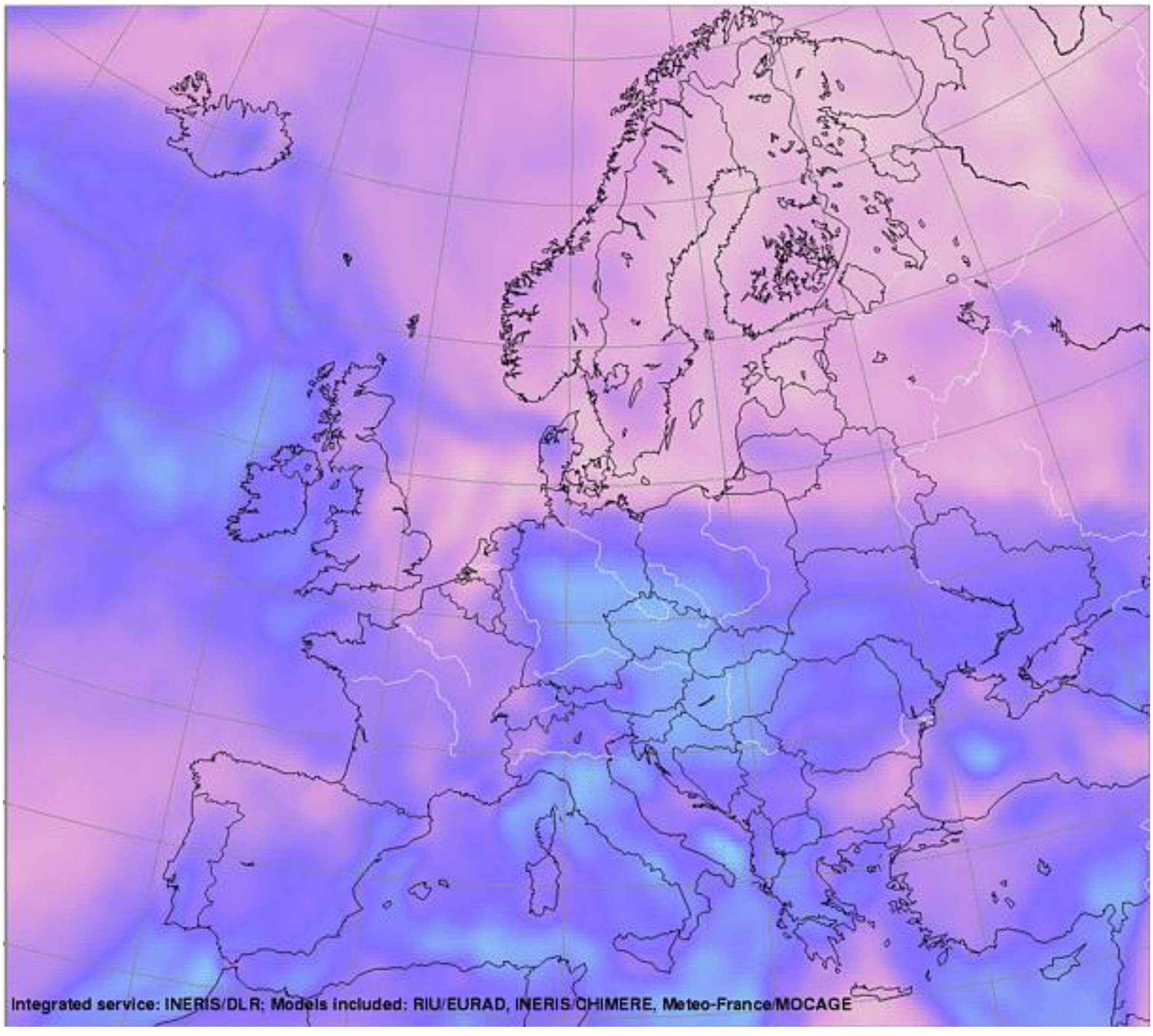
UK Air Quality Forecasting: Annual Report 2011



Report for Defra and the Devolved Administrations

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Executive summary

This report covers the operational activities carried out by Ricardo-AEA on the UK Air Quality Forecasting Contract for the year 2011. The work is funded by the Department for Environment Food and Rural Affairs, the Scottish Government, Welsh Government and the Department of the Environment in Northern Ireland.

During 2011, there was a total of forty-four days on which HIGH air pollution was recorded across the UK. Thirty-nine of these days were due to particulate PM_{10}, one due to ozone, four due to SO_2 and none due to NO_2.

The forecasting success and accuracy for this year is summarised in Box 1, together with the results from the previous calendar year. The overall forecasting success and accuracy rate performance for HIGH episodes is improved compared to the previous year, partly due to a successfully forecast period of MODERATE and HIGH PM_{10} particulate matter concentrations during extensive pollution episodes in the early part of 2011.

The performance for the MODERATE band forecasts was again high, with an overall accuracy figure of over 80% as seen in previous years (this is perhaps the most meaningful and consistent figure from year-to-year). Please note that due to the current definition of +/- 1 index value in each band, success rates can be reported as greater than 100 %.

Box 1 – Forecast success/accuracy for incidents above 'HIGH' and above 'MODERATE' in 2011 *(and 2010)*

Region/Area	***HIGH***		***MODERATE***	
	% success	***% accuracy***	***% success***	***% accuracy***
Zones	57 *(12)*	39 *(9)*	119 *(137)*	89 *(84)*
Agglomerations	14 *(25)*	11 *(19)*	*118 (129)*	81 *(72)*

During this year one ad-hoc report and several detailed news items were provided to Defra and the Devolved Administrations. Most of these activities were related to investigating the possible impact on UK ground-level air pollutant concentrations of the Icelandic Grimsvoten volcanic eruption in May 2011.

There were no reported breakdowns in the service over the year and all bulletins were delivered to the Air Quality Communications contractor on time.

We have continued to actively research ways of improving the air pollution forecasting system by:

1. Investigating the use of automatic software systems to streamline the activities within the forecasting process, thereby allowing forecasters to spend their time more efficiently in maximising forecast accuracy.
2. Improving the CMAQ model runs which can be used for daily and ad-hoc analysis.
3. Improving and updating the emissions inventories used in our models.

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1 Introduction

Ricardo-AEA is contracted by the Department for Environment, Food and Rural Affairs (Defra), Scottish Government, Welsh Assembly Government and the Department of the Environment in Northern Ireland (the DAs) to provide 24-hour air pollution forecasts which are widely disseminated through the media. The forecasts allow individuals who may be affected by episodes of high air pollutant concentrations to take appropriate preventative measures. These can include increasing medication or taking steps to reduce exposure and dose.

A forecast of the following day's air pollution is prepared every day by Ricardo-AEA. The forecast consists of a prediction of the air pollution descriptor for the worst-case situation in 16 zones and 16 agglomerations over the following 24-hours. Forecasts are disseminated in a number of ways to maximise public accessibility; these include the World Wide Web and a Freephone telephone service. Work in 2012/3 will continue to look to improve access to the forecasting service through a number of means, including improving visibility/links to the webpage, increasing uptake/visibility of the twitter feed and developing website plugins for incorporation into public facing websites.

Updates can occur at any time of day, but the most important forecast of the day is the “daily media forecast”. This is prepared at 3.00 p.m. for uploading to the Internet and Air Quality Communications contractor before 4.00 p.m. each day. It is then included in subsequent air quality bulletins for the BBC, newspapers and many other interested organisations.

This report covers and analyses the media forecasts issued during the 12 months from January 1st to December 31st 2011. Results from forecasting models are available each day and are used in constructing the forecast. The forecasters issue predictions for rural, urban background and roadside environments but, for the purposes of this report, these have been combined into a single “worst-case” category (i.e. the forecasts issued are not analysed by environment type within this report).

Twice per week, on Tuesdays and Fridays, Ricardo-AEA also provides a long-range pollution outlook. This takes the form of a short piece of text which is emailed to approximately sixty recipients in the Defra and other government Departments, plus the BBC weather forecasters. The outlook is compiled by examining the outputs from our pollution models, which currently extend to 3 days ahead for Defra and the DAs, and by assessing the long-term weather situation.

Quality control of BBC air pollution forecasts by Ricardo-AEA ceased in 2011, with the Met Office making the decision to take sole responsibility for these predictions.

Forecasts issued by Ricardo-AEA for UK regions and individual local authorities are however checked for consistency with the overall UK forecasts issued on behalf of Defra and the DAs.

2 Development of the WRF-CMAQ Air Quality Forecasting Model

This section provides a summary of 2011 development work on the WRF-CMAQ air quality forecasting model. During this year the main developments included improving the maps and daily model evaluation made available to the duty forecasters. The WRF daily forecast weather maps are now available for public access at http://uk-air.defra.gov.uk/forecasting .

WRF (Weather Research and Forecasting) is a numerical weather model developed in the USA as a collaborative partnership between several agencies including: National Center for Atmospheric Research (NCAR), the National Centers for Environmental Prediction (NCEP), the Air Force Weather Agency and the Naval Research Laboratory. The WRF code and documentation are available at www.wrf-model.org.

The CMAQ (Community Multiscalar Air Quality) model was first developed under the US EPA Models-3 project (Byun and Ching, 1999). It is a comprehensive AQ model, incorporating meteorology, emissions, land use, chemistry and aerosol processes. For the UK AQ forecasting project it is driven by weather from WRF, and the emissions are generated using the NAEI (National Atmospheric Emissions Inventory) and EMEP (European Monitoring and Evaluation Program) Inventory, supplemented by natural emissions calculated using the Biogenic Potential Inventory. In 2011 the emissions were updated to run from latest 2009 base year emissions. CMAQ model code and documentation are available at www.cmaq-model.org.

The beta version of CMAQv5 was made available for testing in July 2011. Initial tests were unfortunately unsuccessful in the UK AQ Forecasting configuration and feedback and recommendations were provided by the Ricardo-AEA project team. CMAQv5 is now being evaluated as part of the Defra project to evaluate CMAQ for national scale modelling. Depending on the outcome, the WRF-CMAQ AQ forecast model may be upgraded in 2013 if there are determined to be advantages with using CMAQv5.

2.1 Improvements to the maps provided for daily forecasting

During 2011 version 1.4 of the mapping tool Verdi became available. Verdi replaced the previous visualization tool PAVE. The new scripting language in Verdi v1.4 is now compatible with the CMAQ forecast operation, and in order to benefit from other features of Verdi and to ensure future compatibility the scripts have been converted. The immediate benefit was to successfully incorporate an up-to-date base map for Europe with correct political boundaries.

The maps and model evaluation tools were updated ready for the new Daily Air Quality Index (DAQI) bands in January 2012. This included updating the colour schemes and indices for the daily air quality maps, creating animations for 8hr and 24hr averages, and adding $PM_{2.5}$.

2.2 Model Evaluation

Air quality forecast model evaluation is an ongoing progress. Model values corresponding to monitoring sites are automatically extracted from the daily forecast output files and stored in a mySQL database along with the provisional and ratified monitoring data from the AURN monitoring network, and weather measurement data from European airports. R scripts are used to produce the daily and monthly evaluations for WRF and CMAQ. Air quality evaluations are produced separately for each forecast species and class of monitoring site (rural, urban background and urban centre). WRF is evaluated where AURN sites and weather monitoring data fall within the same model grid cell. The format of the model evaluation remains under development and is improved as required.

There are currently two distinct levels of model evaluation:

- Daily rolling evaluation to provide guidance to the air quality forecasters of how well WRF and CMAQ represent the current conditions. This evaluation is available on the forecasting dashboard alongside the daily maps, giving an up-to-date indication of model performance under the current meteorological conditions. The WRF and CMAQ skill plots are updated every morning and cover the previous 14 day period. For CMAQ the line plot is extended to the previous 7 days and the next 2 days forecast.
- The same evaluation is used for monthly, quarterly and yearly analysis using ratified (or provisional) monitoring data. This more extended analysis is used to evaluate overall model performance and to guide model development.

2.2.1 WRF automated evaluation

Weather observation data are currently automatically collected each day for airport sites in Europe and around the world. These are collated and distributed on the internet by the University of Wyoming. Data are automatically downloaded each day by the UK AQ Forecasting systems and evaluated against the WRF predictions for wind speed, wind direction and temperature.

Figure 2.1 and Figure 2.2 are examples of the skill analysis produced by the automated WRF evaluation. These are examples of the results for Liverpool in 2011.

Similar skill plots of the rolling previous 14 days are produced daily to provide an evaluation of the current conditions for the duty forecaster.

Figure 2.1 Comparison between modelled and observed temperature for Liverpool airport station for conditions of 2011.

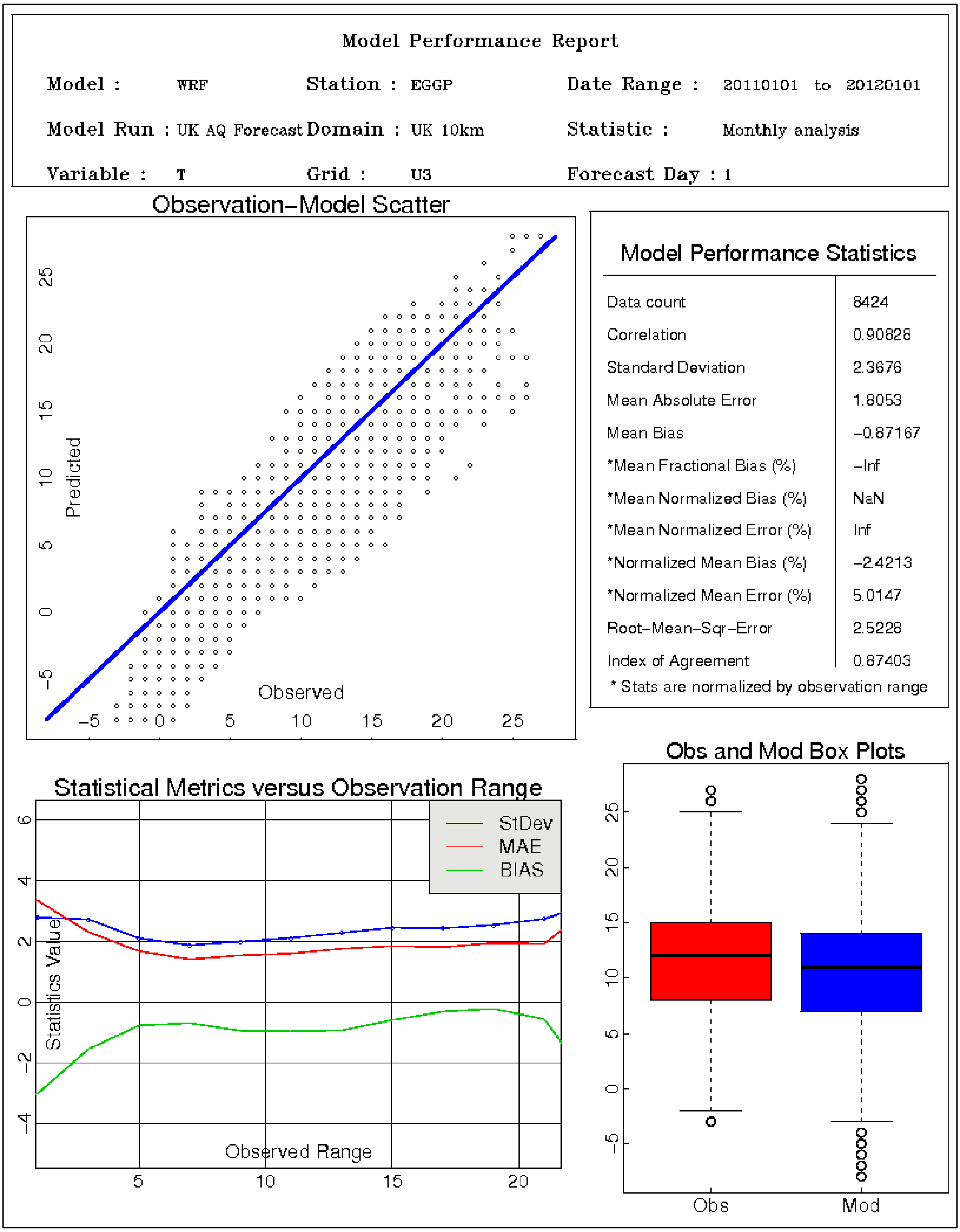
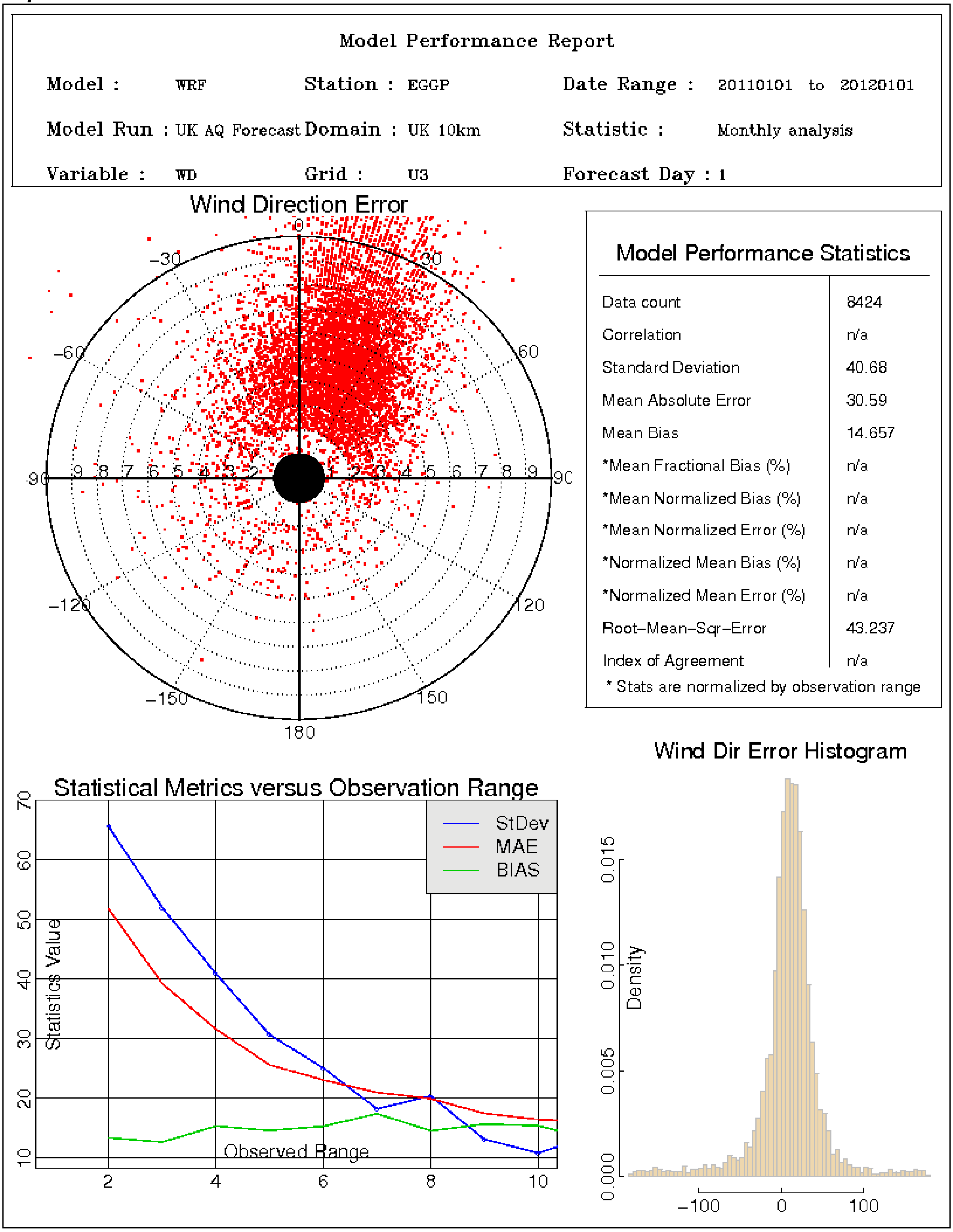


Figure 2.2. Comparison between modelled and observed wind direction for Liverpool airport station for conditions of 2011



2.2.2 Comparison with other models

There are currently no formal comparisons with other AQ forecasting models carried out as part of this contract, although WRF-CMAQ is included in Defra's Model Intercomparison Exercise.

