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OBSERVATION OF HYDROLOGICAL AND SOCIAL RESPONSES TO EXTREME PRECIPITATION USING POST-FLOOD INVESTIGATIONS

OPAZOVANJE HIDROLOŠKEGA IN SOCIOLOŠKEGA ODZIVA NA EKSTREMNE PADAVINE Z RAZISKAVAMI PO POPLAVNIH DOGODKIH

Marco Borga[1]

[1] Department of Land, Environment, Agriculture and Forestry, University of Padova, AGRIPOLIS, Legnaro (PD), Italy

Abstract

The last decade has witnessed the development of methodologies for post-flood documentation of hydrological response to extreme precipitation. These investigations are particularly interesting in case of flash floods, whose space-time scale of occurrences makes observations with conventional hydro-meteorological networks a challenging task. Effective documentation of flash floods requires post-flood survey strategies encompassing accurate radar rainfall estimations, field observations of geomorphic processes associated with the flood, indirect reconstruction of peak discharges and interviews of eyewitnesses. This paper reviews new methodologies to conduct post-flood investigations based on interdisciplinary collaboration between social and physical scientists. These methods, designed to explore the link between crisis behavioural response and hydro-meteorological dynamics, aim at understanding the spatial and temporal capacities and constraints on human behaviours in fast evolving hydro-meteorological conditions. The paper is a tribute to Professor Brilly: a respected scholar, researcher, and educator.

Keywords: flood risk, flash flood, flash flood hazards, flash flood vulnerability.

Izvleček

V zadnjem desetletju je prišlo do razvoja metod za dokumentiranje hidrološkega odziva na ekstremne padavine po samem dogodku. Takšne analize so posebej zanimive v primeru hudourniških poplav, pri katerih so meritve z običajnimi hidro-meteorološkimi merilniki pogosto težavne in predstavljajo izziv. Ustrezna dokumentacija zahteva pravilno strategijo terenskega ogleda po sami poplavi, ki je kombinirana z radarskimi meritvami padavin, terenskim ogledom geomorfoloških pojavov, posredno oceno konice pretoka ter intervjuji z očividci poplavnega dogodka. Prispevek prikazuje pregled metod za izvedbo ustreznih analiz po samem dogodku z upoštevanjem interdisciplinarnega sodelovanja med družboslovnimi in naravoslovnimi znanstveniki. Te metode, ki se uporabljajo za oceno povezanosti med kriznim odzivom v primeru ekstremnih dogodkov ter hidro-meteorološko dinamiko, lahko uporabimo za nadgradnjo razumevanja o prostorski in časovni zmogljivosti ter omejitvah pri človeškem obnašanju v primeru hitro razvijajočih hidro-meteoroloških pogojev oziroma dogodkov. Prispevek je namenjen prof. Brilly-ju, cenjenemu raziskovalcu in profesorju.

[1] Stik / *Correspondence*: marco.borga@unipd.it

Ključne besede: poplavno tveganje, hudourniške poplave, ogroženost zaradi hudourniških poplav, ranljivost zaradi hudourniških poplav.

1. Introduction

Although flash floods generally affect a limited number of persons when compared with other types of floods, they can be considered the most deadly type of flood (Doocy et al., 2013). According to Barredo (2007), flash floods in Europe caused around 2800 fatalities over the period 1950–2005, i.e., 50 casualties per year on average. Similar figures of flash flood-related fatalities were reported for the United States (U.S.) by Ashley and Ashley (2008).

The high risk potential of flash floods is related to their rapid occurrence and to the spatial dispersion of the areas which may be impacted by these floods. Both characteristics limit the ability to issue timely flood warnings. The contracted response time of the flash floods is linked on the one hand to the size of the affected catchments, which is generally less than a few hundred square kilometres (Fig. 1), and on the other hand to the activation of rapid runoff processes, generally surface runoff, that become the prevailing transfer process. Indeed, the sudden nature of the response is a characterizing feature of flash floods. In the USA flash floods are regarded as having a time to peak of up to 6 hours for catchments of up to 400 km^2. Marchi et al. (2010) showed that this definition may apply to the Mediterranean and Continental areas of Europe as well.

The small spatial and temporal scales of flash floods relative to the sampling characteristics of conventional rain and discharge measurement networks make also these events particularly difficult to observe and to predict (Borga et al., 2008). The recognition of the poor observability of flash floods has stimulated the development of a focused monitoring methodology in the last decade, which involves post-flood surveys, use of weather radar observation re-analyses and hydrological modelling (Marchi et al., 2009; Bouilloud et al., 2009; Calianno et al., 2013; Amponsah et al., 2016).

