6.06 INFLUENCE OF MODEL GRID RESOLUTION ON TROPOSPHERIC OZONE LEVELS

Pedro Jiménez, Oriol Jorba and José M. Baldasano
Environmental Modeling Laboratory, Universitat Politècnica de Catalunya (UPC)
Avda. Diagonal, 647, Ed. H, Planta 10. 08028 Barcelona, Spain
E-mail: jose.baldasano@upc.es

INTRODUCTION

The north-eastern Iberian Peninsula (NIP) has a complex topography with a large coast to the Mediterranean sea, and hence the structure of the flow is extremely complicated because of the development of large and local mesoscale phenomena that interact with synoptic flows. The study of photochemical pollution in complex terrains demands a high horizontal spatial resolution. Jang *et al.* (1995) studied the sensibility of ozone (O_3) to the horizontal grid resolution of air quality models, concluding that a coarser grid size tends to underestimate the maximum O_3 levels and to overestimate minimum values, since the grid resolution highly influences the formation and loss processes of O_3, specially photochemical and vertical transport phenomena. Salvador *et al.* (1999) stated the enhancement in the description of meteorological phenomena in a small scale when working with resolutions of 2-km or finer. In order to illustrate the influence of grid size on ground-level O_3, this work encloses a detailed study of the observable differences in values, location and temporal behaviour of tropospheric O_3 in the NIP. Several simulations with the air quality model MM5-Models-3/CMAQ are carried out using different grid resolutions: 8-km, 4-km and 2-km. The high resolution (1-h and 1 km^2) EMICAT2000 emission model has been applied in the NIP. The domain of study covers a squared area of 272 x 272 km^2. The model is configured with 6 and 16 vertical layers to cover the troposphere, with special emphasis in the low troposphere (4,000 meters). MM5 produces meteorological information at 29 sigma levels, and it uses 6-h ECMWF analysis as initial and boundary conditions. The day selected for performing the simulations was August 14, 2000, which is a representative day of a photochemical pollution episode in the Western Mediterranean Basin that covered from 10-19 August 2000. Values around the European threshold of 180 μg/m^3 for tropospheric O_3 were attained. Synoptic situation of this episode corresponds to a typical summertime weak pressure gradient over the Iberian Peninsula. This situation is related to a decrease in air quality. The day was characterized by a weak synoptic forcing, so that mesoscale phenomena, induced by the particular topography of the region would be dominant. A high sea level pressure and almost non-existent surface pressure gradients over the domain characterize this day, with slow northwesterlies aloft (Figure 1).

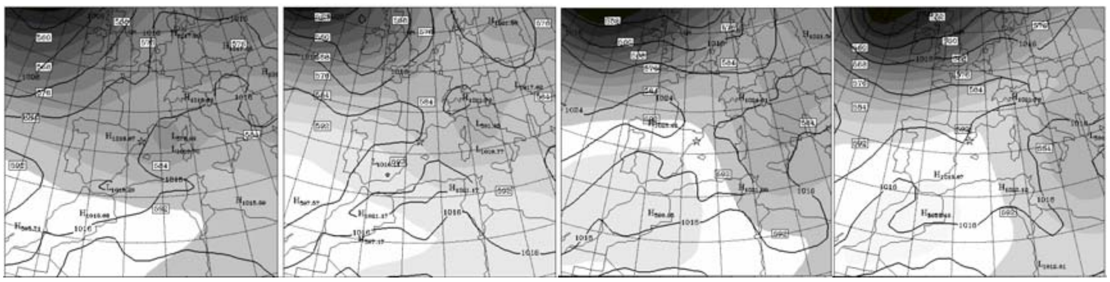

Figure 1. Synoptic situation of 13 August to 16 August, 2000 (shaded map: 00UTC 500 hPa analysis, contour map: 00UTC surface analysis)

