An application of numerical weather forecast and satellite rainfall prediction to flood forecasting

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Abstract In the last years, numerical weather forecast, satellite rainfall estimation and predictions were applying successfully in the world, becoming more accurate and improved. This case study presents an initial results of using Mike11 software with application of numerical weather forecasts (HRM, JMA, ECMWF), satellite (NOAA-USGS, TRMM) rainfall estimation and prediction for flood forecasting on the Red river system in Vietnam. Due attention should be given to the representativeness of the point rainfall locations in view of topographic effects. Development of properly calibrated rainfall-runoff and river routing models for the sub-basins. The tools to be selected should allow for multiple data assimilation options to improve the forecasts. Analysis in a similar manner, extended also to investigations for the sub-basins separately, to increase accuracy and extent lead-time of forecasts to five days.

Key words forecasting; flood; numerical weather forecast; satellite rainfall prediction

During the last years, hydrological-hydraulic models, numerical and satellite rainfall estimation, prediction have being applied in the world and Vietnam, getting more improved and accurate results. With an availability of having good flood forecasting commercial models, numerical, satellite rainfall prediction products, an improvement and lead-time extension of hydrological forecasting become more realistic. This study presents an initial results of using Mike11 software with application of numerical (HRM, JMA, ECMWF), satellite (NOAA-USGS, TRMM) rainfall estimation and prediction for flood forecasting at the Red - Thai Binh river system.

RAINFALL PREDICTION DATA

Comparison of rainfall prediction data HRM, JMA and ECMWF

Carried out comparison of weather forecasts to 48 hours from HRM, JMA and ECMWF for the period of 15 June until 30 September 2004. In a first analysis of the data area-average rainfall has been compared for the domain 16.75^o-26.875^o N, 99.375^o-110.625^o E for HRM and JMA, and 16.75^o-26.25^o N, 99.75^o-108.25^o E for ECMWF. Both areas contain the Red river basin. Results are shown in figures 1 and 2. Fig.1 presents the forecasts for 0-24 hours ahead. Figure 2 presents the forecast for 24 - 48 hours ahead. It shows that the ECMWF precipitation forecasts are, on average, significantly lower than HRM an JMA forecasts, as can also be seen from Table 1. The peak rainfall events seem to coincide very well, especially if one compares ECMWF with JMA.

Numerical rainfall forecasts

For weather forecasting the National Centre for Hydro-meteorological Forecasting (NCHMF) makes use of the High-resolution Regional Model (HRM), originally developed by the Deutsche Wetter Dienst (DWD). The HRM model takes its initial and boundary conditions from the global model GME (DWD) every 3 hours from the internet. HRM runs with two resolutions:

