DOI 10.1051/lhb/2009080

La prévision hydrométéorologique en Espagne dans le contexte du projet européen FLASH

The Hydrometeorological Forecasting in the Framework of the European Project Flash

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Le principal but du projet Européen FLASH est l'amélioration de la prévision hydrométéorologique des crues éclair (Observations, Analysis and Modeling of Lightning Activity in Thunderstorms, for use in Short Term Forecasting of Flash Floods). Avec cette objectif, la contribution espagnole est centrée sur l'intégration des données radar et pluviométriques, données sur les décharges électriques et les sorties du modèle de meso- échelle MM5, sur le modèle hydrologique RIBS (Real-time Interactive Basin Simulator). On prend comme bassins d'étude ces bassins côtiers de la Catalogne, où 11 crues on été enregistrées en 2000. Ces basins ont aussi le problème d'une très grande vulnérabilité due à la concentration de la plupart de la population de la Catalogne, ainsi qu'au tourisme et aux exploitations agricoles. Le projet n'étant encore fini, l'article montre les sources de données, la méthodologie et les résultats obtenus jusqu'àu moment présent dans le cadre du projet..

The principal objective of the European Project FLASH (Observations, Analysis and Modeling of Lightning Activity in Thunderstorms, for use in Short Term Forecasting of Flash Floods) is the improvement of flash flood forecasting. With this aim, the Spanish contribution is centred in the integration of radar and raingauge data, lightning data and MM5 outputs into the hydrological model RIBS (Real-time Interactive Basin Simulator). Eleven case studies which affected the coastal region of Catalonia, between 2000 and 2006, have been selected. This region is characterized by great vulnerability due to concentration of the major part of the population, tourism and agricultural activities. This contribution shows the data and methodology as well as some preliminary results obtained within the project.

I ■ INTRODUCTION

After droughts, floods are the most dangerous meteorological hazard that affects Mediterranean countries, followed by wind storms and hail. The damages of the flash floods recorded in the Gard region (SE of France) in September 2002, were € 1.2 billion with 23 casualties [1]. In Spain, 815 people died in less than 3 hours in Catalonia in 1962 while in 1987, 87 people died in a camping placed in the Pyrenees, in both cases as a consequence of a flash flood. The flash floods recorded in Athens in October 1994 produced damages for € 14 million, and in Israel the floods on 21-22 February 1997 resulted in 11 casualties and important losses in agriculture. In addition to the high frequency of flash floods produced in Mediterranean countries, these floods occur in regions with a great vulnerability due to the high concentration of the population. Although it is still not clear if the number of floods in the Mediterranean region has changed in recent years, there exists complete agreement among the scientific and technical community that the damages produced by floods, and the social impact is rapidly rising [2;3].

Particularly, in Catalonia, a total of 217 flood events were registered between 1901 and 2000, most of them near the coast [4]. The major parts of them were flash floods produced by very convective rainfall events of short duration (less than 6 h), very high rainfall intensity, and maximum total rainfall inferior to 100 mm. They produced local damages and car losses, and, sometimes, some casualties, usually when they tried to cross a water course. Less frequent are catastrophic flash floods associated to highly organized convective systems that can last more than 6 hours and cumulating more than 200 mm of rainfall. Some damages and victims would be avoided with the improvement of flash flood forecasting techniques.

This paper starts with the presentation of the FLASH project, their objectives, partners and work packages, to follow with the presentation of the meteorological radar, the hydrological model and the case studies.

II ■ THE FLASH PROJECT

Forecasting of flash floods is not an easy task, because they are very local and short events. The use of mesoscale models in combination with the use of meteorological radar can improve their forecasting (24-48 h prediction) and nowcasting (less than 3 h prediction) accuracies. But meteorological radars have a spatial limitation : usually, they only cover an area with a radius of less than 200 kilometres. Besides this, although many developed countries have weather radar networks to track storms and precipitation, the majority of the world is not covered by radar observations. In addition, radar coverage is usually sparse and inadequate in mountainous regions - such as most coastal regions of the Mediterranean basin which are prone to flash floods. However, flash floods can be associated to organized convective systems that can affect extensive regions along their cycle of life (like multicellular or Mesoscale Convective Systems, MCS). In these cases, the use of remote sensing information from satellites as well as the lightning activity monitoring, can be very useful. Infrared (IR) measurements from geostationary (GEO) satellites enable following storm development at the relevant space and time scales, but have limited applicability for quantitative precipitation measurement. Alternatively, microwave (MW) observations from low Earth orbiting (LEO) satellites provide more direct and reliable measurements of precipitation and cloud internal structure, but do not properly address the fundamental space-time scales of precipitation and storm evolution. Finally, lightning observations of storms can be carried out from thousands of kilometres away due to the propagation of low frequency electromagnetic waves emitted from lightning discharges.

