Projet ANR PICS – résumés scientifiques

Résumé Français.

La prévision des crues soudaines est d'une importance cruciale pour atténuer les effets dévastateurs de ces crues. Cependant, le développement de systèmes de prévision adaptés rencontre de sérieuses difficultés, en raison du grand nombre de bassins versants concernés, de leurs petites superficies (1 à 500 km²), de leurs très courts temps de réponse aux pluies (limités à quelques heures), et de la connaissance limitée des enjeux exposés. Des premiers systèmes opérationnels de prévision des crues soudaines ont été récemment déployés en France et dans le monde, mais restent largement perfectibles (anticipation limitée, couverture géographique partielle, pas de représentation des impacts). Dans ce contexte, le projet PICS propose une avancée significative, en construisant et évaluant des chaînes intégrées de prévision immédiate capables d'anticiper de quelques heures les crues soudaines et leurs impacts. Cet objectif sera atteint grâce à l'interaction entre des équipes scientifiques aux compétences variées (météorologues, hydrologues, hydrauliciens, économistes, sociologues), et des acteurs opérationnels (sécurité civile, autorités locales, compagnies d'assurance, compagnies d'électricité, opérateurs de réseaux de transport). Les chaînes de prévision conçues dans le projet incorporeront les éléments suivants: des estimations quantitatives de précipitations à haute résolution et des prévisions immédiates de pluie, des modèles pluie-débit distribués conçus adaptés aux petits cours d'eau non jaugés, des modèles hydrauliques pour la délimitation simplifiée des zones potentiellement inondées à partir de modèles numériques de terrain, et enfin plusieurs modèles d'impacts visant à représenter des effets socio-économiques: dommages matériels, inondation d'infrastructures, exposition et vulnérabilité de la population représentées de façon dynamique. Le projet visera à coupler ces différents modèles, à estimer leurs incertitudes et complémentarité, et à évaluer la capacité des chaînes de prévision proposées à répondre aux besoins des utilisateurs finaux. Une attention particulière sera accordée à la cohérence entre les différents maillons de la prévision: variables utilisées, niveaux de résolutions spatiale et temporelle, échelle d'application et degré d'incertitude. Un aspect critique du projet sera également la validation des résultats sur la base d'études de cas. Le contexte des bassins non jaugés est en effet généralement synonyme de pénurie de données. Pour cette raison, un effort particulier sera consacré à la constitution de jeux de données de validation appropriés (impacts, zones inondées, etc.) et à définir des stratégies de validation pertinentes. Les études de cas comprendront des événements majeurs observés récemment en France : inondations de juin 2010 dans le bassin d'Argens, de l'automne 2014 dans les bassins des Gardons, Vidourle, de l'Hérault et du Lez, et enfin d'octobre 2015 dans les Alpes Maritimes. Cette liste sera complétée au début du projet selon les besoins exprimés par les utilisateurs finaux. Le projet contribuera également à améliorer et adapter les différents modèles utilisés : amélioration des modèles hydrologiques distribués dans des conditions non jaugées, qualification des incertitudes des débits prévus à partir des observations et prévisions immédiates de pluie, amélioration des approches 1-D et test d'un modèle 2-D pour les calculs hydrauliques automatiques à grande échelle, et enfin adaptation des modèles d'impact de façon à exploiter les informations sur les emprises inondées fournies par les chaînes de prévision. Compte tenu de ce programme de travail, le projet devrait permettre des avancées significatives dans le domaine de la prévision immédiate des crues soudaines et de leurs impacts. La large représentation des utilisateurs finaux potentiels dans le projet (groupe utilisateurs et partenaires), facilitera le transfert des résultats du projet vers des applications opérationnelles.

