8.6

MOIST AIRFLOW REGIMES OVER MORE OR LESS SMOOTH MOUNTAINS

Joël Stein

Centre National de Recherches Météorologiques (CNRS and Météo-France), Toulouse, France

1. INTRODUCTION

The Alps are formed by a lot of sub-massifs, peaks and valleys. The response of a conditionally unstable airmass to this orographic forcing involves a lot of scales. In order to decompose this response, a set of numerical simulations has been performed where only the orographic shape is varied. The thermodynamical fields are uniform and deduced from the radio-sounding launched at Cagliari during the MAP IOP2 B and the wind is taken uniform (20 m/s). This radio-sounding is plotted in figure 1 and characterized by important CAPE (> 2000 J/kg) and CIN ($\simeq$ 200 J/kg). After a description of the numerical setup in section 2, the analysis of the 10km mesh simulations and the 2.5 km mesh simulations are presented in section 4 and 5 respectively. Section 6 contains the conclusion.

2. NUMERICAL SETUP

The numerical simulations are performed with the non-hydrostatic model Meso-NH (Lafore *et al.* 1998), using three nested domains (40,10 and 2.5 km meshes), with 2 way interactive grid nesting and cold microphysics (Stein *et al.*2000). The 2.5 km domain (500 x 500 km^2) covers the western part of the Pô valley. In the 10 km mesh model, the convection is parametrized by a mass-flux convection scheme (Bechtold *et al.* 2001) but it is explicitely resolved when the resolution is increased to 2.5 km. The roughness length is set proportional to the orography (0.002m for $Z_s = 0$ and 4 m for $Z_s = 4km$. During 2 days, only the 40 km mesh model is run. Then a supplementary day of simulation is performed with the 40+10 km mesh models to provide the stationnary solution which is discussed in the following section. The convection resolving model is started from this solution and run togeteher with the 2 other models for 12 hours. These final solutions are examined in section 4.

[1] *Corresponding author address*:Joel Stein , CNRM, 42 av. Coriolis, 31057 Toulouse Cedex, France. e-mail:joel.stein@meteo.fr

For the reference simulation, the orography is refined at every step of the nesting procedure. For all the other cases, the orography of the high resolution nested models is interpolated by a spline function from the orography of the model with the lowest resolution (40 km). This former orography is either the 40 km mesh orography, either a filtered version corresponding to 160 km mesh orography or this filtered orography where only the Alps are kept. It should be noted that in these last two cases, not only the small scales are modified but also the scales corresponding to the Alpine half-width.

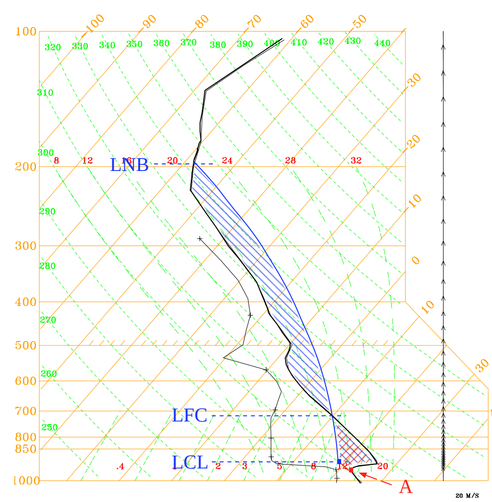

Figure 1: *Radiosounding at Cagliari(Sardinia) the 19 September 1999 at 23 UTC.*

3. IMPACT OF THE OROGRAPHY FOR A PARAMETRIZED CONVECTION

Even if the incoming flow is uniform far upstream, it is no more the case when it reaches Italy. Every orography upstreams of the Alps, create a Foehn effect and a mixing which changes the characteristics of the boundary layer (Fig 2. Low level jets form along the Apennines and the Dinaric Alps. They are due to the combined effect of the pressure gradient and the Coriolis force as the flow slows down before the mountains.

