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2020 COVID-19 lockdown period - Air Quality Analysis: Addendum

Report for Southampton City Council

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1 Introduction

This addendum provides supplementary information to be read in conjunction with our initial report describing analysis of pollutant measurements in Southampton both during and before the recent 'social distancing and subsequent lockdown' associated with the COVID-19 crisis in the UK[1].

The following additional analysis are presented:

- Additional extended time series analysis of pollutant measurements and more detailed road traffic activity data on the A33.
- Cumulative sum difference (cusum) analysis for NOx and NO_2 has now been extended up to the end of July 2020 – this builds on the initial time-series analysis by comparing observations with a business as usual scenario; and simulates removing the effect of weather conditions.
- Partial dependence plots showing how different variables such as traffic flow and wind speed act as explanatory variables and hence affect concentrations of NOx and NO_2, while keeping other variables at a constant level.
- Predictions of 2020 annual mean NO_2 concentrations at each of the automatic measurement sites in Southampton, using the predictive aspect of the above analysis and assumption re. average daily traffic flows.
- Information regarding shipping activity in Southampton during the lock down and subsequent months in 2020.

1.1 Limitations

Please note this report presents an indicative analysis based on the information currently available to us. The information presented should be considered in context with the following limitations:

- All 2020 pollutant measurement data included in the analysis from the automated sites in Southampton **are as of yet unratified**; i.e. no quality assurance checks, data scaling or removal of spurious data has been conducted. **Caution is recommended when interpreting analysis of unratified measurement data. The results and conclusions presented here should be considered in this context.**
- Traffic count data was not available for the roads immediately adjacent to each roadside air quality measurement station. As the best available proxy, count data from the closest relevant ATC site has been presented to provide a comparison where is it within a reasonable distance of the air quality measurement station.
- Quantitative shipping activity data covering the lock down period was limited to the number of cruise ships at berth, Red Funnel Ferry departures, and commercial shipping movements. Information regarding other types port activity was not available; this assessment should not be relied upon as a robust comparison of measured pollutant concentrations with changes in all types of port activity.

[1] Ricardo Energy & Environment: 2020 COVID-19 lockdown period – Air Quality Analysis; Report for Southampton City Council; ED11464138 Issue 1; Date 22nd July 2020

2 Additional analyses

2.1 Extended time series vs Cusum plots – NOx and NO_2

The Cumulative sum difference (cusum) analysis for NOx and NO_2 has now been extended up to the end of July 2020 – this builds on the initial time-series analysis by comparing observations with a business as usual scenario; and simulates removing the effect of weather conditions.

To recap, 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 of the lockdown because we are considering deviations from BAU – which should on average be zero if things continue as normal. The approach is 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.

Updated time series and cusum plots for each of the measurement sites for NOx and NO_2, are presented in turn below. The light blue shaded area of each plot represents the start of social distancing measures coming into force in the UK; the slightly darker blue shaded area represents the lockdown period from 23rd March onward.

The main conclusions from the updated plots are:

- There is some evidence that NOx and NO_2 decreased at all of the measurement sites during the lock-down period but, as concluded in the original report, the reductions are not as clear when compared with other sites in the UK.
- Measured NOx and NO_2 concentrations at Victoria Road in particular did not reduce as much as the other Southampton sites and measured concentrations here seem to have increased when compared with BAU in July and August.

Another cusum plot presented in Figure 5 compares the two AURN Southampton sites with other roadside sites in this part of the UK. The slope of the line showing the cumulative change in concentrations indicates there was a lower reduction in NO_2 at the Southampton sites than at many other sites, with the exception of nearby Bournemouth which is an urban background site where we would not expect to see a significant impact from reduced traffic activity. The reduction was more similar to some background or rural sites; this could indicate that the Southampton sites did seem to behave differently than other UK roadside sites during the lockdown.

