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Comparative hazard analysis of processes leading to remarkable flash floods (France, 1930–1999)

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SUMMARY

Flash flood events are responsible for large economic losses and lead to fatalities every year in France. This is especially the case in the Mediterranean and oversea territories/departments of France, characterized by extreme hydro-climatological features and with a large part of the population exposed to flood risks. The recurrence of remarkable flash flood events, associated with high hazard intensity, significant damage and socio-political consequences, therefore raises several issues for authorities and risk management policies. This study aims to improve our understanding of the hazard analysis process in the case of four remarkable flood events: March 1930, October 1940, January 1980 and November 1999. Firstly, we present the methodology used to define the remarkability score of a flood event. Then, to identify the factors leading to a remarkable flood event, we explore the main parameters of the hazard analysis process, such as the meteorological triggering conditions, the return period of the rainfall and peak discharge, as well as some additional factors (initial catchment state, flood chronology, cascade effects, etc.). The results contribute to understanding the complexity of the processes leading to flood hazard and highlight the importance for risk managers of taking additional factors into account.

1. Introduction

The autumn of 2014 was marked by a series of catastrophic flash flood events in southern France, responsible for economic losses estimated at around EUR 550-600 million[1] and leading to 17 fatalities.[2] One of the main features of these events is their clustering, with a set of 14 flooding events occurring in two months, since the "usual" number is about 3 to 4 per autumn season. This raised the issue of their recurrence: could such events be related to the impact of climate change in Mediterranean regions or simply represent an example of random clustering as already experienced in the past (e.g. during the autumn of 1907). Due to the suddenness of the hazard, such flash floods are generally associated with high fatalities compared with other kinds of floods (Jonkman, 2005; Ruin et al., 2007). This fact raises some concerns in a context of global changes associated with the constantly increasing exposure of humans and assets (SwissRe, 2015). Thus, we should bear in mind that a damaging flood event cannot be summed up as a single physical parameter, which highlights the need to carry out a multidisciplinary analysis to understand the factors involved in destructive flash flood events. As mentioned by Drobinski et al. (2014) as one of the scientific key of the HyMex project, "[...] *there is a need for better understanding the social and natural dynamics of such events in order to improve the forecasting and warning capabilities of the exposed Mediterranean societies to increase their resilience to such extreme and frequent events.*"

Thus, a flood event is generally assessed from the viewpoint of a single discipline such as hydrology or meteorology (Borga et al., 2007; Delrieu et al., 2005), or according to a specific parameter such as risk perception (Burn, 1999) or damage/fatalities (Vinet et al., 2012). A few studies are multidisciplinary, such as the reconstruction of the 1874 Santa Tecla flash food in Catalonia by Ruiz-Bellet et al. (2015), covering history, meteorology, hydraulics and hydrology. However, a flood event is more rarely the subject of transversal studies attempting to dissect the whole flood event system by integrating both the physical and social sciences. This is especially true concerning historical events and more specifically past flash floods.

With regard to these issues, we firstly apply a multidisciplinary evaluation grid (Section 2) which allows the selection of some

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[1] URL: https://www.axa.fr/actualites/cout-assurances-intemperies.html.
[2] URL: http://www.midilibre.fr/2014/12/08/intemperies-un-automne-2014-meurtrier-dans-le-sud-est-avec-17-victimes,1094596.php#xtor=RSS-5.

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interesting case studies. We focus here on three flash floods, occurring in March 1930, October 1940, November 1999, and one flood event resulting from a cyclonic storm in January 1980. Section 3 presents a review of the main causative factors, considering the triggering meteorological conditions, the main characteristics of the precipitation event and the peak discharge. This section concludes with an analysis of correspondence between rainfall and discharge, and focuses on additional factors explaining the hazard remarkability. In Section 4, we summarize the key findings and provide recommendations on the procedure for characterizing flood events.

2. An evaluation grid to define remarkable flood events

2.1. Methodology to define flood remarkability

The EU Flood Directive especially recommends carrying out a "*description of the floods which have occurred in the past and which had significant adverse impacts on human health, the environment, cultural heritage and economic activity and for which the likelihood of similar future events is still relevant*...". Several issues need to be considered to meet the recommendations of the Flood Directive. How to define the "significant adverse impacts" of a past flood event? How to integrate floods from different regimes and spatio-temporal contexts into the same analysis grid? How to consider also social impacts? Scientific studies related to historical flood classification (Brazdil et al., 2006; Kundzewicz et al., 2013) or post-flood investigations of modern events (Calianno et al., 2013) are usually based on the number of fatalities and the economic damage of the flood event. The concept of flood remarkability needs to include social aspects. Some previous studies have considered both the social and hydrological components of a flood event. Creutin et al. (2009, 2013) took account of social aspects when assessing the lead time required for anticipation of flash floods. Ruin et al. (2014) proposed integrating a social component when conducting post-flood investigations. Llasat Botija et al., 2009 used a press media database over the period 1982–2007 to understand the social impacts of flash floods in Catalonia.

