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► To cite this version:

Pierre Javelle, Isabelle Braud, Clotilde Saint-Martin, Olivier Payrastre, Eric Gaume, et al.. Improving flash flood forecasting and warning capabilities. . The Mediterranean Region under Climate Change. A Scientific Update, IRD Editions, 2016, 978-2-7099-2219-7. hal-01449341

HAL Id: hal-01449341

<https://hal.science/hal-01449341>

Submitted on 13 Feb 2017

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3.4.1 Improving flash flood forecasting and warning capabilities

Pierre JAVELLE, Hydrologist, Irstea, , Aix-en-Provence, France

Isabelle BRAUD, Hydrologist, Irstea, Villeurbanne, France

Clotilde SAINT-MARTIN, Hydrologist, Irstea, , Aix-en-Provence, France

Olivier PAYRASTRE, Hydrologist, Ifsttar, Bouguenais, France

Eric GAUME , Hydrologist, Ifsttar, Bouguenais, France

Marco BORGA, Hydrologist, University of Padova, Italy

Jonathan GOURLEY, Hydrologist, NOAA/National Severe Storms Laboratory, Norman, USA

Massimiliano ZAPPA, Hydrologist, Swiss Federal Research Institute WSL, Switzerland

Introduction

The consequences of flash floods can be dramatic in terms of casualties or economic losses. 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). For example, in the recent flash flood that occurred in the French Riviera around Cannes on 3 October 2015, 20 casualties and 650 billion euros of insured damage (source: <http://www.ccr.fr/>) were reported. Flash flood forecasting systems are critically needed to better organize crisis management and rescue operations.

As mentioned in [chapter 1.3.4](#) (Gaume et al. 2016), flash floods are characterized by a rapid increase of river water levels. They often affect small watersheds, generally ungauged. The spatial and temporal variability of rainfall, landscape characteristics and pre-event catchment wetness are important influential factors in flash flood generation, contributing to the large space-time variability of hydrological responses (Borga et al. 2011).

Forecasting flash floods is therefore a complex task. It necessitates the monitoring of large areas, where each small watershed of a few square kilometres can possibly be affected. Real-time observation networks and models must run at small temporal and spatial scales, [on the order of a few minutes and kilometres](#). Furthermore, discharge time series are not available for the majority of the possibly affected watersheds, posing a real challenge for model calibration and evaluation. In this context, radar based [precipitation](#) products [and/or](#)

meteorological forecasts with a high resolution (typically 1 km² grid size) are crucial (Creutin and Borga, 2003). Slight misplacements of the precipitation may for instance lead to warnings attributed to the wrong river network and to inappropriate flood management decisions.

Various approaches exist to forecast flash floods. One of the first proposed approaches is the so-called Flash Flood Guidance (FFG) [method](#) (Georgakakos, 1986). It consists of determining *a priori*, based on rainfall-runoff modelling, the amount of rainfall needed to generate bank-full discharge at the catchment outlet, depending on the initial wetness condition. Gourley et al. (2010) reviewed flash flood forecasting methods used in recent decades in the USA. According to their results, distributed hydrologic models forced by radar-based rainfall estimates outperform FFG in predicting discharge threshold exceedances. Several improvements of existing flash-flood forecasting methods based on distributed rainfall-runoff models have been recently proposed. Various tests have been conducted to assess how forecasting lead-time could be increased valuating quantitative precipitation forecasts (Barthold et al. 2015). In particular, some authors considered how uncertainties associated with these precipitation forecasts (intensity and location of larger rainfall cells) could be accounted for, leading to proposals of ensemble precipitation inputs (Velasco et al. 2013; Armengal, 2015) or a perturbation method applied to deterministic precipitation forecasts (Vincendon et al. 2011). A special issue of the Journal of Hydrology, which is about to be published (Braud et al. 2016), will feature ten papers presenting recent advances in flash flood forecasting. This includes the improvement of the FFG method to better account for rainfall spatial variability and initial soil moisture, the set-up of operational systems, the proposal of ensemble and probabilistic flash flood forecasting systems and the test of satellite-derived rainfall fields.

