A STUDY ON BIAS CORRECTION METHOD FOR RUNOFF GENERATION DATA BASED ON REFERENCE DATA CREATED BY LAND SURFACE MODEL

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Abstract*—Climate change has a great influence on hydrologiccycle and water resources. General Circulation Model (GCM) is generally used for assessing the impact on natural disasters such as floods and draughts due to climate change. To improve the reliability of future climate prediction by GCM, it is effective to correct the bias of that output. From the viewpoint of water management, bias correction for runoff generation data is required. In this study, bias correction was performed for the MRI-AGCM3.2S 3-hourly runoff generation data from 1982 to 2001, by applying Quantile-Quantile Mapping (QQM) method. The target area was Oyodo river basin in Kyushu Island, Japan. Due to an unavailability of runoff generation observation, land surface model SiBUC was utilized for creating reference runoff generation data by using meteorological data such as APHRO_JP precipitation data and JRA-55 reanalysis data. The effect of the bias correction was evaluated by calculating the river discharge utilizing river routing model, 1K-FRM. As a result, the simulated river discharge using bias-corrected runoff generation data showed an improvement compared with that using the original one. However, it was found thatthe simulated river discharge using bias-corrected runoff was overestimated compared with that using reference data especially on high flood events. Therefore, QQM method was independently applied for high runoff generation data and low data by setting threshold values for reference data and original data, respectively. The overestimation result was improved by this advanced approach.

***Keywords*—Climate change, Bias correction, Runoff generation data**

I. INTRODUCTION

Climate change has a great influence on hydrologic cycle and water resources. General Circulation Model (GCM) is generally used for assessing the impact on natural disasters such as floods and draughts due to climate change.To improve the reliability of future climate prediction by GCM, it is effective to correct the bias of that output.However, compared with bias correction for precipitation and temperature, there are few studies on bias correction related to river discharge.

Bias correction method for the MRI-AGCM3.2S 3-hourly runoff generation data using reference data created by land surface model SiBUC was initially proposed by Duong[1]. Bias correctionto runoff generation data showed an improvement in river discharge simulations. However,in bias correction of runoff generation data, Duong pointed out further works needed to be done, for example, considering their temporal distribution pattern.

Based on these backgrounds, the purpose of this study is to revise bias correction method for runoff generation data and simulate river discharge more precisely.In this study, bias correction was performed for the MRI-AGCM3.2S 3-hourly runoff generation by followingDuong’s study and the effect of bias correction was evaluated by simulating river discharge utilizing flow routing model 1K-FRM.

II. METHODOLOGY

Observational datasets are needed to apply bias correction method to GCM runoff generation data. However, runoff generation observation cannot be available. Instead,in this study,reference data is created by land surface modeland it is used as pseudo-observation. In addition, the effect of bias correction is not evaluated with runoff itself but with simulated river discharge by corrected runoff. Based on these matters, the flow of this study is shown in Fig. 1.The MRI-AGCM 3.2S 3-hourly runoff generation data is used as GCM runoff generation data. Quantile-Quantile Mapping (QQM) method was selected as the bias correction method by following Duong’s study.Then, the river discharges are simulated by using original GCM runoff generation data, reference data from land surface model SiBUC and bias-corrected runoff generation data. Duration curves are drawn by 3 kinds of river discharge.The simulated river discharge using bias-corrected runoff generation data is validated referred to that using reference data.

