44. FLOOD EVENTS IN THE LLOBREGAT BASIN: A COMPARISON BETWEEN THE FLASH FLOOD OF JUNE 2000 AND EVENTS THAT HAVE OCCURRED SINCE THE 14TH CENTURY

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ABSTRACT

This paper presents an analysis of the flash floods that occurred in the Llobregat basin (Catalonia, NE Iberian Peninsula) on 10 June 2000 in the context of the historical floods recorded since the 14th century and the climatic framework. To this end, the study shows the rainfall and meteorological analysis of the episode from a dual objective: to understand the main factors which gave rise to rainfall exceeding 150 mm in three hours, and to be able to compare it with previous situations. Such situations have been classified, in the light of the information available.

Although no catastrophic episode occurred in spring during the period 1950-1999, the most similar one from a meteorological point of view and in terms of the area affected was the one recorded in September 1962. Between 1780 and 1950 there are records of 44 flood episodes at the mouth of the River Llobregat, of which 6 were catastrophic, and 38 extraordinary. From all of them, 8 events were recorded in spring: one catastrophic, on 26 May 1853, and the other seven were extraordinary. The 1794 episode shows certain similarities to the 2000 episode.

The analysis of the total series reaches the conclusion that of the 171 flood events that have been recorded between the years 1300 and 2000 at the mouth of the Llobregat river, 69 of them were ordinary, 81 were extraordinary and 21 were catastrophic.

1 INTRODUCTION

During the early morning of 10 June 2000 a downpour occurred over Catalonia (NE Spain) that caused serious damage in the Llobregat, Besós, Francolí and Riera de la Bisbal river basins (Figure 1), due to both the rainfall and flooding and associated landslides and debris flows. The most notable damage consisted of partial destruction to infrastructure at Montserrat Monastery (720 m a.s.l, Figure 1), where some 500 people had to be evacuated, and some of the roads leading up the mountain were destroyed. Besides this, the total destruction of many bridges and sections of roadways was produced, and the flooding of built-up areas and residential zones with the attendant destruction of some dwellings, especially in the tourist municipality of El Vendrell (Figure 1). The episode caused material damage estimated at over 65,000,000 euros and five fatalities.

The episode was spectacular indeed and can be classified as a catastrophic flood episode (*Llasat & Puigcerver*, 1994). But that was not the first such case recorded this century, neither in terms of rainfall intensity or flows nor in terms of the counties affected. We need

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only think back to 25 September 1962, 20-23 September 1971, 6-8 November 1982 and 2-5 October 1987 (*Llasat*, 1987, 1990, 1991; *Ramis et al*., 1994). The most unusual feature of this episode, however, lay in the season of the year at which it occurred. In Catalonia, high-intensity (highly convective) episodes usually occur in summer and at the beginning of the autumn (*Llasat* & *Puigcerver*, 1997; *Llasat*, 2001), and are characterised by their brevity and the fact that they give rise to sudden swelling of Pyrenean watercourses and coastal stream beds. Catastrophic floods, with over 200 mm of precipitation in 24 hours, usually occur in autumn.

This study analyses the flooding episode of 10 June 2000 within the context of historical floods and the climatic framework. To this end, the study starts with rainfall and meteorological analysis (essentially synoptic and thermodynamic) of the episode from a dual objective: to understand the main factors which gave rise to rainfall exceeding 150 mm in three hours, and to be able to compare it with previous situations. Such situations have been classified, in the light of the information available, in: a) historical floods for which no instrumental information is available (from the 14th century); b) historical floods for which instrumental information is available in relation to surface data (1780-1950); c) episodes after 1950, for which synoptic and thermodynamic information is available; d) episodes after 1996, for which numerical models, automatic rain gauge data and meteorological radar imagery are available. In cases a) and b) a meteorological comparison of episodes similar to that of June 2000 has been made. Those classified under a) were used to carry out a frequency analysis of the floods.