Résumé Anglais :

Flash-flood forecasting is of crucial importance to mitigate the devastating effects of flash-floods. However, its development has experienced serious setbacks, due to the large number of affected catchments, their small surface areas (1 to 500 km²), their very short response times (limited to a few hours), and the limited knowledge of the assets being exposed. First operational flash flood warning systems have recently been implemented in France and other countries. Nevertheless, the capacities of these systems can still largely be improved (limited anticipation, limited geographic coverage, impacts not represented). In this context, the PICS project proposes a step forward by designing and evaluating integrated forecasting chains capable of anticipating the impacts of flash-floods with a few hours lead-time. This objective will be reached through interactions between varied scientific teams (meteorologists, hydrologists, hydraulic engineers, economists, sociologists) and operational actors (civil security, local authorities, insurance companies, hydropower companies, transport network operators). The integrated short-range forecasting (or nowcasting) chains designed in the project will incorporate the following components: high resolution quantitative precipitation estimates and short range precipitation forecasts (or nowcasts), highly distributed rainfall runoff models designed to simulate river discharges in ungauged conditions, DTM based hydraulic models for the delineation of potentially flooded areas, and finally several impacts models aiming to represent varied socio-economic effects: insurance losses, inundation of critical infrastructures, and also dynamic population exposure and vulnerability. The project will work towards: effectively coupling these various modelling components, evaluating these components in terms of uncertainties and complementarity, and finally assessing the capacity of these nowcasting chains to meet the end-users needs. A particular attention will be put on the consistency across the various components of these chains, in terms of variables used, spatial and temporal resolutions, application scale, and degree of uncertainty. One critical aspect of the project will also be the validation of the results based on case studies. The small ungauged basins context, indeed, is generally synonym of serious data scarcity. For this reason, a particular effort will be devoted in the project to the gathering of appropriate validation datasets (impacts, flood areas, etc.) and to define relevant validation strategies. The project will include case studies related to recent extreme rainfall events observed in the French Mediterranean area: June 2010 floods in the Argens basin, September-October 2014 floods in the Gardons, Vidourle, Hérault and Lez watersheds, and October 2015 floods in several small basins in the Alpes Maritimes territory. This list of case studies will be complemented at the beginning of the project based on the exchanges with the end users. The project will also entail significant efforts to improve and adapt the different components involved in the modelling chains: improvement of distributed hydrological modelling in ungauged conditions, qualification of uncertainties on discharges estimates based on rainfall observations and nowcasts, improvement of 1-D approaches and test of a 2-D model for large scale automatic hydraulic computations, and finally adaptation of the impacts models to take benefit from information on flooded areas provided by the forecasting chain. Considering this work program, the project should enable significant breakthroughs in the field of integrated flash floods impacts nowcasting. The wide representation of potential end users in the project, as members of the end-users group and as project partners, should finally facilitate the transfer of project results towards operational applications.

Objectifs globaux, verrous/scientifiques/techniques :

The production of appropriate flash flood forecasts, in terms of rainfall intensities, flood peak discharges, and also extent of flooded areas along the river network and corresponding possible impacts (risks to lives, economic losses), is a particularly difficult challenge due to the fast evolution of triggering meteorological events and of catchment basins responses, as well as to the multitude of small watercourses potentially affected. First operational flash flood warning systems have recently been implemented in France (APIC rainfall service in 2013 and *Vigicrues Flash* in March 2017). But these new services only still offer partial geographic coverage, too limited anticipation capabilities, and no estimation of possible flash-flood impacts. Further improvements are thus necessary. The PICS project aims to tackle this challenge, by designing a full forecasting suite for anticipating up to 3-6 hours in advance the impacts of flash floods. This objective requires combining and improving each of the following methods:

