Utilising *Openair* to support multi-stakeholder engagement and the resolution of air quality issues

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For key stakeholders to make informed air quality management decisions it is often necessary for in-depth data analysis to be tailored and concisely presented to meet their needs. Given the complexity of sources, the abundance of relevant data (e.g. monitoring, modelling, process data) and the spatial and temporal scale of these issues, the provision of this information can be challenging, particularly with multiple stakeholders requiring varying outputs. Using a case study which investigated PM_{10} in the vicinity of a steelworks, this paper will illustrate how *Openair* (an open-source air pollution analysis package based on the programming language/statistical package *R (*http://www.openairproject.org/)) can be utilised to analyse relevant air pollution data on a spatial and temporal scale in order to support multi-stakeholder engagement and the resolution of air quality issues.

Keywords: Air quality management, Openair, Particulate Matter, air pollution analysis, multi-stakeholder engagement.

1. Introduction

Air quality management processes are inherently structured around data, thresholds and limits and as such a single number or data point may have to be interpreted in different ways by different stakeholders. For example, an annual mean concentration of 44 $\mu g/m^3$ of PM_{10} may have to be interpreted in number different ways by stakeholders of varying backgrounds, interests and with varying degrees of baseline knowledge. An air quality professional would recognise that this concentration may be 4 $\mu g/m^3$ above an annual mean limit value and therefore understand the implications in terms of national or international compliance. From a regulatory view point there is a need to understand the sources of the elevated concentrations so that regulatory responses can be enforced. A source manager/operator (e.g. industry, transport) needs to understand what contribution their activities are having on the elevated concentration and what it means in terms of source management. A health professional may have less interest in the actual measured concentration and more interest in the population exposed to these elevated concentrations, the spatial extent of the concentration and the subsequent health implications.

However, air quality management is not about single numbers or data points and as such there is a need for data to be interrogated and interpreted in a number of ways, taking into consideration the influence of differing variables (e.g. meteorological conditions), and then presenting this information to all stakeholders to make informed decisions. *Openair* is a tool which facilitates this process and this is illustrated though a case study in which *Openair* was utilised to undertake an independent review of PM_{10} in the vicinity of a steelworks in the United Kingdom (UK) (Hayes and Chatterton, 2009). The results were used to inform stakeholders such as site operators, Environment Agency, local authorities, national government, national advisory bodies and the public and led to a suite of recommendations on taking the management of the site forward.

1.1 Introduction to *Openair*

Openair is an *R* package (R Core Team, 2013) primarily developed for the analysis of air pollution measurement data but which is also of more general use in the atmospheric sciences. The package consists of many tools for importing and manipulating data, and undertaking a wide range of analyses to enhance understanding of air pollution data in more insightful ways. Examples of functionality include importing data from air pollution networks, source identification and characterisation using bivariate polar plots, quantitative trend estimates and the use of functions for model evaluation purposes. Air pollution data can be analysed quickly and efficiently, in an interactive way, freeing time to consider the problem at hand. One of the central themes of *Openair* is the use of conditioning plots and analyses, which greatly enhance inference possibilities. Further information on *Openair* can be found here - http://www.openairproject.org/ and at Carslaw & Ropkins (2012a and 2012b).

1.2 Air Quality Management in the UK

The Environment Act 1995 (HM Government, 1995), places obligations on all local authorities in the UK to undertake periodic reviews and assessments of air quality in their administrative areas. These reviews and assessments form the cornerstone of the system of Local Air Quality Management (LAQM). The LAQM regime plays a key role in assisting Government and the Devolved Administrations to achieve the air quality objectives as defined within the Air Quality Strategy for England, Scotland, Wales and Northern Ireland (Defra, 2007), the Air Quality Regulations (Welsh Government, 2010) pertaining to each area of the devolved United Kingdom and their subsequent Amendments. It also assists the Government and the Devolved Administrations towards achieving the Air Quality Limit Values as set out within the European Union Directive (EU Directive 2008/50/EC).

The Review and Assessment process is a phased risk management process, with the level of detail required being commensurate with a judgement by a local authority of the level of risk of exceeding the objectives specified in the Air Quality Regulations. Should a risk of exceeding an air quality objective be identified, through detailed monitoring and modelling programmes, and the public be shown to be exposed for a time period exceeding that specified in the Regulations then a local authority must declare an Air Quality Management Area (AQMA). The local authority is then required to prepare an Air Quality Action Plan (AQAP) specifying the measures that they intend to implement and the likely timescale in which these measures might reduce pollutant concentrations and/or exposure, in pursuit of achieving the objectives. All of this work must be undertaken with regard to statutory guidance issued under the Environment Act 1995 which includes Policy Guidance (Welsh Government, 2009) and Technical Guidance (Defra, 2009). This LAQM process is discussed in detail in Longhurst *et al.*, (2009).