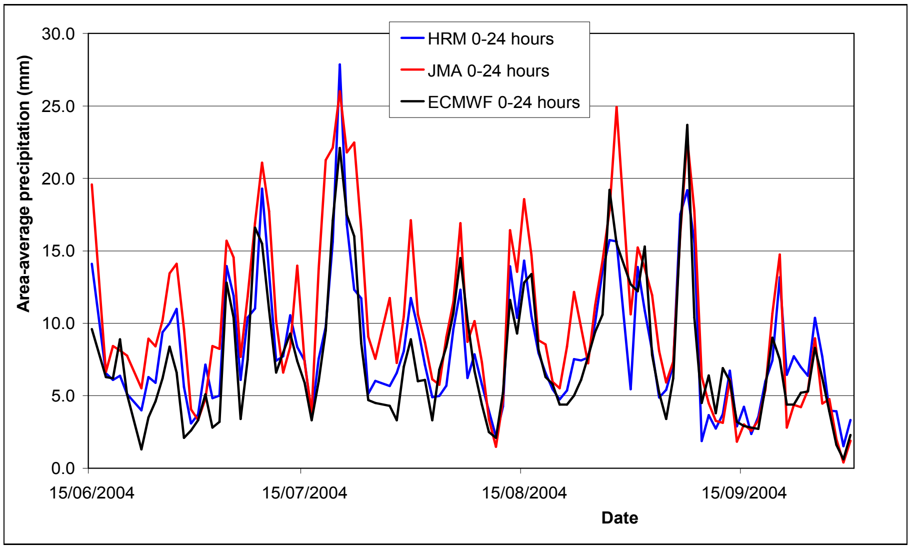

Fig. 1 Area-average rainfall for the domain 16.75°-26.875° N, 99.375°-110.625° E (HRM and JMA) and the domain 16.75°-26.25° N, 99.75°-108.25° E (ECMWF) over the time period 15-06-2004 until 30-09-2004. The lead time of the forecasts is 0-24 hrs.

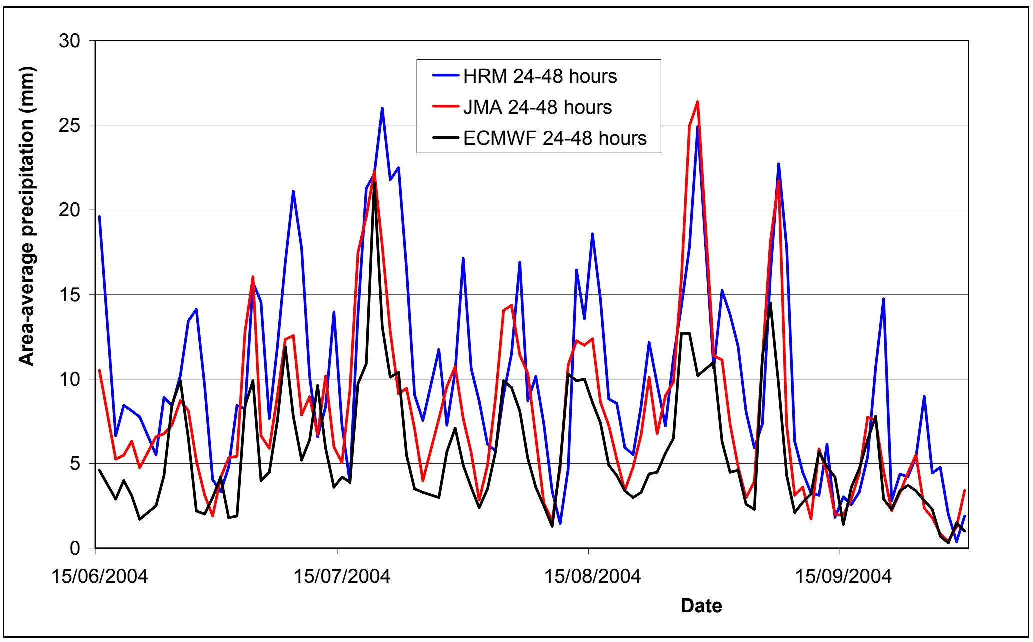

Fig. 2 Area-average rainfall for the domain 16.75°-26.875° N, 99.375°-110.625° E (HRM and JMA) and the domain 16.75°-26.25° N, 99.75°-108.25° E (ECMWF) over the time period 15-06-2004 until 30-09-2004. The lead time of the forecasts is 24-48 hrs

Table 1 Area and time-average rainfall in mm for the domain 16.75°-26.875° N, 99.375°-110.625° E (HRM and JMA) and the domain 16.75°-26.25° N, 99.75°-108.25° E (ECMWF) over the time period 15-06-2004 until 30-09-2004.

Time	HRM	JMA	ECMWF
0-24 hrs.	8.2	10.1	7.6
24-48 hrs.	10.7	8.0	5.7

(a) a coarser resolution with grid spacing 0.25^o (28 km) for the domain 5^oS-35^oN, 80.25^o-130.25^oE) for 20 vertical layers, and

(b) a finer resolution with grid spacing 0.125^o (14 km) for the domain 7.25^o-27^oN, 97.375^o-117.25^oE) for 31 vertical layers. With HRM forecasts on wind, temperature, humidity and rainfall are made for the next 72 hrs. The performance of the HRM model is not satisfactory yet. Monsoon patterns are well forecasted but systems from the sea are not. Since the latter produce the rainfall in the flood season the following performance pattern is observed:

- heavy rains are always underestimated, and
- lighter rains always overestimated.