On a daily basis the duty forecaster visually compares the forecast with the ECMWF (European Centre for Medium range Weather Forecast) and MACC (Monitoring Atmospheric Composition and Climate) regional AQ ensemble forecasts each of which includes up to 11 different air quality forecasts across Europe.

2.3 WRF Forecast data evaluation 2011

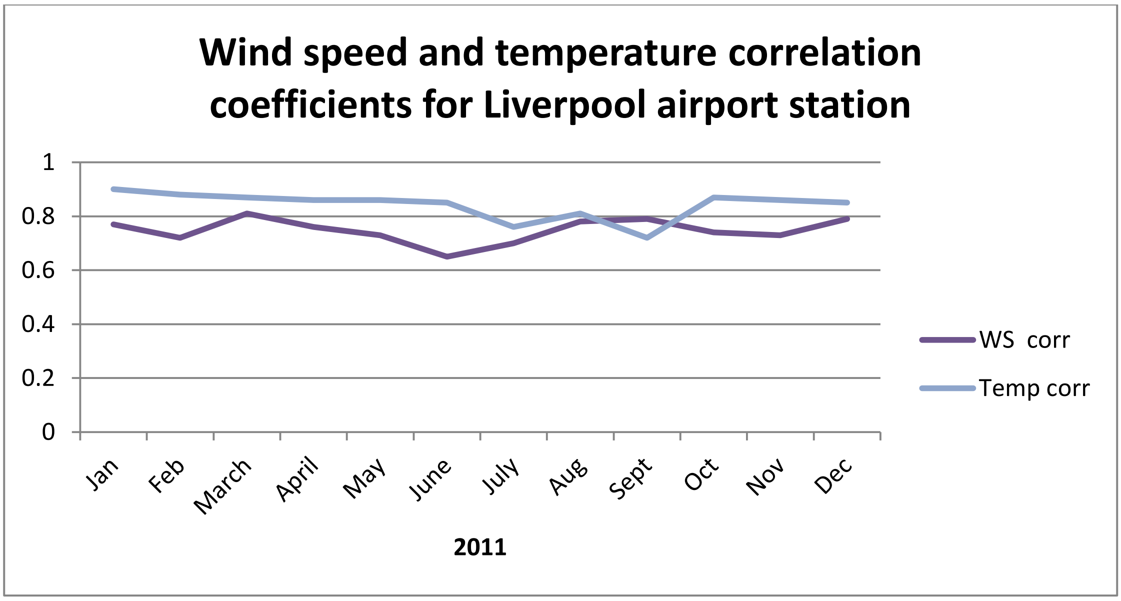
The performance of the WRF forecast for wind speed, wind direction and temperature has been evaluated by comparing the model outputs against surface observations collected from automated meteorological stations located at several different airports across the UK.

The results shown here are for a comparison of modelled WRF 10km gridded data with observed meteorological values recorded at Liverpool airport. The results are not significantly different from those at any other meteorological station data analysed and may therefore be considered representative of the modelling results. A full separate report "Statistical evaluation of meteorological data used for UK air quality forecasting" on the WRF model evaluation has been undertaken.

Figure 2.1 below shows comparison of 2011 measured & modelled temperature at Liverpool Airport. It confirms a good agreement between the observed and modelled temperatures with a correlation coefficient of 0.9 and a standard deviation of 2.3.

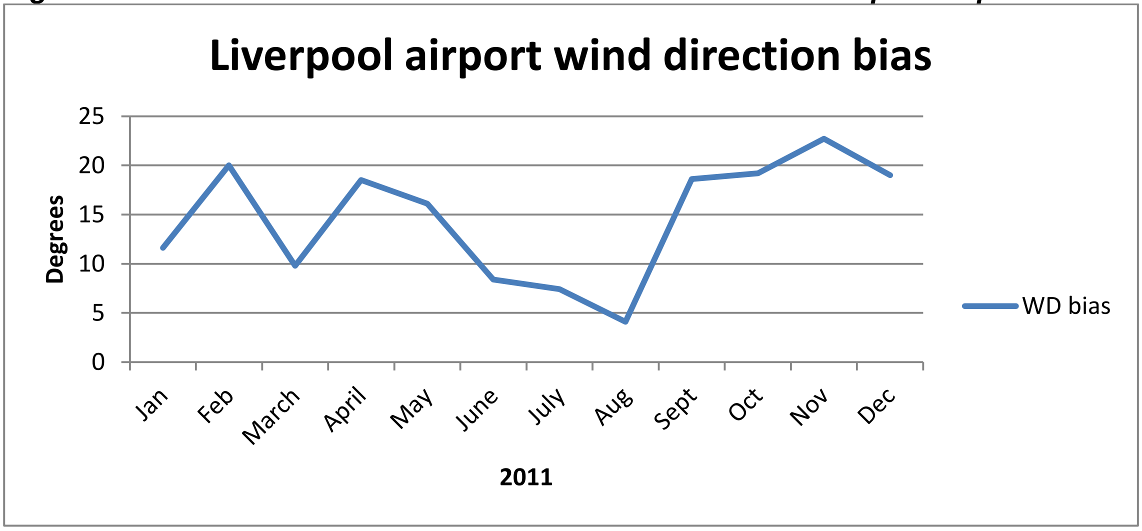
Figure ***2.3*** shows the monthly correlation coefficients time series for wind speed and temperature. In the case of wind speed, the correlation monthly coefficients range from 0.65 and 0.81 for wind speed and 0.72 to 0.9 for temperature, indicating not only a good fit, but also consistency in the capturing the observed conditions throughout the year.

Figure 2.3 Wind speed and temperature correlation coefficients for comparisons of modelled data versus observations at Liverpool Airport station for conditions typical of 2011



A comparison of 2011 modelled and measured wind direction for the Liverpool Airport station is shown in Figure 2.2. It can be seen that modelled wind direction, exhibits a positive average bias of 14.65 degrees. The monthly bias at Liverpool is shown in Figure 2.4 and can be seen to vary between 4 and 25 degrees. The average for the year across monitoring stations is just below 4 degrees. We chose to compare the modelled data from the Liverpool airport station because, being on the west coast, the wind, which tends to prevail from the west south-west, is not subject to local or orographic effects which may make it hard for the model to reproduce. On comparing with other stations farther inland similar bias is observed.

Figure 2.4 Time series of modelled wind direction bias at Liverpool airport station



2.4 CMAQ Forecast data evaluation 2011

Figure 2.5 shows a summary of the annual CMAQ performance for 2011. It summarises the metrics recommended in the model evaluation protocol developed by Derwent et al. 2009. The results show a tendency to overestimate ozone and underestimate PM_{10}. Performance is better at the rural sites than the urban background or urban centre sites. This would be expected as the rural sites are selected to reflect the air quality over a similar spatial scale as the 10km model.

For O_3, NO_2 and PM_{10} more than 50% of the paired values fall within a factor of 2 for each of the site classifications. At the Rural NO_2 sites the bias was only 5.7µgm^{-3}. However because of the low observed values this results in a relatively high normalised bias and error. The Odds Ratio Skill Score shows that the model performs well at predicting the low to moderate threshold, performing best for ozone. If the increase in PM_{10} is due to elevated inorganic PM CMAQ performs better than if it is caused by dust or PM re-suspension.

The relatively low number of modelled values falling within a factor of two of the observation SO_2 (Figure 2.6) reflects the high number of observations that are low and close to the lower limit of the measurement calibration. The actual bias is less than 9µgm^{-3}.

Figure 2.5 Annual evaluation of forecast species for rural, urban background and urban centre AURN monitoring sites 10km model UK simulation and ratified observations

Pollutant	Area type	Normal Mean Bias %	Normal Mean Error %	Factor of 2 %	ORSS
O_3	Rural	19	31	86	0.97
	Urban BG	22	38	77	0.98
	Urban C	47	60	64	0.98
NO_2	Rural	58	93	50	0.94
	Urban BG	5	55	62	0.83
	Urban C	-24	49	58	0.77
PM_{10}	Rural	12	60	64	0.84
	Urban BG	-13	55	58	0.75
	Urban C	-26	53	53	0.81
ORSS – Odds Ratio Skill Score – based on the low/moderate AQI interface					

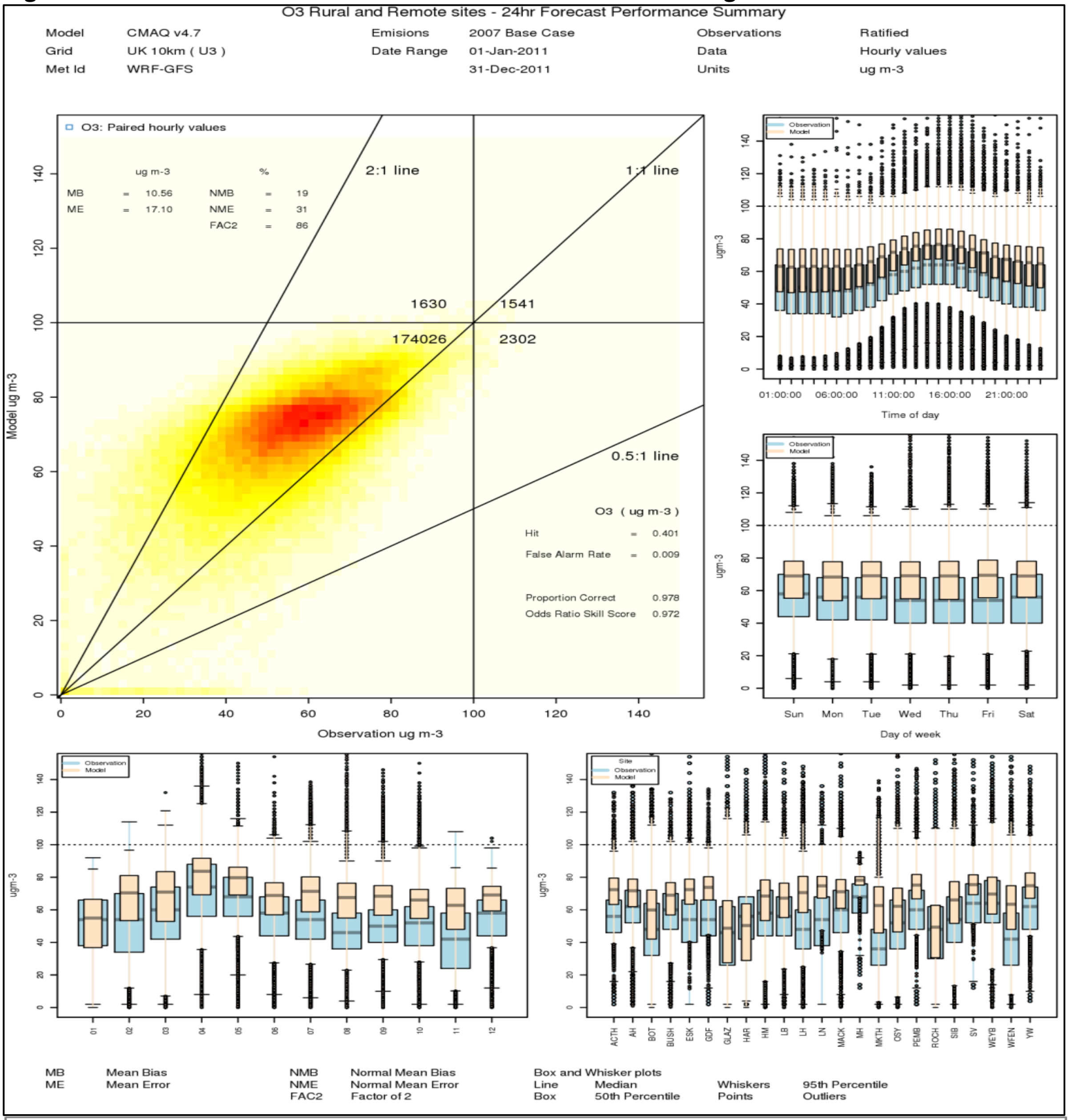
Figure 2.6 Annual evaluation of SO_2 for rural, urban background and urban centre AURN monitoring sites 10km model UK simulation and ratified observations

Pollutant	Area type	Mean Bias µgm-3	Mean Error µgm-3	Factor of 2 %
SO_2	Rural	8.97	10.92	26
	Urban BG	6.88	9.09	36
	Urban C	5.69	7.92	38

The annual skill evaluations for rural ozone and urban background ozone are shown in Figure 2.7 and Figure 2.8 respectively.

At the rural sites the best performance for ozone was during April and May (Figure 2.7), which were periods of relatively higher ozone. The relatively lower ozone periods of August and November were less well predicted. There is little variation in the diurnal and day of week response to ozone. CMAQ generally over predicts ozone at all rural sites except for Harwell, Glazebury and Rochester (these sites are classified as rural but are close to areas of high emissions of NO_x).

Figure 2.7 2011 evaluation of ozone rural AURN monitoring sites.



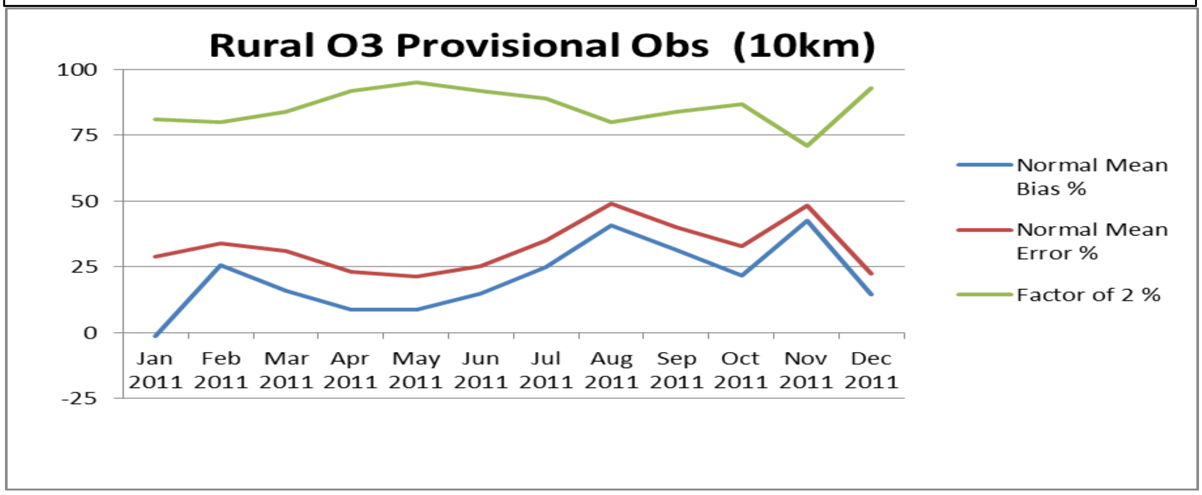
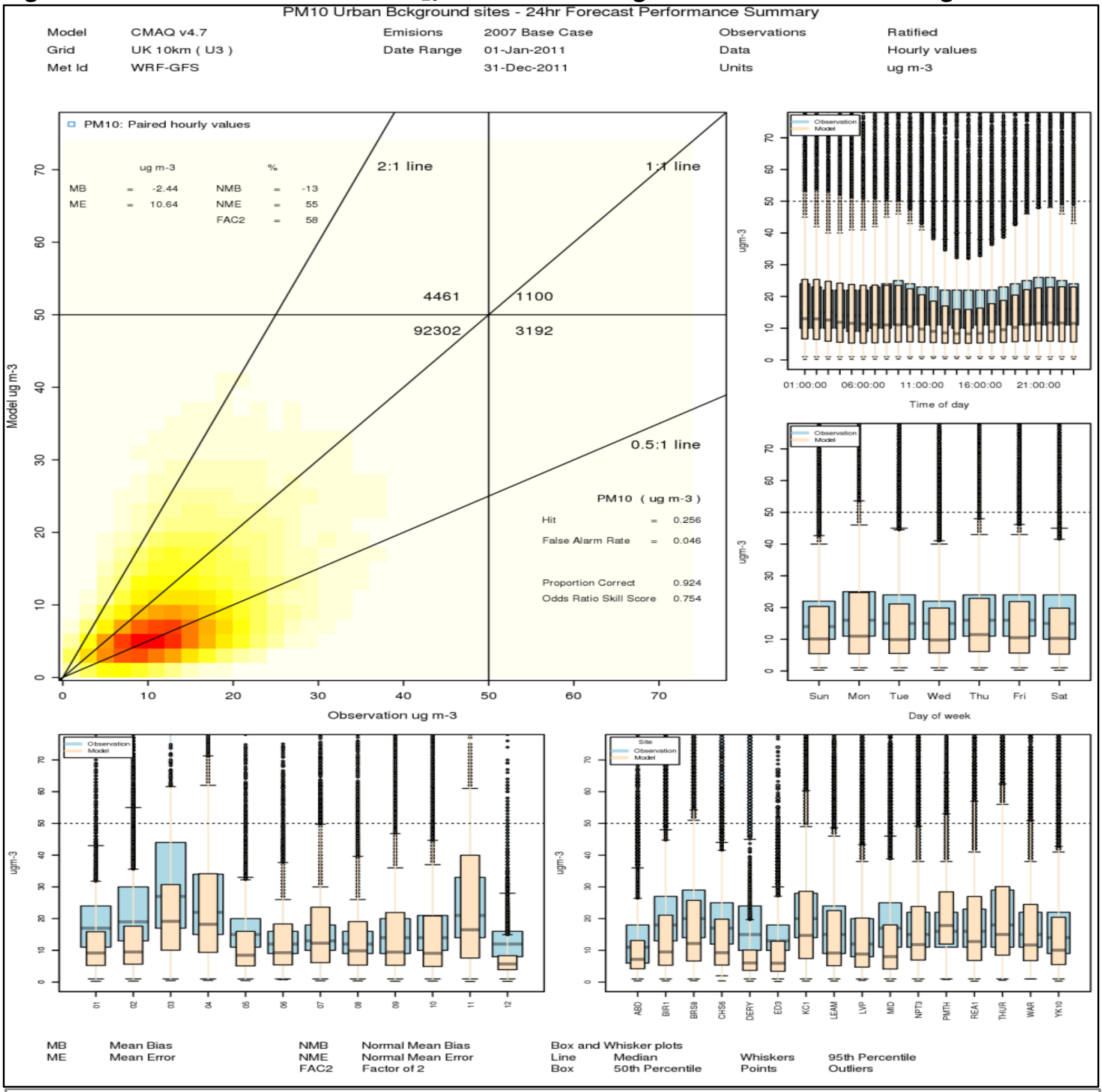


Figure 2.8 2011 evaluation of PM_{10} for urban background AURN monitoring sites.



