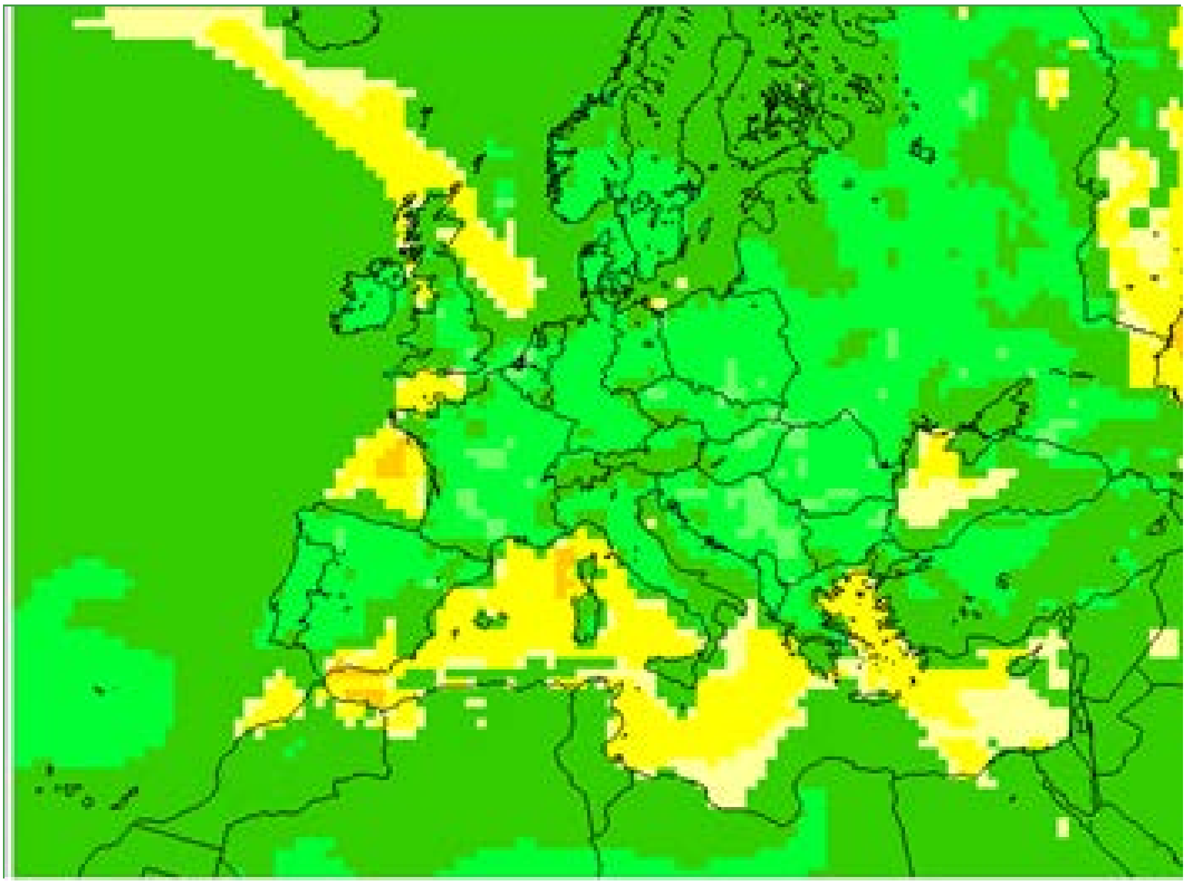
UK Air Quality Forecasting: Annual Report 2009



Report for Defra and the Devolved Administrations

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Executive summary

This report covers the operational activities carried out by AEA on the UK Air Quality Forecasting Contract for the year 2009. The work is funded by the Department for Environment Food and Rural Affairs, the Scottish Executive, Welsh Assembly Government and the Department of the Environment in Northern Ireland.

During 2009, there was a total of eleven days on which HIGH air pollution was recorded across the UK. Six of these days were due to PM_{10}, two days were due to ozone and SO_2 and one day 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 compared not very favourably to the previous year. The success rate performance for the MODERATE band was high, as seen in previous years, with a considerable degree of accuracy. Please note that success rates above 100 % are possible due to the +/- 1 index value acceptance criteria.

Box 1 – forecast success/accuracy for incidents above 'HIGH' and above 'MODERATE' in 2009 *(and 2008)*.

Region/Area	*HIGH*		*MODERATE*	
	% success	*% accuracy*	*% success*	*% accuracy*
Zones	8 *(233)*	4 *(50)*	134 *(129)*	85 *(86)*
Agglomerations	20 *(88)*	8 *(25)*	139 *(135)*	72 *(71)*

During this year, two ad-hoc reports were presented to Defra and the devolved administrations. These detailed the extent and circumstances of pollution episodes and are listed below:

- Air Pollution Forecasting: A UK Particulate Matter Episode from 18th to 22nd March 2009 (Colin Rae, Paul Willis AEA).
- Air Pollution Forecasting: A Particulate Episode in England and Wales on the 15th and 16th April 2009. (Andy Cook, Rachel Yardley AEA).

All episode reports which have been published can be found on the UK-AIR website Library at (http://uk-air.defra.gov.uk/library/).

There were no reported breakdowns 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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Appendices

1 Introduction

AEA is contracted by The Department for Environment, Food and Rural Affairs (Defra), the Scottish Executive, the Welsh Assembly Government and the Department for the Environment in Northern Ireland 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 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 Teletext, the World Wide Web and a Freephone telephone service.

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 2009. 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, 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.

We continue to use a comprehensive quality control system in order to ensure that the 5-day forecasts provided by the Met Office to the BBC are consistent with the “daily media forecasts” and long-range pollution outlook provided by AEA for Defra and the DAs. The BBC requires 5-day air pollution index forecasts for 337 UK towns and cities for use on its BBC Online service. The quality control review is carried out at 3.00 p.m. daily, with the resulting forecast updating onto the BBC Online Web site at 4.00 a.m. the following morning.

The forecasts are also quality controlled for consistency with forecasts issued by AEA for other UK regions and individual local authorities.

2 Development of the WRF-CMAQ model for UK AQ Forecasts

WRF (Weather Research and Forecasting) is a numerical weather model developed in the USA as a collaborative partnership, between several agencies including: National Centre for Atmospheric Research (NCAR), the National Centres 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 regional Chemical Transport Model (CTM), incorporating meteorology, emissions, land use, chemistry and aerosol processes. For the UK Air Quality forecasts 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), supplemented by natural emission calculated using the Biogenic Potential Inventory. CMAQ model code and documentation are available at www.cmaq-model.org.

WRF-CMAQ is used to produce daily AQ forecasts for O_3, NO_2, CO, SO_2 and PM_{10} at a European and UK scale.

During 2009 a number of versions have been developed and made available to the duty forecaster.

- Version 1 – 48km 2day European Forecast available from June 2009 to mid November 2009
- Version 2 - 48km and 12km 2day European and UK Forecast available from mid November 2009 to present day
- Version 3 - 50km and 10km 2day European and UK Forecast under development available 2010

Pre-Contract developments

Prior to starting this contract AEA used WRF-CMAQ for a retrospective study of 2006. The grid-projections now used in forecasting are the same as those used for the retrospective model. To prepare for forecasting we established two independent WRF-CMAQ applications on different computers. One primarily used for retrospective analysis and the second for forecasting, with the resources shared between the computers depending on demand.

Version 1 developments – 48km 2-day European Forecast

The first UK forecasting version was a 2-day forecast using the same European 48km resolution grid as the retrospective study. Using the same model grids and configurations enabled much of the existing developments to be used, particularly the emissions. However the retrospective model is run on a monthly cycle and many of the processes were only semi automated. These needed to be fully automated for a daily service. For the 2006 study WRF used ECMWF (European Centre for Medium range Weather Forecast) meteorological data to initiate it, for the forecasting version WRF was developed to use the NCAR-GFS (Global Forecasting System) data.

Overleaf is a summary of the Version 1 development steps. For convenience they have been segregated into WRF, CMAQ and automation developments.

WRF- developments:

1. Source and automate the download of the NCAR-GFS (Global Forecasting System) data used to initiate WRF.
2. Develop WRF to run using GFS data
3. Automate the scripts for the production of a 2 day forecast, the WRF process has several step each needing to be coordinated
4. Develop the WRF plots and animations

CMAQ-developments:

5. Using the same grid as the retrospective model the same emissions process were used, with development of an automated process.
6. Develop the MCIP (Meteorology Chemistry Interface Process) run script
7. Develop CMAQ run script
8. Develop CMAQ post processing, generating daily max files, plots and animations, extract model data corresponding to monitoring sites.

Automation-developments:

9. Integrate a series of automated scripts to:
    a. Download the GFS data
    b. Run WRF
    c. Create WRF plots and animations
    d. Run MCIP
    e. Create the daily emissions files
    f. Run CMAQ
    g. Implement CMAQ post processing creating plots and data files
    h. Link the WRF and CMAQ plots to the forecasting dashboard

Version 1 included simple error checking and process control, these were developed in more detail in version 2. A daily 2 day European forecast was regularly produced in Version 1 by 9:30 BST. This was the production version available to the forecasters from June to early November 2009.

During initial operation of this version a problem with WRF numerical stability was encountered. This was a known issue with WRF and many of the changes suggested by the on-line fora and user groups were quickly implemented. Whilst this improved the stability, three additional improvements were also considered to increase the probability that an AQ forecast could be produced.

- Changing the WRF process to start from a different initial point – this was tested and proved to be effective.
- Increasing the height of the bottom layer from 15 to 24m - this also increased the stability but less that changing the initial time.
- Reducing the time step increased stability but had the disadvantage of increasing the processing time.

Version 2 developments – 48km and 12km 2day European and UK Forecast

Once the 48km version of the forecast model was operational and stable version 2 commenced development. During this second stage there were a number of objectives identified:

- Increase the stability of WRF
- Introduce the 12km WRF and CMAQ runs
- Produce a timely forecast
    - Evaluate if the 12km 2day forecast could be produced by 14:00
    - Maximise the forecast available by 10:00 and 14:00

- Ensure production of both the forecast should be robust

All of the developments from step 3 to 9 listed above were repeated to develop the 12km option, the additional developments required are summarised into three main sections below.

Increasing the stability of WRF

The two major issues highlighted in version 1 were introduced as part of version 2 development.

- Changing the height of the lowest layer required minimal change to WRF but required significant changes to the boundary conditions for CMAQ.
- The processing was made more complex with the option of starting the simulation from different initial points. WRF now has the option of starting at 18:00, 21:00 or midnight of the previous day for the 48km simulation.

UK 12km simulation

Two different methods can be used to nest WRF forecasts. In the retrospective runs the 48km and the 12km forecasts were produced simultaneously. For the forecast development the 48km version is run initially followed by the 12km. This requires more complex processing but has two advantages:

- It allows more flexibility for jobs to run in parallel reducing the overall run time.
- If there is a problem this approach maximises the chance of at least part of the forecast being produced.

The same emissions and CMAQ processing could be implemented as for the 2006 simulations because the same grid projection was used.

Producing a timely forecast

Most of the developments in this stage were related to optimising scripts to control the process. This ensured the maximum availability of forecasts on any day e.g. if there were a problem with part of the 24hr forecast then the 48hr forecast would still be produced.

In version 2 the forecast process starts at 4:00am each day and the timetable and implementation is designed to be both robust and optimised for delivery time.

The processes were optimised to ensure that on each day the European AQ forecast was produced by 10:00 and the UK by 14:00. During the testing phase Table 2.1 shows that on each day by 10:00 the 48hr European forecast and the 24hr UK forecast were always available. Generally the 48hr UK forecast was available before 14:00. There were only 3 days when the full forecast was not available until after 14:00.

