2.4 Hydro-meteorological chain for flood forecasting in the Toce basin: a multi-model comparison

A. Ceppi,[1] G. Ravazzani,[1] D. Rabuffetti[2] and M. Mancini[1]

[1]*Politecnico di Milano - D.I.I.A.R., Piazza Leonardo da Vinci, 32, 20133 Milano, Italy*
[2]*A.R.P.A. Piemonte - Via Pio VII 9, 10135, Torino, Italy*

Correspondence to: alessandro.ceppi@mail.polimi.it

Abstract

This study is part of the international MAP-D-PHASE Project, whose main objective is to demonstrate the benefits in forecasting heavy precipitation and related flood events, by coupling atmospheric and hydrological models. The analysis is focused on the River Toce, a middle-size alpine basin, in North-West of Italy. The hydro-meteorological chain includes both probabilistic forecasts based on ensemble prediction systems with lead time of a few days and short-range forecasts based on high resolution deterministic atmospheric models. The hydrological model used to generate the runoff simulations is the rainfall-runoff distributed FEST-WB model, developed at Politecnico di Milano. The observed data to run the control simulations were supplied by ARPA-Piemonte. A re-analysis for two precipitation events, affecting the Toce river basin at half June and at the end of November 2007, is shown.

Introduction

In recent years, the interest in the prediction and prevention of natural hazards related to hydrometeorological events has grown, due to the increased frequency of extreme rainstorms (Rabuffetti et al. 2005a). Several research projects have been developed to test hydrometeorological models for flood forecasting, like HYDROPTIMET Project (Rabuffetti et al., 2005b), and AMPHORE Project (Rabuffetti et al., 2008 and Amengual et al., 2008), two recent Interreg IIIB EU Programmes. Despite these improvements, forecasting of highly localized and severe events is still a challenging problem in many areas, particularly where orographic feature and mesoscale structures cannot be properly represented by Global Circulation Model - Ensemble Prediction System (GCM-EPS) because of its coarse horizontal resolution (Federico et al., 2006). For this reason the challenge for numerical weather modelling, in particular for limited area models, is to improve the Quantitative Precipitation Forecasts (QPFs) for hydrological purposes. Following this goal, many research bodies participated during the summer and autumn 2007 at MAP-D-PHASE Project. D-PHASE stands for Demonstration of Probabilistic Hydrological and Atmospheric Simulation of flood

Events in the Alpine region and is a Forecast Demonstration Project (FDP) of the WWRP (World Weather Research Programme of WMO). It aims at demonstrating some of the many achievements of the Mesoscale Alpine Programme (MAP). The MAP FDP will address the entire forecasting chain ranging from limited-area ensemble forecasting, high-resolution atmospheric modelling (km-scale), hydrological modelling and nowcasting to decision making by the end users, i.e., it is foreseen to set up an end-to-end forecasting system. The D-PHASE Operations Period (DOP) was from 1 June to 30 November 2007. In this framework two non-hydrostatic meteorological limited area models are used to predict such phenomena at local scale: one with a spatial resolution of 10 km, supported by the powerful ensemble prediction system (Cosmo-Leps model) and the other with a finer grid, but with one deterministic output only (Moloch model). The hydrological model (FEST-WB), developed at Politecnico di Milano, was forced with observed weather data and QPF data coming from the meteorological models used. The state variables of the model are updated daily by A.R.P.A. - Piemonte that runs the same model with weather observations. The aim of this work is to reproduce a hindcast for two precipitation events, affecting the Toce river basin, the Western watershed of Maggiore Lake basin in North-West of Italy, at half June (convective event) and at the end of November 2007 (stratiform event), in order to estimate how the uncertainty of meteorological forecasts influences the quality of hydrological forecasts and the whole hydrometeorological alert system for a midsize catchment.

Case study

The Toce basin (Figure 2.1) is a midsize watershed located between North-West of Italy (90 %) and South of Switzerland (10 %). The area, closed at Candoglia, covers 1534 km^2 and it is basically an Alpine basin with maximum altitude of 4635 m a.s.l. (East face of Mount Rosa) and minimum altitude of 193 m a.s.l. (height of Maggiore Lake). The lag time of Toce river is about 9 hours.

During the MAP-D-PHASE period three warning codes were adopted to highlight different alert thresholds from a meteorological and hydrological point of view. As shown in Figure 2.2 the yellow line points out a discharge (306 m^3/s) with a return period of at least 60 days, the orange line points out a discharge (694 m^3/s) with a return period of at least 180 days and the red line a discharge (1588 m^3/s) with a return period of at least 10 years.

