Interregional Comparison of Climate Change Impact on Drought

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ABSTRACT

Assessments of climate change impact on drought are essential to develop effective adaptations of water resource management. To understand how the likelihood of droughts will change in the future under the A1B scenario, interregional comparison of climate change impacts on drought was conducted. Before the comparison, precipitation estimations derived by a super-high-resolution global Atmospheric General Circulation Model (GCM20) was validated and GCM20 precipitation shows good reproducibility in terms of drought level and drought season. Flood and Drought Duration Curves (FDC & DDC) was applied and 10 year return period FDC & DDC estimated by GCM20 precipitation in present and future period at selected regions can clearly show the future change characteristics of high and low precipitation in different time intervals. Global maps of future drought level change in 1, 3, 6, and 12 months time intervals estimated by multi-GCM ensemble mean were depicted for more detail and reliable assessment. The global maps seem to indicate with high confidence that future drought levels in the four time intervals decrease in higher latitudes, whereas increase in several regions, such as Mexico, southern Brazil, Mediterranean area, and southern Africa. Global maps of future drought season shift in 1, 3, 6, and 12 months time intervals using GCM20 precipitation were also depicted. The maps seem to indicate that 1 month time interval drought season will shift by 4 to 6 months in Latin America, southern Africa, and Australia. In addition, short term droughts, such as 3 and 6 months time intervals may shift by 1 to 4 months earlier in middle Europe.

Key words: *climate change; drought; GCM20; multi-GCM ensemble mean; drought level change; drought season shift; FDC & DDC*

INTRODUCTION

Nowadays, extreme water-related disasters such as floods and droughts occur more frequently than ever. Droughts may threaten the foundation of people's life, ecosystems, water resources, foods, industries, and human health. The Intergovernmental Panel on Climate Change (IPCC) published its Fourth Assessment Reports (AR4) in 2007. The report indicates that drought-affected areas will be likely to increase in extent and also suggests that it be as important to promote "adaptation" to the impacts of global warming as to promote "mitigation" (IPCC, 2007). To develop the adaptations, a reliable future climate change impact assessment of drought must be conducted. General Circulation Models (GCMs) are powerful tools for future projection of climate. A super-high resolution global Atmospheric General Circulation Model (GCM20) has been developed by Meteorological Research Institute (MRI) in Innovative Program of Climate Change Projection for the 21st Century (Kakushin21), MEXT (Kitoh, A. et al, 2009). The advantage of GCM20 is high horizontal resolution which is about 20 km. However, validation of the precipitation estimation in a viewpoint of drought has not been conducted. One of the useful tools to represent the likelihood of droughts is Flood and Drought Duration Curves (FDC & DDC) defined by Takeuchi (1988). FDC & DDC can represent persistence characteristics of hydrological time series when they assume high and low values, respectively. In addition, a global future drought level change assessment can be applied for a detail and reasonable assessment. Droughts may be simply defined as a decrease of accumulated precipitation in specific time interval. Future drought season shift may also cause adverse impacts on

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water resource management. Since the assessments of FDC & DDC and drought level change cannot provide any information about drought season shift. Therefore, global future drought season shift assessment should be also conducted.

A main objective of this study is to draw an interregional comparison of climate change impacts on drought in different time intervals using precipitation data derived by General Circulation Models (GCMs). To attain the main objectives, four assessments are conducted in this study; (1)To validate precipitation data derived by GCM20 in terms of reproducibility of drought levels and drought seasons in different time intervals, (2)To draw an interregional comparison of future change of extreme events in different time intervals using FDC & DDC, (3)To assess global future drought level changes in different time intervals, (4)To assess global future drought season shifts in different time intervals.

METHODOLOGY

Interregional comparison of future change of extreme events in different time intervals using FDC & DDC: FDC & DDC are defined as $f_{\alpha}^{*}(m|\tau)$ and $f_{\beta}(m|\tau)$ such that:

$$\mathrm{Prob}\left[\max_{t_1 \in S(\tau)} \frac{1}{m}\sum_{t=t_1}^{t_1+m-1} x_t \geq f_{\alpha}^{*}(m|\tau)\right] \leq \alpha\ , \quad \mathrm{Prob}\left[\min_{t_1 \in S(\tau)} \frac{1}{m}\sum_{t=t_1}^{t_1+m-1} x_t \leq f_{\beta}(m|\tau)\right] \leq \beta \tag{1}$$

where $S(\tau)$ is a season to which date τ belongs. The random variable concerned is a seasonal minimum or maximum of moving averages of various intervals m. The mean recurrence intervals of FDC & DDC are defined for the annual series made up of seasonal maximum and minimum of each year, respectively. Instead of probabilities α and β, mean recurrence intervals $T_k = 1/\alpha$ or $1/\beta$ are used. Accordingly, $f_k^{*}(m)$ and $f_k(m)$ are used instead of $f_{\alpha}^{*}(m)$ and $f_{\beta}(m)$.

