DETERMINATION OF COMPLIANCE WITH UK AND EU AIR QUALITY OBJECTIVES FROM HIGH RESOLUTION POLLUTANT CONCENTRATION MAPS CALCULATED USING ADMS-URBAN

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ABSTRACT
The main features and functionality of the urban air quality version of ADMS (ADMS-Urban) have been presented at previous Harmonisation Workshops. The system has now been set up and applied to air quality management, decision support and air quality forecasting in a number of major cities in Europe and beyond, including London. Key recent developments of the system include a regional chemistry model, links to real time and forecasted meteorological data and an advanced emission database (EMIT) for calculating current and projected road traffic emissions from different diurnal traffic flow profiles and vehicle mixes. In this study we consider a detailed analysis of the impact of various road traffic measures, such as high maintenance, low emission zones, increased bus use, reduced traffic flow etc, applied to the Birmingham metropolitan area. We show the impact on compliance or otherwise with the UK National Air Quality Strategy objectives and the proposed EU air quality daughter objectives. We also present high resolution maps of calculations for London of predictions based on projected vehicle emission changes for the years 2004 and 2005. Both these sets of results are being used by policy makers in local authorities in the preparation of their air quality management plans.

KEYWORDS
Air Quality, High Resolution Maps, Air Quality Daughter Directives

1. INTRODUCTION

The UK National Air Quality Strategy (NAQS, DETR 1997) was published in March 1997 and contained health-based air quality standards and objectives to be achieved by 2005 for eight pollutants. These pollutants are benzene, 1,3-butadiene, carbon monoxide, lead, nitrogen dioxide (NO_2), ozone, fine particles (PM_{10}) and sulphur dioxide. In urban areas those objectives most difficult to achieve are predicted to be those for NO_2 and PM_{10} which are as follows:

NO_2 - no exceedence of an hourly mean of 150ppb, no exceedence of an annual mean of 21 ppb

PM_{10} - no exceedence of the 99^{th} percentile of the maximum of the running 24 hour mean of $50\mu gm^{-3}$ (objective is based on measurements carried out using the TEOM analyser or equivalent).

The Strategy also sets out the principles of local air quality management. Local authorities are required to review and assess air quality within their areas and to declare air quality management areas where they consider that one or more of the air quality objectives (with the exception of ozone) will not be met by 2005 through existing measures.

Currently the objectives for NO_2 and PM_{10} are exceeded widely throughout the UK, however it is expected that emissions of most pollutants will decrease markedly by 2005. The reductions will arise largely from the application of more stringent standards to industrial processes through the integrated pollution control and local air pollution control systems, and the coming into force of tighter emission standards for vehicles along with improved fuels through the Auto-Oil Directives.

Subsequent to the publication of NAQS, EU legislation Daughter Directives under the Air Quality Framework Directive have set a range of air quality targets some of which are to be met by the end of 2004 and 2009. These are as follows:

NO_2 - no more than 18 exceedences of $200\mu gm^{-3}$ as an hourly mean to be achieved by the end of 2009; annual mean to be no more than $40\mu gm^{-3}$ (21ppb) by the end of 2009.

PM_{10} - no more than the 35 exceedences of $50\mu gm^{-3}$ as a daily mean; no exceedence of $40\mu gm^{-3}$ as an annual mean to be achieved by the end of 2004. No more than 7 exceedences of $50\mu gm^{-3}$ as a daily mean; no exceedence of $20\mu gm^{-3}$ as an annual mean to be achieved by the end of 2009 (objectives are based on the European gravimetric transfer reference samples or equivalent).

The agreed standards for PM_{10} are much less stringent that those originally proposed. In the UK a proposed revision of NAQS (DETR, 1999) has adopted many of the objectives of the daughter directives.

In this study we present the results of high resolution air quality modelling of NO_2 and PM_{10} for the two major urban areas of Birmingham and London. Modelling for each area has followed a similar approach with the following steps being taken:

(i) Set-up emissions inventory for current (or recent) emissions.

(ii) Validate model performance against available monitoring data.

(iii) Calculate high resolution contour plots for current emissions.

