AN IMPROVED VERSION OF THE MICROSCALE FLOW MODEL MISCAM - EVALUATION ACCORDING TO VDI GUIDELINE 3783/9

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INTRODUCTION

The flow and dispersal model MISCAM has gained a high level of acceptance throughout Germany and some neighboring countries. This can be deducted from the high number of implementations which is expected to reach 100 in the near future. The increasing demand on meteorological expertise based on numerical modeling demands a detailed quantitative validation of this type of models. Since late 2005, an evaluation guideline (VDI 3783/9) for obstacle resolving microscale flow models is available. Recently (*Eichhorn, J. and A. Kniffka,* 2007) the current MISCAM version 5.02 has been thoroughly examined according to this guideline.

One aspect of the guideline is the requirement to repeat the complete evaluation procedure in case of changes of the model code. The current study discusses the question whether or not an improvement of the numerical schemes adopted in MISCAM is reflected by better results of the evaluation. Also the quality of the data sets supplied with the guideline will be examined briefly.

THE GUIDELINE

The guideline (*Schlünzen et al.*, 2004; *VDI*, 2005) is subdivided into five parts. First, the general evaluation (model documentation, publications, comprehensibility of the model) is addressed. The second part (scientific evaluation) specifies the necessary model equations and parameterisations as well as boundary and initial conditions.

The most important part of the evaluation procedure is the validation. Part 3 of the guideline describes a number of test cases, either designated to check the consistency of the model results or to compare simulated and observed data. For the latter, wind tunnel data are used, since field data sets adequately reflecting the complexity of urban flow structures are not yet available. Part 4 summarises the results of the procedure in an evaluation record. Finally, the fifth part specifies additional measures of quality assurance which have to be taken by the end user of the model.

For brevity, this study will solely be concerned with results of the validation runs (Part 3 of the guideline). Model results are validated quantitatively using point-by-point comparisons with reference data, which in case of the consistency checks can be model results themselves. For each test case, hit rates q (in %) are computed from normalised model results P_i and normalised reference values O_i and the number of comparison values n according to

$$q = \frac{100}{n} \cdot \sum_{i=1}^{n} N_i \qquad (1)$$

where

$$N_i = 1 \quad for \quad \left|\frac{P_i - O_i}{O_i}\right| \le D \quad or \quad \left|P_i - O_i\right| \le W$$

$$N_i = 0 \quad else$$

The values to be used in equation (1) for the allowable absolute deviation W and the allowable normalised deviation D are specified within the guideline. For a successful evaluation, the hit rate must not fall below the threshold values given in the guideline for any of the test cases.

IMPROVEMENTS OF THE MODEL CODE

One property of MISCAM up to version 5.02 giving rise to legitimate criticism is the upstream advection scheme adopted for both the advection of momentum as well as turbulence quantities (turbulent kinetic energy, dissipation). Formerly, although known to be of minor accuracy due to its extensive numerical diffusion, the scheme was implemented to save storage as well as computation time – an argumentation which appears inopportune keeping in mind the potential of today's personal computers.

To reduce numerical diffusion as far as possible while keeping the computing time and storage requirements reasonably low, the MISCAM version underlying the current study makes use of a predictor-corrector scheme (*MacCormack*, 1969) to handle momentum advection. For the turbulence variables the MPDATA algorithm (*Smolarkiewicz*, 1989) which is already used in the dispersal model is adopted.

Together with a few minor corrections, for example concerning the lower boundary condition for turbulence variables, the model is expected to perform 'better'. The evaluation process will show if the modifications of the code also lead to a quantifiable improvement of the model results.

RESULTS AND DISCUSSION

A qualitative comparison of wind fields obtained from both model versions affirms the aforementioned assumption that the use of less diffusive advection schemes should lead to more realistic results.

Figure 1 shows x-z-cross-sections of the horizontal and vertical wind component for flow over a cuboid. The simulations carried out with the new version show a slightly more pronounced horseshoe vortex, indicated by the -0.1 m/s contour line of u together with a stronger downwind just below of the stagnation point. Furthermore, gradients near the upper front edge of the building are steeper in case of the less diffusive advection schemes being applied, indicating a better representation of the flow separation. To reproduce the separation realistically, however, would require serious modifications of the model as a whole, since the k-e-closure applied in MISCAM is known to fail in this area.

Since the deviations between both model runs are noticeable but small, the same might be expected from the results of the evaluation procedure. With one exception, results of the consistency checks (steady state, scalability, homogeneity, symmetry, independence on grid resolution and orientation) were identical for both versions. Due to the smoothing effect of the upstream advection scheme, however, steady state was achieved significantly earlier by the former model version. A new stop criterion had to be implemented into the new version to ensure steady state of the computed wind fields in case of two-dimensional configurations, leading to a ~15 % increase of the number of time steps required.

