ONE-WAY NESTING VERSUS TWO-WAY NESTING: DOES IT REALLY MAKE A DIFFERENCE?

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1. INTRODUCTION

A couple of ITMs ago, an interesting discussion took place in the conference room of the meeting concerning the necessity or not of using one-way or two-way nesting techniques when performing simulations over complex terrain. The contribution leading to that discussion (Soriano et al., 1998) had shown results of a simulation carried out in the Barcelona Geographical Area (BGA) for a typical summertime situation in the region. Simulations had been performed with the model MEMO, and one-way nesting techniques where used (actually, in was more a refined-boundary conditions technique), using three domains at 2, 1 and 0.5 km grid size. The comparison of the measurements with the modeled results for the different resolutions used showed that no significant improvement of the results was produced by using nested domains, from which the authors concluded that the topography resolution used in the outer domain was enough to originate the circulatory patterns in the area.

To improve our knowledge on this important factor in a numerical model configuration, a simple but illustrative exercise is proposed in this contribution in order to check if the use of two-way versus one-way nesting techniques does after all produce an improvement of the performance of a mesoscale meteorological model. Comparisons will be shown between simulations conducted with both nesting options for the BGA, a region containing a sea-land interface and complex topography.

The model used for this purpose is MM5 (Dudhia, 1993; Zhang, 1986) one of the few existent mesoscale meteorological models that allows running either with one or two-way nesting. This fact is important since it assures that the Physics of the model will be the same in the two runs. A similar exercise was carried out in Lozej and Bornstein, 1998. On that occasion the simulation was carried out for the San Francisco Bay Area during a winter wave cyclone situation that led to important precipitation in the region. In fact, the authors found weak results in the predicted amount of rainfall for all the nesting cases, which they blamed on the poor quality of the initial condition used.

Besides, in this occasion, in order to check if the influence of choosing one or the other nesting option is more important depending on the meteorological situation, simulation have been performed under different meteorological situations.

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2. NESTING TECHNIQUES FOR MESOSCALE MODELING

It is well know the importance of the orographic features in a given region in the establishment of the circulatory patterns of air masses in general and air pollution in particular within its airshed. For a mesoscale mo del to be capable of reproducing this behavior, it is necessary to introduce a well resolved terrain file, with a resolution such that these orographic features are not smoothed away. The other fact is that the simulation domain has to be large enough to include all the terrain characteristics that are believed to participate in the circulation of air masses, and these can often be far away from the study area. Both conditions would lead to the ideal situation of simulating over a large domain with a very high resolution. However, computational and practical constrains do not allow this approach to be used, since it would require simulation over a large number of cells at small time steps (due to small cell size), and therefore large simulation times and memory requirements.

Nesting techniques are the solution to minimize these problems, increasing spatial resolution only in the domains well small scale phenomena might occur and are relevant for the reproduction of all the forcing mechanisms in the study area. At the same time, outer domain (or domains) are also included at a coarser resolution, to assure the introduction of larger scale forcings into the inner domain. The interaction between the domains is the big issue at this point, and can be carried out basically through to different techniques: one-way or two-way nesting.

MM5V3 allows the choice of any of these two different types of interaction between the coarser and the inner domains. In the one-way nesting, the model is first run for the outer domain to create an output that is interpolated in time and space to supply the nest as a boundary file, which is run after the coarser domain has finished. For a two-way nesting, both domains are run at the same time and completely interacting. Nest's input from the coarse domain is introduced through its boundary, while feedback to the coarse mesh occurs all over the nest interior, as its values are replaced by combination of fine domain values.

In general, two-way nesting is believed to work better because it allows smaller scale features feedback upscale and influence features in the larger scale. However, detractors of two-way nesting claim that this method somehow “pollutes” results obtained in the outer domain, since they are not longer the solutions of the equations of the system.

3. MODELING SCENARIOS

Two different scenarios have been studied in the BGA in order to see if the chosen nesting option in the model was a more determinant factor under some meteorological situation than under others.

