PREDICTION OF FUTURE RAINFALL VARIATIONS DUE TO GLOBAL WARMING IN THE KYUSHU ISLAND BY LARGE ENSEMBLE EXPERIMENTS

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ABSTRACT

According to the IPCC Fifth Assessment Report, the intensity and frequency of concentrated torrential rain due to global warming will increase. Since the increase in torrential rain is most likely to have a big influence on human society, high accuracy prediction is necessary. However, in the previous prediction database, there are not enough ensemble number of the predictions for probabilistic evaluation of the uncertainty associated with extreme weather. Therefore, in this study, I used a large scale ensemble climate prediction database d4PDF composed of numerous ensemble experiment data. By analyzing d4PDF, I attempted to verify the probabilistic evaluation of future predictions and the changes of extreme weather which is low-frequency and local-scale events. I used the regional experimental results in d4PDF which covers the entire Japan. I analyzed the data for 2,500 years of past experimental data and the data for 5,400 years of the 4°C rise experiment data and the data for 3,240 years of the 2°C rise experiment data in Kyushu Island. About annual total precipitation, I compared real data with past experimental data and confirmed that the 1 hour precipitation has a bias in the model and the 48 hours precipitation has no model bias. For the probability evaluation of torrential rain in entire Kyushu, I used the general polar of distribution. The conclusion is that the total annual precipitation will increase in entire Kyushu due to the effect of global warming, and both the intensity and frequency of torrential rain will increase. In addition, about the change in torrential rain, there are regional differences in the change of torrential rain - the precipitation is relatively small in the northern Kyushu, but it is large in the southern Kyushu.

Keywords: *global warming, d4PDF, model bias, heavy rain, Kyushu Island*

1. Introduction

According to the Intergovernmental Panel on Climate Change (IPCC) Fifth Report1), Human activity continues to affect the Earth's energy budget through changes in land surface properties and changes in atmospheric concentrations caused by emissions of gases and aerosols that are important in thermal radiation. This indicates that it is likely that various types of climate change are already occurring. Regarding the rainfall targeted in this study, it has been concluded that the area where the number of strong precipitation events has increased since about 1950 on land is more likely to be higher than the area where the number of strong precipitation events has decreased. Therefore, it is highly probable that extreme rainfall will increase in the future. In order to evaluate the impact of global warming on precipitation and to formulate efficient and effective flood adaptation measures, it is essential to predict climate change and quantitatively evaluate the uncertainties involved. The recently developed ensemble climate prediction database (database for Policy Decision making for Future climate change, hereafter d4PDF) 2), which contributes to global warming countermeasures, can statistically evaluate the frequency and intensity of precipitation by performing a number of ensemble experiments. To date, many researches and projects utilizing the d4PDF4 ℃ rise experiment have been progressing, and much knowledge has been obtained. For example, Hoshino and Yamada 3) analyzed the change in average basin rainfall after a rise of 4 ° C in the first-class river basin in Japan, and found that average rainfall increases and the rate of change varies by region. Kuzuba and Senda 4) used d4PDF to calculate the spatial distribution of 1 hour precipitation with a 100-year recurrence interval, and showed that the values tended to increase in western Japan and the Pacific Ocean. Hoshino *et al.* 5) applied mechanical downscaling data of d4PDF to two basins in Hokkaido and showed that spatiotemporal concentration of rainfall within the same basin became significant after warming. Uemura *et al.* 6) also analyzed the two basins in Hokkaido and showed that the annual maximum rainfall in the basin for 24 hours and 72 hours increased about 1.4 times. On the other hand, there are few examples of analyzes on changes in precipitation and flood risks using the results of the d4PDF2 ° C rise experiment 7) published in August 2018. The 2 ° C rise experiment reproduces the “near-future” climatic conditions in the mid-21st century, rather than the RCP8.5 scenario in which the greatest temperature rise is expected to take place. It is very important to know how much the flood risk is increasing at this stage in considering future adaptation measures. In addition, by comparing the results of the 2 ° C rise experiment and the 4 ° C rise experiment, it would be indirectly possible to know the effect of global warming mitigation measures on flood risk reduction. Furthermore, the Kyushu region faces the Sea of Japan, the Pacific Ocean, the East China Sea, and the Seto Inland Sea, and has various climatic characteristics due to the central Kyushu Mountains 8), and the effects of global warming are complicated. However, there are few analysis carried out. Therefore, this study focuses on the Kyushu region, where many flood disasters have already occurred, and examines the characteristics of rainfall change after warming using d4PDF 4 ° C rise experiment and 2 ° C riseexperiments.

