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APPENDIX AVAILABLE ON REQUEST

Research Report 155

The Impact of the Congestion Charging Scheme on Air Quality in London

Part 1. Emissions Modeling and Analysis of Air Pollution Measurements

Frank Kelly et al.

Appendix M. Bivariate Polar Plot Analysis

Note: Appendices Available on the Web may appear in a different order than in the original Investigators' Report, and some remnants of their original names may appear in Table and Figure numbers. HEI has not changed the content of these documents, only the letter identifier.

Appendix M was originally Appendix I.

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This document was reviewed by the HEI Health Review Committee but did not undergo the HEI scientific editing and production process.

APPENDIX M

Bivariate Polar Plot Analysis

Introduction

From the outset of developing an analytical framework to examine the impact of the CCS, the availability of air pollution measurements from just one long-term roadside site within the CCZ, namely Shaftsbury Avenue, was identified as being a major limiting factor. To compensate in part for this limitation, we examined ways in which the most appropriate and valuable information could be extracted from this dataset.

Pollution measurements at roadside monitoring sites are influenced not just by traffic emissions from the adjacent road(s), but also by a range of other, local and distant, emissions sources. Work undertaken in this chapter was designed to identify the portion of the pollutant dataset that would be directly related to emissions from the road(s) adjacent to a site. By comparing mean concentrations within the ‘road emission’ portion in the 2 years before and after introduction of the CCS during charging hours only, an assessment could be made as to whether the intervention has affected emissions at the roadside CCZ site, while minimising the effects of larger scale changes in ambient pollution concentrations due to meteorological variation.

Bivariate polar plots provide a graphical representation of the wind speed and direction dependence of any measurement at a particular monitoring site, thereby allowing a qualitative method of identifying the direction and certain characteristics of primary emission sources surrounding a monitoring site and their likely significance relative to overall mean concentrations. There are currently few references describing their use in such an urban scenarios. Carslaw et al (2006) utilised them to demonstrate emissions surrounding an airport), and their application here is considered developmental.

Application to ambient monitoring data

Methods

This analysis used 15-minute mean pollutant measurements taken during congestion charging hours from Shaftesbury Avenue, Camden (CCZ - Roadside) combined with wind speed and direction data to produce an input grid. This grid was then processed by a surface mapping programme to produce the polar plots using Kriging to interpolate between grid points (Point Kriging with a linear variogram slope 1 anisotrophy ratio1 angle 0). Regional pollution sources were removed by subtracting corresponding mean concentrations from the Suburban Outer London Indicator sites. Separate plots were produced for the 2 years pre- and post-CCS periods using NO_2, NO_X and PM_{10} measurements.

As no meteorological sensors were co-located with the pollution monitors, wind data were taken from a meteorological station in an open location in Suburban Outer London approximately 20km away (Erith). When assessing the relationship between wind speed and direction and pollution concentrations in relation to a particular pollution monitoring site, regional, neighbourhood and micro-scale variations have to be considered. The fact that this analysis used regional-scale wind data will have introduced uncertainty related to the unknown differences between regional and neighbourhood-scale meteorology. However, as the primary output of the analysis was an assessment of change in concentrations this uncertainty is of lesser importance given that local geography surrounding the site did not change between pre- and post-implementation periods.

The data analysis produced a polar grid of pollution concentrations for each 10 degree wind direction bin and each 1 m s^{-1} wind speed bin. Due to prevailing weather conditions, not all bins contained pollutant data points. A polar plot showing frequencies of data points in each bin was produced to investigate where interpolation between points would be greatest and to set analysis parameters. Figure M1 shows the percentage of total readings in each bin for the pre- and post-CCS dataset (26,918 and 25,503 respectively). The crosses indicate the input bins where there was at least 1 data point; the blue contour shows the cut-off frequency of 0.1% (27 or 26 readings).

The distribution of data reflects the characteristics of the prevailing weather conditions over London. These comprise maritime low pressure systems approaching from the Atlantic to the west, which typically bring more stormy weather than continental high pressure systems approaching from the south. South-westerly winds of 1 to 4 m s^{-1} are the most frequent. There are very few wind speeds greater than 6 m s^{-1} from any direction. Winds from the north are the least frequent, with few or no input points in either plot above 3 m s^{-1}. To minimise uncertainty caused by large areas of interpolation between input points, the input grid was bounded at 6 m s^{-1}. Second, to limit the influence of outliers within very low frequency bins, bins with less than 28 readings (0.1%) were also excluded.