(iv) Estimate emissions for future years relevant to air quality legislation (UK National Air Quality Strategy and EU daughter directives).

In this paper it is not possible to describe in detail each of these steps; instead we refer the reader to relevant texts (Carruthers et al 1998a,b) and focus here on the most important aspects of the studies. In Section 2 we present some background to the two cases and a summary of the emissions. Section 3 describes key aspects of the model set-up, Section 4 examples of validation and Section 5 some examples of high resolution contour plots.

2. EMISSIONS IN LONDON AND BIRMINGHAM

Greater London has a population of some 8 millions, but little manufacturing industry, thus, emissions of NO_X and primary PM_{10} are dominated by road traffic. Some heavy industry is concentrated along the Thames to the east of the city, however this has little impact on compliance with UK and EU air quality standards for NO_2 and PM_{10} (having a greater impact on the SO_2 standard).

The atmospheric emission inventory used for this study is based upon that prepared by London Research Centre (LRC) for Greater London (LRC, 1997). The Inventory includes estimates of emissions from all significant identifiable sources within the M25 motorway which runs around the edge of London, including those due to utilities, industry, transport and domestic energy consumption. Emissions data are expressed for each individual source and also as total emissions arising from 1km×1km Ordinance Survey national grid squares. The nominal base year for the inventory in 1995, although road traffic emissions are for a 1996 base year.

The West Midlands conurbation has a population of approximately 3 millions with the city of Birmingham at its centre. In this area industrial emissions contribute a greater proportion of emissions. The LRC inventory (LRC, 1996) contains aggregated emissions data on a total of 1211 1km × 1km grid squares. Annual emissions are estimated for a wide range of pollutants; these include those for which objectives are defined in NAQS and also other pollutants including black smoke and carbon dioxide. In addition, data are available on the co-ordinates for, and activity rates of, large industrial (Part A) and smaller industrial (Part B) processes and the road network.

For both cities future emissions are based mainly on estimates of changes in traffic emissions which take account of, in Birmingham, regional growth predictions and, in London, the London Traffic Survey (LTS) transport model, and in both cities prediction of emissions based on fuel changes and estimates of percentages of vehicles conforming to the various new emissions standards (EURO II, EURO III etc) have been used. Summaries of emissions of NO_X and PM_{10} for London and Birmingham are shown in Tables 1(a) and 1(b). These show very significant emission reductions by 2005.

Scenario	NO_x (T/a)	% reduction from base	% reduction from 2005	PM_{10} (T/a)	% reduction from base	% reduction from 2005
base (1995)	46889.0	-	-	4846.52	-	-
2005	19508.3	58.39	-	3415.80	29.52	-
2010	15143.2	67.70	22.38	3103.78	35.96	9.13

Table 1(a) Calculated total emissions for the base case (1995) and for 2005 and 2010

Source	Emission rate (T/Yr)			
	NO_x		PM_{10}	
	Baseline	**2005**	**Baseline**	**2005**
Major road	96683	25023	6616	1336
Minor road	12665	3036	933	207
Non-road	42365	40945	2291	2289
Total	**151713**	**69005**	**9840**	**3831**

Source	Percentage contribution			
	NO_x		PM_{10}	
	Baseline	**2005**	**Baseline**	**2005**
Major road	63.73	36.26	67.22	34.87
Minor road	8.35	4.40	9.48	5.40
Non-road	27.92	59.34	23.28	59.75

Table 1(b). Greater London Emissions by source type; 1995 and 2005 emissions

3. MODEL SET-UP

3.1 ADMS-Urban

The model used in both studies is ADMS-Urban (Carruthers et al 1997). This model is now used in many cities in the UK and worldwide, as it has been described elsewhere it is therefore not discussed in detail herein. Key aspects of the model are the treatment of the dispersion from many sources at high resolution and links to complex emissions inventory databases.

3.2 Meteorological data

The London study employed 2 year sequential data (1996, 1997) from Heathrow Airport whilst the Birmingham study used 3 years sequential data (1994, 1995, 1996) from Birmingham Airport.

