ABSTRACT

The urban forcing on thermo-dynamical conditions can largely influence local evolution of the atmospheric boundary layer, producing mesoscale perturbations of the lower atmosphere. The new generations of high-resolution numerical weather prediction models (NWP) is nowadays largely applied also to urban areas, whose correct representation is critical. The model WRF has been used to reproduce the circulation in the urban area of Rome. A sensitivity study is performed using different Planetary Boundary Layer (PBL), surface and urban canopy schemes (UCM); the significant role of the surface forcing in the PBL evolution has been also verified by comparing model results with observations from LIDAR, SODAR, sonic anemometers and surface stations. The model MM5 is used as further mean of comparison. Three meteorological events have been studied. The WRF model shows a reiterated tendency in overestimating vertical transmission of horizontal momentum from upper to low levels, as also a tendency in underestimating vertical motions.

1. MODEL CONFIGURATION

The non-hydrostatic WRF ARW (Advanced Weather Research and Forecasting) model is used for this study; it is a primitive equations model with a terrain following vertical coordinate and multiple nesting capabilities [1]. Four two-way nested domains are used (Fig. 1); the mother domain is centred at 41.116N, 11.625E over the Mediterranean basin and it has a spatial resolution of 21.2 km. The nested domains enhance spatial resolution from 7.1 km, for domain 2, to 0.78 km for the inner one; this last encompasses the city area and its surroundings. The following model configuration has been used [1]:

- 35 unequally spaced vertical levels, from the surface up to 100 hPa, with a higher resolution in the planetary boundary layer;
- long wave RRTM and short wave Dudhia schemes for radiative transfer processes;
- Kain-Fritsch cumulus convection parameterization is applied to domains 1 and 2; whereas no cumulus scheme is used for domains 3 and 4;
- Morrison two-moment bulk scheme for microphysics.

Several numerical experiments have been performed using both different PBL parameterizations and different combinations of PBL schemes with surface schemes. The following parameterizations are used for boundary layer:

- the non local Yonsei University (YSU) scheme [3], new generation of Medium Range Forecast scheme (MRF) [2];
- the local 2.5 closure scheme Mellor-Yamada-Janjic (MYJ) [4], [5].

Moreover different combinations of surface schemes (the similarity theory surface model, MM5-MO, or the Eta surface layer, MOY-MYJ) together with a land-surface parameterizations (the 5-layer thermal diffusion scheme, TD-MM5, or the Noah land surface model, NoahLSM) have been used [1]; these have been coupled also with different urban canopy models for investigating specifically the urban boundary layer.
dynamics (UCM1 or UCM2 refer respectively to single or multiple layers scheme) [1]. In the following table a summary of simulations performed with the various combinations of parameterizations is shown. Acronyms in the first column will identify each simulation hereafter.

Table 1: Outline of performed simulations. On first column the identification acronym of each simulation is shown. On other columns are indicated the parameterizations used (see the text for acronyms).

<table>
<thead>
<tr>
<th>Simulations</th>
<th>PBL</th>
<th>SURF</th>
<th>LANDSURF</th>
<th>UCM</th>
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<tr>
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<tr>
<td>MM5-MRF</td>
<td>MRF</td>
<td>MO-MM5</td>
<td>TD-MM5</td>
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</table>

The ECMWF analysis for temperature, wind speed, relative humidity, and geopotential height at 0.25 degrees of resolution are interpolated to the WRF horizontal grid and to vertical levels to produce the model initial and boundary conditions for all the experiments.

2. THE CASE STUDY

Three different meteorological scenarios are chosen to investigate the model capability in reproducing local conditions associated with or without large scale signals in the urban area of Rome:

1. winter case with weak advection and convection;
2. weak convection caused by strong advection;
3. summer like convection case.

In this paper only some result of the second category case will be presented, but main evidences and conclusions that will be highlighted are valid also for the other cases. Based also on measurements availability, the 6-7 February 2008 has been chosen as representative of category 2. Feb 6 is characterized by low pressure conditions in the south-east of Italy and a high pressure entering from north-west. During Feb 7, the anticyclone rapidly enters producing an intrusion of cold air which triggers weak no precipitating convection. During Feb 6 south-eastward weak wind is blowing over central Italy, whereas on Feb 7 the wind speed increases blowing mainly from east. The cold advection intrusion destabilizes the lower atmosphere.

3. SOME RESULT

The PBL parameterizations used show differences in developing dynamics around the urban area of Rome. The local parameterization MYJ produces a lower PBL than the non local YSU in case of strong advection. Temperature and humidity maps on the highest resolution domain (not shown) show that MYJ scheme produces a warmer and wetter field than YSU outside the urban area independently from the season; an opposite tendency has been detected inside the city area mainly during night time. MYJ moreover shows a smoother temperature gradient than YSU between urban heat island area and surroundings during night time, also weakening wind intensity in the low Tiber valley.

To the aim of investigating the two schemes ability in reproducing the PBL characteristics, the WRF results are compared with measurements inside the urban area in this section. The model results are compared with observations by a sonic anemometer, a LIDAR and a SODAR installed on the roof of the building of Physics Department within the Campus of Sapienza University of Rome (41.9N, 12.5E, 75 m a.s.l.).

Simulations for the 6-7 February 2008 case study last 48 hours starting at 00UTC of the first day. Model results have been extracted on the highest resolution domain (0.78 km for WRF and 1km for MM5), at the same coordinates and at the same height in the case of anemometer comparison.

