Effects of orographic representation on simulations of cyclone development and mesoscale aspects of IOP 15

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Introduction

The deep cyclogenesis episode in the lee of the Alps of IOP 15 (6-7 November 1999) is characterised by distinct orographic modification of both the synoptic and mesoscale fields (Buzzi and Malguzzi, 2000; Buzzi, 2000). In the former paper, it was shown that the structure of the orographic perturbation on the geopotential field is essentially dipolar at low levels, but becomes more symmetric with respect to the Alpine divide in the mid and high troposphere. In the same work, it was emphasised that the standard BOLAM model run at 21 km resolution, similar to the operational run performed during the MAP SOP, was affected by a geopotential error field of several dam. The model uses a mean representation of the orography, smoothed to reduce grid scale variability. The structure of the forecast error projects strongly onto the mountain induced perturbation, as obtained by additional numerical experiments. This was considered as an indication that the orographic representation was deficient in different aspects, although the forecast error cannot be ascribed entirely to the orography. In the present work, alternative ways of representing the orography are considered, by introducing variations into the standard formulation of the sigma (terrain following) coordinate system, as implemented in BOLAM. The results of different experiments are compared with different MAP SOP observations. Particular attention is devoted to the representation of different fields both north and south of the Alps, since the orographic perturbation posses a scale of the order of thousand kilometres. In addition, mesoscale fields have been considered in the vicinity of the Alps, with particular emphasis on precipitation that was locally heavy, though not very persistent, during the initial stages of cyclogenesis.

The numerical experiments with different orography representations

The experiments considered here have been performed using the BOLAM model (version '2000') with the same nesting strategy implemented for the MAP SOP, but employing much larger integration domains and using the ECMWF analysis fields as boundary conditions in the larger domain. The latter has a horizontal resolution of 21 km, 167x177 points and 38 vertical levels. The domain has been enlarged with the aim of reducing possible detrimental boundary effects and of enclosing the whole structure of the large scale wave and the orographic perturbation over it. The inner domain has a resolution of 6.5 km, with 300x300 points and 44 levels. The inner area is five times larger than that used for the operational high resolutions runs during the MAP SOP, allowing the description of both the large ridge north of the Alps and the cyclone to the south (see Fig. 1). For each experiment, one outer and one inner domain runs have been made, with consistent representations of the orography.

The "control sigma" (CRT-S) experiment uses the standard sigma representation of the orography, as derived from the 1 km GLOBE DEM, averaged over the model grid and smoothed with a 5 point iterative spatial filter. With this procedure, the maximum height of the Alps at the resolution of 6.5 km (all the subsequent description is referred to this resolution) is of about 2800 m (attained in the area of Monte Rosa). The second experiment has been done with an enhanced orography (ENH-S: "enhanced sigma"), conceptually similar to an 'envelope orography', for which the maximum elevation reaches 3500 m. However, a more faithful representation of the actual height of the Alpine divide is obtained in this way at the expense of an increase of the error due to the use of terrain-following coordinates. To such an error various terms contribute, the largest being related to pressure gradient, advection (see, for example, Shär, 2000) and horizontal diffusion. In order to maintain this error type as small as possible, alternative ways of representing the orography have been explored, in which the sigma surfaces, including the lowest one (σ=1), are kept relatively smooth. The 'additional' orographic variance, that seems necessary to reduce the model error, is represented with the two different methods described below.

In the first case, implemented in the experiment called MIX-L ("mixed linearized"), the basic orography, defining the model sigma surfaces, is a smoothed version h_s of the total orography h_t. The latter is modelled by an 'additional' vertical velocity $w = \mathbf{V}_h \bullet \nabla (h_t - h_s)$, prescribed along the lowest model boundary ($\mathbf{V}_h$ is the horizontal wind vector). This approximation is commonly made in analytical representations of topographic obstacles, provided they are of small amplitude (in these cases usually $h_s = 0$). Scaling arguments and numerical tests, made both with idealised and realistic conditions, indicate that $h_t - h_s$ should not exceed a few hundred meters. We have chosen the two orography definitions in such a way that $h_t - h_s \leq 400$ m, with a maximum of h_s of about 3300 m. The model implementation is made by introducing an appropriate value of $\dot{\sigma}$ (the vertical velocity in sigma coordinates) at σ=1, which implies modifications in the tendency equation for the surface pressure and in the definition of $\dot{\sigma}$ at all levels. This method does not assure exact mass conservation, since the lowest sigma surface is no more a material surface, but tests indicated that this problem is not serious.

