PROJECTION OF RIVER DISCHARGE OF JAPANESE RIVER BASINS UNDER CLIMATE CHANGE SCENARIO

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ABSTRACT

The impact of climate change on river discharge in Japanese river basins is analyzed by feeding future climate projection data into a 1km-spatial resolution distributed rainfall-runoff model. The projection data used consists of daily surface and subsurface runoff generation data downscaled by hourly precipitation for the current climate experiment (1979-2003), the near future climate experiment (2015-2039), and the future climate experiment (2075-2099), which were simulated by a high resolution general circulation model (MRI-AM20km) developed by the Meteorological Research Institute, Japan Meteorological Agency. The main findings of river discharge projection are as follows: 1) clear changes of hourly flood peak discharge, daily drought discharge and monthly discharge were detected; 2) for each discharge, the degree of the changes differs according to location; and 3) the changes appear in the near future climate experiment, which become clearer in the future climate experiment.

1 INTRODUCTION

Global warming will give us a serious impact on our life. Frequencies and magnitudes of floods and sedimentation disasters are predicted to increase due to the change of precipitation extremes. The IPCC, the Intergovernmental Panel on Climate Change, 4th assessment report (IPCC, 2007) describes increase of global average surface temperatures, increase of global average sea level, and potential increase of frequency of heavy rainfall, and so on based on long term observations. The report also shows the projections of climate change according to several greenhouse gas emission scenarios and the impacts of climate change on water-related disasters and water resources.

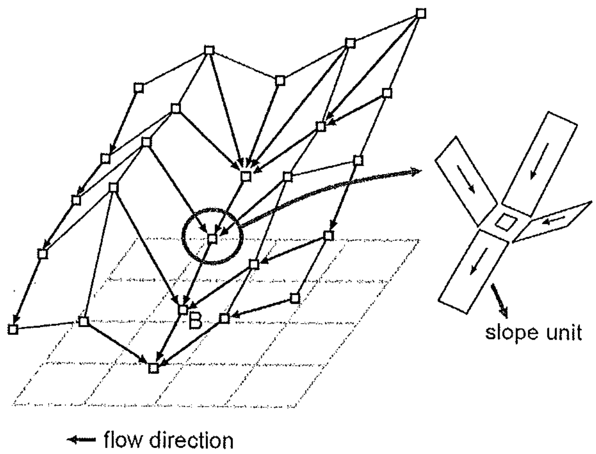

Figure 1. Schematic drawing of a watershed model using DEMs

To cope with water-related disasters induced by climate change, both mitigation measures and adaptation measures are essential. Mitigation measures are efforts to reduce greenhouse gases, and adaptation measures are actions to avoid/mitigate disasters under global warming. Research institutes and governmental organizations in charge of disaster prevention/mitigation have responsibility to predict future climate and possible change of water-related disasters and water resources, and to make planning and implementation for adaptation measures. To establish adaptation measures, the following are important themes to be studied together across the related fields:

1) Projection of the future extremes, especially precipitation and typhoon developments, using advanced atmospheric models.

2) Impact analyses of climate change on water-related disasters and water resources. Analyses of the changes in frequency and magnitude of water-related disasters such as floods and droughts using future climate projection data are essential to establish adaptation measures.

3) Planning and implementation of adaptation measures based on the impact analysis studies of climate change on water-related disasters and water resources.

In this paper, a future river discharge of Japanese river basins using the latest GCM outputs and a distributed hydrologic model is predicted. Then, the change of flood and drought risks is analyzed. In section 2, a distributed hydrologic model used for a river discharge projection is described. In section 3, a future climate projection data used for river discharge simulation is explained, which is provided by the general circulation model with 20km spatial resolution (MRI-AM20km) developed by the Meteorological Research Institute in Japan. In section 4, the simulated river discharge projection is analyzed based on hourly, daily and monthly time scale, and the impact of climate change on river flow are discussed.

2 DISTRIBUTED HYDROLOGIC MODEL

2.1 Watershed model

The topography of the catchment is modelled using the eight direction method which assumes the flow direction one-dimensionally to the steepest gradient direction illustrated in Figure 1. Each slope element determined by the flow direction is represented by a rectangle formed by the two adjacent nodes of grid cells. The watershed model is developed using a digital elevation model GTOPO30, which cover the globe with about 1 km spatial resolution. Figure 2 shows the delineated catchments at the Kanto region, Japan. The area, length, and gradient of each rectangular slope element used for runoff and channel routing are calculated according to the watershed model.

