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Spatial structure of intense Mediterranean precipitation

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1 Introduction

The French Mediterranean coast is prone to intense rainfall and subsequent catastrophic (flash-)floods (e.g., Delrieu et al., 2005). In order to further our understanding of the mechanisms generating such intense precipitation, with a particular focus at the meso-scale, the Cévennes-Vivarais Mediterranean Hydro-meteorological observatory (OHMCV) has been started in 2000. It covers an area of about 160×210 km^2 on the west of the Rhône river (see Figure 1). Among other sensors, this area is covered by 3 operational weather radars from the french operational network ARAMIS of Météo France, as well as by a network of about 500 daily and 200 hourly rain gauges.

Within this favorable framework, the objective of the present paper is to study the spatial structure of intense Mediterranean rainfall, and its variability from one event to the other. The quantification of the variability of intense rainfall is particularly relevant with respect to hydrological applications concerning flash-flood forecasting and mitigation.

The paper is organized as follows: the data set is briefly described in Section 2; Section 3 is devoted to the structural analysis; and finally Section 4 presents some conclusions.

2 Data

We focus in this paper on 4 intense rain events which occured during the Bollène-2002 experiment (see Boudevillain et al., ERAD2006-P-00221, these proceeedings), namely the 08-09 September, the 21 October, the 21 November and the 24 November 2002 events. These events are representative of the variety of Mediterranean rain systems and their main characteristics are summarized in Table1. The 08-09 September 2002 event is exceptional regarding the total rain amounts recorded in 28 hours: they were larger than 400 mm over an area of 1800 km^2 and the maximum total rain amount was about 700 mm. This event mainly results from a stationary V-shaped mesoscale convective system (MCS) over the Gard plains. The 21 October 2002 and 21 November 2002 events, with maximum rain amounts of about 60 and 100 mm respectively, correspond to cold fronts passing through the region within westerly meteorological regimes. The 24 November 2002 event, with a maximum rain amount of about 150 mm, occurred in a southerly meteorological regime, and is characterized by widespread and long lasting rainfall with embedded convection and complex dynamics.

Within the OHMCV region, we focus on a domain of 80×150 km^2 (see figure 1). The 2D rain-rate fields we use as starting point for our structural analysis are obtained by combining Bollène radar measurements with the rain gauge network measurements. Briefly, this method is based on the interpolation of the ratio between the total event rain amounts estimated by the radar and by the rain gauge. By this way, a ratio value is calculated at each gauge location, and these values are then interpolated, using a kriging method, in order to have a multiplicative factor for each radar pixel. These corrective factors are then applied to the hourly and 5-minute time resolution radar measurements.

3 Structural analysis

3.1 The variogram

In order to study the spatial structure of intense Mediterranean rainfall, we adopt a geostatistical approach based on the (semi-)variogram γ defined as

$$\gamma(d) = \frac{1}{2} E\left[(Z(x+d) - Z(x))^2 \right] \quad , \qquad (1)$$

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Table 1. Main characteristics of the selected rain events (in 2002) over the OHMCV region.

Date	Spatial extent	Maximum rain amount (mm)	Duration (h)	Meteorological features
08-09 Sep.	$>$ 200 mm: 5500 km^2 $>$ 400 mm: 1800 km^2	700	28	Southwestern-southern regime; stationary V-shaped MCS + cold front; flash-floods and catastrophic flooding in the Gard plains.
21 Oct.	$>$ 20 mm: 15000 km^2 $>$ 50 mm: 1500 km^2	60	10	Western regime; cold front with embedded convection.
21 Nov.	$>$ 30 mm: 10000 km^2 $>$ 50 mm: 2000 km^2	100	22	Western regime; active cold front with embedded convection.
24 Nov.	$>$ 50 mm: 12000 km^2 $>$ 100 mm: 2000 km^2	150	48	Southern-southeastern regime; widespread rainfall with occasional rainy bands with various orientations.

where d denotes a distance, E is the expectation operator, Z is a random function and x a position vector. In the following, we will assume that Z is a second-order stationary random function, which implies:

$$\gamma(d) = C(0) - C(d) \quad , \tag{2}$$

where C is the (auto-)covariance of Z. For such a stationary process, the semi-variogram reaches a sill (the variance of the field $C(0)$) at a given characteristic distance, namely the range, which corresponds to the decorrelation distance.

