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Hydrologic Prediction under Global Warming at Tone and Yodo River Basins using the Output of Global 20-km Mesh GCM

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Synopsis

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

Keywords: AGCM output, hydrologic impact, 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. Human induced changes in atmospheric composition have been also one of the important external factors.

The fourth assessment report of the Inter-governmental 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 at this moment, and now we are in the stage of estimating its potential impacts on our society and nature.

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). This study sets out to investigate the possible impacts of climate change in a hydrological view point including water resources and flood producing mechanisms using the output of very high resolution atmospheric model, AGCM20 (20-km in spatial and 1 hour in time resolution). The AGCM20 has been developed and currently tested under 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. The data used in this study is test running output of the AGCM20.

The most realistic and widely used approach to simulate the hydrological impacts of climate change is to combine the output of GCM with a physically based hydrological model that successively descries hydrologic phenomena. In this study, hydrologic models using an object oriented hydrologic modeling system (OHyMoS library; Takasao et al., 1996; Ichikawa et al., 2000) of Kyoto University has set up 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, and, by this reason, these major basins are regarded as the primary concern for the water-related problem under the future climate change condition. The 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.

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. Here, the output has checked with AMeDAS observation data. 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

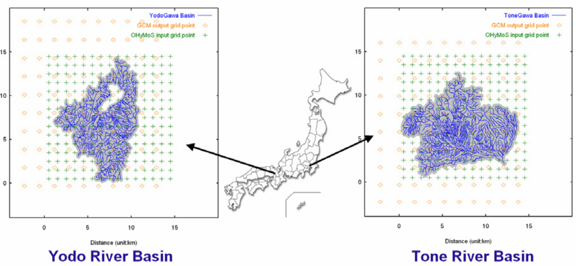
AGCM20 and its output

The hydrologic data used in this study are the output of the 20-km-mesh super high-resolution global atmospheric general circulation model (AGCM20) running on "Earth Simulator". 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 adopts observed monthly mean climatologic sea surface temperature (SST) as a boundary condition for controlled simulations – simulations for the past time using observed atmospheric variables. For the boundary condition of projection simulations, the SST was estimated from the previous AOGCM outputs for the IPCC AR4 (The Fourth Assessment Report of the Intergovernmental Panel on Climate Change). From the model experiment, AGCM20 shows the superiority in simulating orographic rainfall and Baiu frontal rain bands (Kitoh and Kusunoki, 2007).

Hydrologic Modeling System, OHyMoS

To investigate the hydrologic impacts on Tone River and Yodo River basins by the climate change, a distributed hydrologic model shown in Fig.1 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.



Basin	Outlet	Area(km^2)	Characteristics
Yodo River	Hirakata	7,281 (8,270)	Upper basin of Osaka Flood
Tone River	Kurihashi	8,588 (16,840)	Upper basin of Tokyo Flood & WR

Fig.1 Locations of Tone River and Yodo River Basin and the developed channel network for the hydrologic modeling system

3. AGCM20 output analysis

Hydrologic Data Types

Hydrologic data from the AGCM20 are mainly rainfall, snowfall, evaporation and transpiration values, which are for the hydrologic model input for long-term simulations. As shown in Fig.2, each variable are interacting each other upon the soil layer. The values adopted in this study are four variables that come in/out soil layer; (1) through-fall (rainfall) to soil (PRCSN), (2) snowmelt to soil (SN2SL), (3) evaporation from soil (EVPSL) and (4) transpiration from soil root zone (TRNSL), which are all provided in daily resolution. One more variable, precipitation from the atmosphere (PRECIPI) is available in hourly resolution, and this data has utilized when the daily PRCSN data are downscaled into hourly data for the hydrologic model simulations. In other words, the rainfall input data for the hydrologic model has daily PRCSN amounts and hourly PRECIPI shapes.

The PRECIPI variable includes rainfall and snowfall as well, and has a tendency being larger than PRCSN around 0.5~1mm in a day even in non-winter season, which is mainly because of interception loss. Since the SN2SL value specifies snowmelt amount into soil, it is not able to compare day by day the values of PRECIPI and PRCSL+ SN2SL.