Flash flood events also offer a template to study the relation between flood dynamics and the social response in the context of fast spatial and temporal changes of the flooding conditions. Based on several studies performed in Europe concerning social responses to flooding, Parker et al. (2009) define two categories of contextual factors influencing the responses to flood warning: physical characteristics and social circumstances. Among physical characteristics, the severity of the flood and the time available between the warning and the flood appear the most important factors for social responses. Concerning social characteristics, people’s experience, their knowledge concerning flood risk and the distribution of responsibility for responding to flooding are identified as the main influencing factors for floods.

Often, flash floods happen so quickly that the exposed communities have no time to even access rescue services. Nevertheless, individuals and improvised groups manage to inform, organize and protect themselves on their own, without any official involvement (Creutin et al., 2009). Investigating human and environmental circumstances of personal stories experienced by individuals and groups in such a crisis is crucial for learning more about the link between environmental conditions and social settings. This type of analysis also provides key information for the improvement of individual and organisational preparedness and mitigation of flash flood risk in general. Along this line of research, a few studies (Creutin et al., 2009; Ruin et al., 2014; Lutoff et al., 2016) have recently shown that integration of physical and social processes investigation under the form of common research questions and methodology is feasible and useful. In a broader context, this line of research has been substantially contributed to by Mitja Brilly and colleagues, as shown by Brilly (1992), Brilly and Polic (2005) and Spitalar et al. (2014).

This paper provides a concise review of methods based on post-flood investigations for the analysis of hydrological and social responses to extreme precipitation.

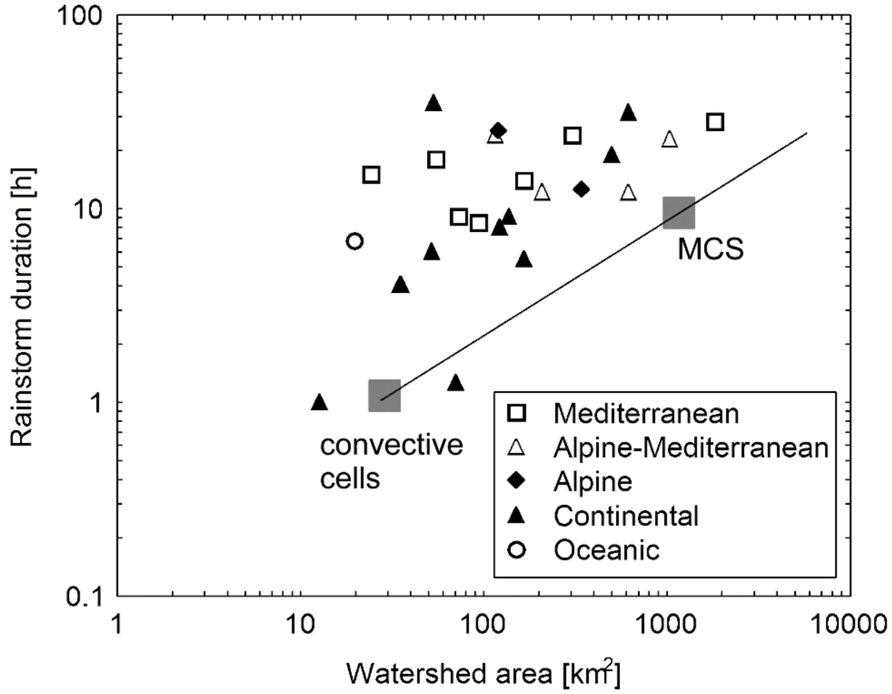

Figure 1: *Spatial and temporal scales for a number of extreme flash floods analysed by Marchi et al. (2010). For each flood, the largest impacted watershed size and the corresponding rainstorm duration were considered.*

Slika 1: *Prostorski in časovni vidik večjega števila ekstremnih poplav, ki jih je analiziral Marchi s sod. (2010). Za vsako poplavo je upoštevano največje prizadeto porečje ter pripadajoče trajanje padavinskega dogodka.*

a) b) c)

Figure 2: *Post flood survey: a) Examples of a high water mark. The vegetation removed from the rocky bank and the moss drenched with silt on the downstream side of the tree show the highest level reached by floodwater (red line). b) The arrow shows a tree with the flood mark and a phase of the topographic survey of the river section. c) Surveying the stream bed.*

Slika 2: *Raziskave po poplavah: a) Primeri določanja najvišjih gladin poplavnih voda. Na najvišjo gladino poplavne vode nakazujejo sprana vegetacija s kamnin in spremembe na mahovju na dolvodni strani drevesa. b) Puščica prikazuje drevo s poplavno označbo in del topografske analize rečnega odseka. c) Preučevanje dna struge.*

2. Post-flood surveys of hydrological response

Observations of traces left by water and sediments during a flood provide an opportunity for developing spatially detailed estimates of peak discharges along the stream network during post-flood surveys (Fig. 2). This is particularly helpful for better understanding the role of rainfall accumulation and rates and of soil and land use properties in runoff generation for flood events characterised by sharp gradients in runoff response properties and lack of streamgauge data (such as flash floods).