It is suspected that the assimilation of observations in GME for this part of the world is not optimal, so the boundary conditions delivered by GME are inadequate. It is intended to improve this by taking the boundary conditions in future from the AVN/NCEP global model, which is foreseen for late 2005.

Since 2001 also every 6 hrs weather forecasts for the next 72 hrs are obtained from JMA of Japan. This provides rainfall data at a coarser 1.25^ox1.25^o grid (140 x 140 km). Its rainfall forecasts are generally much better. Therefore, the HRM and JMA forecasts have been combined to see if this results in better flow forecasts, with calibrating coefficient k = R_{JMA}/R_{HRM}

The European Centre for Medium-Range Weather Forecasts (ECMWF) delivers weather forecasts for the whole world on a grid-basis, up to 10 days ahead. The grid of the data covers the domain 16.75^o-26.25^o N, 99.75^o-108.25^o E.

Numerical daily rainfall forecasts were collected for the period 15 June until 30 September from above mentioned sources.

Satellite rainfall estimation, prediction

Collection from NOAA-USGS satellite rainfall estimation with calibration to surface synoptic stations from GTS and 3-day rainfall forecasts by MM5; 7-day forecast GFS by AVN/NCEP. TRMM (Tropical Rainfall Measure Mission) data with 3-hour cumulative rainfall.

APPLICATION OF HYDROLOGICAL - HYDRAULIC MODELS

Used NAM and hydrodynamic model Mike11 for flood forecasts at the Red river system with rainfall prediction from numerical weather forecasting products. The Red river basin with area 169000 km2 divided into 27 sub-basins.

The NAM model was calibrated with observed rainfall and discharge records of the years 2004. Runoff calculated from rainfall by NAM linked as inflow from tributaries or upper reaches or lateral flow into main stream by Muskingum routing. Flow routing in main stream was made by hydrodynamic Mike11. Calibrated results of hydrological and hydraulic models are shown in figures 3-5.

From these figures it is observed that a reasonable fit is only obtained for the Lo at Vu Quang. For the Da at Hoa Binh upstream (reservoir inflow) the model strongly overestimates the peak flows, whereas for the Thao the opposite applies (Table 2). This reflected in the values for the Nash-Sutcliff criterion, defined by equation (1):

$$n_{NS} = 1 - \frac{\sum_{i=1}^{N}(Y_{sim,i} - Y_{obs,i})^2}{\sum_{i=1}^{N}(Y_{obs,i} - \overline{Y_{obs}})^2} \quad (1)$$

