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# A HYDROMETEOROLOGICAL FLOOD FORECASTING SYSTEM FOR THE RESERVOIR CONTROL IN THE RED RIVER

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## 1. INTRODUCTION

The Red River is a transnational watershed located across China, Laos and Vietnam. The total area is about 169.000 km$^2$ (including the Thai Binh river delta system). Its source originates in China, flows to the southeast entering into Vietnam at Lao Cai (41.000 km$^2$) and discharges into the East Sea. Three main tributaries in the Red River system are called, in Vietnam's territory, Lo, Thao, and Da rivers from East to West (Figure 1). These three main tributaries join together at a junction close to Viet Tri upstream of Hanoi, the capital of Vietnam, where the watercourse takes the name of Red River (Song Hong). The Red river Delta is a very important area from a political, educational, cultural and economic viewpoint (Ngo, 2005). Vietnam is affected by severe floods throughout its territory (see for instance Plate, 2007 for the Mekong river floods). The causes of severe floods in the Red River Delta are monsoons such as tropical monsoon from North Indian Ocean, equator monsoon from the South and monsoon from the Pacific Ocean, and weather turbulences such as frontal systems, tornadoes, storms, and tropical storms. The combination of these weather systems causes heavy rain over the basins of Da, Lo and Thao rivers.

Floods are formed from the upstream area of the basin and then concentrate in the three main rivers. They route along the watercourse and join at Viet Tri. After that, the flood flows through Hanoi, then to Thai Binh river system and the sea (see Le, 2007). In the Red river system, there are three large dams gauging major reservoirs operating now: the Hoa Binh reservoir (with $9.6 \cdot 10^9$ $m^3$ storage) is in the Da river, the Thac Ba (with $2.49 \cdot 10^9$ $m^3$ storage) and Tuyen Quang reservoirs (with $2.245 \cdot 10^9$ $m^3$ storage) in the Lo river (Figure 1). Others are under construction or are planned in the Da and Lo rivers. The missions of these reservoirs are: the protection of the Ha Noi capital and the Red River Delta against floods up to 250 years return period at Son Tay (upstream of Hanoi), keep the water level at Hanoi less than 13,4 m above the sea level, generate hydropower and supply water for irrigation. A forecasting system in the Red River basin was setup in order to protect the capital and other important areas around. The system is developed and implemented at the Vietnamese National Flood Control Bureau. The warning time is the time lag of the basin in the Vietnamese territory. In this paper, we describe and discuss a new hydro-meteorological system used for research and already tested for demonstration purposes (Ranzi et al., 2008; Ngo et al. 2008) in order to extend the lead time for flood control for Hanoi, also providing flood forecast for the operation of the major reservoirs

