Statistical analysis of river discharge projected using the MRI-AGCM3.2S dataset in Indochina Peninsula

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Abstract To evaluate the impacts of climate change on river discharge in the Indochina Peninsula region, a distributed flow routing model (1K-FRM) with kinematic wave flow approximation was applied. Generated runoff data from the MRI-AGCM3.2S dataset corresponding to the present climate experiment (1979–2008), the near future climate experiment (2015–2044) and the future climate experiment (2075–2104) were fed into the flow routing model 1K-FRM to project river discharge in the Indochina Peninsula. The MRI-AGCM3.2S is the latest version of the super-high-resolution atmospheric general circulation model (AGCM) with a horizontal grid size of about 20 km, which was jointly developed by the Meteorological Research Institute (MRI) and the Japan Meteorology Agency (JMA). In this study, the impacts of climate change on river discharge in the Indochina Peninsula region were investigated by comparing projected river discharge of the present climate, the near future climate and the future climate experiment. From the results, clear changes of annual mean discharge, annual maximum daily discharge and annual minimum daily discharge were detected with the degree of changes differing according to location. In addition, the statistical significance of river discharge changes in the region under climate change was examined by performing statistical analyses on the projected river discharge.

Key words Indochina Peninsula; river discharge; 1K-FRM; climate change; general circulation model; statistical test

INTRODUCTION

According to the Intergovernmental Panel on Climate Change (IPCC), global average temperature has increased roughly 0.74°C over the last century. The main reason is the anthropogenic increase of greenhouse gas concentrations (IPCC, 2007a). The IPCC also reported, with high confidence, that hydrological systems are being affected by temperature increases. The frequency and magnitude of hydrological extremes such as flood and drought events may also be influenced by changing climate.

One approach to estimate the effects of global warming on hydrology and water resources is to use outputs of general circulation models (GCMs) as inputs for hydrological models. Many GCMs have been developed to simulate the present climate and have been used to project future climate change. They serve as a powerful tool for studying global climate and its variability. The climate simulations from the GCMs can be converted by hydrological models to relevant water resources variables for evaluating the hydrologic and water resources effects of climate change.

In this study, river discharge in the Indochina Peninsula region was simulated using a super-high-resolution atmospheric general circulation model (AGCM) with 20 km spatial resolution and a distributed flow routing model with kinematic wave approximation. The AGCM runoff generation data for the present climate experiment (1979–2008), the near future climate experiment (2015–2044), and the future climate experiment (2075–2104) under the SRES A1B scenario were used as input data for the flow routing model.

The objective of this study was to investigate the changes of river discharge in the Indochina Peninsula region under climate change. The statistical significance of river discharge changes was also analysed to locate possible hotspot basins in the region where significant changes related to floods, droughts, and water resources could occur.

METHODS

Flow routing model

The flow routing model 1K-FRM is a distributed hydrological model with kinematic wave flow approximation (Hunukumbura *et al.*, 2012) applied to investigate the impacts of climate change on river discharge. It was developed by Hydrology and Water Resources Research Laboratory of

Kyoto University (http://hywr.kuciv.kyoto-u.ac.jp/products/1K-DHM/1K-DHM.html). 1K-FRM was based on a catchment topography model. The topographic information used for the flow routing model 1K-FRM was generated from processing the scale-free global streamflow network dataset (Masutani *et al*., 2006) with a spatial resolution of 5 arc minutes. The flow direction is defined using an 8-direction method, which assigns flow from each grid cell to one of its 8 neighbours, either adjacent or diagonally, in the direction with the steepest downward slope. Each slope element determined by flow direction is represented by a rectangle formed by the two adjacent nodes of grid cells. Then the runoff is routed according to the flow direction information by applying the kinematic wave flow model to all slope elements.

Climate change data

The AGCM used in this study is MRI-AGCM3.2S, which was jointly developed by the Meteorological Research Institute (MRI) and the Japan Meteorological Agency (JMA). It is the latest version of 20 km spatial resolution AGCM provided by MRI and JMA (Kitoh *et al*., 2009). Outputs from MRI-AGCM3.2S included various atmospheric and hydrologic variables for three climate experiments: the present climate (1979–2008), the near future climate (2015–2044), and the future climate (2075–2104). The runoff generation data from the MRI-AGCM3.2S dataset was fed into the flow routing model to project river discharge in Indochina Peninsula under climate change.

Statistical analysis

Relative change in river discharge To examine the changes in river discharge in the Indochina Peninsula region under climate change, the ratio of annual mean discharge, mean of annual maximum daily discharge, and mean of annual minimum daily discharge for the near future climate and the future climate to the one for the present climate were calculated and analysed (Duong *et al*., 2013).