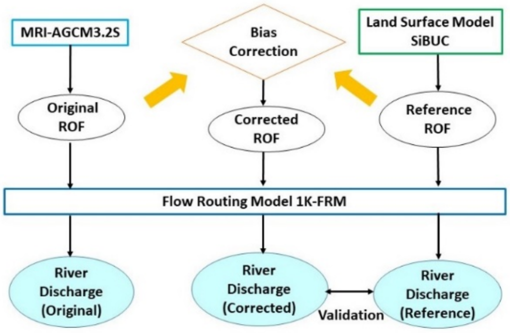

Fig. 1 The flow of this study

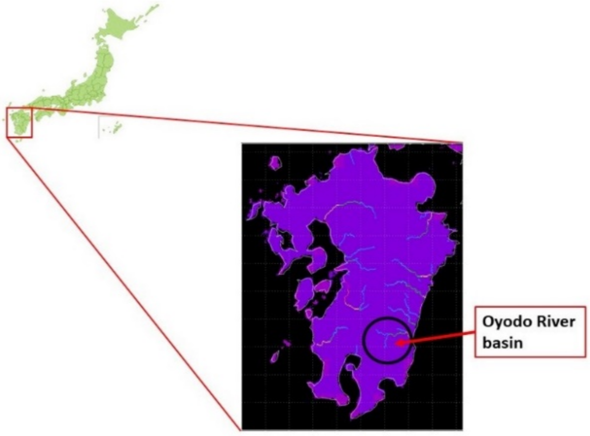

Fig. 2 The study area- Oyodo River basin

III. SIMULATION DESIGN

A. Study Area

The target area in this study is Oyodo river basin in Kyushu Island, Japan. Fig. 2 shows the location of Oyodo river basin.Oyodo River is a first-class river flowing from Kagoshima prefecture to Miyazaki prefecture. The total length of Oyodo River is about 107 km and the catchment area is about 2230 km^2.

B. Flow Routing Model 1K-FRM

1K-FRM is a flow routing model based on kinematic wave theory. It was developed by Hydrology and Water Resources Research Laboratory of Kyoto University[2].1K-FRM calculates river discharges with each unit, slope unit and river unit.Different Manning roughness coefficients are set in each unit.The kinematic wave model is applied to all units and runoff is routed according to the flow direction information.The spatial resolution of this model is 30 seconds (1-km).The basic form of the kinematic wave flow equation is:

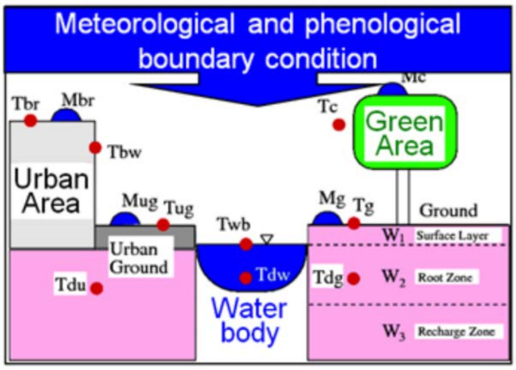

Fig. 3 Schematic image of SiBUC model

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_{\mathrm{L}}(x,t) \tag{1}$$

$$Q = \alpha A^m, \alpha = \frac{\sqrt{i_0}}{n}\left(\frac{1}{B}\right)^{m-1}, m = \frac{5}{3} \tag{2}$$

where, $A(x,t)$ is the flow cross-sectional area, $Q(x,t)$ is the flow discharge, $q_{\mathrm{L}}(x,t)$ is the lateral inflow per unit length, i_0 is the slope, n is the Manning roughness coefficient, and B is the width of the flow. Equation (1) is the continuity equation. It is derived from the principle of mass conservation within a control volume. Equation (2) is derived from Manning's laws which are flow resistance laws of open channel uniform flow.

C. Land Surface Model SiBUC

The land surface model Simple Biosphere including Urban Canopy was developed by Tanaka [3] in Disaster Prevention Research Institute in Kyoto University. SiBUC model uses mosaic approach, which couples independently each land-use patch of the grid element to the atmosphere, to incorporate all kind of land-use to land surface scheme.

In SiBUC model, each land surface grid is classified into three land use categories, urban area, water body, and green area.Fig. 3 shows the schematic image of surface elements in SiBUC model.

The fractions of these land-use categories are fixed for each grid cell in SiBUC model. And surface fluxes are obtained by averaging the surface fluxes over each land-use weighted by its fractional area.In this study, the spatial resolution is the same as that of the MRI-AGCM 3.2S (20-km).

Fig. 4 shows the schematic image of water budget in the green area model of SiBUC and Table. 1 shows the variables used in the model. Soil is expressed by three layers and the governing equations for the three soil moistures are based on Richards' equation with forcing terms of evapotranspiration (E_s,$E_{dc,1}$,$E_{dc,2}$) and infiltration (P_1). Equation (3) to (5) is the governing equations to soil moisture of three layers.

$$\frac{\mathrm{d}W_1}{\mathrm{dt}} = \frac{1}{\theta_s D_1}\left[P_1 - Q_{1,2} - \frac{1}{\rho_w}\left(E_s + E_{dc,1}\right)\right] \tag{3}$$

