



Challenges of Decision Making in the Context of Uncertain Forecasts in France

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Abstract

Flood is a major risk in France and an operational hydrometeorological organization (a team of 450 employees for national coordination and local services) is in place since 2003 for surveying the main river courses, about 22,000 km which can be damaged by flash flood, fluvial flood, and coastal flood hazard. Besides the building of a national network of hydrometric station, with real-time access of data on the Internet, the services are responsible for flood vigilance, over the next 24 h, and for more detailed forecasts at shorter lead-time. The information is disseminated since 2006 on the www.vigicrues.gouv.fr website. Hydrological and hydraulic deterministic models are used to increase the forecast lead-time for some 500 hydrometric stations located close to

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vulnerable flood areas. Within the set of information integrated into the operational procedure, ensemble meteorological forecasts are used by the hydro-forecasters to evaluate rainfall distribution in the following days. Besides those routine activities, the European Flood Awareness System (EFAS) platform, the ensemble based forecasting system, has been tested since 2009 for some 60 flood events to study how the system can be best used within the French flood vigilance and warning procedure. During the first years of the evaluation, the results stayed quite difficult to be accounted for in the operational activities, as the number of false alarms and missed events was too high. Since 2013, the tendency is completely different, with the production of Flash Flood reports for watersheds smaller than 3,000 km². The localization of the impacted area and the timing is better foreseen; this tendency should be even improved when real-time discharges of main gauging stations will be transferred to EFAS.

Keywords

Vigilance · France · Operational flood forecasting services

1 Introduction

Two thirds of the 36,000 French cities are subject to one or more natural disasters (floods, earth quakes, clay deformation), with more than 6 million people living in flood prone areas. Reduction of the natural risk is therefore a national priority in order to adapt to these phenomena and to minimize their impact. Risk prevention policy is put in place with the aims of reducing the consequences of potential damages.

The risk prevention policy is based on a large set of activities including long-term adaptation measures (control of urban development and construction following legal standards and risk prevention master plans, reduction of vulnerability, adaptation to risk and climate change to prepare for future crises); resilient infrastructure development (protection, security of protection infrastructures); provision of training and real-time information to the citizen; and other short-term crisis management measures. This covers not only the surveillance, forecasting, and warning activities during crises but also all the preparative measures linked to the awareness of hazards and vulnerability, the gathering of historical information and for analyzing past crises, as well as preparedness to crises situations.

Here, we discuss how the French hydrometeorological services translate flood forecast information, including probabilistic forecasting, into so-called vigilance maps and written information to the public services and the population.

2 Vigilance Procedure and Communication

A new disaster awareness system called vigilance procedure was established in France following the devastating storm of 1999 along the Atlantic coast. Although the storm level (intensity, location) had been well estimated by meteorological

forecasters, the public underestimated the effect of the storm. Vigilance procedure provides clear instructions to the public on what to do in the case of a possible natural hazard over the following 24 h. It combines information on current situation and forecasts of the vulnerability of the area, in order to determine the right level of action to be taken by the services in charge of the security of the citizen and by the citizen themselves. Vigilance implies that the extents of natural hazards are continuously assessed and that threshold levels are set based on historical events, model simulations, local knowledge, and any type of information that allows linking hazard to impact on citizens and assets. Vigilance ensures that not only the technical and civil security services are aware about the level of any future events but also that the public is informed and become responsible for its own behavior. For this, communication means need to be in place for real-time assessment and coordination, and responsibility and information flow between the various technical services, civil security, and local services must be agreed. The vigilance procedure is used for hydrometeorological disasters including heavy rainfall and floods, as well as for meteorological and health related hazards, such as strong wind, snow-haze, avalanche, storm, heat wave, cold wave, wave-storm surge.

In the French risk prevention policy, the terminology makes a difference between *vigilance*, a warning procedure produced by technical services (either meteorological or hydrological) to the civil services and to the public for preparing to react properly in case of natural hazard, and *alert*, which triggers civil protection actions and is launched by the Prefect (the administrative coordinator at each of the 100 departments) when the danger is confirmed, when the forecasts indicate that safety measures and assistance become necessary.

3 Flood Vigilance

Flood vigilance information is produced by a coordinated effort of some 20 local flood forecasting services across France, responsible for a series of watersheds, and one national hydrometeorological and flood forecasting center (SCHAPI). Together with the services in charge of the hydrometric stations, this organization is operated by about 450 persons, performing either daily in normal situation or 24/24 h and 7/7 days during crises. All of them are technicians or engineers of the Government at national and regional level.

