Provisional Analysis of Welsh Air Quality Monitoring Data – Impacts of Covid-19

Report for Welsh Government

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Welsh Government

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Executive summary

- This provisional analysis has been carried out by Ricardo Energy & Environment (Ricardo) on behalf of the Welsh Government and includes air quality monitoring data up until 31st May 2020. The source of the measurement data is the "Air Quality in Wales" website at https://airquality.gov.wales/
- Ricardo has developed statistical models for air quality monitoring sites in the Welsh Air Quality Network (WAQN) for NO_x, NO_2, O_3 and $PM_{2.5}$ from January 2018 to 31st May 2020. These models have been used to estimate the effect of Covid-19 lockdown actions on air pollutant concentrations. The models are used to develop a counterfactual (business as usual, BAU) of the expected concentrations if Covid-19 had not occurred.
- From the 16th March (the start of recommended social distancing) to 31st May 2020 it is estimated that NO_x and NO_2 concentrations decreased on average by 49% and 36% respectively, compared with BAU at roadside sites, with smaller reductions at urban background sites.
- Analysis of changes in the diurnal pattern of NO_x concentrations shows that the decreases are during the daytime and consistent with a pattern of reduced road traffic.
- The analysis of eight ozone sites indicates that concentrations of ozone increased by 18% on average, with stronger increases at locations which would normally experience highest NO_x. This is as expected since NO in high concentrations quickly scavenges O_3 to form NO_2.
- Weekly trends in deviations in NO_x concentrations from business as usual suggest that concentrations at the end of May were still considerably lower than expected. Extending the analysis into June and beyond would help to show if and how concentrations recover and the potential impact of increased congestion.
- The analysis of $PM_{2.5}$ and PM_{10} concentrations is considerably more challenging due to the strong dominance of regional background contributions. In terms of absolute concentrations of $PM_{2.5}$ (in 2020) averaged across 9 sites, the period after lockdown experienced much higher average concentrations than the period from 1st January to lockdown (11.4 μm^{-3} and 8.2 μm^{-3}, respectively).
- Further detailed analysis estimates that the local contribution to $PM_{2.5}$ concentrations has decreased by less than 1.0μm^{-3} on average across all urban $PM_{2.5}$ monitoring sites in Wales due to the Covid-19 restrictions. However, this estimate is uncertain because the change is small in absolute terms.
- Analysis of the small changes in the diurnal pattern of $PM_{2.5}$ concentrations at a busy roadside location shows that the decreases are during the daytime and consistent with a pattern of reduced road traffic.
- Analysis of the small changes in the diurnal pattern of $PM_{2.5}$ concentrations at a background location shows that there are also decreases during the daytime consistent with a pattern of reduced road traffic. These changes are however very small with a high degree of uncertainty.
- Similar to $PM_{2.5}$, reductions in the local contribution to PM_{10} concentrations are predicted by the modelling after lockdown; typically, around 2-3 μm^{-3}. However, the robustness of these estimates is uncertain for several reasons e.g. it depends on the appropriateness of the site used for subtraction of the regional background, the changes are small in absolute terms and there are many local factors that could be important but are unknown.

- The analysis of black carbon measurements from Cardiff shows that concentrations were decreasing before lockdown, with some evidence of an accelerated reduction at the time of lockdown. Compared with business as usual, concentrations are estimated to have reduced by 45%.
- Analysis of a limited sample of traffic data shows a significant drop in vehicle flows at the time of the lockdown, mostly in the Car/Light Van and Bus categories as expected. The fall-off in vehicle counts for the heavier goods vehicles is less significant.
- From the limited traffic data available there appears to be a clear correlation between the drop in vehicle numbers and the reduction in NO_x concentrations observed in the air quality measurements.
- Further analysis will be required when the measurements and emissions data are finalised. This may help to draw out more clear information about the source apportionment for particulate matter, and to provide more robust conclusions on the contribution of local vs. regional factors for both ozone and particulate matter.

Table of contents

1 Introduction

This provisional analysis has been carried out by Ricardo Energy & Environment on behalf of the Welsh Government and includes air quality monitoring data up until 31st May 2020. The source of the measurement data is the "Air Quality in Wales" website at https://airquality.gov.wales/

1.1 Background

The quantification of the effect that Covid-19 has had on air pollutant concentrations is important to understand. While it will take some time to understand the full impacts of actions related to Covid-19 on emissions and concentrations of different pollutants, it is clear that road vehicle activity decreased considerably since the lockdown on 23rd March. It is less clear however, what the changes in the concentrations of air pollutants has been. While it may seem obvious when road vehicle activity has decreased so dramatically that air pollution for some pollutants would improve, it is not so straightforward to understand and quantify the effect.

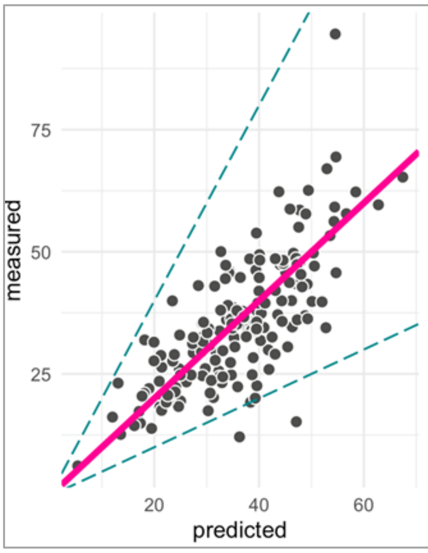
A simple approach might be to compare the period after lockdown to the period before lockdown to consider how concentrations of pollutants have changed. Or perhaps a comparison of the same period from previous year or years. However, the variation in meteorology, from daily to seasonal changes, can easily mask the actual changes related to changed activity that have occurred. This is a very common problem when analysing air pollution data: is a change related to a change in activity or a change in the weather?

1.2 Statistical models

To make progress, it is useful to develop statistical models to set up a counterfactual i.e. to predict what the concentration of pollutants would have been if Covid-19 had not occurred. Over the years a range of modelling approaches and applications have been developed (Carslaw and Taylor, 2009; Carslaw et al., 2012 and Grange and Carslaw, 2019). These approaches are example of the application of statistical techniques such as Boosted Regression Trees and Random Forests. Both techniques work well at explaining hourly or daily concentrations of pollutants in terms of commonly measured (or modelled) meteorological data such as wind speed, direction and ambient temperature. In essence, models can be developed and tested over a period and then used to predict concentrations over a new period.

In this case use was made of the deweather (https://github.com/davidcarslaw/deweather) R package. The models were based on hourly concentration data from https://airquality.gov.wales/, and meteorological data from the WRF regional scale model run by Ricardo over the period January 2018 to May 2020. Model variables include basic meteorological measurements such as wind speed, wind direction, ambient temperature and variables to account for the temporal variation in emissions such as (local) hour of the day and day of the week. The models are evaluated against randomly withheld data i.e. data not used for model development.

An example of model performance is shown in Figure 1 for the Newport M4 site for NO_2. The scatter plot and statistics show how well the model performs against data not used for model development. The statistics presented are those commonly applied to evaluating the performance of Air Quality Models (Derwent et al., 2010). It can be seen that the test data exhibit a small Mean Bias (MB) of 0.55 μm^{-3}, and relatively small Mean Gross Error (MGE) of 6.39 μm^{-3}. Results for FAC2 (the fraction of results within ½ and 2 times the observations, and the correlation coefficient r are also good ($r^2 > 0.5$). It should be noted that improvements in performance would be expected if surface meteorological data were used in place of modelled data.



statistic	value
Test data	NA
n	172.00
FAC2	0.99
MB	0.55
MGE	6.39
NMB	0.02
NMGE	0.18
RMSE	8.74
r	0.76
COE	0.38
IOA	0.69

statistic	value
Training	NA
n	684.00
FAC2	1.00
MB	0.08
MGE	3.51
NMB	0.00
NMGE	0.09
RMSE	4.54
r	0.95
COE	0.69
IOA	0.85

Figure 1 Example model performance for daily mean NO_2 concentrations at the Newport M4 Junction 25 site from 2018 to May 2020.

The models are then used to predict hourly concentrations from 1st March onwards at each site. This approach sets up a BAU case where the underlying emissions remain at levels typical of the immediate period pre-lockdown. From 1st March onwards it is therefore possible to compare predicted (i.e. business as usual, the counterfactual) concentrations with actual measured concentrations and consider their differences. Predicting from 1st March allows a period where concentrations did not deviate much from BAU before social distancing advice (16th March) and lockdown (23rd March). It is therefore possible to see at most sites when they deviate from BAU, as described next.

1.3 Cumulative sum (cusum) analysis

The analysis in this report also considers how measured concentrations deviate from BAU using a **cusum analysis**. A cusum analysis accumulates the deviation in concentration from BAU, which helps to highlight possible **change-points** in time series. While the idea is simple, it is effective in the current context because we are considering deviations from the BAU – which should on average be zero if things continue as normal. The approach is especially useful when the changes are small (perhaps at background sites) and where it is very difficult to see a change from the raw data alone.

As an example, a time series has been generated using random data between 9.5 and 10.5, and halfway through the time series the values increased by adding 0.2, as shown in Figure 2. The original time series is shown by the plot of the left of Figure 2. It is not clear from this plot when a change may have occurred. By plotting the cusum of values (Figure 2 (B)), it can be seen there is a clear change in the slope halfway through the time series. The approximately level gradient shown in the first half of the cusum plot shows that values were neither higher nor lower than the average. The positive (and approximately constant) gradient in the second half of the cusum plot shows there was a change in the mean value, roughly halfway through the time series. In fact, if one takes the change in cusum values from halfway through to the end of the time series (about 10 units in this case), and divide by the number of points (50), a value of 0.2 is calculated, which is the average increase in the second part of the time series.

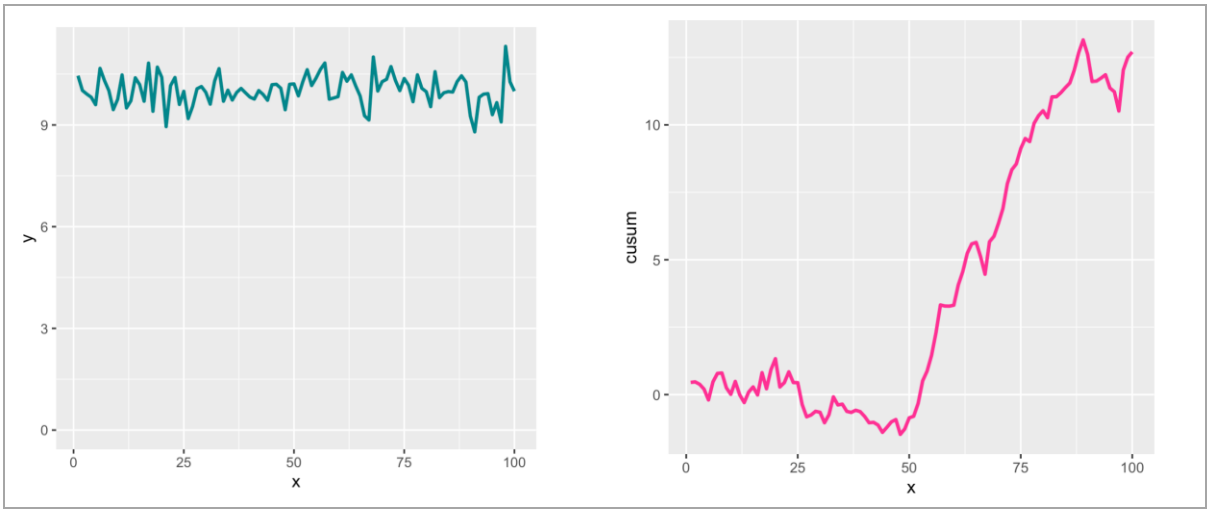


Figure 2 Example of a cusum analysis. Left: a random time series that varies between 9.5 and 10.5 is shown. At t = 50 a value of 0.2 is added to all values between 51 and 100. Right: shows the cumulative sum plot of the accumulated deviations from the mean.

The cusum analysis helps to provide an additional level of inference i.e. not only is a change in concentration calculated, but the timing of that change is considered. Given the Covid-19 situation, one might expect the changes to be closely related to the lockdown date. However, the timing of changes will not be perfect and depend on the random variation that exists in air quality data and the uncertainty of the models used to predict BAU. While not considered here, it is possible to determine whether a change is statistically significant and provide a 95% confidence interval in the timing of the change.

2 Results

2.1 NO_x and NO_2 Summary

A total of 23 air quality measurement sites in Wales have been analysed for NO_x and NO_2. The estimated changes in NO_x and NO_2 concentrations are shown by site type in Table 1. These results show that the greatest reductions in NO_x are seen for Traffic sites, which is to be expected. It is generally the case that the change in NO_2 is less than that for NO_x, which is discussed later.

Table 1 Summary percentage changes in NO_x and NO_2 concentrations between business as usual and measured concentrations in the post-lockdown period to 31st May 2020.

Site type	% NO_x change	% NO_2 change
Remote	-22.8	-21.5
Rural background	-20.8	-37.1
Traffic	-48.3	-37.9
Urban background	-39.8	-35.1
Industrial background	-38.5	-40.5

2.1.1 NO_x Analysis

Figures 3 to 5 present the detailed analysis of change in NO_x concentrations at a range of air pollution monitoring sites across Wales from February 1st to May 31st 2020

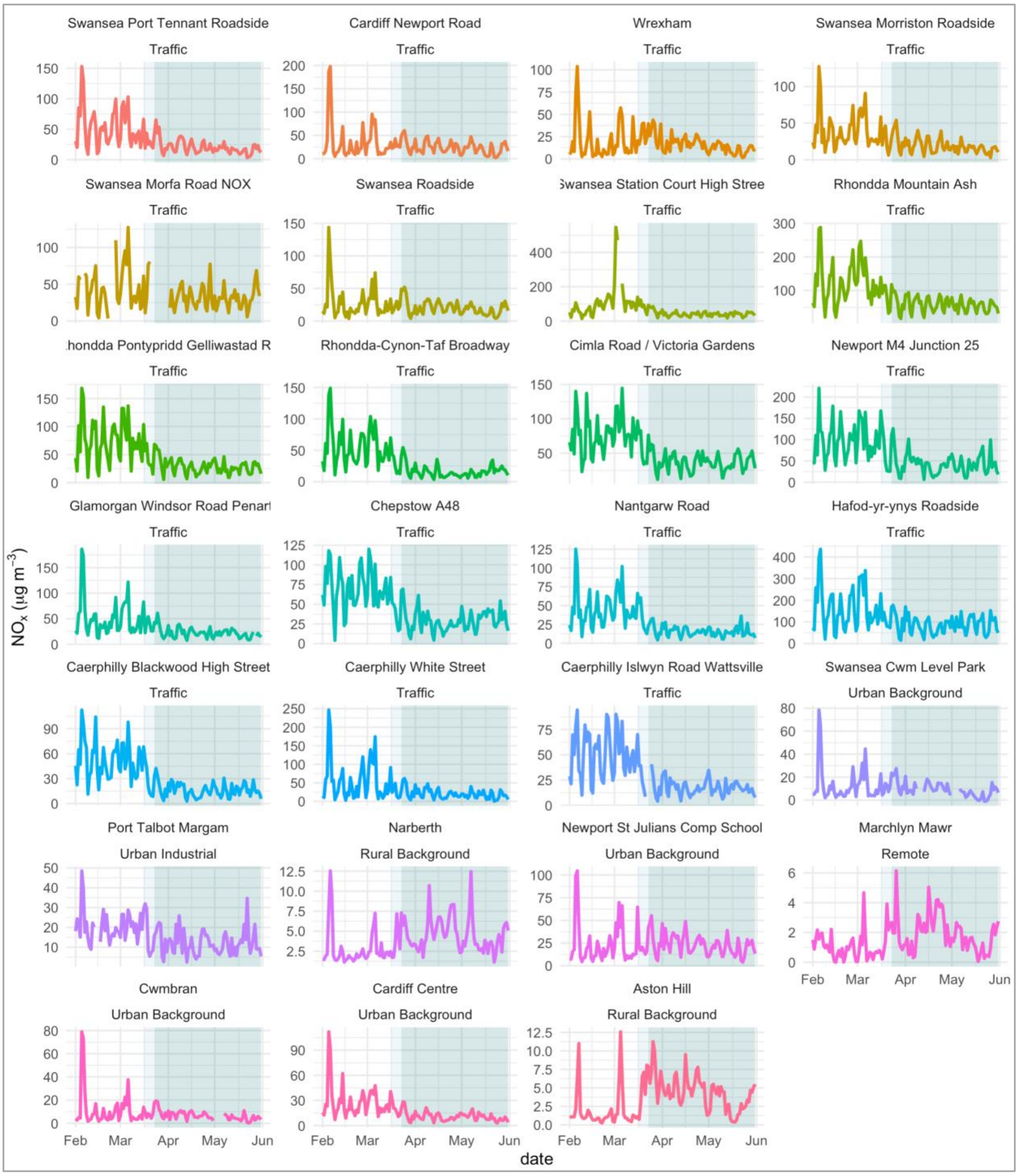


Figure 3 Daily mean concentrations of NO_x at a range of air pollution monitoring sites across Wales from February 1st to May 31st 2020. The light blue shaded rectangle shows the period from 16th March, when social distancing was first recommended. The darker shaded rectangle shows the period from the start of the 'lockdown' that began on the 23rd March.