The present chapter focuses on two examples of recent advances in France, illustrating what performances could be achieved in the coming years by improved flash flood forecasting systems. The first example shows how effective flash-flood warnings can be proposed for small headwater streams, based on a simplified 1 km² rainfall-runoff model fed with rainfall [estimated from weather](#) radar data. The system, called AIGA, is running operationally over a large area in the South-East of France (Javelle et al. 2014). The second examples show how the impacts of flash floods can be directly forecasted to help crisis management services identify the areas at risk.

Highly distributed flash flood warnings: example of the AIGA system

The AIGA method was initially developed for the South of France (Lavabre and Gregory, 2006). Its real-time outcomes have been tested over the last five years, with end-users from the "Provence, Alps, "Côte d'Azur" region in the framework of the RHYTMME project (<http://rhytmme.irstea.fr>). It will be operationally implemented at the national French level in 2017. The AIGA method is based on a simple 1 km² grid distributed rainfall-runoff model (fig. 1) forced by radar rainfall estimates (fig. 2). The model, regionally calibrated and based on about 700 measured discharge series, is presented in greater detail in Javelle et al. (2016). It forecasts future discharge values along the modelled stream networks for all stream reaches with upstream watershed areas of at least 5 km². The theoretical return periods of the forecasted discharges, evaluated on the basis of a calibrated regional flood frequency method (Aubert et al. 2014), are then computed and mapped (fig. 3).

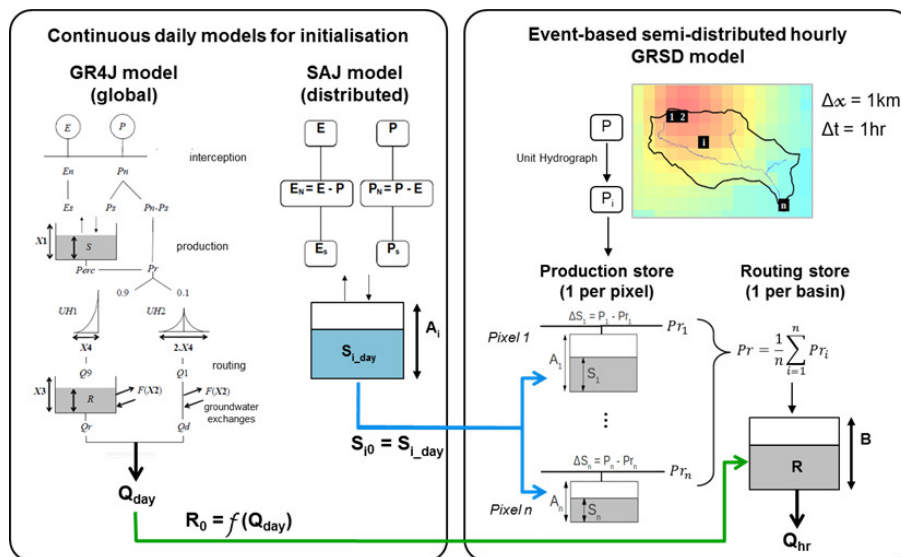


Fig. 1. Rainfall-runoff model included in AIGA, with precipitation (P) and evapotranspiration (E) as inputs, and daily and hourly streamflows (Q_{day} and Q_{hr}) as outputs (Javelle et al. 2016).

Two screen snapshots of the RHYTMME platform illustrate the type of outcomes produced by the AIGA method. These figures correspond to a major recent flash flood event which occurred on 3 October 2015 on the French Mediterranean coast which resulted in 20 fatalities and 650 million euros of insured damage. The intense rainfall event affected a narrow coastal and densely urbanized band of about 300 km² (fig. 2). The maximum rainfall intensity was measured in the town of Cannes: 175 mm in 2 hours. The 50-year peak discharge has been exceeded on several small coastal streams according to the AIGA method (fig. 3).