Table 2.1 WRF-CMAQ runtimes for the 48km+12km simulation (hours)

WRF-CMAQ runtimes 10/11-6/10/2009	Average	Min	Max
European Forecast			
End of 48hr forecast	08:08	07:31	08:44
UK and European Forecast			
End of 24hr forecast	09:55	09:04	11:15^
End of 48hr forecast	13:03	11:47	14:49^

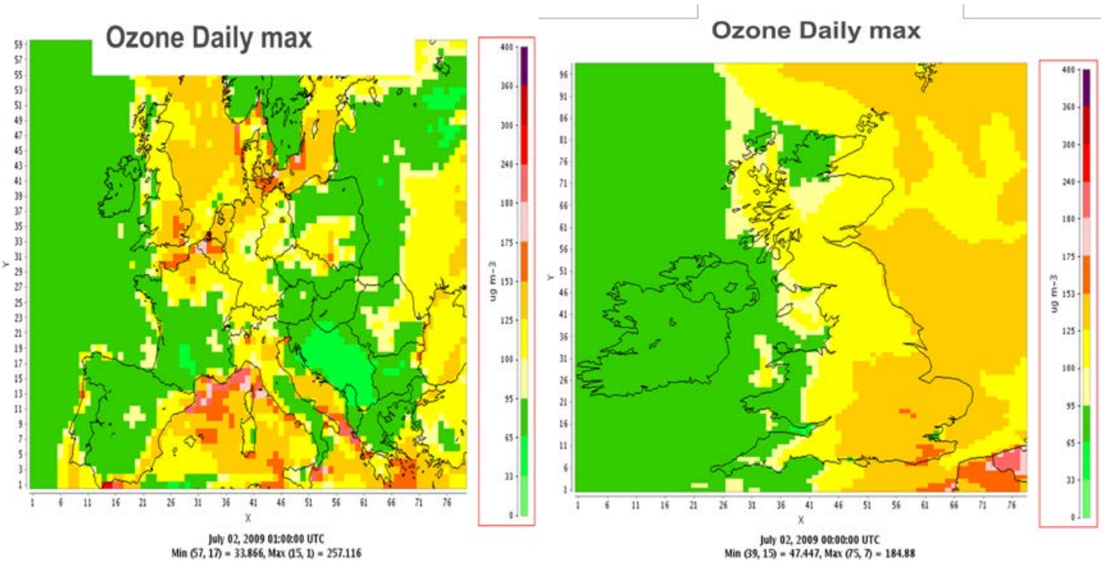
^ 29/11/09 both WRF and CMAQ took longer than average

2.1 Pollutants

The Pollutants covered by the forecast at present are O_3, NO_2, SO_2, CO, PM_{10} and $PM_{2.5}$. CMAQ produces large daily concentration file in excess of 2.3 Giga bytes of data. PM is represented by a large number of species these are combined to represent total PM, equivalent to the PM captured by the monitoring method.

The current plots are designed to assist the forecasters and use the same air quality bands that are required for the forecast. **Figure 2.1.** shows an example of the spatial distribution of ozone daily maximum, the hourly information is also available as an animation.

Figure 2.1 *Example of Daily maximum Ozone 2nd July 09*



2.1.1 Model Evaluation

Model values corresponding to monitoring sites are extracted from the CMAQ files and stored in a mySQL database along with the provisional and ratified monitoring data.
Monthly evaluations of all monitoring site for ozone are shown in ***Table 2.3***. This evaluation includes all paired observation and modelled hourly values. The Normalised Mean Bias and Error (NMB, NME) are the statistical values recommended in the Model Evaluation Protocol developed by Derwent et al. 2009. For all months more than 50% of the paired values should fall within a factor of 2 (FAC2) as recommended in the Model Protocol.

Both the 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.

Table 2.2 *Monthly evaluation of Ozone forecasts for July to December 2009 for all rural or urban background AURN monitoring sites.*

Ozone		NMB %	NME %	FAC2 %
Europe v1				
Jul-09	All sites	36	43	88
Aug-09	All sites	44	52	80
Sep-09	All sites	24	36	84
Oct-09	All sites	18	37	79
Europe v2				
Sep-09	Rural	41	50	84
Sep-09	UrbanBG	48	67	72
Oct-09	Rural	24	36	82
Oct-09	UrbanBG	56	70	57
Nov-09	Rural	13	22	91
Nov-09	UrbanBG	40	48	71
Dec-09	Rural	1	26	84
Dec-09	UrbanBG	35	54	61
UK v2				
Sep-09	Rural	39	48	83
Sep-09	UrbanBG	49	63	69
Oct-09	Rural	27	36	82
Oct-09	UrbanBG	64	74	56
Nov-09	Rural	14	21	93
Nov-09	UrbanBG	41	46	74
Dec-09	Rural	2	25	84
Dec-09	UrbanBG	37	52	63

2.2 2009 Model Development Summary

During 2009 an operational UK version of the WRF and CMAQ Air Quality forecasting model has been established to produce daily forecasts in a timely and robust manor. In visual comparisons the European forecast is similar to the other European model included in the PROMOTE ensemble. An initial evaluation shows predicted ozone concentrations within the recommendations of the Model Evaluation Protocol.

3 Analysis of forecasting success rate

3.1 Introduction

Analysis of the 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 based on provisional data, as used in the daily forecasting process. Any obviously faulty data have been removed.

The analysis treats situations where the forecast index was within ±1 of the measured index as a successful prediction, as this is the target accuracy we aim to obtain in the forecast. Because the calculations of accuracy and success rates are based on a success being ±1 of the measured index, 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 2009 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 exceedence 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 2009

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

ZONES	Central Scotland	East Mids	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	2	0	1	3	0	0	0	0	0	0	0	0	3	0	0	3	12
Forecasted days	0	1	2	3	0	1	0	1	1	0	0	2	1	1	1	1	15
Ok (f and m)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Wrong (f not m)	0	1	2	3	0	1	0	1	1	0	0	2	1	1	1	1	15
Wrong (m not f)	2	0	1	3	0	0	0	0	0	0	0	0	3	0	0	2	11
Success %	0	100	0	0	100	100	100	100	100	100	100	100	0	100	100	33	8
Accuracy %	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	4

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

AGGLOMERATIONS	Belfast UA	Brighton/Worthing /Littlehampton	Bristol UA	Cardiff UA	Edinburgh UA	Glasgow UA	Greater Manchester UA	Leicester UA	Liverpool UA
Measured days	1	1	0	0	0	5	0	0	0
Forecasted days	0	2	1	1	0	1	1	1	1
Ok (f and m)	0	1	0	0	0	1	0	0	0
Wrong (f not m)	0	2	1	1	0	0	1	1	1
Wrong (m not f)	1	0	0	0	0	5	0	0	0
Success %	0	100	100	100	100	20	100	100	100
Accuracy %	0	33	0	0	0	17	0	0	0

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

AGGLOMERATIONS	Nottingham UA	Portsmouth UA	Sheffield UA	Swansea UA	Tyneside	West Midlands UA	West Yorkshire UA	Overall
Measured days	0	0	0	1	0	1	1	10
Forecasted days	1	1	1	2	1	1	0	15
Ok (f and m)	0	0	0	0	0	0	0	2
Wrong (f not m)	1	1	1	2	1	1	0	14
Wrong (m not f)	0	0	0	1	0	1	1	9
Success %	100	100	100	0	100	0	0	20
Accuracy %	0	0	0	0	0	0	0	8

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 **

ZONES	Central Scotland	East Mids	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	26	68	114	105	72	20	8	40	46	29	45	78	62	56	50	91	952
Forecasted days	47	75	96	110	93	34	27	81	52	36	50	95	55	57	66	52	1082
Ok (f and m)	52	80	130	135	104	39	29	83	61	40	67	110	70	72	72	88	1271
Wrong (f not m)	6	12	7	16	3	6	4	6	7	3	2	10	5	5	9	7	135
Wrong (m not f)	4	7	10	10	1	0	0	1	3	7	1	5	5	1	4	13	86
Success %	200	118	114	129	144	195	363	208	133	138	149	141	113	129	144	97	134
Accuracy %	84	81	88	84	96	87	88	92	86	80	96	88	88	92	85	81	85

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

AGGLOMERATIONS	Belfast UA	Brighton/Worthing/Littlehampton	Bristol UA	Cardiff UA	Edinburgh UA	Glasgow UA	Greater Manchester UA	Leicester UA	Liverpool UA
Measured days	7	64	40	27	19	32	14	32	13
Forecasted days	21	66	44	37	13	28	32	42	30
Ok (f and m)	12	83	51	40	22	35	27	44	29
Wrong (f not m)	11	11	7	6	3	8	10	8	6
Wrong (m not f)	3	1	1	2	3	9	2	2	3
Success %	171	130	128	148	116	109	193	138	223
Accuracy %	46	87	86	83	79	67	69	81	76

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

AGGLOMERATIONS	Nottingham UA	Portsmouth UA	Sheffield UA	Swansea UA	Tyneside	West Midlands UA	West Yorkshire UA	Overall
Measured days	17	48	15	51	0	35	19	433
Forecasted days	39	54	28	47	30	53	28	610
Ok (f and m)	30	58	26	56	14	49	27	603
Wrong (f not m)	16	12	8	8	16	15	6	169
Wrong (m not f)	0	5	3	10	0	6	9	59
Success %	176	121	173	110	100	140	142	139
Accuracy %	65	77	70	76	47	70	64	73

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 episodes year 2009

Pollutant	*No. of HIGH days*	*No. of MODERATE days ^*	*Maximum concentration* (Index)*	*Site with max concentration*	*Zone or Agglomeration*	*Date of max conc.*	*Forecast success HIGH days (%)**** [no. incidents, zone or agglomoration days] **
Ozone	2	140	258 (Index 8)	St. Osyth	Eastern	06/08	0 % [2]
PM_{10}	6	61	173 (Index 10)	Glasgow Centre	Glasgow Urban Area	27/11	9 % [20]
NO_2	1	19	701 (Index 9)	Glasgow Centre	Glasgow Urban Area	09/11	100% [1]
SO_2	2	4	625 (Index 7)	Grangemouth	Central Scotland	15/06	0% [2]

^ a MODERATE day is not counted on any HIGH day.

** Maximum concentration 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 TEOM instruments.

3.2.1 General trends

The high pollution episodes of 2009 and their causes are detailed in the sections which follow.

There were six significant HIGH PM_{10} episodes experienced in 2009, as illustrated in figures 3.1, 3.2 and 3.4.

Two single HIGH pollution days were recorded for ozone during this reporting year, one at the beginning of July and the second one in August, as shown in figure 3.3. The HIGH days were the result of measurements made at Brighton Preston Park on July 2nd and St Osyth on August 6th 2009.

There were two HIGH days and four MODERATE days for SO_2 measured during the calendar year. 80 % of the MODERATE days occurred as a result of exceedances at the industrial Grangemouth monitoring site. Figure 3.5 shows the frequency of the exceedances.

There were one HIGH day and nineteen MODERATE NO_2 days measured throughout the year, as shown in figure 3.6. The one HIGH day was measured at the Glasgow Centre site. Eleven MODERATE days were measured at the busy Camden Kerbside site.

3.2.2 Particulate matter

The first particulate episode of the year occurred between 18th March and 22nd March 2009, when the UK experienced an episode of increased PM_{10} and $PM_{2.5}$ concentrations. London Marylebone Road and Sandy Roadside experienced moderate levels of PM_{10} on the 17th March, which was one day before the other sites started to pick up the episode. It is believed that the elevated levels detected at these two sites were in-fact not connected to source of the rest of the episode. London Marylebone Road and Sandy Roadside sites both reached air pollution index 5 on 17th March a full day before other sites recorded air pollution indices above 3. For the remainder of the episode both sites did not exceed air pollution index 3.

The data from London Marylebone Road did not exhibit the distinctive rise seen at other stations and instead fell between the period of 18th – 22nd March. At this kerbside site PM_{10} from local emissions masks any small increase in PM_{10} from long-range transport. The Air Pollution Index is calculated from a running 24hour mean it can be concluded that the air pollution index of 5 on the 17th of March was heavily influenced by the relatively high concentrations late on the 16th March. For these reasons it has been concluded that London Marylebone Road was not significantly affected by the general conditions of this widespread particulate episode.

From Wednesday 18th to Sunday 22nd March twenty nine sites reached the MODERATE band or higher. Of the twenty-nine sites measuring MODERATE band or above, eighteen were located in England, two in Northern Ireland, three in Scotland and five in Wales. Only one site Hull Freetown measured levels of PM_{10} particulate matter at air pollution index 7 (HIGH).

Air mass back-trajectory plots revealed the cause of this particulate episode was long range transport of particulate matter building up over the Benelux region during the 16th/17th March as shown in the PROMOTE and NAAPS forecasts. The air masses arriving over the UK on 18th March 2009 had already passed over this region. This incoming air probably picked up particulate matter building up over the area during the 16th/17th March as shown in the PROMOTE and NAAPS forecasts. During the 19th – 21st March forecast back trajectories showed that air masses started to re-circulate over the UK, having already passed over

Northern Europe. The SKIRON dust model confirms that Saharan dust did not play a significant part in the March 2009 UK particulate episode.

Over the second episode, Wednesday 15th and Thursday 16th April, thirty one sites in the National Air Quality network measured particulate PM_{10} levels in the MODERATE band. Four of the sites went on to measure in the HIGH band. The elevated levels of particulates that were measured had been primarily caused by long range transport of particulates from over Europe and the east which had arrived in the UK on the 15th April, combined with localised pollution levels at the sites. All the sites measuring an exceedance were located in England and Wales. Four of the MODERATE band sites were located in South Wales and the remainder were geographically widespread across England. Eight of the sites measuring an exceedance were situated near a busy road, twenty were in an urban area and three were described as urban industrial. Two of the HIGH sites were located in London and two in East Anglia. Half of the HIGH sites were in urban areas.

