HYDROLOGICAL PREDICTION OF CLIMATE CHANGE IMPACTS ON TONE AND YODO RIVER BASINS

Sunmin Kim[1], Yasuto Tachikawa[2], Kaoru Takara[3] and Eiichi Nakakita[4]

[1] Assistant Professor, Disaster Prevention Research Institute, Kyoto University
Gokasho, Uji, Kyoto 611-0011, Japan, e-mail: sunmin@flood.dpri.kyoto-u.ac.jp
[2] Associate Professor, Department of Urban and Environmental Eng., Kyoto University
C1, Nishikyo-ku, Kyoto 615-8540, Japan, e-mail: tachikawa@mbox.kudpc.kyoto-u.ac.jp
[3] Professor, Disaster Prevention Research Institute, Kyoto University
Gokasho, Uji, Kyoto 611-0011, Japan, e-mail: takara@flood.dpri.kyoto-u.ac.jp
[4] Professor, Disaster Prevention Research Institute, Kyoto University
Gokasho, Uji, Kyoto 611-0011, Japan, e-mail: nakakita@urh.dpri.kyoto-u.ac.jp

ABSTRACT

The most realistic and widely used approach to estimate the hydrological impacts of climate change is to combine the output of the GCMs with a hydrological model that contains physically-based mathematical descriptions of hydrologic phenomena. This study sets out to investigate the possible impacts of climate change in a hydrological view point including water resources and flood producing mechanisms on two main river basins of Japan, Tone River and Yodo River basins. The output of very high resolution atmospheric model is analyzed, and the runoff simulation results with the hydrologic model are described.

Keywords: hydrologic impact, AGCM output, distributed hydrologic model, OHyMoS

1. INTRODUCTION

The climate system is a complex and interactive system consisting of many factors, such as atmosphere, land surface, oceans and other bodies of water, and living things as well. The climate system evolves in time not only by its own internal dynamics but also by external factors that affect climate. Human induced changes in atmospheric composition are also one of the external factors. The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC) shows that there has been apparent increase in the globally averaged temperatures since the mid-20th century, which is primarily caused by human activities such as fossil fuel burning and deforestation. As a consequence, it is very likely that anthropogenic warming has had a discernible influence on many physical and biological systems. Climate change is an unequivocal truth, and now we are in the stage of estimating its potential impacts on our society and nature.

This study sets out to investigate the possible impacts of climate change in a hydrological view point including water resources and flood producing mechanisms. Recently lots of efforts are concentrated in the studies for the future projections of the climate condition using atmospheric and oceanic general circulation model (AOGCM). The most realistic and widely used approach to simulate the hydrological impacts of climate change is to combine the output of AOGCM with a hydrological model that contains physically-based mathematical descriptions of hydrologic phenomena. This study uses the output of very high resolution atmospheric models (20-km in spatial and 1 hour in time resolution), which is running under the Innovative Program of Climate Change Projection for the 21st Century (or Kakushin21 Program) of the Ministry of Education, Culture, Sports, Science, and Technology (MEXT), Japan.