3.3 Background concentrations

NO_2

For Birmingham a constant background for NO_2 (5ppb) was added to the model calculations; in the London study a generic reaction set was used to calculate the interaction between ozone (O_3), NO and NO_2; this set parameterises the generation of NO_2 by organic pollutants in one reaction.

Background concentrations of pollutants were provided by hourly data from a range of rural sites with the site lying closest to directly upwind being chosen for each hour.

PM_{10}

It is now recognised that the PM_{10} concentration is made up of three significant components, comprising primary emissions, a secondary or long range contribution, mainly sulphate and nitrate from oxidation of gaseous emissions, and a coarse component covering other contributions (eg resuspension). In both conurbations the secondary component is estimated from daily measurements of sulphate – at Birmingham from the UK rural network, in London from a city centre site. The coarse contribution is taken as constant 8μgm^{-3} in London and 5μgm^{-3} in Birmingham.

Backgrounds for 2004 and 2005 have been estimated by adjusting the measured background according to reductions in emissions of NO_X and according to long range transport modelling (sulphate).

4. MODEL VALIDATION

Examples of comparisons of calculated and monitored data are presented for NO_2 (annual mean and hourly maximum) and for PM_{10} annual mean and 99th percentile of rolling 24 hour means (Tables 2 and 3), together with, in the case of London where many more data are available, estimates of the model error represented by the fractional bias. The model generally performs well for mean values but there is some tendency to overpredict maximum values of nitrogen dioxide in London. Two different chemistry schemes were used to predict NO_2 concentrations. These are a correlation based on measurements of NO_X and NO_2 from an urban site (Derwent and Middleton 1996) and a generic reaction set. Also shown in the tables are predictions of the various averages for 2005; these show the impact of the significant emission reductions on concentrations.

Site	annual mean			98th percentile of hourly mean			hourly macimum		
	monitored	total modelled 1995 emissions	total modelled 2005 emissions	monitored	total modelled 1995 emissions	total modelled 2005 emissions	monitored	total modelled 1995 emissions	total modelled 2005 emissions
Birmingham Centre	23.67	23.83	17.85	55.00	46.45	41.2	123.50	136.00	60.8
Birmingham East	20.13	16.96	12.30	48.00	39.95	33.3	189.00	117.95	73.9

(a) NO_2 (ppb); 1995 meteorology

Site	annual mean				99th percentile of rolling 24 hour averages			
	monitored	total modelled	primary	secondary	Monitored	total modelled	primary	Secondary
Birmingham Centre	24.61	30.12	15.51	9.51	74.99	79.56	36.06	52.41
Birmingham East	22.68	18.46	3.89	9.51	66.22	71.98	13.54	52.41

