Intercomparison of Numerical Urban Dispersion Models - Part II: Street Canyon in Hannover, Germany

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1. Introduction

Microscale computational fluid dynamics (CFD) models have become a useful and popular tool for assessment and prediction of air quality in urban areas. The proper validation of such a model is a crucial prerequisite for its practical application. Within the framework of the European research network TRAPOS (see URL below) a working group on computational fluid dynamics modelling was established and model intercomparison exercises were launched (see URL of the working group below). Different numerical models employing the widely used 'standard k-ε -model' were applied to well defined test cases comprising a variety of 2 and 3 dimensional configurations for which measurements from wind tunnel or field studies were available.

This paper, which is the second in a sequence of two, presents the results of five models (CHENSI, CHENSI-2, MIMO, MISKAM, and TASCflow) for a street canyon (Göttinger Strasse) in Hannover, Germany. The intercomparison of the models in the cases of a single cavity and a surface mounted cube are subject of part I (Sahm et al., 2001).

2. Methodology

2.1 Models

The CFD codes applied in this exercise are frequently used by the different participating institutions. A more detailed description of the codes can be found in the model inventory [URL see below] or in a table which compares the numerical schemes and boundary condition and can be downloaded [see URL of the TRAPOS CFD working group].

2.2 Field and laboratory data set

A very comprehensive field data set was obtained from measurements in Göttinger Strasse in Hannover. The State Environmental Agency of Lower Saxony operates a permanent monitoring station in this four-lane street canyon with a traffic load of ca. 30000 vehicles/day [NLÖ, 1993]. The width of the canyon is 25 m and buildings on both sides of the street are ca. 20 m high.

In addition to street and background concentrations and meteorological data from a 10-meter mast on top of a nearby building also traffic counts are available.

The data set was chosen for its completeness and quality as was shown in previous studies [Schädler et al. 1996, Ketzel et al. 2000]. Another advantage of this field data set is the additional availability of wind tunnel measurements both for the concentration at the receptor point and for the flow field inside the street canyon, performed at the University of Hamburg [Liedke et al. 1998 and Chauvet et al. 2000].

2.3 Test case

Figures 1 and 2 show the central part of the modelling domain. The dimensions of the domain are 370m x 440m x 240m resolved by 59 x 72 x 24 grid boxes. The grid, the inflow and boundary conditions were exactly defined and used by all codes. The test case description can be downloaded [see URL of the TRAPOS CFD working group] and used also for other numerical models.

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3. Results and Discussion

Figure 3 shows the flow field for approaching flow from 260° in a horizontal plane 10 m above ground level as it was calculated by the five CFD codes and measured in the wind tunnel. The general flow pattern - the strong flow parallel to the street in its northern part and the vortex with vertical axis at the south end of the street - are well reproduced by all the codes. Close to the observation point, the wind tunnel experiment showed an area with very low wind speeds as it was also reproduced by most of the codes. For the details of the flow we observe large differences between the different codes and between codes and wind tunnel results.
The dimensionless concentrations observed or calculated at the observation point are illustrated in Figure 4 as a function of the wind direction. Agreement is found for the general shape of the dependence for most of the codes, i.e., low concentrations for wind direction from 60° to 90°, when the observation point lies in the so-called windward side and high concentrations for the leeward situation for wind direction from 230° to 290°. It is observed that the differences between the concentrations calculated by the different codes for a specific wind direction are within a range of factor 2 up to factor 7.
The reasons for these discrepancies should be found in order to use these codes in practical applications. The authors are now in the process of evaluating the results more in details. This set-up was the most complex one in the series of test cases of the inter-comparison exercise performed and shows as expected the greatest quantitative differences among the model results. Some points of the discussion are: Are all used codes designed and evaluated for this type of application? Is the test domain suitable for all codes with respect to the grid resolution, size and complexity? Is the given observation point appropriate for such a comparison? It is clear that the measuring point lies in a region with very complex flow patterns and strong gradients in flow and concentration fields. Thus any small difference in the predicted direction of the impinged flow may lead to a quite different flow pattern at this location resulting to large discrepancies among the predicted values.

