

1.10 APPLICATION OF A NEW EVALUATION GUIDELINE FOR MICROSCALE FLOW MODELS

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INTRODUCTION

Numerical models of microscale flow and pollutant dispersal are of increasing importance in the context of meteorological consulting. Therefore, quality insurance is a most relevant issue for model developers.

The new VDI guideline 3783/9 'Environmental meteorology - Prognostic microscale windfield models - Evaluation for flow around buildings and obstacles' (draft, VDI, 2003) allows developers to examine their models by running a series of validation runs addressing different topics such as stationarity and scalability, numerical accuracy, plausibility of results as well as comparisons to wind tunnel measurements.

THE MODEL MISCAM

The numerical flow and dispersal model MISCAM (Microscale Air Pollution Model) as well as its further development stages have been presented at various occasions, including the Harmonisation Conferences at Oostende (1996) and Rhodes (1998), the Urban Air Quality Conferences at Loutraki (2001) and Prague (2003) and finally at the International Conferences on Urban Climatology at Essen (1996) and Lodz (2003). Since the main topic of the current study is the evaluation of the flow model, a brief description of the physical and mathematical framework should be sufficient.

The flow model consists of the three-dimensional equations of motion, using the anelastic Boussinesq approximation to eliminate sound waves. Due to the small horizontal extension of the model domain the Coriolis force is neglected. Also the current model version does not include heat transport, the temperature field is assumed to be horizontally homogeneous. A constant thermal stratification, however, may be prescribed and will be accounted for within the turbulence model.

Turbulence is handled by a k - ε -Model, adopting the modifications suggested by *Kato, M. and B. E. Launder* (1993) and *Lopez, S. D.* (2002) to avoid unrealistic high production of turbulence kinetic energy near stagnation zones.

The equations of motion are solved using the splitting procedure by *Patrinos, A. N. A. and A. L. Kistler*, (1977) which is an elegant method to ensure mass conservation.

All equations are solved numerically on a Cartesian grid of Arakawa-C type. Upwind differencing is used for momentum advection, optionally a predictor-corrector scheme (*MacCormack, R. W.*, 1969) may be applied. A standard ADI algorithm is used for the diffusion equations. The pressure equation is solved by means of a simple but robust red-black SOR procedure.

The model is initialized by a one-dimensional pre-run. Wind and turbulence profiles are kept constant on inflow boundaries while the flow components on outflow boundaries are corrected to ensure overall mass conservation.

THE TEST CASES

An in-depth description of the evaluation guideline will be given in another talk at the Harmonisation Conference. In this place, only a short summary of the test cases will be given.

Two groups of evaluation procedures are defined:

- Consistency checks (stationarity, scalability, dependance on grid resolution)
- Accuracy checks (comparison with wind tunnel data)

As an example for the first group, Figure 1 shows results of MISCAM for the stationarity check. The flow across a two-dimensional beam has been simulated, once using the stationarity criterion supplied by the model itself (a), once using twice the number of timesteps as before (b). Even a close inspection of Figure 1 does not yield any visible differences between both runs. A statistical evaluation in terms of 'hit rates' gives a 100 % - fulfillment of the evaluation criterion as given by the guideline.