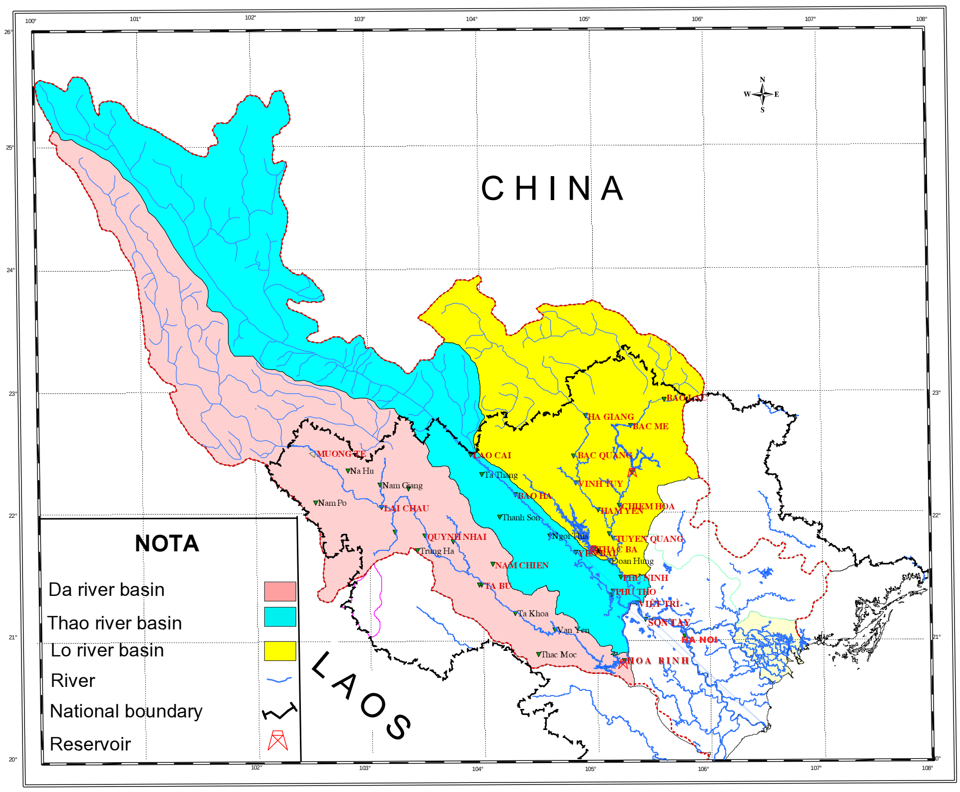


*Figure 1. Red river basin with major reservoirs, rainfall (in black) and hydrometric (in red) stations in Vietnam*

upstream. It is composed of a mesoscale meteorological model coupled with a conceptual, continuous time, distributed hydrological model.

The hydrometeorological chain together with some results of relevance for the operation of reservoirs are described in the following. In the second section the main features of the meteorological model and of the hydrological model are briefly described. In the third section the output of the meteorological model in terms of predicted areal rainfall is compared with ground raingauge observations and the predicted hydrographs is compared with data of some hydrometric stations close to major reservoirs referred to five major floods occurred in 1973 (the 'century' flood for Hanoi), 1996, 2000, 2002 and 2007. Uncertainties in the runoff measurements due to the actual effect of reservoirs are briefly discussed.

## 2. THE HYDRO-METEOROLOGICAL SYSTEM

### 2.1 THE METEOROLOGICAL MODEL

The BOLAM model, used for meteorological forecasting, is a limited-area, primitive equation, terrain-following coordinate, hydrostatic meteorological model. It was developed starting in the early 1990's at CNR-ISAC in Bologna – Italy (BOLAM stands for Bologna Limited Area Model: Buzzi et al, 1994) and is used operationally in the Mediterranean area, as in Italy, Greece and Cyprus for meteorological forecasting.

The initial and lateral boundary conditions for the study have been obtained from the ECMWF archives, by retrieving the 6-hourly analyses available at 0.5°x0.5° resolution. Hybrid model level data have been directly interpolated on the limited area BOLAM grid, using a pre-processing program, similar in principle to that for the GFS data, but interpolating from the hybrid ECMWF to the hybrid BOLAM levels directly, in order to avoid un-necessary interpolations using pressure levels. Snow cover, sea surface temperature, and soil temperature and wetness at four soil layers have been derived also from the ECMWF analyses. In this study, for simulation of precipitation in the Red River catchment basin, the BOLAM model has been applied at a relatively high spatial resolution, using a horizontal grid distance of 8 km. However, initial and boundary conditions are available from the global model, at a much lower spatial resolution (of the order of 50 km) and with a temporal interval of 6 hours. In order to provide the high resolution simulations with more suitable boundary data, a dynamical downscaling chain has been organized: global analysis data, after undergoing a pre-processing procedure, have been used as initial and boundary conditions for simulations at a low spatial resolution (about 19 km), intermediate between the analyses resolution and the inner grid resolution. The coarse model integrations are conventionally named "BOLAM-father" runs. Output data obtained from the BOLAM-father simulations have been used, by applying a suitable interpolation procedure called "nesting", as initial and boundary conditions for simulations at high spatial resolution. Such model simulations are conventionally indicated as the "BOLAM-son" runs. In the BOLAM-father configuration, the following parameters for the numerical solution have been used: rotated geographical system with the coordinate origin set at 21.3°N and 102.5°E; horizontal grid distance of 0.17° (about 19 km in both latitudinal and longitudinal directions); 38 hybrid levels in the vertical; basic time step of 150 s; output data storage time step is 3 hours and the duration of each continuous run is 72 hours. The domain of the BOLAM-father runs is depicted in Fig 2a. In the BOLAM-son configuration, the following parameters have been used: same rotated geographical system as for BOLAM-father; horizontal grid distance of 0.077° (about 8 km); 40 hybrid levels; time step of 72s; output data storage every 1 hour; duration of each continuous run of 48 hours. The domain of the BOLAM-son runs is shown in Fig 2b.

