IMPORTANCE OF RAINFALL MEASUREMENTS FOR THE FLOOD FORECASTING OF THE MEKONG RIVER BASIN

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ABSTRACT

This paper presents the results of an application of a grid based distributed hydrological model, BTOPMC (Block-wise use of TOPMODEL with Muskingum-Cunge method) to the Mekong River basin. The BTOPMC model was particularly developed for modelling large river basins based on the extended TOPMODEL concepts. The model has been tested in various regions of the world and proven to be robust for hydrological modelling and flood forecasting. Most of the model parameters are physically based; hence the number of parameters to be calibrated is few. Therefore the model is also suitable for modelling and analyzing the long term effects on the hydrology of large river basins due to human impacts and climatic variations. The model employs latest publicly available GIS/RS data as input and it is possible to obtain the output results at any location of the basin which is very important for integrated water resources management. In this study most of the input data to the model such as elevation data, land cover, soil map and texture, NDVI (normalized difference vegetation index), radiation, could cover, sunshine duration, diurnal temperature range, mean temperature, vapour pressure, wind speed etc. are obtained from publicly available data sets. The model results are verified and the performance is evaluated using observed data at different locations. Model results are compared with gauged precipitation data and satellite based precipitation (3B42 V6) data as input. The model capability for forecasting flood events at different locations is checked and found to be acceptable. However it was observed that the lack of gauged precipitation data in Cambodia, Laos and Vietnam tends to hinder the model performance. Nevertheless the model performance can be improved significantly with proper precipitation input. The overall results justify the physical soundness of the model; hence the BTOPMC model can be successfully applied for hydrologic modelling and river flow forecasting of the Mekong River basin.

Key words: BTOPMC, Mekong River, distributed hydrological model, grid-based

INTRODUCTION

It is commonly known fact that the lower Mekong River basin (LMB) is affected by severe floods almost in annual basis and encounters heavy social, environmental and economical losses. On the other hand more than half of the LMB residents who sustain their livelihood on fisheries and agriculture gain from floods. The fishery and agriculture practices in the LMB are specific and the people are practicing those methods for several decades (MRC, 2003). In this concern flooding is required for some extent, for the survival of livelihood and ecosystems of the LMB. Therefore only structural measures will not be a proper solution for the flooding in the LMB. One solution could be resettling all the people in the flood prone areas though it is difficult to change their livelihood. Therefore focus on non structural measures; particularly flood forecasting and establishing an effective early warning system in the LMB is essential. Usually the flood characteristic in the upstream areas of LMB is quick and flash flood type while it is slow and long in the downstream areas. Due to the flash nature of flooding, there is high number of fatalities in the upstream areas of the LMB compared to the downstream areas. Therefore short term flood forecasting can be more important in the upstream areas of the LMB while mid term to long term flow forecasting is essential in the whole LMB in order to reduce the economical and social losses. Mid term to long term flow forecasting is particularly beneficial to government officials to plan the transportation, food, evacuation and rescue activities, farmers to plan their cropping, flood rescue organizations (NGOs, voluntary) to prepare in advance, and water resources managers and policy makers to plan their future activities for the sustainable development of the Mekong River basin.

In this study, a grid based distributed hydrological model, BTOPMC (Block-wise use of TOPMODEL with Muskingum-Cunge method) is applied to the Mekong River basin for river flow modelling. The model results are verified and the performance is evaluated using observed data at different locations. Further the model capability of producing the flood event hydrographs is investigated.