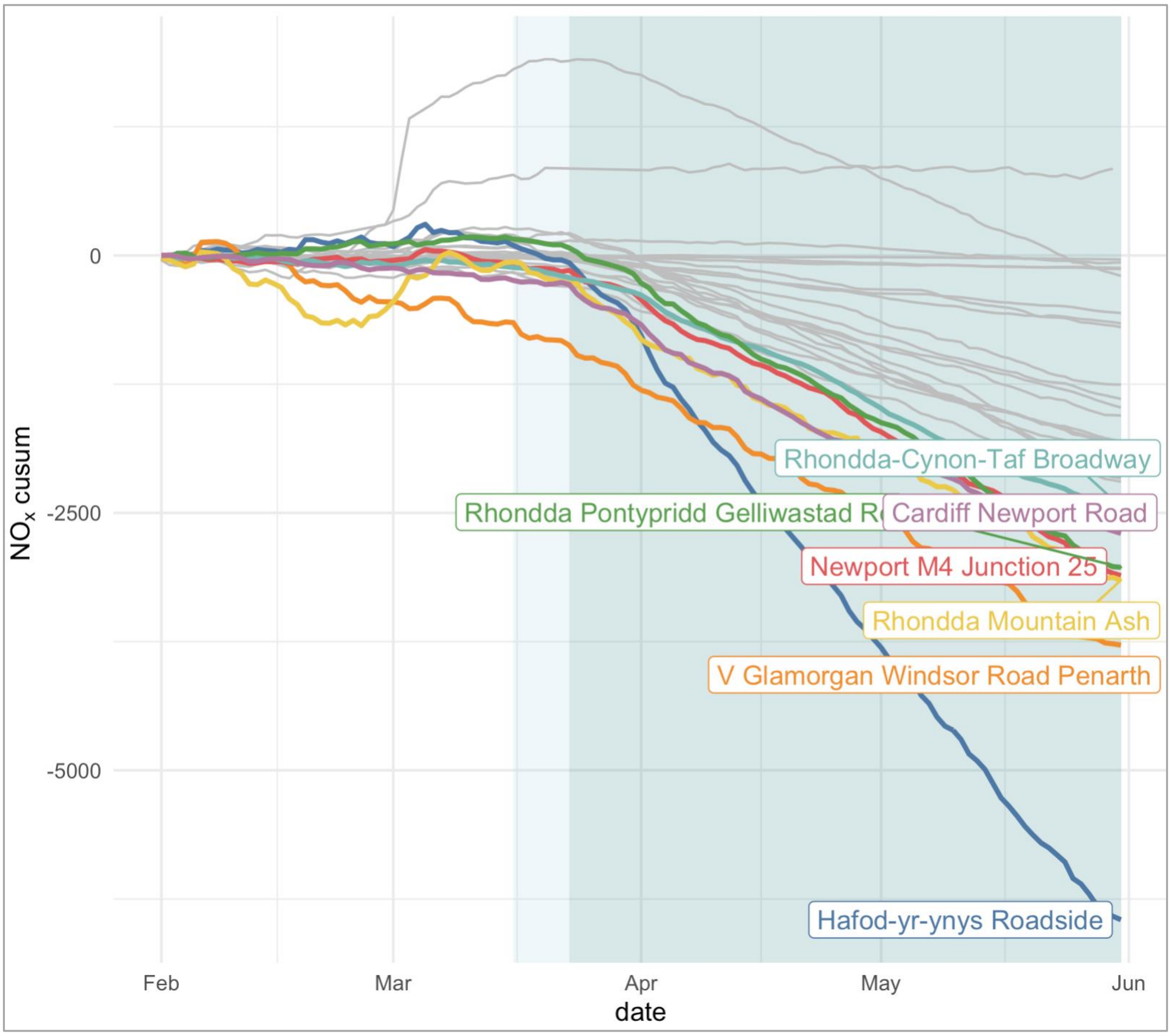


Figure 4 The cumulative sum (or cusum) of measured minus business as usual NO_x at a range of air pollution monitoring sites across Wales. The light blue shaded rectangle shows the period recommended social distancing from 16th March, the dark shaded rectangle shows the period from the start of the lockdown starting 23rd March. Labelled sites show those that experienced the greatest changes.

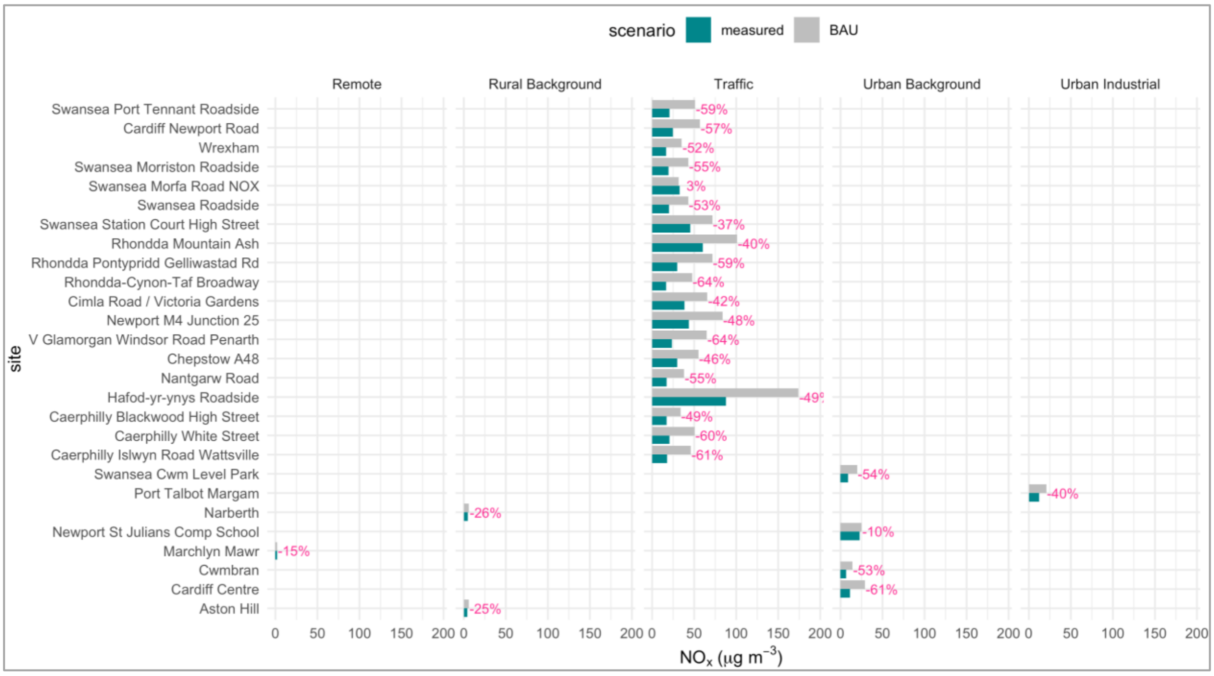


Figure 5 Measured and estimated business as usual NO_x concentrations by site. The numbers show the percentage change in concentration relative to business as usual.

Figure 6 shows how the diurnal profile of NO_x concentrations is predicted to have changed pre and post lockdown at the A48 Chepstow site. In this case the diurnal profiles have been adjusted for meteorological variation, which can strongly affect diurnal variations in pollutant concentrations (especially wind speed and temperature). The 'before' profile is strongly similar to the profile that might be expected for that of vehicle emissions of NO_x – highest weekdays and lowest at weekends and with evidence of a morning and evening peak. The 'after' profile (pink line) is much lower than the before profile, as expected due to reduced traffic. The shaded blue region shows the difference between before and after i.e. a decrease. The profile of the shaded area is also indicative of that for road traffic and provides further evidence that it is road traffic emissions that have strongly decreased.

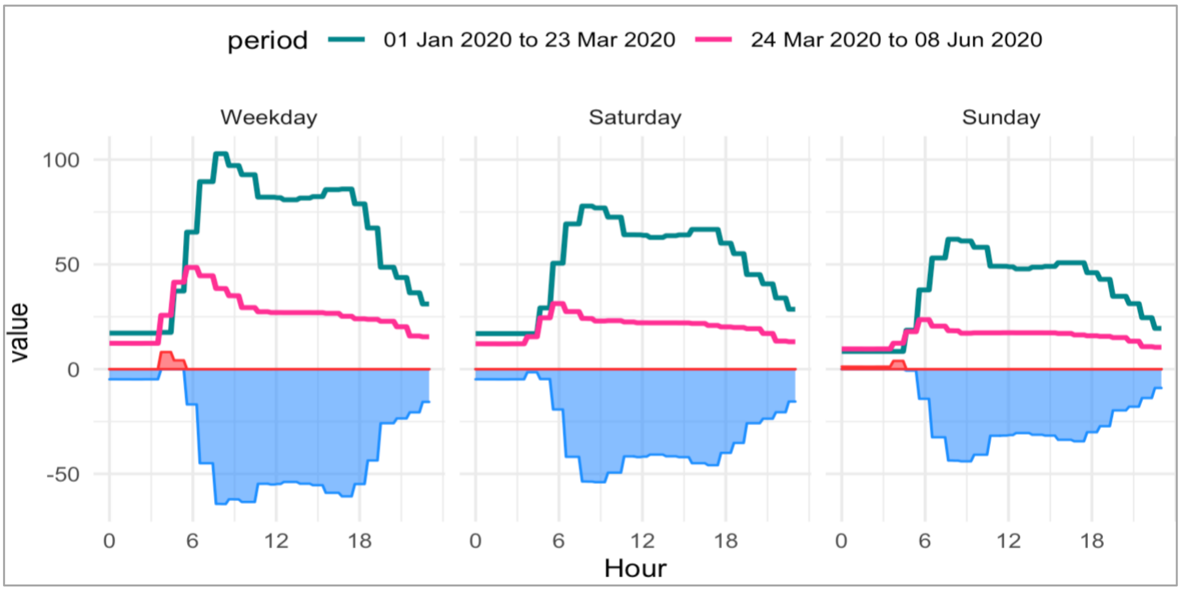


Figure 6 Meteorologically adjusted NO_x diurnal increment at the Chepstow A48 before and after lockdown. The change in concentration between the two periods is shown by the blue shaded area and shows there has been a decrease in the NO_x after lockdown.

The model developed can be used to provide a trend in the predicted change in NO_x concentrations by week, as shown in Figure 7. These trends are likely most useful for the traffic and urban background sites where there are many sites and the predicted change in NO_x concentration is relatively large. For the most part, the plots show a clear deviation to reduced NO_x around the time of lockdown, with weak evidence that concentrations are returning to their usual levels. It will be important to continue to consider these trends after May 2020 to understand the extent to which concentrations recover to their ‘business as usual’ levels.

From limited analysis of sites in York (where traffic data were available), it seems that even though recent traffic flows (up to early June) were about 75-80% of normal, concentrations of NO_2 were still considerably lower than expected. It has been noted that while vehicle flows have increased, congestion has not. It may be the case therefore that lower than expected concentrations of NO_x and NO_2 might occur until congestion increases. These effects and their quantification will need a deeper investigation but could be important from an air quality perspective.

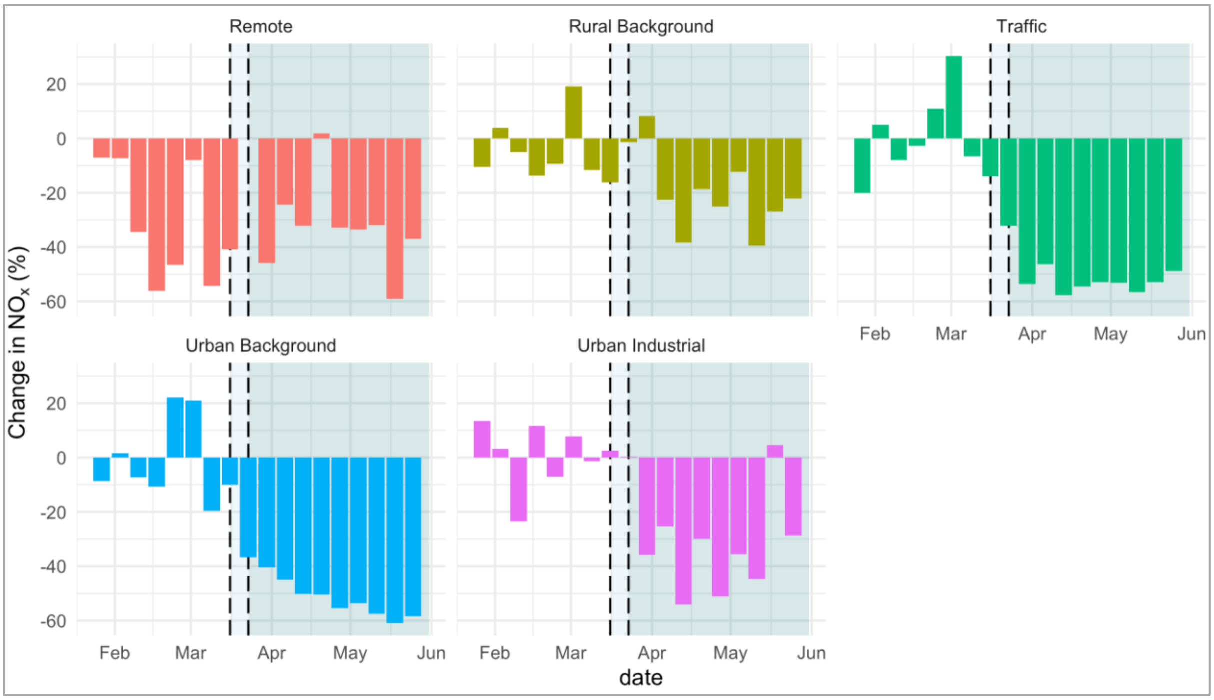


Figure 7 Estimated change in weekly mean NO_x concentrations aggregated by site type.

