Investigation of a UK Sulphur Dioxide Episode – 2nd September 1998

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1 Introduction

On the evening of September 2nd 1998 a number of calls were made to the UK authorities by the general public concerned about localised 'smog' and air pollution in the Midlands and South Yorkshire region of England. Analysis of air quality data from monitoring sites in this region revealed a peak in sulphur dioxide of six and a half times the air quality standard at Nottingham giving a recording of 'very high' (15 minute mean >400ppb) and recordings of 'high' (15 minute mean between 200-400 ppb) at other sites in the area.

Short range dispersion models commonly used by the UK Environment Agencys were found to be inappropriate for modelling this episode; the distance the pollution plume travelled required spatially varying meteorological information (Environment Agency Report, 2000). The Met Office investigated the meteorology of this episode and applied NAME, a Lagrangian atmospheric dispersion model, to simulate the period of interest. The cause of the episode appeared to be driven by a period of low wind speed allowing pollutants to accumulate before being dispersed by light winds later in the day. Hourly sulphur dioxide emission data were obtained from coal-fired power stations and major industrial sources in the region and these were fed into the NAME model along with time varying three-dimensional meteorology from the Met Office's numerical weather prediction model (the Unified Model, Cullen 1993).

2 The NAME Model

The UK Met Office's dispersion model NAME (Nuclear Accident ModEl) was developed following the Chernobyl incident to simulate the transport of airborne pollutants (Physick and Maryon, 1995, Maryon et al 1991). Model validation includes the ETEX experiment (Ryall and Maryon 1998) and comparison with observed data for a number of trace gases measured at Mace Head at hourly timescales (Ryall et al 1998).

NAME is a Lagrangian model in which emissions are simulated by releasing large numbers of particles into the three-dimensional model atmosphere. The particles are labelled with their release location and time of origin, making it possible to identify the relative contributions of particular sources to a receptor area. Each particle is released with an initial mass of a pollutant, to which dry and wet deposition processes are applied. The three-dimensional wind field passively carries the released particles, with turbulent mixing represented by prescribing horizontal and vertical turbulent velocity components. There are several options available, of varying complexity, to determine these components which are described in detail in Ryall and Maryon 1998. In this study the near source diffusion scheme using inhomogeneous vertical profiles of turbulent velocity variance and Lagrangian timescales was applied to particles for the first hour of their lives. After the first hour a simplified scheme based on diffusion coefficients was employed using a longer timestep of 900 seconds. The model was run both with and without plume rise; the scheme used in this study for plume rise was based on the well known Brigg's formulae (Briggs 1984).

The model boundary layer depth varies with time of day and is calculated in NAME using wind and temperature profiles from the Unified Model using a combination of Richardson number and parcel techniques. Errors in the boundary layer depth can result in inaccuracy in turbulent diffusion, advection and deposition leading to errors in calculated air concentrations.

3 Weather conditions for 2nd September 1998

On 1st September an occluded cold front moved eastwards over the British Isles and became blocked over the North Sea by a large high pressure centred over Scandinavia. This resulted in an area of slack pressure over Britain behind the front, giving calm conditions and a dry night. Mist and fog patches formed overnight, with light and variable winds and areas of fog over eastern parts of Britain persisting into the afternoon of 2nd September. A low over northern France moved north during the day bringing cloud and rain into southern parts of England by the afternoon and into parts of central England and the Midlands by evening. In the course of the afternoon of the 2nd, the surface winds gradually became light north-easterly over the East Midlands. At Nottingham the upper winds were light and variable at first, with a broadly south-westerly drift above about 800m. By midday the boundary layer flow was north to north-east, but the flow remained light south-westerly above about 700m; by late afternoon the upper winds were north-easterly up to about 1500m, but more north to north-easterly at low level.

4 Model Setup

Hourly emissions of sulphur dioxide on 2nd September 1998 from the major sources across central England were obtained. This, together with meteorological data from The Met Office's numerical weather prediction model (the Unified Model), was used to drive NAME.