European particulate forecasting models suggested that the elevated levels were due to long range transport of a combination of secondary pollution from Europe, smoke from fires which had originated from the east and dust from sandstorms over northern Africa. The relative contributions from the three sources were modelled to be approximately in these proportions: 80 % from dust storms in North Africa, 4 % from fires in the east and a 16% contribution from European pollution sources.

In the south of England most of the elevated measurements occurred on the 15th April and had cleared by the following day. However, in the north of England the elevated levels continued onto the 16th April and had slowly dispersed throughout that day. Sites in Wales had measured a dramatic and sustained decrease in particulate levels on the morning of the 16th.

Three days prior to the particulate episode across England and Wales, dust from sandstorms in North Africa were could be seen through satellite imagery travelling north-westwards across the Mediterranean Sea, towards Italy and Sicily.

Bonfire Night celebrations yielded a higher number of exceedences this year when compared to 2007. Figure 3.8 below shows a comparison of the exceedences with earlier years.

Additionally figure 3.9 shows the overall number of PM_{10} exceedences annually from all pollution sources from the year 2000 onwards, indicating that there is downward trend since 2007.

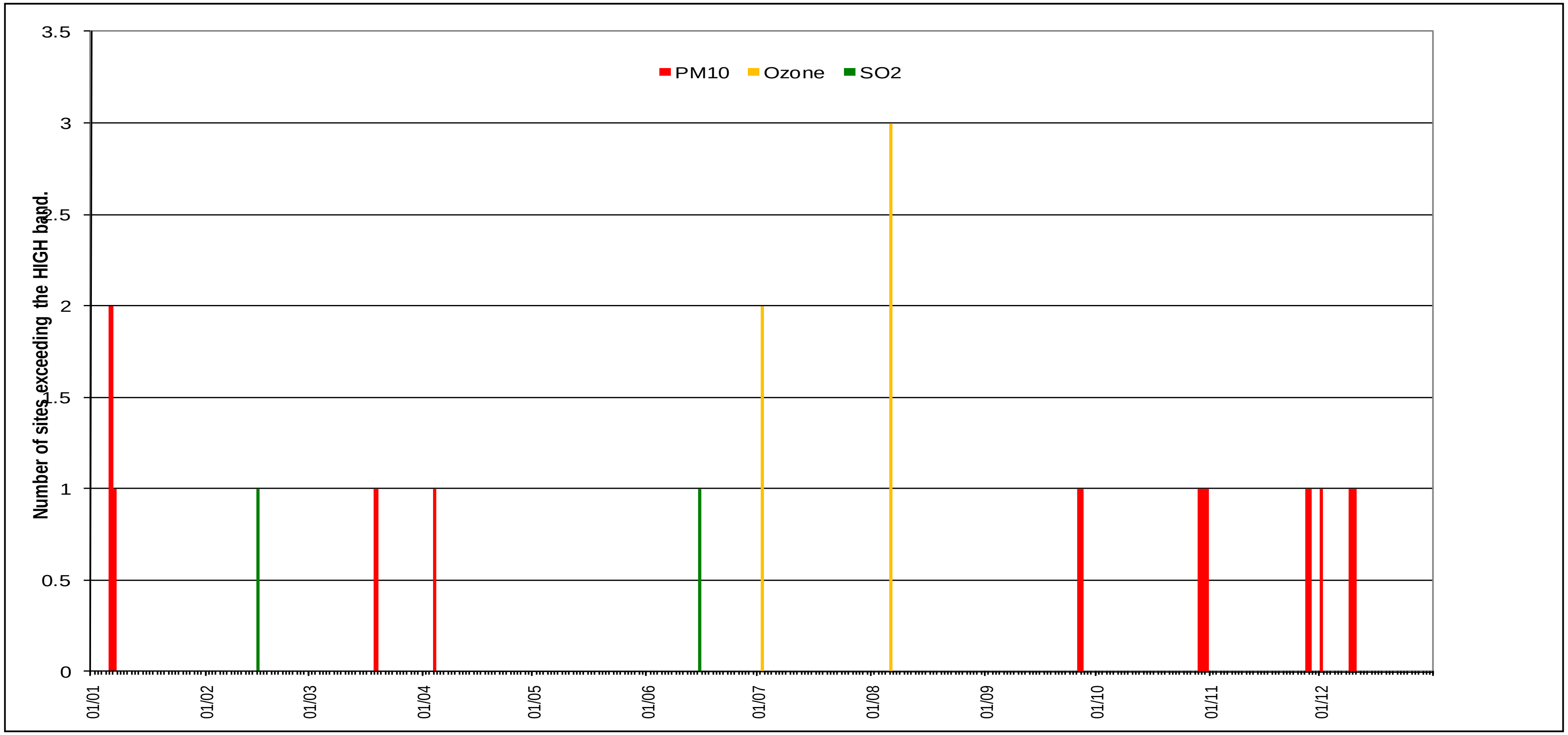


Figure 3.1 *Number of stations with air pollution levels of HIGH and above for days throughout 2009.*

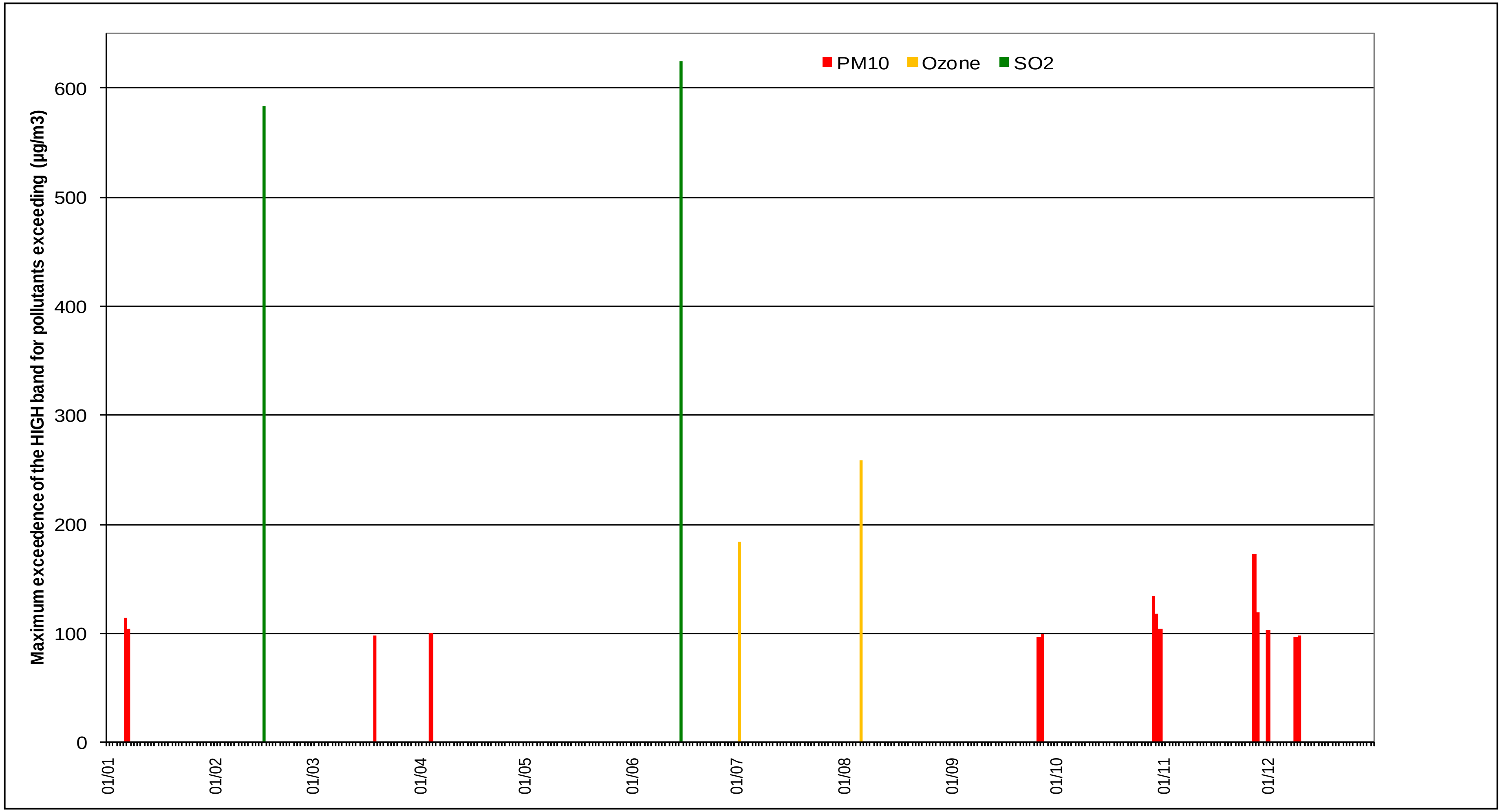


Figure 3.2 *Maximum exceedance when air pollution levels were HIGH and above for days throughout 2009*

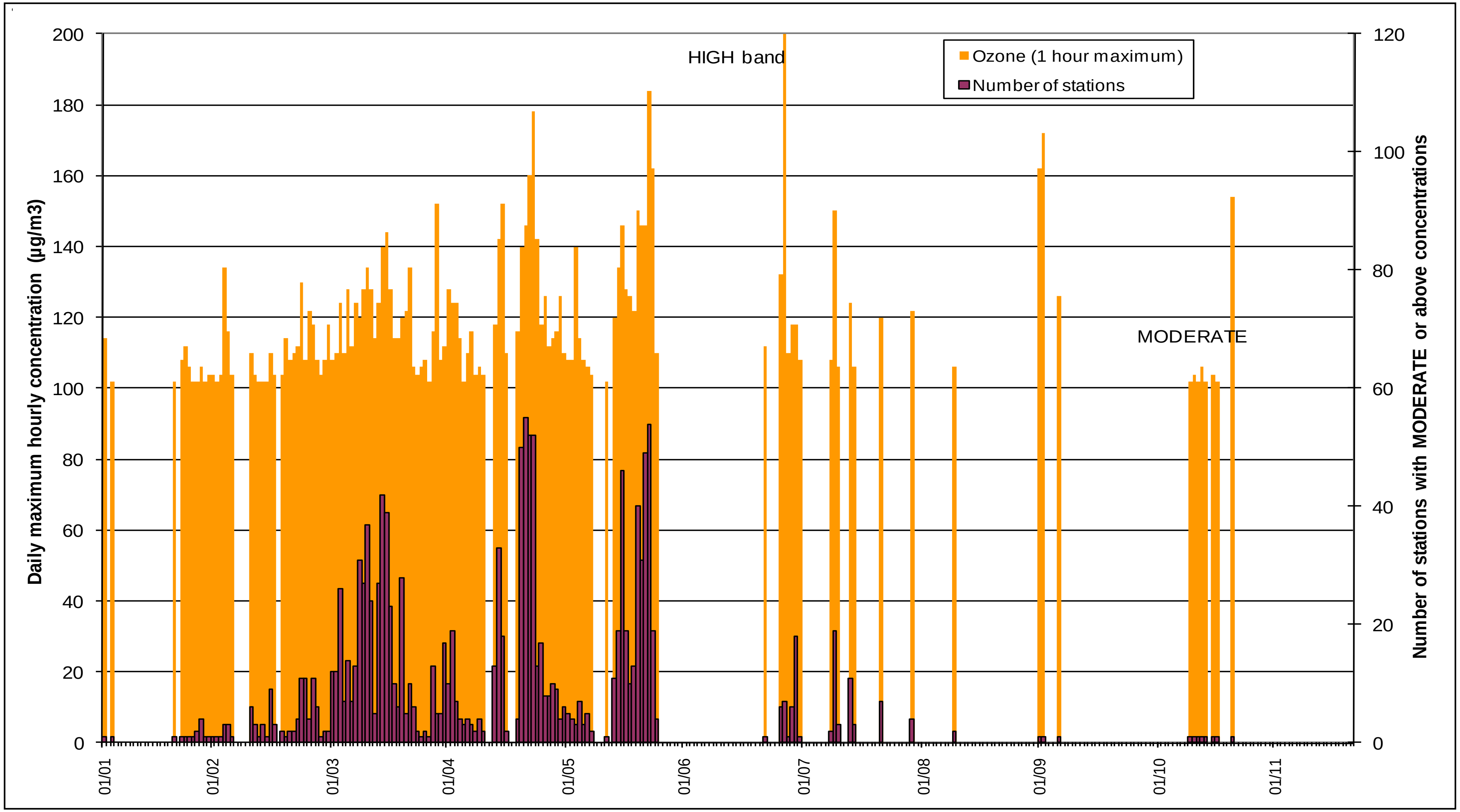


***Figure 3.3** Daily maximum hourly ozone concentration across AURN Network with total number of stations measuring moderate or above levels of ozone over 2009.*

