Characteristics of River Discharge Simulation Using NHRCM 5km Output by a Distributed Hydrologic Model in Thailand

AuliaFebianda Anwar Tinumbang[1], Kazuaki Yorozu[1], Yutaka Ichikawa[1] and YasutoTachikawa[1]

Abstract A river discharge estimation using a detailed projection of climate data and hydrologic model is important to make a basin-level assessment including climate change impact. Recently, a result of a first version of NHRCM 5km-spatial resolution is available for Thailand area, provided by JMA/MRI. The objective of this research is to evaluate river discharge simulated by using the NHRCM 5km output. Before the river discharge simulation is performed, a 20-years-mean NHRCM 5km rainfall was verified with APRHODITE observation data. It was found that NHRCM 5km rainfall was underestimated in the most of Thailand region. However, some area in the northern region, which almost corresponds to Bhumibol dam catchment, was overestimated, particularly in the rainy season. Hence, it showed a better accuracy. After that, the river discharge was simulated using NHRCM 5km output as forcing data by a coupled of a land surface model SiBUC and a flow routing model 1K-FRM. The simulated river discharge was evaluated with the observed inflow data. The 20-years-mean monthly river discharge showed an overestimated result during rainy season. This is consistent with the rainfall analysis, but only the total amount of rainfall could not explain the reason of overestimation. The analysis of heavy rainfall day (more than 20 mm/day) showed a large number of events during rainy season, which might be the reason of overestimated river discharge.

Keywords *NHRCM 5km, distributed hydrologic model, river discharge*

[1]Department of Civil and Earth ResourcesEngineering
Graduate school of Engineering, Kyoto University
Kyoto, Japan

Introduction

The impact of global warming for the future water resources is attracting widespread interests for scientists, policymakers, engineers, etc. In order to predict the changes and impact of global warming, particularly for regional level assessment, the output of high-resolution global climate model (GCM) is generally used. In the recent years, many researchers already developed regional climate model (RCM) with a fine grid-spacing. For example, Sasaki *et al*. [1] developed a Non-hydrostatic Regional Climate Model (NHRCM) with 5km spatial resolution. This model performance was tested in Japan applying multiple nesting method. The outer boundary was an output from Atmospheric General Circulation Model 20km and the inner boundary was created by NHRCM15km. It showed the annual mean surface temperature and precipitation had a good agreement with observed data. This fine resolution model also had a better reproducibility of the local features, such as it could reproduce a heavy precipitation events which could not be obtained from the results of GCM. In this study, we utilized the output of NHRCM 5km which was applied for Thailand region and conducted a river discharge simulation by using a distributed hydrologic model. The objective of this research is to evaluate the NHRCM 5km output data from river discharge view point.

Methodology

A. NHRCM 5km output data

The Non-hydrostatic Regional Climate Model (NHRCM) with 5km spatial-resolution is developed in Japan Meteorological Agency Meteorological Research Institute by Sasaki *et al*. [1]. The outer boundary condition for NHRCM 5km for Thailand region is obtained from the result of the NHRCM with 25km spatial resolution nested within present climate simulation using MRI-AGCM version 3.2H with grid spacing of 60km [2]. The product of NHRCM 5km consists of 20 years data for the current climate (1980 – 1999) and future climate (2080 – 2099) under SRES A1B. However, only the result of current climate data is used in this study. For each year, the simulation starts from April to May in the following year (in total 14 months). The first two months data are discarded because it is assumed as model spin up simulation.