The within CCZ - Roadside monitoring site at Shaftesbury Avenue is located to the south west of a complex junction approximately 5m from the kerb. The surrounding roads are all single lane with a mix of vehicles. Unfortunately, no Automatic Traffic Count (ATC) or Manual Classified Count (MCC) data were available for this specific location. It lies on one bus route with a frequency of approximately every 10 minutes during the day and 20 to 30 minutes at night. A map of the surrounding road layout is shown in Figure M2 and an aerial view photograph is shown in Figure G1.

Results

The bivariate polar plots for Shaftesbury Avenue NO_X are shown in Figure M3. The contours for each period were similar, with a dominating pollution source to the north east of the monitoring site and concentrations increasing steadily from south to north. The map in Figure M2 indicates that this is the direction of the major junction adjacent to the monitoring site. It appeared from the plots that NO_X concentrations from the principal source to the north were lower in the post-CCS period. Peak concentrations were recorded during winds of 1 - 4 m s^{-1} from between 330 and 80 degrees north.

The polar plots for NO_2 were similar to those of NO_X with the dominating source from the direction of the road junction (Figure M4). It is interesting to note that NO_X:NO_2 ratio during southerly winds was around 2:1, while the ratio is 3:1 or higher during northerly winds. While the peak interpolated concentrations appeared to decrease in the post-CCS plot, the more general decrease evident in the NO_X plots was not repeated for NO_2.

Due to the large range of sources of PM_{10}, many of which are independent of vehicle emissions, the PM_{10} polar plots were more homogeneous than those of NO_2 and NO_X. However, the junction to the northeast was still discernable as the main source of PM_{10} in both plots (Figure M5) and appeared to have increased in the post-CCS plot. Peak concentrations were related to lower wind speeds than those for NO_X and NO_2.

Discussion

With this analysis method we sought to isolate the component of the pollutant dataset directly related to emissions from the road(s) adjacent to a particular monitoring site. The hypothesis being that this component, as recorded by a roadside monitoring site within the CCZ, is the most likely to show a signal due to changed vehicle numbers.

The use of bivariate polar plots in this application revealed important characteristics of the monitoring dataset from the only roadside site within the CCZ. Firstly, the contour plots of NO_X. NO_2 and PM_{10} provided a visual indication of the meteorological conditions that gave rise to peak concentrations of each pollutant. These plots showed that the road junction to the north east of the monitoring site is the principal source of NO_X and NO_2 pollution and, to a lesser degree, PM_{10} pollution. They also gave an indication of changes in mean concentrations relating to vehicle emissions from this principal source.

Secondly, this analysis highlighted the importance of considering prevailing weather conditions when positioning a roadside monitoring site. The Shaftesbury Avenue monitoring site is located on the south west side of a busy junction. The wind frequency analysis showed that while the main pollutant source was to the north east, winds from this direction were very infrequent (18% pre-CCS, 15% post-CCS of the total for wind directions between 330 and 80 degrees, wind speeds 1 – 4 ms^{-1}). If this monitoring site were located on the opposite side of the junction, mean concentrations of NO_X, NO_2 and PM_{10} would have been higher and detection of a change in pollutant concentrations due to any traffic-related emissions change arising from the CCS may have been more likely.

This analysis has shown that the decrease in NO_X concentrations measured during charging hours at Shaftesbury Avenue, Camden (CCZ – Roadside) over the 4-year period was driven by decreases in emissions primarily from the road source to the north east of the monitoring site. However, the method was unable to differentiate between the effects of improved vehicle emissions technology independent of the CCS, and the effects of decreased vehicle numbers directly as a result of the CCS.

The NO_2 analysis revealed little or no change in NO_2 emissions from the principal vehicle source to the north in the ambient measurements. This finding contrasts with large increases in NO_2 concentrations measured at other roadside/kerbside sites within Inner London, most notably Marylebone Road (CCZ Boundary), as revealed in the CUSUM screening analysis (Chapter 4 and Appendix H). At least some of this increase has been attributed to regenerating particle traps now fitted to all of London's buses (AQEG, 2007). The contrasting NO_2 trends may be related to the fact that the Shaftesbury Avenue monitoring site lies on only one bus route with a frequency of 6 buses an hour, whereas Marylebone Road is adjacent to a bus lane carrying five bus routes with a peak frequency of 42 buses an hour.