Figure 1: Measured NOx concentrations - times series February to August 2020

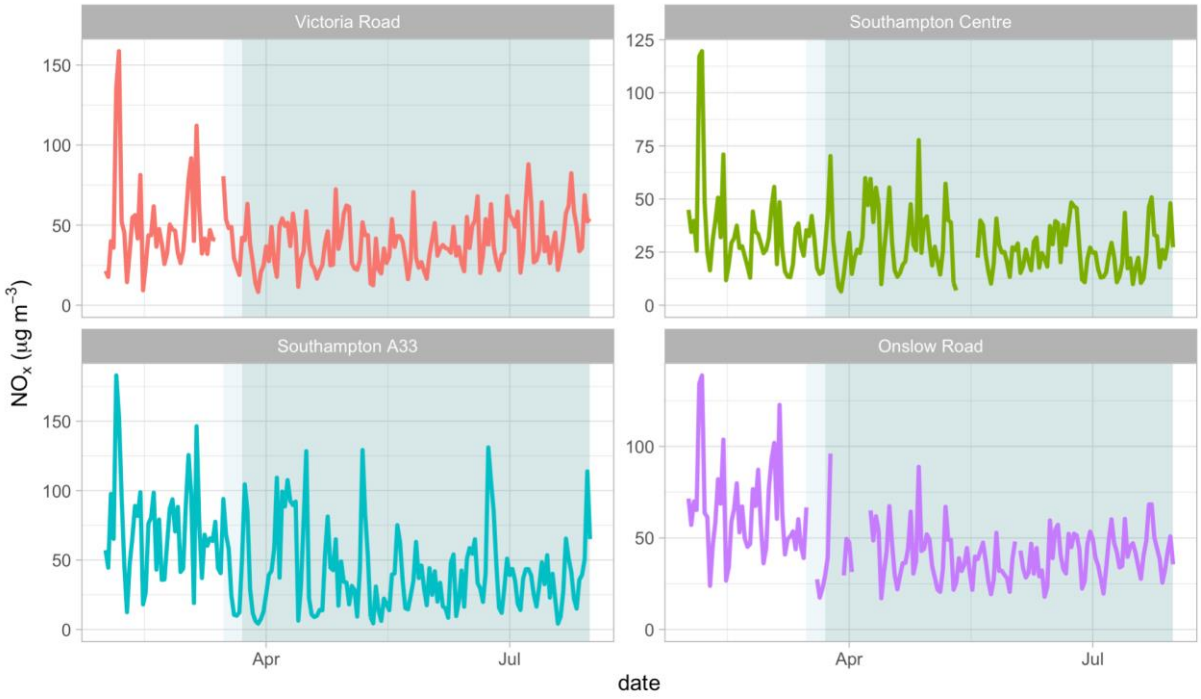


Figure 2: Measured NOx concentrations – cusum analysis

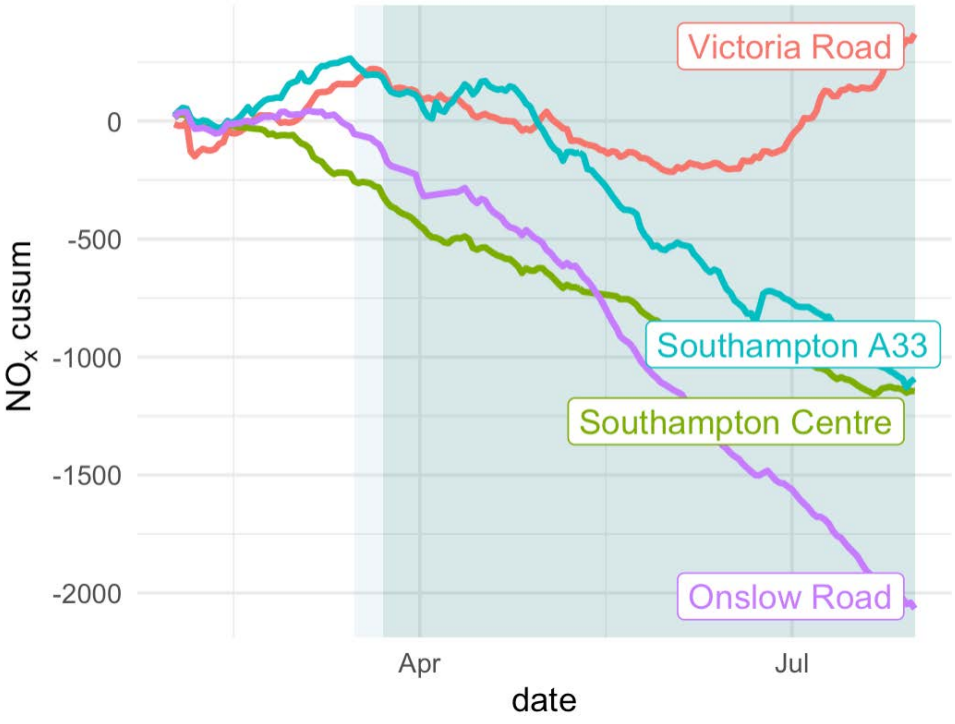


Figure 3: Measured NO_2 concentrations – Time series February to May 27th 2020

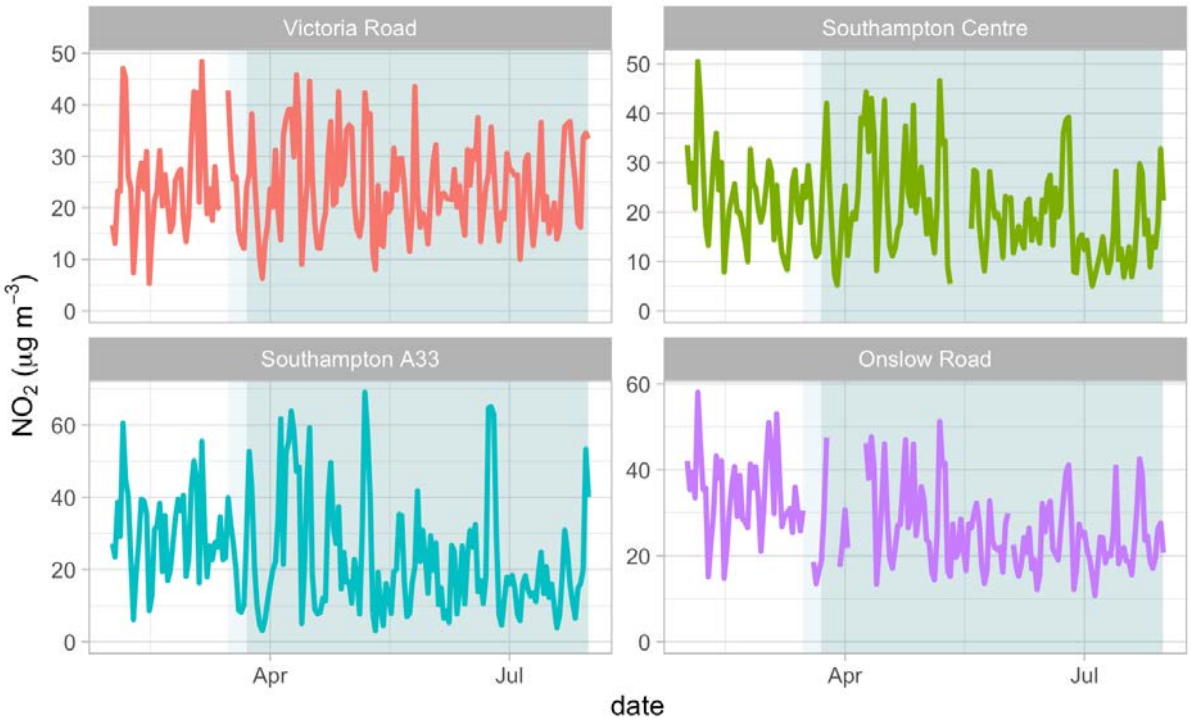


Figure 4: Measured NO_2 concentrations – cusum analysis

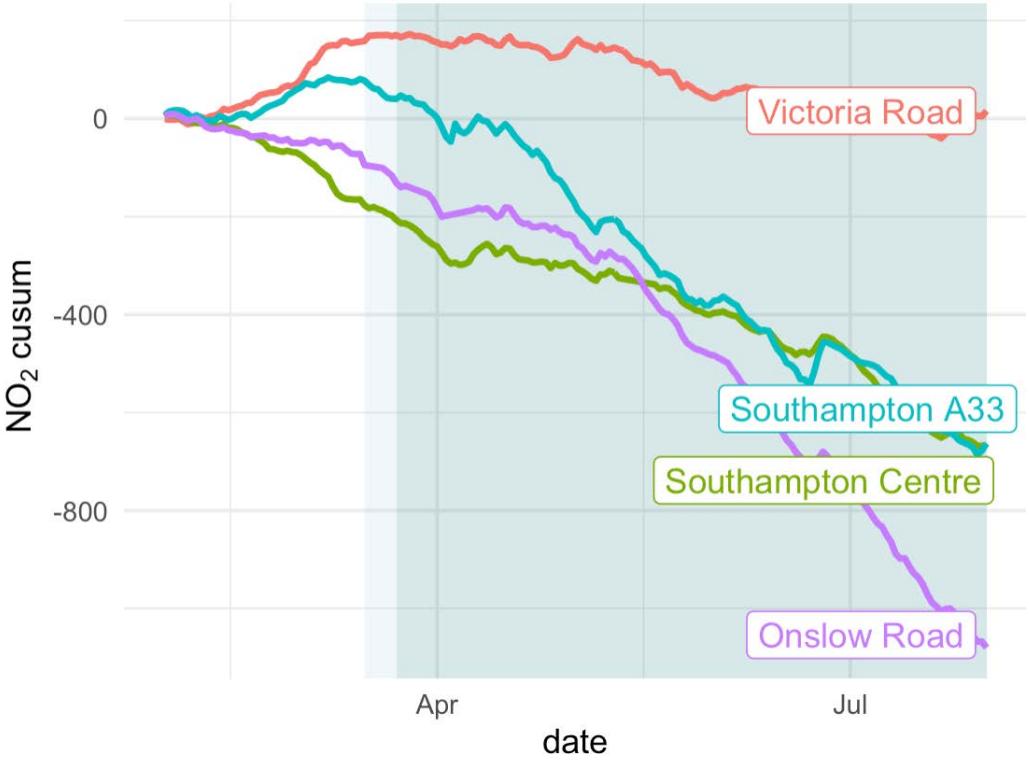
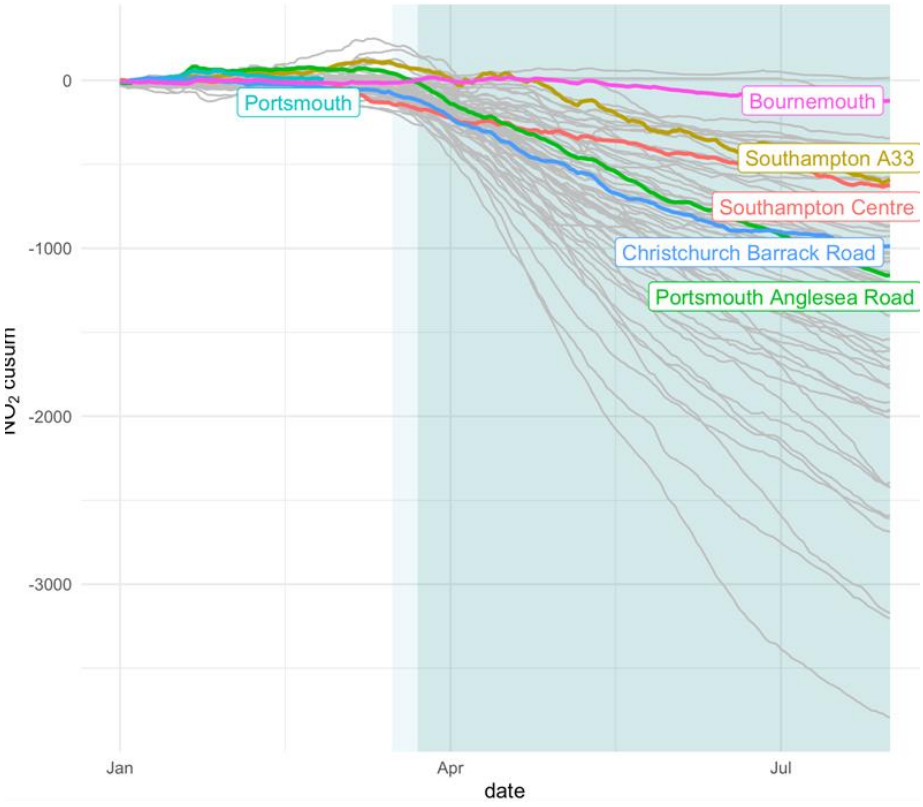