The goal of the vigilance procedure is to deliver twice daily, or more frequently, information on the level of hydrometeorological hazard before and during a disaster to the responsible party in charge of alerting the responsible services of the government, such as mayors at local level, the prefects at department level, the civil security services, and the general public. Vigilance information is provided for the upcoming 24 h. Four levels of vigilance are used for meteorological hazards (by Météo France) and for hydrological hazard (by the flood forecasting services). The levels are represented by four color codes: green, yellow, orange, and red. Green stands for no flood risk, yellow for localized floods with minor damages or rapid increase of water level, orange for more dangerous events with people at risk and damages on infrastructures and houses, and red stands for major floods extensively threatening

people and property and involving the support of national civil security services. For each of those vigilance levels, behavioral guidelines have been provided to decrease the risk on people and assets. The visualization of vigilance does not include information about the probability or uncertainties, e.g., there is no color shading or changing intensity of colors reflecting the probability range of the event. Instead, the vigilance maps are accompanied by bulletins where the uncertainties are expressed verbally and ranges of waterlevel forecasts are described either in the text itself or in attached files.

The flood hazard level classification is performed for linear segments of river network covering 22,000 km of streams under surveillance. The 250 linear segments, called river sections, ranging up to 40 km long, were identified depending on the need for detailed forecasts, the localization of vulnerable urbanized areas, and the availability of measuring hydrometric stations. All the gauging stations are linked to one of these river sections, and they relate water levels in the river course to damages in the area. Each of the past events can be classified on the vigilance scale, as shown on Fig. 1.

The products delivered by the flood forecasting services range from hydrographs at hydrometric stations to maps and bulletins for the river network. Since 2006, the website www.vigicrues.gouv.fr has provided direct access to real-time measures of some 1,500 stations, as well as to national and local vigilance information. This information is either sent to the decision-making public authorities or made available for free access on the Internet (Fig. 2). Radio and TV are also major tools of the dissemination process. Two of the regional services also provide applications to registered users when threshold levels are reached at selected measuring stations. This functionality will be implemented at national level in the near future, with the upgrading of the flood vigilance web services. Real-time communication gives therefore fast and easy access to field data, as well as to flood forecasting (vigilance levels and local forecasts). With continuous improvements (for example, access to historical data and event description), it is a very effective tool for increasing the participation of people to hazard and crisis management (Fig. 2).

The vigilance procedures for hydrological risks are fully aligned with the ones for meteorological risks – from the exchange of data to the dissemination of a joint meteorological and hydrological vigilance map, produced since 2007 at the request of the Ministry of Interior in order to deal with a unique concerted and expertized access to decision-making information.

4 Operational Activity at Local and National Level

A set of meteorological and hydrological information is used by SCHAPI for assessing the global hydrometeorological situation over the current day and the next days across France. This information at the national scale is valuable for ensuring that the local vigilance levels and forecasts produced by the 20 regional services are consistent and in line with the behavior of the main watersheds, as most of the main river courses are surveyed by a series of regional services. For the next

River section GARONNE TOULOUSAIN (1)		REFERENCE STATIONS OF THE RIVER SECTION A reference station is the station selected for defining the vigilance color of the river section			
Vigilance	Explanation and expected consequences	STATION: CAZERES / GARONNE		STATION : TOULOUSE / GARONNE	
		Historical flood	Water level	Historical flood	Water level
R E D	Level 4 : Major risk of flood directly and extensively threatening people and property <i>Rare and catastrophic flood, numerous human lives threatened, generalized overflow, generalized and simultaneous evacuations, disruption at large scale of urb a., agricultural and industrial activities</i>	June 1875	8,60 m	June 1875	8,32 m
O R A N G E	Level 3 : Risk of flood with considerable overflow liable to significantly affect the daily life and security of people and property <i>Generalized and damaging overflow, threatened human lifes, evacuations, greatly affected circulation, partly disruption of social, agricultural and economic activities</i>	May 1977	4,74 m	February 1952	4,57 m
		February 1952	4,00 m	June 2000	4,38 m
				May 1977	4,31 m
Y E L L O W	Level 2 : Risk of high or rapid rising water not involving significant damage but requiring particular vigilance in the case of seasonal and/or outdoor activities. <i>Disruption of activities related to the river courses, localized overflow, localized secondary road closures, isolated houses involved, inundated cellars, dirruption of agricultural activity</i>	June 2000	3,70 m	January 2004	3,52 m
		January 2004	3,06 m	February 2003	3,38 m
G R E E N	Level 1 : no particular vigilance required <i>Normal situation</i>	February 2003	2,66 m	November 2011 April 2004	2,70 m 2,67 m
		April 2004	1,59 m		