$$f_k^{*}(m) = f_{\alpha}^{*}(m)/\bar{x}\ , \qquad f_k(m) = f_{\beta}(m)/\bar{x} \tag{2}$$

where $\bar{x}$ is a mean value of total time series.

Under most situations, available data are insufficient to precisely define the risk of high and low precipitation. To describe a probability of occurrence in maximum or minimum precipitation event of various intervals, 10 year return period quintile values are estimated by frequency analysis. It is generally known that annual maximum series of hydrological variable is well approximated by Gumbel distribution, whereas annual minimum series of hydrological variable is well approximated by Weibull distribution. Therefore in this study, Gumbel distribution is applied to estimate quantile value of annual maximum series and Weibull distribution is applied to estimate quantile value of annual minimum series. Parameters of these distributions are estimated by L-moment method using sample data of annual series. A statistical test is used to check whether the annual series are well approximated by these distributions. A simple but powerful goodness-of-fit test is the Probability Plot Correlation Coefficient (PPCC) test which is developed by Filliben (1975). The PPCC test uses the correlation coefficient r between the ordered observed values and the corresponding fitted quantiles which is determined by plotting positions. If the value of r close to 1.0, it suggests that observed values may have been drawn from the fitted distribution. One of threshold value to check the acceptance of Gumbel and Weibull hypothesis refers to a critical point (Vogel, 1986; 1989).

Target regions to depict FDC & DDC are selected based on two rules. One of the rules is the result of a global future drought level change assessment, which is described below. The regions where future drought levels are projected to increase are selected. The other rule is the major crop producing area.

Global future drought level change assessment: Future drought level change is defined by relative change in 10 year return period minimum accumulated precipitation in the future period, relative to that in the present period. The 10 year return period quantile values are estimated by Weibull distribution. The methodology of estimate quantile value by Weibull distribution which is described above is used. In this assessment, multi-GCM ensemble analysis is applied to reduce the uncertainties which GCMs future projections contain. The multi-GCM ensemble of future drought level change is simply calculated by averaged future change rate of 16 GCMs. Since each GCM resolution is different from the others, the averaged future change rate is calculated in 2.0° grid. Time intervals for assessing prolonged droughts are set as 1, 3, 6, and 12 months considering total growing period of three major grains, wheat, maize and rice.

Global future drought season shift assessment: Future drought season shift is defined by difference between present and future drought season. First, the months of annual minimum precipitation in present and future period are recorded and frequency bar charts are drawn. Second, centroids of total frequency in present and future period are estimated. Finally, difference between the centroids of present and future period indicates the drought season shift. Time intervals are set as 1, 3, 6, and 12 months.

DATA

In this study, data sets of precipitation estimation on world land areas in present and future period derived by GCM20 and 15 AOGCMs in CMIP3 are used. The present period precipitation data was estimated under 20c3m scenario, whereas the future period precipitation data was estimated under A1B scenario. The AOGCMs precipitation data used here is derived from 15 AOGCMs that have completed at least one model run and provided archived precipitation for a present period 1981-2000 and a future period 2081-2100. GCM20 precipitation estimation for a present period 1979-2004 and a future period 2075-2099 is used in this study. The total number of grids on land areas of GCM20 accounts more than 450,000. Since a computer capacity is limited, it is difficult to handle the precipitation data in all the grids in land areas. Therefore, target grids are selected in 2.0° grid in latitude and longitude and 1.0° averaged precipitation is calculated in every target grids.