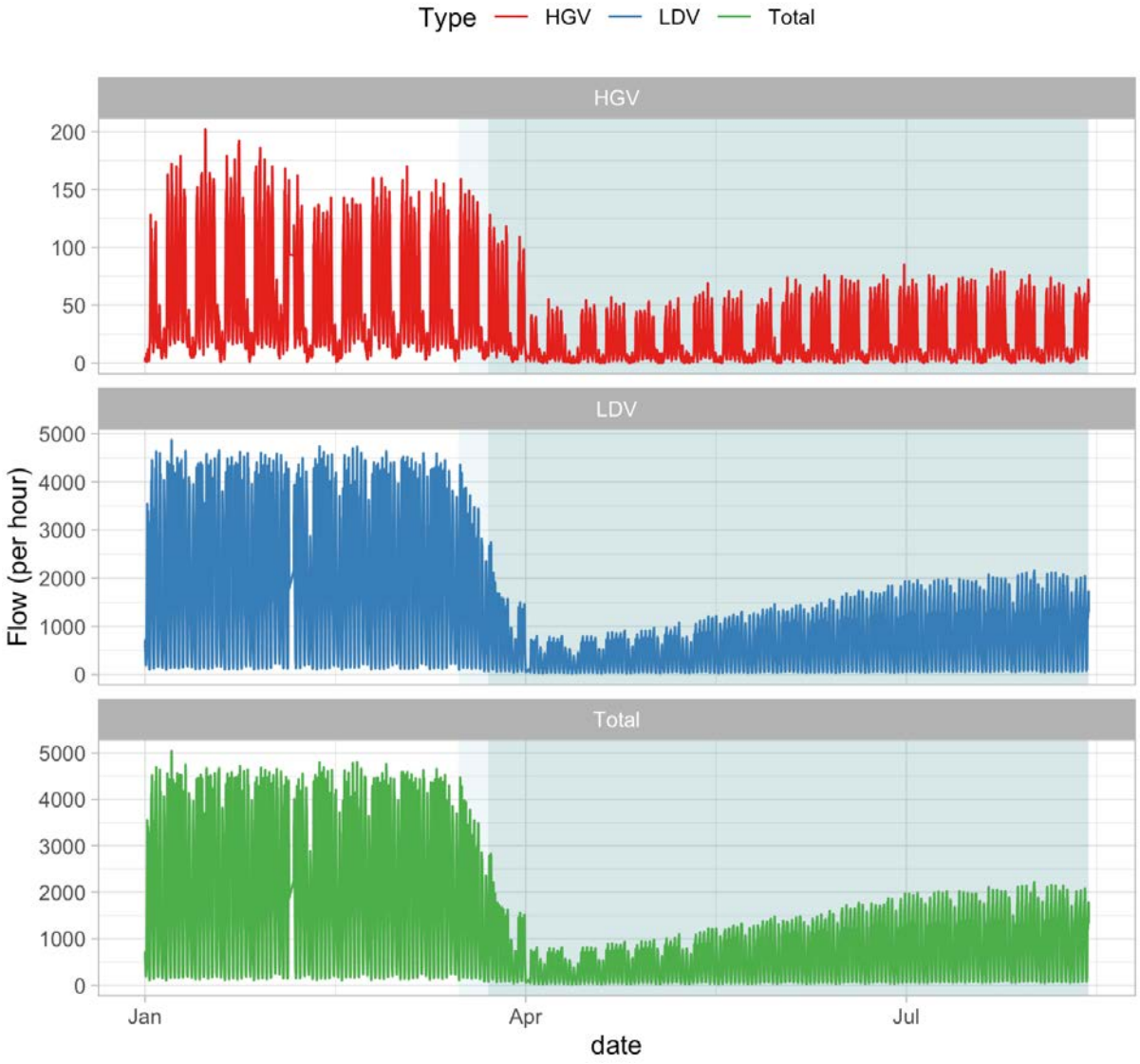
Figure 5: Cusum analysis of measured NO_2 concentrations – Southampton AURN sites vs other nearby UK AURN measurement sites



2.2 Road Traffic activity

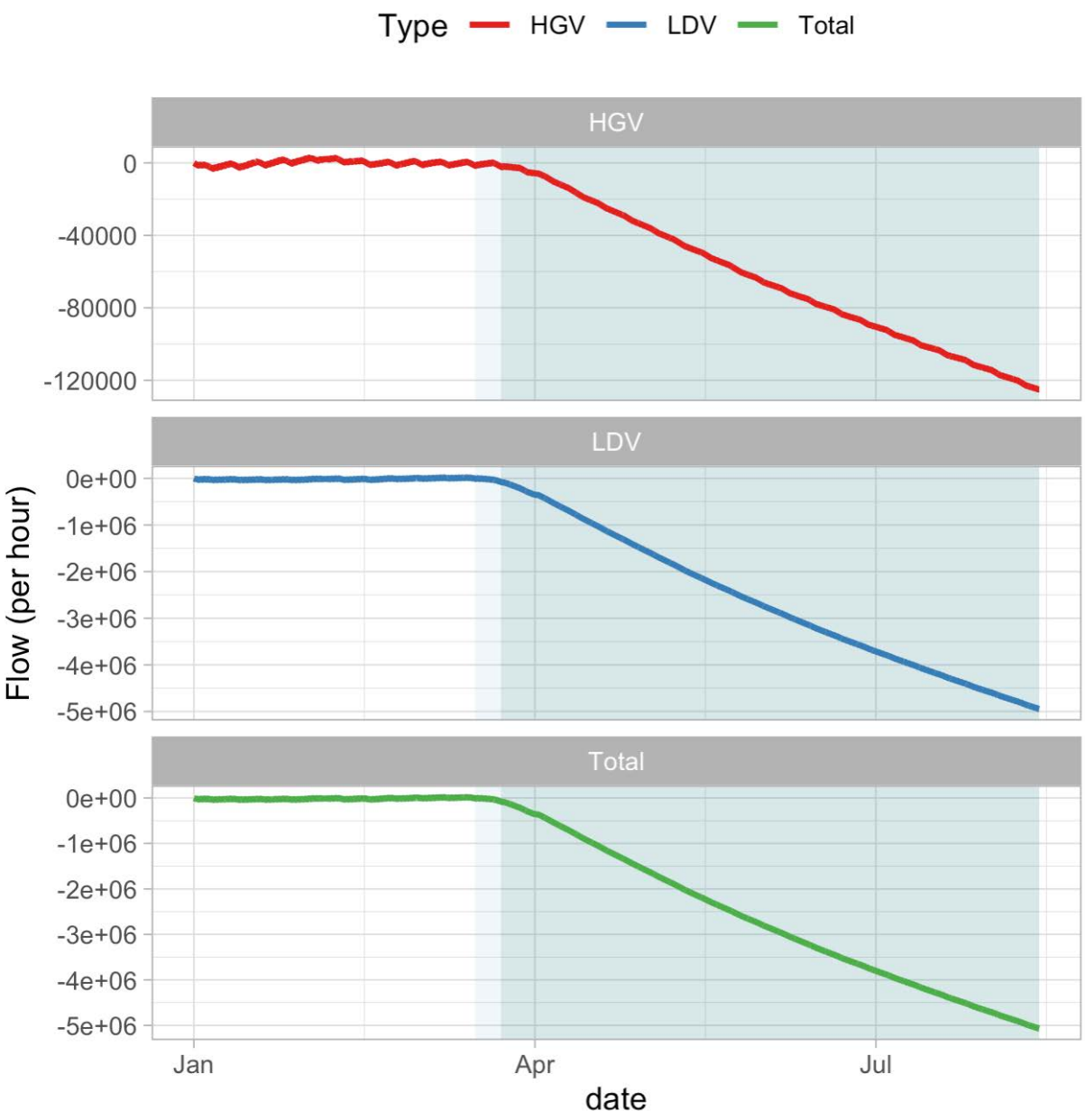
Measurements of traffic flow and type are not available directly adjacent to all the air quality sites, ATC data captured at Redbridge Road is thought to be most representative of the traffic on the A33 rather than the other measurement locations in Southampton. As shown in Figure 6, there is an obvious change in the flows of light duty vehicles (LDV) and heavy duty vehicles (HDV) around the time of the lockdown date of 3rd March 2020. The greatest reductions in vehicle flows were seen for LDVs.