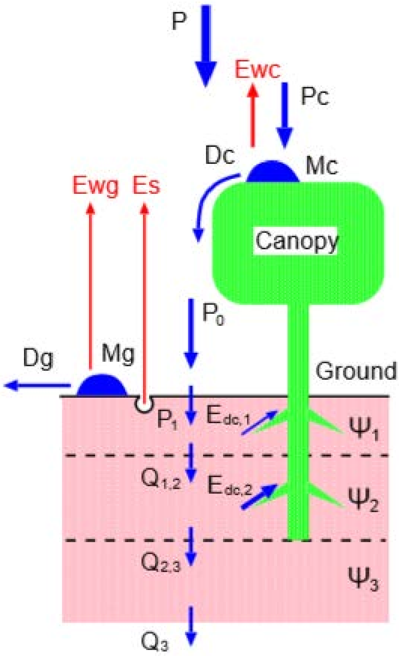

Fig. 4 Schematic image of water budget in the green area model of SiBUC

$$\frac{dW_2}{dt} = \frac{1}{\theta_s D_2}\left[Q_{1,2} - Q_{2,3} - \frac{E_{dc,2}}{\rho_w}\right] \quad (4)$$

$$\frac{dW_3}{dt} = \frac{1}{\theta_s D_3}\left[Q_{2,3} - Q_3\right] \quad (5)$$

In this model, after precipitation reaches the ground, some of the water infiltrates through the soil following Darcy's law and the rest becomes surface runoff. Sub-surface runoff is calculated from the third layer of the soil. Runoff generation is the total sum of surface runoff and sub-surface runoff. It is used as input into flow routing model 1K-FRM.

D. Data

1) GCM Runoff Generation Data

GCM data used for this study is 3-hourly runoff generation data from the super-high resolution (20-km) atmospheric general circulation model MRI-AGCM3.2S. It is one of the latest atmospheric GCMs based on a model jointly developed by the Japan Meteorological Agency (JMA) and the Meteorological Research Institute (MRI) [4]. The MRI-AGCM provides data for three climate experiments: present climate experiment (1979-2008), near future climate experiment (2015-2044), and future climate experiment (2075-2104). The data used for future projection were based on the Special Report on Emissions Scenarios (SRES) A1B scenario. In this study, only the output of present climate experiment is used.

2) Meteorological Data

The meteorological data to force land surface model SiBUC includes seven components: precipitation, air temperature, specific humidity, surface pressure, wind speed, long wave radiation and short wave radiation.

In this study, the product of the Japanese 55-year reanalysis (JRA-55) project was utilized to use as inputs to SiBUC. The Japanese 55-year Reanalysis (JRA-55) is the second reanalysis project conducted by Japan Meteorological Agency (JMA) using more sophisticated Data Assimilation system based on the operational system as of December 2009, and newly prepared past observations [5].

Symbol	Definition	Units
W_i	soil moisture stores	-
D_i	root depth	M
θ_s	soil water content at saturation	-
ρ_w	water density	kg m^{-3}
E_s	direct evaporation of water from the surface soil layer	kg m^{-2} s^{-1}
$E_{dc,i}$	abstraction of soil moisture by transpiration	kg m^{-2} s^{-1}
P_1	infiltration into the upper soil layer	ms^{-1}
$Q_{i,i+1}$	flow between soil layer	ms^{-1}
Q_3	gravitational drainage from recharge layer	ms^{-1}

Table. 1 List of variables used in the green area model of SiBUC

However, JRA-55 precipitation and surface radiation data are forecast data, not reanalysis data. Therefore, other data sources are considered to use as substitution.

For precipitation data, the Asian Precipitation - Highly-Resolved Observational Data Integration Towards. Evaluation of Water Resources (APHRODITE's Water Resources) project was selected. APHRODITE's Water Resources project was conducted by the Research Institute for Human and Nature (RIHN) and the Meteorological Research Institute (MRI/JMA) from 2006 to develop state-of-the-art daily precipitation datasets on high-resolution grids covering the whole of Asia [6]. In this study, precipitation data to force land surface model for Kyushu area was extracted from the APHRO_JP V1207 [7] dataset with spatial resolution of 0.05 degree. Temporal resolution of APHRO_JP precipitation data is daily.

And the Surface Radiation Budget (SRB) dataset was used as long wave radiation and short wave radiation.Surface Radiation budget (SRB) dataset is produced and achieved by the NASA Langley Research Center Atmospheric Sciences Data Center (NASA/GEWEX). It is produced on a 1 degree x 1 degree global grid using satellite-derived cloud parameters and ozone fields, reanalysis meteorology, and a few other ancillary datasets. The SRB dataset contains 3-hourly long wave and short wave radiative fluxes.

