THE ROLE OF RAINFALL RADAR DATA IN FLASH FLOOD ALERT

Alain Kapfer
RHEA SA
11, rue du Vieux Pont
92000 Nanterre - France
Voice : 33 - 1 41 20 92 00
Fax : 33 - 1 41 20 92 29

KEYWORDS : flash flood, warning, alert, rainfall measurement, radar data.

ABSTRACT

In France, Flood Warning Agencies (Services d'Annonce des Crues or SACs) effectively monitor 16,000 km of water courses. But their mission essentially concentrated on reaches where flooding could be predicted and announced from rising waters in upper basins.

Following the catastrophic events caused by flash floods, mostly since 1988, there has been a demand for setting up warning units for small water courses or upstream of basins, that is, where a knowledge of precipitations is required if flood prediction is to be effective.

In this context, the only alternative seems a quantitative exploitation of radar rainfall data, however subject to several constraints. It should also be noted that a proper knowledge of rainfall is not a sufficient element : a chain of alert requires a quick successsion of actions from detection of a potentially dangerous situation to decisions on flood prevention and safety measures in the field. Nevertheless, there are still some areas where implementing a system of alert cannot be envisaged.

INTRODUCTION

In France, the 1988 disaster in Nîmes and repeated impressive and dramatic floods since 1992 (Vaison-la-Romaine) have made the general public aware of the risks related to intense precipitations and occupation of areas which can be flooded. A parliamentary committee was set up with an inquiry mission. It submitted a report in November 1994 (Mariani et al. 1994).

Thus, there is social pressure to limit the consequences of such events. This influences not only the evolution of measures and regulations concerning town planning, water course maintenance but also alert systems. In this respect, system limit and reliability are questioned.

Indeed, a credible system must be capable of detecting with a minimum level of uncertainty (to avoid generating undue false alerts) any situation involving potential risks, anticipating the event as early as possible so as to give sufficient time for alert to be passed on to the sites concerned and for adequate protection measures to be taken locally.

In this context, for flash floods due to intense precipitations, the use of radar rainfall data is of prime interest. Existing alert systems could be extended upstream of certain catchment areas and additional means set up on new basins which have not been monitored so far.

The purpose of this paper is to set out the contribution of radar rainfall data to the system and how to make use of it in optimum conditions. After a brief reminder of some of the events which developed awareness in France, we will see the organization of flood alert and need for data on precipitations to implement a flash flood alert system before concluding on the contribution of radar to flash flood hazard prediction and prevention.

SINCE 1988, AN EVENTFUL HISTORY

On October 3rd, 1988, the city of Nîmes woke up under a storm and soon found itself invaded by torrential waters rushing down the hills surrounding it. The Cadereaux (generally dry thalwegs) discharged the runoff of a rain that had persisted for several hours with intensities of several tens of mm/hr. Cumulative rain depths exceeding 400 mm were measured.
Unfortunately, 9 people died and damage was valued at 4,100 million French Francs.

Violent storms hit the city of Narbonne in 1989, then the cities of Privas in 1990 and Orange in 1991. Each time, rainfall totals reaching nearly 300 mm in few hours were recorded. The geomorphologic conditions and the occupation of regions that had been hit limited the human consequences, however.

In September 1992, a Cévennes-type episode occurred again in the South of France with catastrophic human consequences in the département of Ardèche (4 dead) and principally Vaucluse (37 dead, 29 of which at Vaison-la-Romaine and 5 people missing). One week later, the department of Aude was hit (3 dead, 5 missing). Overall, the disaster hit 718 boroughs with damage rising to FF 3,000 million.

In turn, both 1993 and 1994 saw a succession of very violent floods in small basins but also exceptionally high waters in the Rhône valley. During the summer and autumn 1993, 22 people were killed. Damage was estimated at FF 3,900 million, 1342 boroughs were affected.
During the 1993-94 winter, 2750 boroughs were inundated, 21 people died and damage has been estimated at FF 3,500 million.
1994 Summer and Autumn also brought about violent floods in the South of France (e.g., Nice airport flooding).

FLOOD ALERT ORGANIZATION

The state, although under no legal obligation to do so, has set up flood alert systems along 16 000 kms of water courses (out of 250 000 km) (Godard 1994). The main water courses are monitored and this covers the major part of the population exposed to the risk of inundation. There are 52 SACs in France (Flood Warning Agencies).

