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PRECIPITATION CHANGES IN JAPAN UNDER THE A1B CLIMATE CHANGE SCENARIO

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Output of a super-high-resolution atmospheric general circulation model was analyzed to understand changes of precipitation pattern over Japan in the coming century. AGCM20 output, which is providing climate condition of near-future (2015~2039) and future term (2075~2099) under the A1B scenario, shows that annual precipitation increase slightly (2~5% in the most region) in the next century and more increases in summer season. However, evapo-transpitation amount is also likely to be increased in the future, thus net-water-resources in most regions beside Kyushu and Hokkaido is going to be decreased down to -5.7%. Analysis on extreme event changes are given, and several limitations and characteristics on the AGCM20 precipitation output are discussed.

Key Words: *Climate change, Japan, AGCM, precipitation, seasonal pattern, extreme events*

1. INTRODUCTION

Rapid evolution of general circulation models (GCMs) in the last three decades allows us to expect reasonable hydrologic dataset from the model output. In 2007, Japan's Ministry of Education, Culture, Sports, Science, and Technology (MEXT) launched the Innovative Program of Climate Change Projection for the 21st Century (Kakushin21), and have developed a super-high-resolution atmospheric model having 20-km spatial and 1-hour temporal resolution (hereafter AGCM20). This is the finest resolution output available by the time this paper is written. The AGCM20 provides two terms of future projection run output based on the A1B climate change scenario, which are near-future term (2015~2039) and future term (2075~2099). The controlled run using an observed sea surface temperature (SST) provides the present term (1979~2003) atmospheric data[1), 2), 3)]. The AGCM20 has finished producing its first run output in 2009, and is preparing for the second run.

This paper provides preliminary analysis results on the precipitation output using the first run output of the AGCM20. Firstly, the controlled simulation output was evaluated using the AMeDAS observed precipitation data to check the reproducibility of the model. Recoding duration of the AMeDAS data is covering the controlled run period with very fine observation network, thus it may provide reasonable index to evaluate the AGCM20 precipitation output.

Secondly, changes of future precipitation pattern in Japan were examined using the AGCM20 output. The evaluation was fulfilled simply by comparing the present term output and the near-future (future) term output, and it is focusing on two points, water resources change and extreme events change.

Lastly, this paper describes some characteristics and limitations of the AGCM20 output according to the analysis results given in this paper as well as the previous studies of Kim et al.[4)] and Takara et al.[5)]. The information can be useful for possible future users who want to carry out hydrological impact analysis research with the AGCM20 output data.

The organization of this paper is as follow: Section 2 describes about the AGCM20 output data including description on the model and simulation conditions. Evaluation on the controlled simulation output (1979~2003) is also given in this section. Section 3 provides examination results on the projection run output, and illustrates precipitation changes in Japan focusing on seasonal variation and extreme events. Section 4 describes several characteristics and limitations of the AGCM20 output, and the last section concludes this paper with summarizing the analysis results.

2. AGCM20 OUTPUT

(1) Super-High Resolution Atmospheric Model

AGCM20 is the state-of-the-art atmospheric model in a sense of its fine resolution. The model conducts simulation using triangular truncation at wave number 959 with a linear Gaussian grid (TL959) in the horizontal based on 1920 × 960 grid cells about 20 km in size and 60 levels in the vertical. Test running results during the model development showed advantages in simulating orographic rainfall and frontal rain bands by its very fine spatial resolution[2].

AGCM20 uses the HadISST1 dataset[6] as observed monthly mean climatologic sea surface temperature (SST) for a boundary condition of the controlled simulation. HadISST1 provides global sea ice and sea surface temperature (GISST) datasets from 1871 uniquely combining monthly, globally complete fields of SST and sea ice concentration on a 1° latitude × 1° longitude grid[6]. Future SST for the projection simulation was estimated from the ensemble mean of GCM simulation output under the A1B emission scenario[7] from the model output of the Coupled Model Intercomparison Project Phase 3. According to the A1B scenario of Special Report on Emissions Scenarios (SRES)[7], IPCC, the global average temperature is expected to increase 2.5°C and the CO_2 concentration to become 720 ppm by 2100. The A2 scenario that was based on the RCM20 of the Kyousei program was expecting 860 ppm of CO_2 concentration by 2100.

