VALIDATION OF MESOSCALE METEOROLOGICAL SIMULATION OVER PO VALLEY FOR AIR QUALITY APPLICATIONS

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Abstract: Very high ground level concentrations of PM in winter and of ozone in summer often occur in Northern Italy, due to the high anthropogenic emissions and frequent stagnant meteorological conditions that characterize the area. These problems are not only related to urban, but also to suburban areas through the entire Po Valley. In such a situation it is important to use deterministic Chemical Transport Models, that allows to evaluate the effect of different air quality control policies on secondary pollution concentrations. Chemical Transport Models generally are part of more complex deterministic modelling systems, encompassing also emission models, meteorological models, and initial and boundary condition processors. Meteorological models are an important module of deterministic modelling systems and, due to their complexity, require high computational costs to perform simulations. In fact they solve a full set of non-hydrostatic equations that describe atmospheric dynamics and thermodynamics, and conservation equations, usually considering two-way interacting nested domains. Within the HPC-EUROPA (Pan-European Research Infrastructure on High Performance Computing) cooperation project, that allows to use clusters of CPUs all around Europe, the meteorological fields over Northern Italy were simulated using RAMS4.4 in parallel mode, creating a database for future air quality assessments. In the present work a CPUs cluster of the Italian computing centre CINECA have been used. The meteorological simulations have been performed considering three nested grids. The first grid covers an area that encompasses the entire Europe, the second grid is focused on Mediterranean sea, while the third one is limited to the Po Valley area. The spatial resolution of the three grids is respectively 128 km, 32 km and 8 km. The number of cells for the three grids is respectively 40x40, 86x86 and 102x102, with 33 vertical levels covering the domain from surface to roughly 20 km height. The entire 2004 year has been simulated through 72 simulations of 126 hours each, considering a spin-up time of 6 hours and 16 CPUs each simulation. In this paper the model configuration and the validation of the simulated meteorological fields are presented.

Key words: *Meteorological model, Model validation, Air quality models.*

1. INTRODUCTION

Chemical Transport Models (CTMs) (Carnevale et al., 2008) are useful tools to plan air quality control policies. These CTMs are part of more complex modelling systems (Volta and Finzi, 2006), also encompassing emission models and meteorological models.

Meteorological models, focus of the application presented in this work, are generally constructed around the full set of nonhydrostatic, compressible equations that describe atmospheric dynamics and thermodynamics, plus conservation equations for scalar quantities such as water vapour and liquid and ice hydrometeor mixing ratios. These equations are supplemented with a large selection of parameterizations for turbulent diffusion, solar and terrestrial radiation, moist processes including the formation and interaction of clouds and precipitating liquid and ice hydrometeors, kinematic effects of terrain, cumulus convection, and sensible and latent heat exchange between the atmosphere and the surface, which consists of multiple soil layers, vegetation, snow cover, canopy air, and surface water. Due to their complexity, meteorological models are very time consuming; a solution to this computational time demand is through the use of supercomputers, or cluster of computers. This aspect is even more important when the final target is to perform long-term simulations with air quality models, and so also the meteorological model has to be run for long periods (as in example for 1-year long simulations, as presented here).

Focus of the study presented in this paper is to develop and validate a long-term meteorological simulation (1-year) for air quality applications. The meteorological model applied in this work has been run in the frame of the HPC-EUROPA project (Pan-European Research Infrastructure on High Performance Computing). The presented application is devoted to the evaluation of the performances of a mesoscale meteorological model (RAMS4.4, Cotton et al., 2001) over the area of Northern Italy for the year 2004; the created meteorological dataset will be used for a future air quality application. In this paper a comparison of modelled and measured meteorological fields is performed for two stations located one in the Eastern and one in the Western part of the Italian domain. The selected domain is often affected by severe secondary pollution episodes (Vecchi et al., 2004; Gabusi et al., 2005), and for this reason is of extreme importance to develop for this area sound meteorological and air quality modelling applications.

2. DOMAIN FEATURES AND MODELLING SETUP

RAMS, the Regional Atmospheric Modelling System (Pielke et al., 1992; Cotton et al., 2001) is a well-known numerical code for simulating and forecasting meteorological phenomena, and it has been applied in this study.