Two 24 hour model runs were performed, each starting from 2300 UTC 01/09/1998, with one implementing a plume rise scheme for the sources and the other without considering the effects of plume rise as a worst case scenario. The near source scheme using inhomogeneous velocity variance profiles was applied during both runs for the first hour of each particle's life. In total, just over one million particles were released into the model atmosphere over the 24-hour period. The model domain covered the area from 52.0°N to 54.0°N and 3.0°W to 0.0°E, with a grid of resolution 0.05° which results in a grid square size of approximately 5.6km longitude and 3.4km latitude. Model data was output as 15-minute average concentrations at a number of monitoring sites. In addition, fields of hourly averaged boundary layer concentration were output for the domain.

5 Results

Figure 1 shows one hour mean boundary layer concentration maps in ppb of sulphur dioxide for 16.00 GMT and 21.00 GMT on 2nd September 1998. The locations of the major sources are shown together with the location of the monitoring sites at Nottingham and Birmingham. Figure 2 shows timeseries plots of concentration in ppb for Birmingham and Nottingham. The model output for the case with plume rise is shown as a dashed line, the case without plume rise as a solid line, and the measurement data from the DETR observation sites as a dotted line. The model predicted plume progression shown in Figure 1 demonstrates the movement of the peak in a south-westerly direction from Nottingham in the late afternoon to where it impacted upon Birmingham in the late evening. The measurement data shown in Figure 2 reflects this pattern well. The timing of the modelled peak at Nottingham is a little early, but the peak at Birmingham is very consistent. In both cases the model failed to capture the full extent of the episode. The 'worst case scenario' (i.e. without taking account of the plume rise due to buoyancy and momentum on the modelled sources) shows, as expected, greater concentrations than the case with plume rise scheme implemented. The effect of applying plume rise also delays the modelled peak slightly, achieving a better match with observed data at Nottingham but making the timing a little late at Birmingham.