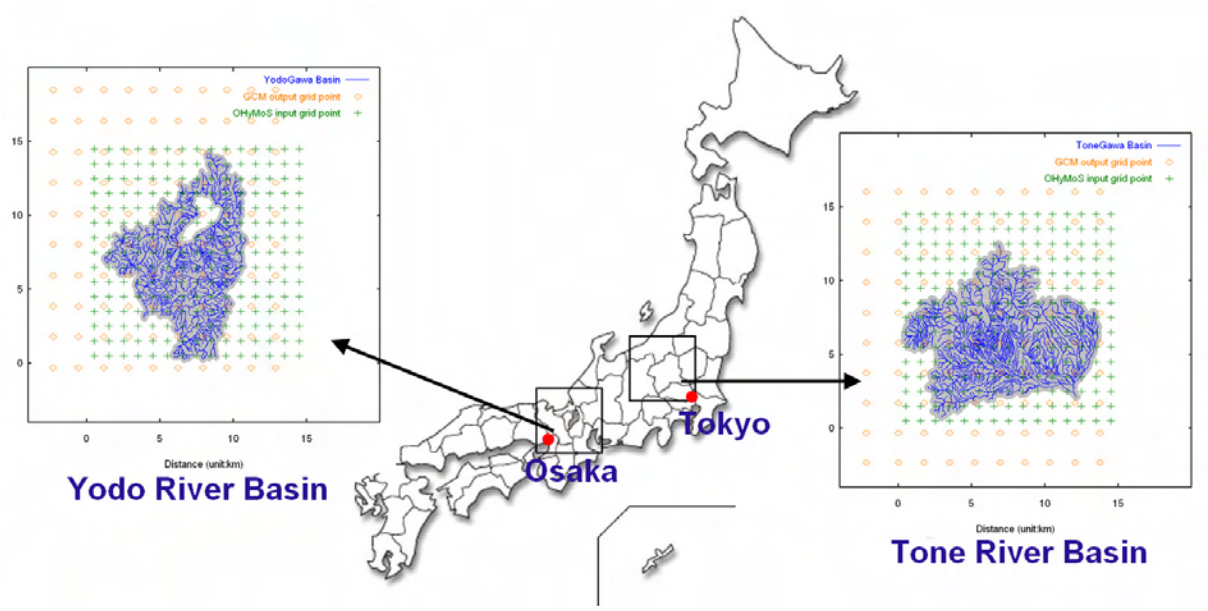

Figure 1. Location and the channel network of subject basins, Tone River and Yodo River

Hydrologic models using the OHyMoS library (Takasao et al., 1996; Ichikawa et al., 2000) of Kyoto University has utilized for Tone river basin (8,772 km^2) and Yodo river basin (7,281 km^2). Both river basins are located on the upper area of Tokyo and Osaka respectively (see Figure 1), and, by this reason, these major basins are regarded as the primary concern for the water-related problem under the future climate change condition. Hydrologic models are calibrated under the present conditions using the recent observed hydrologic data, and the current dam operation rules for the flood control function are also to be considered. Based on the given conditions, the hydrologic model simulates long-term discharges for several critical points in the basins using the output of the GCM.

The organization of this paper is as follows. In the next section, a brief description on the AGCM output and the hydrologic model used in this study are presented. This section is followed by an analysis on the given AGCM output. Then, the runoff simulation procedure and results with the hydrologic model are described. Finally, discussion on the results and conclusions are presented.

2. HYDROLOGIC DATA AND MODEL

AGCM20 and its output

The hydrologic data used in this study are the output of a 20-km-mesh super high-resolution global atmospheric general circulation model (AGCM20) on the Earth. The Earth Simulator is a parallel-vector supercomputer system of Japan Meteorological Agency (JMA), which is one of the fastest computers in the world.

JMA have developed a prototype of the next generation of global atmospheric model with a collaboration of Meteorological Research Institute (MRI), Japan for the use of both climate simulations and weather predictions Simulator (Mizuta et al., 2006). The developed model performs its simulation at a triangular truncation 959 with the linear Gaussian grid (TL959) in the horizontal, which means 1920 × 960 of grid cells of about 20 km size, and with 60 levels in the vertical. Refer to "Mizuta et al. (2006)" for more details on the AGCM20.

AGCM20 is a global atmospheric model, and adopts the monthly mean climatologic sea surface temperature (SST) as a boundary condition for controlled simulations. For the boundary condition of projection simulations, the SST was estimated from averaged values of other GCM model outputs. From the model experiment, AGCM20 shows the superiority in simulating orographic rainfall and Baiu frontal rain bands (Kitoh and Kusunoki, 2007).

