A meteo-hydrological model intercomparison as tool to quantify forecast uncertainty at medium-sized basin scale

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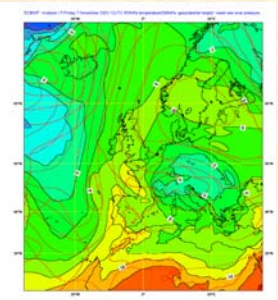
Purpose

A meteo-hydrological model intercomparison is proposed, in order to estimate the uncertainty associated with discharge forecasting. The hydrological models TOPKAPI and HEC-HMS were used to generate discharge simulations. The non-hydrostatic numerical mesoscale models Lokal Modell (LM) and MM5 provided quantitative precipitation forecasts (QPFs). The comparison is performed in terms of streamflow simulations driven by rainfall observations, to be aware of the performance of both hydrological models, as well as by QPFs, in order to evaluate the reliability of the discharge forecast resulting by the one-way coupling. Different configurations of LM and MM5 have been adopted, trying to improve the description of the phenomena determining the precipitation amount; in particular, the impact of different initial and boundary conditions and the horizontal resolution increasing are investigated. The accuracy of these forecasts is assessed exploiting the hydrological models as validation tools.

The study is performed for an intense precipitation event, which affected northern Italy and caused a flood event of the Reno river, a medium-sized catchment in the Emilia-Romagna Region.

Description of the case study

The 7-10 November 2003 event

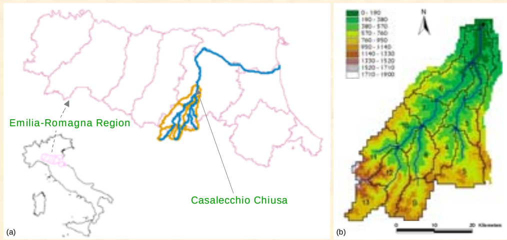


On November 6, at 00 UTC, an upper level deep trough, located over the Balcanic area, evolved into a cut-off low. Later, this cyclonic vortex cut-off moved backward from the Adriatic sea on November 7, 2003, at 00 UTC and in the next 36 hours reached the Alpine region, causing intense precipitation over the the central part of the Apennines chain, in particular over the Reno river basin.

The maximum water level at Casalecchio Chiusa was 1.75 m (corresponding to a discharge value of about 760 m^3/s), at 20 UTC, November 8, representing the 13th event in terms of flood event magnitude over a historical archive collecting 90 events from 1981 to 2004.

⇐ *Figure 1:* MSLP field (orange solid lines), temperature at 850 hPa (color shaded) and geopotential height at 500 hPa (orange dashed lines) for 12 UTC, 07/11/2003.

The watershed of interest



⇑ *Figure 2:* (a) The upper Reno river basin (~1000 km^2) in the Emilia-Romagna Region, northern Italy. The discharge forecasts are evaluated at Casalecchio Chiusa, the closure section. (b) The Digital Elevation Model (DEM) and the sub-catchments defined in the implementation of HEC-HMS model for the Reno river basin.

The hydrological models: HEC-HMS and TOPKAPI

HEC-HMS

- physically, semi-distributed, and event-based rainfall-runoff model
- the loss rate is calculated using the Soil Conservation Service Curve Number (SCS-CN)
- a synthetic unit hydrograph (UH) model provided by SCS is used to convert precipitation excess into direct runoff
- baseflow is calculated by means of an exponential recession method to explain the drainage from natural storage in the watershed
- the flood hydrograph is routed using the Muskingum method
- the calibration process is performed by the combination of a subjective procedure and an automatic one, which uses as objective function the univariate-gradient search algorithm. For the implementation on the Reno river basin, the Curve Number, soil imperviousness, recession parameters and flood wave celerity are calculated as average values among three events selected depending on similar characteristics with respect to the case study in terms of antecedent soil conditions, type of rainfall and amplitude of the discharge peak