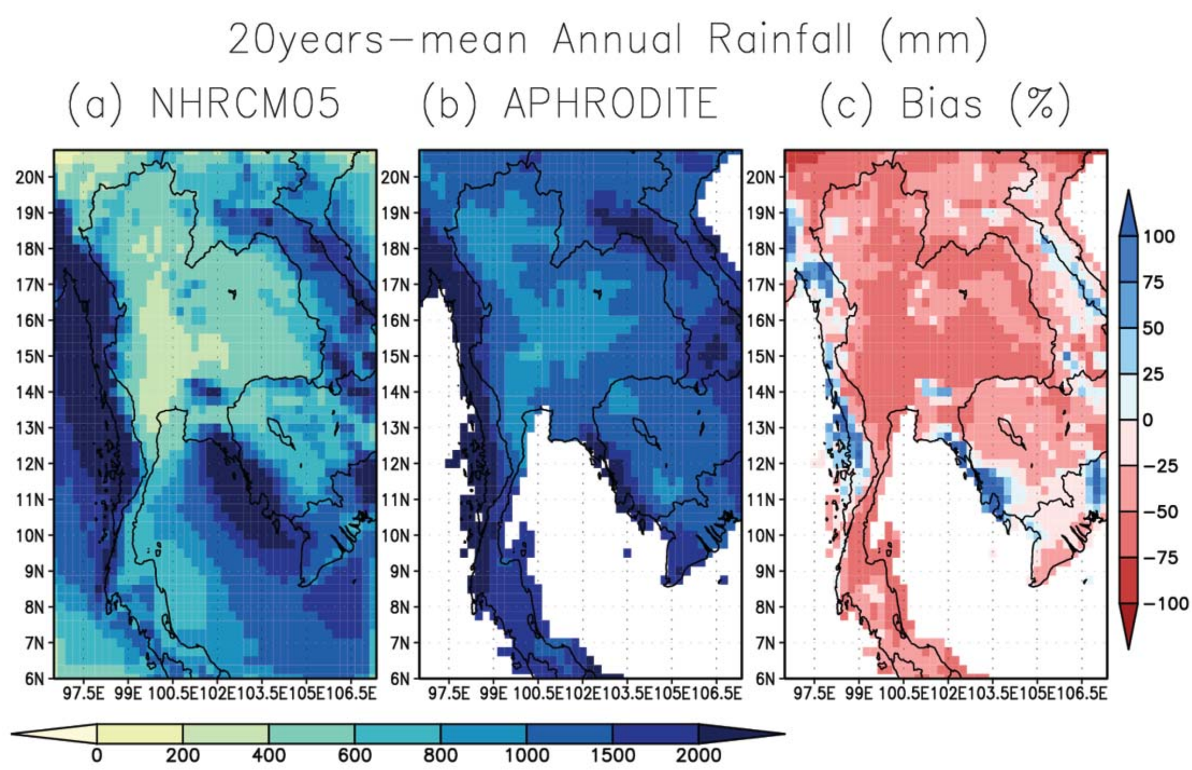

Fig. 1. 20-years-mean (1980 – 1999) annual rainfall (unit: mm) of (a) NHRCM 5km, (b) APHRODITE, and (c) bias (unit: %) of NHRCM 5km
rainfall relative to APHRODITE. Red color represents underestimated value of NHRCM 5km while blue color is overestimated result.

B. Observed rainfall and inflow discharge data

In this research, the observed rainfall data that is used for evaluation of NHRCM 5km rainfall output data is obtained from Asian Precipitation – Highly-Resolved Observation Data Integration towards Evaluation of water resources(APHRODITE) [3] with 0.25° spatial-resolution. In addition, the observed inflow data with daily records in Bhumibol Dam is acquired from the Electricity Generating Authority of Thailand (EGAT).

C. Distributed hydrologic model

A distributed hydrologic model, which is a coupled of land surface model SiBUC (Simple Biosphere including Urban Canopy) and a flow-routing model 1K-FRM [4] is used for conducting a river discharge simulation. SiBUC [5] is a land surface model which implements a mosaic scheme that can consider a mixture of land use, paddy field, and irrigation system in the model. 1K-FRM [6] is a distributed flow routing model, developed based on one-dimensional kinematic wave theory to conduct a river discharge simulation. The forcing data used for SiBUC model is obtained from NHRCM 5km output rainfall, surface pressure, humidity, short-wave radiation and long-wave radiation in downward direction, wind speed, and air temperature. The SiBUC model is used with a spatial resolution of 3 minutes and temporal resolution of 1-hour. 1K-FRM is utilized with 1-km spatial resolution and the output with 1-hour temporal resolution. The runoff output from SiBUC model is given to 1K-FRM to conduct a river discharge simulation. This model was tested for 2011 Thailand big flood and showed good performance for simulating river discharge [7].