The model has been applied over Northern Italy, an area with very high secondary pollution concentrations, and where it is particularly difficult to implement effective air quality control policies. This domain is extremely interesting because it contains the Lombardia region, an area counting 10 million inhabitants, and one of the most industrialized in Italy, characterized by high urban and industrial emissions. Furthermore in this area stagnant meteorological conditions, low wind speed and temperature inversion are frequent both in winter and summer. For these reasons, the European PM10 legislation is often not respected. PM measurement campaigns (Vecchi et al., 2004, Giugliano et al., 2005, Lonati et al., 2005) and multiphase modelling applications (Volta and Finzi, 2006, Cuvelier et al., 2007) have been performed in the domain suggesting that the secondary fraction of PM10 on the considered area is relevant. From these issues it is clear how the reconstruction of correct meteorological fields over this domain is of vital importance to correctly feed Chemical Transport Models.

To be able to consider in the simulation both synoptic and local meteorological patterns, three nested grids have been created for RAMS simulation (Figure 1, left).

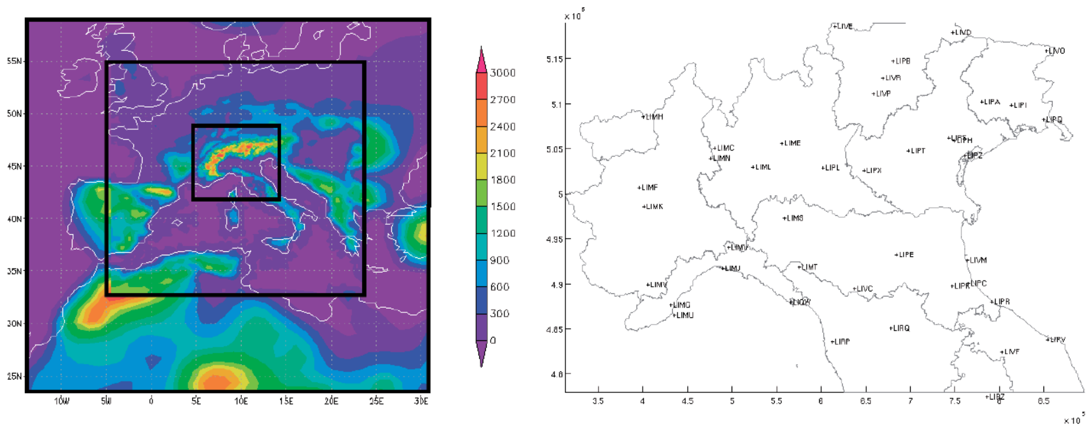

Figure 1. The three nested domain (left) and the location of the validation measurement stations (right).

With the first grid the modelling simulation covers an area that encompasses the entire Europe, with latitude roughly between 23 and 59 degrees, and longitude between -13 and 31; the second grid, focused on Mediterranean sea, has latitude from 32 to 55, and longitude from -4 to 24; the third one, limited to Po Valley area, has latitude from 42 to 49 and longitude from 4 to 14. The resolution of the three grids are respectively 128 km, 32 km and 8 km. The number of cells for the three grids is respectively 40x40, 86x86 and 102x102, with 33 vertical levels covering the atmospheric layers from surface to roughly 20 km height.

The entire year 2004 has been simulated through 72 simulations of 126 hours each, considering a spin-up time of 6 hours and using 16 CPUs for each simulation, with a total computational time of 10000 hours. Standard dataset of RAMS have been used, i.e. USGS topography and land use at 30s resolution, and global monthly climatological sea surface temperature data at 1 degree resolution. NCAR reanalysys (Kalnay et al., 1996) data with 2.5 degrees of resolution have been used to provide initial and boundary conditions to RAMS simulations. No measurements have been ingested in the model simulation. Chen scheme have been used for both short wave and long wave radiation parameterizations.

