TRIGGERING AND STATIONARITY FACTORS FOR HEAVY PRECIPITATING EVENTS OVER SOUTHERN FRANCE.

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1. INTRODUCTION

As many other Western Mediterranean regions, Southern France is concerned by devastating flash-flood events particularly during the fall season. The warm Mediterranean Sea at this time of the year and the orography form a strong topographic component acting on the genesis and evolution of the quasi-stationary heavy precipitating systems. The Mediterranean Sea provides the moisture supply to the strong low-level southerly flow that impinges the mountain ranges of the surrounding countries.

The goal of this study was to use a kilometric-scale model to underline the synoptic and mesoscale factors leading to the stationary of these events, which are often responsible for accumulation of huge rainfall. Three representative cases of High Precipitating Events (HPEs) over Southern France have been simulated with the high-resolution (2.5 km) research MESO-NH model.

2. THE CASE STUDIES

The study focuses on three HPEs: 13-14 October 1995 (Cévennes case), 8-9 September 2002 (Gard case) and 12-13 November 1999 (Aude case). The last two cases were extreme flash flood events with considerable precipitation totals: 690 mm in only 24 hours near the city of Alès in 2002, and more than 500 mm during the same period in Lézignan-Corbières in 1999, both leading to the death of several tens of people and several billions Euros of damages (Fig. 1). All of these three events occurred within the favourable region for very heavy precipitation (Nuissier et al., 2007a). Moreover the Gard event was not only characterized by persistent torrential precipitation, but also by an unusual location, well upstream of the Massif Central's foothills. The Cévennes case was less paroxismic (near 250 mm in less than 24 hours) but more typical and representative of flash-flood episodes over moutainous areas of Southern regions of France.

A description of the meteorological events may be found in Ducrocq et al. (2002) for the 1995 case and in Ducrocq et al. (2003a) for the 1999 one, respectively. Delrieu et al. (2005) proposed a comprehensive description of both meteorological and hydrological aspects for 2002 case.

3. THE NUMERICAL EXPERIMENTS

The French Méso-NH non-hydrostatic mesoscale numerical model (Lafore et al., 1998) has been used for the simulation of the three HPEs. The numerical experiments presented in this study use two nested domains with nearly 2.5-km and 10-km grid meshes respectively. Several numerical experiments have been performed for each case in order to highlight the mechanisms leading to stationarity of the precipitating systems. Table 1 lists all experiments used for studying the precipitating event. The **REF** ones use as initial conditions a large scale analysis provided by the 4D-Var ARPEGE operational system (global NWP system operated by Météo-France). For Cévennes and Gard cases, in order to improve the simulation of the convective systems, a second set of initial conditions have been used for **MDA** experiments. The Mesoscale Data Assimilation procedure of Ducrocq et al. (2000) has been applied to obtain mesoscale initial conditions based on mesonet surface observations, radar reflectivity and brightness temperature. The initialization procedure does not concern Aude case, as the **REF** simulation from the ARPEGE analysis for this case had already give realistic results. For the **NOC** experiments, the cooling induced by the evaporation of liquid water has been removed. For the **NOR** simulations, the Massif Central has been removed, the Alps and Pyrenees being kept as identical in the model.