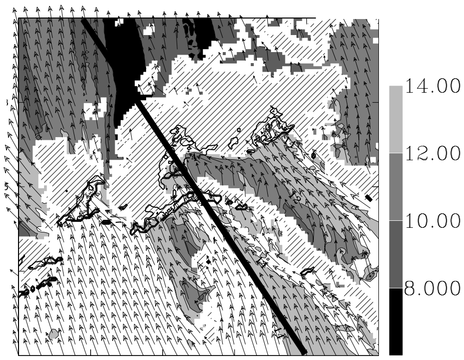

Figure 2: *vapor mixing ratio and horizontal wind at 500 m ASL. Instantanous rain flux at the surface every 4 mm/hour*

The vertical cross section passing above the Monte Rosa massif (Fig 2) shows a strong gravity wave, vertical convective transport and turbulent mixing on the upwind side of the Apennins and of the Alps (Fig 3).

All these features are progressively transformed as the orography is smoothed or modified, the 3-hourly accumulated rain is plotted for all these cases on Fig 4 and 5. The distribution of the rain (mainly produced by the convection scheme) on the Alps shows preferred location for the convection initiation in the main concavities of the Alps themselves. Moreover, the two jets along the Apennins and the Dinaric Alps provide a supplementary forcing for the convection as indicated by the less intense rainfall reported in the Alps alone experiment. It should be noted that the rain is also important on the Ligurian Apennins and the Massif Central. This rain distribution has been summed over the whole simulation domain and is given in Table 1 for the different orographies. The impact of the smoothing remains moderate and it indicates that the convection scheme closure is not very sensitive to the low level forcing. The vertical cross section passing above the Monte Rosa massif (Fig 2) shows a strong gravity wave, vertical convective transport and turbulent mixing on the upwind side of the Apennins and of the Alps (Fig 3).

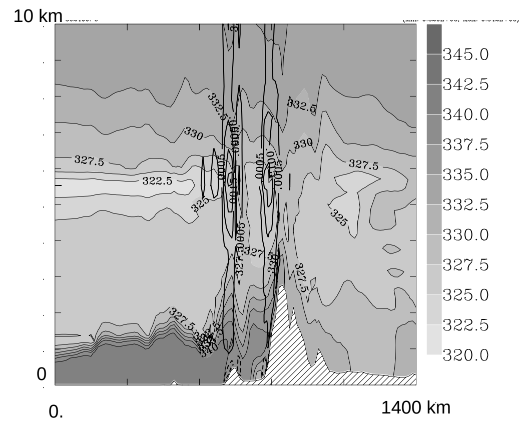

Figure 3: *Equivalent Potential temperature (grey scale) and diabatic heating (heavy isolines) provided by the convection scheme. The cross section location is indicated on Fig 2*

Reference	40km oro.	160km oro.
130	130	100
Alps alone	Milano RS	
xxx	173	

Table 1. *total rain ($10^6 kg/s$) fallen over the whole simulation domain of the 10 km mesh model for the different orographies.*

Complementary simulations have been performed in order to document the impact of the sounding characteristics by using the Milano sounding launched at the same moment. The CAPE of the Milano sounding is weaker than the Cagliari one but the convection distribution and amplitude are quite similar. The impact of the diabatism has also been tested by switching it off. The circulations upstreams of the Alps appears very similar with the moist case for the Cagliari sounding. The explanation is likely in the local impact of the convection. It also clearly points towards the importance of the roughness effects on the drying effect behind all the mountains.

4. IMPACT OF THE OROGRAPHY FOR A RESOLVED CONVECTION

A temporally periodic solution is obtained after 6 hours of simulations with 3 nested models. The rain