Statistical significance The statistical significance of river discharge changes in the Indochina Peninsula region was assessed with a comparison of means of projected river discharge data for the near future climate experiment and the future climate experiment with those for the present climate experiment, to evaluate whether the changes in river discharge are statistically significant or just occur by chance.

The approach for comparing those statistics is chosen based on the distribution of projected river discharge data. If the data are normally distributed, a parametric approach can be employed to determine if the difference in the means was statistically significant. In cases where the data are not normal distributed, non-parametric approaches can be used.

In this study, the Shapiro-Wilk W test (Gilbert, 1987) was applied for the data normality test. The W test is performed by testing the following null hypothesis, H_0: the sample data are normally distributed. The results of the test for normality are shown in the section of Test for normality. Based on those results, statistical significance testing methods were chosen.

The parametric Welch correction t-test (Zar, 2010) was applied for the river discharge data which have a normal distribution. The non-parametric Mann-Whitney U test (Gilbert, 1987) was performed to test for the statistical significance of non-normal distribution river discharge data. The null hypothesis H_0 for the statistical significance testing can be defined as follows: there is no significant difference between annual mean discharge/mean of annual maximum daily discharge/mean of annual minimum daily discharge for the near future climate/the future climate and the present climate ($\mu_{\text{near future}} = \mu_{\text{present}}$, $\mu_{\text{future}} = \mu_{\text{present}}$).

RESULTS AND DISCUSSION

Changes of river discharge in the Indochina Peninsula under climate change

The ratio of annual mean discharge, mean of annual maximum daily discharge, and mean of annual minimum daily discharge for the near future climate and the future climate to those for the

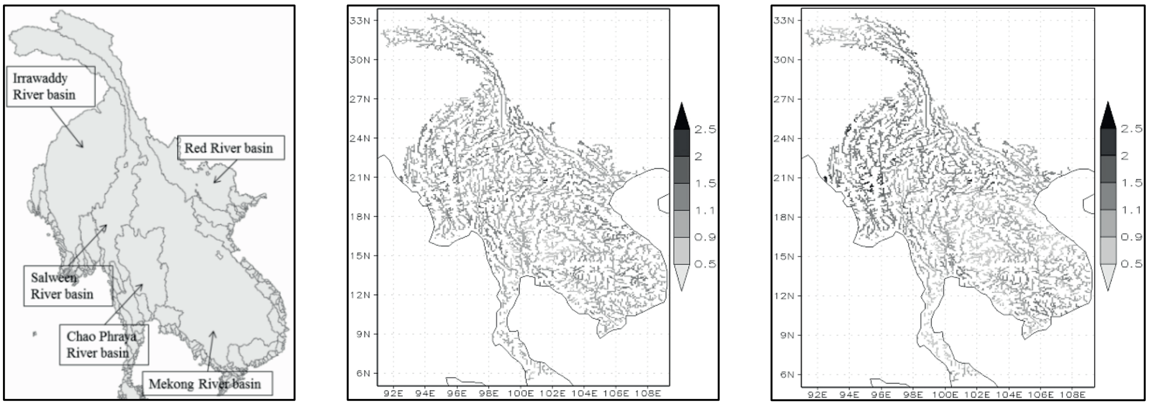

Fig. 1 Map of the study area (left); ratio of annual mean discharge for the near future climate to the present climate (middle), and the future climate to the present climate (right).

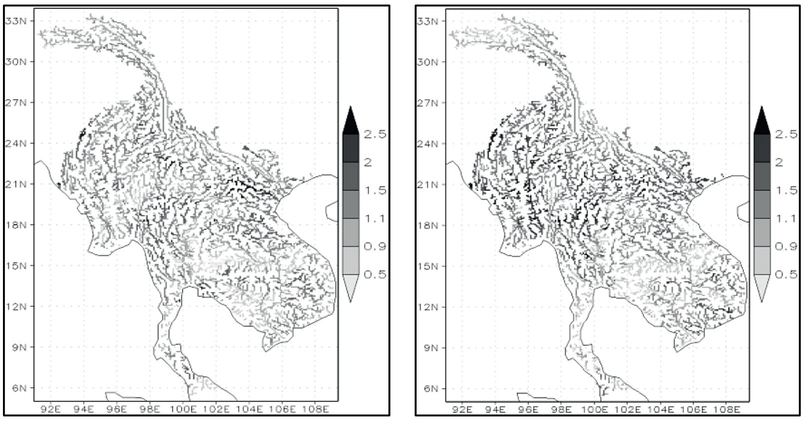

Fig. 2 Ratio of mean of annual maximum daily discharge for the near future climate to the present climate (left), and the future climate to the present climate (right).

