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COMPARISON OF GROUND-LEVEL CENTRELINE CONCENTRATIONS CALCULATED WITH THE MODELS OML, AERMOD/PRIME, MISKAM AND AUSTAL2000 AGAINST THE THOMPSON WIND TUNNEL DATA SET FOR SIMPLE STACK-BUILDING CONFIGURATIONS

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Abstract: In 1990 a comprehensive data set on dispersion behind rectangular buildings was compiled in the US EPA wind tunnel (Thompson, 1993). In that study the dispersion for a variety of building shapes, stack heights and stack locations has been systematically investigated. The data set includes measurements of ground-level centreline concentration distributions. In this study the data set is used to analyse the performance of several dispersion models with more or less sophisticated approaches for handling building effects. The models are the Danish OML model, the US AERMOD/PRIME model and the German models MISKAM and AUSTAL2000.

Key words: *OML, AERMOD, PRIME, MISKAM, AUSTAL2000, model comparison, wind tunnel, stack-building configuration*

INTRODUCTION

Concentration measurements in a wind tunnel for various configurations of a point-like emission source and a box-shaped building were performed by Thompson (1993) and later analysed and applied for model validations, among others by Olesen *et al.* (2009) considering the models AERMOD, OML and MISKAM. In this study the model AUSTAL2000 is added to the model intercomparison and MISKAM has been rerun as meanwhile version 6 has been released.

THOMPSON'S WIND-TUNNEL DATA

In 1990 a comprehensive data set on dispersion behind rectangular buildings was assembled in the US EPA wind tunnel, through efforts led by R. Thompson. The data set systematically analyses the dispersion for a variety of building shapes, stack heights and stack locations. These data were originally used to estimate the so-called Building Amplification Factor. However, the potential of the data set extends much beyond this purpose.

The data set includes around 250 scenarios, with systematic variation of the following parameters:

- *Building shape:* Four building geometries were considered, as well as a baseline scenario without building. The buildings were a cube and rectangular buildings with twice or four times the width of the cube. The wind direction was always perpendicular to the building face.
- *Stack height:* In terms of relative stack height (stack height divided by building height), emphasis was on five values ranging from 0.5 to 3.0. There are some scenarios for additional stack heights.
- *Stack location:* The streamwise location of the stack varied, so there are scenarios with the stack upwind of the building, on top of the building and downwind of the building. Altogether 17 locations were considered, extending from 14 building heights upwind to 12 building heights downwind. Not all combinations of stack locations with the other parameters were considered.

From the NERI group the Thompson database was made available as an Excel spreadsheet with embedded graphs and macros. The Excel spreadsheet also contains the results of OML and AERMOD model simulations. For further details see: http://atmosphericdispersion.wikia.com/wiki/Thompson_Wind_Tunnel_data.

Measured wind and turbulence profiles were also provided by Thompson. The data have been analysed by the NERI group who deduced a slightly unstable stratification of the flow in the wind tunnel.

MODEL DESCRIPTION

In this study the models OML, AERMOD, MISKAM and AUSTAL2000 have been applied. In the following a brief model description is given. For further details see the literature in the references.

OML

OML is a Gaussian model for regulatory purposes. OML exists in a standard version and in an experimental version ("research version"). Both are described in detail by Olesen *et al.* (2007). In the present study, the standard version was used (OML version 5.0).

The basis of the standard OML model is an empirical procedure developed by Schulman and Scire (1980). According to the building downwash algorithm as implemented in OML, building influence has two main effects: it increases the initial dilution of the plume and it decreases the plume rise. Normally, both effects contribute towards an increase of ground level concentration. The total effect can be considerable.

AERMOD

Like OML, AERMOD is a regulatory model. AERMOD was originally developed without any algorithm for building effects. A separate model addressing building effects, PRIME, was developed during the late 90's (Schulman *et al.* 2000), and has been included in AERMOD since 2002.

The original dispersion model PRIME made use of Pasquill-Gifford dispersion parameters, which is different from the methodology used in AERMOD (and OML). When integrated into AERMOD, PRIME was modified to make use of AERMOD's methodology to parameterise dispersion. The concentrations computed by PRIME are used in the wake of a building, while beyond the wake concentrations are gradually adjusted to those computed by AERMOD itself. For the AERMOD computations in the current study, AERMOD version 04300 (with PRIME) was used. In the following, the designation AERMOD is used for “AERMOD with PRIME”.