(b) PM_{10} (μgm^{-3}); 1996 meteorology

Table 2. Birmingham comparisons of monitored and model data

Monitoring site	NO_2 concentration (ppb)				NO_X concentration (ppb)				data capture (%)
	Mean	Max	99th %	98th %	Mean	Max	99th %	98th %	
Bank									
Derwent-Middleton	35.6	150	88.3	73.8	137.3	837.9	618.8	548.7	
GRS	46.3	201.4	116.6	94.2					51.32
Monitored	39	148.8	102.5	96.5	220.3	1066.7	915.4	890.2	
Bloomsbury									
Derwent-Middleton	27.0	86.0	52.1	49.3	79.9	619.8	373.2	333.2	
GRS	37.6	174.2	97.7	83.3					66.85
Monitored	36.3	131.0	82.4	74.9	74.4	791.0	300.2	229.9	
Bridge Place									
Derwent-Middleton	22.9	72.6	45.4	44.0	57.5	550.5	251.1	219.7	
GRS	32.8	189.3	94.4	91.3					68.66
Monitored	31.2	172.0	85.0	76.0	59.6	596.0	321.0	238.3	
Earls Court									
Derwent-Middleton	25.4	79.1	47.8	46.1	70.3	575.0	307.4	275.9	
GRS	35.9	184.0	100.9	85.5					70.33
Monitored	27.2	118.0	75.7	68.0	56.8	765.0	332.2	258.0	
Hackney									
Derwent-Middleton	23.1	73.6	50.4	47.5	62.0	531.2	348.9	298.7	
GRS	32.6	155.4	100.7	82.6					66.10
Monitored	32.2	135.0	83.1	73.0	79.7	864.0	378.7	296.0	
Islington									
Derwent-Middleton	23.8	68.1	52.1	49.3	65.9	518.1	374.2	338.4	
GRS	33.1	183.8	94.0	80.5					54.03
Monitored	31.1	166.8	86.3	76.3	52.4	879.8	299.6	217.6	
Marylebone Road									
Derwent-Middleton	38.4	112.0	76.1	73.1	175.6	720.2	563.1	543.8	
GRS	49.4	145.0	112.4	98.5					15.54
Monitored	49.0	150.0	108.0	100.0	195.8	966.0	533.2	463.8	
North Kensington									
Derwent-Middleton	21.5	72.6	45.9	44.6	54.1	525.4	263.5	241.8	
GRS	30.5	144.7	96.7	78.6					69.37
Monitored	24.3	125.0	73.0	65.0	46.3	697.0	346.5	241.0	
Old Kent Road									
Derwent-Middleton	25.3	85.2	45.6	43.7	70.8	614.2	251.7	207.1	
GRS	35.4	133.9	91.8	85.0					17.13
Monitored	36.1	102.0	75.0	71.0	83.4	666.0	247.9	208.0	
Senator House									
Derwent-Middleton	26.7	109.5	48.8	47.6	77.0	784.0	347.6	298.3	
GRS	35.8	113.3	78.2	71.8					43.82
Monitored	31.6	196.2	85.3	67.9	59.1	598.8	307.1	218.1	
Swiss Cottage									
Derwent-Middleton	29.8	175.4	56.5	52.0	98.5	908.3	431.7	367.6	
GRS	41.5	201.4	115.1	95.4					66.43
Monitored	36.6	136.0	87.0	79.0	135.4	1005.0	533.9	439.8	
Walworth Road									
Derwent-Middleton	23.7	59.1	44.3	43.4	58.90	446.7	228.2	207.5	
GRS	31.9	111.5	73.9	67.3					38.70
Monitored	25.2	147.0	65.0	57.0	47.9	560.0	184.1	140.2	
Averages									
Mean Modelled	36.9	161.5	97.7	84.5	84.0	635.9	363.3	323.4	
Mean Monitored	33.3	144.0	84.0	75.4	92.6	787.9	391.6	320.1	
Fractional Bias	-0.12	-0.15	-0.17	-0.13	-0.01	0.18	0.02	-0.12	

Table 3. Model data comparisons for NO_X and NO_2 (ppb) 1997 meteorology at sites in London, showing the mean and the maximum, 99^{th} percentile (99th%) and 98^{th} percentile (98th%) of hourly average concentrations

5. HIGH RESOLUTION MAPS

Examples of high resolution maps for Central London are shown in Figures 1 to 4; these show, using 1997 meteorological data, the annual mean NO_2 concentration for 1996 and 2005 emissions and for 1996 meteorological data, the 99th percentile of the 24 hour rolling average concentration of PM_{10} for 1996 and 2005 emissions. In the case of NO_2, reductions are again significant although not as dramatic as reductions in NO_X, as O_3 is often the key determinant of NO_2 concentrations where NO_X levels are elevated. Road emissions of NO_X are seen to remain dominant even in 2005. In the case of the PM_{10} maps note that by 2005 the impact of road emissions is relatively limited because of the significant reduction in PM_{10} road traffic emissions to small levels relative to other sources. However, by 2005 the air quality target (50µgm^{-3}) still shows widespread exceedence across Central London.

6. DISCUSSION

We have presented a selection of model calculations from ADMS-Urban performed for Birmingham and London. These illustrate both the good performance of the model and the output of high resolution contour maps of concentration contours corresponding to various air quality objectives for current and future emissions. This allows the model to be used for studies corresponding to NAQS and the EU directives. In addition the model is also used in air quality forecasting with meteorological forecasts enabling predictions of exceedence of air pollution alert thresholds.

