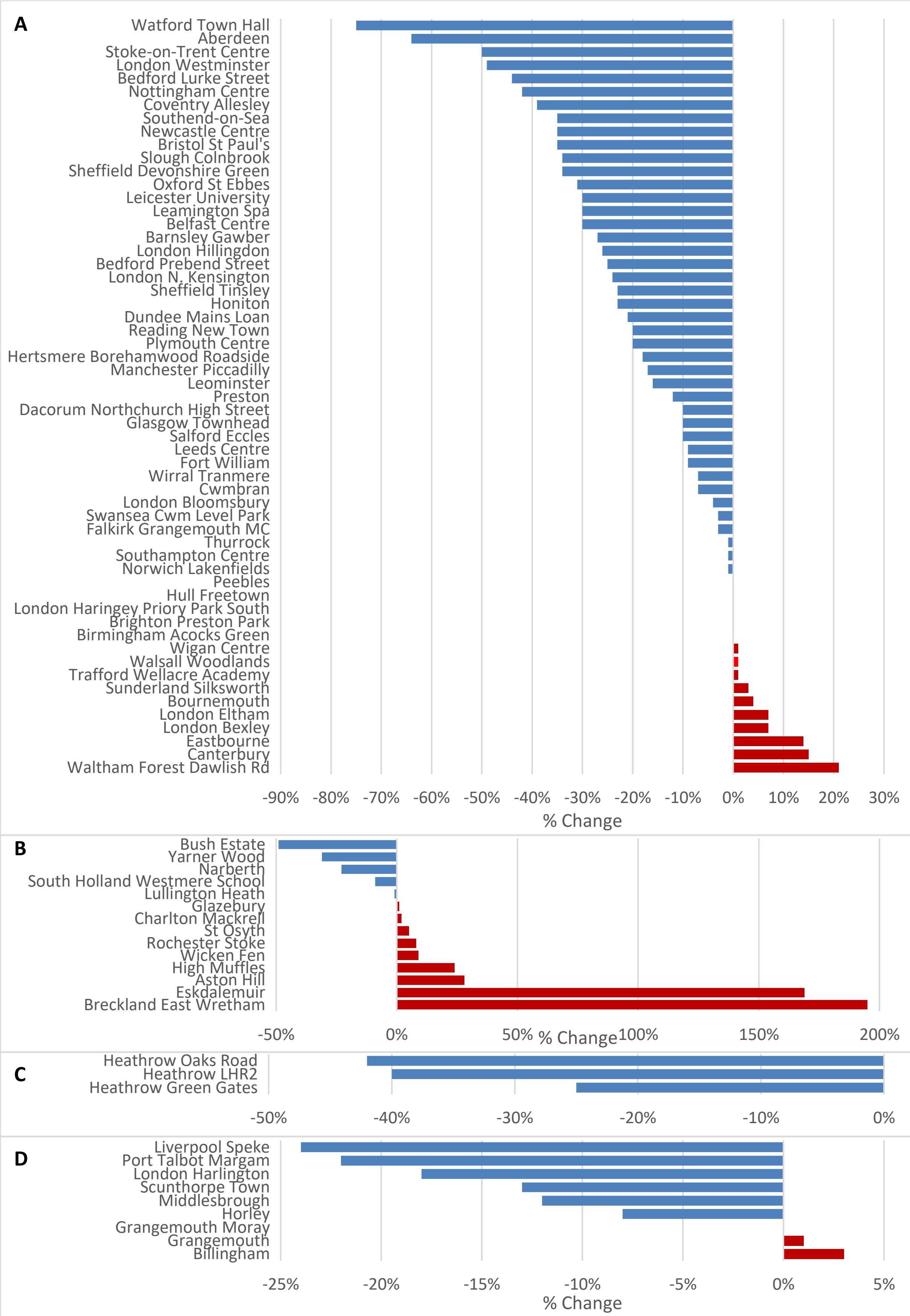


Figure A3.2: Relative Change in BRT-adjusted NOx at [A] 57 Urban Sites and [B] 14 Rural Sites, [C] 3 Airport Sites, and [D] 9 Industrial Sites (comparing mean of period 24th Mar to 9th Apr 2020 with period 1st Jan to 14th Mar 2020). Shown using Different Horizontal Scales

