Flash floods, hydro-geomorphic response and risk management. Preface of the special issue

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## 1. Introduction

Each year, natural disasters are responsible for fatalities and economic losses worldwide with 101 billion USD in economic losses and 7000 fatalities reported for 2014 (SwissRE, 2015). Even if earthquakes are responsible for most of these fatalities, flash floods and landslides are recognized as a significant source of threat to human lives (SwissRE, 2015). Jonkman (2005), in a global assessment of flood-related casualties, showed that flash floods lead to the highest mortality (number of fatalities divided by the number of affected people). They are also often associated with shallow landslides and geomorphic processes that can increase threat to human lives. Analysis of a global data set of fatalities from non-seismically triggered landslides (Petley, 2012) shows that 2620 fatal landslides were recorded worldwide in the period 2004–2010, causing a total of 32,322 recorded fatalities. In addition, heavy precipitation events, at the origin of flash floods and shallow landsliding are expected to increase in the future (e.g. Scoccimarro et al., 2015 for a recent study in Europe). Progress in flash floods and landslides understanding, forecasting and warning is therefore still needed to increase to disentangle the complex interactions between hazards, exposure and vulnerability and to increase resilience (Borga et al., 2014).

A previous special issue of J. Hydrology entitled “Flash floods: observations and analysis of hydro-meteorological controls”, published in 2010 (Borga et al., 2010), provided first insights about the value of data collection specifically targeted towards flash floods studies and advanced common frameworks for flash flood data analysis and for flash flood forecasting. The present Special Issue “Flash floods, hydro-geomorphic response and risk management” extends the focus by examining hydrogeomorphic responses of intense rainfall and advancing analyses of socio-economic impacts and of risk management options and policies.

New data at higher resolution are now available and a number of papers of the present special issue exploit these new data to provide new insights into flash flood and landslides process understanding. Progresses in flash flood and landslide forecasting are also illustrated by several papers which report on various initiatives in different countries. A significant numbers of papers address socio-economic impacts, showing the value of multi-disciplinary approaches (e.g. Ruin et al., 2014), as advocated in the new Panta Rhei (Montanari et al., 2013) decade of the International Association of Hydrological Sciences.

## 2. Overview of the special issue

This special issue of the Journal of Hydrology entitled “Flash floods, hydro-geomorphic response and risk management” contains 47 papers. Several papers present new insights gained in flash flood and landslide processes understanding based on new data analyses and modeling studies, mainly thanks to data sets with higher space-time resolution. Flash flood and landslide forecasting are also topics of active research. Studies addressing socio-economic impacts and how they can be related to flash flood physical characteristics are also presented, in relation with new data collection (including historical events) and analyses, often involving pluri-disciplinary teams. Some papers also address risk perception by people. Several studies also address jointly flash floods and landslides as they are often related. They show how a common appraisal using approaches developed both in geomorphology and hydrology can be complementary.

The papers included into this special issue are organized in four main topics:

1/ Advancing flash flood understanding and forecasting using new data collection and modelling studies

2/ Shallow landslides and geomorphic processes understanding, modelling and forecasting

3/ Flash flood forecasting

4/ Advancing understanding of vulnerability and risk perception associated to flash floods and landslides

Case studies are mostly concentrated in the Mediterranean region and in the USA, but several papers from more northern countries, the Middle East, Japan, China and Papua New Guinea show that flash floods and landslides are a concern in all parts of the world.

*Theme 1: Advancing flash flood understanding and forecasting using new data collection and modelling studies*

The first theme “Advancing flash flood understanding and forecasting using new data collection and modelling studies” contains 15 papers. Quantitative Precipitation Estimation (QPE) and description of rainfall space-time variability are still active topics leading to several papers aiming at improving QPE accuracy and space-time resolution to be consistent with flash floods and urban hydrology studies (1 $km^2$ and 1 h resolutions). Methods rely mainly on more or less sophisticated merging of radar and rain gauges data and the quantification of uncertainties (Berg et al., 2016; Boudevillain et al., 2016). Llasat et al.