A high incidence of calm conditions and easterly winds increasing transboundary transport of particulate pollution, led to unusually high PM_{10} concentrations across London following introduction of the CCS in 2003. While the method accounts for regional sources of PM_{10} pollution by removing the suburban component from the Shaftesbury Avenue measurements, decreased dispersion rates associated with these easterly winds caused an unusually high 'London' component of PM_{10}. The PM_{10} polar plot analysis reflects this with increased concentrations from a range of wind conditions. However, the disproportionately large increase in peak concentrations from the primary emissions source to the north of the monitoring site suggests that local PM_{10} emissions may also have increased. The reasons for the PM_{10} increase are not obvious, but may be related to a change in vehicle mix from petrol to diesel due to the large increase in taxi use (Chapter 1).

The novel use of bivariate polar plots to characterise pollutant concentrations surrounding an urban monitoring site has proved useful in this scenario, but would benefit from further development. Notably in transforming the qualitative assessment of change into a quantitative assessment, including an estimation of the uncertainty of outputs. Research is ongoing to develop this methodology in a range of air quality time series studies.

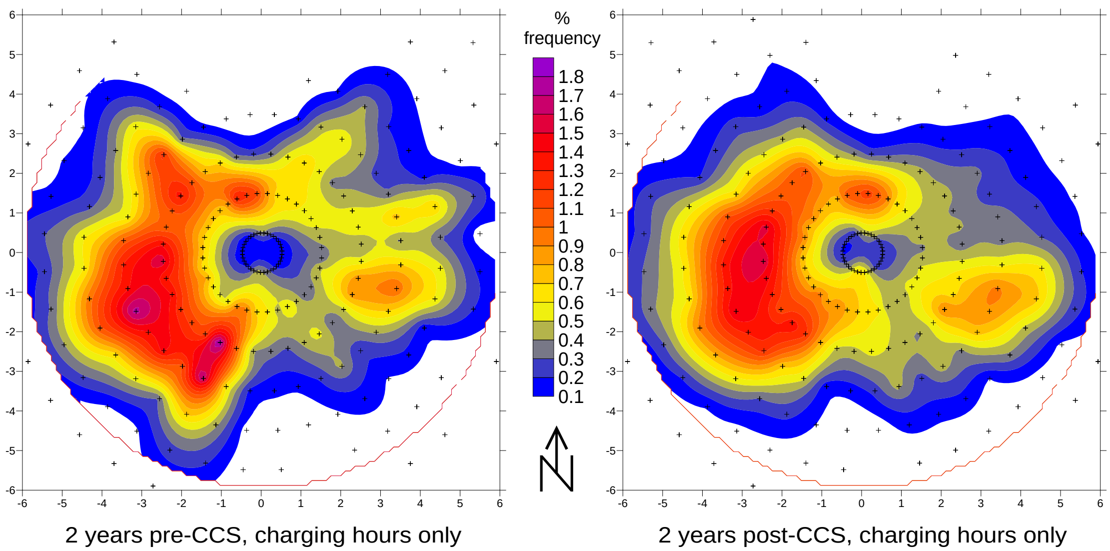

Figure M1. Polar plot showing the frequency of wind data points in each grid bin (scale shows % of total). The blue contour represents less than 0.1% of the total. Wind speed is represented on the radial axis (0 to 6 ms^{-1}), wind direction on the polar axis (North upward).