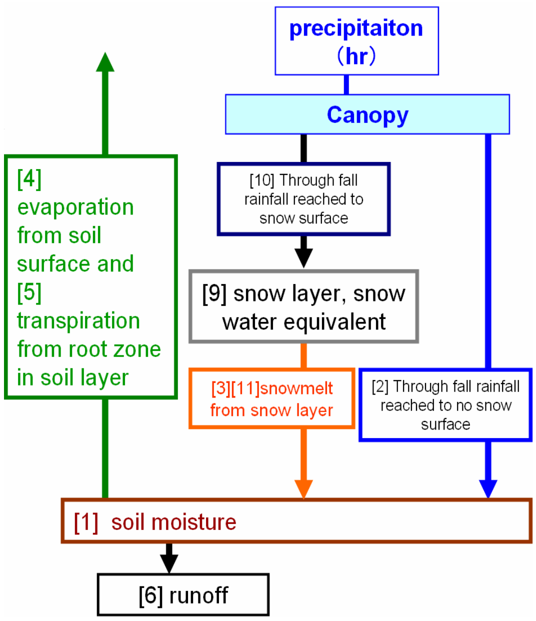


Fig.2 Structure of hydrologic data from AGCM20

Analysis on Tone River Basin

Basin averaged precipitation values on Tone River were calculated from the output of AGCM20. The basin averages is an arithmetic mean of 24 grids of AGCM20 that covers the Tone River basin (see Fig.3). Ten years of present term, 1979~1988, and another ten year for future term, 2075~2084 of the AGCM20 output, (PRCSN, SN2SL, EVPSL and TRNSL) were analyzed in this study.

While the annual precipitation amount into soil (PRCSN+SN2SL) shows slight increase in the future term comparing to the present term, snowmelt amount (SN2SL) shows significant decrease in the future (see Fig.4). 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.

As the annual precipitation amount is expected to increase in the future, annual evaporation and transpiration amount is also to be increase in the future according to the AGCM20 simulation results. Fig.5 shows annual amount changes of the evapo-transpiration (EVPSL+TRNSL) in the Tone River basin. Decadal average of the annual evapo-transpiration of the present term is 500.67mm and for the future term is 596.22mm, which means 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).

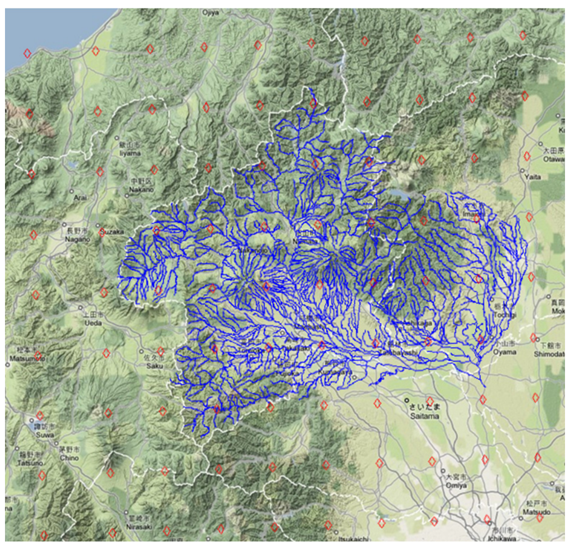


Fig.3 Tone River channel network (blue lines) and AGCM20 output grid points (red marks)

