5.3 IMPLEMENTATION OF AN URBAN CANOPY PARAMETERIZATION IN WRF-CHEM. PRELIMINARY RESULTS.

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1. INTRODUCTION

The importance of the interactions between the urban structure and the atmosphere for citizens' life is becoming more and more evident. Not only the pollutant dispersion and urban climate are affected by city structure, but also energy consumption, is in a certain way related to urban boundary layer behavior. The comprehension of these effects, and their feed-backs mechanisms, are essential in order to plan futures sustainable urban growth strategies.

A key tool for this purpose is a meteorological model with detailed Urban Canopy Parameterization (UCP). In this contribution the technique used to implement the UCP of Martilli et al (2002) in WRF-CHEM (Grell et al. 2005) is described in details and the first preliminary results are presented.

2. UCP

The UCP takes into account the impact of the vertical (walls), and horizontal (streets and roofs) surfaces on the momentum (drag force approach), turbulent kinetic energy, and potential temperature equation. The radiations needed for the energy budget at the walls and road take into account the shadowing, the reflections and trapping in the urban street canyons. Although more complex, this parameterization is more detailed than other schemes.

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Since the aim of the work is not the day-to-day forecast, rather the cases studies, the CPU constraints are less strict and the choice is justified. The UCP is coupled with the turbulence scheme of Bougeault and Lacarrere (1989), which has been also implemented in WRF. The nature of the coupling is in the introduction of source terms in the TKE equation within the urban canopy, and the modification of the turbulent length scales to account for buildings effects. The detailed formulation of the UCP is described in Martilli et al. 2002, and we will make reference to this work in the following.

3. METEOROLOGICAL MODEL

The Weather Research and Forecasting (WRF-Version 2) is a next-generation mesocale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs (http://www.mmm.ucar.edu/wrf/users/) . It is the result of the collaboration between different institutions (among the others, NCAR, NOAA, NCEP). The WRF system has a variety of physical parameterizations, and two dynamics solvers: one called EM (Eulerian Mass), developed at NCAR, and one called NMM (Nonhydrostatic Mesoscale Model), developed at NCEP. In this study, the EM dynamical solver is used. It is expected, however, that the developments of the present work can be easily transferred to the NMM version, when needed.

4. METHODOLOGY

In the implementation, the following steps are performed:

- Since WRF uses a staggered grid, the first step is to interpolate the velocities from the faces of the cell to the center where the temperature and the other scalars are defined.
- The second step is the computation of the terms of the equations due to urban and rural surfaces. For every grid point a percentage of urban area is defined. If the percentage is greater than zero the new implemented urban routine is called. The basic for the computation of the urban terms is that the source/sink terms induced by the presence of the buildings and introduced in the equations for momentum, temperature and TKE, can be written as $D_\psi^{urb} = a_\psi^{urb}\psi + b_\psi^{urb}$ where $\psi = u, v, \theta, tke$. In this step, then the $a_\psi^{urb}, b_\psi^{urb}$ parameters are computed for momentum, temperature and TKE, using the values of the wind velocities interpolated at the center of the cell. Moreover, the modification of the length scales induced by the presence of the buildings are computed.
- The third step is to call a standard surface layer routine (for example the NOAH scheme) in order to compute the surface source/sink terms (that may also be written as $D_\psi^{rur} = a_\psi^{rur}\psi + b_\psi^{rur}$) from the vegetated surface.
- The fourth step is a weighted average accounting for the percentage of urban areas urb_f in the cell as $a_\psi = (urb_f)a_\psi^{urb} + (1 - urb_f)a_\psi^{rur}$. $b_\psi = (urb_f)b_\psi^{urb} + (1 - urb_f)b_\psi^{rur}$. Similarly the length scales are averaged.
- a_ψ, b_ψ and the length scales are passed to the boundary layer routine, with the closure of Bougeault and Lacarree (1989).
- Using the Bougeault and Lacarrere (1989) scheme the turbulent coefficients are estimated.
- The tendency due to the vertical turbulent transport and the surface sink/source terms are estimated implicitly for the potential temperature and the turbulent kinetic energy.
- The a_u, b_u , a_v, b_v and the turbulent coefficients are interpolated at the faces of the cell, where the wind components are defined.
- The tendencies due to the vertical turbulent transport and the surface sink/source terms for the wind components u, v are computed implicitly at the faces where the winds are defined.