- the rainfall nowcasting methods, which should provide rainfall forecasts at high time and space resolutions in the 0-6 h anticipation range, and the explicit quantification of the corresponding uncertainties (Vincendon *et al.*, 2011; Alfieri *et al.*, 2011; Liguori *et al.*, 2012; Caseri *et al.*, 2015). Rainfall nowcasts should combine extrapolation techniques based on quantitative radar estimates for 1 or 2 hours lead-times, and numerical weather prediction for lead times up to 6 hours (Auger *et al.*, 2015);
- the flood forecasting methods based on robust and regionalized hydrological models. These methods should be able to simulate flood discharges in all small ungauged headwater streams (i.e. 1-500 km²). The use of proxy data (flood impact data) in ungauged areas for the calibration and validation of these models is a particular challenge (Randrianasolo *et al.*, 2010; Naulin *et al.*, 2013; Javelle *et al.*, 2014);
- the hydraulic modelling methods for the automatic computation of reasonably accurate inundation maps (Pons *et al.*, 2014). These methods should provide results for a large range of discharge values (flood magnitudes), and over an extended and dense river network including small headwater streams (Le Bihan *et al.*, 2016). The limits of the available topographic and bathymetric data and the possibilities of the new high resolution acquisition devices have to be evaluated;
- lastly, the methods enabling the evaluation of impacts in inundated areas, based on first-hand knowledge and dynamic representation of the exposure and vulnerability of individuals and property across a given territory. These methods should account for the strong variability over time and space (Ruin *et al.*, 2014; Terti *et al.*, 2016; Debionne *et al.*, 2016; Shabou *et al.*, 2016).

Significant breakthroughs have been achieved on each of these issues over the recent years, by the various teams involved in the PICS project. Until now however, progress has remained somewhat compartmentalized. Therefore, the PICS project aims at gathering this individual know-how to design and test first integrated flash-flood impacts forecasting chains. This objective entails (1) establishing an appropriate coupling of the various models, with data requirements and complexity levels adapted to the nowcasting context; (2) assessing the uncertainty and complementarity of the different modelling steps based on advanced validation strategies and new data sources, and identifying the main limiting factors (input data, modelling components, etc.); (3) adapting the completed chains to fulfil the end users operational needs. This will be achieved through the contribution within a single project of partners from the various necessary scientific fields

(meteorologists - hydrologists - hydraulic engineers - economists - geographers), alongside operational actors (crisis managers, insurers, infrastructure managers, citizens).

Programme de travail :

The project proposes to design and test integrated forecasting chains for flash-flood impacts forecasting. The characteristics and objectives assigned to these forecasting chains will be defined with the support of knowledge gained by future potential users (end users group, see hereafter). The forecasting chains will be evaluated over selected test case studies, at a broad enough scale to assess their subsequent applicability at a regional, or even national, scale. Interactions are expected between scientists and end-users, but also between scientists coming from different disciplines (i.e. meteorology, hydrology, hydraulics, social sciences…).

The project is structured in four scientific work packages (WP1 to WP4), and a general coordination and dissemination work package (WP0). It is organized around a central work package (WP4), in which integrated forecasting chains will be tested. This WP4 offers the greatest potential of innovation of the project: all the contributors and end-users of the project will meet and interact in this WP. The three other scientific work packages are designed with the objective in mind of improving, adapting, and evaluating uncertainties of the various key components to be incorporated in the integrated forecasting chains, namely:

- the short range (0-6h) discharge forecasts (WP1), obtained by coupling the state-of-the-art very short-range precipitation forecasts with distributed hydrological models,

- the methods for flood areas estimation (WP2), which include innovative 1D and 2D hydraulic computations methods to convert flow rates into flood areas delineation and water heights / speeds,

- the socio-economic impacts modelling methods (WP3), which have to proceed with an explicit integration of information relative to the flood areas and water heights / speeds for the estimation of impacts of different nature.

The end users group will include at least the state civil security authorities (DGSCGC), one local firemen and rescue service (SDIS 30 or 83), the national center for flood forecasts (SCHAPI), one municipality (city of Cannes), one insurance company (AXA Global P&C), two electric power companies (EDF, CNR), and one public transport company (SNCF). One risk identified may be the capacity of the methods involved in the project to address the issues raised by this end users group. On this specific point, a discussion will be organized at the beginning of the project to define common and reasonable objectives, accounting for the current state of the art.

