Sensitivity tests of MM5 modelling system over a coastal region in Portugal

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Abstract

The west coast of Iberian Peninsula, surrounded by the Atlantic Ocean, is characterized by complex topography and some favourable synoptical situations, which imply the occurrence of mesoscale circulations, namely sea/land breezes and anabatic and katabatic flows. Air quality standards are strongly influenced by these patterns leading to the enhancement of photochemical pollutants levels.

In order to evaluate air quality levels in Aveiro study region, a field campaign was carried out from 24th June to 2nd July of 2001, which covered the highest ozone (O_3) episode noticed in the region during the year of 2001. To correctly assess air quality over Aveiro region not only measurements are required but also the application of an integrated system of meteorological and photochemical models. Aiming to achieve more satisfactory air quality results both models must be evaluated over the interested region. Accordingly, meteorological model evaluation should be performed firstly.

In this scope, the Pennsylvania State University/National Center for Atmospheric Research Mesoscale Meteorology Model (MM5) was applied using its nesting capabilities. Sensitivity analyses were also done in order to better understand how grid size influences model results and its behaviour under distinct meteorological situations. MM5 modelling system was applied to two 48 hours periods during summer 2001, in the North part of Portugal.

MM5 application to this region presented a good skill when simulating anticyclone conditions. This study should be considered as pilot, because other periods have to be simulated in order to achieve consistent results for the study region.

1 Introduction

High levels of photochemical pollutants, like ozone, frequently affect south European countries and the concern with this subject substantially increased during the last decade. In the west coast of Portugal, where the human activities are concentrated, several episodes of photochemical pollution have been verified. This coastal zone is strongly influenced by the nearby Atlantic Ocean, with frequent sea/land breeze circulation.

Studies on atmospheric circulations over the Iberian Peninsula have shown particularities concerning summer dynamics [1]. Frequently, there is the development of a low thermal pressure area in the centre of the Peninsula, which allows mesoscale processes enhancement such as land-sea breezes. This type of circulations encourages photochemical production of air pollutants leading to smog episodes, which can cause health problems to the population and environmental degradation.

Global numerical weather prediction can provide information about the present and time evolution of the atmospheric situation (wind speed, wind direction, temperature, humidity, etc.). This information is fundamental to estimate the transport, production, dispersion and removal of air pollutants. Nevertheless, global meteorological models are not suitable for regional studies of transport of pollutants due to their coarse resolution (1º » 100 km). These models do not simulate properly mesoscale and regional phenomena, but their results may be refined with mesoscale models using dynamical downscaling. In dynamical downscaling, GCM simulations are used to drive regional climate models, which simulate mesoscale circulation and physical processes in the land-atmosphere system. The knowledge and characterisation of mesoscale atmospheric flow patterns, as well as, the description, by mathematical models, of dispersion and transformation mechanisms of photo-oxidants are fundamental.

The main purpose of this work is to evaluate the performance of the meteorological model (MM5) under two different meteorological patterns and analyse sensitivity of results to grid resolution.

2 MM5 modelling system

Version 3 of the Pennsylvania State University/ National Center for Atmospheric Research Mesoscale Meteorology Model (MM5V3.4), is a powerful meteorological model that contains comprehensive descriptions of atmospheric motions; pressure, moisture and temperature fields; momentum, moisture and heat fluxes; turbulence, cloud formation, precipitation and atmospheric radiative characteristics.

MM5 is a non-hydrostatic prognostic model with a multiple nesting capability, applying one way or two-way nestings. The most interesting features in MM5V3.4 are related with its different physics parameterisations that can be selected by the user and being capable of running in different computational platforms [2]. MM5 has various physics options with distinct parameterisations.

The user can set different parameterisations for cumulus schemes, planetary boundary layer schemes (PBL), explicit moisture schemes, radiation schemes and ground temperature schemes [2].

MM5 is a wide spread community model with strong user support, that is being tested all over the world [3, 4]. In Iberian Peninsula several institutions are applying MM5 as a real time weather forecast tool (http://meteo.usc.es; http://artico.lma.fi.upm.es).

