

## Results of the European project RAPHAEL and follow up

Roberto Ranzi

University of Brescia, Via Branze, 38, I-25123 BRESCIA, Italy

The results of the European Project RAPHAEL and of successive applications of some of its outcomes for forecasting floods using high resolution hydrological and meteorological models are presented.

### *The RAPHAEL project objectives*

The basic objective of the RAPHAEL project (Runoff and Atmospheric Processes for flood Hazard forecasting and control) was *to develop, implement and demonstrate the use of coupled meteorological and hydrological models at the regional scale in order to improve flood forecasting and management in complex mountain watersheds*. With this guideline, the basic additional specific objectives were:

-to apply coupled high resolution atmospheric-hydrological models and carry out a multi-scenario modelling experiment to show the potential use of advanced flood forecasts in view of the control of hazardous flood events;

-to validate meteorological data generated by numerical weather prediction models and meteorological observations by means of runoff measurements and distributed hydrologic water balance calculations;

-to investigate the benefits of remotely-sensed and radar-derived data (e.g., land cover, albedo, vegetation and snow cover, rainfall) as related to sub-grid parameterisation of both meteorological and hydrological models.

The project was coordinated by Prof. Baldassare Bacchi, from the University of Brescia and was developed with the contribution of 10 other partners

EU partners:

1. *Universita' di Brescia, Dipartimento di Ingegneria Civile*, Brescia - I (B. Bacchi, R. Ranzi, G. Grossi, L. Falappi, M. Pilotti, A. Clerici)
2. *Politecnico di Milano, Dipartimento di Ingegneria Idraulica, Ambientale e del Rilevamento*, Milano - I. (R. Rosso, M. Mancini, N. Montaldo, S. Marzocchi, V. Toninelli)
3. *FISBAT-CNR*, Bologna - I. (A. Buzzi, G. Minardo, L. Foschini)
4. *University of Muenich, Department of Geography and Geographical Remote Sensing*, München - D. (W. Mauser, R. Ludwig, S. Taschner)
5. *VISTA - Remote Sensing Applications in Geosciences*, Wessling - D (H. Bach, G. Lampart, M. Braun)
6. *DLR-Institut für Physik der Atmosphäre*, Oberpfaffenhofen - D. (P. Meischner, M. Hagen)
7. *CNRS, Université Paul Sabatier, Laboratoire d'Aerologie*, Toulouse - F. (E. Richard, G. Charney, S. Cosma)

Non EU partners:

8. *Swiss Meteorological Institute*, Zurich - CH. (P. Binder, P. Kaufmann)
9. *Institute of Geography, ETH*, Zurich - CH. (H. Lang, J. Gurtz, K. Jasper)
10. *Atmospheric Environment Service-Environment Canada*, Dorval - Canada. (R. Benoit, G. Bergeron)

11. *University of Waterloo, Department of Civil Engineering, Waterloo - Canada.* (N. Kouwen, J. Innes)

### *Developed methodology*

The achievement of the objectives needed the organisation of a multidisciplinary working group able of setting up and solving the problems connected. Groups were first organised on the basis of the main skills of each member. Meteorologists, hydrologists and radar experts of eleven research partners from Italy, France, Switzerland, Germany and Canada, characterised by very different experience and scientific background even at their inside, worked hard both separately and then jointly. Fundamental was the first phase where a common language was searched and found and the standards used in different countries for the data collection and distribution were homogenised in a common format for the purposes of the project.

Two specific target area have been identified: the Ammer watershed (709 km<sup>2</sup>), in the Bavarian Alps that experienced a major flood in May 1999, and the Lago Maggiore watershed upstream the Miorina water barrier (6599 km<sup>2</sup>), across Switzerland and Italy. The last basin is drained by the Ticino, Maggia, Verzasca and Toce rivers and other minor tributaries and is located in the core of one of the most rainy areas of Europe. Eight major flood events, four for each of the study areas, occurred in the recent years were investigated on the basis of detailed hydrometeorological data and numerical simulations.

As far as the quantitative meteorological forecasts are concerned a wide range of forecasts were made available to hydrologists as a results of simulations using four advanced mesoscale models, implemented in two different modes. The first one, denoted as 'analysis mode', is representative of the best forecasting possibility given the available 'exact' information about the initial and boundary conditions of the atmosphere, as far as the accuracy of meteorological monitoring and the data assimilation procedures into the large scale Regional and Global Circulation Models (such as the German EM-Europa Model or the ECMWF, used in the project) allow. The second one, called 'forecast mode' and operationally more interesting, is representative of situations similar to reality, when high resolution Limited Area Models' simulations might be requested and the initial and boundary domain conditions are driven from the operational forecasts of GCMs.

Hydrological simulations of flood routing for all the considered watersheds in the two study areas were carried out through distributed modelling taking into account both the physiographic (slope, aspect, etc.) and the hydrological (land use, permeability) characteristics, typical of the different areas. This implied the acquisition of a huge amount of distributed information that needed the use of satellite images, for the estimate of the distribution at the basin scale, coupled to direct field and laboratory measurements. Different hydrological models were improved by including, even if through simple schemes, the river section geometry and the sites of the artificial reservoirs. Refinements and comparisons were also carried out on the Snow-Soil-Vegetation-Atmosphere schemes of vapour and energy fluxes exchanges between the surface and the atmosphere, by either testing the parameters sensitivity or comparing results with those obtained by LAMs. Further analysis dealt with the sensitivity of the hydrological output to possible errors of Numerical Weather Prediction models.