2.1.2 NO_2 Analysis

Figures 8 to 10 present the detailed analysis of change in NO_2 concentrations at a range of air pollution monitoring sites across Wales from February 1st to May 31st 2020

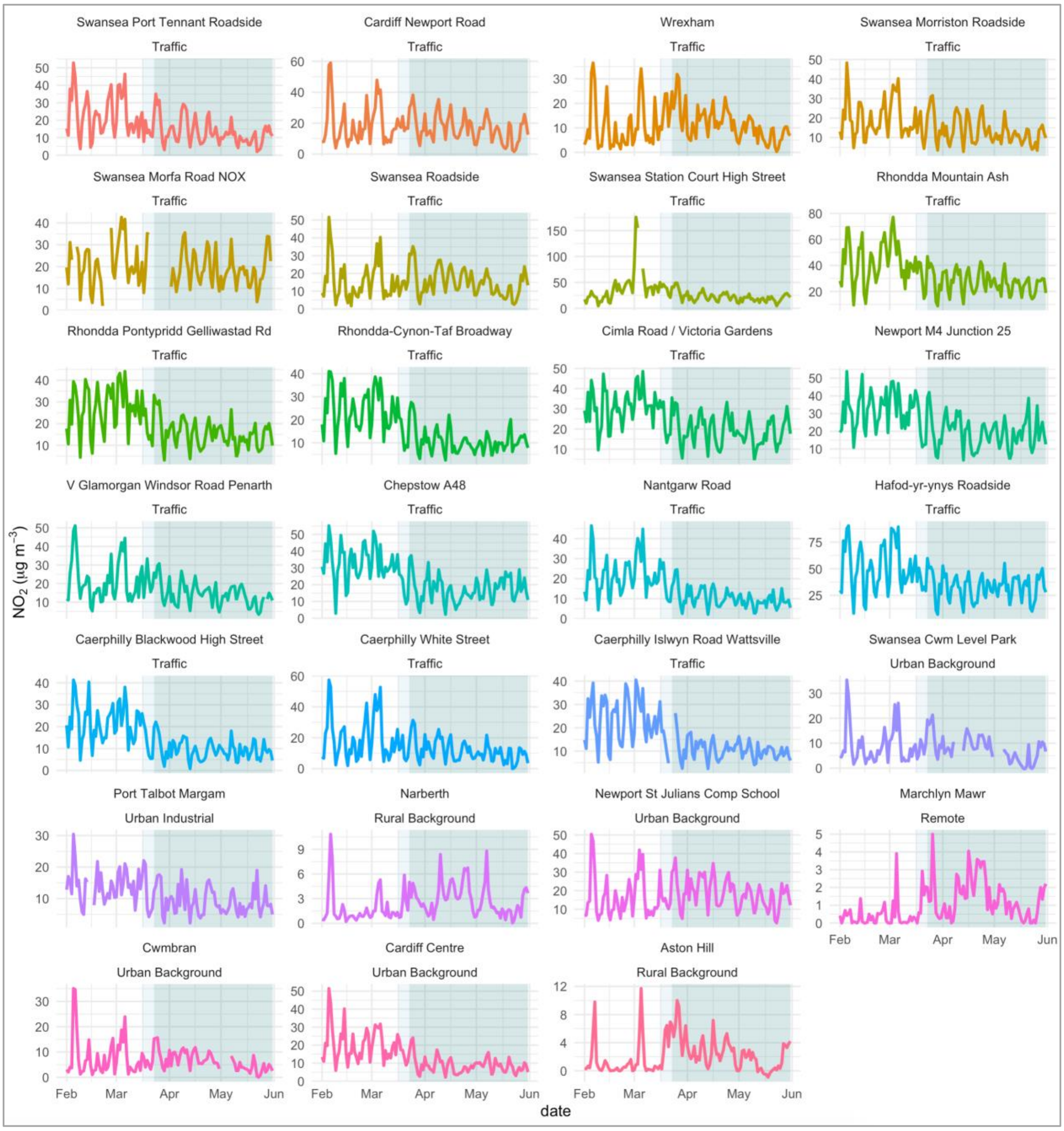


Figure 8 Daily mean concentrations of NO_2 at a range of air pollution monitoring sites across Wales from February 1st to May 31st 2020. The light blue shaded rectangle shows the period from 16th March, when social distancing was first recommended. The darker shaded rectangle shows the period from the start of the 'lockdown' that began on the 23rd March.

The cusum plot for NO_2, shown in Figure 8, highlights that nearly all sites show a decrease in NO_2 with the Hafod-yr-ynys site showing the greatest reduction. This location shows a similarly large reduction in total NOx (Figure 4).

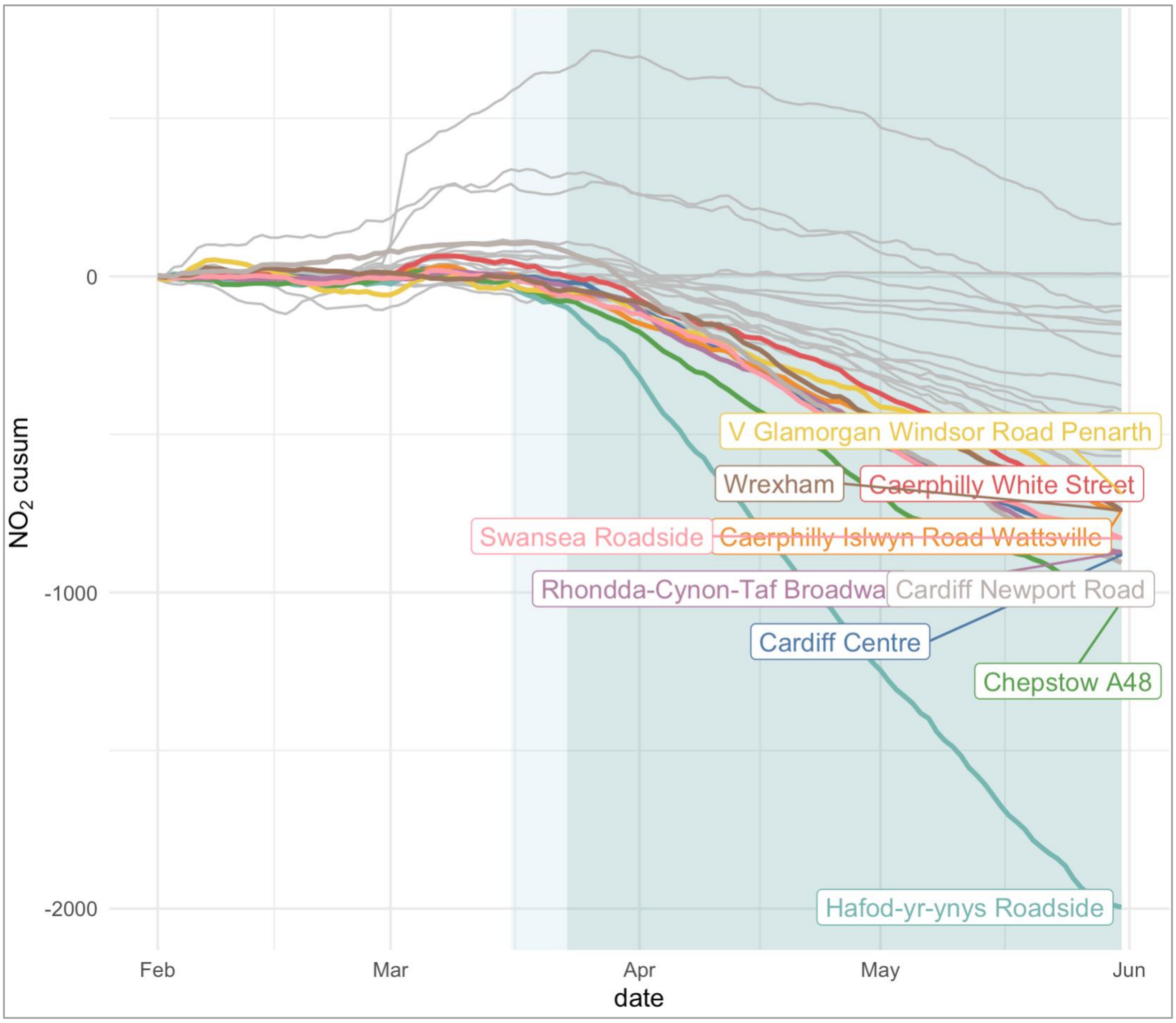


Figure 9 The cumulative sum (or cusum) of measured minus business as usual NO_2 at a range of air pollution monitoring sites across Wales. The light blue shaded rectangle shows the period recommended social distancing from 16th March, the darker shaded rectangle shows the period from the start of the lockdown starting 23rd March. Labelled sites show those that experienced the greatest changes.

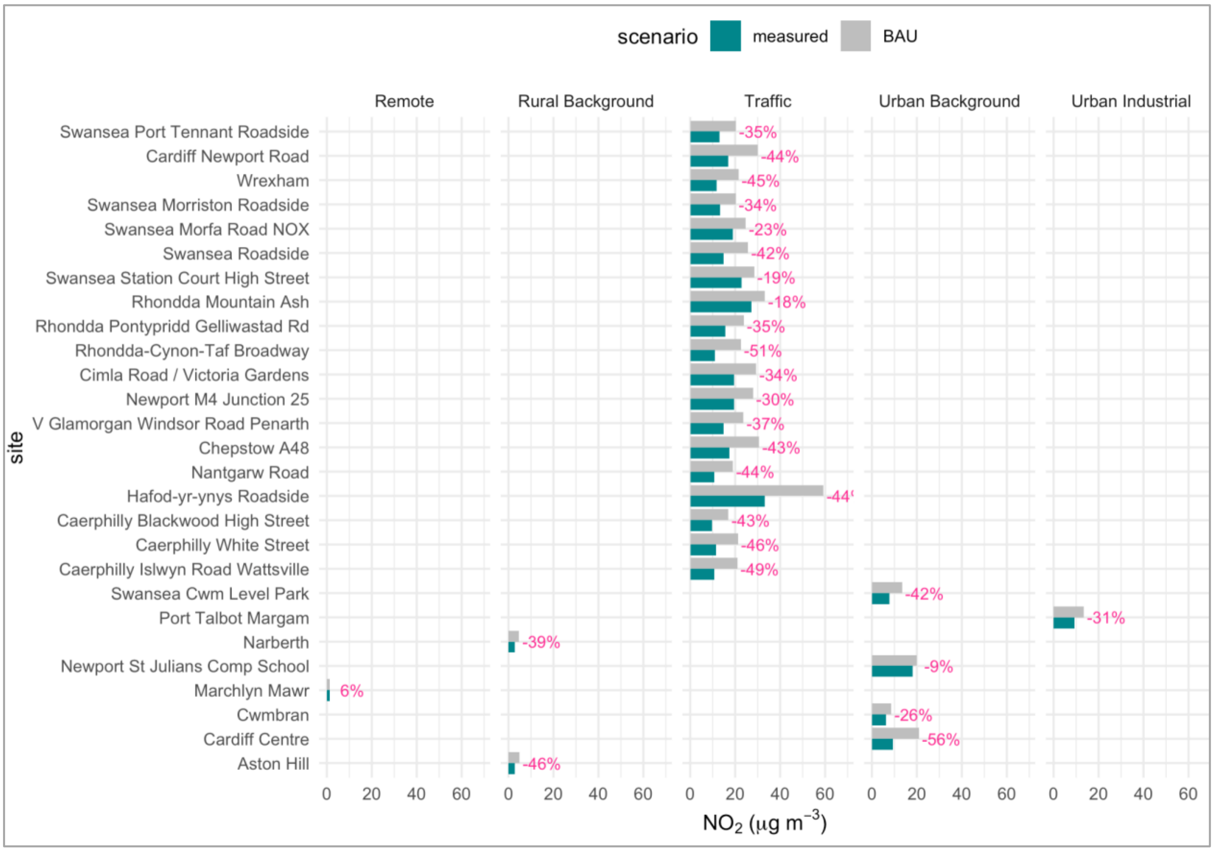


Figure 10 Measured and estimated business as usual NO_2 concentrations by site. The numbers show the percentage change in concentration relative to business as usual.

2.1.3 Relationship between NO_x, NO_2 and O_3

The relationship between NO_2 and ozone is closely coupled in the atmosphere. The main effect for the sites analysed in this report is that as NO_2 and NO_x concentrations decrease, O_3 will tend to increase. This is because O_3 reacts with NO (nitric oxide) to form NO_2. A reduction in total NO_x emissions will therefore tend to increase concentrations of O_3 close to roads because there is less NO available to react with O_3.

It is also useful to consider how the relationship between predicted changes in NO_x and NO_2 varies in the post lockdown period, as shown in Figure 11. In this plot the change in NO_x and NO_2 is that between the measured and business as usual concentrations. There are a few things to note from this Figure. The relationship between NO_x and NO_2 is non-linear. Sites with lower absolute concentrations of NO_x tend to show a greater proportionate reduction in NO_2 when NO_x is reduced. This non-linear relationship is expected and is in some ways a good test that the statistical models are representing the processes correctly. The reasons for this behaviour are complex but can be explained by the fact that sites with high NO_x will often have little or no O_3 available (because it has all reacted with NO of which there is an excess). The initial reduction in NO_x can still result in little or no O_3 available and hence little corresponding change in NO_2 is seen. This effect is seen where the curve flattens out in Figure 11.

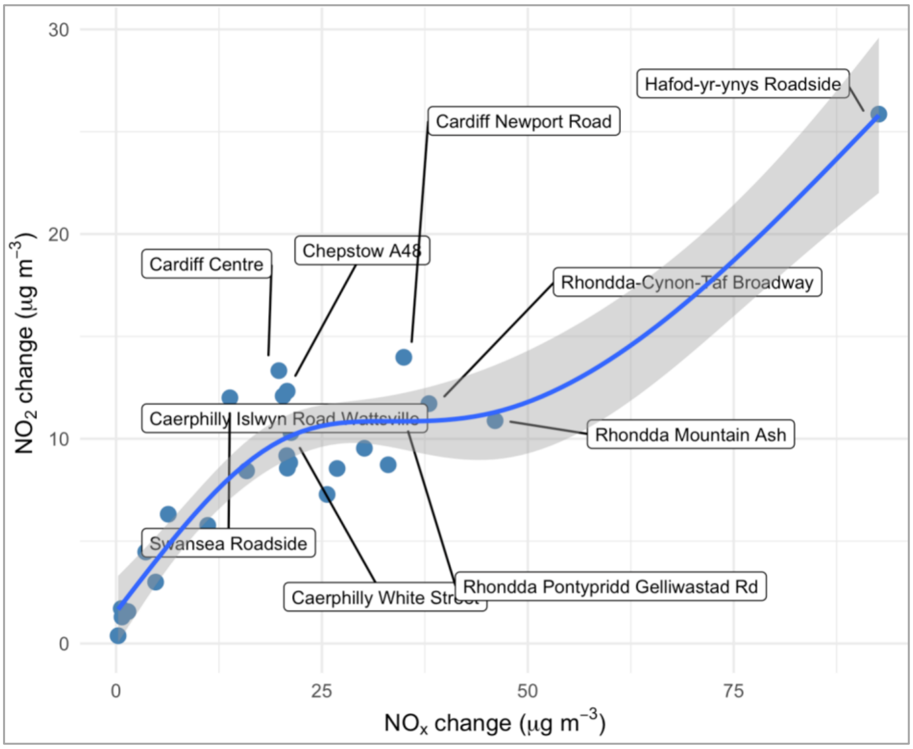


Figure 11 Change in NO_x and NO_2 concentrations in the post-lockdown period compared with business as usual. Only sites where the change in NO_2 > 10 μm^{-3} are labelled.