Meteorological models

The hydrometeorological chain includes both probabilistic forecasts based on ensemble prediction systems with lead time of a few days and short-range forecasts based on high resolution deterministic atmospheric models, in order to predict the QDF (Quantitative Discharge Forecast). The probabilistic forecast was supplied by Cosmo-Leps model (COnsortium

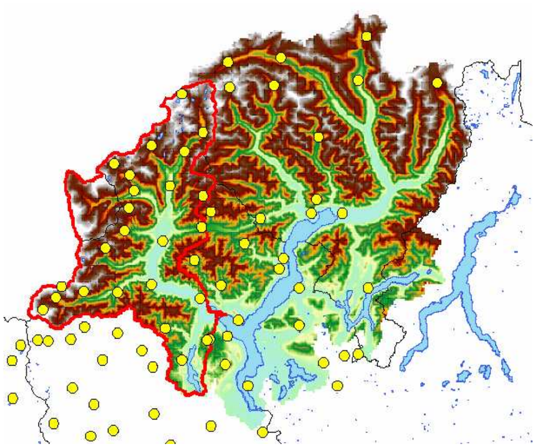

Figure 2.1: Geographical map with the raingauge stations located in the Maggiore Lake basin. The red line bounds the Toce basin.

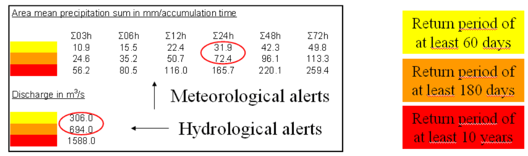

Figure 2.2: Warning codes used for Toce basin at Candoglia during the DPHASE period.

for Small-scale Modelling - Limited-Area Ensemble Prediction System) of A.R.P.A. Emilia-Romagna (Marsigli et al., 2005, Montani et al., 2008). 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 5 days as lead-time; the run starts every day at 12:00 UTC, while the hydrological simulation begins 12 hours later at 00:00 UTC. The deterministic forecast was supplied by Moloch model of I.S.A.C. - C.N.R. (Davolio et al., 2007). The spatial resolution is 2.2 km (0.02), while the temporal resolution is 1 h, with 50 vertical levels, nested on BOLAM, based on ECMWF and 2 days as lead-time; the run starts every day at 00:00 UTC, at the same time of the hydrological simulation.

Hydrological model

The hydrological model used to generate the runoff simulations is the rainfall-runoff distributed FEST-WB model, developed at Politecnico di Milano. FEST-WB computes the main process of the hydrological cycle: evapotranspiration, infiltration, surface runoff, flow routing, subsurface flow and snow dynamics. The computation domain is discretized with a mesh of regular square cells, within which water fluxes are calculated. The models needs spatially distributed meteorological forcing. The observed data at ground stations are interpolated to a regular grid using IDW technique, considering the effect of topography such as elevation, aspect and shadow (Rabuffetti et al., 2008). Runoff is computed according to a modified SCS-CN method extended for continuous simulation where the potential maximum retention, S, is updated at the beginning of storm as a linear function of the degree of saturation (Ravazzani et al., 2007). The actual evapotranspiration, ET, is computed as a fraction of the potential rate tuned by a function that, in turn, depends on soil moisture content (Montaldo et al., 2003). The estimation of ETP is computed with Priestley and Taylor

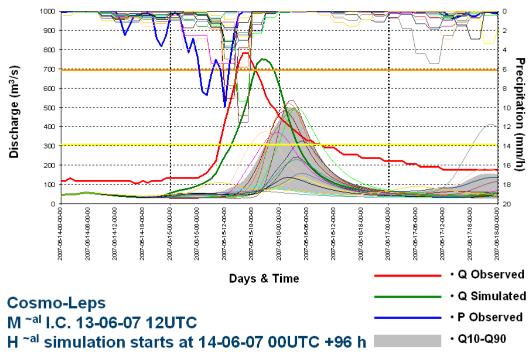

Figure 2.3: Ensemble QDF for Cosmo-Leps model from 14 June to 17 June 2007.