To provide more realistic condition in the AGCM20 projection simulation, ensemble mean of the SST was additionally composed with an annual variation of the current HadISST1 SST. Refer to Mizuta et al.[1] and Kitoh and Kusunoki[2] for details on AGCM20 and Kusunoki and Mizuta[3] for simulation environment details.

(2) Evaluating the Controlled Simulation Output using the AMeDAS Observation Data

Reliance on GCM output, especially on the projection run output can be achieved through an evaluation of the model reproducibility for the current climate condition. Before the projection output was analyzed in this paper, the 25 years of controlled run output of AGMC20 was evaluated using the AMeDAS observation data. For a reasonable comparison, the point-gauged AMeDAS data was converted into the 20-km grid-based spatially averaged data as the AGCM20 output format. Inverse-distance weighting factor method was adopted for the AMeDAS data conversion.

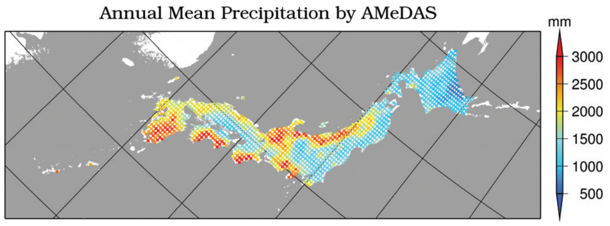

Fig. 1(a) Annual mean precipitation of Japan, observed by the AMeDAS (1975~2003) and converted into 20 km grid data, showing 1684.3mm of mean value.

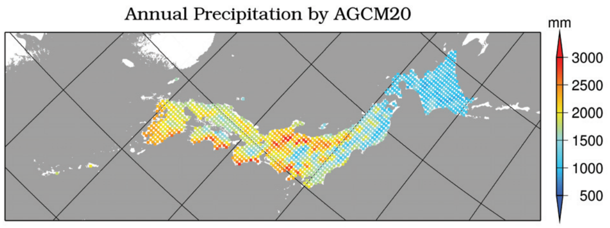

Fig. 1(b) Annual mean precipitation from the controlled run output (1975~2003) of the AGCM20. It shows 0.78 of spatial pattern correlation to the observation, and the mean annual precipitation is 1703.8mm.

First of all, annual mean precipitation was estimated from the converted AMeDAS observation data and the AGCM20 output data (see **Fig. 1**). According to the AMeDAS observation, annual mean precipitation during 1979 and 2003 is 1684.3 mm, and the AGCM20 output shows 1703.8 mm of annual mean for the same duration, which shows very good consistency. Spatial distribution pattern of the annual mean precipitation also shows considerably good match between the AGCM20 output and the AMeDAS observation, showing 0.78 of pattern correlation.

Winter precipitation such as heavy snowfall in Hokuriku mountainous area along the northern seashore of Kanto and Tohoku region is showing successful reproducibility. Summer heavy rainfall in Kyushu, Shikoku and Kansai region, which is mostly due to frontal rain-band and Typhoon, is also well presented in the model output. However, it is noticeable that the clear spatial pattern of the observed precipitation is presented in somewhat smoothen way in the AGCM20 precipitation output. It is mainly because of topographic information in the AGCM20, which also has 20-km spatially averaged elevation values. The 20-km resolution topographic data has rather flattened shape comparing to the original topography. Even though there is several physical parameterization schemes are applied in the AGCM20 to properly consider the influence of flattened sub-grid scale topographic data[1], the performance of the atmospheric model still shows some limitations. However, the model performance is an encouraging result considering that the output is from a global atmospheric model.

