APPLICATION OF A MODIFIED VERSION OF RAMS MODEL TO SIMULATE THE FLOW AND TURBULENCE IN PRESENCE OF BUILDINGS: THE MUST COST732 EXERCISE.

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INTRODUCTION

The complex configuration of an urban site produces small-scale fluid dynamics that superposes to the atmospheric mesoscale flow and turbulence. Thus, modelling atmospheric flows and pollutant dispersion in urban areas is a problem of peculiar characteristics. Generally, advanced CFD models are used to simulate the flow structure around buildings, obstacles or urban canyons.

We propose an alternative approach starting from the large scale down to the microscale flow, by using the latest version of the atmospheric model RAMS6.0. In it, a Cartesian grid extending from sea level to the model top is implemented and the so called ADaptive Aperture method is used for defining the presence of buildings and dealing with arbitrarily steep topography. This version of RAMS enables simulation with very high resolution, in the order of metres. This approach allows to include the boundary layer processes, the interaction with the surface and the soil, the radiation and the moist processes etc., and it also takes advantage of the several capabilities, like data assimilation and nudging, offered by the atmospheric models. We apply a modified version of RAMS6.0, where we implemented both a standard version of the k-ε turbulence closure model and, lately, also its renormalization group (RNG k-ε) version. This last is claimed to overcome the k-ε deficiencies in the simulation of flow impingement and separation.

Here, the modified version of RAMS6.0 is used in the MUST exercise of COST732 Action. Test-simulations of the flow and turbulence have been performed using both closure schemes.

THE NUMERICAL MODEL AND TURBULENCE SCHEME

The Regional Atmospheric Modeling System (RAMS) is a worldwide-adopted atmospheric model, simulating atmospheric processes on scales from an entire hemisphere down to the microphysics in the planetary boundary layer. For a comprehensive review of the RAMS model we refer mainly to Pielke et al. (1992) and Cotton et al. (2003).

In the current version of RAMS (RAMS6.0), a new coordinate system was implemented, the so called ADaptive Aperture (ADAP hereafter; Walko and Tremback, 2002), which allows for arbitrarily steep and overhanging topography and makes possible the use of a Cartesian grid extending from sea level to the model top. This version of RAMS enables simulation with very high resolution (order of metres) of the flow in an urban environment and the ADAP method is especially suitable for application such as flow around buildings.

In simulating urban environments, a critical role is played by the turbulence closure. RAMS model uses turbulence parameterisations that are suitable to atmospheric flow, like the Mellor and Yamada 2.5 level, while in studying the flow around buildings two-equation models, like k-ε or k-ω closures, are generally applied. In past years, a standard version of the k-ε turbulence closure model was implemented and tested in RAMS (Trini Castelli et al, 2001 and 2005, Ferrero et al., 2003).

The k-ε scheme, however, showed some deficiencies when applied to the simulation of flow impingement and separation (Castro and Apsley, 1997). For this reason, we have recently implemented in RAMS also the renormalization group (RNG) version of the k-ε scheme (Reisin et al., 2006). The basic idea of the RNG method lies in the systematic removal of small scales of turbulence by representing their effects in terms of larger-scale motions and a modified viscosity (Yakhot et al., 1992). In both schemes, the Reynolds stresses and turbulent fluxes in the Navier-Stokes equations and in the transport equation for a passive scalar are parameterised on the basis of the K-theory in terms of grid resolvable variables. The RNG k-ε turbulence scheme as in Yakhot et al. (1992) differs from the standard k-ε turbulence scheme by an additional extra strain rate term R in the turbulence dissipation equation to account for non-equilibrium strain rates, and employs different values for the model coefficients. The prognostic equations of turbulent kinetic energy dissipation rate e (1) reads:

$$\frac{\partial \varepsilon}{\partial t} + U_j \frac{\partial \varepsilon}{\partial x_j} = -C_{\varepsilon 1} \frac{\varepsilon}{k} \overline{u_i u_j} \frac{\partial U_i}{\partial x_j} + \frac{\partial}{\partial x_j}\left(\frac{K_m}{\sigma_\varepsilon} \frac{\partial \varepsilon}{\partial x_j} \right) - C_{\varepsilon 2} \frac{\varepsilon^2}{k} - R, \qquad (1)$$

where $R = \frac{C_\mu \eta^3 (1 - \eta/\eta_0)\varepsilon^2}{(1+\beta_0 \eta^3)k}$, with $\eta = \frac{k}{\varepsilon}\left[\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\frac{\partial U_i}{\partial x_j}\right]^{1/2}$.