Indirect methods for flood peak estimation include the slope-area, contracted opening, flow-over-dam, or flow-through-culvert. However, the important thing to note here is that the survey needs to capture not only the maxima of peak discharges: less intense responses within the flood-impacted region are important as well. These can be contrasted with the corresponding generating rainfall intensities and depths obtained by weather radar re-analysis, thus permitting identification of the catchment properties controlling the rate-limiting processes (Zanon et al., 2010). Clearly, not all the river sections may be suitable for indirect peak discharge estimation. However, Borga et al. (2008) have shown that, provided that a careful logistical planning and properly staffed infrastructure is ensured, post-event surveys may deliver a spatially consistent analysis of the flood response. Surveying the geomorphic response, through mapping of landslides/debris flow initiation and deposition areas, is important as well. This may help to properly identify the flow processes that occurred in the basin and hence to avoid questionable peak discharge estimates. Rain-triggered geomorphic processes may place considerable limitations to the reliability of indirect methods for flood peak estimation. For instance, scour and/or fill may occur after the high water marks are left by the current. The effect is that the cross-section geometry surveyed after the flood is different from the one existing at the time of the peak flow. Since geomorphic impacts are typically more severe in sub-basins where runoff generation is more intense, these errors may have a considerable impact on outcomes from post-flood surveys.

Marchi et al. (2010) have shown the advantages of integrating indirect peak discharge estimates with spatially distributed model-based flood simulations. With this integration (Fig. 3, where specific emphasis is placed on evaluating geomorphic impacts), simulated flood hydrographs are first compared with indirect peak discharge estimates, then model based analysis is carried out where modelled flood hydrographs are consistent with field-derived peak observations. The comparison between rainfall-runoff model simulations and indirect peak flow estimates may be used to remove erroneous field-derived estimates and isolate consistent hydrological simulations. The analysis of the modelled flood hydrographs allows one to evaluate the water balance at the event scale and to provide estimates of the runoff coefficients (ratio of event runoff to event rainfall). Analysis of event runoff coefficients may provide essential insight into how different landscapes ‘filter’ rainfall to generate runoff and how the observed differences can be explained by catchment characteristics (Blume et al., 2007; Norbiato et al., 2009). A critical step in the integrated flash flood analysis is to quantify how field-model-based peak estimates are close enough, taking into account the relevant uncertainties (Amponsah et al., 2016).

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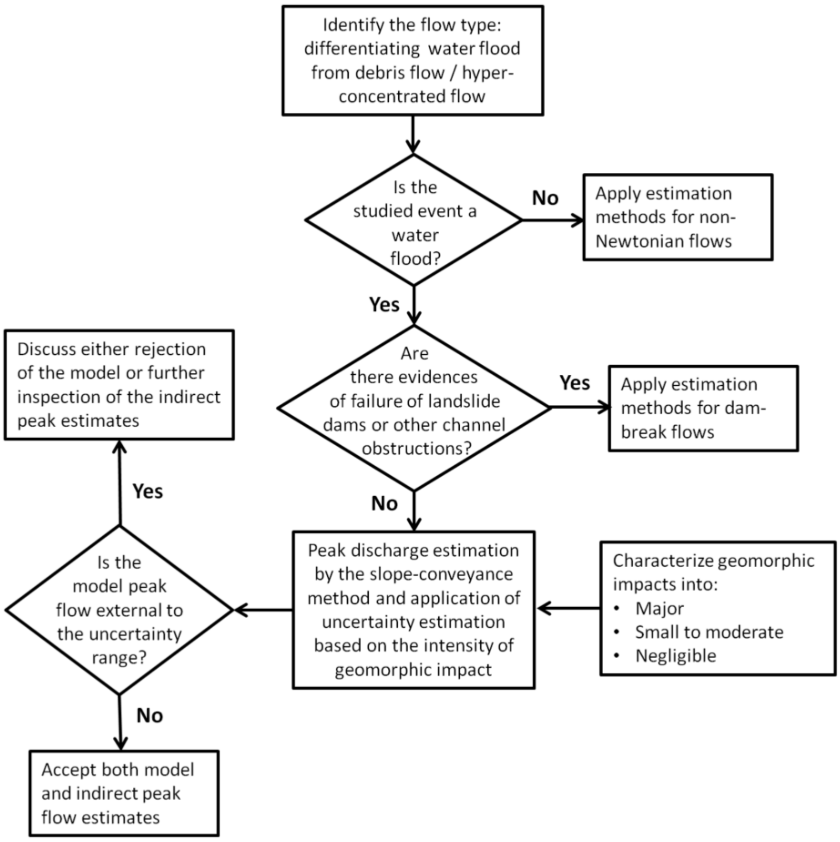