The second type of alternative mountain representation is a sort of combination of sigma and 'step' (or 'box') orography. The corresponding experiment is called MIX-B ("mixed box"). Again, the sigma surfaces are defined by a smooth orography h_s, which in this case, at variance with the case above, must be lower than the total orography h_t (in order to represent 'valleys'), so $h_t - h_s \geq 0$. At the grid points on the sigma surfaces immediately above the surface, but having heights smaller than h_t, the horizontal velocity components are made to vanish. The definition of h_s is obtained from the total orography h_t in such a way that the horizontal flow is blocked only where mountain slopes exceed a certain steepness. In this particular case, the maximum height for h_s is 2850 m, while h_t is the same as in ENH-S. This method is certainly more efficient than the previous one (MIX-L) in representing drag and blocking effects associated with mountain steepness, and is not affected by dynamical approximations.

Results

Fig. 1 shows, as an example, the 30 h (24 h for the inner domain) forecast of m.s.l.p. in the inner domain for the CRT-S and the ENH-S experiments, verifying 7 Nov. 1999, 06 UTC. The corresponding analysis is not shown, but can be found in Fig. 2 of Buzzi and Malguzzi (2000). The CRT-S case (left panel), although describes quite accurately the intensity, shape and position of the lee cyclone, probably overestimates the intensity of the small scale cyclonic core over the Tyrrenian sea while puts too high pressure over the Western Mediterranean. The largest error appears in the too weak and too narrow pressure ridge north of the Alps. Pressure is also too low over and east of the Adriatic. The enhanced mountain experiment (Fig.1, right panel) reduces the m.s.l.p. error almost everywhere but over the Western Mediterranean (however, the geopotential error is reduced in the mid-high troposphere also over this region), at the expense of a larger noise due to the steeper orography. The m.s.l.p. field immediately north of the Alps is now even too strong, although at upper levels the correction to the geopotential error is still insufficient.

Considering that the height field error varies mainly in a north-south direction across the Alps and changes also with height, in order to better describe the characteristics of the various experiments, the geopotential and temperature fields have been plotted along the cross-section shown in Fig. 1 (left). Dots aligned close to the cross-section represent the position of the upper air soundings available at 06 UTC of 7 Nov.(note that about 40% of the available soundings derive from special MAP SOP stations). Fig. 3 shows the 700 hPa geopotential height in the ECMWF analysis (about 50 km resolution) and in the various experiments at 6.5 km resolution. It is clear that the amplitude of the geopotential wave strongly depends on the orography representation and that the CRT-S case underestimates it. The other experiments improve the geopotential ridge north of the Alps (especially MIX-B), but tend to increase the error to the south, where MIX-L performs quite well (but the geopotential error decreases to the south at upper levels in almost all experiments). Fig. 4 allows to compare the temperature profile at the same level directly with the RAOB observations. In this case, the different experiments have a small relative spread and behave generally better than the control. The mixed blocked orography seems to give the most accurate results, especially north of the Alps.

Finally, Fig. 4 shows the 24 h precipitation fields in two most different cases: CRT-S and MIX-B. Although the differences are relatively small for such small scales, and the quality of the forecasts is relatively good in both cases in getting the two observed maxima in the Lago Maggiore area and over the northern Apennines, the MIX-B case is somehow better in reproducing the precipitation structure over the central Po Valley.

