OROGRAPHIC INFLUENCE ON QUASI-STATIONARY INTENSE CONVECTION IN THREE DIMENSIONS

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Abstract: Some of the most intense local flood events are due to quasi-stationary convection that may insist on the same place for many hours, producing high values of accumulated precipitation. One of the elements that favour the anchoring of the convective system (MCS) is the orography. In one of the most severe floods (Gard basin in Southern France, 8-9 Sept. 2002), the orography of the Massif Central played a rather unusual role, favouring the onset and maintenance of the MCS at some distance upstream of the main orographic slope. The low level upstream convergence induced by the Massif Central seemed to have played a role in the triggering of the convection. In this work the initial atmospheric conditions of this event have been largely idealized, taking horizontally uniform values for wind, temperature and humidity profiles, and a simplified isolated orography representing only the Massif Central. A convective system is initiated in the non-hydrostatic simulations, embedded in a quasi-stationary solution of flow over the orography. It is shown that the triggering of convection occurs in the convergence zone upstream of the orographic obstacle. The subsequent evolution of the convective cells is not as stationary as in the real event of reference, unless modifications are introduced in the wind profile. Although the results obtained in such simplified conditions do not reflect all the observed characteristics of the real event, they contribute to a better understanding of the problem of interaction between strong convection and orography.

Keywords: *convection, orography*

1. INTRODUCTION

The predictability of flash floods triggered by strong atmospheric convection is generally low, due to the short time scales of convective instability, so that NWP short range forecasts, even at very high resolution, need to be complemented with rainfall observations at a few hour time scale (Collier, 2007). However, orography may trigger convective cells in the same place for a comparatively long time (associated with the time scale evolution of the larger scale flow), and then increase predictability in some cases (Cosma et al, 2002). In addition, orography can modify the impinging flow in such a way that the formation of quasi-stationary or slow moving convective cells or mesoscale convective systems (MCS) is favoured. Some of the most intense local flood events are due to quasi-stationary MCS's that may insist on the same place for many hours, producing high amounts of accumulated precipitation.

Orographic convective triggering and maintenance of quasi-stationary convection can occur through several different mechanisms, including forced uplift on the upstream slope, upstream blocking, formation of convergence areas in the orographically modified flow upstream and downstream, differential heating, lee waves etc. The complexity of the orographically modified flow, including turbulence interacting with precipitation microphysics (Rotunno and Houze, 2007), makes it necessary to simplify the general problem in order to better understand underlying mechanisms. For example, in the case of conditionally unstable flows over idealized two-dimensional mesoscale orography, different convective regimes were identified by Chu and Lin (2000) and Chen and Lin (2005). In the first regime, convection propagates upstream together with the downdraft-generated density current, while in the second quasi-stationary convection over the mountain crest or its nearby slopes is attained.

The purpose of the present work is to generalize the study of interaction between the onset of severe convection and orography to three dimensions, but keeping the basic flow essentially two dimensional. The original motivation was inspired by the previous observational (Delrieu et al, 2005) and numerical or mixed (Chanchibault et al, 2005; Anquetin et al, 2006; Davolio et al, 2006 and 2007) studies of one of the most severe floods that occurred on 8 and 9 September 2002 in the Mediterranean region, namely in the Gard basin, located south-east of the Massif Central in Southern France. In this case, a MCS insisted more or less over the same area for more than 12 hours, but undergoing different stages during which the larger scale atmospheric circulation changed its characteristics, so that a combination of factors favoured the persistence of the system. The idealized study presented here takes into account the first stage, during which convection was initiated, and remained at some distance upstream of the main orographic slope. In this respect, it is possible to say that the orography of the Massif Central played a rather unusual role, considering that the climatological maximum of precipitation is located on the upstream slope of the Massif, in the Cevennes area (Cosma et al, 2002). It is well known, in general, that both stratiform and convective orographic precipitation tend to occur on the upstream slope of a ridge, but with the location and amount of precipitation being subject to important modifications associated with the flow regime (depending, in turn, on the Froude number – see, for example, Miglietta and Buzzi, 2001; Rotunno and Houze, 2007) and with the vertical and horizontal transport of liquid and frozen water species.

The low level upstream convergence induced by the Massif Central played a role in triggering the convection, while the convective downdraft(s) and associated low level cold outflow appeared to interact with the orography in the mature stage of the MCS, influencing the subsequent evolution of the system (references above).

In the present work, in order to study in isolation the role of orography in triggering the convection and influencing its subsequent evolution, the initial atmospheric conditions have been largely idealized, taking horizontally uniform conditions for wind, temperature and humidity profiles, while a simplified isolated orography has been considered.

