A METEO-HYDROLOGICAL PREDICTION SYSTEM BASED ON A MULTI-MODEL APPROACH FOR ENSEMBLE PRECIPITATION FORECASTING

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Abstract
The precipitation predicted by a numerical weather prediction model, even at high resolution, suffers from errors which can be considerable at the scales of interest for hydrological purposes. In the present study, the uncertainty related to the meteorological model error is taken into account by implementing a multi-model forecasting approach, aimed at providing multiple future precipitation scenarios driving the same hydrological model. Therefore, the estimation of the uncertainty associated with the meteorological prediction can be exploited by the hydrological model, propagating the error into the hydrological forecast.
The proposed meteo-hydrological forecasting system is implemented in a real-time configuration for several episodes of intense precipitation affecting the Reno river basin, located in northern Italy (Apennines). The episodes are associated with flood events of different intensity.
The coupled system seems promising in order to provide useful information concerning the discharge peaks (amount and timing) for warning purposes.

1. Introduction

In order to extend the lead time between warning and occurrence of a flood event, an appropriate prediction of the hydrological responses for medium-sized catchments (from 1000 to 10000 km^2) is only possible if hydrological models are coupled with numerical weather prediction (NWP) models, using the predictive potential of both the atmospheric and the hydrological models.
This approach suffers from several sources of uncertainty, lying in the hydrological and meteorological models themselves; however, for real-time forecasting the error in rainfall prediction prevails on the other sources of uncertainty (Krzysztofowicz, 1999). To cope and deal with the above uncertainties, ensemble forecasting techniques are beginning to be applied to hydrological prediction. The scientific community has recognized the importance of dealing with uncertainty, especially with respect to risk-related events, and has

started to use this concept in hydrological modelling, adapting existing concepts of probabilistic forecasting from atmospheric modelling to flood forecasting (Kwadijk, 2003; Hamill et al., 2005; Siccardi et al., 2005).
In the present study, a multi-model approach to the quantitative precipitation forecast (QPF) problem has been attempted, in order to have a range of possible meteorological inputs to feed a hydrological model. In this way, the uncertainty associated with the meteorological forecasts provided by the proposed multi-model ensemble can propagate into the hydrological model, providing an estimation of the uncertainty associated with the discharge prediction. It is important to note that such uncertainty represents only that fraction of the total uncertainty in the forecasting process related to the atmospheric model error and the multi-model ensemble is aimed at representing only this part of uncertainty.
The proposed methodology is implemented for several episodes of intense precipitation that affected the Reno river basin, an Italian medium-sized catchment, whose upstream portion is located to the north-eastern slopes of the northern Apennines (Figure 1).

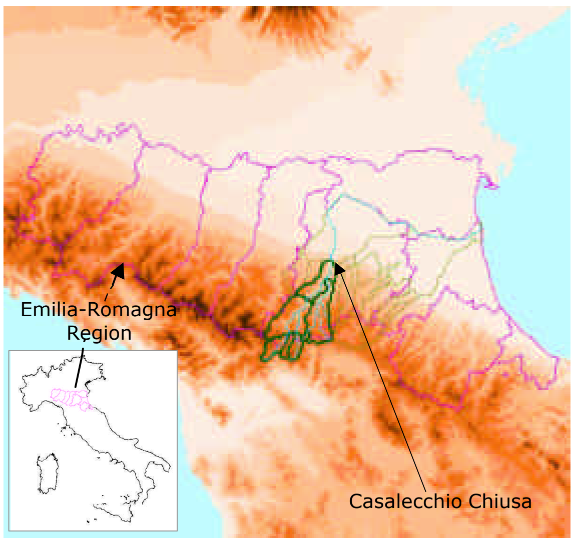

Figure 1. Localisation of the Reno river basin, its sub-catchments (light green line) and the main river. In evidence (dark green line) the upper basin closed at Casalecchio Chiusa river section.

