1.31 COMPARISON OF RESULTS OF AN OBSTACLE RESOLVING NUMERICAL MODEL WITH WIND TUNNEL DATA

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INTRODUCTION

An accurate flow field is an important precondition for the simulation of pollutant dispersion within street canyons. Hence, the simulated flow field of numerical dispersion models needs to be thoroughly validated before it can be used for pollutant dispersion studies. A validation approach as suggested by Schlünzen et al (2004) contains several different phases including the comparison with high-quality reference data. Following their guideline evaluation criteria are also given for the application of a numerical model to a new domain.

Within project VALIUM the urban area in the surrounding of the Göttinger Straße in Hanover, Germany has been investigated (*Schäfer et al.*, 2004). Besides field measurements and wind tunnel experiments numerical studies were performed to investigate chemical transformation and dispersion within the urban canopy layer. These were performed using the microscale chemistry model MICTM (*Grawe, D.*, 2004) which uses MITRAS model results (*Schlünzen et al.*, 2003) as input data. To evaluate the flow field results, wind tunnel measurements are used. They offer the advantage of well-known boundary conditions and reproducibility as well as a very fine spacial resolution.

METHOD

The comparison of the flow fields from MITRAS model results and wind tunnel data was performed by calculating hit rates as well as correlation coefficients for each wind component separately. Hit rates were calculated according to the technique outlined in *Schlünzen et al* (2004): Two allowed deviations are defined, an absolute deviation W and a relative deviation D, such that a hit-rate q can be calculated from

$$q = \frac{N}{n} = \frac{1}{n} \cdot \sum_{i=1}^{n} N_i$$

$$\text{with } N_i = \begin{cases} 1 & \text{if } \left| \frac{P_i - O_i}{O_i} \right| \le D \quad \vee \quad |P_i - O_i| \le W \\ 0 & \text{else} \end{cases}$$

where O_i and P_i denote the values from reference data and model result, respectively. Actual values for the allowed deviations are based upon those used for a complex test case by *Schlünzen et al* (2004), and take into account the precision of wind tunnel measurements as well as uncertainties arising from the comparison itself, e.g. linear interpolation, where there are non-linear gradients, or the different obstacle representations in the wind tunnel and the numerical model. For this study the following allowed deviations have been used:

$$W = 0.1\,{}^{m}\!/\!_{s} \quad \text{and} \quad D = 0.25$$

MODEL SET-UP AND REFERENCE DATA

The comparison has been carried out for the urban area around Göttinger Straße in Hanover, Germany. Model domains of both, the wind tunnel and the numerical model, cover an area of approximately 1×1 km^2 around the main street canyon (see Figure 1). The building structure within the domain is composed of mainly residential houses with an average height of 20 m to the east, while lower warehouses and open parking areas dominate the domain towards the southwest. Wind tunnel measurements for the reference data were carried out in the large boundary layer wind tunnel at the University of Hamburg, using a detailed model, scaled 1:250. Flow measurements of the horizontal wind vector were carried out using a 2d-LDV system (*Pascheke, F.,* 2004; *CEDVAL*, 2004).

The obstacle resolving numerical model MITRAS has been compared with these data using a non-uniform grid with a horizontal resolution of 1.5 m in the most relevant street canyon and up to 15 m at the lateral boundaries of the domain. The vertical resolution is 1.5 m next to the ground and coarsens up to 30 m at the model top some 300 m above ground. The obstacle representation for both models was harmonized as much as possible, especially for the building heights. However, differences occur in some areas, e.g. due to the representation of the buildings in the numerical grid, but are mainly restricted to areas away from the main street canyon.