Hydrologic modelling system, OHyMoS

To investigate the hydrologic impacts on Tone River and Yodo River basins by the climate change, a distributed hydrologic model was developed based on an object-oriented hydrologic modeling system, OHyMoS (Takasao et al. 1996; Ichikawa et al. 2000). OHyMoS enables the user to easily build any complex hydrologic system by connecting a number of element models. One of the main element models of the system is Kinematic Wave model (Takasao and Shiiba, 1988; Tachikawa et al., 2004), which is for overland flow and channel routing as well. Dam element model to simulate dam operation with decision-making processes of the dam operator is also included in the system. In the case of Tone River basin, 2151 element models for the sub-catchments and the same number of the river routing element models compose the total system.

3. AGCM20 OUTPUT ANALYSIS

Tone River Basin

Basin averaged precipitation values were calculated using the output of the AGCM20, PRCSL and SN2SL. PRCSL stands for the net precipitation that goes through the soil and SN2SL is for the snowmelt amount that reaches to the soil. The basin averages is an arithmetic mean of eighteen grids of AGCM20 that covers the Tone River basin. Ten years of present term, 1979~1988, and another ten year for future term, 2075~2084 of the AGCM20 output were firstly analyzed in this study.

While the precipitation including both variables shows slight increase in the future term comparing to the present term, snowmelt amount shows significant decrease in the future, as shown in Figure 2. Decadal average of the annual snowmelt amount for the present term is 368.29mm and for the future term is 167.90mm, which is about 55% of decrease. Annual evaporation and transpiration amount is also to be increase in the future according to the AGCM20 simulation results as shown in Figure 3. Decadal average of the annual evapo-transpiration for the present term is 500.67mm and for the future term is 596.22mm, which is 19.1% of increase in the next century. Increase of the evaporation amount (56.49mm of increase) is larger than the increase in the transpiration amount (39.06mm of increase). However, net-precipitation (precipitation – evapotranspiration) amount is to be decreased in the future from 1132.31mm to 1071.84mm and from 1144.28mm to 1065.90mm in Tone River and Yodo River Basin respectively.

The increasing of precipitation and evapo- transpiration as well is the key evidence that proves the considerable temperature increase in the future. Significant change in the snowmelt amount gives more concrete proof on the global warming situation. The results from the AGCM20 are consistent with the general outcomes from the other form of GCM simulations.

Figure 4 and 5 show decadal average (from 1979 to 1988 for the present term, from 2075 to 2084 for the future term) of the precipitation and evapo-transpiration for each month in the Tone River basin showing how the seasonal pattern is going to be changed in the future.

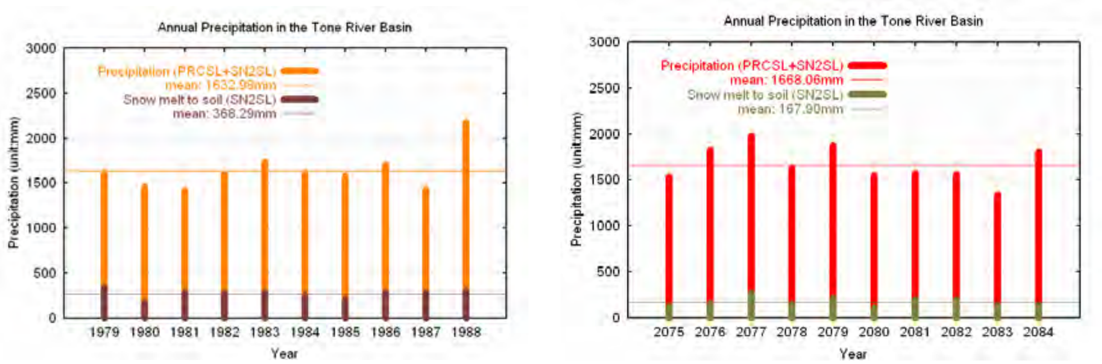

Figure 2. Annual precipitations in the Tone River basin for the present (1979~1988) and future (2075~2084)

