Coupling of different scale atmospheric models for environment modelling of urban areas

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ABSTRACT

Multi-scale modelling system with downscaling from regional to city-scale with the Environment - HIgh Resolution Limited Area Model (Enviro-HIRLAM) and to micro-scale with the obstacle-resolved Micro-scale Model for Urban Environment (M2UE) is suggested and demonstrated. The M2UE validation results versus the Mock Urban Setting Trial (MUST) experiment indicate satisfactory quality of the model. Necessary conditions for choice of nested models, building descriptions, areas and resolutions of nested models are analysed. Such modelling systems can be used not only for advanced planning safety measures, post-accidental analysis or health/environment impact assessment modelling, but also in the nearest future for operational forecasting or emergency preparedness modelling in a case of terror acts, accidental releases, fires, etc.

Introduction

Atmospheric processes on the micro-meteorological scale depend not only on the local features, but also on larger scale processes, e.g. those of the meso-meteorological or even regional scales. Micro-meteorological and dispersion models for inhomogeneous areas, like urban domains, are sensitive to the choice of boundary conditions. In many research models and test studies the boundary conditions are simplified or artificial, mostly based on the assumptions of horizontal homogeneities in corresponding directions on the inlet and outlet boundaries of the considered domain.
However, in most of the urban simulations for real conditions only a small part of the urban area is considered in a micro-meteorological model and urban heterogeneities outside the simulation domain affect the micro-scale processes. Therefore, it is important to build a chain of models of different scales with nesting of high resolution models into larger scale lower resolution models.

Suggested methodology and models

For nesting from the regional- to meso- and city-scale the Enviro-HIRLAM online integrated NWP-ACT model is used (Baklanov et al., 2008). Several levels of urban parameterisation are considered in the model, they could be chosen depending on considered scales: for regional scale urban parameterisations are based on the roughness and flux corrections approach (EMS-FUMAPEX, 2005); for urban-scale on the building effects parameterisation, BEP (Martilli et al., 2002).
For local- and micro-scale nesting the M2UE model is used. This is a comprehensive CFD-type obstacle-resolved urban windflow and dispersion model (based on the Reynolds averaged Navier-Stokes approach and k−eps turbulence closure), the M2UE, developed in Tomsk State University. For microscale M2UE modelling in this study we are focusing on dynamical processes. Because of the absence of the analysis of radiation/thermal effects in the MUST experiment; radiation processes are not included here, but could be considered in the model. Boundary and initial conditions for the nested M2UE model are used from the Enviro-HIRLAM or other larger scale model simulations with corresponding interpolation keeping the mass-consistency.

Model evaluation / M2UE output for BEP module

M2UE was tested for downscaling for urban air pollution and emergency preparedness modelling in combination with the Enviro-HIRLAM meso-scale model. Results for the meso and city-scale were considered in Baklanov et al. (2008), so here we concentrate only on downscaling studies with M2UE up to the street-scale and possible up-scaling to consider the street-scale effects on wind-flow and pollutant transport on the local- and city-scales.

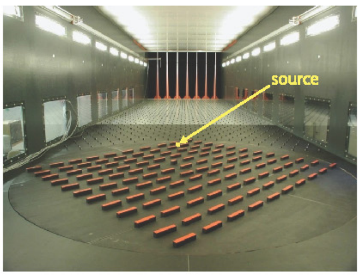

Figure 2 shows results of the M2UE model validation versus the MUST. The main point of the MUST is to simulate the real urban obstacles (with the use of non-regularly arranged 120 containers) and to measure the flow parameters/scalar transport in case of different meteorological conditions. The emission source is located in the far coner of array of containers (Fig. 1).