1.3 Air Quality Management in Neath Port Talbot

Neath Port Talbot County Borough Council (NPTCBC) have undertaken their Review and Assessment duties since the commencement of LAQM in 1998. The Council identified the risk of an exceedence of the PM_{10} 24-hour air quality objective (24-hour mean of 50µg/m^3 not to be exceeded more than 35 times a year) and the Taibach Margam Air Quality Management Area for PM_{10} (24-hour objective) was declared on the 1st of July 2000 (Figure 1).

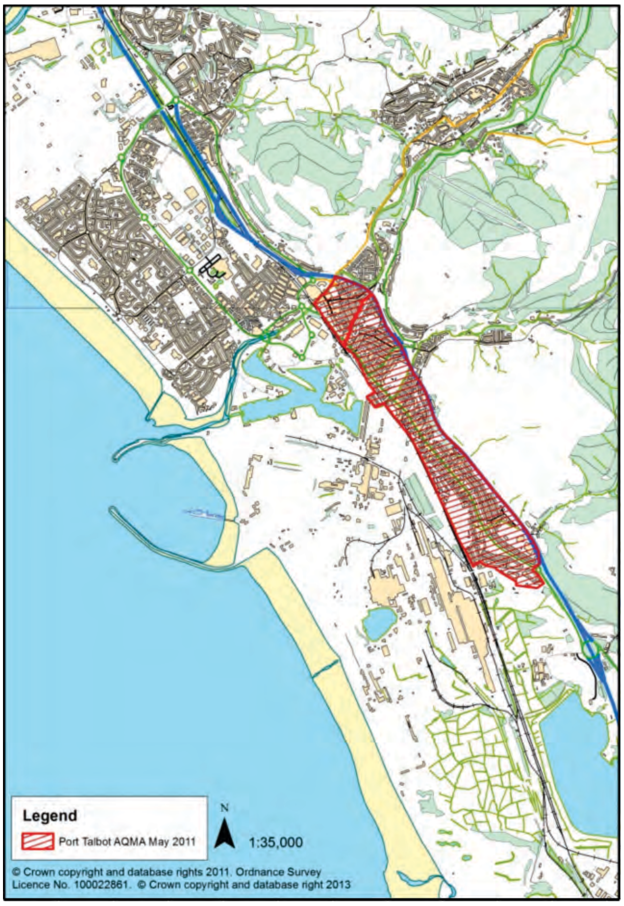

Figure 1. Neath Port Talbot Air Quality Management Area.

Subsequently, as required by the Environment Act 1995, NPTCBC undertook a further technical assessment of air quality in which their source apportionment study identified the Port Talbot Steelworks site as the primary source of PM_{10} emissions impacting on the AQMA. As required by the legislation NPTCBC has developed an AQAP in collaboration with various stakeholders including the site operators (Tata Steel) and Natural Resources Wales (formerly Environment Agency Wales) and has subsequently continued with their statutory LAQM duties (Neath Port Talbot County Borough Council, 2002). At a national level, the Welsh Government has also developed a Short Term Action Plan to address potential exceedences in accordance with the EU Directive 2008/50/EC (Welsh Government, 2012). In 2009, due to the complex nature of the site and the abundance of reports and historical data related to the AQMA, the Welsh Government commissioned the University of the West of England (UWE), Bristol to undertake an independent review of PM_{10} in the vicinity of the steelwork (Hayes and Chatterton, 2009). The findings of this independent review and the subsequent recommendations provide the basis of this case study.

1.4 Introduction to the Taibach Margam AQMA and potential sources

As illustrated in Figure 1, the AQMA (red hatchings) is located between the M4 motorway (blue line) which is the primary route between west Wales and London and the steelworks site (located to the south-west of the AQMA). The M4 and the boundary of the steelworks site have been utilised by NPTCBC to delineate the AQMA boundary. In additional to the M4, the A48 passes through the middle of the AQMA and is one of the primary routes into the town of Port Talbot and, at the time of this study, was heavily utilised by HGVs accessing the steelworks and other sites.

The steelworks is a large complex site around 28km^2 with a working 'heart' of 8km^2, around 50km or roads (many unsurfaced), 100km of railway and approximately 25,000 vehicle movements per day (Environment Agency Wales, 2009). Figure 2 illustrates the process map for the site and the following brief description provides an insight into the complexity of the site and the potential sources of particulates.

- **Stockyards (green and grey)**: Most of the raw materials of coal, coke and iron-bearing ores are imported through the deep water harbour and stored in one of the two main stockyards (ore to the north of the site and coal to the south).
- **Coke Ovens (grey)**: Coal is carbonised to coke in a series of heated ovens with minimal air. Coals of differing properties are blended to form a coke with the required properties needs for the blast furnace. The heating process drives off volatiles and the coke is quenched and transferred by lorry to the blast furnace.
- **Sinter Plant (orange)**: Raw materials are blended in long beds and the sintering process produces a fused and partially reduced form of iron that can be used to make molten iron more efficiently.
- **Blast Furnace (orange)**: Blast furnaces convert iron ores into molten iron using carbon, in the form of coal and coke. The molten iron is captured in 'torpedoes' (cylindrical rail cars) and the slag is either granulated (used in cement) or run into pits to cool and subsequently crushed.
- **Basic Oxygen Steel-making (BOS) (orange):** The 'torpedoes' transfers the molten iron to the BOS plant and converted to steel. This process produces desulph slag which is crushed.
- **Steel Slag Processing (yellow):** Slag from the BOS process is stored in pits and either reprocessed to extract residual metal and subsequently crushed (steel slag) or treated as waste and subsequently sent to landfill (desulph slag).
- **Hot & Cold Mills (pink):** Steel slabs are heated and rolled into a ,long thin coil of metal. This is an energy intensive process.
- **Power Plants (light blue):** Producing steel is vert energy intensive both in electricity and steam. Waste gases from the Coke Ovens and Blast Furnace are used as fuels.

