HOW TO DETERMINE URBAN BACKGROUND CONCENTRATIONS FROM TRAFFIC FLOWS IN NEIGHBOURING STREET CANYONS?

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INTRODUCTION

Hourly background concentrations are required in the application of street canyon models, like e.g. the OSPM model (Berkowicz, R., 1998). These background concentrations should reflect in detail the hourly contributions stemming from other (surrounding) roads, as well as contributions from industrial stacks, domestic heating and the regional background. In many cases these background concentrations are estimated by regional scale models with a limited temporal or spatial resolution (Mensink, C. *et al.*, 2003).

In order to obtain detailed urban background concentrations, a novel approach has been developed consisting in the coupling of a street canyon model (OSPM) and a Gaussian model (IFDM). OSPM calculates the contribution of the traffic emissions inside a particular street, whereas IFDM computes the background contributions, including the concentration levels caused by the surrounding streets, industrial stacks and domestic heating within a domain with a 20-30 km radius. Both models are integrated into an advanced computer program, as will be discussed in more detail in section 2.

The coupled system was applied to a city quarter in Ghent, Belgium. For this exercise, traffic emissions were obtained dynamically from the traffic simulation model PARAMICS. The dynamic emission allocation is derived from emissions measurements (Mensink, C. *et al.*, 2005) and is used to calculate for each time step and for each car, the emission of 5 pollutants (PM, VOC, NO_x, VOC and CO_2) depending on the type of car, its speed and its acceleration. These emissions are recorded for every meter along the streets. Results of this application of the coupled OSPM-IFDM model are presented in section 3.

METHODOLOGY

The general framework for the applied methodology is shown in Figure 1. The input data for both the OSPM model (street canyons) and the IFDM model (urban background contribution from other streets and stacks) consist of stack and traffic emissions and of meteorological data obtained from nearby meteorological towers. The calculation of the traffic emissions is based on the output of PARAMICS (Quadstone, 2004). For every individual simulated vehicle, PARAMICS provides its position and its instantaneous speed and acceleration. Driving behaviours, vehicle accelerations, etc, … are modelled in a detailed way, which is important in order to accurately model noise and emissions produced by vehicles. Macroscopic traffic models do not take into account these parameters. The emissions are allocated dynamically (Mensink, C. *et al.*, 2005) using a set of specific emission functions. For this application, the specific emission functions are based on the extended dataset of VITO's on-the-road-vehicles emission measurements (De Vlieger, I., 1997).

The Danish Operational Street Pollution Model or OSPM (Berkowicz, 1998) is widely used for impact assessments of traffic emissions in street canyons. In OSPM the concentrations are computed by a combination of a plume model for the direct contributions from the traffic emissions and a box model for the re-circulating part of the pollutants, using parameterisations to describe the local flow and dispersion characteristics. Turbulence generated by traffic is creating additional diffusion. This is included in the model.

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Figure 1: General framework for the integration of the OSPM model (street canyons) and the IFDM model (urban background contribution from other streets)

The model has been tested for different street configurations and various meteorological conditions. Concentrations for PM, NO_x, CO, ozone and benzene can be calculated both on leeward and windward side of the street. The model needs as input the (varying) height of the buildings along the street, the width, length and angle of the street, meteorological data (wind speed and wind direction at 10 m above roof level) and background concentrations.

The Belgian bi-Gaussian model IFDM is a reliable tool for the impact assessment of time varying emissions from point sources (industry), area sources (residential heating) and line sources (traffic lanes) (Cosemans et al., 1997). IFDM is presently the regulatory impact assessment model in Flanders. It's basically a bi-Gaussian atmospheric transport and dispersion model generating time series, cumulative frequency distributions and statistics of hourly concentration and depositions over a specified period of time. The values are calculated for an arbitrary set of receptors, which can be defined by a regular grid superimposed on the region of investigation (Figure 2) or equally spaced along a street canyon network (Figure 3). Output of aggregated hourly values, e.g. into daily averages, is possible. As input data, the model requires hourly time series of the emissions (or averaged over a time interval) and the hourly meteorological conditions. A complete model description is available in the Model Documentation System (MDS) of the EEA at http://etc-acc.eionet.eu.int.

OSPM and IFDM have been integrated into a new Fortran program (dashed box in Figure 1) that allows for the computation of the impact of all emissions affecting the urban region, taking into account the street canyon effect for those receptors where this is required. The existing IFDM user interface for data entry, application management and data reporting has been adapted for this integrated model as well. This implies that standard IFDM-output, such as percentiles of hourly or daily concentrations, yearly averages, average concentration for each hour of the day,... are reported in a way ready for post-processing by existing and newly written software.

The first step in the application of the integrated model system, is the reading of the traffic emission data from the files generated by the PARAMICS traffic simulation software. For the IFDM sub model, a network of line sources is derived from these data resulting in hourly emission data for each line source. These emissions are possibly complemented by emissions from industry and residential heating. All emissions are used to compute the background air pollution over the entire urban region, including the pollution due to upwind sources that enters the street canyons.