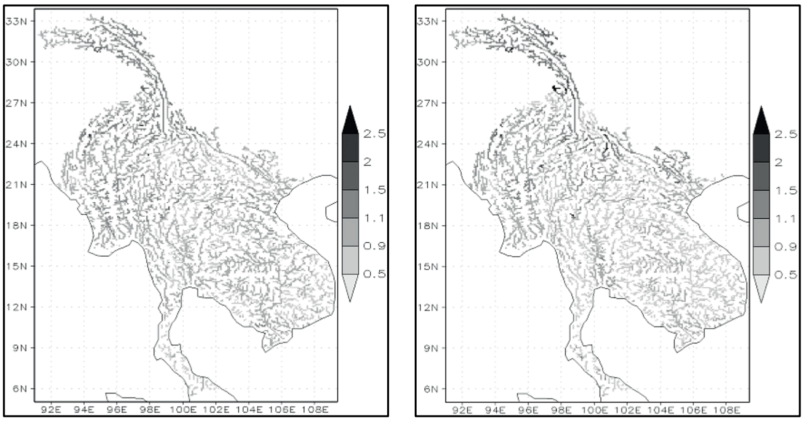

Fig. 3 Ratio of mean of annual minimum daily discharge for the near future climate to the present climate (left), and the future climate to the present climate (right).

present climate in the Indochina Peninsula region were calculated and are shown in Figs 1, 2, and 3. The scale bar indicates the ratio range.

Figure 1 shows that the change in annual mean discharge in the near future is not so clear. Most of the region has a ratio between 0.9 and 1.1. However, in the future climate, the area with changes in annual mean discharge and ratio range become larger, especially in the Irrawaddy River basin and the upper most parts of the Salween River basin and the Mekong River basin. A decreasing trend of annual mean discharge was also detected at the Chi-Mun sub-basin of the Mekong.

For the mean of the annual maximum daily discharge, there are significant changes in the near future climate in the upper part of the Irrawaddy River basin, the Salween River basin, and northwestern Vietnam (see Fig. 2). The changes which appeared in the near future climate become more visible in the future climate. The Irrawaddy River basin, the Salween River basin, and the Red River basin showed a noticeable increase in the mean of annual maximum daily discharge in the future climate. The ratio range in some areas is larger than 2.5. It means that flooding risk in those areas could increase.

From Fig. 3 it can be seen that there is an increasing trend in the upper most part of the Mekong River basin and the Salween River basin in the near future climate. However, in the middle part of the Mekong River basin and southern part of Vietnam, the mean of annual minimum daily discharge tended to decrease. In the future climate, these trends become clearer.

Test for normality

The results of the data normality test using Shapiro-Wilk W test are shown in Figs 4, 5 and 6. Those figures show the W statistic values of annual mean discharge, mean of annual maximum daily discharge, and mean of annual minimum daily discharge data for the present climate, the near future climate, and the future climate.

In the Shapiro-Wilk W test, if the calculated W statistic is smaller than the critical W statistic value, the null hypothesis is rejected. The critical W statistic value can be obtained from a table of W critical values based on data sample size n and significant level α. In climate science, the significant level of 0.05 or 5% is often selected. With a data sample size of 30, the statistic table

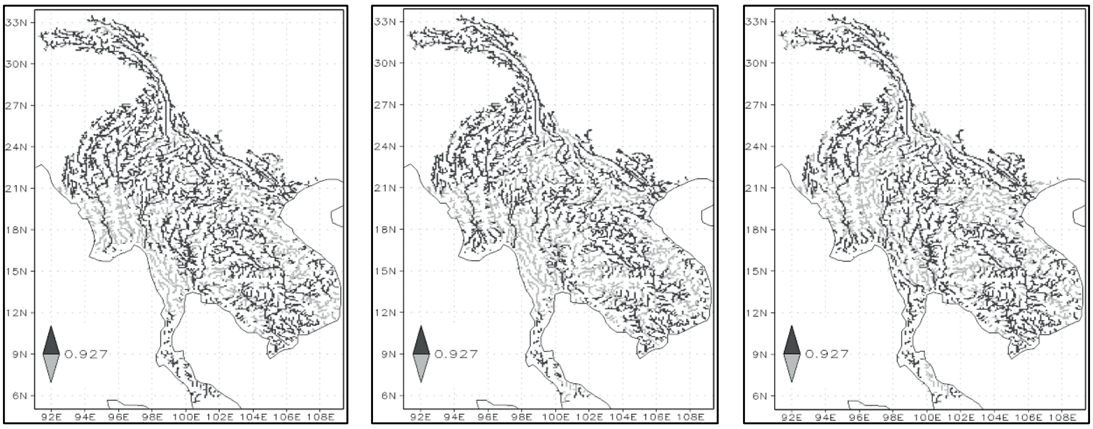

Fig. 4 W test statistic of annual mean discharge data for the present climate (left), the near future climate (middle), and the future climate (right).

