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Flash floods and heavy rain events in Catalonia: analysis of the 1996–2000 period

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Abstract The Western Mediterranean area is commonly affected by heavy rainfall and floods, mainly in the autumn. In particular, during 1996–2000, an important number of catastrophic floods have affected Spain, Italy and France. In this paper, the meteorological situations of heavy rainfall events produced in the northeast of the Iberian Peninsula between 1996 and 2000 have been analysed. During this period, catastrophic (June 2000, October 2000, ...) and extraordinary floods (January 1996, August 1999, ...) occurred during different seasons of the year. First, the precipitation data obtained from an automatic network constituted by 126 raingauges have been analysed with the aim of classifying the events from a temporal and spatial point of view. Secondly, a meteorological study (thermodynamic, synoptic and mesoscale analysis) has been done for the most important events in order to identify the main factors responsible for the rainfall and the event evolution. Specific consideration of Mediterranean cyclogenesis has been made in relation to the MEDEX project (WMO). The analysis has been completed with the data from the meteorological radar of Barcelona. Although all this information will allow an improvement in the knowledge of these kind of events and their forecasting in the Mediterranean region, specific work has been done to improve the nowcasting of convective systems by using the radar information.

Key words Catalonia; cyclones; floods; meteorological radar

INTRODUCTION

The Mediterranean region presents very specific meteorological features. This fact, together with well-defined geographical characteristics (its location favours the influence of tropical and polar air masses; a warm sea; it is surrounded by an almost continuous barrier of mountains, with some altitudes exceeding 4000 m) means that we can speak of a Mediterranean Meteorology (Jansà, 1966, 1997; Llasat *et al.*, 2000). The most important features of this Meteorology are a high concentration of cyclogenesis, heavy rainfall events and very strong local winds. These characteristics are well observed in eastern Spain, and in particular in Catalonia (Martín, 1997; Ramis *et al.*, 1997).

Heavy rains in the northeast of the Iberian Peninsula caused at least 13 casualties between 1996 and 2000. In this paper, the main heavy rainfall events that occurred during this period are analysed. First of all, a selection criterion based on the pluviometric features of each event has been introduced. Secondly, those cases that verified the criteria have been selected. The meteorological characteristics for the main events were then analysed, with the goal of obtaining an event classification. Finally,

the analysis of convective structures has been done using meteorological radar in order to improve the knowledge of the factors of the convective systems that usually affect the northwest of the Mediterranean Region.

CASE SELECTION AND PLUVIOMETRIC ANALYSIS

The pluviometric data were obtained from the Automatic System of Hydrologic Information (SAIH) of the Agencia Catalana del Aigua (Generalitat de Catalunya). Beside other sensors, this network comprises 126 tipping-bucket automatic raingauges with a rainfall overturning of 0.1 mm. The precipitation is cumulated and registered every 5 minutes. The region (Fig. 1) analysed is well described in many other papers (e.g. Llasat, 2001).

The selection criteria used for considering a heavy rain event was: $P > 100$ mm/24 h in one or more raingauges; $P > 60$ mm/24 h in at least five raingauges; $P > 35$ mm/1 h in one or more raingauges; $P > 200$ mm for all the events in at least one raingauge, where P is the cumulated precipitation.

Once all the 5-minute rainfall series were analysed for the period 1996–2000, 43 heavy rainfall events were found. Most of them were produced in summer and autumn