3 Methodology

The coastal zone covered by this study is strongly influenced by the nearby Atlantic Ocean, with frequent sea/land breeze circulation. Aiming to contribute to a better understanding of these mesoscale phenomena, a field campaign was carried out in a coastal region, named Aveiro, from 24th June to 2nd July of 2001, which covered the last ozone episode noticed in the region. Measurements of all the main meteorological parameters and of ozone and its precursors concentrations were taken at surface and in altitude, in different stations. The obtained meteorological data were used to validate MM5 simulation results.

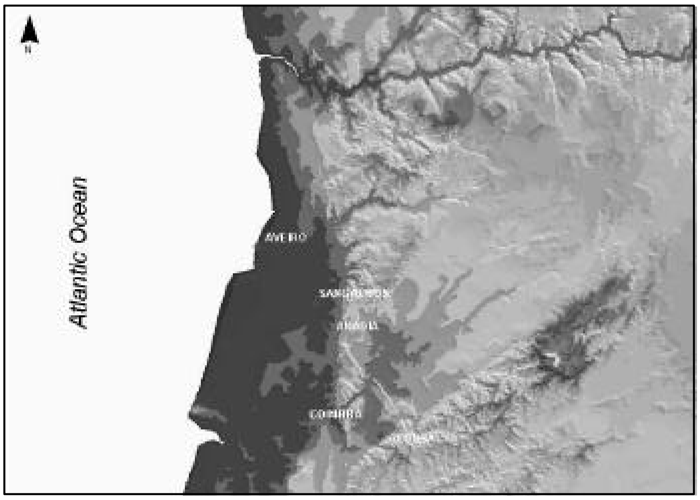
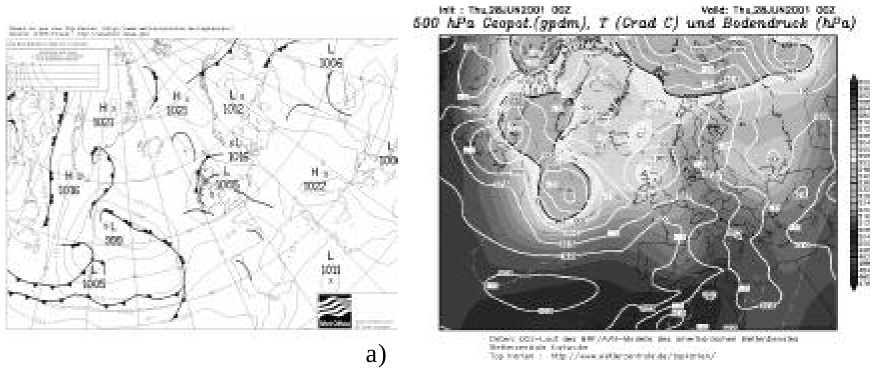
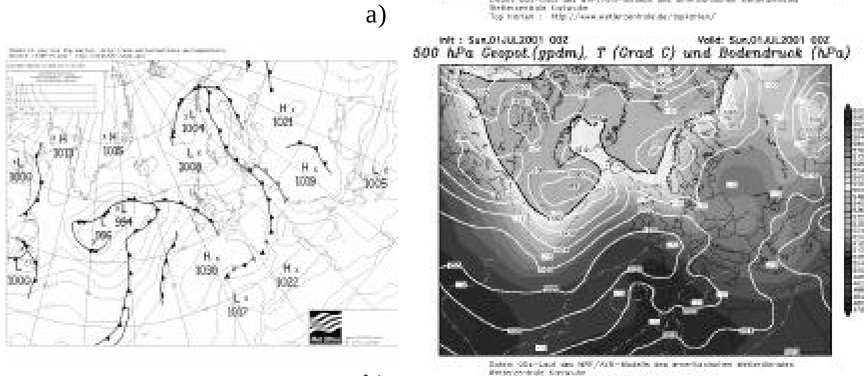


Figure 1. Meteorological stations considered in the field campaign.