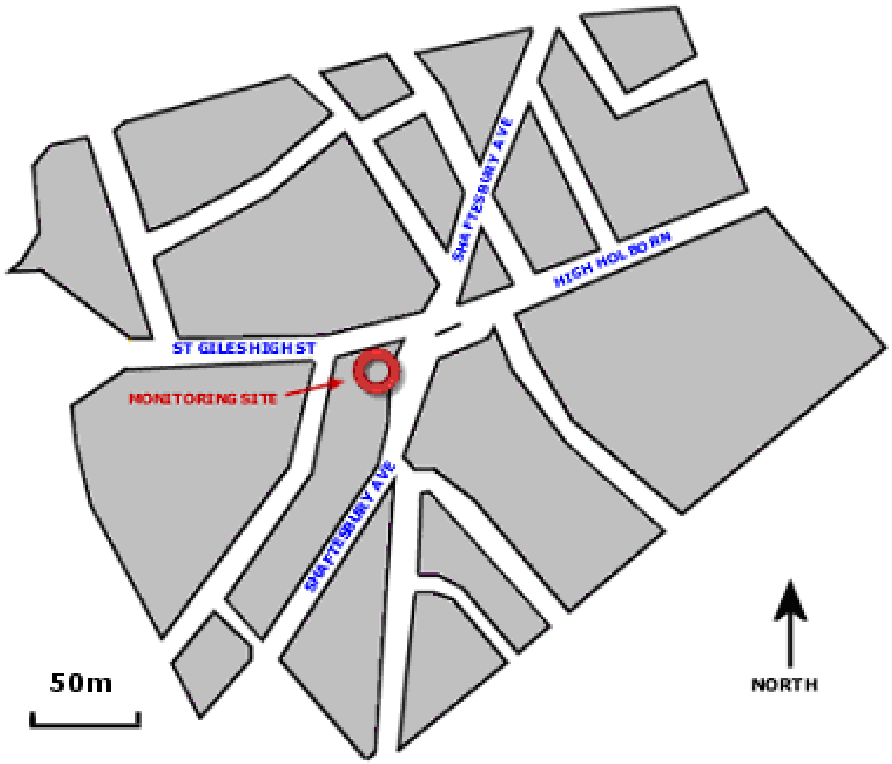

Figure M2. Road layout surrounding the Shaftesbury Avenue monitoring site.

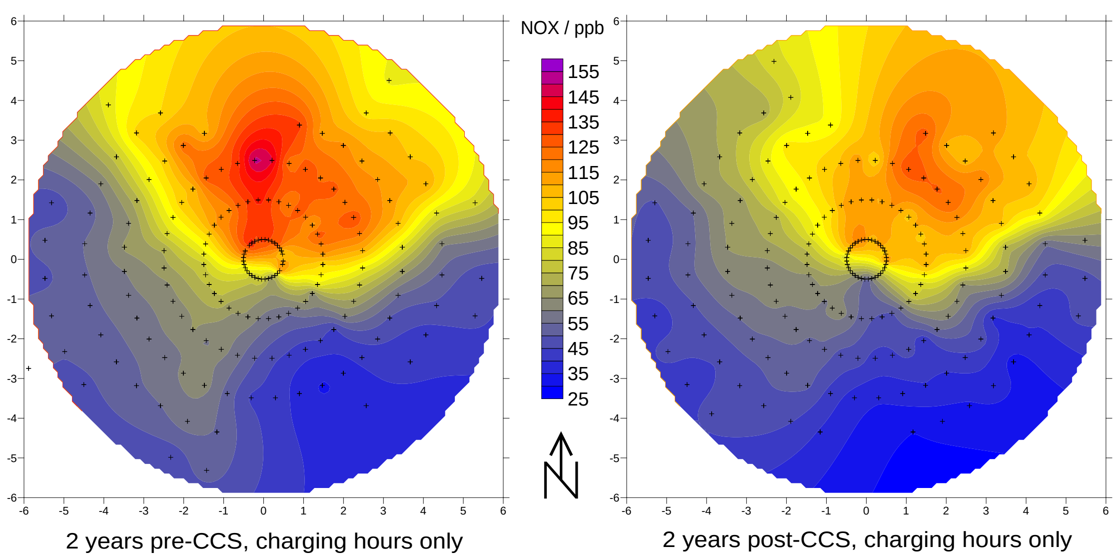

Figure M3. Polar plots for NO_X at Shaftesbury Avenue within the CCZ (CC hours only, suburban component subtracted). Crosses show input grid data points. Wind speed is represented on the radial axis (0 to 6 ms^{-1}), wind direction on the polar axis.