An intensive post-event survey was carried out after the event. Peak discharges were estimated at different ungauged river sections. Extensions of inundated areas were georeferenced. The type and location of damage and fatalities were reported based on field witness accounts and a press review. Social networks also proved to be a valuable source of information (Saint-Martin et al. 2016). This post-event documentation helped confirm the accuracy of the forecasts provided by the AIGA system. The overall consistency between the forecasted peak discharge return periods and the location of the fatalities and main damages can be seen for instance in [fig. 3](#).

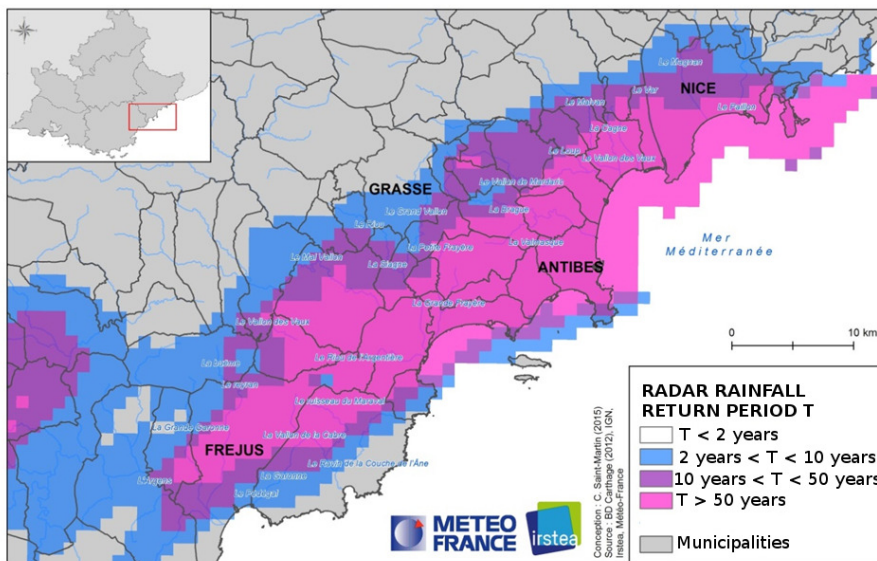


Fig 2. Return period of the cumulative radar rainfall intensities measured on 3 October 2015 (screenshot of the RHYTMME platform).

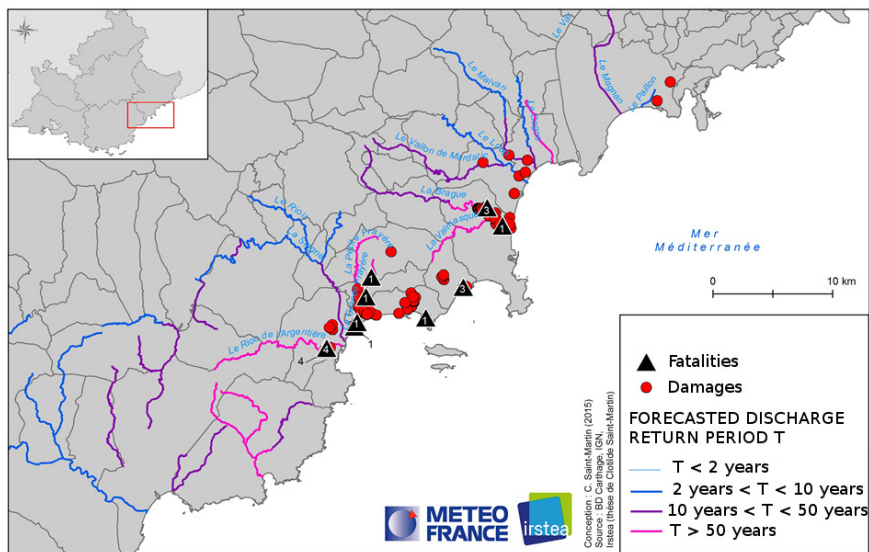


Fig. 3. Return period of the forecasted peak discharges for various stream sections for the 3 October 2015 flash flood event (screenshot of the RHYTMME platform). Location of the fatalities and main reported damages after the event.

