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2020 COVID-19 lockdown period – Air Quality Analysis

Report for Southampton City Council

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Ricardo

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1 Introduction

The following report provides an 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.

We have presented various analyses of air quality measurements in Southampton and how they relate to observed meteorological conditions. The analysis includes measurements of nitrogen dioxide (NO_2) and fine particulate matter in the PM_{10} and $PM_{2.5}$ fractions; and has been conducted using the R openair package and a cumulative sum difference (cusum) method.

Four types of analysis are presented:

- Weather conditions – typical, pre-lock down and during lock-down
- Time series analysis – pollutant measurements vs road traffic activity data and weather conditions.
- Cumulative sum difference (cusum) analysis – 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.
- Directional analysis using bivariate polar plots – presenting measured pollutant concentrations varying by wind speed and wind direction. **Please note:** In addition to this report, we have also provided these plots presented on polar maps in html file format that can be interactively viewed by the reader using a web browser.

1.1 Limitations

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

- All 2020 NO_2, PM_{10} and $PM_{2.5}$ pollutant measurement data included in the analysis from the automated sites in Southampton **were unratified at the time of conducting the analysis**; no quality assurance checks, data scaling or removal of spurious data has been conducted for these pollutants. **Caution is recommended when interpreting analysis of unratified measurement data. The results and conclusions presented here should be considered in this context.**
- No analysis of 2020 SO_2 data measured at the Southampton Centre AURN measurement site has been presented due to measured concentrations being so low during the period when social distancing and lock-down restriction were in place; i.e. ambient SO_2 concentrations measured at the Southampton Centre AURN site indicate that there are no significant sources influencing SO_2 levels at that location.
- 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.
- At the time of writing we were unable to access shipping activity data covering the lock down period, so could not provide a direct comparison of measured pollutant concentrations with changes in activity in the harbour (this is now included in an Addendum to this report)

2 Analysis

2.1 Weather conditions

The effect of the weather is an important consideration when analysing air quality measurement data. This is particularly relevant when comparing pollutant measurements and considering nearby sources between two distinct time periods e.g. in this case ‘pre-lockdown’ and ‘during-lockdown’ conditions. If weather is not considered it can lead us to spurious conclusions about the causality of a change in concentrations. We might assume, for instance, that a reduction in concentrations of a pollutant is linked to a drop in emissions, when in fact it may be due to higher winds creating more favourable conditions for pollutant dispersion.

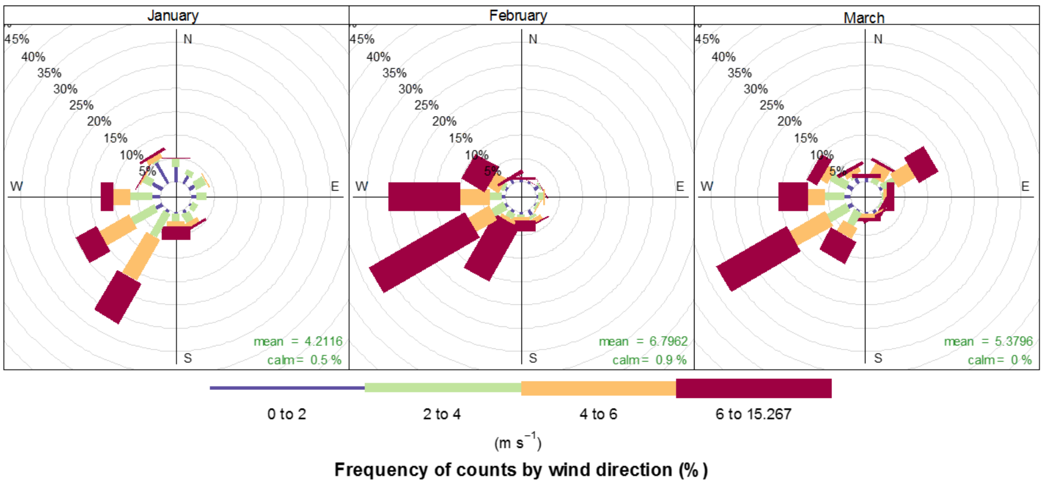
The frequency of wind speed and direction are presented for each period in 2020 using simple wind roses (Figure 1) and in more detail using polar frequency plots (Figure 2). Please note: The observations presented here are from the Bournemouth meteorological measurement station as data capture was very low at the Southampton airport measurement station during the lock down period.

The main observations from these diagrams are:

- South westerly winds were predominant during the pre-lockdown period, whereas north easterly winds were more frequent during the initial days of the lock-down and in May
- The highest south westerly wind speeds occurred during February and early March prior to the lockdown.

Figure 1: Wind roses - periods in 2020 before and during the lockdown period

Pre-lockdown Jan 1st to 22nd March 2020



During-lockdown March 23rd to 27th May 2020

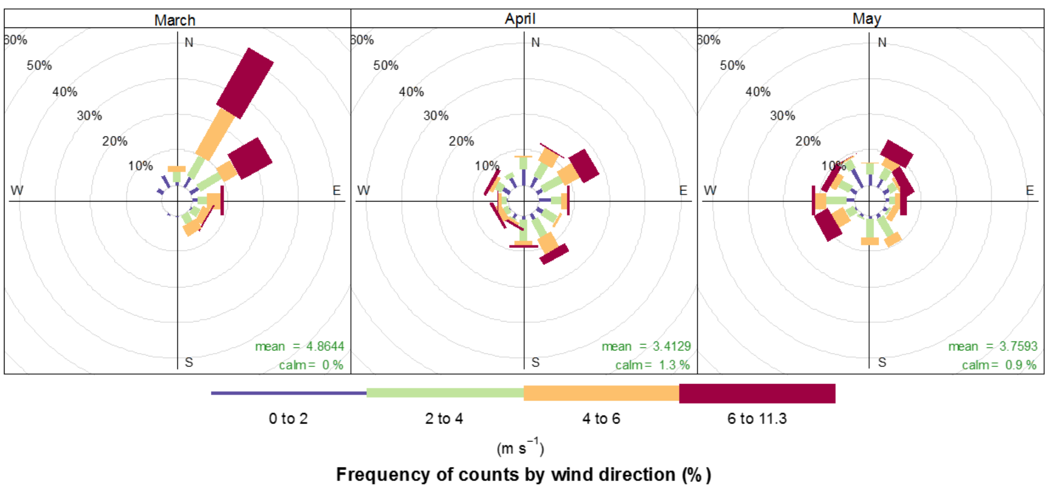
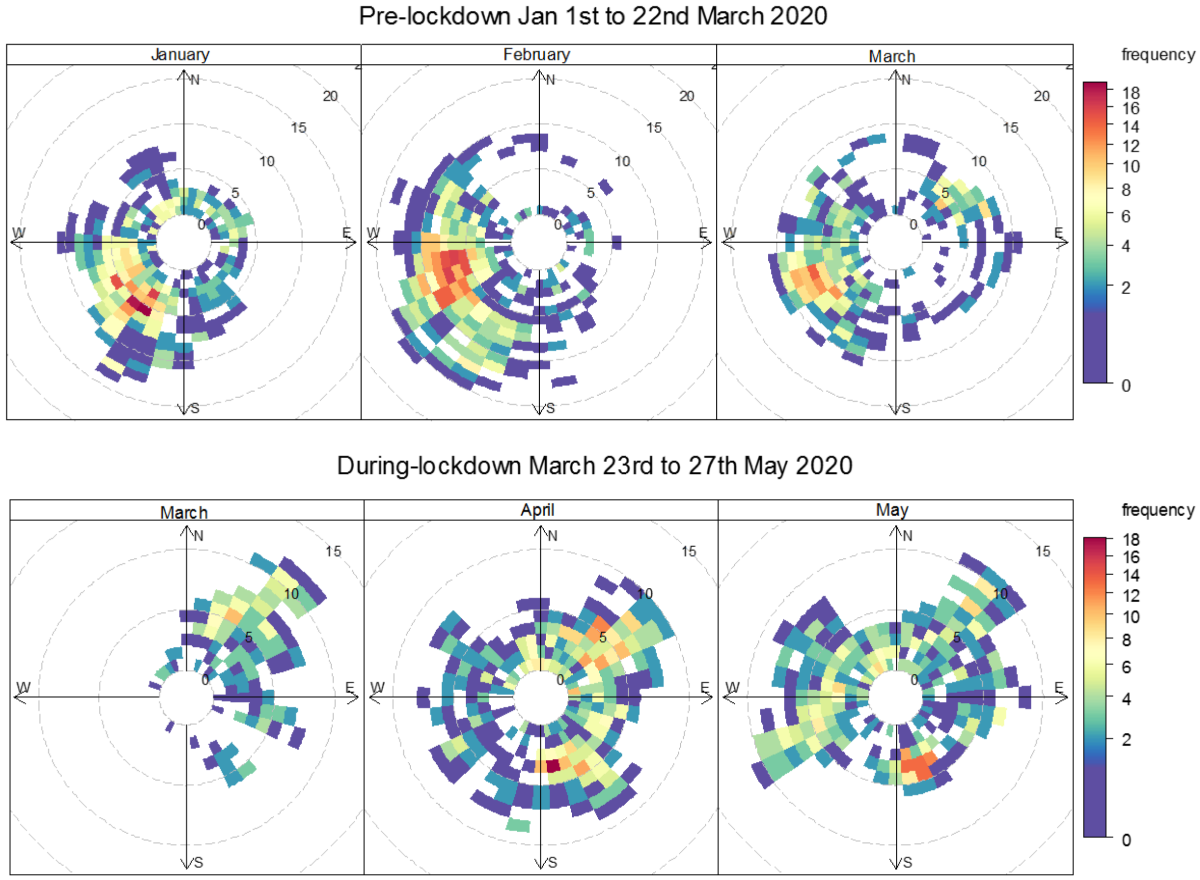


Figure 2: Polar frequency of wind speed and direction



Note: Wind speed units ($m.s^{-1}$)

2.2 Time-series analysis

In this section we present time-series analysis of measured pollutant concentrations at roadside measurement sites in comparison with observed daily traffic activity during the period 6th March 2020 to 15th May 2020.

We also present time-series of measured pollutant concentrations at the Southampton urban centre/urban background. Comparison with traffic activity was not considered relevant at the Southampton centre site, as urban centre/background sites are typically located away from major road sources.

At the time of writing, we were unable to access shipping activity data covering the lock down period, so could not provide a comparison of measured pollutant concentrations with changes in activity in the harbour.

2.2.1 Roadside measurement sites

At roadside locations NOx concentrations are generally closely linked to primary emissions from vehicles and should show the direct impact of reduced local traffic activity on air pollution. NO_2 will be from a mixture of primary vehicle emissions and secondary chemical reactions but should again be closely linked to local traffic activity. Changes in PM_{10} concentrations are also associated with nearby traffic activity but are also linked to secondary atmospheric formation; so are more likely to be influenced by background concentrations and regional/transboundary fluctuations

Southampton City Council operate three roadside air quality measurement stations and one urban centre/ urban background site. Automatic traffic count (ATC) sites are located throughout the city road network.

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.

The ATC locations used at each monitoring site are listed in Table 2.1. There was no data available that represented a reasonable proxy for traffic at Victoria Road. As stated above, comparison with traffic activity was not considered relevant at the Southampton centre site, as urban centre/background sites are usually located away from major road sources.

Table 2.1: Traffic count locations used as

Air quality measurement site	Pollutants measured	Nearest available automatic traffic count location
Southampton A33 roadside AURN	NOx, NO_2, PM_{10}	Millbrook Rd West
Onslow Road (roadside)	NOx, NO_2	Thomas Lewis Way
Victoria Road (roadside)	NOx, NO_2	No available nearby proxy
Southampton centre AURN (urban centre/ background)	NOx, NO_2, PM_{10}, $PM_{2.5}$ O_3, SO_2	N/A as not roadside measurement site

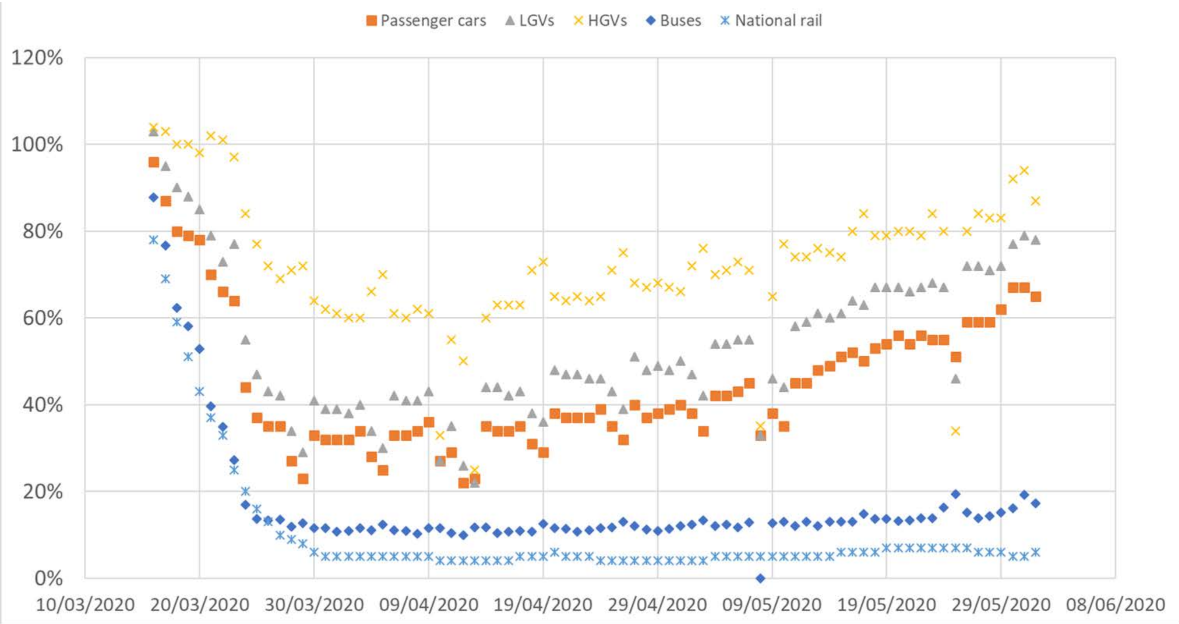
2.2.1.1 Southampton A33 (roadside) AURN measurement site

Time-series plots showing hourly measured concentrations of NOx, NO_2 and PM_{10} at the Southampton A33 site during the period 6th March 2020 to 15th May 2020 are presented in Figure 4 with the corresponding daily traffic activity at Millbrook Road West shown in Figure 4.

To consider these plots in context with the timing of government guidance related to the COVID 19 crisis, and hence public and traffic activity; social distancing was advised on the 16th March and lockdown was enforced one week later on the 23rd March.

It's clear from the traffic activity plot that the daily number of vehicles decreased significantly from March 16th onwards; and by the beginning of April, weekday counts appear to be around 20% of the counts observed in early March. Daily counts then slowly increase throughout April and early May to approximately 30% of the pre-lock down observations. This is broadly in line with UK Government statistics[1] for the trunk road network over the same time interval (shown in Figure 3 below); a sharp decrease is observed until late March before a gradual increase in traffic in later weeks.

Figure 3: Use of transport modes in the UK- March to June 2010. Source: UK Government



The NOx, NO_2 and PM_{10} time-series covering the same period do not show a similar decrease in measured pollutant concentrations. The peak concentrations for all pollutants appear to have been measured during the week in April (6th to 13th) when traffic activity was at its lowest.

It is important however to consider the effect of the weather when comparing air pollution data before and after an intervention that directly changes emissions from a nearby source. In most situations, increasing wind speed results in lower concentrations due to increased mechanical turbulence in the lower atmosphere and enhanced dilution/advection.

A simple analysis of measured NO_2 using calendar plots is presented in Figure 6; two plots have been produced which show daily concentrations laid out in a calendar format; the second plot includes vectors representing wind direction and speed on each day.

When considering wind speed and direction which are the predominant determinants of pollutant dispersion over short distances of a few metres, it's also important to consider the location of the air quality measurement site relative to nearby emission sources. The Southampton A33 AURN analyser is located a few metres north of the southeast bound carriageway of the Redbridge Road section of the A33.

Examination of the calendar plots indicates that the highest NO_2 concentrations are measured on days when the average wind speed was low i.e. dispersion was poor.

The peak concentrations measured during the week in April (6th to 13th) when traffic activity was at its lowest during the lockdown also coincide with low average wind speeds in a direction roughly perpendicular to the route of the A33 i.e. from the south east.

Similarly, on the 24th and 25th March just after the lockdown began, low winds speeds from a south easterly direction coincide with higher measured NO_2 concentrations; whereas over the next few days up to the end of March, strong north easterly winds coincide with much lower daily measured NO_2

[1] https://www.gov.uk/government/statistics/transport-use-during-the-coronavirus-covid-19-pandemic

concentrations. During these conditions road traffic emissions from the A33 would be blown in the opposite direction from the analyser which is placed to the north of the carriageway; dispersion would also occur more readily as a result of the higher wind speeds.

Examination of other days during the lockdown when the highest NO_2 concentrations were measured also coincide with low winds speeds from a south easterly direction.

2.2.1.2 Onslow Road (roadside) measurement site

Time-series plots showing hourly measured concentrations of NOx and NO_2 at the Onslow Rd air quality measurement site during the period 6th March 2020 to 15th May 2020 are presented in Figure 4 with the corresponding daily traffic activity at Millbrook Road West shown in Figure 5.

The traffic activity plot for Thomas Lewis Way shows a similar pattern to the A33 count whereby the daily number of vehicles decreased significantly from March 16th onwards; and by the beginning of April, weekday counts appear to be around 30% of the counts observed in early March. Daily counts then slowly increase throughout April and early May to approximately 45% of pre-lock down levels.

There are missing periods in the NO_2 measurement data during mid to late March and early April. From the available data, peak NO_2 measurement also seem to follow a similar temporal profile to the A33 measurement site with maximum concentrations being measured during the same weeks of April and May. From these time-series plots, it is difficult to see any clear change in NO_2 concentrations that can be linked with the reduction in road traffic activity.

Measured daily average NO_2 calendar plots are presented in Figure 6 Similar to the calendar plots for the A33 measurement site, the highest daily average NO_2 concentrations at Onslow Road during the lockdown period were measured on days when low winds speeds were observed and dispersion of localised emissions was likely to be poor. The Onslow Road analyser is located a few metres east of the roadside.

