PLUVIOMETRIC REGIME ASSOCIATED TO SHALLOW CONVECTION IN MOUNTAINOUS AREA

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Abstract: It is well known that relief plays a particular part in rain triggering and enhancement. Our study is focussed on the Cévennes-Vivarais area where the topography and the specific meteorological situation lead to an important hydrometeorological potential risk. From a climatologic point of view, we consider that these rains result in two kinds of convection: a deep convection governed by synoptic conditions in which relief has little impact and a shallow convection strongly controlled by the circulation of air within relief. This study aims at understanding and analysing the atmospheric parameters that control shallow convection in this region. The methodology is first based on the exploration of the meteorological and pluviometric data bases in order to identify the meteorological characteristics associated to shallow convection. Our results show that shallow convective events can be characterized by specific vertical profiles of the dynamics variables (wind velocity, shear), thermodynamics variables (wet bulb, potential temperature, stratification) and humidity. Then we propose a generic sounding that is used as input to the MesoNH meteorological model.

Keywords: *shallow convection, soundings, atmospheric processes*

1. INTRODUCTION

Rainfall in mountain regions generally result from two kinds of convection: the deep convection and the shallow convection. The deep convection is governed by synoptic conditions and relief has small impacts. The shallow convection is strongly controlled by the circulation of the flow in relief. By simplifying, relief acts in two ways. The first one is an orographic enhancement. When a perturbation arrives on relief, rainfall can be enhanced by seeder-feeder mechanism or small convective cell development for example. In that case, it is difficult to distinguish the part of rain due to perturbation or due to small convective cells. This enhancement explains difference between annual rain accumulation in relief and in valleys. The second one is an orographic triggering. In that case, rain only results from an upstream blocking, ascents along the slopes or leeward convergence. We will use the term "orographic rain" to refer to this stationary rainfall triggered by relief and associated with shallow convection.

In Mediterranean areas, the warmed sea is an important energetic reserve for fall convection. The Cevennes Vivarais area steadily undergoes deep and shallow convective events that can lead to catastrophic flash floods. In our case the orographic rainfall produces less intense rain intensities (typically less than 10 mm per hour) than deep convective event. Nevertheless, its hydrological impact is critical due to its strong spatial heterogeneity and the significant amounts of rain accumulated over time (Barros and Kuligowski, 1998). Many studies have already been done to bring to the fore spatial and temporal characteristics of orographic rain and to understand the influence of factors such as atmospheric conditions, ground state (Anquetin et al., 2006; Bowning et al., 1974; Wratt et al., 2000; Miniscloux et al., 2001, Cosma et al., 2002; Chiao and Lin, 2003; Kirshbaum and Durran, 2004; Kirshbaum and Durran, 2005 a-b). They have shown that orographic rain are located on relief, last a long time since they are associated with a stationary flow and their banded structure is parallel to the flow. Their intensity is low and their vertical extension does not exceed 6km. As far as meteorological factors are concerned, Lin et al. (2001) have shown that some main ingredients can produce orographic rain: a strong low-level wind, a high horizontal flow of humidity, a conditional instability. The relief geometry has also its influence to produce convergence. All these influences have been observed and simulated (Smolarkiewiczt et al., 1988; Cosma et al., 2002, Anquetin et al., 2003, Chiao and Lin, 2003; Kirshbaum and Durran, 2005a-b). Vetter (2004) has shown the potential of the meteorological MesoNH model to be used in climate driven mesoscale applied climatology in a simplest 2D configuration and Cosma et al. (2002) have brought to the fore that MesoNH is able to reproduce one specific orographic rainfall event.

This work aims at studying the climatology associated to shallow convection in the Cévennes-Vivarais region and investigating the use of MesoNH to capture the observed climatology. In order to extract orographic events from data bases, criteria are proposed. The statistical coherence of the corresponding events is then analysed and a generic sounding is proposed.

2. DATASET

The Cevennes region is situated southeast of the Massif Central. This relief is a southeasterly facing slope starting from the Mediterranean shore and the Rhône Valley. The altitude of the mountain range varies from sea level up to 1500m in roughly 30km. This hilly mass is dissected by deep (500m depth) and narrow (10 km wide) valleys oriented NW-SE. According to elevation contours, three sectors can be identified: 1) a terrace (below 200m) called "plain", 2) a hilly sector (between 200 and 500m) called "piedmont", and 3) a mountainous sector (above 500m) called "mountain".