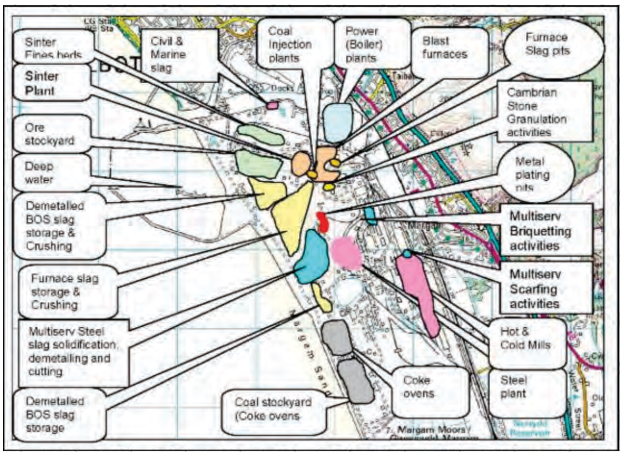

Figure 2. Steelwork process map (Taken from EAW, 2009).

2. Data Sources and Data Analysis

2.1 Data Sources

Four main sources of data were used within the project. These were data from the UK Automatic Urban and Rural Network (AURN); four Environment Agency Wales monitoring sites; five monitoring sites within the steelworks site; and the Met Office ***MIDAS*** Land Surface Observation Station data. Only AURN data is presented in this paper, this is Table 1 on the next page. (for the full data set analysis see Hayes & Chatterton, 2009).

2.2 Data Analysis

Using *Openair*, the data was used to analyse both spatial patterns and historic trends in concentrations in order to understand the air quality situation within the study region. The analysis of available data for this study was undertaken in three main categories including:

- **Spatial and Temporal Analysis**: The first two sets of analyses investigated the available datasets from the monitoring stations and examined them in terms of a) spatial patterns including annual variations in monitored concentrations and b) temporal patterns of pollution including long-term trend analysis, short-term analysis, seasonal trends etc.
- **Exceedence Analysis:** The third set of analyses focussed on locations where exceedences have been identified and particularly on those days or hours where the relevant air quality objective concentrations have been exceeded.

Table 1. Details of monitoring locations and data utilised

	Site	PM_{10}	$PM_{2.5}$	PM_1	CO	NOx	O_3	SO_2	Wind Spd	Wind Dir.	Other Met	Time Res.
AURN	Port Talbot (Groeswen) aka ***Hospital***	✓	✗	✗	✓	✓	✓	✓	✓	✓	✓	1hr
	Port Talbot (Margam) aka ***Fire Station***	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	1hr
	Narberth (Remote site-Pembrokeshire)	✓	✗	✗	✗	✓	✓	✓	✗	✗	✗	1hr
	Swansea (roadside site)	✓	✓	✗	✗	✓	✗	✗	✗	✗	✗	1hr
Met Office	***Mumbles*** Head	✗	✗	✗	✗	✗	✗	✗	✓	✓	✓	1hr

3. Results

The following section provides a sample of the analysis undertaken and discusses the primary conclusions. Due to the scale and depth of the case study analysis not all of the outputs are provided in this paper but can be found in the main report (Hayes & Chatterton, 2009). This paper primarily focusses on the AURN data (the 'best' and longest running dataset). Section 4, discusses how the analysis and conclusions were utilised to engage the various stakeholders and the subsequent management decisions taken forward.

3.1 Spatial Analysis

The main analysis in this section was carried out using the *polar plot* function in *Openair*. These are bivariate plots of pollution concentrations indicating how pollution concentrations vary by wind speed and wind direction. These plots are calculated using statistical smoothing techniques to show a continuous surface. The monitoring station is represented by the graph origin at the centre of the plot. The angles show the wind direction (e.g. the upper quadrants show concentrations with winds coming *from* the north), the distance from the origin indicates the wind speed (e.g. the further out the high concentrations appear the higher the wind speeds when they were monitored, calm conditions appearing closer to the origin).

Figure 3 shows polar plots for all pollutants at the Hospital AURN site from 2000-2007.