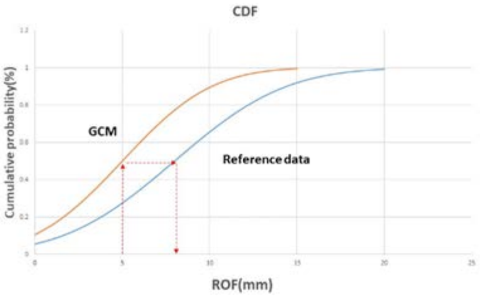

Fig. 5 Schematic representation of QQM method

IV. BIAS CORRECTION FOR GCM RUNOFF GENERATION DATA

A. Application of Quantile-Quantile Mapping(QQM) Method

To correct biases in GCM runoff generation data, quantile-quantile mapping (QQM) bias correction method was selected. The bias correction based on QQM method has been widely used to correct outputs of climate models.Teutschbein and Seibert [8]compared the various bias correction methods and showed that the QQM method is more effective than the other methods.

In QQM method, GCM outputs and observations are sorted to construct cumulative distribution functions (CDFs). These CDFs are used to define the quantiles of simulated values and observations. Then, GCM simulated values are substituted with those of the identical quantile from the observational dataset. Fig.5 shows the schematic representation of QQM method.

In this study, runoff data simulated by SiBUC model were used as reference data to correct the MRI-AGCM3.2S runoff generation data. The effect of bias correction is evaluated by simulating river discharge using flow routing model 1K-FRM.

B. Results

Fig.6-a shows the duration curves of 20 years from 1982 to 2001 at Kashiwada station in Oyodo River basin. The red line indicatesthe simulated river discharge using original GCM runoff generation data, the blue line indicates that using reference data and the black line indicates the observational river discharge. It can be seen that the simulated river discharge using reference data is closer to the observation in the high peak discharge(larger than 100 m^{3}s^{-1}) compared with that using original GCM outputs. Therefore, land surface model SiBUC is considered to reproduce runoff better than the MRI-AGCM3.2S. In addition, theriver discharge simulated using bias-corrected runoff generation data showed an improvement compared with that simulated using original one. However, shown in Fig.6-b whose horizontal axis is logarithm, there were also a problem that the river discharge simulated using bias-corrected runoff generation was overestimated in high peak discharge as compared with that using reference data.

Fig. 7 shows a histogram of two kinds of runoff generation data, GCM outputs and reference data, in July for 20 years. The red bar indicates the result of GCM and the blue one indicates that of reference data. Shown in Fig. 7, the frequency of high runoff amount is higher in reference data than that in GCM outputs.Therefore, the runoff of reference data which is assumed to be dominated by surface runoff can be substituted with the runoff of original GCM outputs which is assumed to be dominated by sub-surface runoff. Fig. 8 shows the time series of runoff generation data in original GCM outputs and bias-corrected data. The red line indicates the result of original GCM outputs and the purple one indicates that of bias-corrected data.Both lines show high runoff value on July 8th, but relatively large value can be seen continuously in bias-corrected data after the flooding event while relatively low value can be seen in original GCM data after that. As shown in Fig. 8, relatively large values that contribute to flooding may appear continuously. It is occurred due to the difference of frequency distributions between original GCM data and reference data.This is considered to be one of the causes of overestimation in simulating river discharge.

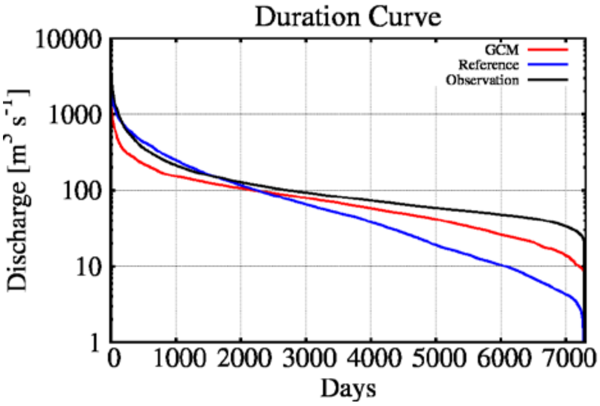

Fig. 6-a Duration curves of 20 years at Kashiwada, Oyodo River basin(vertical axis islogarithm)

