Journal of Hydrology 530 (2015) 591–603

Contents lists available at ScienceDirect

Journal of Hydrology

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

Historical damaging flood records for 1871–2011 in Northern Portugal and underlying atmospheric forcings

Mónica Santos [a,*], J.A. Santos [b], M. Fragoso [a]

[a] Institute of Geography and Spatial Planning, Universidade de Lisboa, Edifício IGOT, Rua Branca Edmée Marques, 1600-276 Lisboa, Portugal
[b] Centre for the Research and Technology of Agro-Environmental and Biological Sciences, CITAB, Universidade de Trás-os-Montes e Alto Douro, UTAD, Quinta dos Prados, 5000-801 Vila Real, Portugal

ARTICLE INFO

Article history:
Received 1 August 2014
Received in revised form 1 October 2015
Accepted 4 October 2015
Available online 22 October 2015
This manuscript was handled by Andras Bardossy, Editor-in-Chief, with the assistance of Axel Bronstert, Associate Editor

Keywords:
Damaging floods
Circulation weather types
Northern Portugal

SUMMARY

A long time series of damaging flood records in Northern Portugal for 1871–2011, gathered from a large number of documentary sources, is analyzed. The relationships between damaging floods (DFs) and relevant circulation weather types (CWTs) are also assessed. The DFs database has 1861 records and CWTs are identified using the 20th century reanalysis dataset v2. A coefficient of effectiveness (CE) is calculated for each weather type in order to assess DF–CWT relationships. Furthermore, conditions in the 10 days preceding a DF outbreak, type of flood and season were taken into account in CE calculations. The DF occurrences were responsible for 186 killed people, 59 injured, 29 missing, 1873 displaced and 15,924 homeless people. The monthly frequencies each CWT show that anticyclonic (A) and easterly wind (E) types are prevalent in winter, whereas R tends to prevail in the summer half of the year. However, the results show that the cyclonic (C) type has a positive frequency with DF occurrence (i.e. anomalously frequent), both on the DF day and on the nine previous days. The C type is commonly associated with south-westerly flow and unsettled weather conditions over Portugal, which are favorable to rain-generating mechanisms. The results also highlight some seasonal variation: in autumn, winter and spring, the C type is largely related to DFs, while the A and E types acquire higher preponderance in the summer. In effect, the latter two CWTs may trigger thunderstorms and heavy precipitation episodes in the Douro River catchment in summer.

1. Introduction

Floods are the natural hazards causing more damages worldwide. In 2012, it is estimated that floods affected 62,281,619 people and killed 3401 (UNISDR, 2012). As an illustration, in the Madeira island (Portugal), a flash flood on 20 February 2010 resulted in 45 deaths (Fragoso et al., 2012). Other examples are the flash floods in the Lisbon region on 25 November 1967 that caused 700 deaths, or the river flooding in December 1909 that caused 25 reported deaths along the Douro River. Between 1865 and 2010, floods were responsible for 1012 deaths, 478 injured, 13,372 displaced and 40,283 homeless people in Portugal (Zêzere et al., 2014). These numbers were assessed under the framework of a research project devoted to create, disseminate and exploit a GIS database (DISASTER database) on disastrous landslides and floods in Portugal for the period of 1865–2010 (Zêzere et al., 2014). This dataset was obtained from a systematic survey of news published in national and regional newspapers.

Flood damage databases, particularly high impact floods, are commonly based on insurance claim data, institutional reports, and media reports, especially news disseminated by newspapers with long and continuous periods of publication. The Portuguese DISASTER database on hydro-geomorphological disasters followed other recently produced historical repositories on catastrophes, such as the flood database for Catalonia (Spain) (Barnolas and Llasat, 2007), the SICI information system, concerning the occurrence of landslides and floods in Italy (Guzzetti and Tonelli, 2004), or the flood database for Athens (Greece) (Diakakis, 2014). These efforts also represent, to some extent, a strategy to improve the current knowledge on flood risks in Southern Europe, given the scarcity of instrumental data on river discharges. In fact, the longest and continuous river discharge data series for Northern Portugal is available only for the period from the 1950s onwards. Therefore, the analysis of the DISASTER flood occurrences under a climatological perspective allows an innovative and timely assessment of historical flood records in this region.