SACs are on the alert as soon as anticipated or detected rainfall exceeds set thresholds or water depths. They can track how the flood progresses through remote transmission of data logged by their measurement network and using modelling tools when possible (Godon, Odier 1994). When pre-set alert levels are exceeded, they contact the Prefect and suggest that he alerts the mayors of the boroughs since the mayors are responsible for the safety of populations over the territory of their boroughs.
Then, SACs keep the Prefect informed of the progress of the flood. Information is put at the mayors' disposal. This organization offers the advantage of centralized information at Prefect level, the alert resources (gendarmerie and national police) and rescue resources (firemen, civil defence) also being controlled by the Prefect. But it means that time elapses between the moment the information on the hydrologic situation is available to a SAC and the moment it is transmitted to the mayors and then to the populations. This is a limitation in the case of flash floods.
In addition, most SACs have been set up in basin parts having a sufficient response time to allow warning from the time upstream flooding starts propagating.
Thus, few basins subject to flash floods are monitored by a flood warning system set up by the state.

MONITORING MEANS FOR SMALL BASINS

Nonetheless, in some basins having fast response times (less than 10 hours in the south of France and in Finistère), the state did set up flood warning agencies. Some urban communities have also organized monitoring and alert systems on their territories (Nice for the Paillon basin, Marseille, Bordeaux and the départements surrounding Paris).

In all cases, the first step in situation monitoring resorts to the forecast broadcasted by Météo France. These forecasts extend from 12 hours to 3 - 5 days and cover surface areas of several thousand square kilometers. They are relatively qualitative.

The second step deals with the observation of data collected by the telemetering network of the alert agency : rainfall and runoff data. We note that there is a weakness in the system concerning the hours preceding the event, between the due date indicated in Meteo France forecast and the possible occurence of the event, if it occurs. This weakness is partly offset by satellite and radar observations. These qualitatively exploited images allow technicians to see in advance the coming disturbances (satellite images) and the precipitations (radar images).
With satellite images, you can follow a disturbance but you don't know exactly the precipitations it may cause. From the observation of radar images, the agencies can learn the times rainfall starts and finishes and have an indication on rainfall intensity and coverage.

Several agencies have hydrological rainfall-discharge conversion models at their disposal, which are activated after data collection. In these models, a major limitation is due to the quality of rainfall data inputs (LHF-EDF/DTG-RHEA, 1994). Indeed, generally, rainfall data are provided by rain gauges, which means punctual measurements and often daily accumulations.
An improvement is obtained by interpolating pluviographic data, at an hourly time step for instance. But rainfall can be so heterogeneous in space that during intense precipitations, errors in evaluating gross areal rainfall amount with a network of chart-recording rain gauges may exceed a factor of 5. And these errors are thus even bigger for net rainfall and runoff simulation results (figures 2 and 3).

REQUIREMENTS FOR INFORMATION ON PRECIPITATIONS

Summarily, intense precipations capable of producing flashfloods in catchment areas of up to 1000 sq. km can be divided into 2 categories (Roche et al. 1990) :

- local rainstorms of limited extension (some tens of sq. km) of short duration (up to one hour) and capable of dropping up to 100 mm of rainfall (figure 1),
- more extensive precipitating systems (several hundred sq. kilometres) persisting for several hours and of a variable intensity without being necessarily exceptional (some tens of mm/hr). Combined rainfall for such episodes may largely exceed 200 mm (figure 3).

During these episodes, the precipitations can be very heterogeneous. Thus, from many rainfall studies conducted by RHEA, values such as shown below and found on two typical rainfall events : that of July 18th, 1994 on Trappes radar (RHEA 1994) and that of September 22nd, 1992 on Nîmes radar (Kapfer 1993) have been obtained.

At the same time, the average intensity of precipitations over 1 sq. km can vary from a few mm/hr to over 120 mm/hr over a distance less than 2 km.
On one spot, the intensity factor can vary from 1 to 15 in 5 minutes (from 10 to 150 mm/hr). The accumulation of precipitations, for localized rainstorms can vary from 0 to over 80 mm over a distance of 3 km. For rainstorm systems, variation can range from less than 20 mm to over 200 mm over a 5 km distance.

The diameter of intense storm cell cores is a few kilometers long (rarely over 10 km). Typically, the trace of a rainstorm system accumulation exceeding 200 mm (Cévennes precipitations) on the ground is 25 to 50 km long and less than 10 km wide.