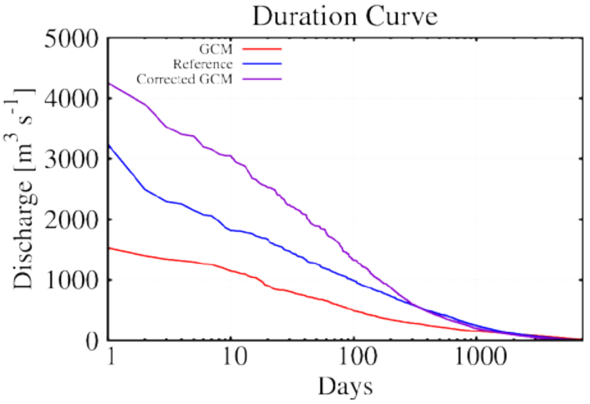

Fig. 6-b Duration Curves of 20 years at Kashiwada, Oyodo River basin (horizontal axis is logarithm)

V. REVISION OF BIAS CORRECTION

A. *Grouping QQM method*

In order to improve the overestimation, a revision of bias correction was considered to be effective. The purpose of this revision is to reduce the frequency of high runoff generation data that contribute to flooding after bias correction and to improve the overestimation of river discharge.

The frequency of high runoff amount is higher in reference data than that in GCM outputs and after bias correction, relatively large values that contribute to flooding may appear continuously and it may cause overestimation in simulating river discharge. Therefore, it is considered to be needed to reduce the frequency of high runoff amount in bias-corrected runoff generation data for improving overestimation results. In consideration of the difference in frequency distribution in the two kinds of data, a threshold is set for each data and divides each data into high runoff generation data contributing toflooding and low runoff generation data not contributing to flooding.Threshold values are set for reference data and original data, respectively.In this study, the number of datawhich is larger than the threshold value in original datasets is set to be smaller than the number which is larger than the threshold value in reference datasets. As shown in Table. 2, twokinds of threshold patterns were applied in this study.QQM method was applied for high runoff generation data and low data independently. This method is called grouping QQM method.

B. *Results*

Fig.9 shows time series of 4 kinds of runoff generation data. The red line indicates the result of original GCM outputs, the purple one indicates that of simple QQM method, light blue one indicates that of pattern1, pink one indicates that of pattern2. By applying grouping QQM method, itcan be possible to reduce the amount of runoff generation data at the time of flooding, compared with simple QQM method.

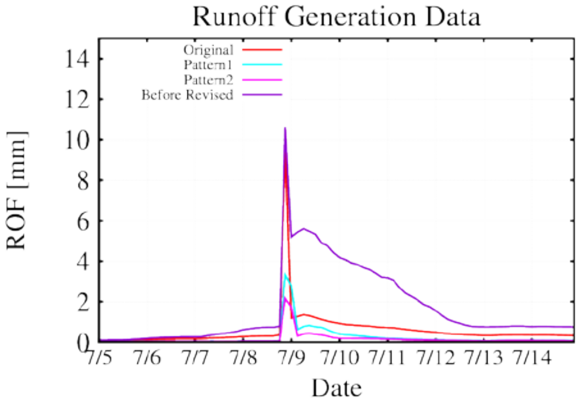

Fig. 9 The effect of bias correction on runoff generation data

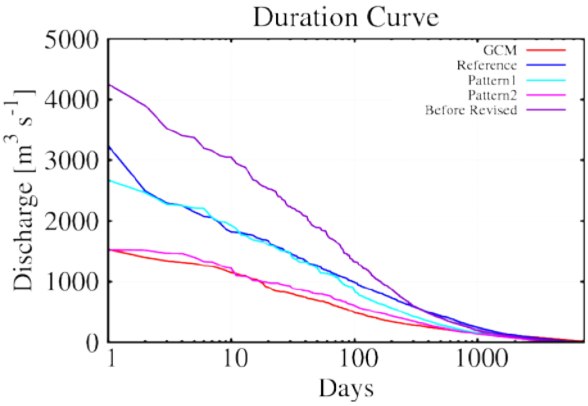

Fig. 10 The effect of bias correction on river discharge

	Threshold value of original GCM outputs	Threshold value of reference data
Pattern1	Applying 5% value from largest on each month of each cell	Applying 10% value from largest on each month of each cell
Pattern2	Applying 2.5% value from largest on each month of each cell	Applying 10% value from largest on each month of each cell

Table. 2 Pattern of threshold value

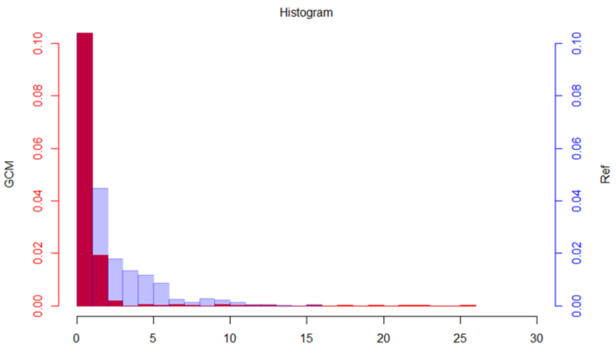

Fig. 7 Histogram of runoff generation data in GCM outputs and reference data in July for 20 years