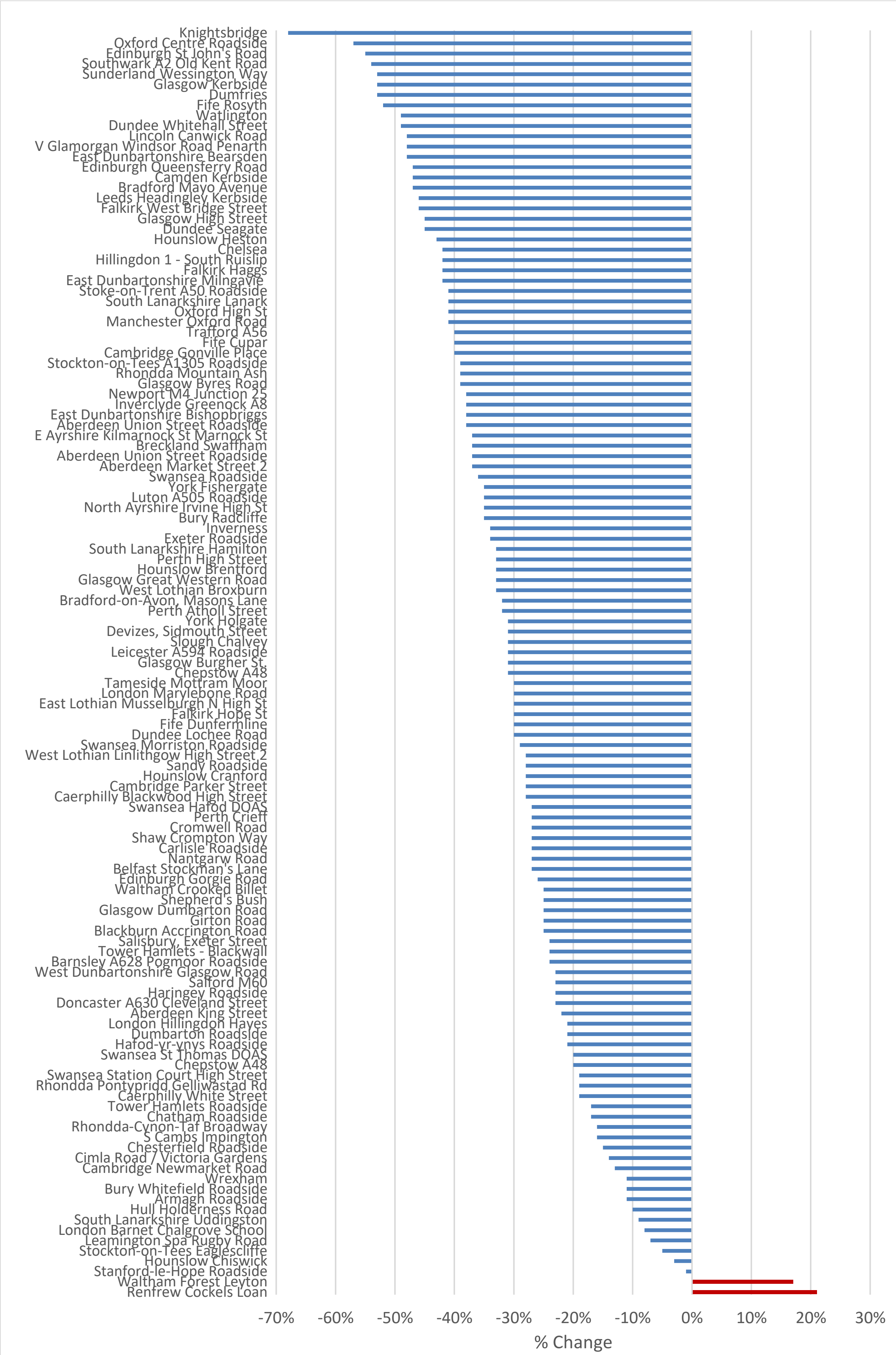


Figure A3.3: Relative Change in BRT-adjusted NO_2 at 123 Road Sites (comparing mean of period 24th Mar to 9th Apr 2020 with period 1st Jan to 14th Mar 2020)