For catchment areas covering at least 30 to 50 sq. km, which could be equipped with an alert system (Tourasse 1992), it is therefore useful to know how rainfall is distributed in space with a 1 sq. km resolution. In fact, in the densest pluviographic networks, the rain gauge density is 1 for 10 sq. km in urban areas and 1 for 100 sq. km in rural areas.

The need for time data is twofold :

- The data discretization time step must be as fine as possible. It can be 1 min. for pluviographic data and 5 minutes for radar data. When the displacement of the rain cells exceeds 15 km/hr, it is useful to generate intermediate radar images by advection.
- The data acquisition time step must enable the user to apprehend the progress of the event as a whole but should not swamp him with data. In the SACs, the minimum time step for pluviographic data acquisition is 30 minutes because the extension of the area to be monitored and the application of the regulations on alerts and information generate tasks leaving little time for a more intensive exploitation of data. The desirable time step from a hydrological point of view is a 15-minutes time step.

A radar is a tool which can meet both conditions because its acquisition time step is 5 min. but it gives synthetized space information, very representative of the situation when images are animated and combined.
However, a radar makes an indirect reading of precipitations. Its data is to be calibrated. A conventional method is to corect them with the help of pluviographic data. Consequently, using radar rainfall data does not eliminate the need for operating a pluviographic network.

QUANTITATIVE EXPLOITATION OF RADAR IMAGES

Radar rainfall data is an indirect measurement of precipitations. In fact, it is the measurement of raindrop reflectivity in the volume scanned by the radar beam.
Raw data can therefore be fouled by errors due :

- to the measuring principle : "instantaneous" measurement of a continuous phenomenon and exploration of a volume represented by one value for 1 sq km : measurement of reflectivity related to the raindrop diameters to the power of 6, water volume being related to diameters to the power of 3,
- to the environment explored : heterogeneousness of the environment, 0° isotherm increasing the reflectivity, temperature gradient capable of modifying the linear propagation of the beam, obstacle creating interference clutter and masks,
- to the signal processing electronics.

The result expected by the hydrologists is a value for the areal rainfall of the precipitation. For a quantitative exploitation of radar rainfall data, it is thus essential to :

- minimize the risks of errors on raw data,
- correct raw data.

The hydrologic objective must therefore be one of the key elements when selecting the location of a radar. It is indispensable to be able to send out at a small site angle so that the beam does not rise too quickly. The area to be monitored must not be more than 90 to 100 km away. The French Ministry of the Environment has agreed to participate in Aramis network densification (Meteo France radar network) so as to allow a quantitative exploitation of radar data in the Mediterranean region. The measuring capability is one of the key factors for positioning radars (Comité Aramis 1995).

The conditions of radar exploitation must also integrate hydrologic requirements. They should tend to produce as steady a measurement as possible.
Various methods exist to quantify precipitations based on raw data. They are to be adapted as a function of the space-time scale desired by users and the problems they are faced with.
Calibration based on pluviographic data seems to be admitted by every one but the correction method can vary. Advection of images is however essential if you wish to compare radar and pluviographic rainfall data, above all for convective rains which generate flash floods.
As the basins to be monitored are often piémont zones (continuous alluvial cones), it is useful to deal with ground clutter. Mask processing can also be necessary.

All these processes show that raw radar information cannot be used without due consideration of meteorological and hydrological contexts. But for flash floods, rainfall measurement obtained by combining adapted radar data and pluviographic data is better than the existing (or even projected) pluviographic information in real time and at fine time steps.

THE CONTRIBUTION OF RADAR TO FLASH-FLOOD ALERTS

In a flash flood with consequences on human activity there is the existence of a risk and vulnerability. The risk will depend on the type of precipitation, the catchment area morphology, on the soil nature and plant cover... Vulnerability will be defined by the occupation of the ground and the nature of the activities created by this occupation.
To obtain an effective alert, all risk situations must be identified first. The contribution of radars will be, in differed time as in real time, to help identify the types of rain (Bressand, Kapfer, 1994).
In differed time, you can make use of case studies to analyze an event, work out a model and then make simulations.
A precise knowledge of precipitations sometimes helps to relativize, from a hydrological point of view, the most spectacular consequences of an event and refocus a hydrological analysis. This can be useful to improve the accuracy of models.
Thus on September 22nd, 1992, the heaviest precipitations in the Vaucluse departement did not occur upstream of Vaison-la-Romaine but farther South, in the Brégoux basin (Kapfer, 1993). The hydrological disorders observed on this basin are sometimes more impressive than at Vaison-la-Romaine (Gilard et al, 1993).