The Hafod-yr-ynys site shows much greater changes in NO_x and NO_2 than at other sites. At this site it is likely that a large fraction of the change in NO_2 concentration is due to reduced primary NO_2 emissions. This is because sites with very high NO_x concentrations have little or no O_3 available to produce NO_2 (it has all been consumed), so the only way to increase NO_2 as NO_x increases is through direct emissions of NO_2 from road vehicles, which likely explains the disproportionately large decrease in NO_2 seen at Hafod-yr-ynys.

2.2 Ozone concentrations

It might be expected that ozone concentrations would increase due to a reduction in NO_x; at least at roadside and urban background locations. This is because ozone reacts with NO (to produce NO_2) and a reduction in NO emissions from traffic would reduce the depletion of ozone. The situation for rural locations could be different and more strongly influenced by regional, continental air masses (considered later for $PM_{2.5}$). The measured daily mean trends shown in Figure 12 provide some indication that O_3 increased over the period.

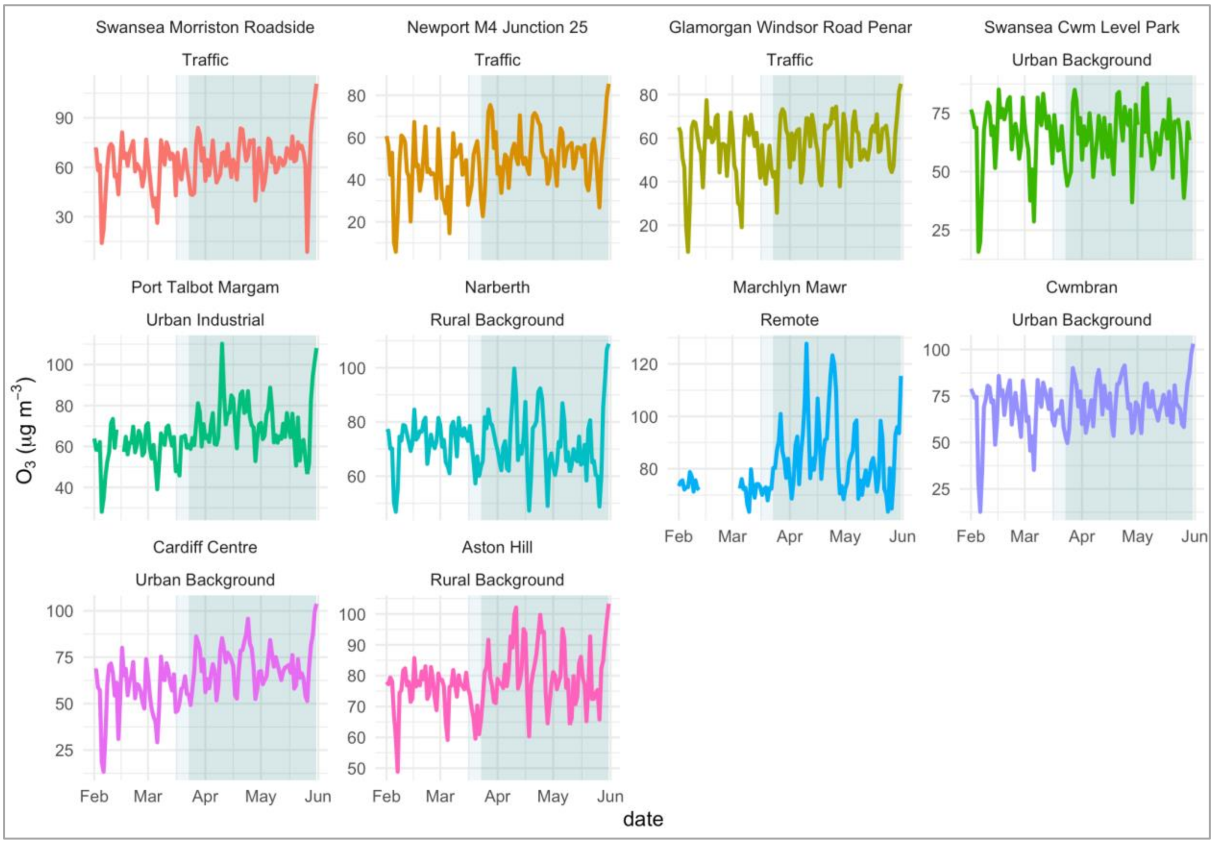


Figure 12 Daily mean concentrations of ozone at a range of air pollution monitoring sites across Wales from February 1st to May 31st 2020. The light blue shaded rectangle shows the period from 16th March, when social distancing was first recommended. The darker shaded rectangle shows the period from the start of the 'lockdown' that began on the 23rd March.

The cusum plots for ozone in Figure 13 provide stronger evidence that O_3 concentrations increased after the lockdown particularly for sites that would tend to have higher concentrations of NO_x.

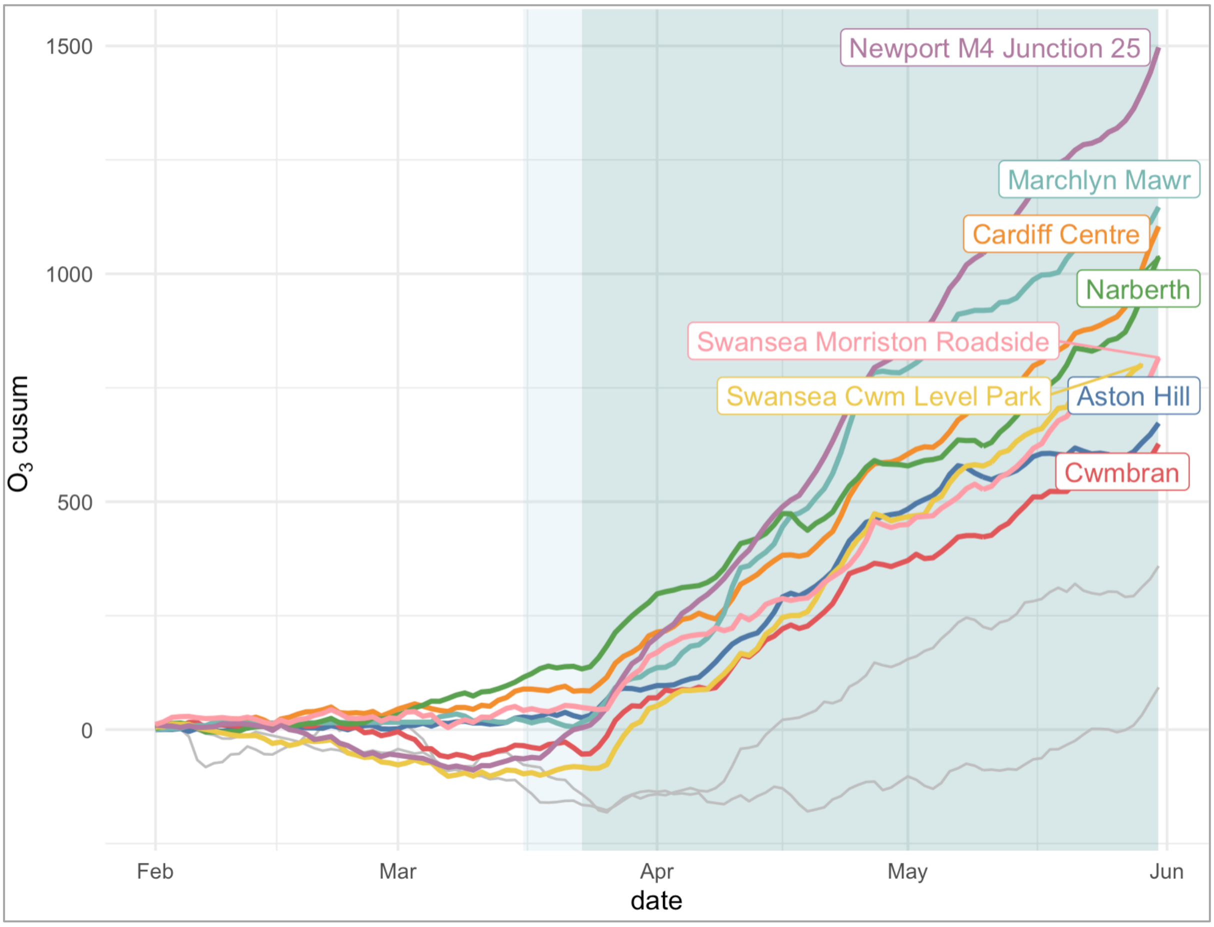


Figure 13 The cumulative sum (or cusum) of measured minus business as usual ozone at a range of air pollution monitoring sites across Wales. The light blue shaded rectangle shows the period with recommended social distancing from 16th March, the darker shaded rectangle shows the period from the start of the lockdown starting 23rd March. Labelled sites show those that experienced the greatest changes.

2.3 $PM_{2.5}$ concentrations

The effects on $PM_{2.5}$ are considerably more complex than NO_x and NO_2 because of the significant contribution from regional pollution transport i.e. sources from continental Europe. For example, a simple analysis of $PM_{2.5}$ concentrations in 2020 before and after the lockdown to mid-May, as shown in Figure 14, would suggest that concentrations have increased. This is however typical of previous years where increased agricultural activity and releases of ammonia across Europe lead to the increased likelihood of secondary nitrate $PM_{2.5}$ during March and April in Wales and elsewhere in the UK. Indeed, as considered here, the first six weeks since lockdown showed an exceptionally high proportion of winds from the east, which is based on London but would be expected to be similar across much of the UK.

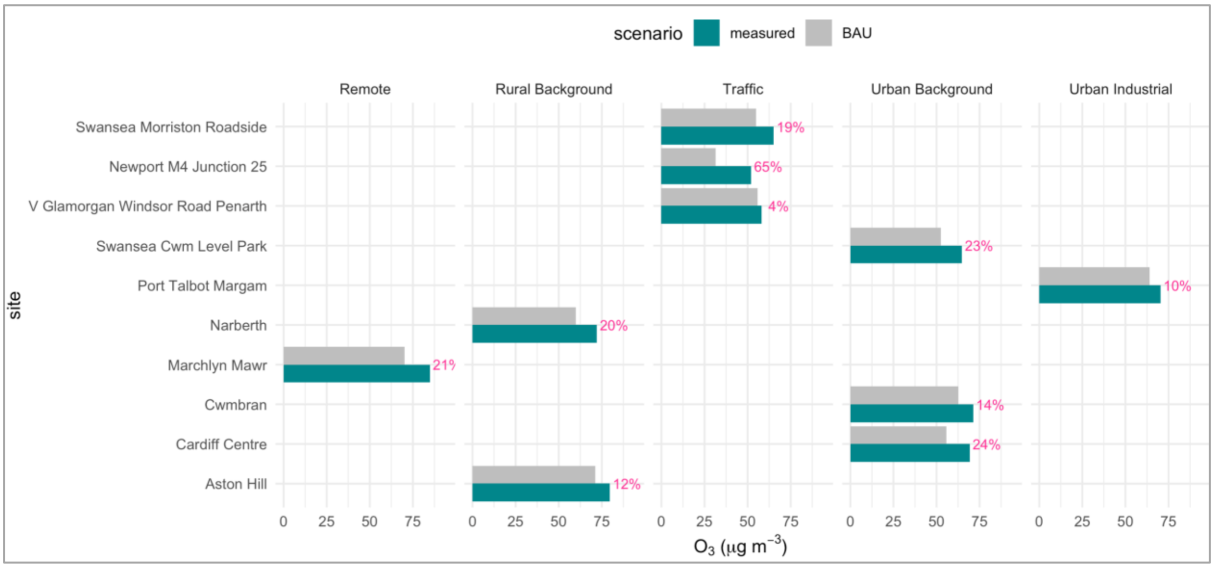


Figure 14 Measured and estimated business as usual $PM_{2.5}$ concentrations by site. The numbers show the percentage change in concentration relative to business as usual.

Figure 15 shows an example of a site with the highest $PM_{2.5}$ concentrations in the WAQN at the A48 Chepstow site during 2020. What is clear from this plot, even at a busy roadside location, higher concentrations of $PM_{2.5}$ are seen after the lockdown period than before. These increases are associated with imported $PM_{2.5}$ from regional sources rather than being dominated by local e.g. road transport sources. Across all $PM_{2.5}$ sites the post-lockdown concentrations were much higher than pre-lockdown concentrations (11.4 and 8.2 μm^{-3}, respectively), which illustrates the potential problem in trying to quantify a change in concentration is the post-lockdown period.

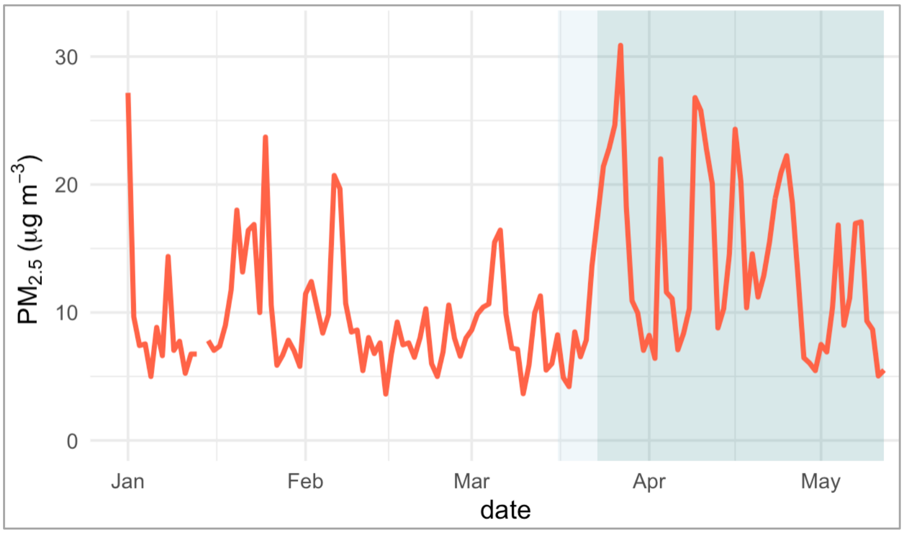


Figure 15 Daily mean $PM_{2.5}$ concentrations at the A48 Chepstow site during 2020. The light blue shaded rectangle shows the period from 16th March, when social distancing was first recommended. The darker shaded rectangle shows the period from the start of the 'lockdown' that began on the 23rd March.

As an example of the contributions by air mass origin, Figure 16 shows whether grid squares were associated with high (defined as 90th percentile) $PM_{2.5}$ concentrations at the Newport site. This shows that for the period after 16th March was strongly associated with high $PM_{2.5}$ concentrations from continental Europe, which were more or less absent in the earlier part of the year.

