

HE Dynamic Speed Limits: Summary of Air Quality Analysis

David Carslaw and Nigel Bellamy April 2017

Purpose and approach

- To analyse air quality and traffic data for motorway locations to determine whether there is evidence that dynamically managing traffic conditions e.g. through speed limits, might potentially improve air quality. This has been undertaken to review the potential operating approach of the M1 J23-35a Smart Motorway scheme.
- The approach is two-fold. First, an analysis of raw data has been undertaken to develop an overview of the factors affecting concentrations. Second, detailed statistical models have been developed to better understand the meteorological and traffic factors controlling air pollution concentrations and to predict what might happen to air pollutant concentrations if different dynamic measures were introduced.
- This document provides a very high level synopsis of the work undertaken to date, plus it outlines the key indicative findings to date, and areas for potential future research and analysis.

Data

- Considerable time required to process and standardise the traffic and air quality data from a range of locations including the M60 J13-14, M25 J13-14 and M1 AB8 & AB9.
- The data raw data consists of 1-minute average information on vehicle flow and speed for each lane of a motorway in both directions. Vehicle type (four categories of vehicle based on length with the first two categories representing 'short' vehicles and the latter two 'long' vehicles) flows are also given but only for total flows for each side of the motorway. The data does not therefore provide information on vehicle type by lane and importantly, the speed of different types of vehicle in each lane. For this reason, several assumptions are required to format the data for use in statistical models.
 - The hourly mean speed of long vehicles is assumed to be represented by the 10th percentile speed in lane one.
 - The hourly mean speed of short vehicles is assumed to be the flow-weighted mean speed in lanes 2 and 3 (and lane 4 if it is present).
- There are outstanding queries on the speeds provided from the MIDAS data for the M1 site, which came in a different format via NTIS. At this stage analysis from this site has halted until these queries can be satisfactorily resolved.
- Of particular importance was the differentiation between short and long vehicles in MIDAS data. While flows of short and long vehicles are given in each lane, the vehicle speed is the vehicle-weighted average speed in each lane. Estimates were made of the short and long vehicle speed by taking the 10th percentile speed in lane 1 as being representative of long vehicle flows, and the average of (median) lane 2 and (mean) 3 speeds for short vehicles.
- Flows and speeds were summarised for two-way flows. The data tend to become highly correlated if either the lanes are considered separately or each side of the motorway was considered separately.
- Ideally, the speed and flow of short and long vehicles would be measured separately, which would likely improve the ability of the model to predict the influence of speed changes on the concentrations of NO_x and NO₂.

An important aspect of the data analysed is how correlated the different variables are. The plot below shows the correlation coefficient as a percentage (100 – perfect correlation) with the shape and colour also representing the correlation (think of the ellipses as small scatter plots). The plot is shown for M60 data in 2013, with A and B representing each side of the motorway. It shows for example that some variables are highly correlated with one another e.g. each side of the motor way flows of short vehicles ($r = 0.91$).

NO_x is positively correlated with all the vehicle flows (suggesting that, as the flows increase, the concentration of NO_x does also). NO_x is negatively correlated with vehicle speed. Care is needed when considering these correlations because high vehicle speeds will tend be associated with low vehicle flows (and hence lower NO_x). The interrelationship between these variables is at the heart of the challenges in modelling the concentrations.

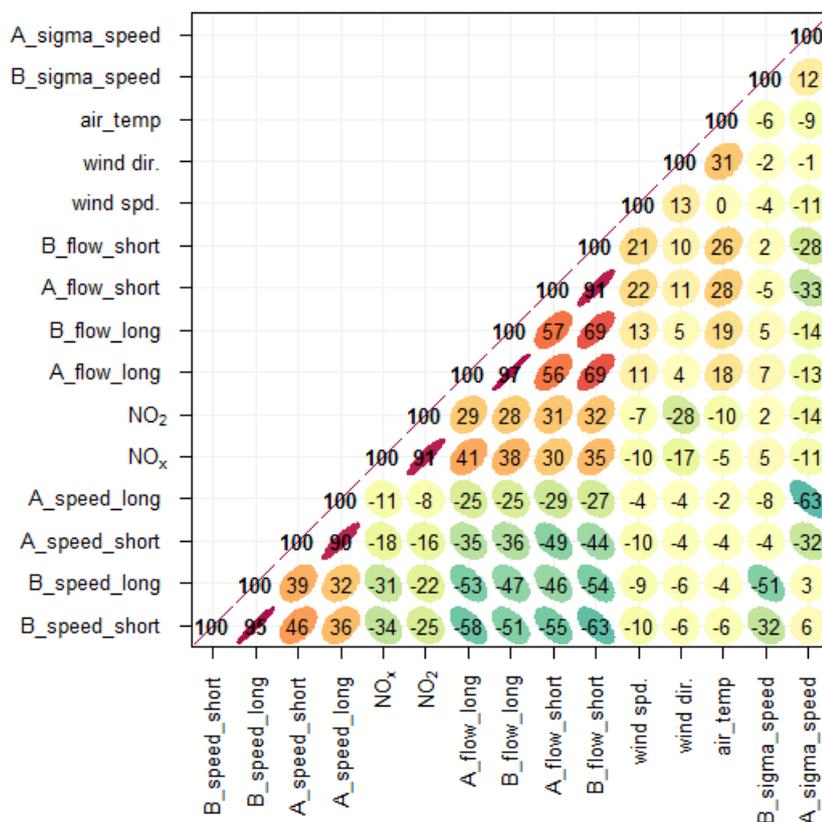


Figure 1 Correlation matrix showing how traffic and meteorological variables are correlated with one another.

Raw data characteristics – M60

- It was important to consider the characteristics of the raw data to understand whether it indicated any unusual behaviour and to help better understand some of the statistical model outputs.

As an example of the relationships between variables, data from the M60 in 2013 were used. The data have been filtered for weekday conditions only. There is a general tendency for concentrations of NO_x to increase with increasing flow of long vehicles:

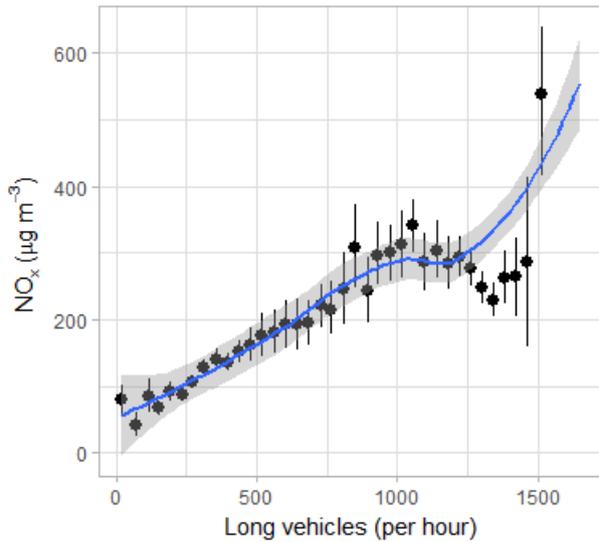


Figure 2 Relationship between long vehicle flow and concentration of NO_x at the M60 site for 2013.

Similarly, also for short vehicles:

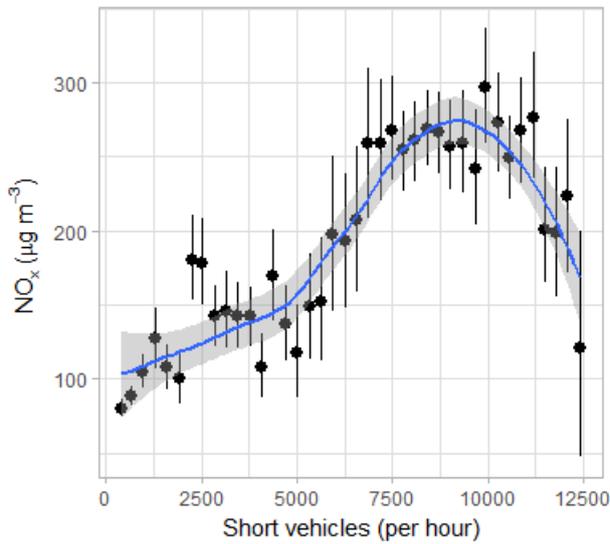


Figure 3 Relationship between short vehicle flow and concentration of NO_x at the M60 site for 2013.

While the plots above look to show relatively strong relationships between the variables, some care is needed because many of the variables are inter-related. For example, the plot below shows how the flows of long and short vehicles are related to the concentration of NO_x by binning the data. The flows only take up some values e.g. there are effectively no conditions when the flow of long vehicles is 1000 vehicles per day and the flow of short vehicles is 4000 veh/day.

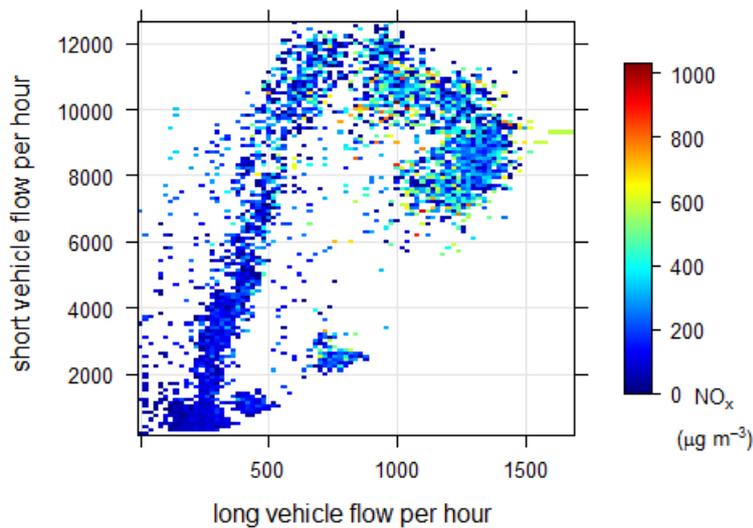


Figure 4 relationship between long vehicle flow and short vehicle flow at the M60 site for 2013 and the concentration of NO_x. The data have been averaged using 2-D binning.

The plot above does not reveal the underlying pattern of the relationship between these variables. This is because there is considerable variation in the concentration of NO_x between each bin. A better method is to fit a model (surface) to the data to reveal the underlying pattern of the relationship. In this case, use was made of a Generalized Additive Model (GAM) to flexibly fit a model linking the flows and the concentration of NO_x. Fitting a model considerably improves the identification of the underlying relationship (below). Now it can be seen that the highest concentrations of NO_x occur when the flows of short and long vehicles are high.

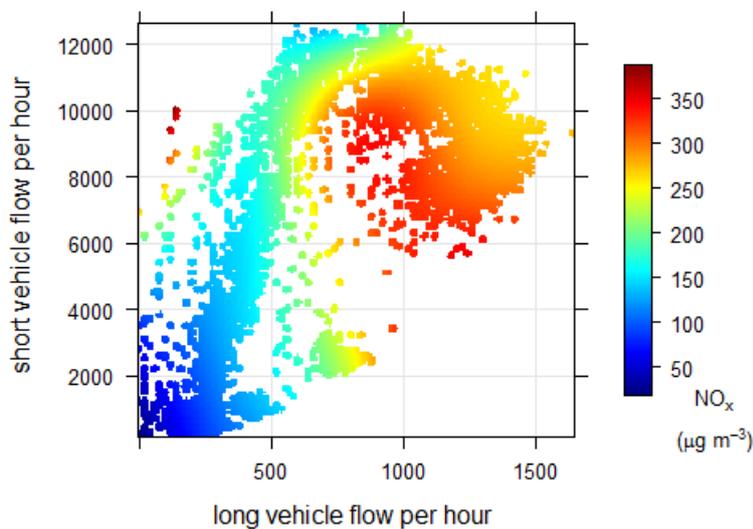


Figure 5 relationship between long vehicle flow and short vehicle flow at the M60 site for 2013 and the concentration of NO_x. The data have been averaged using 2-D binning and then a smoothing function applied.