This analysis in differed time will then be used in real time to better predict the hydrological consequences of a precipitation.
A tool for exploiting rainfall radar data in combination with pluviographic data has been developed by RHEA. It is the Calamar system (from the French "CAlcul de LAMes d'eau à l'Aide du Radar" or radar calculation of areal rainfall).
Calamar has been adopted in several major communities (jointly by the Sanitation Authorities of 3 départements around Paris : Seine Saint-Denis, Val-de-Marne and Hauts-de-Seine, Sanitation Association of Paris Conurbation, Urban Communities of Bordeaux and Marseille) and the Flood Warning Agency of the department of Gard.

Each user has at his disposal a geographical data base describing the catchments basins areas to be monitored. For each of this catchment areas, the tool calculates the precipitations integrating the radar pixel values which apply to the areas. For the agencies, it means having on-line knowledge of the areal rainfall in each of the catchment areas through visualization of a rainfall hyetogram or rainfall accumulation chart starting from a given time (start of precipitation for instance). This result can also be transmitted to a rainfall-discharge simulation model (LHF-EDF/DTG-RHEA, 1994).
A prediction module for the areal rainfall in the next hour based on radar image extrapolation is also integrated in Calamar.

An exact knowledge of the precipitations on all the catchments areas monitored, updated every 5 minutes, enables a warning agency to anticipate on rain consequences : passing of alert thresholds (pre-determined by studies), identification of the situation with typical scenarios to which preset actions have been linked.

As a result, situations can be assessed in less time and with better precision and modeling and decision-aiding tools can be brought into play.
These resources should also enable a flood warning agency to integrate every risk situation as Calamar

contributes to an automatic, permanent "indefatigable" monitoring of situations and is a tool capable of generating hydrological alarms.

CONCLUSION

When the objective is to make flood warning toward upper basins more effective, and to extend this mission to basins subject to flash floods, the quantitative exploitation of radar rainfall data is a must.
This proved true for basins in the south of France using Nîmes radar.
Aramis radar network will be completed in the arc formed by the Mediterranean region. But this action should not stop here. Indeed, it is necessary to set up data processing and transmission means as well as operational tools capable of quantifying precipitations on catchment areas based on rain gauge and radar data.
Today such a tool exists, its is the Calamar system developed by RHEA.
It is also essential to set up teams to handle this data and operate the alert transmission chain.

REFERENCES

Mariani et al. 1994. "Inondations : une réflexion pour demain". Rapport de la commission d'enquête parlementaire sur les causes des inondations et les moyens d'y remédier. Assemblée nationale n°1641.

Godard, N. 1994. "La mise en oeuvre des nouvelles orientations de la politique de prévention des inondations en France, adoptée en janvier 1994". La Houille Blanche, n° 8-1994 , pp. 91-93.

Godon, C., Odier, M. 1994 L'annonce des crues : une des priorités du ministère de l'Environnement en matière d'inondations"" in Actes du colloque Crues et Inondations, SHF, Nîmes 09/1994, pp 659-663.

LHF-EDF/DTG-RHEA 1994. "Crues-éclair. Apport d'un outil intégré Mesure-Modélisation-Radar - Maquette de démonstration - Faisabilité". Ministère de l'Environnement, Direction de l'Eau. 09/1994.

Roche, PA. et al. 1990. "Suivi et prévision des précipitations extrêmes" Rapport à Monsieur le Directeur de l'Eau, Ministère de l'Environnement, avril 1990.

RHEA. 1994. "Etude des pluies des 18 et 19 juillet 1994 sur le département du Val-de-Marne". Direction des Services de l'Eau et de l'Assainissement du Val-de-Marne - EA07, 10/1994.

Bressand, F., Kapfer, A. 1994. "Apport des données radar de pluie pour la prévision et la gestion des crues rapides" in Actes du colloque Crues et Inondations, SHF, Nîmes 09/1994, pp 567-572.

Kapfer, A. 1993. "La pluie du 22 septembre 1992 sur le département de Vaucluse. Impact sur les bassins versants". Ministère de l'Environnement, Agence de l'eau Rhône Méditerranée Corse, février 1993.

Tourasse, P. 1992. "Crues et laves torrentielles : prévision et surveillance, aspects hydrologiques" in Actes du colloque des 24, 25 et 26 juin 1992, SHF.

Comité Aramis, 1995. "Choix des sites radar sur le sud-est". Rapport au Comité Consultatif Aramis du 17/01/95.