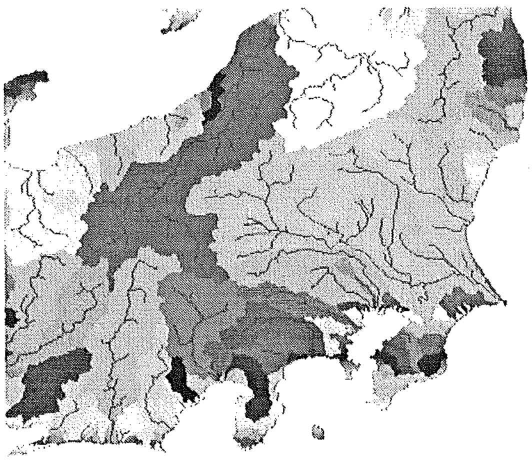

Figure 2. Delineated catchments generated by the flow direction map at the Kanto region

2.2 Flow model

The kinematic wave model is applied to all rectangular slope elements to route the water to downstream according to the derived watershed model. The continuity equation for each rectangular slope element is:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q(t) \tag{1}$$

Where t is time; x is distance; A is cross-sectional area; Q is discharge; and $q(t)$ is the lateral inflow per unit length of slope or channel given as runoff generation provided by MRI-AM20km. The Manning type relation of the discharge and the cross-sectional area:

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

is combined with the continuity equation to route the water, where i_0 is slope; n is roughness coefficient; and B is width of the flow. The slope i_0 is determined according to the watershed model. The model parameters of the flow model are B and n. The value of B is determined using the regression relationship $B=aS^c$, where S is the catchment area, and a and c is constant parameters. The value of n is determined to $0.03\mathrm{m}^{-1/3}\mathrm{s}$ when the size of the catchment is larger than $250\mathrm{km}^2$ and $11.0\mathrm{m}^{-1/3}\mathrm{s}$ when smaller than $250\mathrm{km}^2$. There values are tuned to reproduce the observed data at two different catchments and applied to all basins.

The flow model was applied to all catchments and 75 years runoff simulations were conducted. The simulated river discharge data was stored for 10 minute time interval and about 4km spatial resolution.

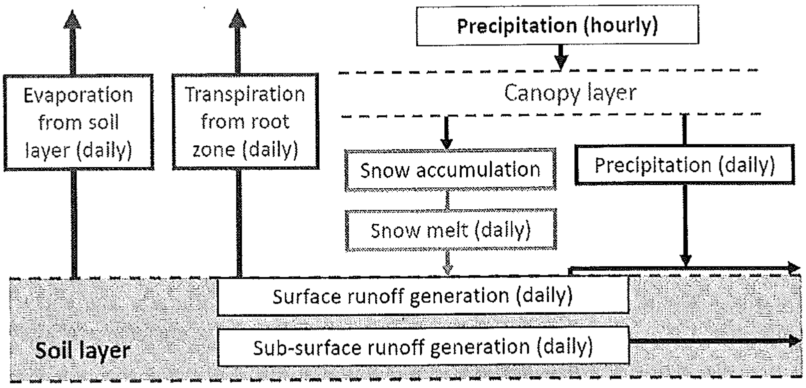

Figure 3. Hydrologic projection variables related to river discharge provided by MRI-AM20km

3 GCM DATA USED FOR RIVER FLOW PROJECTION

The projection data used here is simulated by the general circulation model with 20km spatial resolution (MRI-AM20km) developed by the Meteorological Research Institute in Japan. MRI-AM20km realizes 1920×960 of grid cells of about 20 km spatial resolutions (Kitoh *et al.*, 2009). The products of MRI-AM20km consists of various atmospheric and hydrologic variables of the current climate experiment (1979-2003), the near future climate experiment (2015-2039), and the future climate experiment (2075-2099), which were simulated under the SRES A1B scenario (IPCC, 2000).

The river discharge for Japanese basins is predicted by feeding the future climate projection data into the 1km-spatial resolution distributed hydrologic model. The hydrologic projection variables related to river discharge is shown in Figure 3. The inputted data to the distributed hydrologic model is the daily surface runoff generation and the daily sub-surface runoff generation data, which are simulated by the land-surface process model embedded in the MRI-AM20km.