The relationship with vehicle speed of short vehicles for the side of the motorway closest to the monitoring site shows that there is a tendency for the concentration of NO_x to decrease with increasing vehicle speed. However, as discussed above, there are many other factors that could also affect the relationship – in particular at higher vehicle speeds there will tend to be fewer vehicles and therefore lower emissions.

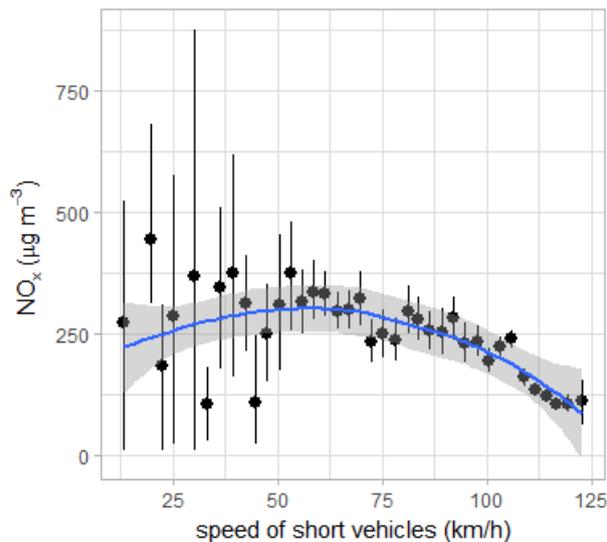


Figure 6 Relationship between the speed of short vehicles and the concentration of NO_x for the M60 site in 2013.

- The Figure below shows the variation between the flow of short vehicles, their speed and the concentration of NO_x (shown by the colours). The plot is an example based on 2013 data from the M60 site. The relationship is typical of that expected in flow-speed curves. An interesting and potentially important aspect of the plot is that as the speed increases above 60 mph (shown by the dashed horizontal line) between 6,000 and 8,000 vehicles, the concentration of NO_x tends to **decrease**. This behaviour is opposite to the effect expected from a consideration of vehicle emissions alone, which tend to increase. The highest NO_x concentrations are seen for high flows (> 6,000 vehicles) and speeds below ~60 mph. These conditions are consistent with flow breakdown and traffic instability.

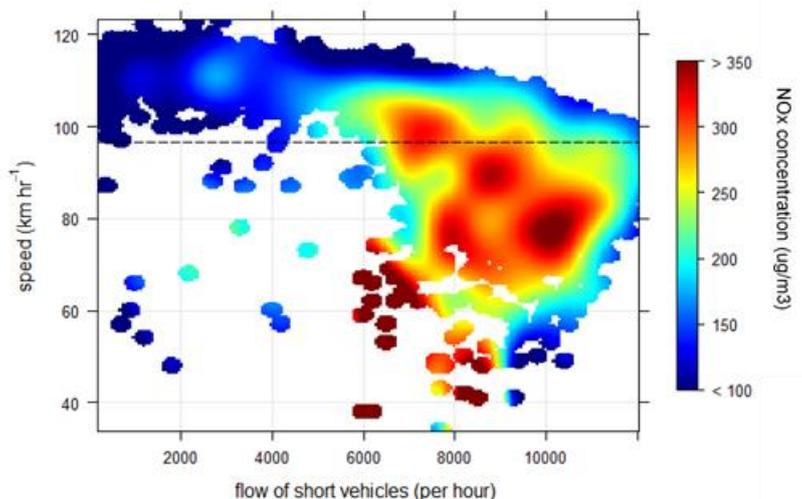


Figure 7 Concentration of NO_x as a function of short vehicle flow and speed for the M60 in 2013.

- The periods where traffic flow undergoes most acceleration and deceleration are likely to be important for vehicle emissions. The 1-minute average MIDAS data were

analysed and the standard deviation of vehicle speed calculated for short vehicles as described above.

- The plot of the standard deviation of speed (shown below) very clearly shows the area of highest speed variability corresponds to the flow breakdown region. As expected, the highest speeds are associated with little speed variability. Large amounts of speed variability are highly likely to be associated with higher emissions due to the importance of acceleration events leading to higher emissions. These two plots taken together therefore suggest that the highest concentrations of NO_x occur when the vehicle flows are high together with high speed variability.

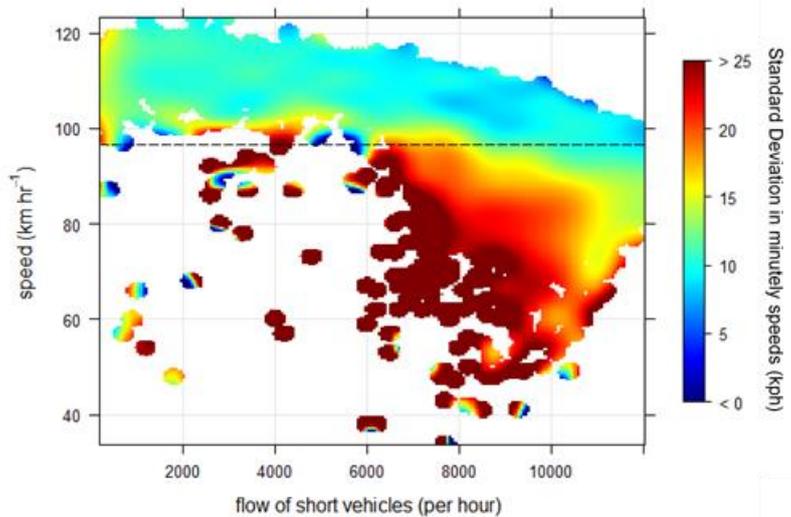


Figure 8 Vehicle speed variability for short vehicles as a function of the concentration of NO_x and short vehicle speed for the M60 in 2013.

- A further indication of the effect of speed, based on the speed variation (standard deviation of speed) and NO_x can be gained by considering a narrower range of conditions. In the plot below the flows are those between 8,000 to 10,000 for weekday conditions. These conditions represent high flows of short vehicles and a relatively narrow range of long vehicles i.e. where changes in NO_x concentrations may be expected to be driven more by vehicle flow dynamics rather than variations in vehicle flows. The plot shows the concentration of NO_x (colour scale) and how it varies by the standard deviation of speed and speed of short vehicles. The plot shows that as the standard deviation of speed increases, the speed tends to decrease while NO_x concentrations tend to increase. Therefore, reducing speed in a model explaining NO_x concentrations would tend to increase the speed variability and potentially increase the concentration of NO_x .

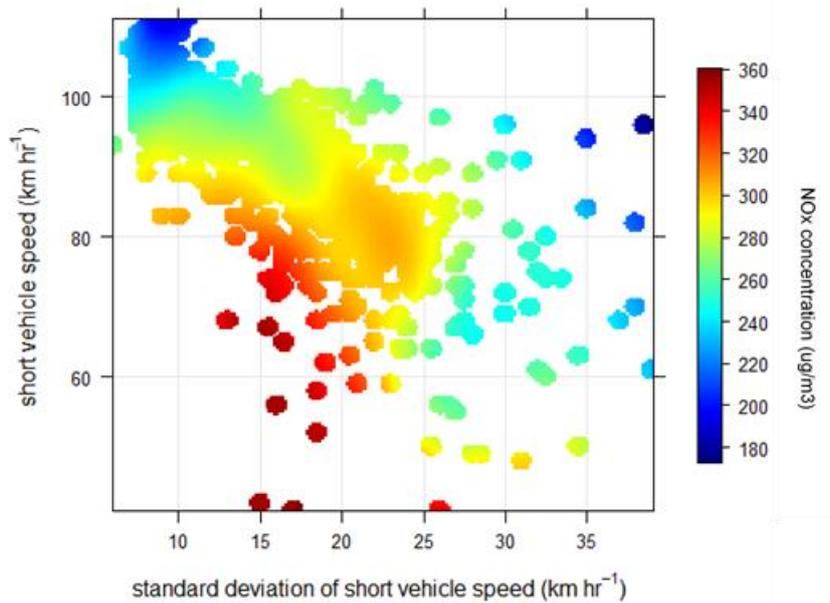


Figure 9 Relationship between short vehicle speed and the standard deviation in short vehicle speed as a function of NO_x concentration.

- At the M60 site, speed control at 50mph was introduced in the autumn of 2014. The introduction of speed control allowed the data to split between conditions of speed control and no speed control (for data covering 2014 and some of 2015). The time series plot shows that speed quickly decreased after July (the decrease commences when the average speed cameras were installed, but were not in operation and had protective coverings from July, and then revealed and commissioned in September). However, there is no significant effect on vehicle flows (long or short) because of the speed control. This means that the changes to measured response in air pollution can be confidently attributed to speed related behaviour. It also challenges the assumption used in DMRB/TAG appraisals that drivers and demand responds quickly to a change in journey time.

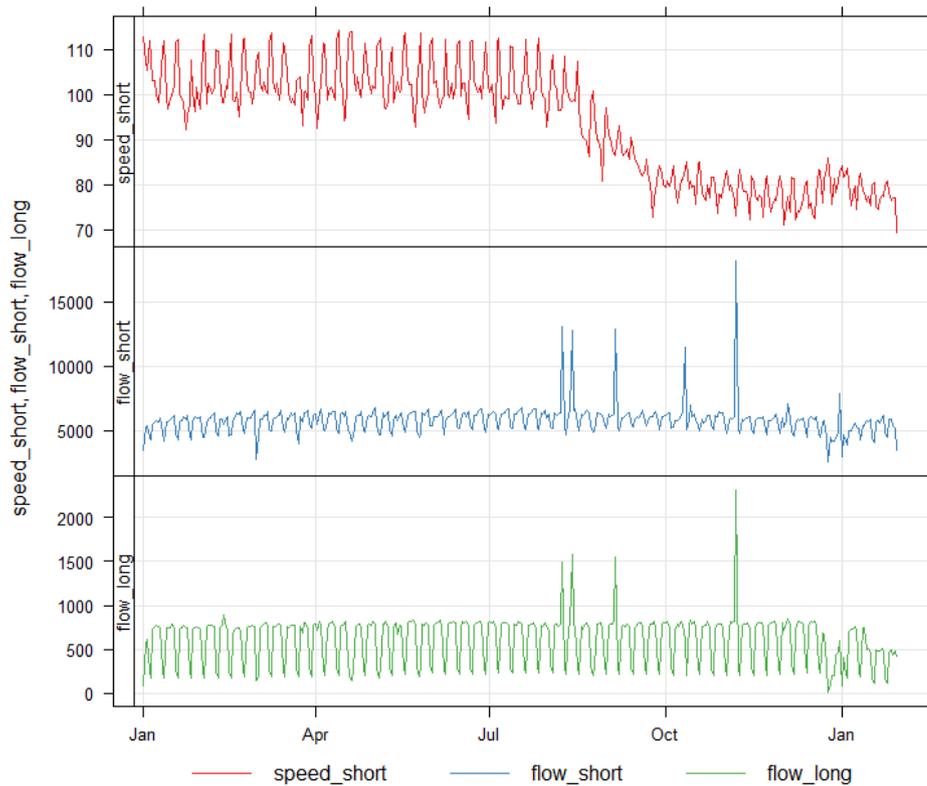


Figure 10 Daily mean flow of long and short vehicles and short vehicle speed at the M60 for 2014/2015.

- The no speed control data broadly reflect the previous plot for NO_x (Fig 1). For speed control, there is a very clear decrease in speed as expected, but there are still conditions corresponding to flow breakdown where high NO_x concentrations are observed, which occur at the same speeds of 60-80kph. There is also no evidence of an increase in NO_x with increases in speed from 80kph upwards, in fact the opposite appears to be the case and is contrary to the emissions factors predicted by Copert based tools.

