Modelling urban pollution dispersion by using MISKAM

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ABSTRACT

The micro-scale flow and dispersion model MISKAM is a CFD code for the prediction of pollutant dispersion in built urban environment. In this paper the application of MISKAM is shown on the example of the Millennium City Centre project in Budapest. Simulations for two building configurations and five main wind directions were performed to predict the change of the annual mean concentration level in the investigated area as consequence of construction of the city centre. Comparison of results to earlier wind tunnel data helps to check the accuracy and reliability of MISKAM code in practical application.

INTRODUCTION

Urban air pollution caused by car traffic is getting one of the most important environmental problems in cities. To determine the wind field and the concentration distribution in urban microscale areas (length scale up to 5 km) use of obstacle resolving methods are necessary. Traditional solution is the physical modelling in wind tunnels, but also numerical simulation (CFD) can be used for this purpose.
Although current advanced CFD simulations use sophisticated tools like unsteady flow with LES to understand and describe pollution dispersion mechanisms better, their use needs deep knowledge in fluid mechanics, and costs much time. Different requirements at the environmental regulatory side (e.g. large amount of modelled buildings, fast model preparation, limited simulation time and computer capacity) make simpler methods necessary, at the expense of more limited accuracy.
The microscale flow and dispersion model MISKAM fulfils the mentioned requirements [1].

About MISKAM

MISKAM (Microscale Flow and Dispersion Model) was developed by Dr. J. Eichhorn, University of Mainz, Germany, for urban pollutant dispersion simulations. Engineering Bureau Lohmeyer, Karlsruhe developed the user interface WinMISKAM. MISKAM was evaluated according VDI 3783 Part 9 „Environmental Meteorology – Prognostic microscale wind field models – Evaluation for flow around buildings and obstacles“ [2], and it is in regulatory use at environmental agencies, consulting organisations, experts etc. in Germany and France. (Due to the predefined boundary conditions and other parameters its use requires only basic knowledge in fluid mechanics.)
MISKAM solves the Reynolds averaged Navier-Stokes equation with a modified k-ε turbulence closure in a non-uniform Cartesian grid for the flow field, and it calculates the concentration of transported passive scalars using the Eulerian

dispersion equation. The modelled area can not contain steep relief. Buildings are modelled with blocks. Thermal effects, buoyancy and chemical reactions cannot be modelled. Pollution sources are volume sources. MISKAM can simulate neutral and stable atmospheric conditions (vertical temperature gradient -6.48 K/km, and -10 - -6.48 K/km, respectively). In second case, the turbulence mixture factor K_m is set lower than in the first case.
MISKAM uses upwind numerical scheme. The high numerical diffusion of this scheme is partly compensated at the dispersion with Smolarkiewicz correction steps.

The Millennium City Centre project
In the southern part of Budapest, on the riverside of the Danube, the construction of a group of tall buildings has been planned (Fig. 1.). Significant change of the pollution level was supposed in the neighbouring district due to the

- 20% growth of individual traffic induced by the City Centre
- decreased ventilation caused by the new buildings
- area’s very busy main street, bounded by buildings from one side becomes a street canyon.

Wind tunnel and numerical investigations carried out by the Department of Fluid Mechanics of BUTE in 2002 [3,4] gave a prediction on the pollution level and ventilation in the Millennium City Centre and its environment. For numerical simulation FLUENT and the above mentioned MISKAM (v4.22) was used. Recently, further MISKAM simulations have been carried out using denser grid and other refinements of the modelling, the results of which are shown in this paper.