Figure 2 shows the comparison of the horizontal wind speed between WRF and the sonic anemometer (YSU and MYJ respectively on panel a and b). The anemometer shows weak wind speed during Feb 6, except for a maximum (Fig. 2, red line) observed at approximately 15UTC, whereas an increase of the wind strength is observed before midday of the second day. YSU simulations (Fig.2a) show that the model has an enough good performance in predicting horizontal wind speeds during weak advection conditions of the first day, even producing an overestimation; on the other hand it produces a big error (up to ~ 8 m/s), respect to measurements, after the wind speed increase during Feb 7. No appreciable differences are produced by combining the non local PBL with different surface schemes (Fig. 2a, blue and yellow lines) or with the UCM1 (green line). MM5 model, instead, shows a better agreement for this variable during Feb 7 (Fig. 2a, cyan line), even missing maximum registered in the first day afternoon.

On the other hand the MYJ simulations (Fig. 2b), even having trends similar to YSU, show a better agreement with measurements. MYJtd and MYJNoahNOURB (Fig. 2b, orange and black lines) reproduce with very good approximation the maximum between 12 and 18 UTC of Feb 6; they still produce an overestimation during the second day, but reducing the maximum error.
to 6 m/s. Activation of UCM2 (Fig. 2b, pink line), reduces horizontal wind intensities causing an underestimation that partially decreases the error during 7 February, even worsening the agreement in the first part of the simulation. In any case, the higher complexity of the multi-layer urban scheme (UCM2) allows to obtain effects on the MYJNoahLSM simulation, no detectable in the corresponding simulation of YSU with UCM1; this allows to assess the fundamental importance of representing the subscale effects of the urban canopy layer.

The further comparison with SODAR vertical profiles (an example is shown on Fig. 3 for YSUNoahUCM1 and MYJNoahUCM2) allows to address the WRF overestimation of horizontal wind (Fig. 2), to an excess of forcing of upper layers dynamic on the urban canopy layer. The SODAR shows a weak horizontal wind component reinforcing after 1:00UTC of 7 February (Fig. 3a), generating a structure with four peaks of maximum intensity. The WRF model, independently of the configuration, reproduce dynamics occurred during the event even overestimating intensities and producing a delay in reinforcing the field during the second day (see for example Fig. 3c; other simulations, except the MYJNoahUCM2, show very similar results).

Figure 2 Time series of horizontal wind speed for YSU (a) and MYJ (b). Colours code is: YSUtd (blue); YSUNoahNOURB (yellow); YSUNoahUCM1 (green); MM5-MRF (cyan); anemometer measurements (red) and errors (grey); MYJtd (orange); MYJNoahNOURB (black); MYJNoahUCM2 (pink).

Figure 3 Time series of the horizontal wind speed vertical profile on Feb. 6-7, 2008 for the SODAR measurements (a), YSUNoahUCM (b) and. MYJNoahUCM2 (c) simulations. Time is on x axis and height on ordinate axis.

During Feb 7 the WRF simulations show wind speeds more intense than the SODAR ones below 200 meters (ex. Fig 3b), with the maximum structure generally located at lower level than the observed one. This helps
to confirm the previous hypothesis of an excess of horizontal momentum vertical flux from high to low levels, that affects also the overestimation inside the urban canopy verified by the anemometer. An upward displacement of maximum structure is produced by MYJ PBL if UCM2 is activated (Fig. 3c); this improves the agreement with SODAR. UCM2 activation correctly slows down the air intrusion from upper levels, decreasing the downward transmission of horizontal momentum. This turns in a better reproduction of horizontal wind field also inside the urban canopy. The correction is confirmed by the increase of the correlation between simulated and measured data. The two PBLs produce similar correlation scores; MYJ PBL shows a higher score (0.84) than YSU (0.83) also when UCM2 is switched off, increasing it to 0.85 if urban canopy is used. On the other hand an increment of the underestimation of vertical wind field (not shown) is registered when urban canopy model is used with the local PBL. Principal conclusions highlighted by the comparison presented in this paper together with further ones performed for other variables and instruments (not shown for brevity reasons) are summarized in next section.

4. CONCLUSIONS
The model WRF has been used to reproduce the circulation in the urban area of Rome. A sensitivity study have been performed using local and non local PBL parameterizations combined with different surface schemes. The comparison with the anemometer and surface stations showed a WRF tendency to overestimate horizontal wind component at low levels regardless the background conditions of the case study, even if the higher order closure local scheme (MYJ) produces lower biases. This overestimation can be addressed to an excess of the vertical flux of horizontal momentum. In general coupling with Noah LSM improves speed values; further activation of UCM produces a reduction of speeds respect to the anemometer if the local PBL is used. This turns in a better agreement with measurements. Moreover coupling with an advanced land surface-hydrology model (NoahLSM) produces more detailed surface forcings on most variables that introduce realistic and high resolved features on PBL time series when very local circulation conditions happen, mainly if coupled with a urban canopy scheme. Upper levels investigations by SODAR and LiDAR showed a WRF tendency in underestimating vertical motions. A multi-layer urban canopy model (UCM2) allows both to uncouple the canopy layer from upper PBL when large scale advection poorly drives lower levels horizontal dynamics and to introduce a larger variability of vertical wind profile. Both PBLs tend to overestimate PBL height, when turbulence terms not relied to diurnal cycle contribute to the layer growth. No evident differences have been found on suburban areas when a urban canopy model is used, except in the case of see-breeze regime (case 3.) when a weakening of circulation is verified also outside and far from the urban area when the multi-layer urban canopy model and the local PBL scheme are used.

5. REFERENCES