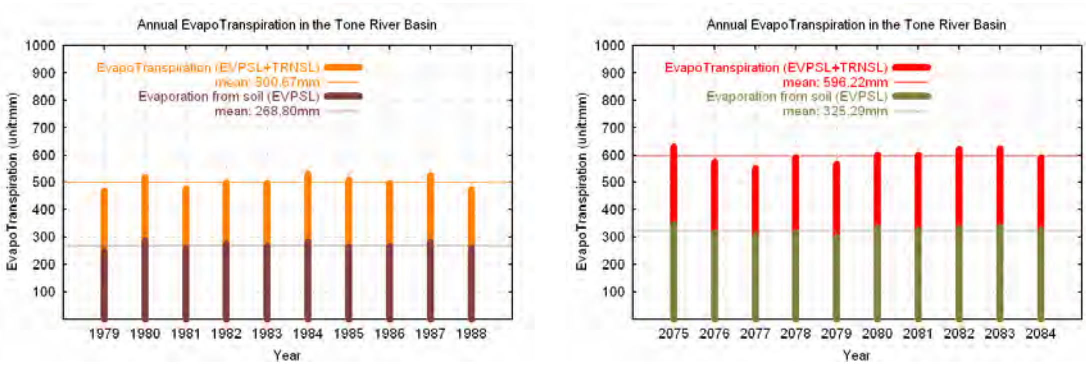

Figure 3. Annual evpo-transpiration in the Tone River basin for the present (1979~1988) and future (2075~2084)

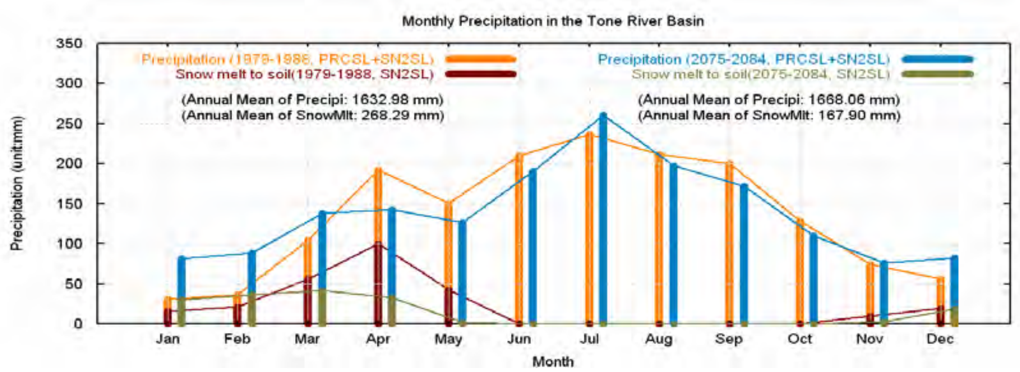

Figure 4. Monthly precipitation pattern of the Tone River basin, decadal average for the present and future

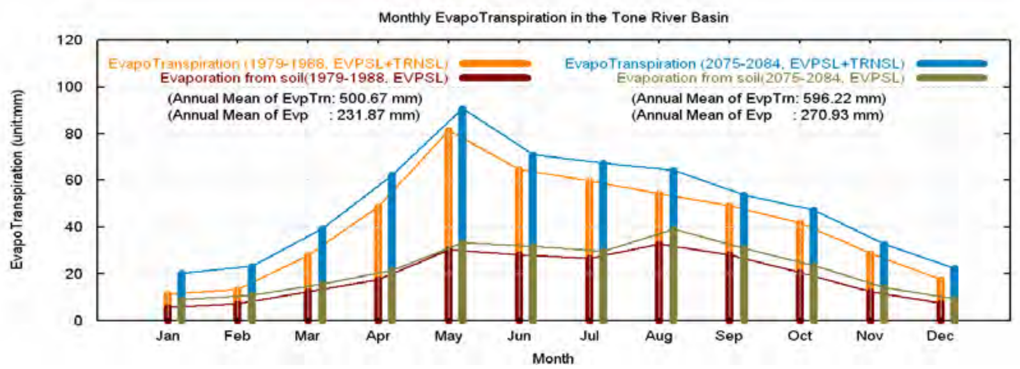

Figure 5. Monthly evapo-transpiration pattern of the Tone River basin, decadal average for the present and future

The most noticeable change is the increase of the precipitation amount in winter season. In the future term, there is a significant increase of precipitation (besides snowmelt amount) in December, January and February. On the other hand, the precipitation in spring and summer season decrease in the future only except in the middle of summer, July. Overall, the seasonal variation of the present term is going to be diminished in the future. Another change is the decrease of snowmelt amount in spring, especially in April. The decadal average of the annual snowmelt amount for the present term is 368.29mm and for the future term is 167.90mm, which is about 55% of decrease. These two main changes diminish the seasonal variance of the current precipitation pattern in the future.