References

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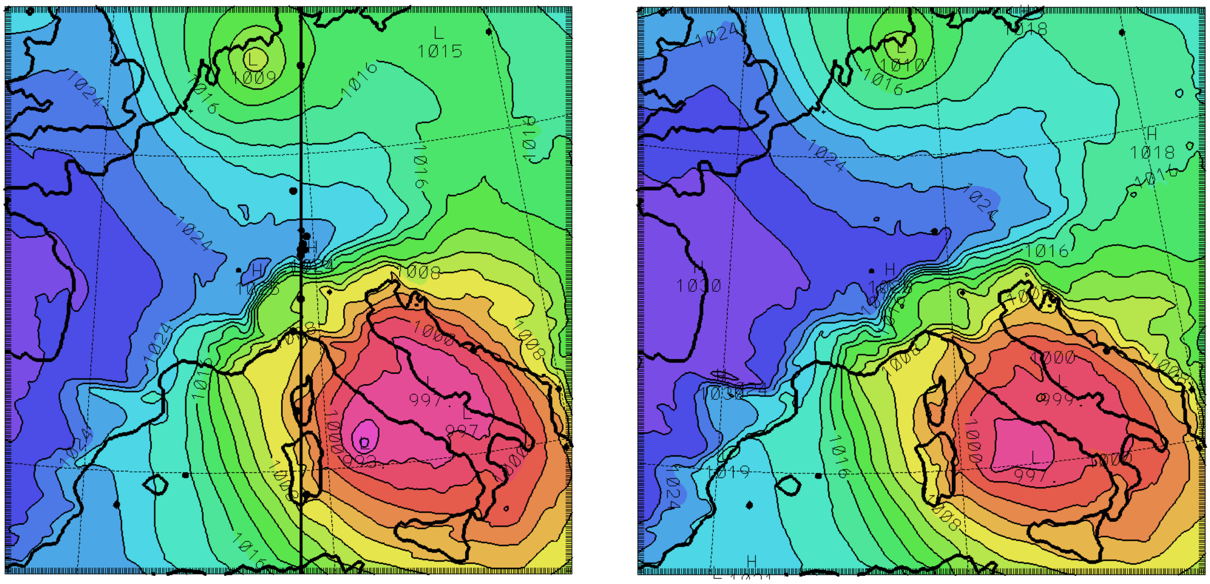

Fig. 1: mean sea level pressure in a 30 h forecast verifying 7 Nov. 1999, 06 UTC. Left:CRT-S; right: ENH-S.

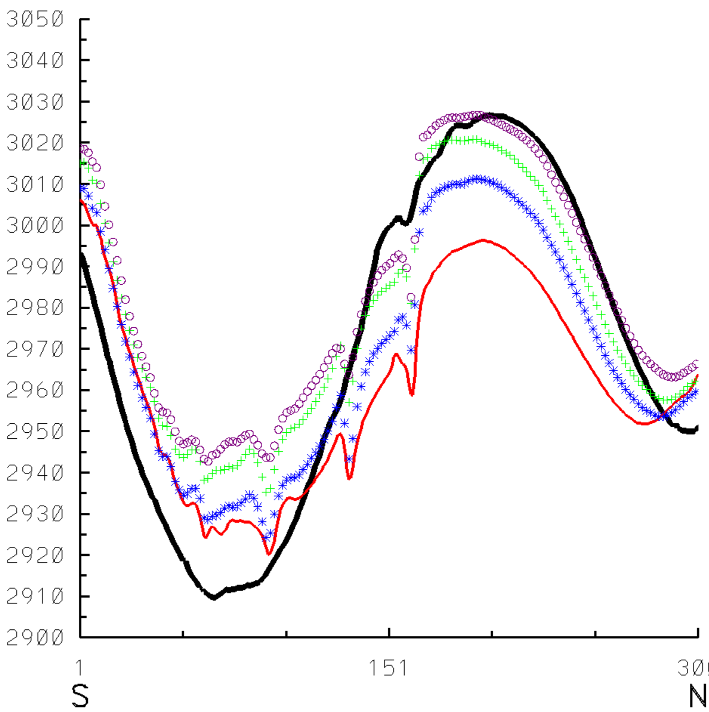

Fig. 2: profile of geopotential height at 700 hPa along the cross section shown in Fig. 1 (left), 7 Nov. 1999, 06 UTC. Thick (black): ECMWF analysis; thin (red): CRT-S; crosses (green): ENH-S; stars (blue): MIX-L; circles (purple): MIX-B.