The large contribution from European sources, which seem to be similar to other years, might in itself seem surprising. A large fraction of $PM_{2.5}$ concentrations during Spring episodes would be expected to be ammonium nitrate. Given that mainland Europe has also experienced significant reductions in road transport NO_x over the same period, it might be expected that there would be a reduced formation of ammonium nitrate. From the $PM_{2.5}$ concentrations observed in Wales, this does not appear to be the case – although speciated data would help to understand whether this is the case or not. Nevertheless, it does seem from initial analyses that significantly reduced NO_x emissions in Europe have not led to clear reductions in the formation of $PM_{2.5}$. Further detailed analysis may show that even greater reductions in European NO_x will be required to appreciably affect $PM_{2.5}$ concentrations.

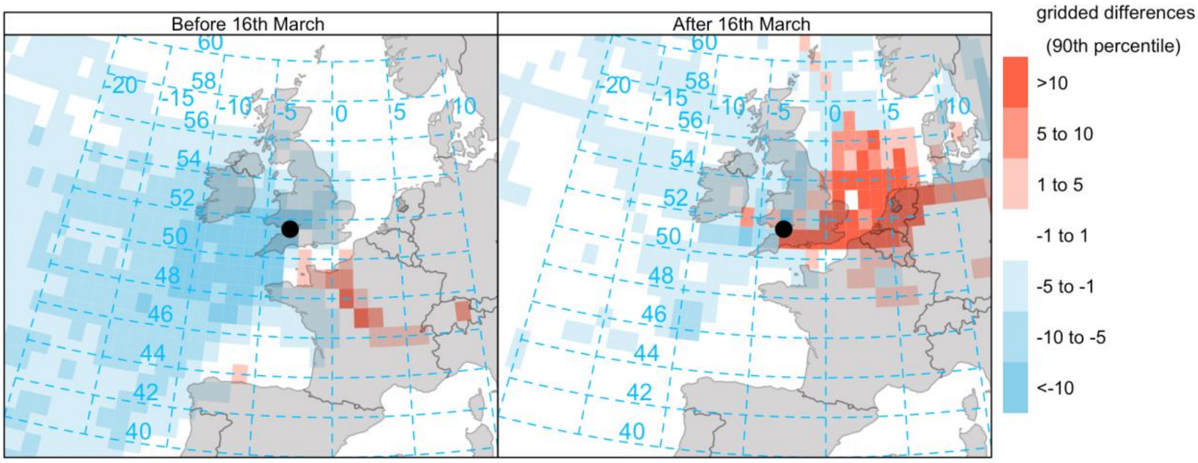


Figure 16 Back trajectory air mass origins. The colour of the scale represents the percentage of time a grid square had concentrations above or below the 90th percentile value for 2020.

An alternative to analysing absolute concentrations is to consider increments in $PM_{2.5}$ above rural background sites. However, the difficulty with this approach is that there are very few rural background $PM_{2.5}$ monitoring sites in the UK in general. For the current analysis the Chilbolton site in England has been used for wind directions from the east and the Narberth site in Pembrokeshire used when the wind is from the west. Another benefit of considering the increment above background for $PM_{2.5}$ is that the concentration ought to respond more to local meteorology (as used in the models), rather than regional meteorology, which is not represented in the models.

Figure 17 shows the daily mean variation in the increment of $PM_{2.5}$ above rural background from March 2020 to early May 2020. The trends are generally noisy and there is no obvious change in concentration after lockdown.

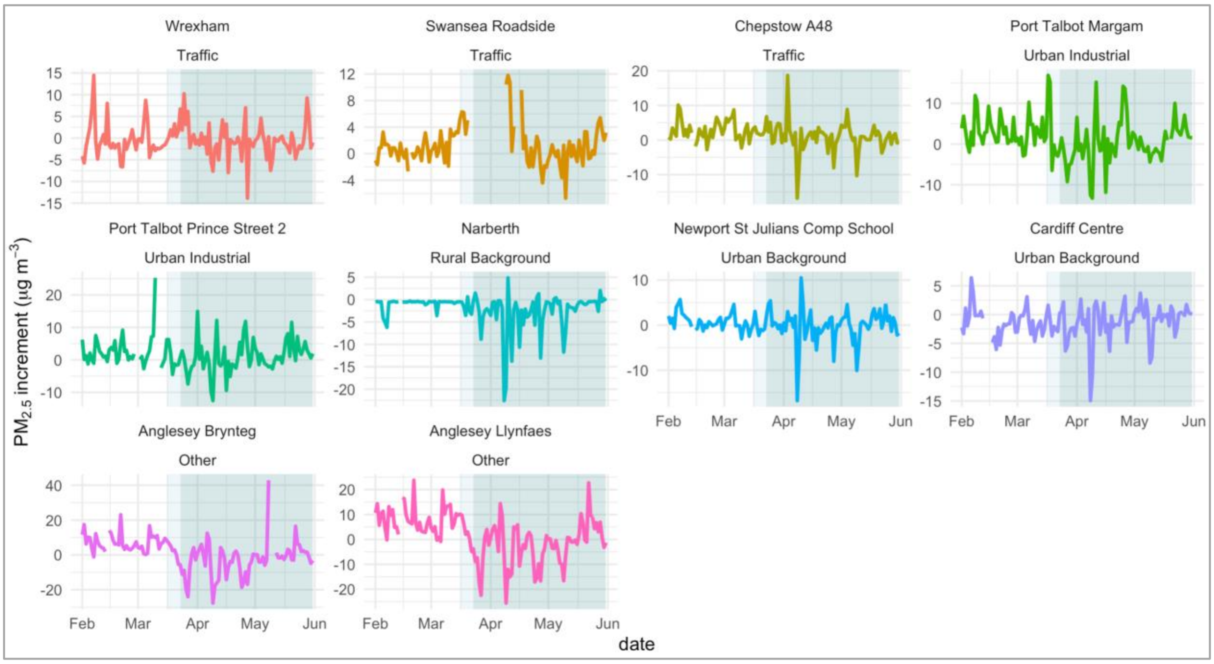


Figure 17 Daily mean $PM_{2.5}$ increment above background at a range of air pollution monitoring sites across Wales. The light blue shaded rectangle shows the period with recommended social distancing from 16th March, the darker shaded rectangle shows the period from the start of the lockdown starting 23rd March.

The cusum plot shown in Figure 18 generally shows that the increment in $PM_{2.5}$ concentrations has tended to decrease since lockdown, but the trends are mixed and there is much less evidence of clear changes compared with NO_x, NO_2 and O_3. The cusum plot will be very sensitive to deviations from expectations if they are persistent. However, the changes seen in Figure 18 are mixed in terms of site type e.g. the largest reductions are not necessarily at roadside sites. This finding perhaps suggests there could be local and complex site-specific changes

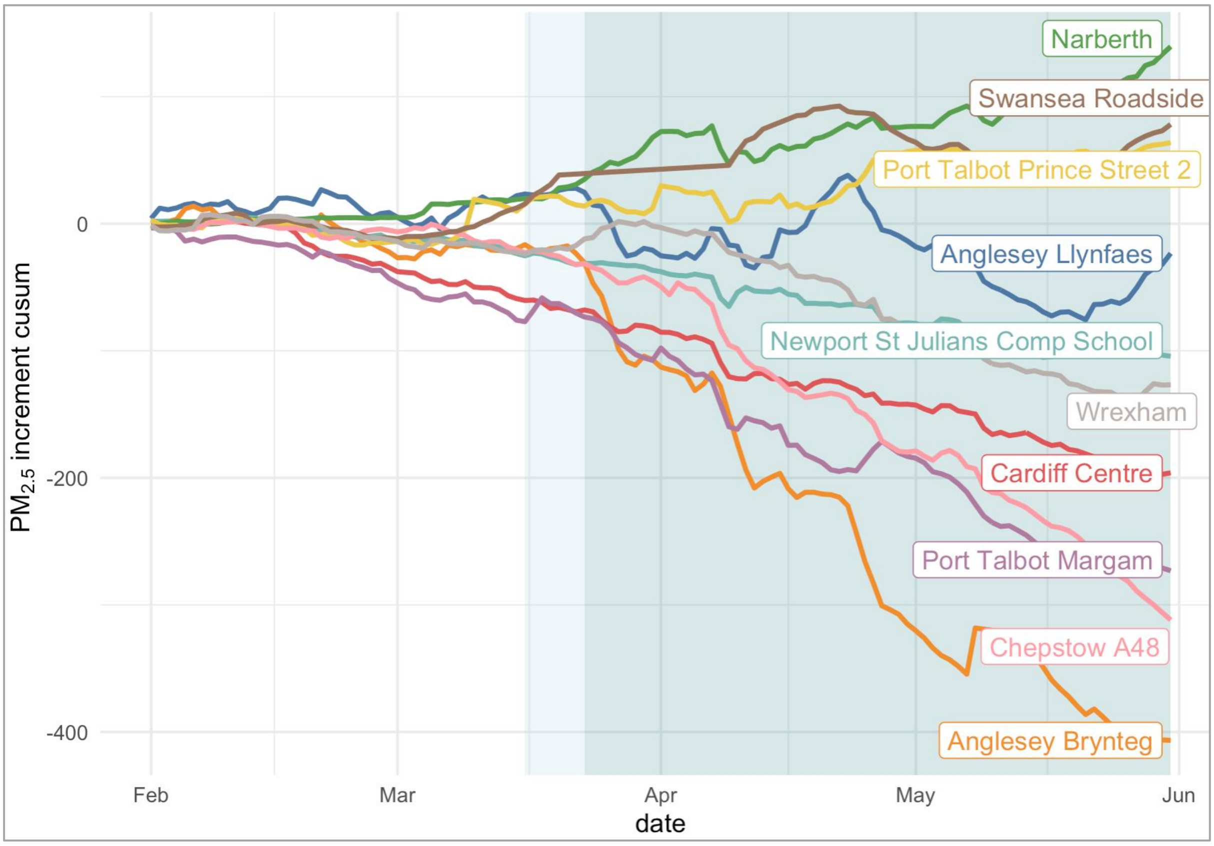


Figure 18 The cumulative sum (or cusum) of measured minus business as usual $PM_{2.5}$ increment above background at a range of air pollution monitoring sites across Wales. The light blue shaded rectangle shows the period with recommended social distancing from 16th March, the darker shaded rectangle shows the period from the start of the lockdown starting 23rd March.

Another way to consider changes in $PM_{2.5}$ is to consider how the diurnal variation in the increment in $PM_{2.5}$ changes before and after the lockdown using the Boosted Regression Tree models. Used in this way, the models should reveal diurnal profiles that are more closely related to emissions and not other factors that can strongly affect diurnal; concentration profiles such as wind speed and temperature. Figure 19 shows how the diurnal concentration increment profile changed before and after lockdown. Before lockdown there was a clear 'hump' in the profile each weekday period, which is diminished after lockdown. The difference in $PM_{2.5}$ concentration between before and after is shown by the shaded area, which seems to indicate that most of the reduction in $PM_{2.5}$ occurred in the middle part of the day. These results likely reflect a profile dominated by road vehicles that is then reduced.

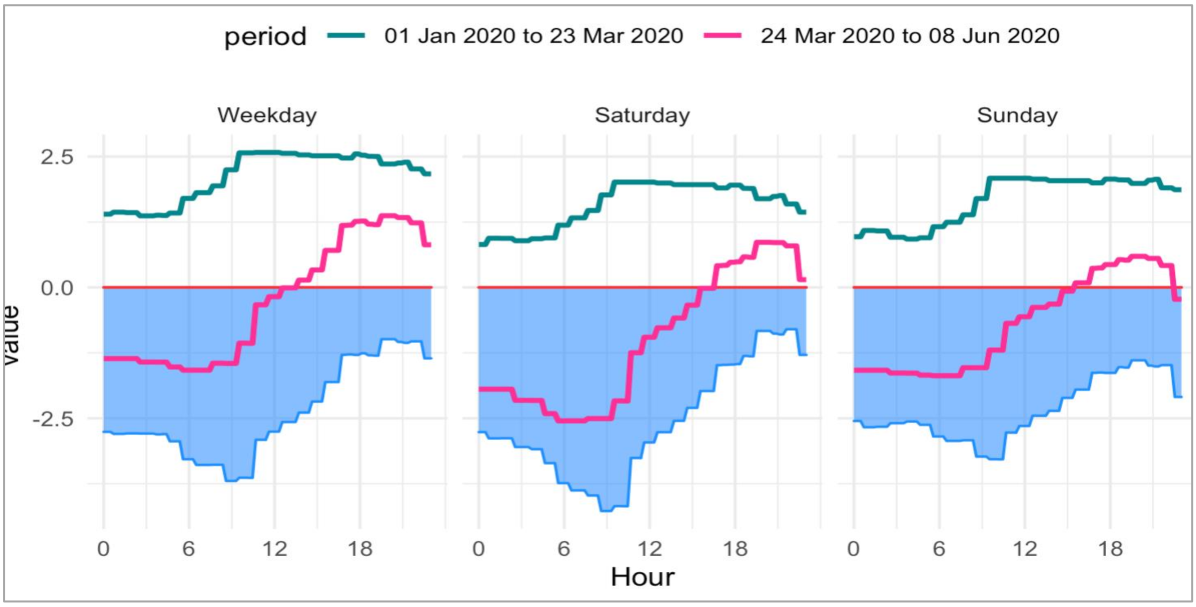


Figure 19 Meteorologically-adjusted $PM_{2.5}$ diurnal increment at the Chepstow A48 before and after lockdown. The change in concentration between the two periods is shown by the blue shaded area and shows there has been a decrease in the $PM_{2.5}$ increment after lockdown.

At the background Newport St Julians site the changes are similar compared with the A48 site, as shown in Figure 20, which might indicate similar causes affecting changes in $PM_{2.5}$. It should be stressed however that the modelling of such small differences in $PM_{2.5}$ concentration will be uncertain.

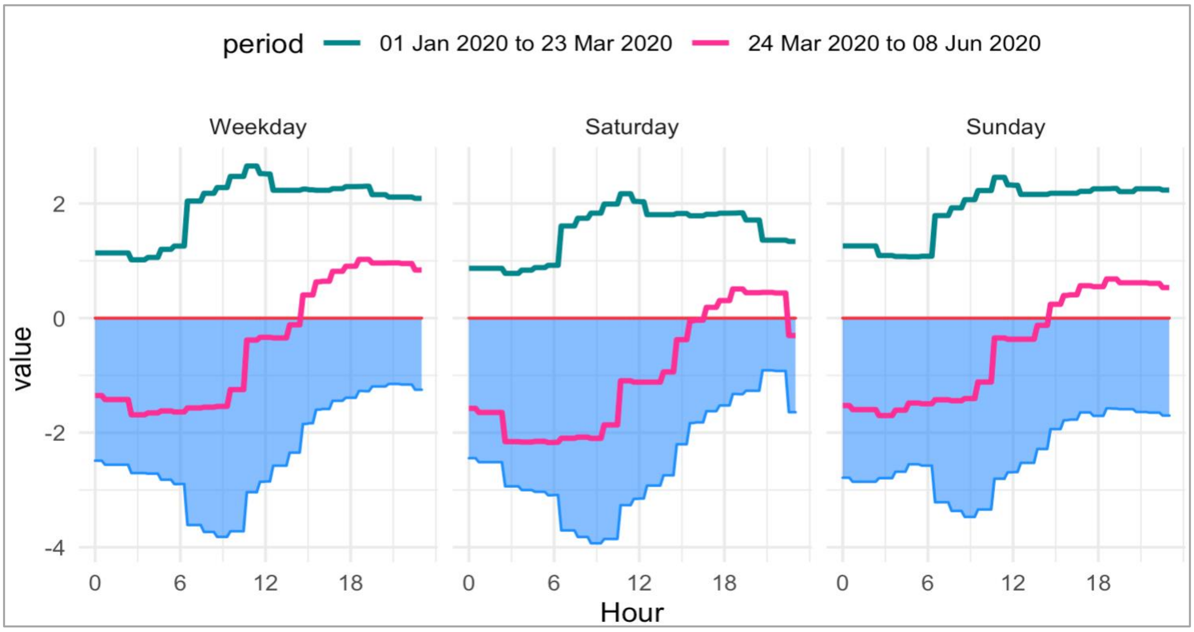


Figure 20 Meteorologically-adjusted $PM_{2.5}$ diurnal increment at the Newport St Julians before and after lockdown. The change in concentration between the two periods is shown by the blue shaded area and shows there has been a decrease in the $PM_{2.5}$ increment after lockdown.