The monthly evapo-transpiration pattern of the future term has the same pattern to the present term in overall, only with an increased amount. The decadal average of the annual evapo-transpiration for the present term is 500.67mm and for the future term is 596.22mm, which means 19.1% of increase in the next century.

Yodo River Basin

Similar to the Tone River basin case, annual precipitation amount in Yodo River basin shows slight increase in the future and snowmelt amount is decreased. Figure 6 shows decadal average (from 1979 to 1988 for the present term, from 2075 to 2084 for the future term) of the precipitation for each month in Yodo River basin. There is little snow in Yodo River basin even in the present term (95.79mm annually), and this amount is going to be decreased down to 15.96mm in the future. There is increase of precipitation in winter season and decrease of snowmelt amount in spring, which is the same phenomenon to the Tone River basin case.

The decadal average of the annual evapo-transpiration for the present term is 599.44mm and for the future term is 684.22mm, which means 14.14% of increase in the next century. Increase of the evaporation amount (46.84mm of increase) and the increase in the transpiration amount (47.94mm of increase) show similar increase (see Figure 7).

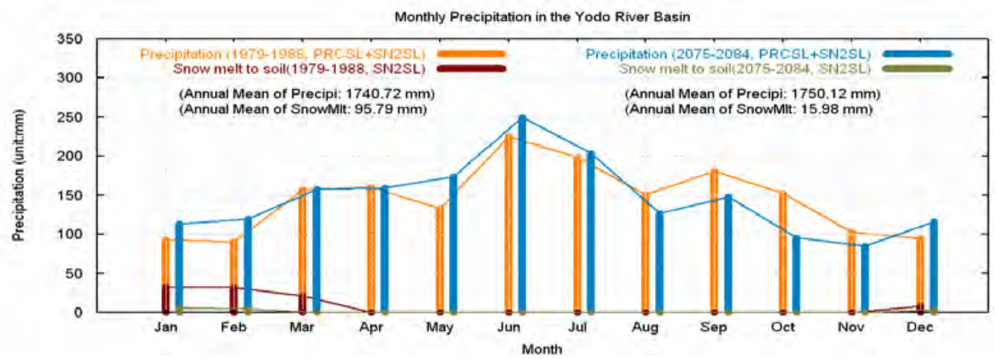

Figure 6. Monthly precipitation pattern of the Yodo River basin (decadal averages)

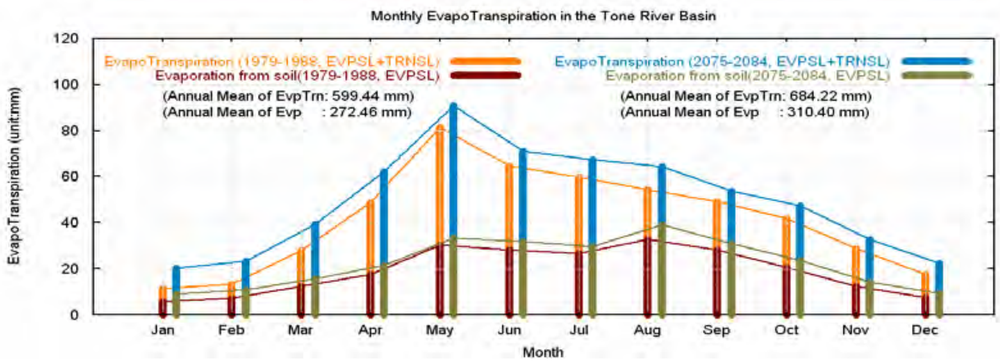

Figure 7. Monthly evapo-transpiration pattern of the Yodo River basin (decadal averages)