where: n_{NS} = Nash-Sutcliff criterion; Y_{sim} = simulated discharge

Y_{obs} = observed discharge; $\overline{Y}_{obs}$ = average of observations

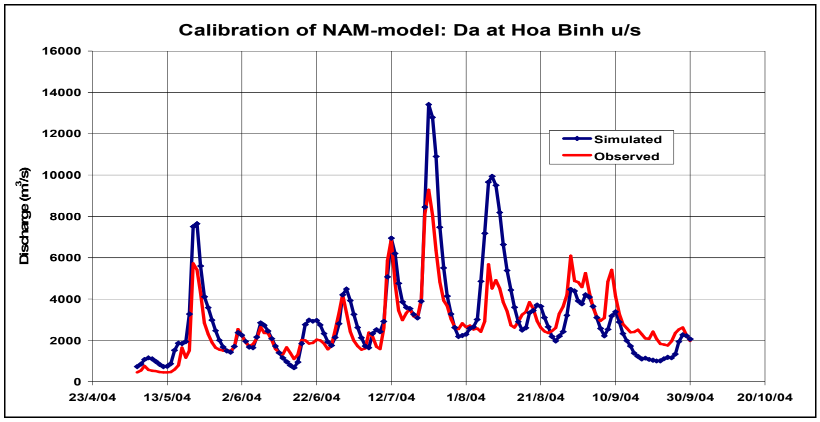

Fig. 3 Calibration of NAM model for Da basin at Hoa Binh

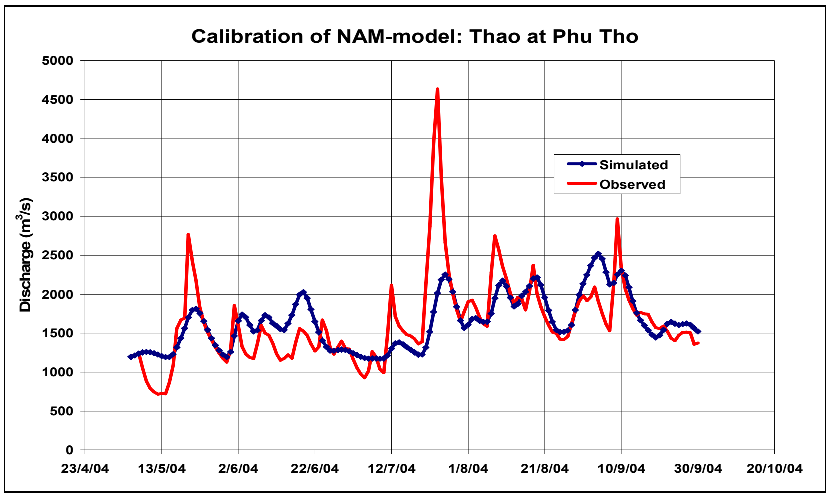

Fig.4 Calibration of NAM model for Thao basin at Phu Tho

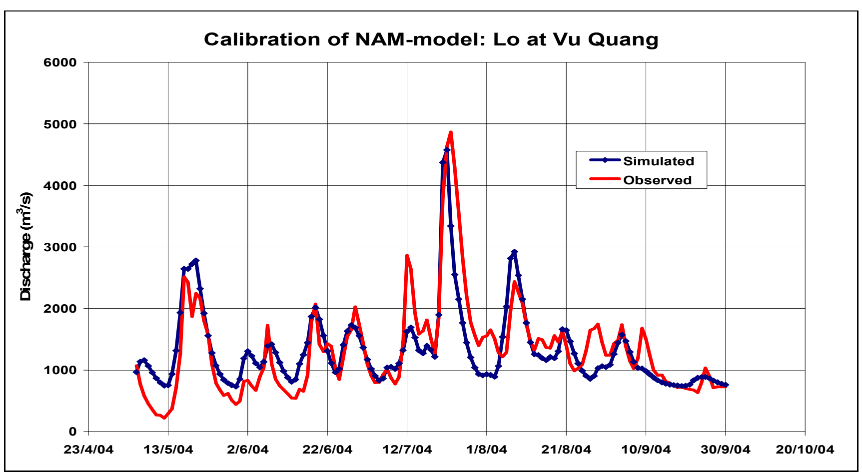

Fig. 5 Calibration of NAM model for Lo-Gam-Chay basin at Vu Quang

The values for n_{NS} found for Da at Hoa Binh, Thao at Phu Tho and Lo at Vu Quang are presented in Table 2 together with the standard error and the fraction of the variance explained by the model R^2.

Table 2 Quality of NAM model calibration

Location	Standard error	R^2	n_{NS}
Da at Hoa Binh	855 m^3/s	0.70	0.23
Thao at Phu Tho	440 m^3/s	0.41	0.37
Lo at Vu Quang	443 m^3/s	0.68	0.68

So, observed rainfall at gauge points that scarcely distributed, un-optimal or unrepresentative for small sub-basins may be the one of main causes impacted on calibration of NAM parameters. In other side, it is necessary to determine, calibrate the parameters, boundary and initial conditions for small sub-basins in the Lo, Thao rivers basins.