2.4 PM_{10} concentrations

Concentrations of PM_{10} above regional background tend to show a reduction after lockdown, which is best seen in Figure 22. It is difficult to understand the sites that show the greatest reduction in PM_{10} e.g. Cwmbran, Anglesey Llynfaes and Cardiff Centre, as they are a mix of site types in different geographic locations. These findings might suggest the influence of very local changes in activity or source behaviour that would need further investigation to understand. Nevertheless, on average across the PM_{10} network of sites, there does appear to have been a reduction in PM_{10} increment above background of about 2-3 µm^{-3}. Similar to $PM_{2.5}$, the robustness of this estimate is uncertain for similar reasons e.g. it depends on the appropriateness of the site used for subtraction of the regional background, the changes are small in absolute terms and there are many local factors that could be important but are unknown.

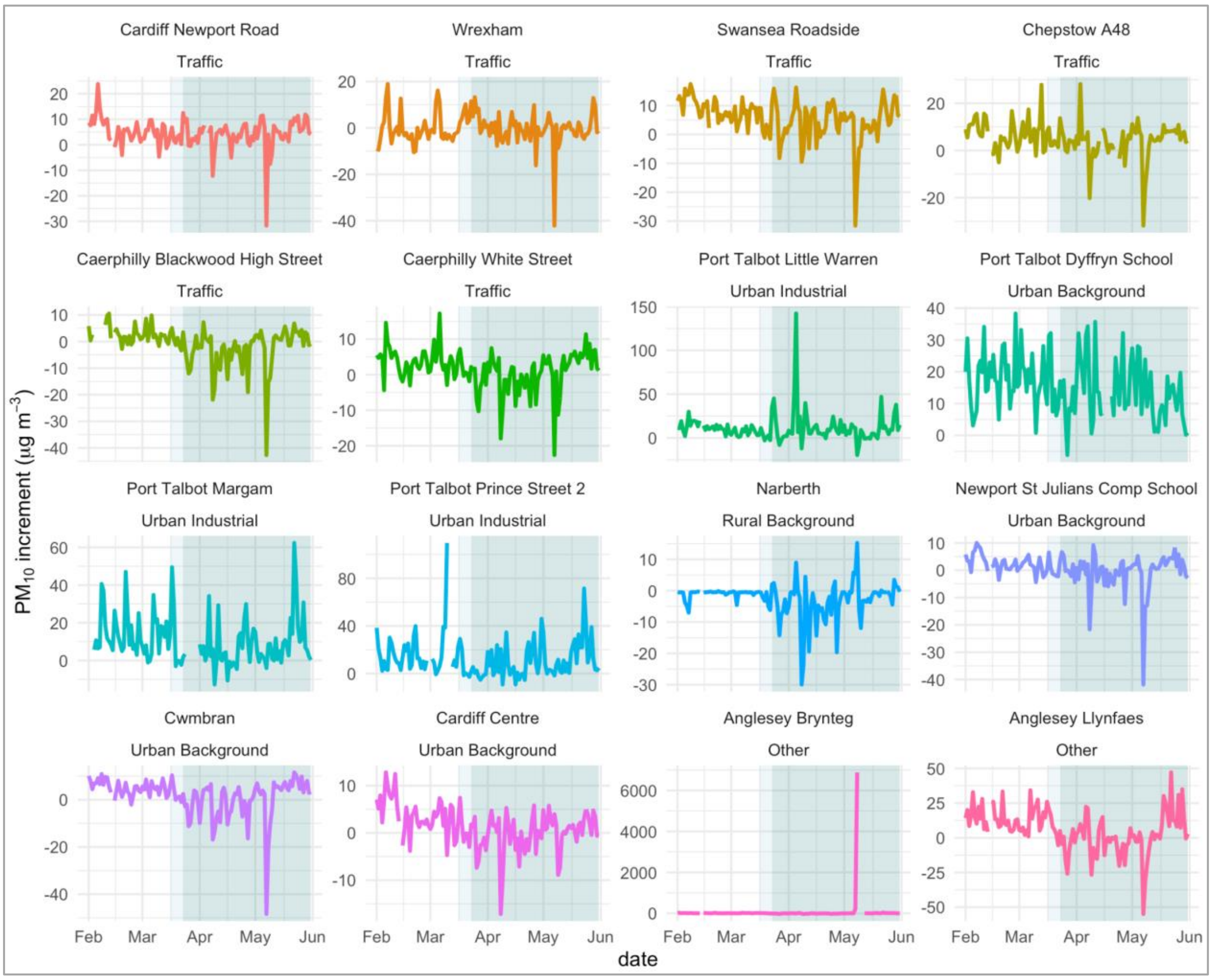


Figure 21 Daily mean PM_{10} increment above background at a range of air pollution monitoring sites across Wales. The light blue shaded rectangle shows the period with recommended social distancing from 16th March, the darker shaded rectangle shows the period from the start of the lockdown starting 23rd March.

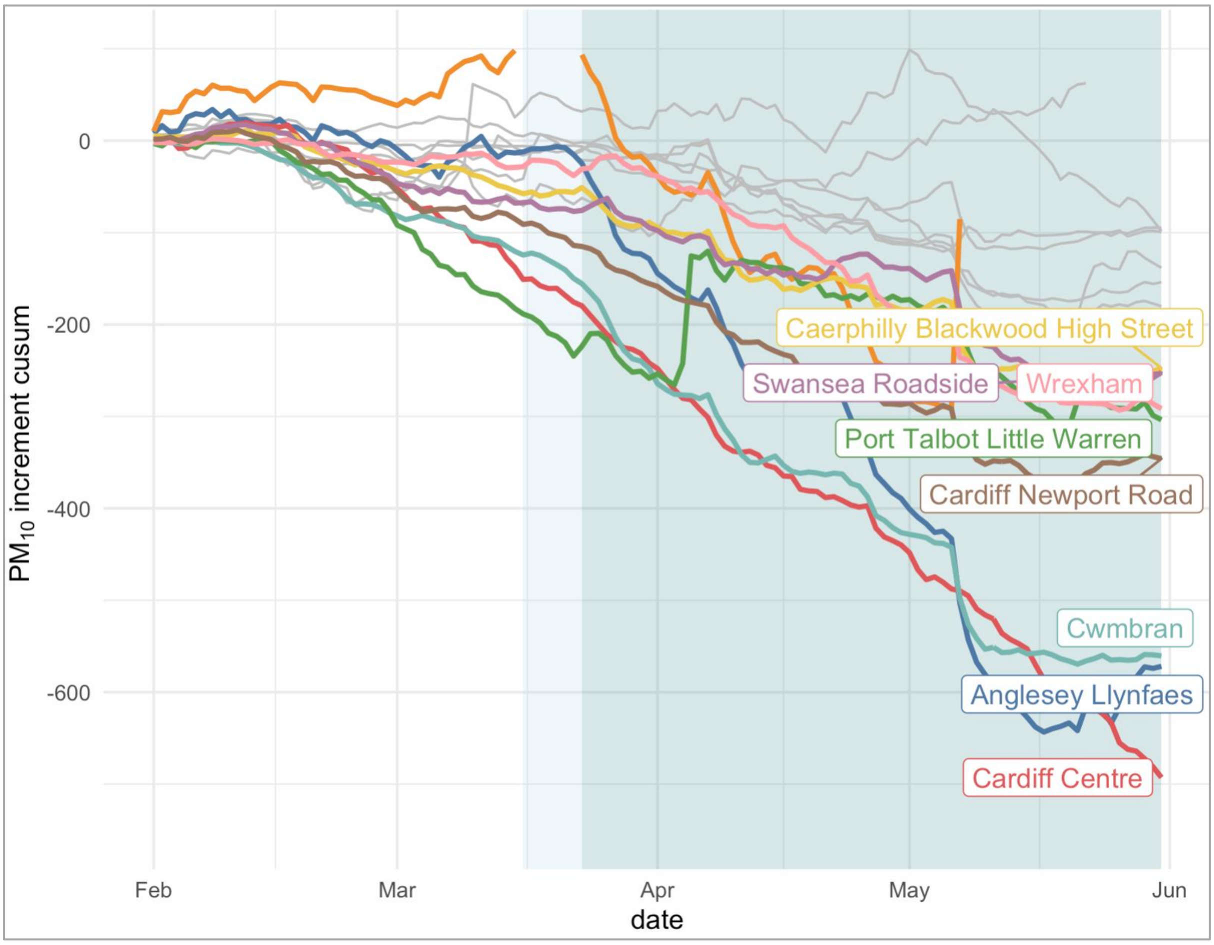


Figure 22 The cumulative sum (or cusum) of measured minus business as usual PM_{10} increment above background at a range of air pollution monitoring sites across Wales. The light blue shaded rectangle shows the period recommended social distancing from 16th March, the darker shaded rectangle shows the period from the start of the lockdown starting 23rd March.

2.5 Black carbon

Black carbon is measured in Cardiff, with the time series of daily concentrations shown in Figure 23. The modelled analysis indicates that black carbon concentrations were predicted to decrease ahead of lockdown; best seen in Figure 25. There is some uncertainty in these estimates because of missing data early in 2020 and clear local source influences (see in Figure 23). However, Figure 25 does indicate an accelerated reduction in concentrations from the lockdown period, which is suggestive of a response to the reduction in emissions due to Covid-19.

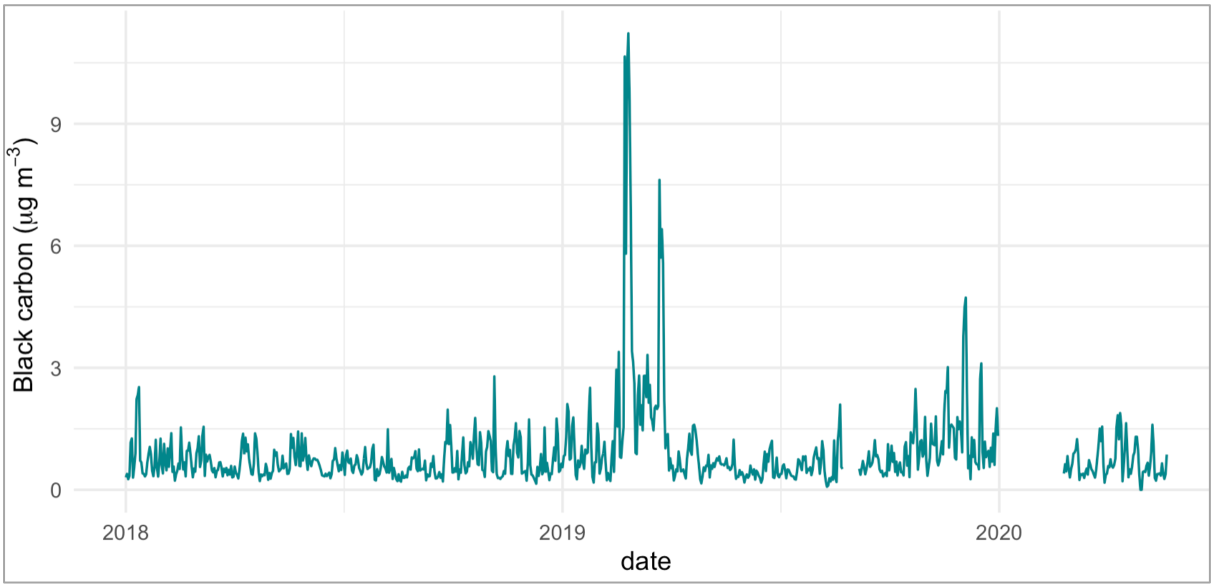


Figure 23 Daily mean black carbon concentrations for the Cardiff site for the period 2018 to 2020.

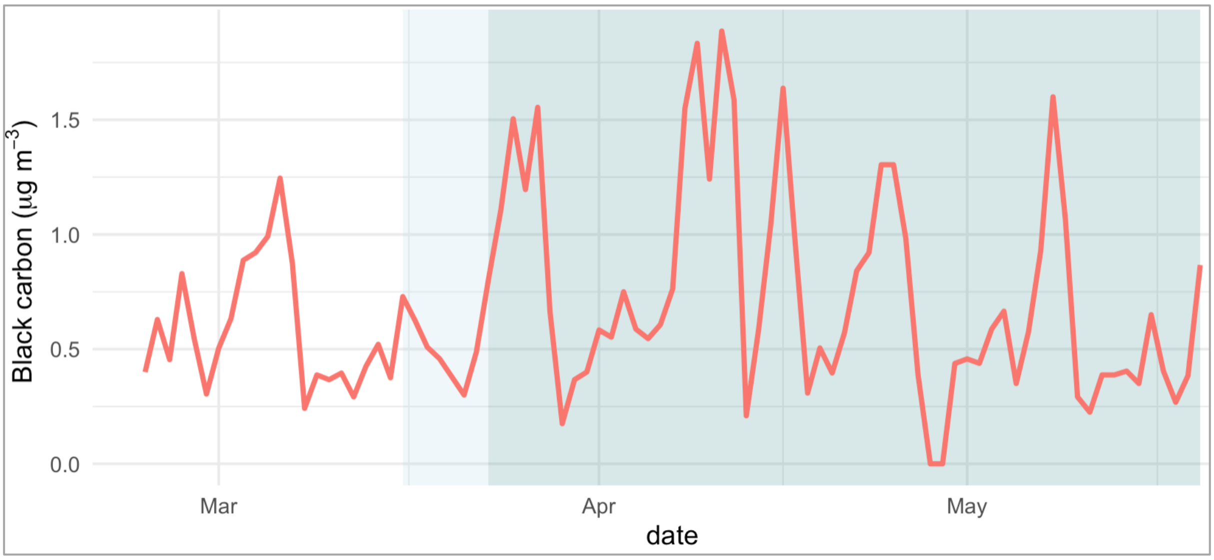


Figure 24 Daily mean black carbon concentrations for the Cardiff site for the period March to May 2020.