2. Data and method

d4PDF consists of a global experiment using the Meteorological Research Institute Global Atmosphere Model MRI-AGCM3.2 with a horizontal resolution of about 60 km and a regional experiment using the Meteorological Research Institute Regional Climate Model NHRCM with a horizontal resolution of about 20 km. In this study, analysis was performed using the results of the latter regional experiment covering Japan. The seawater temperature as the boundary condition gives the results of the six models (CCSM4, GFDL-CM3, HadGEM2-A0, MIROC,

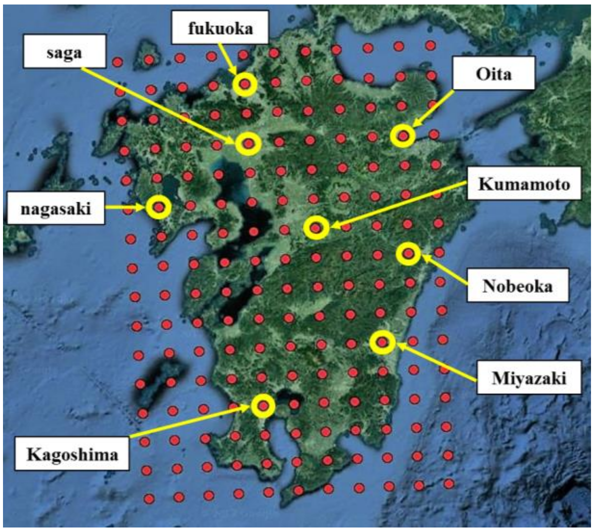


Figure1 Analysis target area

MPI-ESM-MR, MRI-CGCM3) used in the fifth coupled model intercomparison plan CMIP5. The red dots in Figure1 shows the analysis target points of d4PDF used in this study. Of these, grid points on land are analyzed, and those on the sea are excluded from rainfall analysis points.

In this study, we used four datasets from d4PDF: (1) past experimental data, (2) 2 ° C rise experiment data, (3) 4 ° C rise experiment data, and (4) actual measurement data from the Meteorological Agency AMeDAS. The past experimental data is a data set obtained from experiments reproducing past climates, the 4 ° C rising experimental data is a data set obtained from experiments expressing a climate in which the global average surface temperature rose 4 ° C compared to before the Industrial Revolution, The experimental data of 2 ° C rise is a data set obtained from an experiment expressing a climate in which the global average surface temperature rises 2 ° C compared to before the Industrial Revolution. In this study, 2500 years of past experiments in the Kyushu region (January 1961-December 2010 x 50 members), 5400 years of 4 ° C experiments (January 2051-December 2110 x 90 members), 2 ° C An analysis of the ascending experiment for 3240 years (January 2031 to December 2090 x 54 members) was analyzed, and its characteristics and trends were analyzed. Based on the results, a probabilistic evaluation of future changes in 1 hour and 48 hours annual maximum precipitation in the Kyushu region was performed. In addition, using rainfall values and d4PDF data measured at 92 locations in the Kyushu region obtained from the Meteorological Agency AMeDAS (data for all locations where data from 1950 to 2018 exist), the model bias of d4PDF was Verification was performed quantitatively.

