AN INVESTIGATION INTO THE ORIGINS OF PM10 ANOMALIES RECORDED AT A REMOTE LOCATION IN NW ENGLAND

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INTRODUCTION

Throughout 2004 PM_{10}[1] concentration was measured every 10 minutes at Hazelrigg Weather Station, a rural site situated 2 km south of Lancaster (Figure 1). The annual mean PM_{10} concentration recorded at Hazelrigg was 6 µg/m³, of which approximately 70% was composed of $PM_{2.5}$. However, particle mass distribution varies significantly with wind direction (Figure 1) and this can be used to infer particle source. Westerly winds are a major source of PM_{10} (concentration ~8 µg/m^3) and comprise up to 53% PM_{COARSE} (d = 2.5-10 µm). Morecambe Bay is interpreted as the likely origin of these abundant coarse particles. The south-southeast is the other major particle source and contains two distinct traces; a strong $PM_{2.5}$ component (average concentration ~6.5 µg/m^3) interpreted as secondary particles formed from the nucleation of primary gaseous pollutants emitted in more industrialised central Lancashire, and an anomalous coarse component discussed below.

Several periods of anomalously high PM_{10} concentrations were recorded in 2004, the majority of which can be associated with either a) high spring tides and brisk westerly winds or b) light

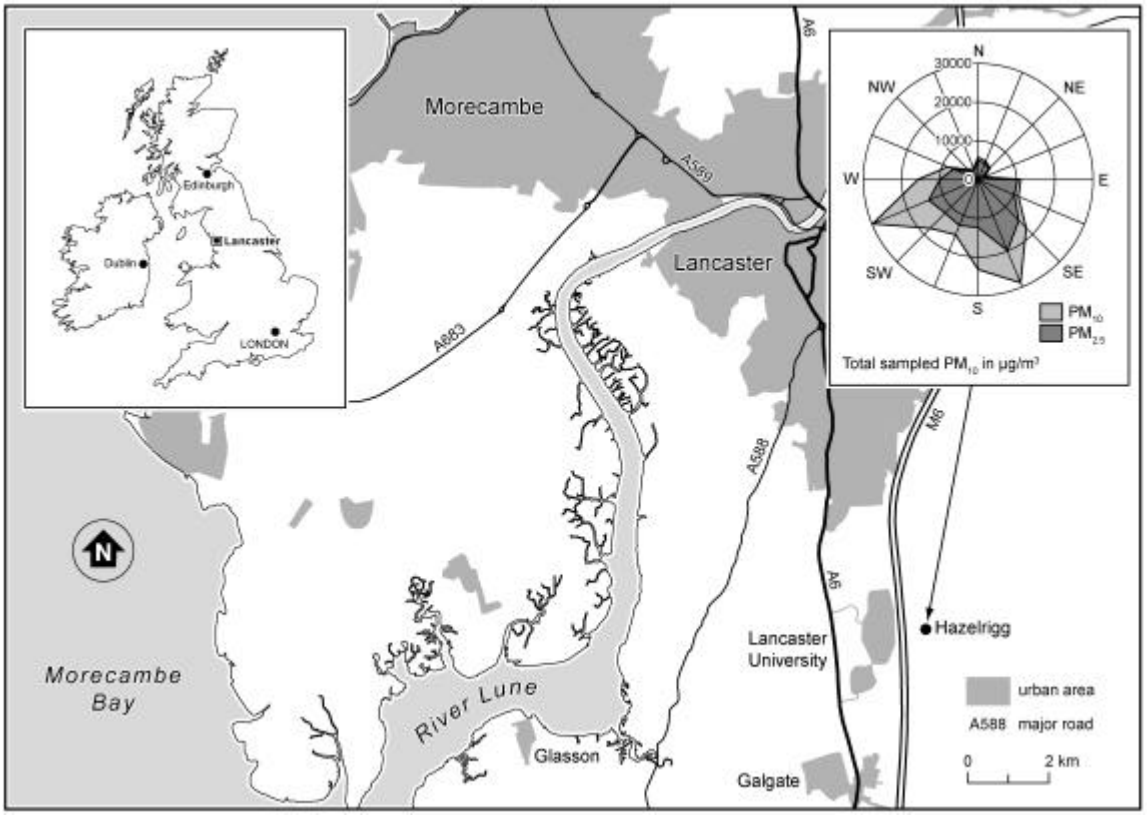

Figure 1 Location of the sampling site (Hazelrigg) and a wind rose displaying total sampled PM_{10} in 2004 measured in µg/m^3.