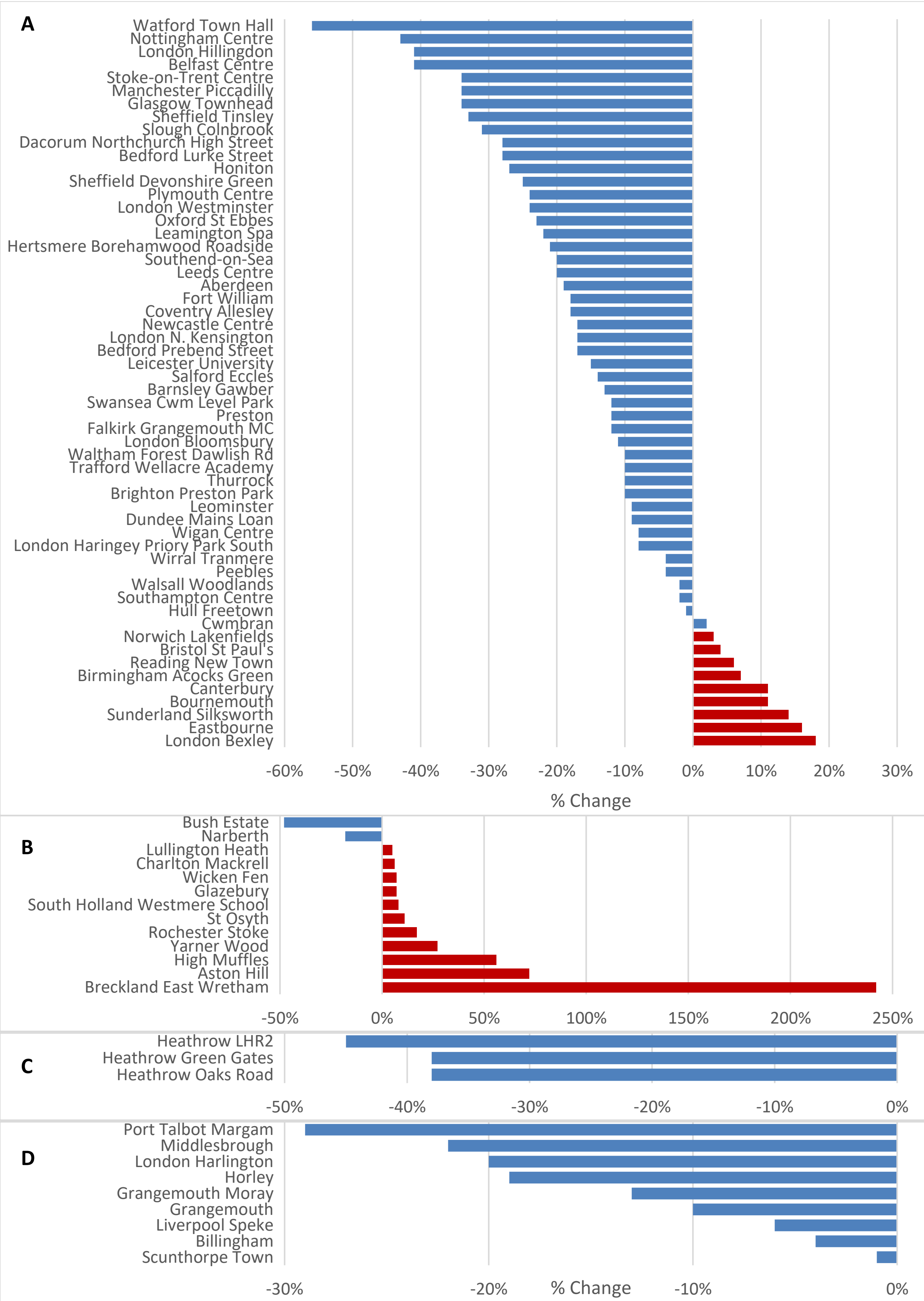


Figure A3.4: Relative Change in BRT-adjusted NO_2 at [A] 56 Urban Sites and [B] 13 Rural Sites, [C] 3 Airport Sites, and [D] 9 Industrial Sites (comparing mean of period 24th Mar to 9th Apr 2020 with period 1st Jan to 14th Mar 2020). Shown using Different Horizontal Scales