TOPKAPI

- distributed physically based model, run in a continuos mode
- it combines the kinematic approach with a DEM describing the basin, to transform rainfall-runoff formulation into three 'structurally-similar' non linear reservoirs equations, describing hydrological and hydraulic processes (sub-surface flow, overland flow, channel flow)
- all the equations are solved for each cell of the DEM, under three basic assumption: Dunne mechanism (saturation from below), vertical lumping (local transmissivity depends on the total water content of the soil), constancy in space of the time variation of the water storage
- the parameter values are shown to be scale independent and obtainable from DEM, soil and land use maps in terms of slope, soil permeability, roughness and topology. The calibration process has been performed using a meteo-hydrological data-set available from 1990 to 2000

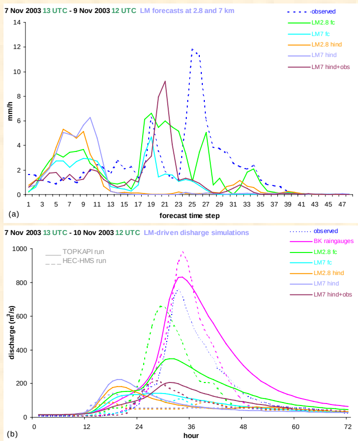
The meteorological models: Lokal Modell and MM5

Name	Model	Horizontal resolution (km)	Grid points	Levels	Initial and boundary conditions	Assimilation	Nesting procedure
LM7 hind+obs	LM	7	234 x 272	36	ECMWF analyses	continuous	1-way
LM7 hind	LM	7	234 x 272	36	ECMWF analyses	-	1-way
LM2.8 hind	LM	2.8	265 x 270	36	LM 7 analysis and forecast	-	1-way
LM7 fc	LM	7	234 x 272	36	LM analysis ECMWF forecasts	-	1-way
LM2.8 fc	LM	2.8	265 x 270	36	LM7 analysis and forecasts	-	1-way
MM5 hind+obs	MM5	7.5 and 2.5	151 x 151	23	ECMWF analyses	continuos	2-way
MM5 hind	MM5	7.5 and 2.5	151 x 151	23	ECMWF analyses	-	2-way
MM5 fc	MM5	7.5 and 2.5	151 x 151	23	ECMWF analyses and forecasts	-	2-way

⇑ *Table 1*: Summary of meteorological models configuration.

- convective parameterization scheme: for LM, Tiedtke scheme in the 7-km run, explicit representation in the 2.8-km run; for MM5, Kain-Fritsch for coarse domain
- the forecast range is +72 h for all LM runs (except for "LM7 hind+obs" where is +60 h) and +48 h for all MM5 runs
- all the LM runs and the 2.5-km MM5 runs provide hourly data, whereas the 7.5-km MM5 runs provide data cumulated every three hours

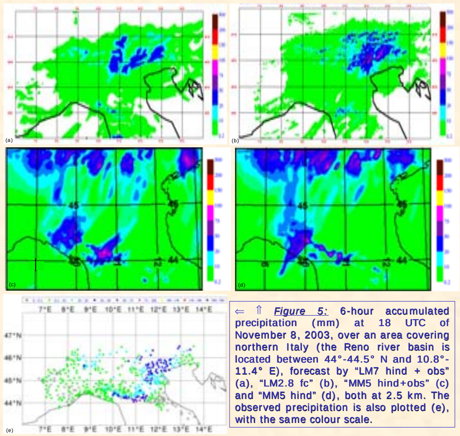
The meteo-hydrological coupling



LM-based predictions

- all the LM configurations miss the high precipitation amount observed around the +25h forecast range (Fig. 3-a). The best prediction is provided by "LM2.8 fc", even if characterised by a wrong temporal distribution and an underestimate of about 10% in terms of total amount. A signal is provided by "LM7 hind+obs", predicting a high peak though out of time-phase with respect to the observed one. Generally, all the runs underestimate the precipitation over the central Apennines area, the model error being only marginally due to localisation problems in this case (Fig. 5 a-b, only two LM runs are displayed).
- The "LM2.8 fc"-driven streamflow simulation is best for both hydrological models, but the TOPKAPI run noticeably underestimates both the observed and raingauge-driven curves, while the HEC-HMS run is more satisfactory (Fig. 3-b). The remarkable difference in model's response is mainly due to the different infiltration schemes adopted by the two models. TOPKAPI exploits the first 24 hours of QPFs to saturate the soil (following the Dunne mechanism), whereas HEC-HMS exploits this amount of rainfall directly to calculate runoff (following a Horton mechanism), subtracting an initial abstraction. With the CN method, the efficiency of the watershed in producing runoff increases while precipitation occurs, once the initial infiltration threshold is exceeded. In the evaluation of such result it has also to be considered the previous calibration task of HEC-HMS, which provides an overestimate of the observed peak: it seems that the calibrated initial conditions of the antecedent soil moisture are greater than for the case under study, inducing a major runoff production.