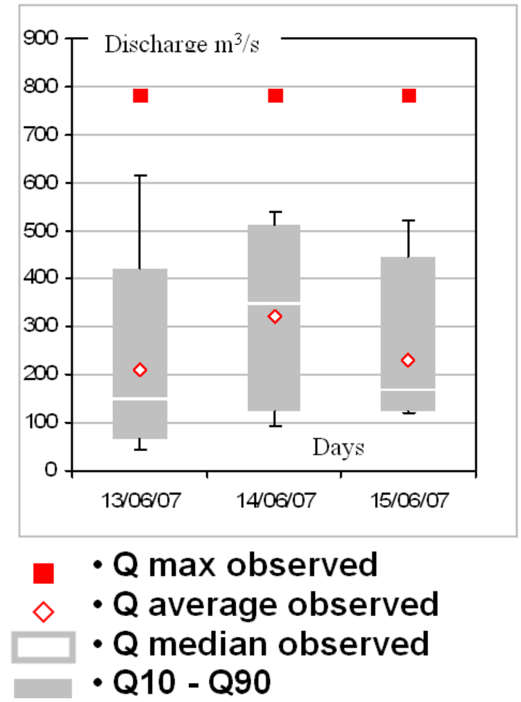

Figure 2.4: Box-Whisker plot for Cosmo-Leps. The date is referred to the day of the initial hydrological simulation.

(1972) equation. The surface and subsurface flow routing is based on the Muskingum-Cunge method in its non-linear form with the time variable celerity (Montaldo et al., 2007). The snow model includes the snow melt and the snow accumulation dynamics. The snow melt simulation is based on the degree day concept (Martinec et al., 1960). The melt rate is proportional to the difference between air temperature and a predefined threshold temperature (Saladin et al., 2004).

13-15 June 2007 event

The synoptic analysis over Europe showed a low depression located South-West of the British Isles with cold air moving eastward over the Po Valley, triggering convective cells on the southern edge of the Alps (about 100 mm of total rain over Toce basin in about 48 hours). The hydrological simulation (green line), done by FEST-WB model, has reached a peak of 750.7 m^3/s and it presents 3 hours of delay as peak time error compared to the observed discharge (red line) of 783.2 m^3/s. The QPF predicted by Cosmo-Leps model shows a general underestimation in all three days of simulations for all 16 members. This affects the forecasted discharge (Figure 2.4) that has never exceed the second alert threshold as shown in Figure 2.3.

The Moloch model, instead, has predicted, one day in advance, the peak discharge, exceeding the second threshold like the observed and simulated discharge, even if there is an evident

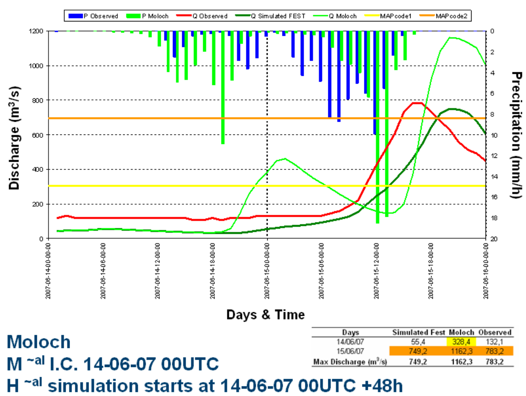

Figure 2.5: QDF for Moloch model (light green curve) from 14 June to 15 June 2007.

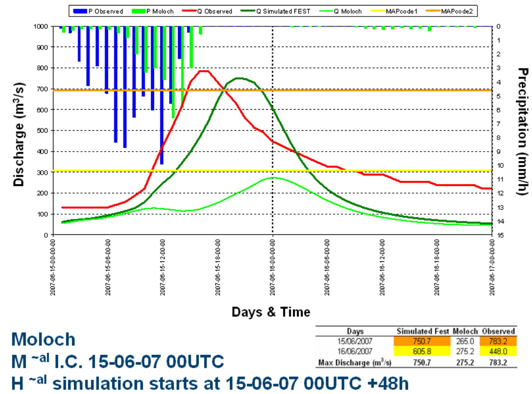

Figure 2.6: QDF for Moloch model (light green curve) on 15 June 2007.

error in time and volume as shown in Figure 2.5. On the contrary, on the same day of the peak event, the QPF was totally underestimated and the discharge has not exceeded even the first alert threshold (Figure 2.6).