The hourly pluviometric data are taken from a discontinued data set of three continuous periods: 1972-1980, 1986-1988, 2000-2005.

The meteorological data set comes from Meteo France and is based on 1) 29200 ground station records ($\Delta t = 3h$) at 2 stations (Nîmes and Mont Aigoual), 2) 21944 soundings at Nîmes.

3. CHARACTERIZATION OF OROGRAPHIC RAINS

3.1 Criteria for the selection

In order to extract shallow convective events from the pluviometric and the meteorological data sets, it is first necessary to characterize these events. The criteria for the extraction are then proposed based on a detailed comparison (not shown here) between a typical well known orographic event (i.e November 14th 1986; Miniscloux et al.,2001) and a well documented deep convection event (i.e September 8th 9th 2002 Delrieu et al., 2005). This analysis provides two types of criteria (Godart et al., 2007): A) pluviometric criteria : 1) the rain spatial distribution must present cumulated rainfall within mountainous area larger than in the plain region, 2) the intermittency must decrease with altitude ; and B) meteorological criteria : 1) a southerly wind at Nîmes, 2) a low vertical wind shear below 2000m, 3) the wind speed must exceed 7ms^{-1} at Nîmes. The orographic events are then selected using the following procedure : 1) use the meteorological criteria to extract the soundings from the meteorological data base, 2) apply the pluviometric criteria for the selected events in phase 1).Among the 21944 soundings, only 880 rely on the three meteorological criteria. We notice that the events with southerly wind are generally associated to low wind shear. Applying the pluviometric criteria, 79 soundings are finally extracted. These 79 soundings correspond to 36 shallow convective events. To analyse these soundings, we calculate the mean, the coefficient of variation and quartiles 10% and quartiles 90% of some atmospheric variables. The results are shown in the next section.

3.2 Results

The vertical profiles of relative humidity and wind velocity are given in Fig 1. We notice (Fig1.a) that the average relative humidity is high in the lowest layers and then decreases rapidly. Below 850 hPa, the quartile 10% is around 80% of humidity and then drops under 50% of humidity. During the deep convective event of 8 September 2002 (Fig 1a), the relative humidity remains high around 100% up to 700 hPa. Thus relative humidity profiles are different during shallow convective events and deep convective events. In Fig1b, the average wind velocities are higher in the whole analysed atmospheric depth during the shallow convective events than during the deep convective event. The velocity gradient is positive with altitude. On the contrary, the velocity gradient is negative from 850 hPa for the deep convective event. In that case, the two-dimensional wind shear can favour convection (Kirshbaum and Durran, 2005b). During the shallow convective events, the 2D wind shear is negligible, which leads to a less developed convective activity. The stability is studied with the Brünt Väisälä frequency. The instability is limited in the lowest layers, which are wetter. A stable layer is present at about 3250-3500m, which confirms that orographic rainfall are associated with shallow convection. The shallow convective events have a considerable potential of instability between the ground and 700 hPa (3500m) as noticed by Kirshbaum and Durran (2005 a).
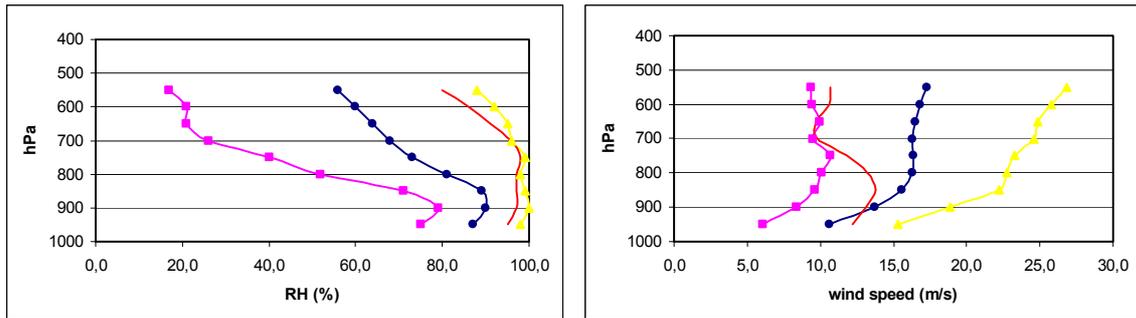
Figure 1 : Average profile of (a) RH and (b)wind speed for shallow convection events (circle), quartile 90% (triangle),quartile 10% (square). The plane line stands for the profile at 12 UTC 2002, September 8th