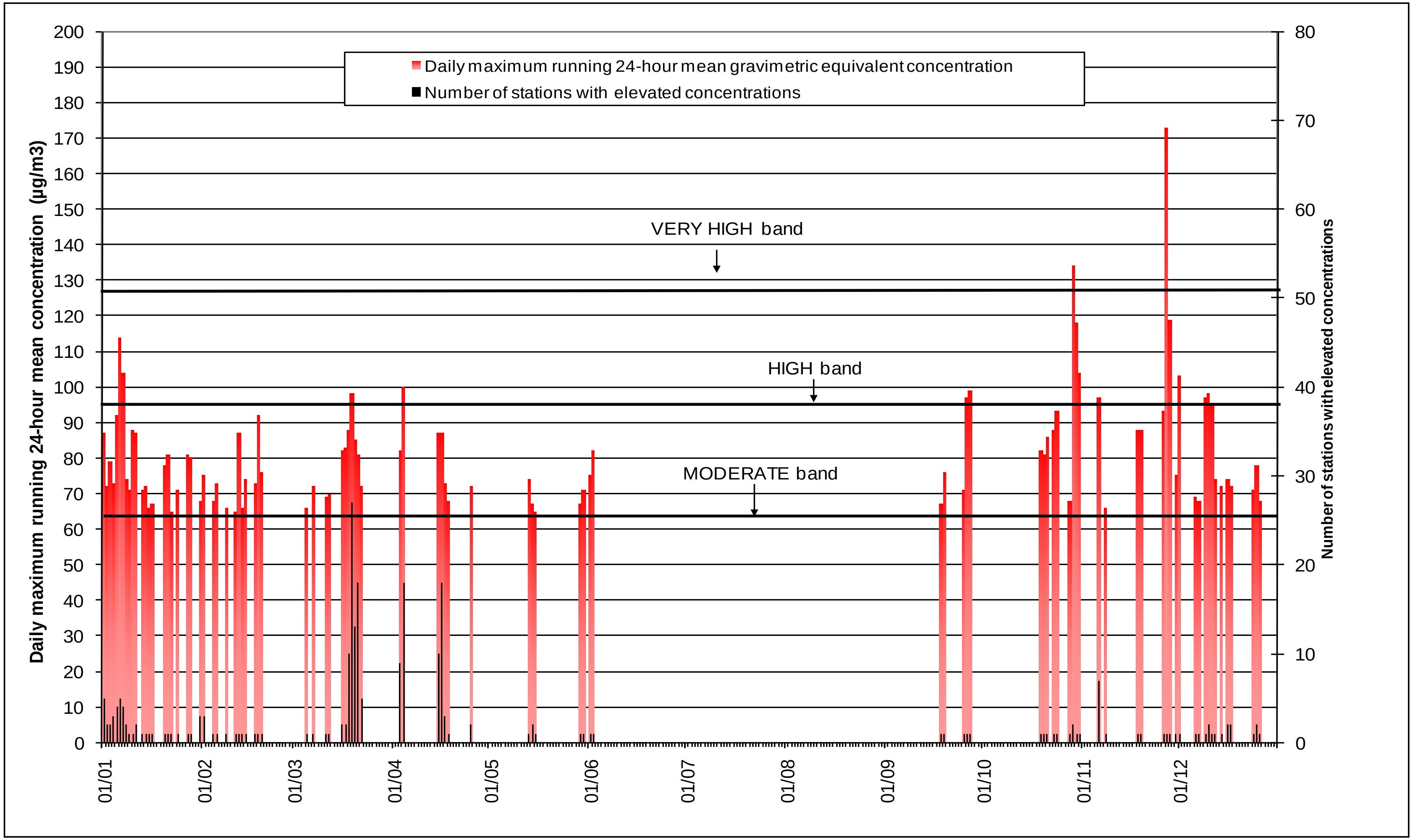


Figure 3.4 *Daily maximum running 24-hour mean PM_{10} concentration across AURN Network with total number of stations measuring moderate or above levels over 2009*

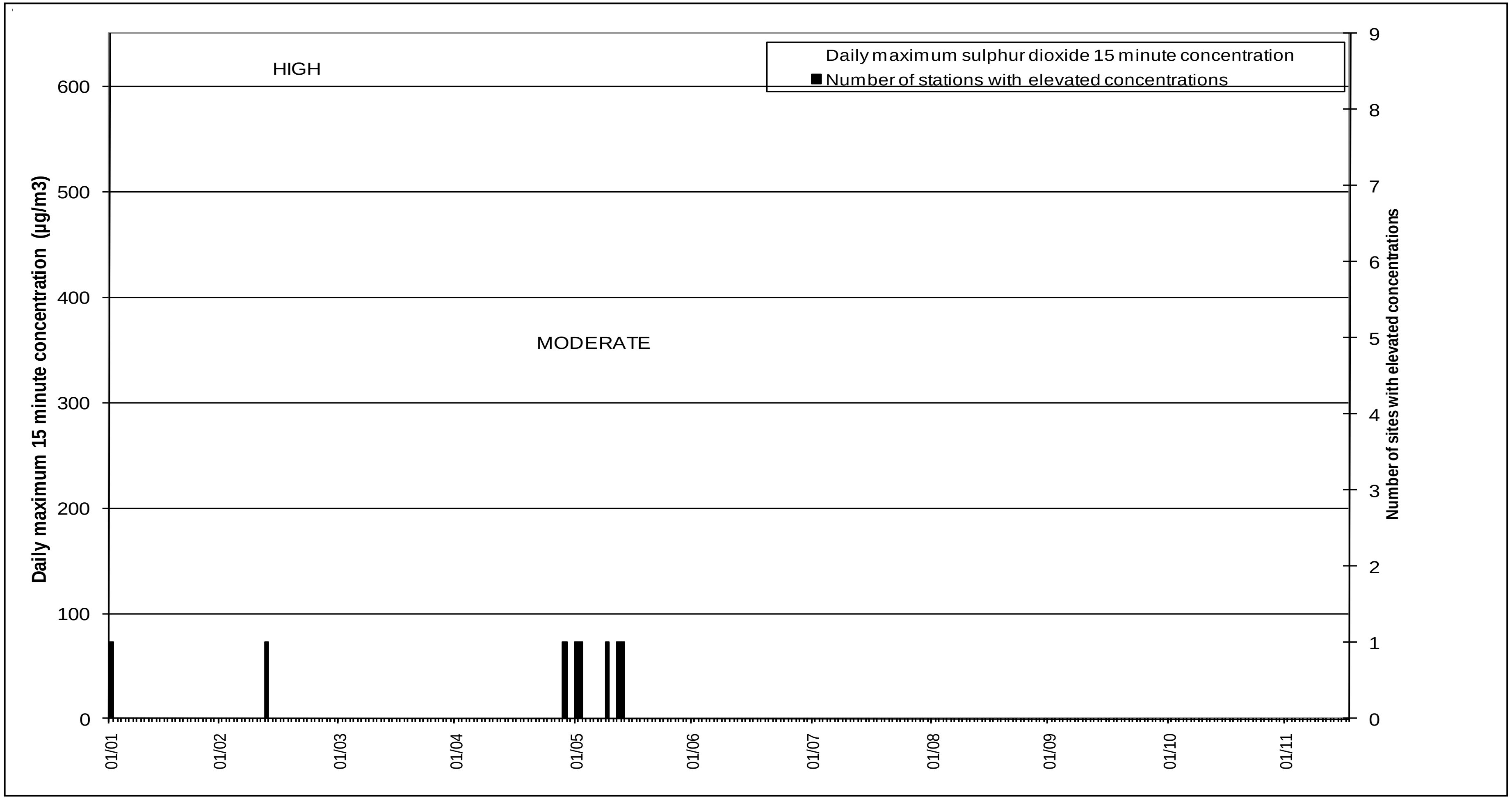


Figure 3.5 *Maximum 15 minute average concentrations of SO_2 across AURN Network with total number of stations measuring moderate or above levels over 2009*

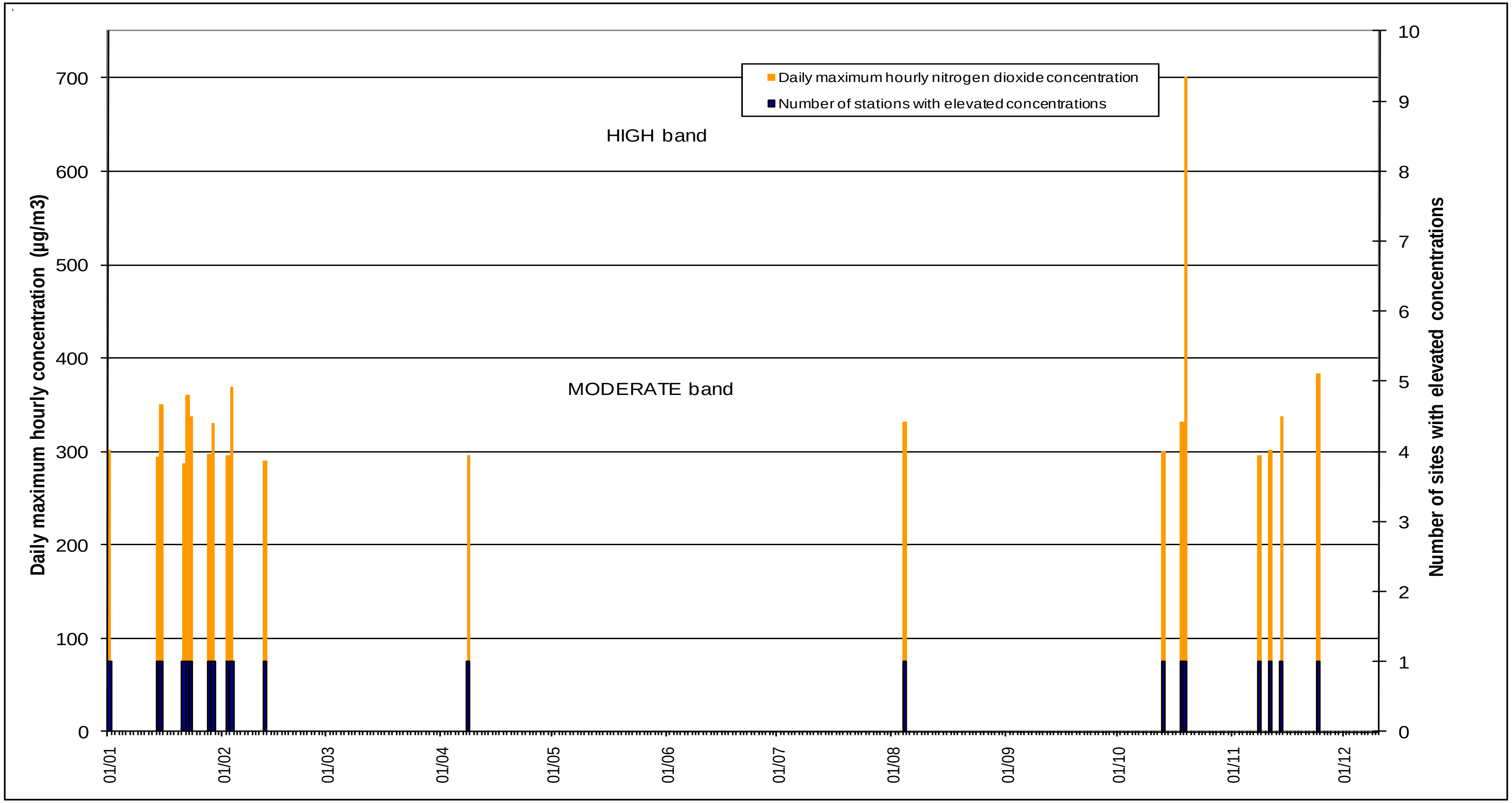


Figure 3.6 *Daily Maximum hourly average of NO_2 across AURN Network with total number of stations measuring moderate or above levels over 2009*