Figure 6: Hourly flows of traffic split by LDV, HDV and Total vehicles.



The cusum plots for the traffic data provide a very clear indication of when flows of vehicles changed, as shown in Figure 7. The clearest decrease in LDV and HDV flows occurred around the lockdown date. The plot is a good demonstration of how the cusum approach works and helps to also understand the changes seen for pollutant concentrations.

Figure 7: Cusum plots for traffic data.



The traffic data can also be used directly in the statistical models to help explain the concentrations of NO_x and NO_2. As noted above, the traffic data is not ideally representative of traffic in the immediate vicinity of the air quality sites but is likely a strong indicator of changes at the A33 site in particular. The main benefit of the data available is that it provides a continuous hourly record (i.e. similar to air quality data) of flows of HGVs and LDVs, which can usefully be included in the models.

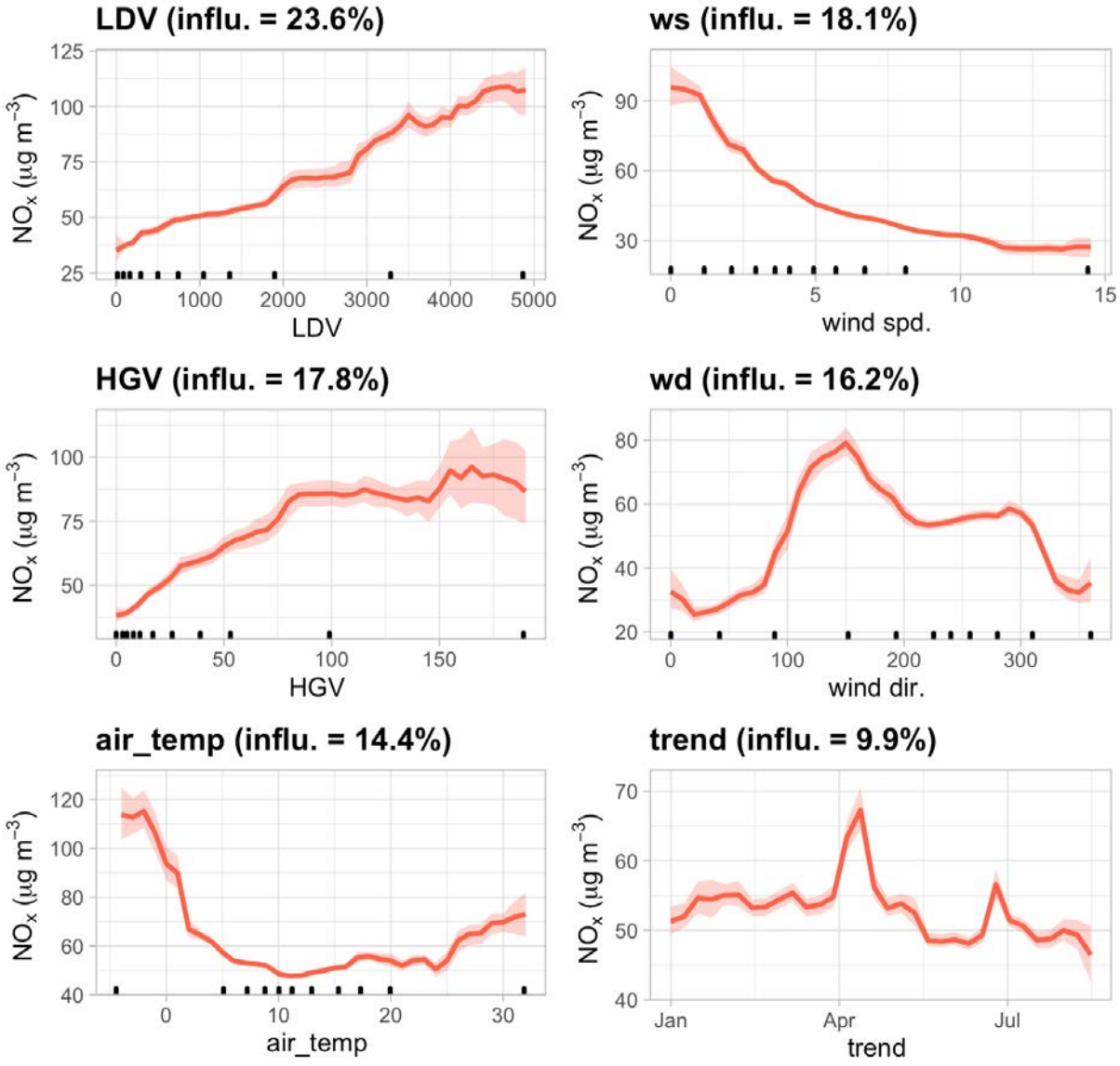
The main benefit of the inclusion of traffic data in the models is two-fold. First, it helps to show the extent to which HGVs and LDVs contribute to concentrations of NO_x and NO_2. Second, by accounting for the traffic flows in the model, any residual features seen in the trend will likely be controlled by other factors. In essence, the trend will reflect factors that are not explicitly included in the models.

2.3 Partial dependence plots

One of the useful outputs from the models is called a *partial dependence plot*, shown in Figure 8. These plots show how different variables such as traffic flow and wind speed affect concentrations of NO_x, while keeping other variables at a constant level. They provide a good indication of how each variable affects the concentration of NO_x without the potentially confusing influence of many other factors.

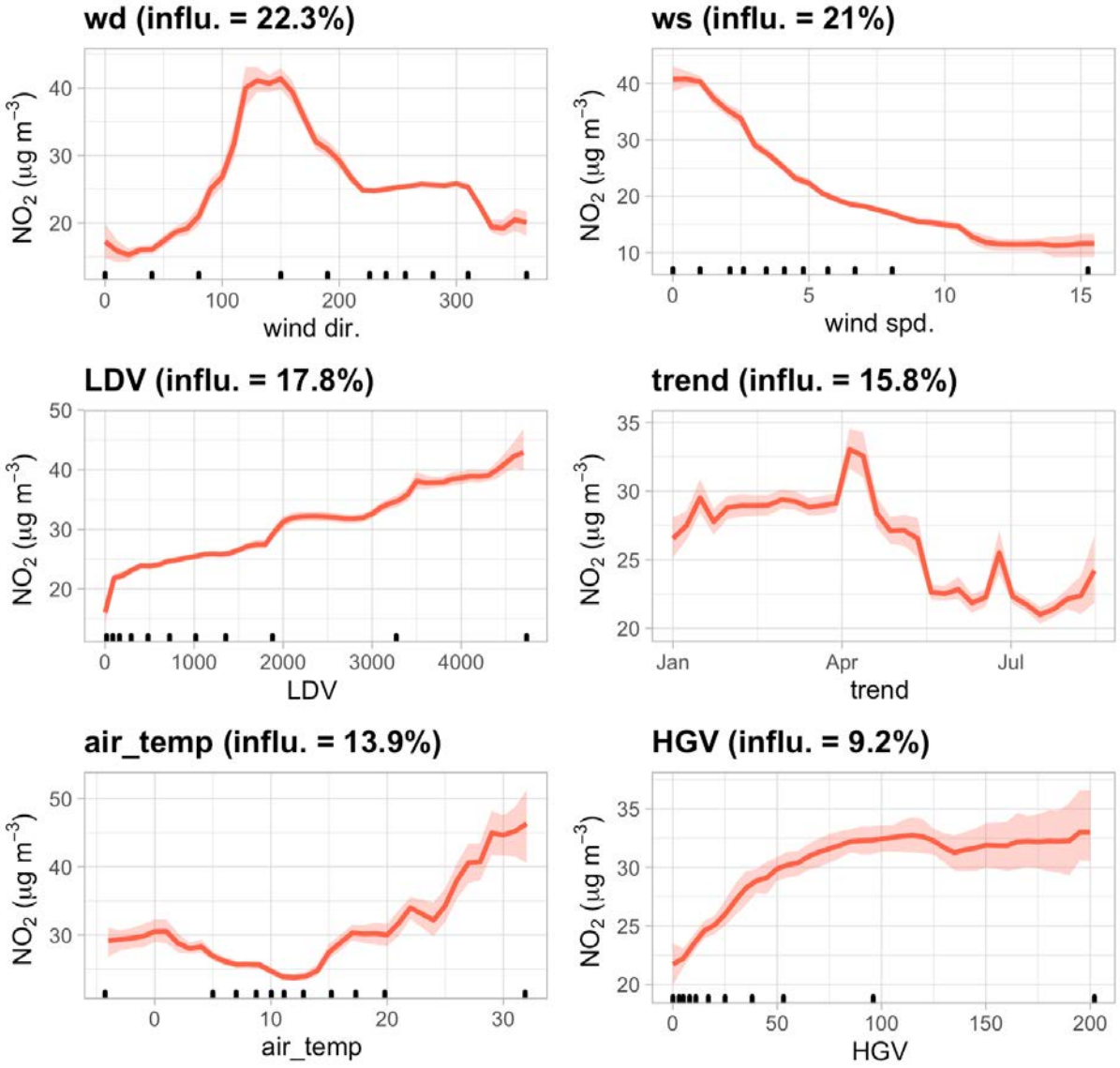
The analysis reveals that the best explanatory variable for NO_x concentrations is the flow of LDVs and not HGVs, as shown by the 'influence %' in each plot. As expected, the concentrations of NO_x tend to increase with increasing flows of vehicles. Also expected is that concentrations tend to decrease with increasing wind speed and increasing temperature due to increased turbulence and more efficient dispersion. The trend plot shows a slight decrease in NO_x concentrations overall, but a prominent peak in early April. This peak cannot be explained by traffic flow or meteorological data, which would suggest another contribution. It is difficult from this analysis alone to identify the cause of the peak in NO_x at this time but interesting to note it is timed with increases in PM_{10} seen at the Southampton Centre site.