The case studies will be partly located (but not exclusively) in the Mediterranean Region: indeed, several recent flood events in this region offer a particularly favourable context in terms of data availability (including damage data), applicability of the different modelling components to be integrated in the forecasting chains, and feasibility of complementary Lidar data acquisition. The final list of selected case studies will be defined at the beginning of the project based on the exchanges with the end-users group. The objective will be to select the most relevant areas and events for each forecasting chain to be tested.

One critical aspect of the project will be the capacity of validation of the results of the integrated forecasting chains: forecasted impacts, but also estimated discharges and flooded areas. To limit the associated risks, a particular effort will be put in the project on gathering and formatting appropriate

and varied validation data, related to all components of the modelling chains (discharges, inundation patterns and impacts). A specific task will also address the question of the appropriate validation methodologies, considering the nature of validation datasets available for each case study.

Retombées scientifiques, technique, économiques :

The scientific benefits of this project mainly pertain to an improved capacity of forecasting risks related to flash floods, plus an increased capacity to evaluate the results of this forecasting exercise. The scientific dissemination of these benefits will rely on publications in international scientific journals and on technical presentations delivered in international scientific conferences, as well as national conferences addressing the various operational actors. A bilingual (English/French) website devoted to the project will be launched to promote exchanges via social media (Twitter, blog, Facebook, etc.) and therefore accelerate and extend the spread of the project's results. A final scientific seminar will also be organized. This outreach strategy will benefit from the dynamic generated by the two hydrometeorological forecasting research networks currently operating at the international scale, i.e. the HyMex program (http://www.hymex.org/), and the HEPEX initiative (www.hepex.org), within which several PICS project partners are already active. The existence of these two communities will indeed ensure a large diffusion of the project's scientific results.

The societal and economic benefits are directly related to the actors involved as project partners or as members of the end-users group:

- The SCHAPI (Ministry of Environment, Energy and Ocean affairs) is directly interested by the project in the perspective of future improvements of the new *Vigicrues-Flash* warning system. The results of the PICS project should provide options and opportunities for futures updates of *Vigicrues-Flash*: integration of rainfall forecasts, improvement of the rainfall-runoff model, integration of a simplified representation of impacts, etc.
- The national civil security and crisis management authority (DGSCGC, Ministry of Interior) also benefits from the project outcomes in terms of future updates of its operational systems. These systems include (1) the "SYNAPSE" GIS decision-making support tool, enabling the gathering of all information related to crisis events and their consequences, and including computations of population impacted by a natural event; and (2) the "SAIP" system which is a smartphone application recently launched (2016) to directly inform the population in case of danger. Given that the PICS projects will provide significant progress on both the delineation of flooded areas and the dynamic estimation of population exposure, it should help to improve these systems in the future.
- Local Crisis managers and civil security officers (municipalities, fire safety agencies) will also benefit of enhanced capacities of anticipation and qualification of impacts of forthcoming flash-floods. The anticipation and the information on impacts are indeed crucial components of an efficient local crisis management.
- The anticipation of floods is also a key challenge for hydropower companies, which are very active in France in the development of hydrological forecasting. These companies directly benefit from the PICS project for the enhancement of their own flash flood anticipation capabilities.
- The managers of transport infrastructures should also take benefit from the project's results for the purpose of analyzing sensitivity of the road and railway networks to flooding, and of providing real time warnings on inundation risks.
- Finally, the project outcomes bring value to insurance (AXA) and reinsurance (CCR) companies by providing information to anticipate the volume of claims and associated financial costs after a flood. Particularly, the insurance losses model of the CCR may directly

benefit from the progress provided by the project in terms of hazard description (flooded areas), which may help to define future adaptations of this model. This last significant benefit of the project for private companies justifies its inclusion in the “PRCE” funding instrument.