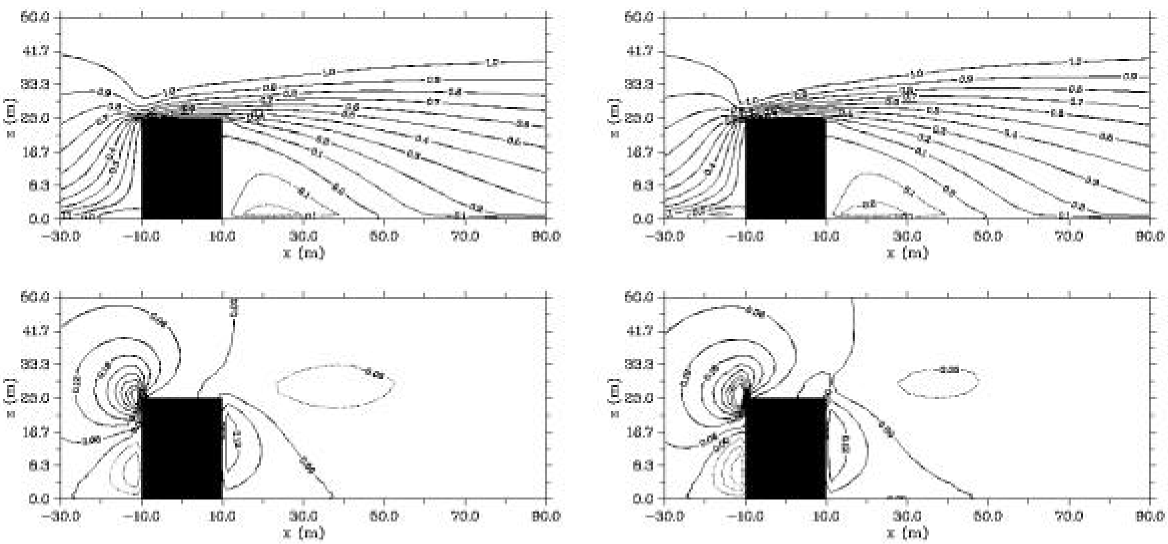

Fig. 1; Contours of horizontal wind component u (upper figures) and vertical wind component w (lower figures, both in m/s) for flow over a cuboid, vertical cross sections in the plane of symmetry. Left: upstream advection scheme; right: revised advection schemes.

Next, the model results in comparison to wind tunnel data will be considered. The hit rates for the test cases as specified in the guideline[1] are compiled, allowing a direct comparison of both versions' performance. As expected, deviations between both versions are small. Fortunately, the hit rates predominantly grow due to the improvements of the code.

Table 1. Hit rates for Cartesian wind components u, v and w for comparisons to wind tunnel data. See guideline (VDI, 2005) for specification of test cases. Values in brackets refer to MISCAM 5.02.

Test case	c1	c3	c4	c5	c6
Obstacle type, flow direction	Beam, 270°	Cube, 270°	Cube, 225°	Cuboid, 270°	Array of Cuboids, 270°
D	0.25	0.25	0.25	0.25	0.25
W	0.06	0.06	0.07	0.10	0.10
$q_{required}$ (%)	66	66	66	66	66
q_u (%)	86 (87)	94 (93)	85 (84)	77 (77)	92 (93)
q_v (%)	./.	98 (97)	76 (76)	90 (88)	68 (67)
q_w (%)	96 (95)	93 (93)	81 (81)	87 (86)	81 (81)

Fulfilment of the guideline can be attested to both MISCAM versions. Nevertheless, this statement must not be interpreted as a charter for users to apply the model to arbitrary situations. Failure to meet the evaluation criteria of the guideline, particularly the consistency checks, however, would be a clear demand to revise the model code.

Since the obstacle configurations used in the guideline are far from being representative for realistic urban settings, additional verification runs for more complex configurations are advisable. The next update of the guideline should incorporate some realistic cases which are already available (e.g. the Göttinger Straße setup).

[1] Since no computation of hit rates is involved in case c2, this case does not appear in the table.

Also, a thorough examination of the wind tunnel data seems appropriate, since some of the data sets exhibit internal inconsistencies. For example, measured wind vectors for the diagonal flow around a cube (test case c4) lack the symmetry along the diagonal plane. This might serve as an explanation for the asymmetry of hit rates for *u* and *v* (see Table 1) which is significantly reduced if the inflow profile is turned into the direction (223°) of the undisturbed wind profile as recorded in the wind tunnel.