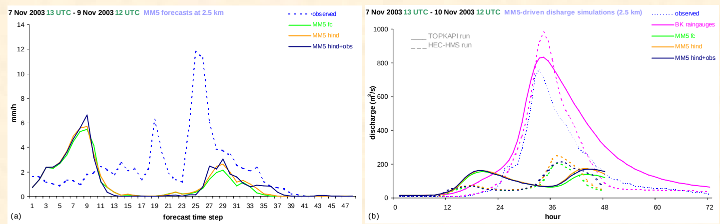
⇑ *Figure 3:* (a) Hourly precipitation forecasts, area-averaged over the upper Reno river basin, provided by the different configurations of LM, run at 2.8 and 7 km, against the observed rainfall (blue dotted line). (b) Corresponding discharge predictions, compared to the observed streamflow (blue dotted line) and the raingauge-driven simulations (fuchsia lines). The rainfall spatial distribution has been derived by applying a Kriging-based method. The TOPKAPI runs are displayed by continuous lines, the HEC-HMS runs by dashed lines.



⇐ ⇑ *Figure 5:* 6-hour accumulated precipitation (mm) at 18 UTC of November 8, 2003, over an area covering northern Italy (the Reno river basin is located between 44°-44.5° N and 10.8°-11.4° E), forecast by "LM7 hind + obs" (a), "LM2.8 fc" (b), "MM5 hind+obs" (c) and "MM5 hind" (d), both at 2.5 km. The observed precipitation is also plotted (e), with the same colour scale.

MM5-based predictions

- The different runs of MM5, run at 2.5 km, provide quite similar forecasts: the highest values are predicted in the first 12-h period, then a no rain period is foreseen and finally rainfall is again forecasted within the time-range 24-36 h, but with lower values in respect to the first period (Fig. 4-a). In terms of total amount, the event is heavily underestimated by all configurations (about 50%). This error is mainly due to localisation problems, since heavy precipitation is forecast westward of the basin (Fig. 5 c-d, only two runs are displayed).
- The corresponding discharge forecasts provided by HEC-HMS (Fig. 4-b) show a slight increasing of the streamflow in response to the first raining period and higher values in response to the second period (contrasting to the rainfall rate). This result is owed to the CN loss method, which effect has been yet explained in the discussion of LM-based predictions. On the other hand, TOPKAPI produces quite similar discharge peaks for the two periods.
- The forecasts provided by MM5 run at 7.5 km are rather similar with respect to the 2.5-km run, even if the rainfall amount is slightly lower. The corresponding discharge curves lay below the 2.5-km ones, but the differences are negligible (not shown).



⇑ *Figure 4:* As in Fig. 3 but for forecasts based on the different configurations of MM5, run at 2.5 km.

Conclusions

- The very high-resolution (2.8 km) configuration of LM, where an explicit description of the deep precipitating convection is adopted, considerably improves the rainfall forecast, as well evidenced by the corresponding discharge predictions. The impact of model resolution increasing is not noticeable for the other LM run. The different runs of MM5 provide similar forecasts, not allowing to highlight the impact of the different configurations. In particular, high and low resolution MM5 forecasts resembleeach other due to the two-way nesting procedure.
- The different infiltration schemes adopted by the two hydrological models play a major role in governing the model's response. HEC-HMS seems to perform better in case of intense precipitation event.
- The different scenarios of discharge provided in an independent way by the two different hydrological models, each forced with the QPFs provided by the LM and MM5 models, can be regarded as members of an ensemble of discharge prediction which enables to convey a quantification of uncertainty about the meteo-hydrological forecasting chain.
- The coupling of atmospheric and hydrological models can be regarded as a complementary tool to evaluate QPFs for the verification of meteorological model performance.

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Acknowledgements

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