[1] the mass concentration that is collected by a size-selective inlet of diameter 10µm at 50% efficiency

southerly winds and cold, dry winter conditions that promote gas-particle conversion and limit mixing. However, a series of anomalies with no apparent meteorological driver were detected in the particle record. These events took place midweek and in the early hours of the morning (Table 1). These PM_{10} anomalies are defined by a change in the $PM_{2.5}/PM_{10}$ ratio driven by an influx of PM_{COARSE} comprising 50-80% of total PM_{10}. The maximum concentration (< 465 $\mu g/m^3$) occurs near the event start followed by a gradual decline in concentration occasionally including some peaks of lesser magnitude. Weather conditions are typically dry and calm with light winds (~ 3m/s) blowing only from the south or south-southeast. Given the odd timing and the lack of apparent source these PM_{10} anomalies were assumed anthropogenic in origin, probably produced from the combustion of a banned particulate-rich material such as tyres. To test this hypothesis a rigorous and systematic dispersion modelling approach was used to locate a possible source for the midnight PM_{10} emissions.

DISPERSION MODELLING

ADMS 3.2 was selected to model atmospheric dispersion of the assumed combustion plume and hence back trace the pollution source. Although the model is widely used in industry and by regulatory bodies to disperse regular point source emissions over lengthy periods of time, this study represents the first known application of ADMS 3.2 driven by 10-minute data to model non-regulated emissions from a fire of unknown origin.

Initially, particle characteristics and wind data were used to define a probable area in which the burn site could be located. Stokes Law[2] was applied to calculate the minimum settling velocity ($1.7x10^{-3}$ m/s) of the coarsest particle (d = 10μm) and hence the maximum distance the plume could have travelled. Assuming the fire was 2m in height and taking a minimum observed wind speed of 1 m/s reveals the maximum distance the coarsest particle could have travelled was 1,174 m. Combining this with wind direction data produced a probable source sector (1,840 m^2) with outer radii of 146° and 180° extending south-easterly from Hazelrigg for 2,500 m (Figure 2). This was taken for radii length rather than 1,174 m to account for any inaccuracies involved in calculations and to see how the dispersion model worked at longer distances. Land use

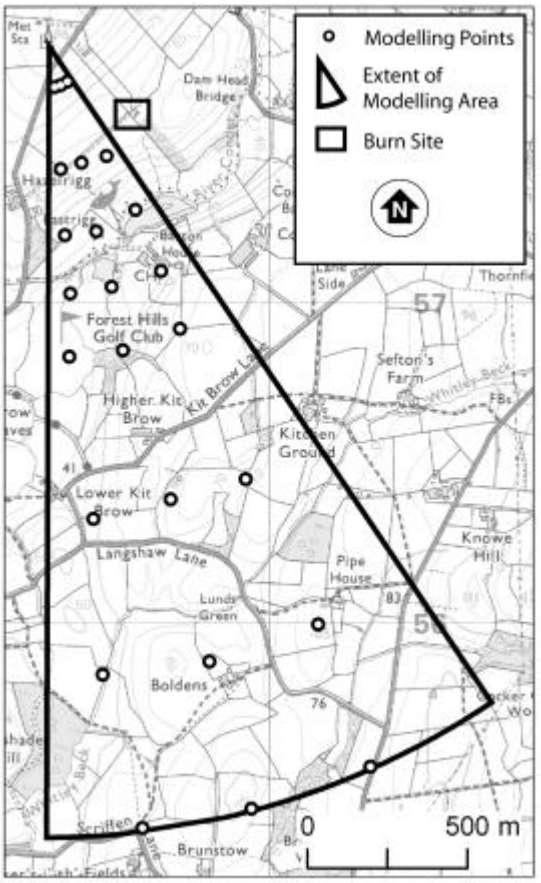

Figure 2 The probable source area and the modelling points. A burn site was later discovered to the east of this sector.