4. RUNOFF SIMULATIONS WITH A DISTRIBUTED HYDROLIGIC MODEL

Using the distributed hydrologic model with OHyMoS, runoff simulations on Tone River and Yodo River were carried out. The simulation for each term, present and future term, has been fulfilled continuously with the hourly based rainfall input data. The evaporation and transpiration data were also considered as a daily uniform value. Figure 8 and 9 show the runoff simulation outputs of the station Kurihashi, Tone River basin for the present and the future term, respectively.

In the Tone River model output, the snowmelt pattern change in the future term gives apparent effect on the runoff simulation results. See the red elliptical mark in the present term results. The runoff of March, April and May of the present term is because of the snowmelt, which has diminished and be distributed all over the winter and spring season as the green elliptical mark in the results for the future term. On the other hand, the results from the Yodo River basin do not show the snowmelt runoffs.

The runoffs of the present term have two main terms; one is from July to August and the other is from September to October, which are the because of the rainy season and the typhoon season (see two red triangle mark in Figure 8). The runoffs of the future term do not show this division and merged in one group.

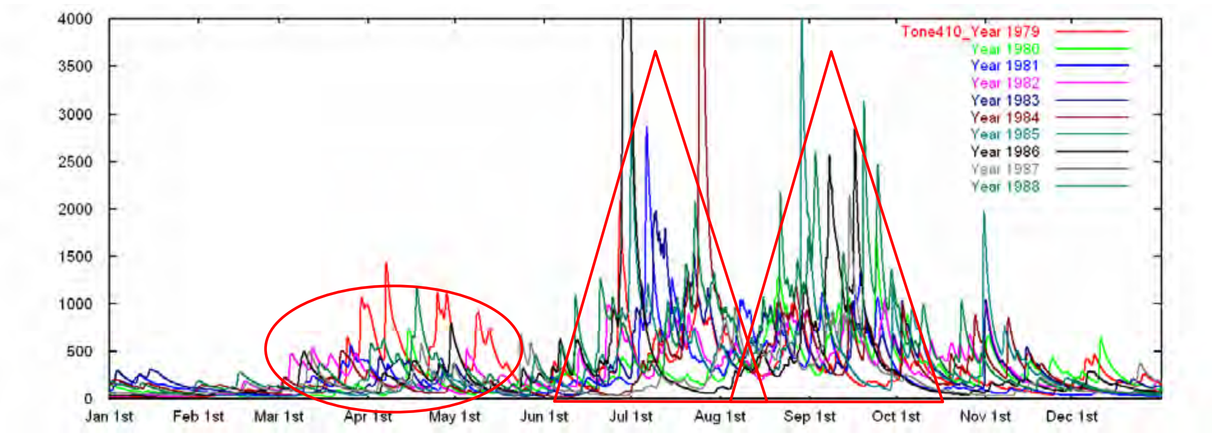

Figure 8. Runoff simulation results at Kurishashi, Tone River for the present.