THE BTOPMC MODEL

The BTOPMC (Block-wise use of TOPMODEL with Muskingum Cunge method) is the runoff generation module of the grid based distributed hydrological model YHyM developed at the University of Yamanashi (Japan). The BTOPMC is particularly developed for conducting hydrological simulations in large river basins (Takeuchi *et al.*, 1999; Ao *et al.*, 2003a, 2003b; Zhou *et al.*, 2003, 2006; Ishidaira *et al.*, 2000; Hapuarachchi *et al*., 2004a,b) based on TOPMODEL (Beven and Kirkby, 1979; Beven and Binley, 1992; Quinn *et al.*, 1995) concepts. In the TOPMODEL, the whole catchment is considered as a collection of many hill slopes where hill slope is the unit of water balance and there is no water exchange between hill slopes. The discharge is only generated at the hill slope outlet which is proportional to the inverse exponent of saturation deficit of the outlet grid cell. However considering a large basin, generally the grid cells are chosen large; hence there can be many hill slopes even in a single grid cell and not necessarily the recharged water of whole upstream area contribute to the outlet as base-flow. To replicate this natural phenomenon, BTOPMC introduces a new discharge density function by which the fraction of effective contribution area at any grid cell to the total upstream catchment area can be determined. By this modification, the topographical index is redefined in the BTOPMC with the effective contribution area. Yet all the basic mathematical equations are same as in the TOPMODEL and the topographical index plays the key role in runoff generation from topography dominant sloping areas. In the application of BTOPMC model, the whole basin is divided into some blocks (or sub-basins) within which groundwater is shared.

The YHyM is a comprehensive system which has been integrated with different modules such as a meso-scale precipitation module, a potential evaporation module, a snow accumulation/melt module, a runoff generation module, a sediment transport module, a water quality module, and a water use/control (dam operations) module. However users are free to select the modules depending on their modelling objectives. The core module, BTOPMC consists with four sub-models named topographic, parameter identification, runoff and flow routing. In this application, the runoff generation module integrated with snow accumulation/melt module and evapotranspiration module is used to simulate the Mekong River basin. The topographic features of the basin such as the basin boundary, flow accumulation and direction, channel slope and length, grid area etc. are extracted using the digital elevation map (DEM) by the topographic sub-module in the runoff generation module. Flow routing is carried out using the Muskingum-Cunge method (Cunge 1969; Ao *et al.*, 2003a, 2003b). The three dimensional physiographic heterogeneity of the basin is considered in the model mutually in terms of topography, soil types, geology, vegetation cover, and rooting depth. A detailed description about the model can be found in the literature stated in the first paragraph of this section.

INPUT DATA AND MODEL APPLICATION

Climate data used for this study cover the period 1992–2000 for precipitation, air temperature, relative humidity, cloud cover, wind velocity, and radiation (Table 1). Input data from 1992 to 1996 are used for calibrating the model and from 1997 to 2000 for validating the model. The whole basin is divided into nine sub-catchments (Figure 1) considering the natural sub-basins and the Köppen climate classification. The spatial resolution of grid cells is two minutes and the temporal resolution is 24 hours. In the calibration process, the observed discharge from eleven gauging stations and the precipitation measured at 171 gauging stations over the catchment are used (Figure 1). Spatial variation of precipitation is considered based on the Thiessen polygon method. Spatially distributed monthly average potential evapotranspiration is calculated using the Shuttleworth-Wallace method (Shuttleworth *et al.*, 1985, 1990, 1993; Zhou, *et al.*, 2004, 2005). However the human impacts on water resources (e.g. dam operations, irrigation and domestic water use etc.) are not considered due to the lack of observed data.

Table 1. Basic data used in the Mekong River application

Data type	***Source***	***Source Spatial Scale***	***Content and temporal scale***
NDVI	NOAA AVHRR	8 x 8 km	Monthly 1981-2000
Topographic	USGS-GTOPO30	30 x 30 second grids (~ 1 x 1 km)	Global data
Land cover	IGBP Version 2	30 x 30 second grids 1 x 1 km grids	Global data, April 1992 to March 1993
Soil	FAO	0.25 x 0.25 degree grids (~ 25 x 25 km)	Global data, 1995
Meteorological data to estimate PET	CRU TS 2.0	0.5 x 0.5 degree grids (~ 50 x 50 km)	Global, monthly data from 1901 to 2000
Precipitation	Uni. Yamanashi database from composite sources (Mekong River Commission and Chinese Academy of Sciences)	Point data	171 stations, daily data from 1992 to 2000 in the Mekong River Basin
Observed discharge		Point data	11 stations, daily data from 1992 to 2000 in the Mekong River Basin
Temperature		Point data	24 stations (upper Mekong River Basin), daily data from 1992 to 2000 in the Mekong River Basin
3B42 V6 precipitation data	NASA	0.25 x 0.25 degree	Global data - daily (and 3 hourly) grided data since 1998