[2] Stokes Law is $Vg = rd^2gC_c/18h$ where ρ is particle density (water~1000 kg/m^3), g, gravitational acceleration (9.8 m/s^2), Cc the Cunningham Slip Coefficient (~1 for coarse particles) and η air viscosity ($1.8x10^{-5}$ Pa s).

within the source area includes pasture (80%), woodland (6%) and a golf course (11%). The dispersion model was run at increasing distances from the receptor until 2,500 m along three different radii (155°, 165° and 175°, Figure 2) to systematically assess the potential of each point to be the burn site. At each location the emission rate necessary to produce the maximum concentration observed in the particulate record to within 10-minute resolution was noted.

ADMS 3.2 was driven by several assumed and observed parameters. Model default values were used for molecular mass, specific heat capacity and surface roughness (0.3), however 10-minute meteorological data collected at Hazelrigg (wind speed, wind direction, temperature and precipitation) and John Lennon Airport (cloud cover; http://badc.nerc.ac.uk/data/ukmo-midas) were entered to recreate actual atmospheric conditions. Several trial simulations revealed a source width of **1 m** and buoyant emission height of **3 m** to be appropriate. Tyre burning produces 50 kg of PM_{10} per tonne (AP42; http://www.epa.gov/ttn/chief/ap42), and assuming a combustion rate of one tonne/hour gives an emission rate of **14 g/s**. Tyre combustion generates 20 GJ/tonnes of heat energy of which 99% is lost via conduction and radiation producing a fire temperature of **500 °C** (*Abbott, pers, comm.*, 2006). Tyres produce approximately five tonnes of hot gas per tonne of tyre which at 500 °C would occupy around 100,000 m^3 giving an emission velocity of **3 m/s**. Terrain data at 10 m resolution was included in the model and a 10 minute averaging time was applied to account for lateral spread of the plume.

Non-regulated fires do not burn uniformly and emission rates tend to increase to an initial maximum before decreasing more slowly as the fire wanes (*Mulholland*, 1995). As ADMS is restricted to hourly emission factors unsuitable for the short duration of the observed fires, several trial simulations were run to create more appropriate time-varying emission factors. The collated results showed at a distance of 200m the emission rate needed to produce the

Table 1. Characteristics of the 2004 PM_{10} anomalies including the maximum recorded concentration and observed time. The lower half of the table lists the emission rates (in g/s) needed to produce the maximum observed concentration. Emission rates in grey are considered unrealistically large (>20g/s, see text) and thus an unlikely burn site location.

Date (in 2004)	22 Jan	11 Feb	16 Mar	10 May	18 May	03 Jun	14 Jul
Start	17:51	18:42	00:39	02:39	05:29	20:59	03:27
End	04:01	02:22	00:59	08:29	06:49	01:19	05:37
Duration (min)	620	470	20	360	90	260	140
Maximum Concentration ($\mu g/m^3$) & time	434 21:01	32 20:32	82 00:39	254 02:49	131 05:59	465 23:49	100 03:47
Ave Wind Speed	2 m/s	< 1 m/s	6 m/s	<1 m/s	3 m/s	2 m/s	4 m/s
200m	**6.5**	**2**	**1.5**	**5**	**1.9**	**13**	**1.5**
400m	**15**	**2.4**	**4.5**	**6**	**5.3**	**22**	**4**
600m	**17**	**1.5**	**9**	**5.5**	**11**	75	**9**
800m	28	**1**	**20**	**7.5**	**18**	>100	18
1000m	44	**2**	40	**12**	23	>100	23
1500m	55	**4**	96	30	34	>100	35
2000m	70	**6**	>100	40	48	>100	50
2500m	90	**8**	>100	59	62	>100	65

maximum concentration of a particular event observed within the PM_{10} record was approximately four times that required for the minimum. This factor was applied to the emission rate needed to produce the observed maximum value, producing 4 separate emissions rates, and four separate simulations were run for each event where different sections of each output curve selected to produce the final time-varying output curve.