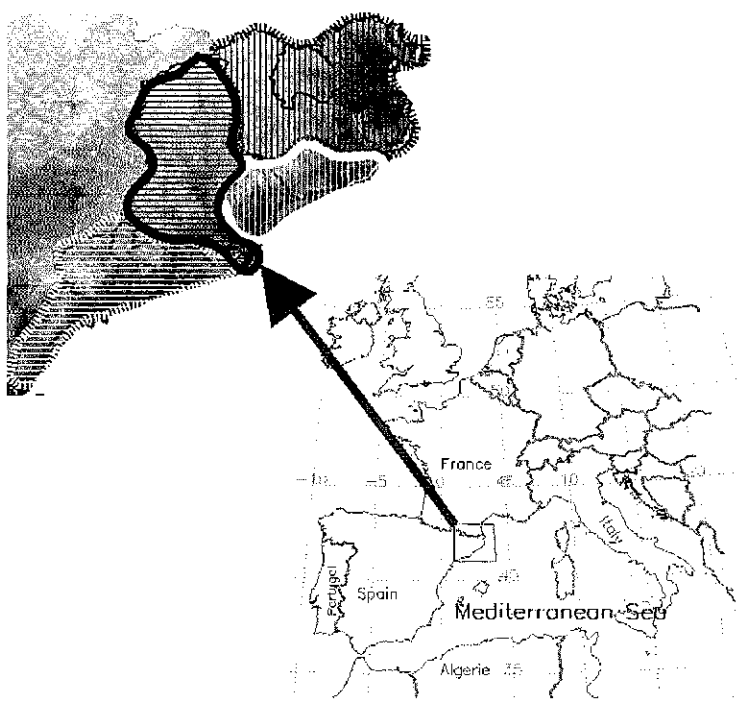

Fig. 1 Map showing the location of the internal basins of Catalonia and their distribution in four areas: Northern basins (black vertical lines); Llobregat basin (black horizontal lines); Central Coast basins (white vertical lines); and Southern basins (white horizontal lines). Orography of the region is shown (shaded contours). Light areas show higher altitudes.

(more or less 70% of the total), but it is important to bear in mind that a significant number of cases were observed along all the seasons (e.g. five events in winter, the season with the least number of cases).

The pluviometric analysis of the events showed that most of them affected a wide area. In fact, about 50% of the cases produced accumulated rainfall values that exceeded the 60-mm/24 h threshold in more than five raingauges placed in different basins. On the other hand, maximum values were also studied. A figure of 34 episodes (79%) have overcome the 5-minute intensity threshold of 100 mm h^{-1}, meanwhile the daily-cumulated rainfall was over 80 mm in 25 cases (58%).

Finally, the area most affected by the heavy rains was the Northern Area (Fig. 1), where nearly 50% of the events produced the maximum rainfall values. However, all the areas were seriously affected (maximum values exceeding the 60-mm/24 h threshold) by more than five events during the study period. It is important to remark that all areas of the region have a risk of being a flood prone area.

MESOSCALE STUDY: INFLUENCE OF MEDIUM-SCALE LOWS

Convective instability and a feeding flow of warm and wet air at low levels are both important keys in the heavy rain events produced in this region (Llasat & Puigcerver, 1997). The other necessary ingredient is a mechanism that triggers the instability process (Doswell, 1982). These conditions are usually produced in Catalonia by two kinds of meteorological scenario. In the first one, which is the most common (88% of cases), a large-scale disturbance (a deep low, or trough, placed generally over the Atlantic, close to the northwest Spanish coast) produces an east or southeast flow of Mediterranean (Fig. 2(a)), warm and moist, air over the region. That disturbance is generally placed near the British Isles or to the west of the Iberian Peninsula. Also, the presence of a front crossing the Iberian Peninsula, is usual (52%) helping to increase the instability in Catalonia. However, the passage of the front over the region tends to inhibit the convection and, then, to finish the event. In general, those events affect a widespread area and produce elevated cumulated rainfall values. On the other hand, a less common type of episode (12%) is produced into a general north flow. The orographic effect of the Pyrenees (Fig. 2(b)) helps to change the low-level flow, and the result is the existence of isolated storms, especially near the coast (the most analysed cases are those that affected the Central Coast; Pascual, 2002). This kind of event affects small areas; the cumulated rainfall is not really elevated, but strong rainfall intensities are recorded. The seasonal distribution of the last type has a clear maximum in summer, whilst the other kinds of events can be produced throughout the year, although the maximum frequency occurs during late summer and autumn.

In spite of the obvious differences between the two cited types of heavy rain events, in general a common factor exists for both: the presence of a mesoscale surface cyclone or a secondary trough (77%) placed near the region. The main role of those phenomena is the re-distribution of the low-level flow and the production of low-level convergence. The characteristics of the low-level flow will be very different, depending on the type of event. The lows linked to the first type of event have, in general, greater dimensions than "summer and local" ones. These last cases are formed