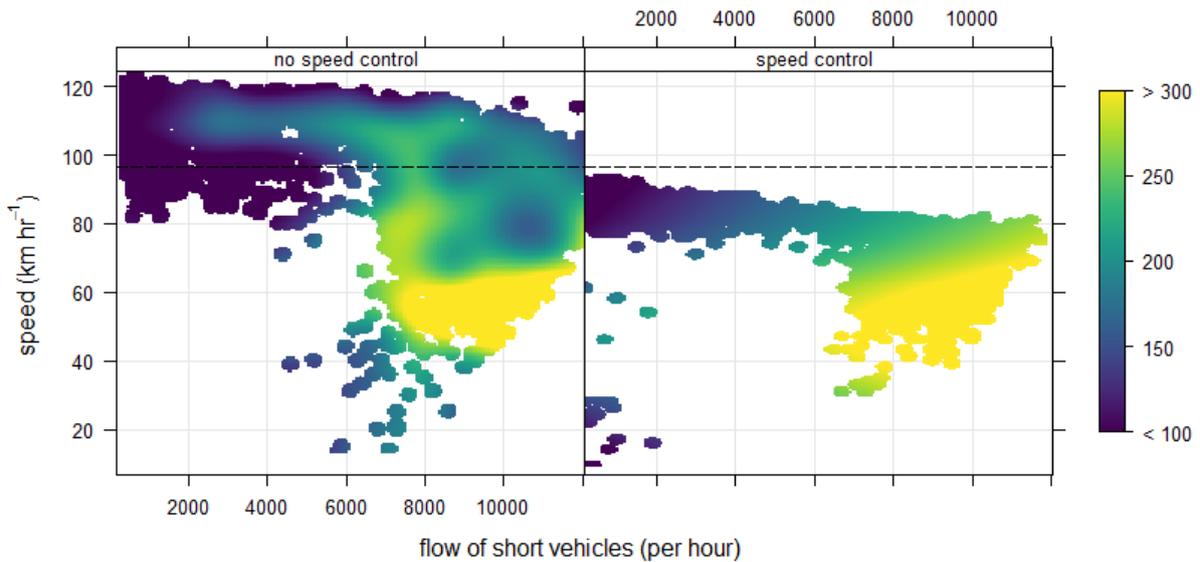


Figure 11 NO_x concentration as a function of flow and speed of short vehicles. The data have been split by no speed control and speed control at 50 mph. Note that the speed control data only covers 3 months.

- The importance of the effect of reducing speed limits, and the measured response can be further refined by considering other features within the datasets.
- The standard deviation of speed shows that the effect of speed control significantly reduces the variability in speeds where conditions are 50mph/80kph and above. There is also a more general reduction in variability at lower speeds.
- The frequency of vehicle flows shows the same patterns for flow, but with reduced speeds under the speed control period, with the most frequent occurrences compressed down into a lower range of speeds around 80kph. This is to be expected given that overall flows were not affected by the speed limit reduction.

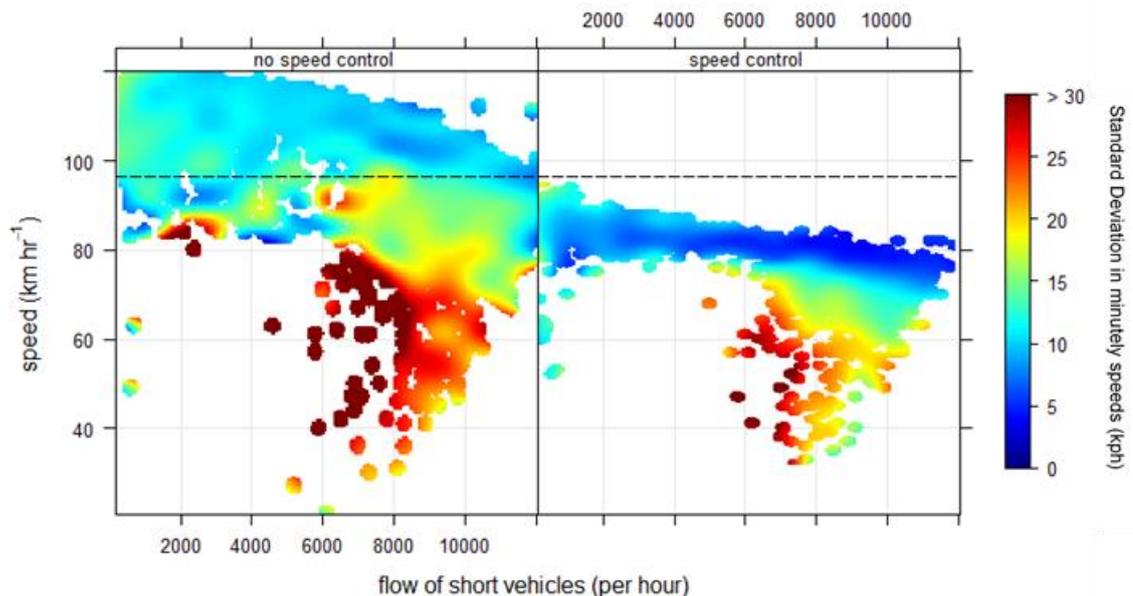


Figure 12 Variation in the standard deviation of short vehicle speed on the M60 for 2014/1015 for no speed control and speed control.

- It also shows the periods where changes to traffic behaviour would occur most frequently, and therefore the impacts of a speed limit reduction would have the greatest influence on annual mean air quality.

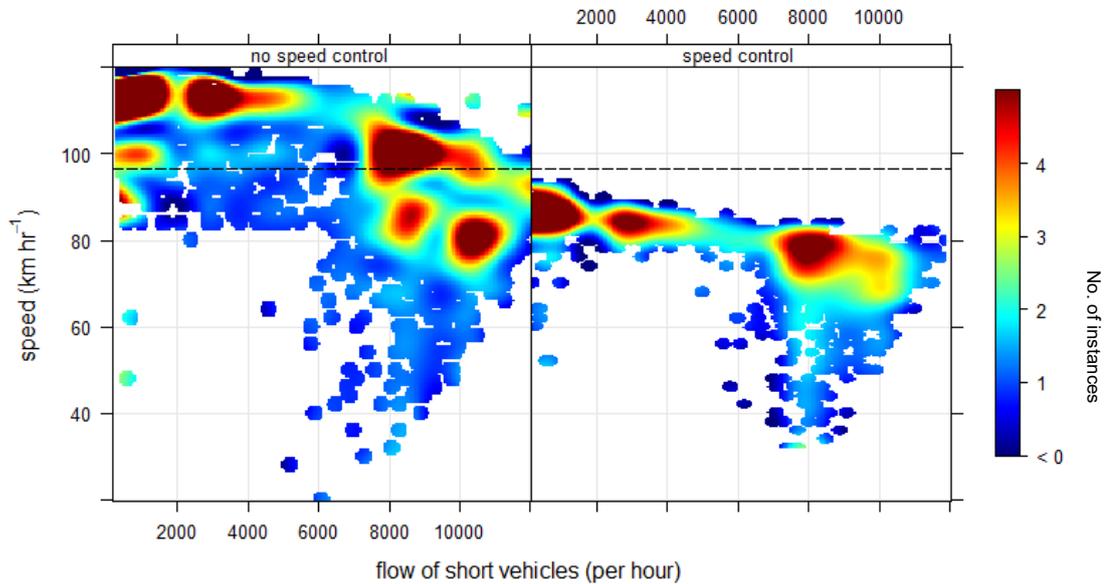
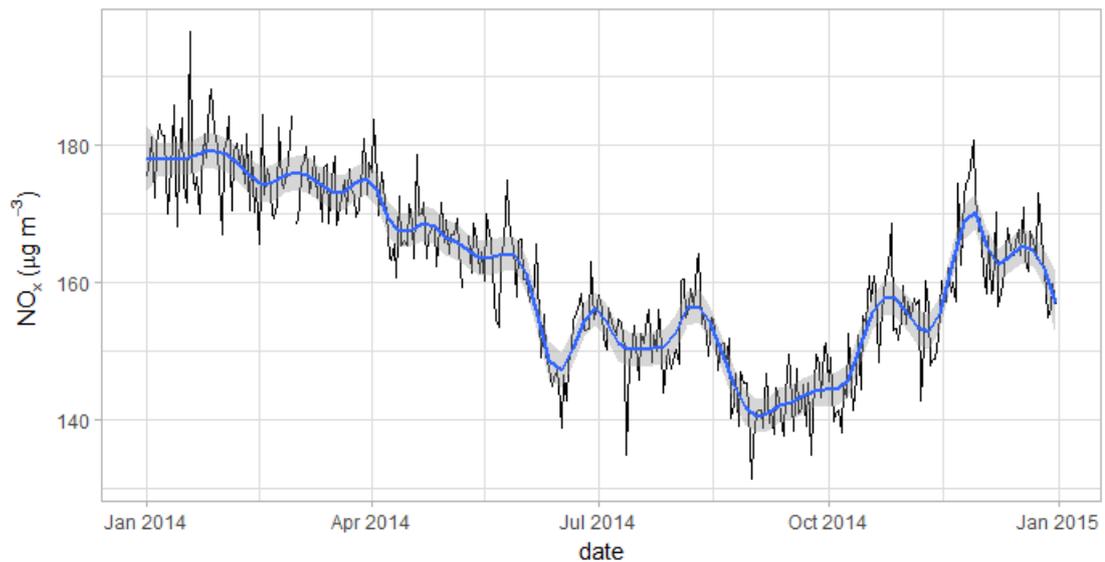


Figure 13 Frequency of data for the no speed control and speed control conditions for the M60 in 2014/2015.

- There are relatively few instances of very low speeds (<60kph), and concentrations are not so elevated as those for higher speeds, especially without speed control.
- Concentrations at lower flows (<4000 veh/hr) do not appear to change between the with and without speed control scenarios.
- At higher flow conditions when speeds don't appear to be restricted, in the without speed control dataset this appears to be associated with lower concentrations. The same flows operating at the highest speeds under speed control do not appear to lead to such low concentrations. This may indicate that application of speed control does not lead to any improvement in roadside concentrations, and may in fact produce a small worsening.
- It needs to be recognised that whilst traffic conditions have not changed notably between the datasets, these are raw data from different time periods and with

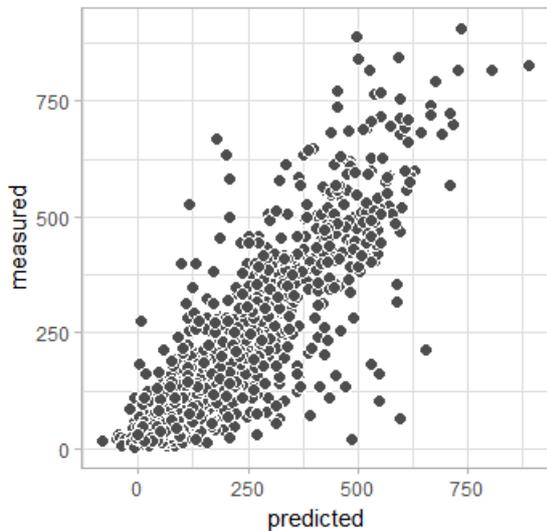
different meteorological conditions.