3. Results and discussions

3.1 Verification of model bias

Verification of model bias by creating a histogram

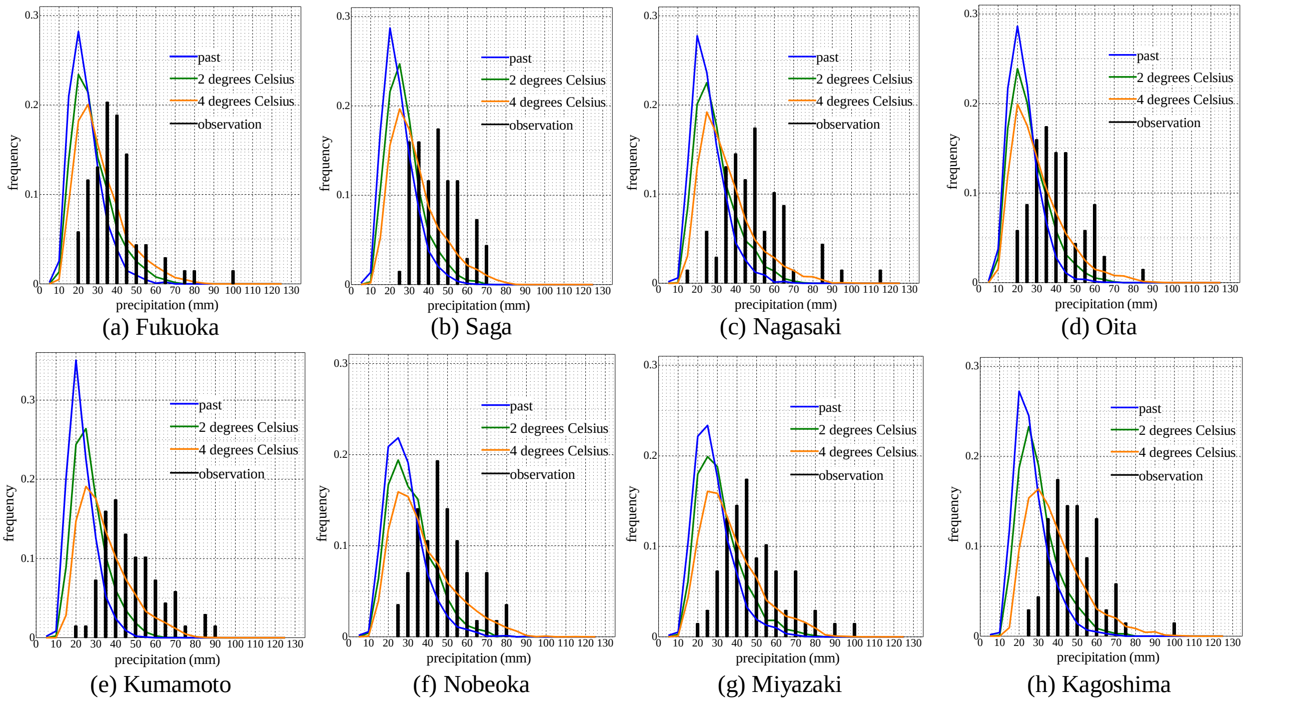


Figure2 Comparison of d4PDF data of 1 hour annual maximum precipitation and actual measurement data (frequency is evaluated from 0mm to 5mm)