In one of the studied cases, the synoptic situation was predominant, and a synoptic forcing was introduced through important geostrophic winds in the region. In the other case, a meteorological situation with weak synoptic forcing was chosen, so that mesoscale phenomena, induced by the particular topography of the region, would be dominant.

3.1. Modeling Domains

Both runs have been performed over the same simulation domains. Four nested domains were selected, which essentially covered Europe (Domain 1, D1), the Iberian Peninsula (Domain 2, D2), Catalonia (Domain 3, D3) and the BGA (Domain 4, D4). D1 has 90x55 54-km cells. D2 has 115x94 18-km cells. D3 has 76x79 6-km cells. D4 has 61x61 2-km cells. The vertical resolution consisted for all domains of 23 ?-layers, with the lowest one situated at 18-m AGL. The upper boundary was fixed at 100 hPa. Time steps used for the simulations are, respectively, 150, 50,15 and 6 seconds. Initialization and boundary conditions (BC) for the regional model are introduced from reanalysis data from the ECMWF global model. Data were available at a 1-degree resolution (100-km approx. at the working latitude) at the standard pressure levels every 6 hours.

Figure 1 shows the domains and the topography of D3 and D4. The topography in D3 is essentially dominated by the Pyrenees (a mountain range separating Spain and France with mountains of 3000-m height). In the south of the domain, the Ebro Valley will also play an important role in the establishment of the flow patterns. In D4, main features are mountain ranges oriented parallel to the coastline and two river valleys at both sides of the city of Barcelona and running approximately perpendicular to the coast.

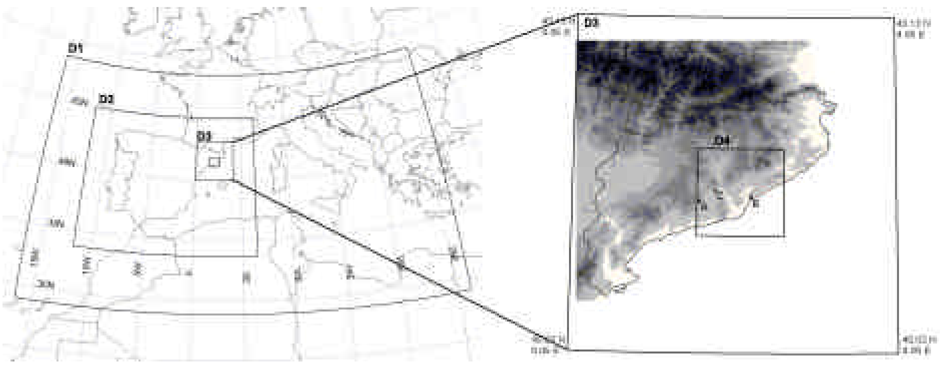

Figure 1. The four simulations domains used in the simulations, and detailed topography of D3 and D4. Letters A,B,C designate surface stations used for validation in sections 4 and 5.

Finally, simulations only for D4, including initial and boundary information from ECMWF, have also been performed. They have been used as control cases to see how well the most inner domain was able to reproduce the circulatory patterns and how different it was from the simulation where information from outer domains is introduced.

3.2. Synoptic Situation: The Western Anticyclonic Advection of June 29, 2000 and the Summertime Barometric Swamp of August 14, 2000

The synoptic situation on June 29, 2000 can be described, using the typical situations described for the Iberian Peninsula as a western anticyclonic advection. A high-pressure area was located over the Atlantic, to the west of the Portugal, advecting westerly winds over most of the Peninsula. The map at 500 hPa also indicated winds from the west (see maps at http://infomet.am.ub.es/arxiu/avn). Radiosondes launched in Barcelona that day confirm the interpretation of the maps (Atat the Web site of the Catalan Meteorological Service, http://www.gencat.es/servmet/radio).

Maps corresponding to the 14th of August, 2000 were characterized, both at surface level an in height, by very low baric gradient. This fact, and the strong solar heating, produced the development of mesoscale phenomena. These phenomena in the region are mainly sea-breezes, up-slope and down-slope winds and valley channeled winds. The heating was so intense that a thermal low started to develop in the Peninsula. Again, synoptic maps for the day are available at the Infomet Web site mentioned above.

