A Nationwide background air quality forecasting system for the U.K.

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1 Introduction

Air quality forecasts are of growing interest to U.K. government agencies both national and local, and to the general public. The former use this information to help define and implement abatement strategies, e.g. traffic management schemes. People sensitive to poor air quality need to know when to take medication and/or change their daily routines to minimise health risks.

In order to improve the clarity of the forecasts for the general public the DETR[1] (in collaboration with NETCEN[2] and DoH[3]) have proposed an air quality index (DETR 2001) which combines the effects of the pollutants into one number (1-10, where 1=good and 10=very poor). Each pollutant (NO_2, PM_{10}, SO_2, CO, O_3) is assigned a separate index value (1-10) dependent on their air concentration with respect to their individual health effects (see table 1). The overall index value is the maximum of these five values. The current scheme has four bandings; low, moderate, high and very high which relate to index values 1-3, 4-6, 7-9 and 10 respectively.

Table 1: Proposed new air quality indices for each pollutant (Ozone: maximum of 8-hourly running mean and hourly mean).

New Index	Ozone 8-hourly running /hourly mean (ppb)	Nitrogen Dioxide Hourly Mean (ppb)	Sulphur Dioxide 15-Minute Mean (ppb)	Carbon Monoxide 8-Hour Running Mean (ppm)	PM_{10} Particles 24-Hour Running Mean (μgm^{-3})
		LOW			
1	0-16	0-49	0-32	0.0-3.2	0-16
2	17-32	50-99	33-66	3.3-6.6	17-32
3	33-49	100-149	67-99	6.7-9.9	33-49
		MODERATE			
4	50-62	150-199	100-132	10.0-11.5	50-57
5	63-76	200-249	133-166	11.6-13.2	58-66
6	77-89	250-300	167-199	13.3-14.9	67-74
		HIGH			
7	90-119	300-332	200-266	15.0-16.5	75-82
8	120-149	333-366	267-332	16.6-18.2	83-91
9	150-179	367-399	333-399	18.3-19.9	92-99
		VERY HIGH			
10	≥ 180	≥ 400	≥ 400	≥ 20	≥ 100

The U.K. Met. Office have developed an operational U.K.-wide air quality forecasting system providing information covering the next 72 hours. The system utilises the Lagrangian dispersion model, NAME, and the latest 3D meteorology, to provide twice-daily forecasts for four individual pollutants (NO_2, PM_{10}, SO_2, CO) across the whole of the U.K.

[1] Department of Environment, Transport and the Regions, U.K.
[2] National Environmental Technology Centre (http://www.aeat.co.uk/netcen/airqual/index.html)
[3] Department of Health, U.K.

In order to assess this air quality system NAME has been used to model NO_2, PM_{10} SO_2 and CO at 19 urban areas across the U.K. over 1999 using hindcast meteorology. The air concentrations for each pollutant have been converted into maximum daily species-specific indices and an overall index value and compared to the index values derived from 'background' urban measurements (with ozone excluded).

Ozone was removed from the analysis because it is not as yet modelled by NAME, it is currently forecast using an ozone trajectory model. It is also worth noting that the proposed index ratings for ozone will, even on a very unpolluted day, give an index value of 2 or 3 because of its baseline level of around 35±4.3ppb (Derwent 1998). For all of the other pollutants, index values of one are by far the most common.

NAME Model

NAME is a Lagrangian particle model (Ryall, 1998) in which emissions are simulated by releasing large numbers of particles into a 3-D model atmosphere. Each particle is released with an initial mass of pollutant at a random location within a pre-defined emission volume and at a random time within a defined computational timestep (15 minutes in this study). Species-dependent dry and wet deposition occur at each timestep. If the particle mass falls to zero or if it leaves the model domain (latitude range [-14^o to 15^o], longitude range [44^o to 63^o]) it is no longer considered.