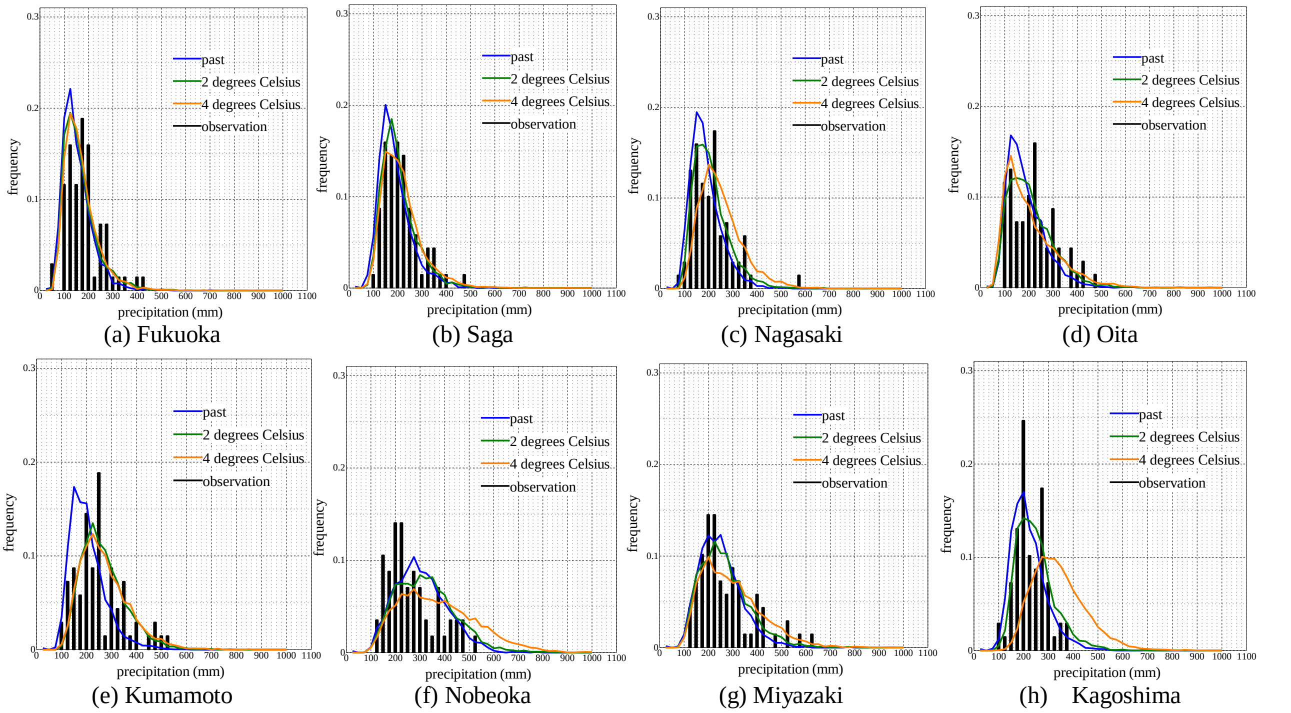


Figure3 Comparison of d4PDF data of 48 hours annual maximum precipitation and actual measurement data (frequency is evaluated from 0mm to 25mm)

of 1 hour (5 mm increments) and 48 hours annual maximum precipitation (25 mm increments) of d4PDF past experimental data closest to each observation point at 92 points in the Kyushu region was performed. As a result of verification at all points, it was thought that the trend was generally represented at eight points in the Kyushu region (each prefectural capital location + Nobeoka), and only those results are shown in Figure2 and Figure3. The line graph drawn by the blue line shows the past experimental data, and the bar graph drawn by the black line shows the measured data of the Japan Meteorological Agency. We verify the model bias by comparing these two graphs. From Figure2, it can be seen that 1 hour annual maximum precipitation differs greatly between past experiments and measured data, and that the measured data has higher intensity precipitation more frequently. On the other hand, from Figure3, it can be seen that for the 48 hours annual maximum rainfall, high intensity precipitation occurs more frequently in the measured data, but the bias is relatively small. To compare this bias quantitatively, the most frequent rainfall was extracted from the past experimental data and the actual measurement data. The difference was divided by the actual measurement data, and the numerical values expressed as percentages were compared. The average value of all points at 92 sites in the Kyushu region deviated from the measured data by 48.7% for 1 hour annual maximum rainfall. On the other hand, 48 hours maximum rainfall was 20.8% off from the measured data. Therefore, it was found that the bias was smaller in the case of 48 hours maximum precipitation than in the case of 1 hour annual maximum precipitation. From these results, for 1 hour annual maximum rainfall, the local heavy rain due to the development of cumulonimbus on several km scale and several hours scale is not reproduced by d4PDF calculated on 20km mesh, and the bias becomes large. Regarding the 48 hours annual maximum rainfall, since the actually measured rainfall is included in the 48 hour time scale even in weather conditions where heavy rain on a several-hour scale occurs, the one-year annual rainfall of d4PDF. It is considered that the weakness of the case was alleviated and the bias was reduced. In the future, it is necessary to correct the bias when assessing the specific flood risk.

3.2 Future changes in intensity and frequency of 1 hour and 48 hours annual maximum precipitation

As a result of verifying the model bias, it was confirmed that the model bias exists in the future forecast of d4PDF, although the degree differs. However, it is possible to qualitatively verify future changes in precipitation by comparing d4PDF datasets that have similar model biases.

Therefore, in this study, we created a histogram of the annual maximum rainfall for 1 hour and 48 hours at 176 locations in the Kyushu region from d4PDF, and compared the experimental data (past, 2 ° C rise, 4 ° C rise) for the future. The change of the frequency of torrential rain was examined. In this paper, we show the results of the eight locations shown in the study of bias.