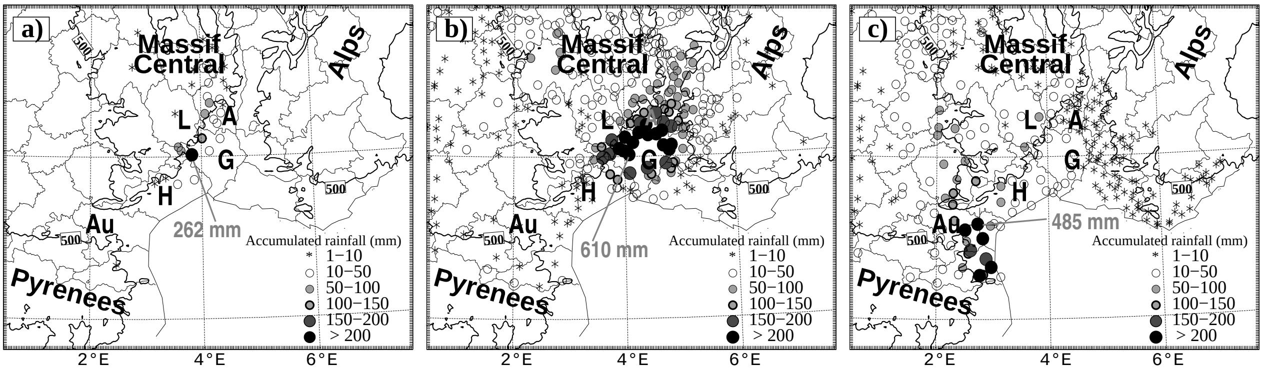

Figure 1: Accumulated surface rainfall (in mm) from Météo-France's rain gauge network for : **a**) from 21 UTC, 13 October 1995 to 08 UTC, 14 October 1995; **b**) from 12 UTC, 8 September 2002 to 12 UTC, 9 September 2002; **c**) from 12 UTC 12 November 1999 to 06 UTC, 13 November 1999 (from Nuissier et al., 2007a)

Table 1: Characteristics of the different sets of initial conditions and sensitivity experiments for the case studies.

	Characteristics
REF	Initial conditions= Large scale ARPEGE analysis
MDA	Initial conditions= Mesoscale Data Analysis following Ducrocq et al. (2000) procedure
NOC	No cooling associated with evaporation of liquid water
NOR	Removing of Massif Central from 10-km and 2.5 km domains

4. SYNOPTIC AND MESOSCALE INGREDIENTS

The three HPEs form in slow-evolving synoptic-scale environments favourable to the development of convective systems (diffluent upper-level southerly flow, PV anomalies,...). At low-levels, a southerly to easterly moderate to intense flow provides conditionally unstable and moist air as it moves over the Mediterranean Sea. The two extreme cases (Gard and Aude) differ from the more classical event (Cévennes) from larger low-level moisture fluxes. Weaker values of conditional convective instability as in the Aude case is counterbalanced by a stronger warm and moist low-level jet.

Furthermore, backward trajectories and sensitivity experiments have been performed in order to finger out for each case, the smaller-scale mechanisms that are responsible for triggering and maintaining the precipitation systems over the region. Hereafter, the more realistic simulations for each convective system (**CTRL**) are compared to the sensitivity experiments.

4.1 Gard case: a low-level cold pool blocked in the Rhône valley

The sensitivity experiments (also confirmed by the observations) reveal that a low-level density current, resulting from the diabatic cooling associated with the evaporation/sublimation and melting of hydrometeors, form just beneath the simulated MCS. Indeed, the consequence of removing diabatic cooling (**NOC** experiment) is a shift of the simulated MCS over the foothills of the Massif Central (Fig. 2a). Clearly, it demonstrates that triggering of the Gard event over an unusual location far upstream of Massif Central foothills is explained by a low-level cold pool centered beneath the MCS, which forces the conditionally unstable low-level jet to rise, thus leading to continuous formation of new convective cells over the leading edge of the cold pool. **NOR** experiment (Fig. 2b) shows that the Massif Central helps to block and focus the cold pool beneath the storm within the Rhône valley, through a weakening of the accumulated simulated rainfall especially over Western region of Gard plains.

4.2 Cévennes case: a typical orographic forcing

For the Cévennes case, due to nearly saturated low-levels that prevailed for that case, no significant cooling beneath the MCS has been observed or simulated. However, Fig. 3 shows that the surface rainfall almost disappears when the Massif Central is removed (**NOR** experiment). Therefore, this state clearly shows the key role of the Massif Central in that case in forcing the low-level southerly converging flow to lift and thus, trigger deep convection.

4.3 Aude case: a strong upper-level synoptic-scale precursor

Finally, for the Aude case, removing of the Massif Central relief or removing of diabatic cooling (Fig. 4) do not have any significant impact on the location of the simulated MCS. However, those are primary low-level mesoscale ingredients which mainly act in locally enhancing heavy precipitation over the region, in addition to larger-scale favourable meteorological conditions aloft.