The time-scale of daily runoff generation data is insufficient to reproduce the hourly flood peak discharge, thus it was downscaled using the time-series of hourly precipitation data of MRI-AM20km to add the same hourly distribution pattern into the daily surface runoff generation data. We confirmed that river discharge simulation with the timely downscaled surface runoff generation and daily subsurface runoff generation data successfully reproduced almost similar river discharge simulated by using hourly precipitation, daily snowmelt, daily evaporation and daily transpiraion (Tachikawa *et al.*, 2010). Thus, the timely downscaled surface runoff generation data and daily subsurface runoff generation data were used as inputted data to the distributed hydrologic model.

4 IMPACT OF CLIMATE CHANGE ON RIVER FLOW REGIME

Runoff simulations of 75 years for the current climate experiment (1979-2003), the near future climate experiment (2015-2039), and the future climate experiment (2075-2099) were conducted. Runoff simulation data of 10 minutes interval and about 4km spatial resolution were stored, and hourly mean, daily mean, and monthly mean discharge data were analyzed to discuss the change of the flood risk and drought risk.

4.1 Change of flood risk

Annual maximum hourly discharge data was compiled and the statistical characteristics were analyzed. Figure 4 shows the change ratio of the mean of the annual maximum hourly discharge for the current climate experiment and the near future climate experiment, and the current climate experiment and the future climate experiment. Generally, except for the central-west part of Japan, the mean of annual hourly discharge increases.

Figure 4. The ratio of the mean of the annual maximum hourly discharge for the current climate experiment and the near future climate experiment (left), and the current climate experiment and the future climate experiment (right)

Figure 5 shows the change ratio of the standard variation of the annual maximum hourly discharge for the current climate and the near future climate experiment, and the current climate and the future climate experiment. The change appears in the near future climate experiment and it becomes clearer in the future climate experiment. The spatial pattern of the change of the mean in Figure 4 shows a similar spatial pattern to the change of the standard deviation in Figure 5. The mean and the standard deviation of the annual maximum hourly discharge increase at the same catchments, which indicate the increase of the magnitudes of the *T*-year flood.

Figure 5. The ratio of the standard deviation of the annual maximum hourly discharge for the current climate experiment and the near future climate experiment (left), and the current climate experiment and the future climate experiment (right)

For each 25-years experiment, the GEV distribution is fitted to the annual maximum hourly discharge for all points. To estimate the parameters of the GEV distributions, the PWM method was used. The goodness-of-fit was evaluated using SLSC (standard least-square criterion) and COR (coefficient of correlation). Most of locations showed good agreements of fitting. The values of SLSC were 0.02 to 0.04 and the values of COR were more than 0.98. Using the fitted GEV distributions, the 100-year hourly maximum discharge was obtained and the change ratio of each experiment was obtained. Figure 6 shows the change ratio of the 100-year annual maximum hourly discharge.

Figure 6. The change ratio of the 100-year annual maximum hourly discharge for the current climate and the near future climate experiment (left), and the current climate and the future climate experiment (right)

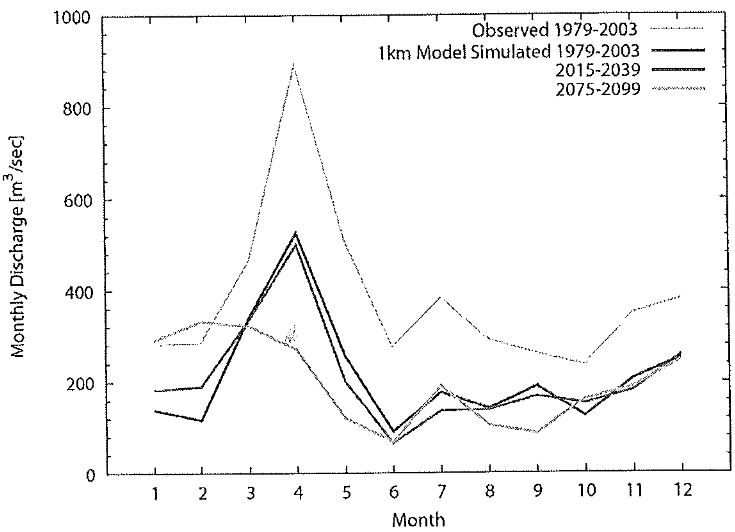

Figure 7. The change of monthly mean discharge at the Mogami River basin (6,500km^2) which locates the heavy snowfall area at the central part of Japan