Figure 4: Southampton A33 (roadside) analyser – Time series of (provisional) measured NO_2 and PM_{10} hourly mean concentrations ($\mu g.m^{-3}$) 16th March to 15th May 2020

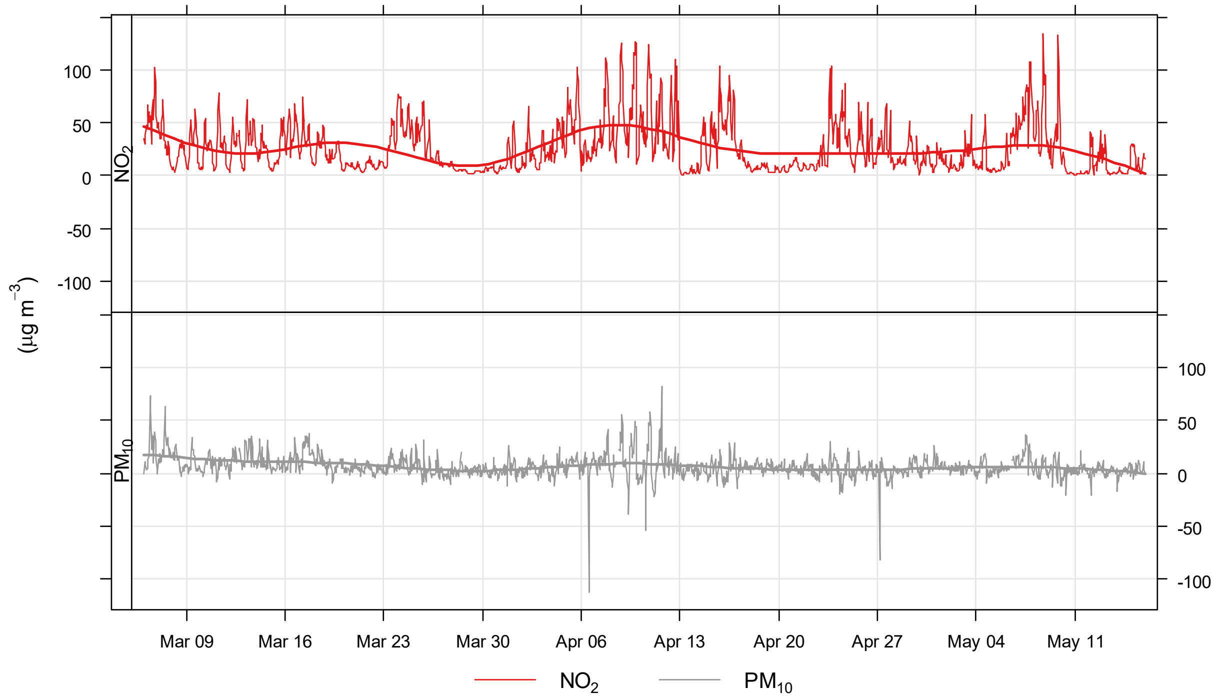


Figure 5: Millbrook Road West automatic traffic count site – Time series of daily average traffic flow (veh/day) 16th March to 15th May 2020

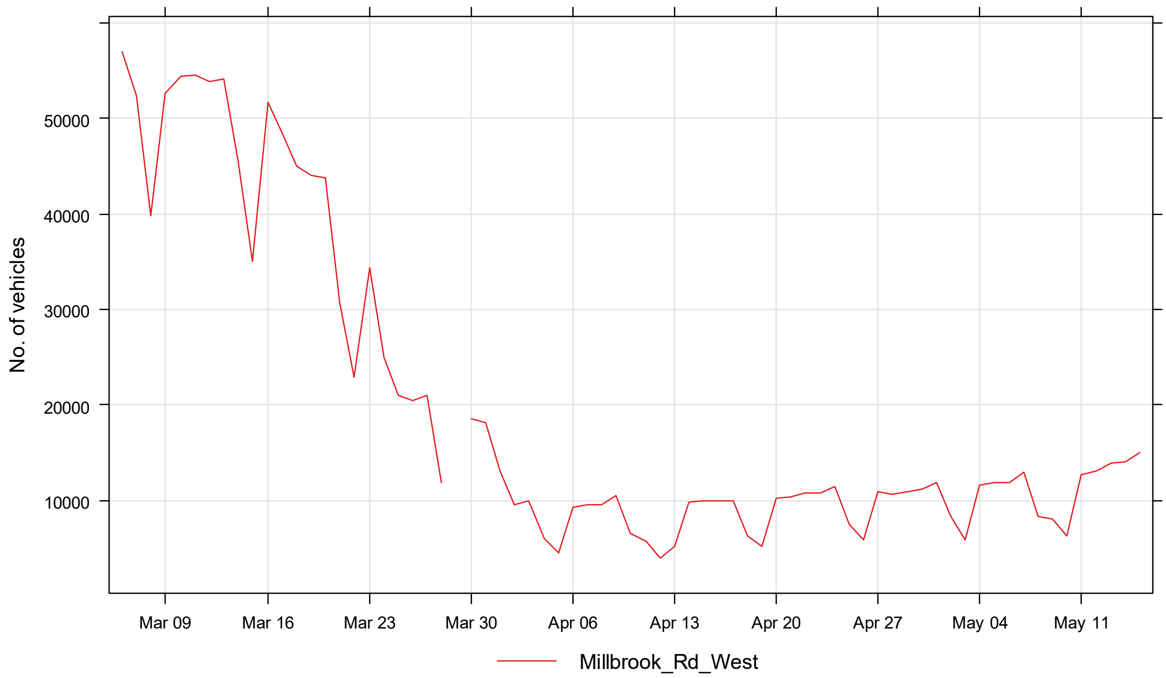


Figure 6: Southampton A33 (roadside) analyser (provisional) measured NO_2 daily mean calendar plots January to May 2020 (lower plot shows wind direction and speed vectors)

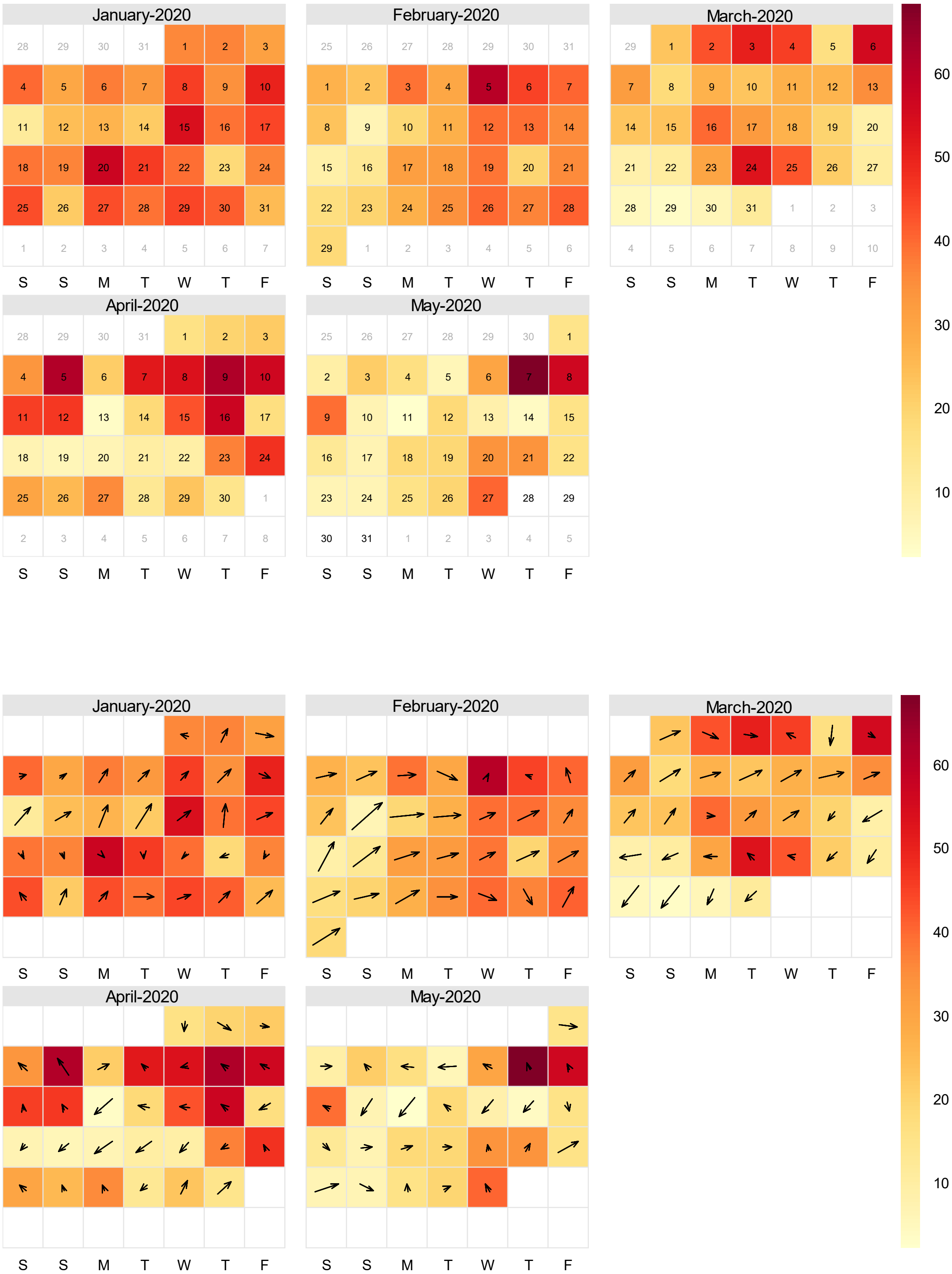


Figure 7: Onslow Road (roadside) analyser – Time series of (provisional) measured NO_2 hourly mean concentrations ($\mu g.m^{-3}$) 16th March to 15th May 2020

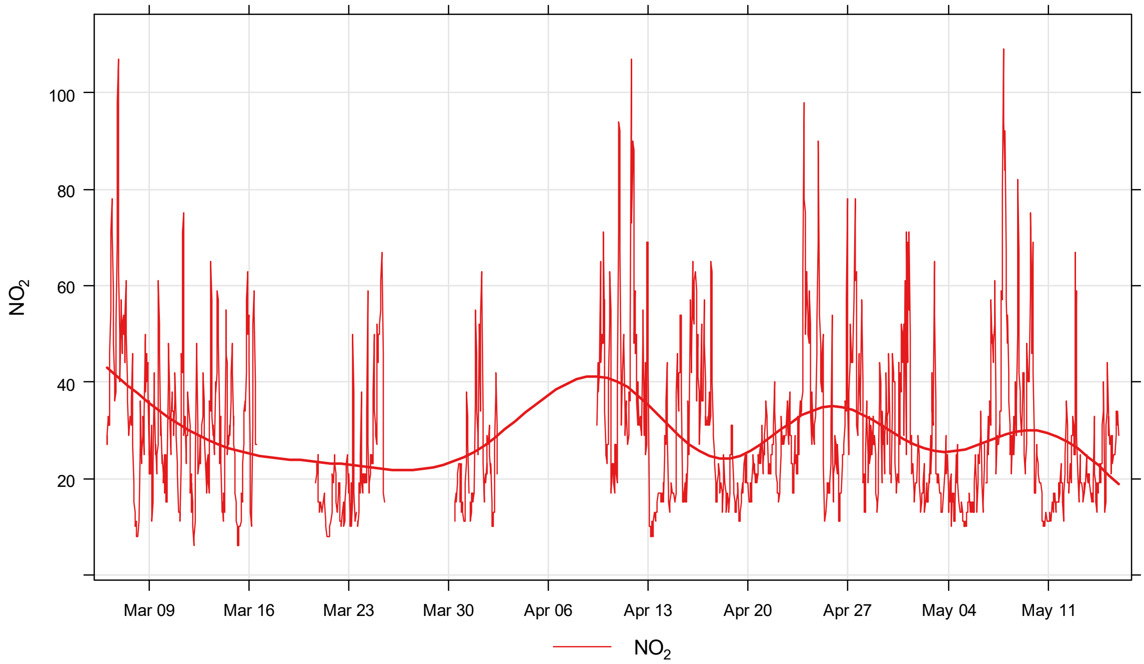


Figure 8: Thomas Lewis Way automatic traffic count site (closest proxy traffic count to Onslow Rd) – Time series of daily average traffic flow (veh/day) 16th March to 15th May 2020

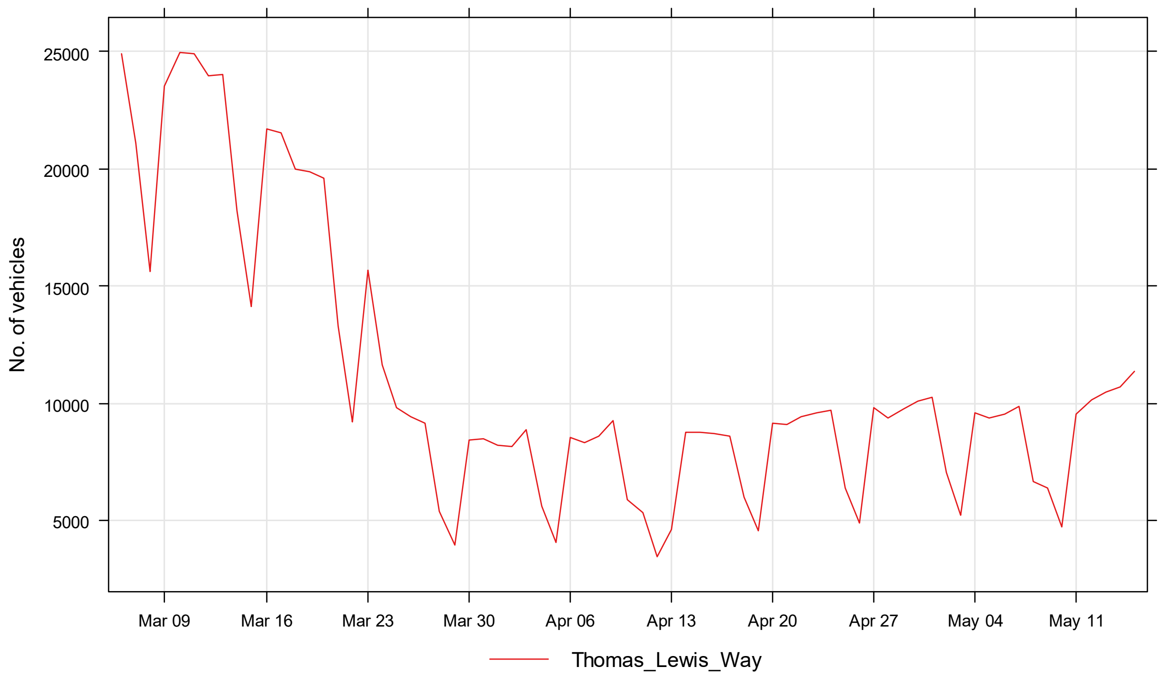
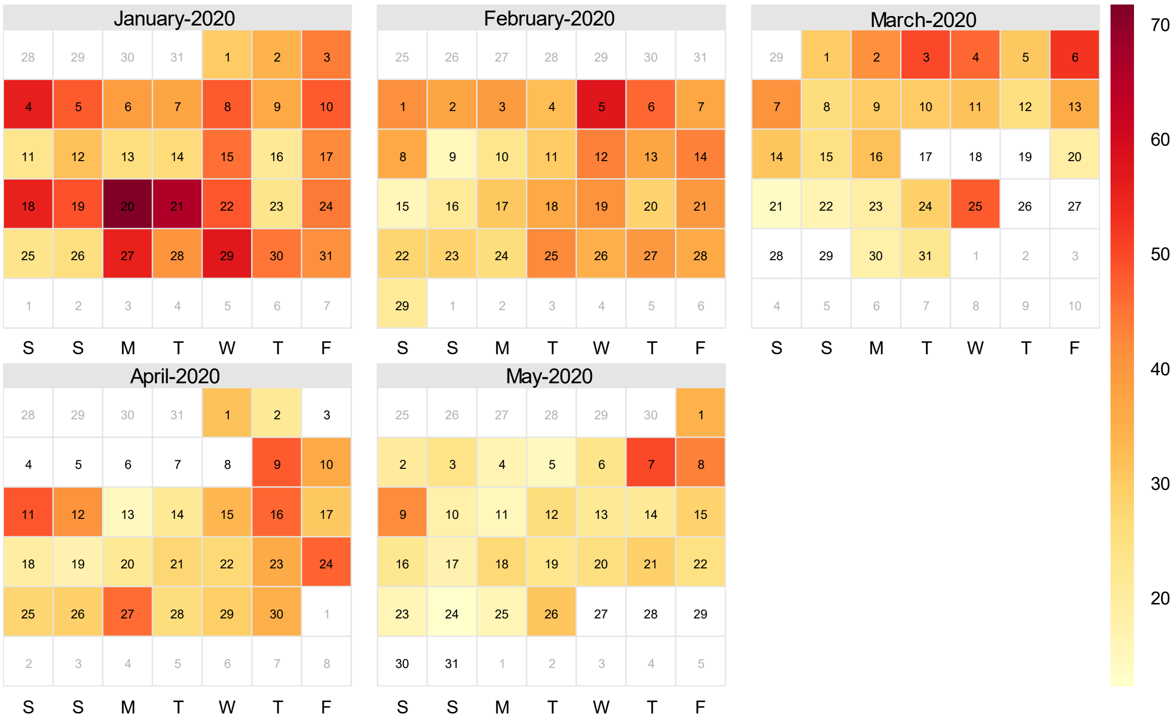
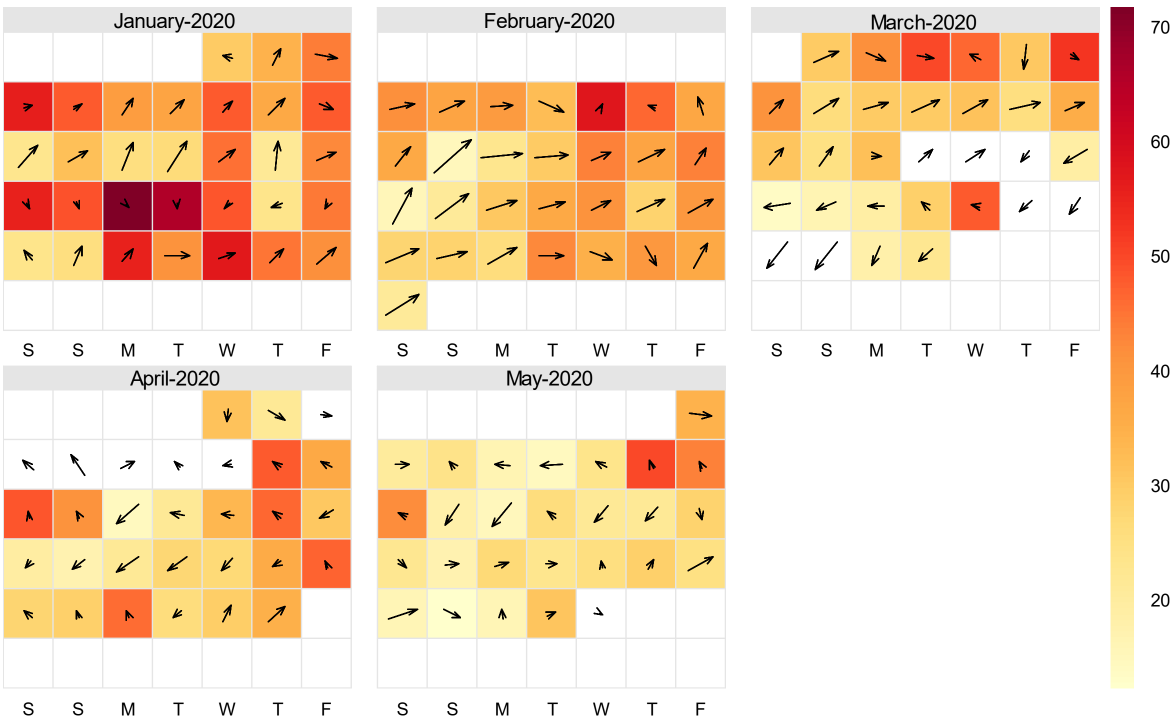


Figure 9: Southampton Onslow Road (roadside) analyser (provisional) measured NO_2 daily mean calendar plots - January to May 2020 (lower plot shows wind direction and speed vectors)





2.2.1.3 Victoria Road (roadside)

A time-series plot showing hourly measured NO_2 concentrations at the Victoria Road air quality measurement site during the period 6th March 2020 to 15th May 2020 is presented in Figure 10. There was no traffic count data available that represented a reasonable proxy for traffic at Victoria Road, it is reasonable to assume that a similar reduction in traffic occurred during the lockdown as at other locations in the city.

Again it is difficult to see any clear change in NO_2 concentrations that can be linked with the reduction in road traffic activity following the lockdown. The Victoria Road analyser is located a few metres to the west of Victoria Road.

Measured daily average NO_2 calendar plots for the Victoria Road site are presented in Figure 11. Similar to the calendar plots for at both the A33 and Onlslow Road measurement sites, the highest daily average NO_2 concentrations at Onslow Road during the lockdown period were measured on the same days when low winds speeds were observed and dispersion of nearby emissions was likely to be poor.

