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ASSESSING UNCERTAINTY OF REAL-TIME HYDRO-METEOROLOGICAL FORECASTS BASED ON ENSEMBLE PREDICTION SYSTEM

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ABSTRACT

Nowadays coupling meteorological and hydrological models, it is recognized by scientific community as a necessary way to forecast extreme hydrological phenomena, in order to active useful mitigation measurements and alert systems in advance. In order to quantify uncertainty of flood prediction, the hydrological community is increasingly looking at the use of Ensemble Prediction Systems (EPS) instead of single (deterministic) forecasts for flood warning. From hydrological perspective, the use of EPS, as input to a hydrological model, is an important tool to produce river discharge predictions and to assess uncertainty involved in forecasting precipitation.

The development and implementation of a real-time flood forecasting system with a hydro-meteorological operational alert procedure is described in this study. The goal is to evaluate how the uncertainty of meteorological forecasts influences the performance of hydrological predictions in terms of Quantitative Discharge Forecasts (QDFs) over two Alpine catchments for some precipitation events, occurred between 2007 and 2008 in the Piedmont region, North-West of Italy. In this analysis, we try to understand how the effect of meteorological model spatial resolution and the soil moisture initial conditions can influence discharge forecasts and warnings. Further, we focus the attention on key role of air temperature which is a crucial feature in determining the partitioning of precipitation in solid (snow) and liquid phase (rainfall) that can affect the river discharge prediction in autumn season over the Piedmont watersheds.

1. INTRODUCTION

The number of great natural catastrophes is increasing worldwide, as underlined in the last Munich Re report (*Munich Re*, 2011): 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, the coupling of 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 utilization of hydro-meteorological chains by international agencies and research centres. This is also related to an increase in projects regarding flood forecasts like EFAS in 2003 (*Thielen et al.*, 2009; *Bartholmes et al.*, 2009), HEPEX in 2004 (*Schaake et al.*, 2006; *Thielen et al.*, 2008), the European COST Action 731 (Propagation of Uncertainty in Advanced Meteo-Hydrological Forecast System) between 2005 and 2010 (*Rossa et al.*, 2010; *Zappa et al.*, 2010), the Mesoscale Alpine Programme (MAP) between 1994 and 2005 (*Ranzi et al.*, 2003 and 2007) 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).

In this study we present a re-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 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 the effect of 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 the distributed hydrological model (FEST-WB): one with a coarse spatial resolution, supported by the EPS (the COSMO-LEPS system based on COSMO model) and the other with a finer grid, but with one deterministic output only (the MOLOCH model).

2. Area of Study

The subject area is the Piedmont Region, located in North-West Italy (fig. 1). In particular in this paper two river basins are analyzed: the Toce and Sesia (table 1).

Gauging station	River	Drained Area [km^2]	Lag Time [h]
Candoglia	Toce	1534	9.0
Palestro	Sesia	2606	18.8

Table 1. Main characteristics of the catchments involved in the analysis.

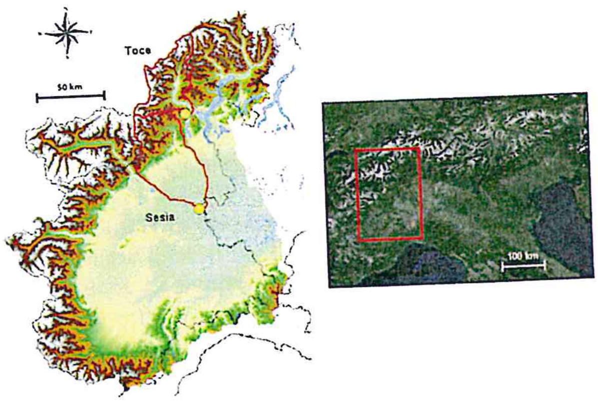

Figure 1. Digital Elevation Model (DEM) of the area in the study. The boundaries of each basin are shown in red, while watershed gauging stations are illustrated with yellow dots.