Figure 8: Partial dependence plots for different variables for concentrations of NO_x at the A33 site. The panels are ordered in terms of their influence on concentrations.



Largely similar responses are seen for NO_2 concentrations compared with NO_x, as shown in Figure 9; although there is perhaps stronger evidence that there is a clearer downward trend in NO_2 compared with NO_x. This downward trend might reflect wider emissions reductions across Southampton rather than the reductions in emissions along the A33. Similar to NO_x, there is evidence of a peak in concentrations in early April.

Figure 9: Partial dependence plots for different variables for concentrations of NO_2 at the A33 site. The panels are ordered in terms of their influence on concentrations.



2.4 Predictions for the rest of 2020

The impact that Covid-19 has had on road traffic activity and emissions to air will strongly affect the NO_2 annual mean concentrations measured in 2020 and hence issues related to compliance. The statistical models that have been developed for each site can be used to predict the likely concentrations of NO_2 for all of 2020. To do so requires two key assumptions. First, a scenario on how the rest of the year will develop in terms of reduced traffic activity and second, the impact of meteorology on the rest of the year. Taking the first issue, we have run a scenario that assumed the reduced activity will be similar to that for July 2020 (although a range of assumptions could be used). Second, the rest of the year (most of August to the end of December 2020) could experience a range of meteorological conditions. To tackle this, a range of different meteorological conditions have been simulated from assuming the rest of 2020 has meteorology the same as the same period in 2010 and 2011 etc. through to 2019 i.e. 10 different meteorological scenarios.

The results from the analysis are shown in Table 1 and demonstrate in all cases considerably reduced concentrations for NO_2 in the range 21 to 27 $\mu g.m^{-3}$ i.e. all sites meeting the Limit Value of 40 $\mu g.m^{-3}$ by a considerable margin. Clearly, the actual outcome for 2020 will depend on the extent to which traffic volumes return to (or exceed) pre-lockdown levels and the effect of the weather over the rest of 2020.

Table 1: Predicted annual mean NO_2 concentrations at Southampton air quality measurement sites. The range in values reflects 10 different 'meteorological years' for August 2020 to December 2020.

Site	Predicted 2020 NO_2 annual mean ($\mu g.m^{-3}$)
Southampton Centre	21 (18 – 24)
A33	21 (18 – 26)
Victoria Road	27 (24 – 29)
Onslow Road	26 (22 – 30)

Figure 10 to Figure 13 show the measured concentrations at all four of the Southampton measurement sites together with the predicted range of possible NO_2 concentrations from late July onwards.

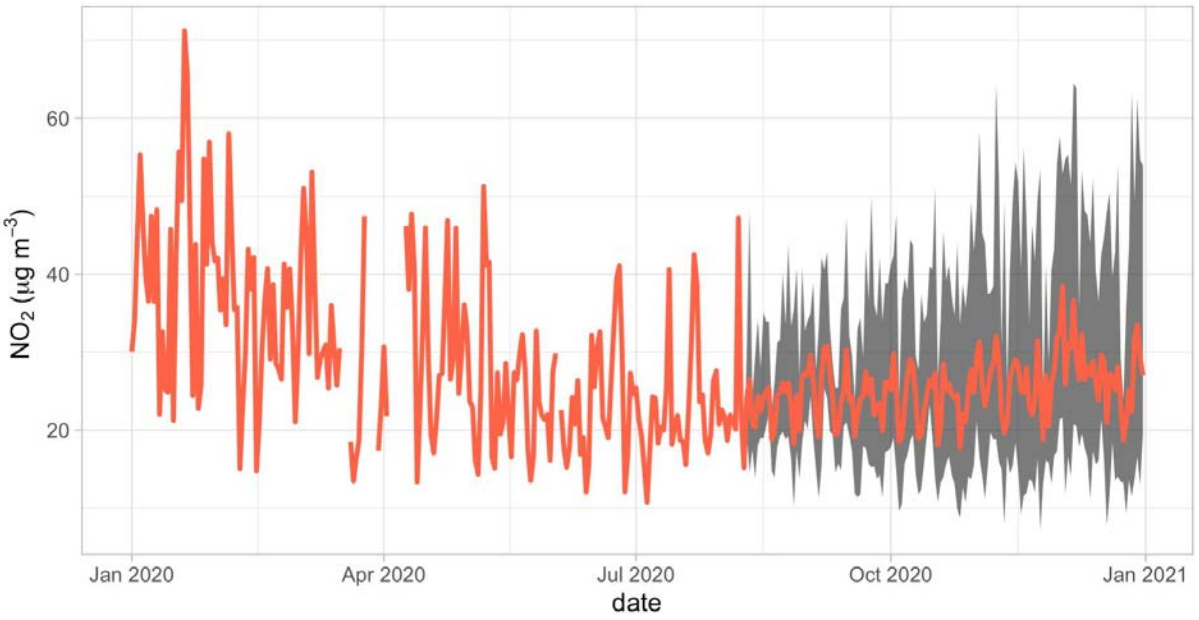


Figure 10: Daily mean NO_2 concentrations at Onslow Road. The first part of the plot (up to late July) shows measured concentrations. From late July onwards the estimated average predicted NO_2 concentration is shown together with the range of concentrations (grey shading) depending on the meteorological year.

