# Implementation of a real-time warning and mapping system for natural hazards triggered by rainfall in mountainous and Mediterranean areas of Southeastern France

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C. Fouchier*[1], P. Mériaux[1], F. Atger[2], S. Ecrepont[3], F. Liébault[1], M. Bertrand[1], C. Bel[1], D. Batista[4], P. Azemard[4], C. Saint-Martin[1], P. Javelle[1]

1 Irstea, Aix-en-Provence and Grenoble, France
2 Météo-France, Aix-en-Provence, France
3 UMR SAS Agrocampus Ouest, Rennes, France
4 Cerema, Aix-en-Provence, France

*Corresponding author: catherine.fouchier@irstea.fr

## Abstract

Due to its mountainous topography and its Mediterranean climate, the Provence-Alpes-Côte d'Azur (PACA) region in Southeastern France is particularly prone to flash floods, debris flows and mass movements (landslides and rockfalls). A mapping system for these rainfalls induced hazards has been tested by local and regional authorities and Government agencies since 2011 as part of the RHYTMME[1] project. This system allows, thanks to radar rainfall estimation and rainfall-runoff modelling, the real-time warning and monitoring of flash floods wherever they may occur in the PACA territory. It is also intended to enable, during intense rainfall events, the localisation of the streams susceptible to generate debris flows and of the slopes the more likely to trigger landslides and/or rockfalls.

## 1. Introduction

Natural hazards occurring in mountainous areas (flash floods, debris flows, landslides, rockfalls) are largely dependent on rainfall. A good knowledge of these hazards and the ability to forecast them, therefore largely depend upon an accurate estimation of precipitations. In order to improve the risk management in the mountainous area of Southeastern France, Irstea and Météo-France have led the RHYTMME project with the support of the European Union, the Provence-Alpes-Côte d'Azur region and the French Ministry for ecology, sustainable development and energy (Westrelin et al., 2013). The goal of the project is to improve the ability to forecast and localize high-risk rainfall-induced hazards in the Provence-Alpes-Côte d'Azur administrative area. This goal is currently under achievement thanks to:

- the deployment of 3 X-band, dual-polarization radars in the Alpine region of southeast France, that allows to i) mitigate the coverage gaps of the French national radar network, mainly due to ground echoes and radar beam shielding by mountains, and ii) provide more accurate real-time quantitative precipitation estimates in this mountainous region;
- the implementation of a real-time warning and mapping system for rainfall induced natural hazards, fed by rainfall radar data and whose outputs are made available via the Internet to operators in charge of risk management (local and regional authorities, emergency and rescue services, road and rail networks managers, ...).

We describe here the achievements of the RHYTMME project regarding rainfall and related natural hazards warnings. The hazards warning system informs end-users on the imminence and the severity of hydro-meteorological events. The rainfall and flash flood hazards are real-time monitored while static information is currently given for debris flows, landslides and rockfall.

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[1] acronym for Hydrometeorological Risks in Mediterranean and Mountainous Areas, in French: Risques Hydrométéorologiques en Territoires Montagnards et Méditerranéens.

## 2. Flash flood warnings

To address the issue of rainfall and flash-flood warning, Météo-France and Irstea have developed the AIGA threshold warning system which compares real-time rainfall and runoff data with frequency estimates of rainfall and runoff (Lavabre and Gregoris 2006, Javelle et al. 2014). The real-time rainfall data are the radar rainfall accumulation information for different durations (1 hour, 2 hours, … 72 hours) provided every 15 minutes by the radar network at the spatial resolution of 1 $km^2$. These data are compared to regionalized rainfall frequency estimates computed, in a previous research work, for the same durations and at the same 1 $km^2$ spatial resolution and for different return periods on the whole French territory (Neppel et al. 2014). Rainfall warnings are then provided on maps displaying the estimated return periods of the different radar rainfall accumulations for the ongoing event. The real-time runoff data are provided by a distributed conceptual hydrological model fed by the 1-hour radar rainfall grids and run every 15 min at a 1-$km^2$ resolution. It produces real-time peak discharge estimates along the river network which are compared to regionalized flood frequency estimates previously computed (Aubert et al. 2014). Runoff warnings are then provided on a river network map according to the estimated return period of the computed peak discharge. Figure 1 shows an example of the rainfall and runoff warnings emitted by the RHYTMME warning system, thanks to the AIGA method, for the 26/10/2012 storm event which occurred in the neighborhood of the city of Toulon. The main interest of the AIGA method, implemented in the RHYTMME warning system, is to be able to deliver to operational services rainfall warnings in any 1 $km^2$ of their area of interest and runoff warnings anywhere on the river network they monitor, even at ungauged locations.

