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# REAL-TIME HYDRO-METEOROLOGICAL FORECASTS IN THE UPPER PO RIVER BASIN

## 1. Introduction

The number of great natural catastrophes is increasing worldwide, as underlined in the last Munich Re report: since 1980 a total number of 773 natural disasters were mainly caused by meteorological and hydrological events (46% and 28% respectively). This fact, combined with the increased antropization of our territories that makes them less resilient to climatic and hydrological variability especially under prolonged and alternating periods of droughts and intense rainfalls, has a strong impact on society with potentially high financial losses.

Indeed, coupling meteorological and hydrological models has become one of the most importance challenges in the scientific community during the two last decades; in particular, in recent years we have assisted to a widespread diffusion and use of hydro-meteorological chains by international agencies and research centres. This is also related to an increase in projects regarding flood forecasts like the Mesoscale Alpine Programme (MAP) between 1994 and 2005, the EFAS project in 2003, HEPEX in 2004, the European COST Action 731 (Propagation of Uncertainty in Advanced Meteo-Hydrological Forecast System) between 2005 and 2010, and in 2007 the D-PHASE Project (Demonstration of Probabilistic Hydrological and Atmospheric Simulation of Flood Events); this latter has shown recent improvements in the operational use of an end-to-end forecasting system, consisting of atmospheric models, hydrological prediction systems, nowcasting tools and warnings for end users (Zappa *et al.* 2008, Rotach *et al.* 2009, Ranzi *et al.* 2009).

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In this study we present an analysis for two different types of precipitation events that occurred during the D-PHASE Operational Period (DOP) over the Toce basin, in order to evaluate certain effects regarding discharge forecasts due to hydro-meteorological sources of uncertainties, and a hindcast occurred in November 2008 over the Toce and Sesia basins analysing the atmospheric forcing errors that can affect river discharge predictions. To better investigate the effects of temperature error on the peak discharge, we introduce a sensitivity analysis which allows us to consider jointly errors in the precipitation and temperature fields, evidencing both their individual effect and their interactions.

Two non-hydrostatic meteorological limited area models are used to force hydrological simulations: one with a coarse spatial resolution, supported by the Ensemble Prediction System (the COSMO-LEPS system based on COSMO model, Marsigli *et al.* 2005) and the other with a finer grid, but with one deterministic output only (the MOLOCH model, Malguzzi *et al.* 2006).

The hydrological model used to generate the runoff simulations is the distributed FEST-WB (Flash–flood Event–based Spatially–distributed rainfall–runoff Transformation – Water Balance) model, developed at Politecnico di Milano. This model is based on the solution of the equations describing the physical phenomena at local level, in particular for each elementary unit in which the river basin is subdivided; this allows to describe the hydrological answer to meteorological variables either at local and at catchment scale (Mancini 1990; Montaldo *et al.* 2007; Rabuffetti *et al.* 2008; Ravazzani *et al.* 2007).

## 2. Results and discussion

### 2.1. *The june 2007 event: effect of model spatial resolution*

The June event (13-15 June 2007) was the most severe and relevant during the Map D-Phase period on the Maggiore Lake basin. The synoptic analysis over Europe on 15 June 2007 showed a "cold drop" located South-West of the British Isles, triggering moist flow from the Mediterranean Sea towards the Alps and the Po Valley, causing convective cells with associated thunderstorms on the Lake Maggiore basin; 85-95 millimetres fell in only 24 hours (between 14 and 15 June) over the Toce basin.

The two meteorological models were characterized by an opposite behaviour in terms of forecasted cumulative precipitation between 14-15 June, in comparison with the observed mean basin values: in fact, there was an underestimation for the COSMO-LEPS model (- 28%) and an overestimation for the MOLOCH model (+ 20%). Because of this, the COSMO-LEPS issued a meteorological and hydrological yellow warning, vice versa the MOLOCH issued an orange warning (for a complete review about alert thresholds, see Ceppi 2011).

The maximum observed discharge at Candoglia was 783.2 $m^3 s^{-1}$ on 15 June at 17:00 UTC (however this discharge value exceed the orange warning, it caused no flood damage in the catchment area), while the simulated maximum discharge by the FEST-WB forced with observed hydro-meteorological data was 750 $m^3 s^{-1}$ at 20:00 UTC; despite this delay in reaching the peak (+ 3 hours), the hydrological model achieved a good performance, issuing the correct warning.

The response of the hydrological model was different when implemented with the forecasted meteorological forcings. Although better simulations were obtained with the one day ahead run (i.e. 24-48 hours before the main peak discharge), the median value of the COSMO-LEPS ensemble predictions has shown very poor results with a total underestimation of the peak discharge (- 56 %), which was also forecasted about 10 hours later than the observed time; furthermore all 16 members of the COSMO-LEPS model were affected by errors in terms of timing and amount of rainfall over the Toce river basin for this event. An opposite result was obtained using the MOLOCH model. In fact, with the one day ahead run, the peak discharge was overestimated by 48 % (1162.3 $m^3 s^{-1}$), but the magnitude of the event was correctly predicted, issuing an orange warning.