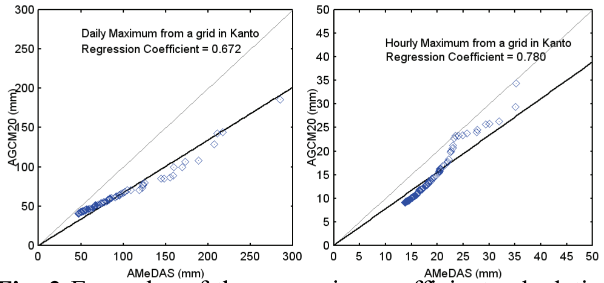

Fig. 2 Examples of the regression coefficient calculation with the daily and hourly maximum precipitation values of the AGCM20 output and the AMeDAS.

Reproducibility of daily and hourly maximum precipitation of each grid was evaluated by checking 100 maximum precipitation of the AGCM20 controlled run output and the AMeDAS observed one within the same period. The 100 maximum values of daily and hourly precipitation were selected by choosing 4 maximum values of each year during 25 years. As shown in **Fig. 2**, a regression coefficient was calculated using one pair of 100 maximum values on each grid. Desirable reproducibility on the extreme value will be showing 1.0 regression coefficient. If it is less than 1.0, it means that the AGCM20 output has generally underestimated extreme values compared to the observation and vice versa. Regression coefficient is depending on the choosing sample numbers however, this simple evaluation method provides direct and clear understanding on the overall model performance related to extreme values.

From the **Fig. 3**, which expresses the regression coefficients on each grid, it is very clear that the AGCM20 output has underestimated daily and hourly maximum in most part of Japan. The same characteristics on the controlled run output of the AGCM20 was also found in detailed analysis of Takara et al.[5] using the precipitation output data over the Tone River basin. This underestimation on the extreme precipitation values reveals that the 20-km spatial resolution might be still insufficient to simulate sophisticated sub-grid scale orographic rainfall.

To understand the model performance on seasonal variation, monthly mean precipitation was estimated, and correlation of each month's spatial distribution pattern were calculated (see **Fig. 4**). Except the late summer season, from July to October, the AGCM20 precipitation output shows very high performance level. The reason of the low spatial pattern matches in the late summer season is due to difficulty in the simulation of unstable atmospheric conditions in summer season.

3. CHANGES IN PRECIPITATION PATTERN AND ITS AMOUNT

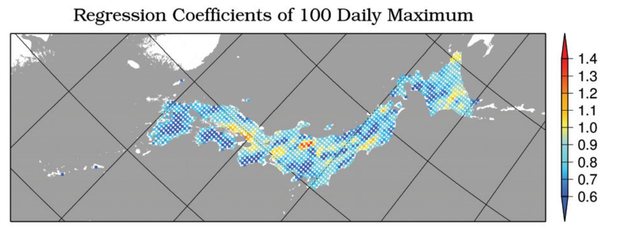

Fig. 3(a) Regression coefficient of 100 daily maximum precipitations from the AGCM20 controlled run output to the AMeDAS observed one.

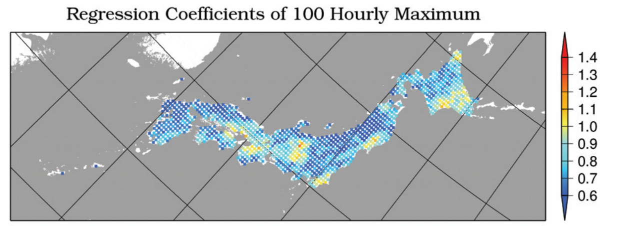

Fig. 3(b) Regression coefficient of 100 hourly maximum precipitations from the AGCM20 controlled run output to the AMeDAS observed one.