(2016) illustrate the value of high temporal rainfall resolution (1 to 5 minutes) to study the impact of convective rainfall on flash floods and on their evolution in northeast Spain. Silvestro et al. (2016) illustrate how the description of the space-time resolution of rainfall can explain the occurrence of a severe flash flood in Genoa (Italy) highlighting the needs for a better knowledge and forecasting of rainfall space-time patterns, a correct description at space scales of less than 8 km and time resolution of less than 3 h being needed to correctly reproduce observed characteristics of the flood. Pino et al. (2016) use the new NOAA 6 Hourly 20th Century V2 Reanalysis Data Composites to analyze the synoptic factors associated with 24 catastrophic flash floods that affected the NE Iberian Peninsula over the period 1842-2000. Such analyses are valuable as they can be used to assess possible impact of climate change on the occurrence of flash floods. Halbert et al. (2016) also show the value of historical data and post-event discharge estimation in flood frequency analysis. They compare local and regional approaches when historical flash flood and/or data from post-event surveys are included in the analysis using a Monte-Carlo approach. They show that historical and post-event data enhance results robustness for both approaches.

The value of high resolution data sets to advance flash flood understanding and modelling is demonstrated in several papers. Camarasa-Belmonte (2016) use data collected since 1988 by a rain gauge – discharge network with 5 minutes time step in the Valencia region (Spain) to identify and analyze the controlling factors of flash floods in ephemeral streams. She is able to identify two types of events characterized by different characteristics in terms of rainfall amount and intensity. Le Bourgeois et al. (2016) use high temporal resolution soil moisture time series and inverse modeling to identify soil hydraulic properties associated with schist geology soils in the French Cévennes-Vivarais region, prone to flash floods. They show that rainfall can infiltrate in the weathered bedrock but that the hydraulic conductivity of this horizon is too low to avoid saturation at the weathered bedrock-soil interface, leading to local soil saturation and sub-surface flow. The method can be generalized to other geologies to better characterize infiltration capacity in flash flood prone areas. Asano et al. (2016) acquired high resolution (1 minute) surface flow and velocity in a headwater river stream to better understand flow conditions during flash floods. This provides useful information for the use of non-contact methods for gauging flooding rivers. Gazquez et al. (2016) show how hourly temperature monitoring in a cave located in a karstic area in southeast Spain provides insight into the timing and space distribution of a flash flood without the requirement of discharge measurements. These results are of great interest as flow in karstic areas is poorly documented, although karstic areas occupy a significant area in Mediterranean regions. Flash floods are often associated with matter transport that can have an impact on coastal areas. Capello et al. (2016) documented a flash flood in Genoa (Italy) and measured physico-chemical characteristics of the water led by the flood in the coastal area. They show that the impact is significant but of short duration and that wind conditions are more influential on the dynamics of the area.

Other papers try to better understand processes active during flash floods, combining observations and modeling in a hypothesis testing framework (Clark et al., 2011). Vannier et al. (2016) propose a distributed hydrological model set up at the regional scale in the Cévennes-Vivarais region and highlight the role of geology in modulating the hydrological response between and during flash floods. They use both continuous and post-event data to assess the model performance. Using a data driven approach to build a semi-distributed model, Adamovic et al. (2016) also highlight the role of geology in shaping the hydrological response of Mediterranean catchments. They show that a model based on the hypothesis of dominant sub-surface flow is able to reproduce quite well observed flash floods in wet conditions and low vegetation period. On the other hand, in dry and vegetated periods, the role of evapotranspiration must be taken into account. Vincendon et al. (2016) show how an improved representation of soil water transfer allows the setting of a regional scale modeling without calibration. They also use proxy data (road cuts) to assess the validity of the proposed modeling. Grillakis et al. (2016) use a semi-distributed model to assess the role of initial soil moisture on flash floods comparing results in Austria and Crete. The impact of soil moisture on flood peak appears to be quite low. An interesting point of this study is that initial soil moisture was derived from satellite data, which is of interest in data scarce areas (see also Tekeli et al., 2016).