In concern with the medium term and long term flood forecasting, gauged precipitation data are inadequate for accurate predictions. Though there are methods and models to predict the precipitation using gauged data, their accuracy seems suspicious due to the lack of gauged data and poor physical representation. However, the satellite (GIS/RS) based precipitation products and global climate model (GCM) results are becoming popular recently. To check the applicability of satellite based precipitation in the Mekong River basin, the 3B42 V6 (NASA, 2003) precipitation product (Table 1) is used in this study and compare the simulated results with gauged precipitation data. Two peak flow events are considered (1998.07.01~1998.10.31 and 2000.05.15~2000.10.31) and compare the simulation results with gauged precipitation input. In this application, the same parameter set calibrated using gauged precipitation data is used.

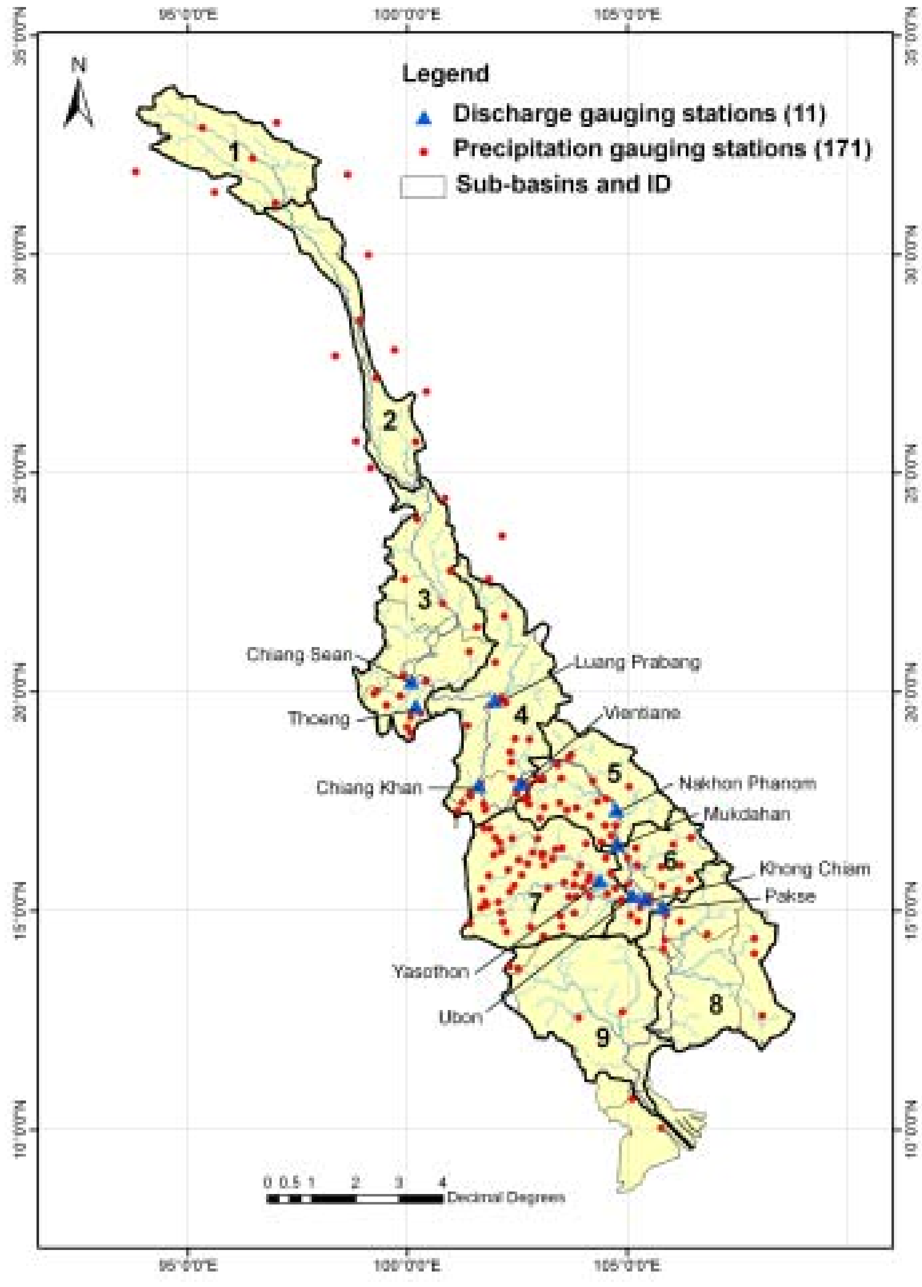

Figure 1. The Mekong River basin

RESULTS AND DISCUSSION

The model performance (using gauged precipitation data) of some selected stations for the calibration and validation periods is given in Table 2. Simulated and observed hydrographs (upstream of Pakse), variation of evapotranspiration, and soil moisture during the period 1997 to 2000 are shown in the Figure 2. The overall model performance in the validation period is good.

However it is noted that peak flow events are sometimes over estimated though low flows are simulated well enough (Figure 2). Further analysis on the distribution of precipitation over the basin reviled that the annual average precipitation of the stations at the border of Thailand and Laos (North-West, North-East and East of Thailand) is very high (1725~2625 mm) compared to the other data available locations of the basin. Unfortunately there are very few precipitation gauging stations in Laos, Cambodia and Vietnam that has continuous data from 1992 to 2000. As a result, the precipitation in Laos, Cambodia and Vietnam is approximated using the nearest stations (Thiessen polygon) in the Thailand border. Therefore the areas in Northern and Eastern Laos generate huge runoff together with the areas of Eastern Thailand at the same time. Certainly the annual precipitation in the areas of North Eastern and Eastern Laos is high. But in reality these precipitation events in Laos and Thailand do not happen simultaneously. Also in the upstream areas of Chiang Sean (in China), there are no adequate precipitation gauging stations present (only one station per 6360 km^2). It was noted that the over prediction of the river flow simulated by the BTOPMC during the wet season is mainly caused by the misinterpretation of the distribution of input precipitation due to lack of gauged precipitation. In fact the model accuracy (discharge and potential evaporation) of the internal points of some sub-basins (Thoeng and Ubon) have been checked and found to be well simulated. This assures that the model can achieve acceptable equal accuracy at each point in the basin, which is extremely important for the water resources management and planning.