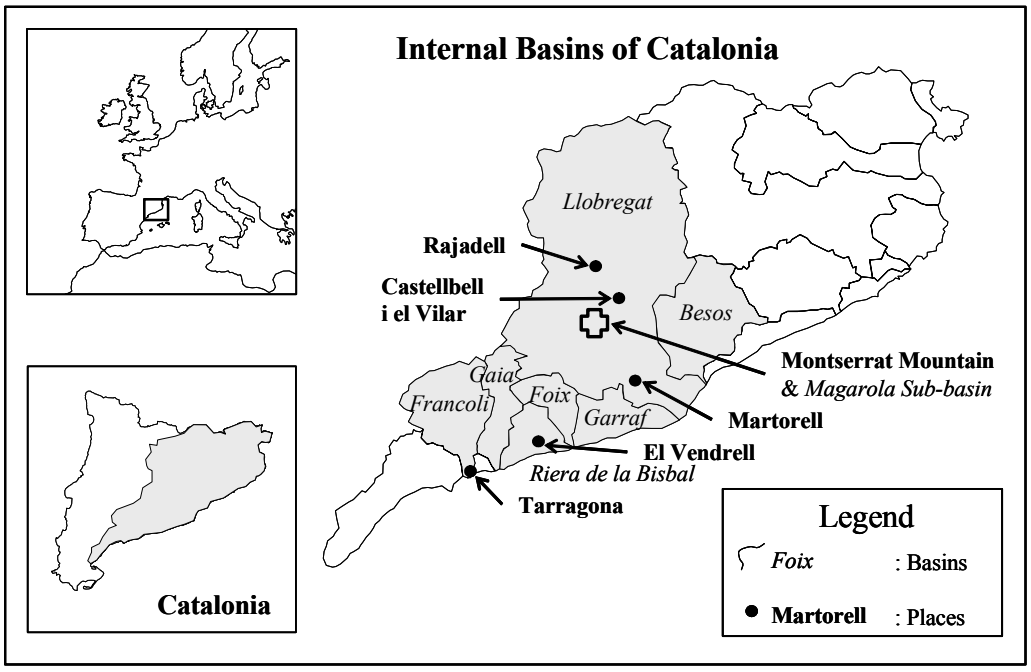

Figure 1. Map showing the location of the Internal Basins of Catalonia and the basins and places most affected by the high rainfalls.

2 RAINFALL AND HYDROLOGICAL EVOLUTION

Figure 2 shows the accumulated rainfall distribution in the Internal Basins of Catalonia (I.B.C.) from 2100 UTC on 9th June to 2100 on 10th June. It can be observed that the maximum quantities were recorded in the basin of the River Llobregat, with 224 mm at

Rajadell, and in the basin of the Riera de la Bisbal, with 134 mm at Bisbal del Penedés, over 100 mm of which was recorded in less than 2 hours. A value of over 100 mm was also recorded in the basins of the Francolí, Gaià and Foix. All the sub-basins of the I.B.C. recorded accumulated rainfall above 50 mm.

The rainfall over the basin of the Francolí between 2130 UTC on 9th June and 0300 on the 10th led to an increase of over 2 m in its level as it passed through the city of Tarragona. In the case of the River Llobregat the highest increase was recorded at Castellbell i el Vilar around 0009 UTC, with over 4.5 m and a peak flow of some 1100 m^3/s. It might be noted that the rises in the levels of the affected rivers were very sudden, with a response in some places that took place in less than 1 hour.

3 ANALYSIS OF THE MONTSERRAT EVENT

Given that the purpose of this study is to analyse the floods of 10th June 2000 within the historical-climatic context of the last 500 years, this meteorological analysis will only focus on the main synoptic and hydrologic aspects of the event.

The synoptic situation on 9th June shows the entry from the western part of the Iberian Peninsula of a cold front associated with a low situated to the north of the British Isles, while Catalonia itself was under the influence of an anticyclone that affected Central and Eastern Europe and much of the Mediterranean (Figure 3a). At high altitude a cold trough could be detected (Figure 3a), the axis of which was situated over Portugal at 0000 UTC and gave rise at 850 hPa (Figure 3b) to cold westerly winds over the western sector of the Iberian Peninsula, and warm southerly winds over the eastern sector. Notable at 850 hPa (Figure 3b) was a strong confluence of SE and SW winds over Catalonia. Thus the region had the basic factors that precede heavy rainfall situations in the East of the Iberian Peninsula (*Llasat & Puigcerver*, 1994): an anticyclonic situation over Catalonia and the Mediterranean sea, with an influx of very warm and moist air, which permits the generation of considerable instability that remains latent until some factor, whether orographical or dynamic, triggers the convection.