21-23 November 2007 event

The synoptic analysis over Europe showed a typical autumn pattern with a deep depression on Atlantic Ocean, bringing moist flow from South-West towards the Italian Alps (about 80 mm of rain on Toce basin, after a long dry period of two months). First of all the FEST-WB discharge simulation with real data has been completely underestimated on 21 (Figure 2.7) and 22 November, due to a not correct initial value of river discharge. Data assimilation of observed discharge, not used in FEST-WB, may provide better results. Therefore, even if Moloch and Cosmo-Leps models have shown a general overestimation of rainfall in terms of volume and intensity, the forecasted discharges remained underestimated. Only on the peak flow day (23 November), after two days of precipitation, a perfect synchrony between the observed and forecasted precipitation (Figure 2.8) and discharges peak is pointed out both for Cosmo-Leps (Figure 2.9) and Moloch model (Figure 2.10). Anyway the observed, simulated and forecasted discharge has never exceeded the first threshold (306 m^3/s) in any model, i.e. no alert was issued for this event.

Conclusions

This analysis has shown the results of the hydro-meteorological chain with a multi-model comparison, using the weather models output (Cosmo-Leps and Moloch) as input into the hydrological model (Fest-WB) to predict a QPF (Quantitative Precipitation Forecast) and a QDF (Quantitative Discharge Forecast). The proposed hydro-meteorological forecasting system has been implemented in a real-time configuration, in order to provide useful information concerning the discharge peak (magnitude and timing). High resolution meteorological

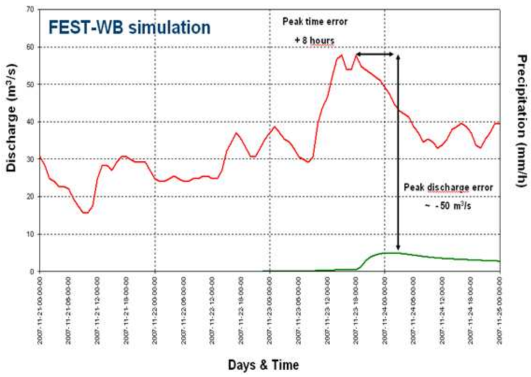

Figure 2.7: Observed (red line) vs simulated discharge by FEST-WB model with initial conditions start on 21 November.

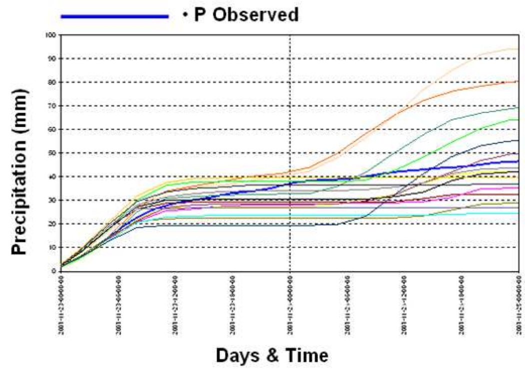

Figure 2.8: Forecasted mean area accumulated precipitation by Cosmo-Leps model on 21 November.

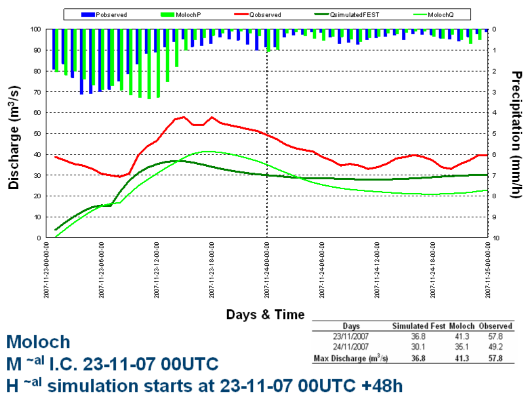

Figure 2.9: QDF for Moloch model (light green curve) on 23 November 2007.

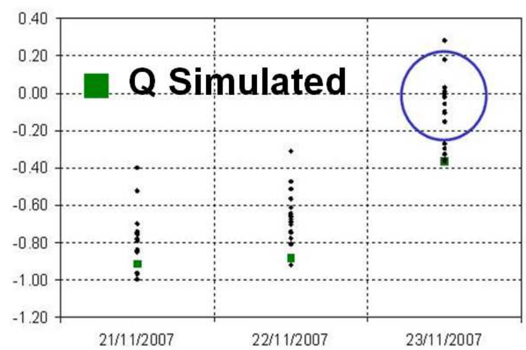

Figure 2.10: QDF error for Cosmo-Leps ensemble members (black dots) and FEST-WB (dark green dot).

model seems to show greater reliability on the prediction of flood on complex topography, but the number of investigated flood events is too small to draw conclusions. Future studies could be addressed to better evaluate the temporal and spatial scale for the total rainfall volume, above all for the convective events. For stratiform events further analyses could be carried out on snow melt temperature which affects the liquid precipitation and therefore the forecasted runoff, like in November event where the snow melt limit was very changeable.