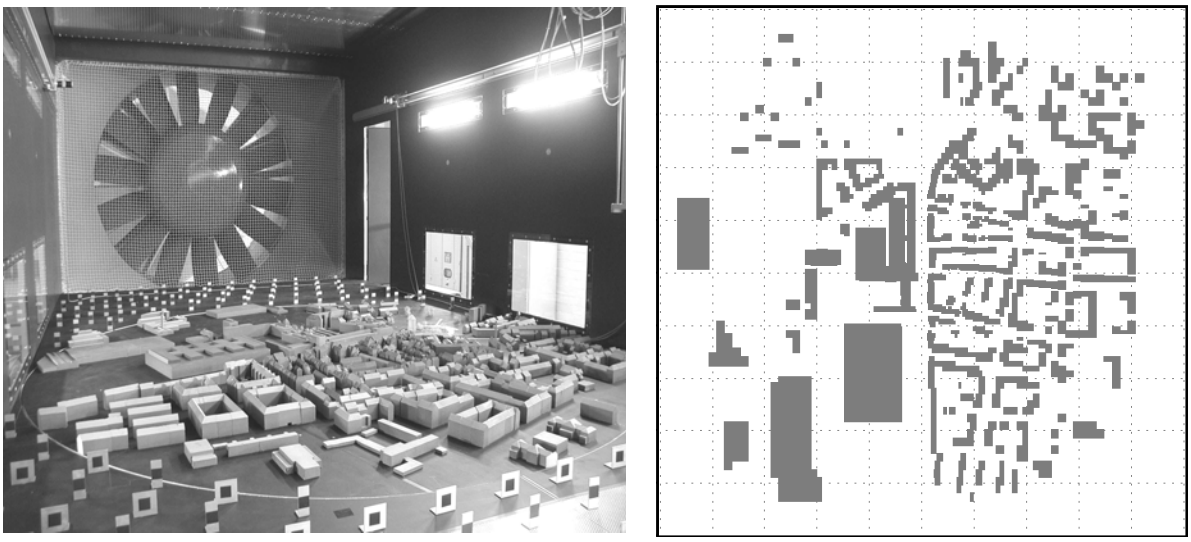

Figure 1. Picture of the physical model in the wind tunnel (left), and horizontal sketch of the obstacle representation in the numerical model (right).

Wind tunnel reference data were available for three different directions of the approaching flow. These were selected taking into account statistics of the real wind conditions within the area as well as the sensitivity of the flow patterns with respect to the approaching flow directions. To challenge the numerical models, preference was given to directions with higher sensitivity. The horizontal wind vector was measured at two different heights in a focus area close to the main street canyon. Some 360 measurement points have been used per level. Since measurement points in the wind tunnel do not necessarily correspond to a grid point of the numerical model, numerical model results were interpolated towards the wind tunnel points using a tri-linear interpolation.

RESULTS

Since wind tunnel measurements and numerical model runs are based on different incoming flows and both results scale with the governing wind speed, a measure is needed for both datasets to scale them appropriately. This reference speed is a crucial factor in the comparison as it has an impact on every value of the flow field. Wind tunnel and model results were scaled with their average value, which is calculated from the measured and interpolated data, respectively. By this scaling the average speeds within one level are the same, but patterns can be different. Thus the model evaluation solely compares differences in the flow pattern.