Numerical forecasted rainfall from HRM, JMA and ECMWF used as inputs for NAM and Mike11 models, applied and calibrated for flood season of 2004 year. Results at some sites are shown in tables 3, 4, 5 and figures 6 - 9.

Table 3 Comparison of flow forecast errors using HRM and JMA rainfall data, lead time 1 day

Station	No error correction				With error correction			
	Standard error		n_{NS}		Standard error		n_{NS}	
	HRM	**JMA**	**HRM**	**JMA**	**HRM**	**JMA**	**HRM**	**JMA**
Hoa Binh	1043	909	0.66	0.62	596	637	0.84	0.82
Phu Tho	440	435	0.34	0.36	231	240	0.81	0.81
Vu Quang	511	564	0.48	0.47	297	374	0.84	0.82
Average	665	636	0.49	0.48	375	417	0.83	0.82

Table 4 Comparison of flow forecast errors using HRM and JMA, lead time 2 days

Station	No error correction				With error correction			
	Standard error		n_{NS}		Standard error		n_{NS}	
	HRM	**JMA**	**HRM**	**JMA**	**HRM**	**JMA**	**HRM**	**JMA**
Hoa Binh	845	979	0.62	0.56	778	793	0.67	0.72
Phu Tho	434	469	0.39	0.28	333	280	0.60	0.75
Vu Quang	515	599	0.47	0.41	442	349	0.63	0.80
Average	598	682	0.49	0.42	518	474	0.63	0.76

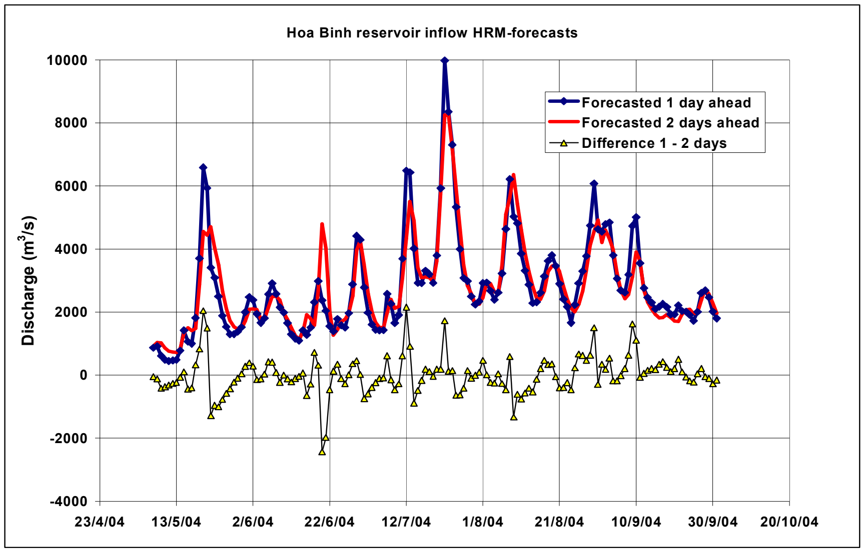

Fig. 6 Forecasted (1 and 2 days ahead) inflow to Hoa Binh reservoir and their difference; based on HRM and using error corrections to simulated flows