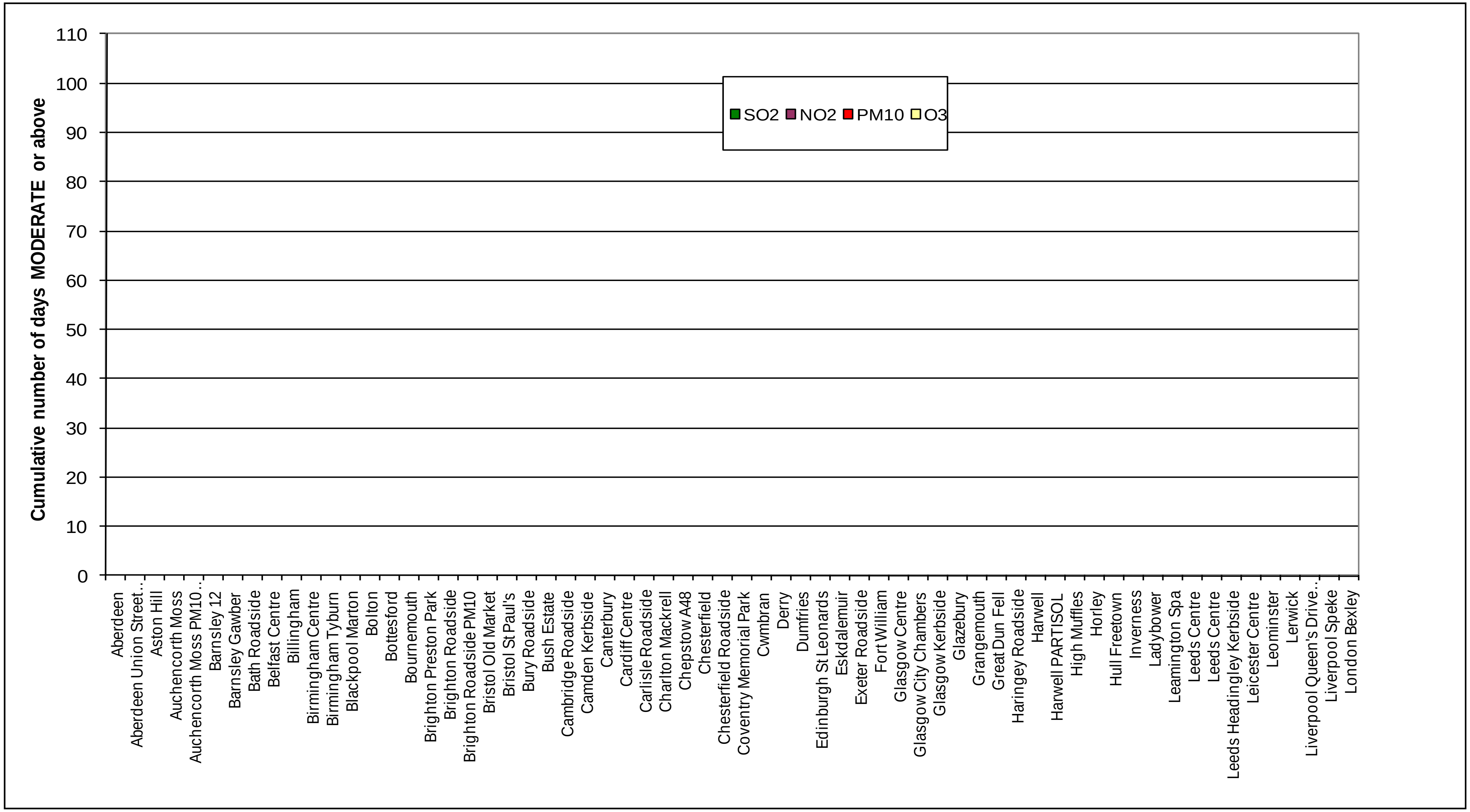


***Figure 3.7** Number of pollutant days moderate and above for each AURN Network station over 2009 (site names A-L) – provisional data*

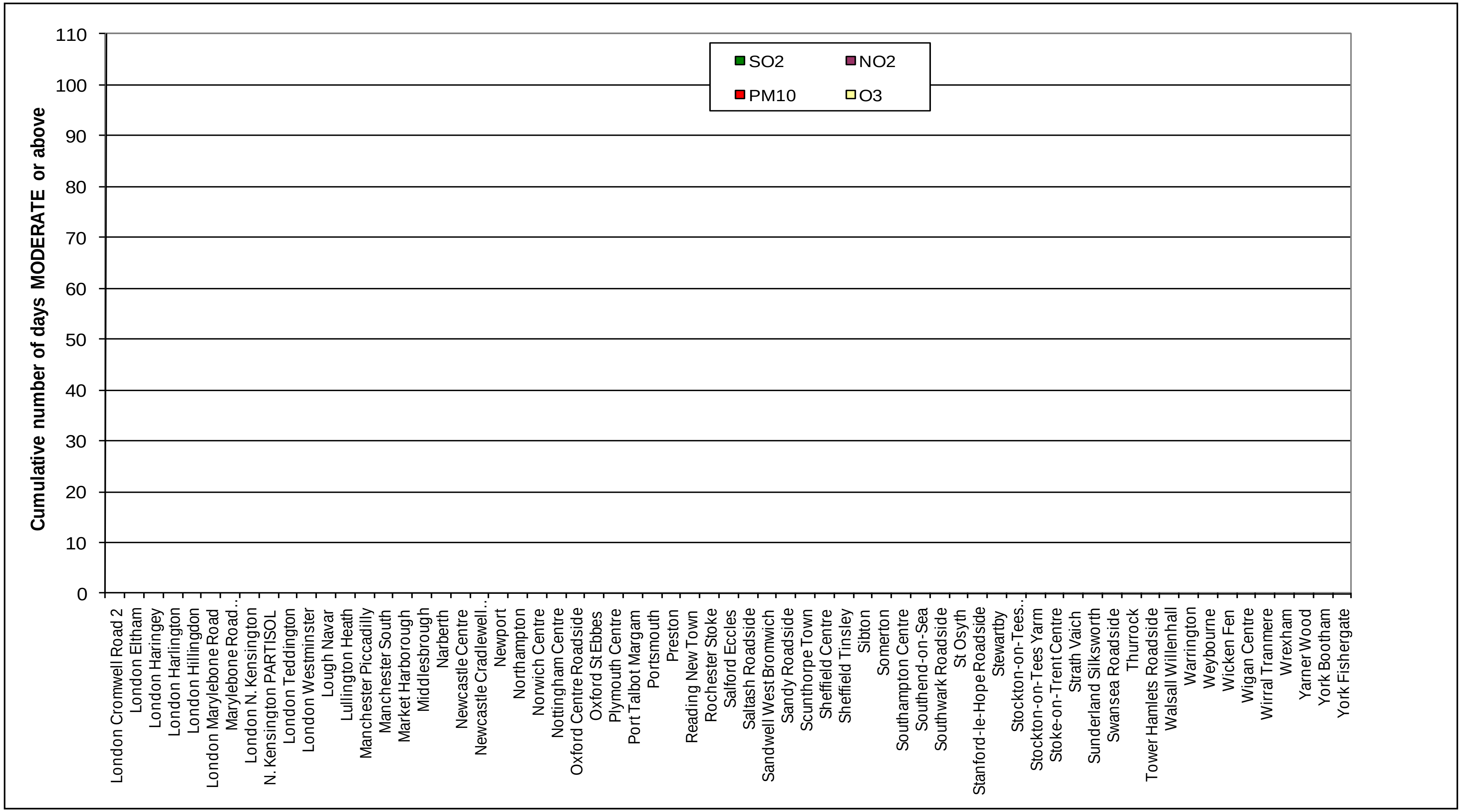


Figure 3.8 Number of pollutant days moderate and above for each AURN Network station over 2009 (site names L-Y) – provisional data

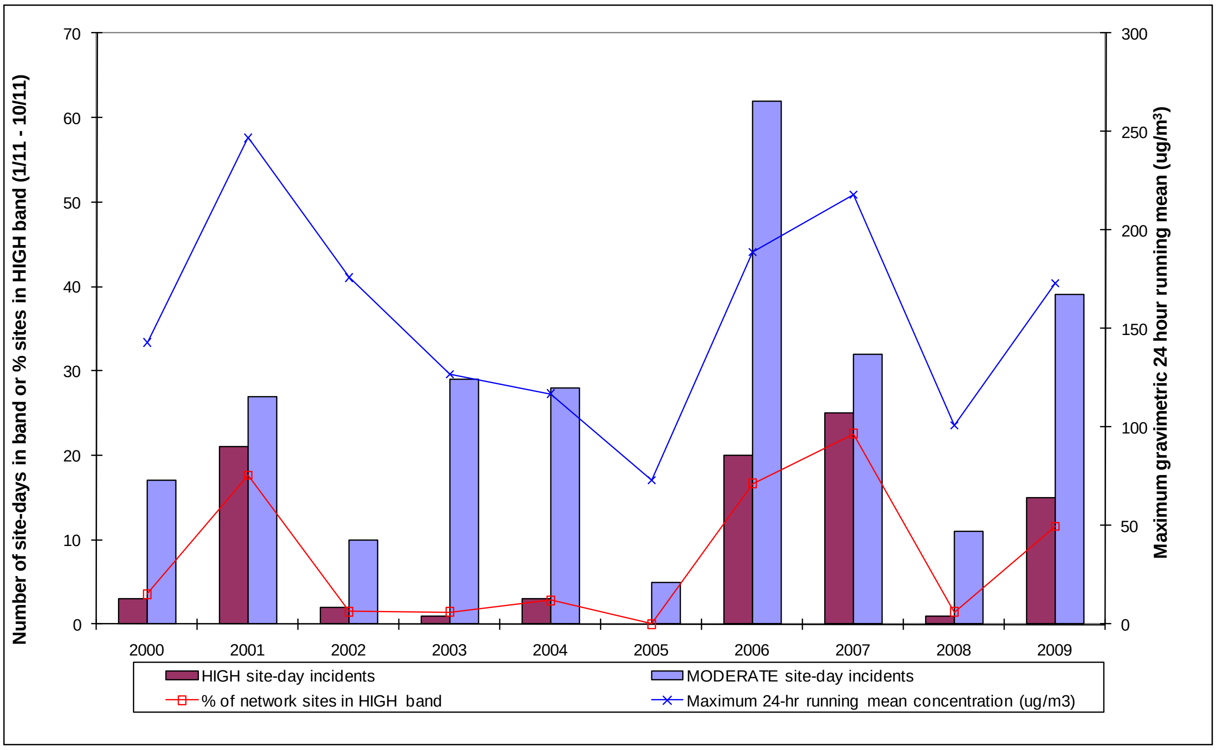


Figure 3.8 Number of sites exceeding the MODERATE and HIGH PM_{10} bands over 1st November to 10th November annually from the year 2000 onwards with additional descriptive statistics.

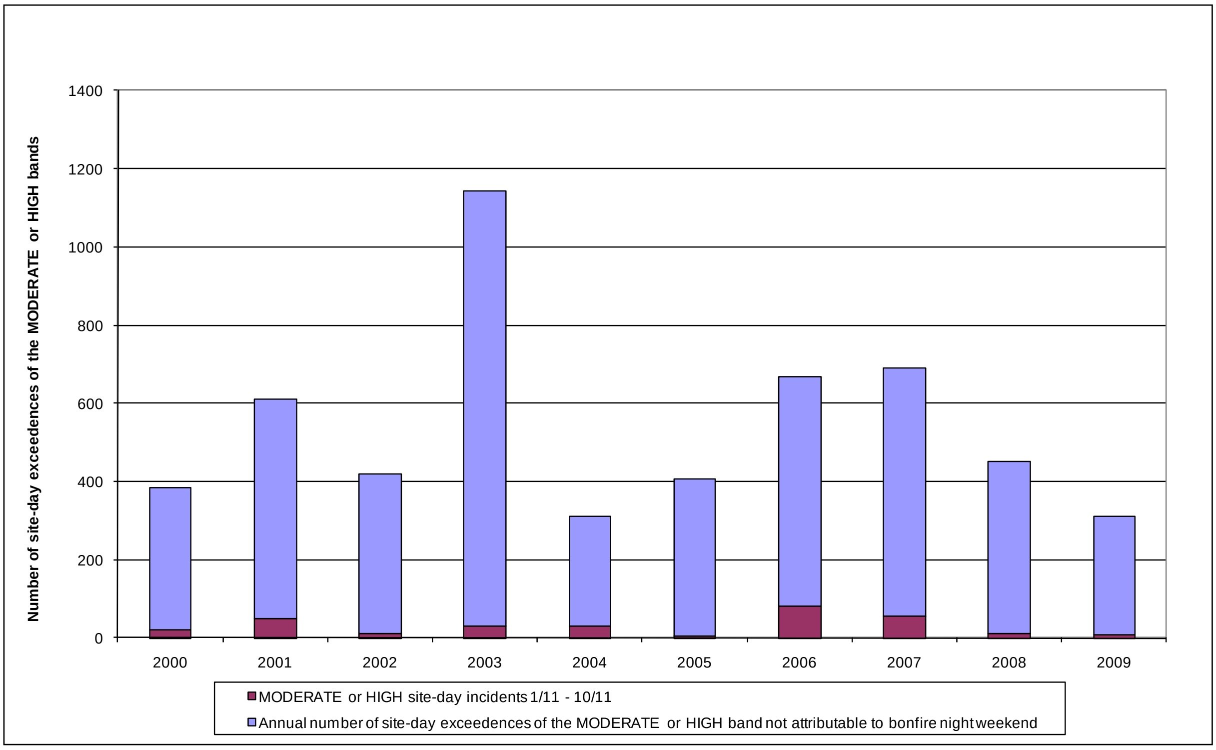


Figure 3.9 *Annual number of site-day exceedences of the MODERATE or HIGH PM_{10} band for 2000 – 2009.*

3.2.3 Ozone

MODERATE days were measured at a substantial number of network sites between the middle of January to mid May 2009. Figure 3.3 earlier illustrates that there were then only short periods of elevated ozone from late June until early September, with a final late summer episode in mid October. Only two sites, namely Brighton Preston Park and St Osyth reached the HIGH band during summer 2009. The first HIGH day measured at Brighton Preston Park occurred on July 1st when a significant number of MODERATE exceedances were measured at network sites. The next HIGH day at St. Osyth was measured on August 6th and increased concentrations were restricted to East Anglia only during this period.