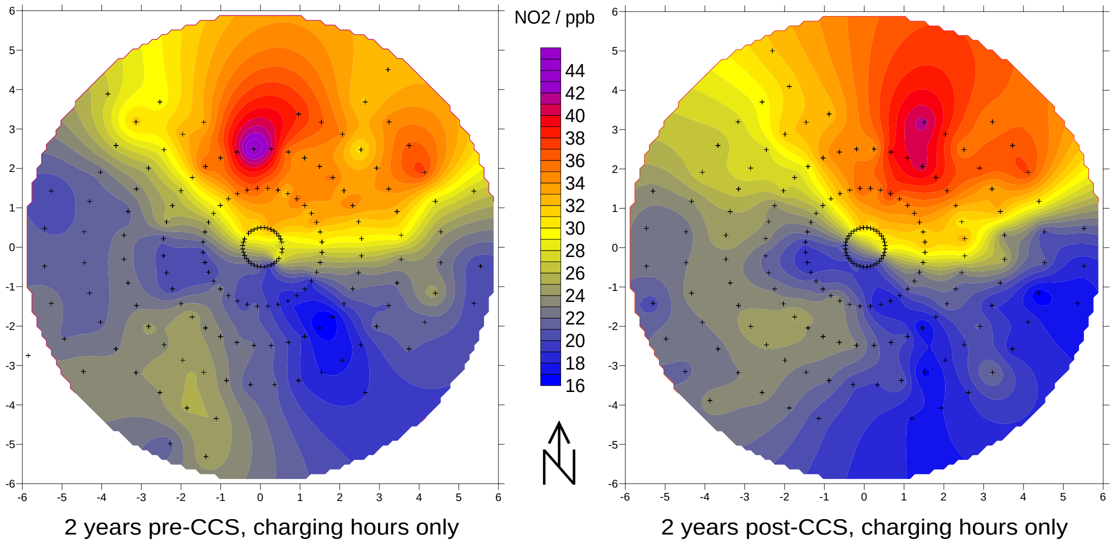

Figure M4. Pre- and post-CCS polar plots for NO_2 at Shaftesbury Avenue within the CCZ (CC hours only, suburban component subtracted). Crosses show input grid data points. Wind speed is represented on the radial axis (0 to 6 ms^{-1}), wind direction on the polar axis

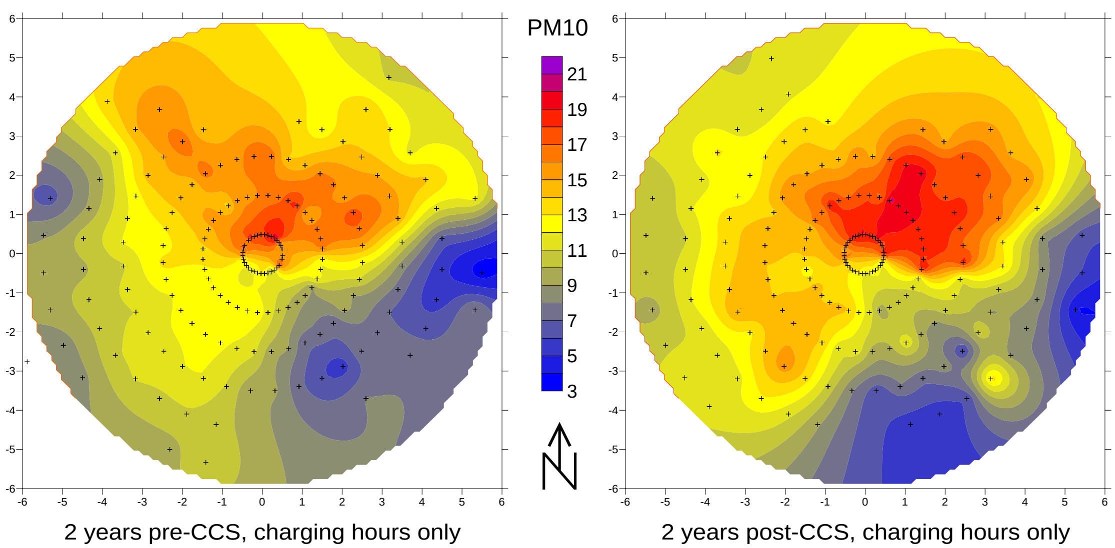

Figure M5. Pre- and post-CCS polar plots for PM_{10} at Shaftesbury Avenue within the CCZ (CC hours only, suburban component subtracted). Crosses show input grid data points. Wind speed is represented on the radial axis (0 to 6 ms^{-1}), wind direction on the polar axis

Table M1. Statistical summary of interpolated output grid concentrations from Shaftesbury Avenue (CCS hours only, suburban component removed).

Input data	minimum	mean	maximum	standard deviation	upper quartile mean	upper quartile change
NO_2 pre-CCS / ppb	16.2	26.2	44.6	6.0	34.9	3%
NO_2 post-CCS / ppb	16.5	26.2	41.3	6.6	36.0	
NO_X pre-CCS / ppb	34.6	76.0	151.8	30.1	117.8	-7%
NO_X post-CCS / ppb	27.8	69.7	127.5	28.5	109.9	
PM_{10} pre-CCS / µg m-3	3.5	11.3	19.8	3.0	15.1	6%
PM_{10} post-CCS / µg m-3	4.0	11.9	20.3	3.3	16.0	