Another questionable data set is multi-building case c6. The flow field should be symmetric in planes perpendicular to the flow direction. This symmetry, however, could not be examined since measured data are available only for parts of the 'upper' half of the domain. A close inspection of these data suggests the suspicion that the inflow must have been rotated against the *x*-axes.

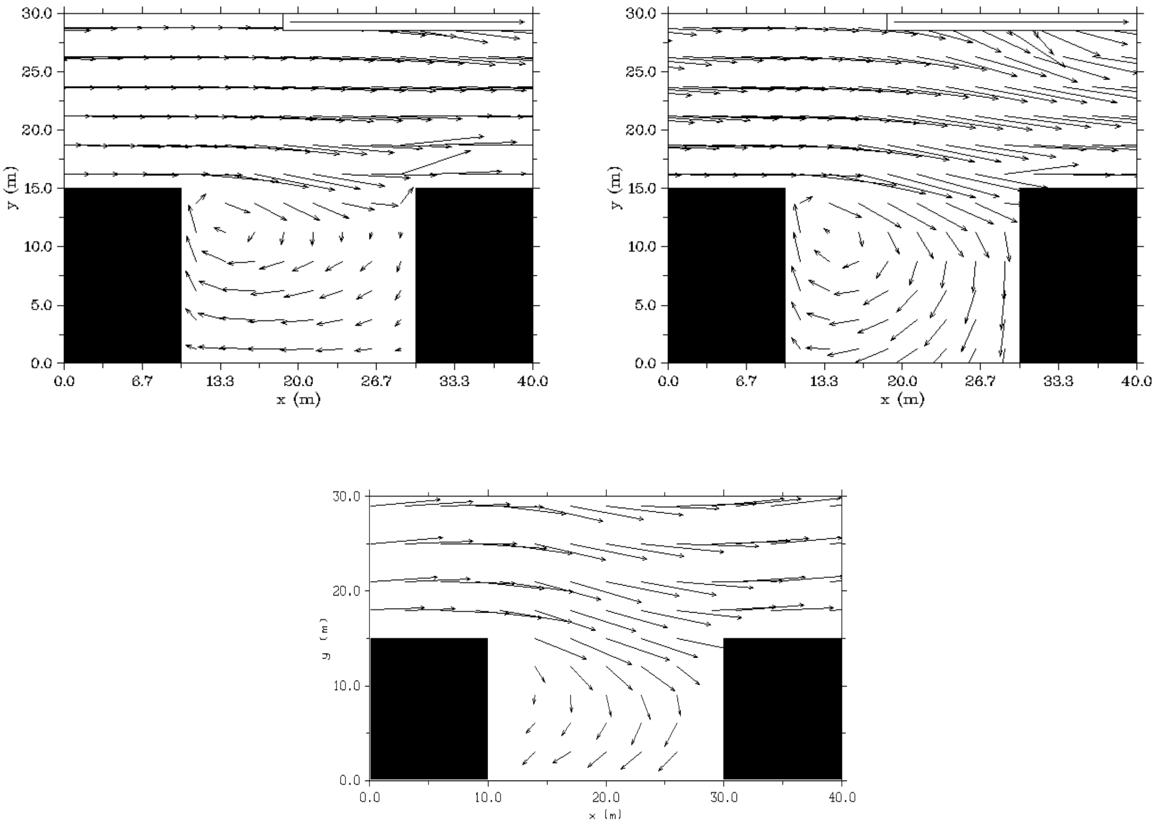

Figure 2: Wind vectors near the surface for flow through array of obstacles. Upper left: computed, inflow direction 270°; Upper right: computed, 250°; Lower right: wind tunnel data.

As can be seen in Figure 2, a rotation of the inflow profile by 20° leads to a significantly better agreement with the measured wind field in the area between the buildings. Major deviations still occur near the rear boundary of the section of the domain represented in the figure. The hit rate for the *y*-component rises to 84 % in case of the rotated inflow profile.

4. CONCLUSIONS

- MISCAM fulfils the requirements of the evaluation guideline in both versions tested.
- The implementation of improved numerical algorithms increases the plausibility of simulated wind fields.
- Results of the evaluation procedure are virtually unaffected by the code modifications. At least, the new model version exhibits a predominant increase of hit rates.
- Some of the wind tunnel data sets appear to suffer from internal inconsistencies.
- There is a need for more complex test cases to represent realistic urban building configurations.

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