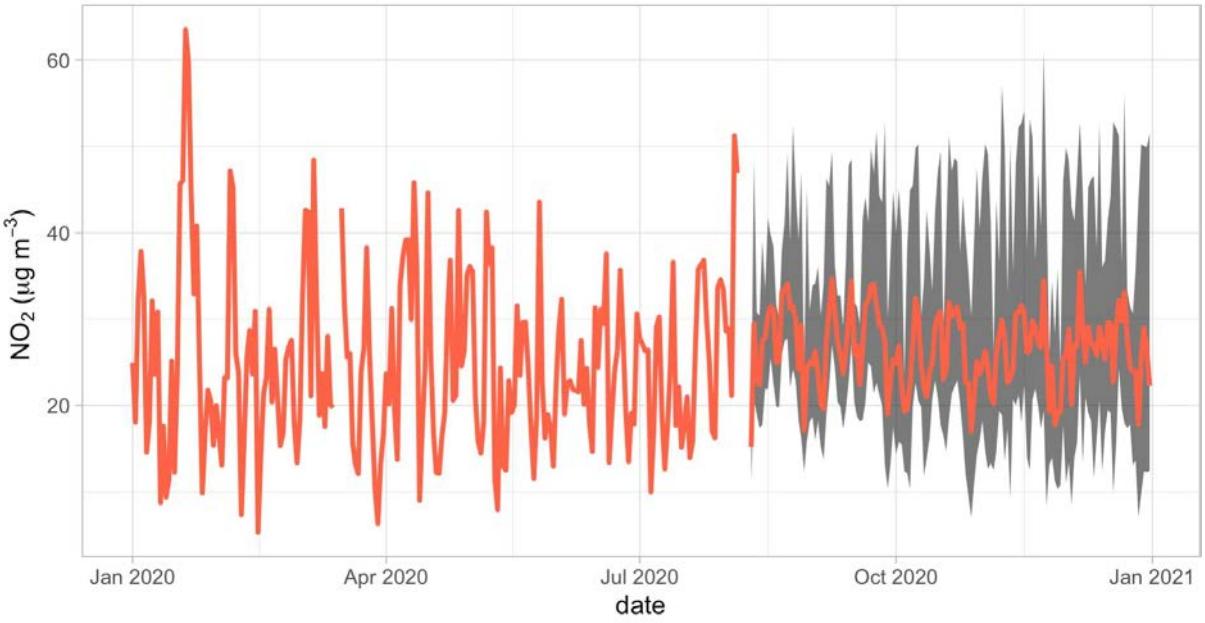


Figure 11: Daily mean NO_2 concentrations at Victoria Road. The first part of the plot (up to late July) shows measured concentrations. From late July onwards the estimated average predicted NO_2 concentration is shown together with the range of concentrations (grey shading) depending on the meteorological year.

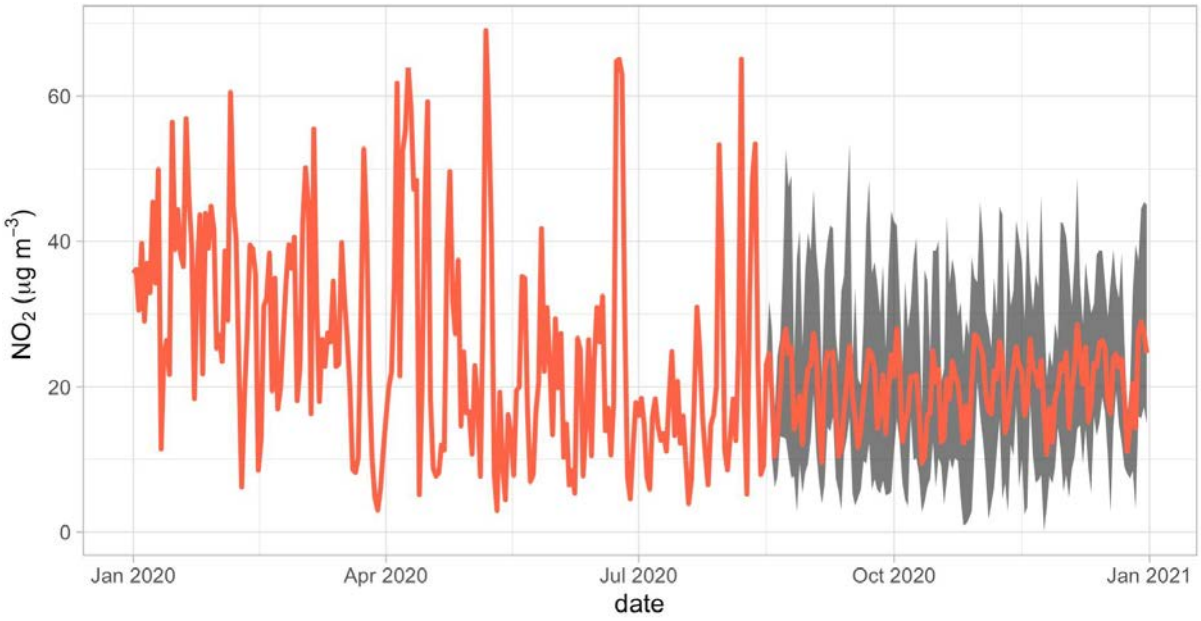


Figure 12: Daily mean NO_2 concentrations at the A33 site. The first part of the plot (up to late July) shows measured concentrations. From late July onwards the estimated average predicted NO_2 concentration is shown together with the range of concentrations (grey shading) depending on the meteorological year.

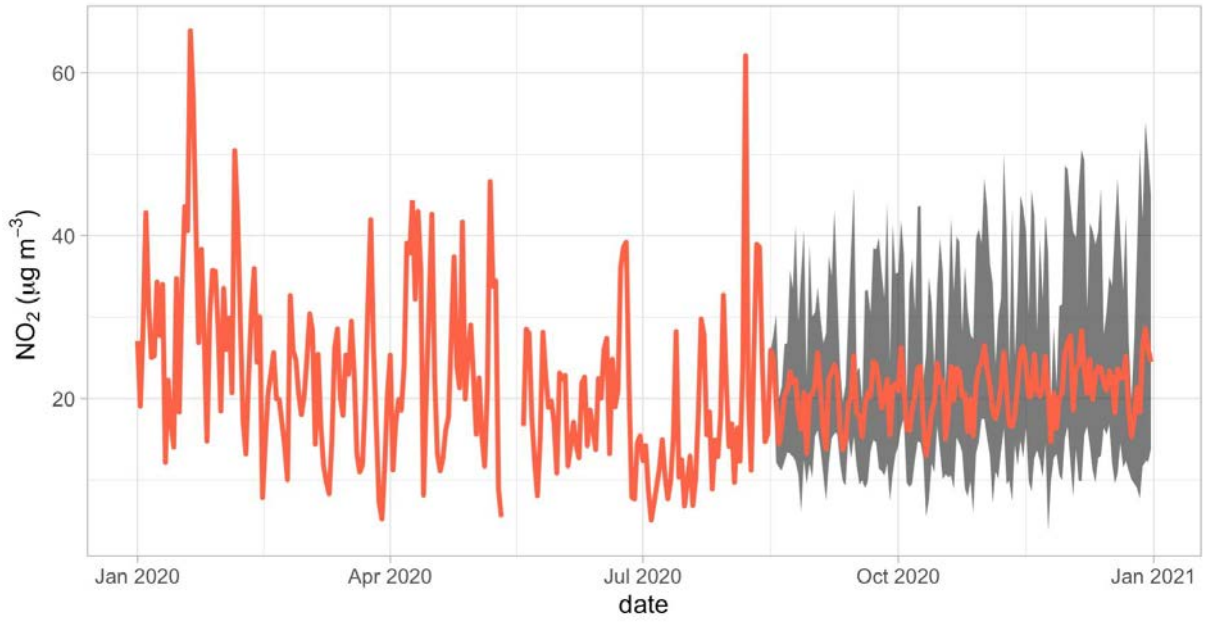


Figure 13: Daily mean NO_2 concentrations at Southampton Centre. The first part of the plot (up to late July) shows measured concentrations. From late July onwards the estimated average predicted NO_2 concentration is shown together with the range of concentrations (grey shading) depending on the meteorological year.

2.5 Shipping activity

Shipping activity in the Southampton port area was affected by restrictions during the recent COVID-19 crisis. This is likely to have had some effect on emissions to air from shipping when compared with business as usual. To assist with our analysis, Associated British Ports (ABP) and Red Funnel have kindly provided both qualitative and quantitative information regarding some of the changes to shipping and port activity at Southampton during the lock-down period.

In summary:

- The automotive function at the port was not operational during the lock-down period, normal operation is estimated to have commenced again in late July. During this time no vehicle import/export via Southampton occurred via roll on-roll off (RoRo) vehicle carriers. Prior to the lock down restrictions, approximately 130 to 150 RoRo vehicle carriers would arrive and depart from the port in a normal month; it is therefore reasonable to conclude that the reduction in this activity at the port will have reduced the associated emissions to air.
- Container freight shipment activity continued as usual.
- Records of the numbers of Cruise ships berthed at the Western Docks were provided (please see time-series chart and further commentary presented below)
- The Red Funnel passenger ferry to the Isle of Wight has operated on a reduced service throughout the lock-down period and a reduced (but greater frequency than during the initial lock down) service is currently operating.

2.5.1 Cruise ship activity

ABP's records of the number of cruise ships berthed at the Western docks during the period 14th March 2020 to the 31st July 2020 are presented in a time-series bar chart in Figure 14. This trend data indicates that the number of cruise ships at berth was on average greater during the period from Late-March to mid-June and appears to have reduced during late June and July. There is however no clear spike in the number of cruise ships that were berthed that can be correlated with periods when measured pollutant concentrations were at a maximum e.g. in early April 2020.