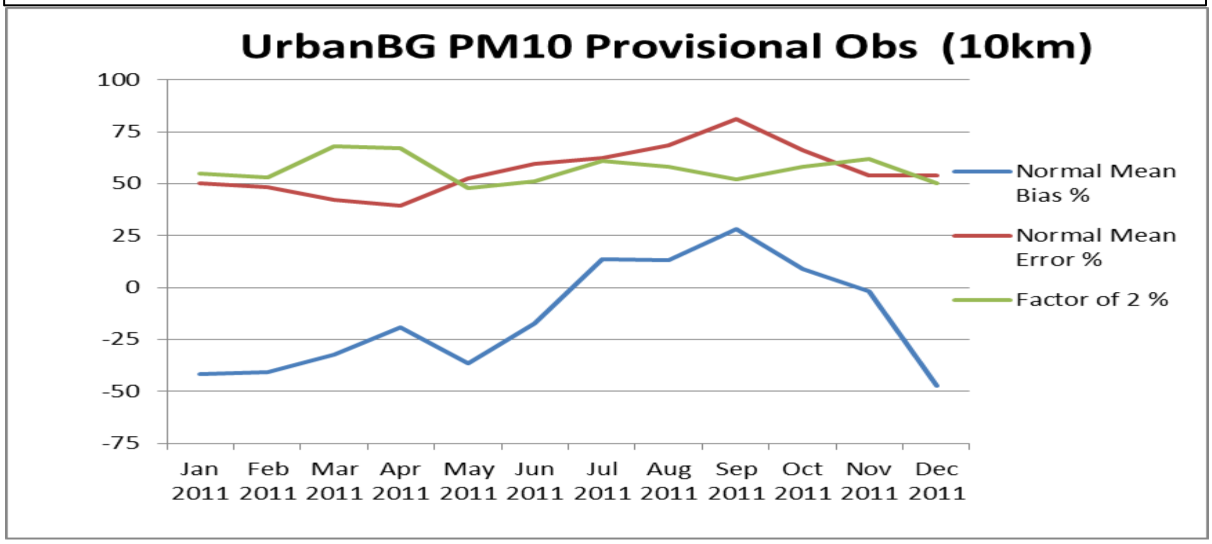


Figure 2.8 shows the annual evaluation of CMAQ performance for PM_{10} at urban background sites. During 2011 PM_{10} tended to be under predicted during winter and spring but over predicted in late summer and autumn. CMAQ has a stronger diurnal profile than the observations, tending to under prediction of PM_{10} in the mid to late afternoon. CMAQ performs similarly at all monitoring sites except for Derry. During 2011 there were periods of elevated PM in March/April and November. These corresponded with air masses moving in from central and northern Europe and then remained circulating over south east England. During these periods CMAQ forecast the end of the episodes well.

Both the model evaluation protocol and the Gems Evaluation (Agnew et al. 2007) document stress the requirement to evaluate the models for the metrics they are to be used for. This will evaluate the skill of the model at providing the regulated metrics, but often these are 8hr or daily averages and will disguise the ability of the model to predict the hourly and seasonal peaks and troughs in the measurements. Model evaluation is developing, and will evolve to take into account the Defra model inter-comparison and provide the information required by the duty air quality forecaster.

2.5 Summary of Model Development and Performance

WRF and CMAQ continue to be used successfully each day to produce daily predicted maps and animations to support the UK duty air quality forecasters. The WRF weather maps are published for public access on the UK-AIR website at http://uk-air.defra.gov.uk/forecasting/wrf-summary.

The currently operational version of WRF can accurately reproduce observed wind speed and temperature values but has a noticeable positive bias in the predicted wind direction. This bias has been observed by other WRF users and is being investigated, but does not appear to adversely affect the ability of CMAQ to forecast pollutant concentrations across the UK and Europe.

CMAQ forecasts are shown to accurately represent seasonal and daily variations in ozone and PM_{10} concentrations. There is evidence of a slight positive bias in ozone predictions, and an underestimation in PM_{10} concentrations. Both of these are likely to be due to inaccuracies in the underlying pollutant emissions inventories - which are updated with improved versions annually as they become available.

During the extended periods of increased PM concentrations in March and April 2011 CMAQ accurately tracked the progress of the events across Europe and forecast the end of the pollution episodes well.

3 Analysis of forecasting success rate

3.1 Introduction

Analysis of forecasting performance is carried out for each of the 16 zones and 16 agglomerations used in the daily forecasting service. Further details of these zones and agglomerations are presented in Appendix 2. Forecasting performance is analysed for a single, general pollutant category rather than for each individual pollutant and has been aligned to the forecasting day (a forecasting day runs from the issue time, generally 3 pm). This analysis of forecasting performance is mainly based on the provisional data available and used in the daily forecasting process. However, provisional data are only subject to initial screening checks and it is possible for erroneous results to be reported. To provide a fairer measure of true forecast accuracy any faulty data clearly identified during later stages of the ratification process have therefore been removed from the analysis presented here.

The analysis treats situations where the forecast index was within ±1 of the measured index as a successful prediction since this is the target accuracy we aim to obtain in the forecast. . Using this method it is possible to record rates in excess of 100% rather than 'true' percentages. Further details of the text descriptions and index code used for the forecasting are given in Appendix 1.

The forecasting success rates for each zone and agglomeration for January - December 2011 are presented in Tables 3.1 (forecasting performance in zones) and 3.2 (forecasting performance in agglomerations) for 'HIGH' days. Tables 3.3 and 3.4 show the same statistics for the MODERATE band. Table 3.5 provides a summary for each pollutant of the number of days on which 'HIGH and above' pollution was measured, the maximum exceedance concentration and the day and site at which it was recorded. The forecasting performance Tables 3.1 and 3.2 give:

- The number of 'HIGH' days measured in the PROVISIONAL data
- The number of 'HIGH' days forecast
- The number of days with a correct forecast of 'HIGH' air pollution, within an agreement of ±1 index value. A HIGH forecast is recorded as correct if air pollution is measured HIGH and the forecast is within ±1 index value, or it is forecast HIGH and the measurement is within ±1 index value. For example measured index 7 with forecast index 6 counts as correct, as does measured index 6 with forecast index 7.
- The number of days when 'HIGH' air pollution was forecast ('f' in the tables) but not measured ('m') on the following day to within an agreement of 1 index value.
- The number of days when 'HIGH' air pollution was measured ('m') but had not been forecast ('f') to within an agreement of 1 index value.

The two measures of forecasting performance used in this report are the 'success rate' and the 'forecasting accuracy'.

The forecast success rate (%) is calculated as:

- (Number of episodes successfully forecast/total number of episodes measured) x 100

The forecast accuracy (%) is calculated as:

- (Number of episodes successfully forecast/[Number of successful forecasts + number of wrong forecasts]) x 100

3.2 Forecast analysis for 2011

Table 3.1- Forecast Analysis for UK Zones 'HIGH' band and above *

Zone	Central Scotland	East Midlands	Eastern	Greater London	Highland	North East	North East Scotland	North Wales	North West & Merseyside	Northern Ireland	Scottish Borders	South East	South Wales	South West	West Midlands	Yorkshire & Humberside	Overall
Measured days	*4*	*0*	*2*	*6*	*0*	*0*	*0*	*0*	*2*	*2*	*0*	*2*	*0*	*1*	*2*	*2*	*23*
Forecasted days	*1*	*0*	*3*	*3*	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*2*	*0*	*0*	*1*	*1*	*12*
Ok (f and m)	*1*	*0*	*3*	*4*	*0*	*0*	*0*	*0*	*1*	*0*	*0*	*2*	*0*	*0*	*0*	*2*	*13*
Wrong (f not m)	*1*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*1*	*0*	*0*	*1*	*0*	*4*
Wrong (m not f)	*3*	*0*	*1*	*4*	*0*	*0*	*0*	*0*	*1*	*2*	*0*	*1*	*0*	*1*	*2*	*1*	*16*
Success %	*25*	*100*	*150*	*67*	*100*	*100*	*100*	*100*	*50*	*0*	*100*	*100*	*100*	*0*	*0*	*100*	*57*
Accuracy %	*20*	*0*	*75*	*50*	*0*	*0*	*0*	*0*	*50*	*0*	*0*	*50*	*0*	*0*	*0*	*67*	*39*

Table 3.2- Forecast Analysis for UK Agglomerations 'HIGH' band and above *

Agglomerations	Belfast Metropolitan Urban Area	Brighton/Worthing/ Littlehampton	Bristol Urban Area	Cardiff Urban Area	Edinburgh Urban Area	Glasgow Urban Area	Greater Manchester Urban Area	Leicester Urban Area	Liverpool Urban Area
Measured days	*0*	*0*	*0*	*0*	*0*	*2*	*3*	*0*	*2*
Forecasted days	*0*	*2*	*0*	*0*	*0*	*0*	*1*	*0*	*0*
Ok (f and m)	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Wrong (f not m)	*0*	*2*	*0*	*0*	*0*	*0*	*1*	*0*	*0*
Wrong (m not f)	*0*	*0*	*0*	*0*	*0*	*2*	*3*	*0*	*2*
Success %	*100*	*100*	*100*	*100*	*100*	*0*	*0*	*100*	*0*
Accuracy %	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*

*Table 3.2 (cont'd) - Forecast Analysis for UK Agglomerations 'HIGH' band and above **

Agglomerations	Nottingham Urban Area	Portsmouth Urban Area	Sheffield Urban Area	Swansea Urban Area	Tyneside	West Midlands Urban Area	West Yorkshire Urban Area	Overall
Measured days	*0*	*0*	*0*	*8*	*0*	*2*	*4*	*21*
Forecasted days	*0*	*2*	*0*	*1*	*0*	*1*	*0*	*7*
Ok (f and m)	*0*	*0*	*0*	*2*	*0*	*1*	*0*	*3*
Wrong (f not m)	*0*	*2*	*0*	*0*	*0*	*0*	*0*	*5*
Wrong (m not f)	*0*	*0*	*0*	*6*	*0*	*1*	*4*	*19*
Success %	*100*	*100*	*100*	*25*	*100*	*50*	*0*	*14*
Accuracy %	*0*	*0*	*0*	*25*	*0*	*50*	*0*	*11*

***Please refer to the start of section 3 for an explanation of the derivation of the various statistics, success >100 % may occur.**

Table 3.3- Forecast Analysis for UK Zones 'MODERATE' band and above *

Zone	Central Scotland	East Midlands	Eastern	Greater London	Highland	North East	North East Scotland	North Wales	North West & Merseyside	Northern Ireland	Scottish Borders	South East	South Wales	South West	West Midlands	Yorkshire & Humberside	Overall
Measured days	*40*	*61*	*99*	*100*	*51*	*54*	*11*	*28*	*61*	*35*	*34*	*78*	*45*	*70*	*58*	*52*	*877*
Forecasted days	*29*	*61*	*85*	*103*	*43*	*38*	*10*	*26*	*51*	*33*	*32*	*85*	*61*	*68*	*62*	*34*	*821*
Ok (f and m)	*47*	*75*	*106*	*113*	*65*	*60*	*16*	*31*	*71*	*39*	*49*	*95*	*71*	*84*	*75*	*49*	*1046*
Wrong (f not m)	*5*	*2*	*4*	*10*	*2*	*4*	*1*	*4*	*1*	*5*	*2*	*5*	*1*	*1*	*1*	*2*	*50*
Wrong (m not f)	*6*	*2*	*9*	*22*	*1*	*4*	*0*	*2*	*4*	*8*	*0*	*9*	*0*	*3*	*3*	*10*	*83*
Success %	*118*	*123*	*107*	*113*	*127*	*111*	*145*	*111*	*116*	*111*	*144*	*122*	*158*	*120*	*129*	*94*	*119*
Accuracy %	*81*	*95*	*89*	*78*	*96*	*88*	*94*	*84*	*93*	*75*	*96*	*87*	*99*	*95*	*95*	*80*	*89*

Table 3.4 - Forecast Analysis for UK Agglomerations 'MODERATE' band and above *

Agglomerations	Belfast Metropolitan Urban Area	Brighton/Worthing/ Littlehampton	Bristol Urban Area	Cardiff Urban Area	Edinburgh Urban Area	Glasgow Urban Area	Greater Manchester Urban Area	Leicester Urban Area	Liverpool Urban Area
Measured days	*16*	*47*	*34*	*23*	*4*	*4*	*35*	*10*	*35*
Forecasted days	*14*	*42*	*33*	*30*	*6*	*7*	*30*	*18*	*31*
Ok (f and m)	*19*	*55*	*43*	*35*	*5*	*3*	*31*	*17*	*39*
Wrong (f not m)	*1*	*5*	*0*	*1*	*4*	*5*	*6*	*5*	*1*
Wrong (m not f)	*2*	*2*	*4*	*2*	*0*	*2*	*12*	*2*	*3*
Success %	*119*	*117*	*126*	*152*	*125*	*75*	*89*	*170*	*111*
Accuracy %	*86*	*89*	*91*	*92*	*56*	*30*	*63*	*71*	*91*

Table 3.4 (cont'd) **- Forecast Analysis for UK Agglomerations 'MODERATE' band and above ***

Agglomerations	Nottingham Urban Area	Portsmouth Urban Area	Sheffield Urban Area	Swansea Urban Area	Tyneside	West Midlands Urban Area	West Yorkshire Urban Area	Overall
Measured days	*22*	*28*	*22*	*61*	*8*	*61*	*30*	*440*
Forecasted days	*24*	*35*	*20*	*46*	*10*	*49*	*16*	*411*
Ok (f and m)	*29*	*41*	*27*	*63*	*14*	*69*	*27*	*517*
Wrong (f not m)	*4*	*6*	*2*	*4*	*1*	*1*	*1*	*47*
Wrong (m not f)	*5*	*2*	*5*	*16*	*2*	*6*	*6*	*71*
Success %	*132*	*146*	*123*	*103*	*175*	*113*	*90*	*118*
Accuracy %	*76*	*84*	*79*	*76*	*82*	*91*	*79*	*81*

***Please refer to the start of section 3 for an explanation of the derivation of the various statistics, success >100 % may occur.**

Table 3.5 – Summary of HIGH pollution episodes in 2011

Pollutant	No. of HIGH days	Maximum concentration* (Index)	Site with max concentration	Zone or Agglomeration	Date of max conc.	Forecast success HIGH days (%)*** [no. incidents, zone or agglomeration days] **
Ozone	1	180 (Index 7)	Manchester South	Greater Manchester Urban Area	22/04	0% [1]
PM_{10}	39	203 (Index 10)	Port Talbot Margam	Swansea Urban Area	06/02	41% [39]
NO_2	0	342 (Index 4)	Camden Kerbside	Greater London Urban Area	06/05	100% [0]
SO_2	4	771 (Index 8)	Liverpool Speke	Liverpool Urban Area	07/02 & 02/07	0% [4]

* *Maximum concentrations relate to 8 hourly running mean or hourly mean for ozone, 24 hour running mean for PM_{10}, hourly mean for NO_2, 15 minute mean for SO_2 and 8 hour running mean for CO. Units ug/m3 throughout, except CO units mg/m3.*
*** The number of incidents is the total of the number of HIGH days in all zones and agglomerations (i.e. a HIGH day on the same day in many zones or agglomerations is counted as many incidents, not just one)*
**** The success rates for the number of HIGH days in table 3.5 have been calculated using calendar days (ie midnight to midnight) and therefore may not necessarily agree with the success rates calculated within the forecast analysis tables 3.1 and 3.2, which are calculated based on media forecast days starting generally at 3 pm each day.*
! The forecast success rate for PM_{10} has been calculated using both FDMS and BAM instruments.

3.2.1 General trends in monitoring site data

One HIGH day was recorded for ozone during 2011, occurring in April. There were many days throughout the year when MODERATE ozone air pollution was recorded, as shown in figure 3.3. The HIGH day was the result of an unusually elevated measurement made at the Manchester South monitoring site on April 22nd.

There were thirty nine HIGH band PM_{10} episodes experienced in 2011, 4 VERY HIGH and numerous MODERATE band PM_{10} episodes, as shown in figures 3.1, 3.2 and 3.4.

There were four HIGH days and eighteen MODERATE days for SO_2 measured during the 2011 calendar year. The highest measured 15-minute concentration of 771µg/m^3 was recorded twice at the Liverpool monitoring station. The remaining two HIGH days were recorded at Grangemouth which is identified as an industrial targeted air quality monitoring site. Figure 3.5 shows the frequency of the SO_2 exceedances for 2011.

Three MODERATE NO_2 days were measured throughout the year, as shown in figure 3.7. The MODERATE days were measured at two roadside air quality sites, namely Camden Kerbside and Marylebone Road. There were no HIGH NO_2 days measured during 2011.

