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Regional reconstruction of flash flood history in the Guadarrama range (Central System, Spain)

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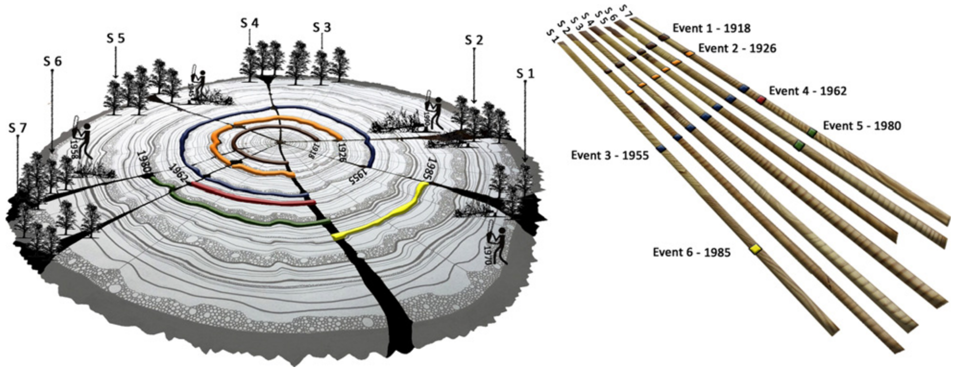
HIGHLIGHTS

- Flash floods represent a regional natural hazard in Guadarrama range.
- Dendrochronology allows fill the lack of systematic data in mountain environments.
- Regional studies and quality samples allow reducing the number of collected samples.
- We complement existing records with 8 events covering the last ~200 years.
- Forest management could limit the amount of proxy evidence of flash flood events.

GRAPHICAL ABSTRACT



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ABSTRACT

Flash floods are a common natural hazard in Mediterranean mountain environments and responsible for serious economic and human disasters. The study of flash flood dynamics and their triggers is a key issue; however, the retrieval of historical data is often limited in mountain regions as a result of short time series and the systematic lack of historical data. In this study, we attempt to overcome data deficiency by supplementing existing records with dendrogeomorphic techniques which were employed in seven mountain streams along the northern slopes of the Guadarrama Mountain range. Here we present results derived from the tree-ring analysis of 117 samples from 63 *Pinus sylvestris* L. trees injured by flash floods, to complement existing flash flood records covering the last ~200 years and comment on their hydro-meteorological triggers. To understand the varying number of reconstructed flash flood events in each of the catchments, we also performed a comparative analysis of geomorphic catchment characteristics, land use evolution and forest management. Furthermore, we discuss the limitations of dendrogeomorphic techniques applied in managed forests.

1. Introduction

Flash floods are natural processes in mountain environment and typically triggered by intense, but short-lived precipitation events (Borga et al., 2014). The process is characterized by its sudden occurrence combining high stream power and sediment transport rates

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which make it one of the most harmful natural hazards in mountain and hillslope environments (Borga et al., 2008, 2014; Marchi et al., in press). Recent studies suggest that climate change may have an impact on the triggering of flash floods and that the occurrence may increase at the global scale (Beniston, 2009; Giorgi et al., 2011). Specifically in Spain, Benito (2006) and Benito et al. (1996, 2015) have reported on the flood sensitivity of Spanish rivers to climate change and suggest that variations in climate characteristics may increase the irregularity of the flood regime and droughts and thereby favor the generation of flash floods in Mediterranean basins. Changes in precipitation may have a direct impact in the future occurrence of extreme hydrological events (Beniston et al., 2011; Gobiet et al., 2014; Stoffel and Huggel, 2012; Stoffel et al., 2014a), which could in turn affect the future development of mountain environments (Beniston et al., 2012). In this context, flash flood processes in mountain environments could become an important issue in Mediterranean environments over the next few decades (Borga et al., 2014).

Nevertheless, the analysis of flash flood activity in mountain environment still poses several scientific challenges, which are mainly related to the lack of systematic records (Stoffel et al., 2010). Long-term records of flash flood activity are often missing in remote environments, which in turn prevent the study of their impacts as well as a rational analysis of their drivers and ultimately meteorological triggers. On forested slopes, trees growing next to mountain streams can be used as a biological proxy and thus provide valuable proxy records to define the spatio-temporal patterns of past process activity with sometimes up to seasonal accuracy (Ballesteros-Cánovas et al., 2015a; Stoffel and Wilford, 2012; Stoffel et al., 2005, 2010, 2012). Intense flash flood events often cause damage to multiple trees (Ballesteros-Cánovas et al., 2015a; Sigafoos, 1964), which will respond with different growth disturbances, hereafter referred to as GD (Shroder, 1978; Stoffel and Corona, 2014). These GD have been widely used to reconstruct past activity of numerous hydrogeomorphic processes in different mountain ranges (see Ballesteros-Cánovas et al. (2015a); Stoffel et al. (2013) for a recent review), but such studies have generally focused on specific catchments (Astrade and Bégin, 1997; Ballesteros-Cánovas et al., 2011a,b, 2015b,c; Casteller et al., 2015; Ruiz-Villanueva et al., 2010; Šilhan, 2015; St. George and Nielsen, 2003; Stoffel et al., 2008; Zielonka et al., 2008), and have, with only a few exceptions, looked at the regional scale (i.e. Ballesteros-Cánovas et al., 2015c, in press; Bollschweiler and Stoffel, 2010; Procter et al., 2011; Schraml et al., 2015; Šilhan et al., 2015; Stoffel et al., 2014b). However, according to Procter et al. (2011), the regional assessment of past hydro-climate related processes could be of substantial help in terms of reducing lack of data and maximizing the information available in a given area. In addition, regional assessments allow for a better assessment of the complexity of the linkages between climate and flash floods at these scales (Ballesteros-Cánovas et al., 2015c; Glaser et al., 2010; Merz et al., 2014). Moreover, intra-catchment geomorphic and land-use comparisons are believed to yield insights into different and often varying hydrologic response of catchments (Blöschl, 2006; Costa, 1987; Glaser et al., 2010), which will in turn be useful for large-scale flash flood hazard delineations based on morphometric indexes (Fernández and Lutz, 2010; Guzzetti and Tonelli, 2004).