The dominant synoptic situation in this region between 0000 UTC and 1200 UTC of the 10th June 2000, the interval over which practically all the rain fell, showed a conjunction of the following factors:

- Mesoscalar depression (meso-α) at the surface which extended from the Balearic Islands to the I.B.C and led to the convergence of water vapour at low levels, while playing a direct part in triggering the potential instability accumulated previously (the location of the convective system on the radar imagery pointed to the existence of a line of convergence that was advancing over Catalonia along a SW-NE axis), as will emerge from the thermodynamic analysis.
- Conjunction of the cold depression in the upper atmosphere and the surface depression, thus deepening the depression.
- Strong wind from the E-SE at low levels (more than 30 kt at 950 hPa) and from the SSW at high levels, over the affected area, that produced a marked shearing, a phenomenon which favours the production of multicellular storms. This wet flow from the Mediterranean impinged perpendicularly to the mountain ranges.
- Strong orographical component in focusing and sustaining the convection, which combined with the advance of the depression at low levels, was to cause emergence of the spatial evolution features of the heaviest rainfalls.

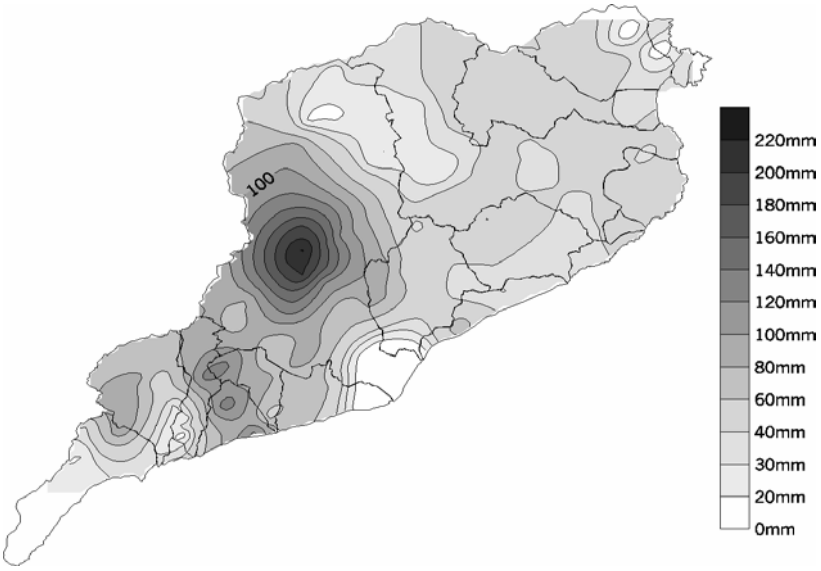

Figure 2. Distribution of accumulated rainfall between 21:00 UTC of 9th June 2000 and 21:00 UTC of 10th June 2000.

4 THE 10TH JUNE 2000 FLOOD EPISODE FROM THE PERSPECTIVE OF PREVIOUS HISTORICAL FLOODS

As noted in the previous section, the studies undertaken in order to estimate the flow recorded in the most severely affected basins, together with their return period, have revealed given values ranging between 200 and 500 years. Good climatic referencing of the "Montserrat" event would require availability of historical information for a sufficiently long period of time for it to be representative. That is why this paper has had recourse to gathering of information both on the historical floods recorded in the Llobregat basin and the longer series of instrumental data.