Possible causes of the 2011 air pollution episodes are detailed in the sections which follow the charts.

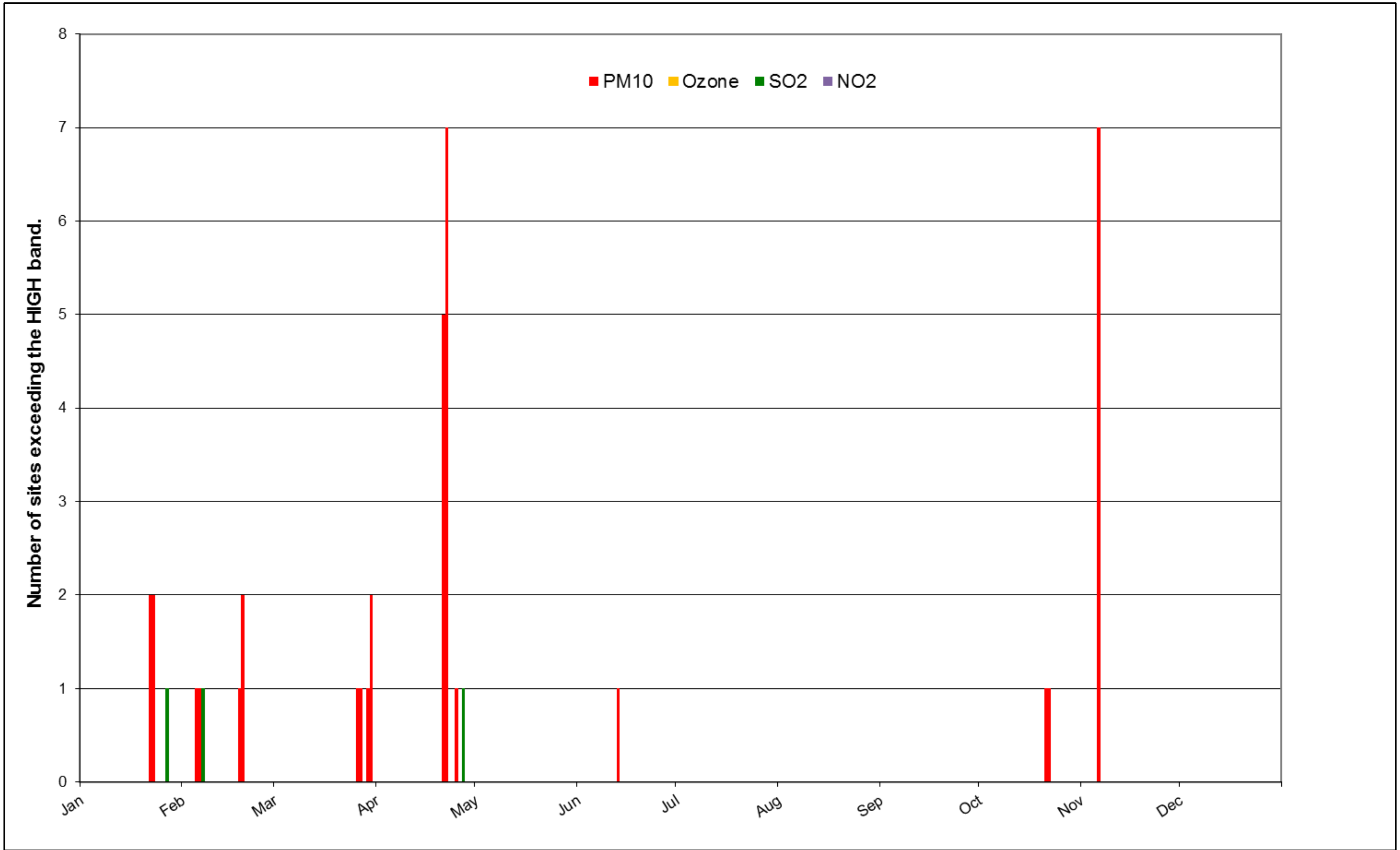


***Figure 3.1** Number of stations with air pollution levels of HIGH and above for days throughout 2011.*

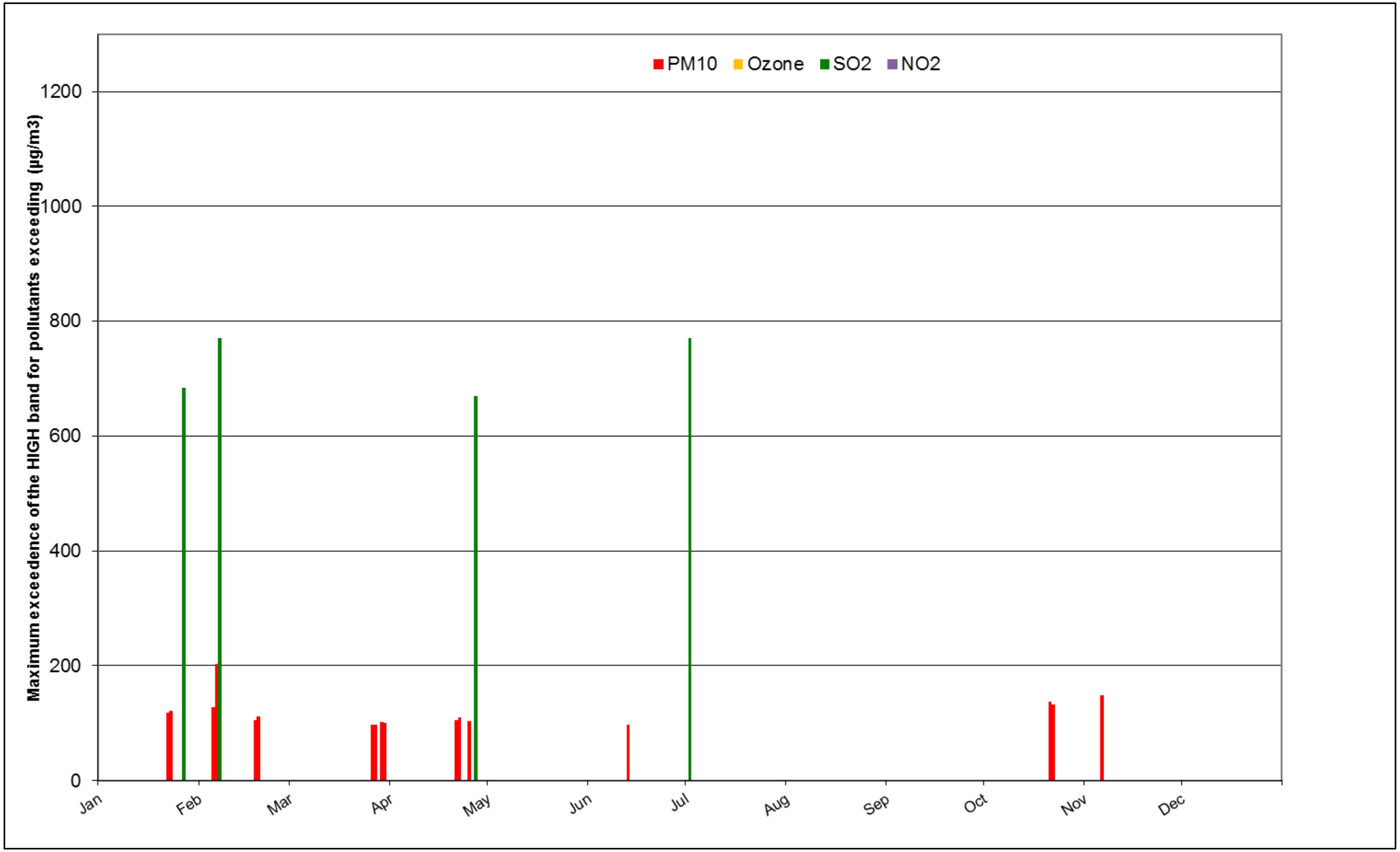


Figure 3.2 Maximum exceedance when air pollution levels were HIGH and above for days throughout 2011.

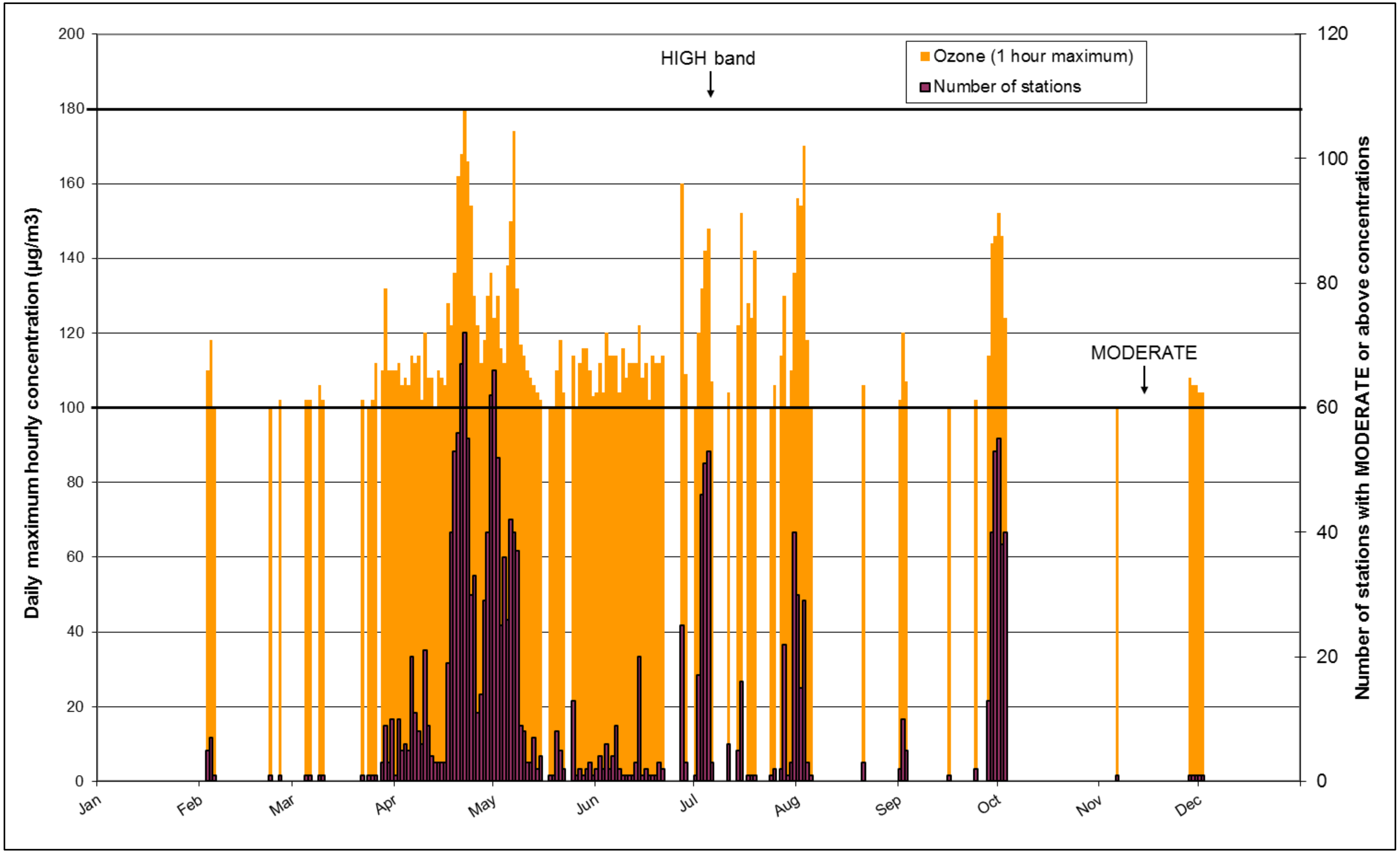


Figure 3.3 Daily maximum hourly ozone concentration across AURN Network with total number of stations measuring moderate or above levels of ozone during 2011.

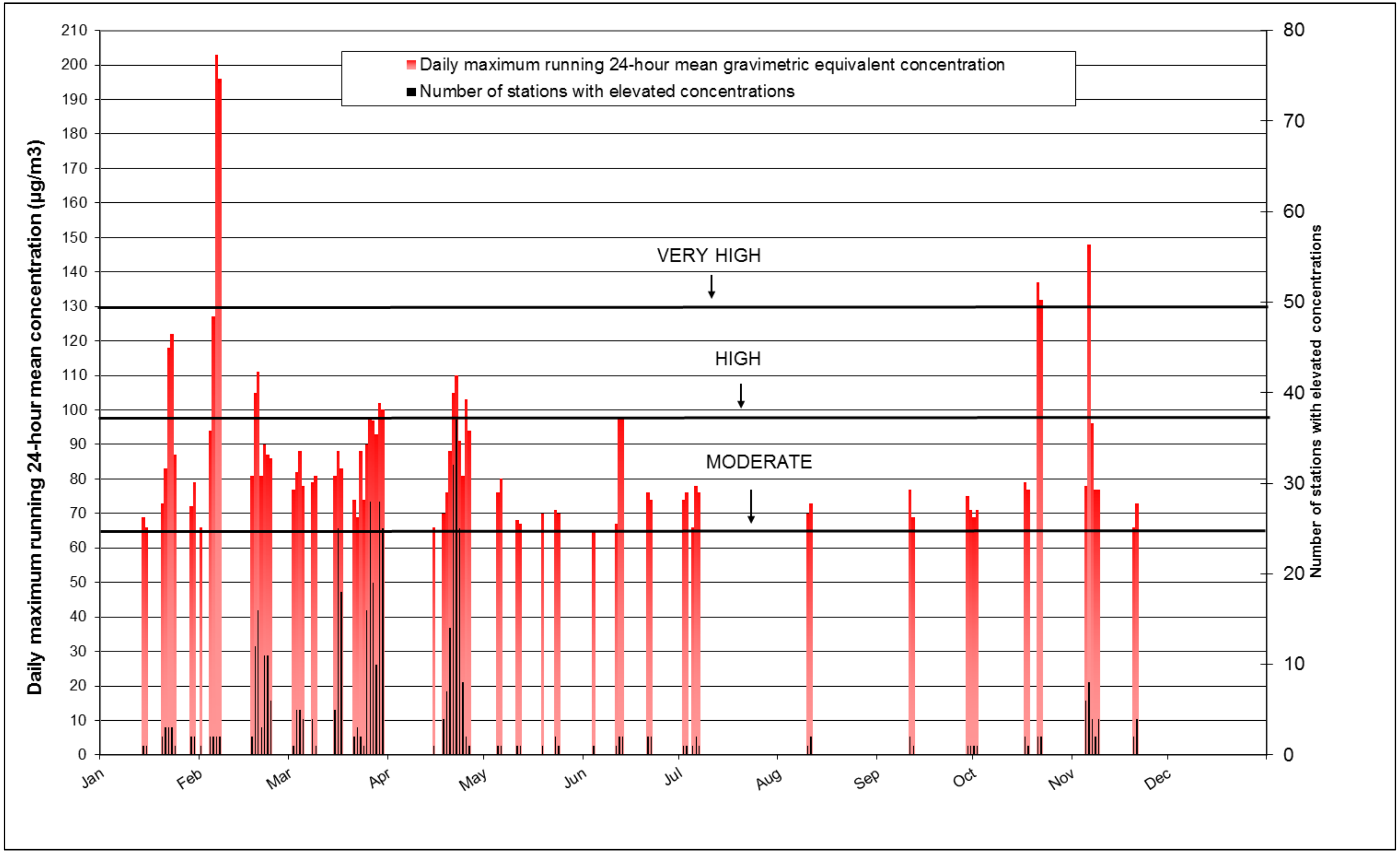


Figure 3.4 Daily maximum running 24-hour mean PM_{10} concentration across AURN Network with total number of stations measuring moderate or above levels during 2011.

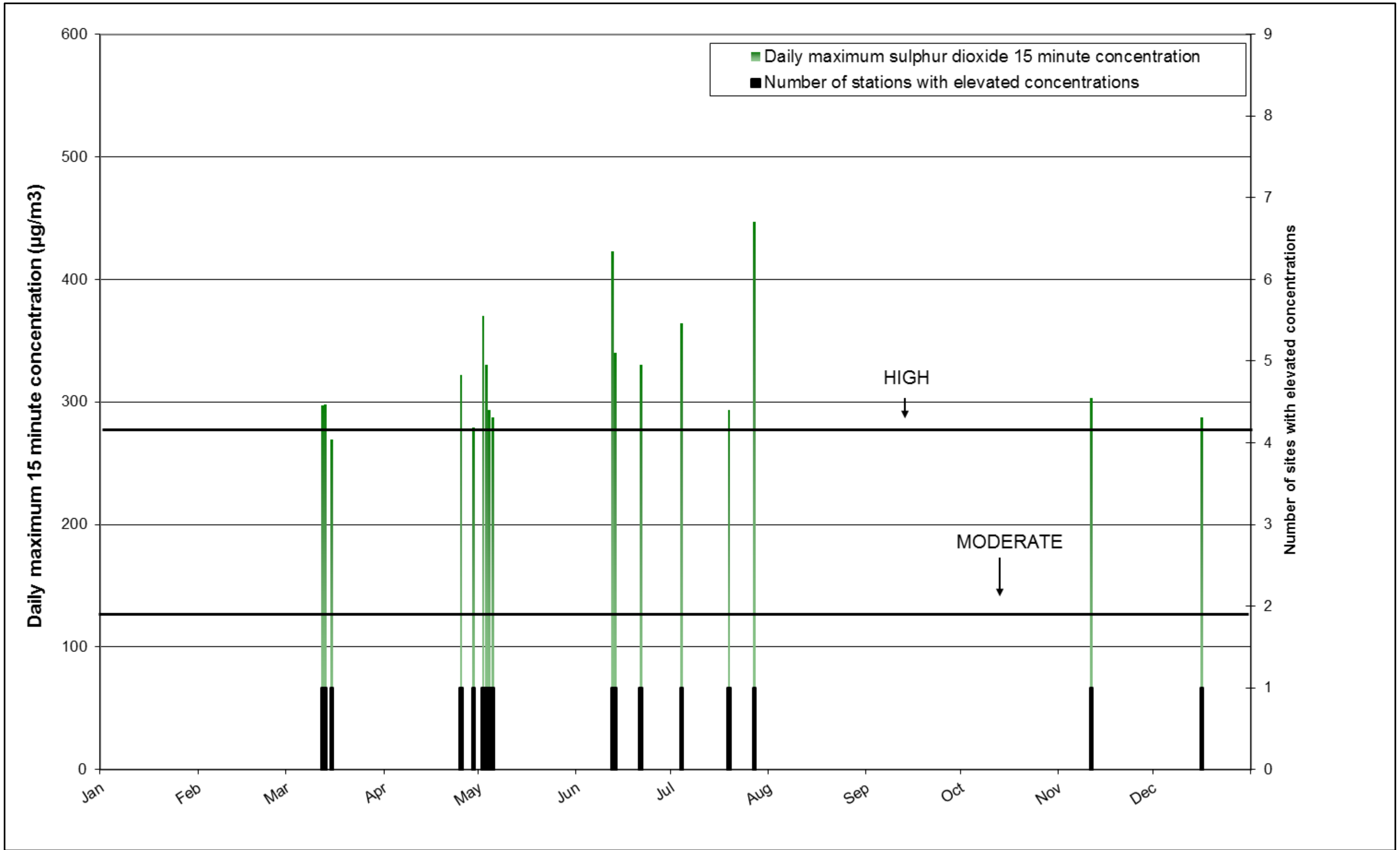


Figure 3.5 Maximum 15 minute average concentrations of SO_2 across AURN Network with total number of stations measuring moderate or above levels during 2011.