3. MODEL EVALUATION AND ANALYSIS

To validate the model, measurements have been derived by the ds464.0 NCEP (National Centre for Environmental Prediction) ADP (Automated Data Processing) Global Surface Observations dataset. These data, that can be freely downloaded by http://dss.ucar.edu/datasets/ds464.0/, are available from February 1975, and include SYNOP and METAR measurement networks.

Time series of temperature, wind speed and wind direction measurements have been extracted by the ds464.0 NCEP ADP dataset for the entire 2004. The validation stations are shown in Figure 1, right. In this work results are shown for only two validation stations: LIMU (in the South-West corner of the domain) and LIPQ (in the North-East part of it). Measurement station data have been compared with modelled time series derived by the 8 km simulation, so considering the smallest (and with the finest resolution) domain.

Temperature validation

In Figure 2 the modelled (blue continuous line) and observed (red crosses) daily mean Temperature are shown, for the entire 2004 and for the two selected stations. LIMU station is close to the sea, and so influenced by sea breeze; LIPQ station is instead more in the hinterland and more representative of Po Valley meteorology. For both stations it is possible to appreciate how the model is overestimating temperature during winter, and underestimating during summer.

The same information is shown in Figure 3 for monthly mean temperature. While at LIMU station the model is performing better than LIPQ one, it is clear the overestimation/underestimation trend stressed in Figure 2. This trend is common to roughly all the considered validation stations (not shown here).

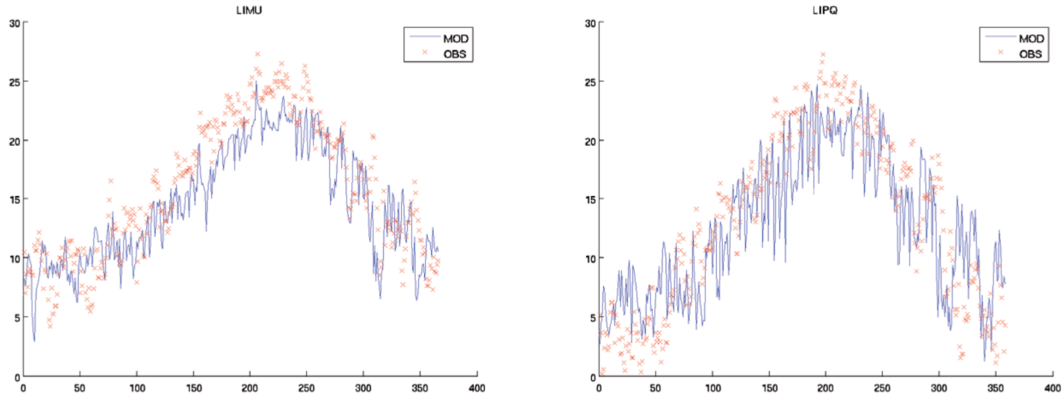

Figure 2. Daily mean temperature (2m level) comparison, between modelled (MOD) and observed (OBS) values at LIMU (left panel) and LIPQ (right panel).

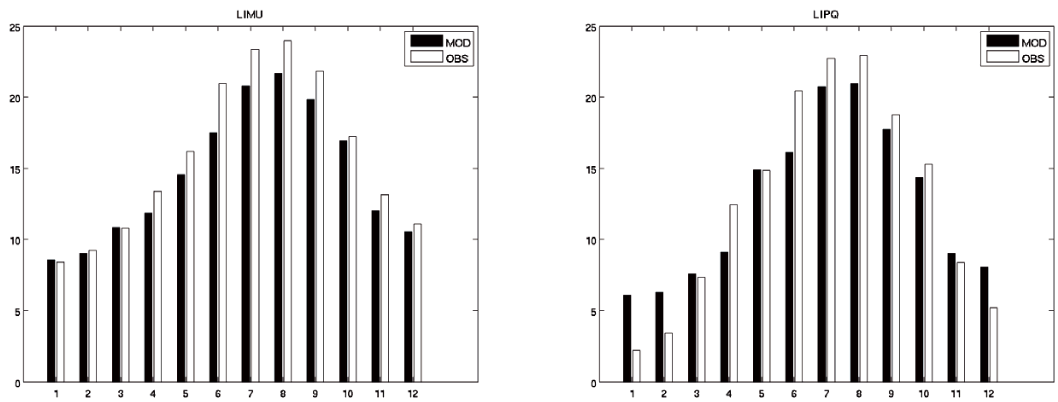

Figure 3. Monthly mean temperature (2m level) comparison, between modelled (MOD) and observed (OBS) values at LIMU (left panel) and LIPQ (right panel).