2. MODEL SETUP

The model atmosphere was prescribed by imposing vertical profiles of wind, temperature and humidity as initial conditions and as lateral boundary conditions of the simulations. Such profiles were derived from the ECMWF analysis at 06 UTC of 8 Sept. 2002, which proved to be the best initiation time for the realistic simulations (Davolio et al, 2007), by sampling an area over the Gulf of Lion upstream (with respect to the low level meridional flow) of the Massif Central, averaging on a domain of 2°x2° centred around 42°N, 4.5° E. However, a slight vertical smoothing was applied and changes were introduced on the reference profile, as specified below.

Two models and related grids were used. The hydrostatic BOLAM model was first employed to integrate the initial state on a relatively large domain (1200 x 1200 km), surrounding the Massif Central, with horizontal resolution of 12 km, 40 hybrid levels, no planetary rotation, and fixed lateral boundary conditions. The scope of such integrations is to obtain a reasonably stationary solution in the presence of an isolated orography. The model orography was derived by smoothing to some extent the Massif Central (obtained from the 1 km resolution USGS DEM) and flattening the surrounding mountains (Alps and Pyrenees), so that near the model lateral boundaries the ground remains flat. In addition, in most of the experiments a transition from sea (in a southern portion of the domain) to land was imposed, in order to simulate the presence of the Mediterranean sea. The BOLAM model was run without atmospheric radiation, without convective parameterization and without surface fluxes of heat and moisture, while boundary layer parameterization and stratiform microphysics were left active. In the BOLAM runs, cloud forming condensation develops over the mountain, but without significant precipitation, starting from the reference profiles of humidity derived from the ECMWF analysis. If convective parameterization is activated, precipitation occurs due to the conditional instability of this state, corresponding to a CAPE of about 1500 J/kg.

The non-hydrostatic MOLOCH model was nested into the BOLAM grid, over a domain of 500x500 km, using initial conditions and fixed lateral boundary conditions, derived from the BOLAM run after quasi-stationary flow over the orography was met. The model used full physics (including surface fluxes), except for radiation and without earth rotation, for consistency with the BOLAM dynamics. The orography was prescribed in a similar way as for BOLAM, leaving only the Massif Central with a more detailed representation of small scales, as allowed by the model finer grid spacing (2.5 km in the horizontal, with 50 hybrid levels). Each integration was carried on for a period of 7 hours, in order to capture the formation of convection and its subsequent evolution for a time period much larger than the time scale (0.5-1 h) typical of isolated convection, and corresponding roughly to the first stage (triggering phase – Davolio et al, 2006) characterizing the real event. The purpose of the MOLOCH experiments is to study the conditions that allow the initiation of convection, with particular regard to the atmospheric vertical profiles of wind, temperature and humidity, and to the role played by the orography in modifying the upstream flow. In addition, the subsequent evolution of the MCS is studied as a function of the above parameters. It is clear, however, that one cannot directly compare the life cycle of the simulated convective system with that of the event that inspired this work, mainly due to the imposition of uniform and stationary conditions, without rotation and baroclinicity. More realistic (including semi-idealized) experiments were already presented and discussed by

Chancibault et al (2006), Anquetin et al (2006), Davolio et al (2006), Davolio et al (2007).

3. EXPERIMENTS AND RESULTS

As indicated above, the initial atmospheric state was prescribed to be horizontally uniform, with profiles sampled over the Gulf of Lion from the ECMWF analysis. Such profiles show quasi-saturated conditions near the level of 700 hPa, but lower relative humidity, around 80%, in the layer below. It has been necessary to modify the humidity profile, increasing the low level humidity by 12%-13% where unsaturated, that is, bringing the relative humidity of the PBL from ~ 80% to ~ 90%, in order to obtain convection developing in the non-hydrostatic model. Such modification is consistent with the need of altering the low level humidity through assimilation of surface and radar data to obtain realistic precipitation amounts (Chancibault et al, 2006; Davolio et al, 2007). In the present case, in which baroclinic effects associated with the eastern side of the synoptic scale trough are suppressed, the spontaneous triggering of convection is hindered by the absence of large scale ascending motions. With such modified profile and with a smoothed orography representing the Massif Central, deep convection develops in a region located at the foot of the mountain, on its southern side, and then drifts to the east, detaching from the orography as the precipitation-induced downdraft grows and a density current propagates to the south-east.

Figure 1a shows the wind field at the lowest model level (80 m above the surface), in the reference experiment initialized with the modified sampled profile described above, prior to the initiation of convection. A stagnation area is clearly visible on the south-eastern of the Massif Central, where the low level flow is impinging the steeper part of the slope. The existence of a flow-around regime (at least at low levels) is indicated by the pronounced diffluence of the wind field around the mountain and the reverse flow north of it. The (dry) Froude number NH/U is larger than unity at low levels, being estimated around 2 (see also Davolio et al, 2006). Possible reductions of static stability due to condensation effects can be considered small since a thin cloud appears only near above the mountain top, with no appreciable precipitation. Figure 1b shows the total precipitation, accumulated over a period of 7 hours, in the same experiment. The occurrence of strong convection, associated with the onset and growth of a MCS near the south-eastern flank of the mountain, is reflected by the accumulated precipitation field. Convection starts about 1 hour after the initial time at the foot of the slope, in the stagnation area shown in Fig. 1a, and then propagates to the east, with partial splitting into two major cells, one drifting E-NE and the other, the stronger one, drifting E-SE. The latter cell persists throughout the run and is still active at the end, having created its own downdrafts and associated gust front, propagating mainly in the opposite direction of the low level wind.