In this paper, we investigate and compare past flash flood activity in seven headwater catchments that exhibit considerable differences in forest cover and historical forest management in the Sierra de Guadarrama range (Spanish Central System). Based on a first series of data reported in a previous study (Ballesteros-Cánovas et al., 2015b) as well as highly resolved field data (i.e. LiDAR, aerial pictures, meteorological time series and forest management data), we analyze the role of geomorphic features and land use catchment predisposition on flash flood triggering. We also discuss hydro-meteorological causes of past events based on data from a nearby rain gauge, prior to focusing on the role and limitations of logging (or forest management history in other words) on the suitability of mountain forest catchments to be studied with dendrogeomorphic approaches.

2. Study site

The mountain catchments under investigation are located in the Guadarrama Mountain range (Spanish Central System; Fig. 1) which extends in a southwest to northeast direction for about 80 km, thereby dividing the Duero Basin (northwest) from the Tagus Basin (southeast). The range has a maximum altitude of 2428 m a.s.l. (Peñalara peak, Fig. 1). A total of seven adjoining catchments have been selected for this study, namely the Quebradas (QUE), Paular (PAU), Altozano (ATZ), Juncional (JUN), Cárcavas Del Valle (CV), Pintadas (PIN) and Valhondillo (VLH) streams. Moreover, we compare data reconstructed for these streams with results from existing dendrogeomorphic analyses of the adjacent Puentes (PU) and Majabarca (MJB) catchments (Ballesteros-Cánovas et al., 2015b).

With the exception of VLH, a tributary of Lozoya River (Tagus Basin), catchments considered in this study are tributaries of the Eresma River (Duero Basin) and located in the Montes de Valsaín (hereafter Valsaín Forest). All catchments are within the recently created Sierra de Guadarrama National Park.

As a result of the well-documented history of forest interventions since the late 18th century in the Valsaín Forest, detailed records exist on forest management interventions (Dones and Garrido, 2001) and for individual allotments (i.e. exploitation areas).

The catchments selected in this study generally have a NW orientation except for PAU catchment where the orientation is towards the W and for VLH catchment where water flows to the NE. Granitic and gneissic lithologies are dominant and determine a regular and rounded topography. The presence of gelifraction processes produces sufficient amounts of loose sediments which are then mobilized during intense hydro-geomorphic events. The distribution and orientation of the drainage network is associated with the local fault system with predominance of north-western features in the study area (Bullón, 1986; Pedraza et al., 2005). Arborescent vegetation at the study sites is formed primarily by *Pinus sylvestris* L., a species typical for subalpine altitudes (1600–2000 m a.s.l.) in the Guadarrama Mountain range (Ruiz del Castillo, 1976).

Climate in the area is defined as Mediterranean with continental influences which can be considered 'humid continental with warm summers' (type 'Dsb' according to the Köpper–Geiger classification, Peel et al., 2007). Average annual precipitation is 1223 mm with large amounts of rainfall typically in April and May as well as between October and January. Mean annual air temperature is 6.9 °C with monthly means ranging from 0.4 °C in January to 17 °C in July at the level of the meteorological station Navacerrada situated at 1894 m a.s.l. (AEMET, 2011). Results from the previous study (Ballesteros-Cánovas et al., 2015b) carried out in the PU and MJB catchments suggest that the rainfall thresholds triggering flash floods vary with the seasonality of events. Therefore, flash floods occurring in spring were typically released during events with lower rainfall totals than those triggered in autumn and winter, therefore suggesting an important role of snowmelt processes in the triggering of flash floods (Ballesteros-Cánovas et al., 2015b).

3. Material and methods

3.1. Dendrogeomorphic analysis

In this study we used standard dendrogeomorphic procedures to date past flash flood activity from trees, following the guidelines of Stoffel and Corona (2014). In a first step, field surveys were performed focusing on the detection of geomorphic features typically created by flash floods, such as lateral levees, terminal lobes as well as bank and/or terrace erosion. Based on this recognition, we sampled trees located in the transport-reaches of the fluvial systems and at locations where obvious interactions took place between the mobilized sediment and living trees. Only trees with visible signs of disturbance have been