Result and Discussion

A. Characteristics of NHRCM 5km rainfall output data

The reproducibility of NHRCM 5km rainfall for Thailand region was analyzed by comparing with APHRODITE observation data. First, the NHRCM 5km rainfall was aggregated from the original resolution to 0.25° resolution, which corresponds to APHRODITE grid spacing. The 20-years-mean annual rainfall was calculated for both NHRCM 5km and APHRODITE data.

The calculated result of 20-years-mean annual rainfall of NHRCM 5km and APRHODITE are shown in Figure 1(a) and 1(b), respectively. The result of NHRCM 5km rainfall shows that the amount of rainfall in the central part of Thailand is lower than northern part, and the southern part of Thailand is the highest. The APHRODITE observed rainfall also shows the similar trend. Therefore, it can be said that the NHRCM5km rainfall output could catch the spatial distribution of the observed rainfall.

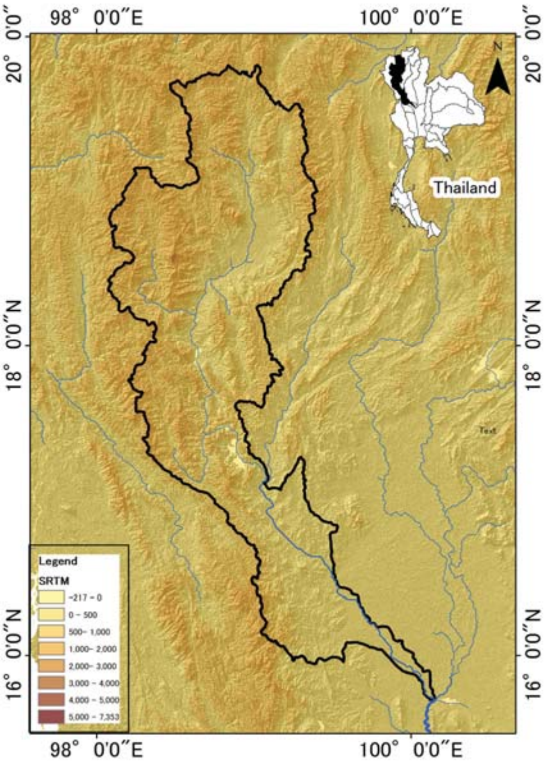

Fig. 2. Ping River Basin. Red circle shows Bhumibol Dam location.

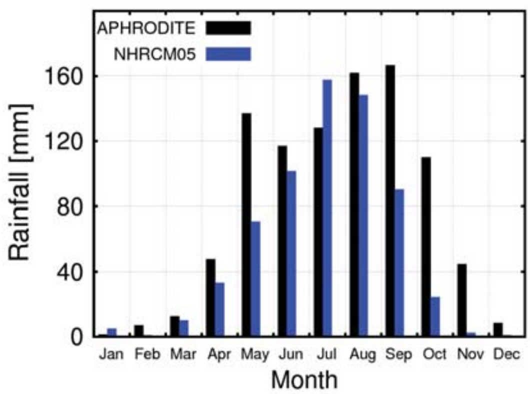

Fig. 3. 20-years-mean basin average rainfall in the Bhumibol Dam catchment. Black color shows APHRODITE rainfall and blue color shows NHRCM 5km rainfall.

However, the absolute value of NHRCM 5km is mostly underestimated in all over the region. This result is clearly shown from the calculation of 20-years-mean bias in the Fig. 1(c). The bias of NHRCM 5km is calculated in (1),

$$B = (R_n - R_a) / R_a \qquad (1)$$

with B is bias, R_n is NHRCM 5km rainfall, and R_a is APHRODITE rainfall. Although, it can be seen that there is an overestimation result in some region in the upper part (shown in black circle) and in the eastern part of Thailand. The bias in these regions is comparatively smaller than other regions. Based on this result, the upper region in Thailand, which almost corresponds to Bhumibol Dam catchment, was selected for river discharge simulation.

Bhumibol Dam catchment is located in 98–99.5°E, 17–19.9°S. It is located in the upper part of Ping River Basin (Fig. 2), with the area is about 26,400 km^2. The result of 20-years-mean basin average rainfall for NHRCM 5km and APHRODITE in the upper part of Bhumibol Dam catchment is shown in Fig. 3. From this result, the total amount of rainfall is overall underestimated and thatin June, July, and August (JJA) shows a better accuracy compared to other months. And then, the NHRCM 5km rainfall produces the peak of rainy season on July, while the observed peak rainy season is on September.