INFLUENCE OF MODEL RESOLUTION ON WIND FIELDS

Topographical variations may have an important effect on mesoscale atmospheric flow and, therefore, play a major role and should be well resolved in modeling exercises. Figure 2 represents the topographic map of the domain at an 8-km, 4-km and 2-km resolution. There are several significant differences between the coarse and fine topography. Nevertheless, we must bear in mind that smoothing is sometimes positive to avoid the strong topographical gradients that may not be properly resolved by the models. Results depict that important mesoscale phenomena within the region do not develop in the domain of study if the horizontal resolution is coarser than 4-km (Figure 2). Under low synoptic forcing, mountain winds develop since the complex topography of the region, while the difference of temperature between the sea and the land enhances the development of sea-land breezes. The daily cycle of these flows constitutes an important part of the mechanism that drives the transport of air pollutants within the region. The results show how the see breeze development is well captured by all simulations, even though, particular canalizations of the flow are only appreciable at 4- and 2-km resolutions. With lower resolutions, wind fields present a too smoothed structure. More differences appear with mountain-winds, which are not developed at 8-km. Only with an increased resolution, the meteorological model is able to reproduce the mountain-wind system. The vertical structure of the flows is also influenced by the best representation of the topography when working with high horizontal resolution. An enhancement of vertical motions is observed, and the vertical structure of the see-breeze is improved, and several orographic injections appear when increasing the resolution.

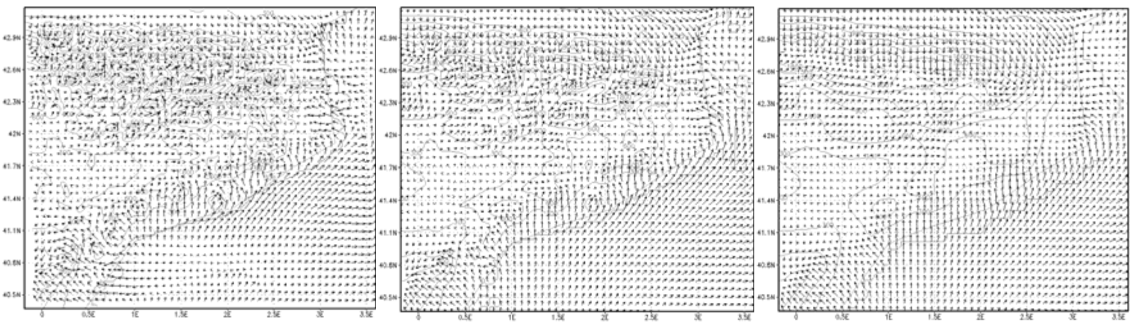

Figure 2. Surface wind field in Catalonia for August 14, 2000. 2-km grid (left), 4-km (centre) and 8-km grid (right) at 12 UTC.

For evaluation purposes model results were compared with surface and aloft wind measurements. Validation data of 52 surface stations located across the domain, and a radiosonde launched in Barcelona (in the centre of the domain in the coast) were used. Table 1 shows the root mean square error (RMSE) of wind speed at 10 m, for the lower, middle and upper troposphere and RMSE of wind direction at 10 m. The general behaviour of the model shows a tendency to overestimate nocturnal surface winds and to underestimate the diurnal flow. A clear improvement is produced with 2-km simulation during the central part of the day. The complex structure of the see-breeze described by the 2-km simulation, and the development of up-slope winds appears to agree in a higher grade with surface measurements. The statistics show how the model presents a better behaviour within the boundary layer, and major disagreement with the radiosonde appears over 1000 m AGL. At night, 8- and 4-km presents better results aloft, while at noon the high horizontal resolution simulation obtains the best statistics.