The air quality system models seven different species (sulphur dioxide - SO_2, sulphate - SO_4, ammonia - NH_3, ammonium sulphate - $(NH_4)_2SO_4$, oxides of nitrogen - NO_x, carbon monoxide - CO and primary particulates less than 10μm in diameter - PM_{10}). The sulphate and ammonium sulphate are not released, they are produced by chemical transformations within the modelled atmosphere and are collectively referred to as the sulphate component of secondary PM_{10}. The total PM_{10} at each location is the sum of its primary and secondary components. Other types of secondary PM_{10}, e.g. nitrate aerosol, are not modelled, however it is currently unclear as to what amount of these other components are actually recorded by the TEOM measurement devices currently used in the U.K. (Malcolm 2001) so their exclusion from the modelling may not be significant. No account is taken of NO_x removal by chemical transformation to nitric acid or other compounds. Likewise the rapid interchange between NO and NO_2 is not modelled, the amount of NO_2 (the pollutant of concern) is estimated from the modelled NO_x using the Derwent-Middleton empirical curve (Derwent, 1996).

U.K. emissions of NO_x, SO_2, primary PM_{10} and CO have been derived from the 1km x 1km and point source 1998 U.K. database produced as part of the U.K. National Air Quality Archive by NETCEN. Low magnitude emissions are grouped together into 10 km x 10 km area sources. The traffic components of each pollutant are temporally weighted to reflect characteristic diurnal and weekly cycles and are released within 20 m of the ground. The actual stack heights of point sources are used where known, otherwise they are estimated to be 50 m. Emissions from point sources are released randomly between the height of the stack and 1.5 times the height of the stack. All other emissions (small industrial and domestic) are released between 10 and 50 m. All non-traffic based emissions are released uniformly in time.

The non-U.K emissions have been derived using the EMEP[4] 50km area inventory and are released randomly within 100m of the ground and uniformly in time. NH_3 emissions over the U.K. are derived from EMEP as well but are released within 20m of the ground.

[4] Co-operative programme for monitoring and evaluation of the long range transmission of air pollutants in Europe

Time series of 15 km x 15 km x (0-100 m) air concentrations at 15 minute intervals centred on each of the nineteen urban sites were averaged into hourly values to enable the comparison with the measurements.

The meteorology driving the modelling was hindcast (i.e. not forecast) data from the U.K. Met. Office Numerical Weather Prediction (NWP) suite. It has a horizontal resolution of approximately 50 km and is updated every three hours (Cullen, 1993).

Measurements

The measurements used for the comparison are ‘background’ levels (either urban background or urban centre sites) stored in the U.K. National Air Quality Archive on behalf of the DETR. Most of the cities chosen only have one suitable (classed as either urban centre or urban background) measurement site, others such as London have several. Where multiple sites are available the hourly values are averaged. Averaging the data reduces the dependence of the values on any one receptor and gives an improved representation of city-wide ‘background’ concentrations.

Results and Discussion

Prior to analysis the data have been refined by removing for each location all days when **both** the measured and modelled overall index values are less than four, i.e. focusing the analysis on days when the air quality was moderate or worse, or when the modelled values produced false positive results. Days when any one species-specific index is missing are removed from the data set. The selection procedure reduced the data set from 19x365 to 216 days. The difference between measured and modelled index values overall and per species is given in table 2.

Table 2 The number of days over all locations when the species-specific measured minus modelled index differ by the given amount (Only data where modelled or measured index is greater than 3 and with ozone excluded).

	(Measured Index) – (Modelled Index)																		
	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9
CO	0	0	0	0	0	0	0	0	0	210	6	0	0	0	0	0	0	0	0
SO_2	0	0	2	1	4	16	27	19	30	100	10	2	2	2	0	1	0	0	0
PM_{10}	0	1	2	5	4	3	10	14	16	27	27	19	50	19	8	4	4	1	2
NO_2	0	0	0	0	0	0	0	0	0	173	42	0	0	0	1	0	0	0	0
Overall Index	0	1	2	5	7	9	25	32	16	3	11	23	45	17	9	4	5	0	2

The measured overall index is correctly modelled on only 3 days, the model over-predicts on 97 days and under-predicts on 116 days, however the model is within 3 of the measured index on 72% of the days. The difference between each species is striking; the model and measured indices for both NO_2 and CO are within 1 on all the days considered, SO_2 shows a tendency to be over-predicted by the model, whereas the reverse is the case for PM_{10}.