7. ACKNOWLEDGEMENTS

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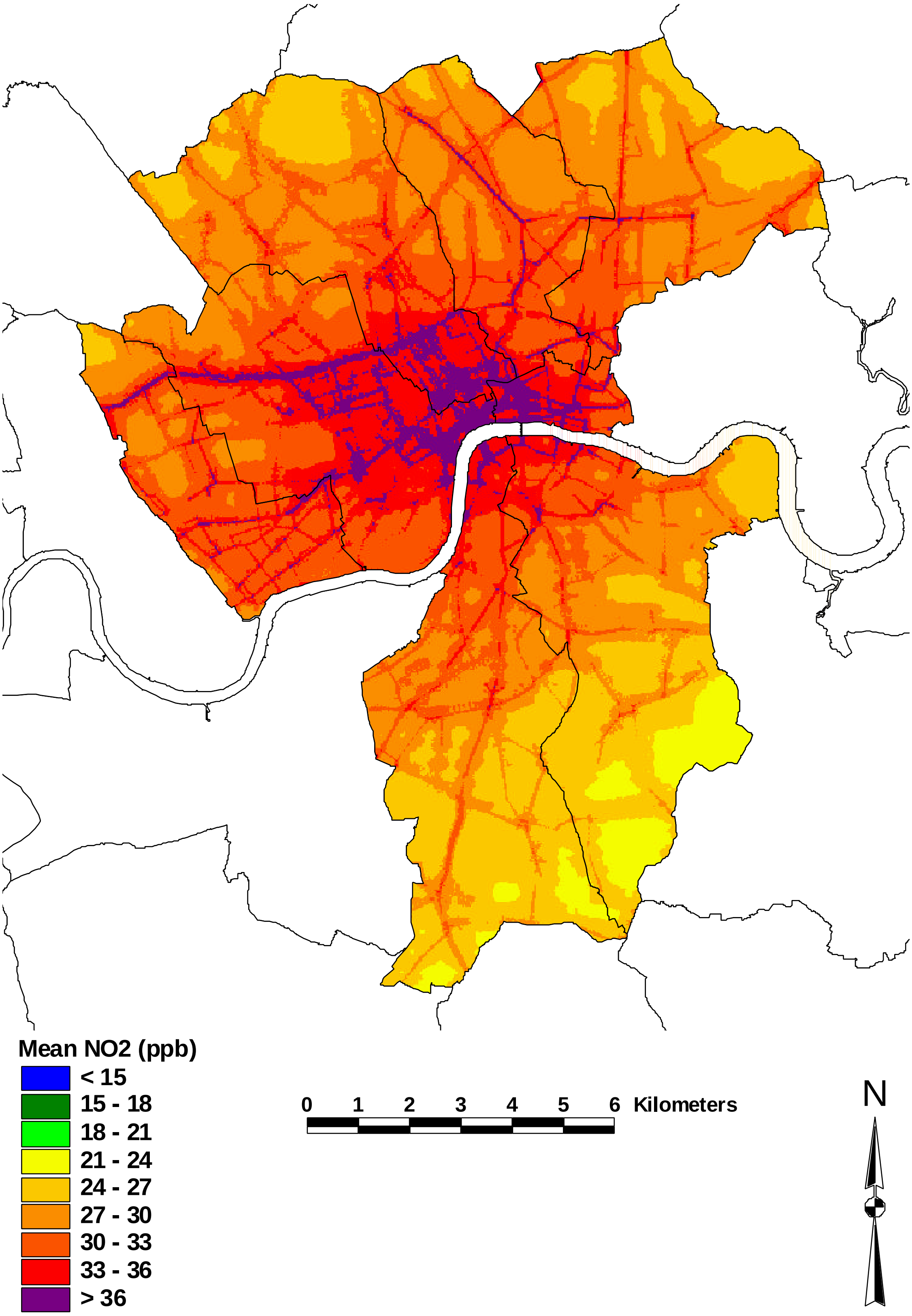

