ARTICLE IN PRESS

Journal of Hydrology xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Meteorological and hydrological analysis of major floods in NE Iberian Peninsula

David Pino [a,b,*], Josep Lluís Ruiz-Bellet [c], Josep Carles Balasch [c], Laura Romero-León [d], Jordi Tuset [e,f], Mariano Barriendos [g], Jordi Mazon [a], Xavier Castelltort [c]

[a] Department of Physics, Universitat Politècnica de Catalunya·BarcelonaTech, Castelldefels, Spain
[b] Institute of Space Studies of Catalonia (IEEC–UPC), Barcelona, Spain
[c] Department of Environment and Soil Sciences, University of Lleida, Lleida, Spain
[d] Escola d'Enginyeria de Telecomunicacions i Aeroespacial de Castelldefels, Universitat Politècnica de Catalunya·BarcelonaTech, Castelldefels, Spain
[e] Forest Sciences Centre of Catalonia, Solsona, Spain
[f] RIUS Fluvial Dynamics Research Group, University of Lleida, Lleida, Spain
[g] Department of Modern History, University of Barcelona, Barcelona, Spain

ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Historical floods
Flash floods
Multidisciplinary reconstruction
Specific peak flow
Twentieth Century Global Reanalysis V2
Stability indices

SUMMARY

This paper analyses the meteorological conditions and the specific peak flows of 24 catastrophic floods that affected NE Iberian Peninsula in the period 1842–2000. We classify these floods according to the affected area, peak flow magnitude, and damages. Additionally, the NOAA 6 Hourly 20th Century V2 Reanalysis Data Composites have been used to analyze the synoptic conditions during each flood and to evaluate several stability indices, such as the convective available potential energy (CAPE), or the lift index.

We found a good correlation between stability indices and the season when the flood occurred. For instance, if maximum CAPE is considered, larger values are found for summer floods, moderate for autumn, and low values during winter floods. We select 5 representative episodes occurred in different seasons and areas to describe in detail the synoptic conditions and to show the temporal evolution of the stability indices. In one the summer floods analyzed in detail, the largest instability, according to all the convective indices, is found. On the contrary, the winter case shows very low values of the convective indices, and autumn cases lay in between. During the other analyzed summer flood instability was low but snow thaw played an important role in producing the flood.

Regarding hydrological variables, clear differences between floods occurred at the coast or at the Pyrenees are found. Coastal specific peak flows are larger than Pyrenean ones, especially for small catchment areas.

We also combine meteorological (rainfall duration, CAPE), hydrological (specific peak flow) and geomorphological (catchment area) variables to show that for many of the analyzed floods these variables are related: the specific peak flow generally shows larger values when CAPE is also large. However some differences appear depending on the season and area. In those summer floods, where snow thaw played doesn't played any role, either Pyrenean or coastal, specific peak flow seems to be correlated with CAPE. For autumn floods, depending on the area different correlations were found: Pyrenean floods seem to be a correlation between CAPE and specific peak flows, but not for coastal ones. For winter coastal floods we couldn't find any correlation between CAPE and specific peak flows.

1. Introduction

Flash floods caused on average 50 casualties per year in Europe, 70% of the total number of deaths due to floods (Barredo, 2007). The fatalities mainly occur in countries surrounding the Mediterranean Sea, where large population density exists at the coastal areas due to the important urbanization processes in this area

* Corresponding author at: Department of Physics, Universitat Politècnica de Catalunya·BarcelonaTech, Castelldefels, Spain.
E-mail address: david.pino@upc.edu (D. Pino).

http://dx.doi.org/10.1016/j.jhydrol.2016.02.008
0022-1694/

occurred during the last decades (Llasat et al., 2010). Particularly in Spain, almost 90% of the victims due to floods are caused by flash floods (Olcina and Ayala-Carcedo, 2002). For instance, the Santa Tecla flash flood on September 1874 affected coastal and pre-coastal areas and caused the death of more than 500 persons (Ruiz-Bellet et al., 2015), or the floods on September 1962, when more than 850 persons died or disappeared (Tomás, 1963; Mazon and Pino, 2012), or more recently, in August 1996 87 people died in Biescas (North of Spain, García-Ruiz et al. (1996)).

Hydrological flash floods are produced by extreme precipitation events due to convective processes, normally of short duration and affecting a limited area. Accumulated precipitation use to be larger than 100 mm in few hours (Llasat et al., 2008; Gaume et al., 2009), but some authors report episodes that lasted up to 34 h (Marchi et al., 2010). This extreme precipitation produced a hydrological response-time usually smaller than 6 h (Georgakakos and Hudlow, 1984), but it can be up to 16 h (Marchi et al., 2010).

There is a change in the response time when the catchment is larger that 350 km^2 (Gaume et al., 2009), although the most destructive floods occur in catchments below this size (Marchi et al., 2010). Additionally, the severity criteria are also ambiguous and can involve rainfall or peak flow return period (Norbiato et al., 2008) and indices that include economic losses.

Despite the fact floods produce huge social and economic impacts, due to its low frequency and the difficulty to obtain reliable measurements there are still many unknowns related to this natural hazard, with scarce reliable quantitative databases (Benito et al., 2005; Brázdil et al., 2006; Barriendos et al., 2014). Additionally, regarding the difficulties to forecast flash floods (Gaume et al., 2009), it is fundamental to increase the knowledge about the spatio-temporal dynamics of flash floods to improve their forecast and the land-use planning. This fact will be important in the coming years because the severity and damages are expected to increase due to global change and the increasing urbanization development Borga et al. (2011).