* Corresponding author at: Institute of Geography and Spatial Planning, Universidade de Lisboa, Edifício IGOT, Rua Branca Edmée Marques, 1600-276 Lisboa, Portugal.
E-mail addresses: monica.s.m.santos@gmail.com (M. Santos), jsantos@utad.pt (J.A. Santos), mfragoso@campus.ul.pt (M. Fragoso).

http://dx.doi.org/10.1016/j.jhydrol.2015.10.011
0022-1694/

The combination of weather and hydrology commonly play a key role in flood processes (Llasat et al., 2005). In fact, the occurrence and intensity of floods depend on weather conditions prior to the event (Kron et al., 2012). Floods are extreme and temporary episodes, mainly triggered either by persistent and moderate precipitation or by abrupt heavy rains. Nevertheless, other conditions, such as soils, surface run-off characteristics, protection measures, land-use and seasonality in the hydrological regimes are also important.

Many works have been devoted to the relationships between atmospheric patterns and rainfall (Andrade et al., 2011; Burt and Ferranti, 2012; Casado et al., 2010; Espinoza et al., 2012; Goodess and Jones, 2002; Hidalgo-Muñoz et al., 2011; Lopez-Bustins et al., 2008; Raziei et al., 2013; Santos et al., 2005, 2007; Toreti et al., 2010; Trigo and DaCamara, 2000) or temperature (Andrade et al., 2012; Carril et al., 2008; Cassou et al., 2005; Cony et al., 2008; Rodríguez-Puebla et al., 2010; Santos and Corte-Real, 2006) or both (Jacobeit et al., 2009; Pfahl, 2014). However, there is a lack of studies covering the links between atmospheric patterns and floods (Pattison and Lane, 2012). Most of studies were focused on the identification the circulation patterns responsible for flood occurrences in different areas, such as Arizona (Duckstein et al., 1993), France and Spain (Bárdossy and Filiz, 2005), the UK (Pattison and Lane, 2012; Wilby and Quinn, 2013), the Alpine–Carpathian range (Parajka et al., 2010), Germany (Petrow et al., 2007, 2009) and central Europe (Jacobeit et al., 2006). Most of these studies have shown that cyclonic weather types are particularly important in flood concurrences.

The link between weather types and a long time series of damaging flood records in northern Portugal is investigated in the present study. The purposes of this work are twofold: (1) to investigate the atmospheric conditions leading to damaging floods and (2) to identify typical atmospheric patterns related to damaging floods in Northern Portugal.

The manuscript is organized as follows: Section 2 describes the study area and datasets of damaging flood records and of atmospheric patterns. The results are presented and discussed in Section 3 and the conclusions are summarized in Section 4.

2. Methodology

2.1. Study area

The administrative region of Northern Portugal covers an area of ca. 21,278 km^2 and depicts strong spatial heterogeneity in the mean annual precipitation totals, ranging from 500 mm in the upper Portuguese Douro Valley to 3500 mm in the Peneda–Gerês mountain range (Fig. 1). The climate in the northwestern area is largely influenced by the proximity to the Atlantic Ocean, while the low-elevation inner areas are much more continental, typifying Mediterranean-like climates (Daveau, 2000). This west–east contrast is due to the mountain relief effect, since the geographic orientation of the main mountain ranges is parallel to the coastline, thus blocking the moist westerly winds blowing from the North Atlantic (Santos, 2009). As such, the Peneda, Amarela and Gerês mountains (on the windward side) record some of the highest precipitation amounts in western Europe (Ferreira, 2005), while inner areas, including the uppermost section of the Douro valley and of some of its tributaries, are among the driest regions in the country (Santos et al., 2014).