Another time-series bar chart comparing the number of cruise ships berthed during the same dates in 2019 versus 2020 is presented in Figure 15. The 2019 berth occupancy data shows a more typical pattern of cruise ship activity whereby up to five berths are in use at the weekends when cruise holidays embark/disembark. It is clear from this comparison that, on average, more cruise ships were at berth during 2020 when compared with the 2019 business as usual activity.

The overall increase in monthly cruise ship activity when compared with 2019 could intuitively be interpreted to indicate that there is likely to have been increased emissions to air from cruise ship manoeuvres and hoteling activity in the harbour. It is however important to consider that as the cruise ships were not passenger laden, energy use and load on the on-board energy generation plant would have been greatly reduced. Energy use from an empty hoteling/berthed cruise ship is significantly less than a cruise ship full of passengers with operational restaurants, galleys, hot water supply and other on-board facilities. Although there was increased berth occupancy, there were no additional manoeuvring of the cruise ships and hence emissions attributable to this once berthed.

2.5.2 Red Funnel ferry operations

Red Funnel kindly provided some information comparing Southampton ferry activity in 2019 with 2020.

The variance in ferry departures when comparing the February to July periods in 2019 vs 2020 was as follows:

- 1/2/2019 > 31/7/2019 = 8,143
- 1/2/2020 > 31/7/2020 = 4,441

All non-running vessels would shut down their engines, however weekly (usually on a Wednesday) ships would be tested and sea trailed. This information indicates that ferry activity has on average been approximately half of that during business as usual.

2.5.3 Other Commercial shipping movements

ABP also provided vessel schedule for each of the dock areas within the port area. Total ship movements during the period 1st March to 31st July 2020 are presented as a time-series plot in Figure 16. The time series does not indicate any significant change in ship movements during the lock - down restrictions. A slight decrease in activity occurred in the early stages of the lock-down restrictions with a slight increase during late April and early May.

2.5.4 Shipping activity conclusions

As described above, there were various effects on the freight, automotive, cruise and ferry shipping functions in the port that will likely have led to both reductions and increases in emissions to air from various aspects of these activities when compared with business as usual. This evidence is limited to the information currently available for these types of shipping activity only, and does not include consideration of other maritime source types e.g. smaller commercial vessels, recreational vessels etc.

There is insufficient information to quantify how much of an effect these changes in typical port activity would have on measured pollutant concentrations in Southampton.

To estimate this, detailed source apportionment calculations would be required; derived from robust lock-down activity emission calculations in combination with atmospheric dispersion modelling. This would require any estimated change in shipping emissions to be modelled in synergy with all other changes to local emission sources such as road traffic and rail activity

Figure 14: Number of cruise ship berths in use per day 14/03/20 to 31/07/20 (7 berths max)

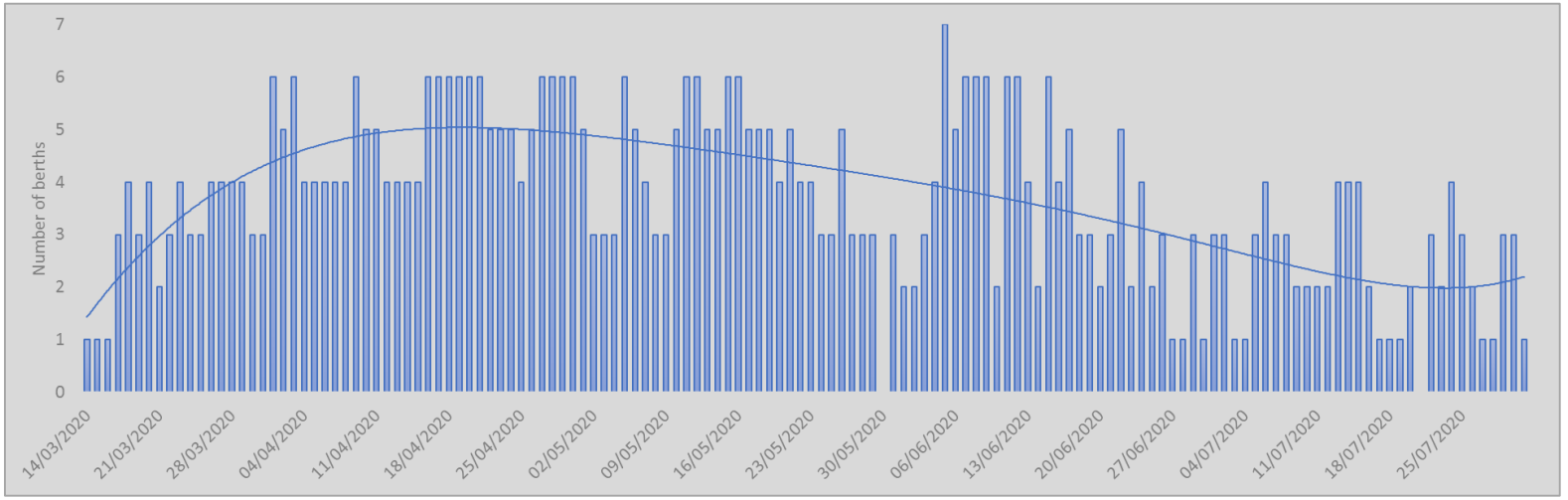


Figure 15: Number of cruise ship berths in use per day – Comparison of 2019 vs 2020 (14/03 to 31/07)