4. Conclusions

This model inter-comparison exercise illustrated that the application of CFD codes to a well defined but relatively complex geometrically test case may lead to quantitative differences in the wind field and consequently the concentration of vehicular exhausts at a location close to building irregularities. These differences may reach a factor of 7. The observed flow pattern generally agrees with the predicted flow fields although differences in the certain locations are found. It is suggested that the accuracy of the CFD modelling result for only one location affected by local gradients should be treated with special care if the results are to be used in practical models. For this purpose, it is possible that an estimation of averages in time (over different inflow situations) or averages in space (to avoid local gradients) is more appropriate.
This model exercise suggests that CFD modelling may be used for recommendations for detecting suitable monitoring sites in order to obtain a representative picture of the air quality in a street canyon. The strong local gradients observed close to irregularities in the building configuration (intersections, gateways, towers, corners etc.) should be avoided.

5. References

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TRAPOS working group on CFD modelling: http://www.dmu.dk/atmosphericenvironment/Trapos/cfd-wg.htm

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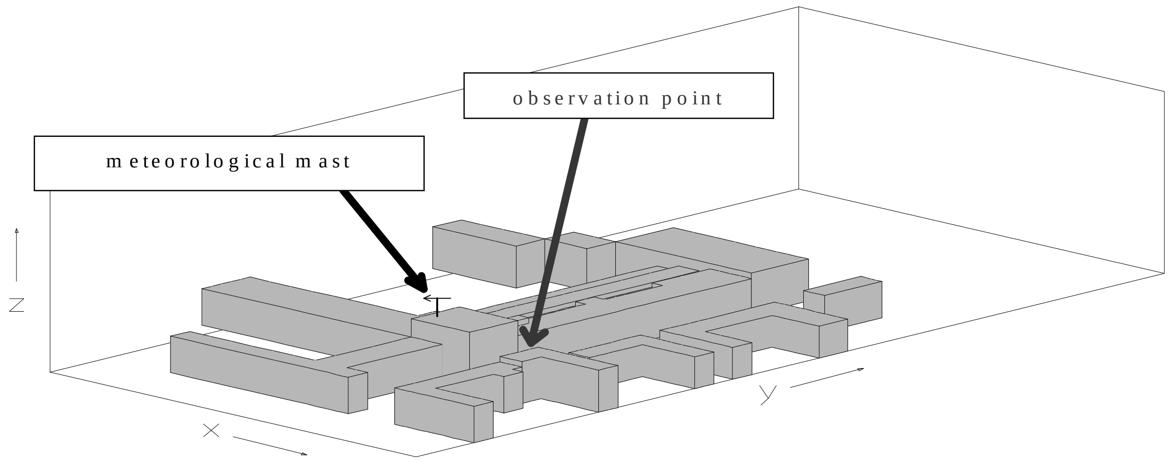

Figure 1: Central part of the modelling domain. The position of the meteorological mast and the point of the concentration measurements are indicated in the sketch.