The Figures clearly show the spatial change pattern of the future flood risk. The important finding is that the change does not happen uniformly. The change ratios differ largely according to location. The areas where the change ratio increases correspond to the areas which have high short term rainfall. The areas where the change ratio decreases are the heavy snowfall regions. Figure 7 shows the change of monthly mean discharge at the Mogami River basin (6,500km^2) which locates the heavy snowfall area at the central part of Japan. Similar change was observed at the catchments in northern Japan which have heavy snowfall in winter season. In the catchments, the difference of annual and monthly precipitation between the current and the future climate experiment are small; but the difference of snow melting is large because of decrease of snowfall to the catchments in the future climate experiment. The monthly peak discharge which occurs from March to May in the current climate shifts to January to March, and the discharge in April to May much decreases in the future climate experiment. As a result, the river discharge for the future climate is smoothened. The discharge change pattern was observed widely in the northern Japan catchments.

4.2 Change of drought risk

The daily mean discharge data was compiled from the simulated time series discharge data and the 355th daily mean discharge from the largest one was obtained for each year, which is called drought discharge as an index to analyze low flow. Figure 8 shows the change ratio of the mean of the drought discharge for the current climate experiment and the near future climate experiment, and the current climate experiment and the future climate experiment. Generally, the western part of Japan has lower drought discharge and the northern part has larger drought discharge. The characteristics become clearer in the future climate experiment.

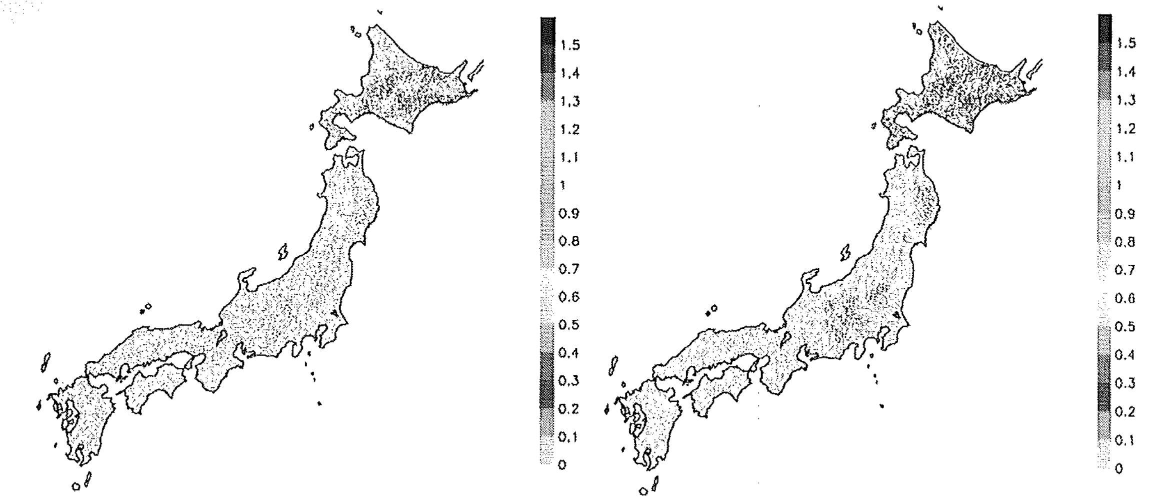

Figure 8. The change ratio of the drought discharge for the current climate experiment and the near future climate experiment (left), and the current climate experiment and the future climate experiment (right)