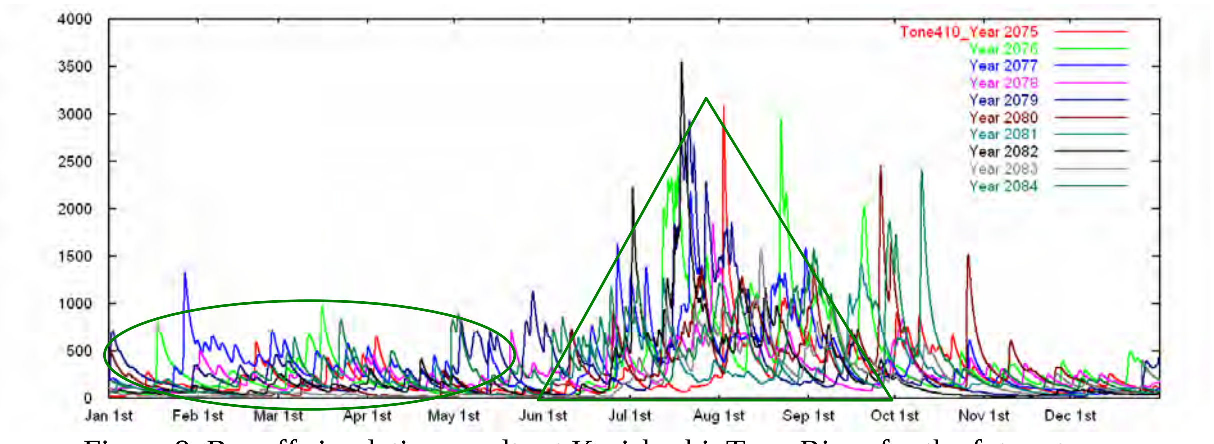

Figure 9. Runoff simulation results at Kurishashi, Tone River for the future term

5. RESULTS ANALYSIS AND CONCLUSION

This study shows brief analysis with the AGCM20 output and the runoff simulation results. This study is currently undergoing with more AGCM20 output. Since hydrologic analysis on the AGCM20 output data has done only with ten years duration for each term, present and future term, it is not proper to extract concrete conclusions at this stage. However, it is worthwhile to describe the analysis on the current results, which will be a roadmap to our next research direction.

The noticeable results from this study are (1) the snowmelt inflow in Tone River basin will change in the next century and it will affect a lot to the seasonal variation of the water resources of the basin (2) the snowmelt change is also there in Yodo River basin, but only with small amount (3) in both Tone River and Yodo River basins, the seasonal variation of the rainfall and discharges is going to be diminished and the water resources would be rather uniformly distributed in the future.

This study has been carried out with the undergoing project, and more AGCM20 output will be available soon. With more enough data availability, this study will extend and strengthen several points as followings. Even though we have much improved technology and computer resources, there is a continuing awareness that models do not provide a perfect simulation of reality, because resolving all important spatial or time scales remains far beyond current capabilities. With the awareness of this fact, first of all, accuracy of the ACGM20 output should be checked, especially for the controlled simulation output of the present term. Controlled simulation output of the ACGM20 can be approved when it is compared with historic observations, on such the items as precipitation, snow and evaporation. Further more, if there is any chronic bias in the AGCM20 output to the historic observation, it should be considered to correct the bias. And this bias correction also should be considered for the output of the AGCM20 projection simulation. The other important point to be considered is the roll of the existed dams in Tone River and Yodo River basins. There are 7 main dams in each basin. Some of them are for flood control and some are for water supply purpose. This dam functions are included in the hydrologic model system and the roll of the current dam usage will be reconsider whether it is proper in the future as it is.

ACKNOWLEDGMENTS

This work is done under the framework of the "Projection of the change in future weather extremes using super-high-resolution atmospheric models" supported by KAKUSHIN Program of MEXT. The calculations were performed on the Earth Simulator.

REFERENCES

Takasao, T., Shiiba, M. and Ichikawa, Y. (1996), A runoff simulation with structural hydrological modelling system, JHHE, Vol. 14, No. 2, pp. 47-55.

Ichikawa, Y., Tachikawa, Y., Takara, K. and Shiba, M. (2000), Object-oriented hydrological modeling system, Proc. of Hydroinformatics 2000, CD-ROM.

Kitoh, A. and Kusunoki, S. (2007), East Asian summer monsoon simulation by a 20-km mesh AGCM, Climate Dynamics, DOI 10.1007/s00382-007-0285-2.

Mizuta R, Oouchi K, Yoshimura H, Noda A, Katayama K, Yukimoto S, Hosaka M, Kusunoki S, Kawai H, Nakagawa M (2006), 20-km-mesh global climate simulations using JMA-GSM model –Mean climate states–. J Meteorol Soc Jpn Vol. 84, pp. 165–185.