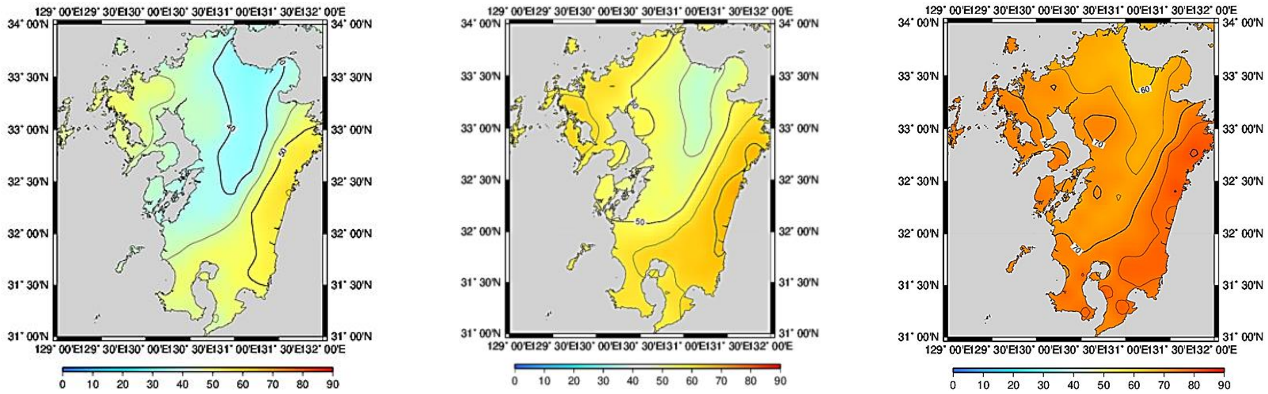
First, 1 hour annual maximum precipitation is examined. From Figure2, it can be confirmed that the frequency of torrential rain increases at all locations as the warming progresses. Next, we focus on the change in the frequency of rainfall over 80 mm. According to the results of (a) Fukuoka, (b) Saga, (c) Nagasaki, (d) Oita, (e) Kumamoto and (h) Kagoshima, rainfall of 80 mm or more has never occurred in past experiments and 2 ° C rise experiments, but it has occurred in 4 ° C rise experiments. Next, the occurrence rate in the 4 ° C rise experiment was calculated. The calculation results are (a) Fukuoka (0.3%), (b) Saga (0.2%), (d) Oita (0.6%), (e) Kumamoto (0.2%), (c) Nagasaki (1.2%), (f) Nobeoka (1.9%), (g) Miyazaki (1.4%), (h) Kagoshima (2.0%).From these results, it was found that there was a difference in the characteristics of torrential rain frequency increase after warming in Kyushu, and that it increased significantly in eastern Kyushu (Miyazaki), southern (Kagoshima), and western (Nagasaki).

Next, the maximum rainfall for 48 hours is examined. From Figure3, it can be confirmed that the frequency of torrential rain increases at all locations as the global warming progresses, as in the case of 1 hour annual maximum precipitation. However, it can be seen that the regional differences are more greatly reflected in the results than in the case of 1 hour annual maximum precipitation. Especially in northern part (a) Fukuoka and southern part (h) Kagoshima, there was a big difference in the change of torrential rain frequency with the progress of global warming. (a) In Fukuoka, the frequency of torrential rain did not change much after warming, whereas (h) in Kagoshima, the frequency of torrential rain was greatly increased due to the effect of warming. It was also found that the frequency of heavy rainfall in (g) Miyazaki and (h) Kagoshima was likely to increase significantly with global warming, as in the case of 1 hour annual maximum rainfall.