The MM5 was applied to two periods of time, 27 June, 06h to 29 June, 06h and 1 July, 00h to 3 July, 00h, 2001. During the first period, 27 to 29 June 2001, the Iberian Peninsula was suffering the influence of an anticyclone on an intensifying process. Between the 1st and 2nd of July 2001, the Iberian Peninsula was under the influenced of a thermal surface low pressure system, common over the Peninsula during summer (Figure 2) [5] (http://www.wetterzentrale.de/topkarten/fsavneur.html; http://www.infomet.am.ub.es/arxiu/mapes_fronts/).



a)



b)

Figure 2. Surface pressure map and geopotential height at 500 hPa for a) 27 June 00h and b) 1 July 00h.

Using MM5 capability of doing multiple nestings, the meteorological model was applied with the two and one way nesting options and for two nests: (i) a large domain covering Southern Europe and North Africa (54 km resolution), (ii) a first nest covering the West part of Iberian Peninsula (18 km resolution), (iii) and a second nest for the North part of Portugal (6 and 3 km resolution) (Figure 3).

MM5 simulations were initialised from the gridded NCAR/NCEP reanalysis data, producing outputs in nested 54 km, 18 km and 6/3 km grids. The grid sizes are 41 x 63, 52 x 55, 30 x 30 (for 6 km resolution) and 60 x 60 (for 3 km resolution) grid points, respectively. All modelling domains have the same vertical structure with 23 unequally spaced σ levels. The Reisner Graupel microphysics moisture scheme, Grell cumulus scheme, and a MRF boundary layer govern the 6 and 3 km grids.

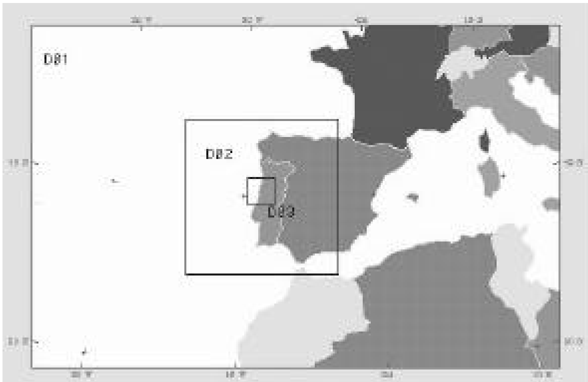


Figure 3. MM5 modelling domains.

4 Results and discussion

As referred, for the present study, meteorological measurements were available at four different locations over the study region: Aveiro, Coimbra, Anadia and Sangalhos. All the simulated results have been compared with meteorological data acquired at those stations. As an example, Figure 4 presents this comparison for Sangalhos station, 27 to 29 June 2001, for the smallest domain with 3 km resolution. As can be seen, MM5 model simulates quite well the local atmospheric conditions characterising the considered period. MM5 outputs follow very well the temporal evolution of the three measured meteorological variables (air temperature, wind speed and direction).

In order to better evaluate model perfomance, and regarding the quantity of data sets that have to be compared, a statistical analysis was applied.

Quality indicators reflect the ability of a model to simulate real world phenomena. Applications of such indicators help to understand model limitations and provide a support for model intercomparison. It should be taken in consideration that model evaluation could not be performed on basis of a single quality indicator. A system of quantitative parameters must be identified for each task related to model developing and then, common quality indicators will be established and applied within the project. The performance of the system of models is evaluated through the application of quantitative error analysis introduced by Keyser and Anthes (1977).