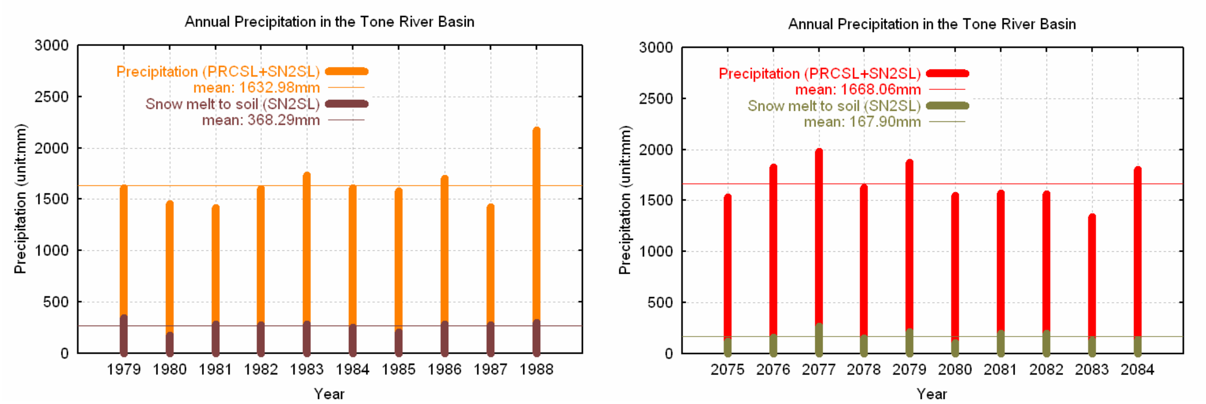


Fig.4 Annual precipitation in the Tone River basin for the present (1979~1988) and future (2075~2084)

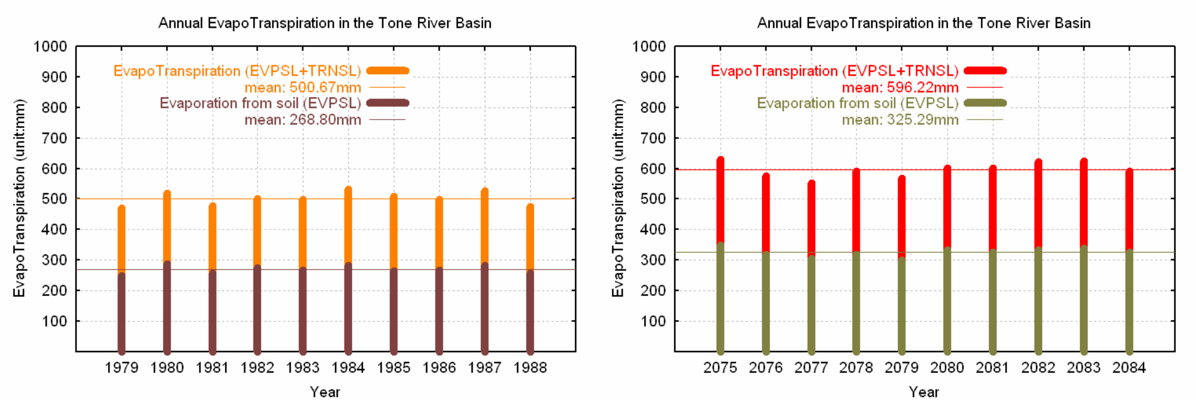


Fig.5 Annual evapo-transpiration in the Tone River basin for the present (1979~1988) and future (2075~2084)

The increase of precipitation and evapo-transpiration as well are 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. However, due to the significant increase of evapo-transpiration amount, net precipitation amount (PRCSL+SN2SL-EVPSL-TRNSL) is to be decreased from 1132.31mm to 1071.84mm in the next century according to the AGCM20 simulation output.

Fig.6 shows monthly variation of precipitation (PRCSL+SN2SL) that are estimated from the decadal average of present term (from 1979 to 1988) and future term (from 2075 to 2084) in Tone River basin. It shows how the seasonal pattern is going to be changed in the future comparing to the present pattern. The most recognizable 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 noticeable 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.

Fig.7 shows monthly variation of evaporation and transpiration (EVPSL+TRNSL) for present and future term. Overall, the monthly pattern of evapo-transpiration of future term has the same pattern to the present term 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.