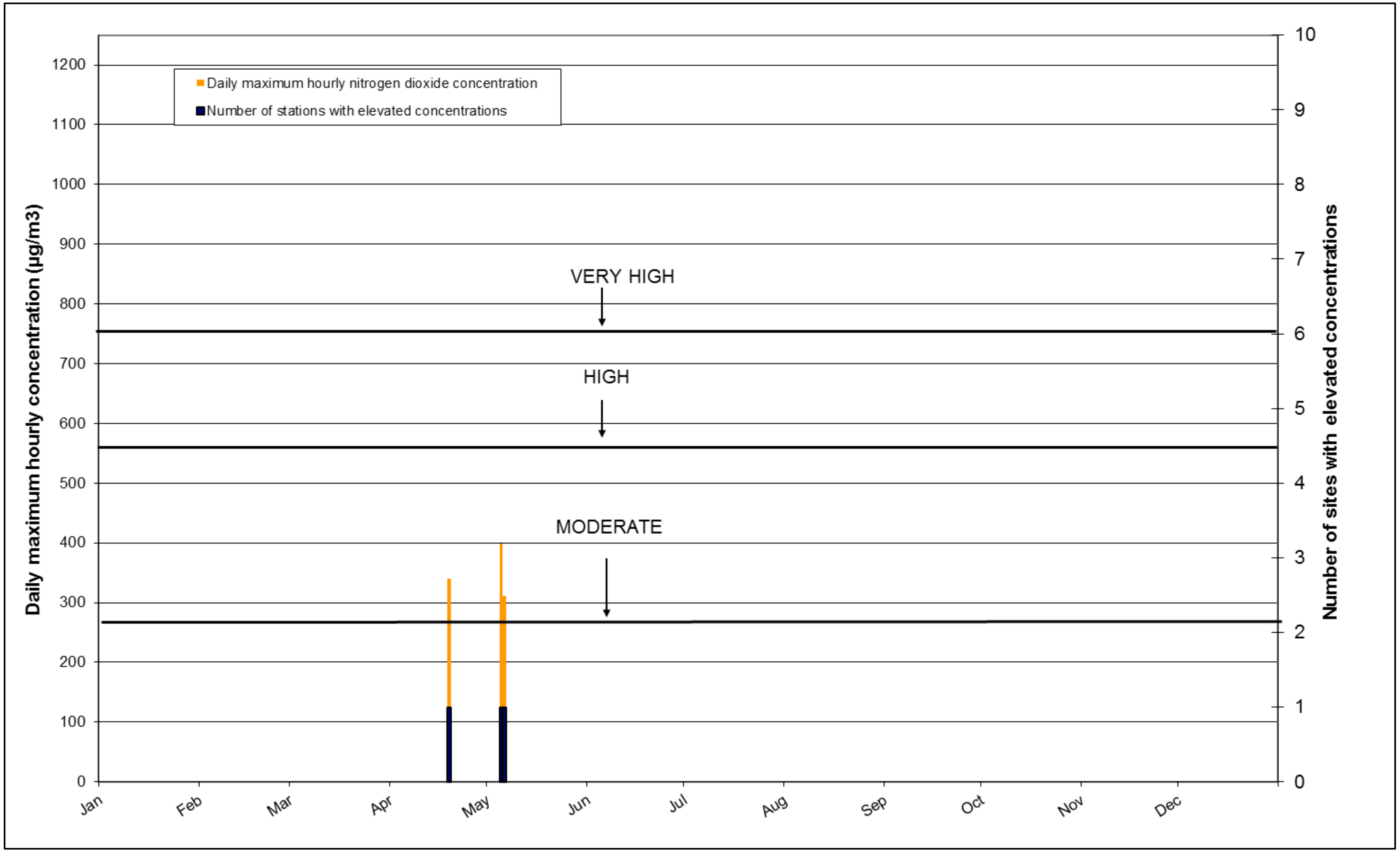


Figure 3.6 Daily Maximum hourly average of NO_2 across AURN Network with total number of stations measuring moderate or above levels during 2011.

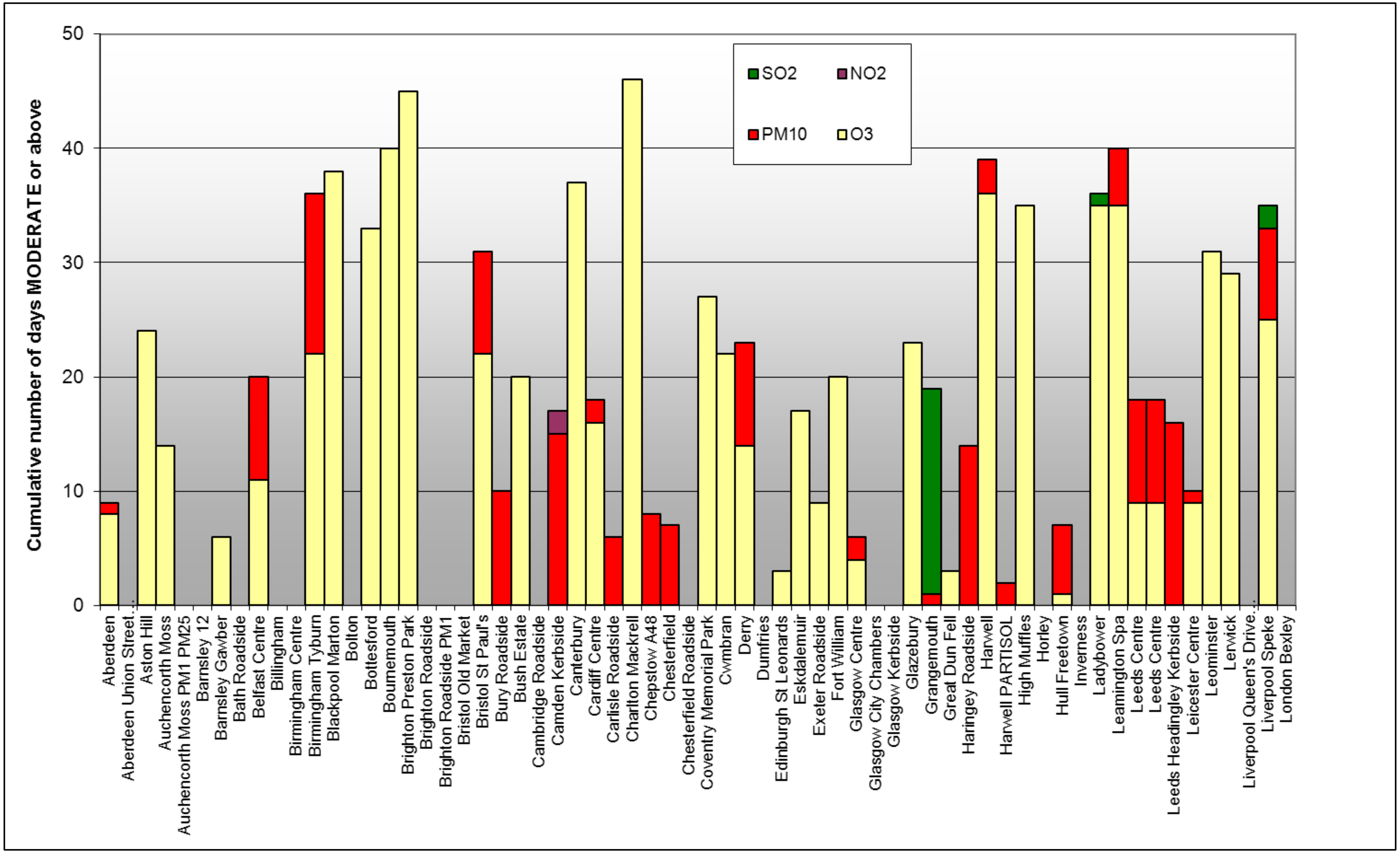


Figure 3.7a Number of pollutant days moderate and above for each AURN Network station during 2011 (site names A-L)

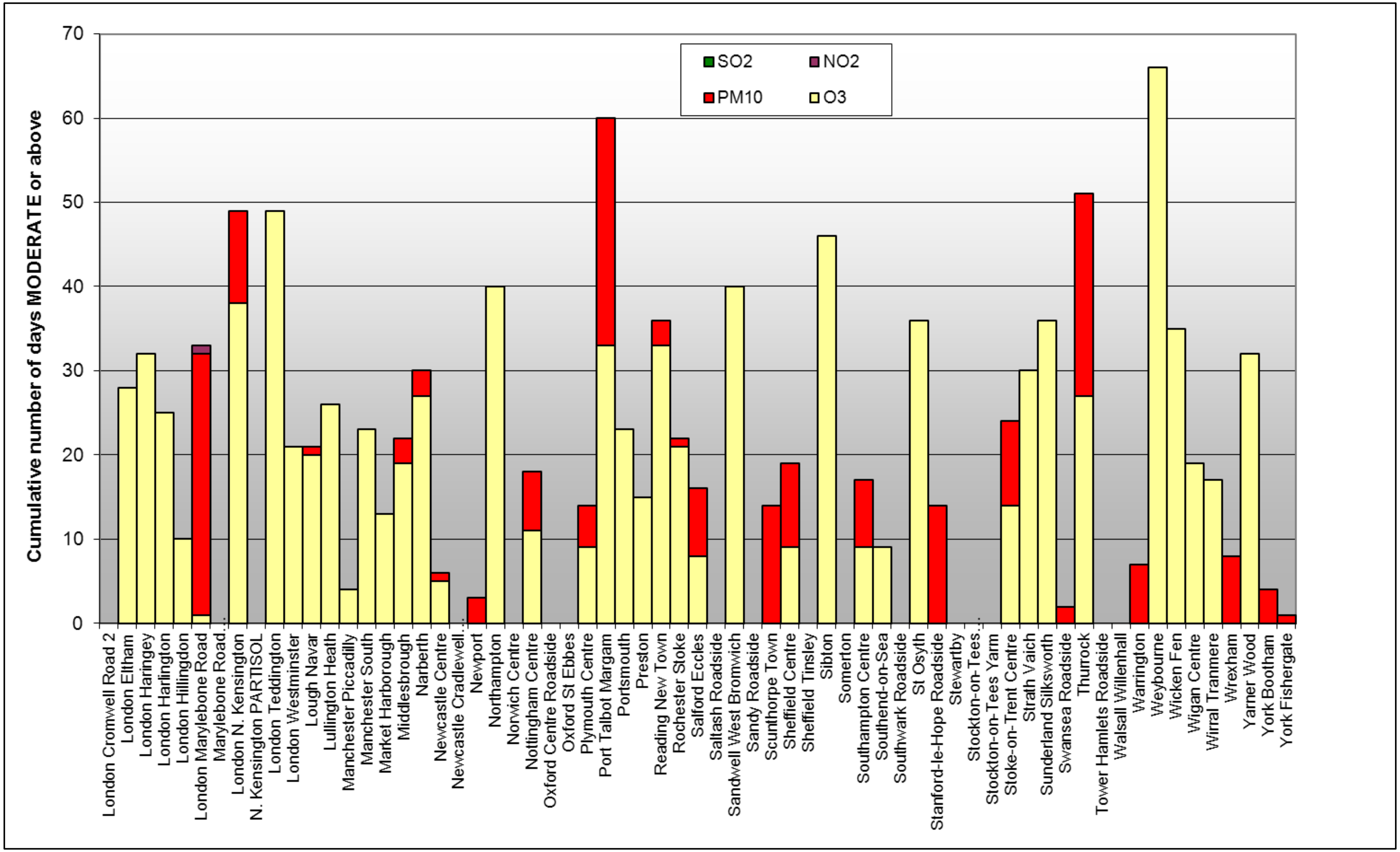


Figure 3.7b ***Number of pollutant days moderate and above for each AURN Network station during 2011 (site names L-Y)***

3.2.2 Ozone pollution episode summary

There was a period of Moderate ozone across Scotland and Northern Ireland late on Thursday 3rd February – probably due to the turbulent weather conditions mixing down stratospheric ozone as weather fronts passed across the regions.

MODERATE days were measured at many of the AURN network sites between the end of March and August. In 2011 only one monitoring site, namely Manchester South reached the HIGH band on April 22nd. Moderate ozone up to air pollution index 5 was recorded widely across the UK from Wednesday September 28th up to the end of the month. This was an unusually late summer pollution episode caused by a period of stable high pressure and exceptionally high temperatures for the time of the year.

Further shorter periods with MODERATE ozone were seen at the beginning of October and also at the beginning of December, as shown in figure 3.3.

Figure 3.8 shows that 2011 was another low year for the number of ozone episodes. The maximum recorded concentration was much lower than 2010, and this was due to an isolated incident on one day at the Manchester South monitoring site in April 2011.

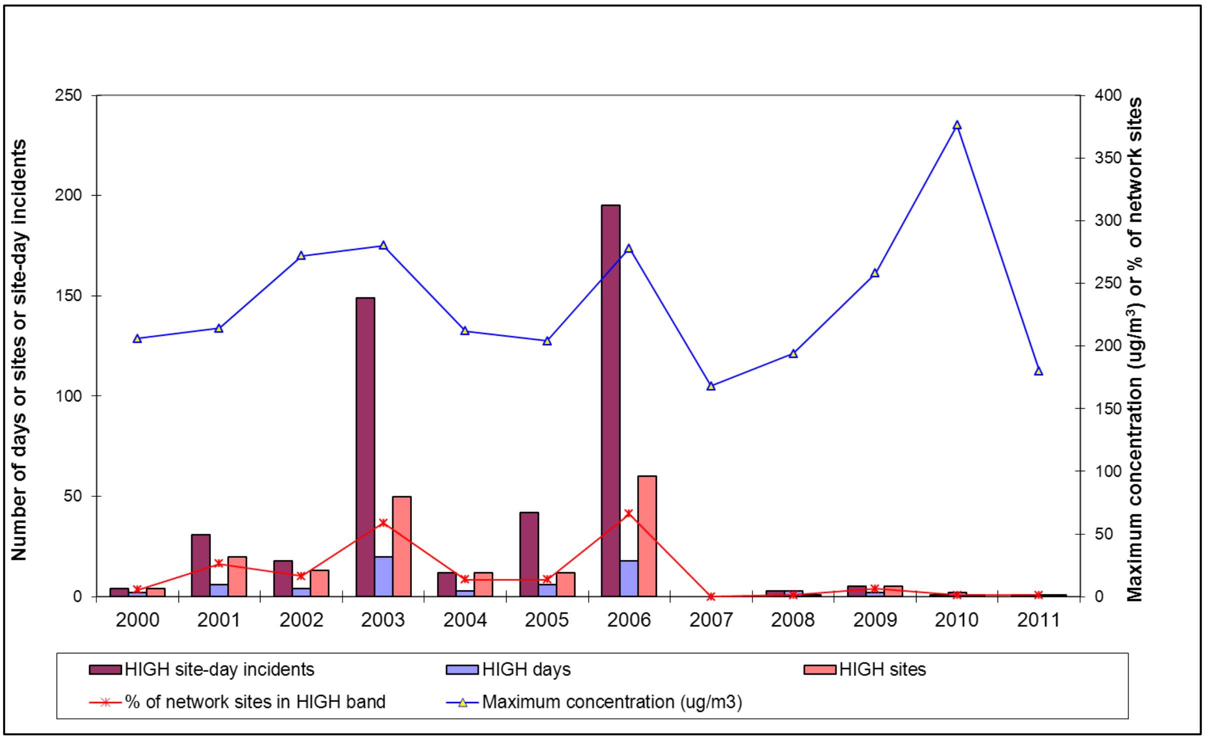


***Figure 3.8** UK ozone episodes summarized for years 2000 onwards.*

3.2.3 Particulate matter pollution episode summary

There was a period of Moderate and High PM_{10} concentrations across Northern Ireland over the weekend from Friday January 21st to Monday January 24th, most likely due to increased burning of solid fuel or fuel oil for domestic heating during cold, calm weather. Overnight frost together with persistent, sometimes freezing fog was reported. A similar episode of Moderate concentrations was recorded from January 29th to 30th.

There was a period of widespread Moderate PM_{10} concentrations across England from Saturday February 19th to Tuesday February 22nd reaching High at Scunthorpe Town. This was modelled closely by the CMAQ forecast which showed a plume of easterly continental air bringing particulates across to England.

Moderate PM_{10} particulate matter was recorded at a number of Roadside and Kerbside sites between March 3rd and March 8th 2011. This was probably due to local emissions on top of a high background caused by long-range transport of secondary particulates from Europe.

On Wednesday March 16th to Thursday March 17th a fairly widespread UK event of Moderate PM_{10} occurred associated with warm temperatures and easterly air masses from continental Europe.

From Friday March 25th to Thursday March 31st another widespread UK (except Scotland) event of Moderate PM_{10} occurred associated with easterly air masses from continental Europe. The event also included High PM_{10} at Plymouth Centre, Leeds Headingly Kerbside, Sheffield Centre and Port Talbot Margam. High secondary particulates across the UK are common at this time of the year, probably due to formation of nitrates from agricultural fertiliser spreading in the nearby European Low Countries – Denmark and The Netherlands especially.

During the period between April 21st and 26th a High and Moderate PM_{10} was subsequently reported at many sites down the eastern side of England, mainly due to easterly continental airflows.

Between May and October there were a localised increase in PM_{10} concentrations reaching Moderate band.