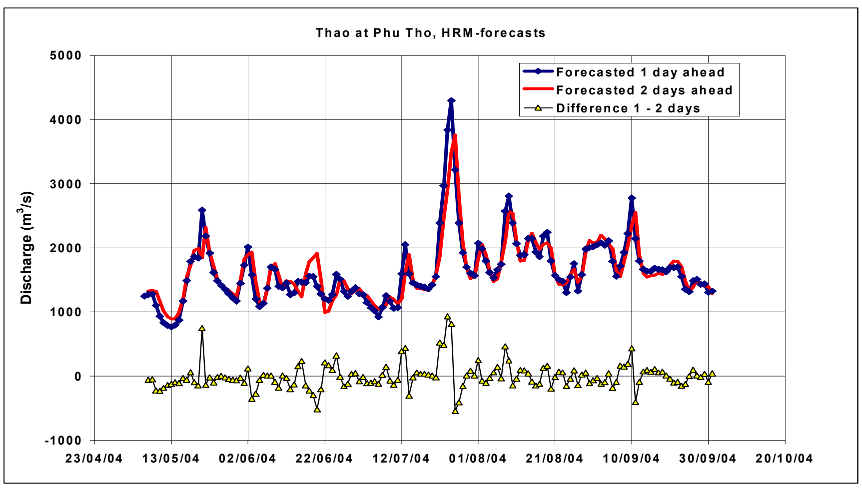

Fig. 7 Forecasted (1 and 2 days ahead) flows in Thao river at Phu Tho and their difference; based on HRM and using error corrections to simulated flows

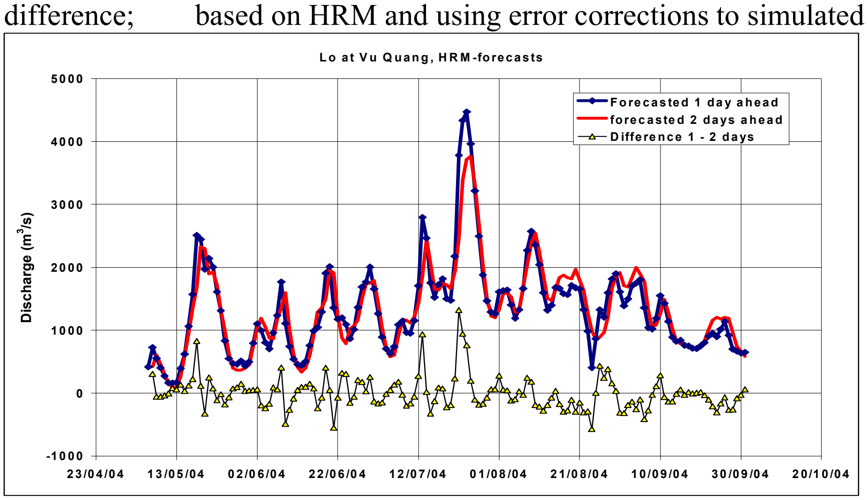

Fig. 8 Forecasted (1 and 2 days ahead) flows in Lo river at Vu Quang and their difference; forecasts based on HRM rainfall data and using error corrections to simulated flows

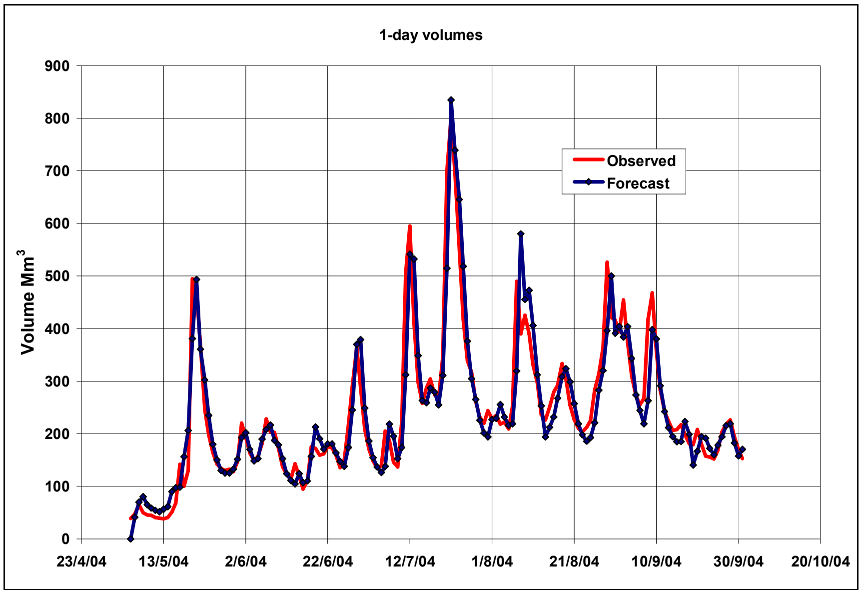

Fig. 9 - One day forecasted and observed inflow volumes to Hoa Binh reservoir

Table 5 Overview of quality indicators of inflow volume forecasts for Hoa Binh reservoir (R^2 = fraction of explained process variance, R = correlation coefficient, n_{NS} = Nash-Sutcliff criterion)