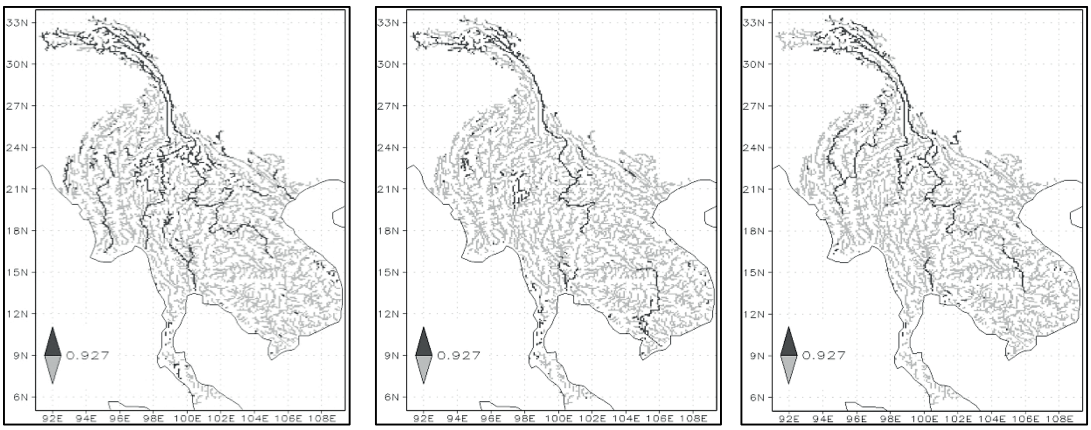

Fig. 5 W test statistic of mean of annual maximum daily discharge data for the present climate (left), the near future climate (middle), and the future climate (right).

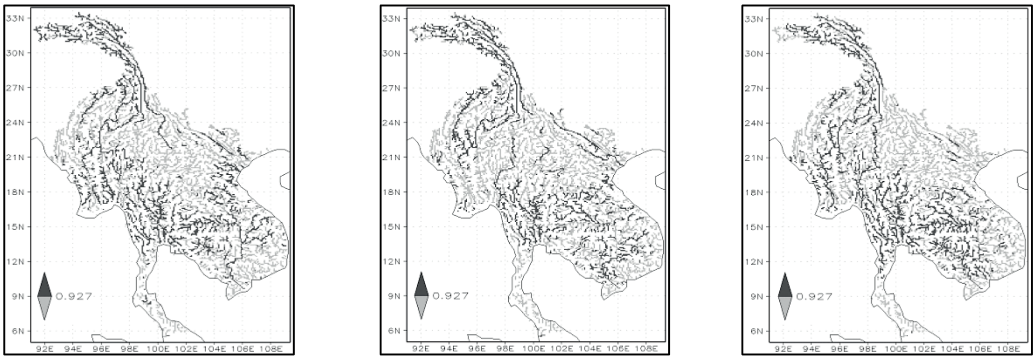

Fig. 6 W test statistic of mean of annual minimum daily discharge data for the present climate (left), the near future climate (middle), and the future climate (right).

provides a critical value of $W^{cr}_{\alpha=0.05} = 0.927$. Therefore, the sample data are not normally distributed when calculated W statistics are less than 0.927 (see Figs 4, 5, and 6).

Test for statistically significant differences between two means

Based on the results of data normality test, the test for statistical significance was carried out. If both river discharge data being compared are normally distributed, the parametric Welch correction t-test is used. In other cases, the non-parametric Mann-Whitney U test is applied. The results of statistical significant test are shown in Fig. 7, Fig. 8 and Fig. 9.

From Fig. 7, it can be seen that, in the near future climate, the change in annual mean discharge in the Indochina Peninsula region is statistically significant only in the main channel of the Irrawaddy River basin. In the future climate, the change in annual mean discharge is statistically significant in middle and upper part of the Irrawaddy River basin, the main channel of the Salween River basin and upper part of the Mekong River basin's main channel.

For the mean of annual maximum daily discharge, the change is statistically significant in the main channel of the Irrawaddy and the Red River basin in the near future climate (see Fig. 8). The statistical significance of river discharge change appeared in the future climate at the Irrawaddy River basin, lower part of the Salween River basin's main channel, main channel of the Mekong River basin in the territory of Lao PDR, and the Red River basin.