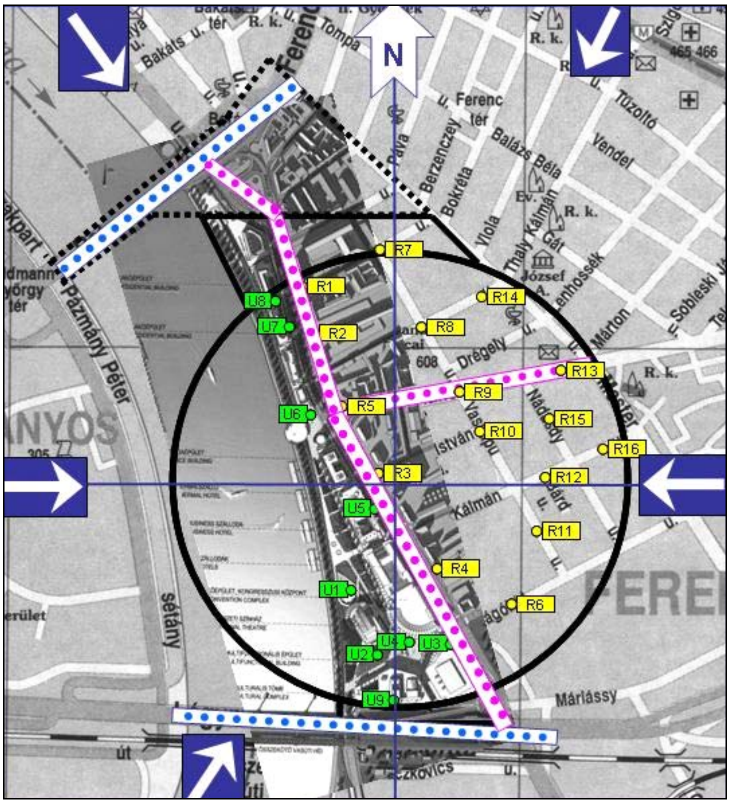

Fig. 1. The investigated area of Budapest
with line sources indicated by row of dots and measurement points

DESCRIPTION OF THE NUMERICAL MODEL

Computational domain and boundary conditions

The size of the model domain is 1250 m × 1660 m × 140 m (domain height is about 4 times average building height). The grid includes 195 × 260 × 40 = 2.028 million cells (Fig. 2.).

Neutral atmosphere is supposed. Wind speed is set to 3.1 m/s at 25m height. MISKAM generates a logarithmic atmospheric boundary layer profile from this data. The other boundaries are also predefined by MISKAM like outlet: outflow, ground and building surface: friction with roughness lengths, top: symmetrical.

Source strengths were taken from vehicle emission and traffic data.

Totally 10 cases were simulated: 5 wind directions (22.5, 90, 213.75, 270, 326.25 degree to N) and two configurations: without and with City Centre. Computational time for one case was about 12 hours on a 2.4GHz PC.