In its current form, the AIGA method has two main limitations. First, the forecasts are based on ~~radar-estimated~~ measured rainfall, limiting the forecasting lead-time and event management capacities. Accounting for rainfall predictions could improve the situation. Second, decision makers have to translate forecasted stream discharges or water levels into possible field consequences to organize rescue operations. The forecasting delays leave very little time to conduct this analysis in real time in the case of flash floods. Ideally, forecasting systems should directly provide indications about possible field consequences to better support decision-making processes in flood event management situations. The next section illustrates, that this last objective will probably be attainable in the near future.

Towards the prediction of the possible impacts of flash floods

Fig. 4 shows one first illustration of the forecast of flash flood possible impacts. The test area is the French Gard department, located in the South East of France. It is the area most frequently affected by damaging flash floods in France: on average one event every year. The objective was to develop a prototype of a warning system to detect road sections at risk of flooding: 2,000 targets (intersections between road and river networks) were identified over an area of 5,800 km². The prototype was based on the combination of (i) a distributed rainfall-runoff model and (ii) a calibrated method rating the susceptibility to flooding of each road/river intersection, to adjust the discharge thresholds at which warnings are generated at each intersection (Versini et al. 2010; Naulin et al. 2013). Warnings and estimated

corresponding flooding risk levels were compared to reported inundation of roads for 10 recent severe flash floods (Figure 4). The results proved to be promising. Overall, the method appeared to be efficient in locating the affected area in the Gard department (fig. 4a). The matching between computed risk levels and actually inundated roads was less satisfactory in the affected areas, with high false alarm ratios due to the difficulty in characterizing a priori the susceptibility to flooding of the intersections (fig. 4b).

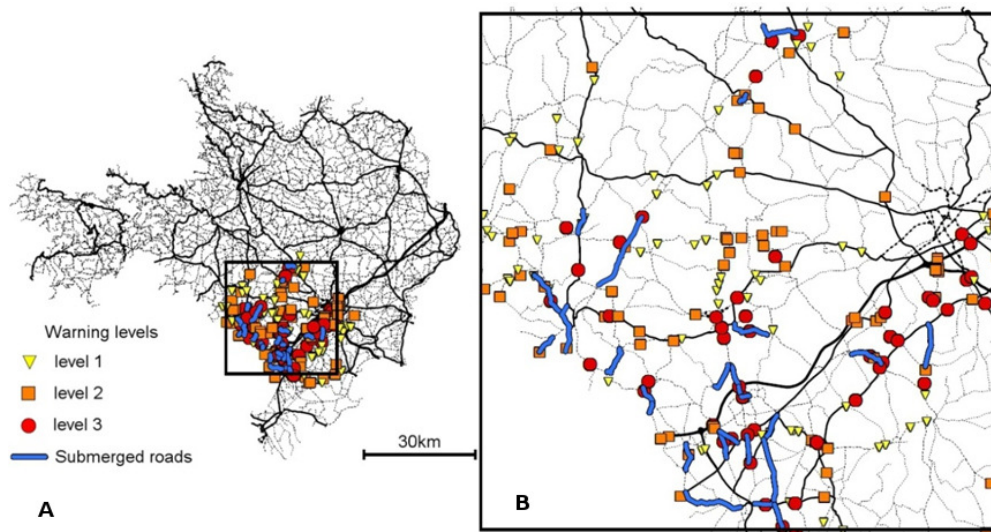


Fig. 4. Map of the maximum alarm levels generated by the PreDiFlood road inundation warning system for the 29/09/2007 event. Comparison with observed road inundations.