Model building

- Detailed statistical models have been developed to explain and predict concentrations of NO_x and NO_2 at a range of motorway sites and for different years. These models use MIDAS traffic information together with local meteorological information (from motorway sites). The models have two main purposes. First, to understand how concentrations of NO_x and NO_2 vary with different variables such as the flow and speed of short vehicles. Second, to predict the likely concentrations of NO_x and NO_2 under different conditions e.g. reduced speed limits.
- Of importance to the analysis is the representation of vehicle speed, separately specified for long and short vehicles. As described above, assumptions need to be made to estimate the speed of vehicles. Many ways of representing speed, or variations in speed were tested. Overall, the explanatory models built did not have a strong dependence on vehicle speed, regardless of how it was estimated. For example, consideration was also given to the analysis of the proportion of positive increases in speed based on the 1-minute data, which did not improve the model performance. It was thought that periods with high proportions of increases in speed from one minute to another would be associated with increased emissions – and vice versa. This behaviour could reflect the deficiency of the data (where the speeds are not given by short and long vehicle by lane) or that speed itself does not have a strong bearing on the concentrations of NO_x .
- The lack of a strong relationship with vehicle speed contradicts most emission factor relationships that tend to have a characteristic 'U' shape relationship. However, the effect of emissions is only one aspect of that affects roadside concentrations. As vehicle speed increases, so too does vehicle-generated turbulence, which would tend to increase plume dilution and compensate for increased emissions. It is difficult to know from the motorways data (and other data) how important these two competing effects are.
- In general, good explanatory models could be built explaining the hourly concentrations of NO_x and NO_2 at the motorway sites for most years. An example of model performance (on randomly withheld data not used for model development) is shown below. These data are for the M60 in 2013. There are some outlier points and these tend to be associated with wind directions that are closely aligned with the

motorway, where a small change in wind direction can have a large effect on predicted concentrations. The performance of the models is as good as can reasonably be expected and will almost certainly be better than hourly estimates made using dispersion models.

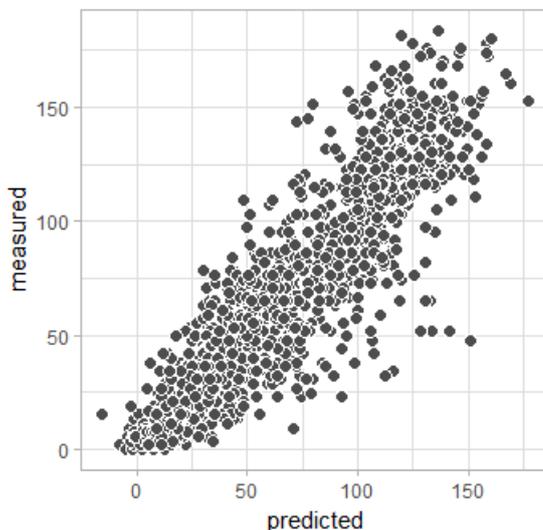


statistic	value
n	1414.00
FAC2	0.73
MB	0.43
MGE	52.50
NMB	0.00
NMGE	0.30
RMSE	83.24
r	0.88
COE	0.63
IOA	0.81

Figure 14 M60 NO_x model performance for 2013 data.

- Similarly, good models could be developed for concentrations of NO₂, as shown below.

Figure X: M60 NO₂ model performance



statistic	value
n	1414.00
FAC2	0.86
MB	0.17
MGE	14.10
NMB	0.00
NMGE	0.22
RMSE	19.43
r	0.90
COE	0.63
IOA	0.81

Figure 15 M60 NO₂ model performance for 2013 data.

- In terms of how important the different predictor variables are for NO_x, the plot below shows the estimated influence of each variable. The most important variable is wind direction (wd) followed by the flow of long vehicles. These two variables tended to be the most important at most sites for most years. It would be expected that wind direction has a very important influence on concentrations because its influence tends to be 'binary' i.e. the wind is either blowing from the motorway towards a site or it is not. The flow of heavy vehicles would also be expected to be important for

concentrations of NO_x and this is confirmed by the models.

Interestingly, the speed of short vehicles is relatively important and shows that as the vehicle speed increases, the concentration of NO_x tends to decrease. This pattern of behaviour was also indicated with the raw data analysis. As discussed elsewhere, some caution is needed when interpreting these results because the effect is not strong and the representation of vehicle speed through the MIDAS data is not ideal. The analysis of the raw data can also help to establish the effects (if any) of vehicle speed.

Overall, the general pattern of variable behaviour with NO_x seems reasonable. For example, concentrations tend to decrease with increasing wind speed and ambient temperature, which is expected from a dispersion point of view and the concentrations increase in a mostly linear fashion with vehicle flows. The variation with wind speed is interesting because NO_x does not fall monotonically with wind speed – instead there is a period of almost constant concentration of NO_x up to about 10 m/s, when it then decreases. Such behaviour could be due to vehicle-generated turbulence i.e. when the wind speed is below a certain level the plume mixing is dominated by vehicle generated turbulence. Only when the wind speed is above a certain value does it begin to dominate over vehicle-generated turbulence.

- It should be stressed that although models with good predictive performance can be developed, there is less certainty in the individual contributions made by the different variables. This is because even though the number of variables have been reduced, there is still correlation among them.

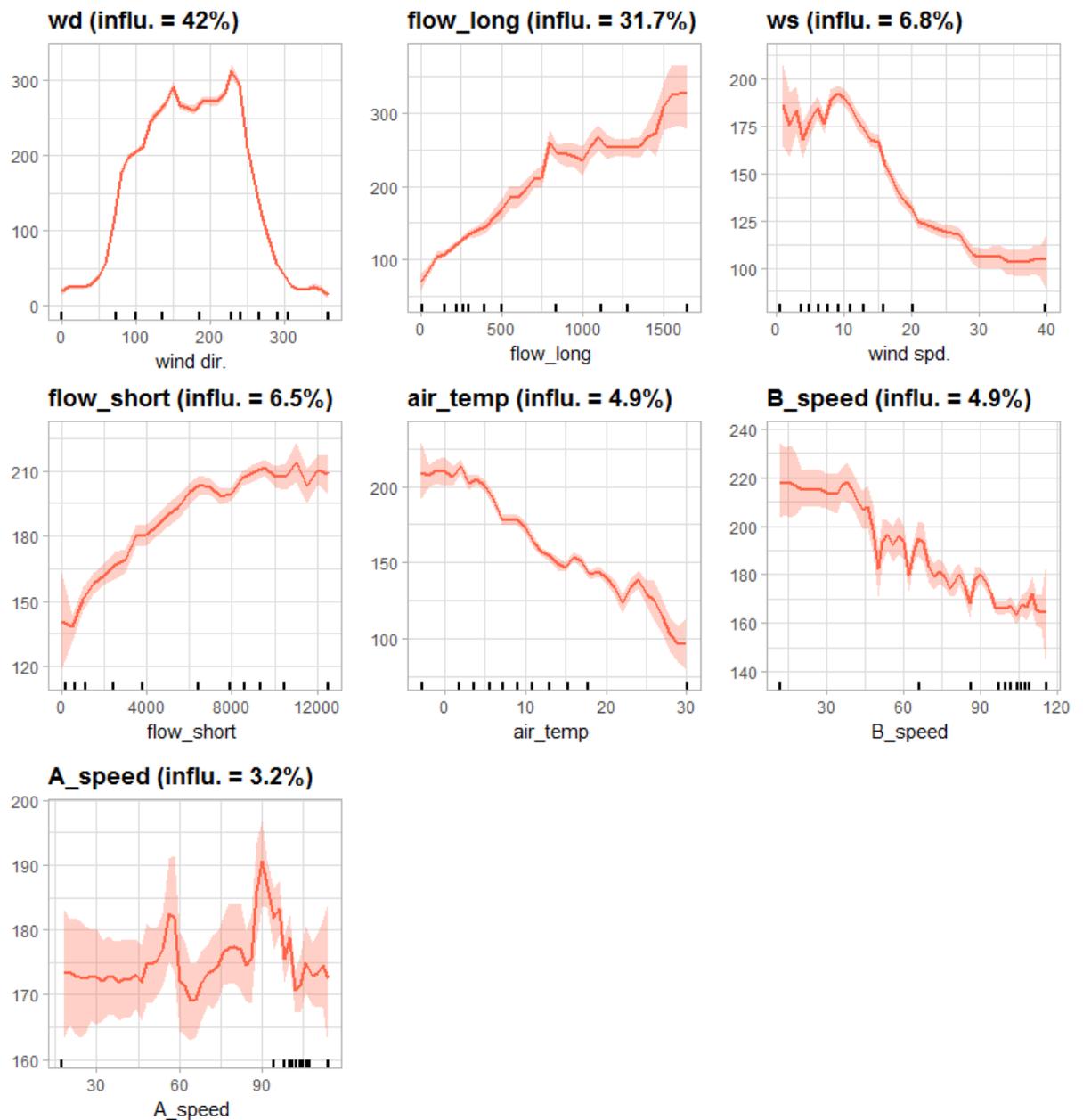


Figure 16 Importance of model input variables and their relationship with NO_x.

- The same analysis for NO₂ shows that short vehicles are more influential than long. This finding may seem surprising because long vehicles clearly dominate the influence on NO_x concentrations. These effects are considered in more detail in a later section.
- The other difference compared with the NO_x influence plot is the behaviour with ambient temperature where NO₂ concentrations tend to increase when the ambient temperature exceeds about 18 °C. This behaviour is very likely due not to temperature per se but to higher background ozone concentrations that are associated with higher ambient temperatures. Higher concentrations of ozone would increase the importance of the NO + O₃ reaction leading to NO₂ production. This behaviour can therefore be explained in terms of actual physical and chemical

influences, which helps to support the validity of the model i.e. it is consistent with the processes involved.

- The influence of speed is again low and equivocal and it is difficult to draw strong conclusions from these results alone.

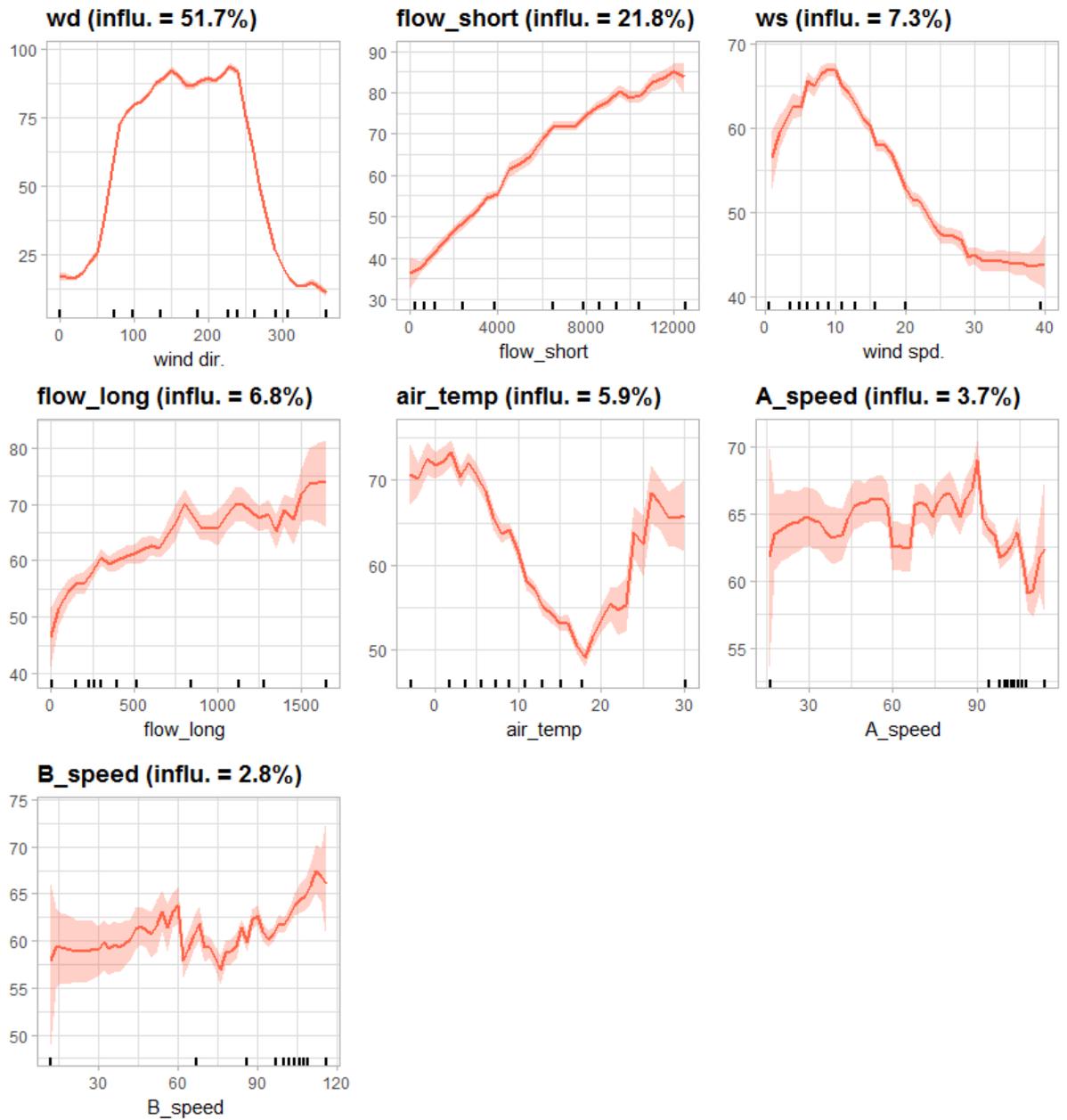


Figure 17 Importance of model input variables and their relationship with NO₂.