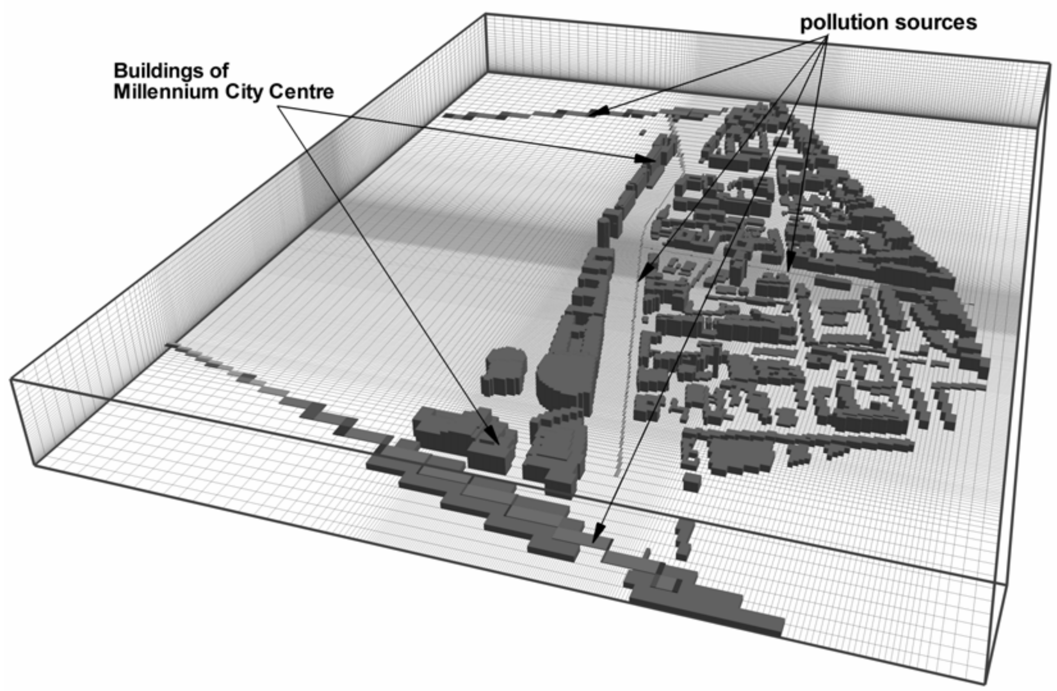

Fig. 2. Computational domain and mesh

RESULTS

Wind field and concentration distribution maps

Calculated data were visualised using Tecplot. Known flow and dispersion effects like street canyon vortices, street channel flows, clean air jets between buildings can be observed. One example of the calculated flow fields with City Centre, wind direction W is shown in Fig. 3.

Comparison with wind tunnel data

Comparison of the experimental and CFD results is based on the dimensionless concentration c^* which must be similar in both cases according [5]:

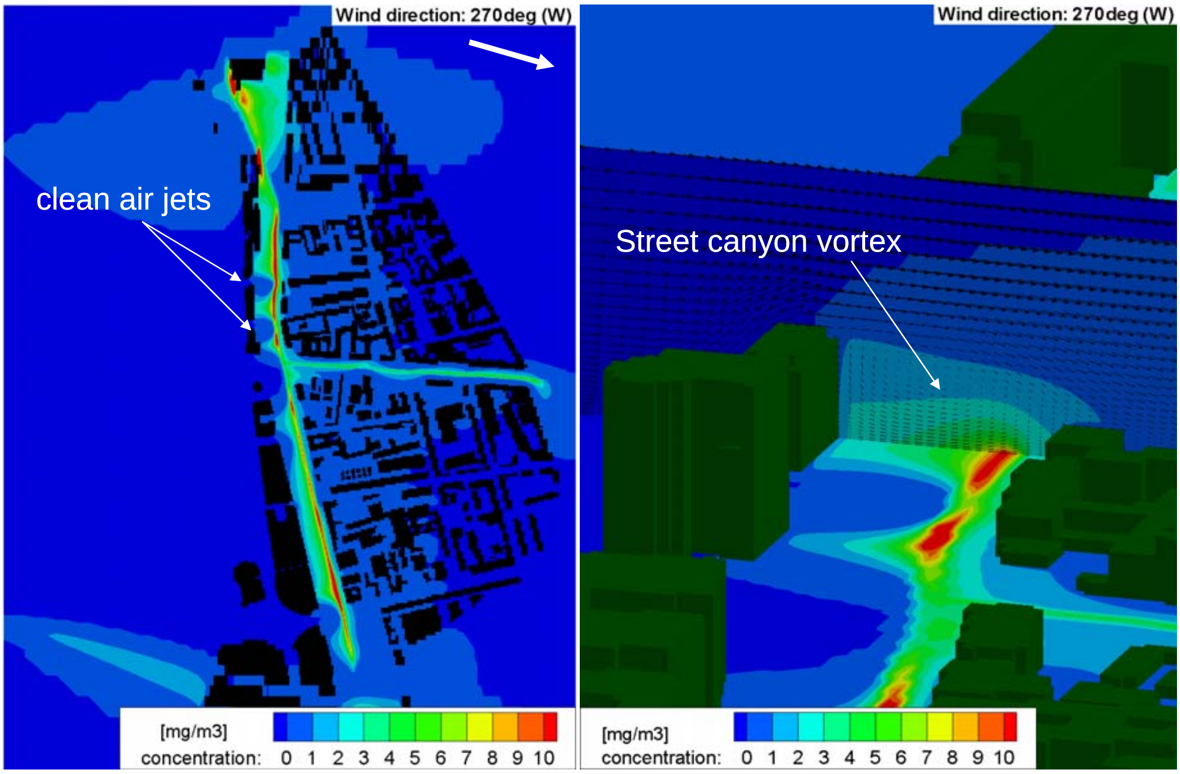

Fig. 3. Pollution distribution in 1.65 m height at wind direction W, with City Centre a) top view, b) detailed view with flow in a cross section of the street canyon

$$\left[c^* = \frac{C \cdot u_{ref} \cdot H}{Q/L}\right]_{\text{Wind tunnel}} = \left[c^* = \frac{C \cdot u_{ref} \cdot H}{Q/L}\right]_{\text{Simulation}},$$

where C [kg/m^3] concentration, H [m] building height, u_{ref} [m/s] wind velocity at building height, and Q/L [kg/s/m] line source strength.