A deeply investigated matter was that concerning the rainfall field description at different spatial aggregation scales. From this point of view very helpful was the rainfall radar monitoring, which outlines the detailed structure of spatial-temporal intermittency, not clearly evident from the interpolation of ground measurements or through numerical prediction models.

### *Flood forecasting of the MAP-SOP and the Piedmont 2000 flood*

During the MAP-SOP 1999 experiment two teams (University of Brescia with CNR-ISAO and University of Waterloo with Environment Canada) tested in parallel two flood simulation chains for issuing flood forecasts in the Lago Maggiore Target Area in quasi-operational mode: these were somehow pioneering experiments using one-way coupled hydrometeorological models. Although these exercises were not framed within the RAPHAEL project they were a natural outcome of its results.

Two distributed hydrological models of the conceptual type (DIMOSOP and WATFLOOD) were forced by the high resolution meteorological forecasts, respectively, of the BOLAM and of the MC2 model. One major flood with a return period of about 4 years occurred on the Toce basin (1532 km<sup>2</sup>) was forecasted quite successfully by both chains in term of flood peak and volume.

The BOLAM+DIMOSOP simulation scheme was further validated through the simulation of the severe October 2000 flood event. Also in this case results were promising in terms of timing and intensity of the major flood peak, although the first rise of the flood was not properly captured, thus suggesting the need for further improvements of the simulation chains.

### **Main results**

As a result of a detailed data collection a likely unprecedented data set of hydrological, meteorological and physiographic data and models' simulations for two areas of the Alps that are affected by heavy precipitation is now available for scientists and end-users as a product delivered to the EU Commission-DGXII. This will be a sound basis for improving the knowledge of atmospheric and hydrological processes in mountain areas. The data and the report are accessible at the address <http://civserv.ing.unibs.it/raphael/> and a CD can be requested to the Project Coordinator.

At the scale of catchments of intermediate size, around one thousands of square kilometres, with a response time of several hours, the coupling of hydrometeorological modelling can become a successful tool. The analyses conducted in the RAPHAEL project and further verifications based on the MAP-SOP 1999 and the Piedmont 2000 floods give some indications in this direction, and many of them are positive ones:

- spatial and temporal scales of mesoscale meteorological models and hydrological models are now sufficiently close for practically all applications;
- the spatial variability and the intermittency of the simulated precipitation fields “look” realistic and, using objective scores, are in agreement with the raingauge and radar observations and the predicted rainfall volumes averaged over 24-48 hours are quite precise also using hydrological measurements and simulations for reference; for shorter time scales of great interest for flash flood warning the timing of the simulations were not completely successful and showed quite a high sensitivity to the initial and boundary conditions used, to the spatial and temporal resolution and, in some cases, to the parameterisation of physical processes. Increasing the spatial resolution of the models does not necessarily improve the forecasts;
- an integrated use of radar images and meteorological models can indicate directions to shift meteorological fields: such exercises showed that the hydrological response was influenced till 20-30% for basins of about 1000 km<sup>2</sup> from a shift of about ten kilometres in different directions; sensitivity analyses experiments and the application of downscaling schemes that preserve the water mass and basic statistics of fluctuations showed that the hydrological response is affected by the meteorological resolution only at scales smaller than the maximum resolution of the original mesoscale models;
- reservoirs can influence the flood volumes and flood peaks up to 10% approximately, in the larger catchments of the Ticino-Toce basin at least, depending on the season and the regulation rules adopted. These could benefit from the use of flood warning systems but significant economic losses could be produced in the case of wrong weather forecasts that remain a realistic possibility;
- sensitivity analyses experiments were conducted and disaggregation schemes, based on the inverse wavelet transform, that preserve the water mass were applied. These experiments showed that the hydrological response is significantly affected by the resolution of the meteorological forcing only in basins with scale smaller than the resolution of the original mesoscale model: in larger basins increasing the spatial resolution of the models does not necessarily improve the forecasts;
- the intercomparison of high resolution hydrological surface schemes based on detailed surface descriptions and the respective surface fluxes of mesoscale models show quite a satisfactory agreement both in terms of the average fluxes and the spatial variability at the event scale and at the annual scale; it can be expected that the assimilation of more detailed surface data into meteorological models will improve the estimated surface fluxes;
- the intercomparison of different hydrological schemes in term of the scale of representation and the degree of conceptualisation does not indicate dramatic differences. Increasing the degree of the detail, the specific knowledge of the catchment characteristics, and the extended use of the physiographic data collected generally results in a more precise simulation of the hydrological response.

Radar data confirm their usefulness in describing the fine space-time structure of rainfall fields. In the complex mountain areas like those investigated their use for hydrological purposes would significantly benefit from the use of real-time raingauge data for their calibration. New data collected within the project, indicate also how different measurement techniques as the differential reflectivity,

$Z_{DR}$ , and the specific differential propagation phase, KDP, can be useful for a more precise estimation of the rainfall intensity.