Similar peak periods at all three sites occurred during:

- 6th to 12th April
- April 16th
- April 27th
- May 7th to 9th

Figure 10: Victoria Road (roadside) analyser Time series of (provisional) measured NO_2 hourly mean concentrations ($\mu g.m^{-3}$) 16th March to 15th May 2020

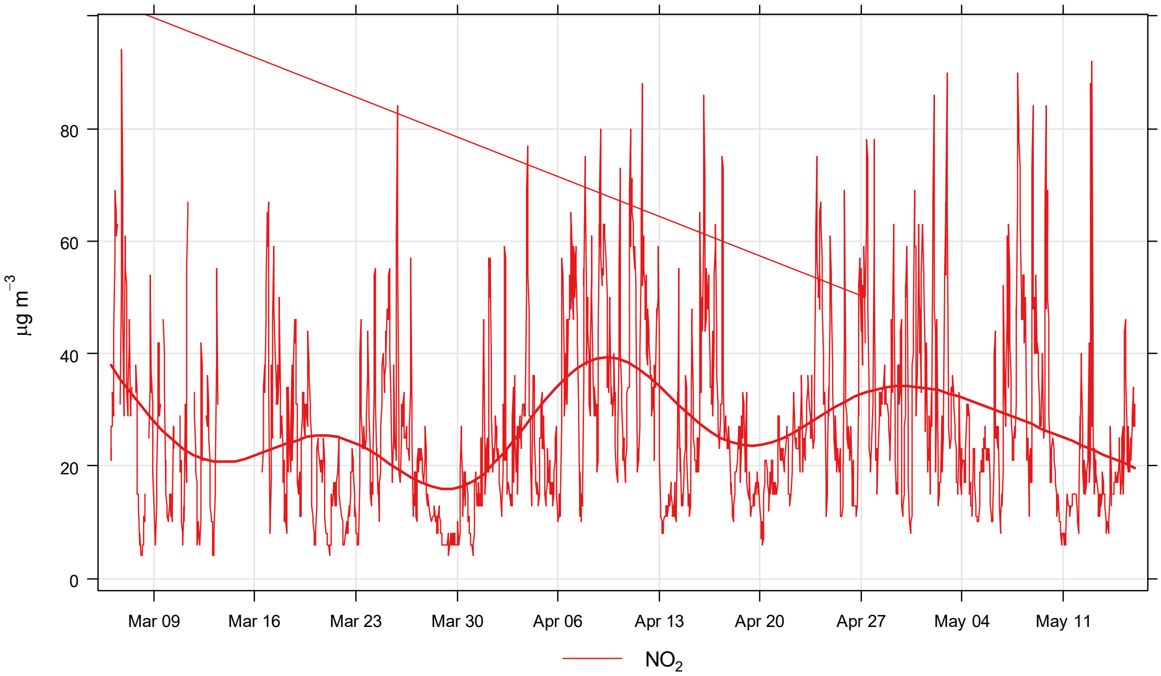
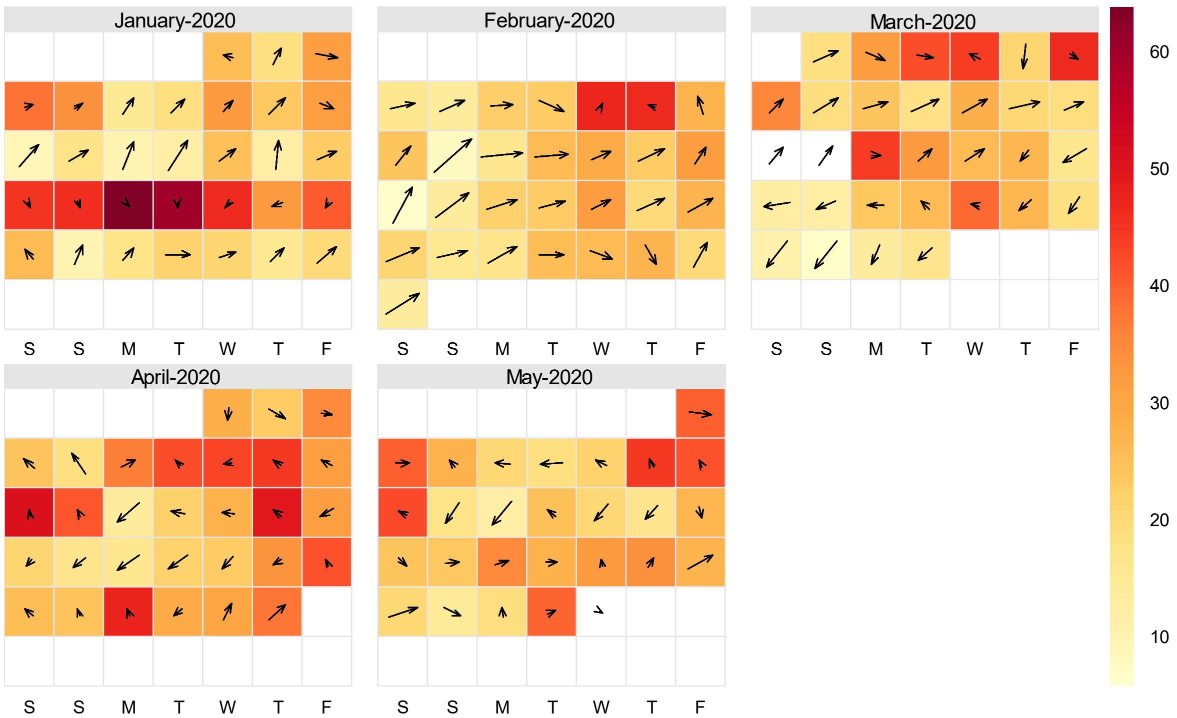


Figure 11: Southampton Victoria Road (roadside) analyser (provisional) measured NO_2 daily mean calendar plots - January to May 2020 (lower plot shows wind direction and speed vectors)



2.2.2 Southampton Centre AURN (Urban Centre) measurement site

Time-series plots showing hourly measured NO_2, PM_{10}, and $PM_{2.5}$ concentrations at the Southampton Centre AURN air quality measurement site during the period 6th March 2020 to 15th May 2020 are presented in Figure 12 followed by calendar plots for NO_2 in Figure 13.

At the urban centre measurement site, we see a similar pattern in the peak periods for all pollutants measured; and there is no clear trend apparent from these time series plots that relates to the significant reduction in traffic activity that occurred from March 16th and March 23rd.

Similar to the NO_2 calendar plots at the roadside measurement sites, the highest daily average NO_2 concentrations measured at Southampton Centre during the lockdown period were measured on the same days when in general, low winds speeds were observed and dispersion of nearby emissions was likely to be poor.

Figure 12: Southampton Centre AURN - Time series of (provisional) measured NO_2, PM_{10} and $PM_{2.5}$ hourly mean concentrations (µg.m-3) during lock-down period 16th March to 15th May 2020

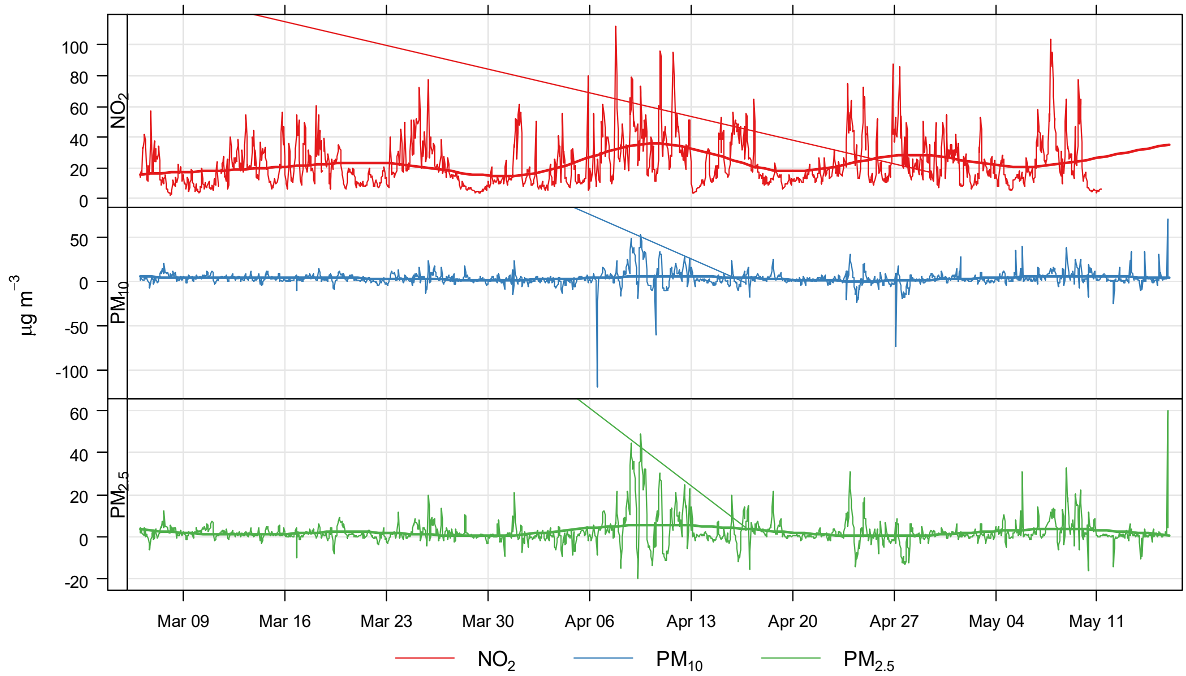
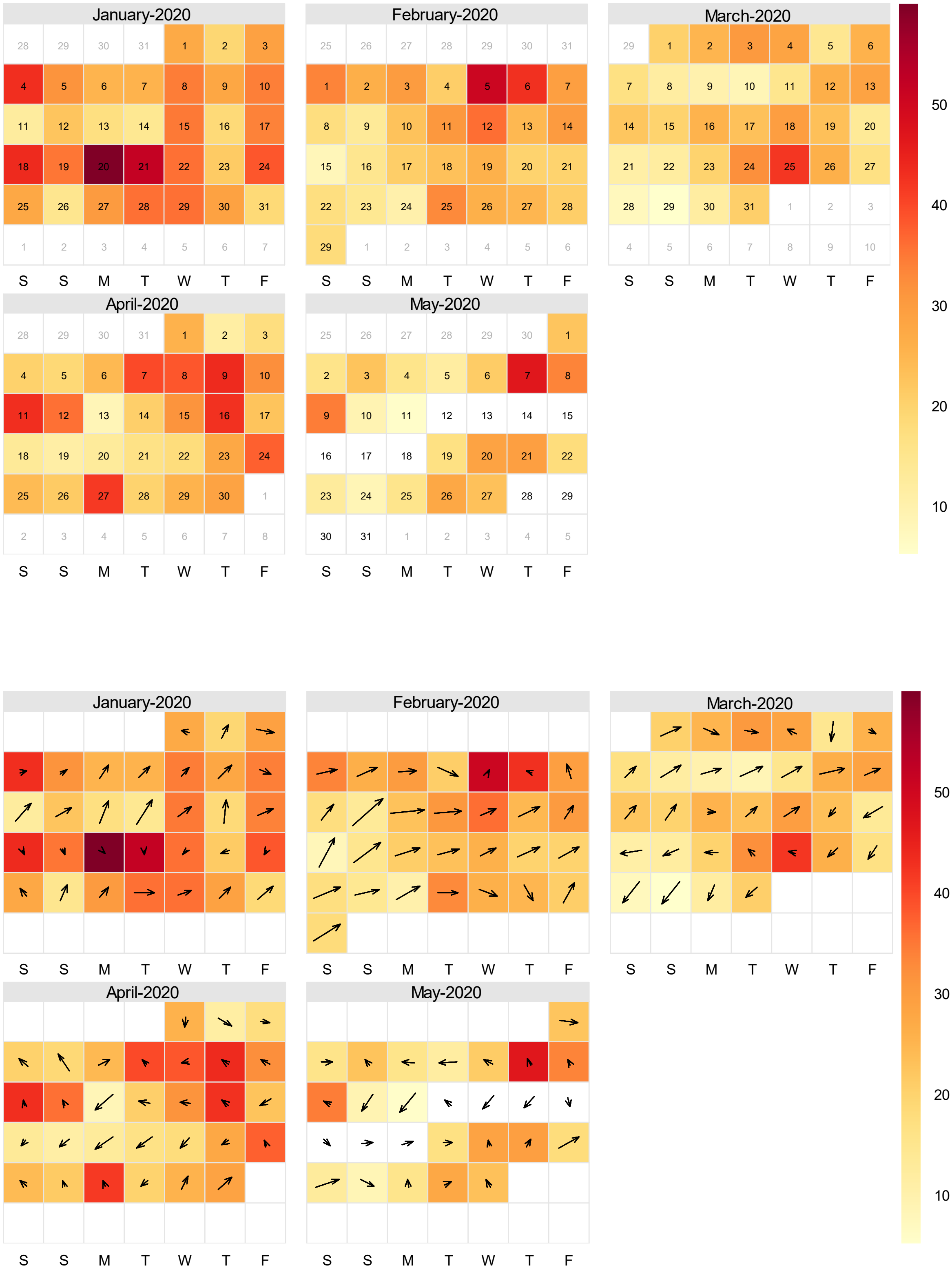


Figure 13: Southampton Centre AURN (urban centre) analyser (provisional) measured NO_2 daily mean calendar plots January to May 2020 (lower plot shows wind direction and speed vectors)



2.2.3 Summary of observations from time-series analysis

The time-series analysis of the data so far indicates:

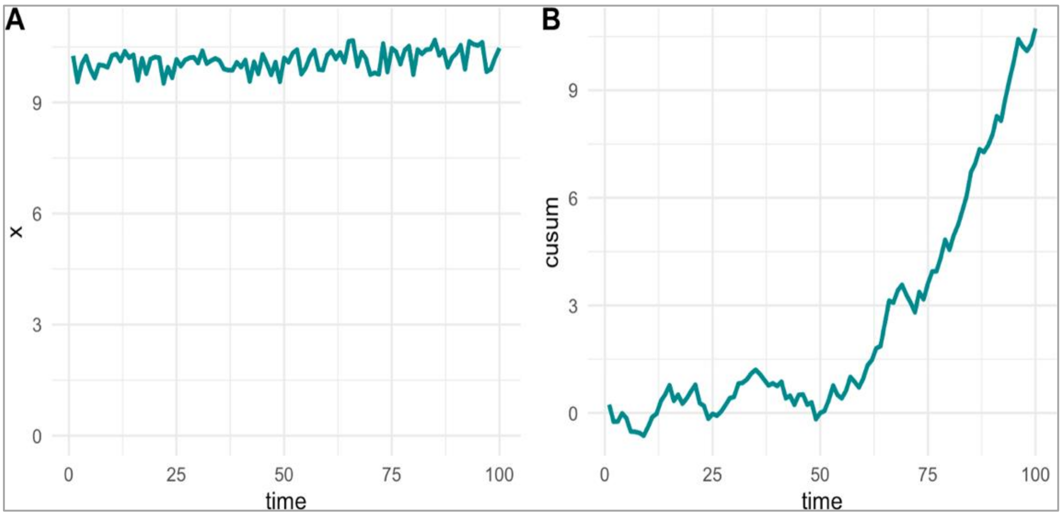
- Daily vehicle journeys decreased significantly from March 16th onwards; and by the beginning of April, weekday counts appear to be around 20 to 30% of the counts observed in early March. Daily counts then slowly increased throughout April and early May.
- There is no clear trend apparent from all of the pollutant measurement time series plots that relates to the significant reduction in traffic activity that occurred from March 16th and March 23rd.
- Peak concentrations of all pollutants were measured at all measurement sites during the same periods in the lock down.
  - April 6th to 12th
  - April 16th
  - April 27th
  - May 7th to 9th
- During each of these periods, low winds speeds were observed, hence dispersion of nearby emissions was likely to be poor.

2.3 Time series vs Cusum plots

In addition to the time series plots presented above, the analysis in this report also considers how measured concentrations deviate from business as usual (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 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.

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 14 the original time series is shown by the plot to of the left of the plot. It is not clear from this plot when a change may have occurred. By plotting the cusum of values (section B of the plot)), 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 14: Example of a cusum analysis.



In (A) 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. B 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.

Time series and cusum plots for each of the measurement sites for NOx and NO_2, PM_{10} and $PM_{2.5}$, 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.

2.3.1 NOx and NO_2

General reductions in measured NOx concentrations during the lockdown period when compared with the pre-lockdown period are apparent from the time series plots (Figure 15) at the three roadside measurement sites. This is not as apparent for the Southampton Centre urban background/centre time series.

The cusum plots presented in Figure 16 indicate that measured NOx concentrations did reduce at all of the Southampton measurement sites when compared with the modelled BAU.

For NO_2, as demonstrated in Section 2.2 above, it is much less clear from the time series plots if there is an overall reduction in measured concentrations when the lockdown was implemented. The cusum plots assist with this and similar to NOx, also indicate that measured NO_2 concentrations did reduce at all sites when compared with the modelled BAU.

The decline in measured NO_2 was not as significant as the decline in NOx emissions at the Victoria Road site; this may however be due to some uncertainty in the measurements as the data used for the analysis has not been ratified/quality assured.

Another cusum plot presented in Figure 19 compares the two AURN Southampton sites with other UK AURN NO_2 measurement sites, of which nearby sites have been highlighted. The slope of the line showing the cumulative change in concentrations indicates there was a lower reduction in NO_2 at the Southampton Centre and A33 Roadside sites than at many other sites. The reduction at the Southampton A33 roadside site was more similar to some background or rural sites; this indicates that measured NO_2 concentrations here didn't follow the same trend as other UK roadside sites during the lockdown.

