MODELLING AIR QUALITY IN THE VICINITY OF THE TRENT AND AIRE VALLEY POWER STATIONS

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ABSTRACT

A UK version of the USEPA Models-3/CMAQ system has been developed by the UK electricity generators Joint Environmental Programme (JEP) to meet the current and future air quality and acid deposition modelling needs of the power industry. The model is capable of simulating the transport, chemical conversion, and deposition of pollutant species on local to national scales at an hourly resolution. An extensive programme of validation has been carried out by the JEP in order to encourage regulatory and scientific acceptance of the model.

The ability of the model to simulate airborne concentrations of sulphur dioxide, nitrogen dioxide and ozone has been assessed through a comparison between modelled and monitored concentration data. The evaluation was carried out for a domain covering the Midlands and the North of the United Kingdom at 4km grid resolution. Modelled concentrations were compared against monitored data from sites in the vicinity of the Trent and Aire valley power stations for periods in January and July 1999.

Models-3 was found to simulate atmospheric concentrations of SO_2, NO_2 and O_3 in reasonable agreement with values measured in the UK and as such, is a suitable tool for the modelling of air quality in the UK and Europe.

INTRODUCTION

The JEP has developed a UK version of the USEPA Models-3/CMAQ system in order to address the air quality and deposition modelling needs of the power industry. To encourage regulatory acceptance of the model, an extensive programme of validation has been undertaken addressing the model performance at simulating acid deposition, airborne particulate matter and episodic pollutant concentrations. As part of this validation programme, the performance of Models-3 at simulating airborne concentrations of sulphur dioxide, nitrogen dioxide and ozone has been examined by comparing modelled data against monitored data from sites in the vicinity of Trent and Aire valley power stations.

SO_2, NO_2 and O_3 are all regulated under the UK Air Quality Strategy Objectives and the First and Third Daughter Directives of the Air Quality Framework Directive. As power stations contribute a significant proportion of UK SO_2 and NO_x emissions, the three species examined are of major interest to the power generation industry.

MODEL SET-UP

Models-3 is an Eulerian model simulating emissions, meteorology, transport, chemistry and deposition on an hour by hour basis. The model domain consists of 4 horizontal nested grids;

an outer grid covering Europe, at a 108km grid cell resolution, a 36km resolution grid covering the UK, a 12km resolution grid covering England and Wales and a 4km grid covering central England, corresponding approximately to the area shown in Figure 1. A twenty-one layer vertical grid corresponding to a total height of 15 km was used for all four grids, the surface layer depth being 40 metres. The RADM2 chemical scheme, coupled with aerosol and aqueous chemistry was selected from the schemes available in Models-3.

Meteorological data were supplied by the UK Met Office and emissions data were derived from the UK National Atmospheric Emissions Inventory [1] and EMEP [2]. The emissions data were processed using the SMOKE emissions modelling system [3] to produce temporally resolved and speciated data suitable for input to Models-3. SMOKE was also used to vertically resolve high-level point source emissions using a plume-rise algorithm. A more detailed discussion of the model set-up can be found elsewhere [4].

COMPARISON WITH MONITORED DATA

Models-3 was run for all four domains for an 18 day winter period covering 1-18 January 1999 and a ten day summer period covering 13-22 July 1999. Concentration data for SO_2, NO_2 and O_3 were extracted from nine JEP monitoring sites for these periods. The locations of these sites together with the locations of the Trent and Aire Valley power stations are shown in Figure 1.

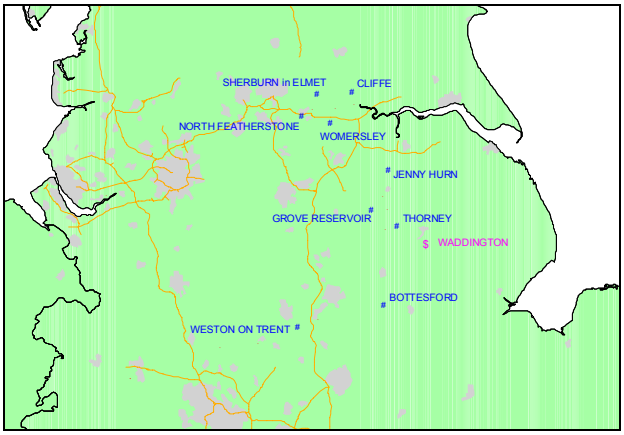

Figure 1. Map showing location of JEP monitoring sites [•] and power stations [+]

The surface layer concentration data were extracted from the Models-3 4km resolution domain grid squares corresponding to the locations of the monitoring sites. Monitored and modelled hourly time-series data for SO_2, NO_2 and O_3 concentrations at each site were compared and scatter plots were generated using data from all sites for the winter and summer periods. Figures 2 to 4 show example winter and summer period time-series plots for Bottesford for SO_2, NO_2 and O_3 respectively, whilst Figures 5 to 7 show the winter and summer scatter plots.