Fig 1. Annual mean NO_2 concentrations for Central London using GRS, base year emissions and 1997 meteorological data

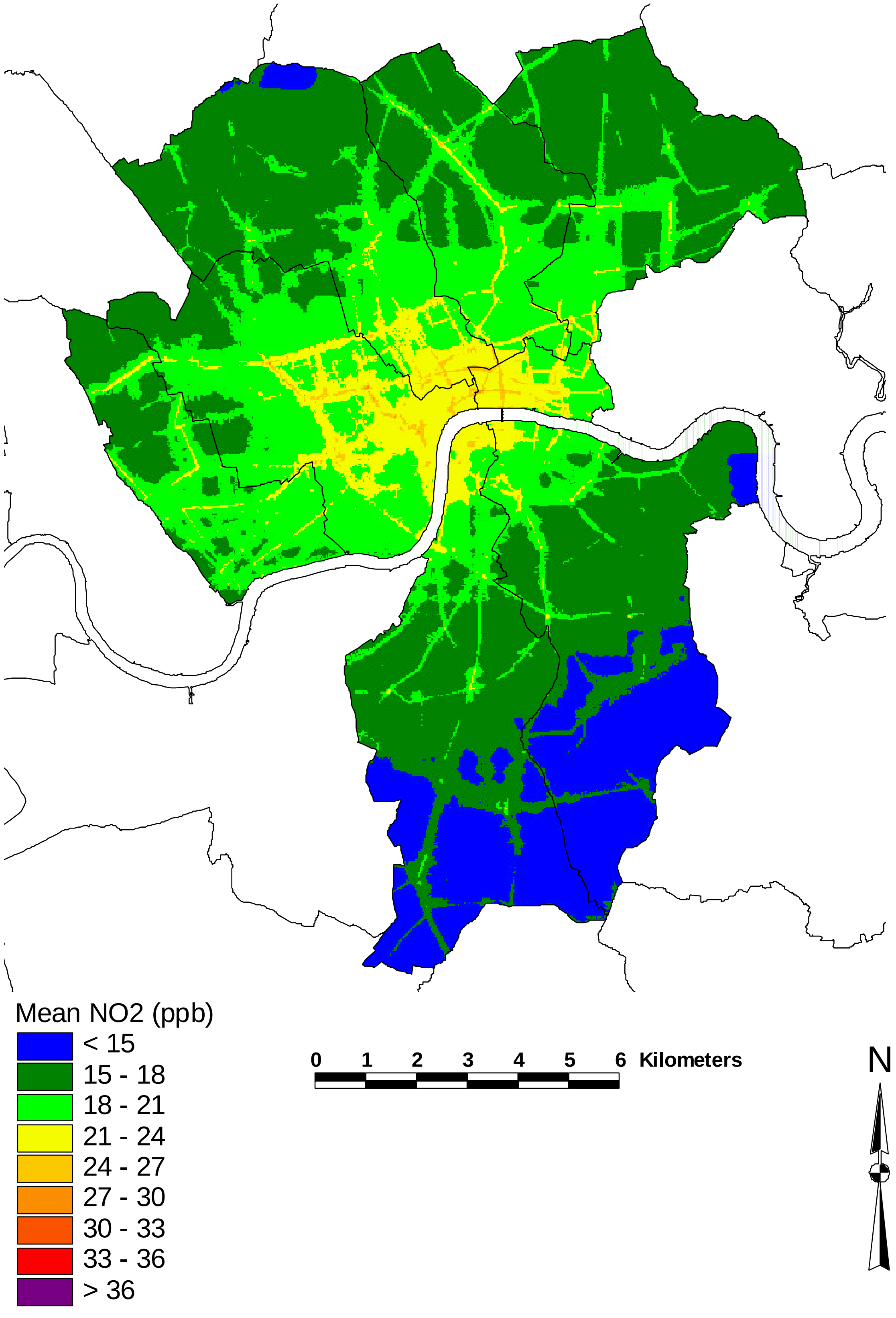

Fig 2. Annual mean NO_2 concentrations for Central London using 2005 emissions and 1997 meteorological data