AUSTAL2000

The Lagrangian particle model AUSTAL2000 calculates the time-dependent atmospheric dispersion of substances and odourants. AUSTAL2000 is the official reference implementation of the instructions given in the German Regulation on Air Quality Control (TA Luft, Appendix 3). The model on which AUSTAL2000 is based is described in the German guideline VDI 3945 Part 3 (2000).

The program system AUSTAL2000 includes a diagnostic wind field model (TALdia) as a pre-processor which calculates the three-dimensional wind fields and, in case of buildings, additional three-dimensional turbulence fields and provides them in form of a wind field library to the actual dispersion program AUSTAL2000 (Janicke, U. and L. Janicke, 2004). Alternatively, other externally generated wind and turbulence fields can be provided in form of formatted text files. AUSTAL2000 has been validated against various data sets, including wind tunnel measurements for isolated buildings and data sets provided in guideline VDI 3783 Part 9 (2005). In this study AUSTAL2000 version 2.4 was applied (Janicke, 2009).

MISKAM

MISKAM is a three-dimensional Eulerian air flow and dispersion RANS model which is designed to describe the flow and the dispersion around buildings (e.g. Eichhorn, J., 1989, Eichhorn, J. and A. Kniffka, 2010).

The flow model consists of the three-dimensional equations of motion, using the anelastic Boussinesq approximation. The Coriolis force is neglected. The heat equation is not included, the temperature field is assumed to be horizontally homogeneous. A constant thermal stratification may, however, be introduced into the turbulence equations for non-neutral conditions. MISKAM applies the k-ε-turbulence closure for calculation of the turbulent exchange coefficients. With the current version 6.0 a second order advection scheme for momentum and turbulence was introduced. Detailed validations have been performed for the version 5.02, see e.g. Eichhorn, J. and A. Kniffka (2010), Flassak, Th. and C. Blessing (2009) and Donnelly *et al.*, (2009). MISKAM is validated according to the German guideline VDI 3783 Part 9 (2005). In this study MISKAM 6.00 was applied. For results of MISKAM 5.02, which are not presented here, please refer to Olesen *et al.* (2009).

TEST CASES

From the Thompson data set 3 building cases with 3 stack heights each, in total 9 cases have been selected:

- No building
- Cubic building
- Wide_4 building (crosswind extension is 4 times the building height)

The point-like emission source is centred on top of the building at a stack height (H_s) above ground of 1.0, 1.5 and 2.0 times the height of the building (H_b). According to the boundary layer height realized in the wind tunnel, a scaling factor of 1000 was applied for all models. Therefore the cubic building has a width, length and height of 150m, the wide_4 building has a width (in crosswind extension), length and height of 600m, 150m and 150m, respectively.

MODEL SETUP

For OML and AERMOD the simulation results were simply adopted from Olesen *et al.* (2007), see there for the model setups.

The MISKAM runs were performed for neutral stratification. An unstable stratification as assumed for the runs with the other three models in this study is not permitted since MISKAM version 5.02. The surface roughness length z_0 was set to 0.10m following a recommendation of Thompson (2010) to apply a ratio of z_0 divided by building height H_b of $6.7\ 10^{-4}$. A numerical grid of 212 x 141 x 69 grid cells was selected for a computational domain of 3600m x 3600m x 1000m. The horizontal grid spacing was 10m in the domain centre (1800m x 1070m) and stretched by a factor of 1.2 towards the domain boundaries. The vertical grid spacing was 1m from 0m to 5m above ground and from 150m to 155m. Between 5m and 150m the grid spacing in- and decreased by a factor of 1.2 and 1/1.2, respectively. Above 155m the grid spacing increased by a factor of 1.2.

For the AUSTAL2000 runs the surface roughness length z_0 and the Monin-Obukhov length L_M were derived from a least-square fit of the measured wind profile with the one implemented in AUSTAL2000. The least-square fit yielded z_0 = 0.29m and L_M = -812m, implying a slightly unstable stratification. The agreement decreased for a fit with neutral stratification (L_M set to infinity, resulting z_0 = 0.05m). Pushing the profile a bit more into the unstable regime (L_M set to -300m, resulting z_0 = 0.47m) did not change much the picture. Additional insight was gained from the measured turbulence profiles and a comparison against the boundary layer profiles implemented in AUSTAL2000. The neutral case clearly underestimated the turbulence that was observed in the wind tunnel. Measured turbulence was better reproduced with the slightly unstable stratification. The AUSTAL2000 runs were therefore performed with L_M = -300m and z_0 = 0.47m. A numerical grid of 340 x 81 x 41 grid cells was selected for a computational domain of 10200m x 2430m x 1200m. In the horizontal direction the grid spacing was set to 30m. In the vertical direction the grid spacing was 10m up to a height of 200m followed by a constant spacing of 50m.