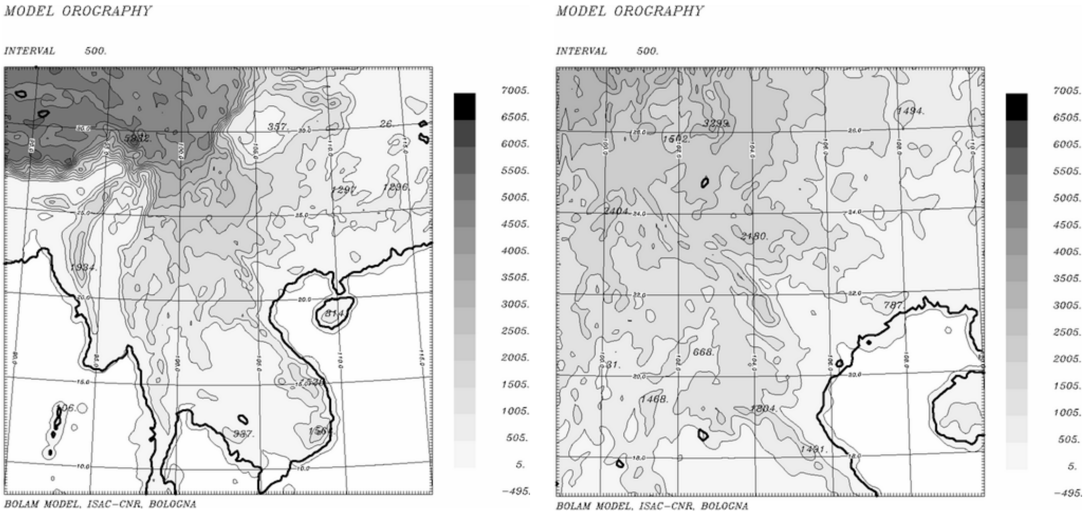



*Figure 2. a) Domain of BOLAM Father b) Domain of BOLAM Son*

### 2.2 The hydrological model

The results of the simulation are used to force a conceptual, distributed hydrological model called DIMOS-Hong. The DIMOS-Hong model (acronym of DIstributed hydrological MOdel for the Song Hong) is a development of the event-based DIMOSOP model (see Ranzi et al., 2003) and was adapted for continuous time simulations of the Red River basin (Ngo et al., 2008). The model is basically built by two components. The first is the soil model that aims at describing in a relatively simple conceptual scheme developed after the SCS model, the