Previous works have analyzed the characteristics of the catastrophic flash floods generally using databases restricted to the second half of the last century (Gaume et al., 2009; Marchi et al., 2010). The 'Prediflood' database (Barriendos et al., 2014) has quantitative data and reconstructions of floods occurred in the NE of the Iberian Peninsula over the last 500 years. By using this database, the most catastrophic flash floods since mid XIX century affecting more than one catchment in the area of interest are selected and studied. For each flood, we analyze the synoptic conditions by using the NOAA 20th Century Reanalysis. Additionally, we estimate some convective indices and relate their values with some hydrological variables, such as specific peak flow.

In Section 2, previous works analyzing the atmospheric conditions producing high rainfall rates in the NE Spanish coastal are described. Section 3 describes the studied area whereas Section 4 explains the methodology used to analyze the floods. The results are presented in Section 5, where a general description of the floods attending the meteorological and hydrological variables is done. Additionally, in this Section 5 representative floods are studied with more detail. The paper ends with some conclusions.

2. Analysis of the atmospheric conditions producing torrential precipitation in Northeast Iberian Peninsula

Torrential precipitation in the Western Mediterranean area and the floods caused by the precipitation have been studied according to climate (Millán, 2014) or analyzing particular episodes. Most studies focus on one of these main areas: trends in precipitation, circulation types associated to precipitation in different areas in the Iberian Peninsula (IP), and the atmospheric conditions of recent important precipitation events. Moreover, most of the studies are limited to analyze the tendencies in the last 50–70 years when the density of automated weather stations was large enough (Ramis et al., 2013).

Regarding general trends of precipitation, Lana et al. (2004), González-Hidalgo et al. (2009), and Barrera-Escoda and Llasat (2015) studied the spatio-temporal trends of rainfall in the Mediterranean area of Spain. Additionally, several authors pointed out the lack of correlation between torrential precipitation records at the Mediterranean coast of the IP and the low variability modes: North Atlantic Oscillation, Mediterranean Oscillation, and Western Mediterranean Oscillation (Rodó et al., 1997; Martín-Vide and López-Bustins, 2006; Martín-Vide et al., 2008; Muñoz-Díaz and Rodrigo, 2006; González-Hidalgo et al., 2009; Castro et al., 2011).

Other authors related circulation patterns and precipitation in the Mediterranean basin (Dünheloh and Jacobeit (2003), see Dayan et al. (2015) for a review) or particularly in the IP (Romero et al., 1999b; Goodess and Jones, 2002; Esteban et al., 2005; Casado et al., 2010; Fernández-Montes et al., 2014). Specifically, Romero et al. (1999a) classified the precipitation patterns in the Spanish Mediterranean area in the period 1964–1993 identifying 11 different patterns and 8 patterns of torrential precipitation (more than 50 mm in 24 h). Romero et al. (1999b) and Romero and Ramis (2002) used this classification to associate the patterns to circulation types obtained from the European Centre for Medium-Range Weather Forecast (ECMWF) gridded data at 925 and 500 hPa. The torrential rainfall at the northeast of the IP were mainly associated to circulation types 8 and 18. Circulation type 8 appears in spring, autumn and summer and presents a surface frontal low over northeast IP. 18 is characterized by a surface low located over the gulf of Genoa. In both types a trough at 500 hPa over the IP brings cold air to the upper levels. Due to the difficulties to obtain an accurate dataset of precipitation, most of these studies only present precipitation events or the tendency of precipitation since the middle of the last century.

Regarding the study of particular episodes in the northeast area of the IP, previous studies analyzed the atmospheric conditions to produce large rainfall rates of some of the events included here, but without considering in many cases the consequences (floods) of these precipitation rates. Additionally, there are few studies analyzing the atmospheric conditions responsible for floods occurring before 1980 (Tomás, 1963, 1972; Alonso and Puigserver, 1978). These studies, except Alonso and Puigserver (1978), only analyzed surface pressure data to describe the synoptic conditions that cause the floods. Alonso and Puigserver (1978) used radiosondes launched at four different locations in the northwestern Mediterranean coast to analyze the upper troposphere conditions during two floods on 1971. Consequently, there are few studies analyzing, by using a high-resolution mesoscale models including data in the upper levels of the troposphere, the atmospheric conditions during a catastrophic flash flood occurred before 1980 in the area under study. Llasat et al. (2007) and Mazon and Pino (2012) tried, with limited success, to reproduce the precipitation occurred during the floods in September 1971 and September 1962, respectively. Two main reasons explain this lack studies analyzing floods that occurred before 1950 in this area:

- First, as it was mentioned before, there only exist reliable and enough density of precipitation measurements in the area since 1950 (Ramis et al., 2013). Consequently, if recorded rainfall, and not the flood itself, is used as starting point for any research, the studies are limited to instrumentation periods. By using the 'Prediflood' database (Barriendos et al., 2014), which largely increase the number of episodes of previous databases (Barnolas and Llasat, 2007), we are able to analyze episodes occurred before this period.