3. MODELS

3.1 Meteorological model

The hydro-meteorological chain includes both probabilistic forecasts based on ensemble prediction systems with a lead time of a few days, and short-range forecasts based on a high resolution deterministic atmospheric model, in order to predict the QDFs (Quantitative Discharge Forecasts).

The probabilistic forecast was supplied by COSMO-LEPS model (Consortium for Small-scale Modelling – Limited area Ensemble Prediction System), implemented and developed by A.R.P.A. Emilia-Romagna in the framework of COSMO Consortium (*Marsigli et al.*, 2005; *Montani et al.*, 2011). The spatial resolution is 10 km (0.09°), while the temporal resolution is 3 h, with 40 vertical levels, 16 ensemble members, nested on ECMWF EPS (European Centre for Medium Range Forecast - Ensemble Prediction System), and 132 h as lead-time; the run starts every day at 12:00 UTC, while the hydrological simulation begins 12 hours later at 00:00 UTC, hence 120 hours of hydrological simulation are available.

The deterministic forecast was supplied by the MOLOCH model (MOdello LOCale in "H" coordinate) of I.S.A.C. - C.N.R. in Bologna, Italy (*Malguzzi et al.*, 2006). The model chain comprises the hydrostatic model BOLAM and the non-hydrostatic model MOLOCH, nested in BOLAM. The MOLOCH model has a horizontal grid spacing of 0.02°, corresponding to about 2.3 km, with 50 levels; moist deep convection is computed explicitly. The forecasting chain is based on the 18:00 UTC, ECMWF analysis/forecasts at 0.25° resolution; BOLAM run starts at 18:00 UTC, MOLOCH is nested at 00:00 UTC, the same time as the hydrological simulation.

3.2 Hydrological model

The hydrological model FEST-WB (Flash–flood Event–based Spatially–distributed rainfall–runoff Transformation – Water Balance), is a distributed model 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).

The FEST-WB computes the main processes of the hydrological cycle: evapotranspiration, infiltration, surface runoff, flow routing, subsurface flow and snow dynamics. The use of a distributed model accounts for the high time-space variability of meteorological forcings, whose fields at ground level are reconstructed from spot measurements through interpolation procedures based on the topography of the river basin.

The snow module of FEST-WB includes snow melt and snow accumulation dynamics. The partitioning of total precipitation, P, in liquid, P_l, and solid, P_s, phase is a function of air temperature, T_a (*Tarboton et al.*, 1994):

$$P_l = \alpha_P P \quad (1)$$

$$P_s = (1-\alpha_P)P \quad (2)$$

where α_P is computed by:

$$\alpha_p = \begin{cases} 0 & \text{if} \quad T_a \leq T_{low} \\ 1 & \text{if} \quad T_a \geq T_{up} \\ \dfrac{T_a - T_{low}}{T_{up} - T_{low}} & \text{if} \quad T_{low} < T_a < T_{up} \end{cases} \tag{3}$$

where T_{low} and T_{up} are air temperatures below/above which all precipitation falls as snow/rain, respectively, to be found by means of calibration (*Corbari et al.*, 2009).

The snow melt simulation is based on the degree day concept (*Martinec et al.*, 1960). The melt rate in m/s, M_s, is proportional to the difference between air temperature and a predefined threshold temperature, T_b:

$$M_s = \begin{cases} C_m(T_a - T_b) & \text{if} \quad T_a > T_b \\ 0 & \text{if} \quad T_a \leq T_b \end{cases} \tag{4}$$

where C_m ($m \cdot °C^{-1} \cdot s^{-1}$) is an empirical coefficient depending on meteorological conditions and geographic location.