Over the Bonfire Night weekend the weather situation was complex with low pressure to the north and south of the UK, but with a tongue of high pressure through the Midlands and stretching north-east across the UK allowed particulate pollution to build up locally to high and very high levels.

There was a short period of Moderate PM_{10} pollution across London from November 21st to 23rd mainly due to easterly continental air arriving over the British Isles.

During December there were no elevated levels of PM_{10} recorded at any AURN site.

Figure 3.9 shows a comparison of the number of MODERATE or worse exceedances with earlier years. Additionally figure 3.10 shows the overall number of MODERATE or WORSE PM_{10} exceedances annually from all pollution sources from the year 2000 onwards.

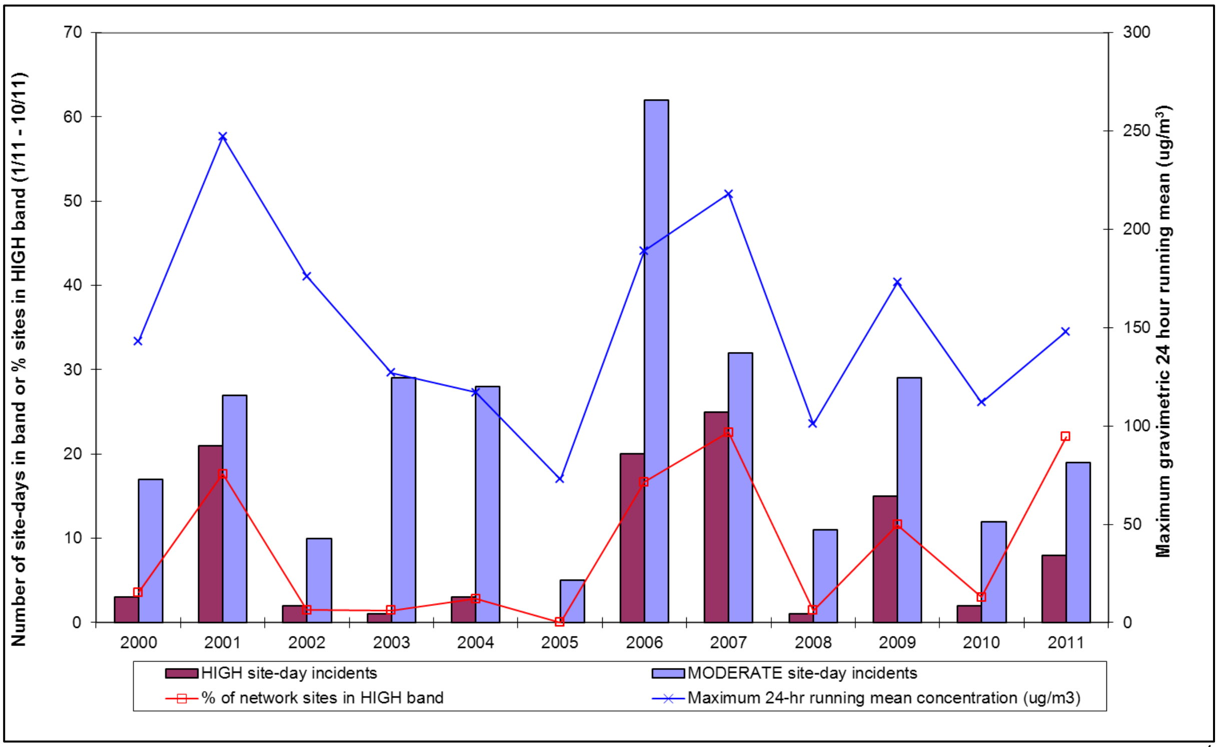


Figure 3.9 Number of sites exceeding the MODERATE and HIGH PM_{10} bands over 1st November to 10th November annually from the year 2000 onwards with additional descriptive statistics.

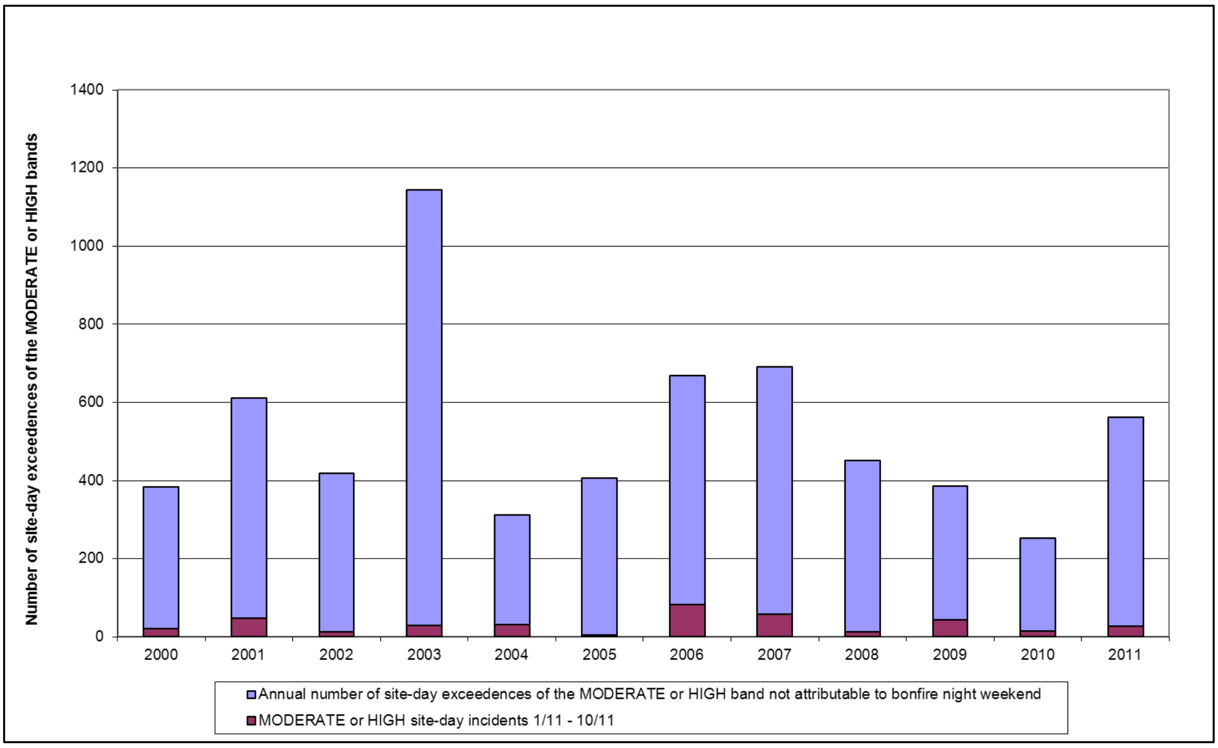


Figure 3.10 Annual number of site-day exceedances of the MODERATE or HIGH PM_{10} band for 2000 – 2011.

3.2.4 Sulphur Dioxide pollution episode summary

There were 46 sites in the AURN air quality monitoring network measuring SO_2 concentrations in 2011. The number of MODERATE or above days per annum measured in the network is shown in Figure 3.11 from the year 2000 onwards. The number of days of MODERATE exceedances per year is low but has been rising since 2007. The exceedances continue to be at monitoring sites in mainly industrial locations; however in 2011 the highest concentration was recorded at Liverpool Speke monitoring site.

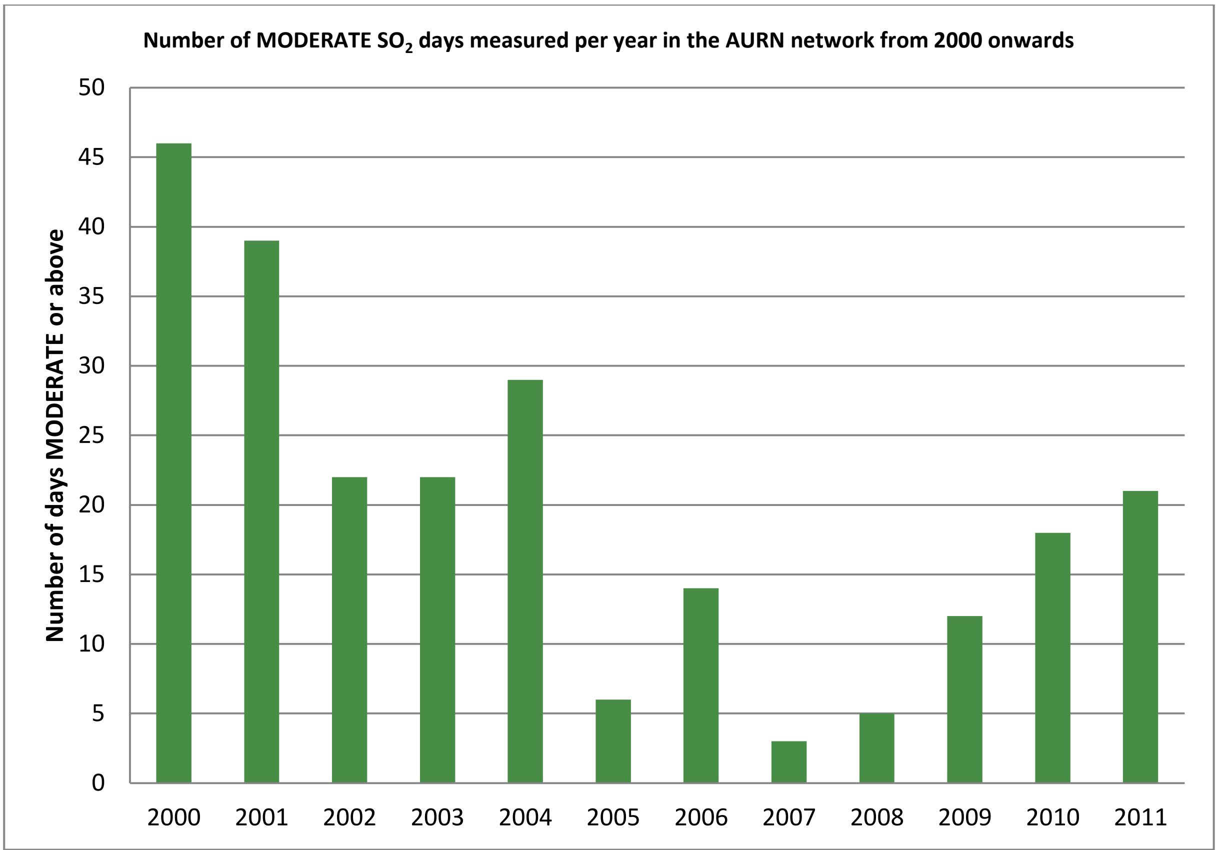


Figure 3.11 ***Number of MODERATE or worse SO_2 network days measured per annum***

A significant reduction in the number of exceedances over years is likely to be the result of an improvement in and proliferation of abatement technologies to control the release of sulphur dioxide and other pollutant species coupled with a downturn in the use of coal for domestic heating.

3.2.5 Nitrogen Dioxide pollution episode summary

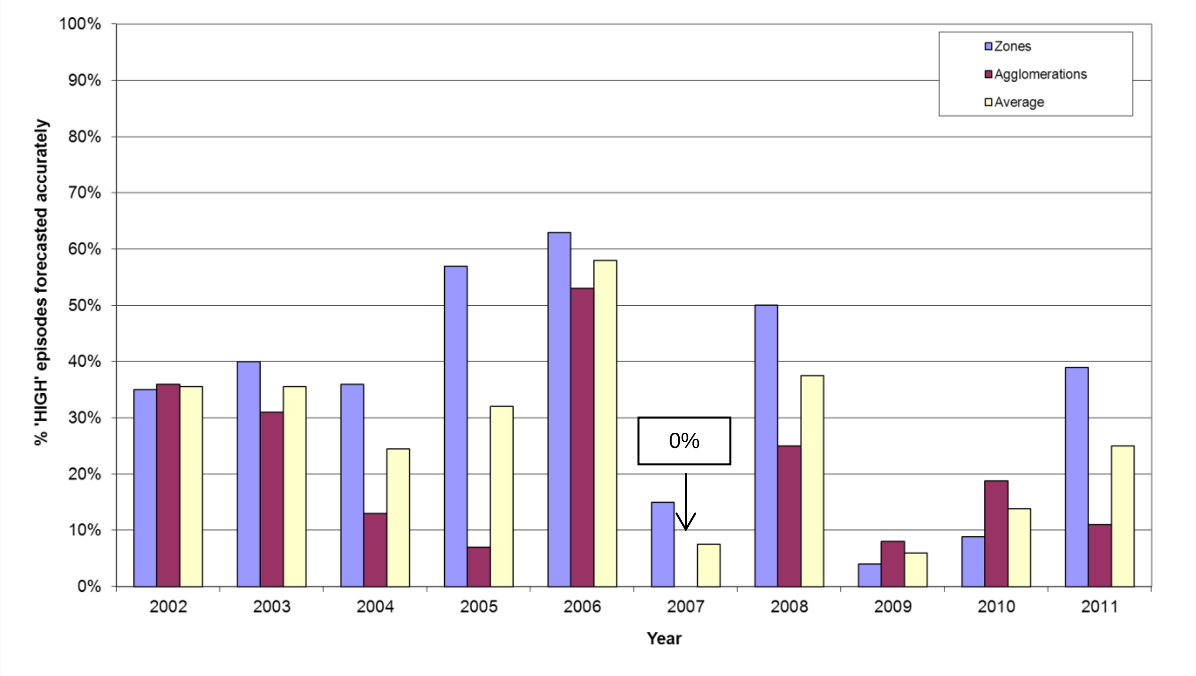
Three MODERATE days for nitrogen dioxide were measured during the year. All of these were experienced at kerbside and roadside sites due to their proximity to road traffic. Two days with exceedances occurred at Camden Kerbside and one day at London Marylebone Road site. There was no HIGH day measured at any AURN site throughout the year 2011.

3.3 Comparison with years 2002 onwards

3.3.1 Overall Forecasting Accuracy Rate

Figure 3.12 shows the forecasting accuracy rates for HIGH pollution episodes for the whole of the UK for years 2002 to 2011. This is the percentage of HIGH days that were accurately forecast according to the criteria agreed with Defra and specified at the beginning of section 3 of this report.

***Figure 3.12** Forecasting Accuracy rate for HIGH pollution episodes for the UK, 2002-2011*



* 2002 was a partial year for forecasting analysis calculations.

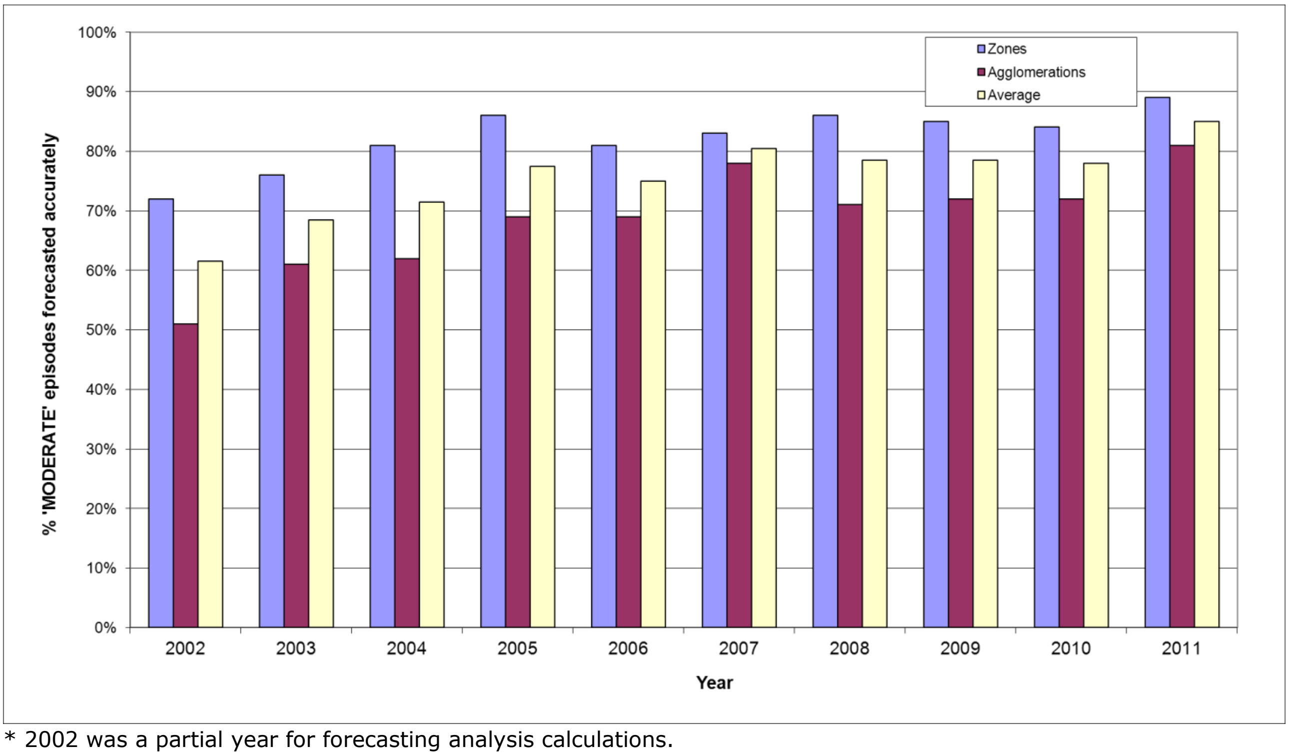
The overall forecasting success rate for the HIGH band in 2011 was better than in 2010, increasing by 30% in zones compared to last year.

This improvement can be linked to extended periods of stable winter and spring weather conditions in 2011 which resulted in incidents of HIGH PM_{10} particulate pollution. These pollution episodes can be tracked and forecast accurately by the forecasting models and the forecasting team. In years where pollution episodes are sporadic, shorter or more localised then the forecast success rates tend to be lower.

In general due to the complex origins of PM_{10} pollution our capacity to successfully predict elevated PM_{10} levels remains less than that for ozone using the forecast models available.

Because of the infrequent nature of HIGH UK pollution episodes in recent years the percentage of MODERATE days that were accurately forecast is perhaps a better measure of forecast performance. Figure 3.13 shows that this has remained stable or increased slightly over the period illustrated.