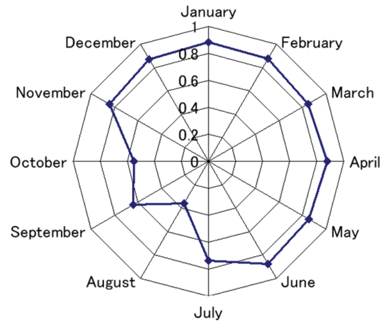

Fig. 4 Spatial pattern correlation of AGCM20 monthly mean precipitation to the AMeDAS observation. Summer season shows lower spatial pattern matches.

Based on the evaluation results on the controlled simulation, it was able to understand that the model shows considerably good performance and provide reliable precipitation output, even though it has some limitations in some aspects. In this section, the overall analysis on the projection simulation results is given using the near-future and future term output of the AGCM20 model. Analysis on water resources is firstly given, and then analysis on the extreme event is provided.

(1) Seasonal Pattern

Annual mean precipitation amount of the near-future term and future term were calculated and changing ratios of those amount compared to the present term output are shown **Fig. 5(a)** and **5(b)** with percentage unit. In the near-future term, most regions in Japan show increased annual precipitation amount and this increasing will be more apparent in the future term. The most significant changes are there in Hokkaido with 6.1 % and 10.6% of increase in the near-future and future term, respectively. The Kanto region is showing rather mild changes with 1.8% and 2.0% of increases in the respected terms.

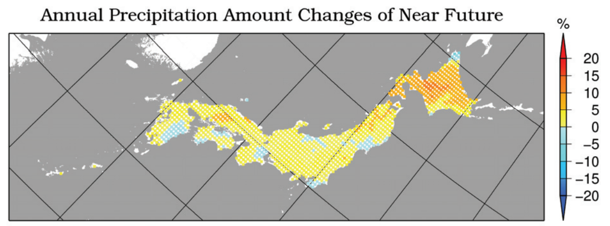

Fig. 5(a) Annual precipitation amount changes in <u>near future</u> compared to present (both are AGCM20).

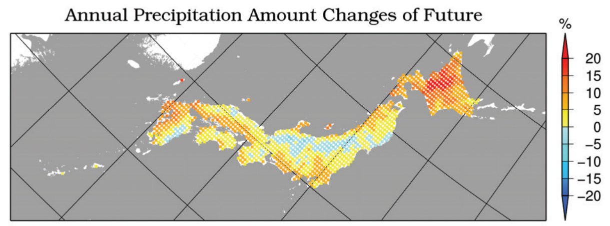

Fig. 5(b) Annual precipitation amount changes in <u>future</u> compared to present (both are AGCM20).

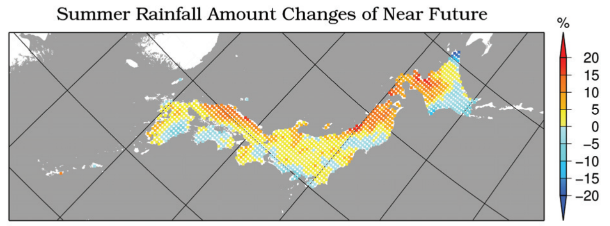

Fig. 6(a) Summer (Jul~Sep) rainfall amount changes in <u>near future</u> compared to present.

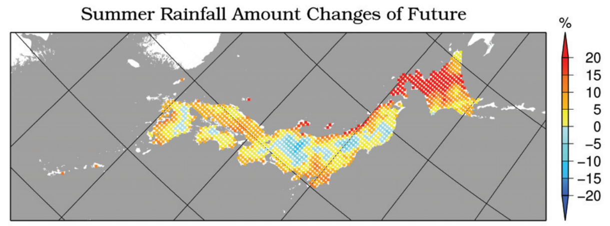

Fig. 6(b) Summer (Jul~Sep) rainfall amount changes in <u>future</u> compared to present.