Wind validation

In Figure 4 the modelled (blue continuous line) and observed (red crosses) daily mean wind speed is shown. In both stations it is possible to stress how the model is overestimating wind speed values, even if in LIMU stations performances are slightly better. The overestimation problem is a common one in Po Valley (Bedogni et al., 2005); this case study application confirms that it is necessary a) to simulate with higher spatial resolution and b) to assimilate meteorological measurements in the modelling simulation, to grasp the Northern Italy wind speed features.

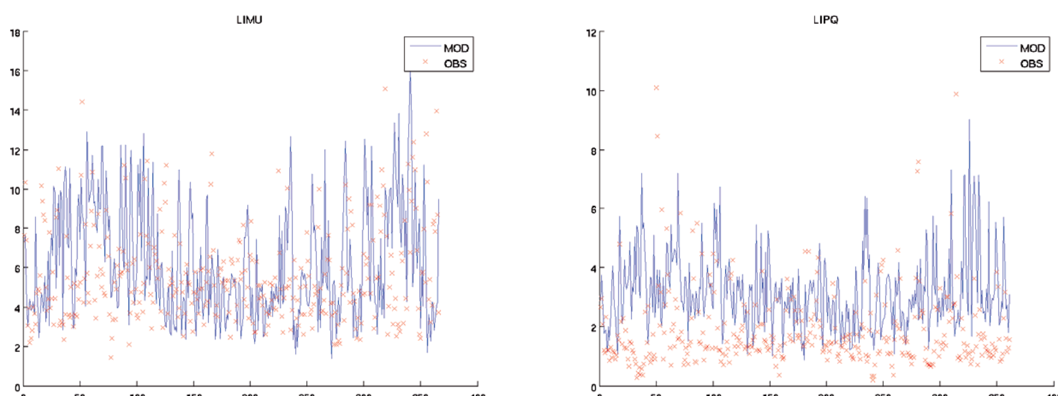

Figure 4. Daily wind speed (10 m level) comparison, between modelled (MOD) and observed (OBS) values at LIMU (left panel) and LIPQ (right panel).

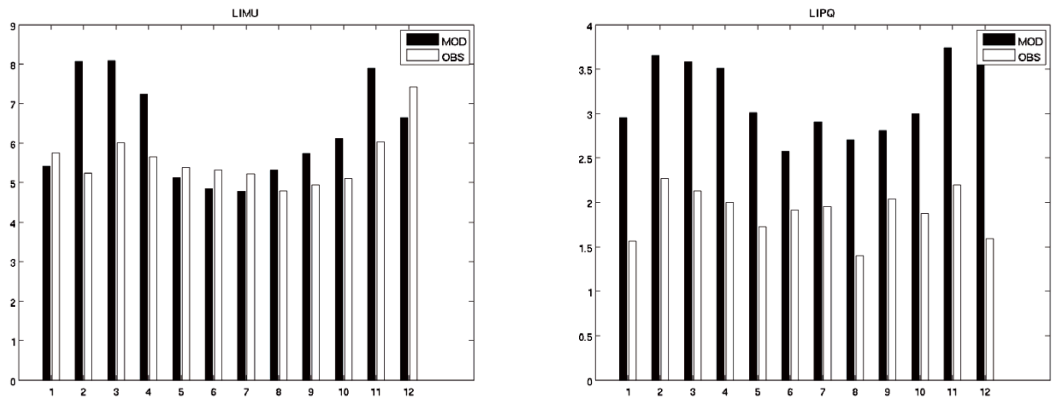

Figure 5. Monthly wind speed (10 m level) comparison, between modelled (MOD) and observed (OBS) values at LIMU (left panel) and LIPQ (right panel).