Warning: the choice of the color will also account for special cases, such as extremely rapid increase of water level, unusual event of the season or seasonal dangerous activity SPC GARONNE-TARN-LOT

Fig. 1 Vigilance section of the Garonne River in the Toulouse area: compilation of past flood events for two gauging stations in relationship with vigilance levels

days, the information is used for preparing and organizing work of the forecasting team (shifts, 24/24 h presence in the office). In any case, a first telephone call occurs between SCHAPI and the national civil security, the Inter-ministerial Center for Operational Crisis Management (COGIC) as soon an orange or red vigilance map is foreseen, therefore before any information is pushed via Internet. During crises, the whole process is continuously repeated, in order to follow the gravity and evolution of the situation.

The operational dataset used by the forecasters to assess the hydrometeorological hazard includes the following information:

- Operational radar-gauge rainfall grids (Tabary 2007) and moisture maps calculated with the SIM model (Noilhan and Mahfouf 1996), both provided by Météo France
- Observed hydrological data records (waterlevels and discharges)
- Deterministic meteorological forecasts at large scale from ARPEGE model from Météo France
- Rainfall quantitative forecasts for the next 3 days, with expertized quantitative forecasts for some 100 meteorologically homogenous subzones over the French watersheds at various ranges, one latest method being produced on 3 h timesteps, as well as comparisons of the available numerical models AROME (Seity et al. 2011) and ECMWF-ENS
- Meteorological hazard at midterm range, with probability rainfall maps of European Centre for Medium-Range Weather Forecasts (ECMWF)
- Medium-range, ensemble hydrometeorological models covering the entire national area, such as EFAS (Thielen et al. 2009) and the SIM-PE provided by Météo France (51 members of the ECMWF ENS forcing the SAFRAN-ISBA-MODCOU hydrometeorological model, Habets et al. 2008)

Each of the local forecasting services is responsible for assessing the extent of future flood hazard along the set of river sections under its responsibility. This means that various types of decision-aiding tools have been developed and are regularly used to provide a vigilance color on each of its river sections, usually at 10 am and 4 pm, for the following 24 h. The vigilance level, color, is often defined by using simple graphic representations of water level, or discharge, increase for ranges of precipitation forecasts over the next day. Additional criteria include initial conditions (e.g., river water level, soil moisture, snow cover, and frozen soil). For some 500 stations, quantitative forecast can be calculated using numerical models to provide values at different lead-times ranging from few hours to 10 days for probabilistic systems. In order to account for the heterogeneity of hydrological conditions at local level, from mountainous to fluvial and coastal watersheds, the forecasters use a quite large number of modeling tools, from empirical, conceptual, global, and distributed rainfall-runoff models to hydrological routing models. Hydraulic propagation is also represented by 1 D models. All models are running with deterministic rainfall distributions, either accumulation or forecasts at various time steps (12 h, down to 3 h) and spatial grids (8×8 km and 2,5×2,5 km, 1×1 km)