Figure 3.10 shows that 2009 has been the third lowest year recorded for elevated ozone levels from the year 2000 onwards in terms of all statistics for the HIGH band; only two HIGH days were measured at the two AQM sites and the highest hourly measurement was approximately 30 ug/m^3 higher than the average of the highest hourly measurement of years from the year 2000 onwards.

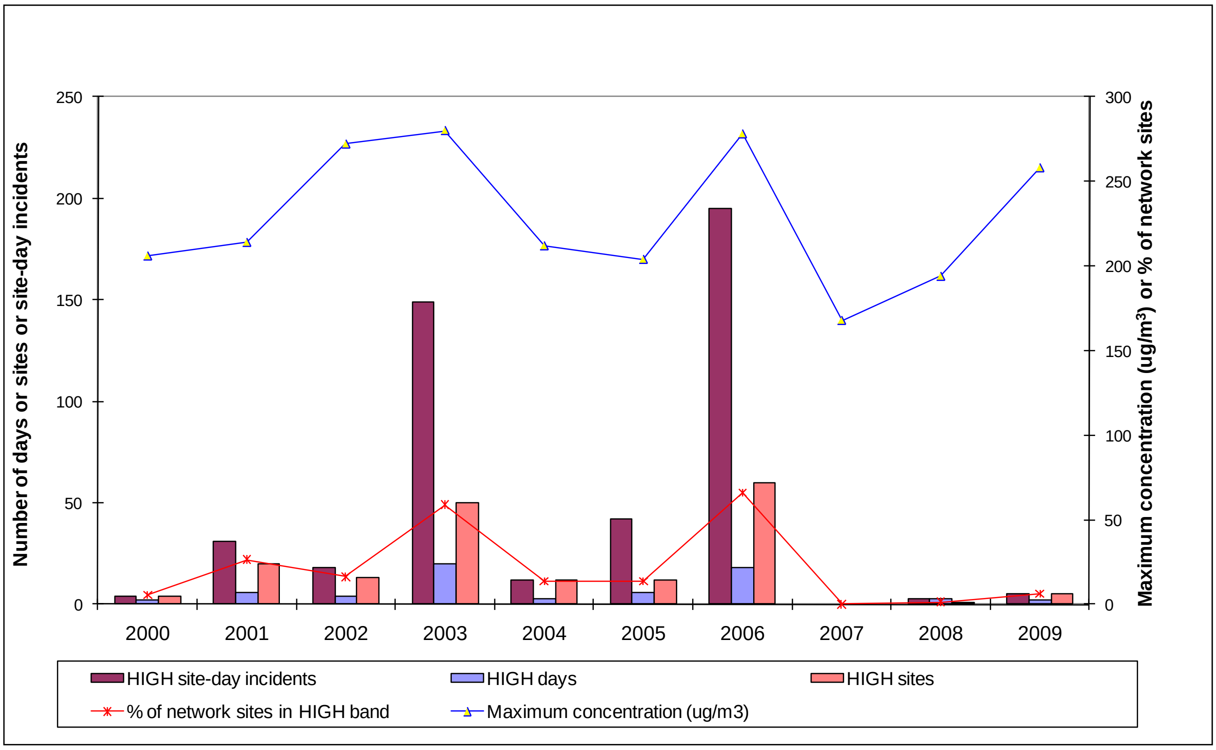


Figure 3.10 *UK ozone episodes summarized for years 2000 onwards.*

3.2.4 Sulphur Dioxide

Moderate or worse concentrations of SO_2 were only recorded at 2 monitoring sites – Grangemouth and Belfast Centre in 2009.

The number of SO_2 measuring sites in the network was reduced from around 75 to 45 instruments from October 2007 onwards. The trend in 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 exceedances per year has fallen dramatically over the last 7 years, by as much as approximately 90% based on an average of the four most recent years. However the number of days MODERATE or above in 2009 was significantly higher than 2007 and 2008.

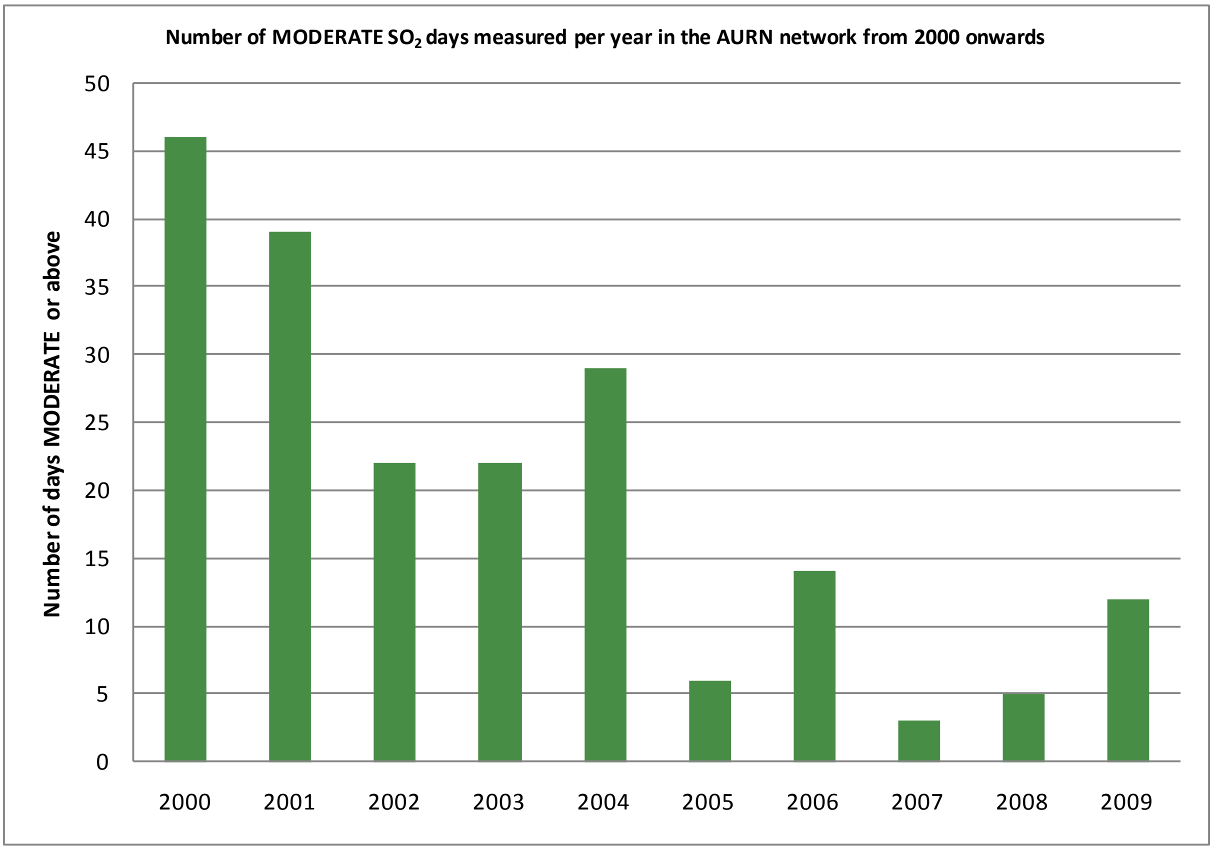


Figure 3.11 *Number of MODERATE SO_2 network days measured per annum*

A significant reduction in the number of exceedences over recent 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

Sixteen MODERATE days for NO_2 were recorded during 2009. The vast majority of these were experienced at kerbside and roadside monitoring sites due to their proximity to emissions from road traffic. Twelve days with exceedances occurred at Camden Kerbside, followed by the Marylebone Road site with 3 days. The majority of the exceedances were measured between January and April primarily as a result of cold weather and poor dispersion conditions.

There was one HIGH day measured at Glasgow Centre site at the beginning of November 2009. This was caused by emissions from a nearby generator during the local Christmas market.

The remaining episodes of MODERATE concentration during the final quarter of the year, were again considered to have been the result of traffic congestion under poor atmospheric dispersion conditions.

Figures 3.7 and 3.8 earlier illustrate the sites and time periods which experienced MODERATE nitrogen dioxide levels during 2009.

3.3 Comparison with years 2003 onwards

3.3.1 FORECASTING SUCCESS RATE

Figure 3.12 shows the forecasting success rates for the whole of the UK for years 2002 to 2009. This is the percentage of HIGH days that were correctly forecast.

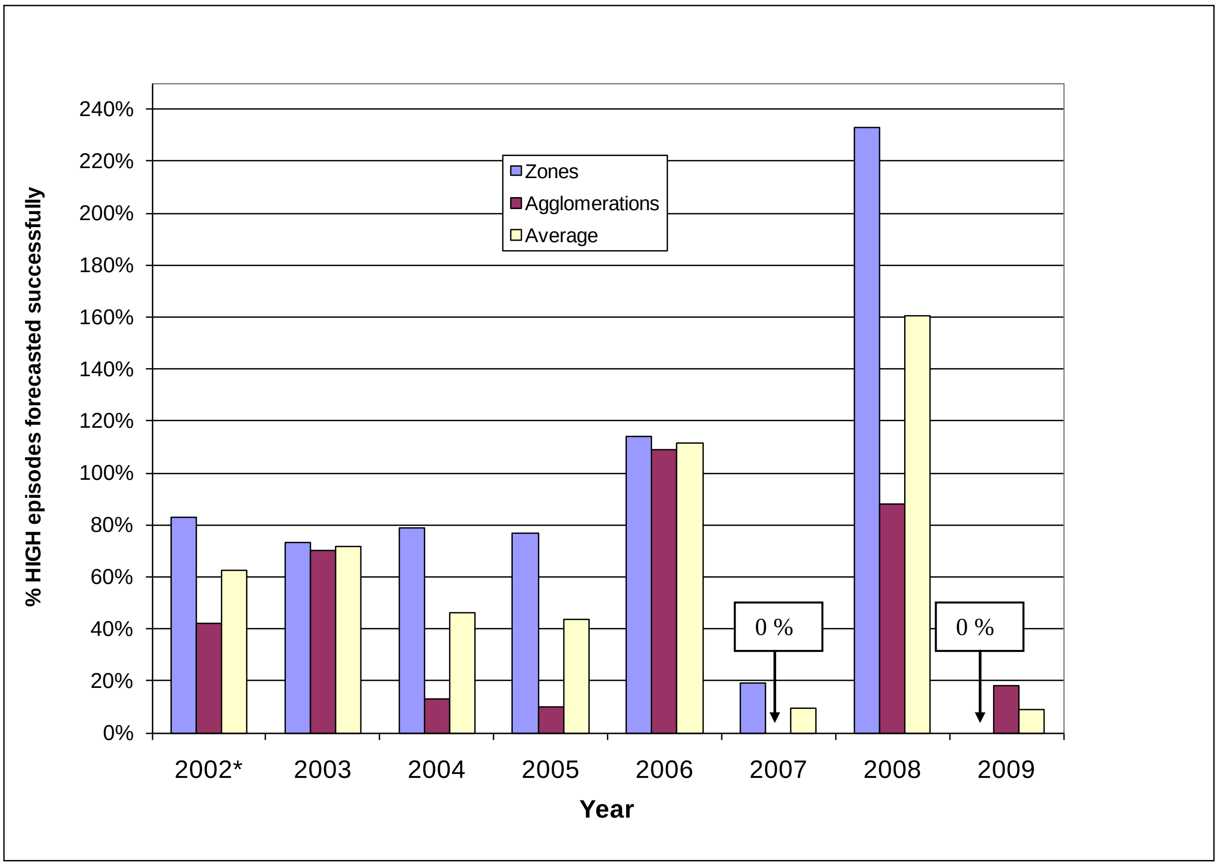


Figure 3.12 *Forecasting Success Rates for the whole of the UK, 2003-2009*

*** 2002 was a partial year for forecasting analysis calculations.**

The overall forecasting success rate for the HIGH band in 2009 was much lower than 2008.