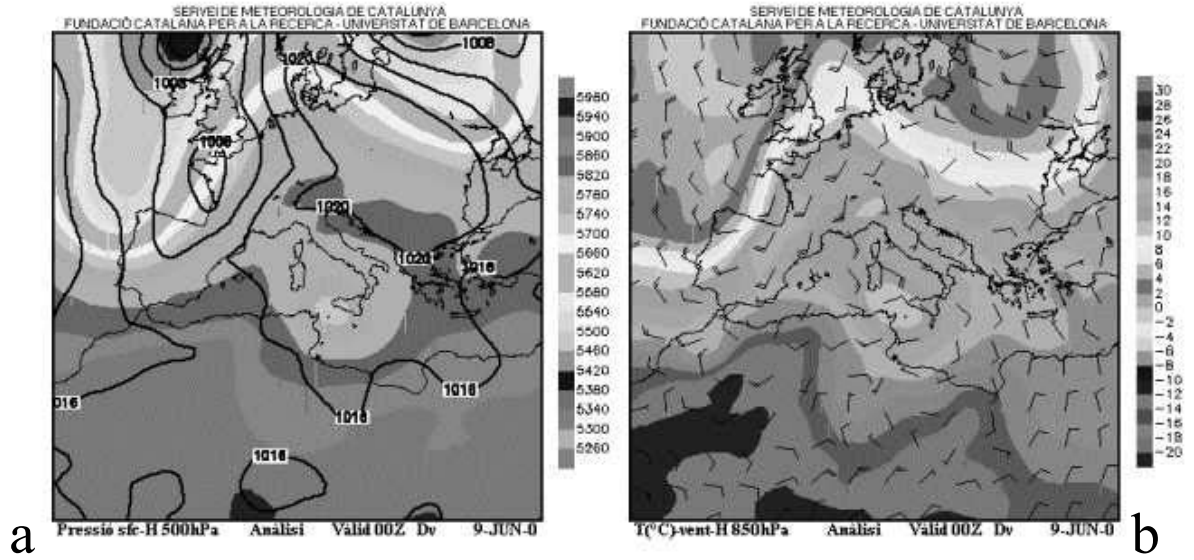

Figure 3. Synoptic situation at 00:00 UTC 9th June 2000: a) Sea level pressure (solid lines, hPa) and geopotential at 500 hPa (shading areas); b) temperature (ºC) and wind (kt) at 850 hPa. Courtesy of the Servei de Meteorologia de Catalunya.

The work with proxy data has been done by collecting the continuous records of floods in municipal and private documentary sources, from various places in Catalonia. The information relates to the damage and destruction caused to infrastructure and crops by water courses bursting their banks. This information occasionally contains references to the meteorological episode itself, and even to hydrological aspects. This documentary information permits reconstruction of the flood series for the last 500 years at various localities in Catalonia. The information gathered is of considerable reliability due to its being contained mostly in official documents, and its dating and verification poses no problem since the information is organised at daily resolution.

In order to have a minimum homogeneity in all the flood series, three types of high water situations have been differentiated according to their impact (*Barriendos & Pomés*, 1993; *Llasat et al*., 1999). Along general lines, they are: 1) simple rises or ordinary floods, 2) extraordinary floods, and 3) catastrophic floods.

In the light of this classification, the episode of 10 June 2000 would clearly lie within the type termed catastrophic floods.

The complete series of catastrophic floods recorded in the lower part of the Llobregat River (El Prat de Llobregat) has been reconstructed from 1315 to 1971 (*Codina*, 1994). The analysis of proxy-data (*Codina*, 1994) and instrumental data reaches the conclusion that of the 171 flood events that have been recorded between the years 1300 and 2000 at the mouth of the Llobregat river, 69 of them were ordinary, 81 were extraordinary and 21 were catastrophic. Although most of them were recorded during the autumn, it is possible to find some cases that occurred in the spring, such as the floods of 2nd May 1603, 9th June 1794 and between the 24th and 26th of May 1853.

The climatic evolution of the standardised values of frequencies of such floods shows a marked oscillation occurred in the last decades of the 16th century and first two decades of the 17th century. The second half of the 18th century showed another moderate increase and, finally, there was a second lengthy and intense oscillation in the middle of the 19th century. These last three oscillations lie within the period of the climatic episode known as the Little Ice Age.

5 CONCLUSION

During the early hours of 10th June 2000 heavy rainfalls and flash floods were recorded in Catalonia that caused damage calculated at over 66 million euros and caused five fatalities. The rain was characterised by its high intensity with a maximum accumulated amount of 224 mm in less than 24 hours. The fact that the episode occurred in the spring makes it rarer, as this kind of episode normally occurs in Catalonia at the end of the summer and particularly in the autumn. Historical data show that in the 17th, 18th and 19th centuries, too, at least one catastrophic flood episode was recorded in the spring season.

Among the meteorological aspects, we might note the stationary nature of the convective system that led to the accumulation of a large amount of precipitation in a short time. That system presented an essentially linear structure (squall line) with the formation of various convective cells within it. In addition to the orography itself, factors that favoured its development were the advection of very warm and moist air at low levels, with the presence of a surface low off the Catalan coast, which induced a flow from the SE and convergence, while a cold air pool was detected in the upper atmosphere (a factor not always recorded in flood episodes in Catalonia).

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