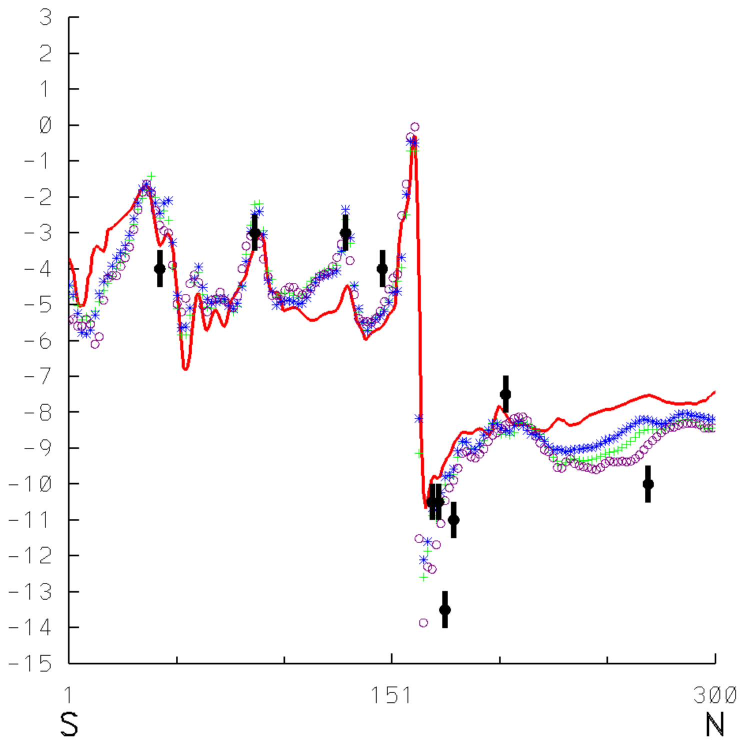

Fig. 3: as Fig. 2, but for temperature. Dots with error bars are RAOB observations (indicated on the line of Fig. 1, left). The ECMWF analysis is not shown.

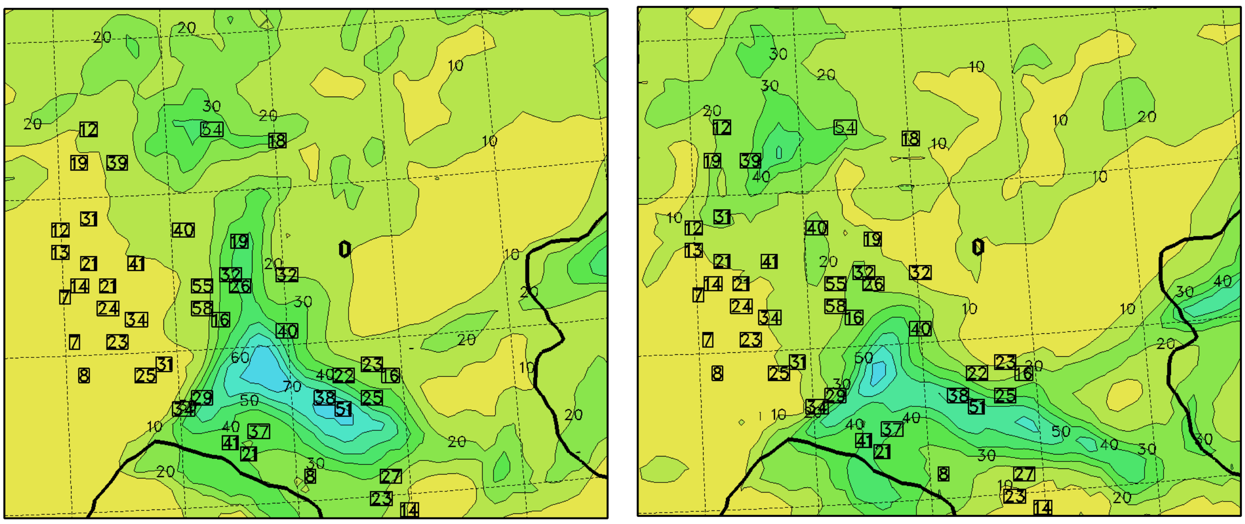

Fig. 4: 24 h accumulated precipitation, ending 06 UTC, 7 Nov. 1999. Observations (mm) in squares. Contour lines (interval 10 mm) for experiments CRT-S (left) and MIX-B (right). Zoomed area over Northern Italy.