Table 1. RMSE statistic of wind speed, and wind direction for 2-, 4-, 8-km simulations at 00, 12, 24 UTC (surface values evaluated with 52 surface stations, aloft values evaluated with a radiosonde)

	RMSE Wind speed (m/s)								
	00 UTC			***12 UTC***			***24 UTC***		
	2 km	***4 km***	***8 km***	***2 km***	***4 km***	***8 km***	***2 km***	***4 km***	***8 km***
SURFACE 10 M	1.71	1.85	1.76	2.04	2.34	2.41	2.00	2.17	2.22
Radio. <1000 m	0.84	1.02	1.04	1.04	1.08	1.34	1.31	0.86	0.86
1000-5000 m	5.03	3.95	3.66	1.55	2.4	2.16	3.7	2.59	2.27
5000-10000 m	8.45	8.92	8.62	5.15	6.22	6.3	3.94	5.29	5.16
	RMSE Wind direction (º)								
	00 UTC			***12 UTC***			***24 UTC***		
	2 km	***4 km***	***8 km***	***2 km***	***4 km***	***8 km***	***2 km***	***4 km***	***8 km***
SURFACE 10 M	95.95	91.33	92.10	44.74	58.17	55.25	89.40	98.59	94.69

INFLUENCE OF MODEL RESOLUTION ON TROPOSPHERIC OZONE

Ground-level O_3 simulation results were compared to the measurements from 48 surface stations in Catalonia, located in both urban and rural areas. The US Environmental Protection Agency has developed guidelines (U.S. EPA, 1991) drawn for a minimum set of statistical measures to be used for the evaluations of tropospheric O_3, where monitoring data are sufficiently dense. Results show the statistical analysis comparison. Those statistical figures are: mean normalized bias error (MNBE), mean normalized gross error for concentrations above a 80 $\mu g/m^3$ threshold (MNGE), and unpaired peak prediction accuracy (UPA). Observation/prediction pairs were often excluded from the analysis if the observed concentration was below a certain cut-off; here a level of 80 $\mu g/m^3$ was used. Categorical statistics have also been used to evaluate the different vertical and horizontal resolution, including parameters as the model accuracy (A), bias (B), probability of detection (POD), false alarm rates (FAR) and critical success index (CSI). These criteria based upon a 120 $\mu g/m^3$ threshold. Table 2 collects the results of the statistical analysis; although there is no objective criterion set forth for a satisfactory model performance, suggested values of ±10–15% for MNBE, ±15–20% for the UPA and ±30–35% for the MNGE to be met by modeling simulations of O_3 have been considered for regulatory applications, as discussed by Russell and Dennis (2000).

Table 2. Summary results for evaluation of O_3 concentrations with different resolutions

	Discrete Evaluation					
	2km/6layers	***2km/16layers***	***4km/6layers***	***4km/16layers***	***8km/6layers***	***8km/16layers***
MNBE	-2.02	-11.38	-9.53	-16.92	-12.86	-13.12
MNGE	19.72	20.89	17.42	21.61	19.27	21.01
UPA	17.08	5.97	-26.07	-19.24	-22.53	-18.49
	Categorical Evaluation					
	2km/6layers	***2km/16layers***	***4km/6layers***	***4km/16layers***	***8km/6layers***	***8km/16layers***
A	90.9	91.6	91.5	92.4	91.6	91.7
CSI	19.0	12.5	3.2	8.9	3.2	10.0
POD	26.4	14.9	3.4	9.2	3.4	11.5
B	0.7	0.3	0.1	0.1	0.1	0.3
FAR	59.6	56.7	72.7	27.3	70.0	56.5

Progressively increasing grid resolution from 8-km to 2-km improves the performance of all statistical parameters. The MNBE is negative for every simulation, ranging from -16.92% for 4km/16layers until -2.02% for 2km/6layers case. The MNGE is similar in all cases studied, being within the aforementioned standards. The UPA does not greatly improve when augmenting the resolution from 8-km to 4-km, but this improvement becomes evident in the

2-km/16layers simulation, yielding values of 5.97% for the highest vertical and horizontal resolution. Respect to categorical forecasting, statistical parameters indicate that A is similar for all resolutions; nevertheless, incrementing horizontal resolution greatly improves the CSI, the FAR and the POD. The value of bias (B<1 for all simulations) indicates that exceedances are under predicted.

