APPLYING MODEL CALCULATIONS TO ESTIMATE URBAN AIR QUALITY WITH RESPECT TO THE REQUIREMENTS OF THE EU DIRECTIVES ON NO_2, PM_{10} AND C_6H_6

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INTRODUCTION

In Norwegian cities air pollution is mainly a wintertime problem related to stagnant meteorological conditions during synoptic high-pressure situations. Because of the large impact on public health the attention have in recent years been focused on the ambient air levels of nitrogen dioxide (NO_2), particulate matter (PM_{10}) and benzene (C_6H_6). Limit levels of NO_2, PM_{10} and C_6H_6 are also defined in the EU Council Directive 1999/30/EC. National pollution and health authorities therefore need detailed information on both present levels of ambient air concentrations and what is to be expected in the future. If exceedances of the EU Directives are to be expected in certain areas, the authorities also want to know the magnitude (in percent) of the different source contributors, for the construction of "blame-matrices". In order to answer these questions, the Norwegian Institute for Air Research (NILU) has performed model simulations and estimated the population exposure for NO_2, PM_{10} and C_6H_6 for the two Norwegian cities of Oslo and Trondheim for the year 2001. These cities were chosen since they are situated in regions with different climatological conditions, thereby reflecting differences both in emissions and dispersion conditions.

Since the highest NO_2, PM_{10} and C_6H_6 concentrations occur in the winter/spring period, due to unfavourable meteorological dispersion conditions, the calculations have only been performed for the winter/spring period. In addition, high concentration levels of PM_{10} are mostly occurring during the winter and spring due to enhanced particle emissions from wood burning (house heating) and resuspended road dust caused by the extensive use of studded tyres in the car fleet.

By applying the Air Quality Information System (AirQUIS), hourly calculations of ground level concentrations have been performed. Both meteorological and air quality measurements existed for the calculation period, allowing for model validation. Emission data were updated according to the newest official estimates. By assuming that all of the highest concentration values occur during the seven months calculation period (January-April and October-December, 2001) the exceedances of the percentile limit values of the EU Council Directive have been estimated. Recalculations have made it possible to establish a ranking of the most important source contributors.

MODEL DESCRIPTION (AIRQUIS)

In this work the Air Quality Information System, AirQUIS, has been used (Bøhler, T. and Sivertsen, B., 1998; http://www.nilu.no/aqm/). This system performs emission-, dispersion- and exposure calculations. The dispersion model applied in this system (EPISODE) is an Eulerian finite difference grid model with embedded sub-grid models for the treatment of line and point sources (Grønskei et al., 1993; Walker et al., 1999). The grid model and the sub-grid models are combined so as to ensure mass continuity. Based on information on the population distribution (stationary distributed according to home addresses), exposure levels are estimated. The application of a sub-grid line source model makes it possible to estimate exposure levels for the population living in the vicinity of the major roads. Obviously there are large methodological uncertainties linked to the calculation of these concentrations, as long as the detailed information of the structure of the buildings along each road segment is missing. However, estimating exposure levels close to roads using grid-averaged concentrations is also inadequate, and therefore the application of rather simplified line source models can be justified.

MODEL VALIDATION

In order to gain confidence in the modelling tools, and to help interpreting the model output, a comparison of measured and calculated NO_2 and PM_{10} values has been performed. The validation was performed using traditional statistical parameters. These statistical parameters are presented in Table 1. In Trondheim measurements both from an urban background station and a street station are available. Unfortunately, for Oslo only observations from street stations were available. The model validation for Oslo is therefore made for two types of street stations; a street station within the central city area (ADT of 20 000 vehicles) and a Thoroughfare at the outskirt of the city centre (ADT of 80 000 vehicles). Note that the statistical figures in Table 1 are solely based on data were both measured and calculated data are available.

Table 1: Statistical parameters used for model validation of NO_2 and PM_{10} for Oslo and Trondheim. The values are based on comparison during January-April and October-December 2001.