- The plot of $PM_{10local}$ suggests that local sources of PM_{10} in particular are more focussed on the SW quadrant.
- The plots of CO and SO_2 show strong similarities in the SW to the PM_{10} plots, indicating that some of the PM_{10} is likely to be attributable to combustion sources.
- The plot of NOx shows a very different pattern, with highest concentrations occurring at very low wind speeds, and a tendency for concentrations to be higher under easterly winds. This suggests that NOx concentrations are liable to be dominated by low-level, sources such as transport, probably with a significant contribution from the motorway to the east, but tending to disperse in windier conditions.
- The O_3 plot shows an inverse relationship to the NOx plot confirming this relationship. There is a notable hotspot on the graph to the WSW, further investigation has shown that this is most prominent in 2003, when the UK experienced severe ozone pollution episodes and does not appear to be clearly associated with steelwork sources to the SW of the monitor.

3.2 Temporal Analysis

Using *R* and *Openair* it is possible to identify trends within long time series and to analyse trends in monthly means and to identify seasonal variations and trends over time.

Figure 4 shows the mean and maximum hourly concentrations over each month since 2000. These plots show a tendency for PM_{10} concentrations to be highest in the middle of the day (10:00 – 16:00) and in the 2nd quarter of the year. The higher concentrations during the steelworks' operational hours suggest that pollution is more likely to be related to either grounding of plumes, or daytime activities raising dust. The plots also indicate seasonal variations in PM_{10} concentrations. The highest mean values tend to cluster between April and July. In those years (e.g. 2005 and 2006) where maximum hourly concentrations are highest in the middle of the day, the peak values again tend to be between April and July. In other years they tend to occur in a less clustered pattern.

Figures 5 and 6 were created using the *time variation* function in *Openair*. This function presents plots showing how average concentrations of pollutants (or other data) vary over time – over an average day, by hour over a whole week, by day of the week and by month of the year. Where a shaded region surrounds the line, this indicates the boundaries of the 95% confidence interval for the averaging. It should be kept in mind when viewing these plots that they represent average concentrations of pollution over

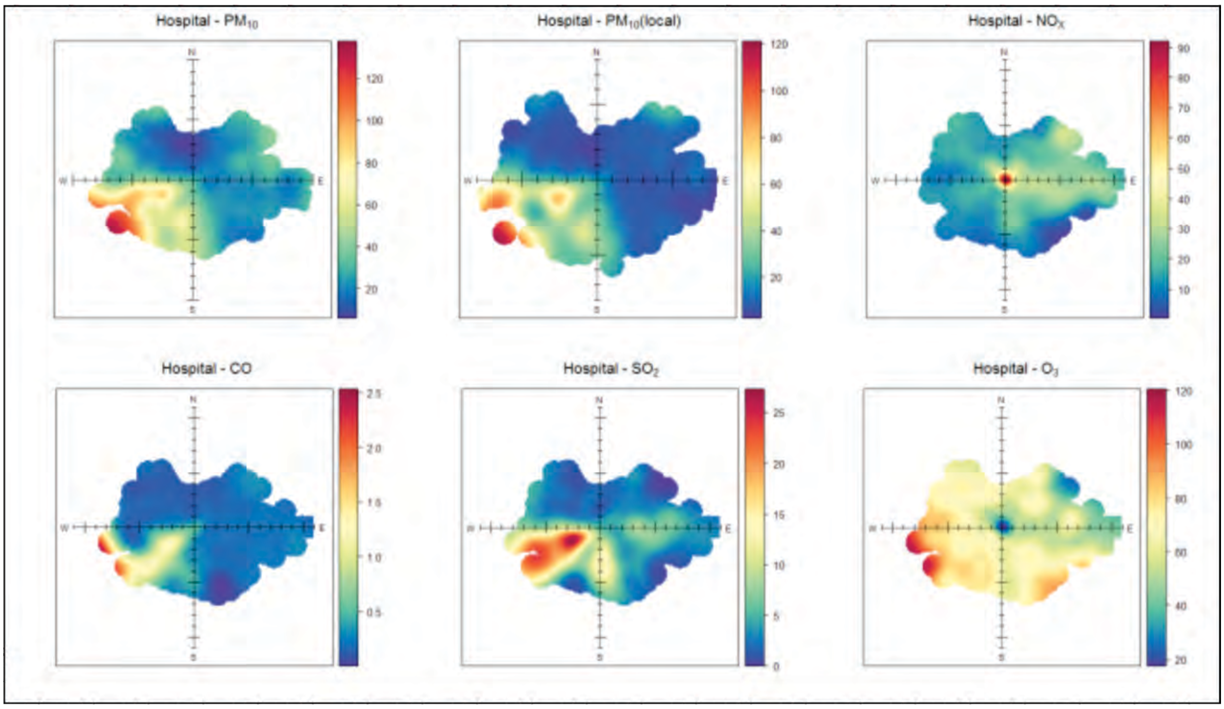

Figure 3. Polar plots for all pollutants at AURN Hospital.