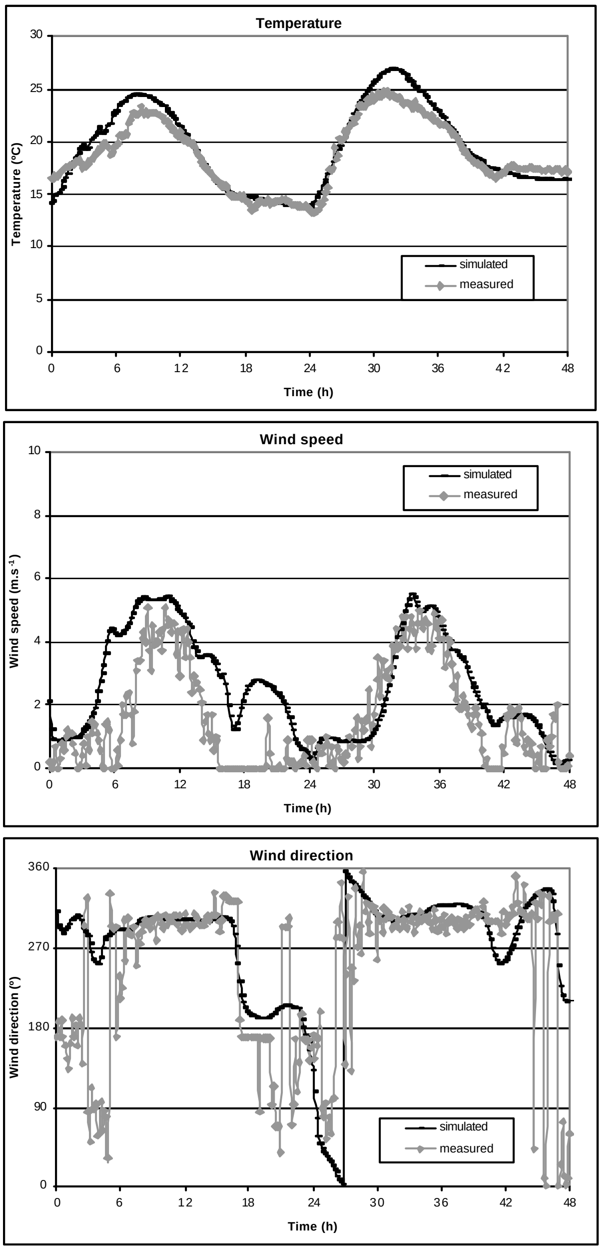


Figure 4. Meteorological measured data and simulated parameters for Sangalhos station for 27 to 29 June 2001.

Consequently, if f_i and f_{iobs} were individual modelled data and observed in the same mesh cell, respectively; f_0 and f_{0obs} the average of f_i and f_{iobs} for some sequence in study, and N the number of observations, then:

$$E = \left\{ \frac{\sum_{i=1}^{N} (f_i - f_{iobs})^2}{N} \right\}^{1/2} \tag{1}$$

$$E_{UB} = \left\{ \frac{\sum_{i=1}^{N} [(f_i - f_0) - (f_{iobs} - f_{0obs})]^2}{N} \right\}^{1/2} \tag{2}$$

$$S = \left\{ \frac{\sum_{i=1}^{N} (f_i - f_0)^2}{N} \right\}^{1/2} \tag{3}$$

$$S_{obs} = \left\{ \frac{\sum_{i=1}^{N} (f_{iobs} - f_{0obs})^2}{N} \right\}^{1/2} \tag{4}$$

The parameter E is the root mean square error (rmse), E_{UB} the rmse after the removal of a certain deviation and S and S_{obs} the standard deviation of the modelled and observed data, respectively. Keyser and Anthes (1977), suggest that rmse decrease significantly after the removal of a constant bias. Further, according to these authors, this deviation corresponds to inaccuracy in specifications of the initial and boundary conditions. It is possible to say that the simulation presents a good skill when:

$$S \approx S_{obs},\ E < S_{obs} \text{ and } E_{UB} < S_{obs}. \tag{5}$$

Notice that this kind of analysis requires that the standard deviation of the measured data and the simulated data should be approximately equal, to guarantee that the natural variability presented by the measured values is correctly simulated by the numerical model.

Tables 1, 2 and 3 present statistical analysis results for each meteorological variable, considering both simulated periods and grid resolutions. Globally, June simulations present better results than July simulations and there are no significant differences in results between 6 and 3 km resolutions.

As regards temperature, for June simulation, the statistical parameters E/S_{obs} and E_{UB}/S_{obs} are consistent with eqn (5), all the results are lesser than 1. Aveiro station presents the worst relation between simulated and observed temperature variability (parameter S/S_{obs}), although the results are considerably close to unity.

Concerning wind speed the worst results were obtained in Anadia station, for all statistical parameters. Its well noticeable that July simulation is worst than June result. For June simulations, Aveiro, Coimbra and Sangalhos stations present good statistical correlations (Table 2).