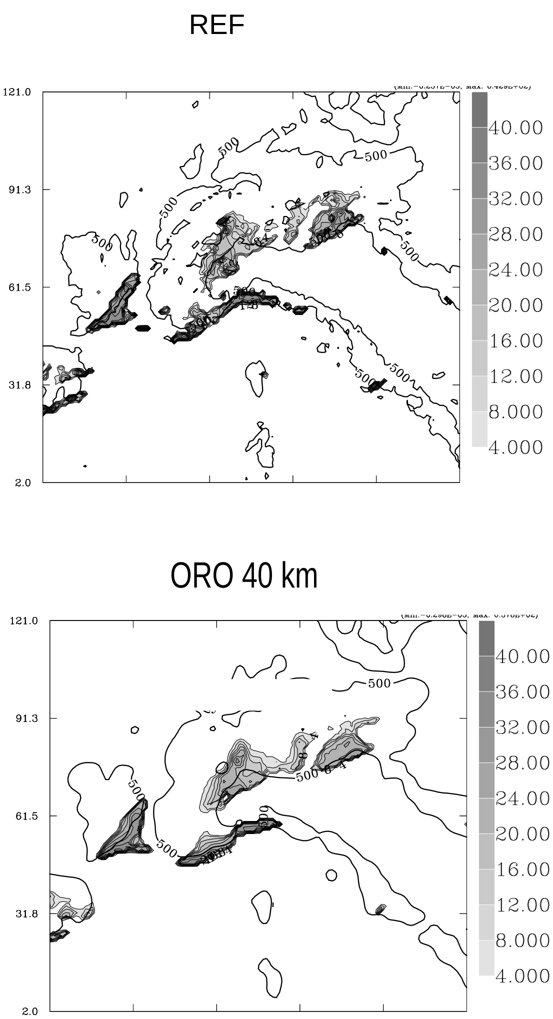

Figure 4: *3-hourly accumulated rain for the different orographies in the 10 km mesh model*

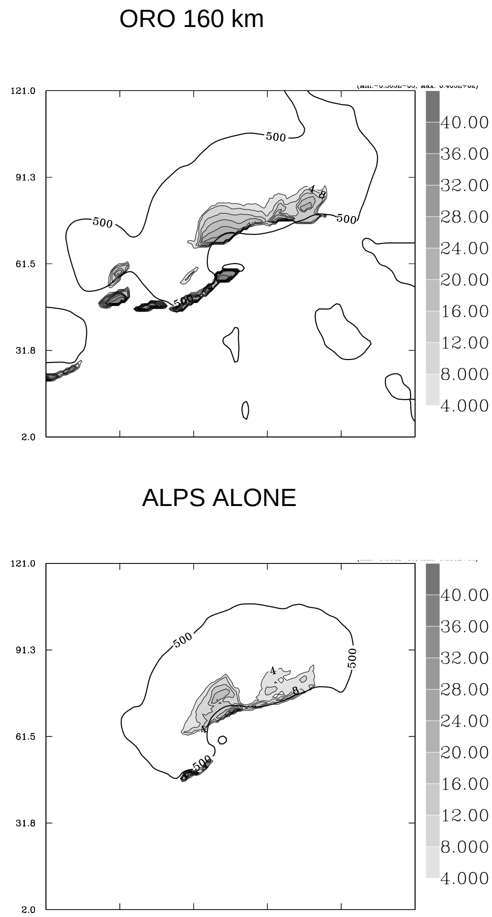

Figure 5: *3-hourly accumulated rain for the different orographies in the 10 km mesh model*

is produced by convective cells which are generated continously at the foothill of the Alps and propagate on the upwind side before being evaporated by the strong alpine Foehn. The spatial separation of the cells is around 15 km and does not depend on the shape of the orography. The accumulated rain is presented for only two simulations (reference and 160 km orography) in Figure 6 a and b. The results were very comparable for the reference and the 40 km orography because at this former scale, the main massif are well represented. Moreover, in both simulations, no rain is found on the Apennins (at the contrary of the 10 km mesh model), except a weak convection line which occurs in the col between Alps and Apennins. This convection line is less developped than in Gheusi and Stein (2002) because of the change of the roughness length in our study.

With this resolution, the behaviour of the convection response to the orographic forcing is different and a shift and a weakening of the convective cells is clear for the 160 km. If the surrounding mountains are also removed (Alps alone experiment), the accumulated rain is everywhere weaker than 4 mm. The Table 2 is the same as Table 1 for the 2.5km mesh simulations and confirms the previous conclusions. Thus, the physical conclusions on the behaviour of the convection are changed when we use a convection resolving model and the rainfall is clearly overestimated by the convection scheme, especially for the smoother cases. The sensitivity experiment using the Milano radio sounding, also gives a stronger convective response on the Apennins in this case as for the 10 km model but the response over the Alps is more widespread and no cellular organization is found in this case(Fig 6c).