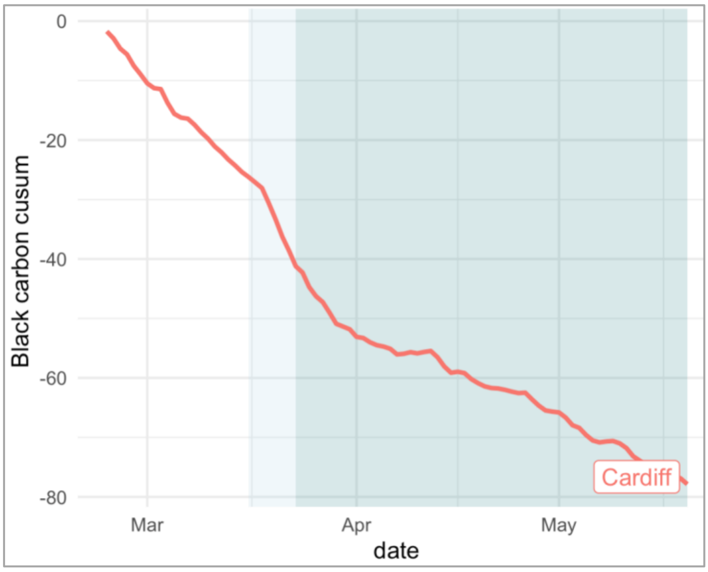


Figure 25 The cumulative sum (or cusum) of measured minus business as usual black carbon for Cardiff. The light blue shaded rectangle shows the period with recommended social distancing from 16th March, the darker shaded rectangle shows the period from the start of the lockdown starting 23rd March.

2.6 Analysis of Traffic Flow Data

For the purpose of this study a sample of traffic flow data was made available to allow comparison with observed changes in air pollutants across Wales. The data consists of daily counts of vehicle numbers from February 24th until June 2nd (for each vehicle type and the total) at the five locations described in Table 2 and illustrated in below.

Note: the two Locations at A550 Deeside Park were at the same place, but sampling from Northbound and Southbound traffic.

Table 2 Locations of the sample traffic counts provided for this study.

Location	Latitude	Longitude
A470 N. of Bridge Street	51.60697	-3.33365
A483 Wrexham BP (Mid) Clwyd	53.04846	-3.02171
A550 Deeside Park (Northbound)	53.19508	-3.02603
A550 Deeside Park (Southbound)	53.19508	-3.02603
M4 Pentyla - Earlswood 40-41 West Glamorgan	51.59874	-3.78424

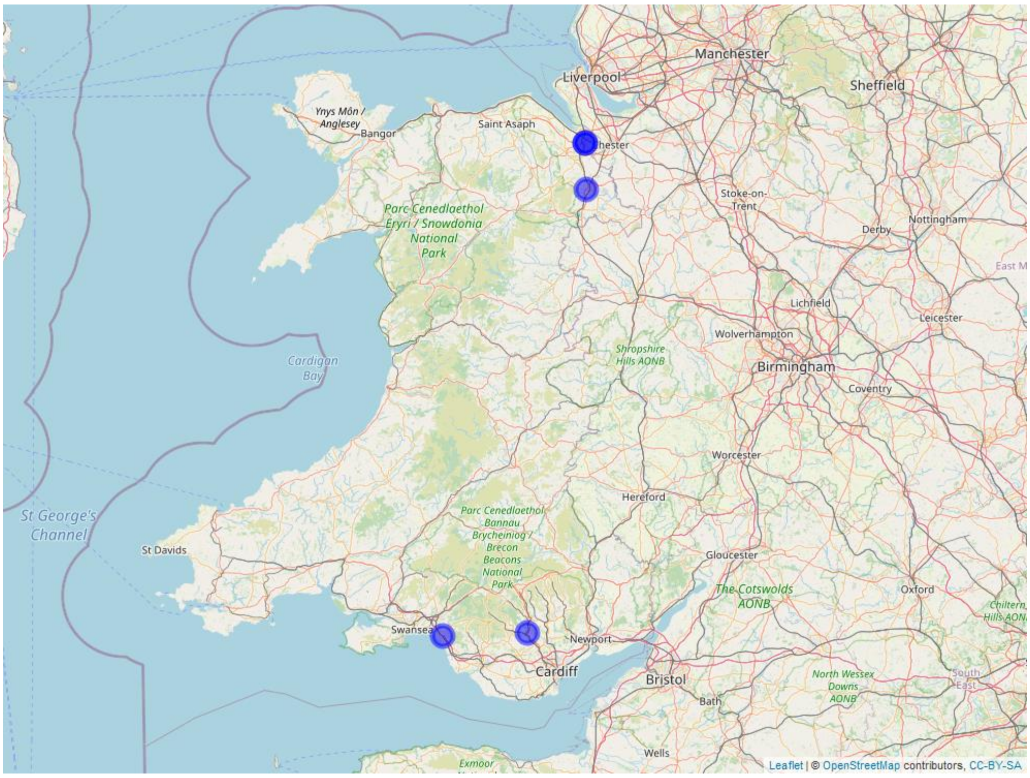


Figure 26 Locations of the sample traffic counts provided for this study.

Table 3 below shows how many days of data were captured each week at each location.

Table 3 Number of days traffic count data captured in each week for each location.

		Location				
Date From	**Week Number**	**A470 N. of Bridge Street**	**A483 Wrexham BP (Mid) Clwyd**	**A550 Deeside Park (Northbound)**	**A550 Deeside Park (Southbound)**	**M4 Pentyla - Earlswood 40-41 West**
Feb 24	9	6	6	2	6	0
Mar 2	10	7	7	0	7	0
Mar 9	11	7	7	0	7	0
Mar 16	12	7	7	0	7	0
Mar 23	13	7	7	5	3	0
Mar 30	14	7	7	7	0	0
Apr 6	15	7	7	7	0	0
Apr 13	16	7	7	7	5	0
Apr 20	17	7	7	7	7	0
Apr 27	18	7	7	7	7	0
May 4	19	7	7	7	7	7
May 11	20	7	7	7	7	7
May 18	21	7	7	7	7	5
May 25	22	7	7	7	7	7
Jun 1	23	2	2	2	2	2

The counts at A470 N. of Bridge Street and A483 Wrexham BP (Mid) Clwyd are complete from Week 10 (March 2nd) onwards. The table suggests that the traffic counts at A550 Deeside Park switched between Northbound and Southbound until Week 16 (April 13th) when counts were taken from both directions. A combined dataset for A550 Deeside Park has been calculated based on the average counts from each direction. Data from M4 Pentyla – Earlswood is only available from week 19 (May 4th) onwards.

The plot below shows the **daily total vehicle counts** for the three complete locations. The light shaded region indicates the period where social distancing measures were implemented (March 16th) and the dark shaded region when lockdown began (March 23rd).
NOTE: The data for A550 Deeside Park (Northbound) is very low on May 12th – with only 4 vehicles recorded. The Southbound count is 12508 vehicles. This may possibly be due to a lane closure on this day, or full counts were not obtained. The data from the Southbound location has been filtered from the combined A550 Deeside Park dataset.

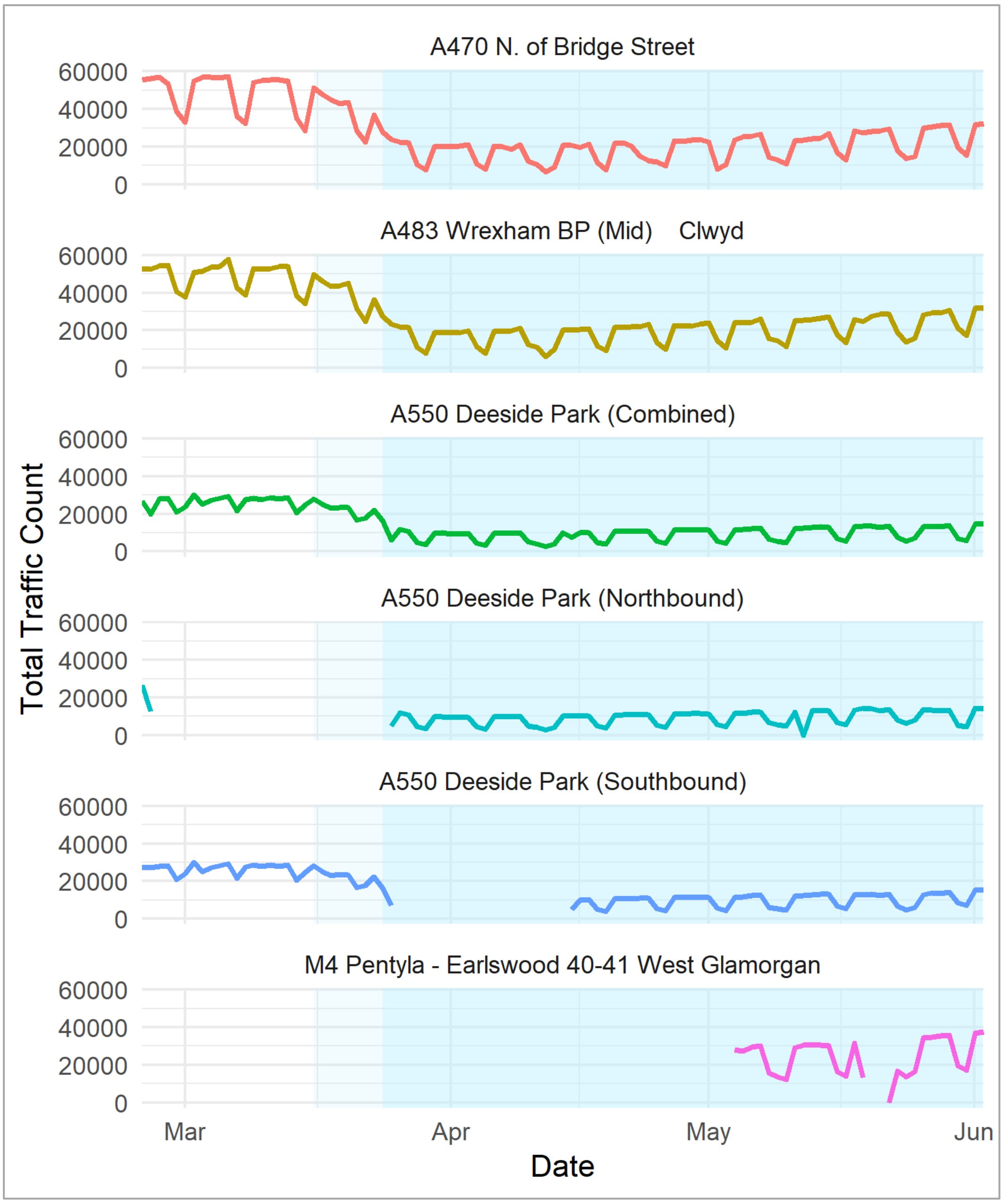


Figure 27 Graphs of daily Total Traffic Counts for February 24th until June 2nd 2020.

The vehicle counts were summed over weekly periods to give totals for each vehicle type. The figures on the following pages provide a breakdown of vehicle types for each site and week. M4 Pentyla has not been included here as there is limited data. Note the different scales in the vehicle counts. NOTE: The number of LGVs in week 21 for A470 N are very high. The data show very high LGV counts at this location on May 18th (2702 counts), 19th (5142 counts) and 20th (1551 counts). These results appear to be suspect.

The graphs in Figures 28 to 30 all show a similar pattern with a significant drop in vehicle flows at the time of the lockdown, mostly in the Car/Light Van and Bus categories as expected. The fall-off in vehicle counts for the heavier goods vehicles is less significant.

From the limited traffic data available there appears to be a clear correlation between the drop in vehicle numbers and the reduction in NOx concentrations observed in the air quality measurements.

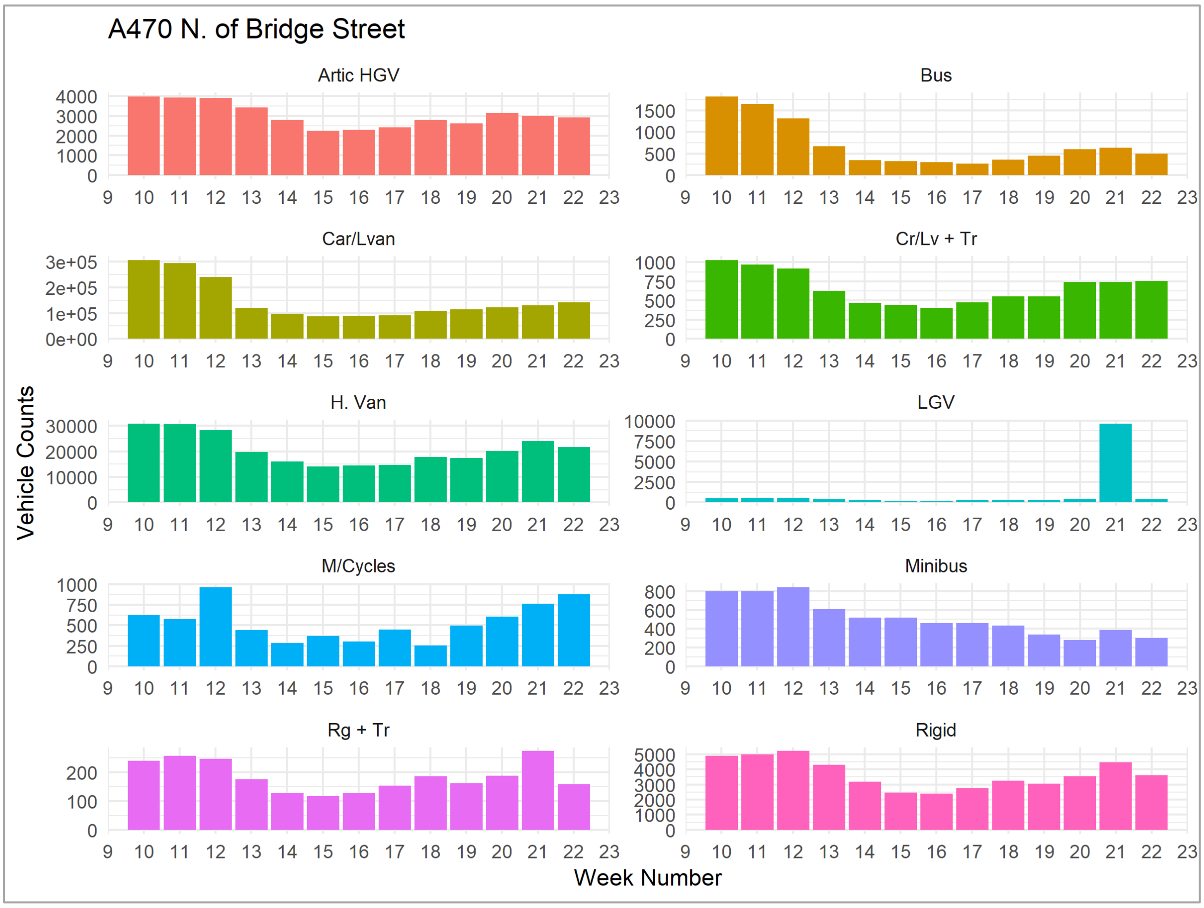


Figure 28 Breakdown of weekly counts by vehicle type for A470 February 24th until June 2nd 2020.