Figure 15: Measured NOx concentrations - times series February to May 27th 2020

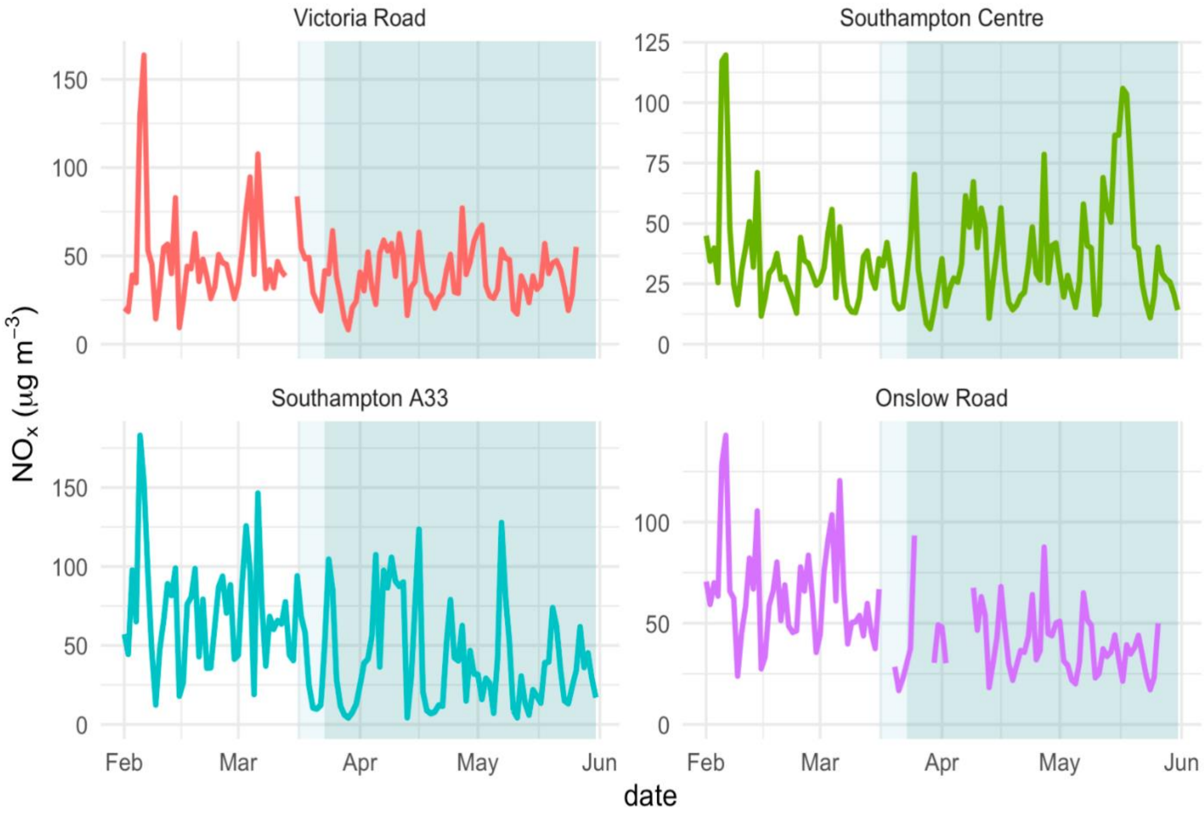


Figure 16: Measured NOx concentrations – cusum analysis

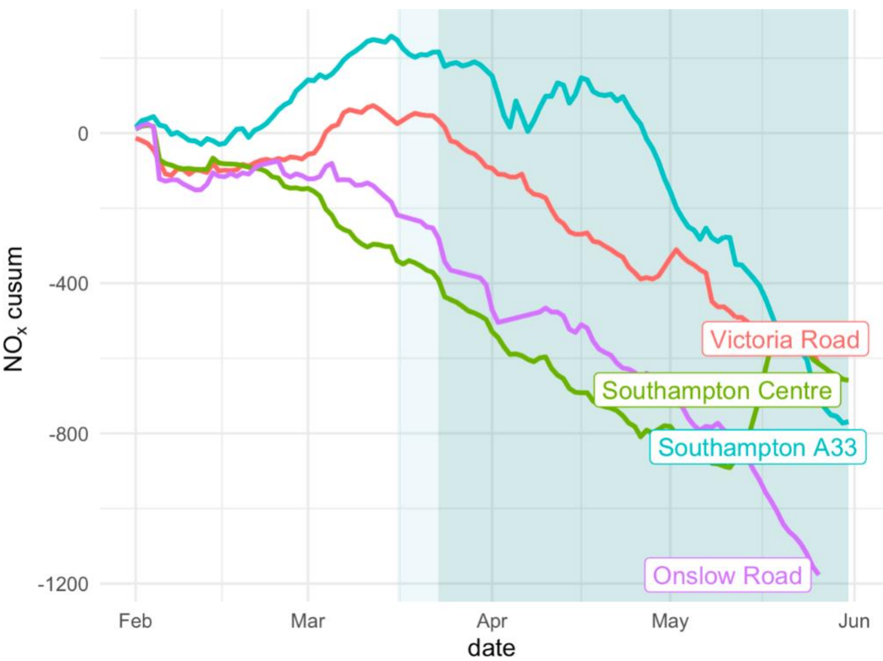


Figure 17: Measured NO_2 concentrations - times series February to May 27th 2020

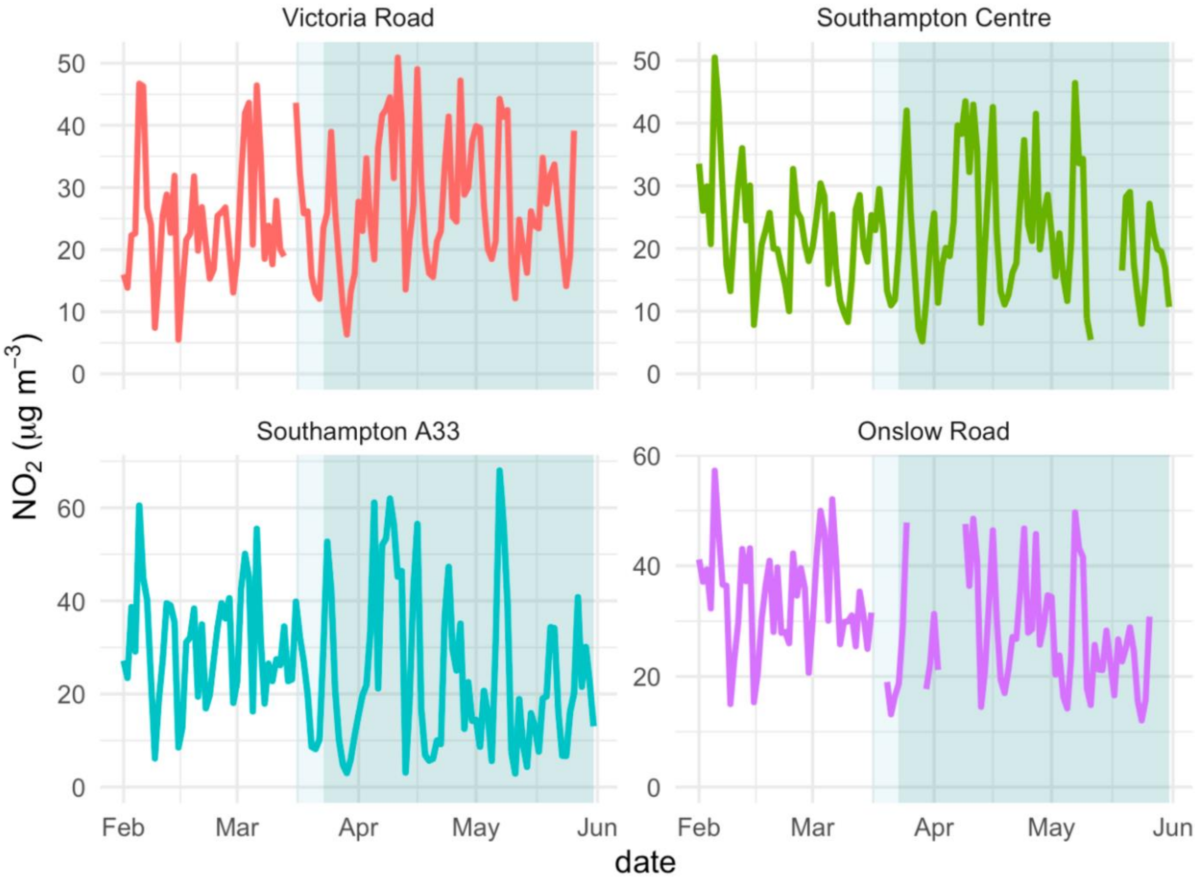


Figure 18: Measured NO_2 concentrations – cusum analysis

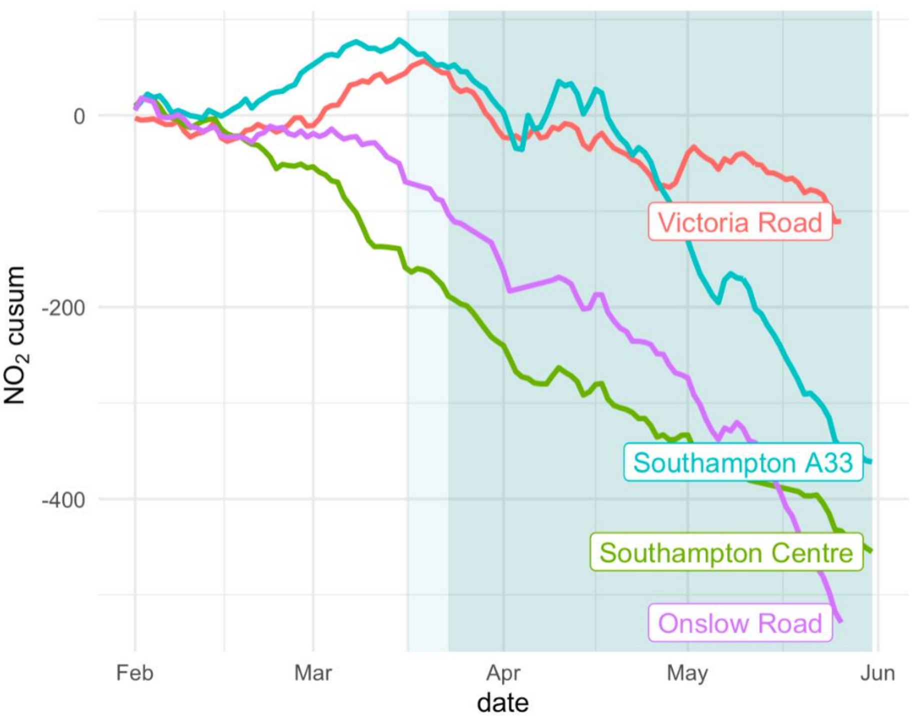
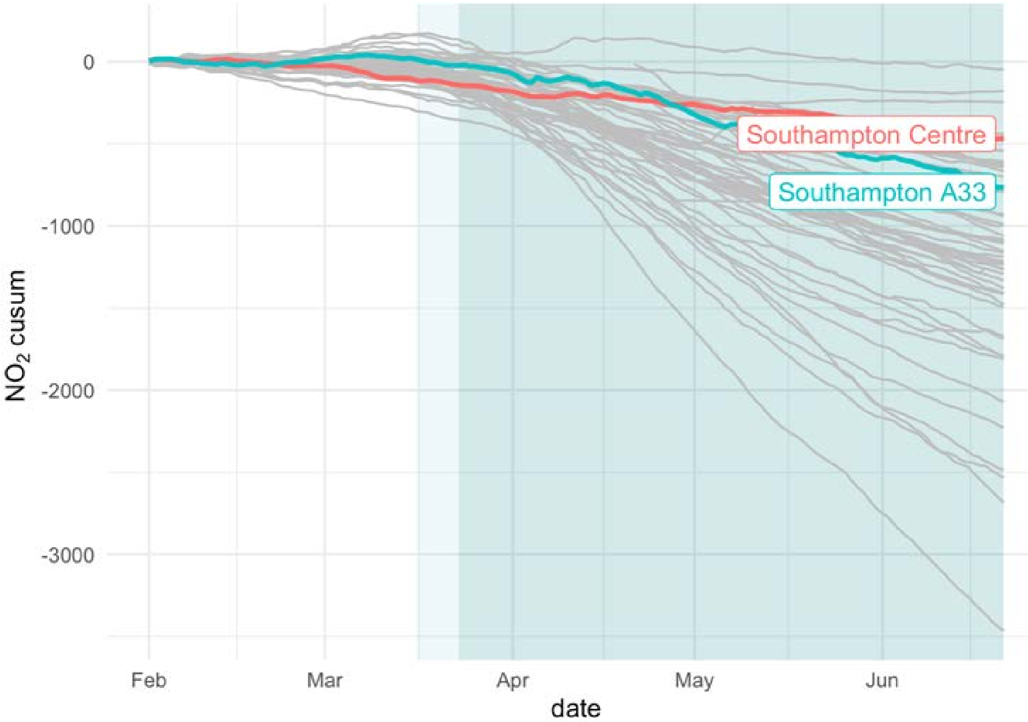


Figure 19: Cusum analysis of measured NO_2 concentrations – Southampton AURN sites vs 60 other UK AURN measurement sites



2.3.1.1 Mean NOx and NO_2 reduction

To put the magnitude of the decrease into perspective, the mean concentrations of NOx and NO_2 for measured during the lockdown vs the modelled business as usual concentrations are presented in Figure 20 and Figure 21 respectively. The percentage change represents the differences between measured and BAU concentrations. In general, the roadside sites show a larger relative decrease compared to the urban background Southampton centre site; indicating the reduction in road traffic activity did reduce measured NOx/NO_2 concentrations. Although not obvious at face value from the time-series analysis and calendar plots, which indicate that fluctuations in measured concentrations seem to be more closely related to the weather conditions than traffic activity; this demonstrates the effectiveness of the cusum analysis.

The mean reduction in measured NO_2 concentrations at the Victoria Road site (1%) is very low when compared with the mean reduction in NOx concentrations (29%); this corresponds with the cusum plots for NO_2 at this site where it appears that NO_2 did not reduce in the same way as the other roadside sites in Southampton. As stated in the introductory ‘Limitations’ section, this may be due to some uncertainty with the measurements as the data used for the analysis had not been ratified/quality assured when conducting this analysis.

Figure 20: Mean measured NOx reduction during lockdown vs business as usual

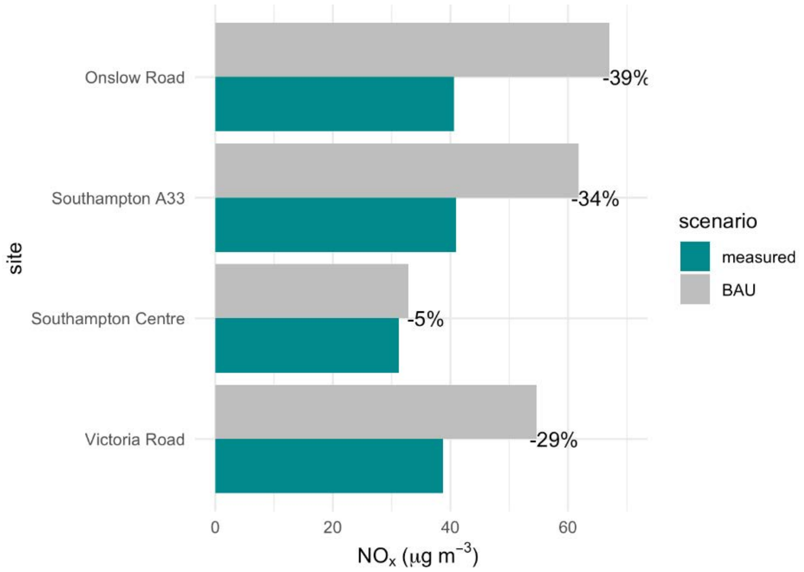
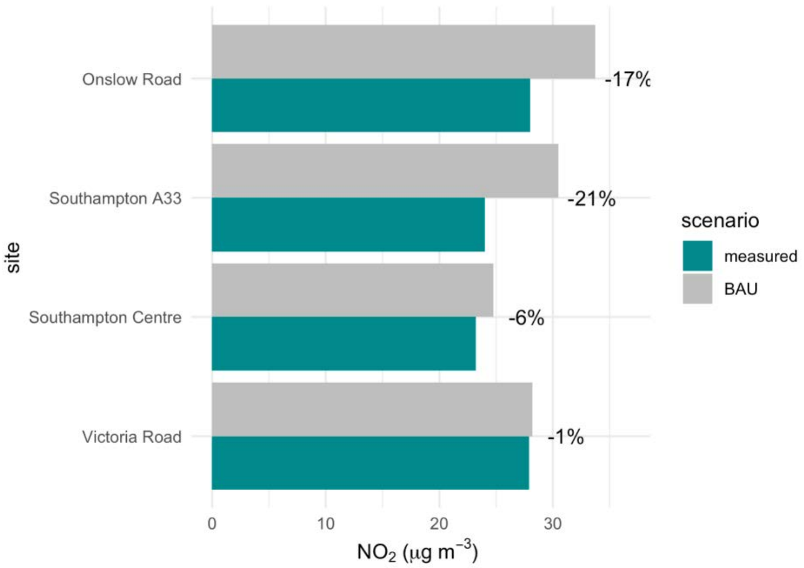


Figure 21: Mean measured NO_2 reduction during lockdown vs business as usual



2.3.2 PM_{10} and $PM_{2.5}$

To understand the likely influence of local sources on PM_{10} and $PM_{2.5}$ concentrations, it was necessary to remove the influence of fluctuations in background particulate concentrations; which tend to make up a large proportion of total measured particulates. The background contribution to particulate concentrations is influenced by regional and transboundary effects, including secondary particulate formation via various atmospheric chemistry processes. The non-background increment for both PM_{10} and $PM_{2.5}$ at the Southampton sites was calculated by subtracting the corresponding hourly mean background concentrations from the Chilbolton rural background site.

It is not clear from the time series plots (Figure 22 and Figure 24) if there is an overall reduction in measured PM_{10} and $PM_{2.5}$ concentrations when the lockdown was implemented.

The PM_{10} cusum plot presented in Figure 23 indicates that measured PM_{10} concentrations appear to increase at the Southampton A33 measurement site when compared with the modelled BAU; whereas at Southampton Centre PM_{10} concentrations are more consistent with BAU but still indicate a slight increase overall.

For $PM_{2.5}$ the cusum plot presented in Figure 25 indicates that $PM_{2.5}$ concentrations declined when compared with BAU in the initial stages of the lockdown; but then increased in a short period from early to mid-April.

Figure 22: Measured PM_{10} concentrations (non-background increment) - times series February to May 27th 2020

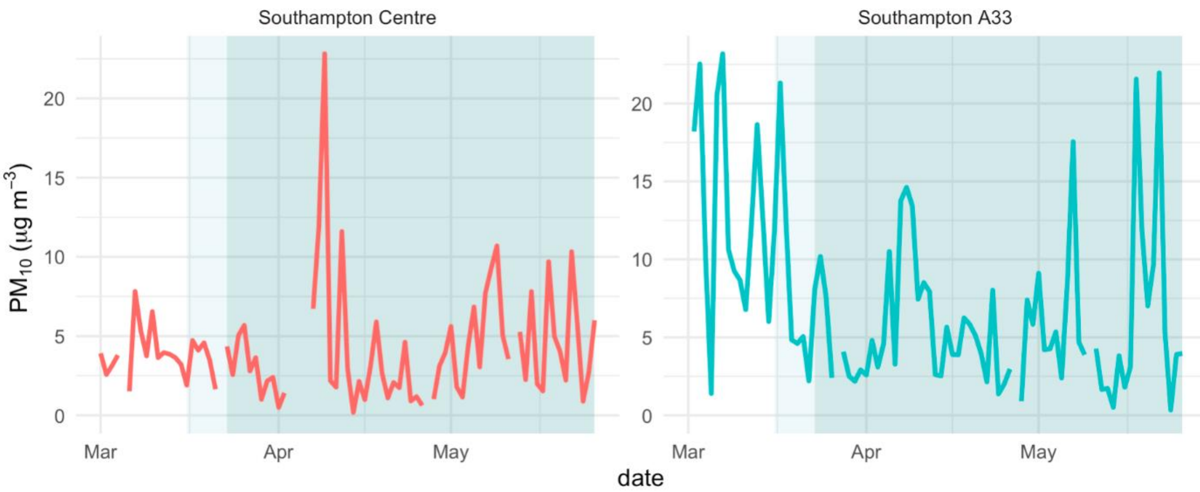


Figure 23: Measured PM_{10} concentrations (non-background increment) – cusum analysis

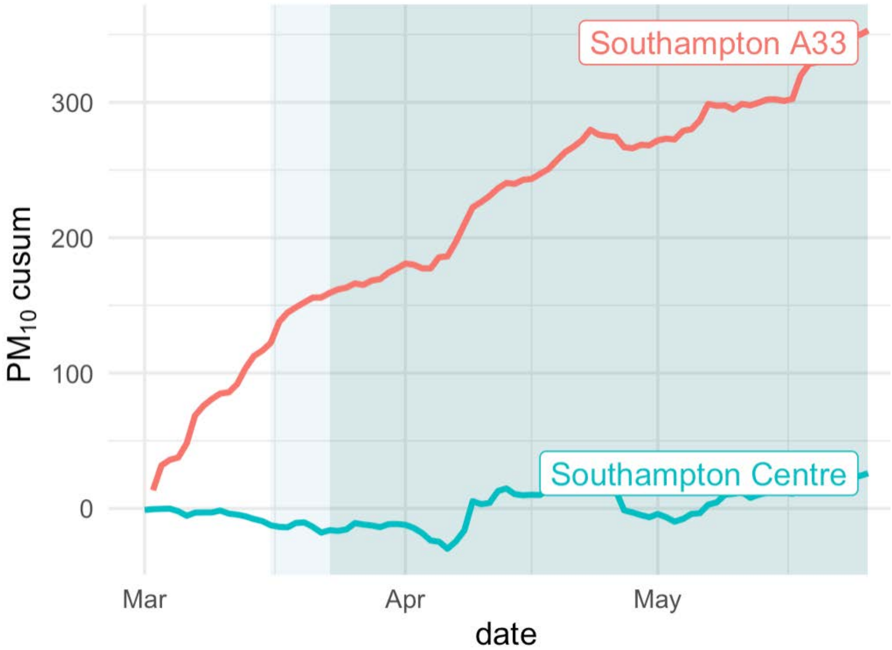


Figure 24: Measured $PM_{2.5}$ concentrations (non-background increment) - times series February to May 27th 2020

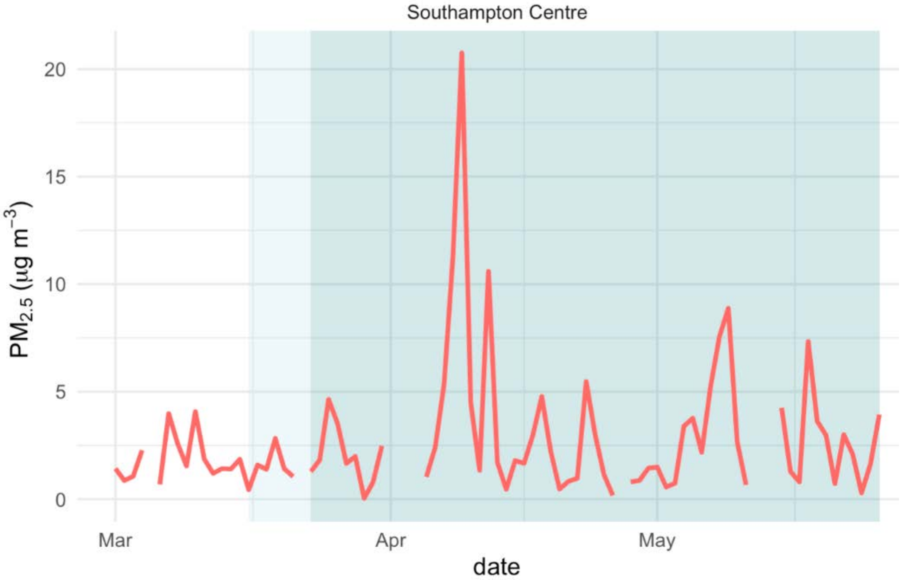
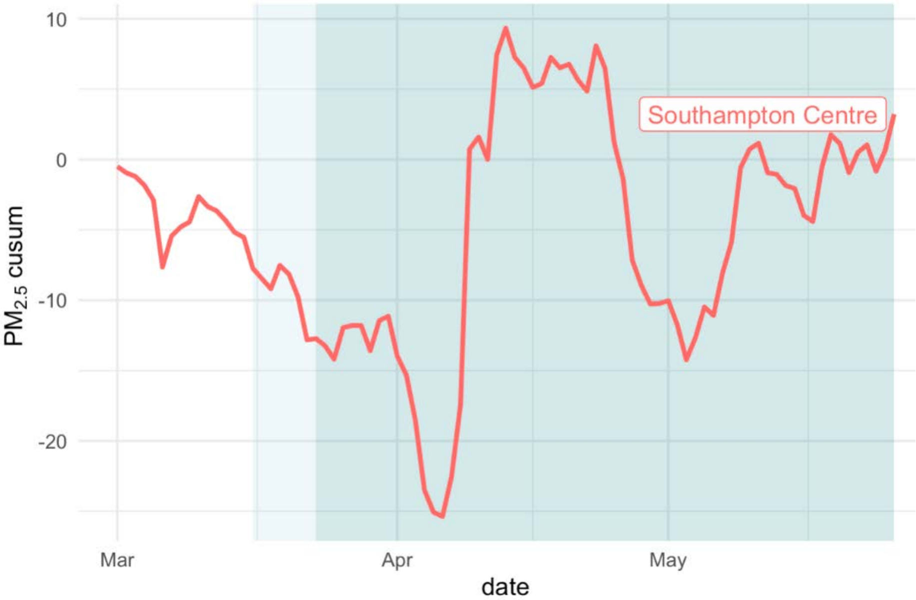


Figure 25: Measured $PM_{2.5}$ concentrations (non-background increment) – cusum analysis



2.3.2.1 Mean PM_{10} and $PM_{2.5}$ reduction

To present the overall change in concentrations compared to BAU in simpler terms, the mean concentrations of PM_{10} and $PM_{2.5}$ after lockdown for measured vs modelled business as usual concentrations are presented below.