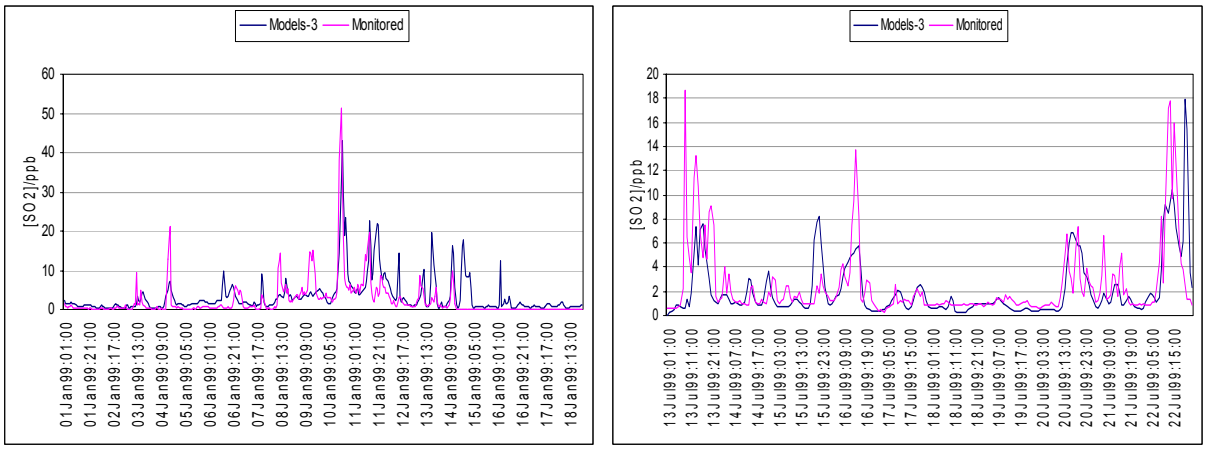

Figure 2. Hourly modelled and monitored surface SO_2 concentration at Bottesford

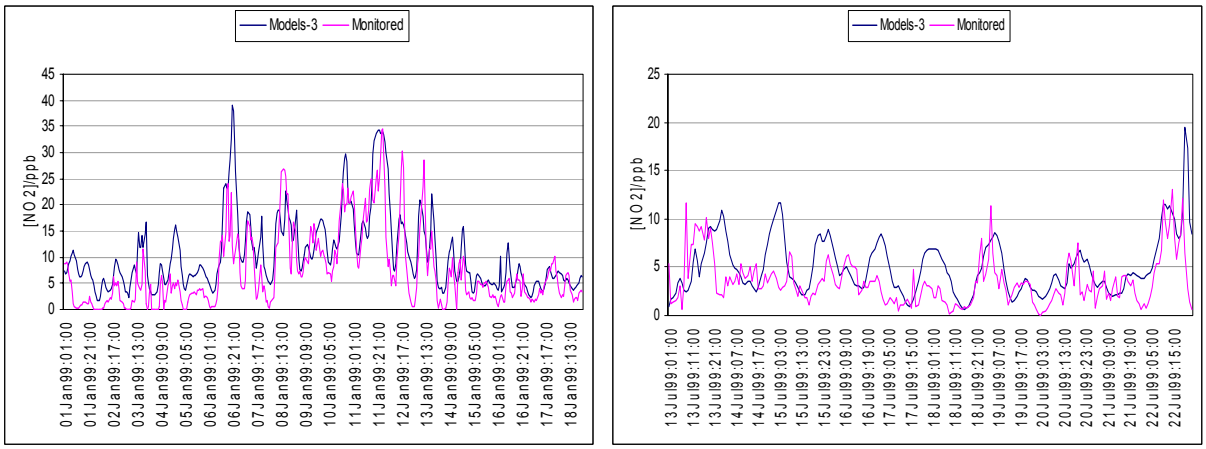

Figure 3. Hourly modelled and monitored surface NO_2 concentration at Bottesford

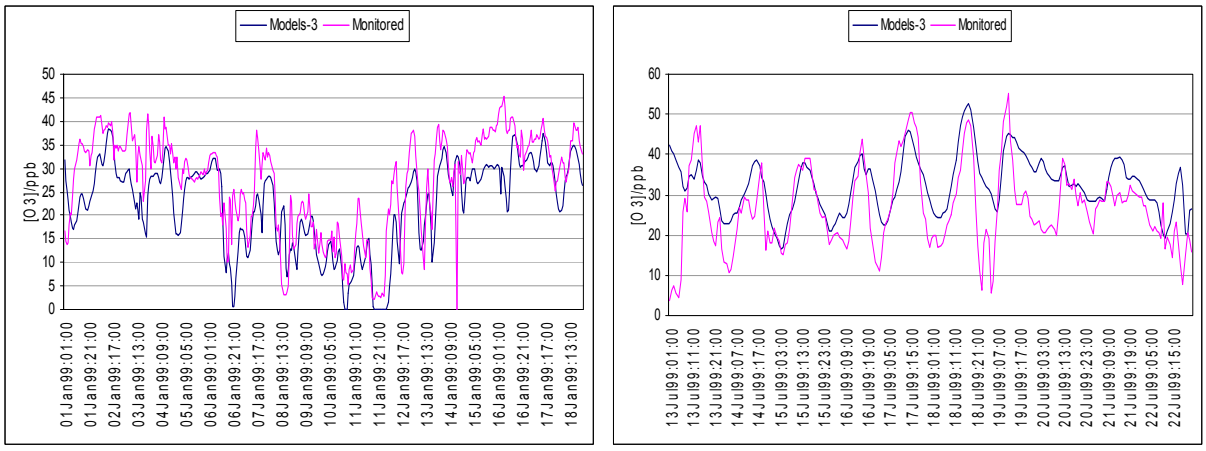

Figure 4. Hourly modelled and monitored surface O_3 concentration at Bottesford

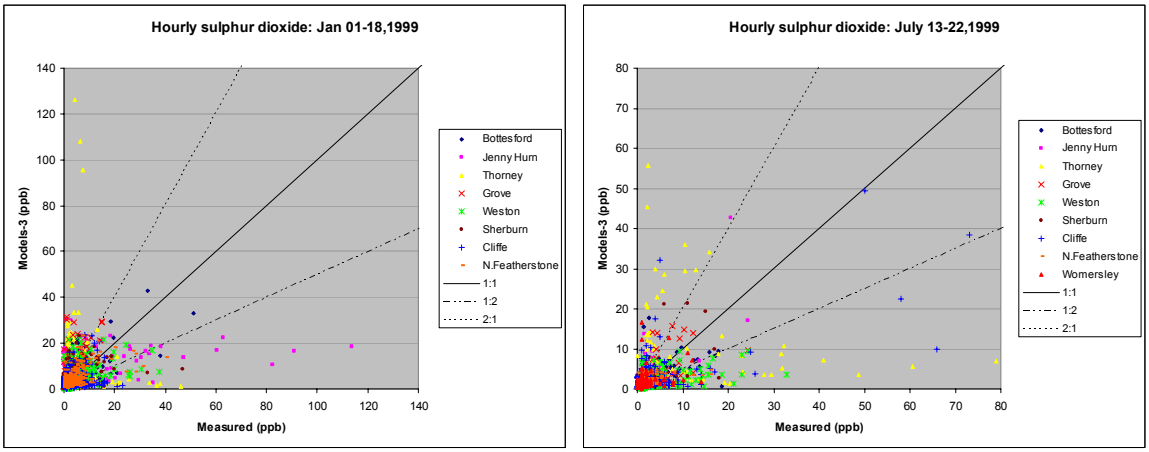

Figure 5. Scatter graphs of modelled and measured hourly SO_2 concentrations

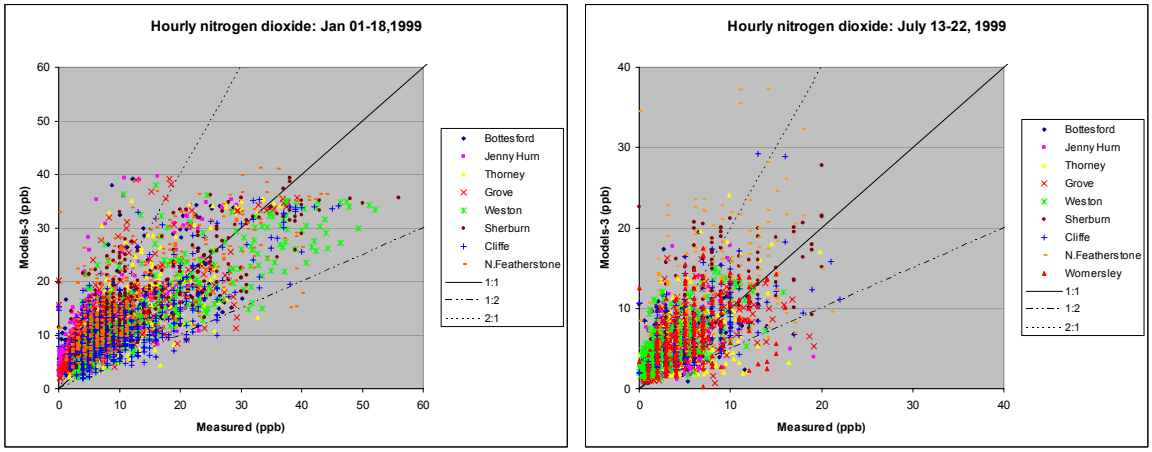

Figure 6. Scatter graphs of modelled and measured hourly NO_2 concentrations

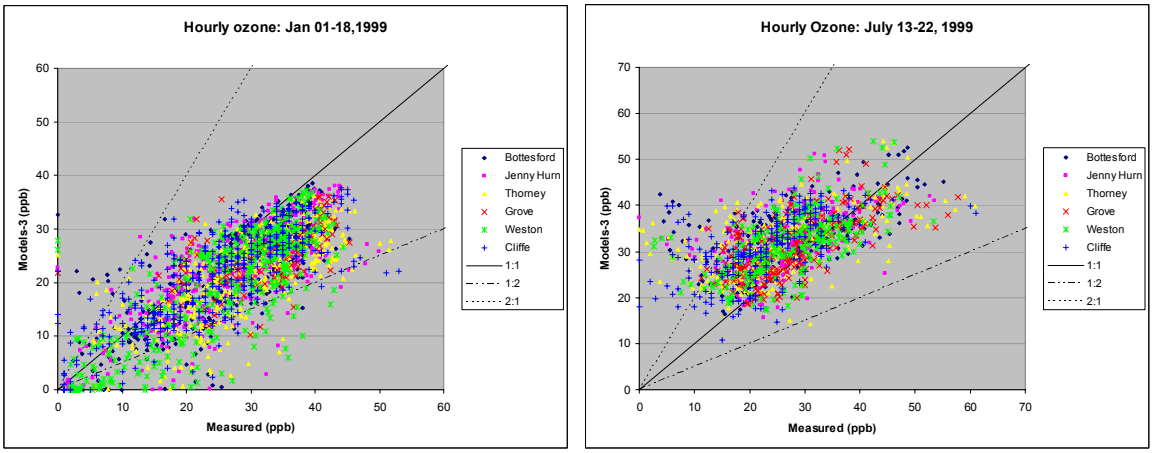

Figure 7. Scatter graphs of modelled and measured hourly O_3 concentrations

SULPHUR DIOXIDE RESULTS

The time-series plots for SO_2 suggested that Models-3 reproduced the timing of SO_2 peaks well. In many cases, such as the Jan 10 peak in Figure 1, the magnitude of the peaks were well