Based on the simulated results by the BTOPMC, the annual average flow of the whole basin at the outlet of which China contributes about 16%, Myanmar 2%, Laos 35%, Thailand 18%, Cambodia 18% and Vietnam 11% is about 465000 MCM. The highest runoff coefficient (0.52, Table 3) is observed in the sub-basin 4 which covers the North East of Thailand and the middle part of Laos (Figure 1) and the lowest is in sub-basins 3 and 6 (0.34) which cover the areas of Northern Laos and Southern Thailand respectively. In addition, the highest volume of runoff per unit area which is basically depending on the precipitation is also observed in sub-basin 5 where the lowest is in sub-basin 1 (Table 3) which covers the Yunnan province and the Tibetan Plateau of China. The model simulated results of potential evapotranspiration, actual evapotranspiration, potential interception evaporation and actual interception evaporation is shown in Figure 2b. Also the annual variation of soil moisture pattern is shown in Figure 2c. The relationship between root zone moisture storage and the actual evapotranspiration is clearly noticeable in Figure 2 emphasizing the physical soundness of the model output. Based on the simulated results, about 59% of precipitation evaporates in the whole basin (Table 3). In addition, the model could replicate the natural variation of saturation deficit, root zone moisture storage, and unsaturated zone moisture storage (Figure 2c).

Further the accuracy of satellite based precipitation data, 3B42 V6 (Table 1) over the Mekong River basin was examined. The simulation results of two peak flow events (1998.07.01~1998.10.31 and 2000.05.15~2000.10.31) are shown in Figures 3 and 4. In both events, the simulation result with SP (3B42 V6 precipitation data) is better than the simulation results with GP (gauged precipitation). It is clearly seen that the amount of 3B42 V6 average precipitation is much lower than the spatially distributed average gauged precipitation (Table 4). This fact emphasizes the above mentioned reason; the over prediction of peak flow events simulated with gauged precipitation data are due to inadequate gauged data. However the satellite based precipitation data are not always accurate though it seems good in this application. Therefore adequate gauged precipitation data is very necessary for validating the models, checking the accuracy of satellite based precipitation products and flood forecasting in the Mekong River basin.