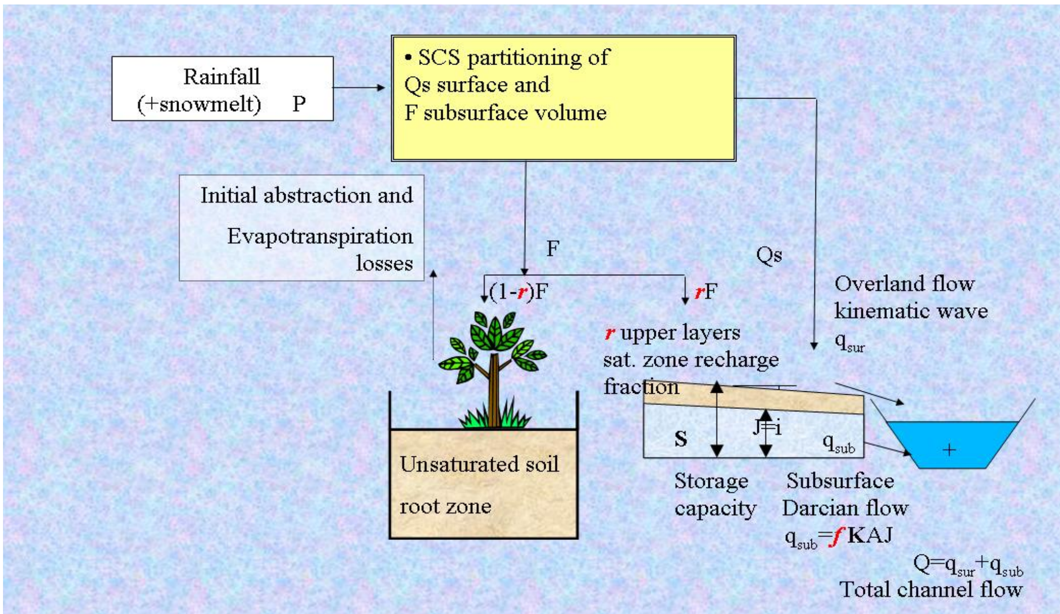



*Figure 3. DIMOS-Hong hydrological model scheme*

complex physical processes that include the interception of rainfall by vegetation, the storage in surface ponds and the partitioning of the resulting rainfall volume into infiltration and runoff (Figure 3). The fraction *r* of infiltration contributes to a saturated subsurface storage which contributes to runoff with a Darcian flow component driven by a topographic surface gradient. The surface runoff component is routed though overland and channel flow with a Muskingum-Cunge scheme.

The topography was represented by the Digital Elevation Model extracted from the Global DEM GTOPO30, provided by the USGS-EROS Data center, in a raster format, lat-long coordinate system. The river network is then determined through a Hortonian ordering scheme and a D8 flow-direction algorithm which is used to determine also the Darcian subsurface flow direction. The other parameters are estimated from landuse and geological maps from USGS, and Vietnamese Geographic Information Systems.

## 3. APPLICATION OF THE HYDRO-METEOROLOGICAL SYSTEM FOR FLOOD FORECASTING

Five heavy flood events occurred in 1971, 1996, 2000, 2002 and July 2007 were investigated. In these events, the 1971 and 1996 are historical ‘big’ flood events. The 2000 and 2002 events are the largest events in the last decade. The July 2007 event was selected as a demonstration event to test the system.

The results of BOLAM model for those 5 events are represented in maps and histograms. Figure 4 shows an example of simulated precipitation for the 1971 event. In order to verify the simulation, the comparisons between observed and forecast rainfall were done. Because of the sparse raingauge data in China, especially for the 1971 and 1996 events, in order to avoid the effect of spatial bias in the comparison, the information in the upper part of the basin is neglected.