reproduced, however in some cases, the size of the peaks were either over or under-estimated. It can be seen from Figure 5 that the majority of the modelled data points fall within 50% of the monitored values, however, some sites, particularly Thorney, show a higher degree of scatter, although there is no bias towards under or over-estimation.

Sulphur dioxide is strongly associated with primary emissions from point sources, particularly power stations and hence the dispersion pattern is generally a highly characteristic plume. Meteorological modelling is complex and with less dispersed emissions, such as plumes, small deviations between real and modelled wind direction may result in modelled plumes clipping or missing monitoring site locations. An examination of the modelled SO_2 concentrations in the grid cells immediately adjacent to the cell corresponding to the monitoring site location was undertaken to assess the extent to which this was responsible for the differences. It was found that agreement with the monitored data was significantly improved, suggesting that it was indeed small deviations in the modelled plume paths leading to the observed differences.

Figure 8 shows the pooled modelled and monitored time-series data respectively for the summer period, with the Thorney data excluded. It can be seen that the three sets of peaks in the modelled data correspond to similar peaks seen in the monitored data. Measured data from the Met Office site at Waddington was used to assess the meteorology on these occasions and it was found that these peak values were driven by low wind-speeds and relatively low boundary layer heights. These conditions are classic for power plant plume 'trapping' leading to elevated ground level SO_2 concentrations. The data suggests that Models-3 performs well at simulating peak levels arising from calm conditions with a low boundary layer.