The terrain covered by snow is supposed to be frozen and hence the melted water is prevented from infiltrating into the soil. Conversely, the liquid fraction of snow water equivalent, R_s, sum of melted water and liquid precipitation, is supposed to flow cell by cell through the snow pack with a linear reservoir routing scheme (*Ponce*, 1989) with a celerity of 1.67 10^{-3} $m \cdot s^{-1}$ (*Salandin et al.*, 2004). When R_s reaches a cell not covered by snow, it is added to the liquid precipitation of that cell.

3.3 Coupling strategy

The hydro-meteorological chain, developed at Politecnico di Milano, is based on hydrological model initialization from meteorological model output, providing river discharge forecasts with some days in advance, and obtaining useful time for decision making, emergency management procedures and civil protection.

Weather model data are in GRIB1 format: each file contains information about computed weather variables (year, month, day and hour of the starting simulation are reported on the file names together with the model name and number of ensemble run).

Four fundamental meteorological fields were extracted: temperature, relative humidity, net solar radiation and precipitation. These meteorological outputs become the driving input into the hydrological model for forecasting discharge simulations at hourly time intervals and these fields are downscaled into hydrological model spatial resolution, using the simple nearest neighbour re-sampling method.

The hydrological model was initialized with a simulation run forced with observed ground measured data, provided by the ARPAP (Environment Protection Regional Agency of Piedmont) hydro-meteorological station network.

4. Results and discussion

4.1 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 (table 2).

Day	Toce
13 June 2007	4.9
14 June 2007	16.3
15 June 2007	68.2
Total precipitation [mm]	89.4

Table 2. Observed rainfall over the Toce basin between 13-15 June 2007.

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 $m^3 \cdot s^{-1}$ 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 $m^3 \cdot s^{-1}$ at 20:00 UTC (fig. 2). 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 (fig. 3) 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 (fig. 2).

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.

The performance was even worse for the forecast initialized two days before the peak event and for the run started on the same day, as is shown in fig 3.

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 $m^3 \cdot s^{-1}$), but the magnitude of the event was correctly predicted, issuing an orange warning (fig. 2).

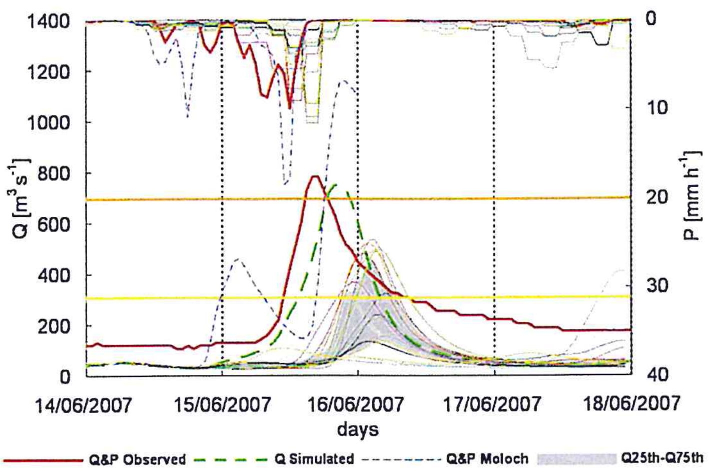

Figure 2. QPFs and QDFs of the FEST-WB model forced with observed meteorological data and with the CLEPS and Moloch model forecast over the Toce basin. The hydrological simulation driven by the two meteorological model was launched on 14 June 2007 00:00 UTC. The discharge value of each ensemble forecast is shown in different colours.