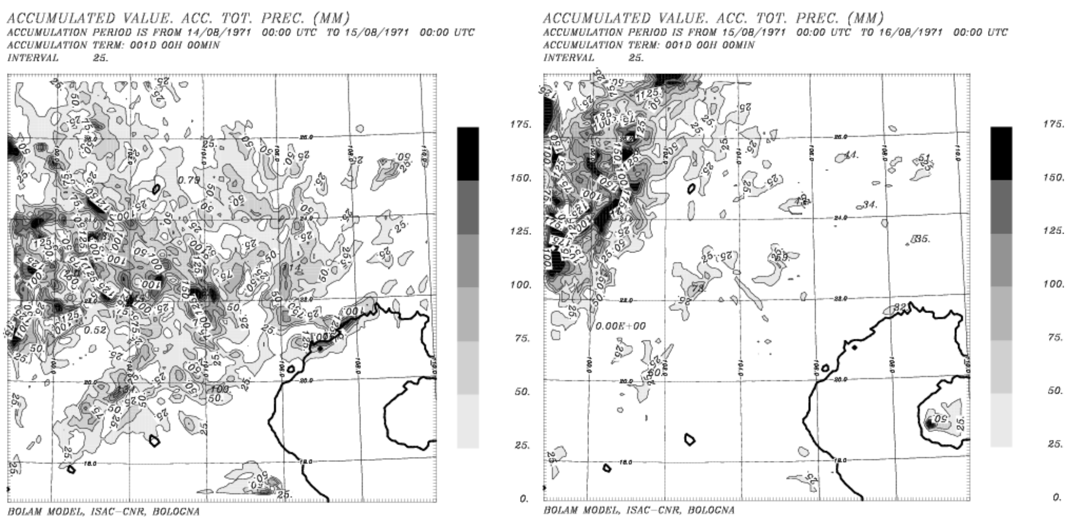
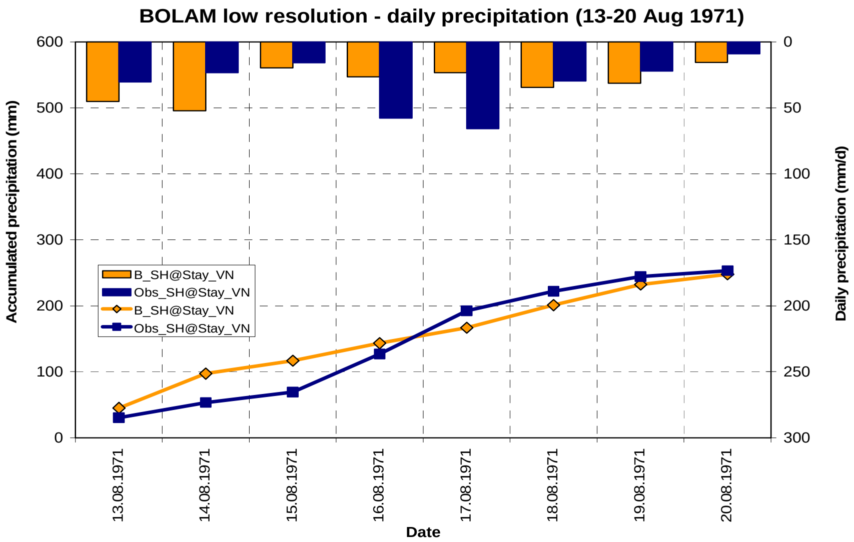
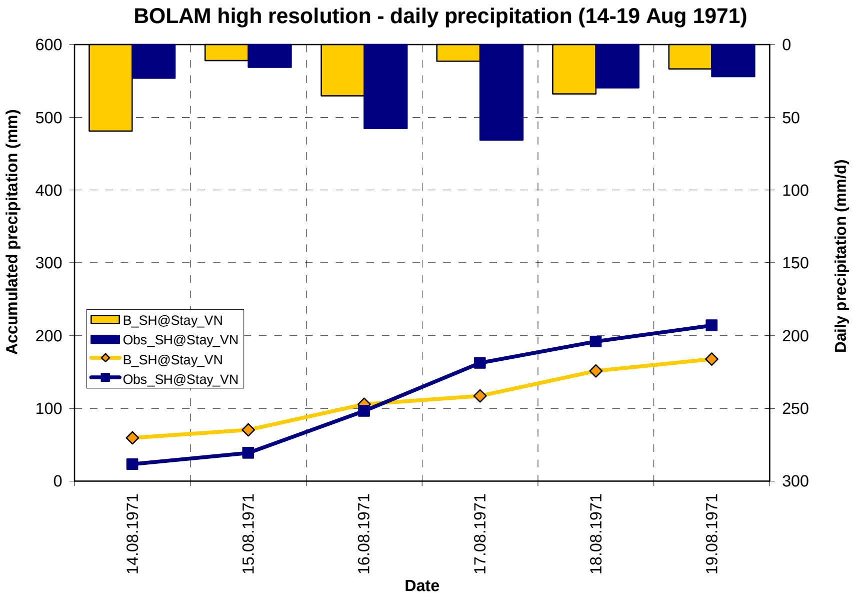