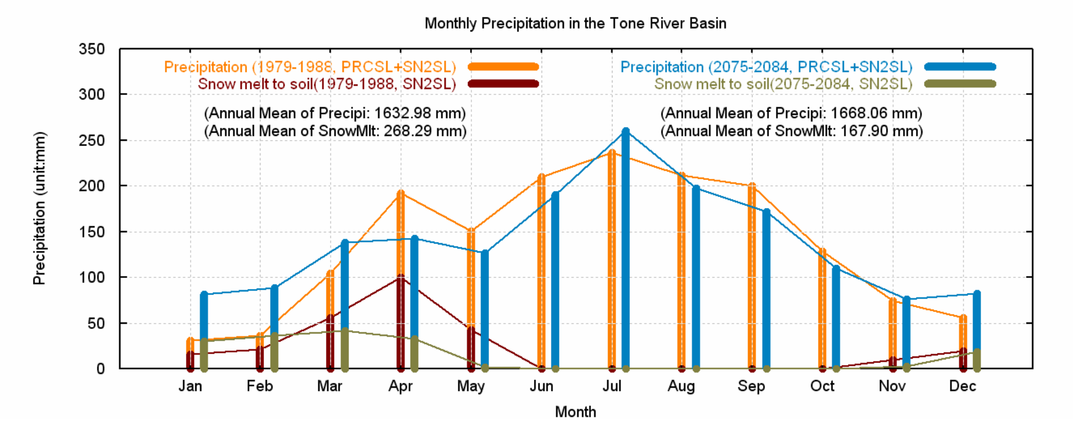


Fig.6 Monthly precipitation pattern of the Tone River basin, decadal average for the present and future

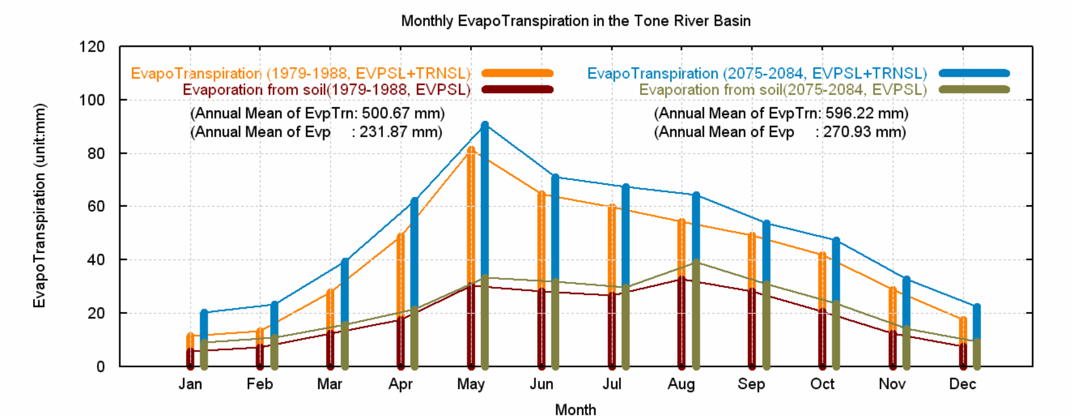


Fig.7 Monthly evapo-transpiration pattern of the Tone River basin, decadal average for the present and future

Analysis on Yodo River Basin

Basin averaged precipitation and evapo-transpiration amounts on Yodo River basin were calculated from the output of the AGCM20. The basin averages is an arithmetic mean of 18 grids of AGCM20 that covers Yodo River basin (see Fig.8). Monthly variation of precipitation and evapo-transpiration can be estimated using the decadal average of present and future, and these are shown in Fig.9 and Fig.10.

As the same to the pattern of Tone River basin, annual precipitation amount shows slight increase in the future and snowmelt amount is decreased as well. Yodo River basin has only small amount of snow (95.79mm annually), however this little amount is going to be decreased down to 15.96mm in the next century. Annual evap-transpiration amount is to be increased in the future. 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 transpiration amount (47.94mm of increase) are about the same.