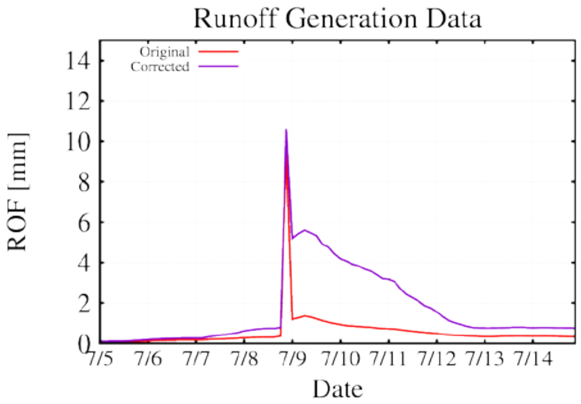

Fig. 8 Time series of runoff generation data in original GCM outputs and bias-corrected data

Fig. 10 shows the duration curvesof 20 years from 1982 to 2001 at Kashiwada station in Oyodo River basin in 5 kinds of simulated river discharge.In addition to the colors of Fig. 9, the blue line indicates the result of reference data. In the high peak discharge, all the two patterns could reduce river dischargecompared with before revision. In Pattern 1, the results that are closer to reference data were obtained. Therefore, they showed an improvement in simulating river discharge by applying grouping QQM method.

VI. CONCLUSION

Bias correction was performed for the MRI-AGCM3.2S 3-hourly runoff generation based on reference data created by land surface model SiBUC and the effect of bias correction was evaluated by simulating river discharge utilizing flow routing model 1K-FRM. Bias correction applying the QQM method is effective by creating reference data of runoff generation data. However, it was found that the river discharge simulated using bias-corrected runoff was overestimated compared with that using reference data especially on high flood events. Therefore, the QQM method was revised by setting threshold values for runoff generation data. By this revision, overestimation of river discharge isimproved and river discharge is simulated more precisely.

As the improvement of the land surface model progresses and the reproducibility of reference data improves, it can be expected that more reliable bias correction is performed.

REFERENCES

[1] D. D. Toan, “Assessment of river discharge changes in the Indochina Peninsula region under a changing climate,” Doctoral dissertation, Kyoto University, 2014.

[2] Hydrology and water resources laboratory, Kyoto University,http://hywr.kuciv.kyoto-u.ac.jp/products/1K-DHM/1K-DHM.html,access 2018/10/24.

[3] K. Tanaka, “Development of the new land surface scheme SiBUC commonly applicapble to basin water management and numerical weather prediction model,” Doctoral dissertation, Kyoto University, 2005.

[4] R. Mizuta, H. Yoshimura, H. Murakami, M. Matsueda, H. Endo,T. Ose, K. Kamiguchi, M. Hosaka, M. Sugi, S. Yukimoto, S.Kusunoki, and A. Kitoh, “Climate Simulations Using MRI-AGCM3.2 with 20-km Grid,”Journal of the Meteorological Society of Japan, vol.90A, pp.233-258, 2012.

[5] S. Kobayashi, Y. Ota, Y. Harada, A. Ebita, M. Moriya, H. Onoda, K. Onogi, H. Kamahori, C. Kobayashi, H. Endo, K. Miyaoka, and K. Takahashi, “The JRA-55 Reanalysis: General specifications and basic characteristics,” Journal of the Meteorological Society of Japan, vol. 93, pp. 5-48, 2015.

[6] 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 Gauge,” Bulletin of American Meteorological Society, vol. 93, pp. 1401-1415, 2012.

[7] K. Kamiguchi, O. Arakawa, A. Kitoh, A. Yatagai, A. Hamada and N. Yasutomi,“Development of APHRO_JP, the first Japanese high-resolution daily precipitation product for more than 100 years,”Hydrological Research Letters, vol. 4, pp. 60-64, 2010.

[8] C. Teutschbein, and J. Seibert, “Bias correction of regional climate model simulations forhydrological climate-change impact studies: Review and evaluation of different methods,” Journal of Hydrology, vol. 456-457, pp.12-29,2012.