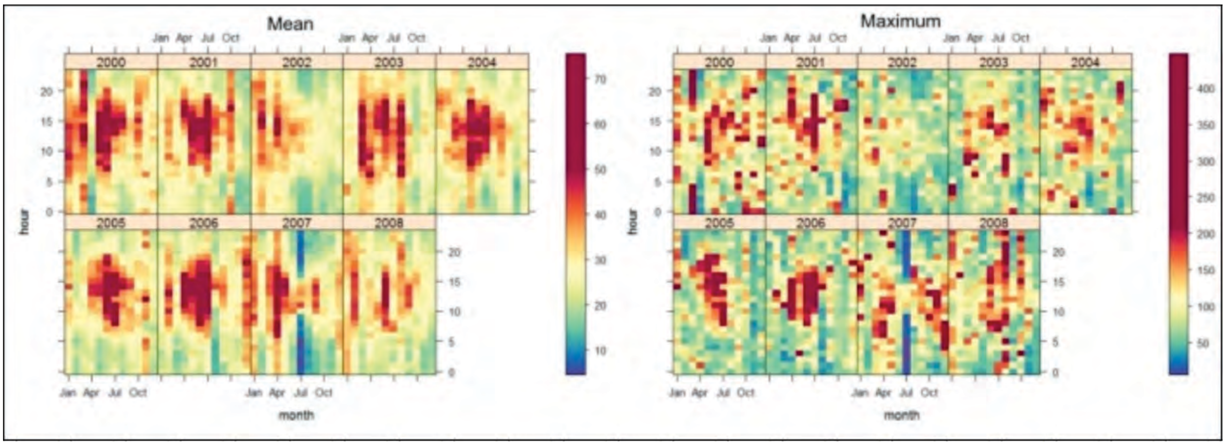

Figure 4. Variation of Mean and Maximum hourly PM_{10} concentrations at AURN sites by month and hour

the relevant time series and will not show up those peak-hours that will lead to exceedences of the daily mean PM_{10} objective.

Figure 5 shows the distinctive afternoon peak in PM_{10} experienced at the Port Talbot AURN site (red), compared to a roadside Swansea AURN site (blue) which is predominantly affected by traffic. The values on the graphs have been normalised. Whilst the Port Talbot data shows the afternoon peak, the data from Swansea demonstrates a more common profile: concentrations rise steeply in the morning associated with the morning rush hour, then drop to a plateau in the afternoon, before rising again for a smaller peak around the evening rush hour. Concentrations at the Swansea site show a much more distinct reduction on Sundays. They also show higher concentrations in the winter period (January to March) where pollution from road vehicles tends to be highest due to poor dispersion. This plot shows the tendency for weekend concentrations of PM_{10} at the AURN sites to be lower.

Figure 6 show the variation by time of PM_{10} compared to other key pollutants at the AURN Hospital site. The distinctive double peak from road traffic is evident for NOx, but not for PM_{10} or CO and SO_2. PM_{10} very closely matches CO and SO_2 suggesting that at this site (and at this time), PM_{10} was influenced by combustion sources.

3.3 Exceedence Analysis

A methodology was designed to evaluate Exceedence Days on the basis of whether the exceedence of the air quality objective was caused by

