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Trends in flash flood events versus convective precipitation in the Mediterranean region: The case of Catalonia

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SUMMARY

The aim of this paper is to analyse the potential relationship between flash flood events and convective precipitation in Catalonia, as well as any related trends. The paper starts with an overview of flash floods and their trends in the Mediterranean region, along with their associated factors, followed by the definition of, identification of, and trends in convective precipitation. After this introduction the paper focuses on the north-eastern Iberian Peninsula, for which there is a long-term precipitation series (since 1928) of 1-min precipitation from the Fabra Observatory, as well as a shorter (1996–2011) but more extensive precipitation series (43 rain gauges) of 5-min precipitation. Both series have been used to characterise the degree of convective contribution to rainfall, introducing the β parameter as the ratio between convective precipitation versus total precipitation in any period. Information about flood events was obtained from the INUNGAMA database (a flood database created by the GAMA team), with the aim of finding any potential links to convective precipitation. These flood data were gathered using information on damage where flood is treated as a multifactorial risk, and where any trend or anomaly might have been caused by one or more factors affecting hazard, vulnerability or exposure. Trend analysis has shown an increase in flash flood events. The fact that no trends were detected in terms of extreme values of precipitation on a daily scale, nor on the associated ETCCDI (Expert Team on Climate Change Detection and Indices) extreme index, could point to an increase in vulnerability, an increase in exposure, or changes in land use. However, the summer increase in convective precipitation was concentrated in less torrential events, which could partially explain this positive trend in flash flood events. The β parameter has been also used to characterise the type of flood event according to the features of the precipitation. The highest values correspond to short and local events, usually with daily β values above 0.5, while the minimum threshold of daily β for catastrophic flash floods is 0.31.

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1. Introduction

Although there is no single definition, a flash flood is usually defined as a sudden flood in a small catchment area (usually less than 1000 km^2), occurring within 6 h or less of the causative event (heavy rain, dam break, levee failure, rapid snowmelt or glacier-outburst flood) and often within 2 h of the start of high intensity rainfall (see www.nws.noaa.gov; for an in-depth analysis of the term ‘‘flash floods” see Gaume and Borga, 2008; Borga et al., 2008; Braud et al., 2014). Flash floods are usually caused by heavy rainfall that can either be local, affecting only one or two catchments, or more extended, producing flash floods as part of the framework of a major flood event.

The Mediterranean region is prone to flash floods, especially in the north-west (Jansà et al., 2014), where littoral and pre-littoral mountain chains favour not only torrential rain concentrated in small catchments, but also heavy rainfall. The short concentration times and the extraordinary runoffs that develop can turn into catastrophic flash floods like those that occurred on 25 September 1962 in northeastern Spain, when 815 people died in less than 5 h (Aulet et al., 2012; Gaume et al., 2009). There are several studies in the literature showing a deeper analysis of specific flash floods in this region, such as the November 2011 case in Genoa, Italy (Fiori et al., 2014); the September 2002 event in the Gard Region, France (Delrieu et al. 2005; Braud et al., 2010; Milelli et al., 2006); and the June 2000 event in Montserrat, Spain (Martín et al., 2007; Milelli et al., 2006). Other works cover flash flood inventories in Europe, such as the article by Gaume et al. (2009) that analyses peak flash flood distributions for seven European regions; the study on flood response time for 25 extreme flash

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floods by Marchi et al. (2010); and the article by Garambois et al. (2014) on the study of flash flood-triggering storms and the resulting hydrological responses for catchments in the Aude region, France.

Most of these studies are focused on hydrological and hydrometeorological modelling, applying the most suitable distributed hydrological models for this kind of event, such as the RIBS (Real Interactive Basin Simulator, Garrote and Bras, 1995a, 1995b), DRiFt (Discharge River Forecast, Giannoni et al., 2000) and HVB (Hydrologiska Byråns Vattenbalansavdelning model, Lindstrom et al., 1997). In these cases the input was provided using sophisticated mesoscale meteorological models such as AROME (Applications of Research to Operations at Mesoscale model, Seity et al., 2011), WRF (Weather Research and Forecasting model, Skamarock et al., 2005) and MESO-NH (Non-Hydrostatic Mesoscale atmospheric model, Lafore et al., 1998), or using a combination of rain gauges and meteorological radar data (Atencia et al., 2011). The recently finished EU funded project DRIHM (Distributed Research Infrastructure for Hydro-Meteorology), was specifically focused on using grid computer facilities to create a Meteorological Model Bridge (MMB) to develop the interoperability of these meteorological and hydrological models, and it was applied to the recent flash floods recorded in Genoa in 2011 and 2014 (Fiori et al., 2014; Hally et al., 2015) and in Catalonia in 2011 (Llasat et al., 2015). However, in spite of the notable improvements achieved over the last few years, modelling high-intensity rainfall associated with convective precipitation is still a major challenge.