*Theme 2: Shallow landslides and geomorphic processes understanding, modelling and forecasting*

In the second theme, “Shallow landslides and geomorphic processes understanding, modelling and forecasting” (10 papers), several papers revisit the threshold approach for landslides or debris flow forecasting. Three papers highlight the importance of high-resolution rainfall data for better estimation of the rainfall threshold relationship, highlighting the need of weather radar rainfall estimates for this task (Abancó et al., 2016; Iadanza et al., 2016; Marra et al., 2016). Peres and Cancelliere (2016) use a Monte-Carlo simulation approach to compute the return period of rainfall triggering landslides. Using high resolution data collected in an experimental catchment, Abancó et al. (2016) analyzed triggering factors of landslides and found that the factors that were better discriminating triggering and non-triggering rainfall were rainfall amount, maximum and average intensity. Bezak et al. (2016) used copula to compute intensity-duration-threshold (IDF) relationships and compared their efficiency with more traditional rainfall-thresholds methods for floods, landslides and debris flow prediction. They show that better results are obtained with the IDF approach. Ciabatta et al. (2016) use an early warning system for landslides set up in the Umbria region (Italy) to assess the impact of climate change on landslides occurrence and show an expected increase of up to 40% by the end of the 21st century as compared to present. Robbins (2016) used a modified Bayesian approach for assessing thresholds of landslide probability associated with rainfall events of satellite-derived specific magnitude and duration in Papua New Guinea.

Flash floods are also often associated with intense debris and sediment transport. The geomorphic impacts of flash floods are also documented. Segura-Beltran et al. (2016) use a combination of a distributed hydrological model, coupled with a 2D hydrodynamic model to get insight into geomorphic processes associated with a severe flash flood that occurred in Girona (Spain). The coupled model is validated using flow depth and flood plain extension. The model is then used to understand how paleochannels and alluvial fans were activated by the flood and how some anthropogenic elements provided disturbances to the flow. Ruiz-Villanueva et al. (2016) propose a model to assess the impact of flood shape and amplitude on the remobilization of woods, making the distinction between floods and flash floods. The model proves complementary to observations and allowed showing for instance a positive correlation between the number of remobilized woods and the length of the flood rising limbs. Albano et al. (2016) tested a new numerical method for fluid dynamics computation in order to simulate the transport of floating bodies by flash floods. The model is evaluated using a laboratory experiment simulating a dam break in a channel with floating bodies, representing for instance cars. Given the good performance of the model, the latter is used to compare several mitigations methods, aiming at limiting floating bodies' entrainment.

*Theme 3: Flash flood forecasting*

The third theme deals with "Flash flood forecasting" with 10 papers. Douinot et al. (2016) assessed the Flash Flood Guidance method in Mediterranean French catchments and proposed improvements to the method in order to take into account rainfall spatial variability. Miao et al. (2016) also revisit the Flash Flood Guidance method to propose a flash flood forecasting system for China. The rainfall threshold identification is based on distributed rainfall-runoff model climatology and binary classification of the resulting data. Zhang et al. (2016) study the impact of radar/rain gauges reanalysis bias correction on the performance on flash flood detection. They show an improvement for larger catchments but the bias correction is detrimental for small catchments. Nguyen et al. (2016) proposed a semi-distributed hydrological model coupled with a 2D hydraulic model, aiming at simulating discharge, water height and velocity for flash flood warning. The model is set up with a priori parameters and not calibrated. A sensitivity test is performed using synthetic precipitation input showing reasonable performance of this non-calibrated model. The latter is also evaluated for several observed events. Tao et al. (2016) use data from the Integrated Precipitation and Hydrology Experiment (IPHEx) where an enhanced rainfall measurement set up was deployed in order to improve QPE to assess, in near real time conditions, the performance of flash flood forecasting systems. They compare different QPE products, data assimilation systems and obtain in particular promising results with the assimilation of discharge data. Artinyan et al. (2016) present an operational flash flood forecasting system set up in the Arda transboundary catchment between Bulgaria and Greece. The system is based on a calibrated distributed hydrological model, with improved river routing. The forecasting system is operated using real time transmitted rain gauge data. The system provides one line forecasting and is evaluated in the paper using a real case study. Tekeli et al. (2016) use satellite derived rainfall to set up a flash flood warning system is Saudi Arabiya. Several papers propose flash flood ensemble forecasting systems. Hardy et al. (2016) propose a probabilistic flash flood forecasting system based on rainfall forecast from an ensemble Quantitative Precipitation Forecast (QPF) products. They also consider errors in intense cells location before feeding the fully distributed, non-calibrated CREST hydrological model. The method is evaluated on a case study in Oklahoma. Ravazzani et al. (2016) assess the value of Ensemble Precipitation Forecast to improve flash flood warning in the urban area of Milano (Italy). They show that this kind of approach provides useful information to improve civil protection warning. Lagadec et al. (2016) address more specifically floods associated with quick runoff that can occur outside the river network. They propose a runoff mapping susceptibility method to the production, transfer and accumulation of runoff. They use proxy data such as regulatory maps and disruptions on roads and railway networks to assess the relevance of their method.