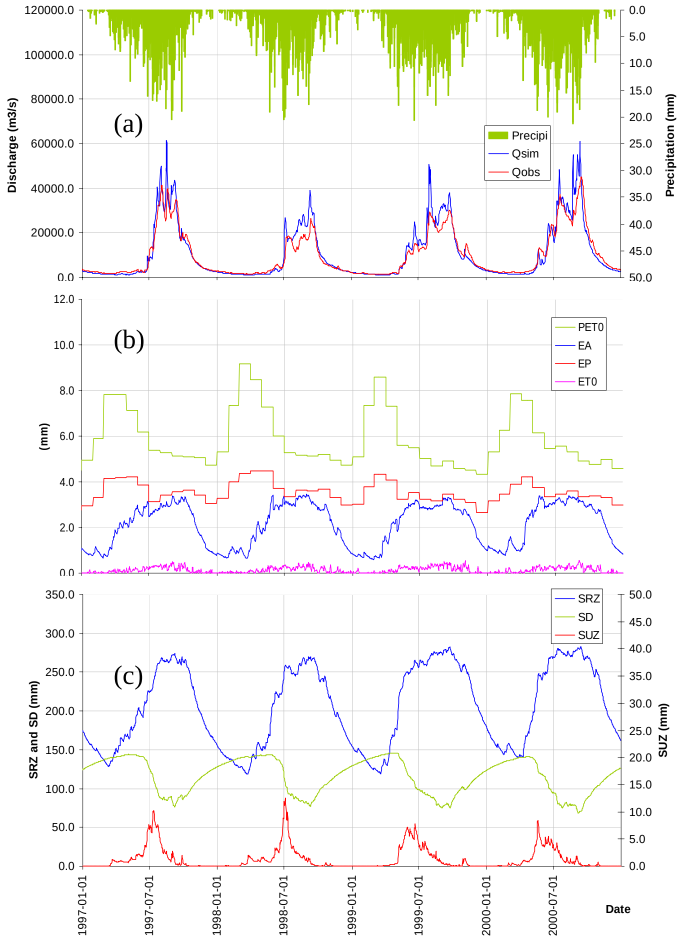

Figure 2. (a) Validation results of upstream of Pakse (Mekong River, 1997-2000) generated from the parameter set calibrated using data from 1992-1996. Qsim and Qobs are simulated and observed hydrographs respectively. (b) Average evapotranspiration calculated by the model. EP is potential evaporation, PET_0 is potential interception evaporation, ET_0 is actual interception evaporation and EA is actual evapotranspiration. (c) Variation of soil moisture over the upstream of Pakse. SD is the average saturation deficit, SRZ is the average root zone storage and SUZ is the average unsaturated zone storage.

Table 2. Overall model performance from 1992 to 2000 (gauged precipitation input)

Period	Station	Nash Coefficient (%)	Vol. Error (%)
Calibration 1992~1996	Chiang Sean	73.7	93.1
	Vientiane	79.3	101.2
	Luang Prabang	78.1	104.7
	Mukdahan	87.1	99.1
	Pakse	76.5	101.7
Validation 1992~1996	Chiang Sean	29.8	122.9
	Vientiane	35.2	134.9
	Luang Prabang	67.8	117.1
	Mukdahan	82.0	111.6
	Pakse	83.2	107.1

Note: Vol.Error=Qsim/Qobs*100

Table 3. Mekong River basin hydrological characteristics simulated by the BTOPMC (Data from 1992 to 2000)