2. Methodology

The coupled forecasting system is built by using the TOPKAPI (TOPographic Kinematic APproximation and Integration) model (Todini and Ciarapica, 2001), a physically-based distributed rainfall-runoff model, to generate discharge forecasts driven by the following different meteorological limited area models:
- BOLAM and MOLOCH, implemented by the Institute of Atmospheric Sciences and Climate - National Research Council (ISAC - CNR), Bologna;
- COSMO Model, suite LAMI (LM), implemented by the Agenzia Regionale Prevenzione e Ambiente - Servizio IdroMeteorologico (ARPA-SIM), Emilia-Romagna Region;
- WRF, implemented by ISAC - CNR, Lecce Section.
The details concerning their configuration are reported in Table 1.

The simulated discharges are evaluated at Casalecchio Chiusa, the closure section of the mountainous basin, which is characterized by a concentration time of about 8-10 hours. In the operational practice, a flood event at such river section is defined when the water level, recorded by the gauge station, reaches or overcomes the value of 0.8 m (corresponding to a discharge value of about 80 m^3/s), corresponding to the warning threshold. The alarm level is set to 1.6 m (corresponding to a discharge value of about 630 m^3/s).

MODEL	Horizontal Resolution (km)	Grid points	Levels	Initial/boundary conditions	Nesting Procedure
BOLAM	8	200 x 240	42	ECMWF analyses/forecasts	/
MOLOCH	2.8	240 x 240	50	BOLAM	1-way nesting
LM7	7	234 x 272	41	ECMWF analyses/forecasts	/
LM2.8	2.8	246 x 240	41	LM7	1-way nesting
WRF7.5	7.5	240 x 200	42	ECMWF analyses/forecasts	/
WRF2.5	2.5	244 x 238	42	WRF7.5	2-way nesting

Table 1. Summary of model configurations.

3. Results

The proposed multi-model approach to QPF has been implemented on five episodes of intense precipitation which are associated to flood events of quite different intensity. In the present work, the performance of the coupled system is discussed for a couple of cases; details on the remaining episodes can be found in Diomede et al. (2006) and in Diomede et al. (2007).

Figure 2 shows the results for the 07-09 November 2003 case study: the event is almost missed, especially in the forecasting of precipitation maxima (right panel), leading to an underestimation of the event magnitude in terms of streamflow (left panel): in this case, a warning would have been issued, but not and alarm. Otherwise, for the 10-12 April 2005 event (Figure 3) all the precipitation forecasts are fairly accurate (right panel) and the corresponding discharge simulations predict the event magnitude correctly (left panel).

For all the analysed events, we can conclude that the spread of the discharge ensemble can be considered adequate to convey a quantification of the discharge forecast uncertainty useful to support civil protection authorities in their decisions. Indeed, the occurrence of the flood events is well captured with a sufficient lead time (the timing error being not crucial with respect to the considered time range), whereas the order of magnitude of the event can be evaluated by the stakeholders considering the ensemble result by a probabilistic point of view.

The outcomes suggest that the hydrological response of the Reno river basin, as simulated by the TOPKAPI model, comes out to be highly sensitive not only to the total precipitation amount, but also to its correct space-time localization. This facet confirms the usefulness of the multi-model approach to take into account at least a fraction of uncertainty related to the QPF. It is worth noting that the obtained results might be affected by the filtering operated by the hydrological model, whose structure strongly affects the performances of the integrated real-time flood forecasting system. Generally, the hydrological model performance appears not to be fully satisfactory, being the calculated curve higher and wider than the observed one. This overestimation can be probably ascribed to three different factors: an inaccurate reproduction of the infiltration processes in the hydrological model, leading to an overestimation of precipitation available for runoff; the method employed to spatially distribute the observed precipitation (i.e. the Thiessen Polygon method) that can cause an overestimation of the total amount of rainfall over region scarcely covered with raingauges; the presence of a small hydroelectric reservoir, located in the upper basin, not modelled within the TOPKAPI framework. Testing different hydrological models might be the subject for future works.

Finally, the coupled system seems to be promising for operational use in the prediction of flood events and for warning purposes. The limitations due to the small number of the ensemble members and to the methods employed to generate their variability must be overcome: we can expect that a larger ensemble, for instance obtained by perturbing the initial and boundary conditions (Tibaldi et al., 2006), will improve the performance of the hydro-meteorological modelling system.