Model predictions

- The model predictions simulate the effect of different speeds – in particular the effect of reducing the speed of vehicles that are above 60 mph to 60 mph. It should be stressed that these simulations do not alter the flow in any way. *In reality, altering the vehicle speed may affect the vehicle flow also but this isn't evident in the M60 speed control flow plots.* This is important because reducing speed based actual data from motorways could move the predicted values to regions where there is increased speed variability (as shown by the standard deviation speed-flow plot) and potentially higher values of NO_x. An alternative approach would be to use a traffic model to predict the change in speed and flow and use both changes in the statistical model.
- The models were used to predict the likely hourly concentrations of NO_x and NO₂ assuming a maximum speed of 50 and 60 mph i.e. any speeds in the base data above these fixed speeds were set at the fixed speed and no adjustment was made to speeds below these fixed speeds.
- The results for NO_x at the M60 site are shown below. For most years reducing the speed to 50 or 60 mph tends to result in an increase in NO_x concentrations, which is particularly evident for the 50 mph limit. As discussed previously, speeds in the base data of around 50 mph are strongly associated with increased speed variability and higher NO_x concentrations. This is not what would be predicted by Copert or HBEFA. It would be useful to review the nature of drive cycles in HBEFA which represent these speeds for motorway road types.

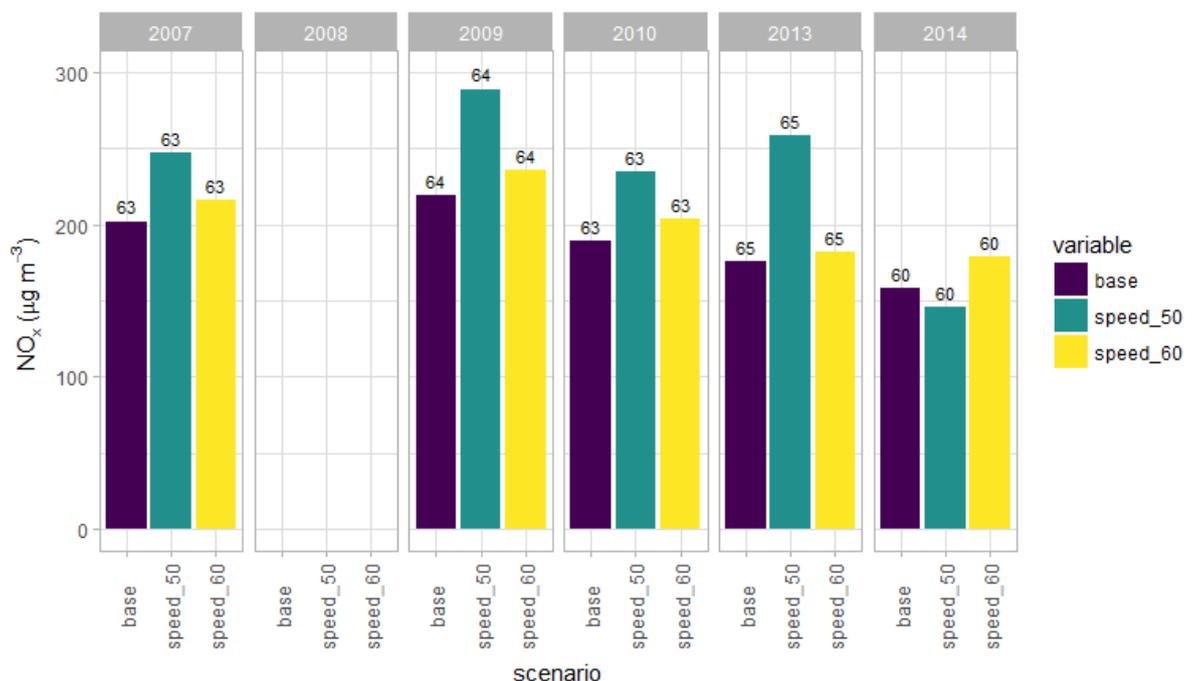


Figure 18 Predictions of annual mean NO_x concentration for different vehicle speed scenarios. The numbers at the top of the bars show the base case speed in mph.

The predictions for NO₂ are shown below and show that the effect of setting a speed limit to 60 mph has a small and mixed response on concentrations.

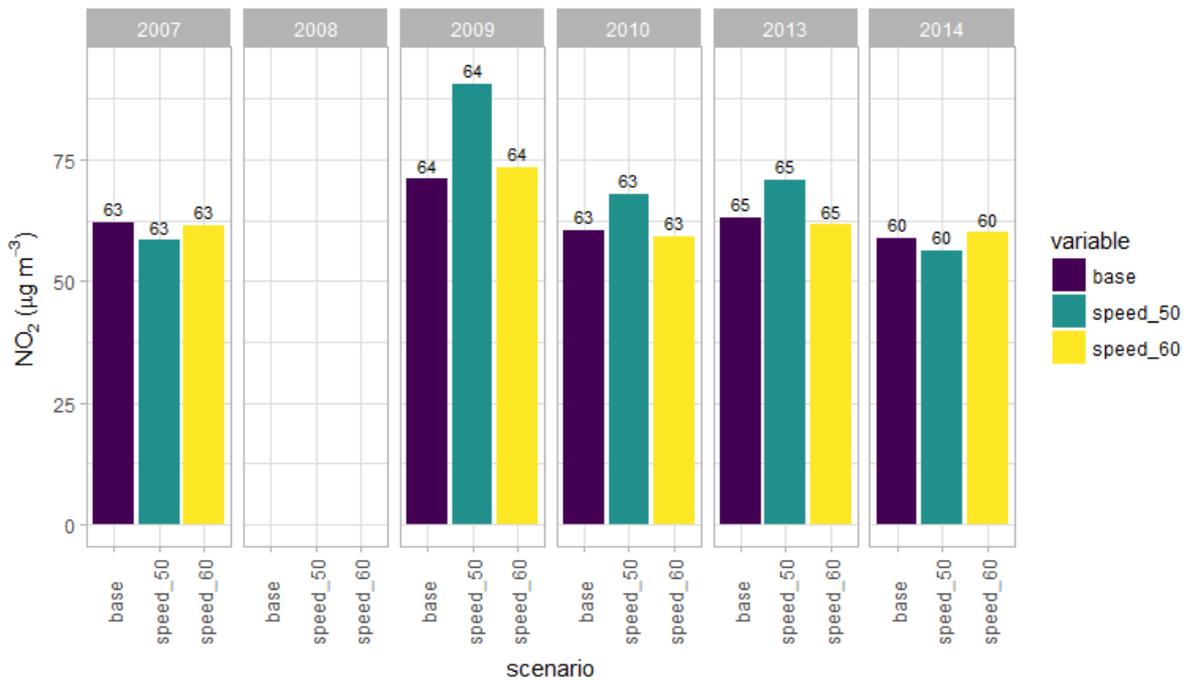


Figure 19 Predictions of annual mean NO₂ concentration for different vehicle speed scenarios. The numbers at the top of the bars show the base case speed in mph.

Summary Results for the M25 analyser

- The general patterns of NO_x as a function of speed and flow observed for the M60 are also seen for the M25; at least in terms of a general decreasing pattern of NO_x concentrations for speeds more than about 60 mph. The plot below shows the distribution of NO_x concentrations as a function of short vehicle flow and speed.

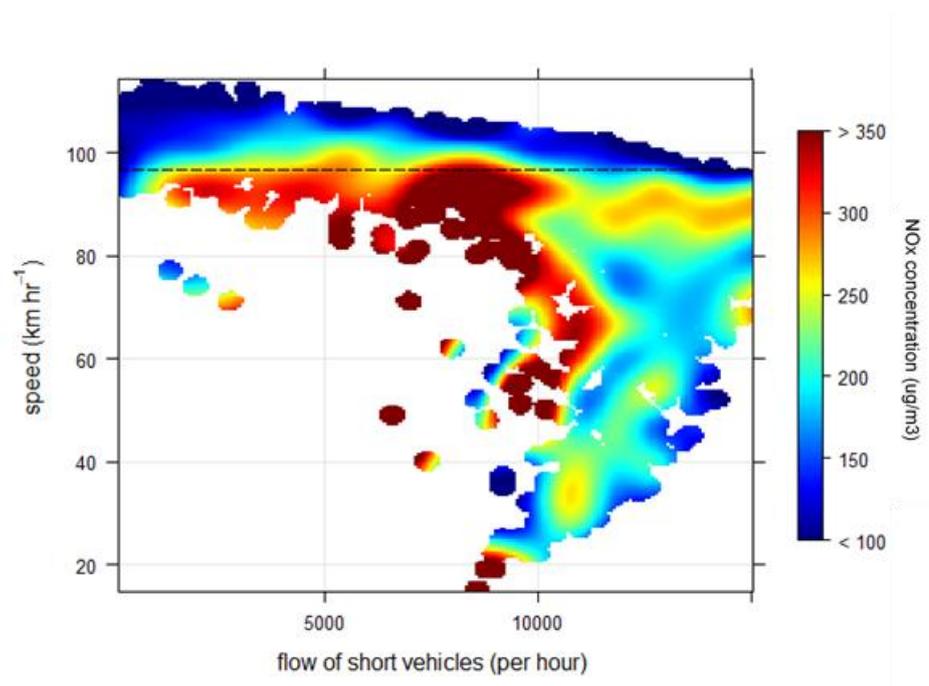


Figure 20 Relationship between short vehicle flow and speed with NO_x at the M25 for 2010.

- There is also a similar pattern of behaviour seen for the standard deviation of vehicle speed (see below). Again, speeds greater than about 60 mph are associated with very little speed variation.

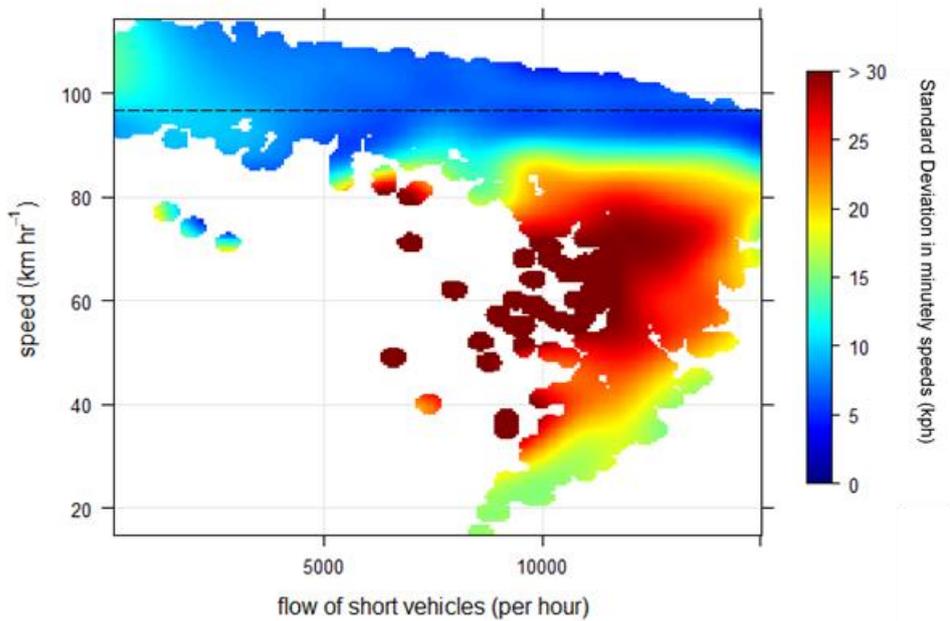


Figure 21 Relationship between short vehicle flow and speed with the standard deviation in short vehicle speed at the M25 for 2010.