Sub Basin ID	Area (km^2)	Area (%)	Precipitation (mm/year)			Actual Evaporation (mm/year)			Interception Evaporation (mm/year)			Runoff (mm/year)			Runoff Vol. (MCM/year)
			Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	
1	59936.8	7.7	402.5	641.3	531.1	268.0	329.1	303.9	6.8	10.1	8.6	141.5	292.6	216.3	12961.8 (0.22, 0.41)
2	51300.4	6.6	653.6	971.2	809.1	427.4	524.2	470.5	23.2	30.6	27.2	192.7	416.5	302.7	15530.1 (0.30, 0.37)
3	114504.3	14.7	1238.5	1782.2	1463.9	649.4	804.2	730.2	66.5	88.2	76.2	446.1	896.6	656.5	75176.0 (0.66, 0.45)
4	107402.2	13.8	1231.0	1796.1	1454.9	810.2	935.4	871.9	71.3	94.3	83.6	295.1	773.9	499.1	53605.0 (0.50, 0.34)
5	71421.6	9.2	1410.9	2485.9	1940.0	784.3	934.5	861.8	45.8	75.5	60.8	526.5	1527.2	1018.1	72716.2 (1.02, 0.52)
6	49501.3	6.3	1217.4	2077.7	1622.8	715.5	956.8	829.4	40.8	63.0	54.0	377.2	1113.8	738.9	36578.4 (0.74, 0.46)
7	105398.3	13.5	979.0	1635.4	1231.8	705.4	894.9	796.4	16.5	26.5	22.4	239.3	729.2	413.5	43582.0 (0.41, 0.34)
8	113953.7	14.6	1387.5	2210.1	1719.2	791.8	1057.0	931.7	54.8	96.4	72.8	307.3	1101.1	712.6	81202.1 (0.71, 0.41)
9	107069.3	13.7	1112.7	1676.1	1442.7	705.1	940.6	852.4	43.2	64.1	54.3	321.7	711.8	536.8	57473.7 (0.54, 0.37)

Note: The numbers in brackets in the Runoff Vol. column are the annual average runoff (MCM) per one square kilometre and the runoff coefficient of each sub-basin.

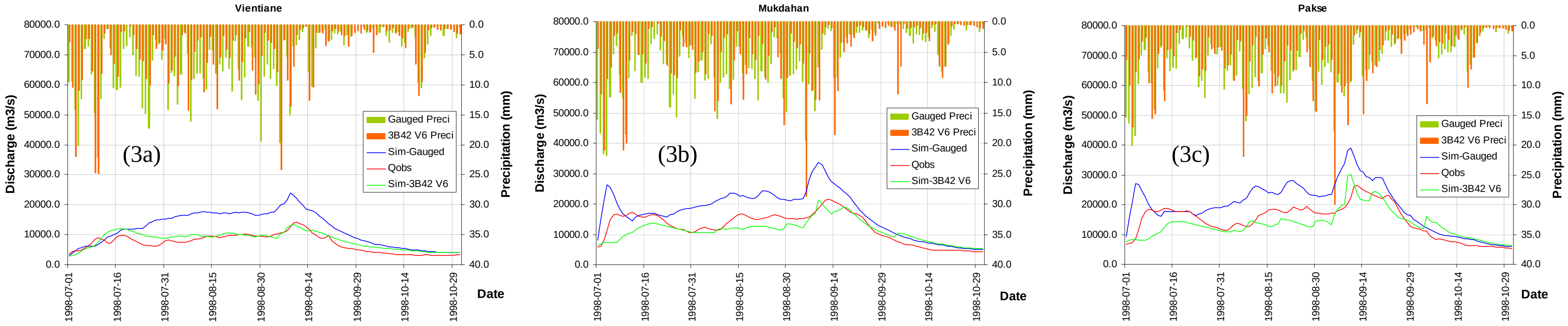

Figure 3. Simulation results of peak flow event from 1998.07.01 to 1998.10.31 using gauged precipitation data and 3B42 V6 satellite based precipitation data