5. CONCLUSION

Reference	40km oro.	160km oro.	Alps alone
28	24	6	0

Table 2. *total rain fallen over the whole simulation domain of the 2.5km mesh model for the different orographies.*

A set of simulations of convective atmosphere has been performed, smoother and smoother orographies have been used to excite either parametrized convection or explicit convection depending on the resolution of the model. The impact of the large scale forcing appears to be more marked in the convection resolving model. The control of the moist regime by only few nondimensional numbers still appears to be a difficult task regarding the variability of the convective response to the shape of the orographic forcing but also to the humidity profiles.

I acknowledge F. Arnal, D. Carrer and C. Labadie for their help for performing this set of simulations.

References

[1] P. Bechtold, J.S. Kain, E. Bazile, P. Mascart, and E. Richard. A mass flux convection scheme for regional and global models. *Quart. J. Roy. Meteor. Soc.*, 127:869–886, 2001.

[2] F. Gheusi and J. Stein. Small-scale rainfall mechanisms for an idealized convective southerly flow over the alps. *submitted to Quart. J. Roy. Meteor. Soc.*,.

[3] J.P. Lafore, J. Stein, N. Asencio, P. Bougeault, V. Ducrocq, J. Duron, C. Fischer, P. Héreil, P. Mascart, J.L. Redelsperger, E. Richard, and J. Vilà-Guerau de Arellano. The Meso-NH atmospheric simulation system. Part I : Adiabatic formulation and control simulations. *Annales Geophysicae*, 16:90–109, 1998.

[4] J. Stein, E. Richard, J.P. Lafore, J.P. Pinty, N. Asencio, and S. Cosma. High-resolution non-hydrostatic simulations of flash-flood episodes with grid-nesting and ice-phase parametrization. *Meteor. Atmos. Phys.*, 72(2-4):203–221, 2000.

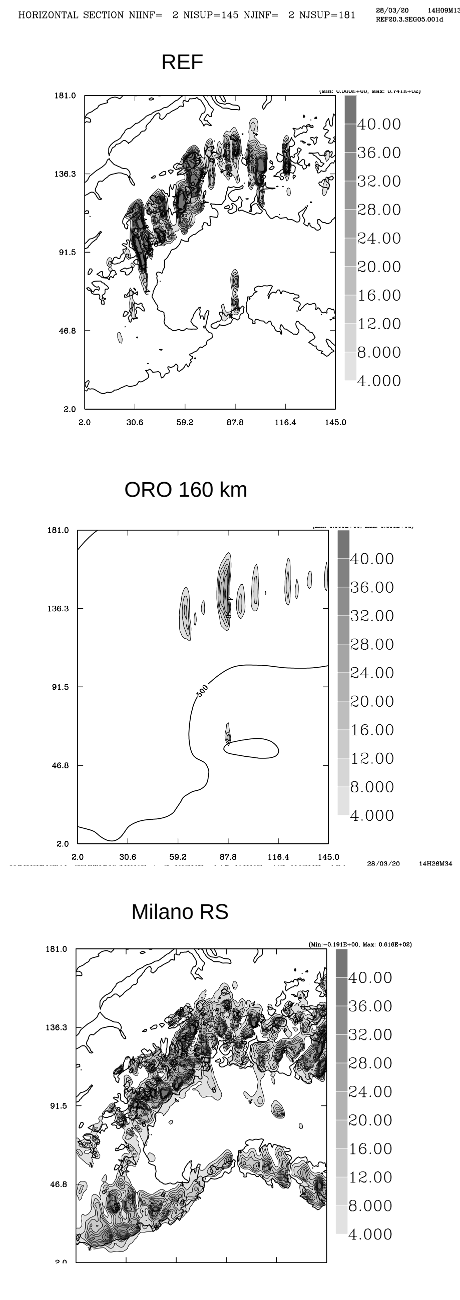

Figure 6: *3-hourly accumulated rain in the 2.5 km mesh model for the reference run (a), the 160 km orography (b) and the reference oro. but using the Milano sounding (c).*