*Figure 4. Precipitation simulation by BOLAM-Son model for the 1971 event.*

The average observed rainfall is calculated by the Thiessen method for the Vietnamese part of the basin only, and then compared with the values predicted by BOLAM over the same area. The verification was done for the five events in the Da, Thao, Lo and Red River basins in both the high and low resolutions mode of BOLAM (Figure 5 and 6). In general, the timing of the precipitation forecast with BOLAM model is reliable and also the time and spatial pattern. For some events, as the 1971 flood, accurate forecasts are provided also in terms of rainfall volumes. But other events are overestimated, especially with the higher resolution model, with forecast values are about 50% higher than observed ones.

a)




b)

*Figure 5. The verification of precipitation at Red river basin predicted for the 1971 'century' flood event by the BOLAM model in a) low resolution and b) high resolution.*

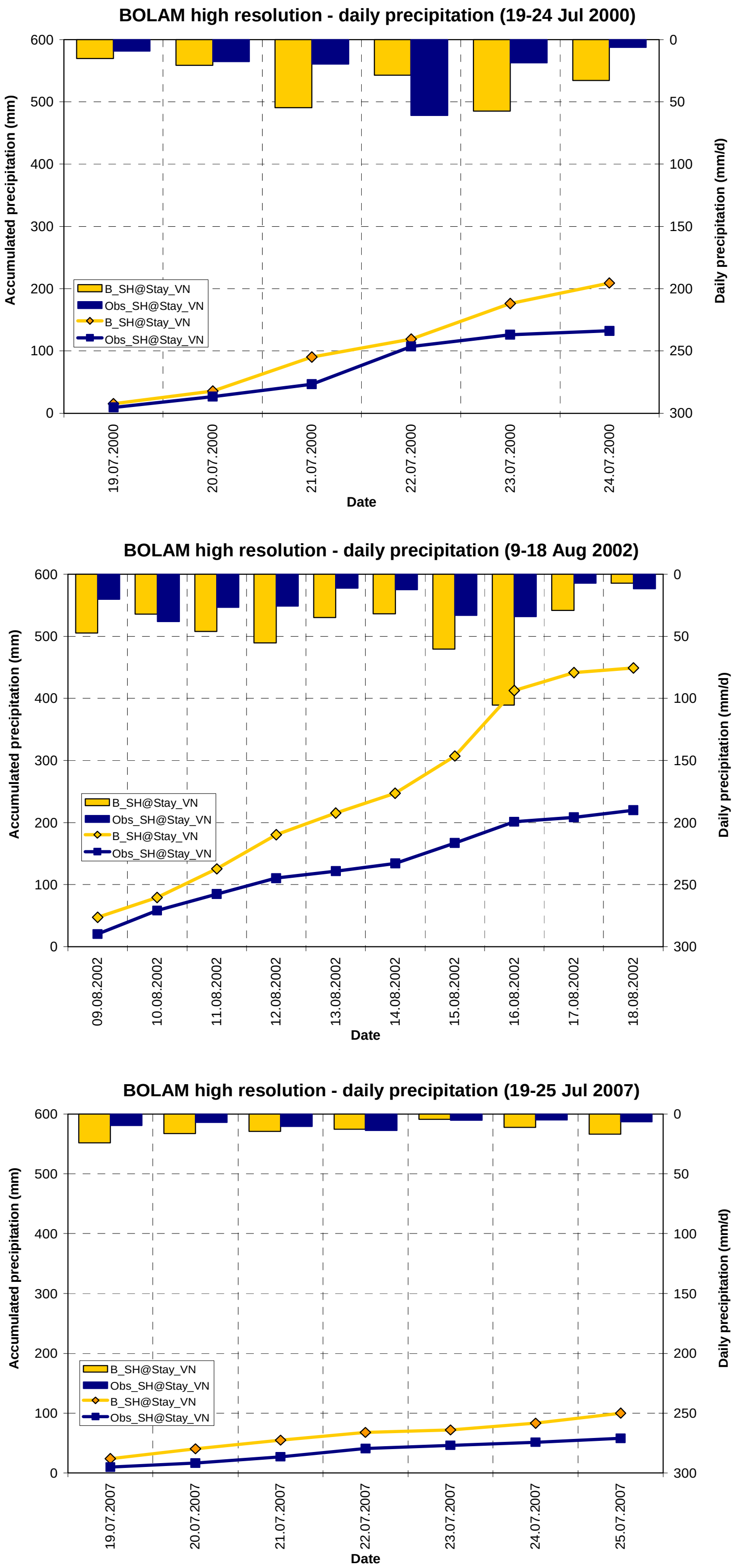



*Figure 6. The verification of the precipitation predicted by the high resolution model for the Red river basin at Son Tay for the last three events.*