3.3 Future change in annual maximum precipitation with a recurrence interval of 50 years

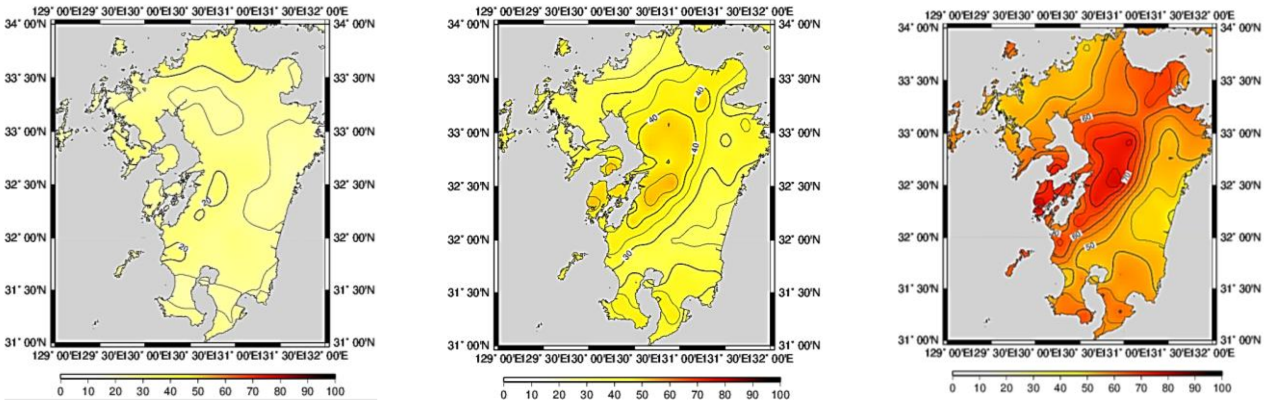
Next, by applying the Gev distribution to all ensemble data at 176 points in the target area, the spatial distribution and change characteristics of the annual maximum rainfall at a recurrence interval of 50 years were verified. From the results, the maximum rainfall for 1 hour and 48 hours with 50-year probability was calculated. Figures4 (a) and 6 (a) show the distributions of 1-hour and 48-hours annual maximum rainfall for a 50-year recurrence interval obtained from past experimental data. Similarly, (b) shows the distribution obtained from the 2 ° C rise experiment data, and (c) shows the distribution obtained from the 4 ° C rise experiment data. Figures5 (a) and 7 (a) show the rate of increase from the past experimental data to the experimental data of 2 ° C rise. Similarly, (b) shows the rate of increase from 2 ° C rise experiment data to 4 ° C rise experiment data, and (c) shows the increase rate from past experiment data to 4 ° C rise experiment data.

Comparing Figure4 (a), (b) and (c), it can be confirmed that as the global warming progresses, the color changes from cool to warm and the precipitation increases. In all experiments, the southeastern and western regions (around Miyazaki, Kagoshima and Nagasaki prefectures) tend to have higher precipitation, and it can be confirmed that 1 hour annual maximum precipitation in Kyushu increases. It can also be confirmed that the distribution characteristics do not change significantly after warming. Comparing Figure5 (a) and (b), it can be confirmed that the rate of increase from the 2 °C rise experiment to the 4 °C rise experiment is greater than the rate of increase from the past experiment to the 2 °C rise experiment. From Figure5 (c), it can be



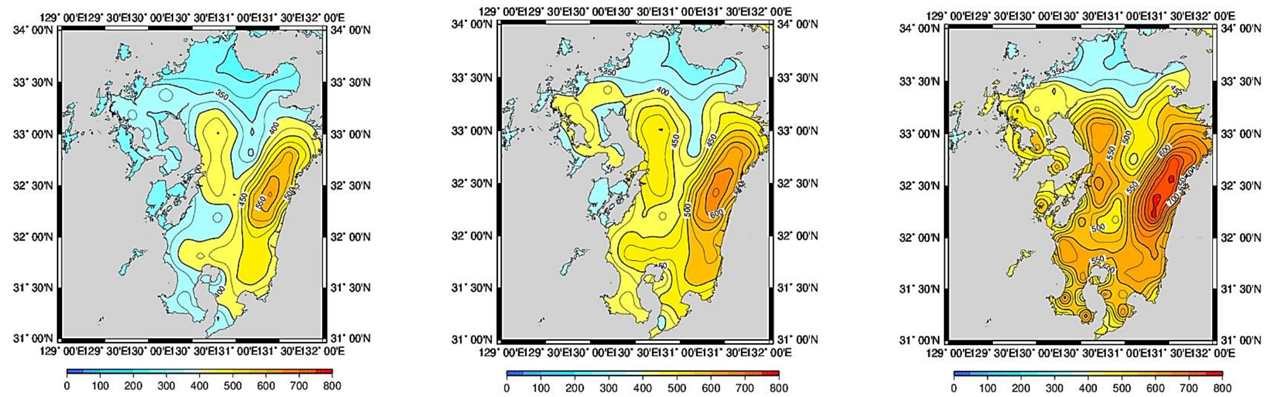
(a) Past experimental data (b) 2 ° C rise experiment data (c) 4 ° C rise experiment data

Figure4 Distribution of 1-hour annual maximum rainfall with a 50-year recurrence interval (mm)