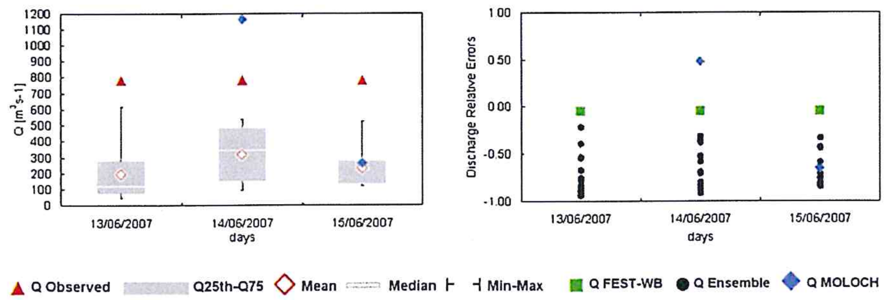

Figure 3. The Box-Whisper plot (left) and the QDF error (right) for the forecasted peak discharge for 15 June on the Toce basin, obtained with the FEST-WB model simulation forced with observed meteorological data (green square) and with the COSMO-LEPS (grey boxes and black whiskers) and Moloch (blue rhombus) model runs, started on 13, 14 and 15 June 2007.

4.2 The November 2007 event: effect of soil moisture conditions

The November event over the Maggiore Lake basin was a stratiform event with light but continuous precipitation over the area, but with very small peak stream-flow over the Toce basin. The weather analysis over Europe on 23 November shows a typical autumnal pattern with an upper level trough, coming from the Atlantic Ocean, moving eastward, trigging humid air from the South toward the Southern edge of Italian and Swiss Alps.

After the long dry period that hit the Southern edge of the Alps from the beginning of October, this precipitation 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 (table 3).

Day	Observed precipitation [mm]
21 November 2007	6.7
22 November 2007	30.6
23 November 2007	34.7
24 November 2007	9.4
Total Precipitation [mm]	81.5

Table 3. Observed precipitation during the 21-24 November event over the Toce basin.

The next two figures show the millimetres of precipitation forecasted by the MOLOCH model (fig. 4) and the expected probability in exceeding the meteorological yellow code by the CLEPS model (fig. 5) with the weather forecasts initialized on 21, 22 and 23 November 2007.

MOLOCH forecast [millimeters of rain]

forecast day	21	22	23	24
21-11-2007	11.7	48.7		
22-11-2007		37.3	52.9	
23-11-2007			41.5	9.0

Figure 4. Millimetres of forecasted rain by the MOLOCH model. The hydrological runs were initialized on 21, 21 and 23 November.

COSMO-LEPS [probability of exceeding yellow code]

forecast day	21	22	23	24	25	26
21-11-2007	0%	100%	25%	25%		
22-11-2007		81%	62%	0%	0%	
23-11-2007			43%	25%	0%	0%

Figure 5. Probability of exceeding yellow code with the CLEPS forecast. The hydrological runs were initialized on 21, 21 and 23 November.

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 $m^3 \cdot s^{-1}$, 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 θ_{res}) before the event generally over the whole Toce basin (fig. 6-left) 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; we found values near to the saturation θ_{sat} only along the main river tributaries (fig. 6-right).

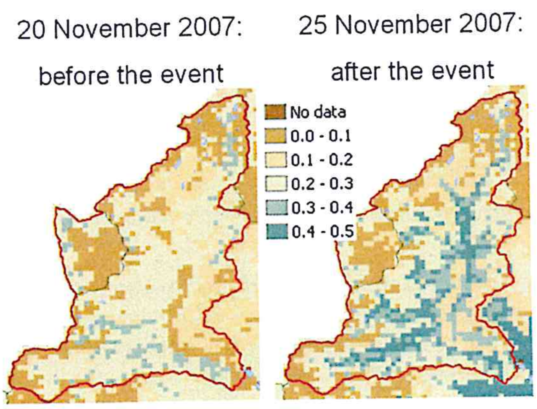

Figure 6. Soil moisture field before (left) and after (right) the 21-24 November event.

4.3 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 (table 4), and a meteorological warning was issued by the regional authority.

Days	Toce	Sesia
1 November 2008	6.5	6.8
2 November 2008	7.2	8.3
3 November 2008	52.2	38.5
4 November 2008	79.0	88.8
5 November 2008	95.4	43.5
Cumulated precipitation [mm]	240.3	185.9

Table 4. Cumulated rainfall over the Toce and Sesia basins during the November 2008 event.