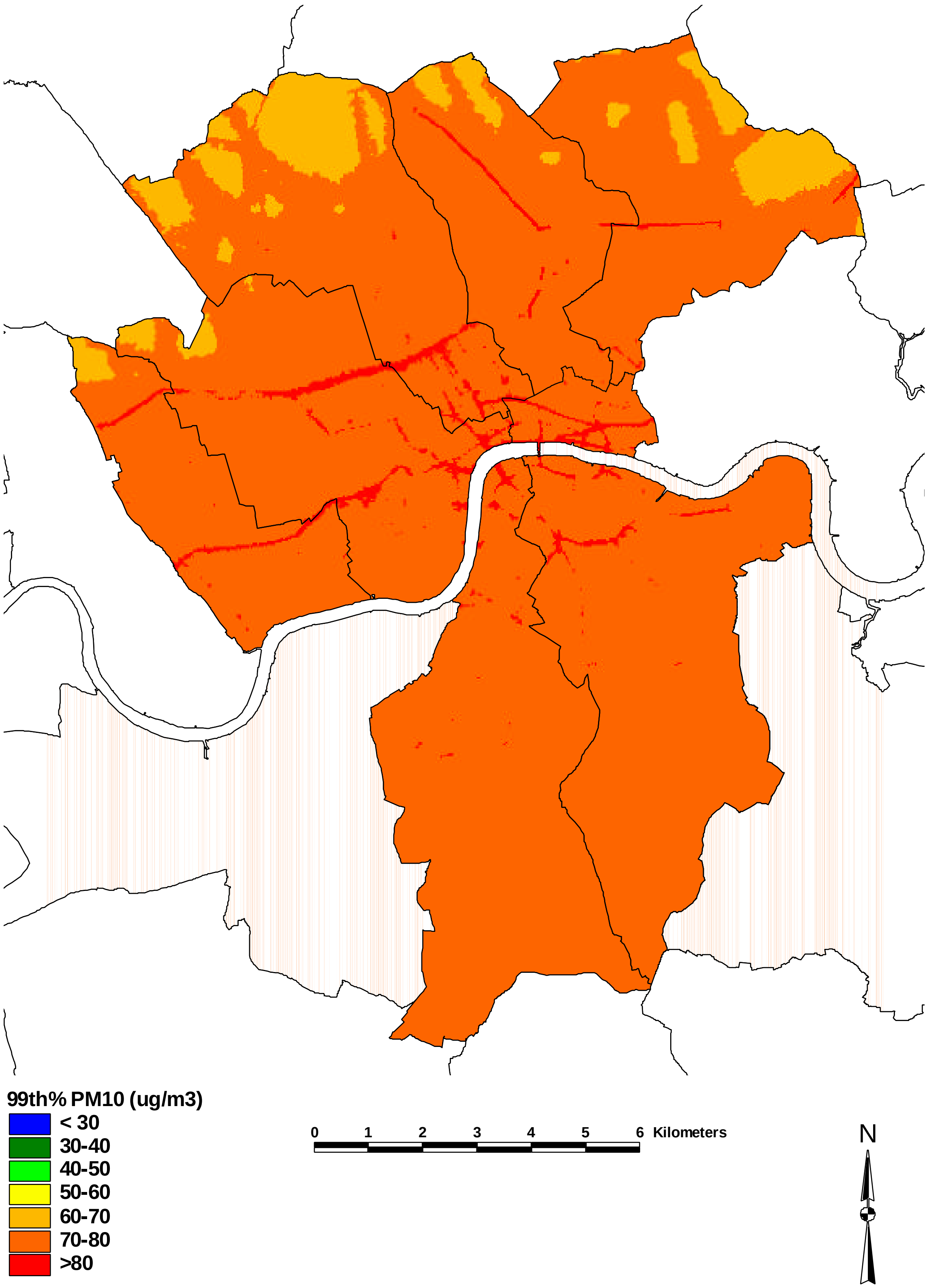

Fig 3. 99th percentile of running 24 hour mean PM_{10} concentrations for Central London using base year emissions and 1996 meteorological data