There were exceptionally few days with high ozone in 2009, and those which occurred were due to unusual meteorology and poorly predicted.

The high episodes for nitrogen dioxide and sulphur dioxide were caused by local emissions and therefore difficult to forecast accurately.

Our capacity to successfully predict elevated PM_{10} levels remains less than that for ozone due to the complexity of the pollutant sources and inaccuracies in the forecast models we presently have access to. This was partially addressed during 2008 by adding various freely available European particulate model run results to our toolset for UK air quality forecasting.

Figure 3.13 shows that although 2009 was an average year in terms of total MODERATE and HIGH band exceedences for PM_{10}, it has also been the lowest so far in terms of HIGH band measurements over the past ten years.

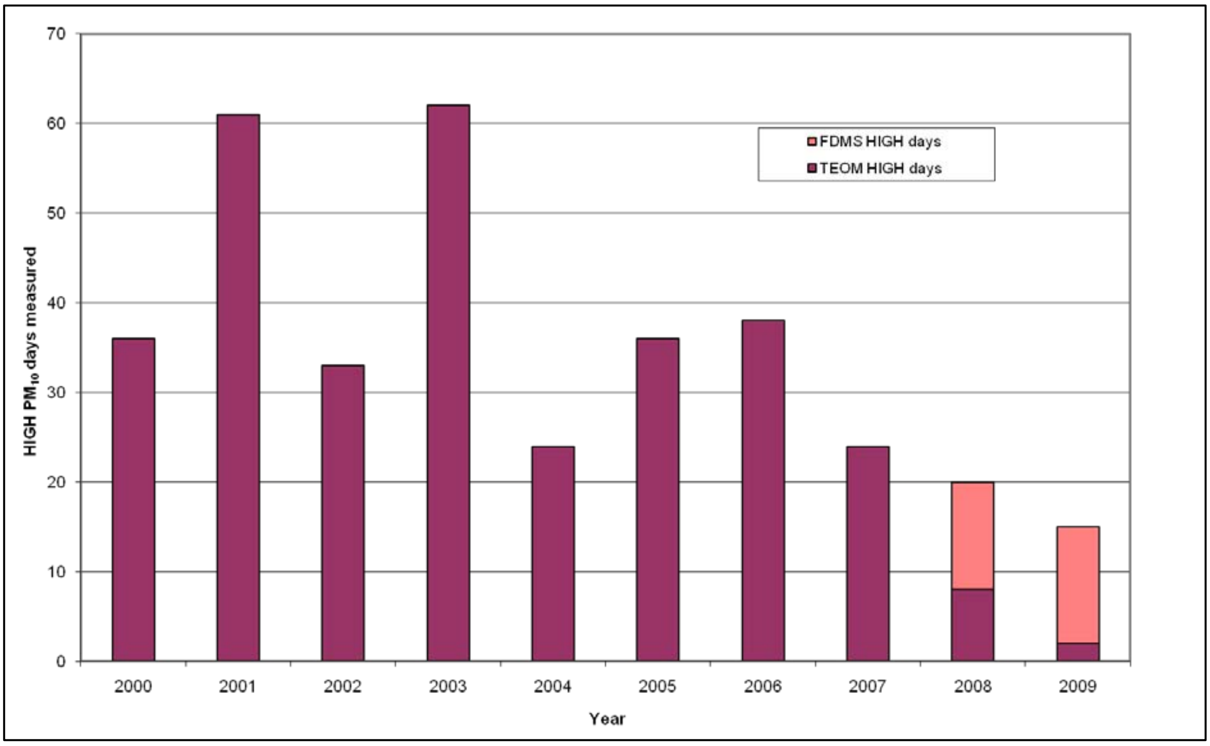


Figure 3.13 *Number of HIGH band measurements for PM_{10} in the UK, 2000-2009.*

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 2009:

- Port Talbot Margam monitoring station is located to the north east of the Corus Steelworks. As a result, emissions from the works are known to contribute to local PM_{10} concentrations when winds are southwesterly.
- Glasgow Central reported elevated PM_{10} and NO_2 concentrations as a result of Christmas market activities.

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.

There was a 100% success rate in uploading the forecast bulletins to the Air Quality Communications contractor and no breakdowns in the service were reported during 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 AEA forecasters and Defra during this period.

The air pollution forecast is always re-issued to Teletext, 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

During this year, two ad-hoc reports were presented to Defra and the devolved administrations. These detailed the extent and circumstances of pollution episodes and are listed below:

- Air Pollution Forecasting: A UK Particulate Matter Episode from 18th to 22nd March 2009 (Colin Rae, Paul Willis AEA).

- Air Pollution Forecasting: A Particulate Episode in England and Wales on the 15th and 16th April 2009. (Andy Cook, Rachel Yardley AEA).

All episode reports which have been published can be found on the National Air Quality Archive at (www.airquality.co.uk/archive/reports/list.php).

In addition to these formal reports, regular contact was maintained with Defra and the Devolved Administrations throughout regarding possible 'HIGH' pollution levels over the UK.

7 Ongoing Research

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.

8 Project and other related meetings

8.1 Project meetings

Regular project meetings continued to be held between AEA and Defra over the course of the year, on January 26th 2009, April 29th 2009 and December 1st 2009.

8.2 Annual air quality forecasting seminar

The Ninth National Air Quality Forecast Seminar took place at the banqueting suite in Birmingham on Thursday 16th July 2009. The event was attended by around 31 delegates who had an interesting day following the agenda described below.

Air Quality Forecasting Seminar –16th July 2009

Agenda	
09:30 – 10:00	COFFEE & REGISTRATION
10:00 – 10:15	Latest Policy Developments at Defra – Sarah Honour
10:15 – 10:30	Paul Willis, AEA – UK Air Quality Forecasting Project Update
10:30 – 11:15	Clare Allen & Andrea Fraser, AEA – WRF/CMAQ model development for UK AQ Forecasts
11:15 – 11:45	Nigel Jenkins – Sussex AirAlert Update
11:45 – 12:15	Patrick Sachon, Met Office – COPD Forecasts
12:15 – 13:15	LUNCH
13:15 – 13:30	Stand-up session – Any news from the participants
13:30 – 14:00	Adrian Simmonds, ECMWF – MACC/GA Project Update
14:00 – 14:30	Lars Gidhagen, SMHI - A Swedish concept of coupling air quality forecasts from the European scale down to local scale
14:30 – 15:00	Tea Break
15:00 – 15:30	Paul Agnew, Met Office - Development of an on-line air quality forecasting system
15:30 – 16:00	David Carslaw, University of Leeds – The Open Source Air Pollution Project

8.3 COST ES0602

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

COST ES0602 Meeting in Budapest, May 11th 2009

Paul Willis attended the COST ES0602 Chemical Weather Forecasting progress meeting at in Budapest at the Hungarian Meteorological Service on May 11th 2009.
Paul made a presentation on innovative public information systems currently under development in the UK, including the use of SMS, Google gadgets, Facebook and Twitter.
On the following day there was a COST fiunded workshop on "Modelling and forecasting atmospheric composition: from individual chemical transport models towards multi-model ensembles". The objectives of the workshop were to evaluate and analyse air quality forecasting models and their operational applications, including the inter-comparison of individual modelling systems and presentation of air quality ensembles. The results of existing major European research projects in this area were reviewed. Finally, the aim was to identify the prominent gaps of knowledge and outline future research needs. Further details of the meeting are available at http://www.chemicalweather.eu/5thMeeting/.

COST ES0602 Meeting in Aveiro, October 13th - 15th 2009

Paul also attended the COST funded joint Pollen & Chemical Weather Forecasting meetings and workshop in Aveiro, Portugal from October 13th – 15th. Paul made the keynote presentation on "Air Quality in Europe" on behalf of the EEA. This included trends analysis, spatial air quality patterns and Directive compliance issues. There was much discussion of the collaboration between EEA and Microsoft to develop the "Eye-on-Earth" concept (http://eoe.eea.europa.eu/) from bathing water to air quality, climate change and other environmental issues. The system includes "participatory sensing" to gather public feedback on the local air quality situation. The meeting also fostered useful interaction between the pollen and air quality communities, including some interesting presentations on the effects of air pollutants on the ability of pollen particles to release their allergens. Early research suggests that in the urban environment pollen particles may be damaged or weakened by air pollution and therefore break open more easily. Preliminary discussions on a common pollen index or joint pollen/pollution air quality index were also commenced.

A summary of the Defra funded UK and European air quality forecast modelling run by AEA is now published on the COST action website alongside the other European research groups - http://www.chemicalweather.eu/Domains.

9 Related projects

AEA ensured that any forecasts, issued under separate contracts, were consistent with the national forecasts 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.

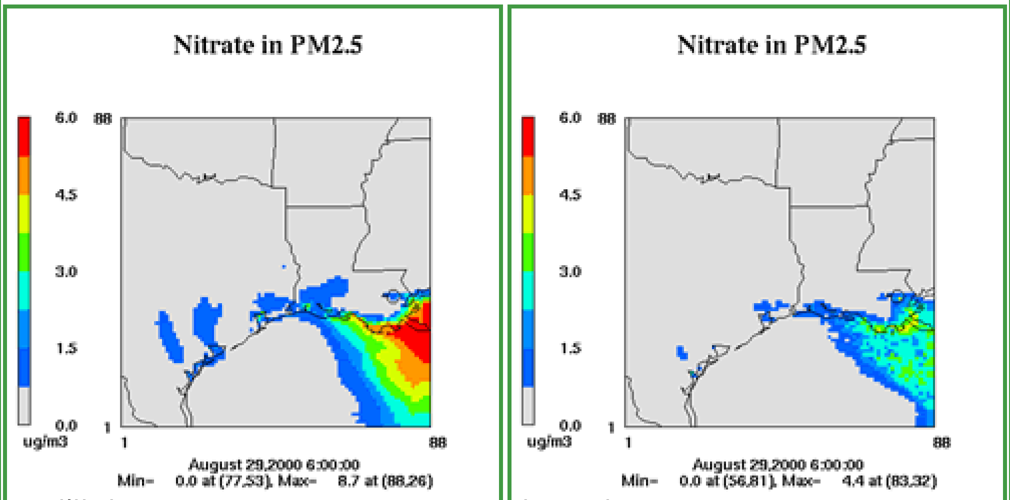
10 Scientific Literature Review

This section reviews a selection of the scientific literature available in the public domain that is relevant to air quality forecasting in 2009.

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

10.1 Forecasting Chemical weather with a coupled meteorology-chemistry model system National Science Foundation

In this 5-year project, NCSU Air Quality Forecasting group is developing a state-of-the-science AQF model system that is capable of forecasting both O_3 and PM in short- and long-term and that is applicable for both research-grade studies and real-time operational forecasts. The AQF model system will be first developed based on the existing NOAA's Weather Research and Forecast Air Quality (WRFAQ) prediction system and then tested, in both retrospective and forecast modes, with testbeds representative of different emissions, chemistry and meteorology in the U.S. A number of sensitivity simulations will be conducted. The proposed research will significantly enhance the fundamental understanding of O_3 and PM, their controlling processes and non-linear interactions, improve the capabilities of air quality models in reproducing and forecasting them, and advance the new discipline of forecasting encompassing weather, climate, air quality, and precipitation forecasting.



equilibrium | dynamic

Predicted daily average nitrate in $PM_{2.5}$ on Aug. 29, 2000 from simulation of WRF/Chem-MADRID with equilibrium and dynamic mass transfer approach.

http://www.meas.ncsu.edu/aqforecasting/research.html

10.2 Monitoring Atmospheric Composition and Climate (MACC)

Monitoring Atmospheric Composition and Climate - is the current pre-operational atmospheric service of the European GMES programme.

Previously the EU-funded GEMS and PROMOTE projects have developed comprehensive data analysis and modelling systems for monitoring the global distributions of atmospheric constituents important for climate, air quality and UV radiation, with a focus on Europe.

The GEMS project concluded on 31 May 2009. Operation and improvement of the systems developed during GEMS is continuing in the MACC programme.

MACC provides data records on atmospheric composition for recent years, data for monitoring present conditions and forecasts of the distribution of key constituents for a few days ahead. MACC combines state-of-the-art atmospheric modelling with Earth observation data to provide information services covering European Air Quality, Global Atmospheric Composition, Climate, and UV and Solar Energy.