RESULTS AND DISCUSSION

In the following the dimensionless concentration c^* is discussed. It is defined as $c^*=(cu_\infty H_b^2)/Q$, where c is the measured or simulated concentration, u_∞ the free-stream velocity (4 ms^{-1}) and Q the emission rate.

Figures 1, 2 and 3 show the along-wind, centreline, dimensionless, ground level concentration profiles up to downwind distances of 20 times the building height for the cases without building, cubic building and wide_4 building and for ratios of stack height (H_s) divided by building height (H_b) of 1.0, 1.5 and 2.0. As the MISKAM computational domain has not been selected large enough MISKAM results are presented only up to a downwind distance of $14H_b$.

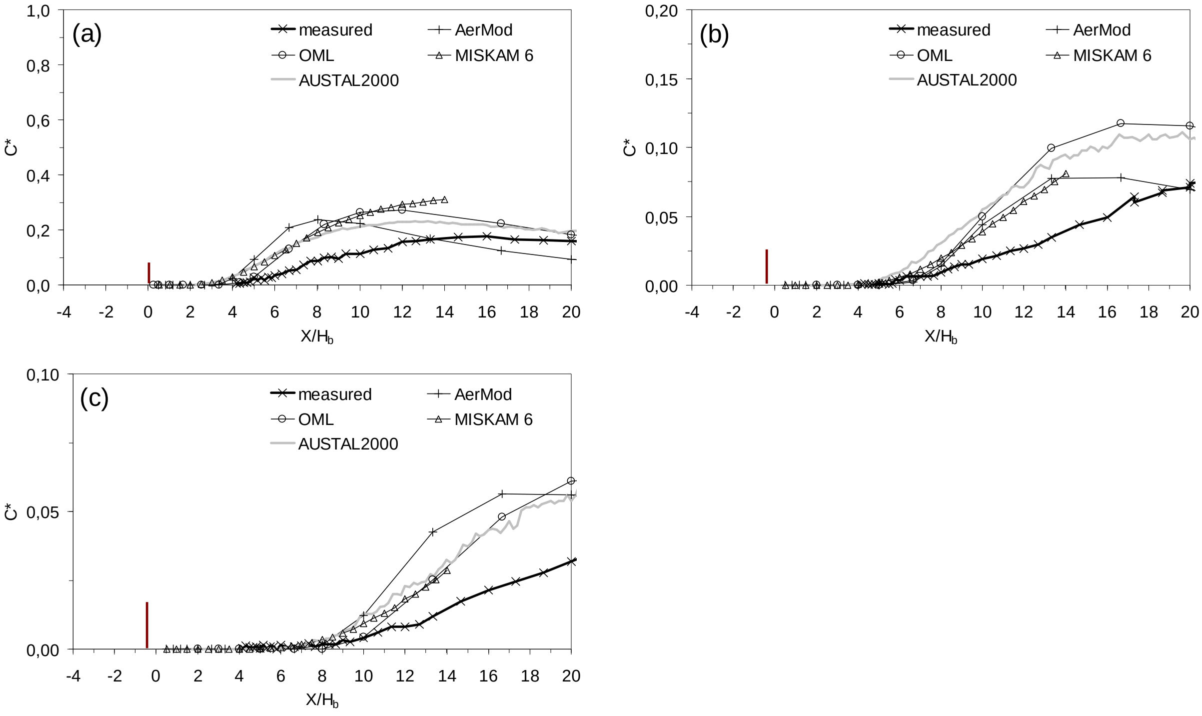

Figure 1. Comparison of measured (thick line marked with x) and modelled, along-wind, centreline, dimensionless, ground level concentration profiles for the case **without building**. Stack height divided by building height H_s/H_b: (a) 1.0, (b) 1.5, (c) 2.0.

