STREET CANYON MODEL INTERCOMPARISON EXERCISE AND VALIDATION STUDY

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INTRODUCTION

Urban air pollution is usually characterised based on measurements at a few fixed points. The only practical way of generalising the data from point measurements to a larger area is to couple the data with models describing transport and dispersion of pollutants in urban streets. Numerical microscale dispersion models are frequently used for local scale air quality assessments, the validity of the results critically depending on the suitability of the models.

The influence of local emissions and other smaller scale effects on concentrations and exceedances is studied in the framework of the Street Emission Ceilings (SEC) project of EEA’s European Topic Centre on Air and Climate Change. SEC primarily aims at developing a harmonised methodology for calculating street increments, i.e. the difference between the hotspot and urban background levels. As an important part of SEC, a model inter-comparison exercise was planned and conducted with the participation of 13 research groups.

Our Laboratory contributed to this model inter-comparison exercise by applying three different street canyon models, namely OSPM (*Hertel and Berkowicz,* 1990; *Berkowicz et al.,* 1997), SEP-SCAM (*Papathanassiou et al.,* 2005) and MIMO (*Ehrhard et al.,* 2000). The models are applied to specific street canyons in three European cities using data from monitoring stations located in the considered domains.

THE MODELS

Two of the selected models, OSPM and SEP-SCAM, are semi-empirical obstacle resolving models designed to work with input and output in the convenient form of one-hour averages. On the other hand, MIMO is a more sophisticated three-dimensional RANS CFD model for simulating microscale wind flow and dispersion of pollutants in built-up areas.

OSPM calculates concentrations of exhaust gases using a combination of a plume model for the direct contribution and a box model for the recirculation part of the pollutants in the street canyon. The emission field is treated as a number of infinitesimal line sources aligned perpendicular to the wind direction at the street level. The plume expression for each of these line sources is integrated along the path defined by the street level wind. The contribution from the recirculation part is calculated assuming that the inflow rate of the pollutants into the recirculation zone is equal to the outflow rate and that the pollutants are well mixed inside the zone. The turbulence within the canyon is calculated taking into account the portion induced by traffic.

SEP-SCAM (Semi-Empirical Parameterised Street Canyon Model) is a street canyon model, recently developed by LHTEE. The model is based on concepts and techniques previously applied in the development of the OSPM, CPB (*Yamartino and Wiegand,* 1986) and STREET (*Johnson et al.,* 1973) models. Concentrations of exhaust gases are primarily calculated along the leeward and windward sides of the street canyon at any specified height above the street level. For the direct contribution of vehicle emitted pollutants the model makes use of a combination of a plume model and an empirical algorithm (*Johnson et al.,* 1973) which has been revised based on experimental results. This modified algorithm handles adequately the potential influence of varying canyon geometry, irregular traffic emissions distribution and street level turbulence on pollutant advection and diffusion. For the recirculation part of the pollutants a box model is used. The concentration distribution across the street canyon is calculated with an empirically-derived algorithm based on a very simplified parameterization of flow and dispersion conditions. The model can handle also situations when an intersection is present: the distribution pattern of concentrations along both sides of the canyon is computed in such a case with a simplified empirical formula based on results of the three-dimensional microscale model MIMO. Following this approach, it is possible to account for the effect of winds blowing through an intersection to the depression of the recirculation vortex.

MIMO solves the Reynolds averaged conservation equations for mass, momentum and energy. Additional transport equations for humidity, liquid water content and passive pollutants can be solved. A staggered grid arrangement is used and coordinate transformation is applied to allow non-equidistant mesh size in all three dimensions in order to achieve a high resolution near the ground and near obstacles. A heating module has also been implemented into MIMO in order to be able to investigate the effects of thermal exchange between the buildings and the street air. This heating module can calculate the heat transfer through conduction, convection and radiation (*Kunz,* 2001).

THE DATASETS

The models were applied to specific street canyons in three European cities: Stockholm (Hornsgatan) and London (Marylebone Rd) for the year 2000, as well as Berlin (Frankfurter Allee) for the year 2002. The aspect ratios (height/width) of the aforementioned street canyons are 1.04, 0.63 and 0.51, respectively.

The meteorological and roof level concentration data required for the simulations and street level concentration data required for the validation were available from measurements at stations located either in the considered domain or at nearby locations. Furthermore, the measurements of the required meteorological data were conducted on 10 meter masts on top of nearby buildings. Emission data was computed using COPERT 3 (*Ntziachristos and Samaras,* 2000) and the local traffic data which was obtained from continuous traffic counts in the considered streets. The emission input data was then modified in the more convenient form of diurnal patterns of one-hour annual averages.

It should be underlined that in order to calculate hourly diurnal and monthly patterns with MIMO, street level dimensionless concentrations (c*) were calculated for 16 wind directions, using the Traffic Produced Turbulence (TPT) scaling method for each case. The different scaling methods to calculate hourly concentration time series from c* values are described in detail elsewhere (*Ketzel et al.,* 2001).