Table 1 List of 16 GCMs whose precipitation estimation is used in this study

No	Model type	Model Designation	Modeling Group	Country
1	AOGCM	CGCM3.1(T47)	Canadian Centre for Climate Modeling & Analysis	Canada
2		CGCM3.1(T63)	Canadian Centre for Climate Modeling & Analysis	Canada
3		CNRM-CM3	Météo-France / Centre National de Recherches Météorologiques	France
4		CSIRO-Mk3.0	CSIRO Atmospheric Research	Australia
5		CSIRO-Mk3.5	CSIRO Atmospheric Research	Australia
6		GFDL-CM2.0	US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory	USA
7		GFDL-CM2.1	US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory	USA
8		GISS-AOM	NASA / Goddard Institute for Space Studies	USA
9		INM-CM3.0	Institute for Numerical Mathematics	Russia
10		IPSL-CM4	Institut Pierre Simon Laplace	France
11		MIROC3.2(hires)	Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC)	Japan
12		MIROC3.2(medres)	Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC)	Japan
13		ECHO-G	Meteorological Institute of the University of Bonn (MIUB), Meteorological Research Institute of KMA (METRI), and Model and Data group (M&D)	Germany & Korea
14		ECHAM5/MPI-OM	Max Planck Institute for Meteorology	Germany
15		MRI-CGCM2.3.2	Meteorological Research Institute	Japan
16	AGCM	GCM20	Meteorological Research Institute	Japan

RESULTS

Validation of GCM20 precipitation data: Reproducibility of GCM20 precipitation estimation in terms of drought levels and drought seasons in 1, 3, 6, and 12 months time intervals is validated. A globally gridded data set of observed station precipitation made by Variability Analysis of Surface Climate Observations (VASClimO) is used as an observed data. The statistical indicator employed for the validation in terms of drought level is the coefficient of determination R^2. One of the results is shown in Figure 1 which is a scatter diagram of GCM20 estimation and observed data in 10 year return period minimum accumulated precipitation of 12 months. Each plotted point indicates the value of GCM20 estimation and observed data in each 1.0° grid of land area. In case of the 10 year return period minimum accumulated precipitation in the four time intervals, 10 year return period quantile of GCM20 is estimated from 26

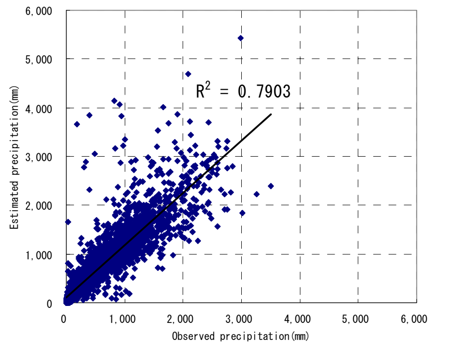

Figure 1 Scatter diagram of GCM20 estimation and observed data in 10 year return period minimum accumulated precipitation of 12 months

samples of annual minimum accumulated precipitation by fitting Weibull distribution, whereas that of the observed data is estimated from 50 samples. The results indicate that GCM20 shows good reproducibility in long term accumulated precipitation, such as 12 months, whereas it has less reproducibility in short term accumulated precipitation, such as 1 month.

Drought season difference between GCM20 and observed data is also estimated. One of the results is shown in Figure 2. The results show that the drought season differences are less than 2 months in most regions. It seems to indicate that the drought season estimated by GCM20 precipitation data has good reproducibility in most regions.

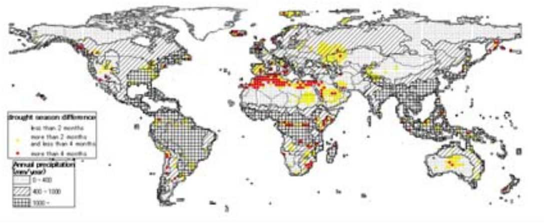

Figure 2 Drought season differences between GCM20 and observed data in time intervals of 3 months

Global future drought level change assessment: PPCC values of the four time intervals in every grid in present and future period are calculated by the samples estimated by each 16 GCMs precipitation data. An example of probability plot of annual minimum accumulated precipitation is shown in Figure 3. In the figure, points are plotted by the ordered observed values and the corresponding fitted quantiles which is determined by plotting positions. The values in the figure indicate the PPCC. Based on the results of Weibull hypothesis accepted grid ratio in four time intervals in 16 GCMs, it is clear that Weibull distribution cannot well approximate the probability distribution of sample data in the four time intervals in every grid of each 16 GCMs. However, finding probability distribution may be complicated and difficult. Therefore, it is assumed that Weibull distribution is suitable for all sample data in all grids of 16 GCMs.