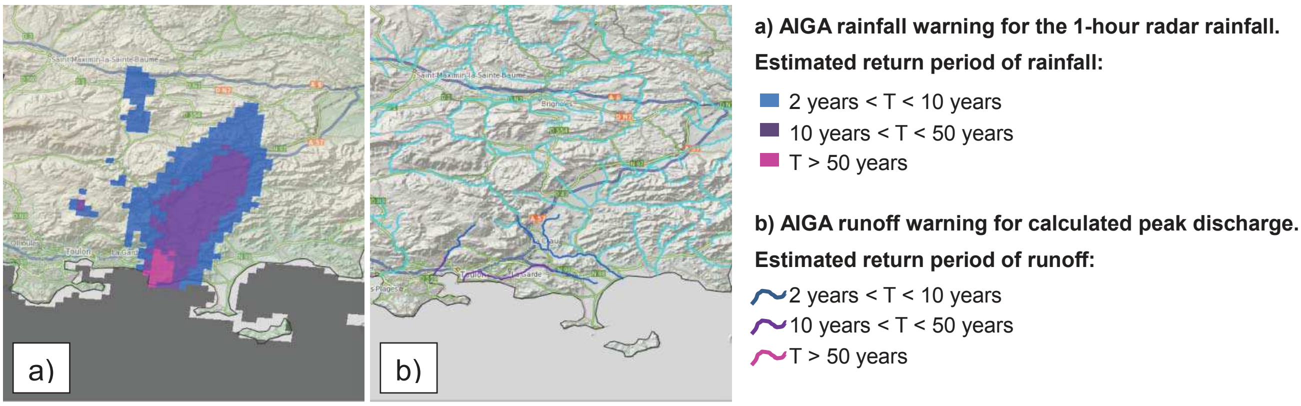


Fig 1: AIGA warnings emitted at 16:00 the 26/10/2012 during a storm event in the neighborhood of Toulon city, southern France. (a) : Estimated return periods for the 1-hour radar rainfall. (b) Estimated return periods for the peak flow discharge computed by the hydrological model. The pixel size is 1 $km^2$.

## 3. Debris flow mapping

The RHYTMME warning and mapping system also provides a regional debris flow susceptibility map (Figure 2). This map has been produced thanks to geomatic and statistical methods integrating the two main predisposing factors to debris flow activity, which are the stream and catchment morphometry, and the sediment availability within the catchment. Within the triggering areas, a map of active erosion patches has been automatically produced based on the analysis of infrared orthophotos (IGN©) with remote sensing methods. A robust statistical model was also developed to predict the debris flow activity based on morphometric indicators to discriminate the bedload transport from the debris flow processes (Bertrand et al. 2013). The integration of these two factors (sediment availability and morphometric conditions) within source areas, allowed predicting the susceptibility to debris flow triggering. More downstream along the stream network, the susceptibility to debris flow propagation was computed for a given reach according to its own probability of debris flow activity (its morphometric characteristics) and the susceptibility to debris flow activity of the reaches located upstream (recursive process). More details can be found in Bertrand (2014). This approach, developed by Irstea and applied in Southern Alps on each catchment smaller than 40 km$^2$, has been validated with field observations.