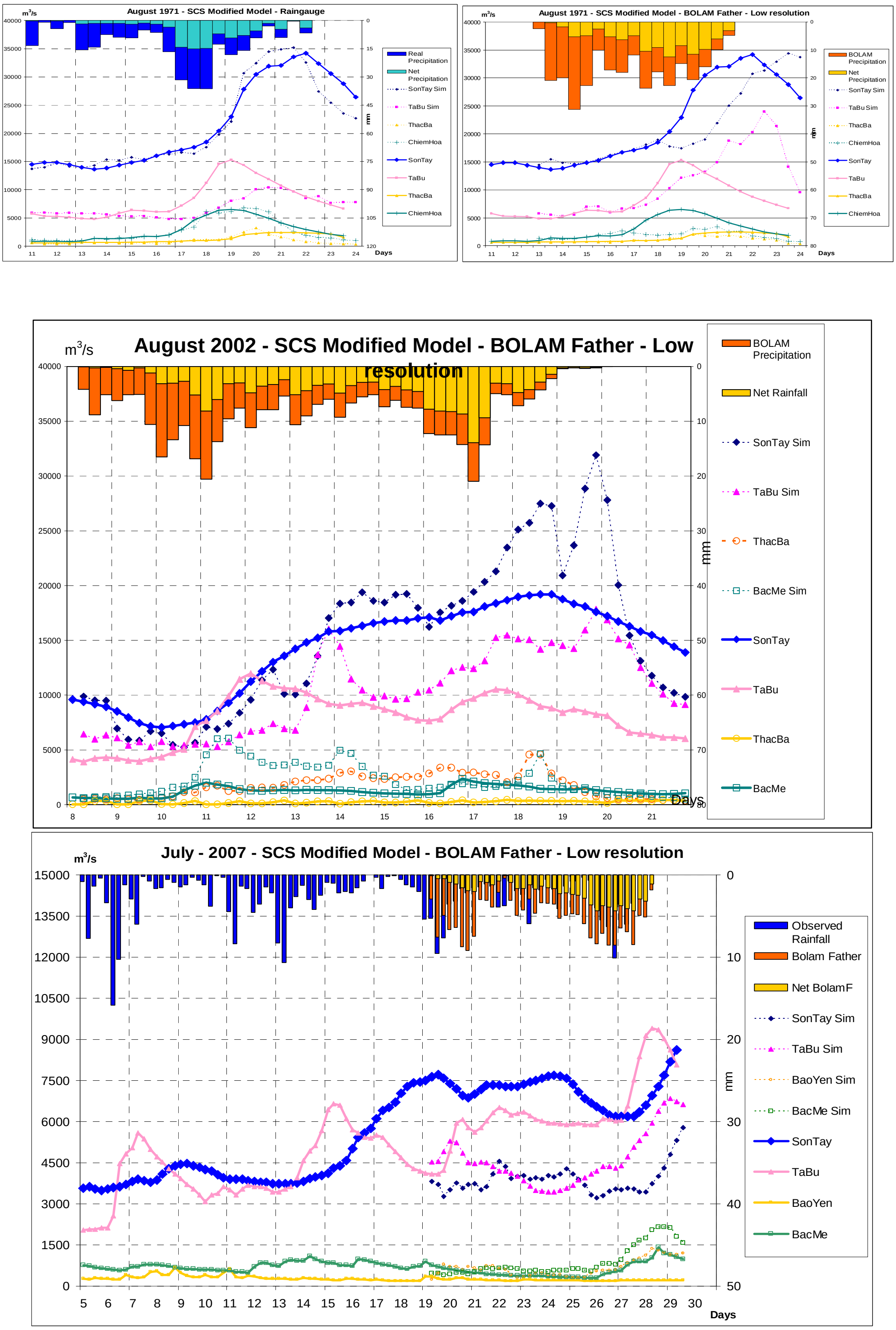



*Figure 7. Runoff simulation for 1971 (top), 2002 and 2007 (bottom) events in Red river basin with observed and forecasted (in low and high resolution mode) precipitation data. The 2007 event was simulated as an actual real-time forecast process, using observations first and then rainfall forecasts.*

However, the model can provide some useful information to extend the forecast time up to 3 days ahead and possibly more.

The hydrological model DIMOS-Hong was used to simulate the runoff with a calibration of just the recharge, *r*, and the lateral transmissivity, *f*, parameters shown in the scheme of Figure 3. Observed or forecast precipitation data were used to force DIMOS-Hong model and some of the simulated results for some hydrometric stations, including Bac Me, Thac Ba and Ta Bu representative, respectively, of the flow into the Tuyen Quang, Thac Ba (Lo River) and Hoa Binh (Da river) reservoirs, are shown in Figure 7. In addition the Chiem Hoa station is representative of floods downstream the Tuyen Quang dam.

Flood hydrographs simulated by the DIMOS-Hong hydrological model are good in timing of the concentration and recession limb. Good results were achieved for the 1971 'century' flood peak and volume, although peak flows are overestimated in other events, especially for the 1996 event. The July 2000 and August 2002 floods were overestimated by the meteorological model. For this reason a sensitivity of the meteorological forecasting using also the non-hydrostatic model MOLOCH is currently being performed at the Vietnamese National Flood Control Bureau. Other uncertainties affect the accuracy of the flood forecast. The effect of reservoirs can not be assessed precisely with the available information. For instance for the 2007 flood the Hoa Binh reservoir was assumed as a pure sink of the inflow, resulting in