Figure 1 compares the dominant pollutants (species-specific index equals the overall index) predicted by the model and those measured. If multiple species are considered dominant they are all recorded as such. If the overall index is one (i.e. all of the species-specific indices are one) then they are grouped into one banding.

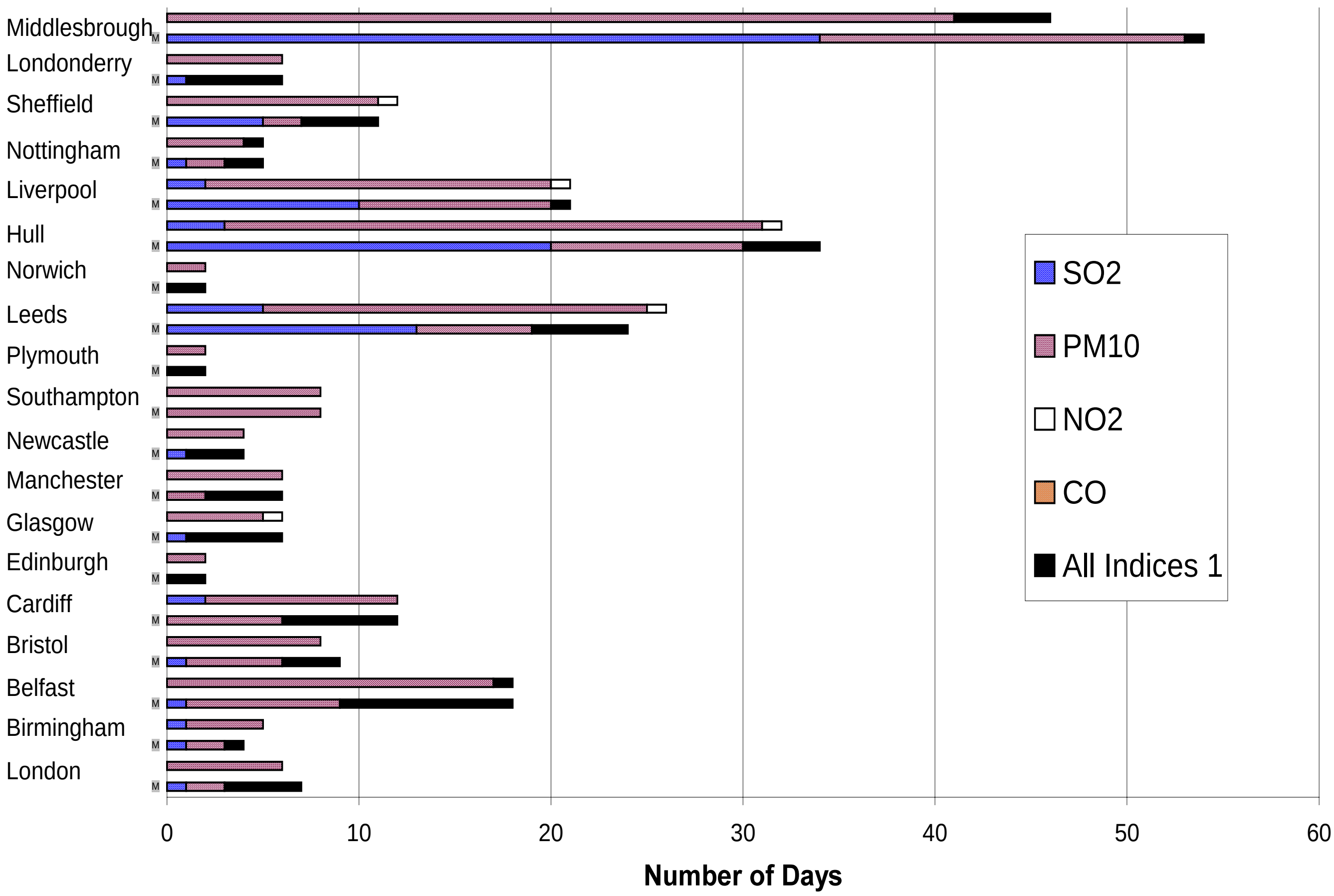

Figure 1 Number of days when each species is the dominant pollutant (can be equally dominant). Each location has bars, the upper is observed (O) and the lower is modelled (M). (Only data where modelled or measured index is greater than 3 and with ozone excluded).

On average SO_2 is modelled reasonably well, with nearly 50% of the 216 data points agreeing with the measured indices. However from table 1 it is also clear that the model is more likely to over-predict than under-predict. This is consistent with the sharp reductions in releases seen at some of the large emitters since 1998, the year the emission data covers, for instance the DRAX power station (NE England) reported a 72% (88 kt per year) cut in emissions from 1998 to 1999 (Air Quality Management, 2000). From figure 1 it can be seen that the model predicts SO_2 to be one of the dominant pollutants on many more days then measured (90 days compared to 13). The locations which are predicted to have the highest number of days with SO_2 as the lead pollutant are Middlesbrough (34 days) and Hull (20 days), both relatively close to the DRAX power plant and hence likely to see the largest changes in SO_2 levels. Plume rise was not directly modelled, its effects were represented by releasing the SO_2 within 1 to 1.5 times the stack height, for some of the big emitters like power stations this maybe insufficient leading to higher modelled ground level concentrations. The SO_2 emissions are dominated by only a handful of sources (approx. 60% U.K. emissions come from 16 sources), this creates a further problem. The modelling uses annual average emission data whereas the actual releases fluctuate on a daily and seasonal basis, e.g. the power station emissions vary according to the demands of the national power grid.

