ENVIRONMENTAL IMPACT ASSESSMENT OF AIR QUALITY IN STREET CANYONS RELATED TO COUNCIL DIRECTIVES 1999/30/EC AND 2000/69/EC

C. Mensink, A. Colles, L. Janssen and J. Cornelis
VITO, Centre for Remote Sensing and Atmospheric Processes, Mol, BELGIUM

INTRODUCTION

Air quality models are recognised as valuable tools for ambient air quality assessment and management as required by Council directive 96/62/EC. On one hand, measurements can be complemented or replaced by models as assessment technique, depending on the difference between limit value and representative actual levels. On the other hand, air quality models may help to develop the action plans required for zones where concentrations of pollutants in ambient air exceed limit values.

Information on the limit values and on the expected quality of the model results is provided in the so-called daughter directives. Accuracy for modelling is defined as the maximum deviation of the measured and calculated concentration levels, over the period considered by the limit value, without taking into account the timing of the events. Council directive 1999/30/EC is related to limit values for SO_2, NO_2, NO_x, PM_{10} and lead in ambient air. Council directive 2000/69/EC is related to limit values for benzene and CO in ambient air. A guideline for the accuracy to be obtained is provided depending on the pollutant considered. An overview of these quality objectives is given in Table 1.

The assessment locations are to be sited at locations where the highest concentrations occur to which the population is likely to be exposed. At traffic oriented sites the assessment point should be representative of the air quality in a surrounding area of at least 200 m². At urban background sites this should be several square kilometres. This implies that an air quality model should focus not only on the urban background, but also on calculating representative values at street level.

For the assessment of air quality in cities, Vito introduced an *integrated model system*, known as AURORA (**A**ir quality modelling in **U**rban **R**egions using an **O**ptimal **R**esolution **A**pproach). This urban air quality management system has been designed for urban and regional policy support and reflects the state-of-the-art in air quality modelling, using fast and advanced numerical techniques. More details of this model are given in section 2.

In section 3 we discuss the application of AURORA to 11 selected streets in the City of Antwerp in order to evaluate the concentration levels of NO_2, SO_2, PM_{10}, CO and benzene. In section 4 the results are analysed and compared with measurements of an urban monitoring station.

THE AURORA MODEL

The integrated model system AURORA (Mensink *et al.*, 2001a) consists of various modules that have been designed and tested, resulting in an urban air quality management tool that can provide reliable answers to policy makers and traffic planners. The model system is implemented in the city of Antwerp and is applied in various EU 5th framework projects (BUGS, DECADE,…).

Table 1. Quality objectives for air quality modelling as provided by the Council directives

Averaging period	SO_2 & NO_2	PM_{10}	Benzene	CO
hourly	50% - 60%	-	-	-
8-hourly	-	-	-	50%
daily	50%	N.A.	-	-
yearly	30%	50%	50%	-

The model input consists of terrain data (digital elevation model, land use, road networks) that are integrated in a GIS system. Meteorological input data are provided, with a resolution up to a few hundred meters, by a separate meteorological model (ARPS). The emission input data are resulting from a detailed inventory and acquisition of existing emission data in combination with emission modelling (Mensink *et al.*, 2000). In this way the emissions are described as a function of space, time and temperature.

The physical and chemical processes are modelled in a modular way following the state-of-the-art in urban air quality modelling and involving large-scale computations. Every module was tested and validated individually before integration in AURORA. The most important parts of the model system are the modules for physical transport phenomena (advection, diffusion, deposition, etc.) and the modelling of photochemical processes and chemical reactions. These modules include some advanced and improved numerical solvers. Concentrations at the street level are estimated by means of the Street box module (Mensink and Lewyckyj, 2001b), using the 3D spatial configuration of the considered street and the related traffic information.

MODEL APPLICATION

The Street box model (Mensink and Lewyckyj, 2001b) has been applied to compute concentrations of the pollutants SO_2, NO_2, PM_{10}, benzene and CO in 11 selected streets in the City of Antwerp for the year 1998. For the five pollutants considered, the hourly emissions inside the streets are obtained from the results of the urban traffic emission module (Mensink et al., 2000). This model computes hourly emissions coming from passenger cars, light duty vehicles, heavy duty vehicles and busses in the Antwerp area, in function of road type, vehicle type, fuel type, traffic volume, vehicle age, trip length distribution and the actual ambient temperature. Cold start emissions and evaporation losses are included in the model. The emission calculations are based on an urban traffic flow model, actually used by the Antwerp City authorities for traffic management purposes. The urban traffic flow model contains a network with 1963 road segments and was implemented in a GIS environment. For each segment of the network the number of vehicles is predicted. The emission factors used in the model are derived from the COPERT-II methodology (Ahlvik et al., 1997) and are presently being adapted to the COPERT-III methodology.