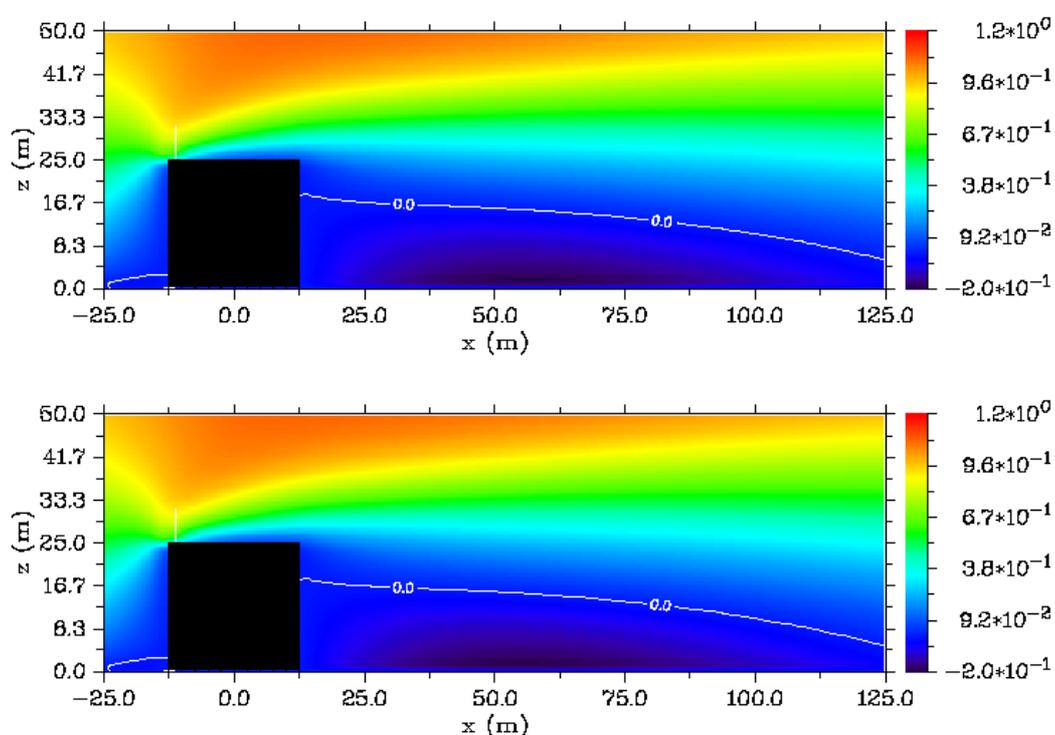


Figure 1. Wind component u (m/s) for two-dimensional flow over a beam. (above) Stationarity criterion of MISCAM applied, (below) number of time steps doubled.

The same configuration is used for an examination of the scalability of wind fields by comparing the results for two different wind speeds.

Other consistency checks address the invariance of wind fields to a rotation of the model domain, examined by comparison of horizontally homogeneous wind profiles for different inflow directions, as well as to changes of grid resolution. MISCAM passes these examinations with hit rates always near 100 % (see Table 1, cases A1 - A3).

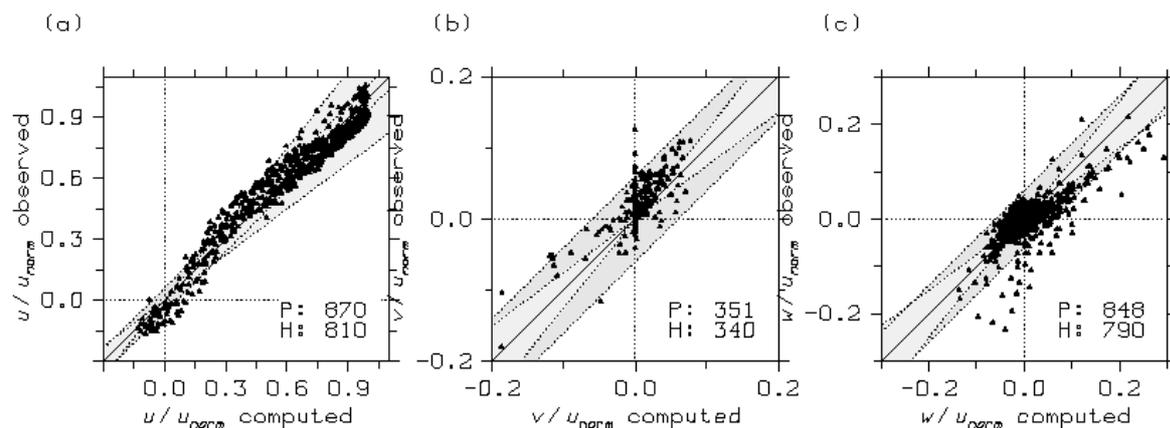


Figure 2. Computed vs. observed normalized wind component u/u_{norm} (a), v/u_{norm} (b) and w/u_{norm} (c) for flow around a cube. u_{norm} is the undisturbed inflow velocity.

The second group of validation runs includes flow simulations for different types of obstacles (cube, rectangular building, array of buildings) for which wind tunnel data are available. The data sets are based on CEDVAL data (Leitl, B., 2000) and are distributed with the guideline. Figure 2 shows results for the flow around a cube. The shaded areas indicate the regions in which a single data point is considered a hit in comparison to the observations. One of two criteria must be met: The difference of computed and observed values must not exceed a prescribed limit (lines parallel to bisecting line, dark shading) or the same difference, normalized by the observed value, must not exceed a certain percentage (light shading). It is evident from Figure 2 that most data points fulfill at least one of these criteria. Since the guideline requires a hit rate of 66 % for comparisons with wind tunnel data, MISCAM passes this case, too. But the figure also reveals some systematic deviations between MISCAM and wind tunnel data. For example, negative values of u are underestimated by the model. In Figure 1 (b) it can be noticed that for a number of grid points the computed value of v equals 0 while the observed values vary between -0.05 and +0.13 m/s. These grid points are located within the plane of symmetry, indicating that the measured flow field was not perfectly symmetrical.