Figure 9 shows that the change in mean of annual minimum daily discharge is statistically significant at the upper most part of the Salween and the Mekong River basin in the near future climate. In the future climate, the change in river discharge was found statistically significant at the upper most part of the Salween and the Mekong River basin, left tributary of the Chao Phraya River basin, and the lower most part of the Mekong River basin's main channel.

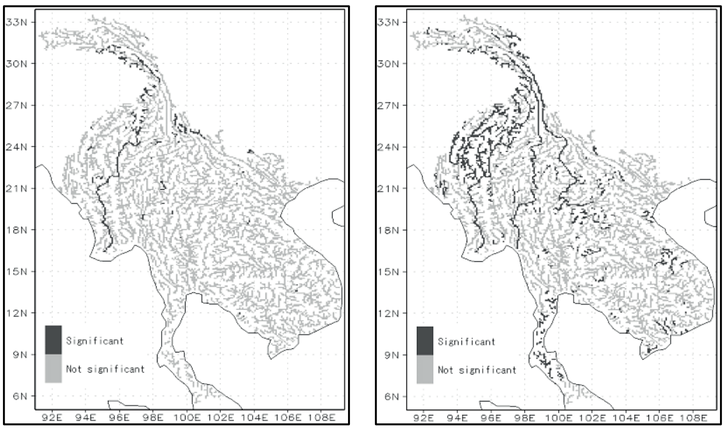

Fig. 7 Statistical significant differences between annual mean discharge for the near future climate and the present climate (left); and for the future climate and the present climate (right).

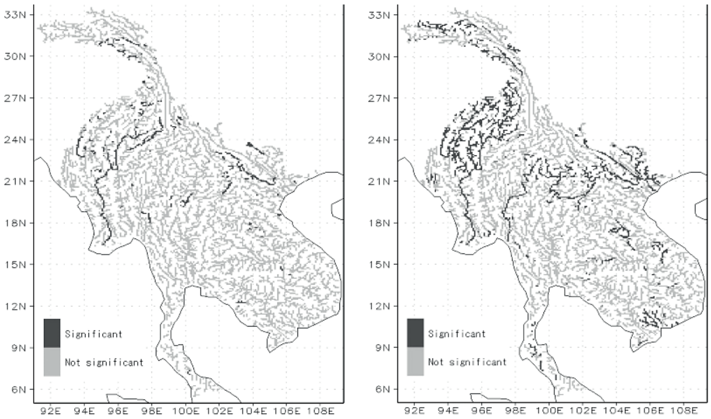

Fig. 8 Statistical significant differences between mean of annual maximum daily discharge for the near future and the present climate (left); and for the future and the present climate (right).

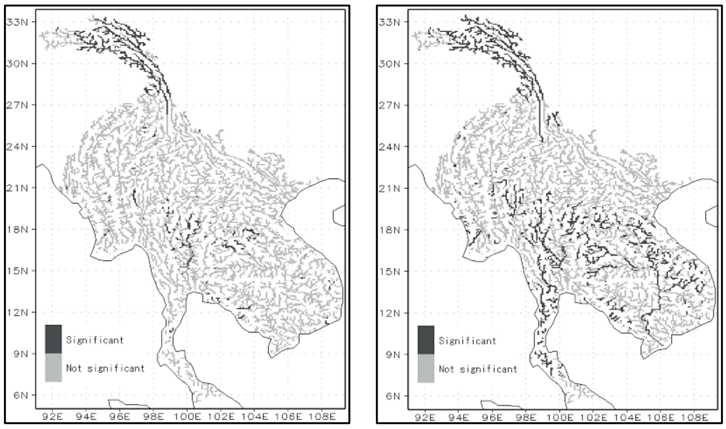

Fig. 9 Statistical significant differences between mean of annual minimum daily discharge for the near future and the present climate (left); and the future and the present climate (right).

CONCLUSIONS

This study investigated the change in river flow under climate change in the Indochina Peninsula region using the distributed flow routing model 1K-FRM and MRI-AGCM3.2S dataset. Statistical analysis was also carried out to examine the statistical significance of river discharge changes in the region. A clear change of river flow was detected and found statistically significant in the Irrawaddy and the Red River basin, and in some parts of the Salween and the Mekong River basin.

For future further work, different GCMs' data will be used to evaluate the uncertainty in climate projection. A detailed distributed hydrological model will be developed for hotspot basins in the region with significant changes in river flow for more comprehensive impact assessment.

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