In this framework, the European Project FLASH (Observations, Analysis and Modelling of Lightning Activity in Thunderstorms, for use in Short Term Forecasting of Flash Floods) have set the goal of using lightning data to better nowcast and forecast the location, intensity and timing of heavy convective precipitation events [5]. With the help of precipitation data, radar data, cloud and meso-scale models, the FLASH project is simulating 23 case studies of past flash flood events recorded in Israel, Cyprus, Italy, Greece and Spain, to better understand the connection between intense precipitation and lightning activity. The rainfall estimate is input into hydrological models to investigate the ability to predict regions of flooding on the ground, together with the time lags between heavy rainfall and flooding. With this objective, different hydrological models are being used to simulate past flash flood events in some Mediterranean regions, with the intention of linking hydrological models with atmospheric forecasts to allow for better forecasting of flash floods. Finally, the societal benefits of such advanced warnings are also investigated into the Project, especially in relation to risk management and societal impacts.

The FLASH Project is coordinated by the Tel Aviv University (Israel). Partners are The Open University (Israel), the National Research Council - Institute of Atmospheric Sciences and Climate (Italy), the National Observatory of Athens (Greece), the University of Barcelona (Spain) and the Ministry of Agriculture, Natural Resources and Environment - Cyprus Meteorological Service (Cyprus). The University of Barcelona collaborates with the Polytechnic University of Madrid (Spain) in order to do the hydrological modelling, and with CLABSA, Meteorological Service of Catalonia, and Civil Protection of Catalonia, as end users.

Figure 1 shows the work packages distribution. WP1 looks at significant floods that have occurred in recent years in Cyprus, Israel, Greece, Italy and Spain, for which precipitation measurements, lightning measurements and model simulations exist. For each case of study a deep analysis that includes meteorological, hydrological and social impact features is made. This WP will result in the assessment of rainfall-lightning relationships for the different regions and event.

WP2 deals with acquiring lightning data from various satellite and ground networks for improving the detection of convection over the Mediterranean area. The primary source of data for

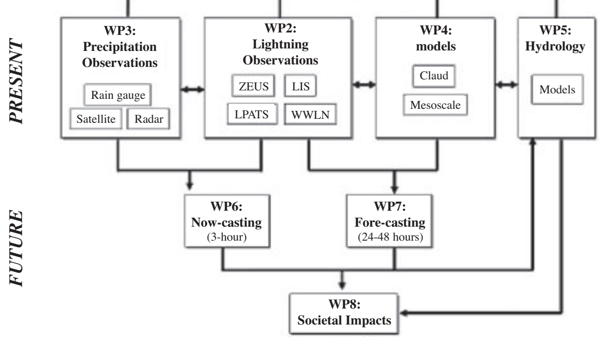

Figure 1. Graphical presentation of work packages of the FLASH Project

this project are from the ZEUS VLF lightning network, However, other data bases and local networks like XDDE (Meteorological Service of Catalonia) are also being used.

WP3 deals with acquiring rainfall data from surface, satellite and radar measurements. Conventional MW brightness temperature (TB) measurements from LEO satellites - provided by the Special Sensor Microwave/Imager (SSM/I) and Special Sensor Microwave Imager Sounder (SSM/I) radiometers onboard satellites of the U.S. are used, joined with lightning data.

WP4 mainly deals with MM5 atmospheric model that is being used to study historic flash floods (WP1) as well as to improve weather forecasting models by assimilating lightning data (WP2) into the model runs, and using it to initialize hydrological models (WP5). Cloud numerical models, like the Explicit Microphysics Thunderstorm Model (EMTM), are also used to study the relationships between microphysics and electrification.