In general, the maximum 1-hr concentration of O_3 (Figure 3) was overestimated by the 2-km resolution (Table 2), being underestimated both by the 8-km and the 4-km simulations. The error reduces substantially when incrementing the vertical grid resolution. The explanation for this behaviour is that model outputs indicate an average of the cell, diluting the very local effects of photochemical phenomena. Figure 3 depicts that an accurate definition of O_3 problem in the region is only achieved when observing the 2-km/16layers case. Average values are underestimated by simulations when using both an 8-km, 4-km or 2-km grid size, exhibiting negative bias resolutions. Figure 4 depicts the average values of tropospheric O_3. They present similarities in the prediction of the lowest values in the BGA, high values in the Pyrenees and capture O_3 depletion in the proximity of Cercs thermal central. Nevertheless, 8-km and 4-km simulations do not show a good agree with observations in north-eastern area of the domain, and therefore a 2-km resolution must be used. The depletion of O_3 during the evening and night in the BGA and the industrial area of Tarragona is only observed with resolutions of 4-km and finer, and is better captured with 16 vertical layers.

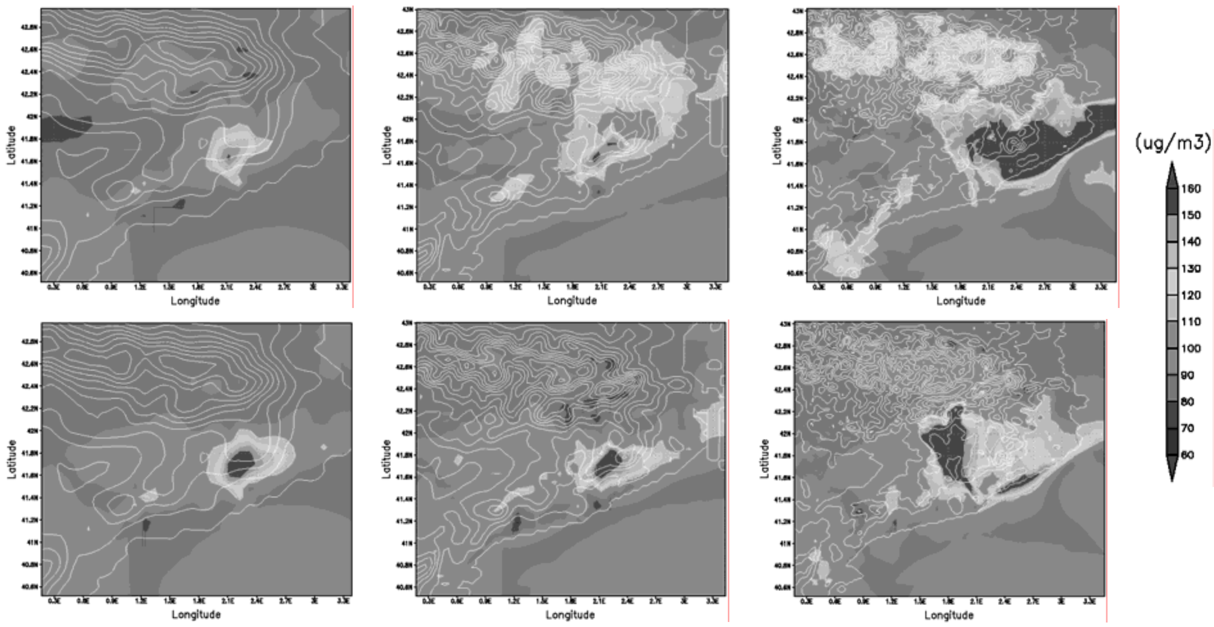

Figure 3. 1-hr maximum levels in the simulation domain for an 8-km (left), 4-km (centre) and 2-km (right) horizontal resolution with 6 (up) and 16 (down) vertical layers.