*Theme 4: Advancing understanding of vulnerability and risk perception associated to flash floods and landslides*

Twelve papers address both physical and social vulnerability to flash flood. In terms of damages, several papers distinguish between "ordinary", "extraordinary", "catastrophic" events (Aceto et al., 2016). However, Schroeder et al. (2016) show that the definition of a generic flash flood severity index, that may apply in different hydro-climatic and/or for different environment (urban, rural) is not straightforward. Boudou et al. (2016) propose a multi-disciplinary approach to define how a flood can be qualified as "remarkable", including information on the hazard intensity, fatalities and damages and impact on society. They analyze more specifically four historical events in France and show which factors contribute to create a "remarkable" flash flood. Aceto et al. (2016) collected a data base of damages from hydro-meteorological events, including flash floods and landslides in the Calabria region. They provide trend analysis on those damaging events. Karagiornos et al. (2016) propose a method to map the susceptibility of the Greek territory to flash flood including structural building vulnerability but also social vulnerability. Ettinger et al. (2016) propose a vulnerability function for buildings based on the reconstruction of a flash flood that occurred in Peru, where field data about damages and flooded areas were collected. Portugues et al. (2016) reconstructed an historical event that occurred in 1957 in Valencia (Spain) in terms of hydraulic and geomorphic elements, using historical sources of information (aerial photographs, water marks). The authors show how man-made infrastructure contributed to the vulnerability during this event. An historical event, which occurred in 1967 in Portugal that led to more than 500 casualties, is analyzed in details by Trigo et al. (2016) in terms of hydrological and social vulnerability. This is made possible by the building of an historical data base about flash floods in Portugal. Garrote et al. (2016) built a stage-damage function for a small village in Spain, based on extensive data collection after a flash flood event. They show that the locally based function provide much more realistic results that nationally based functions. They use this function to assess the cost-benefit or protective measures.

During flash floods, vulnerability is also related to population displacement. Lutoff et al. (2016) propose a multi-scale framework to analyze the social response to flash floods before peak flow and in particular how they organize themselves to face the event. Debionne et al. (2016) present a model aiming at simulating the mobility and exposure to flash floods of commuters during their daily activities.

Several papers address people perception related to flash floods. Morss et al. (2016) conducted a survey to analyze people's perception of flash flood risk, understanding of the flash flood warning levels in the USA and knowledge of people reactions in case of flash floods. Bodoque et al. (2016) performed a similar study in central Spain. Both studies highlight a low perception of risk and a low preparedness.

## 3. Conclusions and directions for future researches

The diversity of topics and originality of results presented in this special issue shows that flash flood and landslides studies are areas of active and innovative research. While in the past, the study of hazard, vulnerability and risk were often tackled separately; several papers in this volume show the value of multi-disciplinary approaches to better understand these combined elements. Some papers have also demonstrated the interest of high space-time resolution data to better understand processes active in flash flood and landslides generation, in particular the value of radar rainfall data to get a correct picture of forcings for flash flood and landslide processes. A new and exciting area of research is the use of information provided by social networks and citizens for a better appraisal of the spatial variability of hazard and impacts (e.g Koswate et al., 2015, Le Boursicaud et al., 2016) that is particularly relevant for flash floods. Radar observations provide the capability to estimate rainfall at scales suitable for flash flood and landslide forecasting. Hydrologic models are just now beginning to use these estimates to forecast the magnitude, specific locations, impacts, and uncertainty associated to flash floods on continental scales. Improved observations from satellite-based and airborne platforms will continue to improve the estimation of rainfall as well as to retrieve hydrologic states such as soil moisture, streamflow, and surface inundation. The expansion of social media and the emergence of “citizen scientists” provide great capabilities for improving observations of flash flood impacts that can improve the forecast models.

Several of the papers presented in this collection make the best out of scarce data available to validate the hypothesis presented. The number of long term data inventory to verify the emerging approaches is limited. In some cases inventories are not updated anymore because of lack of funding. We think that any of the modelling approaches presented would benefit if the community would spend some more time now on retrieving data for future proof of the innovative concepts that are elaborated.

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