At all sites the cusum analysis indicates there was an increase in measured PM_{10} and $PM_{2.5}$ concentrations.

Figure 26: Mean difference in measured PM_{10} during lockdown vs business as usual

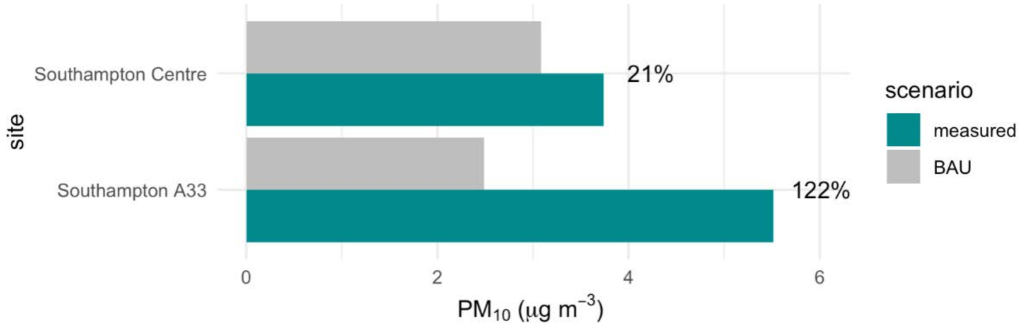
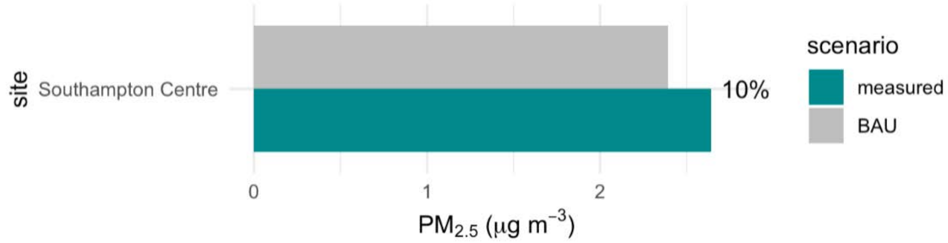


Figure 27: Mean difference in measured $PM_{2.5}$ during lockdown vs business as usual



2.4 Directional analysis – Polar plots

The openair polarPlot function plots a bivariate polar plot whereby concentrations are presented as varying by wind speed and wind direction. This analysis is useful when considering the potential direction of pollutant sources and other factors that may affect dispersion.

PolarMaps have also been produced to show the polar plots superimposed on a leaflet Open Street Map web interface at the location of each air quality measurement site. This helps to provide some additional context regarding the direction of potential pollutant sources relative to each measurement site. We reproduce a high level image of the Polar map outputs in this report; and also provide html files that can be viewed using a web browser. When viewing the html files and connected to the internet, the user can use the typical zoom and pan functionality of the web map interface when viewing the polar plots.

2.4.1 NOx and NO_2

To provide a reasonable indication of a typical year, initially we present polar plots for NOx and NO_2 during all of 2019 (Figure 28 and Figure 29); followed by plots during the 2020 pre-lockdown period, then during the lock-down period.

High level Polar map outputs are also presented in Appendix 1; which we recommend are examined in more detail using the html files supplied along with this report (please view using a web browser).

The NOx and NO_2 polar plots for all of 2019 indicate that:

- At the Southampton A33 site – the highest NO_2 concentrations are typically measured when the wind is from a south easterly direction. This corresponds with a direction roughly perpendicular to the route of the A33 which is likely to be the main source of NOx and NO_2 at this roadside measurement site i.e. during south easterly winds emissions are blown straight along the road towards the analyser.
- At the Onslow Road measurement site which is located a few metres east of Onslow Rd in an open area next to a car park; NO_2 concentrations appear to be at a maximum when the wind is coming from the south west or the north. Maximum concentrations seem to correspond with the location of the analyser relative to the road and hence traffic emissions; and the nearby junction to the southwest; some re-circulation effects during westerly winds may also be apparent here as there is a continuous row of buildings on the opposite side of the road from the analyser.
- At Victoria Road, the analyser is located close to a building façade facing north east. Measured NO_2 concentrations are at a maximum when the wind is coming from the direction of Victoria Rd i.e. south east or from the south west. This could indicate either re-circulation is occurring when the wind from the south west blows over the building façade, or there is another source of NO_2 to the south west of the analyser location.
- At the Southampton Centre AURN site, there is no clear direction for which the highest NO_2 concentrations are measured, the minimum concentrations are measured when the wind blows from a north westerly direction.

During the pre-lockdown period in 2020 the polar plots indicate that NO_2 concentrations measured during various wind speeds and directions broadly correspond with what was observed in 2019 at all of the roadside measurement sites i.e. nothing unusual happened.

During the lock-down period the polar plots indicate:

- At the Southampton A33 site – the highest NO_2 concentrations were still typically measured when the wind is from a south easterly direction throughout the range of low to high wind speeds observed. The correlation between wind direction and the highest measured concentrations corresponds with what was observed during 2019 and the pre-lockdown period. The polar plot indicates that road traffic emissions from the A33 were likely to have been the predominant source of NO_2 at this measurement site during the lock-down period. The polar plot could also indicate that there was another source of NO_2 emissions to the south east but there is no definitive evidence of this.

- Similarly, at Onslow Road; the maximum NO_2 concentrations during the lock down were measured when the wind was from a south westerly direction i.e. towards the junction at the southern end of the road. Compared to the 2019 and pre-lockdown plots, the influence of emissions to the north and west are not as apparent at Onslow Road. This may reflect the reduction in overall traffic flows and hence reduction in traffic queueing on the southbound carriageway of Onslow Road immediately adjacent to the analyser while waiting for the traffic lights to change.
- At Victoria Road there appears to be a correlation between westerly winds and the highest NO_2 concentrations measured during the lockdown period. As discussed above this could be attributable to re-circulation of road traffic emissions from Victoria Road occurring when the wind from the south west blows over the building façade. However, in this case as measured NO_2 concentrations seem relatively high when there is a wind from the west, but there is no clear indication of elevated concentrations when the wind was from an easterly direction; i.e. emissions from road traffic on Victoria Road should be apparent in these conditions. This may provide evidence that there was another source of NO_2 to the south west of the Victoria Road analyser during the lock down period.

Figure 28: NOx polar plot - Southampton 2019 (all year)

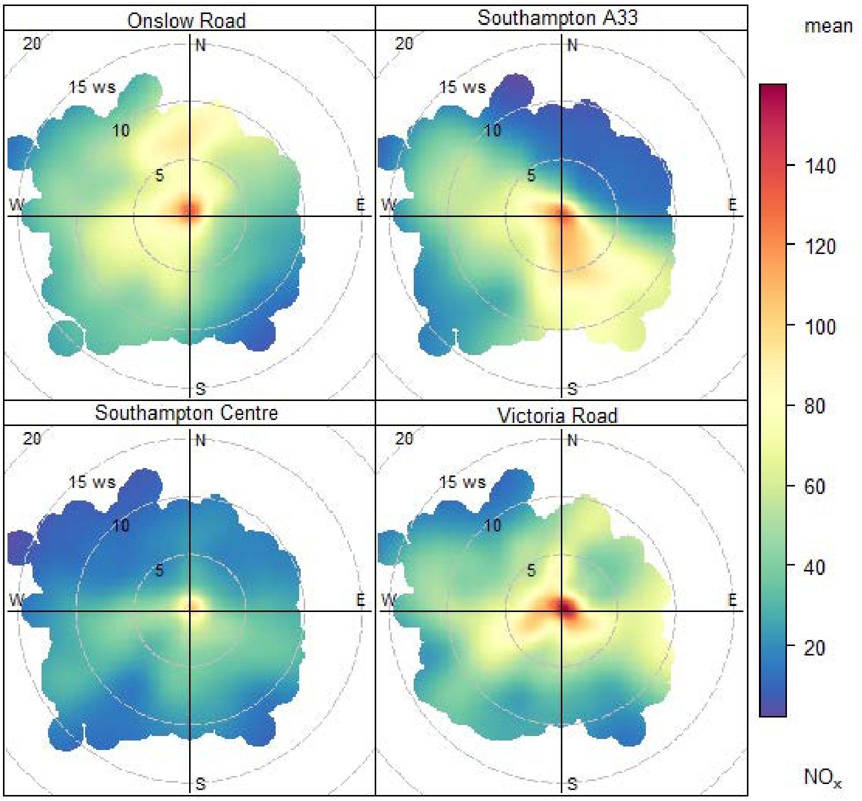


Figure 29: NO_2 polar plot - Southampton 2019 (all year)

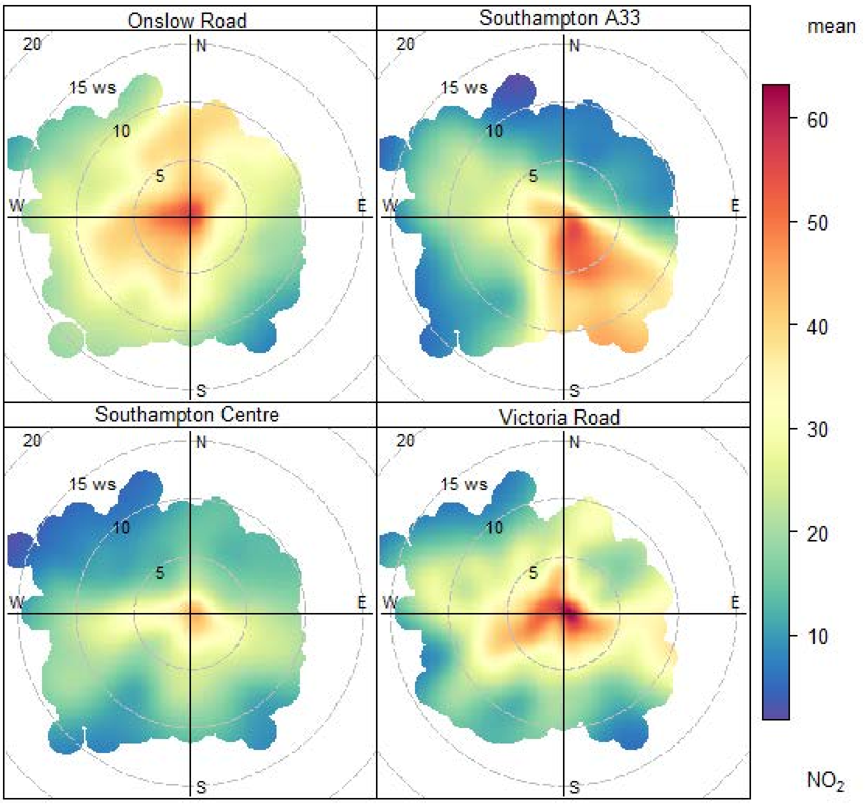


Figure 30: NOx polar plot - Southampton 2020 pre-lockdown period (1st Jan to 20th Mar 2020)

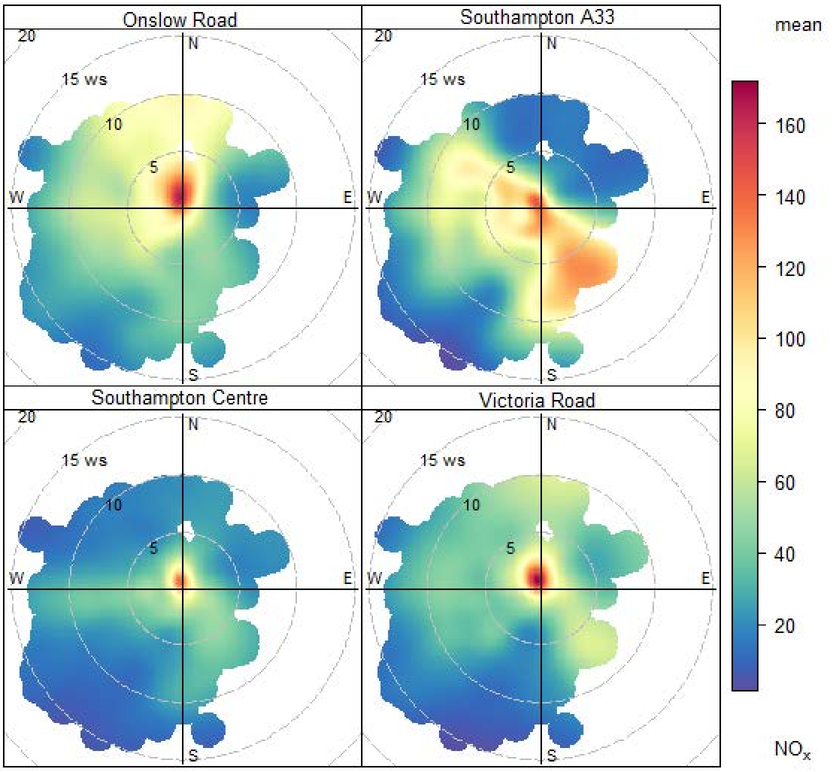


Figure 31: NO_2 polar plot - Southampton 2020 pre-lockdown period (1st Jan to 20th Mar 2020)

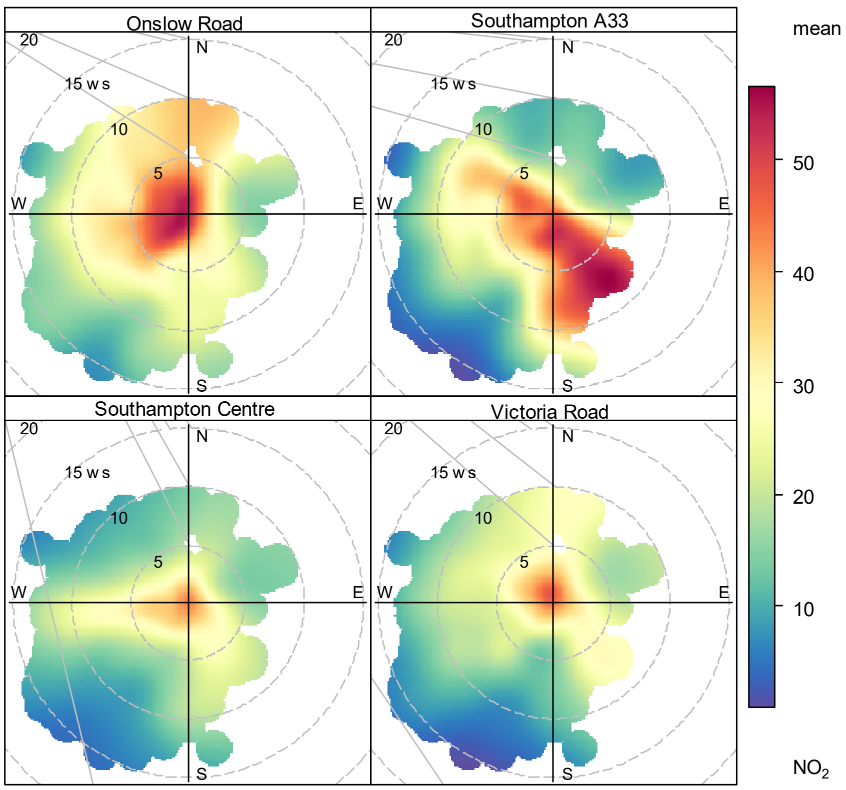


Figure 32: NOx polar plot - Southampton during lockdown period (23rd March to 10th May 2020)

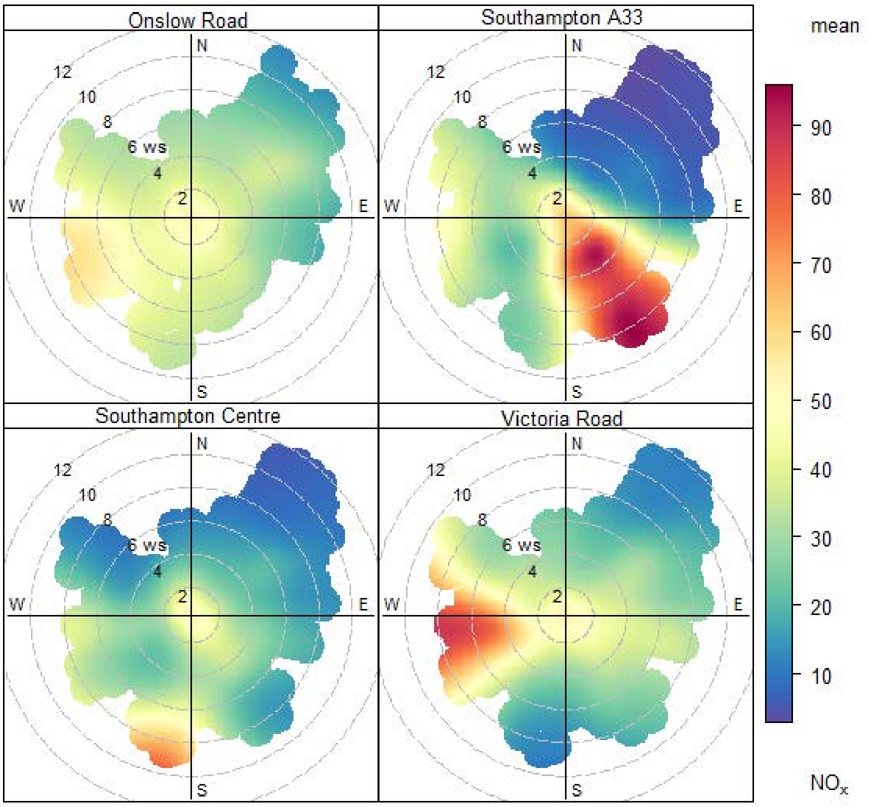
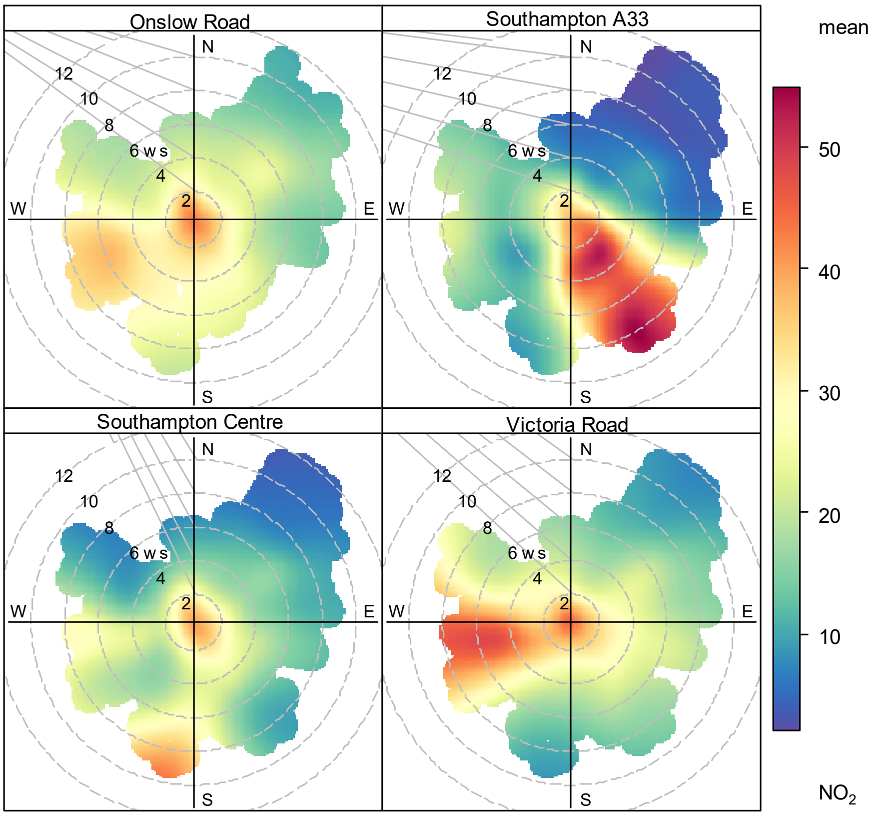


Figure 33: NO2 polar plot - Southampton during lockdown period (23rd March to 10th May 2020)



2.4.2 PM_{10} and $PM_{2.5}$

PM_{10} is measured at the Southampton A33 (roadside) AURN site and the Southampton Centre (urban centre/background) AURN site. $PM_{2.5}$ is measured at the Southampton Centre site only.