Although instability is a necessary condition for the formation of convective cells, other parameters can inhibit or modulate the convection, like the wind shear (Kirshbaum and Durran, 2005a-b). We call "rate of rotation" the sum of angles between wind-vectors along the whole sounding. It represents the three-dimensional wind shear. The average rate of rotation for the 79 soundings is 9°/km (during the 8-9 September 2002 event, it was 23°/km). The quadratic distance to the direction of reference (180°) is 19° (50° the 8-9 September 2002). Such results indicate southerly constant flow with low three dimensional wind shear during shallow convective events, which is not the case during the deep convective event. The two dimensional wind shear, calculated with the ratio of wind velocity in the highest layers (2500m-5000m) and lowest layers (500m-2500m), is about 1,3, which explains that the convection is more shallow since a two dimensional wind shear inhibits convection whereas a three dimensional wind shear favours it (Yates, 2006; Anquetin and al., 2006). The average wind velocity (between the ground and 2000m) is 14m/s and the wind velocity at 1500m (top of Mont Aigoual) is 16m/s. These values are larger than the velocities observed during the 8-9 September 2002 event (9m/s).

Thanks to this analysis, a generic sounding associated with shallow convective events is elaborated (Fig2).
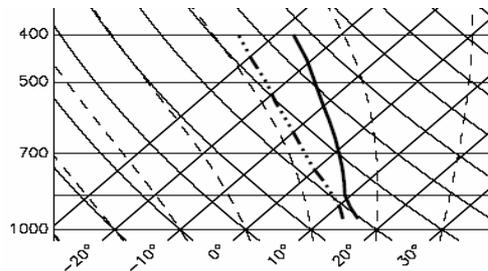

Figure 2 : Generic sounding associated with shallow convective events. The smooth curve is the temperature, the dashed line is the dew temperature

First and preliminary numerical simulation, carried out with the 3D non-hydrostatic model MesoNH (Lafore et al.1998), is performed using this sounding as input. The results show rainfall organized in bands (Fig 3) and a convection limited to the first 4km (Fig 4), which confirms our atmospheric characterization of orographic shallow convection.
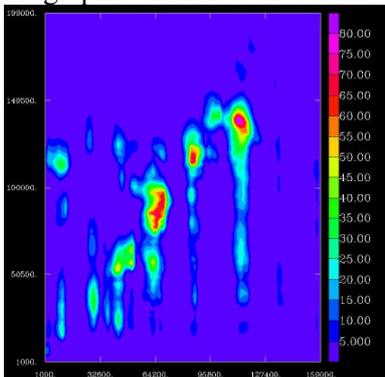
Figure 3: 18h accumulated simulated rain (mm)
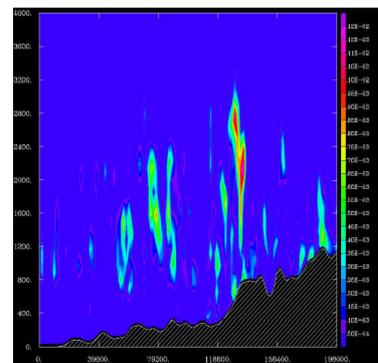
Figure 4: Vertical profile of the simulated cloudy water at t=18h

4. CONCLUDING REMARKS

Orographic rainbands have to be studied at least for two reasons: 1) they constitute a simple example of rain pattern related to the topography; their reproducibility and their sensitivity to the flux conditions can probably be tested further with radar datasets and numerical meteorological models; 2) their impact on the rain climate in mountainous areas is probably strong despite their low intensity; orographic rainbands are able to bring substantial accumulations of more than 100mm day^{-1} distributed in space in a variable manner (Miniscloux et al., 2001). Consequently, they can contribute to the genesis of flash floods. The aim of this work was to bring to the fore some atmospheric characteristics of shallow convective events. The analysis of the statistical characteristic of orographic rainfall has confirmed the stationary nature of these rainfall. Favourable atmospheric conditions for shallow convection are: 1) a southerly wind (between 0 and 2000m, the average angle to 180° is about 19°) with a low three-dimensional wind shear; 2) a high wind velocity (about 14m/s in low level layer), 3) a high low-level relative humidity which decreases rapidly above 1500m, 4) a temperature variation between the ground and 2000m more than 10°C, 5) a stable layer around 3500m. Thus, generic sounding has been proposed. First and preliminary simulations are done using the generic sounding. The results are encouraging and open sensibility studies.

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