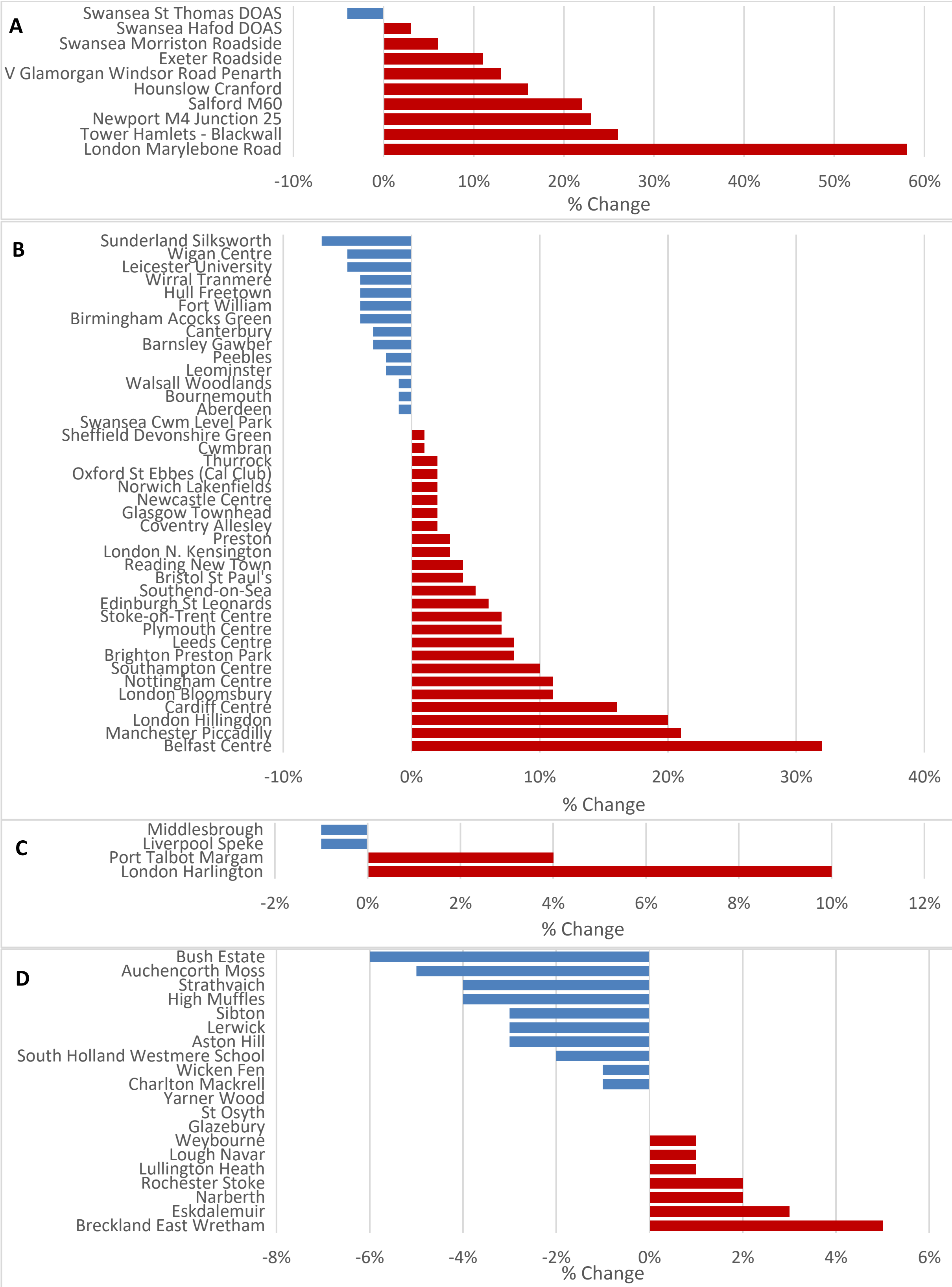


Figure A3.5: Relative Change in BRT-adjusted O_3 at [A] 10 Road Sites, [B] 40 Urban Sites, [C] 4 Industrial Sites, and [D] 20 Rural Sites (comparing mean of period 24th Mar to 9th Apr 2020 with period 1st Jan to 14th Mar 2020). Shown using Different Horizontal Scales