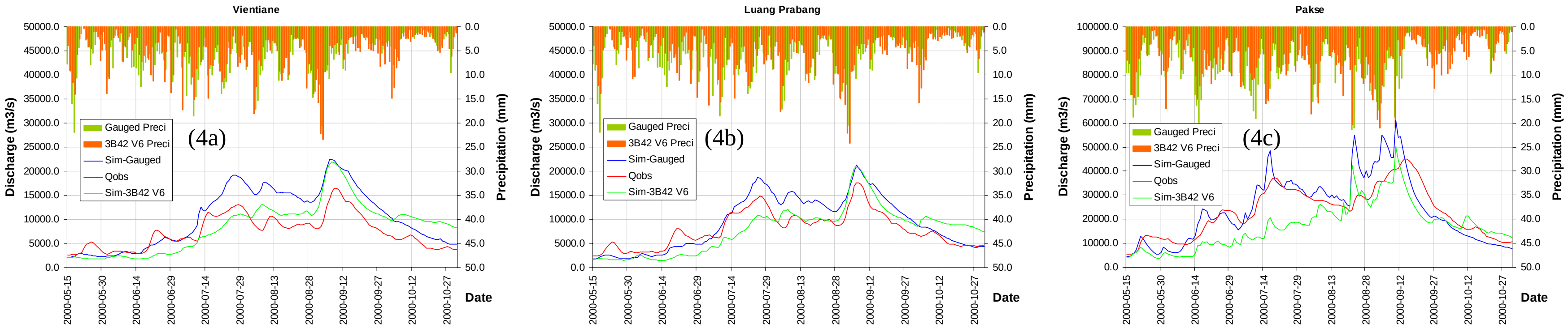

Figure 4. Simulation results of peak flow event from 2000.05.15 to 2000.10.31 using gauged precipitation data and 3B42 V6 satellite based precipitation data

Table 4. Model performance of the selected peak flow events at different locations (simulation results using gauged and 3B42 V6 precipitation data)

Period	Station	Ave. P (mm/d) (Upstream Area)	Nash Coefficient (%)	Vol. Error (%)
1998.07.01~1998.10.31	Vientiane	5.8 (4.7)	-295.7 (69.7)	165.4 (113.9)
	Mukdahan	6.2 (5.1)	-56.4 (63.0)	138.0 (90.7)
	Pakse	6.0 (5.2)	-34.2 (56.2)	132.6 (91.8)
2000.05.15~2000.10.31	Vientiane	6.0 (5.7)	-53.2 (0.6)	140.1 (114.6)
	Luang Prabang	6.0 (5.6)	42.9 (35.9)	117.8 (99.3)
	Pakse	7.3 (6.7)	57.5 (22.6)	104.0 (74.7)

Note: The figures in brackets are the simulation results using 3B42 V6 precipitation input. Vol.Error=Qsim/Qobs*100

CONCLUSIONS

The current study presents the results of an application of a grid based distributed hydrological model, BTOPMC (Block-wise use of TOPMODEL with Muskingum-Cunge method) to the Mekong River basin. The overall performance of the model is good. However it is observed that the accuracy of model results (with gauged precipitation data) is significantly diminished due to the lack of gauged precipitation data. Basically most of the peak flow events are over estimated though the low flow events are well simulated. In this application the Thiessen polygon method is used to approximate the spatially distributed precipitation. Here the area represented by one Thiessen polygon is too large so that when heavy rainfall occurs, the whole area produces much water than reality. Therefore it is essential to establish well maintained adequate number of rain gauges in the Mekong River basin. It is believed that the model performance can be improved significantly with proper precipitation input. Detail analysis on the seasonal variation of soil moisture, evapotranspiration, interception evaporation and runoff estimations indicate that the BTOPMC could replicate the natural hydrological responses of the basin well.

Further simulations conducted using satellite based precipitation; 3B42 V6 data show a better performance than the simulation results using gauged precipitation data. It is also noted that the average 3B42 V6 precipitation is lover than the spatially distributed average gauged precipitation. It could be the main reason for the better performance of the model using 3B42 V6 data. However satellite based precipitation data (3B42 V6) can be utilized where there is no adequate gauged rainfall data. In addition, further analysis is necessary to check the consistency of the accuracy of the 3B42 V6 data. Also it is worth to check the accuracy of different satellite based products and GCM output precipitation over the Mekong River basin.

One of the important advantages of using a grid based distributed hydrological model is that model results can be obtained at any location in the catchment. The distributed output (precipitation, evapotranspiration, discharge, soil moisture, snow melt/accumulation etc.) is multipurpose and not only useful for flood forecasting, but also for other hydrological applications such as, water quality modelling, sediment transport modelling, ground water modelling, water resources planning etc. On the other hand the parameters of distributed hydrological models like BTOPMC are physically sound and require less calibration. It is true that distributed hydrological models need more sophisticated input data than conceptual models. However, in the recent years most of these data are becoming publicly available easing the distributed hydrological model applications worldwide. Therefore in the case of Mekong River basin hydrological modelling and flood forecasting, physically based models (eg. BTOPMC) would be more appropriate than data driven models and conceptual models.

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