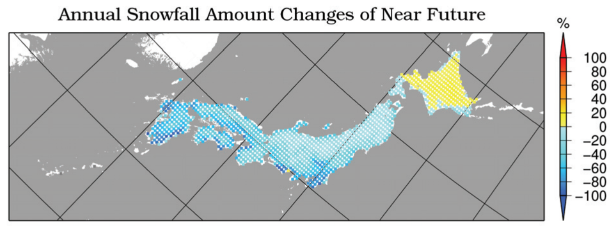

Fig. 7(a) Snowfall amount changes in <u>near future</u> compared to present.

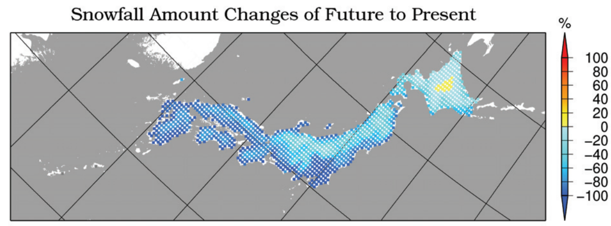

Fig. 7(b) Snowfall amount changes in <u>future</u> compared to present.

Summer season rainfall amount during July and September (see **Fig. 6(a)** and **6(b)**) shows more severe changes, but with similar spatial pattern of the annual mean precipitation changes. Winter snowfall amount is going to be decreased according to the AGCM20 projection simulation output (see **Fig. 7(a)** and **7(b)**). Snowfall amount in the regions between Kyushu and Kansai becomes negligible in the near-future, and most regions in Japan, except Hokkaido, show significant decrease of snowfall in the next century. Hokkaido area also shows some decreased winter snowfall (17.8% of decrease in the future term, however, some inland area of Hokkaido shows increased snowfall due to increased water vapor in the atmosphere.

Not only for the precipitation, but also evapo-transpiration loss was examined using the AGCM20 output data. The model provides the information of evaporation and transpiration amount from the soil layer. According to this information, net-water-resources amount of each region were estimated and presented in **Table 1**. Many previous studies have predicted that climate change would affect the hydrologic cycle in a way of accelerating the current water cycle with more precipitation and more evapo-transpiration[8]. AGCM20 output for the near-future and the future term also show this kind of water cycle change in a manner of increased precipitation and evapo-transpiration as well.

Table 1. Net-water-resources amount in each region (annual amount averaging 25 years)

Region	**Present** (unit: mm)	**NearFuture** (changes: %)	**Future** (changes: %)
Hokkaido	607.6	648.2 (6.68)	645.2 (6.19)
Tohoku	834.4	838.0 (0.43)	789.7 (-5.72)
Kanto	1038.5	1043.7 (0.50)	1002.0 (-3.51)
Chubu	1359.4	1369.0 (0.71)	1296.7 (-4.61)
Kinki	1173.4	1180.1 (0.58)	1152.7 (-1.76)
Shikoku	1268.1	1256.5 (-0.91)	1254.3 (-1.09)
Chugoku	1041.4	1091.4 (4.80)	1063.8 (2.15)
Kyushu	1263.1	1264.8 (0.14)	1290.9 (2.20)
Japan	**1010.1**	**1027.25 (1.70)**	**997.79 (-1.22)**

As a result, available fresh water resources in some regions of Japan, such as Chubu, Kanto and Tohoku is expecting 3~5% of water resources decrease. Drought index investigation in the Tone River basin also showed that the area has higher possibility of mild but long duration of water shortages in the future[5].

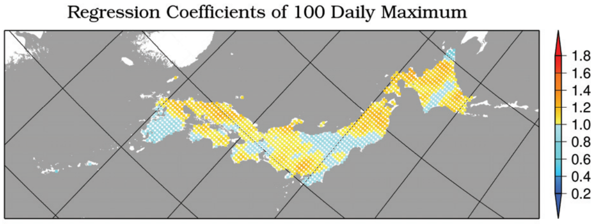

Fig. 8(a) Regression coefficients of <u>near future</u> to present using 100 **daily** maximum values of each grid.