4. THE SYNOPTICALLY-DOMINATED SITUATION OF JUNE 29, 2000

4.1. Control Case: 1 Domain Simulation

Figure 2 shows streamlines simulated by the model at 12 UTC on May 29, 2000 in D4. Comparisons with surface stations are also included. No nesting was performed, and data from the ECMWF was used for initialization and middle times BC.

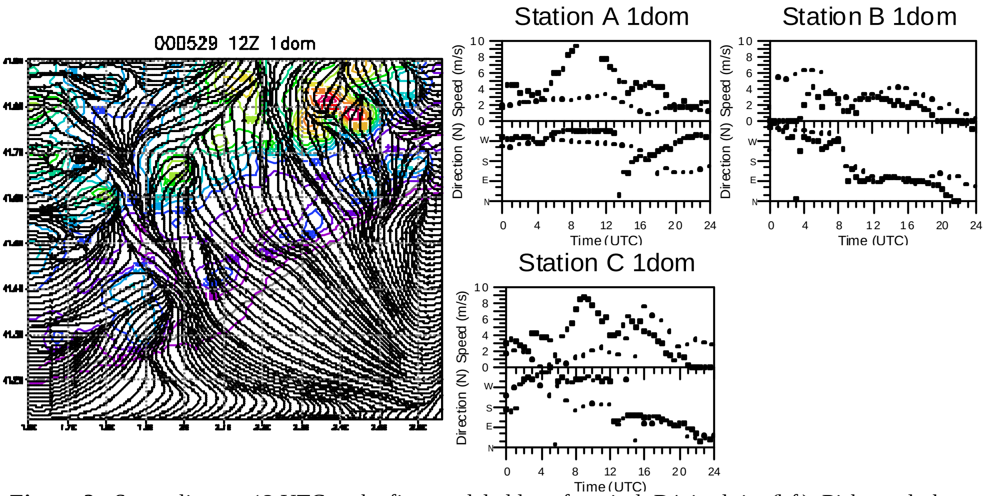

Figure 2. Streamlines at 12 UTC at the first modeled layer for a single D4 simulation (left). Right panels show comparison of simulated wind speed and direction (circles) vs. measurements (squares). Date is May 29, 2000.

Results showed that, even when working with a single domain, the topography in D4 had enough resolution to generate the local winds that overwhelmed the synoptic westerly winds, which can only be observed in the left border of the domain.

As far as the comparison with measurements of surface station, note the model's weak performance at station A, where it failed to reproduce the observed high velocity winds, although westerly winds are modeled during most of the day (introduced trough the BC). This station (see Figure1) is located very close to the border of the domain. The model reproduced quite well wind speed and direction at station B, located by the seaside, showing the influence of the sea breeze. Station C showed poor results specially before midday, where the models simulated too low winds. Velocities in the afternoon were more similar to measurements and the agreement in wind directions also improved.

4.2. Nested Simulations

Figure 3 shows streamlines simulated by the model at 12 UTC on May 29, 2000. The different panels show the results over D3 and D4 and when performing one-way or two-way nesting. Note that differences when comparing simulations on D3 with simulation on D4 occur mainly over the region where both domains overlap. The sea-breeze front, identifiable in the one-way simulation by a convergence line, is broken in the two-way simulation. In D4, the sea-breeze front is also very evident and has almost reached the left border of the domain, penetrating further inland when performing one-way nesting.