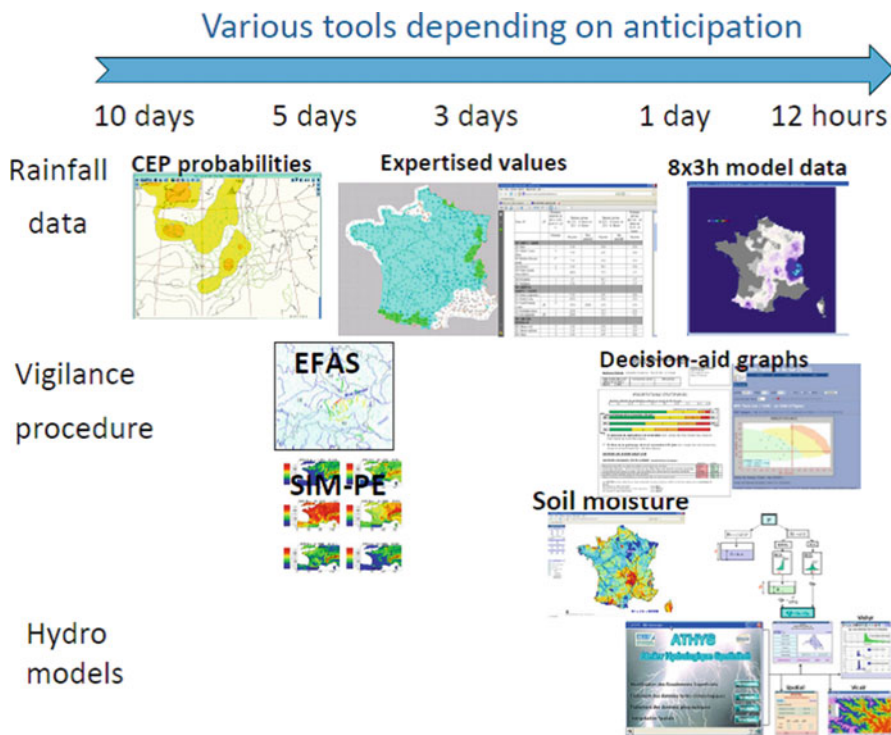


Fig. 3 Use of various meteorological and hydrological information by the forecasters over a 10-day sliding period

issued from numerical weather prediction models and/or from the radar network. When several models are providing a set of forecasts at the same station, the forecaster uses either expert decision or simple routines to determine the uncertainty around the chosen forecast value. These forecasts, and their uncertainty, are disseminated in the bulletin within the comment line of the river sections or as an attached file. The visual representation of the forecast and related uncertainty on the hydrograph is planned in the forthcoming new version of the Vigicrues website.

An illustration of the types of information involved into the assessment of the forecaster over a 10-day period before any event is given on Fig. 3. It shows when the various products provide valuable information and how they complement.

Decision, either for selecting a vigilance color on the 250 river sections or for coordinating the operational activities inside the flood forecasting services, at national and regional level, and for warning the civil security on future events, is based on the whole set of data. No action is taken based on only one source of information. Ensemble products are particularly valuable for early warning, as their forecast range is in line with the reaction time of most of the large watersheds, for which a first signal within 3–5 days before event is an additional criteria to inform the civil security services about a possible flood occurrence.

5 Added Value of Ensemble Platforms

Besides the operational procedure, SCHAPI is also involved into the testing of new products and the development of the national modeling strategy. Ensemble methods are used to assess longer term flood hazard including EFAS and are part of this program since 2009, when the first agreement was signed with the Joint Research Center for testing the platform. Results from SIM-PE (Thirel et al. 2008; Cloke et al. 2009), a similar system developed by Météo France at national scale, are also integrated to this testing procedure. During the last 5 years, EFAS and SIM-PE signals have been checked daily to identify possible areas with future flood events with as much anticipation as possible to compare the signals with the routinely used forecasting tools and the observed vigilance level during the event.

Over the period 2009–2014, each event announced either with EFAS alerts and watches or with orange and red flood vigilance has been evaluated on various criteria, such as the size of the watershed, spatial distribution and type of precipitation (rain/snow), alert level compared to real situation, and lead-time. More than 60 events with orange vigilance and almost 10 with red vigilance have been analyzed and classified into “hits,” “missed,” and “false alarm” groups. Results have shown that the medium-range forecasts provided for watersheds larger than 4000 km² are less useful for forecasters in their decision making for the vigilance maps. With the introduction of the so-called flash flood layers into EFAS in 2012 (see Alfieri in this handbook), the warning on watersheds below 3000 km² is now also provided by the system. In 2013, a ratio of “hits” of about 50% for the relatively large watersheds was observed and a very high ratio of 80% for the Flash Flood reports on smaller watersheds. These improving results are providing more valuable information to the operational forecasters: the system can provide warnings up to 4 days in advance, which is greatly valuable for organizing the forecasting activities and also for first exchanges with the civil security services. Warnings sent only 1 or 2 days before an event by the EFAS system are less informative, as the situation is already localized by other models and the timing is also better defined.

An example from EFAS system for one of the November 2014 events on the Mediterranean shore is shown in Fig. 4, while the corresponding vigilance maps sent over the same period are presented below on Fig. 5. Besides the very good performance of EFAS for the Aude, Têt, and Tech rivers, it is worthwhile to notice that EFAS Flood Watch had been received on November 22 for Hérault (2525 km²) for November 27th, therefore longer anticipation. On the other hand, no signal had been sent for the Berre river, although it reached red vigilance level on Vigicruces on November 30th.

A detailed evaluation of the EFAS flash flood results for 2014 is still underway but first results show that valuable information concerning the area covered by an incoming event and its timing are provided to the operational teams by the ensemble system.