The hourly meteorological values for wind speed and wind direction were obtained from two meteorological towers located in the city. Wind speed at roof level was calculated from a wind profile described by a power law, with the exponent derived from the wind speed measured at heights of 30 m and 153 m respectively. The averaged regional background concentrations needed for the Street box model were computed by means of the Operational Priority Substances (OPS) model (van Jaarsveld, 1990). This model has been applied to obtain concentrations on a 1x1 km² grid covering the Flemish region in which Antwerp is located. OPS is a Lagrangian trajectory model for long-term simulations, ranging from a few days to several years. The model computes concentrations, dry and wet depositions for primary and secondary components. It uses a climatological database with statistical values for 18 meteorological parameters. The climatological database is constructed by a meteorological pre-processor using hourly observations of wind direction and wind speed (measured at two heights), global radiation, temperature, precipitation intensity and precipitation amount. Other input data are related to the receptor characteristics (roughness length) and the emission sources (co-ordinates, dimensions, source strength). The model has been implemented and validated for the Flemish region.

The monitoring station is located in one of the streets (Plantin en Moretuslei) included in this study. It is part of the telemetric network for the monitoring of air quality in the Flemish region. The network is operated by the Flemish Environmental Agency (VMM, 1999a). Averages and percentiles for NO_x, SO_2 O_3, NMVOC and PM_{10} are reported on a yearly base (VMM, 1999b).

RESULTS AND DISCUSSION

For the street "Plantin Moretuslei" in Antwerp the model results for SO_2, NO_2, PM_{10} and benzene are compared with measured values in Figure 1. The error bars show the accuracy levels given in Table 1. The first two bars in Figure 1 show the measured and computed $P_{99,726}$ for hourly averaged values of SO_2. This corresponds to 24 exceedances per year for the hourly values. The next two bars show the $P_{99,178}$ values for daily averages (3 exceedance days per year). The measured and modelled hourly averaged NO_2 concentrations are compared as $P_{99,795}$ value (18 exceedances per year) and as yearly average. Note that in Figure 1 the $P_{99,795}$ values are divided by 10 for scaling purposes. Next in Figure 1 are the $P_{90,41}$ for daily averaged PM_{10} concentrations (35 exceedances per year, 2005), the yearly averaged PM_{10} concentrations and the $P_{98,08}$ for daily averaged values (7 exceedances per year, 2010). Finally the last two bars show the yearly averaged benzene (BZN) concentrations as measured and modelled in the street "Plantin Moretuslei". The figure shows that for all pollutants, the modelled percentiles and averages fall within the accuracy bounds provided by the guideline.

For the same pollutants and percentiles, the modelled values as averaged over the 10 other selected streets in Antwerp are compared with the measured value in the street "Plantin Moretuslei". This is shown in Figure 2. Now the error bars show the standard deviation for the modelled results. In Figure 2 we see that the calculated SO_2 concentrations are hardly varying from one street to the other. This indicates that the hourly SO_2 concentrations are almost completely determined by the background concentration and that the contribution from traffic sources within the street is very limited. The measured values are lower than the calculated values for SO_2 (see Figure 1), indicating that the calculated background concentrations are overestimated.

The results for NO_2 give a completely different picture. The calculated hourly concentrations show much more variation between the individual streets. It is clear that here the concentrations are dominated by the contributions from traffic. Since the $P_{99,795}$ is a very high percentile it is very sensitive to particular circumstances. Despite this, the accuracy bounds are not exceeded.

The calculated PM_{10} concentrations in the 10 streets show little variation from street to street. Also in this case, the background contribution seems to be relatively high. Despite the fact that the maximum deviation between measured and calculated results is only 18% for the P_{90} and 17% for the P_{98}, the model is not correctly representing the PM_{10} situation within the streets. The small differences (< 4%) in the calculated results for P_{90} and P_{98} indicate a very high contribution from background concentrations. But the difference between the measured P_{90} and P_{98} is much larger (44%), which demonstrates that there is much more (daily) variation within the street than the model predicts. Thus in the model results the contribution from the street itself is underestimated.

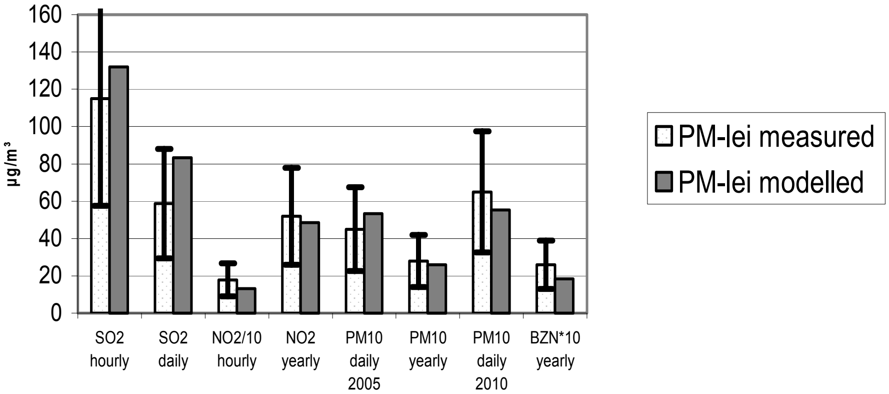

Figure 1. Comparison of measured and modelled limit values for the street "Plantin Moretuslei" in Antwerp, with the error bars indicating the required accuracy levels.