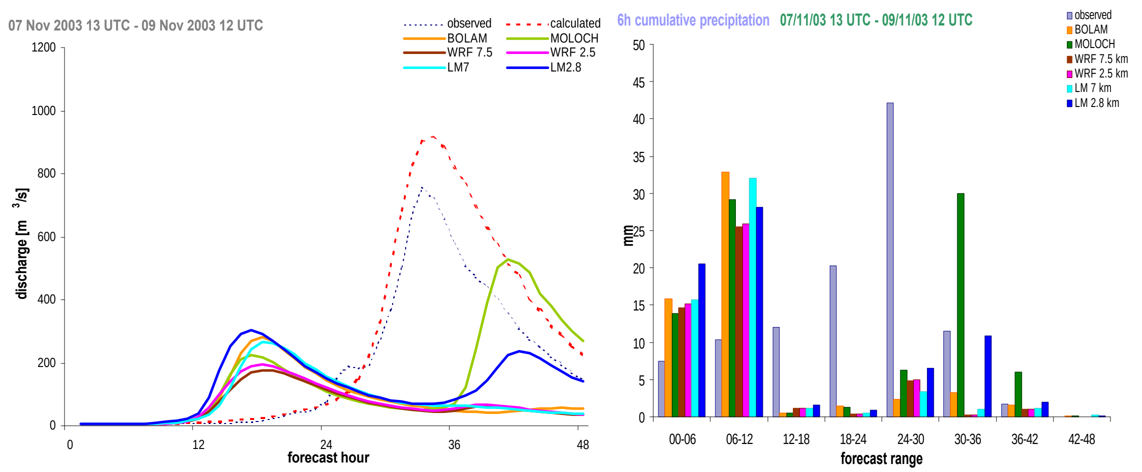

Figure 2. The 07-09 November 2003 event: streamflow forecast (left panel; m^3/s) and QPF averaged over the basin and accumulated over 6-hour periods (right panel; mm), as a function of the forecast range (hours). The different discharge curves have been obtained by feeding the TOPKAPI model with the precipitation forecast by the different meteorological models and with the raingauge observations (red dashed line). The observed discharge (blue dotted line) is also plotted for reference.

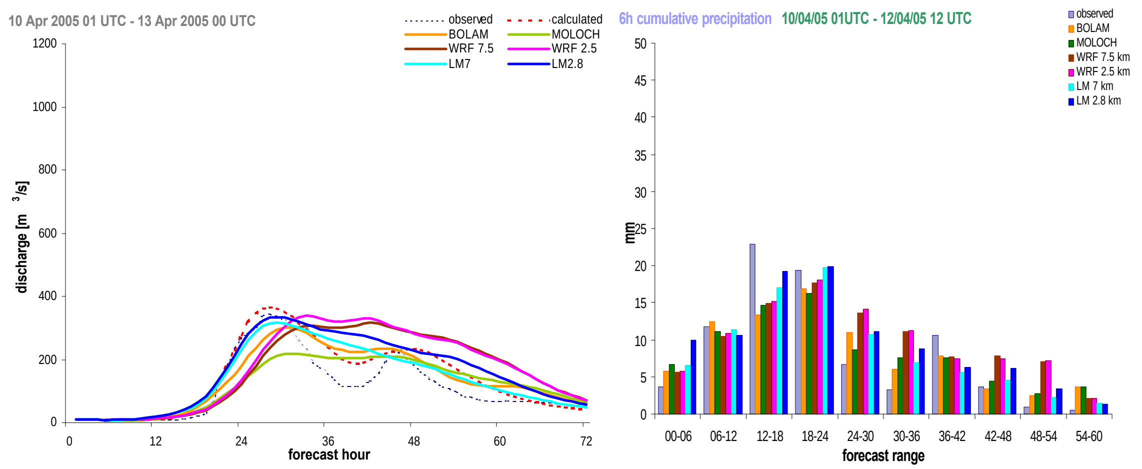

Figure 3. As Figure 2, but referred to the 10-12 April 2005 event.

Acknowledgements

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