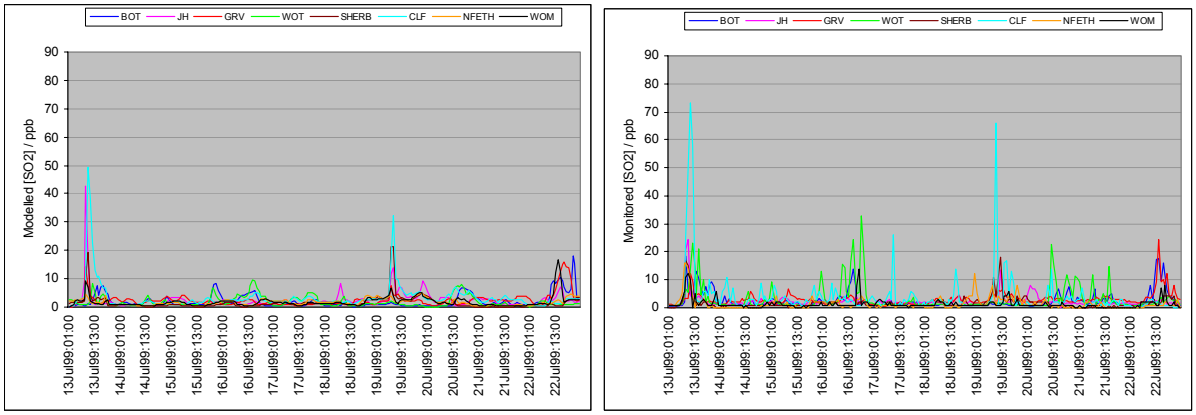

Figure 8. Combined modelled and monitored data for 13-22 July 1999

NITROGEN DIOXIDE RESULTS

The individual site time-series plots suggested that Models-3 reproduced both the variation and magnitude of nitrogen dioxide concentrations well, as shown in Figure 3. Figure 6 shows that the level of agreement between modelled and monitored data was good across all sites for

both the summer and winter periods. The transport sector is the major emitter of NO_x in the UK, and emissions from this sector dominate ground level concentrations, leading to a highly characteristic temporal concentration profile due to the morning and evening rush hours. This profile was well reproduced by Models-3. Examination of the meteorological data from Waddington confirmed that high NO_2 concentrations were associated with very low boundary layer heights trapping ground level emissions.

OZONE RESULTS

The time series data suggest that Models-3 reproduced the temporal variation in ozone concentrations well. It can be seen in Figure 7 that the majority of modelled and monitored data points lie within the 50% bounds. The data do suggest that Models-3 shows a slight tendency to under-estimate ground level ozone concentrations in winter and over-estimate in summer. The reaction and photolysis rate data in Models-3 were compared to IUPAC data and found to be in reasonable agreement. Comparison between Figures 3 and 4 shows the expected inverse relationship between NO_2 and O_3. Overall the differences between modelled and monitored ozone concentrations are not of sufficient magnitude to be of concern.

CONCLUSIONS

The performance of Models-3 at simulating SO_2 was encouraging. The hourly variation was well reproduced and when allowance was made for small deviations in modelled plume paths, the model simulated peak concentrations driven by calm conditions well. Models-3 performed well at simulating NO_2 concentrations and reproduced the expected variations in concentration profiles as driven by rush hour emissions and low boundary layer heights. The model performed relatively well at simulating ozone concentrations, but showed a slight tendency to over-estimate summer concentrations and under-estimate in winter. Overall Models-3 simulated the atmospheric concentrations of SO_2, NO_2 and O_3 in reasonable agreement with values measured at UK monitoring sites and such may be regarded as a suitable tool for modelling air quality in the UK and Europe.

ACKNOWLEDGEMENTS

This work was carried out under the auspices of the UK power generators' Joint Environmental Programme, the current members of which are: RWE Innogy, Powergen, British Energy, Drax Power, AEP, International Power, EDF Energy and Scottish Power.

REFERENCES

[1] National Atmospheric Emissions Inventory http://www.naei.org.uk/
[2] UNECE/EMEP Activity Data and Emission database http://webdab.emep.int/
[3] SMOKE documentation at http://www.baronams.com/products/smoke/
[4] S J Griffiths and K Milne, 2004, Models-3 Validation: The simulation of atmospheric concentrations of sulphur dioxide, nitrogen dioxide and ozone for January and July 1999, Power Technology JEP Report PT/04/BE158/R