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. The FEST-WB model simulation forced with observed data is affected by an underestimation of discharge (about 20%); in fact, the observed value at Palestro gauging station is equal to 2025.7 $m^3 \cdot s^{-1}$, while the simulated discharge by the FEST-WB is only 1685.3 $m^3 \cdot s^{-1}$, thereby not exceeding the alert threshold. Table 5 sums up the reliability and the performance of the hydro-meteorological chain approaching the peak event on 5 November 2008 with the Brier Score index, where we compare the skill scores for alert code 2 at different lead times for the simulations over the Sesia, together with the ones over the Toce catchment, where a different trend was found instead.

	Brier Score (BS) for alert code 2			
Sesia basin	0.77	0.47	0.47	0.14
Toce basin	0.31	0.25	0.31	0.88
lead time [LT]	**4**	**3**	**2**	**1**

Table 5. Brier Score index for alert code 2 with different lead times over the two studied basins. Since the measured values at Candoglia gauging station for the Toce basin were smaller than the alert code 2, the event occurrence is a forecast that the warning threshold will not be exceeded.

As can be seen, a different trend was found on the Toce, where the performance decreases approaching the peak event on 5 November. The BS 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.

The FEST-WB simulation forced with observed data shows a very good match between with the measured value at the basin gauging station (red line in fig. 7) in term of peak discharge (992.6 m^3s^{-1} vs. 916.7 m^3s^{-1}). The predicted QDF by the COSMO-LEPS model over the Toce basin with the 4 November run, shows that a false alarm is forecasted for 5 November with a possible flood occurrence, instead; the ensemble median (S_3 in fig.7) reached a value of 1841.7 m^3s^{-1}, i.e. an overestimation of about 100% in comparison with the observed value at Candoglia (916.7 m^3s^{-1}). Thus, the FEST-WB model was tested for alternative combinations of input variables and the corresponding model output simulations were compared.

4.4 Sensitivity analysis at finite changes

In the following sensitivity analysis, our task was to understand the interaction between forecasted temperature and precipitation errors that can affect the peak discharge on a mountain basin. 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. This method makes it possible to appreciate the effect in the simulations, accounting for both their individual and interaction inputs.

The terms we analyses were decomposed as follows:

$$\Delta f = \Delta f_P + \Delta f_T + \Delta f_{P,T} \qquad (5)$$

where:

Δf_p is the difference between the FEST-WB simulation (referred to as S_0), forced with all observed values, and the FEST-WB simulation forced with the observed temperature field, and the forecasted precipitation values of the COSMO-LEPS model; this latter simulation referred to as S_1;

Δf_T is the difference between the FEST-WB simulation (referred to as S_0), forced with all observed values, and the FEST-WB simulation forced with the observed precipitation field, but with the forecasted temperature values of the COSMO-LEPS model; this latter simulation referred to as S_2;

$\Delta f_{P,T}$ is the difference between the FEST-WB simulation (referred to as S_0), forced with all observed values, and the FEST-WB simulation forced with both the forecasted precipitation and temperature values of the COSMO-LEPS model; this latter simulation referred to as S_3.

As described above, 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, 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.

Figure 7 shows that no big differences exist between the two simulations S_0 and S_1: i.e. putting the COSMO-LEPS precipitation field as input in the FEST-WB model and maintaining the other observed meteorological data (air temperature, relative humidity and solar radiation), the discharge difference (Δf_P) between the ensemble median (blue line) and the FEST-WB (green dashed line) is only 26 $m^3 \cdot s^{-1}$.

Then, we re-run the simulation with the observed precipitation values (again maintaining the observed field for humidity and solar radiation), but this time using the forecasted temperatures of the COSMO-LEPS model. This new simulation is called S_2. The ensemble median Q_{max} conditional on the CLEPS forecasted temperatures (S_2) shows a difference (Δf_T) of 686 $m^3 \cdot s^{-1}$ in comparison with the FEST-WB simulation forced with all observed values (S_0).