Figure 3: *Flowchart for integrated use of indirect flood peak estimates and flood modelling: indirect estimate of peak discharge, uncertainty assessment and comparison with model-based peak flows (from Amponsah et al., 2016).*

Slika 3: *Diagram celostne uporabe ocen konic pretokov ter poplavnega modeliranja: posredna ocena konice pretoka, negotovosti ter primerjave z modeliranimi konicami (povzeto po: Amponsah et al., 2016).*

3. Post flood survey of social response and of linkages with the hydrological response

In a series of papers (Ruin et al., 2014; Creutin et al., 2009, 2013; Ruin et al., 2014; Lutoff et al., 2016), a methodology has been designed to collect pieces of evidence needed for understanding both the hydrological context and the human behavioural responses. After a first field campaign dedicated to the observation of the hydrological response (during which eye-witnesses are also identified and interviewed), a second campaign is carried out which aims at collecting individuals' own stories through semi-structured interviews. It especially focuses on collecting timing and spatial information related to the evolution of the hydrological 'boundary' conditions and the individuals' location and pace of activities. Its objective is to document how individuals switch from routine activities to emergency coping behaviours. Inspired by the activity-based approach, it is structured around a chronological guideline with which the interviewees are invited to recall what they perceived from their environment, what actions they took and who they interacted with at the various places they stayed and while moving in-between places (Fig. 4).

The interviews are typically conducted using a "snow-ball" (nonprobability) sampling strategy in order to capture the effects of social networks in triggering emergency reactions. By crossing the individual stories, this method allows to confirm the timing and spatial characteristics of both social and hydro-meteorological events. Furthermore, the snowball method enables the reconstruction of the social network and the personal interactions emerging during the event. The survey campaign starts with interviewing the contact persons listed by the hydrological post-flood campaign. These people are asked to identify any other people with whom they were in contact (directly or indirectly) at various stages of the event. Then, as much as possible, the team interviews all the contacts they mentioned to get a more precise idea of the specific situations in which they were all involved.

The narratives are then coded to reflect the various types of situations reported. The variable *"place"* is coded to show the type of social places where people were located such as the workplace, a dwelling or a public building. This is based on an assumption that the type of place where people are situated might influence individual responses to warnings as it has been argued in previous research that coming back home and gathering the family there is one of the first drivers of behaviour during a crisis (Drabek, 1986; Mileti, 1995). The variable *"activity"* codes the type of behaviour. Four main categories are selected with the objective of capturing the transition from routine activities that are qualified as *"usual"* and crisis activities including three gradual states that were qualified in previous work as *"information"* (information collection and analysis to decide if and how to act), *"organization"* (organization to prepare and implement a plan of action), and *"protection"* (protective action to get exposed people to safety) (Creutin et al., 2009). The acronym IOP is used to identify the Information–Organization–Protection chain of activities that combine to ''anticipate'' the flood danger.