B. Characteristics of NHRCM 5km river discharge

To conduct a river discharge simulation, first, the forcing data from the NHRCM 5km output was aggregated from the original grid spacing into 0.05°(or 3-minute resolution) grid size. Then, the forcing data was given into SiBUC model to calculate the runoff. After that, the river discharge was calculated by 1K-FRM using the runoff output.

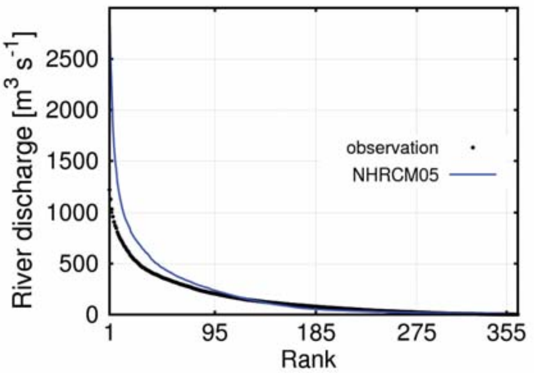

Fig. 4. Flow Duration Curve of 20-years-mean river discharge. Black dots show the observed inflow in Bhumibol Dam and blue line shows the simulated result using NHRCM 5km forcing data.

The simulated river discharge is obtained for daily discharge for 20-years period. The daily river discharge for a year is sorted from the highest to the lowest to draw a Flow Duration Curve (FDC). In total, there are 20-FDCs for river discharge simulation during 1980 – 1999. Then, 20-years-mean FDC was calculated for both simulated river discharge and the observed inflow in Bhumibol Dam. The result isshown in Fig. 4. The first quartile (95th day) represents a high-flow discharge, 2nd quartile (185th day) is a normal-flow discharge, 3rd quartile (275th day) is a low-flow discharge, and 4th quartile is a drought-flow discharge.

The high-flow discharge is about 15% overestimated by NHRCM 5km, while the normal-flow, low-flow and drought-flow, the simulated discharge is well compared with the observed data.

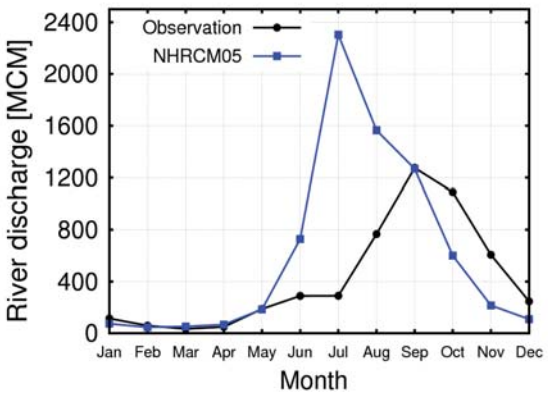

Fig. 5. 20-years-mean monthly river discharge. Black color shows the observed inflow in Bhumibol Dam and blue color shows the simulated result using NHRCM 5km forcing data.

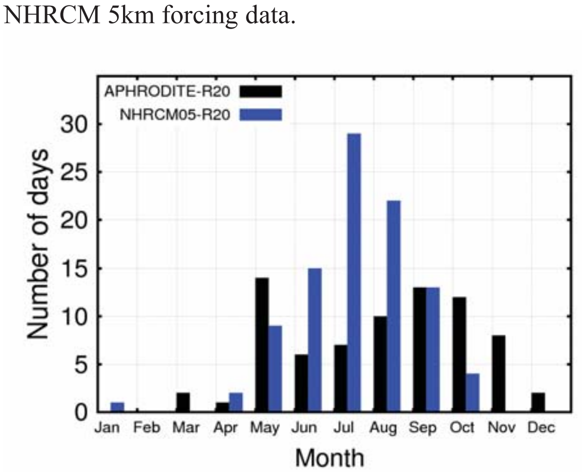

Fig. 6. Number of heavy rainfall days (more than 20 mm day-1) during 1980 - 1999. Black color shows APHRODITE rainfall and blue color shows NHRCM 5km rainfall.