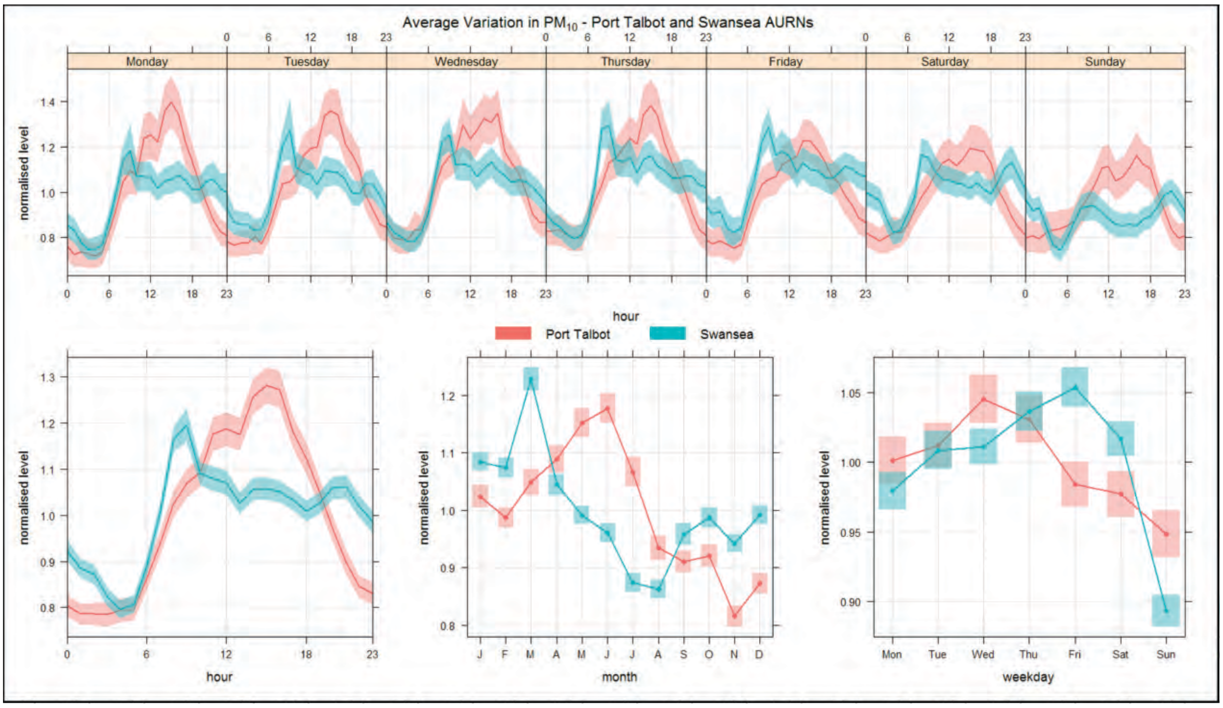

Figure 5. Variation in Average Concentration of PM_{10} at Port Talbot and Swansea AURN sites

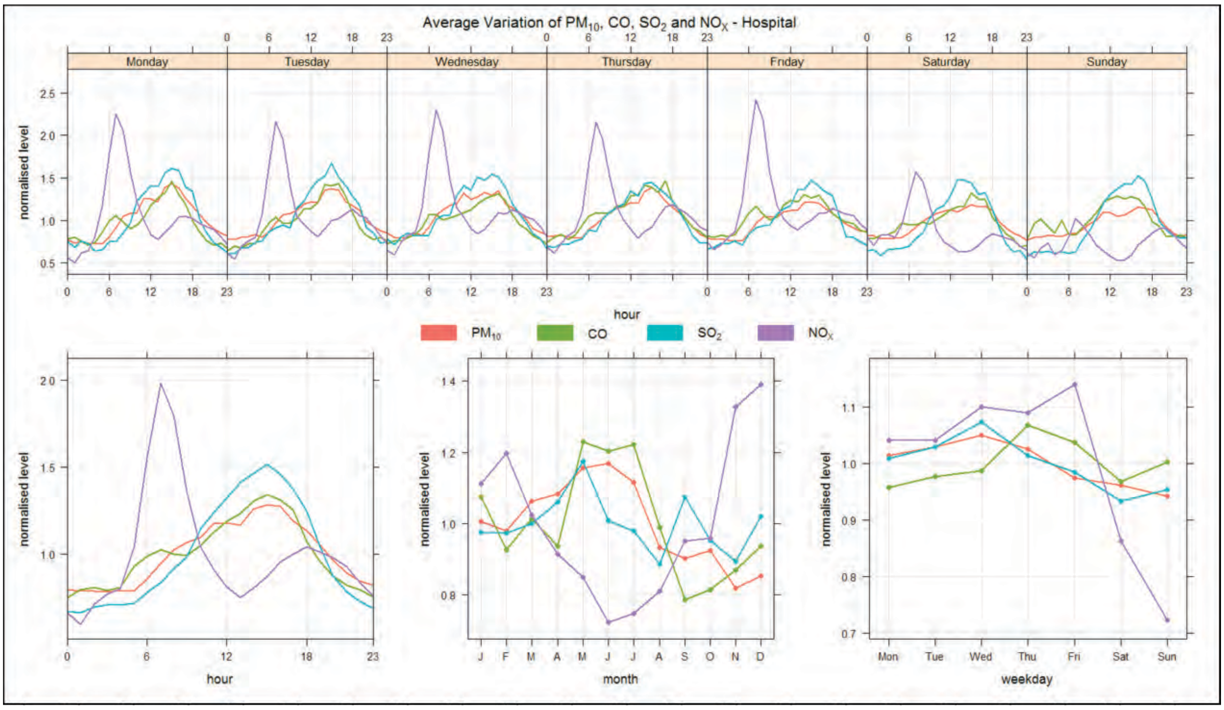

Figure 6. Variation in Average Concentration of PM_{10}, Co, SO_2 and NOx and the AURN Hospital

a single high peak (termed 'Peak' Event), elevated concentrations throughout the day ('Flat') or elevated concentrations for part of the day ('Average'). This method calculates the ratio of the daily maximum concentration to the daily mean concentration. The greater the ratio, the more the daily mean is dominated by a single peak; the lower the ratio, the flatter the diurnal concentration profile for that day. Figure 7 shows plots of the diurnal patterns for three days: the strongest peak event, the Exceedence Day with the closest ratio to the mean, and the Exceedence Day (with 24 valid measurements) with the minimum ratio.

Figure 8 show the relationships between PM_{10} and the other key combustion pollutants CO and SO_2 (N.B. CO has been multiplied by 10 so that it can be plotted on the same scale) on a 'Peak' Exceedence Day, this clearly illustrates that the single large peak occurring in the early hours of the morning, which appears at first sight to be an incidence of plume impacting on the monitor, is actually closely associated with a peak in

CO, confirming the likelihood of this particular exceedence being related to stack emissions from a combustion source. It is interesting to note though that neither the peak in CO nor the peak in PM_{10} relate to an increase in SO_2 concentrations. This exercise can be repeated for 'Flat' and 'Average' events. This Exceedence Day Analysis method provides a clear way to begin classifying the types of pollution events resulting in exceedences of the daily mean objective in order to allow sensible correlations to be made between PM_{10} concentrations, other pollutants and meteorological parameters. Without the use of a framework like this it would be very difficult to identify the likely causes of exceedences without treating each day completely as an individual case, or conflating those exceedences related to peak (probably combustion related) events with those related to continually elevated PM_{10} concentrations caused by sources such as wind-raised dust.