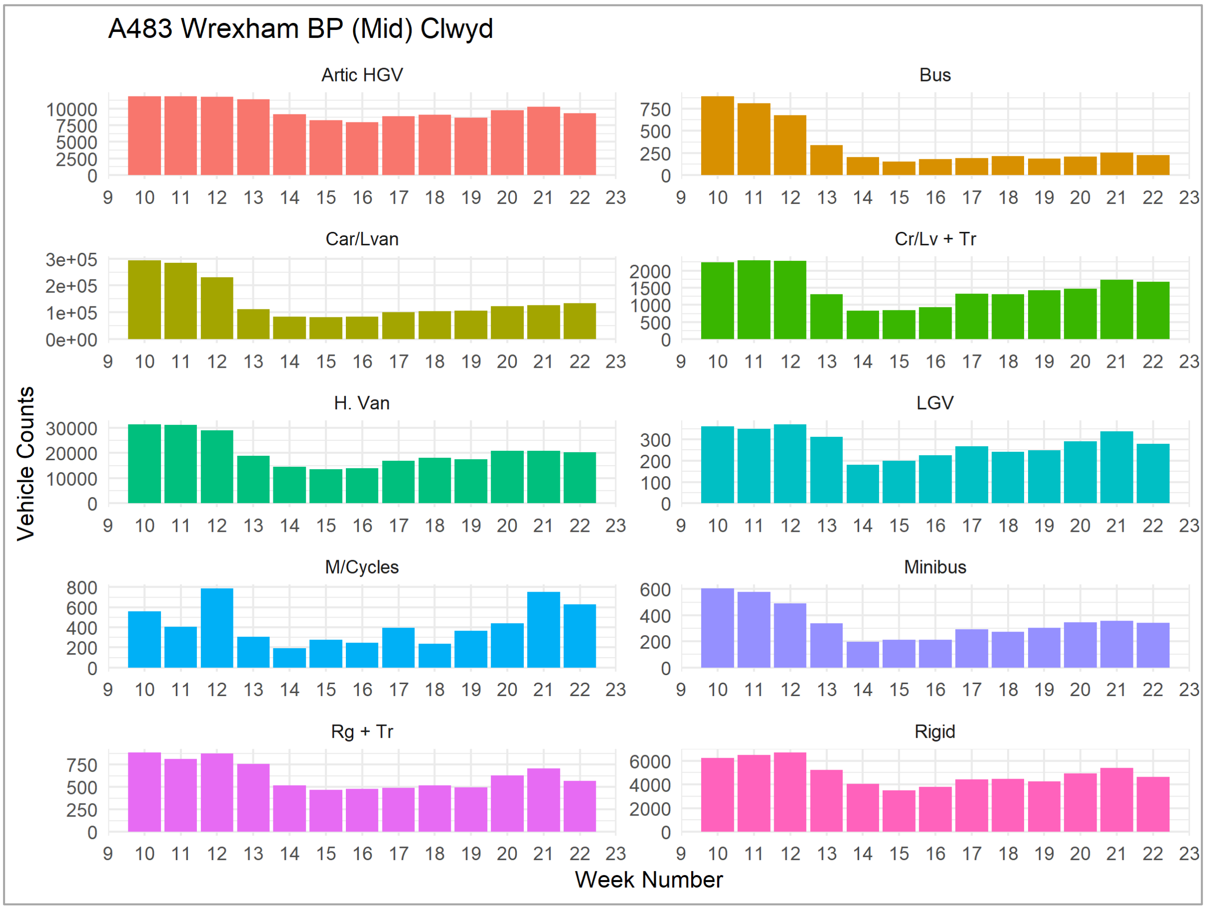


Figure 29 Breakdown of weekly counts by vehicle type for A483 February 24th until June 2nd 2020.

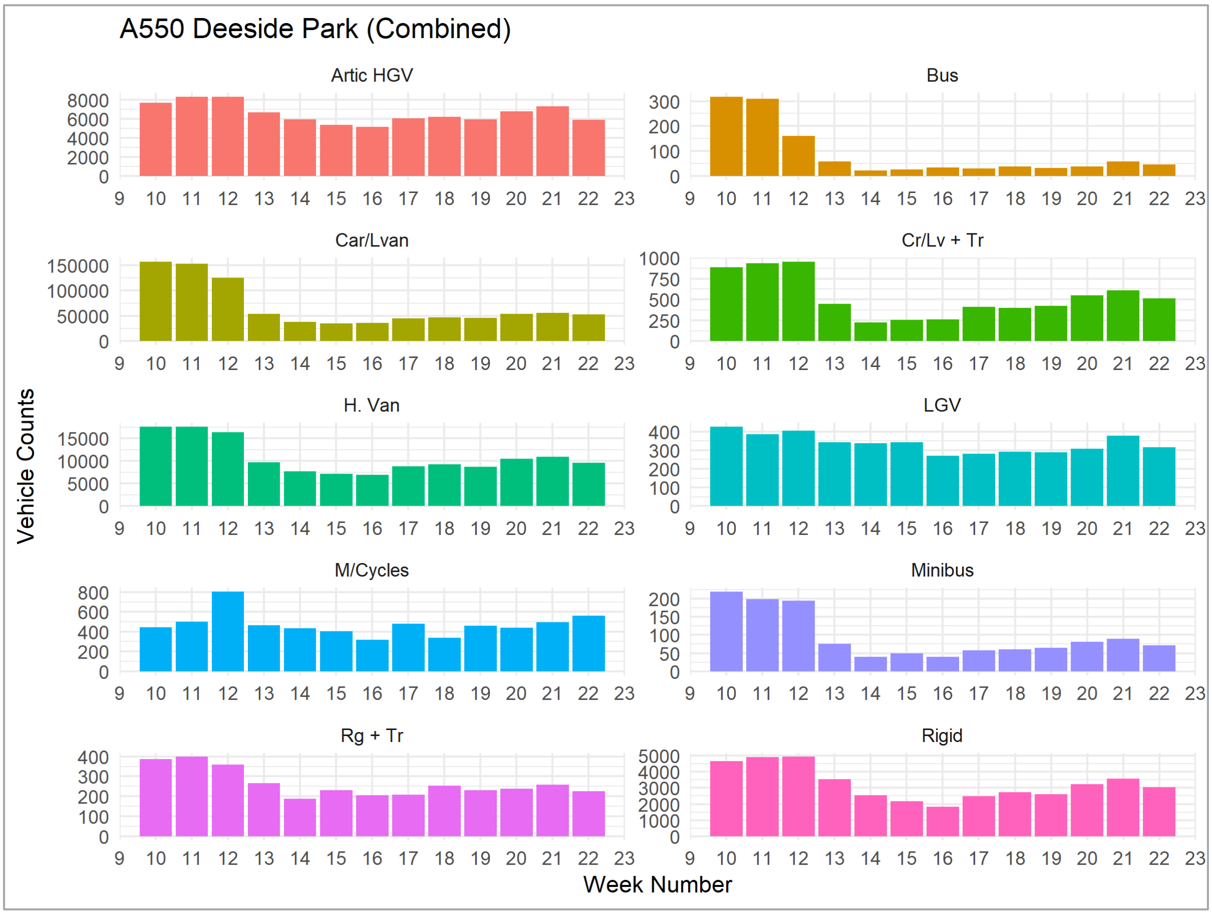


Figure 30 Breakdown of weekly counts by vehicle type for A550 February 24th until June 2nd 2020.

3 Conclusions

From the 16th March (the start of recommended social distancing) to 31st May 2020 it is estimated that NO_x and NO_2 concentrations decreased on average by 49% and 36% respectively, compared with BAU at roadside sites, with smaller reductions at urban background sites.

Analysis of changes in the diurnal pattern of NO_x concentrations shows that the decreases are during the daytime and consistent with a pattern of reduced road traffic.

The analysis of eight ozone sites indicates that concentrations of ozone increased by 18% on average, with stronger increases at locations which would normally experience highest NO_x. This is as expected since NO in high concentrations quickly scavenges O_3 to form NO_2.

Weekly trends in deviations in NO_x concentrations from business as usual suggest that concentrations at the end of May were still considerably lower than expected. Extending the analysis into June and beyond would help to show if and how concentrations recover and the potential impact of increased congestion.

The analysis of $PM_{2.5}$ and PM_{10} concentrations is considerably more challenging due to the strong dominance of regional background contributions. In terms of absolute concentrations of $PM_{2.5}$ (in 2020) averaged across 9 sites, the period after lockdown experienced much higher average concentrations than the period from 1st January to lockdown (11.4 μm^{-3} and 8.2 μm^{-3}, respectively).

Further detailed analysis estimates that the local contribution to $PM_{2.5}$ concentrations has decreased by less than 1.0μm^{-3} on average across all urban $PM_{2.5}$ monitoring sites in Wales due to the Covid-19 restrictions. However, this estimate is uncertain because the change is small in absolute terms.

Analysis of the small changes in the diurnal pattern of $PM_{2.5}$ concentrations at a busy roadside location shows that the decreases are during the daytime and consistent with a pattern of reduced road traffic.

Analysis of the small changes in the diurnal pattern of $PM_{2.5}$ concentrations at a background location shows that there are also decreases during the daytime consistent with a pattern of reduced road traffic. These changes are however very small with a high degree of uncertainty.

Similar to $PM_{2.5}$, reductions in the local contribution to PM_{10} concentrations are predicted by the modelling after lockdown; typically, around 2-3 μm^{-3}. However, the robustness of these estimates is uncertain for several reasons e.g. it depends on the appropriateness of the site used for subtraction of the regional background, the changes are small in absolute terms and there are many local factors that could be important but are unknown.

The analysis of black carbon measurements from Cardiff shows that concentrations were decreasing before lockdown, with some evidence of an accelerated reduction at the time of lockdown. Compared with business as usual, concentrations are estimated to have reduced by 45%.

Analysis of a limited sample of traffic data shows a significant drop in vehicle flows at the time of the lockdown, mostly in the Car/Light Van and Bus categories as expected. The fall-off in vehicle counts for the heavier goods vehicles is less significant.

From the limited traffic data available there appears to be a clear correlation between the drop in vehicle numbers and the reduction in NO_x concentrations observed in the air quality measurements.

Further analysis will be required when the measurements and emissions data are finalised. This may help to draw out more clear information about the source apportionment for particulate matter, and to provide more robust conclusions on the contribution of local vs. regional factors for both ozone and particulate matter.

4 References

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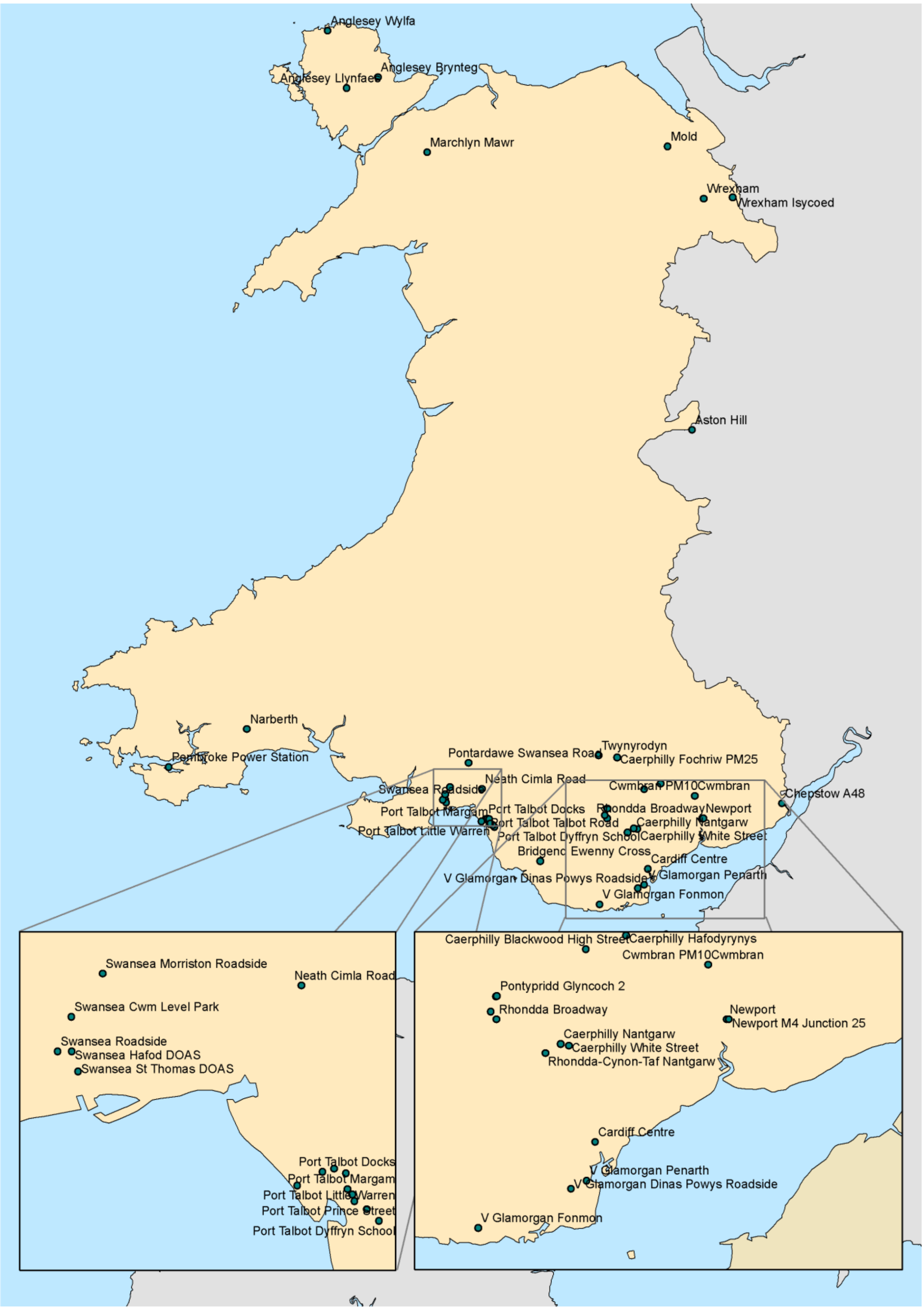
Grange, S. K. and Carslaw, D. C. (2019) ‘Using meteorological normalisation to detect interventions in air quality time series’, Science of The Total Environment. 653, pp. 578–588. doi: 10.1016/j.scitotenv.2018.10.344.

Appendices

Appendix 1 – Map of Automatic Monitoring Sites across Wales



Appendix 2 – Background Automatic Monitoring Sites in Wales

Site name	Site type
Aston Hill	Rural Background
Anglesey Llynfaes	Other
Anglesey Brynteg	Other
Anglesey Penhesgyn 2	Rural
Cardiff Centre	Urban Background
Cwmbran	Urban Background
Marchlyn Mawr	Remote
Newport St Julians Comp School	Urban Background
Narberth	Rural Background
Port Talbot Prince Street 2	Urban Industrial
Port Talbot Margam	Urban Industrial
Port Talbot Dyffryn School	Urban Background
Port Talbot Little Warren	Urban Industrial
Rhondda Glyncoch Garth Avenue	Urban Industrial
Swansea Cwm Level Park	Urban Background
Twynyrodyn	Urban Industrial

Appendix 3 – Roadside Automatic Monitoring Sites in Wales

Site name	Site type
Caerphilly Islwyn Road Wattsville	Roadside
Caerphilly White Street	Roadside
Caerphilly Blackwood High Street	Roadside
Caerphilly Hafodyrynys	Urban Traffic
Caerphilly Nantgarw	Roadside
Chepstow A48	Urban Traffic
V Glamorgan Windsor Road Penarth	Roadside
Newport M4 Junction 25	Roadside
Neath Cimla Road	Roadside
Rhondda Broadway	Roadside
Rhondda Pontypridd Gelliwastad Rd	Roadside
Rhondda Mountain Ash	Roadside
Swansea Station Court High Street	Roadside
Swansea Roadside	Urban Traffic
Swansea Morfa Road NOX	Roadside
Swansea Morriston Roadside	Roadside
Wrexham	Urban Traffic

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