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

10.3 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/

10.4 AIRNow-International

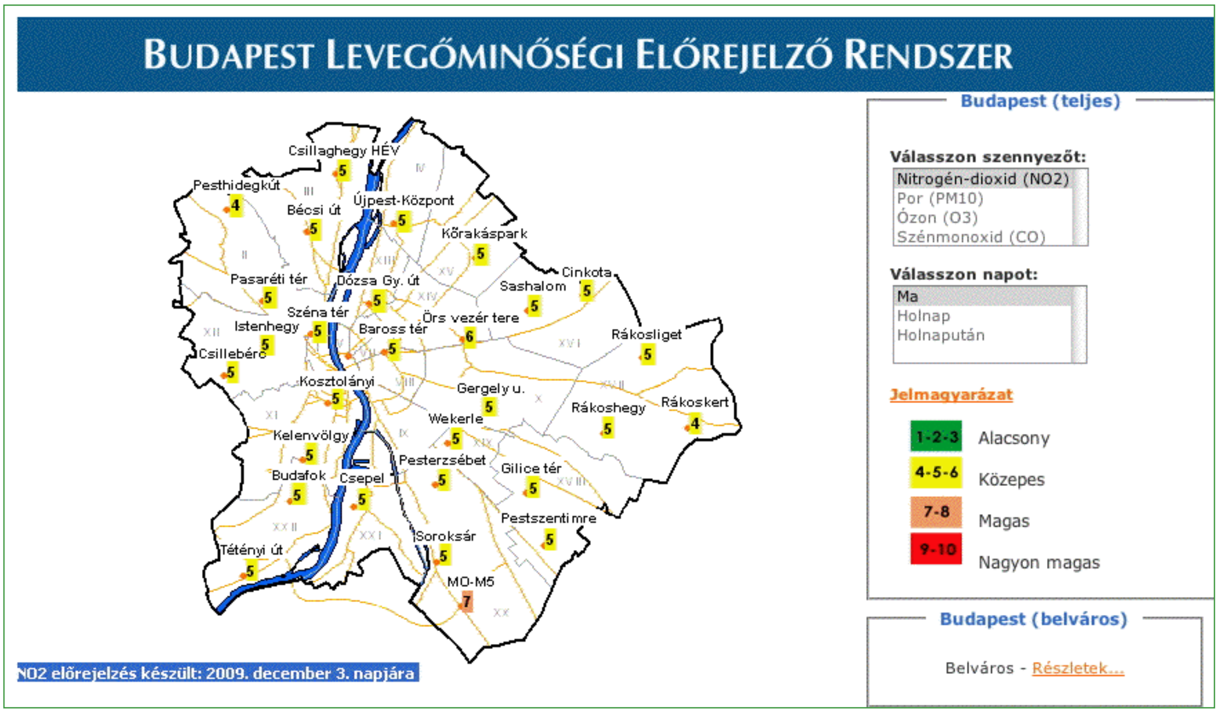
The goal of AIRNow-International is to strengthen relationships among governments and international organizations by sharing the technology to transform air quality data into vital information. AIRNow-International is poised to become the centerpiece of the United States Environmental Protection Agency's (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 Ensemble air quality Modeling forecast System for Budapest and Vienna 2009 (CERC).

On behalf of the European Space Agency, Cambridge Environmental Research Consultants (CERC) installed a high resolution air quality forecasting system for Budapest. Forecasts are produced daily for 3 days by the ADMS-Urban model run in combination with CERC's Rural Predictor that forecasts background concentrations. Predicted air quality levels are displayed as a colour and number index on a map of Budapest. The forecasts have been supported by the Municipality of Budapest and meteorological data are supplied from the Hungarian Meteorological Service.

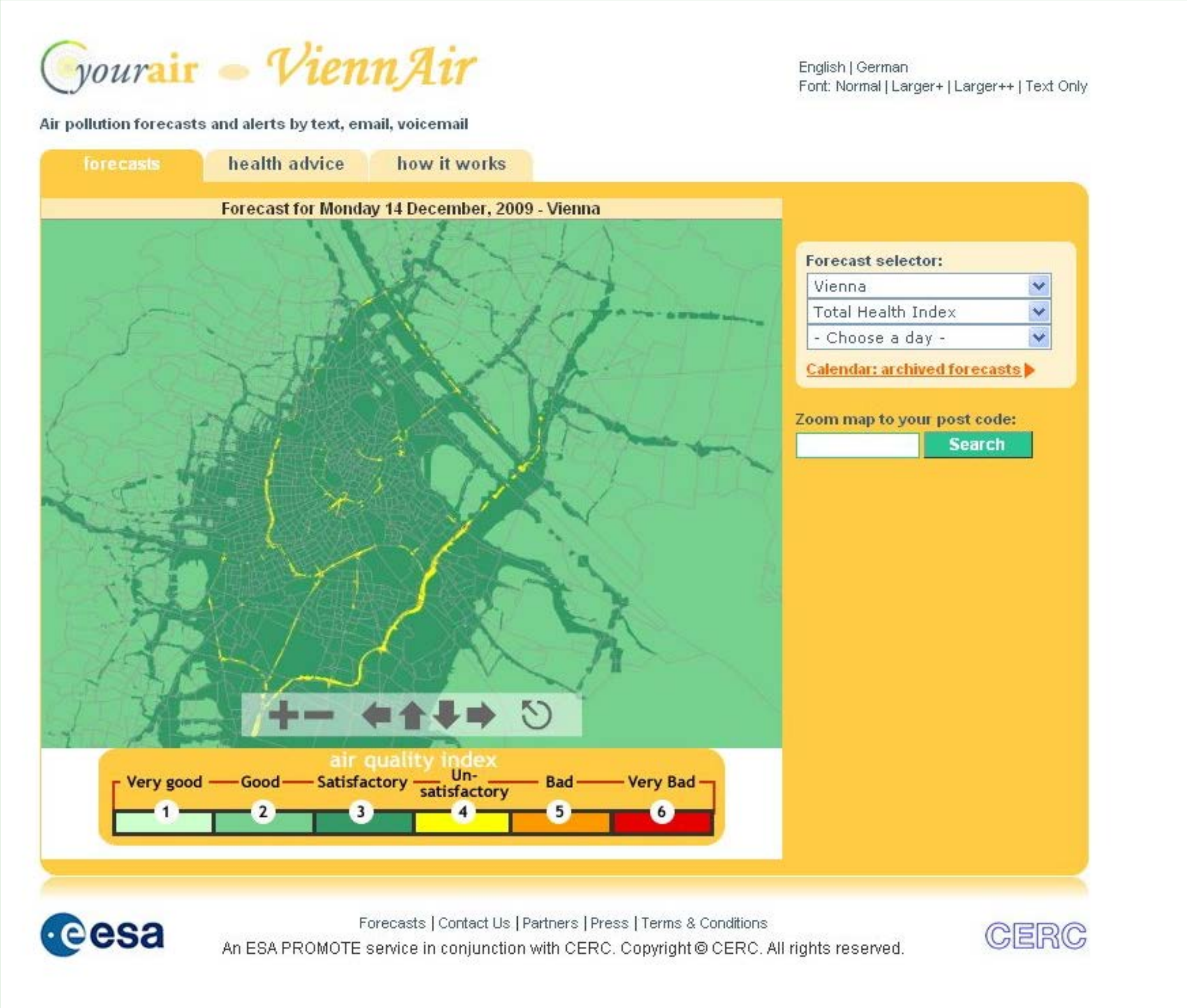
Online forecasts: http://web.t-online.hu/dasy/forecast/Budapest.htm.



The *Vienn*Air system for Vienna was installed in May 2009 in the offices of UBA (Umweltbundesamt GmbH), the Austrian Environment Agency.

Forecasts are currently shown as detailed colour contours overlaid on a zoomable background image. Validation is ongoing and CERC and UBA are working with City of Vienna to integrate the forecast maps with background maps from the City of Vienna map server.

http://www.cerc.co.uk/air-quality-forecasting/austria.html


yourair
ViennAir
English | German
Font: Normal | Larger+ | Larger++ | Text Only
Air pollution forecasts and alerts by text, email, voicemail
forecasts
health advice
how it works
Forecast for Monday 14 December, 2009 - Vienna
Forecast selector:
Vienna
Total Health Index
- Choose a day -
Calendar: archived forecasts
Zoom map to your post code:
Search
air quality index
Very good
Good
Satisfactory
Un-satisfactory
Bad
Very Bad
1
2
3
4
5
6
esa
Forecasts | Contact Us | Partners | Press | Terms & Conditions
An ESA PROMOTE service in conjunction with CERC. Copyright © CERC. All rights reserved.
CERC

11 Forward work plan for 2010

The two tables below summarise both the weekly and annual planned activity for 2010 (Table 10.1 and 10.2 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	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*
Quarterly Reports												
Quarterly Progress Meetings												
Annual reports												
Seminars												

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

http://www.rmets.org/

Atmospheric Environment Journal:
http://www.uea.ac.uk/~e044/ae_newpages/atmosenv.html

The KentAir website:
http://www.kentair.org.uk/pollutionlevels.php

Agnew et al. 2007 Evaluation of GEMS Regional Air Quality Forecasts
http://www.meas.ncsu.edu/aqforecasting/research.html

http://www.cerc.co.uk/air-quality-forecasting/austria.html

http://web.t-online.hu/dasy/forecast/Budapest.htm

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

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

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

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

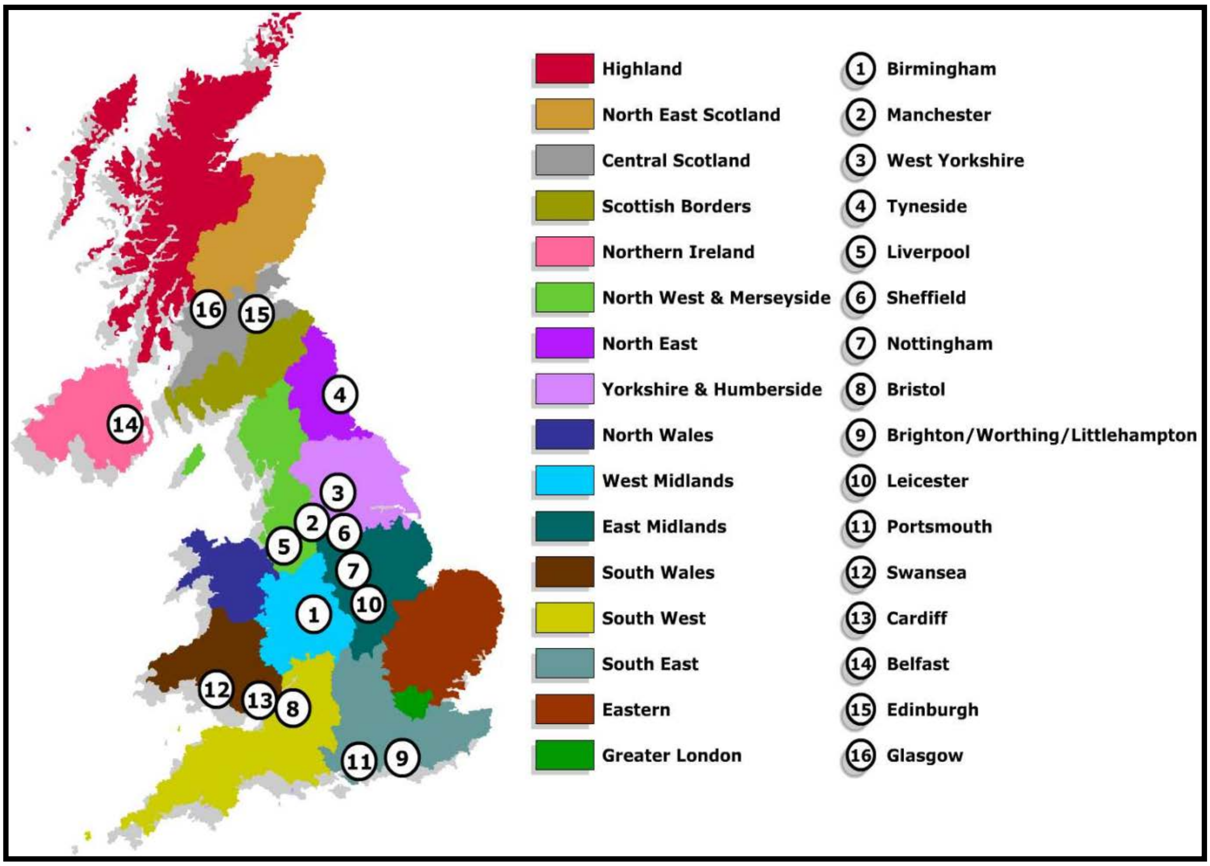
UK Forecasting Zones

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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