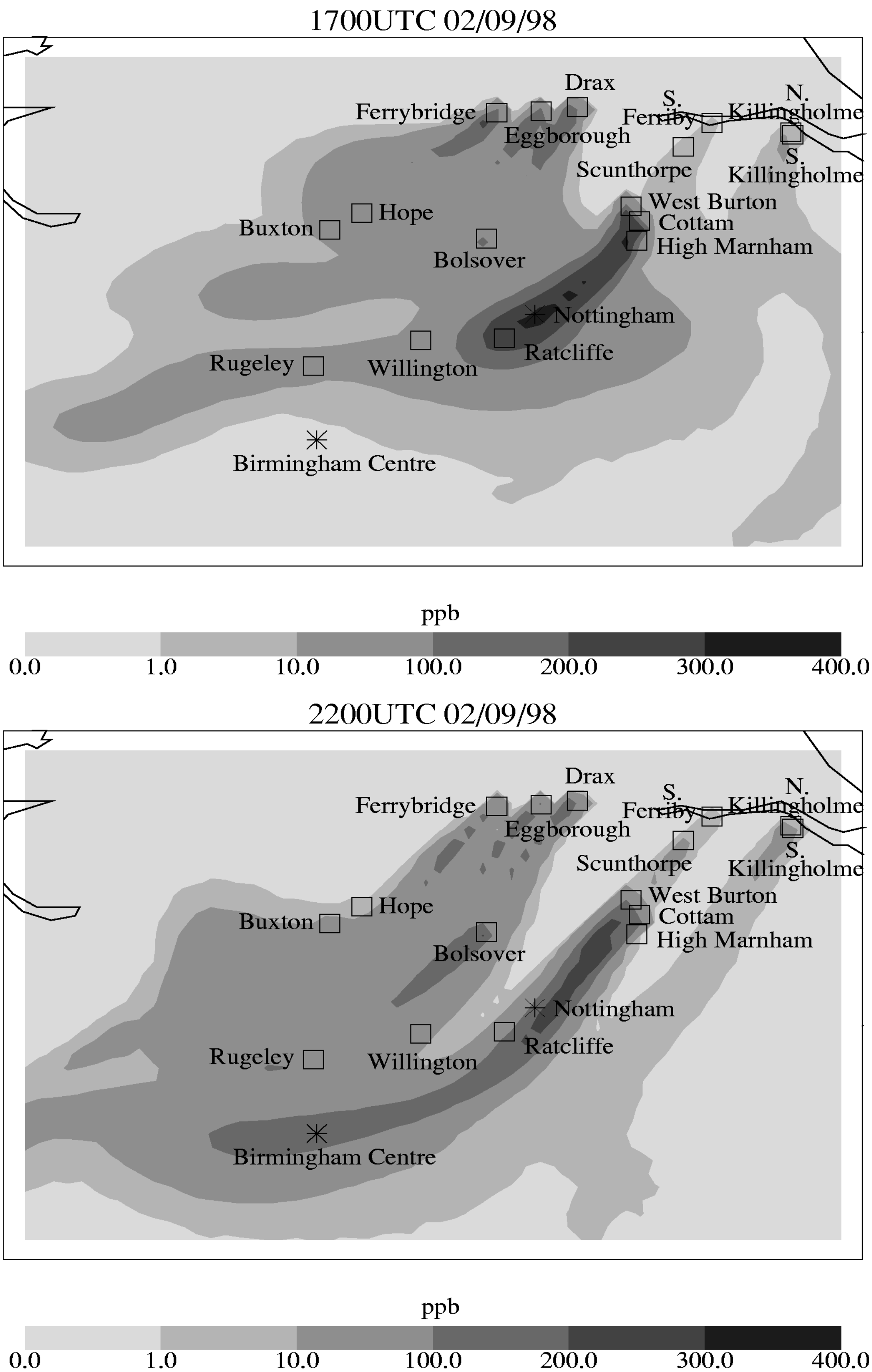

Figure 1 Hourly averaged fields of NAME predicted boundary layer concentrations showing the location of the monitoring sites at Nottingham and Birmingham and the major SO_2 sources.