2.2. Data

2.2.1. Damaging floods

In the present study, a damaging flood (DF, hereafter) is defined as a flood event that have caused some kind of damage reported by national and regional newspapers, regardless of the number of people affected or the economic value of the resulting damages. The methodology used for the data flood collection and storage is summarized in Fig. 2. Five daily newspapers and ten weekly newspapers were systematically checked (Table 1). In total, 145,709 periodicals, corresponding to a surveyed period of 147 years (1865–2011), were analyzed. The daily newspapers *Diário de Notícias* and *Jornal de Notícias* provide the longest time period. Five additional newspapers (*O Século*, *Comércio do Porto*, *O Primeiro de Janeiro*, *Público* and *Correio da Manhã*) were also surveyed for some specific dates in order to complete or validate DF occurrences. It is assumed that the damaging flood events are important enough to be reported by regional/local and national newspapers. Significant amount of work was carried out to check and validate all the damaging flood occurrences, using written press and cross checking different sources, from national to regional and local newspapers (Zêzere et al., 2014).

For each DF occurrence, the following information was collected: sub-type (i.e. river flood, flash flood, urban floods), date, location (municipality, parish and *x*/*y*-coordinates according to the PT-TM06/ETRS89 projected coordinate system), triggering factor and information source (name, source type and reliability of the news, source, date of source, page number), number of deaths, injured, displaced, homeless or missing people, the entities involved and material losses. As this dataset is developed in a GIS (Geographic Information System) environment, each occurrence is coded and georeferenced using a point shapefile (Fig. 2). It is worth emphasizing the high scientific value of this dataset, being a unique historical data source for Portugal.

2.2.2. Circulation weather types

Precipitation in Portugal, including its extreme episodes, is largely controlled by large-scale anomalies in the North Atlantic atmospheric flow (Santos et al., 2007, 2009), with important implications in the Portuguese hydrological budgets and river flows (Andrade et al., 2011). In fact, the latitudinal location of the North Atlantic eddy-driven jet stream is the main underlying mechanism for the occurrence of precipitation extremes in Portugal (Santos et al., 2013b; Woollings et al., 2011), by e.g. governing the phase and magnitude of the North Atlantic Oscillation (NAO Hurrell et al., 2001) and the frequency of occurrence of strong and persistent ridge episodes (SPRE, Santos et al., 2009) in the eastern North Atlantic. Furthermore, both the frequency of occurrence and the strength of precipitation extremes are projected to increase under future climate change scenarios (Costa et al., 2012). Aiming at establishing relationships between flood historical records in the Douro River and the underlying patterns of the large-scale atmospheric flow, the daily means of the sea level pressure (SLP) fields are classified into circulation weather types (CWT). The 56-member ensemble means of SLP, produced by the 20th century reanalysis v2 (Compo et al., 2011), are retrieved from the NOAA Earth System Research Laboratory – Physical Sciences Division (http://www.esrl.noaa.gov/psd/). Data for the full temporal period (1871–2012, 142 years) within a Euro-Atlantic sector (60°W–20°E, 26–64°N) are extracted. Daily means are obtained by averaging 6-hourly data and are defined on a regular grid of 0.20° latitude × 0.2° longitude (~200 km grid spacing).

To identify CWTs, a K-means clustering is applied onto the leading twenty principal components of the daily SLP for the subsector (30°W–10°E, 26–64°N), which represent approximately 98% of the total temporal variance of this field within this subsector. The K-means on the empirical orthogonal basis is a common procedure to reduce the dimensionality of the clustering approach, to improve the signal-to-noise ratio and to attain more stable solutions (Wilks, 2011). SLP has proven to be useful in isolating CWTs over Portugal (e.g. Santos et al., 2005; Trigo and DaCamara, 2000)