This technique is different than the standard technique used in WRF which consists of computing also the tendencies for the wind components at the center of the cell, and then interpolate them at the faces where the wind components are defined. However, in cases with strong momentum sink (as in the case of a drag induced by buildings), the new technique revealed to be more numerically stable.

5. 2D RESULTS.

The modified version of the code has been tested for a 2D case with flat terrain and a city 20km wide located at the center of a 200km wide domain. The horizontal spatial resolution is 2km, the initial wind speed is 3 m s^{-1}, and three atmospheric stabilities have been tested: 2 ^{o}K km^{-1}, 3.5 ^{o}K Km^{-1}, and 5 ^{o}K km^{-1}. During night-time the model is able to reproduce the elevated inversion usually observed in urban areas (Fig. 1). The stability effects seem to only weakly affect the height of the inversion layer.

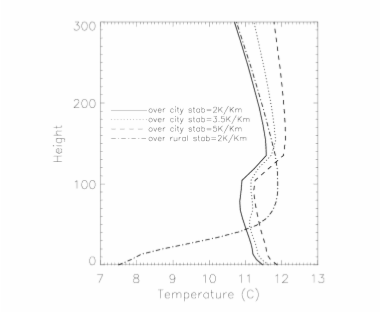

Figure 1. Vertical profiles of Temperature above the city for the three simulations and above a rural area upwind the city for one of them, during nigh-time.

During daytime, on the other hand, the model is able to reproduce the urban plume for all the simulations (see Fig. 2 for the 3.5 ^{o}K Km^{-1} stability case) as well as the decrease of wind speed close to the urban surface, and the increase of wind speed above the city due to the temperature difference between the countryside and the city itself (Fig. 3 for the same case). Numerical results show also that atmospheric stability affects urban boundary layer height during the day and the intensity of the wind speed over the city (the weaker the stability the stronger the wind aloft).

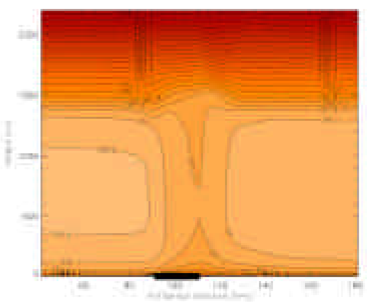

Figure 2. Vertical section of potential temperature during daytime for the 3.5 ^{o}K Km^{-1} stability case.

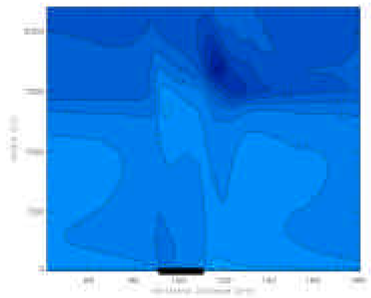

Figure 3. Vertical section of horizontal wind component during daytime for the 3.5 ^{o}K Km^{-1} stability case.

6. CONCLUSIONS AND FUTURE WORK.

In this contribution, the methodology used to implement an Urban Canopy Parameterization in WRF has been described. Simulations in 2D have shown that the new code is able to reproduce typical urban atmospheric features as the nocturnal elevated inversion layer, and urban thermal plume during daytime.

The planned future work consists in performing simulations for an idealized city surrounded by mountains to investigate model's capability to reproduce the interactions between urban and mesoscale circulations. Moreover, WRF_CHEM will be used to investigate, for the same case, the impact of such interactions on photochemistry. Such simulations will give important information for the final step of the work, which consists in real case simulations for cities in complex terrain as Santiago de Chile or Madrid.

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