WP5 aims at using hydrological models to simulate both past and future flash floods. This work package involves three partners from three countries (Israel, Greece and Spain) with different hydrological models and different model calibrations. The idea is coupling the hydrology models with atmospheric models in WP4, and radar data, to allow for the precipitation forecasts to be fed into the hydrology models. Once this stage has been achieved, it will be ready to attempt to use the hydrology model with the precipitation forecasts to assess the likely flooding in particular areas across Europe and the associated societal impact (WP8).

WP6 aims at providing short-term (3-hour) nowcasting for flash floods via an internet website that will be open to the public. WP6 will use the results of WP2 and WP3 for the development of the algorithms that give short-term warnings of flash floods.

WP7 deals with forecasting flash floods and lightning activity 1-2 days in advance. These forecasts will be based on the research in WP2 and WP4 that will develop improved flash flood forecasts. A new lightning parameterization in the UW-NMS, MM5 and WRF models, that relate Lightning Index Activity (LIA) to several dynamics and microphysics variables, is applied to forecast lightning activity.

WP8 deals with the social impacts of flash floods. The current sensitivity/vulnerability of society to flash floods is being analysed. A climatology of floods and their associated damages, that have affected all the Mediterranean region between 1990 and 2006, has been done. This WP also includes a divulgation web site on FLASH FLOODS, transfer of the knowledge, educational dossiers and so on. For more information about the FLASH project you can go to http://gama.am.ub.es/flash/ as well to http://flash-eu.tau.ac.il/

III ■ THE SPANISH FLASH CONTRIBUTION TO THE HYDROMETEOROLOGICAL FORECASTING

● III.1 CASE STUDIES

Eleven flood events with important damages have been recorded in Catalonia between the years 2000 and 2006. The total amount paid out in compensation for damages caused by this type of phenomena between June 2000 and December 2006 has been more than € 155M. All these events have caused flash-floods over the coastal region. To sum up, the most affected places have been Barcelona city (affected in 7 times), Maresme watercourses (6 episodes), Muga basin (5 episodes), Garraf watercourses (4 episodes), Llobregat basin (4 episodes) and Besòs basin (2 episodes). Although all cases have been used to calibrate the hydrological model, only four of them have been selected by the European Project FLASH as case studies : 2 August 2005, 11-15 October 2005, 13-15 November 2005 and 12-14 September 2006.

The 2 August 2005 was a strongly convective event (in some regions more than 80 % of the precipitation was convective), with a maximum of 56 mm in 1 hour and 57,1 mm in 24 hours. Between 11 October 2005 and 15 October 2005 several catastrophic floods as well as landslides, affected the Central and Northern coast ; flash-floods occurred on 13th October, and a total of 393,4 mm was registered in 5 days, of which 254 mm were registered on 13th October alone. Between 13 and 15 November 2005 an extraordinary flood event affected the South of Catalonia ; a maximum accumulated precipitation of 212 mm was recorded over the small catchments, with 102 mm recorded on November 13th. Between 12 and 14 September 2006 several extraordinary flash floods were recorded as a consequence of rainfalls between 100 and 250 mm in 24 hours, with maximum accumulated rainfall of 267 mm in the South of Catalonia, and 256 mm in the North. More information about these cases can be found in [6] and [7] while *Figure 2* shows the other seven cases. About the classification used to distinguish between catastrophic and extraordinary floods, you can see [8]

● III.2 DATA

The rainfall network of the SAIH (Automatic System of Hydrological Information) of the Internal Basins of Catalonia provides the pluviometric data. This network comprises 126 automatic stations giving continuous information on accumulated rainfall at intervals of 5 min. For periods above 1 hour, the rainfall data coverage can be increased with data from XEMA (Automatic Weather Station Network, Catalan Meteorological Service-SMC) that is composed by 158 rain-gauges.

The radar network (XRAD) used pertains to the SMC. It covers an area of 53,000 km^2 over Catalonia and its surroundings. This network is composed by four C-band Doppler radars that allow to have composed CAPPI imagery with spatial resolution of 2 × 2 km^2, time resolution of 6 minutes and vertical resolution of 1 km and 10 levels of altitude.

The MM5 mesoscale model initialized with the NCEP analysis, the data from the radiosonde of Barcelona city and Meteosat satellite images are used to do the meteorological analysis.

