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Historical, hydraulic, hydrological and meteorological reconstruction of 1874 Santa Tecla flash floods in Catalonia (NE Iberian Peninsula)

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SUMMARY

A multidisciplinary methodology for historical floods reconstruction was applied to 1874 Santa Tecla floods occurred in Catalonia (NE Iberian Peninsula), using both historical information and meteorological data from 20th Century Reanalysis.

The results confirmed the exceptionality of the event: the highest modeled specific peak flow was around 14.6 $m^3 s^{-1} km^{-2}$ in a 100 km^2 catchment and all the modeled total rainfall values were above 110 mm in about six hours, with maximum intensities around 60 mm min^{-1}. The peak-flows peak flows' return periods were about 260 years and the rainfalls periods were between 250 and 500 years. The meteorological cause of the rainstorms was the flash triggering effect, initiated by the withdrawal of a mass of hot air at mid-levels.

A sensitivity analysis on the various sources of error shows that peak flow errors from hydraulic modeling ranged from 5% to 44%, and rainfall errors from hydrological modeling were about 36%.

1. Introduction

Flash floods rank among the most dangerous and destructive natural hazards in southern Europe. In spite of this, scientific research about past floods is only recent and mainly focused on modern events. This is a drawback when trying to analyze and classify flash floods in a climatic change context because important information, which old events would provide, is missing.

Fortunately, data about long-past floods can be retrieved from paleographic and dendrogeomorphological evidences and from historical documents. Indeed, historical archives keep raw data – such as maximum water depths, rainfall durations, channel morphologies, atmospheric variables – which, after proper collecting and processing, can enlarge present day records of floods. As said above, the use of this historical information in flood analysis and reconstruction is only very recent and usually restricted to academic research (Bayliss and Reed, 2001; Benito et al., 2004; Gaume et al., 2004; Naulet et al., 2005; Brázdil et al., 2006; Elleder, 2010), but it will most probably become more used because of the EU Directive 2007/60/EC (2007) on flood risk assessment.

Nevertheless, only a few studies so far have tried to thoroughly analyze historical floods by linking hydrological and meteorological information (Petersen et al., 1999; Delrieu et al., 2005; Bürger et al., 2006; Flesch and Reuter, 2012). In this same line, this study presents an applied example of the multidisciplinary methodology (historiographical, hydraulic, hydrological and meteorological) of historical floods reconstruction introduced by Barriendos et al. (2014).

This methodology was applied on a case study: 1874 Santa Tecla floods. The night of 22–23 September 1874 several flash floods occurred in many catchments throughout the eastern part of the Ebro River basin, in Catalonia (NE Iberian Peninsula, Fig. 1). These floods – known as Santa Tecla floods because this was the saint of that day – caused 575 casualties and ravaged an

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approximate area of 10,000 km^2 and are considered, as a whole, one of the heaviest events in the region in the last 500 years.

Luckily, there is a lot of information about this event, especially, maximum water depths in many locations. So far, some of this information has already been used to calculate the peak flows of the floods in six spots located in three catchments (Balasch et al., 2010a, 2011). Here, we enlarged this list with four more sites and two more catchments. In some cases, it was also possible to calculate the hyetograph of the rainfall. Besides this hydraulic and hydrological information, meteorological data of the days before the floods, available from NOAA's 20th Century Reanalysis (Compo et al., 2011), were used to determine the meteorological causes of the floods.

In summary, the objective of this paper was to use a multidisciplinary methodology of hydraulic, hydrological and meteorological reconstruction of historical floods on a study case: the 1874 Santa Tecla floods, occurred in NE Iberian Peninsula.

Although in this paper only this one flood was reconstructed, our long-term objective is to use this multidisciplinary methodology to analyze the heaviest floods occurred in NE Iberian Peninsula in the last 500 years. By doing so with such a thorough reconstruction methodology, we will be able to classify the historical floods of the region according to their meteorological causes and, thus, to improve prediction, planning and readiness.

2. Study area

Heavy rainstorms are frequent in NE Iberian Peninsula. The studied area within this region (Fig. 1) has a complex orography with a maximum altitude of around 1200 m, which plays a main role in uplifting the Mediterranean air flows thus causing severe storms (Romero et al., 1997; Pascual et al., 2004).