Convective precipitation (strictly precipitation associated with convective clouds), can be identified from weather radar imagery (e.g. Rigo and Llasat, 2004), or from new satellite products such as those developed by the Eumetsat Network for Satellite Applications and Facilities (SAF) (http://hsaf.meteoam.it/). However, it is not usually recorded as such and is therefore not identified on climatological records. Only when long term series of rainfall hydrographs are available is it possible to identify convective precipitation through visual inspection and digitisation (Puigcerver et al., 1986). In order to resolve this problem, some authors have identified convective precipitation with thunderstorms (e.g. Rice and Holmberg, 1973). More frequently, a threshold is used that establishes the minimum value below which rainfall is not considered convective (e.g. Dutton and Dougherty, 1979). Llasat (2001) proposed a classification for pluviometric episodes based on their convective nature. In order to do this the β parameter was defined to show the contribution of convective precipitation to total precipitation, calculated on the basis of the surface rainfall intensity and considering the threshold of 1 mm/min or 35 mm/h to categorise convective precipitation into 1-min or 5-min precipitation series, respectively, following Eq. (1).

$$\beta_{L,\Delta T} = \frac{\sum_{i=1}^{N} I(t_i, t_i + \Delta T)\theta(I - L)}{\sum_i I(t_i, t_i + \Delta T)} \tag{1}$$

in which:

ΔT is the time-interval, expressed in minutes.

N is the total number of ΔT integration steps into which the episode is subdivided.

$I(t_i, t_i + \Delta t)$ is the precipitation measured between t_i and $t_i + \Delta t$ divided by Δt, that is, the mean intensity for said interval expressed in mm/min or mm/h.

$\theta(I - L)$ is the Heaviside function defined as:

$\theta(I - L) = 1$ if $I \geqslant L$
$\theta(I - L) = 0$ if $I < L$

where $L = 1$ mm/min when $\Delta T = 1$ min, and $L = 35$ mm/min when $\Delta T = 5$ min.

The classification was corroborated afterwards using radar estimates (Llasat et al., 2007). Depending on the contribution of convective precipitation to total precipitation, β, recorded in the selected period (rainfall episode, meteorological event producing rainfall, daily, monthly or yearly period), the rainfall events or sub-events can be classified as follows (Llasat, 2001):

0. $\beta = 0$ non-convective
1. $0 < \beta < 0.3$ slightly convective
2. $0.3 < \beta < 0.8$ moderately convective
3. $0.8 < \beta < 1.0$ strongly convective

From a climate perspective, thunderstorms and showers, both of convective origin, are usually produced in summer and early autumn, because they are favoured by low level instability and high temperatures. In the Mediterranean region, summer events are usually local and of short duration, while in the autumn, the warmer sea surface temperature, as well as the large number of cyclones and organised perturbations, can give rise to extended catastrophic flash flood events (Jansà et al., 2001, 2014). Although it is not always possible to distinguish between floods and flash floods, their intra-annual variation peaks between August and December in the north-west Mediterranean. This can be seen in the analysis carried out during the HYMEX project, looking at 385 floods that occurred between 1981 and 2010 in north-east Spain, south-east France and south-west Italy (Llasat et al., 2013). In the case of Catalonia, flash floods are concentrated between August and October, which is consistent with the distribution of convective precipitation (Llasat, 2001; Llasat et al., 2014). Although catastrophic events mainly occur in the autumn, like the floods of 25 September 1962 and 7 November 1982, some catastrophic flash floods take place in the summer, like the flash flood event of 31 July 2002 and the most recent flood event of 18 June 2013. Other articles, like the one by Papagiannaki et al. (2013) for Greece, also show that rainfall during the summer-autumn period is the most significant for causing flash floods.

In this context, some authors state the difficulty of estimating intra-annual and inter-annual flash flood distribution, and, consequently, the difficulty in ascertaining trends and potential causes. The fact that a great number of these events take place in ungauged catchments and, at the same time, the unavailability of long-term precipitation series on rainfall intensity, makes it difficult to analyse both flow and heavy rainfall series Usually, trends are calculated using flood data series compiled from damages and impact assessments (i.e. Barrera-Escoda and Llasat, 2015; Llasat et al., 2005; McDonald, 2014) or from other proxy data like tax records (i.e. Brazdil et al., 2014), and, consequently, they refer to the flood as a multifactorial risk, where any trend or anomaly might be caused by a change in one or more factors affecting the hazard, vulnerability or exposure. Authors such as Merz et al. (2012) and Hall et al. (2014) deal with this question in depth. Despite these difficulties, the analysis of the longest available flow series across Europe, recently published by Mediero et al. (2015), points to a clustering trend for flood rich and flood poor periods, where the term “flood” is based on proposed flow thresholds, independently of the damage produced. This kind of clustering is also found when the flood data series is obtained using historical data or proxy data are analysed. This is the case in the recent works by McDonald (2014) on floods in Great Britain over the last millennia, and by Barrera-Escoda and Llasat (2015) on floods in Catalonia (north-east Spain) over the last 600 years. In this sense, regional statistical tools are more powerful and more efficient when detecting trends (Sun et al., 2015). Madsen et al. (2014) reported “some evidence of a general increase of extreme precipitation whereas there are no clear indications of significant trends at large-scale regional or national level of extreme streamflow” in Europe. Mediero et al.

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