Fig. 5 shows the result of 20-years-mean monthly river discharge of NHRCM 5km and observed inflow. The peak discharge simulated from NHRCM 5km was produced much earlier compared to the observed inflow. This might be explained by earlier peak of the basin average of NHRCM 5km rainfall. The simulated monthly river discharge is particularly overestimated during JJA period. Therefore, only the total monthly rainfall could not explain the reason of overestimated simulated river discharge.

The number of heavy rainfall days (more than 20 mm day^{-1}) during 1980 – 1999 is shown in Fig. 6. In this result, the short-term heavy rainfall of NHRCM 5km shows a larger number of events compared to the observed APHRODITE rainfall, particularly in JJA period. From this result, it is thought that more frequent short-term heavy rainfall events from NHRCM 5km output might be one of the causes of the overestimated river discharge of NHRCM 5km. However, the hydrological model itself might also have some influence on this overestimated result. Therefore, the parameter settings or the model structure itself should also be examined to see its effect on the river discharge estimation.

Conclusions

In this research, the first version of NHRCM 5km output data was evaluated. Before the river discharge is simulated, the 20-years-mean NHRCM 5km rainfall was compared with APRHRODITE data, as a reference data. The bias calculation shows that most of NHRCM 5km rainfall was underestimated in most of Thailand region, except in Bhumibol dam catchment. The basin average rainfall for upper part of Bhumibol Dam catchment showed a comparatively smaller bias during JJA period compared to other months. While the river discharge simulation showed an overestimated result particularly during JJA period. The NHRCM 5km rainfall had more frequent events of heavy rainfall days (more than 20mm/day) which might be one of the causes to produce extreme simulated flood discharge.

Acknowledgment

We would like to express our deep gratitude for Dr. Patama who provided and simulated the NHRCM 5km data used in this research under supervision of Dr. Hidetaka Sasaki from JMA/MRI. This study has been supported by TOUGOU Program (Integrated Climate Model Advanced Research Program) 2017-2021 Theme-C supported by MEXT.

References

[1] H. Sasaki, A. Murata, M. Hanafusa, M. Oh'izumi, and K. Kurihara, "Reproducibility of present climate in a non-hydrostatic regional climate model nested within an atmosphere general circulation model," SOLA, vol. 7, pp.173-176, 2011.

[2] R. Mizuta, H. Yoshimura, H. Murakami, M. Msatsueda, H. Endo, T. Ose, K. Kamiguchi, M. Hosaka, M. Sugi, S. Yukimoto, S. Kusunoki, and A. Kitoh, "Climate simulations using MRI-AGCM with 20-km grid," J. Meteor. Soc. Jpn., vol. 90A, pp. 235-260, 2012.

[3] A. Yatagai, K. Kamiguchi, O. Arakawa, A. Hamada, N. Yasutomi, and A. Kitoh, "APHRODITE: Constructing a Long-term Daily Gridded Precipitation Dataset for Asia based on a Dense Network of Rain Gauges," Bull. Am. Meteorol. Soc.,vol, 93, pp. 1401-1415, 2012.

[4] K. Yorozu, and Y. Tachikawa, "The effect on river discharge estimation by considering an interaction between land surface process and river

routing process," Proc. IAHS, vol. 369, pp. 81-86, 2015.

[5] K. Tanaka, "Development of the new land surface scheme SiBUC commonly applicable to basin water management and numerical weather prediction model," PhD thesis, Kyoto University, Japan, 2005.

[6] Hydrology and Water Resources Research Laboratory, "1K-FRM/1K-DHM," http://hywr.kuciv.kyoto-u.ac.jp/products/1K-DHM/1K-DHM. html, last access 2018/10/27.

[7] K. Yorozu, N. Kurosaki, Y. Ichikawa, S. Kim, and Y. Tachikawa, "Astudy on long-term river discharge data generationbydistributed hydrologicmodelandrecombinationatmosphericdata," Journal of Japan Society of Civil Engineers, Ser. B1 (Hydraulic Engineering), vol.74, pp. I_127-I_132, 2018 (in Japanese).