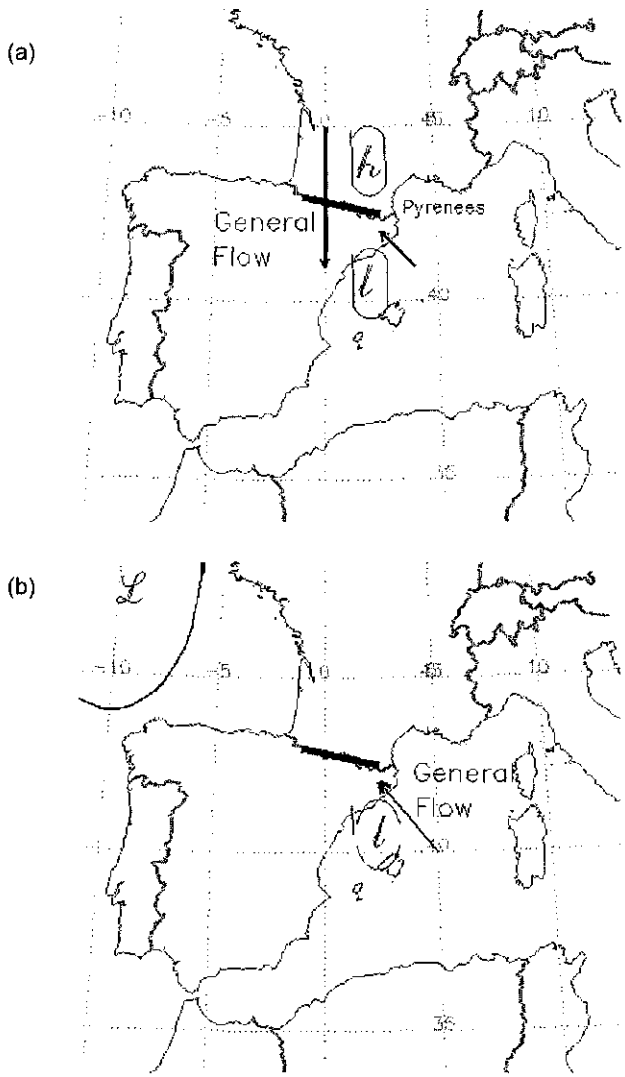

Fig. 2 Typical meteorological situations associated with heavy rains in Catalonia. (a) presence of large-scale low in the Atlantic, together with a mesoscale cyclone in the Western Mediterranean, (b) orographic dipole associated with Northern flow.

by orographic conditions (Pyrenaic orographic dipole); meanwhile cyclogenesis is the most usual case for general events. This last feature has a direct consequence: the distance of the smaller lows to Catalonia is shorter than for the bigger ones.

USE OF METEOROLOGICAL RADAR FOR IDENTIFYING CONVECTION

The meteorological (S-Band) radar of Barcelona of the Spanish Meteorological Office has been used to study the 43 heavy rainfall events with more accurate precision. In

fact, the radar has been used for analysing the convective structures related to those events, from both meteorological and pluviometric points of view. Two different algorithms have been applied in order to identify convective structures. First of all, a two-dimensional method (Steiner *et al.*, 1995) has been applied for obtaining greater structures, which are composed by convective cells (identified with a three-dimensional algorithm; Johnson *et al.*, 1998).

A preliminary study shows that it is possible to establish a certain relationship between each type of weather and the convective organization. Then, it is common that in summer events with Northern flux, convection appears in the form of isolated cells (Fig. 3(a)), which produce high rain rates during brief periods of time (much less than an hour) and affect very small areas. In these cases effective convection is most usual, and strong vertical developments are not common.

On the other hand, for events with large-scale perturbations, two kinds of cases exist, from the point of view of the organization of convection. First of all, the cases with convection embedded into stratiform structures present rainfall patterns with a wide affected area, but with very uniform cumulated rainfall charts, except some peaks (Fig. 3(b)). Finally, probably the most important cases are those with very organized convection (most cases in the form of squall lines, but Mesoscale Convective Systems are also very common), which produce rainfall charts with non-uniform values, but with high cumulated rainfall values in many places (Fig. 3(c)). Meanwhile for the first type of case the efficient convection is more common, for the second type very deep

(a)

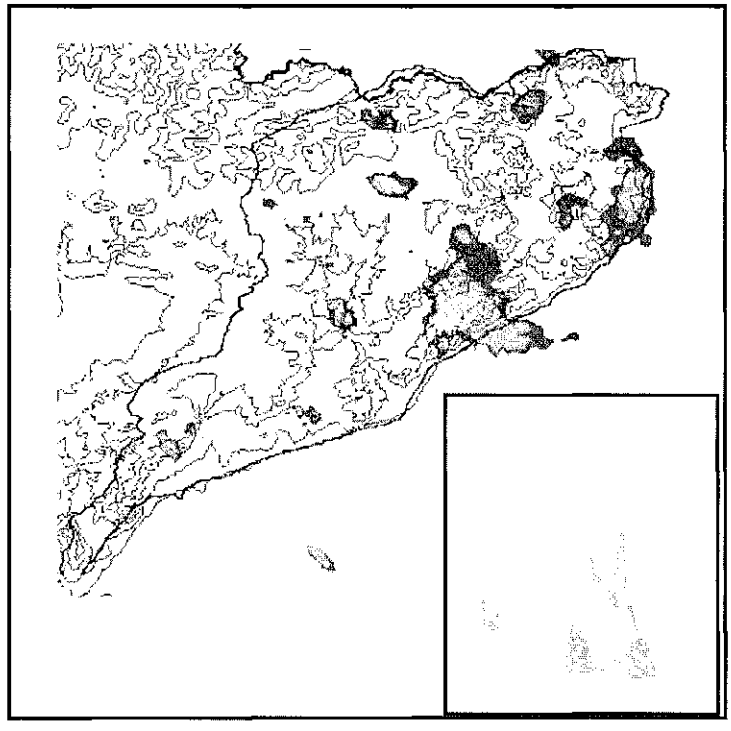

Fig. 3 Radar images for different types of events: (a) isolated cells; continued overleaf.