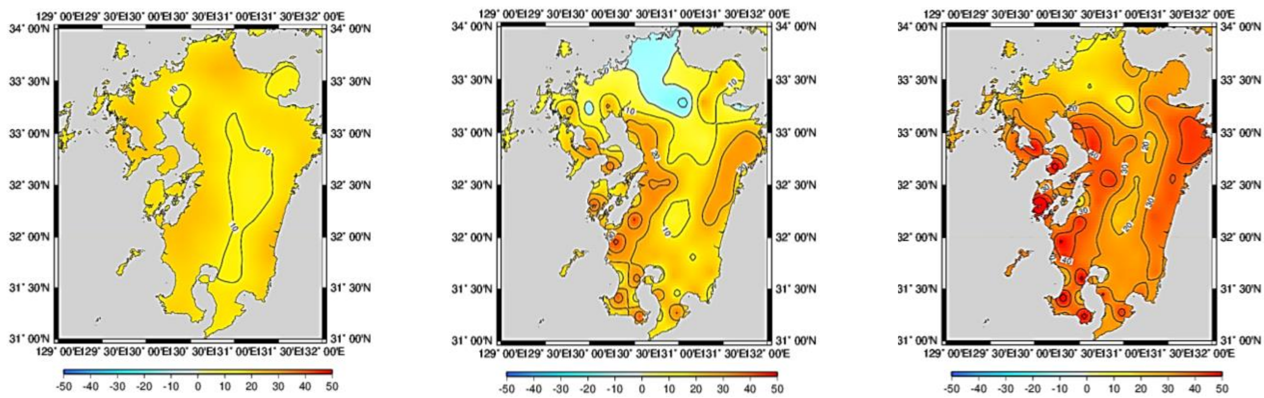
(a) Past → 2 ° C rise (b) 2 ° C rise → 4 ° C rise (c) Past → 4 ° C rise

Figure5 Distribution of 1 hour annual rainfall increase rate for 50-year recurrence interval (%)



(a) Past experimental data (b) 2 ° C rise experiment data (c) 4 ° C rise experiment data

Figure6 Distribution of 48 hours annual maximum rainfall with a 50-year recurrence interval (mm)



(a) Past → 2 ° C rise (b) 2 ° C rise → 4 ° C rise (c) Past → 4 ° C rise

Figure7 Distribution of 48 hours annual rainfall increase rate for 50-year recurrence interval (%)

confirmed that the rate of increase from the past experiment to the 4 ° C rise experiment is large, and that there is an area that records a value near 80 mm. The average value of the whole analysis area is 45.2 mm in the past experiment, 52.9 mm in the 2 ° C rise experiment, and 69.9 mm in the 4 ° C rise experiment.

Compared to the past rise experiment, the increase at 2 ℃ increased about 1.17 times and the increase at 4 ℃ increased about 1.55 times. The increase from the 2 ° C rise experiment to the 4 ° C rise experiment was about 1.32 times. From this result, it was found that the rate of increase in 1 hour annual maximum rainfall increased rapidly when the temperature rose from 2 ° C to 4 ° C. In comparison, it was found that the precipitation tended to be higher in the southeastern and western parts of Kyushu, and the change in precipitation was not so large in the northern part of Kyushu. In addition, it was found that the precipitation tended to be higher in the southeastern and western parts of Kyushu, and that the change in precipitation was not so large in northern Kyushu.

Comparing Figure6 (a), (b) and (c), it can be confirmed that, as with the distribution characteristics of 1 hour annual maximum precipitation, the warmer color changes as the global average temperature rises. However, it can be confirmed that there is a large difference between the regions, with a large change in the southern and western parts of Kyushu, but little change in northern Kyushu. From Figure7 (a), it can be confirmed that the rate of increase from the past experiment to the 2 ° C rise experiment is not so large. Figure7 (b) also confirms that the rate of increase from the 2 ° C rise experiment to the 4 ° C rise experiment increases in some areas and decreases in some areas (northern Kyushu). From Figure7 (c), it was confirmed that the rate of increase from the past experiment to the 4 ° C rise experiment was not so large in the case of the 48-hours annual maximum rainfall compared to the case of the 1-hour annual maximum rainfall. The average value of the entire analysis area is 371.2 mm in the past experiment, 418.1 mm in the 2 ° C rise experiment, and 476.6 mm in the 4 ° C rise experiment. Compared to the past experiment, the increase in the 2 ° C rise experiment was about 1.12 times, and that in the 4 ° C rise experiment was about 1.28 times. The increase from the 2 ° C rise experiment to the 4 ° C rise experiment was about 1.13 times. From this result, the rate of increase in the maximum annual rainfall for 48 hours in the whole area of Kyushu is almost the same as the rate of increase from the past experiment to 2 ° C and the rate of increase from 2 ° C to 4 ° C. However, in the latter case, it was also found that there was a difference depending on the region. It was also found that in most regions, the maximum annual rainfall for 48 hours increased as global warming progressed, but there were some regions in northern Kyushu that decreased.