Flashes are detected by the XDDE (lightning detection network from the SMC). The XDDE is composed by four sensors that use interferometric technique to detect intra-cloud (IC) discharges in the VHF range (108-116. MHz) ;

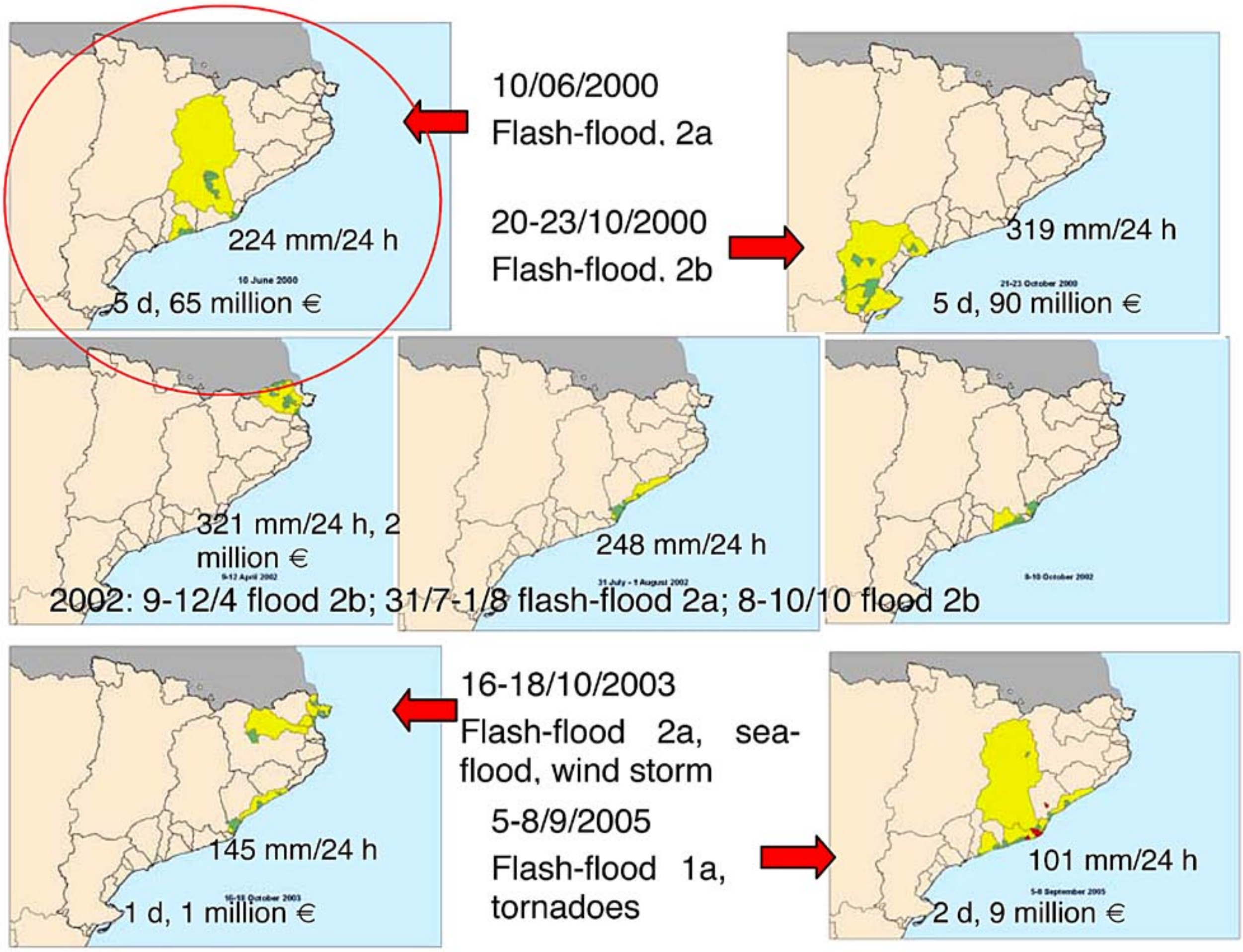

Figure 2. Flash-flood events recorded in Catalonia between 2000 and 2006 that have been used to calibrate the hydrological model. Some information about the most affected catchments, rainfall deaths (d) and damages is also included

its spatial accuracy is around 2-3 kilometres. The system is completed with a LF antenna which detects all return strokes of CG flashes. Lightning data from the ZEUS network is also used.