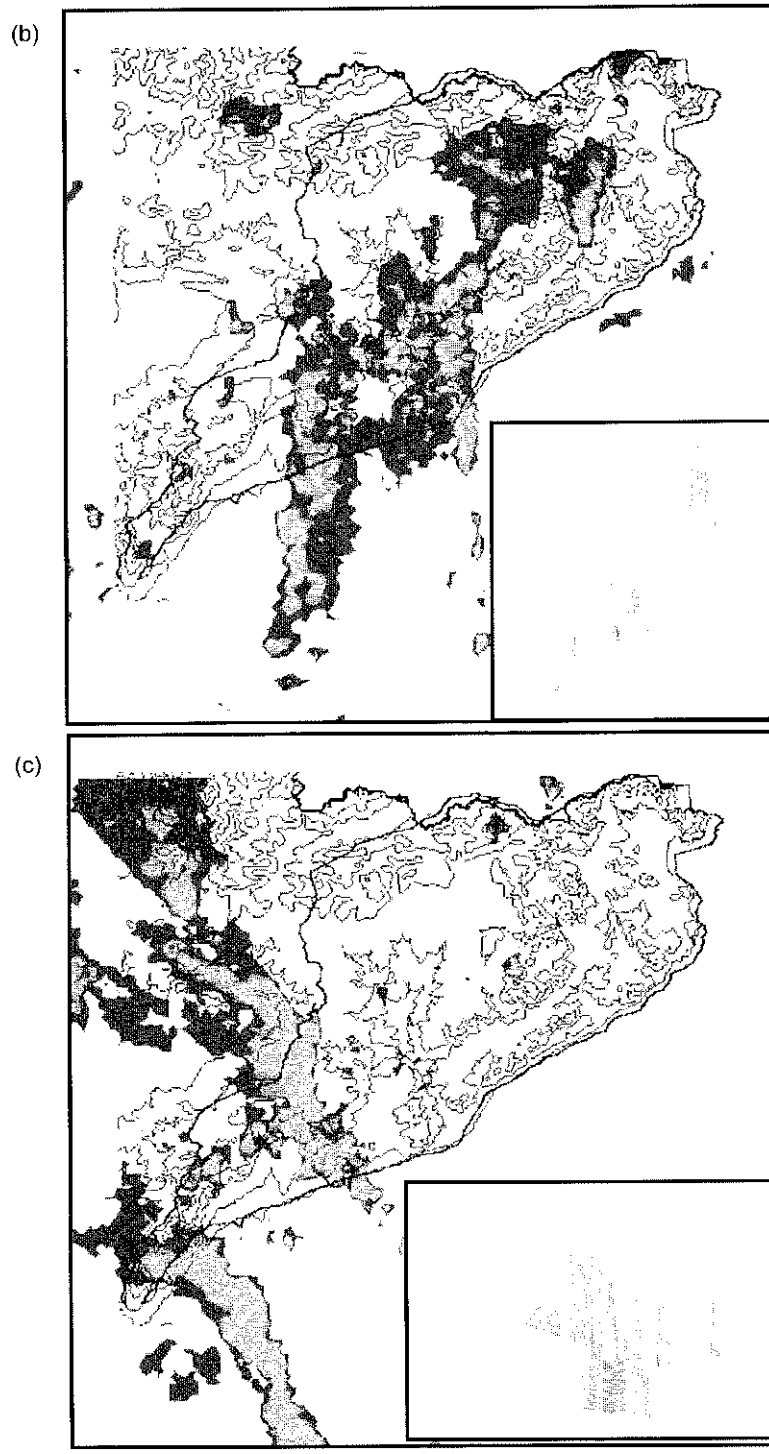

Fig. 3 continued. Radar images for different types of events: (b) convection embedded in stratiform precipitation; (c) well organized convection.

convection is usually observed. These last cases are usually related to severe weather (strong winds, hail, tornadoes, ...).

CONCLUSIONS

A preliminary analysis of the main heavy rain events that affected the northeast of the Iberian Peninsula has been done for the period 1996–2000. Those cases have been selected using a precipitation criteria. Late summer and autumn were the seasons when the greatest number of cases were produced.

The meteorological background with a depression close to the Iberian Peninsula was more usual than with Northern flow in heavy rain events. In most cases a mesoscale cyclone was also detected near the region. The radar analysis allows the classification of three types of cases: isolated cells, convection embedded in stratiform precipitation, and well organized convection.

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