Fig. 4 shows typical distributions of measured and calculated dimensionless concentration as function of wind direction without and with City Centre in few measurement points at two different meshes. Points R1, R5 and U8 are situated near the line sources, U2 is far from them (see Fig. 1.). Although at some wind directions large differences between calculated and measured values can be observed, in majority of cases the agreement is acceptable. Grid dependency (difference between the results from the earlier and current MISKAM mesh) is low, except in some near-source points like U8 and R1.

Comparison of annual mean concentration (c^*) in all 24 measurement points, determined from measured and calculated values by the equation:

$$c^*_{annual} = \sum_{i=1}^{5} c_i^* \cdot p_i$$

is shown in Fig. 5. p_i is wind direction probability.

In points R2 and R3 strong disagreement can be observed. These points are very close to line source (see Fig. 1.). Excluding these two points, the correlation factor is $R^2 = 0.97$ without City Centre and $R^2 = 0.79$ with City Centre. Last worse correlation can partly be explained by differences in geometries of wind tunnel and MISKAM models of the planned buildings. By all means the positive effect of the annual averaging on the correlation factor should be considered.

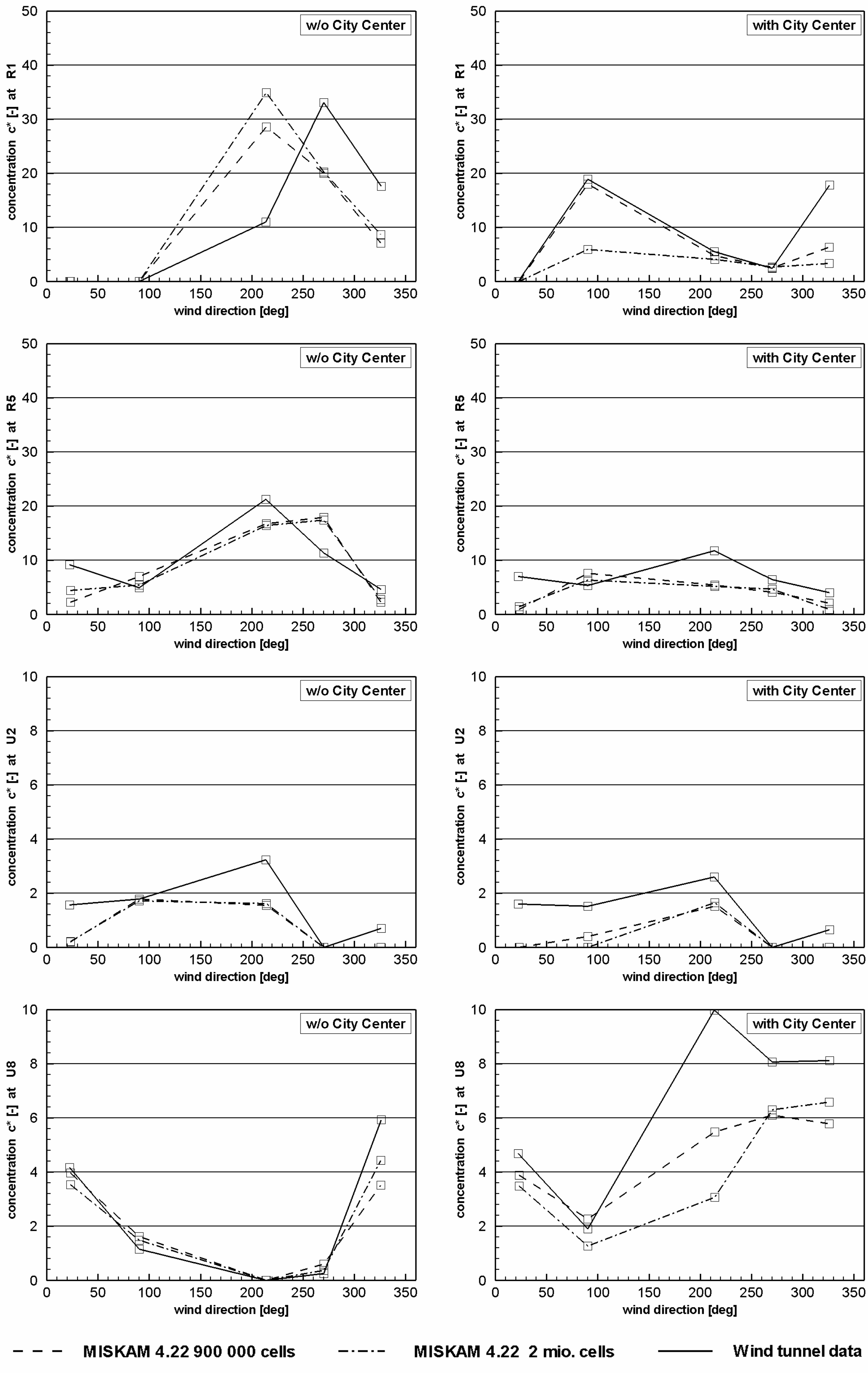

Fig. 4. Calculated and measured concentration as function of wind direction without and with City Centre in points R1, R5, U2, U8

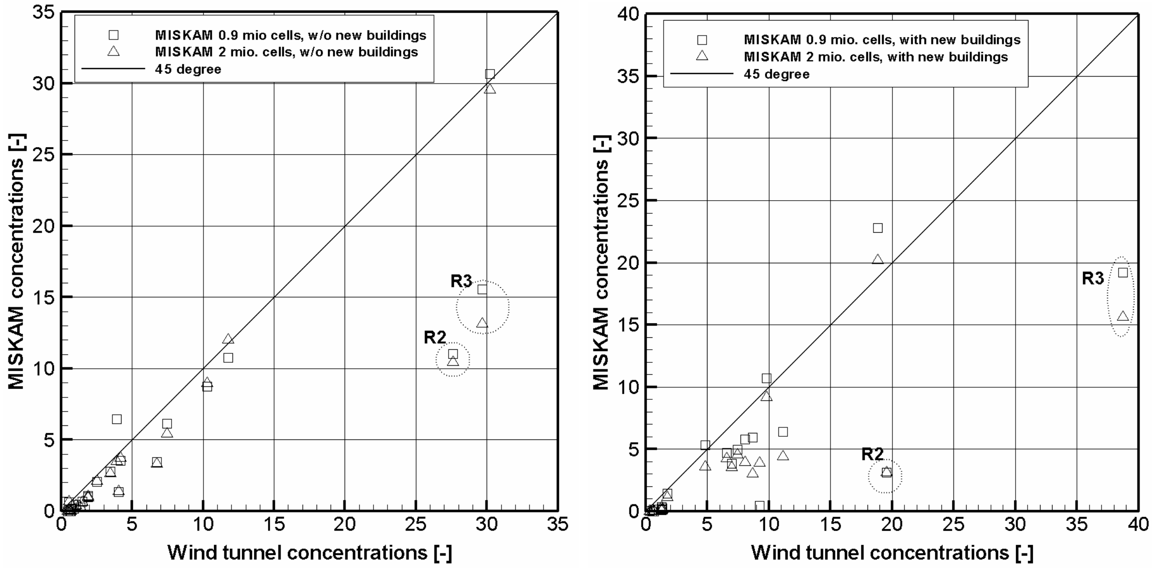

Fig. 5. Correlation of experimental and numerical data (annual mean values) without and with City Centre

CONCLUSIONS

- Use of MISKAM code provides detailed flow and concentration fields so it helps to understand flow and dispersion phenomena in urban area.
- Comparison of calculated concentrations to wind tunnel data shows in most cases acceptable agreements, but in few points also significant differences at some wind directions.
- At near-source points grid dependency and higher error was observed.
- Far source points agree better, and the results are more grid independent.
- More accurate modelling of pollution caused by near sources would be necessary. It is supposed that in the deviation of calculated and measured concentrations the difference between modelling of line sources in wind tunnel and in numerical simulation has significant effect.
- MISKAM is suitable for application in environmental regulatory field.

ACKNOWLEDGEMENTS

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