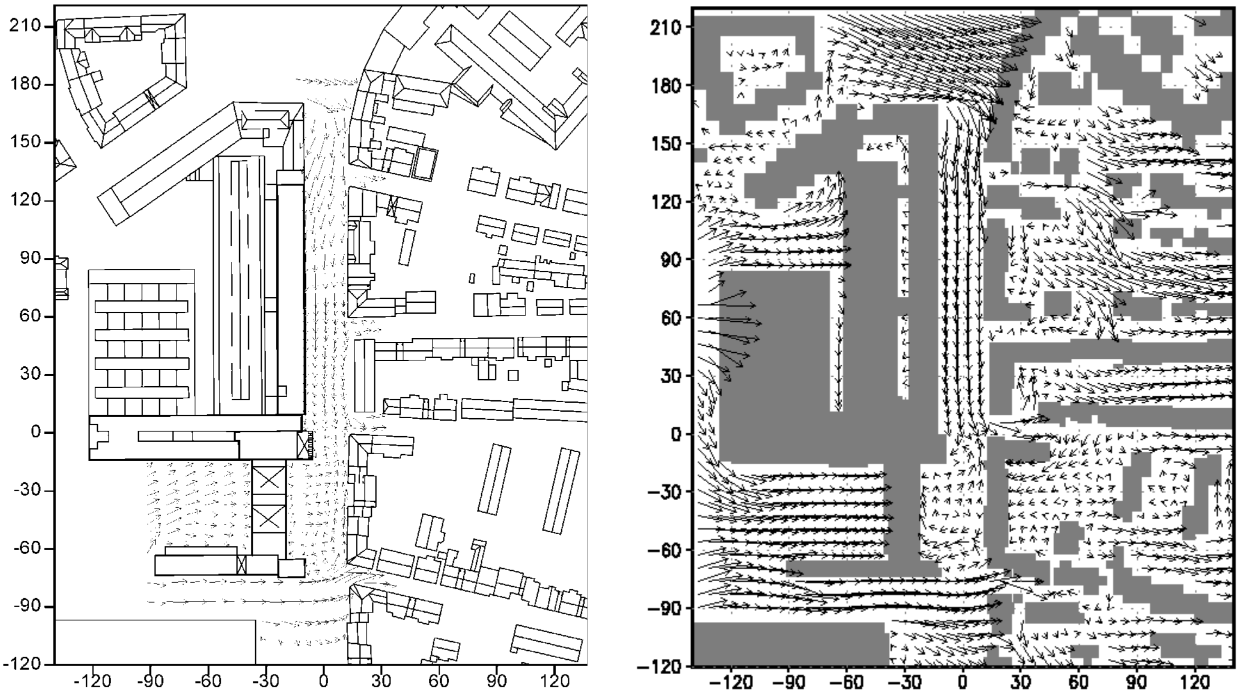

Figure 2. Flow patterns for test case 270° at 10 m above ground for wind tunnel data (left) and numerical model result (right).

Figure 2 shows the flow patterns from both models for a selected test case. The flow fields show an excellent agreement in the bulk of the area. The overall flow patterns are well reproduced, showing the same inflow and outflow conditions for all side-streets respectively. Anyhow, for some locally restricted areas, differences can be found for this wind direction. That might be due to small scale features of some buildings, that cannot be resolved in the numerical model due to restrictions of the grid resolution, e.g. the main building to the left of the street canyon shows some arcades close to the center of the domain, which were accounted for in the wind tunnel, while for the numerical model a more simplified version was used. This can easily lead to differences in a region with very detailed flow structures.

Table 1. Hit rates q for all compared wind fields.

Test case	*Height*	*Hit rate (u)*	*Hit rate (v)*
220°	*3 m*	*61 %*	*52 %*
	10 m	*62 %*	*71 %*
260°	*3 m*	*70 %*	*66 %*
	10 m	*72 %*	*66 %*
270°	*3 m*	*78 %*	*94 %*
	10 m	*84 %*	*84 %*

Table 2. Correlation coefficients R for all compared wind fields.

Test case	*Height*	*R (u)*	*R^2 (u)*	*R (v)*	*R^2 (v)*
220°	*3 m*	*.66*	*44 %*	*.82*	*67 %*
	10 m	*.61*	*37 %*	*.83*	*69 %*
260°	*3 m*	*.85*	*73 %*	*.85*	*73 %*
	10 m	*.88*	*77 %*	*.86*	*75 %*
270°	*3 m*	*.83*	*69 %*	*.92*	*85 %*
	10 m	*.88*	*78 %*	*.92*	*84 %*

Table 1 and Table 2 summarize the hit rates and correlation coefficients calculated for the horizontal components of the wind. Vertical wind was not measured. The received hit rates are above 66% for cases 260° and 270° and sometimes much higher. For these cases the correlation coefficients are consistently very high as well. Considering the suggestion of *Schlünzen et al* (2004) to demand a hit rate of 66% for this type of comparison the results are sufficient. However, this is not the case for an incoming flow direction of 220° . In this case hit rates are below 66% and correlation coefficients are also only between 0.61 (u-component) and 0.69 (v-component). The reason for this has not completely been understood. As can be seen from Figure 3 the differences occur mainly in the southern part of the compared area, while for a case with higher hit rates the differences are more scattered in the area. The differences might have their origin in small differences in the building structures but can also be due to different vertical wind profiles, probably because of different inflow wind profiles. This has higher values in the lower levels for the numerical model. For the 220° case large parking areas can be found upstream of the observed differences, so that here the wind field is more affected by the inflow wind profile than in areas between complex buildings. This leads to stronger south and east wind-components in the numerical model and could therefore cause the differences. Also the treatment of the surface roughness between buildings has some differences between wind tunnel and numerical model. While in the wind tunnel model only little roughness is introduced in the south-western area, where parking areas are found in reality, in the numerical model a roughness of about 0.1 m is used to account for the additional roughness of parked cars. However, more model studies with other incoming flow profiles and different treatments of the roughness are necessary to finally explain the reason for the difference found.