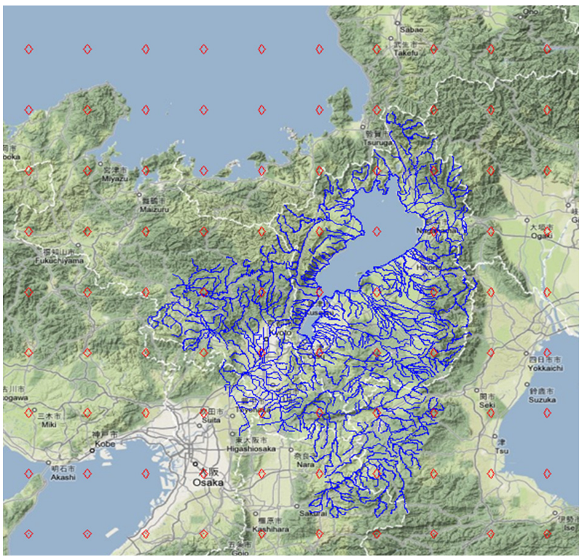


Fig.8 Yodo River channel network (blue lines) and AGCM20 output grid points (red marks)

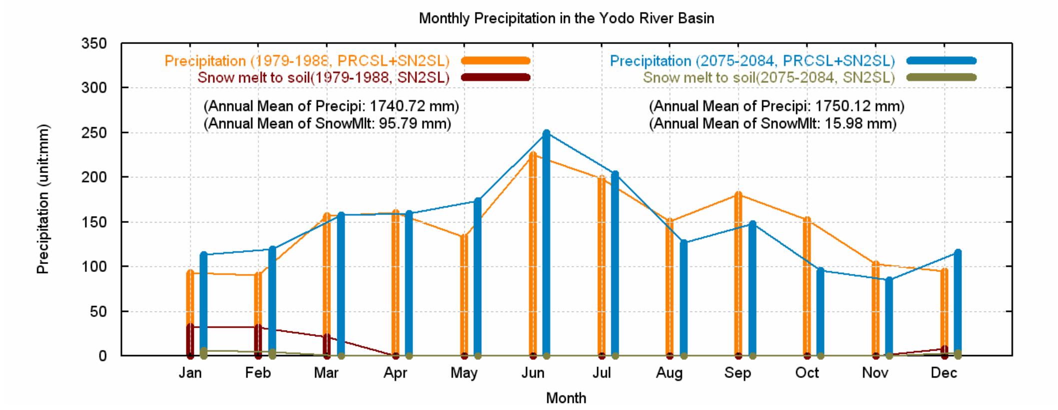


Fig.9 Monthly precipitation pattern in Yodo River basin, decadal average for the present and future

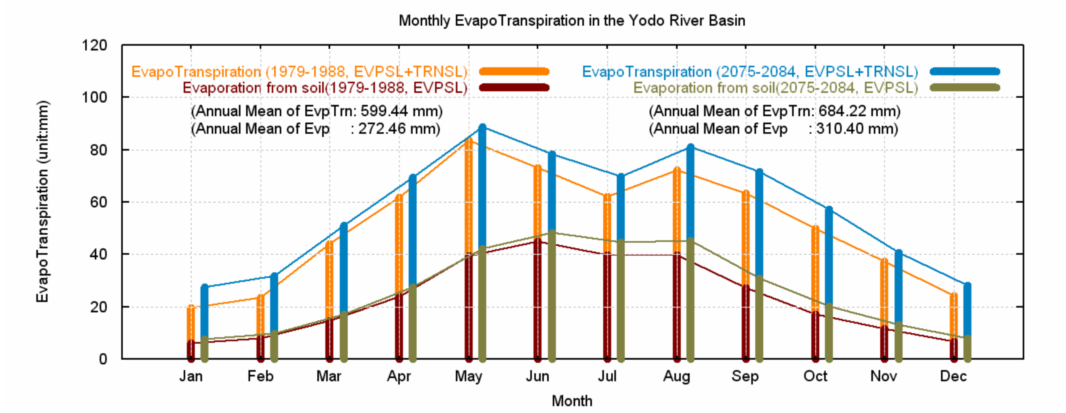


Fig.10 Monthly evapo-transpiration pattern in Yodo River basin, decadal average for the present and future

Monthly precipitation in Fig.9 shows how the seasonal pattern is going to be changed in the future comparing to the present pattern. Recognizable changes are the increased rainfall in winter season (from December to February) and the concentrated rainfall in June and July. There are two distinct rainy terms in Japan; Baiu rainy season in June and typhoon season in September. This distinction is to be disappearing somehow in the future and more rainfall seems to be concentrated in the early summer season. It seems the climate of Japan will change into subtropical one as the global temperature increase.