The results indicate that PM_{10} is the least well modelled. The difference between the measured and modelled index values for PM_{10} range from –8 to +9 (table 1). There are two days when the model is predicting an index value of one when the measurements are recording a 10 (both of these days occurred in Cardiff). When the measurement data for Cardiff was inspected, it was found that these high index value days occurred on the 26th and 27th August 1999, and that both were due to excessively high hourly readings on the afternoon of the 26th (543, 410, 338, 272, 422, 103, 29 μgm^{-3} hourly from 12 noon). Such concentrations must either have been very localised or simply be incorrectly reported. This highlights one of the potential errors in assuming that the measured data always accurately represents a general background concentration.

On the whole the model under-predicts PM_{10} (134 days under-predict and 55 over-predict). Part of the reason for this will be due to those components of PM_{10} which are measured but are not modelled e.g. re-suspended particles, biogenic emissions, Saharan dust etc., these components of PM_{10} do not appear in the emission inventories. At present it is not possible to quantify the magnitude of these 'missing components' or to determine when they are significant. This issue is discussed in more detail in Malcolm, 2001. This paper also describes the time series comparison between model and measured data at London. It shows that in general, although the measured PM_{10} is under-predicted, the actual time-series trends are encouraging (month by month correlations varied between 0.43 and 0.85).

It is interesting to note from figure 1 that the dominant pollutant according to the observations is generally PM_{10} (over 93% of the days recorded PM_{10} as such). The modelling in contrast only attributed the dominant pollutant to PM_{10} on 38% of the days, with SO_2 playing a much more significant part as discussed above.

NO_2 is rarely (5 days) measured as being the dominant pollutant and is never modelled as such. CO is never modelled or observed as the dominant pollutant. Both of these species give good comparisons between measured and modelled indices, although both species rarely exceed an index of one, especially CO.

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