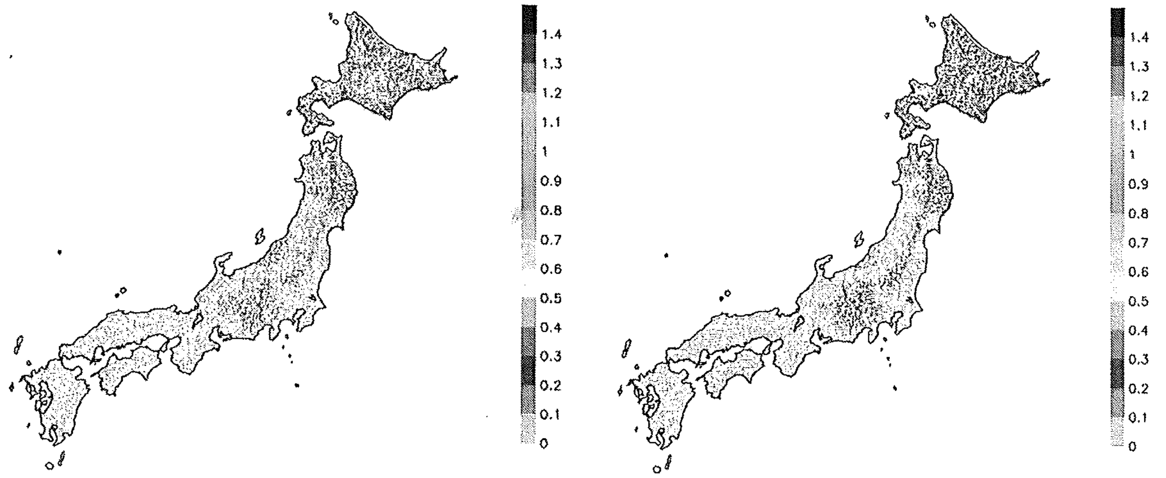

Figure 9. The change ratio of the 10-year draught charge for the current climate experiment and the near future climate experiment (left), and the current climate experiment and the future climate experiment (right)

For each 25-years experiment, the Weibull distribution with the lower bound is zero was fitted to the drought discharge. To estimate the parameters of the Weibull distribution, the PWM method was used. The SLSC values for goodness-of-fit were 0.03 to 0.05. Using the fitted Weibull distributions, the 10-year drought discharge was obtained and the change ratio of each experiment was obtained. Figure 9 shows the change ratio of the 10-year drought discharge. The Figure shows that the drought discharge decrease in the western part of Japan, which means the increase of the drought risk in the region.

5 SUMMARY

The impact of climate change on river discharge regimes in Japanese basins was analyzed by feeding future climate projection data into a distributed rainfall-runoff model. Spatially distributed discharge was simulated with the kinematic wave model according to the watershed model with 1km spatial resolution developed using GTOPO30 topography data. The future climate projection information used for the runoff simulation was daily surface and subsurface runoff generation data temporarily downscaled by hourly precipitation. The projection data consists of three numerical climate experiments, the current climate experiment (1979-2003), the near future climate experiment (2015-2039), and the future climate experiment (2075-2099), which were simulated under the SRES

A1B scenario by a 20km spatial resolution general circulation model (MRI-AM20km) developed by the Meteorological Research Institute, Japan Meteorological Agency. Using the projection data, 75 years river discharge simulations were conducted and the results were analyzed statistically.

At the catchment in western Japan, it is clearly observed the increase tendency of the annual maximum hourly discharge, which leads to the increase of the flood risk. The tendency of the decrease of the 355th daily discharge in a year was also observed widely in the western part of Japan, which leads to the increase of the drought risk. A change of the flow regime was observed at the catchments in northern Japan which have heavy snowfall in winter season. In the catchments, the difference of annual and monthly precipitation between the current and the future climate experiment are small; but the difference of snow melting is large because of the decrease of snowfall to the catchments in the future climate experiment. The monthly peak discharge which occurs from March to May in the current climate shifts to January to March, and the discharge in April to May much decreases in the future climate experiment. As a result, the river discharge for the future climate is smoothened. The discharge change pattern was observed widely in the northern Japan catchments.

Through the 75 years runoff simulations for all catchments, the findings were summarized as follows: 1) a clear change of temporal and spatial discharge patterns appears, 2) the degree of the change differs according to location; 3) in the western Japan, the hourly flood peak discharge increases, which leads to the increase of flood risk; 4) in western Japan, the 355th daily discharge in a year decreases, which leads to the increase of drought risk; 5) in the northern Japan, the monthly river discharge for the future climate is smoothened because of the decrease of snow melting; and 6) the changes appear in the near future climate experiment, which become clearer in the future climate experiment.

6 ACKNOWLEDGEMENTS

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