- The results for 2009 indicate lower concentrations but the vehicle speed variability appears consistent with the main dataset.

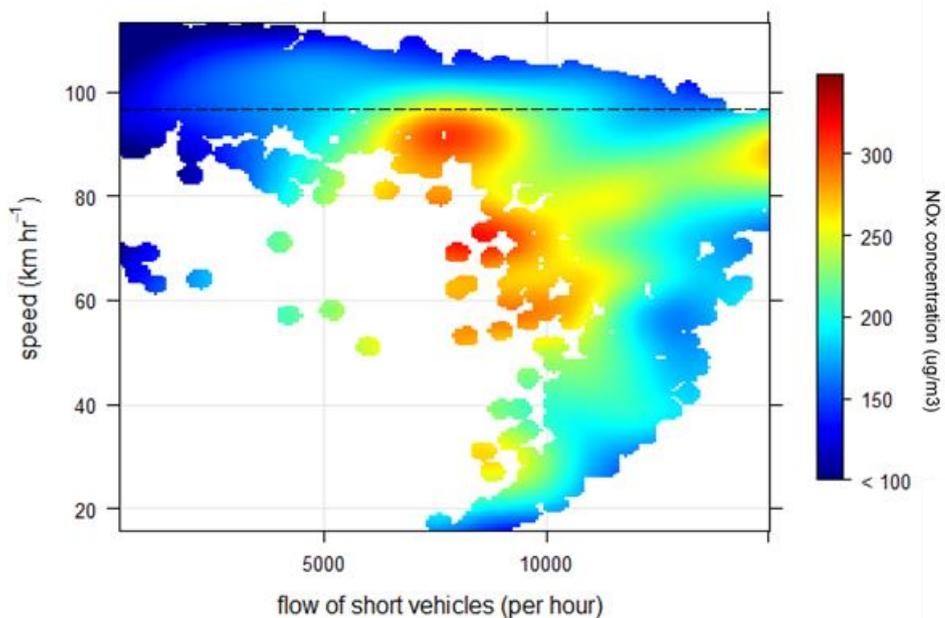


Figure 22 Relationship between short vehicle flow and speed with NO_x at the M25 for 2009.

Figure 15: NO_x concentrations as a function of speed and standard deviation of speeds of short vehicles (M25 2009)

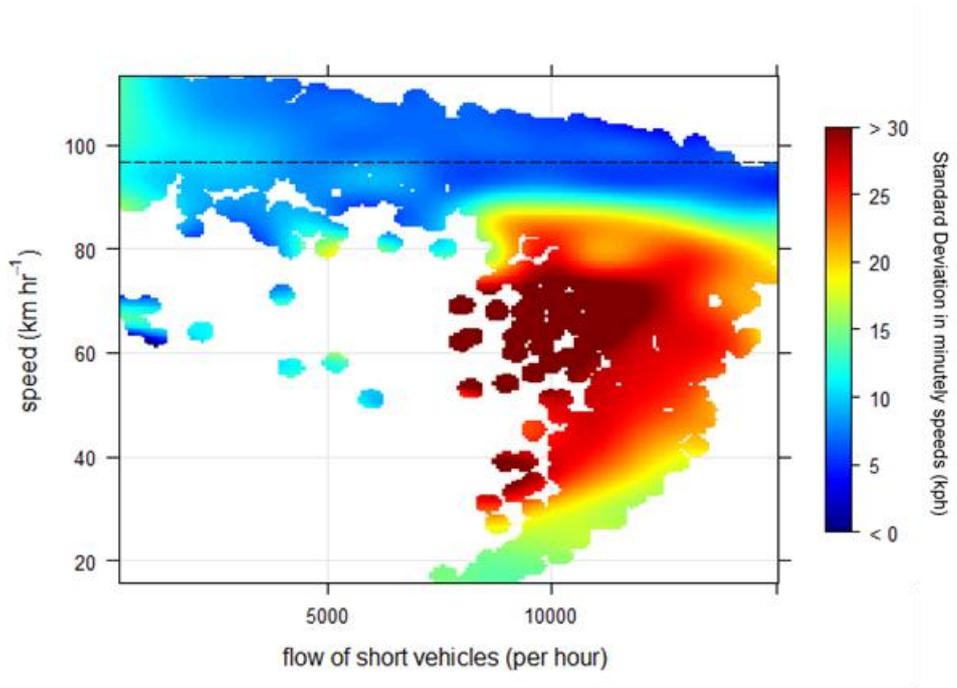


Figure 23 Relationship between short vehicle flow and speed with the standard deviation in short vehicle speed at the M25 for 2009.

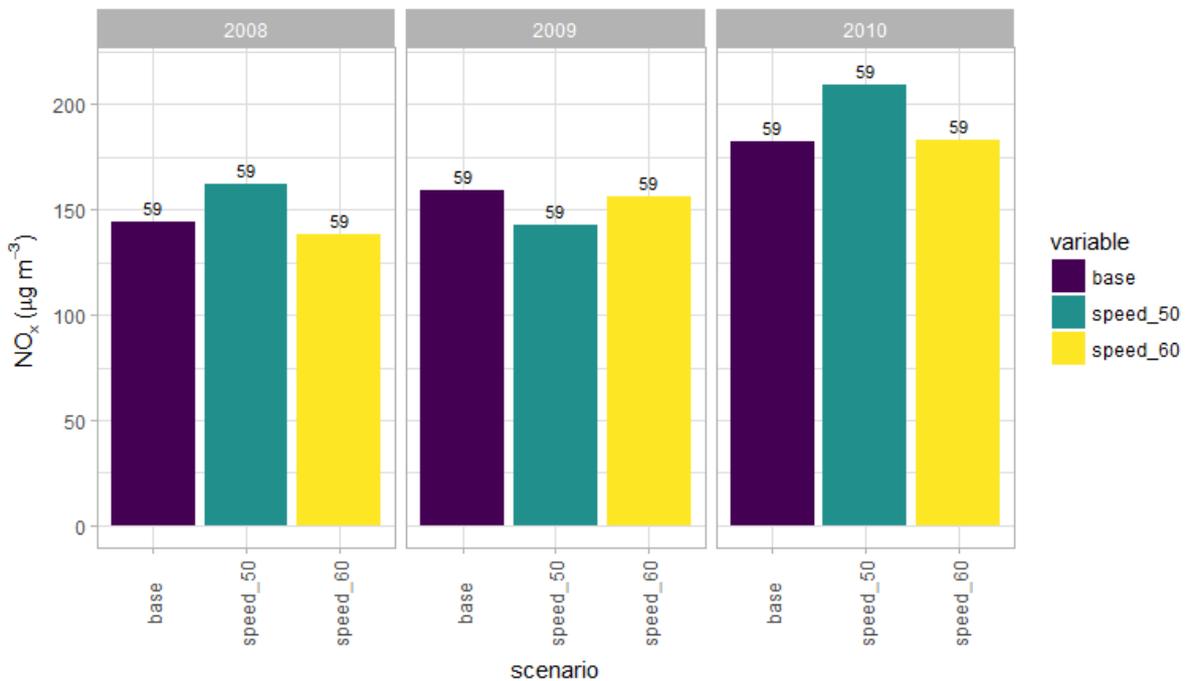


Figure 24 Predictions of annual mean NO_x concentration for different vehicle speed scenarios for the M25. The numbers at the top of the bars show the base case speed in mph.

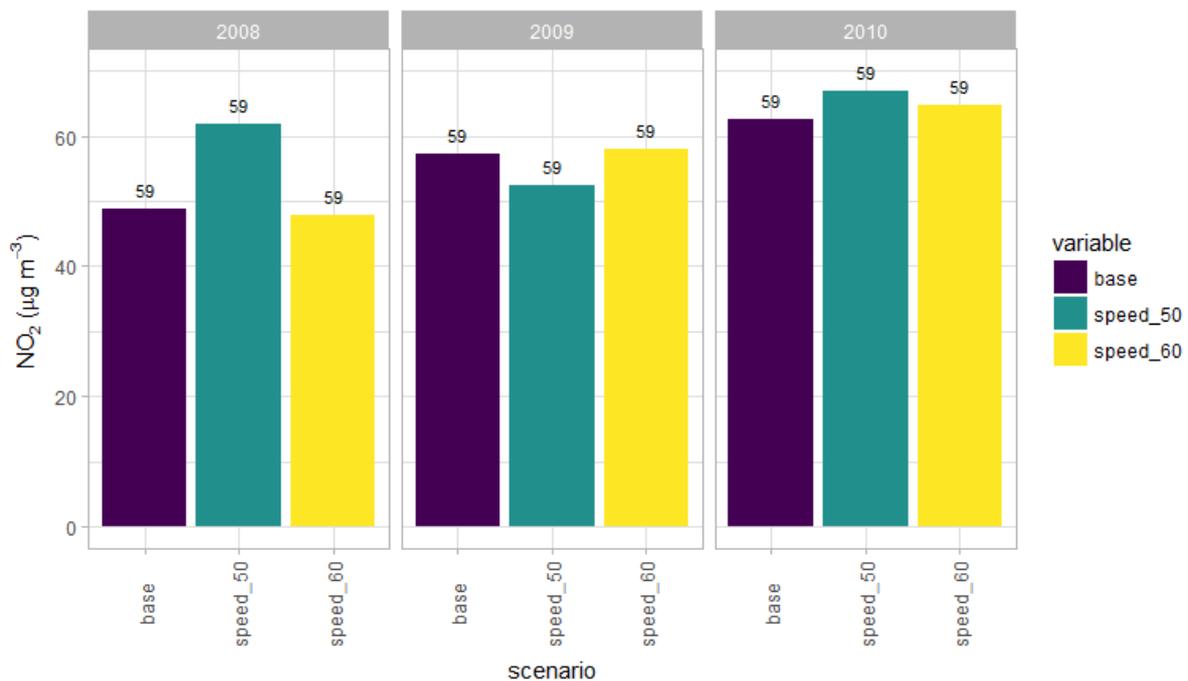


Figure 25 Predictions of annual mean NO₂ concentration for different vehicle speed scenarios for the M25. The numbers at the top of the bars show the base case speed in mph.

Isolating different conditions

One of the difficulties of the analysis of motorway MIDAS data is that it is difficult to know how best to treat multiple lanes of traffic. Ideally, the MIDAS data would provide both the flow and the speed by vehicle type for each lane of the motorway. Such data would both improve the robustness of the analysis as well as simplifying it. However, even with knowledge of the vehicle type and speed for individual lanes of a motorway it can be challenging to summarise the data in a robust way. While it is possible to use individual lane information in statistical models, in practice the data tend to be highly correlated making difficult to understand the influence of individual variables (even though good predictive models can be constructed).

A key attribute of the motorway data for use in statistical models is that the vehicle flows and speed can be highly correlated by lane, making it difficult to represent variables in a model. Another important aspect for near-motorway concentrations is the extent to which each side of the motorway contributes to concentrations.