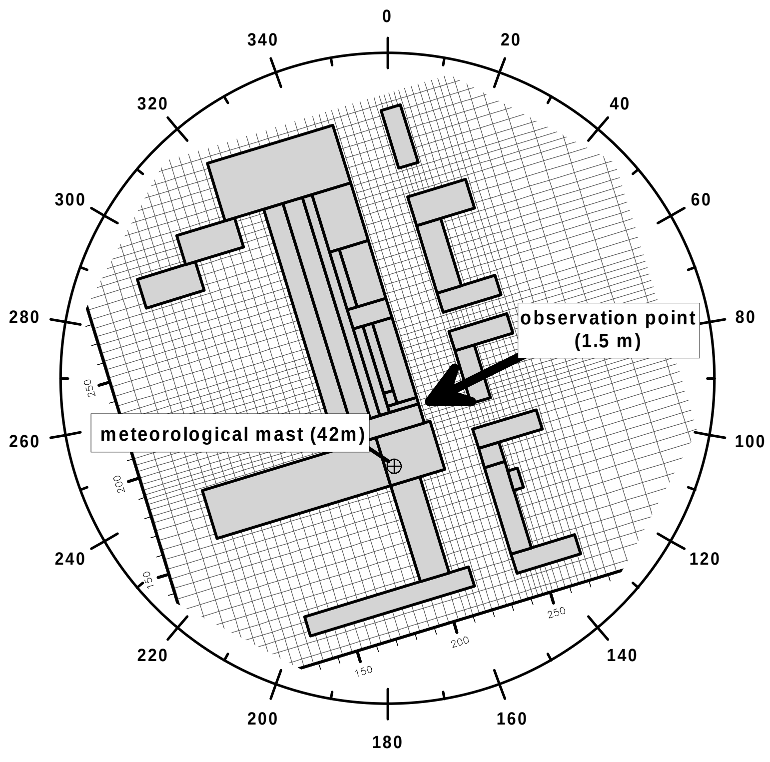

Figure 2: Top view on the modelling area. The grey areas indicate buildings. The mesh shows the resolution of the grid. The circular axis gives the direction with respect to North as it is used for the approaching flow direction in Fig.3 and 4.