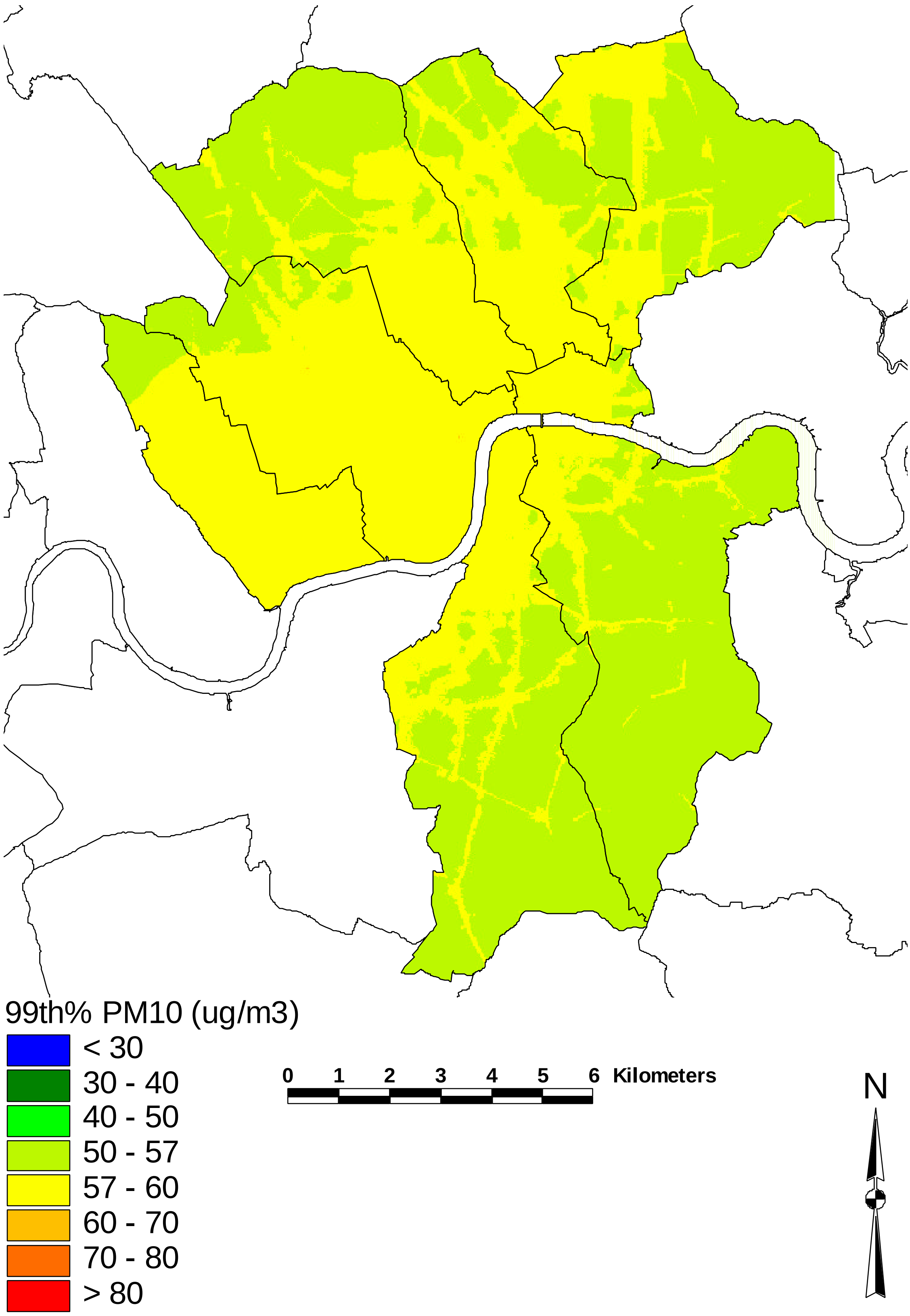

Fig 4. 99th percentile of running 24 hour mean PM_{10} concentrations for Central London using 2005 emissions and 1996 meteorological data