RESULTS AND DISCUSSION

The characteristics of the anomalous PM_{10} events and the emission rates needed to generate the observed maximum concentration are shown in Table 1. In general, the emission rate needed to produce the observed maximum concentration increases with distance and given a likely emission rate of 14 g/s (*Abbott, pers. comm*., 2006) all values greater than 20 g/s can be discounted. Assuming one burn site was responsible for all PM_{10} anomalies, dispersion modelling suggests the source must lie within 600 m of Hazelrigg (as at greater distances unrealistic emission rates are needed). Figure 3 compares the observed PM_{10} concentrations for six of the events with those produced by dispersion modelling, and shows ADMS can reproduce the observed maximum concentration with 10-minute accuracy for all events with the exception of 10th May maximum. This event along with 11th February anomaly are

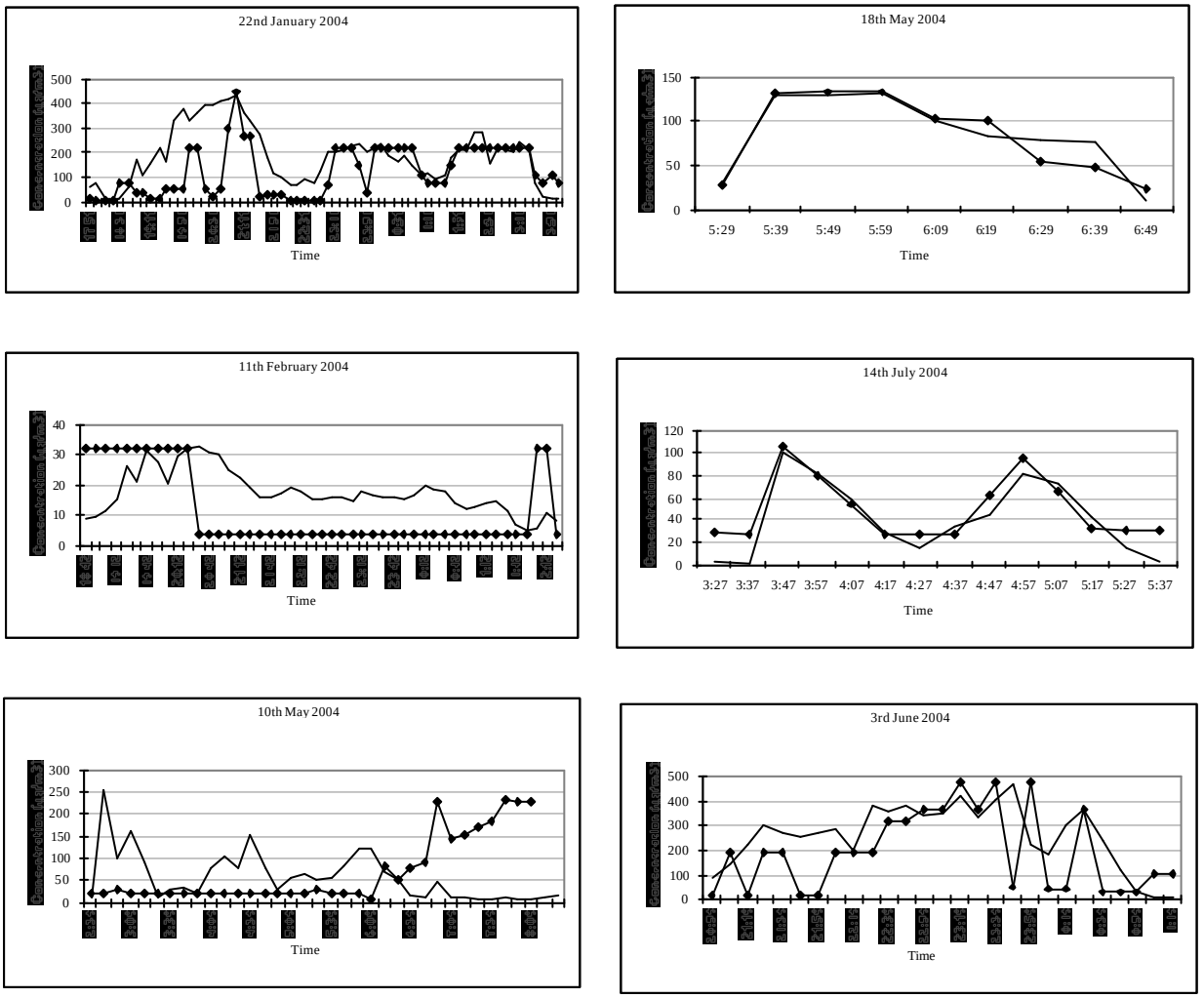

Figure 3. Observed (bold line) and simulated (diamond-marked) concentrations of the 2004 PM_{10} anomalies. Simulations were run at 200m and time-varying data was used for January, 18th May, June and July. February's and 10th May outputs were produced using a constant emission rate.

characterised by very low wind speeds (<1 m/s) that required ADMS to operate at minimum wind speed capacity. Results from these events are least believable and demonstrate the model has low accuracy with low wind strengths. Furthermore the model is overly sensitive to wind direction producing a positive concentration at receptor only when source and wind orientation are approximately parallel. To overcome this a mean wind direction was entered into ADMS for each event. Comparing the composite model output curves with those observed in the particulate record (Figure 3) reveals the simulated data does approximately mirror the observed data for the January 18th May, June and July events. However, minor fluctuations in wind strength at low wind speeds cause major changes in concentration output (e.g. January, June). Although meteorology does have a similar influence on the observed data the effect is over-amplified by the model indicating ADMS 3.2 is overly sensitive to minor meteorological changes. Where meteorological conditions are simple (no rain, constant moderate wind speed, e.g. 18th May, July) the modelled output is most similar to the observed. Both modelled and observed data suggest emission rate is responsible for the magnitude of the concentrations whereas meteorology controls the temporal fluctuations.