Appendix 4 Geographical Distribution for NOx and NO_2

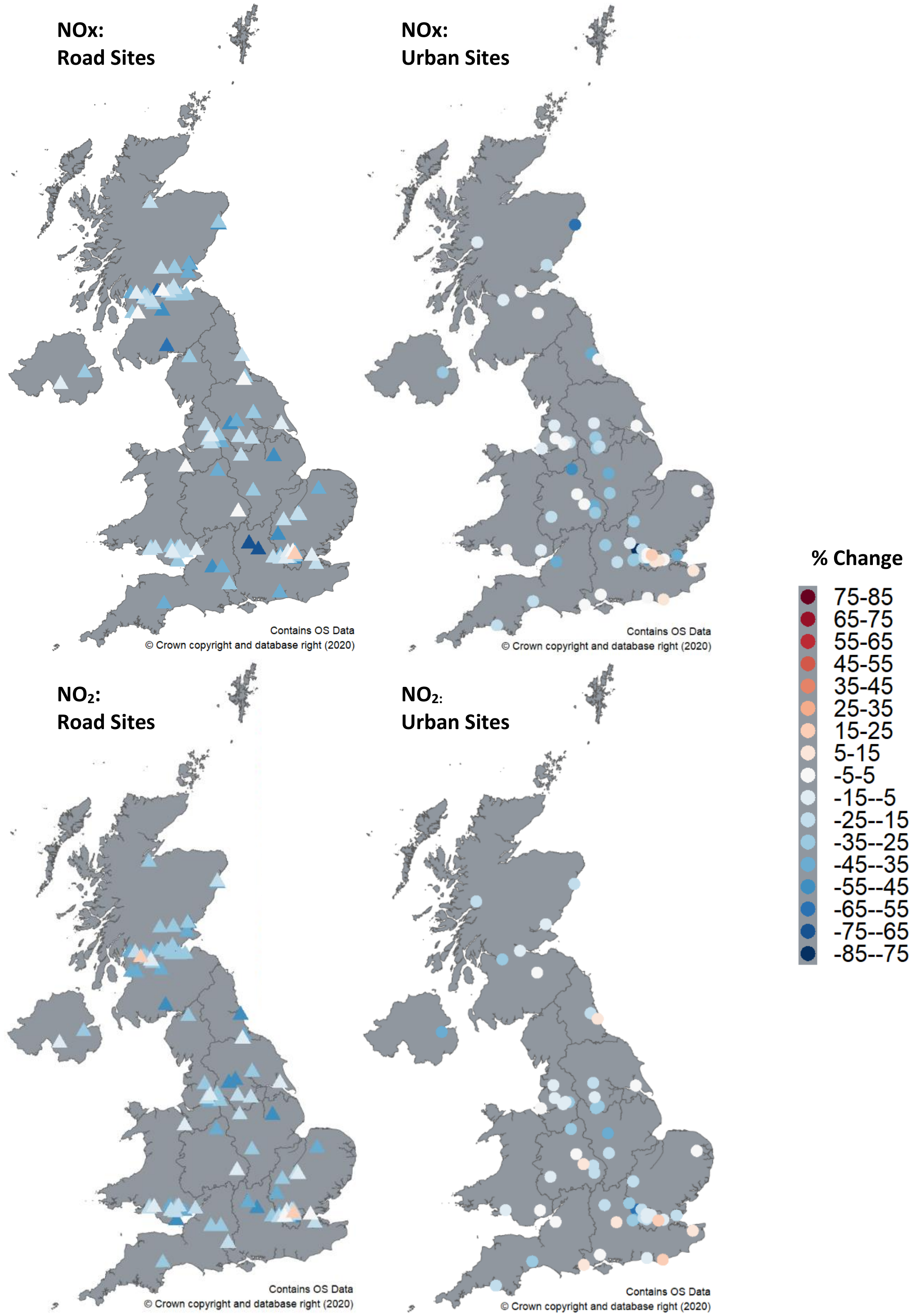


Figure A4.1: Relative Change in BRT-adjusted NOx and NO_2 at Road and Urban Sites (comparing mean of period 24th Mar to 9th Apr 2020 with period 1st Jan to 14th Mar 2020).