RESULTS AND DISCUSSION

Simulation results for street level concentrations of NO_x and $PM_{2.5}$ for the case of Stockholm and London, as well as NO_x and PM_{10} for the case of Berlin are selected to demonstrate the models' performance. Both the diurnal patterns of one-hour annual average concentrations (Figure 1) and the annual patterns of monthly average concentrations (Figure 2) have been calculated. Furthermore, the statistical indices Bias and Correlation Coefficient have been computed for all models with the help of measured street level concentrations (Table 1).

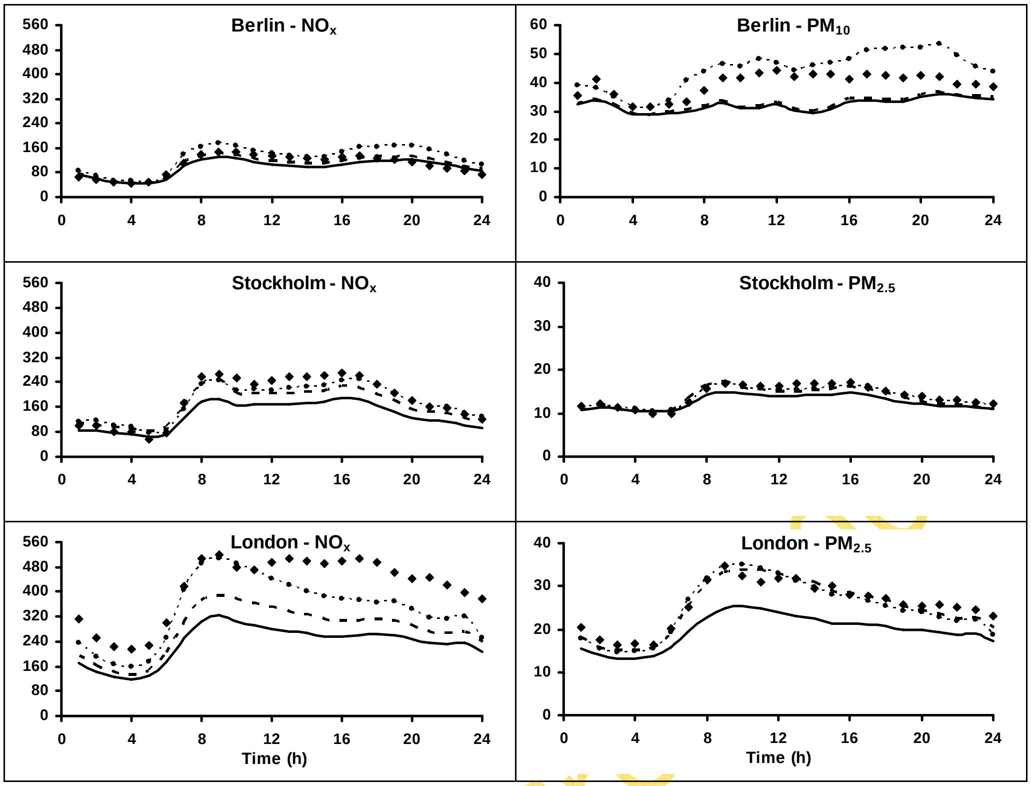

Fig. 1; Diurnal variation of one-hour annual averaged street level concentrations (μg/m^3) computed with OSPM (▬), SEP-SCAM (——) and MIMO (-•-) compared to observations (♦).