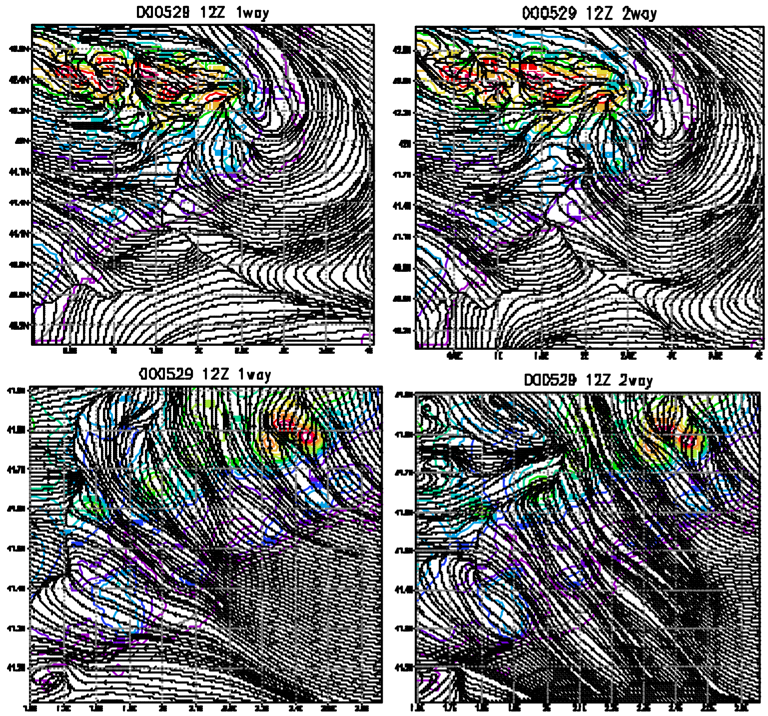

Figure 3. Streamlines at 12 UTC of May 29, 2001, at the first modeled layer for D3 one-way (top-left), D3 two-way (top-right), D4 one-way (bottom-left) and D4 two-way (bottom-right).

Evaluation of the model performance for the two cases was carried out by comparison with measurements for the three stations shown in Figure 1 and is included in Figure 4. Comparisons were performed by representing values of measured wind speed and direction with the simulated value in the corresponding cell, both for domains D3 and D4. Nested simulations, when compared with the one-domain simulation shown in Figure 2, were able to generate higher wind speeds in all stations, more in agreement with measurements. However, speeds in station B, located by the sea and with a higher mesoscale influence, showed worst results when using nesting techniques. A slight improvement of the wind direction was also observed, specially in station C during nighttime, for the one-way simulation. Finally, when comparing results for the same nesting techniques at the different resolutions (D3 and D4), more differences between both resolution were present when using two-way nesting techniques.

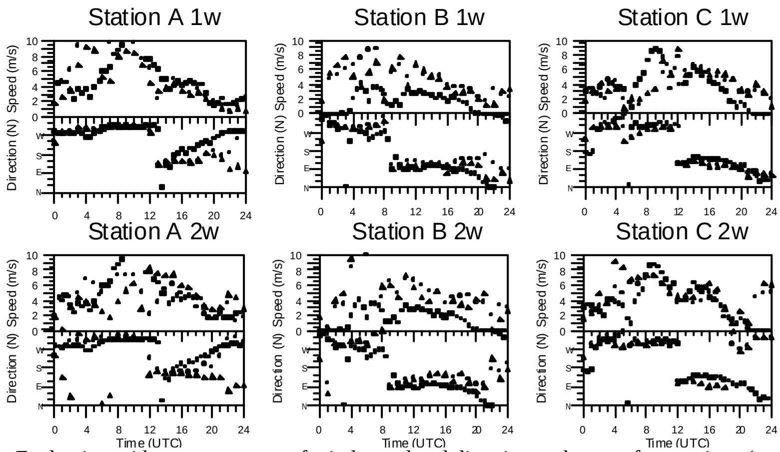

Figure 4. Evaluation with measurements of wind speed and direction at three surface stations (squares) with simulated values in domain D3 (circles) and D4 (triangles). First row corresponds to one-way nesting simulation and second row correspond to two-way nesting simulation. Date is June 29, 2000.

5. THE MESOCALE-DOMINATED SITUATION OF AUGUST 14, 2000

5.1. Control Case: 1 Domain Simulation

Figure 5 shows evaluation and streamlines at 12 UTC for the mesoscale-dominated situation of August 14, 2000 in D4.,for the one-domain no-nested simulation.