In the present work, we have a 2D rain-rate field every 5 minutes along the entire events. We assume that ll the individual fields have the same spatial structure during a given eventand just differ in their variances. Therefore, we adopt the climatological variogram approach (Bastin et al., 1984; Lebel et al., 1987): once the individual fields are normalized by their variances, it is possible to average their variograms without introducing a significant bias, and hence to obtain a more robust estimate of the spatial structure at the event time scale.

In the following, the studied 2D random field is the rain rate R over the sub-domain defined in Figure 1. We are interested in the spatial structure of significant rainfall, so only rain rates above 1 mm h^{-1} are taken into account. As the distribution of R values is significantly skewed and in order to limit the influence of the (few) large values, the calculations will be performed on the log-transform of R. Assuming R is lorgnormally distributed, the range remains unchanged for $R' = \ln R$ (e.g., Journel and Huijbregts, 1978). In this paper, our analysis will be focused on the anisotropy and on the evolution of the range from one event to the other.

3.2 Results

Because the 2D rainfall fields cover an area of 80×150 km^2 at a resolution of 1×1 km^2, it is possible to calculate the mean climatological variogram in two dimensions and therefore investigate its anisotropy. As an illustration, Figure 2 presents the mean 2D climatological variogram corresponding to the 08-09 September event. From this figure, the anisotropy of intense Mediterranean rainfall clearly appears, as indicated by the non-circular symmetry of the map.

The climatological variogram values are extracted in a given direction and the range can be estimated (by visual inspection of the 1D variogram). Following this procedure, the range values have been estimated every 15 degrees (0 being East). The resulting spatial structures for the 4 studied events are given in Figure 3. Although the structures displayed in Figure 3 do not correspond exactly to the sizes and shapes of the rain systems during these 4 events because the range is a decorrelation distance, they nevertheless provide fair indications on the main directions along which the rain systems are organized, as well as their spatial extents. Moreover, the derived structure corresponds to the mean structure over the entire event, and integrate possible variability during the event.

The structure of the 08-09 September 2002 event is characterized by long ranges in all directions, which reflects the intensity and large extent of this exceptional event. The structures of the 21 October and 21 November events present smaller spatial extents and are more elongated along the South-North direction, in agreement with the synoptic meteorological features (see Table 1), i.e., South-North oriented cold fronts crossing the area. The structure of the 24 November 2002 event does not exhibit a strong anisotropy, consistent with the widespread type of rainfall that occured (see Table 1).

4 Conclusions

In this paper, we present the structural analysis, based on the climatological variogram, of 4 intense Mediterranean rain events considered as representative of the Mediterranean climatology. We focus on the estimation of the range of the variogram for various directions in order to investigate the anisotropy of these rain events. The spatial structure varies