## 2.2. *The november 2007 event: effect of soil moisture conditions*

After a long dry period that hit the Southern edge of the Alps from the beginning of October, this rainfall was the first relevant meteorological phenomenon that occurred after 50 days of the dry autumn season of 2007. The observed amount of precipitation during this stratiform event (21-24 November) was about 80 mm as a mean basin value.

According to the D-PHASE threshold, the CLEPS and MOLOCH models issued a meteorological warning (yellow code) expected on 22 and 23 November, but the measured peak discharge on 23 November at the Candoglia gauging station was only 57.8 $m^3 s^{-1}$, which is a very low value, with no alert all.

Due to the dry antecedent soil condition, the FEST-WB hydrological simulations, forced with forecasted meteorological data, performed well, issuing no warning. In fact, looking at the soil moisture field, we find very dry values (near to $\theta_{res}$) before the event generally over the whole Toce basin and even at the end of the rainfall with the soil not totally saturated, as proof of the drought period that hit North-West Italy during the autumn of 2007; values near to the saturation ($\theta_{sat}$) were found only along the main river tributaries.

## 2.3. *The november 2008 event: the role of atmospheric forcings*

In the first five days of November 2008 more than 100 mm fell over the Piedmont watersheds, in particular over the Toce and Sesia, where locally more than 200 mm were cumulated in less than 5 days, and a meteorological warning was issued by the regional authority.

The snow line during this event was located at about 1700-2100 m a.s.l. on the Alpine area. This snow threshold was a key factor in estimating correctly the forecasted discharge at basin scale.

These severe precipitations over the Sesia basin caused an exceeding of the alert code 2 on 5 November.

Different trends in discharge forecasts were found on the Toce, where the performance decreases approaching the peak event on 5 November. In fact the Brier Score index over the Toce remains almost constant at lead times 4, 3, and 2 with a value no greater than 0.31; but with lead time 1 it gets drastically worse (0.88) producing a big false alarm for this basins; this result needs to be investigated in more depth, thus, the FEST-WB model was tested for alternative combinations of input variables and the corresponding model output simulations were compared, in order to understand better which was the error forcing.

## 2.4. *Sensitivity analysis at finite changes*

Since the FEST-WB discharge simulation, forced with the observed field values (precipitation, temperature, humidity and solar radiation), is very similar in terms of peak amount to the measured situation. Thus, following the approach reported in Borgonovo 2010, we apply a sensitivity analysis at finite changes to evaluate different simulation scenarios, considering the effects of interaction between forecasted temperature and precipitation errors that can affect the peak discharge on a mountain basin.

The first two steps of the decomposition involve individual changes in "precipitation" and "temperature" to compare the discharge differences; in particular, we alternated the observed precipitation and temperature fields with the forecasted fields. The humidity and solar radiation field were not changed in this sensitivity analysis instead, and their inputs were always implemented as observed data.

We have evaluated that the false alarm in discharge forecast over the Toce basin prevalently depends on temperature errors, we quantified this overestimation in terms of peak discharge over the Toce and Sesia basins

### 2.5. *Effects of temperature on the peak discharge*

New synthetic temperature fields were created, rising all observed temperature station data in the subject area by 0.5, 1.0, 1.5, 2.0, and 2.5 Celsius degrees.

Because the 1-5 November 2008 event was characterized by a snow line above 1700-2100 m a.s.l over mountain basins, this means rising the snow line about 100 m at a time.

With an increase in temperature from 0.5°C up to 2.5°C over the Toce basin the snow line was risen approximately 500 m, with a difference of nearly 30% in terms of water runoff for the 5 November peak, because the drainage area becomes greater. On the contrary, over the Sesia basin with a completely different ipsographic curve the rise of the snowfall line does not substantially imply any differences in discharge error: whether the 0°C line is at about 1900 m or at about 2500 m a.s.l., the precipitation remains in liquid form in almost the entire basin and in fact the evaluated error variation was only 5%.

## Conclusion

In this study we develop a hydro-meteorological chain as an operating tool to assess the reliability of a real time flood forecasting system, coupling meteorological and hydrological models, analysing the quantitative precipitation and temperature fields in different weather conditions over two mountain basins of the Piedmont Region. The aim was to evaluate how Quantitative Precipitation Forecasts (QPFs) influence the performance of hydrological predictions in terms of Quantitative Discharge Forecasts (QDFs) at different spatial scales (the June 2007 event), and how initial conditions of soil moisture are relevant before a meteorological event (the November 2007 event).

Further, we analysed an event that occurred in November 2008 to better understand the role of atmospheric forcing (precipitation and temperature) conditioned by a significant snow line. Through a sensitivity analysis we calculated the effects of interactions that can modify the discharge prediction. We quantified how the QDF is influenced by temperature errors and is related to the basin's ipsographic curve, and therefore to the percentage of the area that contributes with the most liquid water (rain) in the watershed. This forecast error can have a big impact on hydrological forecasts which are generally quite reliable at 24-48 hours before the main peak discharge.

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