Figure 1. The MUST domain in Hamburg wind tunnel (-45 deg. case)

Profiles of non-dimensional concentration on different distances from the source (Fig. 2): 27m (left) and 50m (right) show that the model describes well the concentration fields between buildings as close to the release site (where models with a statistical description of urban features usually fail) as well as with increasing distance from the site. The output from the micro-scale simulation is used for meso-scale runs with averaged characteristics by the BEP module.
The results of averaging (Fig. 3) show that there is no log law for u_1 at the roof level and above the array of containers. The drag coefficient is not a constant and it is substantially varying with height. The simulations show that the dispersive kinetic energy (dispersive kinetic energy is the kinetic energy due to the time-averaged structures smaller than a grid cell containing one obstacle with sub-grid deterministic motions within the cell) is higher than the turbulent kinetic energy in the canopy. It stresses the importance of a correct parameterization of dispersive stresses in larger scale models because they have a significant effect on the total gradient of sub-grid fluxes.

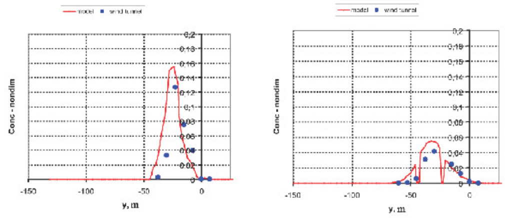

Figure 2. M2UE model validation versus the MUST (-45 deg. case): Profiles of concentration on different distances from source: 27m (left) and 50m (right)

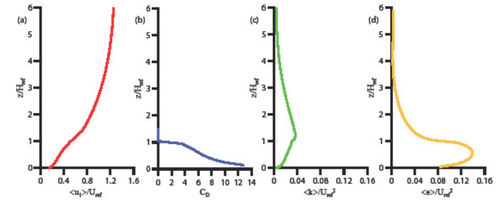

Figure 3. Vertical profiles of averaged variables (0 deg. case): (a) mean axial velocity; (b) drag coefficient (non-dimensional); (c) kinetic energy of turbulence; (d) dispersive kinetic energy

M2UE downscaling for the selected Copenhagen area

Figure 4 shows the considered model down-scaling for a selected area of Copenhagen with the simulation of meteorological fields and air pollution for the two largest areas with the Enviro-HIRLAM model with a statistical description of urban parameters and for the inner smaller area by M2UE resolving the real building structure and using boundary conditions from the larger area simulations.

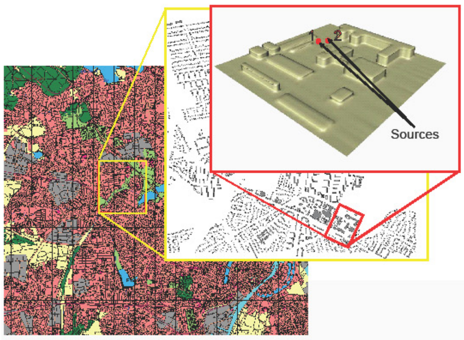

Figure 4. M2UE downscaling for the selected Copenhagen area

For a release position sensitivity study two separate runs are considered, where the release position is moved only by 10 m.

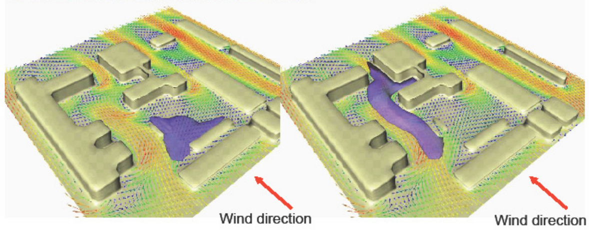

Figure 5. M2UE release position sensitivity study for the Copenhagen area. Near surface velocity field and iso-surfaces of concentration: different release position (position 1 – left and 2 – right).

The analysis of the results (Fig. 5) shows that this small variation of the release site leads to a great change of the plume dispersion: in the second case it is transported quickly between the buildings by the main streams to the outlet border, but in the first case it turned to the right and is much more slowly transported through the other street canyon to the right border of the modelling area. So, further up-scale simulations for these cases show very different speeds of plume transport (which is extremely important in a case of emergency preparedness) and patterns of contaminant concentration and deposition. It is clear that without such a nesting with an obstacle-resolved model it is not possible to describe this effect.

References

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