and where s_k, s_e, C_μ, C_{e1}, C_{e2} are empirical constants. Also the definition for the turbulent viscosity of momentum K_m differ in the two schemes: in the RNG k-e scheme it includes the molecular kinematic viscosity (2a), while in the k-e scheme it reads as in (2b):

$$K_m = \nu \left(1 + \left(\frac{C_\mu}{\nu} \right)^{1/2} \frac{k}{\varepsilon^{1/2}} \right)^2 \quad (2a); \qquad K_m = \frac{k^2}{\varepsilon} \quad (2b)$$

In this work, the following values were assigned to the constants:

RNG k-ε $(C_\mu, \sigma_k, \sigma_\varepsilon, C_{\varepsilon 1}, C_{\varepsilon 2}, \beta_0, \eta_0) = (0.0845, 0.7179, 0.7179, 1.42, 1.68, 0.012, 4.377)$

k-ε $(C_\mu, \sigma_k, \sigma_\varepsilon, C_{\varepsilon 1}, C_{\varepsilon 2}) = (0.09, 1., 1.3, 1.44, 1.92)$

THE MUST CASE IN COST732 ACTION

The work presented here refers to the MUST exercise in the frame of COST732 Action. The following description of the MUST case is an extract from a document by courtesy of Dr. Bernd Leitl, who prepared it for the COST732 community. The Mock Urban Setting Test - MUST data set provides flow and dispersion data measured within an idealized urban roughness. The experimental setup originates from an extensive field test carried out on a test site of the US Army in the Great Basin Desert in 2001 (Yee and Biltoft, 2004). A total of 120 standard size shipping containers were set up in a nearly regular array of 10 by 12 obstacles, covering an area of around 200 m by 200 m. The containers were 12.2 m long, 2.54 m high and 2.42 m wide and formed an idealized roughness. The exact location and orientation of each of the individual obstacles is documented with sufficient accuracy. At the centre of the container array, a so-called VIP van was placed, serving as collection point for sampled wind and concentration data. The size of the VIP van differs significantly from the size of the surrounding containers. The terrain of the field site is characterized as 'flat open terrain', an ideal horizontally homogenous roughness formed by bushes and grass land with a height of approximately 0.5 to 1 m. Other orographical structures, like dunes, were assumed to have no significant effect on the approach flow conditions at the test site. The nearest significant mountains are located 12 and 24 km far from the experimental field. The terrain slope is documented to be 0.5 m per kilometre, rising to the south.

Wind tunnel measurements within a scaled model of the MUST configuration were carried out for instance by Bezpalcova and Harms (2005). The laboratory data represent the reference dataset used in the COST732 exercise.

THE CONFIGURATION OF THE MODEL SIMULATIONS

Since we are primarily interested in testing the applicability of our modified version of RAMS6.0 in real conditions in this work we simulated the Field T1 test case.

RAMS simulation domain extends 265 m in the longitudinal dimension with a grid size of 0.6 m and 321 m in the latitudinal direction with a grid size of 1 m. In the vertical there are 35 levels with a resolution of 0.2 m up to 3.3 m, then stretched with a total height of 36 m.

These preliminary runs were performed on the 0° inflow case, sketched in Figure 1, left. The 120 containers were located with sizes according to the data provided for the MUST case. The measured mean wind profile for the inflow was available at three levels up to 16 m: since RAMS needs an input profile higher than the top of the domain, we extrapolated logarithmically a profile from the observed data available, as in Figure 1, right.