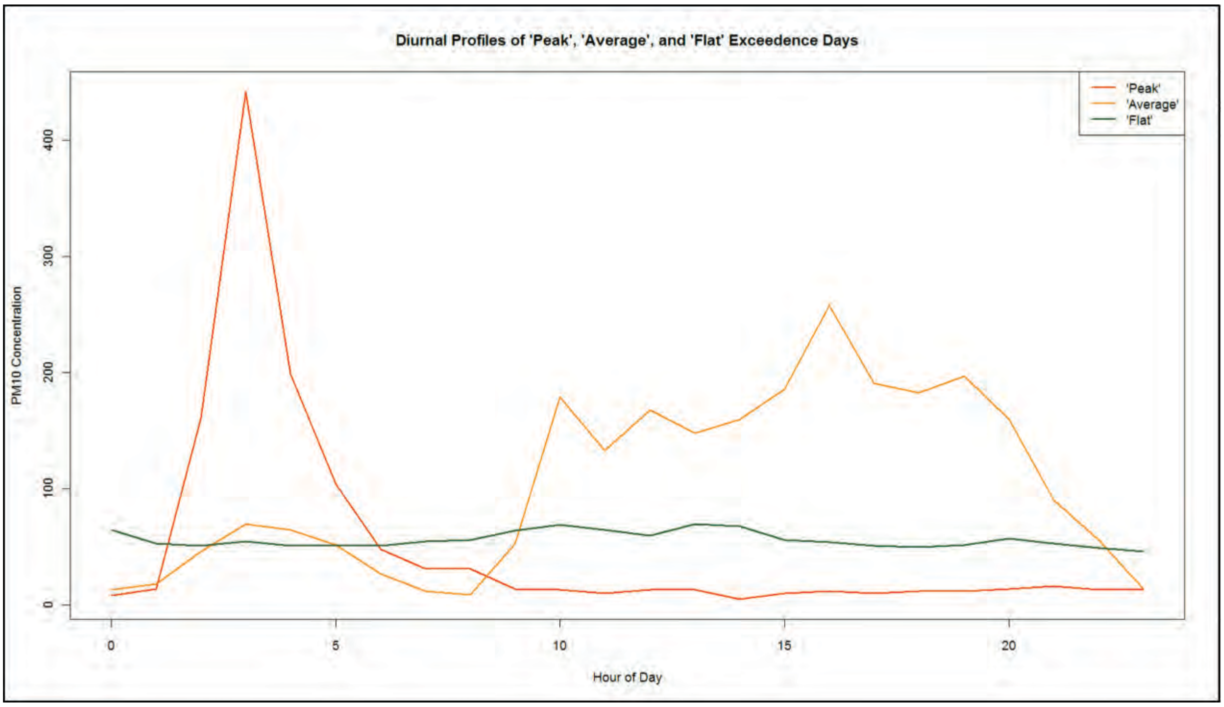

Figure 7. Diurnal profiles for Range of Exceedence Days

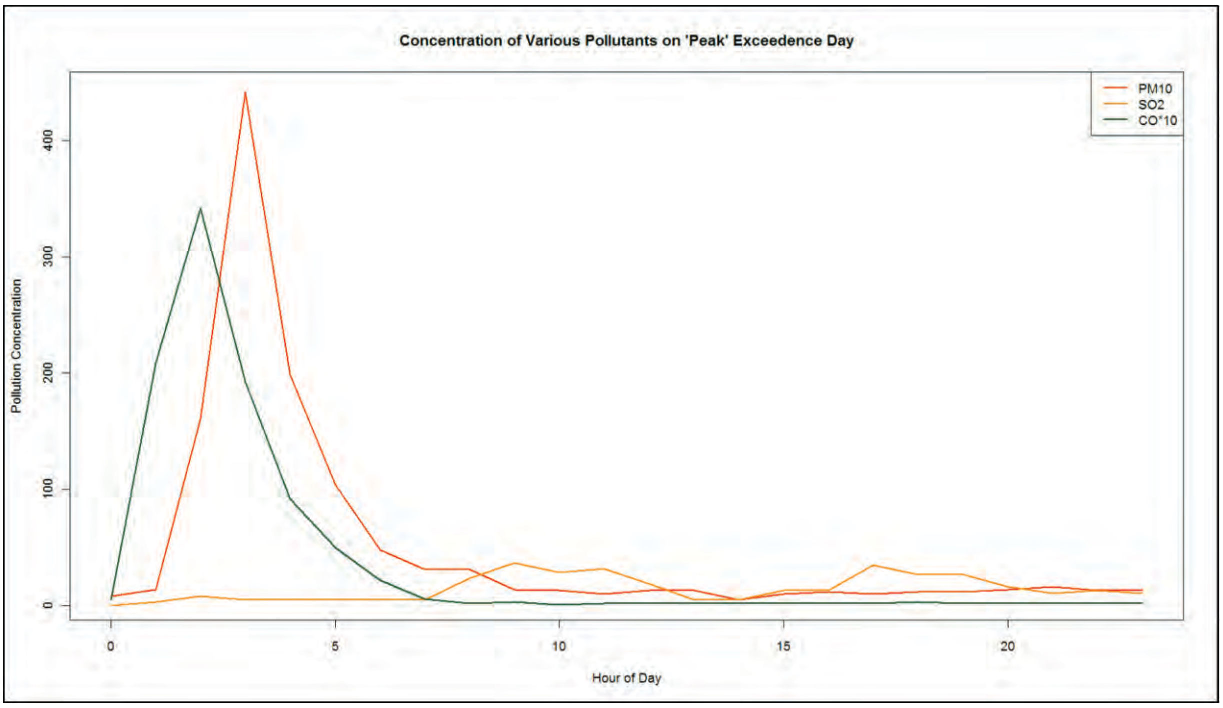

Figure 7. Comparison of Diurnal Profile for PM_{10}, CO and SO_2 on 'Peak' Exceedence Day

4. Discussion & Conclusions

The text accompanying the figures and tables is not intended to be able to completely describe everything that may be evident from the graphs, nor have all the actual analysis and graphics been included in this paper. The analyses presented here attempts to illustrate a range of novel ways in which the pollution data for an area can be analysed and presented using *Openair* to aid the various stakeholders, including technical and non-technical audiences, in understanding the impact of multiple and complex sources on air quality concentrations. Subsequently, the outputs can provide indicators for where future studies should focus their attention.

The key points resulting from this data analysis include:

- Predominant sources of PM_{10} are not in immediate proximity to the monitoring locations (evidenced by negligible impact at low wind speed).
- The relationship of elevated concentrations with higher wind speed suggests that sources may include both/either stacks (where turbulence results in the grounding of plumes) or dust (where wind is able to resuspend it).
- PM_{10} concentrations are dominated by sources to the SW of the AURN stations, indicating sources on the steelworks site as the most likely cause of elevated PM_{10} concentrations in the area.
- There are strong correlations between the direction of the main PM_{10} sources, and sources of CO and SO_2. However, temporal analyses indicate that not all PM_{10} events are related to elevated concentrations of these combustion pollutants. This suggests that PM_{10} events may be being caused by either combustion sources, or dust sources or a combination of the two.
- In some cases, elevated PM_{10} is related to CO but not SO_2. There appears to be an almost inverse relationship between these pollutants at high concentrations, suggesting more than one possible combustion related source, and potentially a 'heat' rather than a combustion source leading to the high CO concentrations.
- PM_{10} pollution related to the site follows a distinctive diurnal profile, with concentrations beginning to rise at around 6am, and continuing to rise until about noon. They then level out and then begin to drop sharply from around 4pm. This pattern may result from either daytime activities on-site resuspending dust, and/or increased daytime insolation leading to increased plume grounding due to convective turbulence.