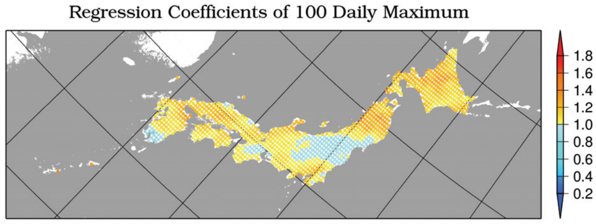

Fig. 8(b) Regression coefficients of <u>future</u> to present using 100 **daily** maximum values of each grid.

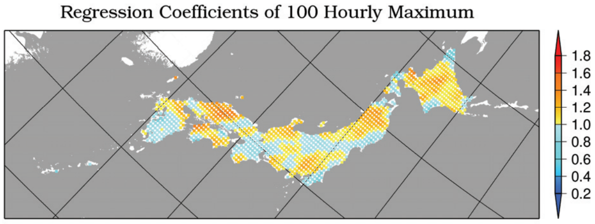

Fig. 9(a) Regression coefficients of <u>near future</u> to present using 100 **hourly** maximum values of each grid.

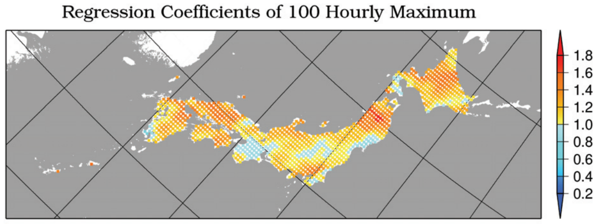

Fig. 9(b) Regression coefficients of <u>future</u> to present using 100 **hourly** maximum values of each grid.

(2) Extreme Events

To understand the possible changes in extreme event in the future, the regression analysis method, which was introduced in the section 2.2, is utilized again using the near-future (future) term maximum precipitation and the present term maximum values. Regression coefficient of 100 (= 4maximum× 25yrs) daily (hourly) maximum values from the near-future (future) and the present term on each grid was calculated and presented in **Fig. 8** (**Fig. 9**).

From the results, it is able to see that the change of extreme events of future is showing regional dependency. Chugoku and Shikoku region shows apparent increase of daily and hourly maximum in the near-future and the future term as well. Also Hokkaido shows increased maximum events in the future. However, Kanto and some part of Tohoku region shows decreased maximum events in both near-future and future term. Analysis on the Tone River basin using the river discharge, which was estimated using the AGCM20 data through a distributed hydrologic model, was also showed mildly decreased peak flow in the future[9].

However, it should be noted here that the maximum data is highly affected by several extreme conditions within the analyzing durations. Even though the regression coefficient analyzing method was introduced to avoid undesirable effect by several abnormally extreme events, such as typhoon events, still it is not confident enough to decide whether the analysis results are expressing generalized changing pattern of future extreme values. Understanding that the model provides just one possible climate behavior under the designed climate change scenario, it is highly desirable to handle several GCM or ensemble simulation output to achieve more confident extreme event analysis.

4. UNDERSTANDING AGCM20 OUTPUT

(1) Scale Variant Reproducibility

GCM output becomes more valuable information to hydrologists when the atmospheric data is converted into river discharge data through a reasonable hydrologic model. The presenting AGCM20 output was converted into river discharge data in the previous study of Kim et al.[4)9)], and surveyed water resources change in the Tone River basin considering dam reservoir operation. In the study, severe bias of AGCM20 was a big problem in the Yagisawa dam basin (167 km^2 of basin area). However, the bias level was alleviated when the analyzing area is getting larger. As shown in **Fig. 10**, simulated discharge for the Yattajima gauging point (covering basin area is 5,134 km^2) in the Tone River basin shows good coincide with the observed discharges. Considering that the covering area of one grid of the AGCM20 output is around 400 km^2, it is able to understand that the AGCM20 output (at least the precipitation output) shows high reproducibility when it is analyzed on a large basin scale. More details on the scale variant reproducibility are given in Kim et al.[9)].