OSLO	NO_2 (Urban street station)		NO_2 (Thoroughfare street station)		PM_{10} (Urban street station)		PM_{10} (Thoroughfare street station)	
	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.
Mean value (µg/m3)	40.0	44,5	46.9	61.3	26.9	21.9	33.3	28.2
Standard deviation (µg/m3)	24.4	28.1	31.3	47.0	23.1	29.5	37.6	40.7
Maximum value (hourly) (µg/m3)	184.7	145.3	311,1	319,0	227.8	350.5	310.4	375.4
Correlation coefficient	0.62		0.68		0.39		0.51	
Root Mean Square Error (µg/m3)	17.5		25.2		17.03		21.1	
Slope of linear regression line	0.72		1,02		0.50		0.55	
Intercept of regression line (µg/m3)	15.8		13.2		8.57		9.56	
TRONDHEIM	NO_2 (Urban background station)				PM_{10} (Urban background station)		PM_{10} (Street station)	
	Obs.	Calc.			Obs.	Calc.	Obs.	Calc.
Mean value (µg/m3)	41.6	32.1			37.7	18.5	39.7	24.6
Standard deviation (µg/m3)	28.6	23.5			33.5	24.5	50.3	32.5
Maximum value (hourly) (µg/m3)	157.3	136.8			354.5	339.3	808.6	283.1
Correlation coefficient	0.63				0.35		0.22	
Root Mean Square Error (µg/m3)	18.1				26.0		31.8	
Slope of linear regression line	0.52				0.26		0.14	
Intercept of regression line (µg/m3)	10.42				9.48		18.4	

The validation reveals that the agreement between observed and calculated values is generally much better for NO_2 than for PM_{10}. The main reason for this is, in our opinion, linked to the uncertainties in the estimated particle emissions emanating from resuspended road dust and wood burning (for house heating). Moreover, the statistical parameters presented in Table 1 shows that the model performs somewhat better in Oslo than in Trondheim. This is seen most clearly at the street station in Trondheim where the observed PM_{10} values are severely underestimated by the model. Apart from the underestimation of PM_{10} in Trondheim, the general impression from the validation exercise is that the model system performs reasonably well.

APPLIED LIMIT VALUES

Air quality objectives were set for the three pollutants: nitrogen dioxide (NO_2), particulate matter (PM_{10}) and benzene (C_6H_6). These were derived from recently proposed or adopted Directives, defining limit values to be achieved in 2010. The relevant objectives are shown in Table 2.

Since the highest concentration levels of the pollution components considered typically occur during winter and early spring in Norwegian cities, it is reasonable to assume that the seven-month winter/spring period would suffice for the calculation of the exceedances of the percentile levels of the EU Council Directive. However, since the Directive also define limit values on yearly averages, the calculated seven months mean value has been scaled by a constant in order to estimate the yearly mean value. The scaling constant has been selected using measured ratios between yearly and winter mean urban concentrations. The yearly mean PM_{10}, NO_2 and C_6H_6 concentration values have thus been found simply by multiplying their winter mean values by the scaling factors 0.8, 0.85 and 0.74, respectively. This is of course a very crude simplification, and it obviously adds to the overall uncertainties of the computational results.

Table 2. The EU Council Directive 1999/30/EC limit levels for PM_{10}, NO_2 and C_6H_6 that are to be reached within 2010.

		2010 EU-Council directive
PM_{10}	Limit level (daily average): Allowed days above the limit level:	50 μg/m³ 7 days
	Limit level for the yearly mean value:	20 μg/m³
NO_2	Limit level (hourly average): Allowed hours above the limit level:	200 μg/m³ 18 hours
	Limit level for the yearly mean value:	40 μg/m³
C_6H_6	No limit level defined	
	Limit level for the yearly mean value:	5 μg/m³

EXPOSURE ESTIMATES

Applying the air quality objectives on the calculated concentration levels during the seven winter/spring months of 2001 for the cities of Oslo and Trondheim, we find that a substantial part of the inhabitants are living in areas where the limit levels are exceeded. As an example the number of inhabitants in Oslo and Trondheim experiencing exceedances of the EU-limit values of daily PM_{10} and hourly NO_2 concentrations, are given in Table 3. As seen from this table a large portion of the population is exceeding the PM_{10} limit value. For the two cities considered no exceedances were found for Benzene.