As a second step, OSPM receptors are created every 10 or 15 meter along the street axes of the street canyons in the region considered. For each receptor, a description of the street canyon geometry and of the emissions therein is generated, as well as a line source which is used to prevent double accounting of the emissions in the street. The contribution from this line source representing the street for which the direct traffic contribution is calculated using OSPM, is subtracted from the background concentration. In this way the genuine hourly background concentration is obtained, without double counting the contribution from the street canyon considered.

RESULTS AND DISCUSSION

The study area for the model application is Gentbrugge, a city quarter in Ghent, Belgium. Traffic flows, traffic emissions and stack emissions were obtained for the year 2003. Hourly emissions and concentrations for $PM_{2.5}$ and NO_x were calculated with a resolution of 25 m, using meteorological data for 2003. Figure 2 shows the yearly averaged urban background concentration of $PM_{2.5}$ for 2003 in Gentbrugge. The black lines represent the road network in the area. Note that the double line in the lower right corner of the figure is associated with a highway. It has its exit located near the bottom of the figure. It is here that we find the highest concentrations of $PM_{2.5}$. The influence of this highway exit stretches away to a few hundred meters down town, where an urban background concentration of 3 µg/m³ is found.

Figure 3 shows a detail of the $PM_{2.5}$ concentrations inside the dashed box plotted in Figure 2. This detailed plot shows a few streets in the northwest of Gentbrugge. The numbers in the figure show the $PM_{2.5}$ concentrations inside street canyons as calculated by OSPM, with inclusion of the urban background contribution. The colours show only the urban background concentrations of $PM_{2.5}$, as calculated by IFDM. These concentrations are a result of all other point and line sources in the neighbourhood. We can observe that on average 40 – 50% of the annual concentrations inside the streets is coming from this urban background.

A final remark should be made on the computational time required to obtain the results. It is in the order of a few minutes, which allows a very quick assessment of the air quality situation. This demonstrates a great advantage of using a Gaussian approach: it is very fast.

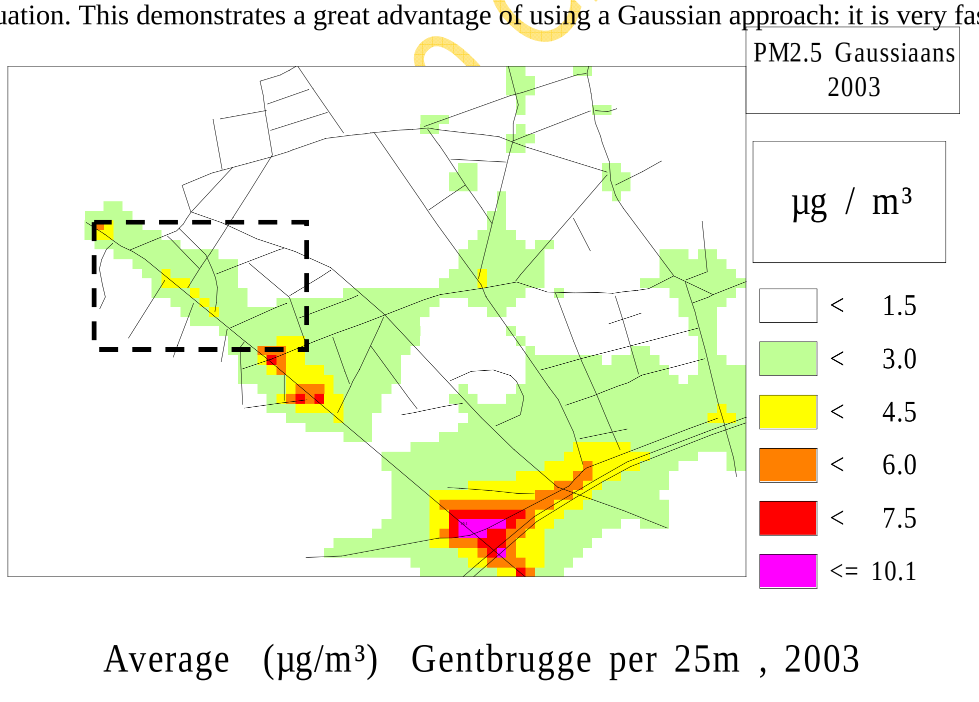

Figure 2 : Calculated urban background concentrations of $PM_{2.5}$ for 2003 in Gentbrugge.