We recall that RAMS is not built to produce steady-state conditions. However, we set the boundary condition so to approach as close as possible a steady state solution and we verified that a quasi-steady flow was reached after 4 minutes of simulation, with a timestep of $4 \cdot 10^{-3}$ s.

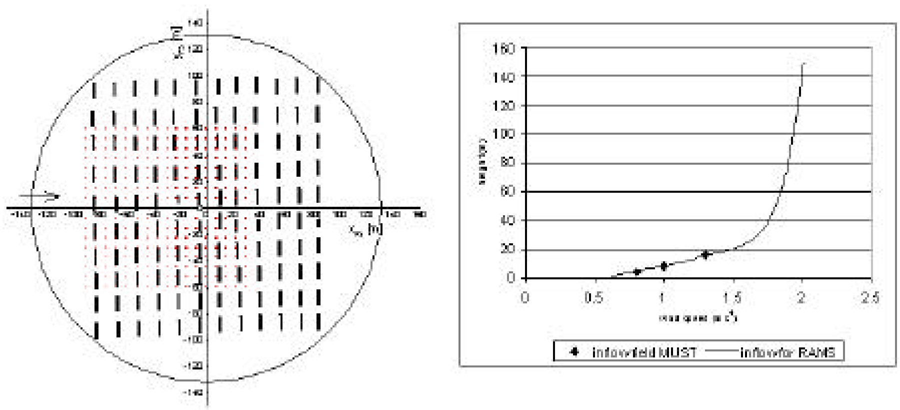

Fig. 1; Geometry of 0° inflow MUST field experiment (courtesy of B. Leitl), left, and wind profile for RAMS simulation initialisation in MUST field test case, right.

RESULTS AND DISCUSSION

Our main goal here was firstly to verify the possibility of using RAMS to simulate the flow in a complex building configuration and to validate its performance. Then, we aimed at testing the closure schemes that we implemented in our modified version of RAMS6.0.

These preliminary simulations with RAMS, properly configured, were successful and produced plausible results: thus far, we are not aware of other works performed with RAMS at this kind of resolution in such complex condition.

In Figure 2 the wind speed vector field is plot for the two runs with different closures, at a height of 1.4 m and after 10 minutes run. We notice that the structure of the flow is very similar, as also confirmed by the wind speed profile plotted in Figure 4 and relative to a point close to the centre of the domain (x=0.4 m, y=0.6 m). Consistent differences occur instead in the turbulent kinetic energy (t.k.e) field, as highlighted in the contour plot of Figure 3, where the point-to-point difference between the values calculated by using k-ε and RNG k-ε is reported. In general, using the k-e closure produces higher value of the t.k.e. This behaviour is particularly evident in Figure 4, where the t.k.e vertical profile close to the centre of the domain is shown.

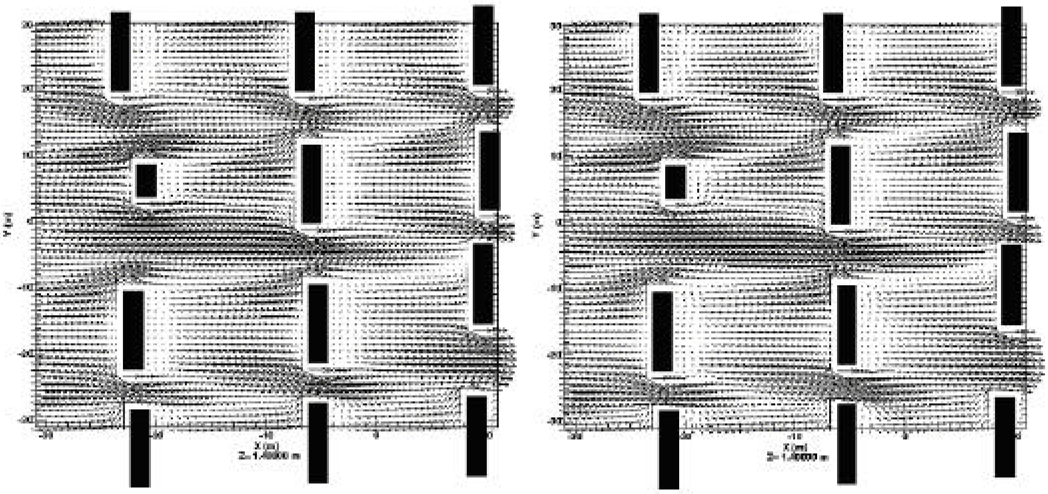

Fig. 2; Wind speed vectors for k-e (left) and RNG k-e simulation (right) simulations.