SUMMARY AND CONCLUSIONS

The effect of grid resolution on the results of an air quality model applied to Catalonia has been illustrated in this work. Simulation of the August 14, 2000 O_3 episode was used to depict the impact of grid resolution on photochemical pollution. For the complex domain studied, a clear improvement in the statistics of O_3 values has been observed when increasing model resolution from 8-km to 2-km.

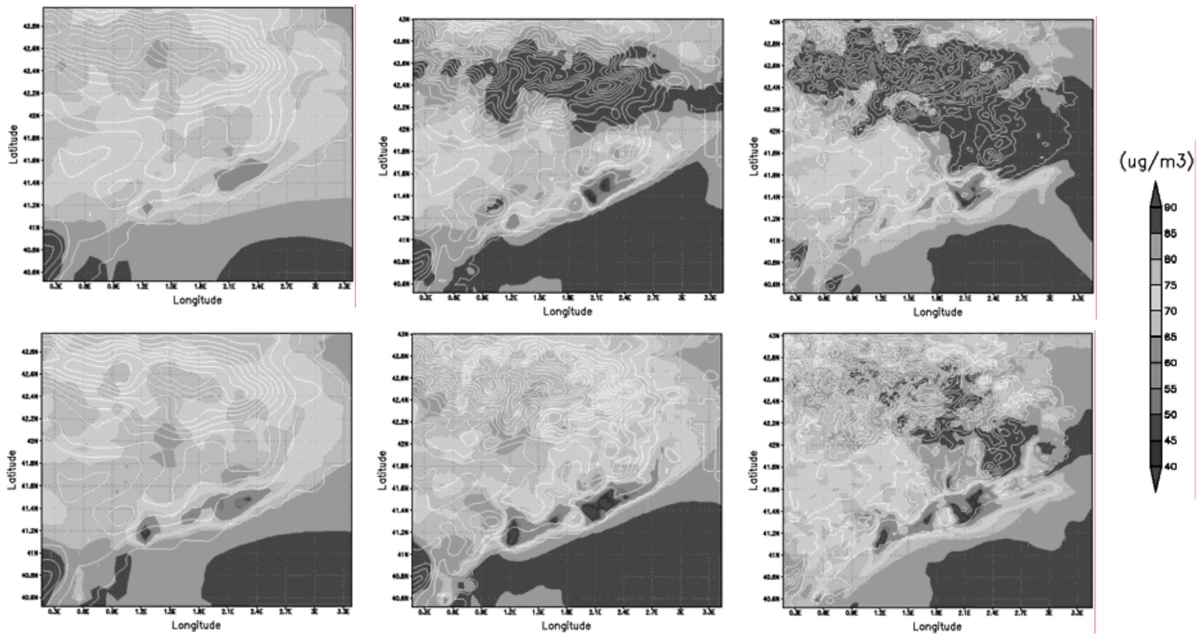

Figure 4. Average levels in the simulation domain for an 8-km (left), 4-km (centre) and 2-km (right) horizontal resolution with 6 (up) and 16 (down) vertical layers.

MM5 simulations clearly show that the wind field improves with finer horizontal grids. The model is unable to reproduce the mountain-wind system with resolutions coarser than 4-km. Statistics of the 2-km simulation present the best behaviour during the development of the sea breeze, but all three simulations overestimate surface flows during the nocturnal period. Model outputs were sensitive to the grid size employed in the simulations, presenting a higher dependence on horizontal grid than in vertical resolution of the CTM. Despite in outline the O_3 patterns do not change dramatically, some small-scale features appear when using a resolution of 2-km that cannot be captured with coarser resolutions. If both discrete and categorical statistical parameters are compared with U.S. EPA's recommended values, a grid resolution of 2-km, both with 6 or 16 vertical layers, is needed when simulating photochemical pollution in the NIP in order to ensure that results are inside the range of error tolerated.

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