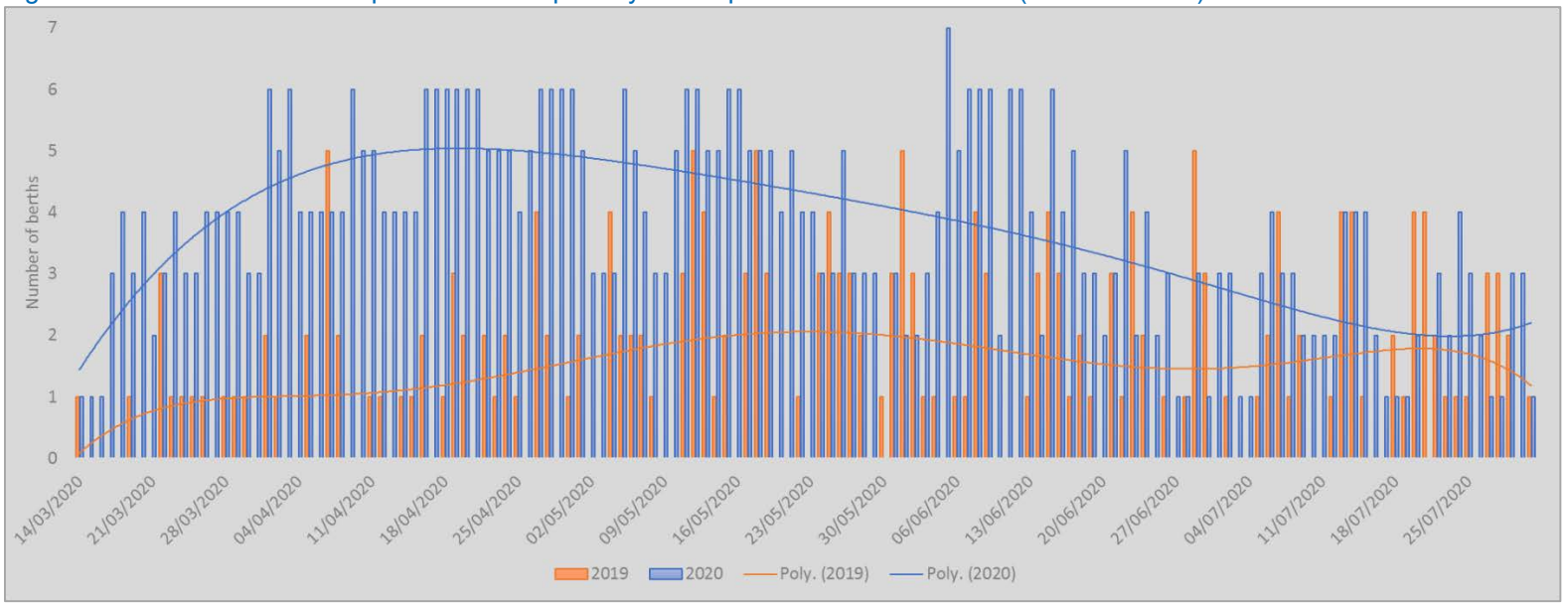
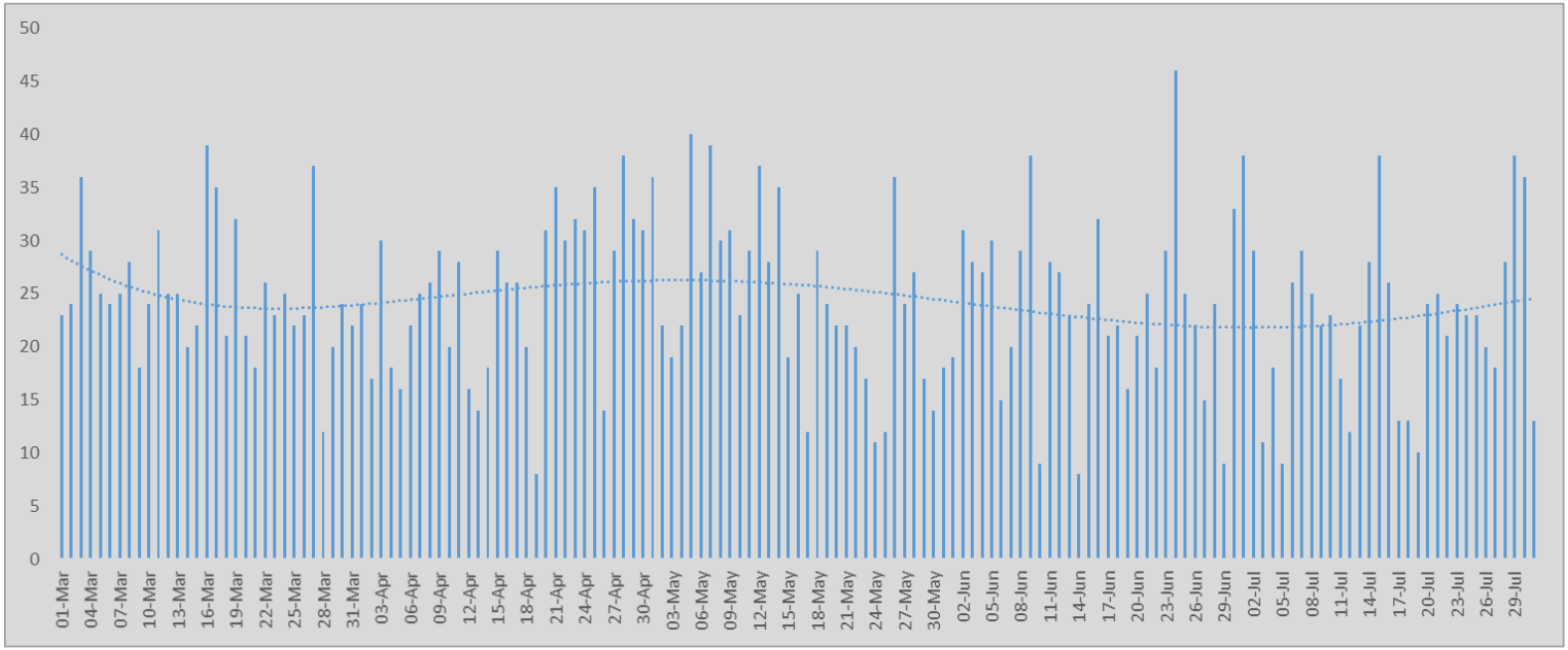


Figure 16: Daily commercial shipping movements at Southampton (all docks combined) 1st March 2020 to 31st July 2020



3 Summary and conclusions of additional analysis

This addendum presents additional content as a supplement to our initial report describing analysis of pollutant measurements in Southampton both during and before the recent 'social distancing and subsequent lockdown' associated with the COVID-19 crisis in the UK

Additional Time series analysis and extended cumulative sum difference (cusum) analysis for NOx, NO_2 and more detailed traffic data

Updated time series and cusum plots at each of the Southampton air quality measurement sites for NOx and NO_2 have been presented. The cusum analysis accumulates the deviation in concentration from an estimate of what would occur during business as usual. The main conclusions from the updated plots were:

- There is some evidence that NOx and NO_2 decreased at all of the measurement sites during the lock-down period but, as concluded in the original report, the reductions are not as clear when compared with other sites in the UK.
- Measured NOx and NO_2 concentrations at Victoria Road in particular did not reduce as much as the other Southampton sites and measured concentrations here seem to have increased when compared with BAU in July and August.

Time series analysis of more detailed traffic count data on the A33 confirmed that there was a significant reduction in daily flows of light duty vehicles (LDV) and heavy duty vehicles (HDV) around the time of the lockdown date of 23rd March 2020. The greatest reductions in vehicle flows were seen for LDVs.

Partial dependence plots and explanatory variables for measured NOx and NO_2 concentrations

Partial dependence plots have been presented. The plots show how different variables such as traffic flow and wind speed act as explanatory variables; and estimate how each of these affect measured NOx and NO_2 concentrations while keeping other variables at a constant level.

The analysis reveals that the best explanatory variable for NOx concentrations is the flow of LDVs and not HGVs, as shown by the 'influence %' in each plot. As expected, the concentrations of NOx tend to increase with increasing flows of vehicles. Also expected is that concentrations tend to decrease with increasing wind speed and increasing temperature due to increased turbulence and more efficient dispersion. The trend plot shows a slight decrease in NOx concentrations overall, but a prominent peak in early April. This peak cannot be explained by traffic flow or meteorological data, which would suggest another contribution.

Largely similar responses are seen for NO_2 concentrations when compared with NOx; although there is perhaps stronger evidence that there is a clearer downward trend in NO_2 compared with NOx. This downward trend might reflect wider emissions reductions across Southampton rather than the reductions in emissions along the A33. Similar to NOx, there is evidence of a peak in concentrations in early April.

Predictions of 2020 annual mean NO_2 concentrations at each of the automatic measurement sites in Southampton

The statistical models that have been developed for each site have also been used to predict the likely annual mean NO_2 concentrations for all of 2020. Two key assumptions have been made regarding reduced traffic activity; and the impact of meteorology on the rest of the year whereby a range of different meteorological conditions have been simulated.

The statistical model results predict considerably reduced annual mean NO_2 concentrations at all measurement sites, range from 21 to 27 $\mu g.m^{-3}$ i.e. all sites are predicted to be compliant with the 40 $\mu g.m^{-3}$ limit value by a considerable margin. The actual NO_2 annual mean concentration measured in 2020 will depend on the extent to which traffic volumes return to (or exceed) pre-lockdown levels and the effect of the weather over the rest of 2020.

Shipping activity

During the lock down period there were various effects on the freight, automotive, cruise and ferry shipping functions in the port. When compared with business as usual, this will have likely led to both reductions and increases in emissions to air from various aspects of these shipping activities,

Analysis of port records indicates that, on average, more cruise ships were at berth during 2020 when compared with the same period in 2019 (example of business as usual) activity. There is however no clear spike in the number of cruise ships that were berthed that can be correlated directly with periods when measured pollutant concentrations were at a maximum during the lock down.

The increased number of cruise ships at berth could intuitively be interpreted to indicate that there is likely to have been increased emissions to air; it is however important to consider that as the cruise ships were not passenger laden, energy use and load on the on-board energy generation plant would have been greatly reduced, hence emissions to air per ship would also likely be reduced.

Final conclusions

In summary, from this addendum and the original analysis, we conclude:

- Measured pollutant concentrations did reduce during the lockdown but potentially less than other similar areas;
- The measurement data indicates an increase in measured concentration of all pollutants in early April that is not explained by traffic or weather;
- Polar plots suggest there could be an impact of some activity in the direction of the port or other nearby industrial sources, but it is not definitive;
- There are clear changes in activity at the port with some likely to reduce emissions and others likely to increase emissions. However, there is no clearly definable spike/change in activity aligned with the spike in NOx/NO_2 in early April.
- Annual average NO_2 concentrations measured during 2020 are likely to be considerably lower than previous years due to effect of lesser road traffic activity during the lockdown restrictions and are expected to be well within the limit values.

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