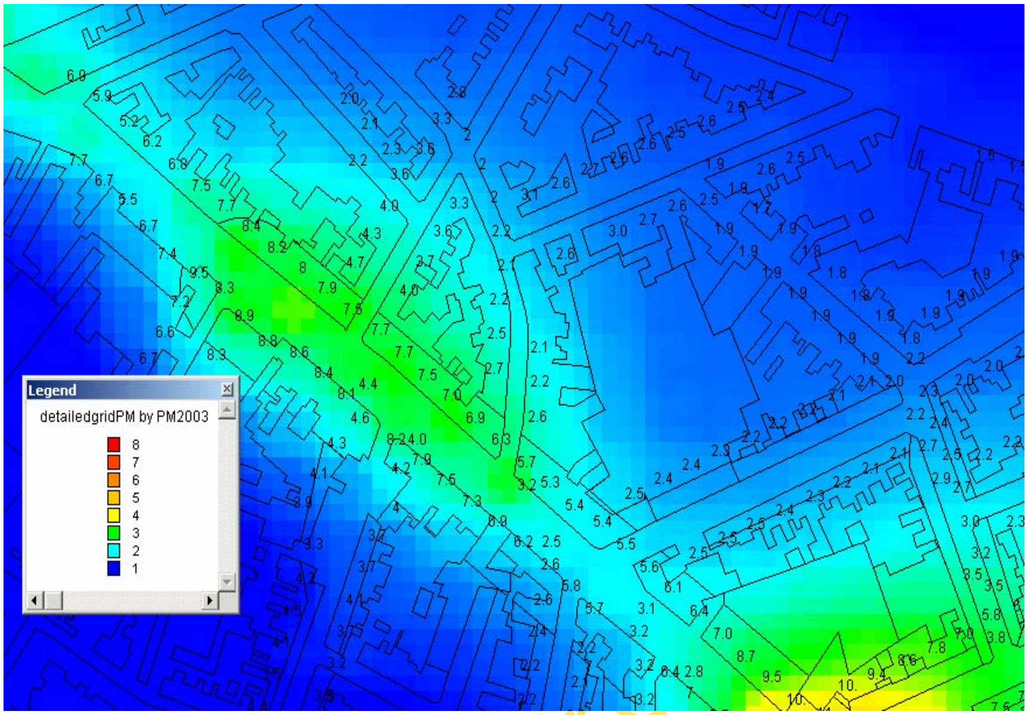

Figure 3 : Calculated concentrations of $PM_{2.5}$ for 2003 in the northwest of Gentbrugge. Numbers show the $PM_{2.5}$ concentrations inside street canyons. Colours show the urban back round concentrations of $PM_{2.5}$ outside street canyons.

The main reason for this is that the background concentration for every individual street can be calculated in a very fast way. Once the entire concentration over the urban area is calculated, the urban background concentration is simply obtained by subtracting the contribution from the line source of the street considered. Other approaches (like e.g. applying a CFD code or an Eulerian type model) have to recalculate the background concentration for every street by starting up a complete new run, in order to avoid double counting of the contribution from the street considered.

CONCLUSIONS

A novel approach was demonstrated based on the coupling of the street canyon model OSPM and the Gaussian model IFDM. OSPM calculates the contribution of the traffic emissions inside a particular street canyon, whereas IFDM computes the background contributions, including the concentration levels caused by the surrounding streets, industrial stacks and domestic heating. The combined modelling tool can be applied within a domain with a 20-30 km radius. Both models are interacting and have been integrated into an advanced computer program. Compared to CFD and Eulerian modelling approaches this integrated modelling approach provides detailed results in a much faster way.

Results show that the background contribution from a nearby highway exit is dominant in streets where low traffic is observed, but even in cases of moderate traffic, the local background concentration can be substantial (40%-50% for $PM_{2.5}$). The results (time series, percentiles, yearly averages) allow a quick evaluation with respect to the limit values presented in the EU directives on ambient air quality assessment and management. The system accurately predicts locations for further assessment, measurement campaigns or action plans.

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REFERENCES

Berkowicz, R., 1998: Street scale models, in *Urban Air Pollution – European Aspects*, J. Fenger, O. Hertel and F. Palmgren (Eds.) Kluwer Academic Publishers, Dordrecht, pp. 223-251.

Cosemans, G., Dumont, G., Roekens, E . and Kretzschmar J.G.,1997: IFDM modelling for optimal siting of air quality monitoring stations around five oil refineries, *Int. J. Environment and Pollution* **8**, 401-407.

De Vlieger I., 1997: On-board emission and fuel consumption measurement campaign on petrol-driven passenger cars, *Atmospheric Environment* **31**, 3753-3761

Mensink, C., Cosemans, G. and Pelkmans, L., 2005: Dynamic modelling of transient emissions and concentrations from traffic in street canyons, *Int. J. Environment and Pollution*, **25**, Nos. 1/2/3/4, 118-130.

Mensink, C., Colles, A. Janssen, L and Cornelis, J., 2003: Integrated air quality modelling for the assessment of air quality in streets against the Council directives, *Atmospheric Environment* **37**, 5177-5184.

Quadstone, 2004: http://www.paramics-online.com