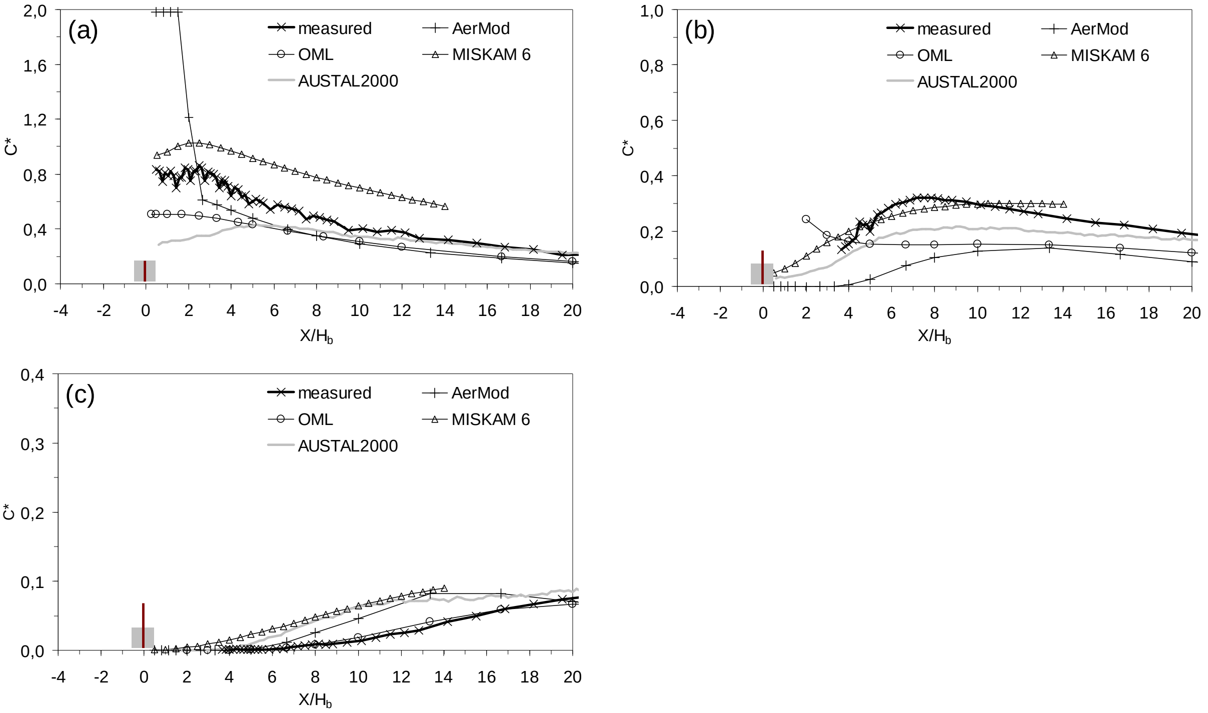

Figure 2. Comparison of measured (thick line marked with x) and modelled, along-wind, centreline, dimensionless, ground level concentration profiles for the **cubic building**. Stack height divided by building height H_s/H_b: (a) 1.0, (b) 1.5, (c) 2.0.