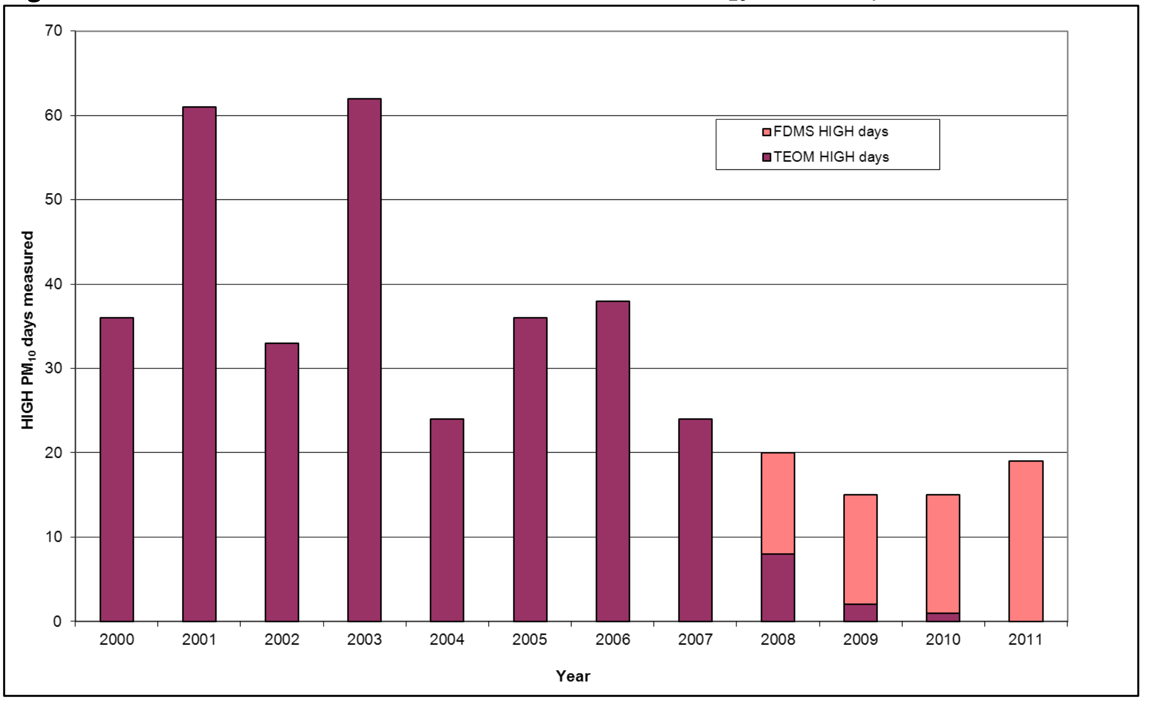
***Figure 3.13** Forecasting Accuracy rate for MODERATE pollution episodes for the UK, 2002-2011*



* 2002 was a partial year for forecasting analysis calculations.

Figure 3.14 below confirms that 2011 was typical of recent years in terms of the overall low number of HIGH band PM_{10} measurements recorded.

***Figure 3.14** Number of HIGH band measurements for PM_{10} in the UK, 2000-2011.*



3.3.2 LOCALISED INFLUENCES

In addition to the difficulties of forecasting long range transport of particulates, there are also problems in forecasting accurately in areas where local effects on pollution are significant and unpredictable. The following are examples of such sites that reported HIGH concentrations during 2011:

- Grangemouth is an industrial site, which often results in unpredictable elevated concentrations of SO_2.
- Port Talbot is close to a steel works with multiple possible sources of particulate matter.

4 Breakdowns in the service

All bulletins were successfully delivered to the Air Quality Communications contractor on time and there were no reported breakdowns in the service over the year.

5 Additional or enhanced forecasts

No formal enhanced forecasts were issued this year as the format of any such additional information is still under consideration. Nevertheless, there have been numerous informal discussions by email and telephone between the Ricardo-AEA forecasters and Defra during this period.

The air pollution forecast is always re-issued to Web and Freephone services at 10.00 a.m. local time each day, but this is only updated when the pollution situation is changing.

The bi-weekly air pollution outlooks have continued to be delivered successfully to Defra and other government departments by email on Tuesdays and Fridays.

6 Ad-hoc Services

Ricardo-AEA provided numerous ad-hoc updates to Defra and the Devolved Administrations during the Icelandic volcanic eruption in May 2011. A brief summary of our findings is presented here.

The Grimsvotn volcano in Iceland erupted on May 22nd sending a plume of volcanic ash towards the UK. The ash particles were large and were observed to be settling out of the atmosphere very quickly. The Ricardo-AEA forecasting team monitored the situation closely using the Met Office Advisory notes and satellite imagery, and also carried out our own additional daily model runs using Hysplit to track the likely path and elevation of the plume.

Figure 6.1 Satellite image of the eruption from Grimsvotn volcano

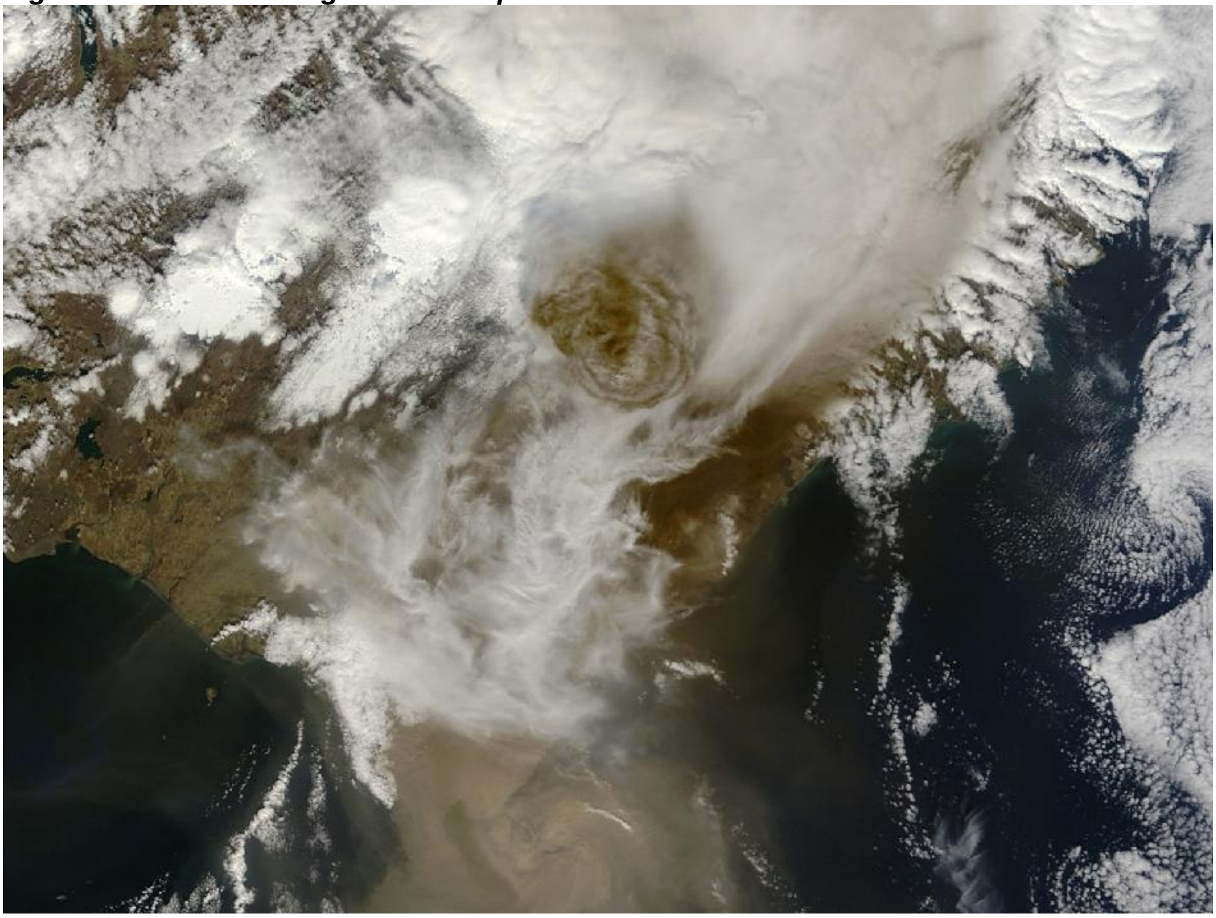


Image Credit: NASA, GSFC, MODIS Rapid Response Team

Daily updates were provided by the forecasting team during the week of the eruption and examples of such analyses are given below.

Figure 6.2 NOAA Hysplit Model Results for 22nd and 24th May 2011.

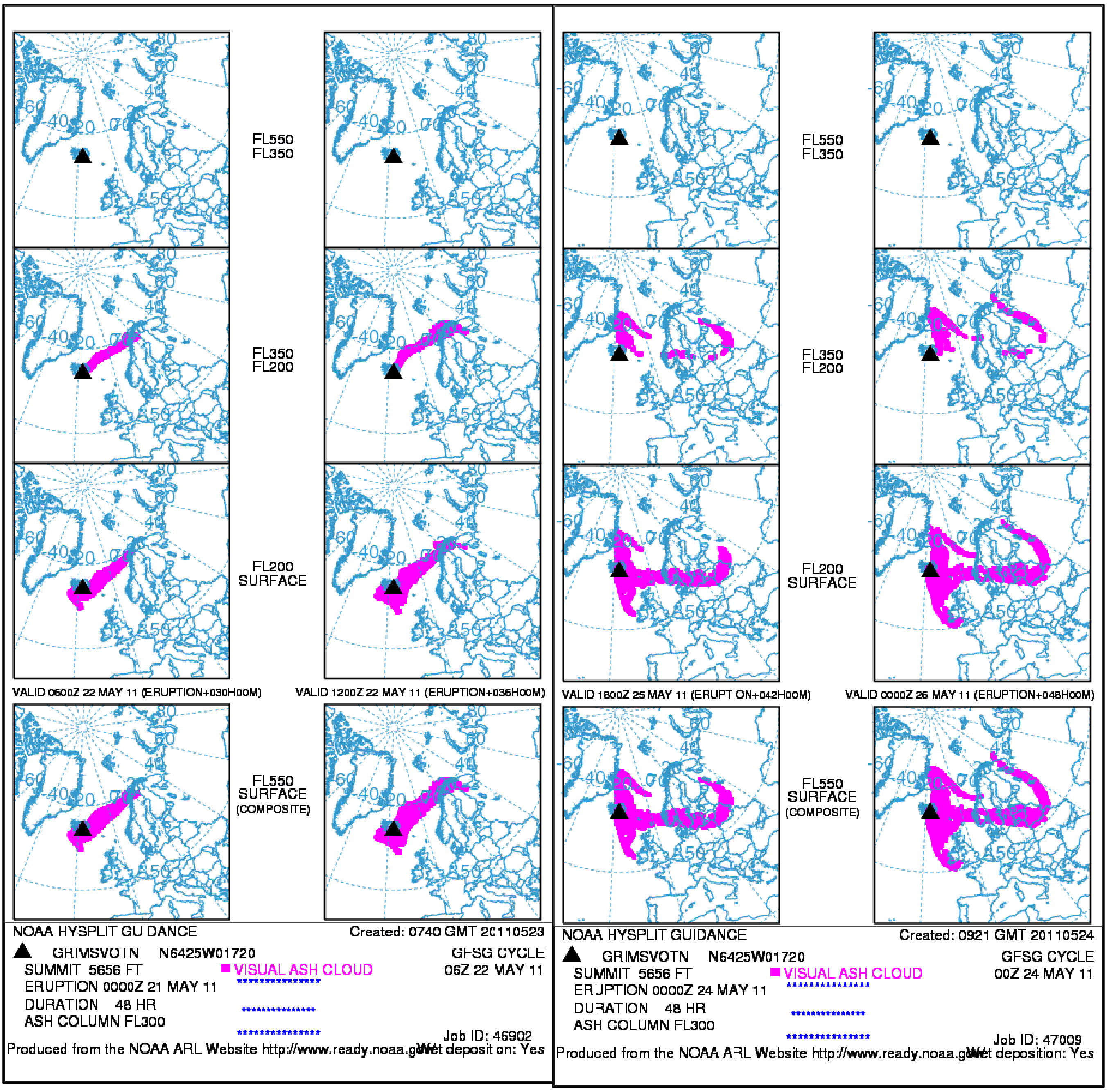
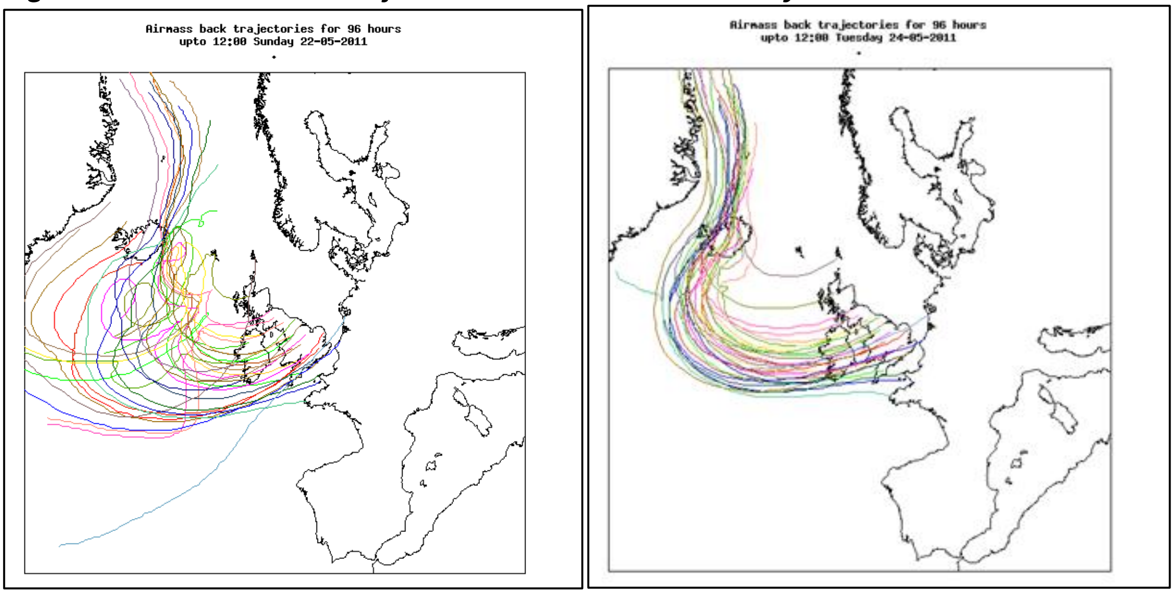
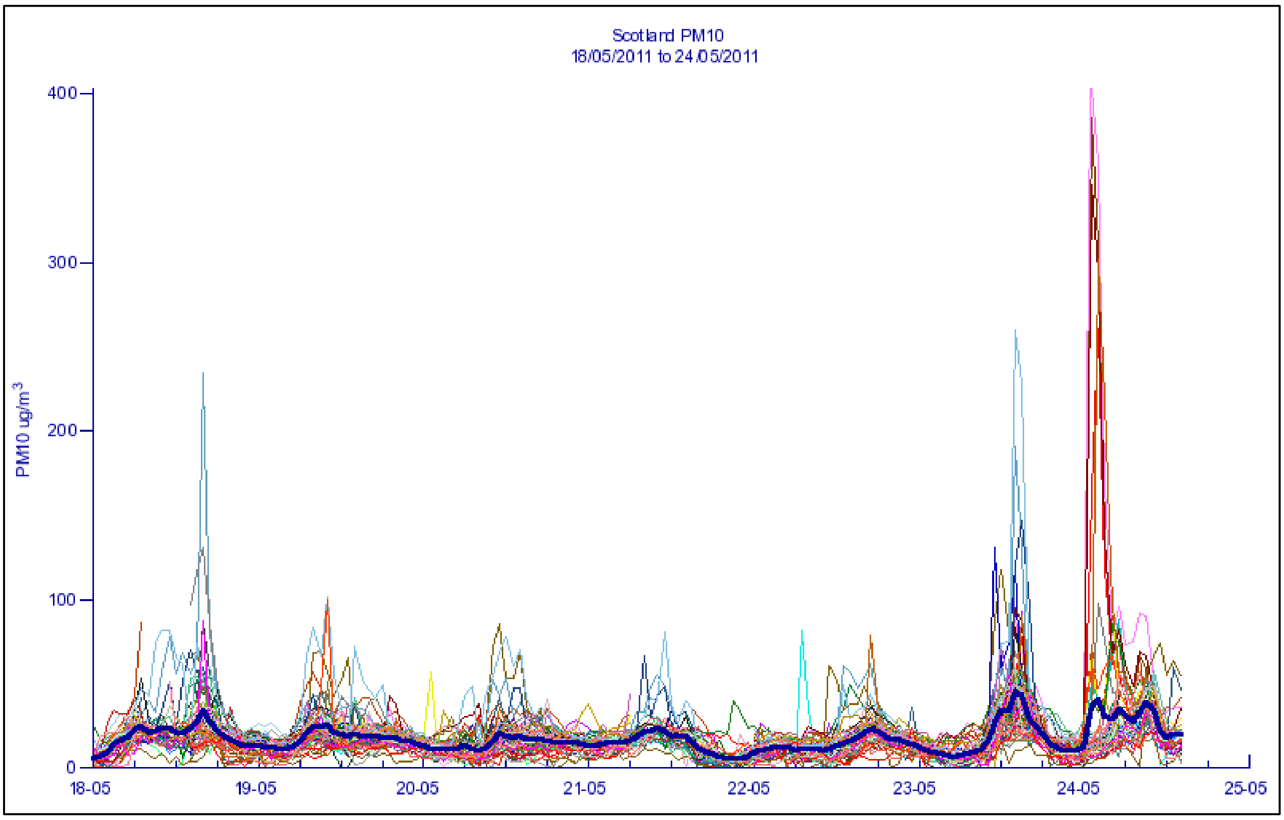


Figure 6.3 Airmass back trajectories for 22nd and 24th May 2011.



The plume was tracked across Scotland and Northern Ireland with some evidence of increased ground-level concentrations of PM_{10} for a few hours at Aberdeen sites in particular, although the peaks were not dramatic in size compared to normal daily variations in concentrations at these locations.

Figure 6.4 PM_{10} concentrations as measured by the AURN sites in Scotland 18th -25th May 2011.



7 Ongoing Research

Ricardo-AEA continues to develop the air quality forecasting systems by:

1. Investigate ways of using automatic software systems to streamline the activities within the forecasting process, thus allowing forecasters to spend their time more efficiently considering the most accurate forecasts.

2. Research the chemistry used in our models, in particular the CMAQ chemical schemes for secondary PM_{10} and ozone.

3. Improve the automated validation analysis and plots.

4. Improve and update the emissions inventories used in our models.

The UK Air Quality Forecasting project maintains close links with the Defra CMAQ model development project in order that real-time operational and off-line developments are closely aligned and optimised wherever possible.