- There appears to be a strong seasonal influence on the occurrence of elevated PM_{10} concentrations, with far more events in the second quarter of the year, followed by the first and third.
- Pollution events take a wide range of forms, with some exceedences of the daily mean objective being caused by a single very high hourly peak, others due to prolonged concentrations just above the objective concentration. The wide range of events between these two extremes suggests that exceedences may be being caused by a range of sources and conditions.

The outputs from the *Openair* analysis was not only provided to the stakeholders directly involved in the management and regulation of the site but also was made publically available together with a non-technical summary. Additionally, the analysis formed the basis of a subsequent assessment of air quality in the region by the UK Air Quality Expert Group (AQEG) and directly underpinned their recommendations, which have subsequently been utilised to develop a comprehensive and informed work programme to understand and manage PM_{10} in the vicinity (Air Quality Expert Group, 2011). This Work Programme includes:

- Advanced dispersion modelling and further development of an emissions inventory.
- Review of meteorological sites and data.
- Retaining monitoring sites and specific recommendations to improve monitoring data including the establishment of a new downwind site.
- Central data repository, accessible by all authorised stakeholders.
- Development of a temporally high resolution monitoring programme in support of a multivariate receptor modelling study.
- Development of an on-site measurement programme to quantify the emissions from fugitive sources.
- Actions set out should be developed as a programme of work to be taken forward in a coherent and consistent manner.
- Working arrangements currently in place should be continued, with all parties contributing in an open and transparent manner.
- Involvement of external peer reviewers to help ensure that the future programme remains focussed and is making best use of the scientific data and analysis resources (currently undertaken by UWE)
- Updating NPTCBC Air Quality Action Plan (local).
- Better utilising the Welsh Government Short-Term Action Plan (national).

5. Acknowledgments

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- Tata Steel
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- Dr David Carslaw and Dr Karl Roper (Openair)
- British Atmospheric Data Centre

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