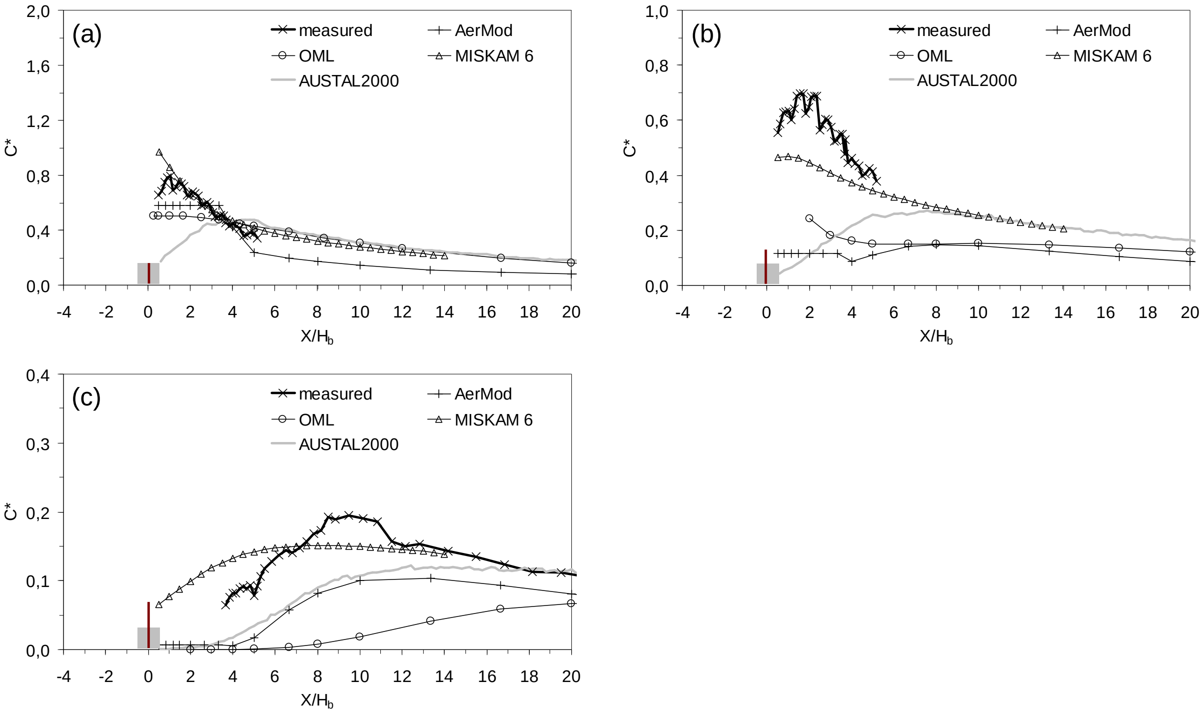

Figure 3. Comparison of measured (thick line marked with x) and modelled, along-wind, centreline, dimensionless, ground level concentration profiles for the **wide_4 building** (crosswind extension of 4 times the building height). Stack height divided by building height H_s/H_b: (a) 1.0, (b) 1.5, (c) 2.0.

The concentration profiles for the case without building and the three H_s/H_b ratios are shown in Figure 1. Nearly all models overestimate the measured concentration in the considered downwind range. In general most model results agree within a factor of 2 with the measured concentrations. Interestingly, in some distance ranges the model results nearly coincide although the measured concentrations deviate by a factor of 2 from the model results.

For the cubic case and H_s/H_b = 1.0 (Figure 2a) the modelled concentrations near the leeward side of the building range from 0.3 (AUSTAL2000) to 2.0 (AERMOD). The measured value is about 0.8. For downwind distances of more than 5 times the building height ($X/H_b>5$) the concentrations simulated by AERMOD, OML and AUSTAL2000 are very close to the measured concentrations. In this regime MISKAM yields higher concentrations, but near the building results of MISKAM are closest of all models to the measurements.

For the wide_4 building the simulated and the measured concentrations are shown in Figure 3. Near the leeward side of the building (i.e. in the building recirculation zone) the simulated concentrations strongly vary across the models by a factor of more than 2. Further downwind the profiles of the different models converge. The larger the ratio H_s/H_b, the further downstream convergence establishes. In the downwind range where measurements are available, the MISKAM results are closest to the measurements.

For H_s/H_b = 1.0 the ground level concentrations in the lee of the cubic and the wide_4 building (cf. Figure 2a and 3a) have a similar maximum value of 0.8. This is not the case for H_s/H_b = 1.5 and 2.0. Here, the location of the maximum concentration as well as the maximum concentrations differ significantly.

CONCLUSIONS

A subset of the Thompson wind tunnel data set has been applied for model validations. For the comparison the well-established models AERMOD, OML, MISKAM and AUSTAL2000 have been considered.

It is interesting to note that all of the models have difficulties to reproduce with standard assumptions the measured concentration profiles for the case without building. A possible explanation is that the actual boundary layer profile in the wind tunnel noticeably differed from the standard boundary layer parameterizations as implemented in the models. This in turn would also effect the model predictions for the cases with building.

For the cubic and the wide_4 building, the simulated concentrations vary across the models by a factor of more than 2 near the leeward side of the building (i.e. in the building recirculation zone). Further downwind the modelled profiles converge. In the downwind range where measurements are available, the MISKAM results are closest to the measurements.

The results for the specific data set of Thompson must be put into context with other validation tests that have been performed for each model in order to evaluate the overall performance of a model. However, this goes beyond the scope of this paper.

In general, the prognostic procedure of MISKAM seems to be better able to account for details of the flow distortion due to the building as compared to the empirical approaches implemented in AERMOD, OML and AUSTAL2000. On the other hand, a prognostic model like MISKAM requires considerably more user skill and computation time. The ability of AUSTAL2000 to apply externally generated wind and turbulence fields in the form of a wind field library may open the possibility to apply MISKAM generated fields for longer time series (for example over a complete calendar year), as it is required in regulatory practice. Such a coupling between a prognostic wind field model and a Lagrangian particle model is presently standardized in a VDI working group for the mesoscale.

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