As it can be observed on Table 3, wind direction statistics obtained for June simulations are quite good. Regarding July simulations, the statistical results decreased in quality.

Table 1. Statistical analysis of MM5 performance for temperature.

			Aveiro	**Coimbra**	**Anadia**	**Sangalhos**
June	6 km	S/S_{obs}	1.50	0.89	0.95	1.21
		E/S_{obs}	0.68	0.40	0.40	0.46
		E_{UB}/S_{obs}	0.68	0.38	0.38	0.34
	3 km	S/S_{obs}	1.45	0.85	0.95	1.22
		E/S_{obs}	0.66	0.64	0.38	0.40
		E_{UB}/S_{obs}	0.64	0.33	0.38	0.35
July	6 km	S/S_{obs}	1.59	0.78	0.84	1.00
		E/S_{obs}	2.30	0.93	1.02	1.39
		E_{UB}/S_{obs}	0.93	0.53	0.49	0.51
	3 km	S/S_{obs}	1.57	0.67	0.84	0.99
		E/S_{obs}	2.13	0.89	0.98	1.34
		E_{UB}/S_{obs}	0.92	0.59	0.49	0.50

Table 2. Statistical analysis of MM5 performance for wind speed.

			Aveiro	**Coimbra**	**Anadia**	**Sangalhos**
June	6 km	S/S_{obs}	1.02	1.02	1.77	0.96
		E/S_{obs}	0.77	0.75	2.14	0.82
		E_{UB}/S_{obs}	0.72	0.69	1.54	0.61
	3 km	S/S_{obs}	0.96	0.93	1.74	1.03
		E/S_{obs}	0.87	0.65	2.18	0.95
		E_{UB}/S_{obs}	0.82	0.60	1.54	0.70
July	6 km	S/S_{obs}	1.01	2.06	1.60	1.18
		E/S_{obs}	1.40	2.41	2.21	1.61
		E_{UB}/S_{obs}	1.34	2.24	1.56	1.43
	3 km	S/S_{obs}	1.07	2.42	1.66	1.03
		E/S_{obs}	1.51	2.92	2.02	1.27
		E_{UB}/S_{obs}	1.45	2.69	1.54	1.13

Table 3. Statistical analysis of MM5 performance for wind direction.

			Aveiro	Coimbra	Anadia	Sangalhos
June	6 km	S/S_{obs}	0.89	1.05	0.57	0.80
		E/S_{obs}	0.82	1.02	1.02	0.92
		E_{UB}/S_{obs}	0.80	1.02	0.91	0.91
	3 km	S/S_{obs}	1.04	1.10	0.60	0.82
		E/S_{obs}	1.00	1.08	1.12	0.98
		E_{UB}/S_{obs}	0.98	1.08	0.98	0.94
July	6 km	S/S_{obs}	1.59	1.09	1.11	1.17
		E/S_{obs}	1.61	1.34	1.38	1.60
		E_{UB}/S_{obs}	1.47	1.24	1.24	1.39
	3 km	S/S_{obs}	1.64	1.05	1.35	0.84
		E/S_{obs}	1.66	1.41	1.69	0.71
		E_{UB}/S_{obs}	1.50	1.25	1.44	0.69

5 Conclusions

From this study it was possible to identify that there are no significant differences between the two grid resolutions performed, 6 and 3 km.

It must be emphasised that the simulation for 27 to 29 June presented much better results than 1 to 3 July simulations. These achievements pointed out that MM5 simulation for high-pressure conditions presents better results than for low thermal conditions, not forgetting that initialisation data have the same source and therefore presenting similar quality levels. This implies the necessity of simulating other periods with the described meteorological patterns in order to get consistent MM5 evaluation.

These results can lead to other questions about photochemical models application, mainly related to meteorological data feasibility, used as input to those models. Photochemical models should be tested against different meteorological situations and sensitivity to different assumptions (grid resolution, physics parameterisation) considered in the meteorological simulation. This represents a considerable field of research in order to better evaluate meteorological and photochemical models interaction and behaviour.

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