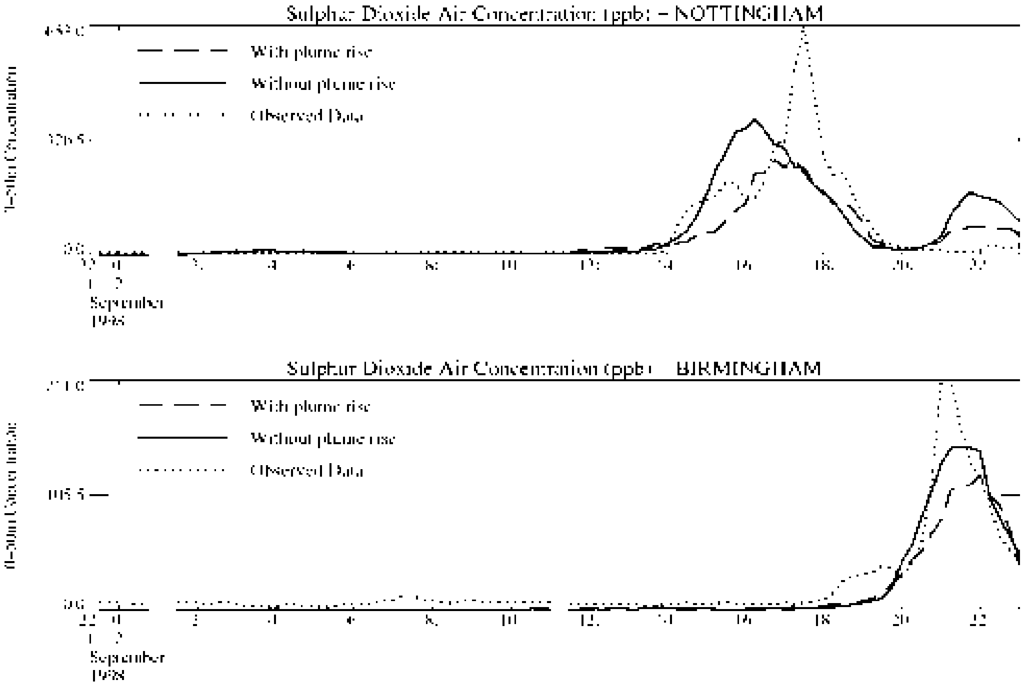

Figure 2 Time series showing 15 minute averaged air concentrations of SO_2 observed at Nottingham and Birmingham compared with NAME predictions with and without plume rise.

Each model particle arriving at the receptor locations is labelled with its point of origin. Table 1 displays this source attribution data for the modelled concentrations at Birmingham and Nottingham. The results show that 47% of the modelled peak at Nottingham was due to the power station at Cottam, with a further 34% and 14% respectively from the nearby power stations at West Burton and High Marnham. Similar contributions made up the plume modelled at Birmingham, with much lower contributions from the Drax and Ferrybridge power stations in both cases.

Table 1 Major contributors to the modelled peaks at Nottingham and Birmingham.

Total	5.1.1 Nottingham		5.1.2 Birmingham	
	%	Modelled ppb	%	Modelled ppb
Cottam	47	181	41	61
West Burton	34	131	31	47
High Marnham	14	54	14	20
Drax	2	9	9	13
Ferrybridge	2	9	2	2
Others	1	1	3	6

6 Discussion

Whilst the NAME model has captured the general spatial pattern and timing of this pollution episode, it has failed to predict the magnitude of the SO_2 observed, even in the worst case scenario without plume rise. One explanation for this under-prediction is that the model diagnosed boundary layer on the 2nd September was much higher than was thought to have occurred in reality. The model boundary layer height peaked at around 800m at 14.00 GMT and was above 500m from 12.00 – 17.00 GMT. The actual likely height of the temperature inversion can be estimated from radiosonde ascent data obtained from a nearby meteorological station, Nottingham Watnall. Ascents were made at 11.15 and 17.15 GMT and indicate weak inversions at heights of 285 m and 350 m respectively. From this it is reasonable to assume that no great depth of boundary layer evolved on this occasion and an anomolously low boundary layer existed on this afternoon. If the pollutant is well mixed within the boundary layer then the effect of reducing the boundary layer height will be to greatly increase the concentration calculated. If however the lower boundary layer results in more material being emitted above the boundary layer initially, then this material might never become mixed into the boundary layer and will result in a lower concentration being calculated.

The nature of the NAME model output is also likely to result in lower concentrations being calculated then are measured. The model is producing a volume average concentration over the grid (5.6km x 3.4 km x 50m depth). In reality the plume is likely to have some structure over this scale resulting from localised meteorological and topographical variations. The NAME model can not resolve these local fluctuations in concentration, and provides an average value. Ideally the model output would be compared with an average of several measurement sites over each city.

7 Conclusions

The NAME model has shown a high degree of skill in modelling the sulphur dioxide episode on the 2nd September in the West Midlands region of the UK. The pattern and the timing of the event compared well with measured data, and the magnitudes modelled at Nottingham and Birmingham were within a factor of two. Likely reasons for the under-prediction are the failure to capture the low boundary layer thought to have existed on that afternoon and also that the model output is a volume average over a finite area and therefore not able to reproduce fluctuations in concentration.

This work has allowed, for the first time in the UK, an attribution of ground level concentrations to emissions from specific power stations at large upwind distances. It is hoped that this capability will provide the UK Environment Agencys with assistance in understanding and predicting future air pollution episodes.

8 References

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