5-minute flow data for 49 stations are provided by the SAIH of ACA (Catalan Water Agency), as well as average daily data for reservoirs. For those cases that have affected Barcelona city and the Besós catchment, flow and rainfall data from CLABSA (the company responsible of the drainage system in Barcelona) are also considered. For the topography, the DTM elaborated by the Spanish National Geographical Service, at original model scale of 1 :200.000, and spatial resolution of 200 m, and vertical resolution of 1 m, as well as the 1 :50.000 topographical maps have been used.

III.3 METHODOLOGY

For the meteorological analysis the MM5 model is run for each selected case. Four two-way nested domains with 54, 18, 6 and 2 km horizontal grid resolution and 23 vertical levels are being used. The outer domain (domain 1) is centred in the NE Spain at geographical coordinate (0.0ºE, 40.0ºN). Initial and boundary conditions are obtained from the 1º resolution FNL NCEP analyses (Global Final Analyses from the US National Centers for Environmental Prediction) available every six hour from 00:00 UTC, which are improved using surface and upper-air observations (ADP, Automated Data Processing observations from the NCEP). This improvement is applied by an objective analysis tool included in the program scheme of the MM5 model. Full physics is used and a Kain-Fritsch scheme is applied to parameterise convection for the first, second and third domains while no convective parameterisation are activated over the fourth domain. Due to the fact that results are not completely satisfactory, other 13 parametrizations are being applied in order to select the best one to simulate coastal heavy rainfall events in Catalonia.

The current temporal resolution of the MM5 model's output is 6 hours. This resolution is not adequate as input for the hydrological model. However, a preliminary approach to link the atmospheric model with the hydrologic one has been carried out. An algorithm has been developed which transforms the coordinate system of MM5 into the hydrological model coordinate system and does an interpolation between the resolution of the atmospheric model (2 x 2 km^2) to the high resolution of the hydrological model (200 x 200 m^2). The necessary future work to finish this link is to determine the best input time resolution for the hydrological model and the best parameterization.

Radar data are used from two points of view. The first one analyses the kind of precipitation system, its internal 3D structure and its cycle of life and trajectory, in order to better understand the meteorological causes of the heavy rainfall produced [9]. The second one also distinguishes between the convective and stratiform contribution (lightning data have also been used to do it), but it is centred in estimating the precipitation field in the surface in order to have the input for the hydrological model. Therefore a Window Probabilistic Matching Method (WPMM) is applied to both convective and stratiform pixels [10], to improve the observed rainfall sub-estimation in Z-R relationships when they are applied to Catalonia. *Figure 3* shows the both new Z/R relationships for convective and stratiform rain types.

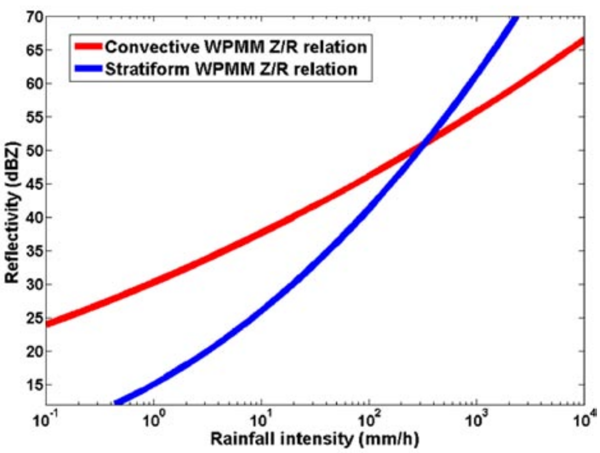

Figure 3. The new two Z/R relation (blue, stratiform, and red, convective) obtained from WPMM method.

Finally, once the rainfall field has been obtained an advection correction, based on cross-correlation between two consecutive images, has been introduced not only to improve the quantitative precipitation estimation, but also to get several time resolutions to be introduced in the hydrological model.