In Figure 5 modelled and observed monthly mean wind speed are shown. Performances are better when measured wind speed values are higher (LIMU station) while worse where measured mean wind speed are lower (LIPQ station). This feature has been verified also in the other validation stations (not shown here).
In terms of wind rose, in Figure 6 results are shown for LIMU (left) and LIPQ (right), for measurements (top) and models (bottom).

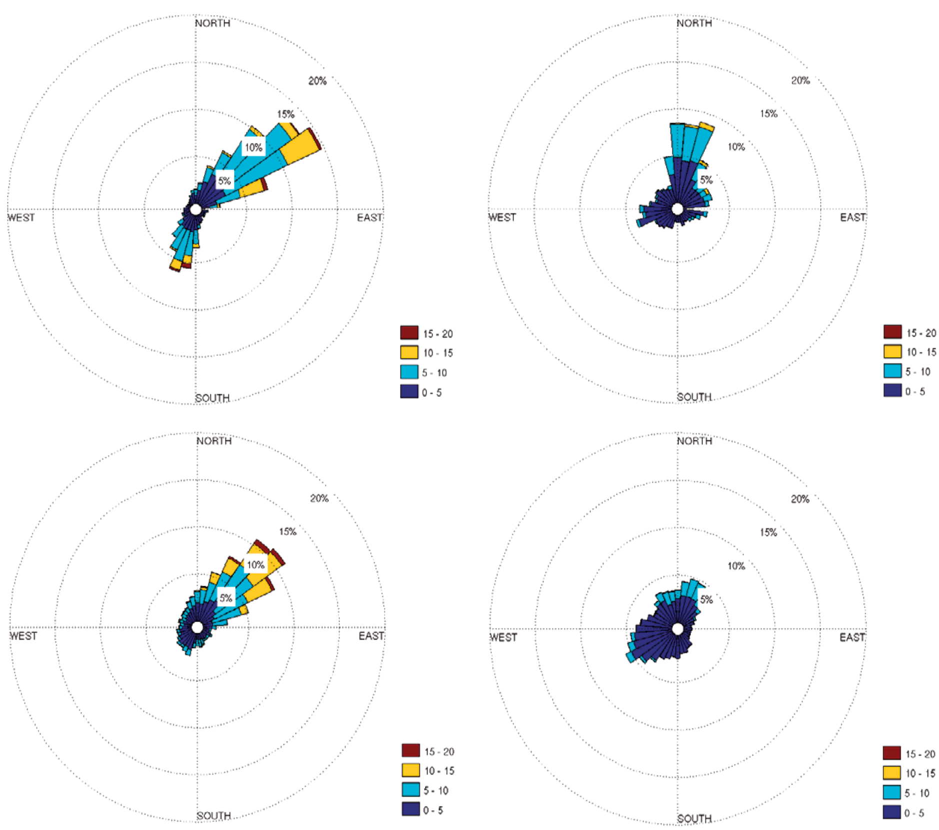

Figure 6. Wind rose for LIMU station (left) and LIPQ (right), for measurement (top) and model (bottom) data.

As stressed in Figure 4 and Figure 5, LIMU station wind reconstruction (left) is better than LIPQ one (right). More precisely, in the case of LIMU station there are two main wind directions, NE and S, and the model is able to represent mainly only the NE direction. In the case of LIPQ station (right) the model wind rose reconstruction is not able to represent the measured wind speed and direction.

4. CONCLUSIONS

During the HPC-EUROPA cooperation project between University of Brescia and the Bulgarian National Institute of Meteorology and Hydrology, a long-term meteorological model run has been simulated. The entire 2004 has been simulated over Northern Italy, and a meteorological dataset for a future air quality application has been prepared. The validation of the long-term meteorological simulation shows that temperature is generally overestimated in winter and underestimated in summer, while wind speed is always overestimated. These modeling limitations can affect air quality simulation results. To improve meteorological model results it is possible to a) improve model spatial resolution; b) assimilate ground measurements in the meteorological simulation; c) investigate in details the role of the surface exchange schemes and parameters used in the model comparing measurements and used initial values.

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