Polar plots representing PM_{10} and $PM_{2.5}$ measurements during all of 2019 are presented here; followed by plots during the 2020 pre-lockdown period, then during the lock-down period. As with the time series and cusum analysis, the background component of PM_{10} and $PM_{2.5}$ has been discounted before running the polarPlot function in openair. This aims to provide information regarding localised sources rather than regional or transboundary fluctuations in fine particulate concentrations.

High level Polar map outputs are also presented in Appendix 1; which we recommend are examined in more detail using the html files supplied along with this report (please view using a web browser).

The polar plots for all of 2019 indicate:

- There is a dominant source of PM_{10} at both measurement sites when strong south westerly winds are observed. As Southampton is on the coast this may be attributable to natural sources e.g. sea salt particles formed during choppy sea conditions; or saltation in the estuary flats. There is no other clear potential anthropogenic local source of fine particulates south west of both measurement sites.
- At the A33 measurement site, similar to NO_2, some of the maximum PM_{10} concentrations are measured when the wind is from a south easterly direction which is roughly perpendicular to the route of the A33; which is likely to be the main source of exhaust and non-exhaust particulate emissions from road traffic at this site i.e. during south easterly winds vehicle emissions are blown straight along the road towards the analyser.
- There is no clear indication of $PM_{2.5}$ emissions from any direction influencing measurements at the Southampton Centre site. Throughout 2019 the highest $PM_{2.5}$ concentrations were measured during very low wind speeds.

During the pre-lockdown period in 2020 the polar plots indicate that

- The maximum PM_{10} and $PM_{2.5}$ concentrations were measured at Southampton Centre during strong south westerly winds; as per comments above this may indicate natural sources of particulates. There are however other potential man-made sources of PM directly south west of the Southampton Centre site
- Particulate emissions from the section of the A33 north west of the A33 measurement site are apparent during winds from that direction.

During the lock-down period the polar plots indicate:

- At the Southampton A33 site – some of the highest PM_{10} concentrations were measured when the wind is from a south easterly direction throughout the range of low to high wind speeds observed. Similar to NO_2 there is a correlation between wind direction and the route of the A33; this was also apparent from the polar plots representing all of 2019 and the pre-lockdown period.
- At the Southampton A33 site during the lock down, the polar plots also show higher PM_{10} concentrations being measured during strong south westerly winds.
- The polar plot indicates that road traffic emissions from the A33 are likely to be the predominant source of PM_{10} at this measurement site during the lock-down period. This does not mean that there are definitely no other sources of particulate matter further south west of the site than the road that are influencing measured concentrations; but it is what we would expect to see at a roadside site with that road alignment.
- At the Southampton Centre site, the $PM_{2.5}$ polar plot during lock down indicates that the maximum concentrations were measured during light to moderate speed south easterly winds. This is not apparent in the ‘all of 2019’ or pre-lockdown polar plots; so could indicate a localised source of fine particulates that was present to the south east of the town centre during the lockdown period.

Figure 34: PM_{10} polar plot - Southampton 2019 (all year)

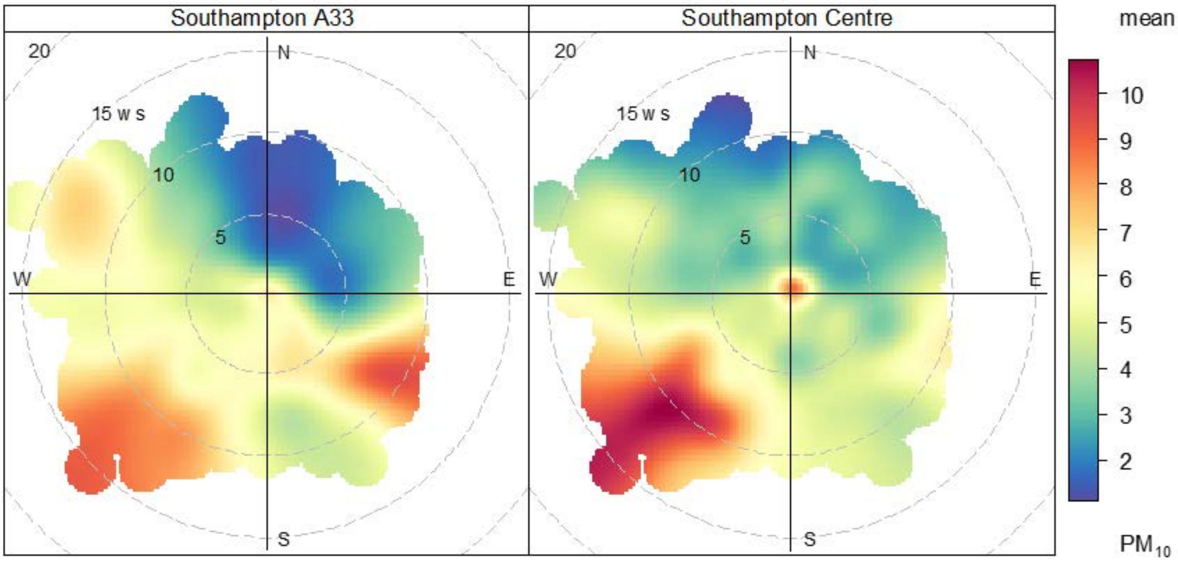


Figure 35: $PM_{2.5}$ polar plot - Southampton Centre 2019 (all year)

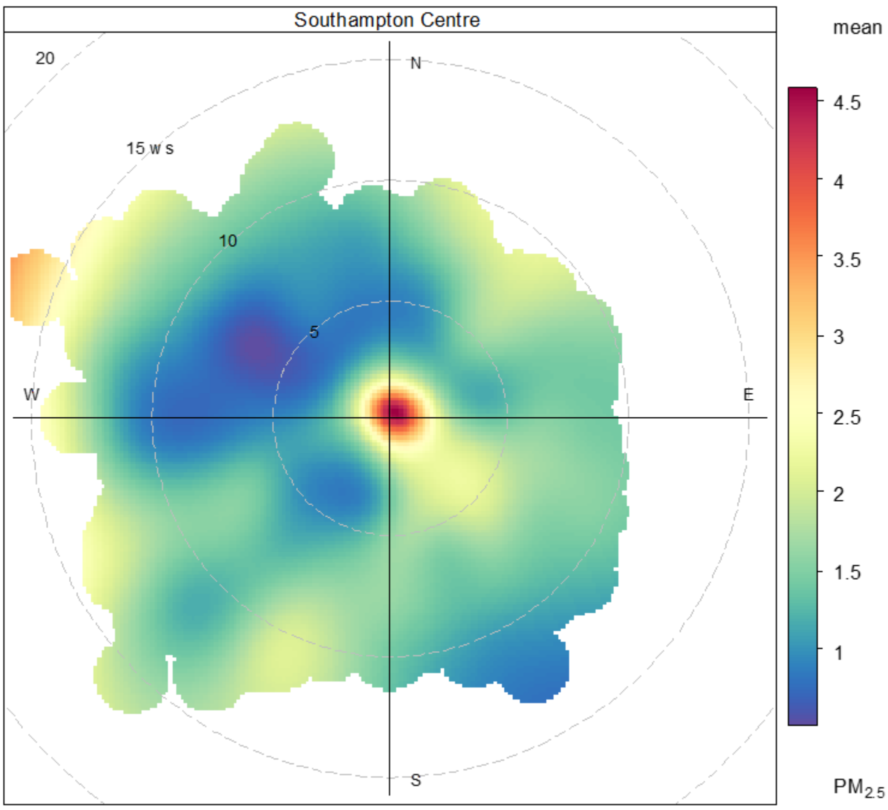


Figure 36: PM_{10} polar plot - Southampton 2020 pre-lockdown period (1st Jan to 20th Mar 2020)

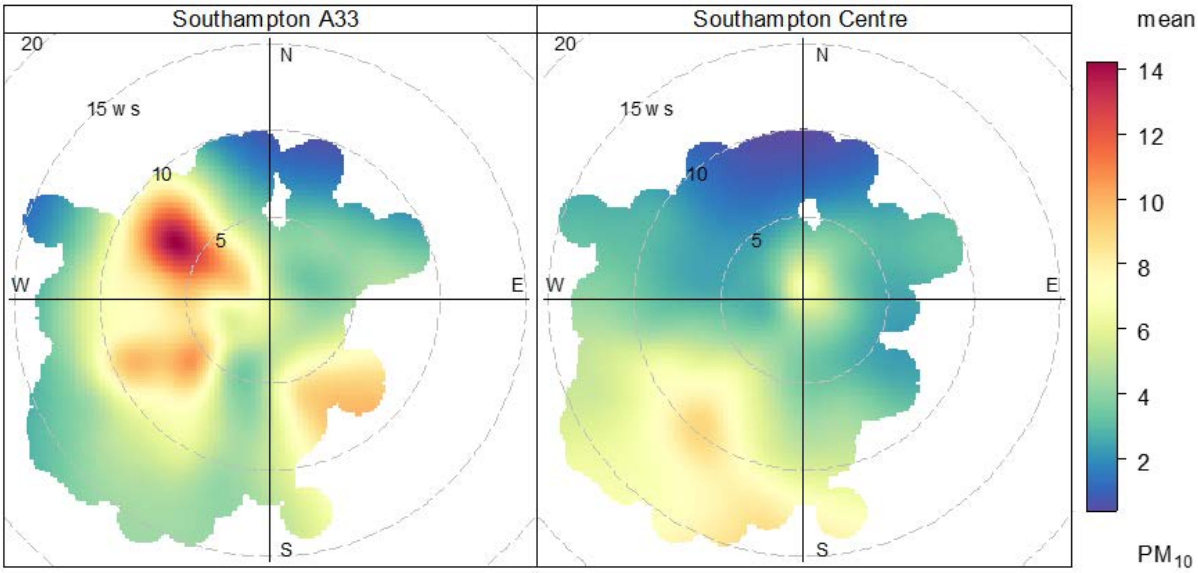


Figure 37: $PM_{2.5}$ polar plot - Southampton Centre 2020 pre-lockdown period (1st Jan to 20th Mar 2020)

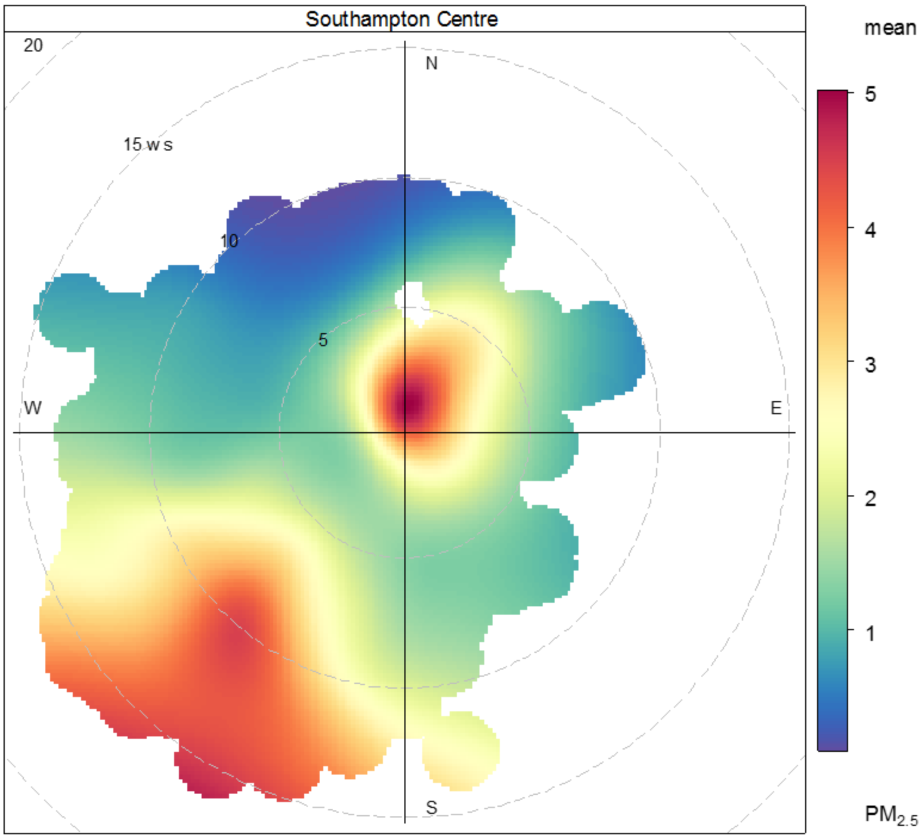


Figure 38: PM_{10} polar plot - Southampton during lockdown period (23rd March to 10th May 2020)

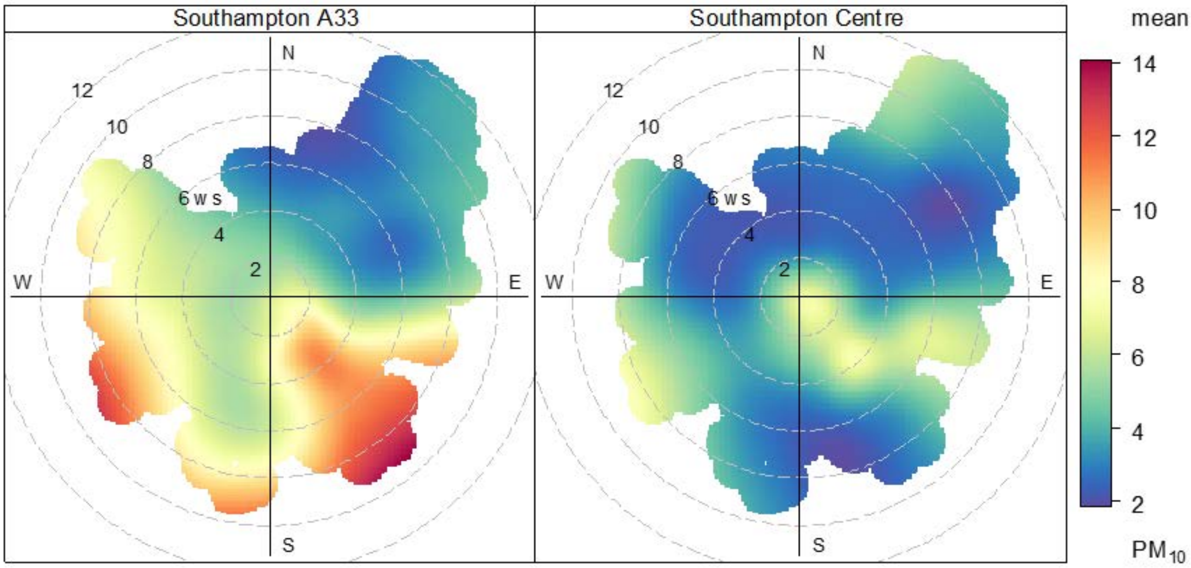
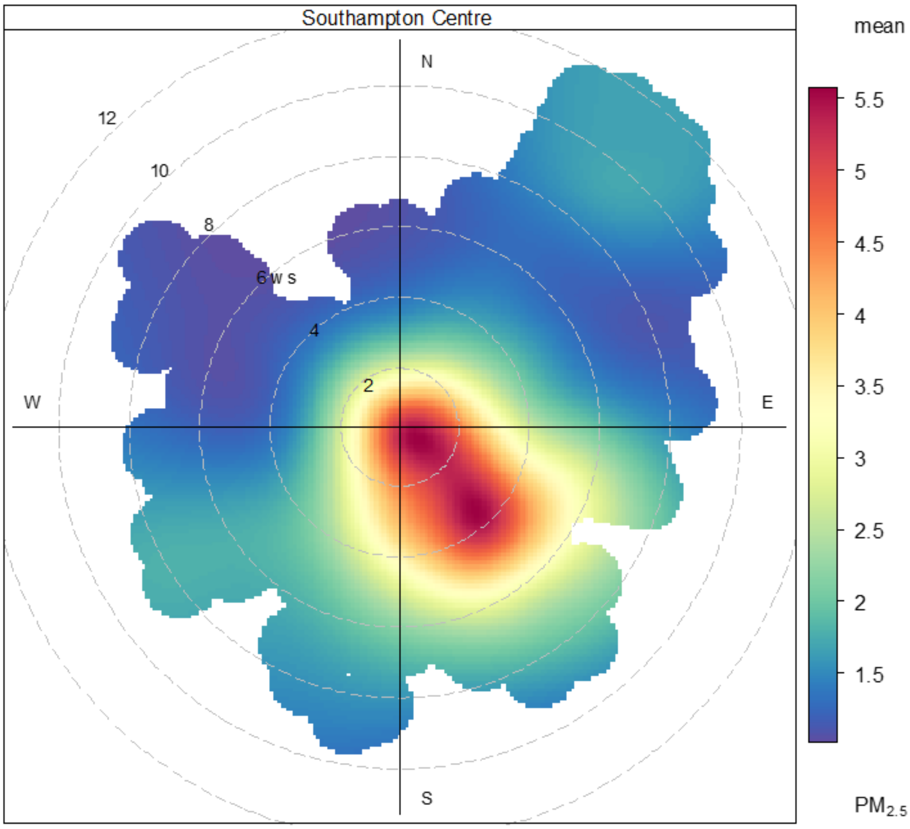


Figure 39: $PM_{2.5}$ polar plot - Southampton during lockdown period (23rd March to 10th May 2020)



3 Summary and conclusions

We have presented various analysis of air quality measurements in Southampton and how they relate to wind direction and speed. The analysis has been conducted using the R package openair and a cumulative sum (cusum) method.

Weather conditions

The analysis includes consideration of weather conditions; which is very important and particularly relevant when comparing pollutant measurements between two distinct time periods - in this case ‘pre-lockdown’ and ‘during-lockdown’ conditions. The main observations from examination of wind speed and direction that influence the comparison were:

- South westerly winds were predominant during the pre-lockdown period, whereas north easterly winds were more frequent during the initial days of the lock-down and in May
- The highest south westerly wind speeds occurred during February and early March prior to the lockdown.

Time series analysis

Pollutant measurements at the roadside air quality measurement sites in Southampton have initially been presented as time-series plots in comparison with automatic traffic count (ATC) data from the nearest relevant location with available data. These time-series plot are further supplemented using calendar plots showing daily average pollutant concentrations, wind speed and direction.

It is clear from the time-series plots of road traffic activity that the daily number of vehicles in Southampton decreased significantly from March 16th onwards; and by the beginning of April, weekday counts appear to be around 20 to 30% of the counts observed in early March. Daily counts then slowly increase throughout April and early May to approximately 30 to 45% of the pre-lock down observations.

At roadside locations NOx, PM_{10} and $PM_{2.5}$ concentrations are directly related to localised emissions from vehicles. Intuitively, it would be reasonable to expect to see reduced local traffic activity directly lead to reduced measured pollutant concentrations. The NOx, NO_2 and PM_{10} time-series covering the lock-down period do not however show a decrease in measured pollutant concentrations. The peak concentrations for all pollutants appear to have been measured during the week in April (6th to 13th) when traffic activity was at its lowest.

It is however important to consider the influence of weather conditions. The peak concentrations measured during that week in April also coincide with low average wind speeds; which at the Southampton A33 site were in a direction roughly perpendicular to the route of the A33 i.e. from the south east.