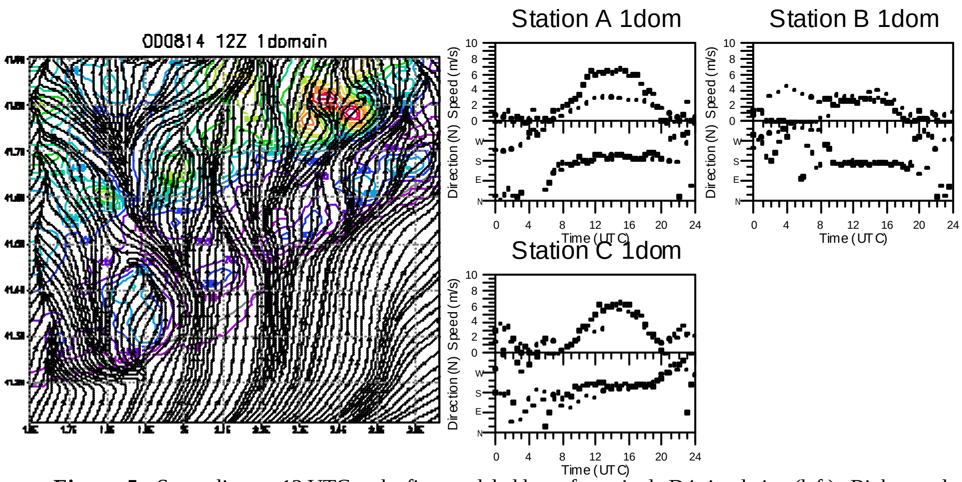

Figure 5. Streamlines at 12 UTC at the first modeled layer for a single D4 simulation (left). Right panels show comparison of simulated wind speed and direction (circles) vs. measurements (squares). August 14, 2000.

Streamlines show a well developed inland sea-breeze flow, which, with the up-valley winds and the up-slope winds produced a general in-shore circulation. Channeling in the river valleys was evident. Note the westerly winds at the left border of the domain, result of the assimilation, in the first rows of cells, of the BC from ECMWF data. Comparison with measurements gave reasonable results, showing that the single-domain configuration was able to generate flows, mainly originated in this scenario by mesoscale phenomena.

5.2. Nested Simulations

Figure 6 shows streamlines simulated by the model at 12 UTC on August 14, 2000. The different panels show the results over D3 and D4 and when performing one-way or two-way nesting. Differences between both simulations were more evident in this case. Note the presence of differences between simulated fields above the sea. If differences are observed over the sea, they should have been originated by larger scale phenomena funneled down to the inner domains. Above the sea, increased resolution does not add further topographical information and therefore no additional forcings are fed back to the coarser domain. As in the previous case, most differences above land were observed on the region where D3 and D4 overlap.