In 2011, during the first step of the Flood Directive, which involved preparing a Preliminary Flood Risk Assessment (PFRA), the French authorities made a selection of 176 flood events from the period 1770–2010, by means of consultation with local risk managers. Several criteria were used: intense event based on flood magnitude and/or spatial extent, diversity of flood typology, economic and social impacts, design event from flood zoning, last major event in memory, etc. The flood events considered as *remarkable* were then compiled into the French historical flood database (http://bdhi.fr/). Boudou et al. (2015) developed a grid with the aim of selecting the most "remarkable" amongst the 176 flood events. This grid is based on three main features: 1/flood intensity; 2/flood severity; 3/spatial extent of the damages (see Fig. 1). We briefly present the three components, each being composed of a set of criteria which are themselves linked with a score (using 3 classes).

2.1.1. The flood intensity

The flood intensity corresponding to the hazard level of the event is composed of three criteria:

- *The maximum return period of the peak discharge or the maximum return period of the rainfall episode.* This indicator has the advantage that it can be used for comparing events of different nature and times of occurrence (Kundzewicz et al., 2013). The maximum score (4) linked with this criterion is based on a return period significantly longer than 100 years, in accordance with an "extreme" event of the Flood Directive.
- *The maximum submersion duration recorded in the area affected by the flood event* is of prime importance in the damage process according to several authors (Merz et al., 2010b; Messner and Meyer, 2006). This indicator is not especially useful for assessing the intensity of flash floods but allows integrating oceanic events associated with long flood durations into the evaluation grid. The maximum score is linked with a submersion duration exceeding 30 days, with strong impacts in terms of crisis management.
- *The presence of factors aggravating the hazard level* (such as dyke breaches, log jams or wave effects). These domino effects can trigger a sudden increase in flow velocity and water depth, and are often involved in the disaster process. The maximum score corresponds to aggravating factors contributing directly to an increase of the hazard level and causing the exposure of new stakeholders to the flood.

2.1.2. The flood severity

The flood severity is assessed by four criteria:

- *The number of fatalities resulting from the flood* is a key indicator frequently used to characterize the severity of a flood event (Brazdil et al., 2006). As an intangible source of damage (Parker, 2000), the number of fatalities is furthermore especially suited for retrospective analyses such as requested in the Flood Directive and, for this reason, it is used in the evaluation grid. The third class (score of 4) corresponds to an event that triggers more than 10 fatalities (minimum value also used by the CRED to integrate a natural disaster into the EM-DAT database).
- *The estimation of economic damage.* From 1983 onwards, we principally make use of the Prim database (www.prim.net/) which reports all damage claims supported by the current French reinsurance system for natural disasters. The third class corresponds to events with damage exceeding a value of EUR 300 billion. Before 1983, a qualitative assessment was made of the economic damage. Based on the classification drawn up by Coeur (2008), three classes are distinguished: the first class is related to sporadic submersion and the second class to sporadic destruction. The third class, corresponding to a severity score of 4, is linked to damage or destruction of road and railway networks over a wide area and the paralysis of communication networks for more than one day.
- *The social, media and political impact of a flood event.* The more significant the impact of an event, the more the event can be judged as striking (and thus remarkable) for society (Merz et al., 2010a). We consider two kinds of impacts according to their time horizon: firstly the short- and medium-term impacts, referring to the crisis management and, secondly, the long-term impacts, occurring months or a few years after the event. The ranking of impacts into three classes is based on their spatial extent and the number of impacts. Several types of short and medium-term impacts are considered: VIP visits (President of the Republic, Prime Minister, etc.) in support of victims, national solidarity effort, extensive media coverage, rumours on the causes of flooding, unfavourable context (war, political crisis). Three main long-term impacts are also considered: establishment of a new risk management policy, judicial consequences, and event still in living memory (memorial site, films, plays, books, etc.).
- *Aggravating factors likely to cause a significant increase in the damage level.* These factors are related to two parameters. Firstly, the occurrence of failures during the warning of the exposed population and, secondly, a high incidence of solid transport or landslides during the triggering rainfall event. The score associated with this criterion is lower, and varies from 0.5 to 2 to avoid placing excessive weight on flash floods which are mainly concerned by this criterion.