Examination of the calendar plots at all roadside measurement sites in Southampton indicate that, in general, the highest NO_2 concentrations measured in 2020 so far, are on days when the average wind speed was low i.e. dispersion of emissions was poor. Peak concentrations of all pollutants were measured at all measurement sites during the same periods in the lock down.

In summary, the time-series analysis did not demonstrate a clear downward trend in pollutant measurement that corresponded with the significant reduction in traffic activity that occurred from March 16th and March 23rd. The maximum measured pollutant concentrations appear to be more related to wind speed and direction.

Time series vs cusum plots

In addition to the time series plots described above, the analysis then went on to consider how measured concentrations deviate from business as usual (BAU) using a cumulative sum (cusum) analysis. The cusum analysis accumulates the deviation in concentration from BAU, which helps to highlight possible change-points in time series. This aims to remove the effect of weather fluctuations from the analysis to provide a better indication of the effect of a change in emissions on measured pollutant concentrations.

The cusum plots presented indicate that both measured NOx and NO_2 concentrations did reduce at all of the Southampton measurement sites when compared with the modelled BAU.

Another cusum plot, which compares the two Southampton AURN measurement sites with other UK AURN sites for NO_2, indicates there was a lower reduction in NO_2 at the Southampton sites than at the bulk of other UK sites. The reduction was more similar to what was observed at some background or rural sites; which could indicate that the Southampton sites did behave differently than other UK roadside sites during the lockdown.

Although not obvious from the time-series analysis and calendar plots, which indicated that fluctuations in measured concentrations were more closely related to the weather conditions than traffic activity. The cusum analysis does indicate that in general, the roadside sites show a larger relative decrease in NOx/NO_2 concentrations when compared to the urban background Southampton centre site; indicating that the reduction in road traffic activity did reduce measured NOx/NO_2 concentrations when weather effects are discounted.

At all sites the cusum analysis indicates there was an increase in measured PM_{10} and $PM_{2.5}$ concentrations during the lockdown period when compared with BAU. It is not clear if this is attributable to natural or man-made sources; additional more detailed analysis of meteorological conditions during the periods when peak particulate concentrations were measured may provide further insight.

Directional analysis – Polar plots

Polar plots present measured pollutant concentrations varying by wind speed and wind direction. This type of analysis is useful if considering the potential direction of pollutant sources and other factors that may affect dispersion.

To provide a reasonable indication of a typical year initially we present polar plots for each pollutant during all of 2019; followed by plots during the 2020 pre-lockdown period, then during the 2020 lock-down period. We have also provided the plots on polar maps in html file format that can be interactively viewed by the reader using a web browser.

There are various and numerous conclusions from the polar plot analysis described in detail in the respective section of this report. The main highlights are:

- At the Southampton A33 site during the lock down period – the highest NO_2 concentrations were typically measured when the wind is from a south easterly direction throughout the range of low to high wind speeds observed. The correlation between wind direction and the highest measured concentrations corresponds with what was observed during 2019 and the pre-lockdown period. The polar plot indicates that road traffic emissions from the A33 may still have been the predominant source of NO_2 at this measurement site during the lock-down period. The polar plot could also indicate that there was another source of NO_2 emissions to the south east but there is no definitive evidence of this.
- At Victoria Road there appears to be a correlation between westerly winds and the highest NO_2 concentrations measured during the lockdown period. Although re-circulation of road traffic emissions should be considered, this may also provide evidence that there was another source of NO_2 to the south west of the Victoria Road analyser location during the lock down period.
- There is a dominant source of PM_{10} at both the Southampton A33 AURN and Southampton Centre AURN measurement sites when strong south westerly winds are observed. As Southampton is on the coast this may be attributable to natural sources e.g. sea salt particles formed during choppy sea conditions. There is no other clear potential anthropogenic local source of fine particulates south west of both measurement sites.
- At the Southampton Centre site, the $PM_{2.5}$ polar plot during lock down indicates that the maximum concentrations were measured during light to moderate speed south easterly winds. This is not apparent in the 'all of 2019' or pre-lockdown polar plots; so could indicate a localised source of fine particulates that was present to the south east of the town centre during the lockdown period.

Overall when trying to relate the various conclusions of the analysis to changes in road traffic and shipping activity; the following points seem relevant:

- Although not obvious from the time-series analysis and calendar plots, which indicated that fluctuations in measured concentrations were more closely related to the weather conditions than traffic activity. The cusum analysis has provided useful information regarding trends for each of the pollutants included when weather effects are discounted; this does indicate a change in local emissions from both road traffic and other activity is apparent in the measurement data.
- Possible more significantly, when compared with other UK AURN sites for NO_2, the cusum analysis indicates that the Southampton sites did behave differently than other UK roadside sites during the lockdown. This could indicate the influence of sources other than road traffic influencing measured pollutant concentrations during this period.
- The directional analysis indicates a correlation between westerly winds and the highest NO_2 concentrations measured during the lockdown period; which may be evidence of a source of NO_2 to the south west of the Victoria Road analyser location during the lock down period.

The conclusions of the analysis should be considered in context with the limitations highlighted in the introduction to the report. There may be some benefit in additional, more detailed, analysis e.g. examination of the likely change in overall NOx and primary NO_2 emissions by examining the daily HGV traffic flows on the A33 during the lockdown; or various additional analysis of shorter time periods within the lockdown when pollutant measurements were at a maximum. We would recommend any additional more detailed analysis is conducted using ratified measurement data.

Appendices

A1 Polar map screen shots

PolarMaps have been produced to show the polar plots superimposed on a leaflet Open Street Map web interface at the location of each air quality measurement site. This helps to provide context regarding the direction of potential pollutant sources relative to each measurement site.

Here, we reproduce a high level screenshot images of the Polar map outputs in this report.

We have also provided html files that can be viewed using a web browser. When viewing the html files and connected to the internet, the user can use the typical zoom and pan functionality of the web map interface to examine the polar plots.

We recommend examining the polar maps in more detail using the html files supplied along with this report (please view using a web browser).

Figure 40: NO_2 polar map- Southampton 2019 (all year)

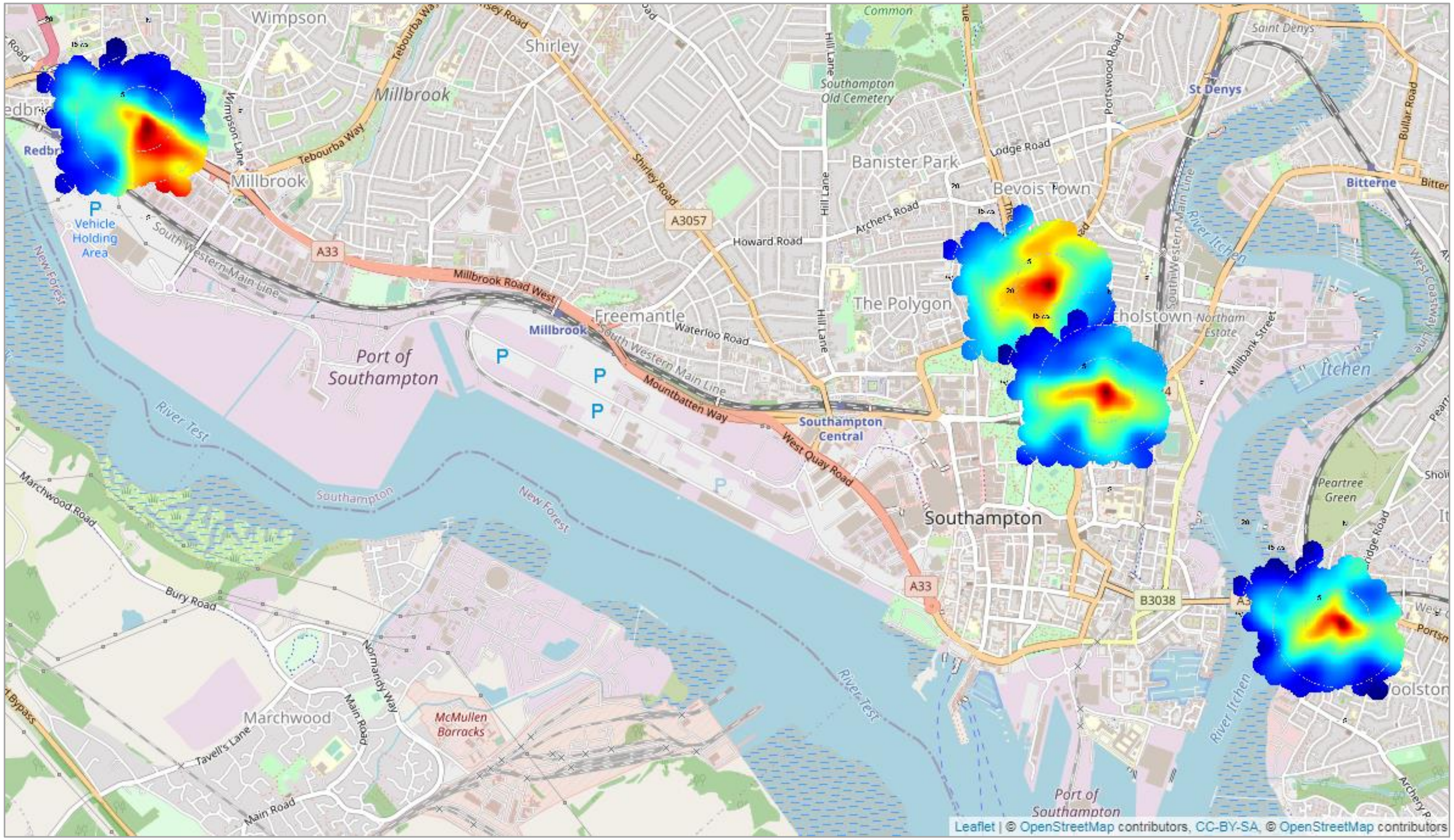


Figure 41: NO_2 polar map - Southampton 2020 pre-lockdown period (1st Jan to 20th Mar 2020)

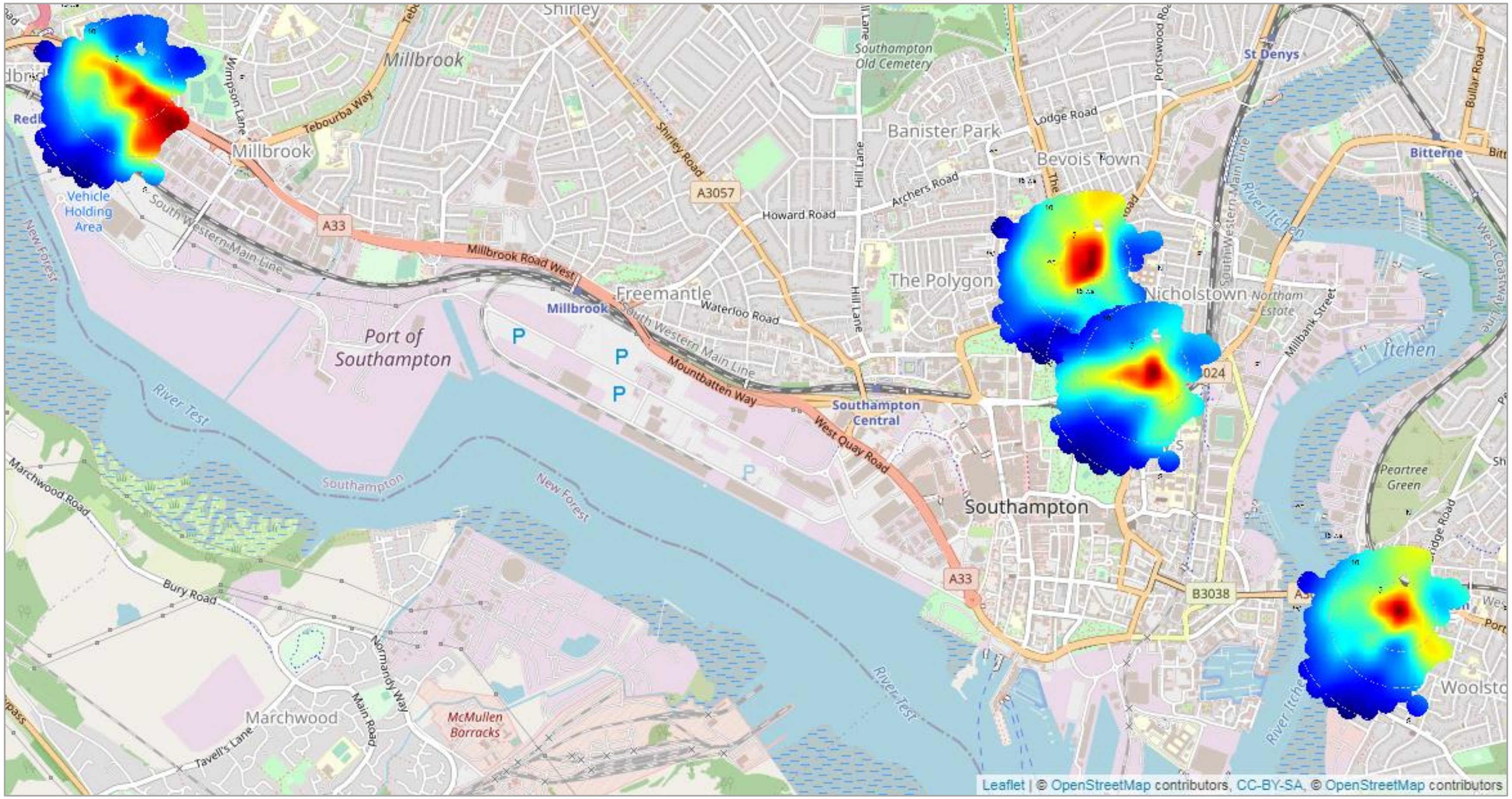


Figure 42: NO_2 polar map - Southampton during lockdown period (23rd March to 10th May 2020)

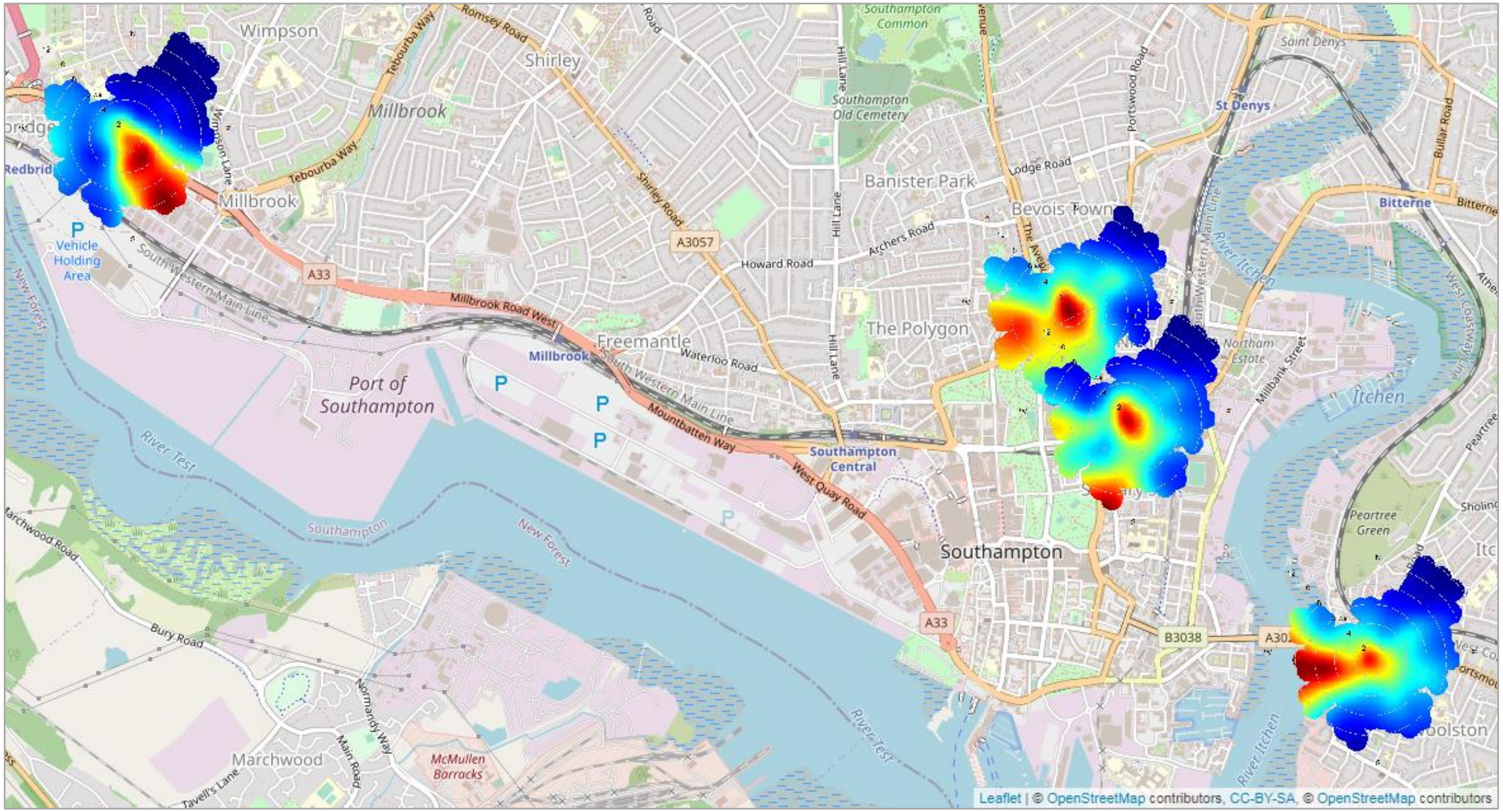


Figure 43: PM_{10} polar map - Southampton 2019 (all year)

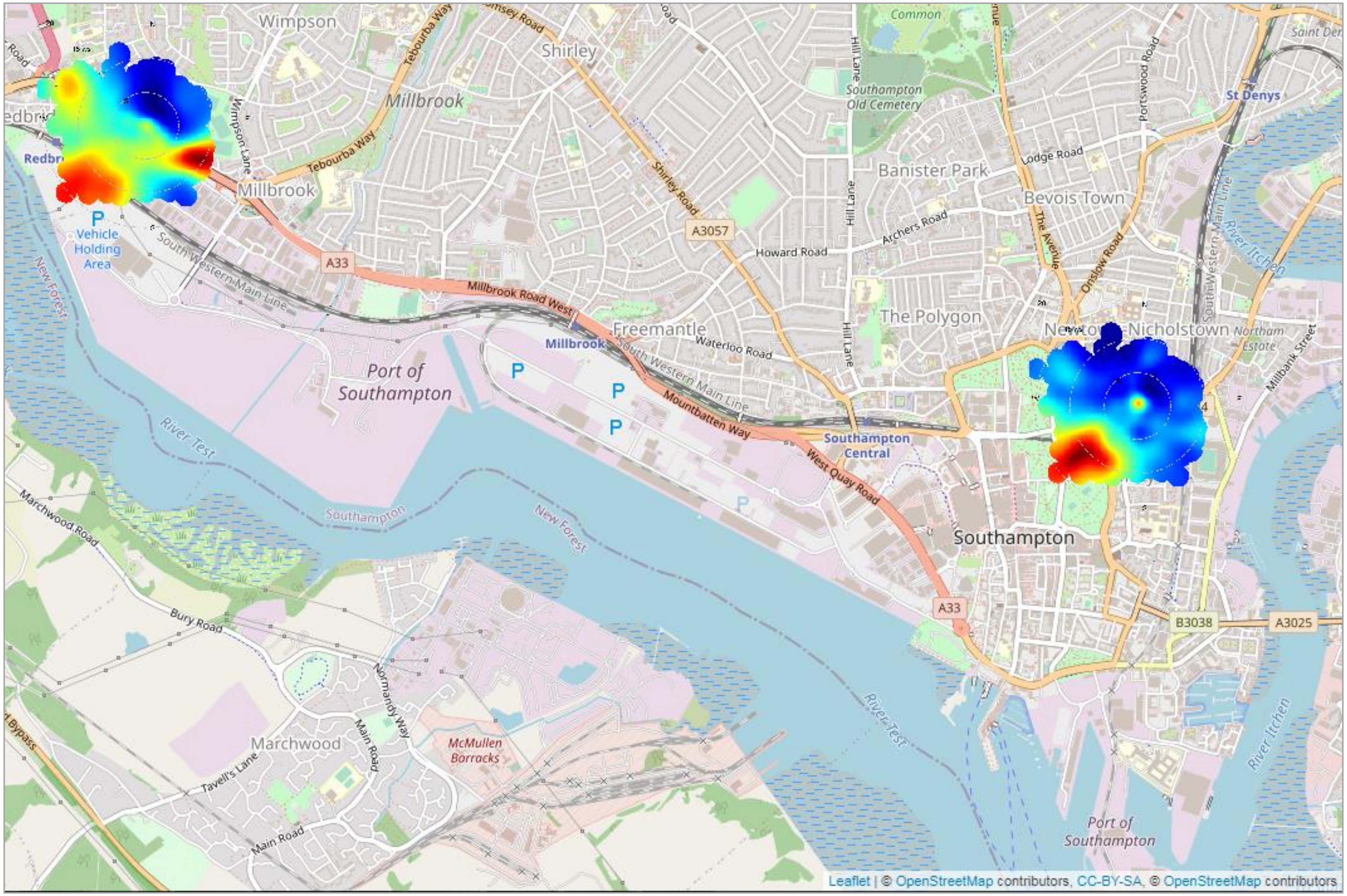


Figure 44: PM_{10} polar map - Southampton 2020 pre-lockdown period (1st Jan to 20th Mar 2020)