The selected hydrological model is the RIBS (Real-time Interactive Basin Simulator). RIBS is a topography-based, rainfall-runoff model which can be used for real-time flood forecasting in midsize and large basins [11]. Model use is especially attractive in connection with meteorological radar and distributed rainfall forecasting methods. RIBS model is largely based on the detailed topographical information provided by digital elevation models (DEM). Basin representation adopts the rectangular grid of the DEM, and other soil properties, input data and state variables are also represented as data layers using the same scheme. The basic objective is to map the topographically-driven evolution of saturated areas as the storm progresses. Two modes of runoff generation are simulated : infiltration excess runoff and return flow. RIBS applies a kinematic model of infiltration to evaluate local runoff generation in grid elements, and also accounts for lateral moisture flow between elements in a simplified manner. Flow propagation to the basin outlet is computed through distributed convolution, using as instantaneous response function for each element a Dirac delta function, with a delay equal to the time of travel from the location of the element to the basin outlet. A reservoir operation module has been added to the discharge results of the rainfall-runoff model, to take into account the flood control effect of reservoirs over the final hydrographs. The model captures the main features of runoff generation processes in watersheds while keeping computational efficiency for real-time use.

In order to build a RIBS model, the following activities have been performed

1. Digital terrain analysis : The original DTM (Spanish National Geographical Service) has been analyzed to extract the drainage network in the study area, comparing the resulting network with the 1:50.000 topography maps. The overall results have been considered acceptable. Derived quantities, such as slopes and travel distances to basin outlets have been also computed from the original DTM data.

2. Soil type classification : Soils in the study basin have been classified according to the available information : topographical maps, geological maps, cultivar maps and Corrine land-use maps. A grided coverage of soil types has been built classifying them according to their potential runoff generation.

3. Initial soil parameter values. An initial set of values for soil model parameters in each class has been prepared. Soil model parameters are : Saturated hydraulic conductivity and Brooks-Corey parameters. Global parameters (anisotropy ratio and exponential decay of hydraulic conductivity) are defined through direct calibration.

4. Hydraulic infrastructure. Data corresponding to hydraulic infrastructure has been introduced in the model. This includes reservoir storage and outlet capacity, and reservoir operation rules.

For model calibration, the model is run for the calibration cases, and an automatic procedure is applied to determine ranges and pdf's of model parameters subject to calibration. The distributed rainfall-runoff model is calibrated by a hybrid method, combining manual and automatic calibrations for heterogeneous data sets, which gives the Pareto set results for every flood event recorded. Every parameter of the rainfall-runoff model is characterized by a probability density function from all these Pareto data sets.

Two calibrations have been done. The first one has been performed using raingauge data from the seven cases prior to October 2005. Initial conditions for the case studies have been defined according to antecedent rainfall. Model initial condition is defined in terms of depth to the water table and initial moisture content. A reference seasonal initial condition is defined for each season with a simplified groundwater recharge model. The model is run with average rainfall in the season until an equilibrium water table depth is attained.

Initial moisture content is specified according to antecedent rainfall. Daily rainfall values were compiled for raingauges in the basin, and a classification was made in dry, average and wet conditions, comparing average rainfall in the previous week to average climatic rainfall.

The second calibration uses the new radar rainfall estimation for the four main case studies. This new calibration has been made for different time resolutions of radar rainfall. These different resolutions, from 2 minutes to 30 minutes, are obtained by means of an advection correction, based on cross-correlation between two consecutives images. Each different resolution is treated as an independent event, giving as result a probable range of input rainfall data. This ensemble of rainfall data is used, together with other sources of uncertainty, such as the initial basin state or the accuracy of discharge measurements, to calibrate the RIBS model by means of a probabilistic methodology. A sensitivity analysis of time resolutions has been done by comparing the different results with real values of streamflow measurement stations.

● III.4 FIRST RESULTS

The application of the new Z/R calibration and the advection correction improves radar rainfall estimation and reduces the bias by 90 %. Once a sound precipitation field has been obtained, different time resolutions could be introduced into the hydrological model. The September 2006 case has been modelled for the Besòs catchment. It has been found that a precipitation time resolution of 15 minutes can be recommended for the simulation of the Besòs basin due to it leads to the minimum RMSE and bias and has a practicable computation time for real-time operational hydrological forecasting.

IV ■ ACKNOWLEDGEMENTS

This study has been supported by the European Project FLASH (FP6-2005-Global-4 (n. 036852) and the Spanish project SEVERUS (CGL2006-13372-C02-02). Our thanks to the Meteorological Service of Catalonia, Catalan Agency of Water and CLABSA for the data supplied.

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