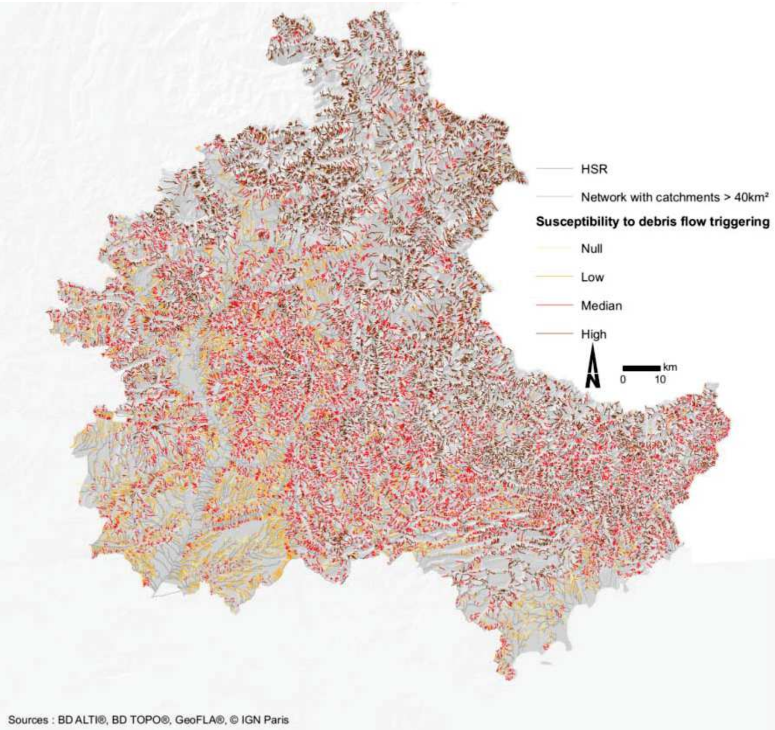


Fig 2: Map of susceptibility to debris-flow activity within the triggering areas.

The debris flow maps – susceptibility to debris flow activity within the triggering areas (figure 2) and susceptibility to debris flow propagation along the stream network – can be displayed in the RHYTMME warning system along with the real time maps of rainfall hazard in order to identify, during intense events, the areas the more likely to generate debris flows.

## 4. Landslides and rockfall mapping

Static landslides and rockfall hazards maps, produced by Cerema, are also available in the RHYTMME warning and mapping system. Cerema has developed a theoretical approach based on a geostatistical analysis of 1712 landslides events and 1567 rockfall events, and their related antecedent rainfall conditions, that have occurred in Southeastern France since 1900 (Batista et al. 2013). This approach is based on the subdivision of the Provence-Alpes-Côte d'Azur region into 13 areas showing a geotechnical homogeneity. In each of these areas, a statistical law calibrated on the observed data was established to assess the average number of hazards, and a simple law was established, relating this average number of hazards to different landslides and rockfall susceptibility factors, such as the slope, the exposure, the distance to the river network and the distance to geological faults. This regional approach enabled to assess the density of landslides and rockfall events in any point of the PACA area knowing the geotechnical area it belongs to and the values of the susceptibility factors in this point. It was then possible to draw maps displaying the susceptibility to landslides and rockfall based upon these densities of landslides and rockfall events (Figure 3).

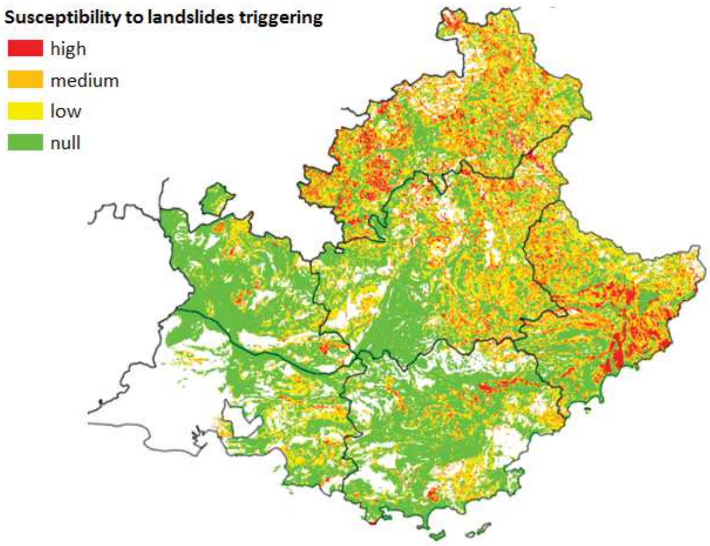


Fig 3: Map of the susceptibility to landslides triggering, taking into account the number of observed events since 1900 in each homogeneous geotechnical area and susceptibility factors.

The landslides and rockfall maps can be displayed in the RHYTMME warning system along with the real time maps of rainfall hazard in order to identify, during intense events, the areas the more likely to generate landslides and/or rockfall.

## 5. Conclusions

The RHYTMME flood warning and mapping system has been successfully tested since 2011 by more than 80 local and regional authorities as well as Government agencies in charge of risk management. On the basis of this experiment, it will be fully implemented and made available to all local authorities of the PACA region by the end of 2016 (approximately 1000 user authorities). Current research work in the field of flood warning focus now on enhancing the current hazard warnings by producing flood risk warnings that will take into account the vulnerability of the exposed territories. Current work in the fields of debris flow, landslides and rockfall now focus on the determination of rainfall thresholds associated with debris flow, landslides and rockfalls triggering. For debris flow, this work is based on the compilation of data from several debris flow monitoring stations recently deployed in active torrents of the French Alps (Bel et al. 2014). The aim is to enable to deliver debris flow, landslides and rockfall warning based on the real time radar rainfall estimation.

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