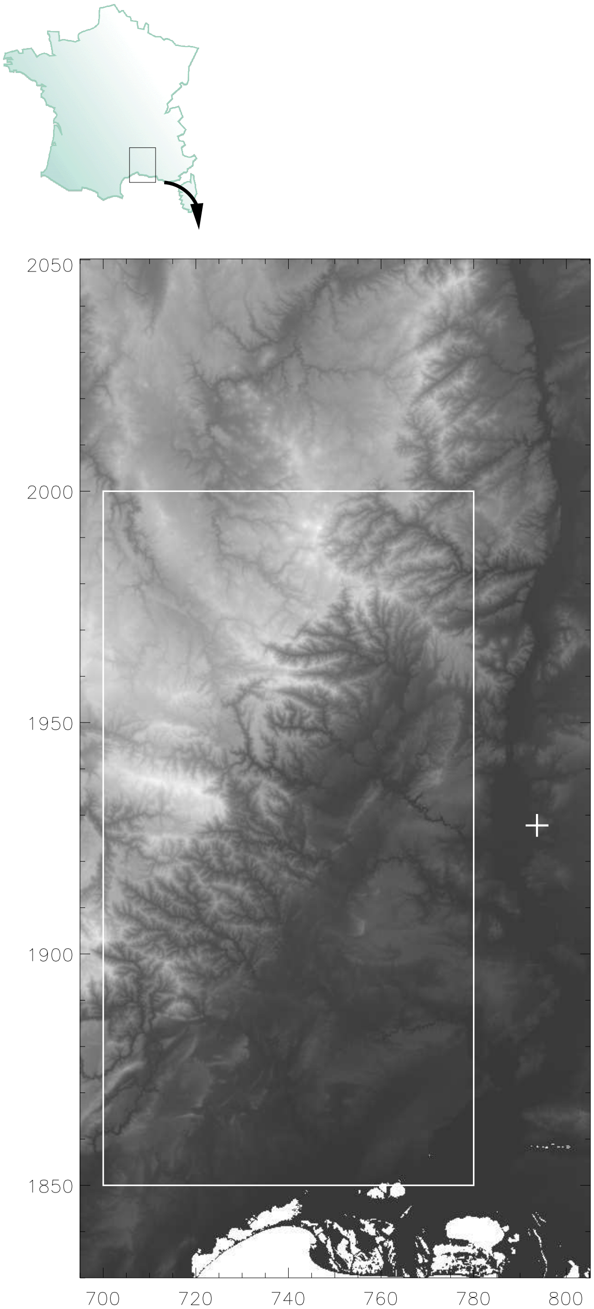

Fig. 1. OHMCV region and topography (altitude ranges from 0 to 1600 m). The x- and y-coordinates are expressed in extended Lambert II, in km. The white rectangle represents the area over which the structural analysis is performed. The white "+" sign marks the location of the radar site at Bollène.

significantly from one event to the other, with range values from 15 km up to about 60 km, and with shapes which are consistent with the synoptic meteorological features of each event.

These preliminary investigations will be extended in order to quantitatively characterize the intense rain cells embedded in these large systems, using the indicator approach with varying thresholds.

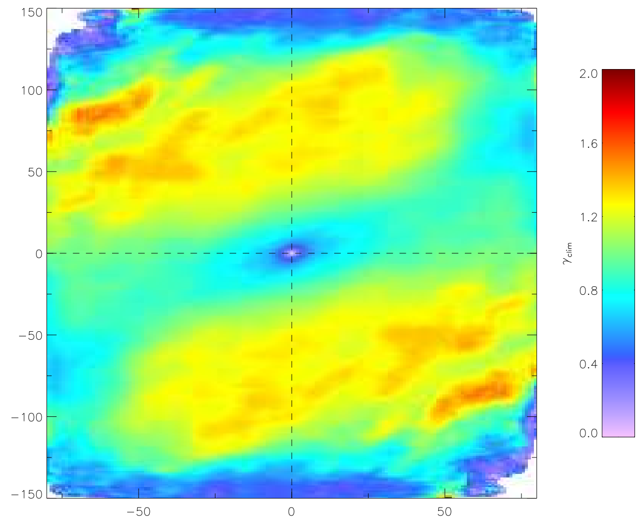

Fig. 2. 2D climatological variogram for the 08-09 September 2002 event. x- and y-coordinates correspond to a distance lag, expressed in km.