Acknowledgments

Thanks to ARPA Emilia-Romagna (A. Montani) for his contribute in providing COSMO-LEPS model data and to ISAC-CNR (S. Davolio) for MOLOCH model data.

References

Amengual, A., Diomede, T., Marsigli, C., Martin, A., Morgillo, A., Romero, R., Papetti, P. and Alonso, S.: 2008. A hydrometeorological model intercomparison as a tool to quantify the forecast uncertainty in a medium size basin. Nat. Hazards Earth Syst. Sci., 8, 819-838.

Davolio, S., Buzzi, A., and Malguzzi, P.: 2007. High resolution simulations of an intense convective precipitation event. Meteorol. Atmos. Phys., 95, 139-154.

Federico, S., Avolio, E., Bellucci, C., Colacino, M. and Walko, L.: 2006. Application of the LEPS tecnique for a Quantitative Precipitation Forecasting (QPF) in Southern Italy: a preliminary study. Nonlin. Processes Geophys., 13, 53-66.

Marsigli C., Boccanera F., Montani A., Paccagnella T.: 2005. The COSMO-LEPS mesoscale ensemble system: validation of the methodology and verification. Nonlin. Proc. Geophys., 12,527-536.

Martinec, J.: 1960. The degree-day factor for snowmelt runoff forecasting, proceedings of general assembly of Helsinki commission on surface waters, IAHS Publ. 51, 1960.

Montaldo, N., Ravazzani, G. and Mancini, M.: 2007. On the prediction of the Toce alpine basin floods with distributed hydrologic models, Hydrol. Processes, 21, 608-621.

Montaldo, N., Toninelli, V., Albertson J. D., Mancini, M. and Troch P. A.: 2003. The Effect of Background Hydrometeorological Conditions on the Sensitivity of Evapotranspiration to Model Parameters: Analysis with Measurements from an Italian Alpine Catchment, Hydrol. Earth Syst. Sci., 7, 848-861.

Montani, A. Marsigli, C., Paccagnella, T.: 2008. Five Years of Limited-Area Ensemble Activities at ARPA- SIM: The COSMO-LEPS system, Cosmo Newsletter n.8.

Priestley, C. H. B. and Taylor, R. G.: 1972. On the assessment of surface heat flux and evaporation using large scale parameters. Mon.Weather Rev., 100, 81-92.

Rabuffetti, D. and Barbero, S.: 2005a. Operational hydro-meteorological warning and real time flood forecasting: the Piemonte Region case study. Hydrology and Earth System Sciences, 9(4), 457-466.

Rabuffetti, D. and Milelli, M.: 2005b. The hydro-meteorological chain in Piemonte region, North Western Italy - analysis of the HYDROPTIMET test cases. Natural Hazard and Earth System Sciences, 5, 845-852.

Rabuffetti, D., Ravazzani, G., Corbari, C., and Mancini, M.:2008. Verification of operational Quantitative Discharge Forecast (QDF) for a regional warning system - the AMPHORE case studies in the upper Po River. Nat. Hazards Earth Syst. Sci., 8, 161-173.

Ravazzani, G., Mancini, M., Giudici, I., and Amadio, P.: 2007. Effects of soil moisture parameterization on a real-time flood forecasting system based on rainfall thresholds, in: Quantification and Reduction of Predictive Uncertainty for Sustainable Water Resources Management, edited by: Boegh, E., Kunstmann, H.,Wagener, T., Hall, A., Bastidas, L., Franks, S., Gupta, H., Rosbjerg, D., and Schaake, J., IAHS Publ. 313, 407-416, 2007.

Salandin, A., Rabuffetti, B., Barbero, S., Cordola, M., Volonte, G. and Mancini, M.: 2004. Il lago effimero sul ghiacciaio del Belvedere: monitoraggio e simulazione numerica del fenomeno finalizzata alla previsione e gestione dell'emergenza, Neve e Valanghe, 51, 58-65, 2004.

Tarboton D. G., Chowdhury T. G., Jackson Thomas H.: 1994. A Spatially Distributed Energy Balance Snowmelt Model, Utah Water Research Laboratory.