In the same line of thought and in the same area, tests are now being conducted to evaluate the extent to which the existing rainfall-runoff and simple hydraulic computation models are able to correctly forecast the extent of the inundated areas on a large stream network and provide indication about the possible number of affected buildings for each stream reach considered (Le Bihan et al. 2016). The forecasts are tested against insurance claims for this specific application, with promising preliminary results. Fig 5 illustrates the added value of an integrated approach forecasting the flash flood impacts (fig. 5b) when compared to a standard approach providing discharge magnitude forecasts (fig. 5a). The spatial distribution of the problematic stream reaches is clearly different for both methods. Unsurprisingly, local exposure and vulnerability are important drivers of the risk level and should be considered in flood event management.

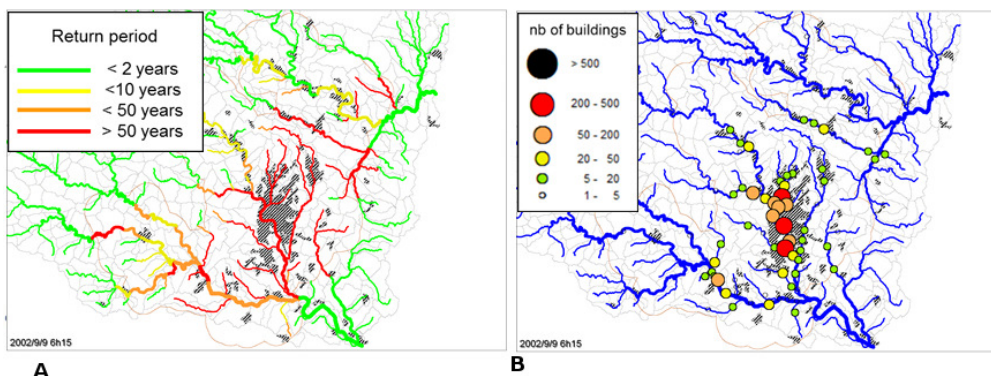


Fig 5. Example of forecasting results obtained for the 08/09/2002 event in the region of Alès (Gard): a) hydrological qualification based on the rainfall run-off model, b) associated impacts estimated (number of inundated buildings)

Conclusion and perspectives

Flash flood forecasting is a new, active and innovative research and development activity. Recent advances in term of hydrological modelling and rainfall measurement and forecasting now facilitate the proposal of operational applications and services, but progress is still ongoing as illustrated above. The challenges posed by flash flood forecasting require the development of interdisciplinary approaches merging competences in hydrology, meteorology, hydraulics and social sciences for a better assessment of exposure, vulnerabilities and risks.

If compared to standard flood forecasting approaches in the case of flash floods, the lack of measurements on most of the affected streams and the necessary prediction of flood impacts, imply the development of new approaches and the valuation of new information such as damage for the validation of the forecasts. Every citizen may become a potential observer and the emerging social networks prove to be extremely useful sources of information if correctly used. A new field of research is emerging, on how to collect and check this data (data mining), and how to use it in combination with flood forecasting models. Improved interactions with decision makers and stakeholders that could be affected by flash floods (for instance road or railway network managers, rescue services...) also present an interesting perspective, as these actors are both, possible end-users of the forecasts and data providers. [Remote sensing approaches also now provide information to detect the areal extent and depth of flooding, as well as to support streamflow estimation. Spaceborne platforms yield observations that are typically too infrequent for the flash flood scale, but observing platforms such as UAVs and aircrafts are increasingly used.](#)

Acknowledgements

Part of the literature review of this chapter was prepared for the preface of the *Journal of Hydrology* special issue about "Flash Floods, hydro-geomorphic response and risk management" which is in press. The work presented here also contributed to the HyMeX (Hydrological Cycle in the Mediterranean Experiment) program (Dobrinski et al. 2014).

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