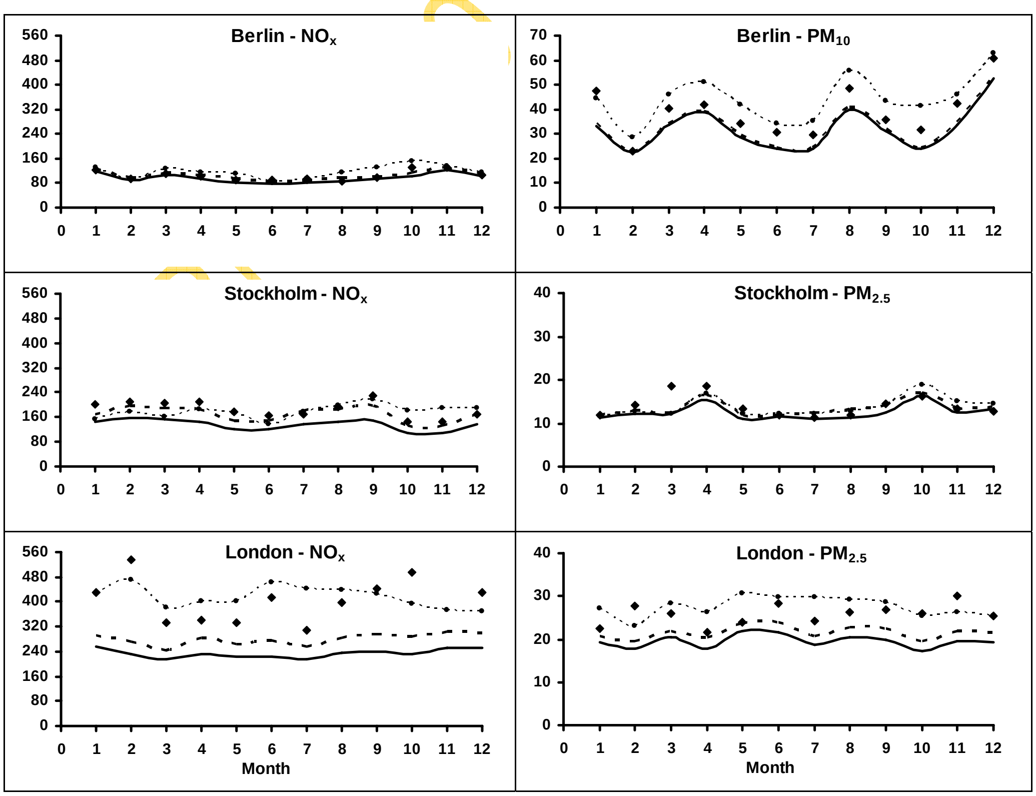

Fig. 2; Annual variation of monthly averaged street level concentrations (μg/m^3) computed with OSPM (▬), SEP-SCAM (——) and MIMO (-•-) compared to observations (♦).

Table 1. Statistical Results

Statistical indices		Bias			Correlation Coefficient		
Models		OSPM	SEP-SCAM	MIMO	OSPM	SEP-SCAM	MIMO
Berlin	NOx	-8.69	0.92	21.77	0.905	0.918	0.917
	PM_{10}	-7.28	-6.56	4.89	0.486	0.552	0.835
Stockholm	NOx	-51.32	-18.77	-8.29	0.995	0.985	0.988
	$PM_{2.5}$	-1.44	-0.49	-0.25	0.980	0.951	0.983
London	NOx	-181.56	-135.79	-72.70	0.962	0.956	0.915
	$PM_{2.5}$	-6.15	-0.59	-0.93	0.986	0.980	0.970

Figure 1 shows that the diurnal patterns of the observed concentrations are generally underestimated by all models with the exception of MIMO, which for the Berlin case study only slightly overpredicts the concentrations. More specifically, the diurnal patterns of the NO_x concentrations are significantly underpredicted by both OSPM and SEP-SCAM, especially for the London case, while MIMO is found to be generally closest to the observed data. The underprediction of the NO_x concentrations by all models for the cases of Stockholm and London could be associated with a possible underestimation of the NO_x emissions.

Regarding the diurnal $PM_{2.5}$ pattern for the cases of Stockholm and London, both MIMO and SEP-SCAM predictions are in good agreement with the measured concentrations, while OSPM exhibits a slight underestimation. For the case of Berlin, the diurnal PM_{10} patterns obtained with OSPM and SEP-SCAM are very similar, yet both underestimating the observed levels. This behaviour is understandable, given the fact that non-exhaust PM_{10} emissions were neglected (the PM_{10} vehicle emissions were assumed to be identical to the $PM_{2.5}$ emissions). In spite of the above mentioned overestimation, the MIMO results appear to agree better with the observed concentrations compared to the other two models.

The model results for the annual variation of the monthly averaged street level concentrations in Stockholm and Berlin are well correlated with the values derived from the observations (Figure 2). Somehow larger deviations are obtained in the case of London. As expected, for each case all three models reveal a tendency to either overestimate or underestimate the monthly averaged concentrations in the same manner as the diurnal variation of the one-hour annual averaged values.

The results from the statistical analysis which are presented in Table 1 confirm that the results of all three models are in satisfactory agreement with the observations, the largest deviations arising in the case of OSPM. As the only model that may be used also for more complex street canyon situations, MIMO is found to perform at least as good as the other two models. It should be noted, however, that despite the good agreement between model results and observations in terms of statistical indices, the differences between the results of individual models are not small, especially regarding the NO_x concentrations in the London case.

CONCLUSIONS

The presented simulation results for the three case studies show that all three models can in principle be applied for the successful prediction of air pollutant concentrations in urban hotspots. The analysis of the results has shown that the predicted concentrations agree satisfactorily with the observed concentrations.

The performance of the newly developed SEP-SCAM model is promising. Yet, the empirical formulas implemented into this model require validation by field observation and wind tunnel studies. In this context, more effort is needed to improve model validation procedures. Towards this aim, model developers should have easier access to quality assured experimental field study results and wind tunnel measurements.

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