Comparing the model output with land use data reveals that if the emissions source lies within 600 m of Hazelrigg in the sector defined by meteorology the burn site must be located within a field, or on the golf course (Figure 2). Following a conversation with the golf course green keeper the location of a burn site east (orientation 130°) of the source sector defined by meteorology was uncovered (Figure 3). This site is located ~330 m from Hazelrigg, and 100 m east of the defined source area. These premises are currently licensed to burn biomass to produce compost however piles of tyres and plastic rubbish bags were observed within the grounds. In addition the green keeper confirmed materials like this had 'probably' been burnt on site. Although this burn site was not located in modelling sector defined by meteorology it is extremely likely that it is the source of midnight PM_{10} anomalies because i) the chances of another burn site within the region are slight, and ii) no other strong south-easterly particle trace has been detected. There are two possible explanations for this. Firstly, measurements of wind direction at Hazelrigg may be inaccurate as data are recorded at 10 m where the strength is greater than at ground level because of surface roughness. A wind speed recorded as 1m/s at 10 m is equivalent to 0.3 m/s at 1 m and measuring the accuracy of a plume moving with such slow velocity is limited. Secondly, the gradient between Hazelrigg and the source is greatest at 130° and buildings in-between the source and receptor would act as an obstacle around which the plume would have to move. The path of least resistance would thus create an apparent wind direction of south-southeast.

This study used a systematic modelling approach to locate the source of a series of midnight PM_{10} anomalies detected by receptor modelling. Simulations were run at a series of points within a probable source area and the emission rate needed to produce the observed maximum concentration noted. Modelling suggested the source was located within 600 m of Hazelrigg and further detective work found a burn site complete with tyres ~330 m from Hazelrigg. This is the likely source of the elevated PM_{10} concentrations observed in the particle record suggesting ADMS3.2 can be used although with some limitations to model emissions from non-regulated fires using 10-minute meteorological data.

REFERENCES

Mulholland, GW, 1995: "Smoke Production Properties," In DiNenno, P.J., et al., Editors, SFPE Handbook of Fire Protection Engineering, 2nd Edition, Chapter 15, Section 2, 2/217-2/227