Table 3. Inhabitants of Oslo and Trondheim that are exceeding the air quality limit of the EU-Council directive that is to be reached within the year of 2010.

OSLO	Total number of inhabitants: 507 467	
PM_{10}	Number of inhabitants exposed above the daily EU limit level:	215 455
NO_2	Number of inhabitants exposed above the hourly EU limit level:	370
TRONDHEIM	Total number of inhabitants: 148 859	
PM_{10}	Number of inhabitants exposed above the daily EU limit level:	14 387
NO_2	Number of inhabitants exposed above the hourly EU limit level:	6

ESTIMATIONS OF SOURCE CONTRIBUTORS

The emission data was at the outset divided in 80 categories. These categories were then grouped into the following 7 emission classes: 1) Wood burning applied for house heating, 2) Industry, 3) Primary industry, government administration and private services, 4) House heating except wood burning, 5) Motorized equipment, 6) Harbour and railway activity, and 7) Road traffic. By recalculating the whole period separately with each of these seven classes, a blame matrix was constructed showing their individual contribution to the hours (NO_2) and days (PM_{10}) of exceedances. The result shows that traffic emissions are the main contributor to exceedances of the NO_2 limit value. For PM_{10} emissions from both traffic and wood burning (house heating) are important and the dominating contributor of the two depends on the actual location. Wood burning is dominating in the central downtown area while traffic is of most importance along the main road system.

DISCUSSION AND CONCLUDING REMARKS

The model validation shows that the model results agree reasonably well with the observations. The model calculations show better agreement with the observations for NO_2 than for PM_{10}. This is particularly the case during dry periods in spring (March-April) when high concentrations of PM_{10} is observed due to enhanced traffic induced resuspention of road dust.

The model results should be treated with care, and especially so because extremes values are considered. As shown in Table 1 the calculated maximum values may deviate significantly from their measured counterparts at some of the stations. The EU Directive defines limit levels for rather high percentile values, i.e. the 19 highest hourly NO_2 value and the 8 highest daily PM_{10} value (see Table 2). The model results also show that small changes in estimated concentrations may lead to severe changes in number of people above the limit values. As an example, the calculated number of people exposed between 50 and 60 $\mu g/m^3$ of PM_{10} in Oslo is approximately 90 000. The total number of people with exceedance above the limit value of 50 $\mu g/m^3$ is 215 000 (Table 3). Uncertainties in calculated results are connected with uncertainties both in input data and in the model algorithms.

These findings support the well-known fact that calculations of extremes are more uncertain than estimates of mean level concentrations. The calculated exceedance levels of the high percentile limit levels in the EU directive (i.e. the number of inhabitants with exceedances) should therefore be interpreted more as indicative estimates rather than exact figures.

Despite the difficulties that have been discussed above, the application of Eulerian dispersion models in predicting urban air quality can easily be justified. Recalculations with prescribed changes in emissions can give valuable information on the qualitative effect of various types of abatement measures. Furthermore, model simulations of this type can be helpful in detecting problem areas, as far as air quality is concerned, at an early stage and thereby provide local authorities with important information with respect to city planning.

ACKNOWLEDGEMENT

The Norwegian Pollution Control Authority (SFT) has supported this work financially. The authors gratefully acknowledge the valuable discussion with Municipality of Oslo, Department of Public Health and Municipality of Trondheim, Department of Environment, Section for Environmental Health Protection and active involvement from colleges at NILU.

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