5. CONCLUSIONS

High-resolution simulations of three representative cases of HPEs over Southeastern France have helped to clearly highlight the mechanisms that lead to stationarity of precipitating systems. Several mechanisms contribute separately or in combination to continuously release the conditional instability of the low-level flow at the same location: **i)** the low-level convergence of the flows themselves due to contouring effects associated with the Alps and Pyrenees; **ii)** the typical orographic lifting due to the Massif Central relief; **iii)** a low-level cold pool generated by the mesoscale convective system itself which acts as a pseudo-orography to force the conditionally unstable and moist low-level jet to rise. A paper in two parts (Nuissier et al., 2007a and Ducrocq et al., 2007b) that fully describes these synoptic and mesoscale triggering factors have been submitted for publication to the Quarterly Journal of the Royal Meteorological Society. More details about the results of the presented study will be given in the 29^{th} International Conference on Alpine Meteorology

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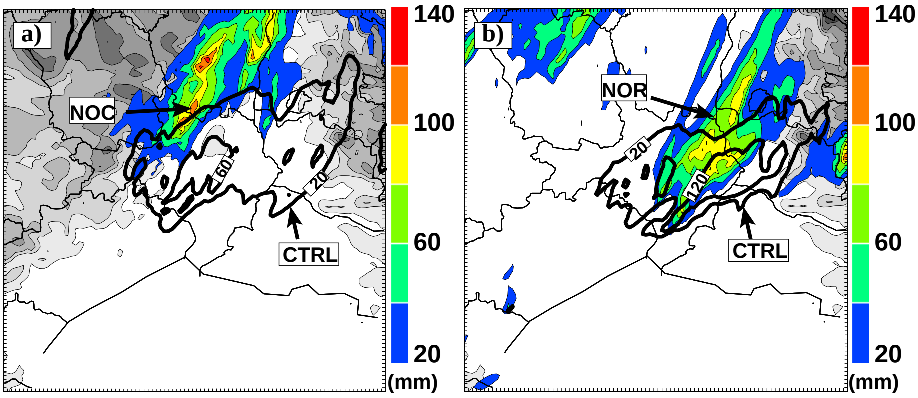

Figure 2: Simulated accumulated rainfall for Gard case : from **a)** the NOC experiment (coloured areas) from 18 till 22 UTC, 8 Sept. 2002; and from **b)** the NOR experiment (coloured areas) from 12 till 22 UTC, 8 Sept. 2002. **CTRL** simulations are shown in solid lines in both panels.

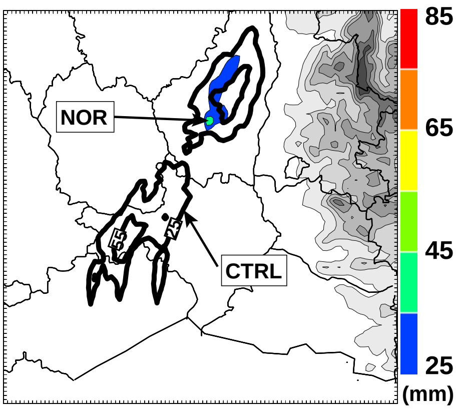

Figure 3: Same as Fig. 2, but except for Cévennes case and for **NOR** and **CTRL**. The considered period is from 00 till 06 UTC, 14 Oct. 1995.

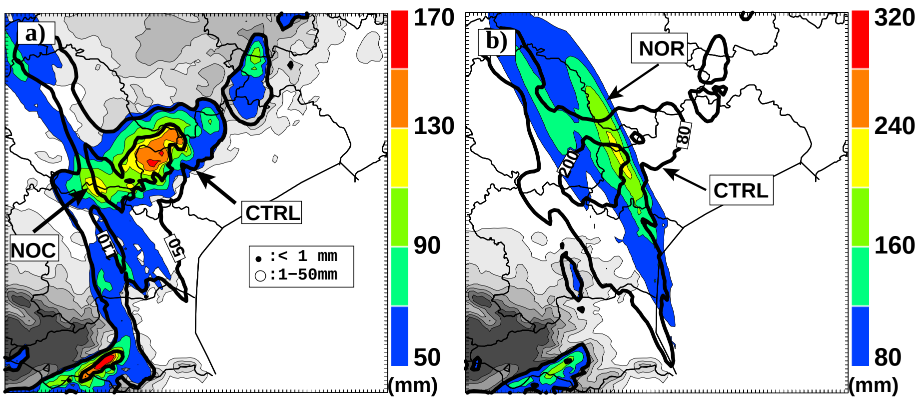

Figure 4: Same as Fig. 2, but except for Aude case. The considered period is from 12 till 00 UTC, 13 Nov. 1999 for panel **a)** and from 12 till 06 UTC, 13 Nov. 1999 for panel **b)** (from Ducrocq et al., 2007b).