Table 1

Test case ¹	# points u	Hits u	# points v	Hits v	# points w	Hits w	Passed
A1	3660	3618	-	-	3512	3512	✓
A2	3660	3618	-	-	3512	3512	✓
A3	33396	33354	33990	33990	31340	31332	✓
C1	650	567	-	-	650	621	✓
C2 ²	-	-	-	-	-	-	✓
C3	870	810	351	340	848	790	✓
C4	706	594	706	554	787	632	✓
C5	1134	882	615	539	516	445	✓
C6	528	490	93	62	433	351	✓

¹ A detailed description of the test cases is given in the guideline

² Case C2 does not include a point-by-point comparison

As can be seen from Table 1, also for the other test cases the hit rates exceed the values claimed by the guideline. Nevertheless, this does not imply that there is a perfect agreement of computed and measured wind fields. To illustrate this, case C6 (flow through a regular array of buildings) will be considered in some more detail.

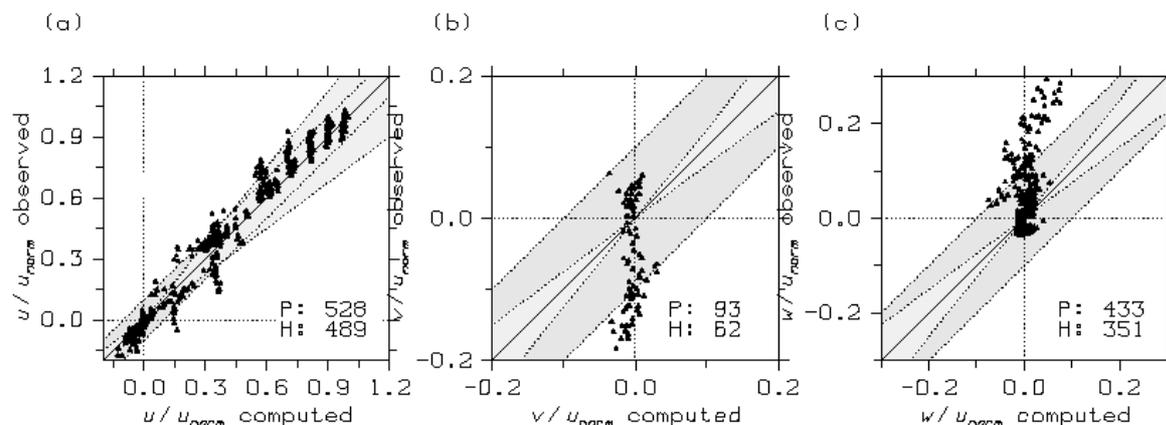
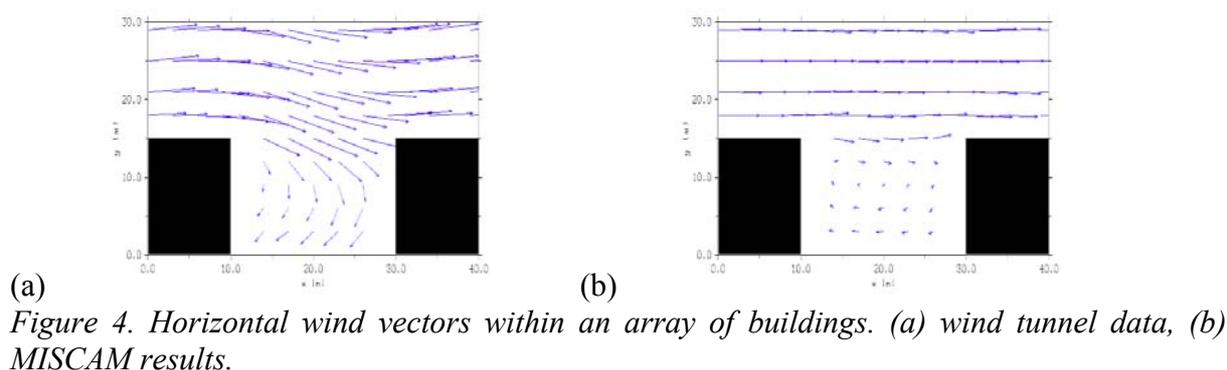


Figure 3. Same as Fig. 2, but for flow through an array of buildings.

Although each wind component fulfills the 66% criterion, Figure 3 shows drastic discrepancies between computed and observed values. Flow along the y -axis as well as the vertical flow component are heavily underestimated by the model.



In Figure 4, a horizontal cross section of the flow field at a height of 12.5 m is shown. The observed flow pattern does not appear to be symmetrical, but is somewhat amplified in y -direction, which was probably caused by a disturbance of the wind tunnel flow. In this case, the evaluation of hit rates is misleading.

FINAL REMARKS

The new VDI guideline serves as a useful tool for model developers to eliminate numerical and mathematical inconsistencies of their models. Also, the comparison of computed wind fields with wind tunnel data for some basic obstacle configurations helps to evaluate the reliability of a numerical model. Care must be taken, however, to avoid an over-interpretation especially for more complex cases like the array of buildings.

In forthcoming papers (Eichhorn, J. And A. Kniffka, 2004a,b) a detailed documentation of all test cases will be given along with an investigation whether or not an improvement of numerical schemes will result in a better performance of the model during the evaluation process.

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