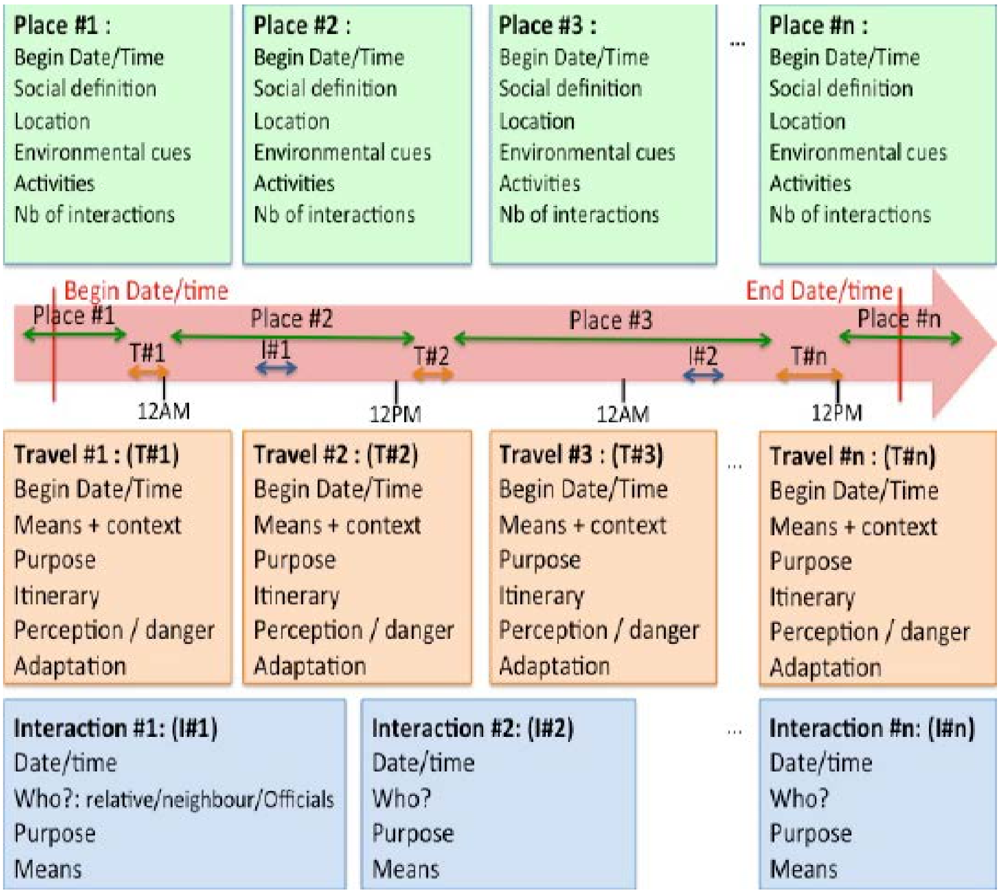

Figure 4: *Semi-structured interview framework used for observation of the social response (from Ruin et al., 2014).*

Slika 4: *Delno strukturiran okvir za izvajanje intervjujev v primeru opazovanja socialnega odziva (povzeto po Ruin et al., 2014).*

The narratives are also coded based on three basic levels of human organization, such as: (1) *Individuals* and households; (2) *Communities* consisting of small groups of people such as neighbourhoods, villages or spontaneous assemblages of people in a store or at an event; and (3) *Institutions* including public services like civil protection or transportation departments. Social media, information technologies and the Internet may add complexity to this categorization and may play an increasing role during flash floods in terms of both formal and informal organization of the anticipation actions.

Analysis of the data collected based on this methodology has assisted social scientists to disentangle the human response into action sequences that are localized at a given place and to formalize the ‘‘timeliness’’ of human actions (Ruin et al., 2014). This exercise contributes to challenge the classical top-down framework of ‘‘official’’ flood warnings delivered by professional risk managers that applies more globally at a regional or national level, and which poorly applies at local level. The data allows one to explore the multilevel resources of human response, showing how individuals and small groups of people emerge during crises to organize their own ‘‘unofficial’’ local protection. These results also seem to confirm that people behave differently based on the local conditions they face during flash flooding. Human actions adapt their pace to the physical context and are in a kind of ‘‘hurrying’’ process as the danger approaches.

The implications of the data analysis for adapting the warning processes to social scales (individual or organisational scales) are considerable, and range, for example, from communication of uncertainty in hydrological forecast to the provision of means to evaluate the level of preparedness at different social and organisational scales.

4. Conclusion

This paper has shown that integrated multidisciplinary investigation of physical and social processes triggered by flash floods, based on common research questions and a coordinated post-flood observation methodology, is feasible and useful. Collecting flash flood peak data at multiple locations based on the integrated methodology advocated here will help to identify the role of runoff production mechanisms and space-time variability of rainfall for flash flood response in different hydro-climatic conditions. It will also assist to better quantify the errors that should be expected when flash flood forecasts are obtained by using hydrological models calibrated based on high frequency events.

The use of integrated multidisciplinary investigation of physical and social processes triggered by flash floods will help to compare the pace and timeliness of the social responses to flash floods across several flood events' dynamics and social contexts. This is crucial to improve the warning and response phase in flood risk management and to forecast the possible human impacts of flash floods. To this end, there is a need to progress in the collection of data and observation on both the social and physical processes at different scales, even the very small ones. New tools could be used for this purpose, including the analysis of social networks, which provide a very impressive mass of information, temporally and spatially specified. Tweeter, Facebook and other social networks constitute very interesting resources and could be explored to observe what people do at specific time and location during an event and in which environmental and hydrological conditions.

This line of research is deeply indebted to the work of Prof. Mitja Brilly and his group of researchers. This paper is dedicated to him on the occasion of his 70th birthday.

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