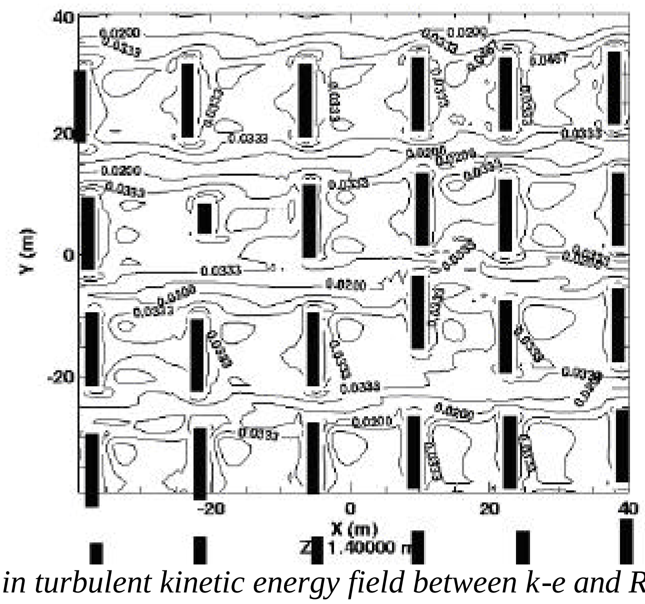

Fig. 3; Difference in turbulent kinetic energy field between k-e and RNG k-e simulations.

This result appears to be in accordance with other results from literature, where CFD models with alternative k-ε-type closure were applied (Murakami, 1998; Wright and Easom, 2003).
We can expect that the differences on the turbulence field related to the choice of the closure scheme have a remarkable effect on tracer dispersion. We are going to investigate also the pollutant dispersion of the tracer experiments carried out in MUST campaign using the latest version of our off-line modelling system RMS (RAMS-MIRS-SPRAY), where a Lagrangian stochastic model is coupled to our version of RAMS6.0. At present, we are acquiring the measured data of MUST field experiment to perform a validation of the simulations against observations.

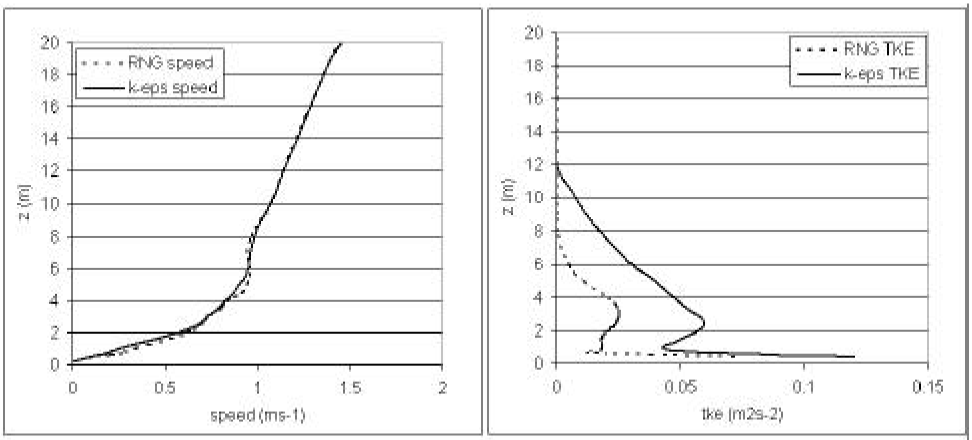

Fig. 4; Wind speed (left) and tke (right) profiles at the domain's centre(x=0.4 m, y=0.6 m)

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