an underestimation in the downstream Son Tay runoff volume. Progresses on this side are expected after further data collection on the actual operations of reservoirs and on hydrometric data collection in real-time hydrometric stations as that available in Ghenh Ga, downstream the Tuyen Quang reservoirs. Considering that the hydrological model's calibration was limited to a few parameters only, on average a reasonably satisfactory result on flood forecasts up to three to five days in advance for most of the investigated events was achieved.

## 4. CONCLUSIONS

The meteorological model can forecast up to three days in advance and the verification indicates that it is good in timing and in the spatial distribution of precipitation but overestimated in terms of accumulated precipitation for most ogf the events. The results show a potential of precipitation estimation in the upstream part of the basin in case a lack of raingauge information occurs. Flood hydrographs simulated by the DIMOS-Hong are fairly well reproduced when observed precipitation is used and when the mesoscale model is accurate in the rainfall prediction as for the 1971 flood.

The test successfully conducted at demonstration level in 2007 encourages the joint effort for a further improvement of the hydrometeorological flood forecasting system, considering the actual regulation of reservoirs and using real-time hydrometric data. The results achieved in this research indicate that the BOLAM-DIMOSHong model chain can provide additional information useful to assist medium term flood forecasting and control for the Red River, thus enabling non structural methods for flood hazard prevention, as the operation of reservoirs, or the setup of flood alert systems for towns and villages along the river and of civil protection plans.

## ACKNOWLEDGEMENTS

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