To simplify the analysis, there are two main approaches that could be used. First, to filter for conditions where one side of the motorway is dominant in terms of flows of short and long vehicles. These conditions would reduce the influence of one side of the motorway and potentially provide a more robust view of the influence of vehicle flows and speeds. Second, select conditions where the traffic behaviour is very similar on each side of the motorway. The second approach avoids the issues of trying to combine very different traffic behaviours.

In testing for the M60, the first approach tended to result in very few hours of data that could be used – even when considering more than one year of data. This is because the traffic flows (and speeds) tend to behave similarly by hour of the day on each side of the motorway.¹ The second approach provided more hours that could be used. As an example, the M60 data for 2013 and 2014 were combined and hours selected where the flow of short

¹ It may be possible in other locations to extract each side of the motorway separately for analysis provided the flows and speeds are not so highly correlated on each side of the motorway.

vehicles on one side of the motorway was +/- 20% of the flow on the other side, together with an equivalent selection for long vehicles. Additionally, the filter for similar speeds for short vehicles was used based on the speed being within +/-20%. Based on the 2013/2014 data the selection resulted in 3343 hours.

By selecting conditions where the flows and speeds are similar on either side of the motorway, it is then possible to combine the flows and speeds without making too many assumptions. The plot below shows the relationship between the flow of short vehicles and vehicle speed, which is broadly similar to earlier plots that used the full (weekday) data set. The similarity of the patterns in NO_x concentration between the full and filtered data sets suggests that no obvious biases are introduced when analysing the full data set in the way the flows and speeds are considered.

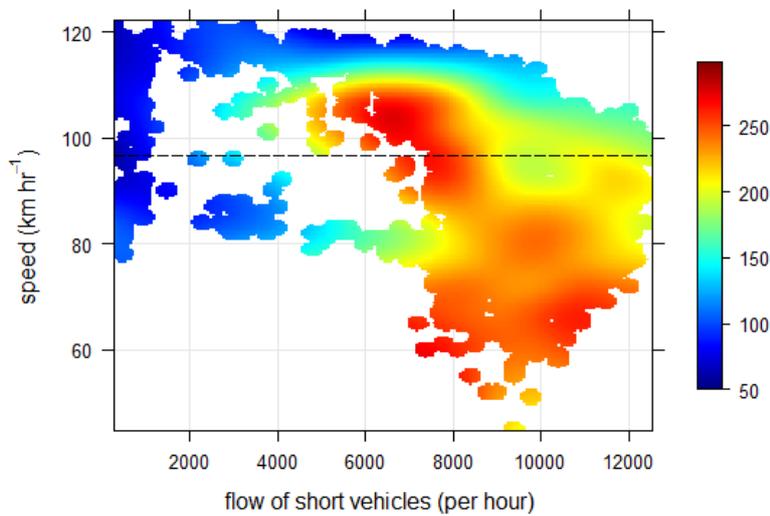


Figure 26 Variation in NO_x concentrations with short vehicle flow and speed for the M60 for filtered data.

Different colour scale, isolating the variation:

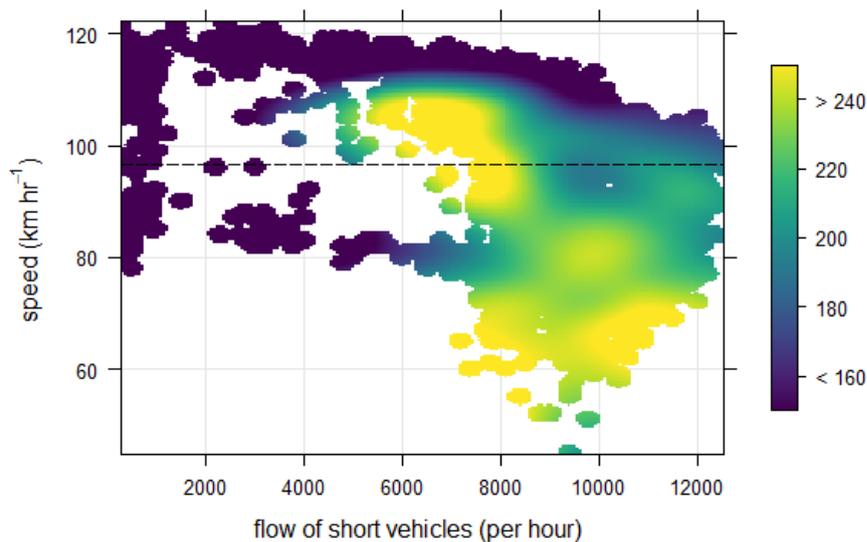


Figure 27 Variation in NO_x concentrations with short vehicle flow and speed for the M60 for filtered data with a different colour representation and scale.

And frequency of data:

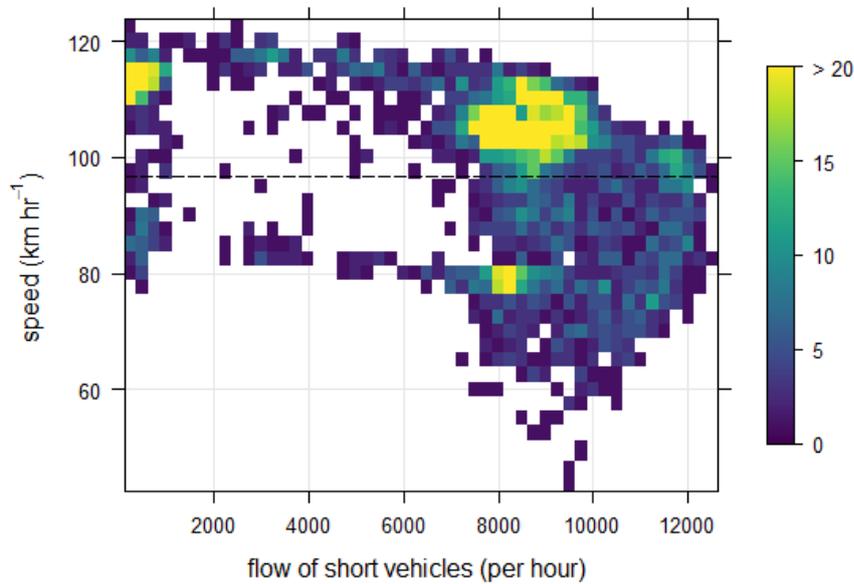


Figure 28 Variation in frequency of NO_x with short vehicle flow and speed for the M60 for filtered data.

The plot above still includes other influences such as meteorology and (most importantly) the flow of long vehicles. The variation in the flow of long vehicles is shown below, which are seen to dominate when the flow of short vehicles is around 8000 per hour. It is likely therefore, that the elevated concentration of NO_x seen in the NO_x plot for vehicle flows of around 7000 per hour and speeds of around 110 km/h (for short vehicles) is dominated by relatively high flows of long vehicles.

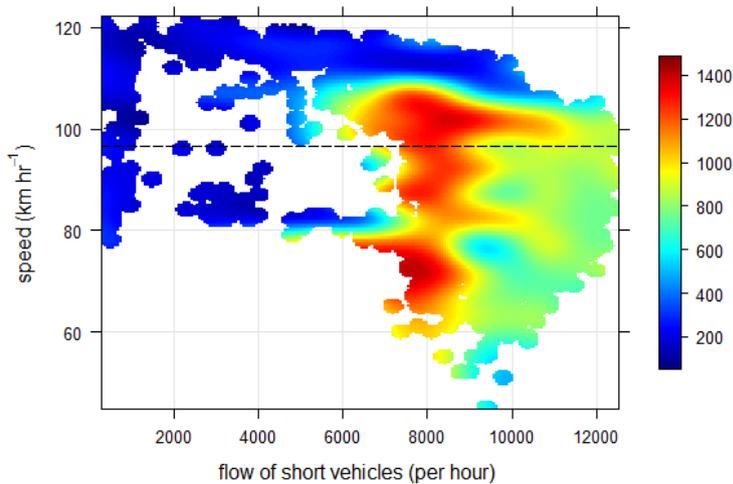


Figure 29 Variation in the flow of long vehicles with short vehicle flow and speed for the M60 for filtered data.

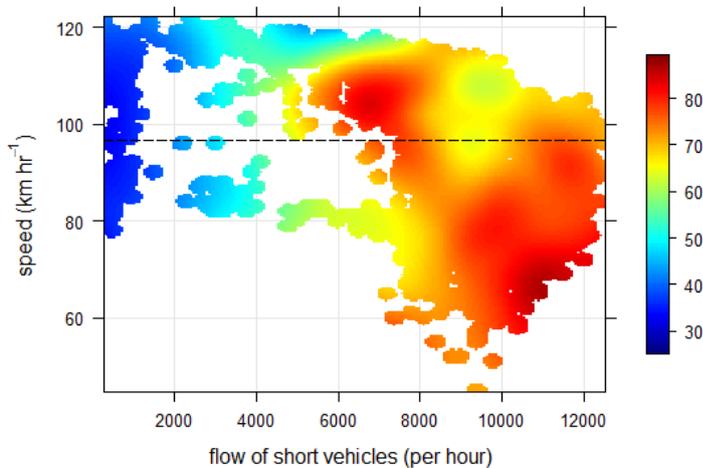


Figure 30 Variation in NO_2 concentration with short vehicle flow and speed for the M60 for filtered data.

Using an estimated emission level

Even with the careful filtering above, there remains uncertainty in the patterns between vehicles flows, speeds and concentrations. The flows of long and short vehicles can further be combined by using estimates of their relative importance for the contribution to NO_x (or NO_2) concentrations. A simple approach is to use a linear regression model to relate vehicle flows by long and short with the concentration of NO_x . The flows and concentrations can be split by weekend and weekday, when there are very different magnitudes of each and corresponding concentrations of NO_x . For 2013 on the M60 for example, it can be shown that a linear regression suggests long vehicles are 5.7 times more important than short vehicles for concentrations of NO_x . This factor can be used to represent a proxy for overall emission level i.e. by assuming short vehicle flows are weighted by one and long vehicles by 5.7. In this way, the analysis avoids treating short and long vehicles separately – which can make interpreting the variations in NO_x or NO_2 concentration by flow and speed difficult due to the ‘unseen’ effect of the long vehicles, for example.

The relationship is shown below relating the emission proxy to short vehicle speed and the concentration of NO_x . Again, this plot indicates that concentrations of NO_x tend to higher for higher levels of emission – but also for lower vehicle speeds. Note that this plot considers weekday variations only.

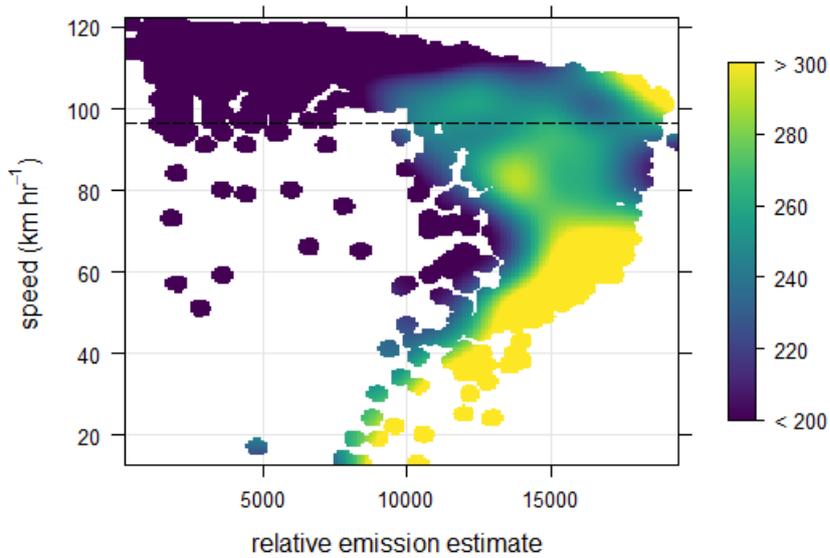


Figure 31 Variation in NO_x concentrations with relative emission and speed for the M60 for filtered data.