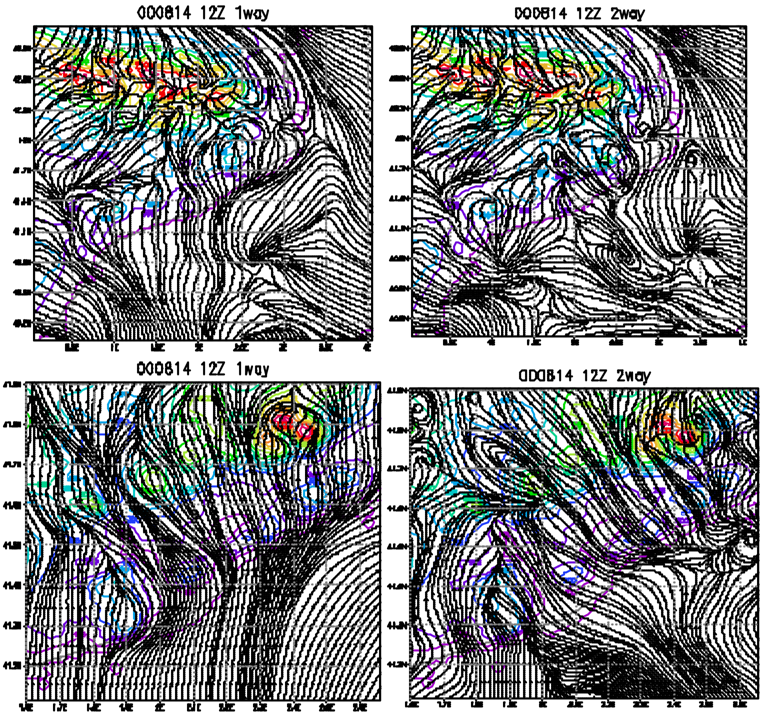

Figure 6. Streamlines at 12 UTC of August 14, 2001, at the first modeled layer for D3 one-way (top-left), D3 two-way (top-right), D4 one-way (bottom-left) and D4 two-way (bottom-right).

Comparison with surface stations are shown in Figure 7. The performance of the model was better than for the synoptically-dominated case, specially for one-way nesting. The model reproduced the daily cycle of the wind, and the timing of the swift from the nighttime to the daytime regime was well captured. Winds during nighttime were very low, which made the prediction of the wind direction difficult. In the one-way simulation, little difference is observed when using a better resolved resolution. Results for D3 and D4 are quite similar. For the two-way simulation, comparisons gave worse results. For station B, located by the sea, this was probably due to differences observed in the simulated fields over the sea when using two-way techniques. Simulated results for station C showed a lot of fluctuation when using two-way nesting, specially on D4.

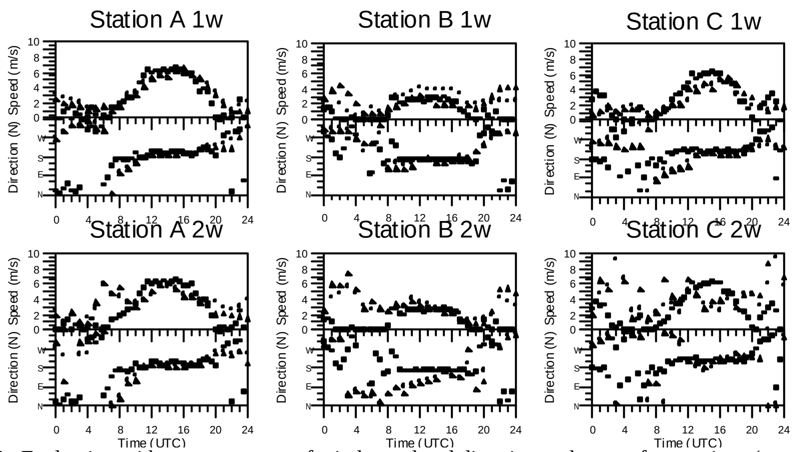

Figure 7. Evaluation with measurements of wind speed and direction at three surface stations (squares) with simulated values in domain D3 (circles) and D4.(triangles). First row corresponds to one-way nesting simulation and second row correspond to two-way nesting simulation. Date is August 14, 2000.

6. CONCLUSIONS

Simulations performed using different nesting techniques have shown that this factor can led to rather different results when applied over a domain with complex orographic features. This differences were more evident on situations on with low synoptic forcing. For the mesoscale-dominated case, differences introduced by choosing one or another nesting technique were more important than those produced by using a higher resolution topography, and two-way nesting gave worst results. For the synoptically-dominated case, the two nesting techniques gave more similar results and differences occurred mainly on the overlapping region of the domains. Predicted values at the different resolutions are not as similar as in the other scenario and in general showed higher speeds than observed, indicating that the synoptic component was overestimated by the model.

7. ACKNOWLEDGEMENTS

The authors thank the Spanish Meteorological Institute (INM) for providing data from the ECMWF, and the Catalan Meteorological Service (SMC) for providing surface station data for validation. Simulations were run on an HP Exemplar V2500 belonging to CESCA (Centre de Supercomputació de Catalunya).

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