Lead time (days)	R^2	R	n_{NS}
1	0.87	0.93	0.82
2	0.82	0.91	0.81
3	0.77	0.88	0.76
4	0.73	0.85	0.70
5	0.67	0.82	0.61

DATA ASSIMILATION TECHNIQUE FOR FORECAST

Flood forecasting systems are typically constructed from a range of hydrological - hydraulic models that are applied in the prediction of discharges and stages in the river system, as a function of observed meteorological conditions and possibly short or medium term forecasts of these. This system consists of 4 modules, such as Real time data acquisition for observed meteorological and hydrological conditions; Hydrologic and hydraulic models for simulation; Forecast of meteorological conditions and Updating and data assimilation.

Data assimilation or updating is a feedback system where the process models in second module are conditioned using the information on the current state of the system modelled. These process models can be considered as a set of equations containing parameters and state variables, where state variables are transient in time, and the parameters are generally held constant at some value determined in the calibration of the model prior to application in the real time environment. The primary goal of data assimilation is to guarantee an up to date representation of the state variables in model terms. This state is then used as an initial state for subsequent forecasts.

Data assimilation and updating procedures may be categorised in four different approaches: Updating of input variables; Updating of model state variables (the Kalman filter that is well proven for linear systems and the Extended Kalman filter for non-linear systems); Updating of model parameters; Updating of model outputs or error correction.

In this study use of error correction: Linear regression equations, based on the observed and forecasted output during the entire forecasting period, have been established for each lead time. In addition an error term is added to the simulation result, by making use of the fact that at least for the shorter lead times the forecast errors are serially correlated. Hence, the following procedure is applied:

$$Q_{t+n\Delta t} = a + b.Q_{NAM,t+\Delta t}(P_{t+n\Delta t}, P_{t+(n-1)\Delta t}, P_{t+(n-2)\Delta t}, \ldots) + c(Q_{obs,t} - Q_{forecast,t}) \qquad (2)$$

where: $n\Delta t$ = forecast lead time

Q_{NAM} = discharge forecasted by NAM model

P = precipitation; a, b, c = regression parameters

So, with above flood forecasting tools, it is possible to produce 2-day flow forecast at upper stream sites in the Red river system. Forecasting error may be caused by many reasons like scarcity of rain gauge points; their un-presentativeness; areal mean rainfall not yet taken into account of orographic effects in view of the topography; not optimum calibration of hydrological and hydraulic models. To increase an accuracy and lead time of flood forecasts, must to create a reliable (consistency checked) set of rainfall, evaporation and runoff data of the hydro-meteorological stations in Da, Thao and Lo-Gam Chay basin for at least 3 recent years to be used for calibration and verification of the forecasting model.

CONCLUSIONS AND RECOMMENDATIONS

(a) It is available using Mike11 software with weather forecasts (numerical and satellite) for lead-time extension and accuracy improvement of hydrological forecasting.

(b) Compare the observed areal rainfall data derived from point rainfall with estimates from radar and satellite and one day forecasts, and when needed adjust the areal rainfall prior to model calibration. Due attention should be given to the representativeness of the point rainfall locations in view of orographic effects.

(c) Develop properly calibrated rainfall-runoff and river routing models for the sub-basins. The tools to be selected should allow for multiple data assimilation options to improve the forecasts.

(d) Analyze in a similar manner, extended also to investigations for the sub-basins separately, to increase accuracy and extent lead-time of forecasts to 5 days.

(e) Analyze the characteristics of the forecast error as a function of lead time, making a base for error calibration and forecasting evaluation.