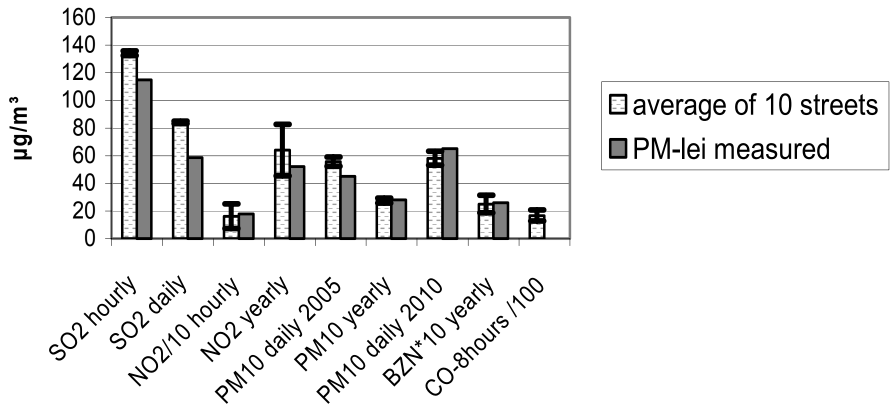

Figure 2. Comparison of the modelled limit values averaged over 10 selected streets in Antwerp and the measured limit values for the street "Plantin Moretuslei" in Antwerp, with the error bars indicating the standard deviation for the 10 streets.

The calculated yearly averages for benzene are ranging from 1,79 to 3,63 µg/m³. This large variation indicates that here the concentrations are dominated by the traffic contribution as well. The measured value of 2,6 µg/m³ fits within this range, with a maximum deviation of 40%. Measurements for CO are not available within the Flemish region. In Brussels the measured CO concentrations varied in 1998 between 0,6 and 2,7 mg/m³. The calculated values for the 10 streets in Antwerp varied between 1,3 and 2,4 mg/m³.

CONCLUSIONS

The AURORA model was applied to 11 selected streets in the City of Antwerp in order to make an assessment against the air quality limit values as provided by the Council directives. Comparisons with an urban measurement station in one of the 11 streets show agreements that are within the uncertainty range given by the guidelines in the EU directives. An analysis of the measured and modelled concentrations and percentiles allows an evaluation of the contribution from traffic for each of the pollutants considered. The model shows that traffic contributions are relatively important for NO_x, benzene and CO and less important for SO_2 and PM_{10}, where background concentrations are predominant. The result for PM_{10} is not confirmed by the measured higher percentiles. The (emission) model seems to underestimates the daily variations in PM_{10} caused by traffic.

REFERENCES

Ahlvik, P., E. Eggleston, N. Gorissen, D. Hassel, A.-J. Hickman, R. Joumard, L. Ntziachristos, R. Rijkeboer, Z. Samaras, and K.-H. Zierock, 1997: COPERT II Computer Programme to Calculate Emissions from Road Transport, Methodology and emission factors, 2nd edition, European Environmental Agency, European Topic Center on Air Emissions.

Jaarsveld J.A. van, 1990: An Operational atmospheric transport model for Priority Substances; specification and instructions for use, RIVM report nr. 222501002, RIVM, Bilthoven, 101 pp.

Mensink, C., K. De Ridder, N. Lewyckyj, L. Delobbe, L. Janssen and Ph. Van Haver, 2001a: Computational aspects of Air quality modelling in Urban Regions using an Optimal Resolution Approach, in: S. Margenov, J. Wasniewski and P. Yamalov (Eds.) Large-Scale Scientific Computing, *Lecture Notes in Computer Science*, **2179**, 299-308, Springer-Verlag.

Mensink, C. and N. Lewyckyj, 2001b: A simple model for the assessment of air quality in streets, Int. *Journal of Vehicle Design*, **27** (1-4), 242-250.

Mensink, C., I. De Vlieger and J. Nys, 2000: An urban transport emission model for the Antwerp area, *Atmospheric Environment,* **34**, 4595-4602.

Vlaamse Milieumaatschappij, 1999a: Air quality in the Flemish region 1998, I. Textual part, Flemish Environmental Agency, Aalst (in Dutch), 178 pp.

Vlaamse Milieumaatschappij, 1999b: *Air* quality in the Flemish region 1998, II. Appendices, Flemish Environmental Agency, Aalst (in Dutch), 118 pp.