As shown in Fig.10, monthly pattern of the evapo-transpiration in the future term has the same pattern to the present term with increased amount. Due to significant increase of evapo-transpiration amount, net precipitation amount (PRCSL+SN2SL-EVPSL-TRNSL) seems to be decreased from 1144.28mm to 1065.90mm in the next century according to the AGCM20 output.

4. Runoff Simulation with a Distributed Hydrologic Model

Using the distributed hydrologic model, runoff simulations on Tone River and Yodo River were carried out. The simulation for each term, the present term and the 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.

Before the runoff simulation using the data of AGCM20, the hydrologic model has been calibrated using observed discharge data. And the same parameter set was applied for both the present term and future term runoff simulation. At the moment when the runoff simulations carried out, uniform parameter set was prepared on Tone River basin. However, the parameter set is to be updated and spatially distributed one will be prepared in the next simulations.

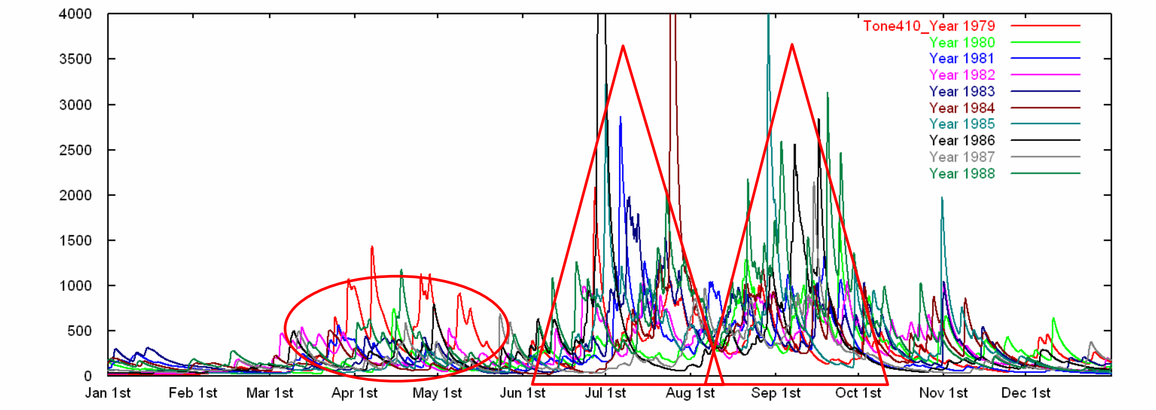


Fig.11 Runoff simulation results at Kurishashi, Tone River for the present term

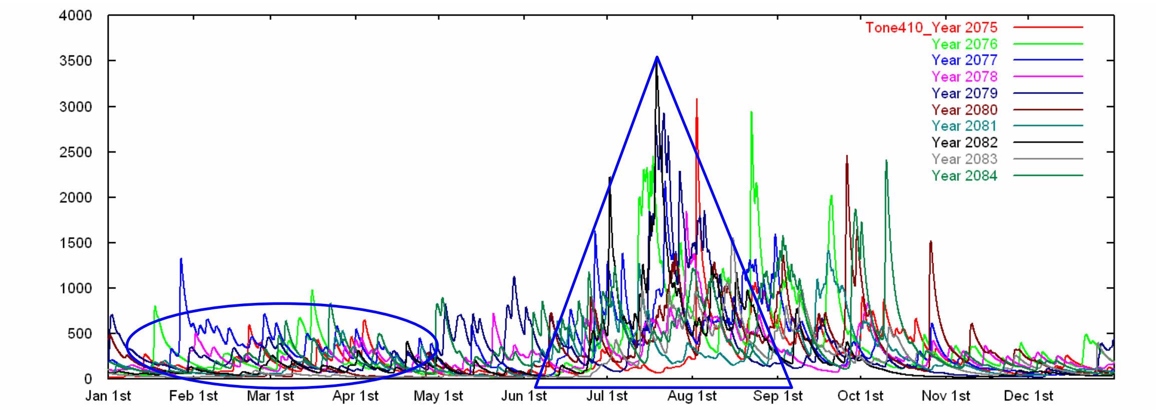


Fig.12 Runoff simulation results at Kurishashi, Tone River for the future term

Fig.11 and Fig.12 show the runoff simulation results at Kurihashi station, Tone River, which were carried out with AGCM20 output of the present term and the future term. From the runoff simulation results, it is clear that the change of snowmelt pattern in the future gives apparent effect on the runoff simulation results. See the red elliptical mark in Fig.11 that shows the runoff simulation results for the present term. The runoff of March and April of the present term is mainly by the snowmelt. However, this runoff has diminished and will be distributed all over the winter and spring season in the future (see blue elliptical mark in Fig. 12).

Another noticeable change in the runoff is concentration of peak discharges in summer season. The peak runoffs of present term have concentrated in two main terms (see two red triangle mark in Fig.11); one is in July and the other is in September, which is because of the rainy season and the typhoon season of Japan, respectively. However, the runoffs of the future term do not show this distinction and merged in one rainy season (see blue triangle mark in Fig.12). The reason is not clear at this moment, and more scrutinized inspection should be followed to find the cause and its effect in future hydrologic system.