4. Conclusion

In this study, we focused on the Kyushu region and examined the characteristics of rainfall change after warming in d4PDF 4 ° C and 2 ° C experiments. First, the model bias was confirmed in d4PDF data by comparison with the measured data. In particular, it was found that 1 hour annual rainfall data was remarkable. This indicates that bias correction is needed when assessing concrete flood risks in the future. It was also found that the annual maximum hourly rainfall increased throughout Kyushu as the temperature increased due to the effects of global warming, and both the intensity and frequency of heavy rainfall increased. Furthermore, it is suggested that the effect of global warming increases when the temperature rises by 4 ° C, and that the amount of increase in precipitation increases. Furthermore, it was found that there was a regional difference in the change of heavy rainfall, and the increase was relatively small in the northern part, but large in the southern part. In addition, as a subject of this research, devising an analysis method can be mentioned. In the present study, point evaluation was performed due to the characteristics of d4pdf, so it is necessary to devise data handling so that interval evaluation can be performed in the future.

REFERENCES

1)IPCC WG1 AR5 : Summary for Policymakers https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_SPM_FINAL.pdf, 2018.

2) R. Mizuta, A. Murata, and M. Ishii: Over 5,000 Years of Ensemble Future Climate Simulations by 60-km Global and 20-km Regional Atmospheric Models, Bulletin of the American Meteorological Society,vol.98,pp.1378-1398, https://doi.org/10.1175/BAMS-D-16-0099.1, 2017.

3)T.Hoshino, T.J.Yamada:ANALYSIS OF ANNUAL MAXIMUM PRECIPITATION OVER FIRST-CLASS RIVER DOMAINS IN JAPAN USINGALARGE-ENSEMBLE DATASET(d4PDF), Annual Journal of Hydraulic Engineering, JSCE, Vol.74, pp.I_187-I_192, 2018.

4) Y. Kuzuha, M. Senda: Consideration On Nonstationarity and Extreme Value Of Precipitation By Using AMeDAS And d4PDF Data , JSCE, Vol.74, No.4, pp.I_325-I_330, 2018.

5)T. Hoshino, T. J. Yamada, M. Inatsu, T. Sato, H. Kawase, S. Sugimoto: Analysis of Spatiotemporal characteristics of Heavy Rainfall under Historical and Warmer Climate Conditions using a Large-Ensemble Dataset(d4PDF), Annual Journal of Hydraulic Engineering, JSCE, Vol.74, pp.I_13-I_18, 2018.

6)S.Masuya,F.Uemura,T.Yoshida,N.Oomura,M.Chiba,S.Tomura,T.Yamamoto,S.Tokioka, H. Sasaki, Y. Hamada,T.Hoshino,T.Yamada:PROBABILITY RAINFALL CONSIDERING UNCERTAINTY BASED ON A MASSIVE ENSEMBLE CLIMATE PROJECTIONS IN ACTUAL RIVER BASIN, Annual Journal of Hydraulic Engineering, JSCE, Vol.74, No.5, pp.I_115-I_120, 2018.

7) M. Fujita, R. Mizuta, M. Ishii, H. Endo, T. Sato, Y. Okada, S. Kawazoe, S. Sugimoto, K. Ishihara, S.

Watanabe. Precipitation Changes in a Climate With 2‐K Surface Warming From Large Ensemble Simulations Using 60‐km Global and 20‐km Regional Atmospheric Models. GEOPHYSICAL RESEARCH LETTERS, Vol.46, 1, p. 435-442, doi: 10.1029/2018GL079885, 2019.
8)JMA：,
https://www.jma.go.jp/jma/kishou/know/kisetsu_riyou/tenkou/Average_Climate_Japan.html.