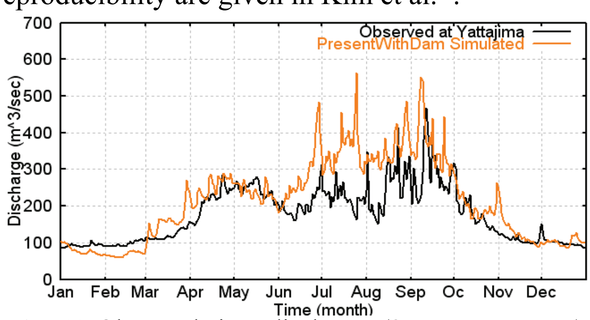

Fig. 10 Observed river discharge (25 years average) at the Yattajima st. of the Tone River and simulated discharge using the AGCM20 controlled run output

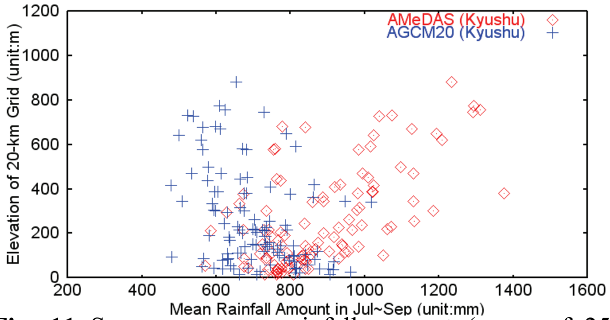

Fig. 11 Summer season rainfall amount (mean of 25 years) in Kyushu, corresponding to 20-km grid elevation. AGCM20 controlled run output was not able to show high correlation with elevation.

(2) Smoothen Orographic Effects

Orographic effect and elevation dependency of precipitation is well known phenomena, especially in mountainous area of Japan[10),11)]. As it was already explained in section 2, the AGCM20 output shows a limitation to simulate clear orographic effects mainly due to its 20-km resolution topographic data. As another proof of this limitation, the AGCM20 precipitation output shows low dependency on topographic elevation, as shown in **Fig. 11**. The figure shows mean rainfall amount during summer season (July~ September) in Kyushu, corresponding to the elevation information of 20-km grid in the AGCM20. While the AMeDAS observed rainfall amount shows clear dependency on elevation (even though it is spatially averaged within the 20-km grid), the AGCM20 output was not able to show reasonable elevation dependency of precipitation. One who wants to carry out hydrologic impact analysis using the AGCM20 output on a certain mountainous area should consider this characteristics in his/her analysis.

5. CONCLUING REMARKS

This paper provides analysis results on the precipitation output from the AGCM20. The controlled run output was firstly evaluated using the AMeDAS observed data, and reproducibility of the model was discussed in two aspects, seasonal and spatial pattern of precipitation and extreme events. The model performance was generally good and it provides reasonable output, and thus it is good enough to understand future precipitation changes.

Changes of future precipitation pattern show slight increases (2~5%) of annual precipitation and more increases in summer season. Evapo-transpitation is also likely to be increased in the future, thus net-water-resources in most regions, except Kyushu and Hokkaido, is going to be decreased down to -5.7%. A simple method using a regression coefficient was introduced to understand overall extreme event patterns. According to the analysis, future extreme events seem to be increased in most regions except some inland part of Kanto.

Spatial scale dependency of the model performance and drawbacks due to 20-km spatially averaged topographic information in the model are also discussed. Further research is under processing to achieve complete understanding on the model performance related to the sub-scale orographic effects in the AGCM20.

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