From this runoff simulation results, it is hard to find increased flood risk in Tone River basin. However, it is clear that the climate change gives an effect on the runoff pattern. Any change in runoff pattern is an important issue on water supply problems. It is necessary to check more details to figure out what kinds of changes and how much of changes will be there under the future climate system. Moreover, the hydrologic model is under upgrading and distributed parameter set will be estimated for Tone and Yodo River basin, and it will be able to provide more detailed and accurate runoff simulation results.

5. Concluding Remarks

Results Analysis

This paper shows brief analysis with the AGCM20 output and the runoff simulation results, and the 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 might be not proper to extract any concrete result or conclusion at this stage. However, it is worthwhile to summarize the current results, which will be useful to our further research direction.

From the previous analysis and simulations, several points that we noticed on 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 this change is not significant as the Tone River basin case (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 (4) peak runoffs of present term have concentrated in two main terms, in rainy season and typhoon season, but this distinction of peak runoff concentration will be merged in one long rainy season in the future.

Further Research Directions

This study has been carried out with limited AGCM20 output, and more AGCM20 output are available soon; 25 years for each present, near-future and future term. Based on enough data availability, this study will extend its direction and strengthen its methods in several points. And the first thing is to check the reproducibility of the AGCM20.

Even though we have very much improved technology and computer resources, however, 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.

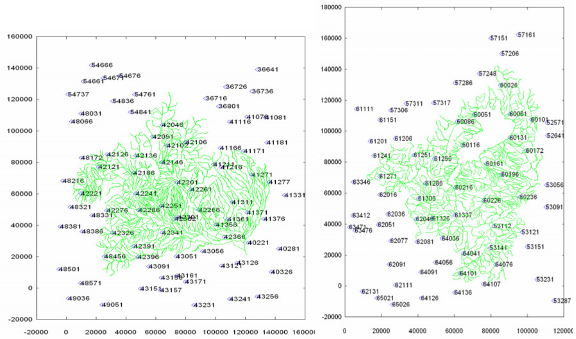


Fig.13 Locations and ID codes (5-digit numbers) of AMeDAS gauge stations on Tone River (left) and Yodo River basin (right)