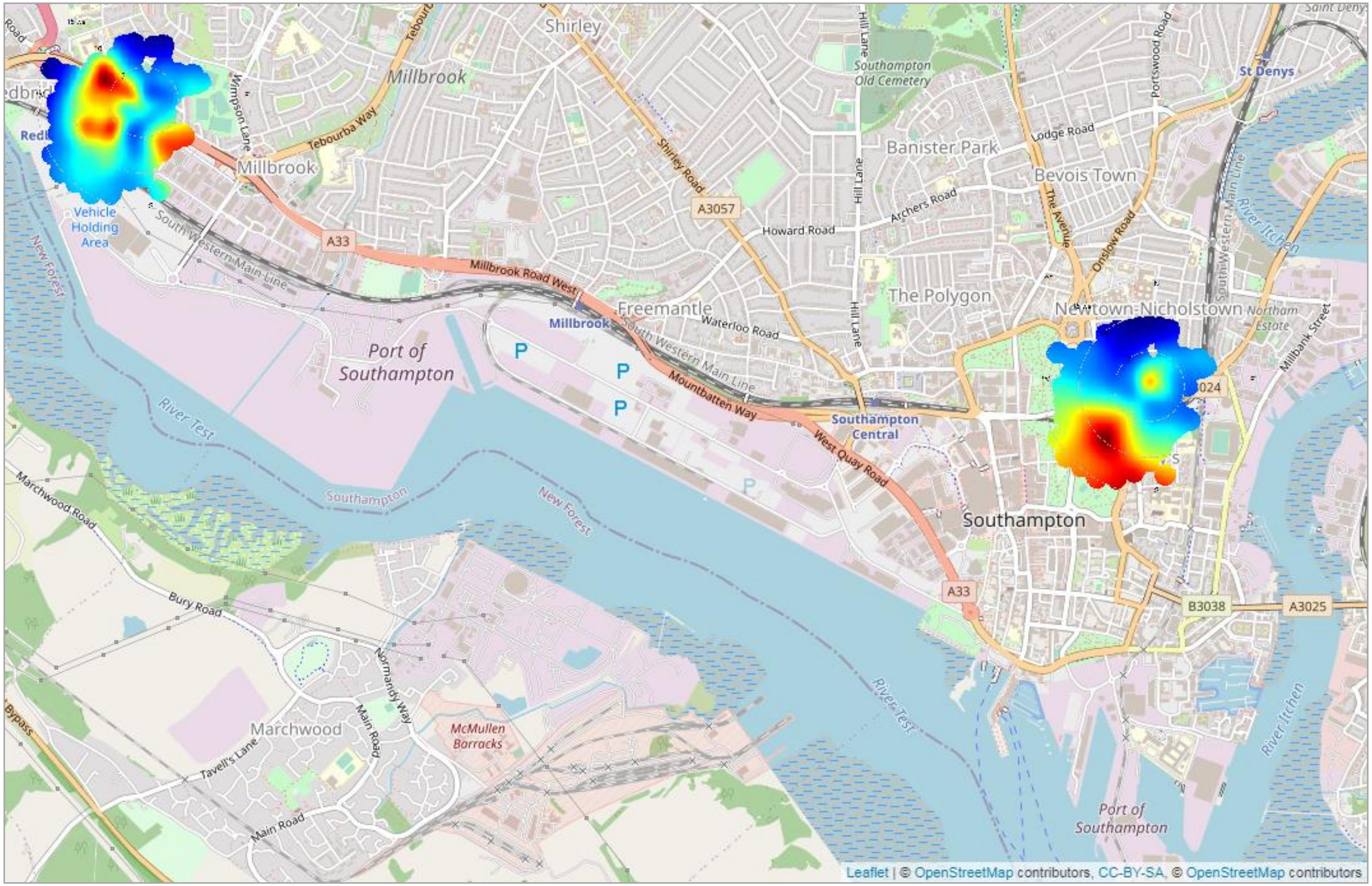


Figure 45: PM_{10} polar map - Southampton during lockdown period (23rd March to 10th May 2020)

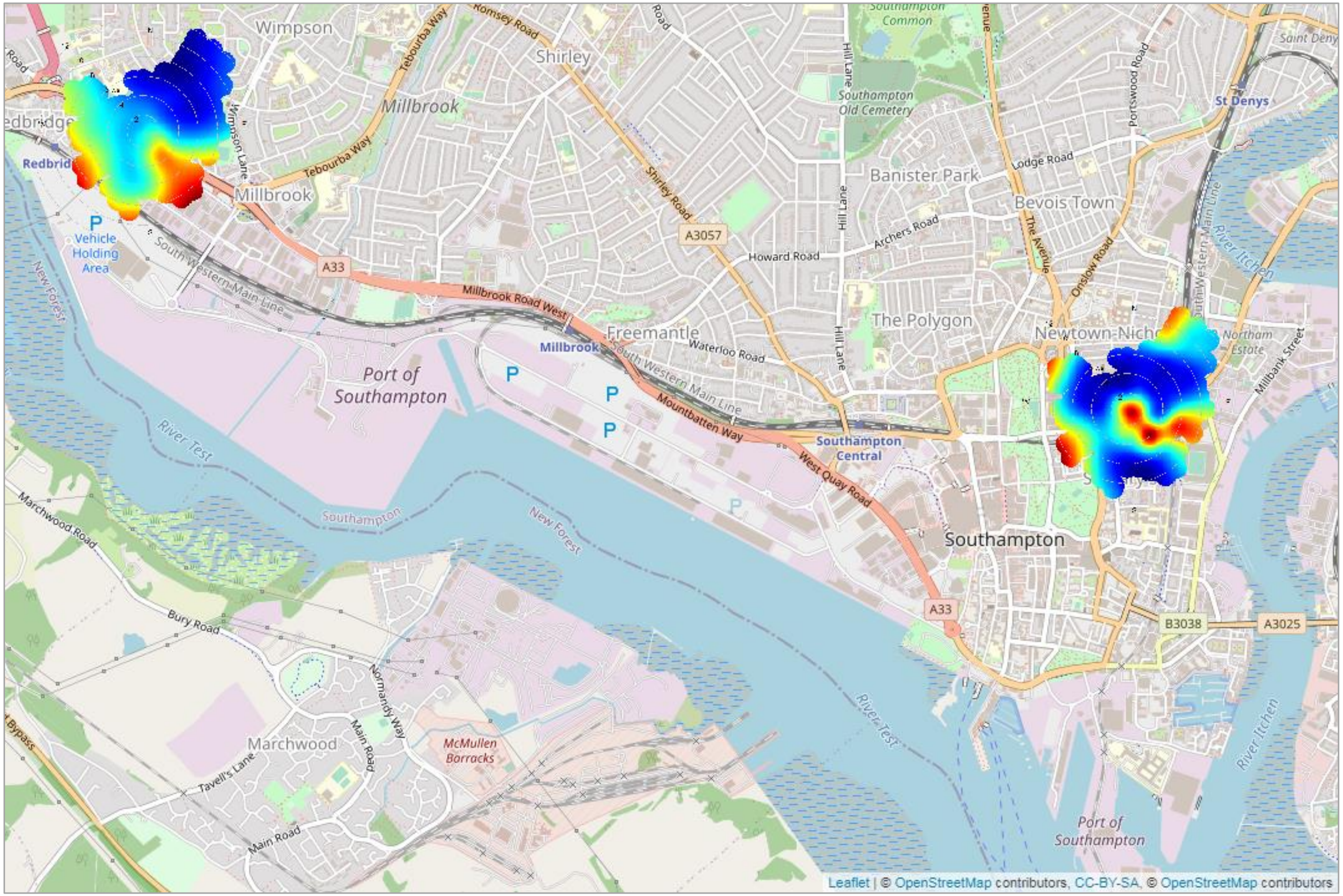


Figure 46: $PM_{2.5}$ polar map- Southampton Centre 2019 (all year)

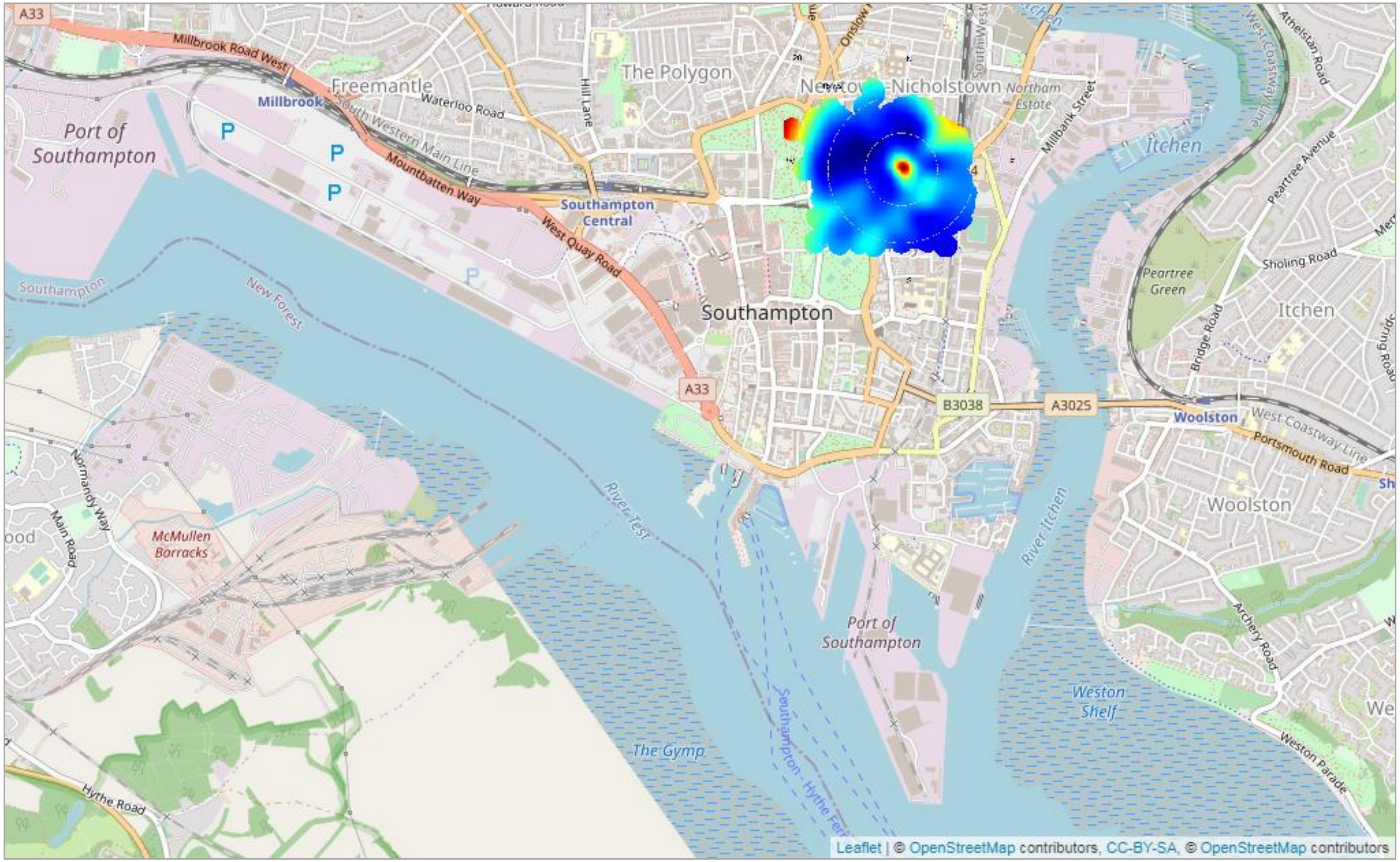


Figure 47: $PM_{2.5}$ polar map - Southampton Centre 2020 pre-lockdown period (1st Jan to 20th Mar 2020)

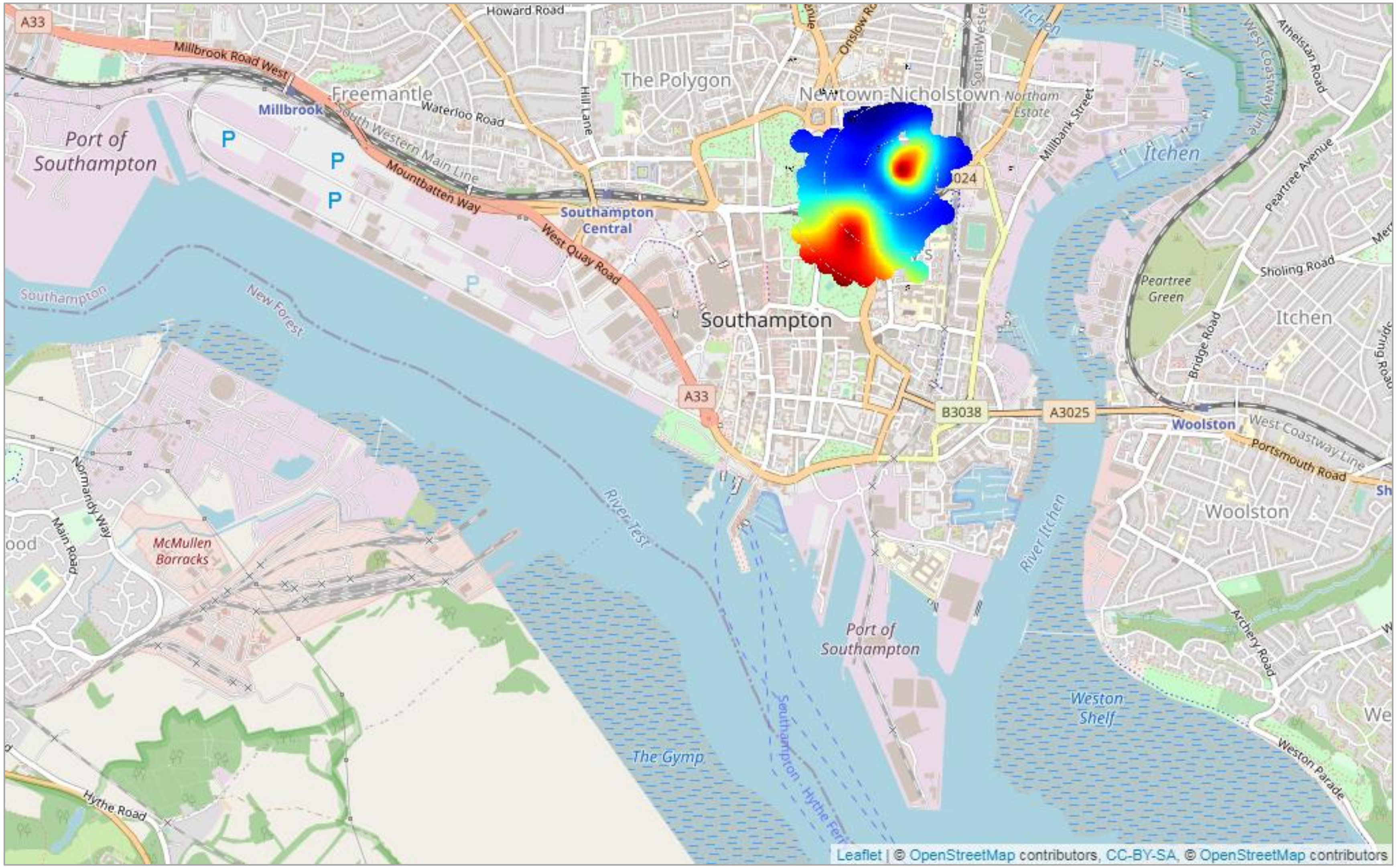
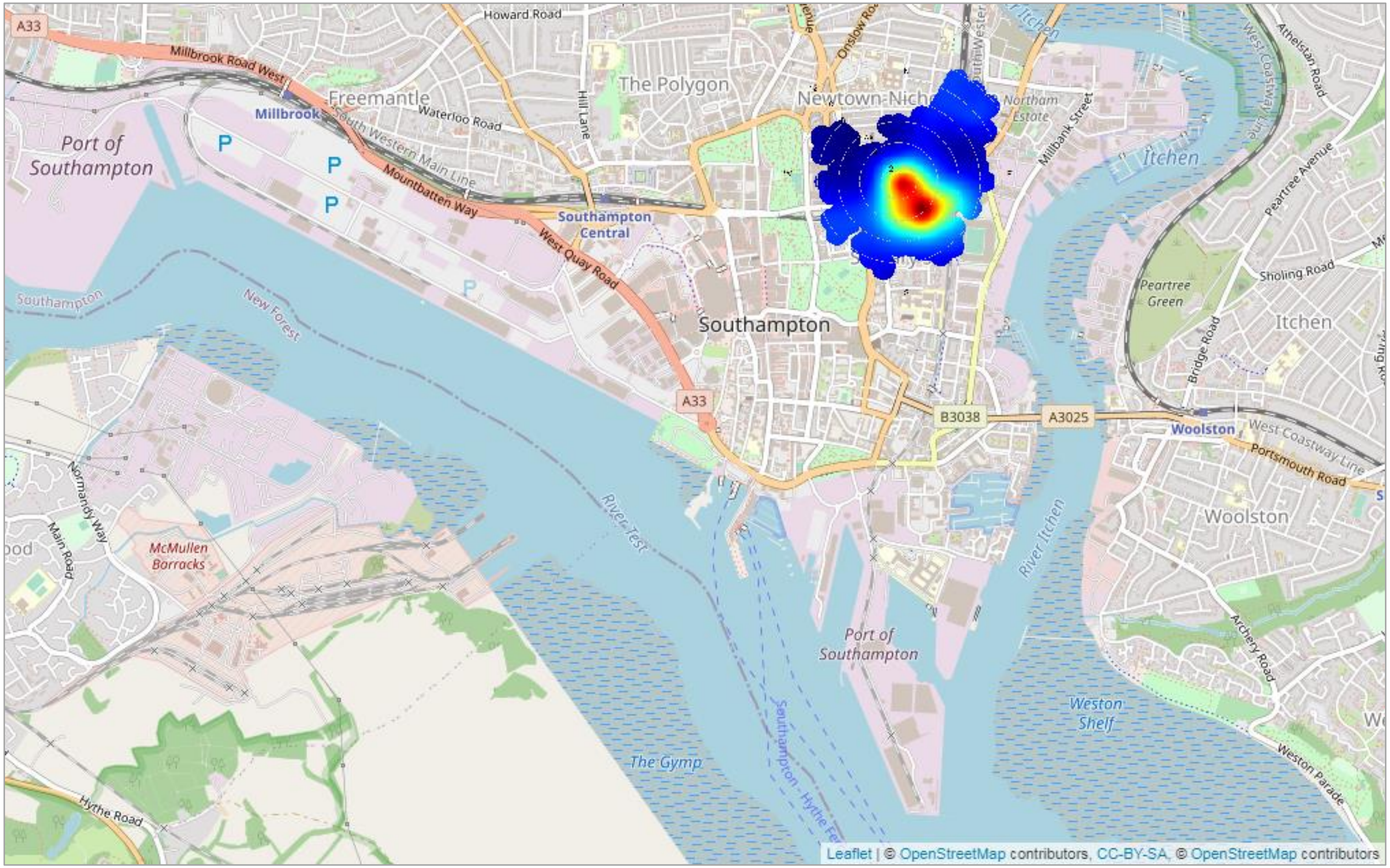


Figure 48: $PM_{2.5}$ polar map - Southampton during lockdown period (23rd March to 10th May 2020)



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