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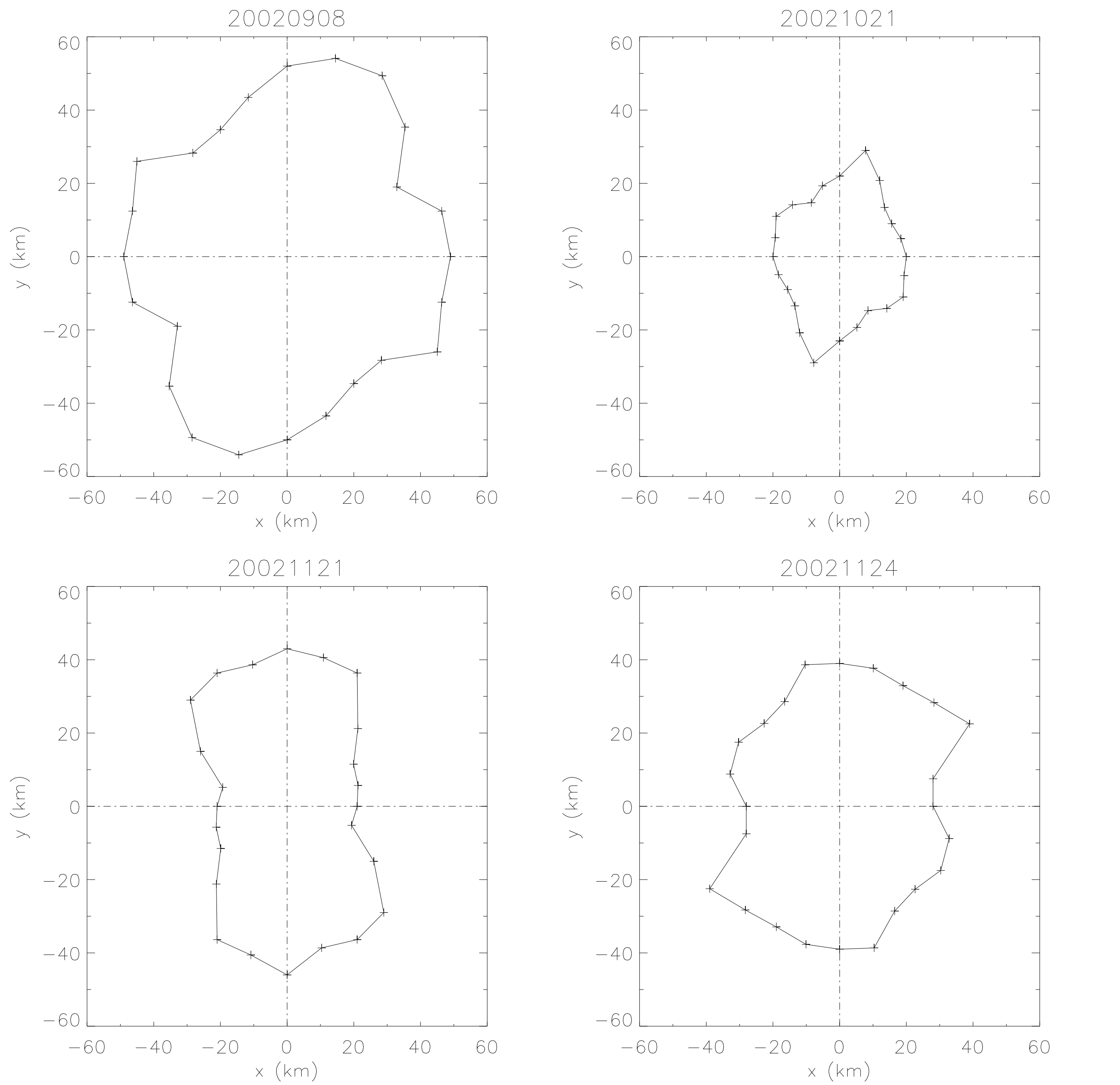

Fig. 3. Range of the climatological variogram as a function of the direction for the 4 studied events. East corresponds to $y = 0$ and North to $x = 0$.