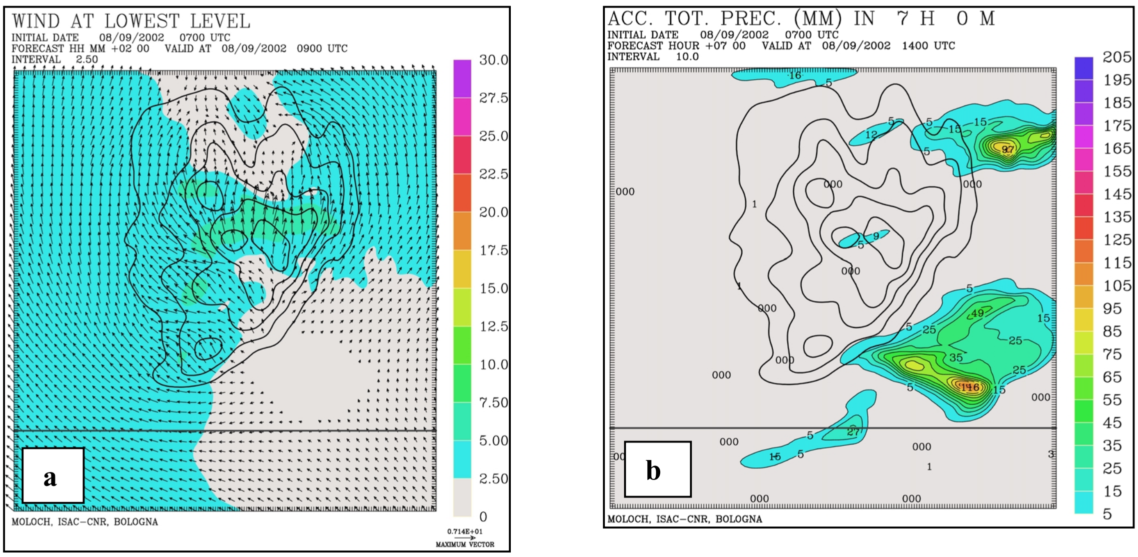

Figure 1: (a): wind at the lowest model level, after 2 hours of integration, at the beginning of the convective development. (b): accumulated precipitation between 1 and 8 hours of integration (interval: 5 mm). In both panels the orography (Massif Central) is plotted with black contour lines at intervals of 250 m.

The eastward drift of the convective system shown in Fig. 1b can be counteracted by adding an easterly perturbation to the reference wind profile, at low-mid tropospheric levels, of about 5-6 m/s. This modification, however, does not seem to be justified by the wind profiles observed in the real event.

4. CONCLUSIONS

This work has been inspired by deep convection episodes associated with flash floods, and in particular by the Gard event of September 2002. The purpose was to investigate the onset and evolution of mesoscale convective systems originated by conditionally unstable, upstream uniform flow interacting with an isolated three dimensional orography. The basic uniform flow was prescribed starting from a sounding extracted from the ECMWF analysis at the beginning of the Gard event.

The most drastic simplification of model dynamics was the assumption of vanishing planetary rotation. This was necessary in order to maintain a realistic vertical wind shear (which is known to be important for the convection organization), but without the associated horizontal temperature gradients that are needed to maintain thermal wind equilibrium with rotation. In fact, the presence of temperature gradients contrasts with the need of obtaining quasi-stationary conditions, because the associated (differential) temperature advection rapidly changes the initial profile and is not compatible with constant lateral boundary conditions. The elimination of baroclinicity is unrealistic for the synoptic scale dynamics, but is commonly accepted as a simplification for studying the convective development on relatively short space and time scales.

With the above conditions and limitations, the area south-east of the Massif Central, where strong low level flow deviation and stagnation where observed as a response to the orographic forcing, is the location where strong convection developed in the numerical experiments. Moreover, such convective cells where long lived and moved slowly eastwards, against the low level flow, developing there own cold pool and gust front, generally more intense than those observed in the real event. They were not stationary, however, unless a suitable modification of the wind profile is introduced. This indicates that the model setup is capable of describing the basic mechanisms for the orographic convective triggering, while the conditions that lead to quasi-stationarity of the convection require more complex flow configurations than those modelled in this work.

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