8 Project and other related meetings

8.1 Project meetings

Regular six-monthly project meetings continued to be held at Harwell and London over the course of the year.

8.2 COST ES0602

COST ES0602 – "Towards a European Network on Chemical Weather Forecasting and Information Systems".

<u>COST ES0602 Meeting in Geneva, April 12th -14th 2011</u>

Paul Willis attended the final meeting of the COST ES0602 action at the WMO in Geneva on April 12th – 14th. Paul is one the two nominated UK representatives along with Paul Agnew of the Met Office. The agenda for the meeting was mainly a review of the action achievements and a workshop of current chemical forecasting and related projects.

<u>CMAS (Community Modelling and Analysis) meeting in the USA</u>

In October 2011 Andrea Fraser attended the CMAS (Community Modelling and Analysis) meeting in the USA – sponsored by the US EPA. The Air Quality Forecasting session included presentations given on the, Canadian, Japanese, United Kingdom and United States air quality forecasting systems. Presentations were also given on the New York, Georgia and Texas state air quality forecasting. Andrea Fraser gave a presentation on the UK air quality forecasting of PM in Spring 2011.
The most interesting features for the UK air quality forecast were:

- Canada – where the heath index is an additive health index taking into account all pollutants and two separate messages are produced one for the general public and a second aimed at people who are 'at risk'. This Canadian system incorporated data assimilation to improve predictions.
- In New York the air quality forecast is produced using an ensemble of meteorology and air quality models, one forecast includes sensitivity study of 100 model perturbations (using DDM). These allow a probabilistic evaluation of the forecast. Similar methods were used in Georgia.
- New York and Georgia used the DDM for forecast based on forecasts including model sensitivity.

In discussions following the presentation incorporation of observational data and improvements to the representation of biogenic emissions were identified as areas to investigate for forecast improvements.

9 Related projects

Ricardo-AEA ensures that any forecasts, issued under separate contracts, are consistent with the national forecasts issued for Defra, the DAs and the BBC.

The KentAir forecast has continued to be issued as a short piece of descriptive text detailing the pollution levels expected in the Kent area for the current and following day. In addition to the AURN network sites, air quality levels measured at sites in the Kent AQ network are also taken into account when making an assessment of the forecast for the region. The forecast issued is also sent to the KentAir website at http://www.kentair.org.uk.

10 Scientific Literature Review

This section reviews a selection of the scientific literature available in the public domain that is relevant to air quality forecasting in 2011.

Recent developments concerned with air quality forecasting are summarised below, with relevant internet links provided at the end of each section.

10.1 MACC-II - Monitoring Atmospheric Composition and Climate - Interim Implementation

MACC-II - Monitoring Atmospheric Composition and Climate - Interim Implementation - is the project that is establishing the core global and regional atmospheric environmental services delivered as a component of Europe's GMES initiative. It is funded under the Seventh Framework Programme of the European Union and began on 1 November 2011. MACC is undertaken by a consortium drawn largely from the partners in the earlier MACC project, whose core systems and service lines provided the starting point for MACC-II.

MACC-II takes as its input comprehensive sets of satellite data from many tens of instruments supplying information on atmospheric dynamics, thermodynamics and composition, made available by space agencies and institutions with which the agencies collaborate to produce retrieved data products. The satellite data are supplemented by in-situ data from meteorological networks and a limited amount of data from networks providing in-situ measurements of atmospheric composition. Data are processed to provide a range of products related to climate forcing, air quality, stratospheric ozone, UV radiation at the earth's surface and resources for solar power generation. Additional in-situ data are used for validating the processing systems and the products they supply. MACC operates a value-adding chain which extracts information from as wide a range of observing systems as possible and combines the information in a set of data and graphical products that have more complete spatial and temporal coverage and are more readily applicable than the data provided directly by the observing systems.

http://www.gmes-atmosphere.eu/about/

10.2 Comprehensive Modelling of the Earth System for Better Climate Prediction and Projection (COMBINE)

The European integrating project COMBINE brings together research groups to advance Earth system models (ESMs) for more accurate climate projections and for reduced uncertainty in the prediction of climate and climate change in the next decades. COMBINE will contribute to better assessments of changes in the physical climate system and of their impacts in the societal and economic system. The proposed work will strengthen the scientific base for environmental policies of the EU for the climate negotiations, and will provide input to the IPCC/AR5 process.

http://www.combine-project.eu/

10.3 Modelling anthropogenically controlled secondary organic aerosols in a megacity: a simplified framework for global and climate models

A simplified parameterization for secondary organic aerosol (SOA) formation in polluted air and biomass burning smoke is tested and optimized in this work, towards the goal of a computationally inexpensive method to calculate pollution and biomass burning SOA mass and hygroscopicity in global and climate models. A regional chemistry-transport model is used as the testbed for the parameterization, which is compared against observations from the Mexico City metropolitan area during the MILAGRO 2006 field experiment. The empirical parameterization is based on the observed proportionality of SOA concentrations to excess CO and photochemical age of the airmass. The approach consists in emitting an organic gas as lumped SOA precursor surrogate proportional to anthropogenic or biomass burning CO emissions according to the observed ratio between SOA and CO in aged air, and reacting this surrogate with OH into a single non-volatile species that condenses to form SOA.
http://www.geosci-model-dev.net/4/901/2011/gmd-4-901-2011.html

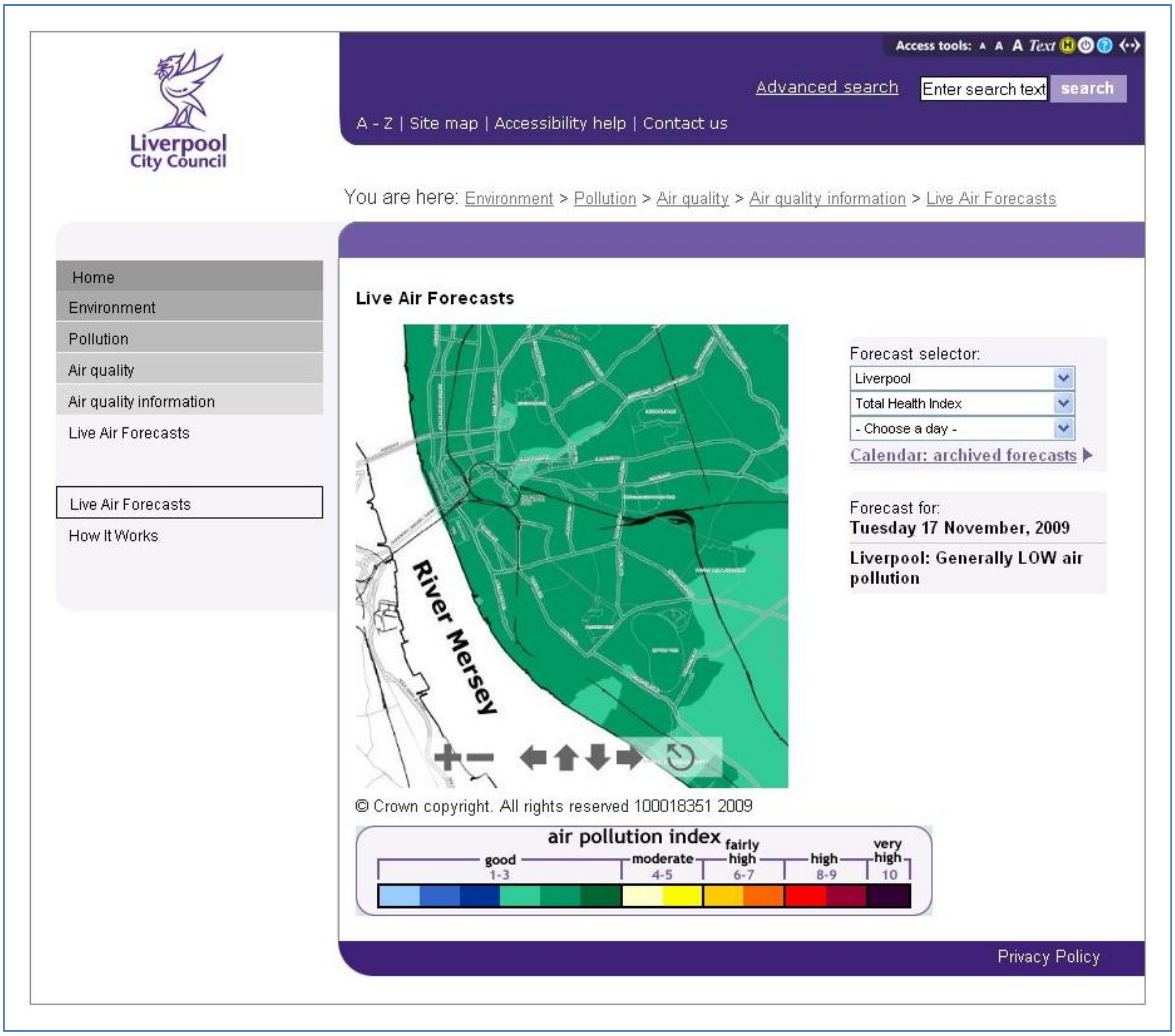
10.4 AIRNow-International

The goal of AIRNow-International is to strengthen relationships among governments and international organizations by sharing the technology to transform air quality data into vital information. AIRNow-International is poised to become the centerpiece of the United States Environmental Protection Agency's (EPA) real-time air quality reporting and forecasting program. The system is a redesign of the AIRNow information technology infrastructure that distributes current air quality information for the United States and Canada. The AIRNow-International software suite is being built to support and embrace the Global Earth Observation System of Systems (GEOSS) concept. The new U.S. EPA AIRNow system, which became operational in Spring 2009, is based on the AIRNow-International system software but with an added forecasting module to store the forecast information provided by U.S. air agencies.
http://www.earthzine.org/2010/01/25/airnow-international-the-future-of-the-united-states-real-time-air-quality-reporting-and-forecasting-program-with-geoss-participation

10.5 Air Quality Forecasting in the United Kingdom (CERC) - Liverpool

Air quality forecasts and alerts have been developed for Liverpool City Council. Validation is on-going with the system expected to go live in Spring 2010. Forecasts are shown as detailed colour contours overlaid on a zoomable background image that will be linked to www.liverpool.gov.uk.

Alerts will be sent to individuals registered by the City Council.



11 Forward work plan for 2012

The two tables below summarise both the weekly and annual planned activity for 2012 (Table 11.1 and 11.2 respectively).

Table 11.1 ***Weekly Activity Chart***

Task 1	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Daily Forecast							
Forecast Outlook Summary							

Table 11.2 Annual Activity Chart

Task 2	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly Reports												
Six-monthly Progress Meetings												
Annual reports												
Enhanced Olympic forecast												

Enhanced forecasting for the London 2012 Olympics is likely to include improved resolution CMAQ modelling, an extended pollution forecast outlook and more detailed daily reports. These developments will be reported in the 2012 annual report.

12 Hardware and software inventory

Defra and the Devolved Administrations have funded the development of the WRF and CMAQ models for UK Air Quality Forecasting purposes. Defra and the Devolved Administrations also own the web pages used to display the forecasts.

No computer hardware being used on this project is currently owned by Defra and the Devolved Administrations.

13 References/Internet links

UK Air Quality Forecasting reports on the UK-AIR library:
http://uk-air.defra.gov.uk/library/

www.cmaq-model.org

www.wrf-model.org

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Appendices

Appendix 1 – UK Air Pollution Index

CONTENTS

Banding	*Index*	*Ozone 8-hourly/ Hourly mean*		*Nitrogen Dioxide Hourly Mean*		*Sulphur Dioxide 15-Minute Mean*		*Carbon Monoxide 8-Hour Mean*		*PM_{10} 24-Hour Mean*
		μgm^{-3}	Ppb	μgm^{-3}	ppb	μgm^{-3}	ppb	mgm^{-3}	ppm	Gravimetric equivalent μgm^{-3}
										Proposed FDMS limits / TEOM limits
LOW	1	0-32	0-16	0-95	0-49	0-88	0-32	0-3.8	0.0-3.2	0 –19 / 0–21
	2	33-66	17-32	96-190	50-99	89-176	33-66	3.9-7.6	3.3-6.6	20–40 / 22-42
	3	67-99	33-49	191-286	100-149	177-265	67-99	7.7-11.5	6.7-9.9	41-62 / 43-64
MOD	4	100-126	50-62	287-381	150-199	266-354	100-132	11.6-13.4	10.0-11.5	63-72 / 65-74
	5	127-152	63-76	382–477	200-249	355-442	133-166	13.5-15.4	11.6-13.2	73-84 / 75-86
	6	153-179	77-89	478-572	250-299	443-531	167-199	15.5-17.3	13.3-14.9	85-94 / 87-96
HIGH	7	180-239	90-119	573-635	300-332	532-708	200-266	17.4-19.2	15.0-16.5	95-105 / 97-107
	8	240-299	120-149	636-700	333-366	709-886	267-332	19.3-21.2	16.6-18.2	106-116 / 108-118
	9	300-359	150-179	701-763	367-399	887-1063	333-399	21.3-23.1	18.3-19.9	117-127 / 119-129
V. HIGH	10	≥ 360 μgm^{-3}	≥ 180 ppb	≥ 764 μgm^{-3}	≥ 400 ppb	≥1064 μgm^{-3}	≥ 400 ppb	≥ 23.2mgm^{-3}	≥ 20 ppm	≥ 128 / 130 μgm^{-3}

Banding	Index	Health Descriptor
LOW	1	Effects are unlikely to be noticed even by individuals who know they are sensitive to air pollutants
	2	
	3	
MODERATE	4	Mild effects unlikely to require action may be noticed amongst sensitive individuals
	5	
	6	
HIGH	7	Significant effects may be noticed by sensitive individuals and action to avoid or reduce these effects may be needed (e.g. reducing exposure by spending less time in polluted areas outdoors). Asthmatics will find that their "reliever inhaler is likely to reverse the effects on the lung.
	8	
	9	
VERY HIGH	10	The effects on sensitive individuals described for "HIGH" levels of pollution may worsen.

Appendix 2 – UK Forecasting Zones and Agglomerations

CONTENTS

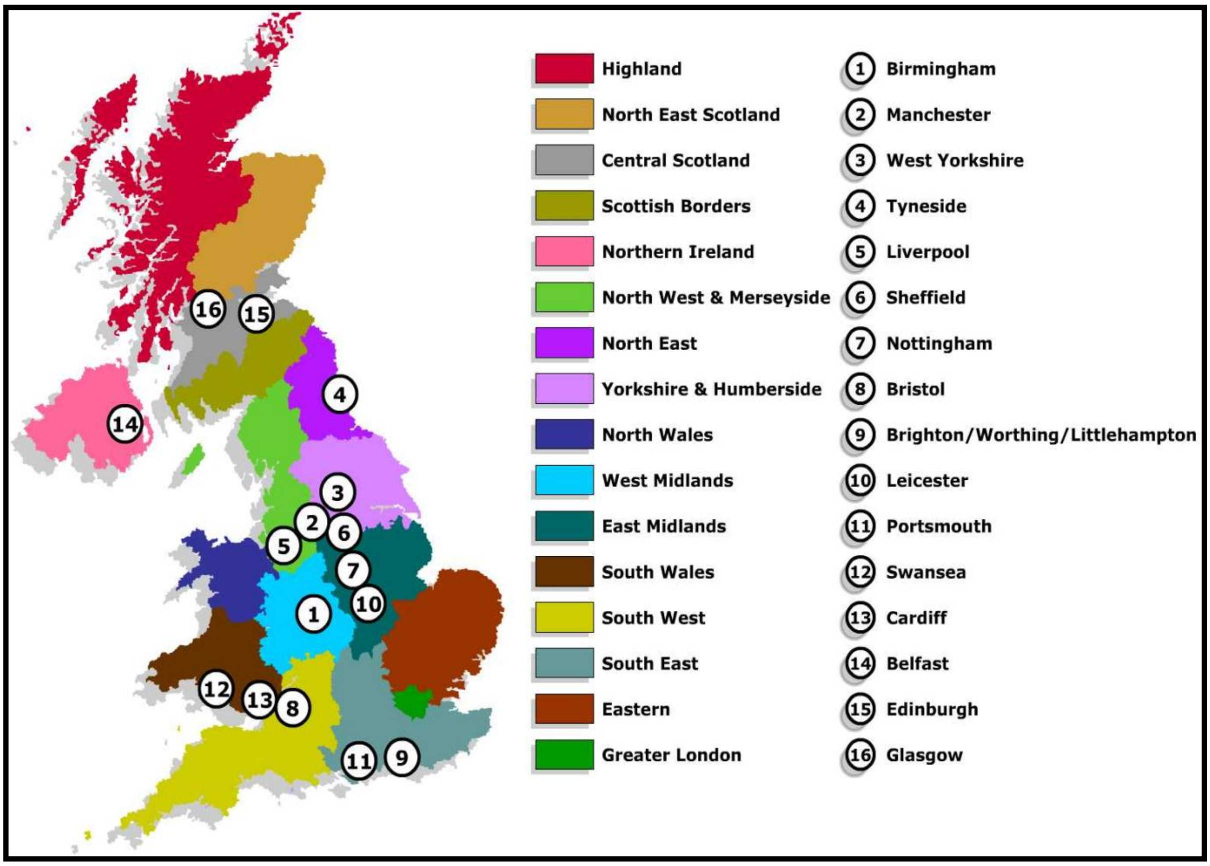
UK Forecasting Zones

Zone	*Population*
East Midlands	2923045
Eastern	4788766
Greater London	7650944
North East	1287979
North West and Merseyside	2823559
South East	3702634
South West	3728319
West Midlands	2154783
Yorkshire and Humberside	2446545
South Wales	1544120
North Wales	582488
Central Scotland	1628460
Highland	364639
North East Scotland	933485
Scottish Borders	246659
Northern Ireland	1101868

UK Forecasting Agglomerations

Agglomeration	*Population*
Brighton/Worthing/Littlehampton	437592
Bristol Urban Area	522784
Greater Manchester Urban Area	2277330
Leicester	416601
Liverpool Urban Area	837998
Nottingham Urban Area	613726
Portsmouth	409341
Sheffield Urban Area	633362
Tyneside	885981
West Midlands Urban Area	2296180
West Yorkshire Urban Area	1445981
Cardiff	306904
Swansea/Neath/Port Talbot	272456
Edinburgh Urban Area	416232
Glasgow Urban Area	1315544
Belfast	475987

Map of UK forecasting zones and agglomerations



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