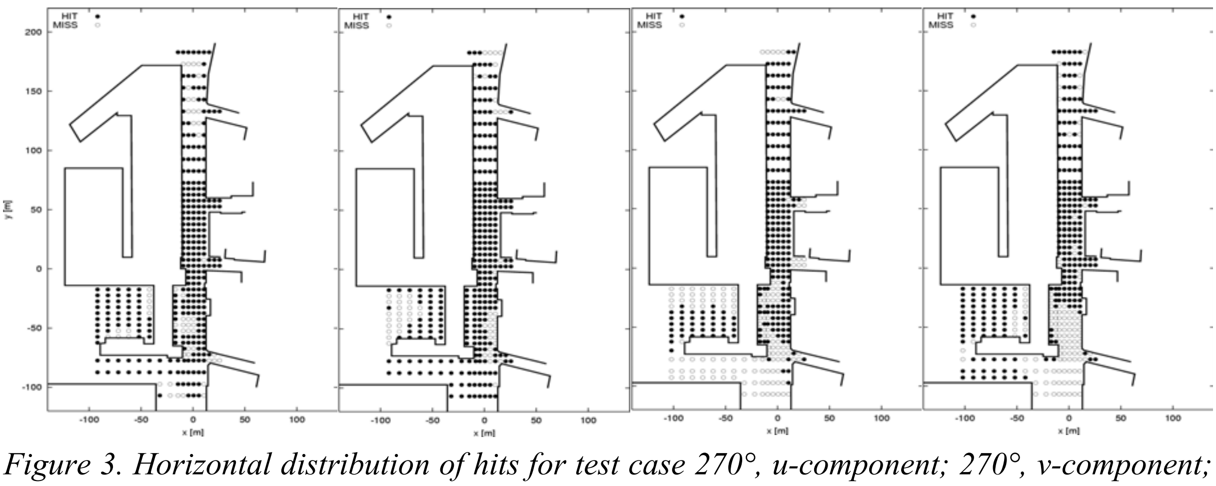

Figure 3. Horizontal distribution of hits for test case 270°, u-component; 270°, v-component; 220°, u-component; 220°, v-component (from left to right).

CONCLUSIONS

It has been shown that the evaluation guideline of *Schlünzen et al* (2004) is a good basis to develop evaluation criteria that are necessary to determine model performance in new application areas. The comparison has shown that a scaling of model results to the same incoming flow speed as used in the wind tunnel is essential for the evaluation. Using a scaling that is based on average measured and simulated values the comparison is restricted to the flow field pattern. The agreement is good in two of the three cases, but less well for incoming flow from 220° . This is one of the flow directions where large differences between different model results were also found in an earlier study (*Ketzel et al*, 1999). To fully understand the reason, more wind tunnel and numerical studies are needed.

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REFERENCES

CEDVAL, 2004: Wind tunnel data sets, Test case C. http://www.mi.uni-hamburg.de/cedval (in preparation).

Grawe, D., 2004: Verknüpfung von Modellen und Daten für die Konzentrationsvorhersage. PhD thesis, Faculty of Earth Sciences, University of Hamburg (in preparation).

Ketzel M., R. Berkowicz and A. Lohmeyer, 2000: Comparison of numerical street dispersion models with results from wind tunnel and field measurements. *Env. Monitoring and Assessment*, **65**, 363-370.

Pascheke, F., 2004: Systematische Untersuchung von mikroskaligen Strömungs- und Transportprozessen in städtischer Bebauung. PhD thesis, Faculty of Earth Sciences, University of Hamburg (in preparation).

Schäfer, K., S. Emeis, H. Hoffmann, C. Jahn, W. J. Müller, B. Heits, D. Haase, W.-D. Drunkenmölle, W. Bächlin, B. Leitl, F. Pascheke, K. H. Schlünzen and M. Schatzmann, 2004: Field measurements within a quarter of a city including a street canyon to produce a validation data set. Presentation in Session 12 at 9th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, Garmisch-Partenkirchen, June 1-4, Germany.

Schlünzen, K. H., W. Bächlin, H. Brünger, J. Eichhorn, D. Grawe, R. Schenk and C. Winkler, 2004: An evaluation guideline for prognostic microscale wind field models. Presentation at 9th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, Garmisch-Partenkirchen, June 1-4, Germany.

Schlünzen, K. H., D. Hinneburg, O. Knoth, M. Lambrecht, B. Leitl, S. Lopez, C. Lüpkes, H. Panskus, E. Renner, M. Schatzmann, T. Schoenemeyer, S. Trepte and R. Wolke, 2003: Flow and transport in the obstacle layer - First results of the microscale model MITRAS. *J. Atmos. Chem.,* ***44****, 113-130.*