The active participation of the operational team in the testing of two ensemble EFAS and SIM-PE platforms during their development phase and thereafter has been a very valuable training for the operational forecasters. It allows them not only to learn about the methodology but also to assess in real-time, as well as a posteriori, the value of the warnings within the overall set of hydrometeorological information

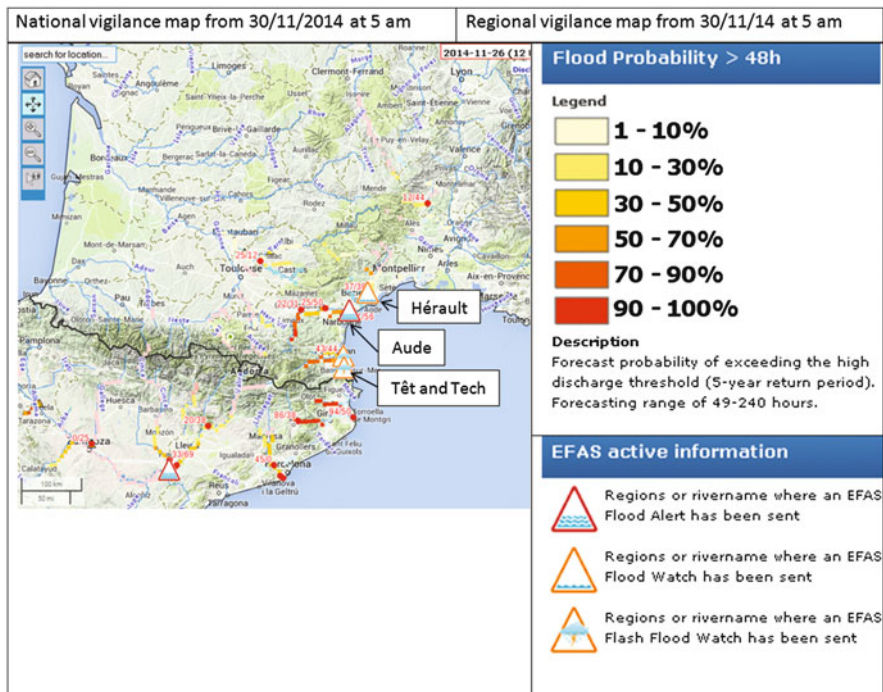


Fig. 4 Flood probability forecast provided by EFAS system for Aude river (5,500 km²) for November 26, 2014 issued 3 days ahead. The red triangles show the flood alert and the orange triangles show thunderstorm for Tech (731 km²) and Têt (1,412 km²)

from various sources which are provided to the forecaster in normal situation and during crises. The forecasters are using additional information to evaluate if the level of warnings issued by the ensemble are in agreement with the local hydrological models and with the real water levels reached during events. This is for example the accuracy of the location and surface of the impacted area, the timing, duration, lead-time and consistency of the signal. In return, the possibility of providing feedback to the developers has allowed improving the systems, reducing false alarm rates, and visualizing information in the best way for the expert users.

In line with the testing of EFAS and the SIM-PE platform, several national projects have been developed, and implemented, by the flood forecasting services and its research partners, in order to concentrate on more local floods and short-term forecasting. The purpose there is to provide new methodologies and tools to deal with the spatial and temporal variability of precipitation forecasts, which are influencing the behavior of smaller, upper parts of watersheds and causing devastating floods over the last years. These new systems aim at providing forecasts for areas which are not yet covered by the river network under “hydrological vigilance surveillance,” and responding therefore to the expectation of the citizens affected by these rapid floods, as well as to the public authorities. Following two tragic events in