The corresponding plot for NO₂ is shown below.

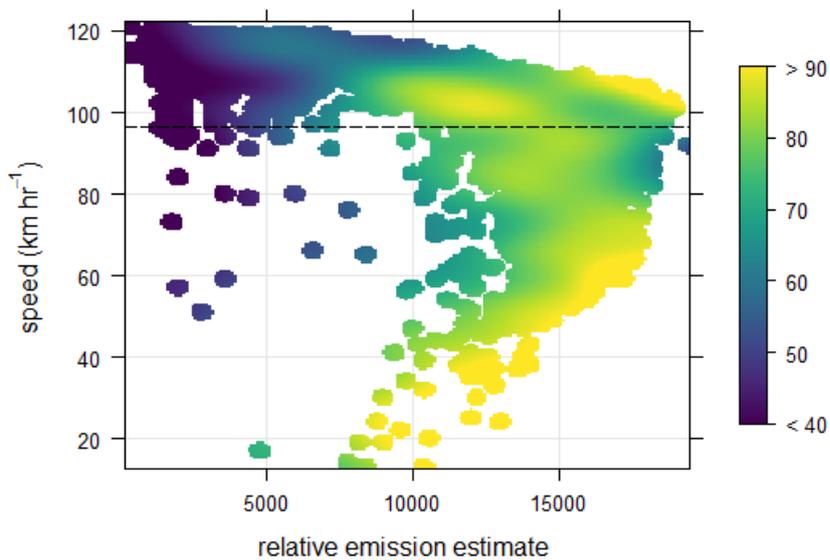


Figure 32 Variation in NO₂ concentrations with relative emission and speed for the M60 for filtered data.

Limitations

There are several limitations of the analysis mostly related to the original data available. These limitations include:

- The MIDAS data does not provide the vehicle speed associated with the vehicle type by each lane of a motorway. This is likely the most important limitation of the current work because several assumptions are required to estimate the vehicle speeds by short and long vehicles, which may not be optimum.
- It can be difficult to summarise the MIDAS data to give an overall vehicle flow and speed when using data from individual motorway lanes. Vehicle flows by vehicle type can also be correlated with one another. While such correlation will not adversely affect model predictions, it is more problematic for understanding the specific contributions to concentrations of NO_x and NO₂.
- For scenarios involving a change of speed, it is likely that the modelled effects are indicative because of the strong coupling of vehicle speed and flow. Refined estimates could be made by also adjusting the vehicle flow – perhaps based on the output from a traffic simulation model.

Other findings

The original aim for this project was to determine whether from observed air quality and traffic flow and speed information, information could be gained on the effects of changes to vehicle speeds to assist some sort of dynamic control over pollutant concentrations close to motorways. However, the techniques used have also yielded other potentially useful information not related to the original aims of the project. These include:

- It is possible to build very good explanatory statistical models to predict concentrations of NO_x and NO₂ close to motorways. Using a combination of meteorological data from the motorway network together with MIDAS traffic flow and speed data, models can be built that explain a high proportion ($r \sim 0.9$) of the hourly variation in concentrations.
- The models strongly suggest that long vehicles i.e. HGVs explain most of variation of NO_x but short i.e. cars and vans explain most of the variation of NO₂. This is an interesting and potentially important finding. The only way in which this situation can arise is if primary NO₂ emissions from light duty vehicles are more important than heavy duty vehicles. This is because the concentration of NO₂ close to the motorway is controlled by two main origins: the formation of NO₂ through the reaction with ozone and the emission of primary NO₂. There is no reason why NO_x emissions from light duty vehicles would behave differently in terms of the NO + O₃ reaction compared with HDVs.

This finding has the important implication that to control NO₂ concentrations close to motorways it might be better to control LDV NO_x emissions rather than HDV NO_x emissions. Further away from a motorway (of the order of 100 m) the proportions of primary NO₂ from light and heavy vehicles will matter less because the reaction of NO with ozone will dominate. This issue should be investigated further e.g. through more analysis and a consideration of primary NO₂ emissions from light and heavy duty vehicles.

Use of other metrics in modelling

The difficulty of using statistical models applied to motorway locations was discussed earlier. Of key importance is the strong correlation between variables such as speed and flow, as well as the correlation between lanes of a motorway. An alternative approach is to combine the speed and flow into a *density* variable, defined as

$$density = \frac{flow}{speed}$$

Where the flow is traffic flow in vehicles per hour and the speed is in km/h. When expressed like this, the density is the number of vehicles over 1 km. The use of density could have several advantages for modelling. First, it avoids the implicit correlation between speed and flow by capturing the variation in a single variable. Second, it is possible to sum density more easily across multiple lanes of traffic.

The density metric needs more consideration; however, an initial investigation of its use has been considered below. In these plots data from the M60 (2013) have been used with the wind direction filtered to maximise the motorway contribution. The plot below shows how the concentration of NO_x varies according to the density of long vehicles. It shows that concentrations tend to increase with increasing density but levels off above about 20 vehicles per km. The levelling off tends to be associated with lower vehicle speeds.

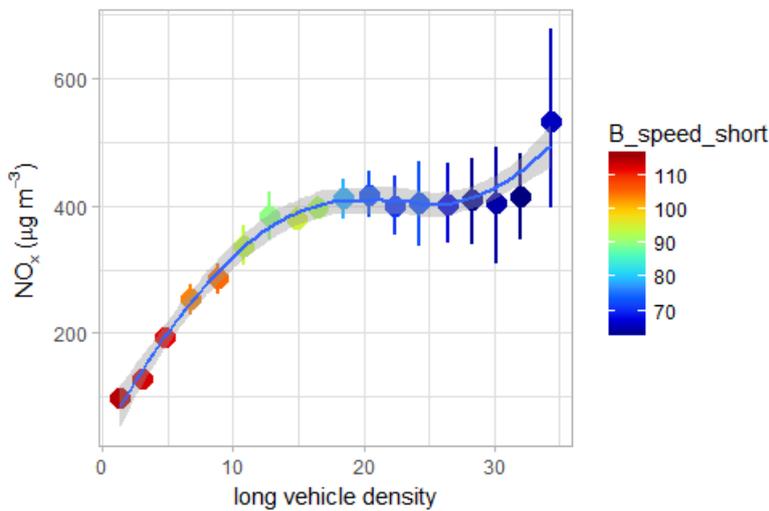


Figure 33 Relationship between long vehicle density and NO_x concentration. The colour represents the speed of short vehicles.

There is a similar behaviour for short vehicles, shown below. This plot also shows there is some levelling-off of the NO_x concentration above about 100 vehicles per km.

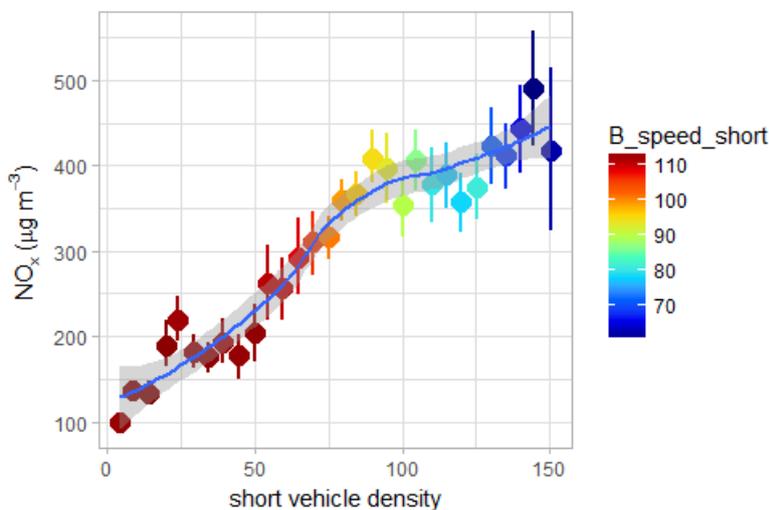


Figure 34 Relationship between short vehicle density and NO_x concentration. The colour represents the speed of short vehicles.

Perhaps more useful is a plot of short and long vehicle density as a function of NO_x concentration. The plot below shows that the concentration of NO_x most clearly increases with increasing long vehicle density.

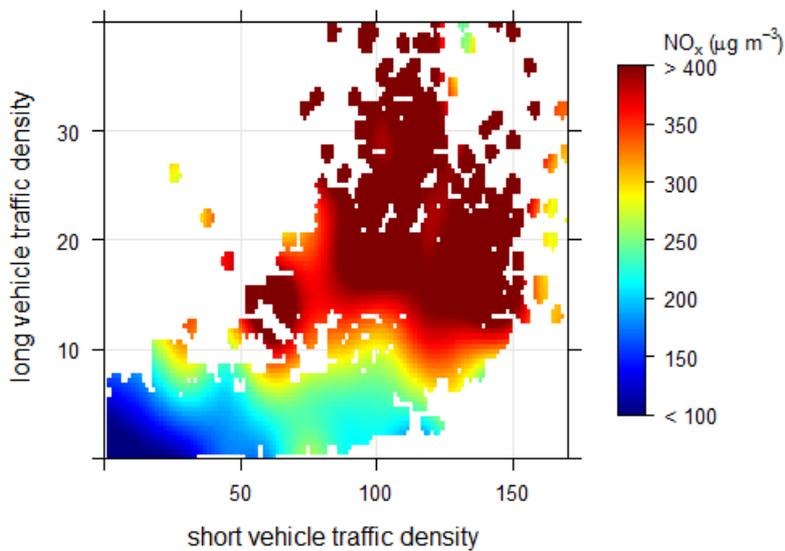


Figure 35 Relationship between long and short vehicle density and NO_x concentration.

By contrast, the plot for NO₂ (below) shows a stronger effect as short vehicles densities increase. This finding is consistent with the statistical modelling that shows a stronger influence of light vehicles for the concentration of NO₂.

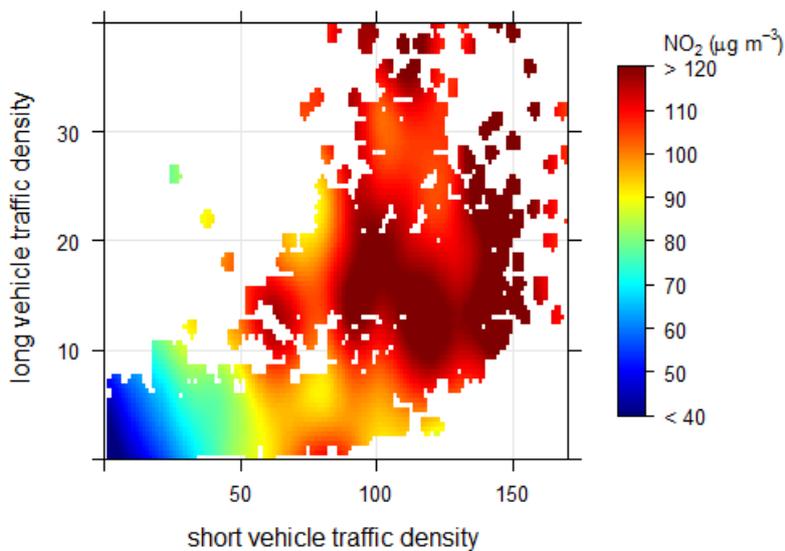


Figure 36 Relationship between long and short vehicle density and NO₂ concentration.

Initial modelling using two density variables (for long and short vehicles) shows that similar model performance can be obtained for NO_x and NO_2 but with fewer variables. Such an approach has the advantage of being more robust and avoiding the strong correlation between variables. Further consideration would need to be given to how to apply scenarios e.g. how best to adjust the

Neutral month based on May 2013 and May 2014, weekday only