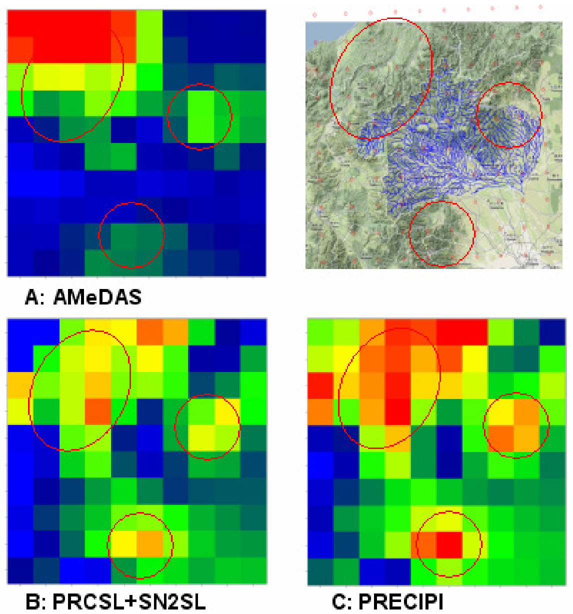


Fig.14 Spatial pattern of annual precipitation by AMeDAS data (up-left), by PRCSL+SN2SL (down-left) and by PRECIPI (down-right) on Tone River basin,

With the awareness of this fact, first of all, the reproducibility of ACGM20 should be checked using the controlled simulation output. The controlled simulation output of the ACGM20 can be approved when it is compared with the historic observation, on such the items as precipitation, snow and evaporation. If there is any critical bias between the AGCM20 output and the historic observation, it should be corrected as much as possible. And this bias also should be considered for the output of projection simulation.

One of reliable and enough data source for historic observations is the AMeDAS data of

Japan Meteorological Agency (JMA). Fig.13 shows the AMeDAS gauge stations on Tone and Yodo River basins with station code-numbers. To utilize this AMeDAS data in reproducibility checking of the AGCM20 output data, the point gauged observed data should be converted into the 20km×20km grid data. Firstly, Tone River basin data have been modified and compared with the AGCM20 output, PRCSL+SN2SL and PRECIPI values.

Fig.14 shows the comparison of the spatial pattern of annual precipitation from AMeDAS data and the two data set of AGCM20 output. Through this brief comparison, it was found that AGCM20 output shows over-estimated values to the observations; annual precipitation estimated from the PRECIPI values are 25% larger than the observed historic annual precipitations, and PRCSL+SN2SL values shows around 13% of over-estimations. On the other hand, annual daily maxima values from the AGCM20 shows smaller amount compared to the historic observations. Since there is noticeable bias in the AGCM20 output, it is necessary to correct or decrease the bias before the data are applied in the hydrologic model simulations.

The other important point to be considered is on the hydrologic model operations. It includes model calibration and proper model composition on a large-scale basin. For any type of large-scale basin, the model calibration is a complex and therefore a time consuming work. However, only a successful model calibration gives a guarantee for the believable simulation results. There are 7 main dams in Tone and Yodo River basin. Some of them are for flood control and some are for water supply purpose. This dam functions are also to be included in the hydrologic model system for the next simulations.

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超高解像度大気モデルの結果を利用した利根川と淀川流域の温暖化インパクト予測

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要　旨

治水施設の能力や管理施策が将来に渡って有効に機能するかを分析するために　温暖化時の水文気象予測情報を河川流量に変換するための分布型流出予測モデルを構築する。従来　温暖化時の治水・利水リスク評価は降水量から得た統計量の変化を分析することに焦点が当てられてきた。しかし　特にわが国のように水工施設が高度に流況を制御している河川流域においては、降水量の分析だけでは不十分で　河川流量の変動を分析してはじめて　温暖化が当該流域の治水や利水にどう影響する可能性があるかを分析することができる。本研究ではOHDISという水文モデルを用いて　わが国の中でも特に高度に流況が制御され　かつ地域社会・経済に大きなインパクトをもつ淀川流域（枚方上流7,281 km2）　利根川流域（栗橋上流8,588 km2）を対象とする。

キーワード:　超高解像度大気モデル，分布型流出予測モデル，温暖化，インパクト評価