Additionally, its location on the western coast of the Mediterranean basin (Fig. 1) favors torrential rainfall, especially at the end of summer and autumn (Llasat et al., 2005), when the warm Mediterranean Sea provides large amounts of heat and moisture to the lower layers of the atmosphere. Moreover, regional climate models forecast a decrease in the average yearly precipitation but, at the same time, an increase in the maximum daily precipitation over this region in this next century (Barrera and Cunillera, 2011).

The complex orography mentioned above implies small catchments (80–300 km^2) with short, steep streams (15–35 km long and 1–2% of slope) and, therefore, with a very quick hydrological response: their very low average flows, less than 1 $m^3 s^{-1}$, can multiply thousands of times in a matter of hours. These catchments, mostly rural but with some populated towns, were the most damaged by 1874 Santa Tecla flash floods, within the 10,000 km^2 affected area.

The hydraulic and hydrological modeling were performed in ten sites along five different rivers, located in the northern half of the affected area, which are, from north to south and from west to east: Sió, Ondara, Corb, Vall Major and Francolí (Fig. 1 and Table 1). All of them have their headwaters either on the Catalan Central Depression ranges or on the Pre-coastal ranges, between 700 and 900 m (Portella, Tallat, Llena, and Prades ranges). All of them but Francolí flow westwards: Sió and Vall Major into the Segre River, the main tributary of the Ebro River, and Ondara and Corb into large alluvial fans. Francolí flows southwards into the Mediterranean Sea.

All of them have scarce flows all year round, with a high-water period around May and long low-water periods, but, due to irrigation, they never dry up, except Vall Major, which is usually dry. In any case, autumn overflowing flash floods are typical, occurring about three or four times per century (Corominas et al., 1985; Novoa, 1987; Coma, 1990).

The geological substrates in these catchments are Cenozoic sediments of the Ebro depression, with some outcrops of Paleozoic and Mesozoic materials of the Pre-coastal ranges in the Francolí catchment. The climate is continental Mediterranean with less than 600 mm of rainfall per year, which decreases as height decreases. The main soil use is dry land cereal farming, whereas the higher areas are covered with Mediterranean forest.

3. Methods

The reconstruction of a historical flood is the calculation of the event's characteristics from indirect information.

The procedure used to reconstruct 1874 Santa Tecla floods consists of four different steps: the historiographical research, the hydraulic modeling, the hydrological modeling, and the meteorological analysis (Barriendos et al., 2014).

This four steps are linked, because the historiographical research feeds other steps with data, because the results of the hydraulic modeling are the input data of the hydrological modeling, and because the results of the hydrological modeling and the meteorological analysis should qualitatively agree between them and with the meteorological information found in the historiographical research (Fig. 2).

It is worth noting the different space scales involved in the hydraulic, hydrological and meteorological reconstructions: typically, the hydraulic reconstruction takes place along a river reach (up to a dozen km^2); whereas the hydrological one takes into account the whole catchment or a part of it (from some dozens to thousands of km^2); and the meteorological reconstruction is done, depending on the meteorological phenomenon causing the event, from a local (hundreds of km^2) to a regional scale (1 million km^2).

3.1. Historiographical research

Historiographical research is the key step in the reconstruction of any historical flood: without correct, reliable information, no correct, reliable modeling can be done.

Historiographical research is mainly based in archive scanning, that is, in the systematic scrutiny of documents in search of any records related to any flood. These documents can hold all kinds of data about the flood: meteorological (start and end times of the rainfall, weather in the previous days), hydraulic and hydrological (time of the peak flow, time of the overbank flow, maximum height reached by the water, height of the water at various times, state of saturation of the catchment's soils), and human and social (number of victims, economic loss). Some of these data are essential in order to reconstruct the flood, and the nature of these documents is mostly official (town council's minutes, notarized documents, local authorities official reports to higher levels of the administration), but they also include contemporary newspapers (Diario de Barcelona, 1874), personal accounts (Salvadó, 1875) and local historians' research (Pleyán de Porta, 1945; Iglésies, 1971; Xuclà, 1977; Piqué, 1986; Coma, 1990; Vila, 1992; Espinagosa et al., 1996; Còts, 2012).

Besides this archive information, flood marks are also very important pieces of information in hydraulic modeling, because they precisely mark the maximum height of the water, which can be equated (with a small, acceptable error) to the height of the water at the peak of the flood.

Twelve flood marks were used in the hydraulic modeling of the ten reconstructed peak flows. Some of them are plaques whereas others are simple carvings on the walls and even others are mere notes found in written documents (Table 2).