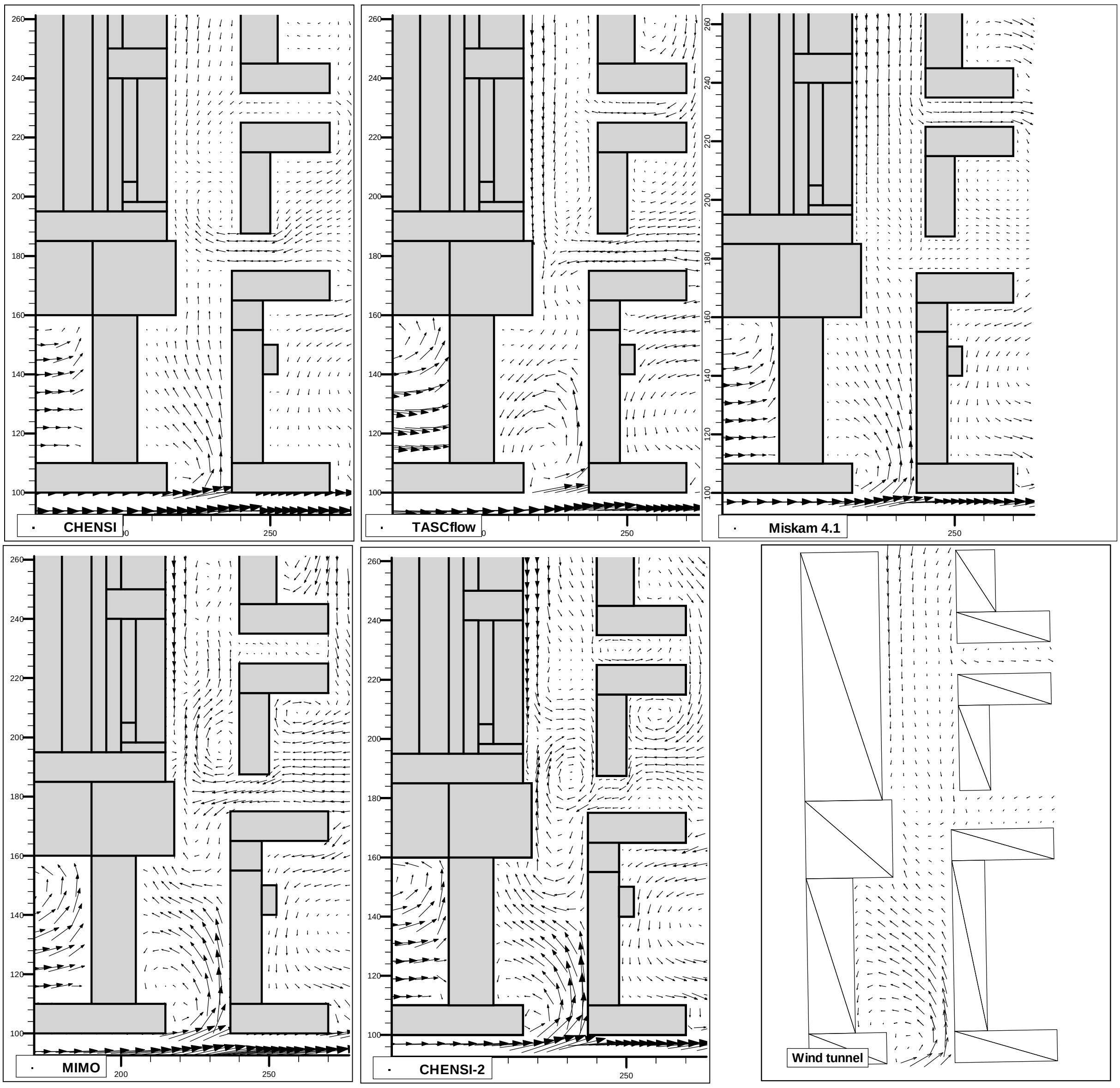

Figure 3: Flow fields calculated by 5 CFD codes and measured in the wind tunnel (see text).

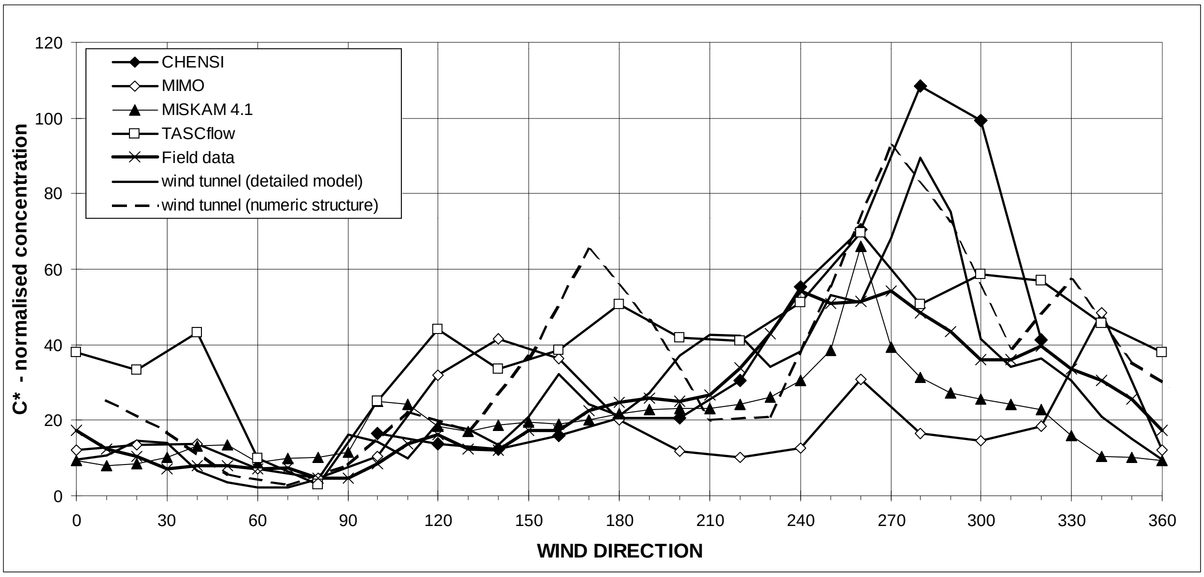

Figure 4: Normalised concentrations in the dependence on the wind direction. Calculated by 4 CFD codes, measured in the field and in the wind tunnel.