The simulation S_2 shown in Figure 7 is the keystone in our analysis and it answers our proposed objectives. The discharge overestimation (ensemble median value of 1678.4 $m^3 \cdot s^{-1}$), exceeding alert code 2 can only be attributed to an error of the CLEPS forecasted temperature (about 3°C higher than the observed temperature!), because it was the only changed variable in this new simulation scenario.

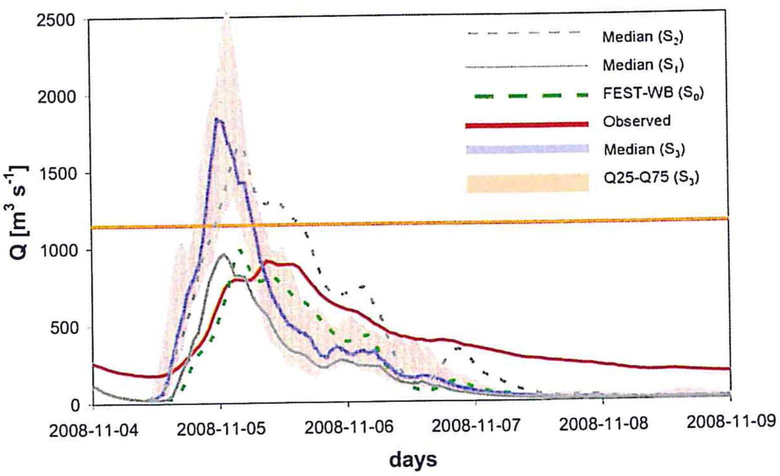

Figure 7. QDF of the FEST-WB simulation (S_3) forced with both forecasted precipitation and temperature fields by the COSMO-LEPS model (*blue line*). *(red line: observed discharge at Candoglia; green dashed line: simulated discharge on the FEST-WB (S_0), forced with observed data; grey line: ensemble median of the S_1 simulation; grey dashed line: S_2 simulation).* The hydrological simulation was initialized on 4 November 2008 over the Toce basin.

Finally, we considered both the forecasted temperature and precipitation fields by the CLEPS model in order to understand the simultaneous interaction of effects of the inputted changes; the latter simulation is referred to as S_3.

Figure 7 shows an increase in the peak discharge: the ensemble median reaches a value of 1841 m^3s^{-1} (grey dashed line), with a difference of about 849 m^3s^{-1} (Δf) in comparison with the FEST-WB simulation (S_0), forced with all observed fields. By eq. (5), the interaction effect ($\Delta f_{P,T}$) is equal to +189 m^3s^{-1} showing that the forecasted discharge error cannot be explained only by individual effects; instead interactions play a relevant role.

This sensitivity analysis is actually composed of two parts. The first part concerns individual effects (S_1 and S_2), while the second part concerns joint effects. Regarding the first part, we establish whether the change of a single variable increases or decreases the value of the CLEPS discharge forecasts. In reference to the second part, we determine whether the joint change in two variables leads to an enhancement or a smoothing out of their individual effects (interference).

4.5 Effects of temperature on the peak discharge

Once 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. 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. These new five temperature fields were put into the hydrological FEST-WB model to obtain five corresponding discharge outputs to quantify temperature errors and their (possible) relative impact over these watersheds in off-line mode. No CLEPS data were used this 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%.

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.

Lastly, it is important to state that in this study we do not pretend to give general rules for the hydro-meteorological field, because, a large number of flood events have to be considered and because hydro-meteorological forecast are not assumed to always be reliable, they should be verified and calibrated with much more events. However, our task is to show what lies behind a hydro-meteorological forecast, how it works, what the limits are, which source of uncertainties must be taken into account in different weather conditions.

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