Gilard, O. et al. 1993. "La crue de l'Ouvèze du 22 septembre 1992 : difficulté d'estimation des débits observés". Sécheresse, n° 3, vol. 4, 09/1993, pp. 165-170.

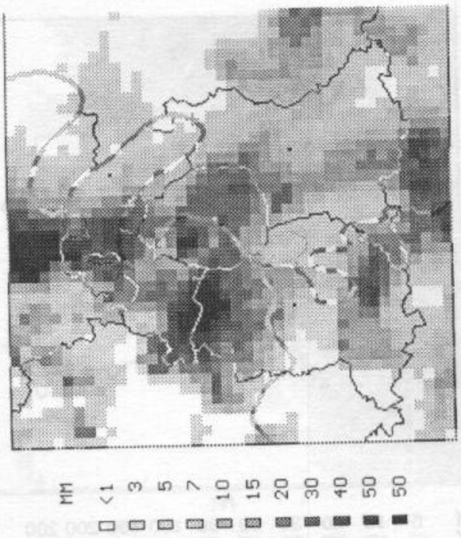

Figure 1 : Heterogeneousness of rainfall accumulation. Trappes radar (region of Paris), july 18th 1994 (1 pixel is 1 sq. km)

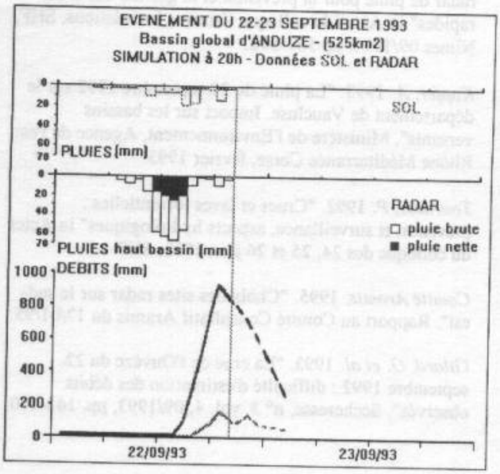

Figure 2 : Flow simulation for the subbasin of the Gardon d'Anduze river in the department of Gard (525 km²).

Comparison between raw and net rainfall from a nine rain gauges network (among which six are localised in the subbasin of the Gardon d'Anduze river) and from Nîmes radar data, september 22nd and 23rd, 1993. Result of a runoff simulation from the two types of rain data.

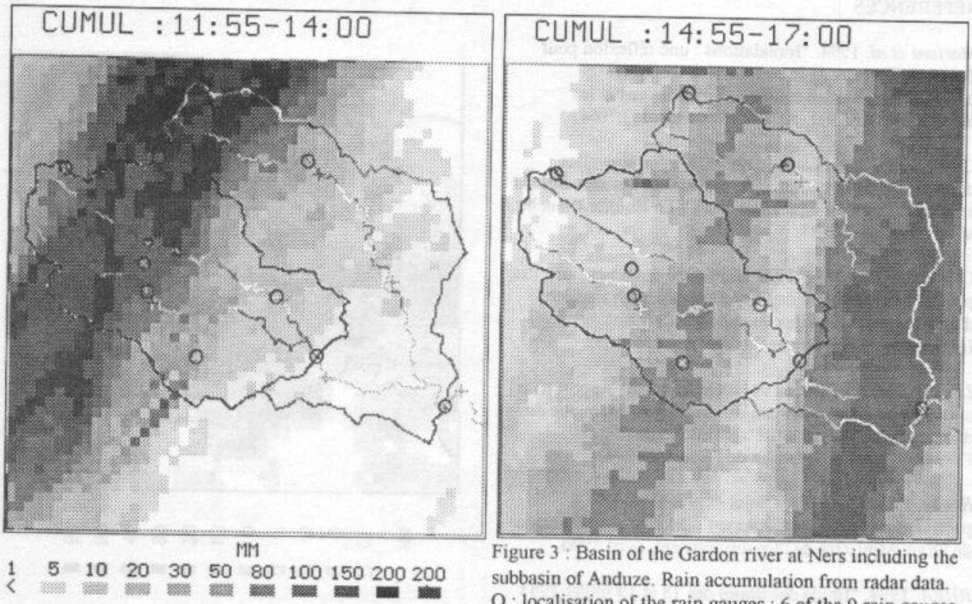

Figure 3 : Basin of the Gardon river at Ners including the subbasin of Anduze. Rain accumulation from radar data. O : localisation of the rain gauges : 6 of the 9 rain gauges are located in the subbasin of the Gardon d'Anduze river.