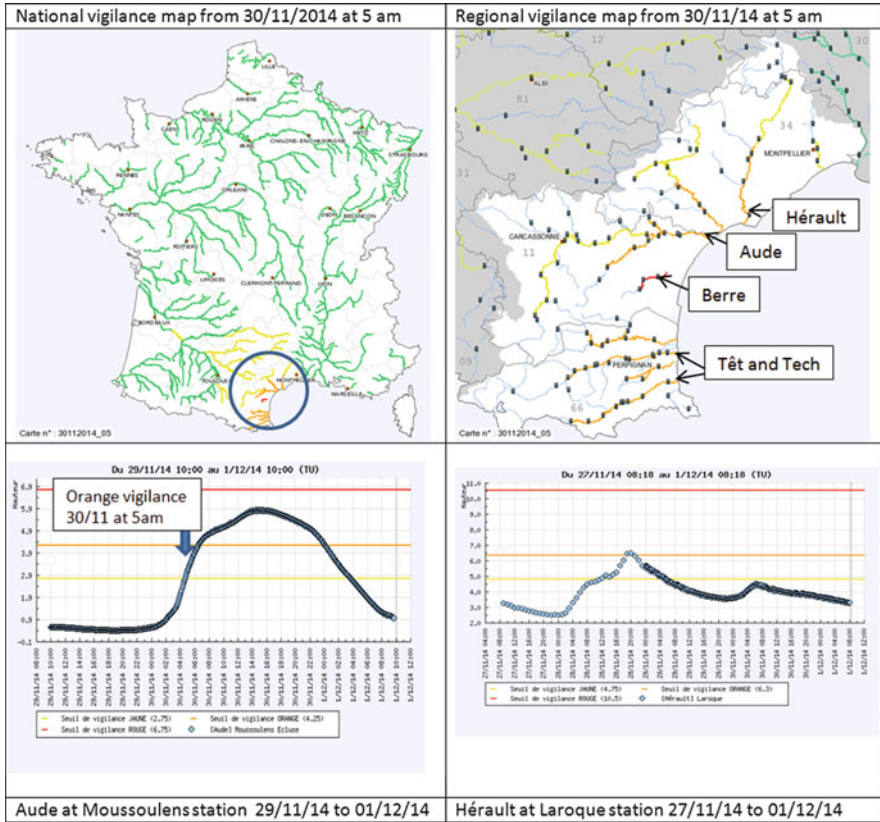


Fig. 5 Vigilance maps and hydrographs of two stations on Aude and Hérault rivers for the November 30, 2014 event

2010 along the Atlantic coast and the Var department Mediterranean area, the ministry in charge of sustainable development acted a national management plan for rapid submersions (MEDDE 2011), to decrease the effects of coastal and small watersheds floods. These two projects are one of the measures of this large program covering four main areas: (a) control of urban planning and adaptation of constructions; (b) improvement of hazard understanding, warning systems, forecasting, vigilance, and alert; (c) security of waterworks and protecting infrastructures; and (d) improvement of resilience.

6 Summary

In France, a major reform of the national and regional flood services in 2002 has been enforced to modernize the former procedures, based on observation of river levels, into a national real-time operational system, delivering forecasting and

warning information on the main river courses (Tanguy et al. 2005). The network covers about 22,000 km of streams (out of the 1,20,000 km of streams larger than 1 m width) and improves the anticipation before flood events for 90% of population at risk, on the basis of a variety of data and numerical hydrometeorological models, including ensemble prediction systems. A complementary procedure is under study for flash floods on small watersheds in order to inform an even larger percentage of the population.

Up to now, the probabilistic information, whether meteorological or hydrological, is mainly used by the operational expert teams, who evaluate the platforms results and provide a “deterministic” assessment to the decision makers (Prefects, civil security). A first success has already been reached by Météo France, the French National Meteorological Service, to convey uncertain warnings to forecasters, technical public authorities, and civil security, by producing a daily map of possible extreme (orange and red) events for the next 2 and 3 days at regional level. The probabilistic information or the degree of uncertainty is not yet translated to the public but a new version of the Vigicrues website will include uncertainty ranges on the forecasts. However, the aim of the vigilance procedure is to make the public aware that a potentially dangerous situation is expected and that adapted behaviors must be followed.

The situation has also evolved inside the flood services: 5 years ago, only the national center, SCHAPI, was convinced of the value of ensemble warnings and ready to invest time to be educated to this new approach and to assess regularly the platform results (EFAS and SIM-PE). Now, several local services, mainly those concerned by short-term rapid floods (6–12 h reaction time of the watersheds), are also interested into this type of information, as EFAS has produced particularly well-located and timely forecasts over the last 2013 and 2014 flood events. Furthermore, the tests performed with the current models under development, CHROME and (AIGA and CHROME), are also providing excellent forecasts, especially in the case of orographic effects and rapid floods.

Through working groups and evaluation of the different components of the EFAS and SIM-PE systems, improvements and needs for adaptation to the national procedures and local hydrological behavior have been identified by the French forecasters. These results can not only be implemented into the European platform but they are also valuable to develop additional dedicated numerical models and approaches. The future of ensemble forecasting is therefore large for operational forecasters, not only in testing and developing new products but also in transferring the information to the end-users, at technical and decisional level, as well as to the public at longer term.

7 Conclusion

With more than 6 million people living in flood prone areas, two thirds of the French cities are subject to one of more natural disasters (floods, earth quakes, clay deformation).

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