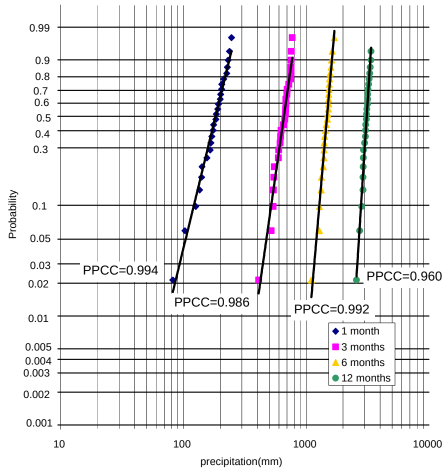

Figure 3 Distribution of the annual minimum accumulated precipitation on the Weibull probability paper and Probability Plot Correlation Coefficient values

Figure 4 shows global maps of averaged future change rate in 10 year return period minimum precipitation estimated by multi-GCM ensemble in 2.0° grid. In the figure, white areas are where less than 66% of the models agree in the sign of the change, whereas black circled areas where more than 90% of the models agree in the sign of the change. Grid ratio of 16 models agree in the sign of the change is shown in Table 2. According to the table, the grid ratios which the 16 models agree in the sign of the change more than 90% in four time intervals are about 30%. The high agreement on the sign of the change of 16 models result can indicate that a future drought level change has high confidence. In the Figure 4, most regions where have the high agreement are located in higher latitude and future drought levels in these regions are projected to decrease with high confidence. On the other hand, there are several regions where future drought levels are projected to increase with high confidence, such as Mexico, southern Brazil, Mediterranean area, and southern Africa.

According to Table 2, the grid ratios which the 16 models agree in the sign of the change is less than 66% in four time intervals are about 26%. It may indicate that future drought level change has low confidence because of the low agreement on the sign of the change of 16 models result. The regions which have the low agreement are indicated as white areas in Figure 4. These regions are located in eastern America, northern Latin America, middle Europe, middle Africa, western Central Asia, and Australia.

Table 2 Grid ratio of 16 models agree in the sign of the change

time intervals for assessing prolonged droughts	16 models agree in the sign of the change		
	more than 90%	more than 66% and less than 90%	less than 66%
1 month	27%	47%	26%
3 months	31%	43%	25%
6 months	38%	36%	26%
12 months	35%	39%	26%

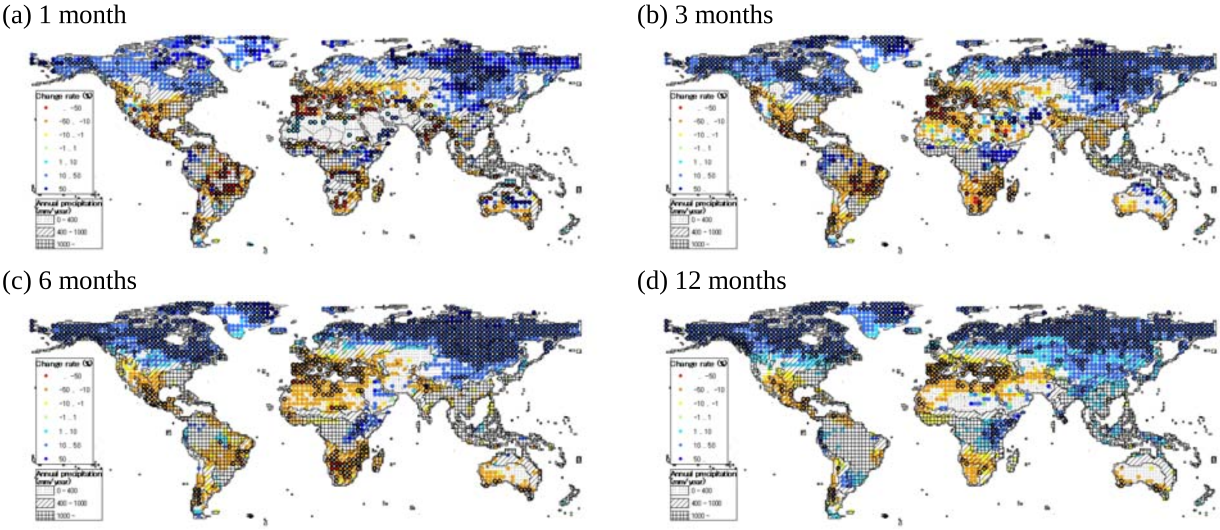

Figure 4 Averaged future change rate in 10 year return period minimum precipitation estimated by multi-GCM ensemble

Global future drought season shift assessment: Global maps of future drought season shift in 1, 3, 6, and 12 months time intervals are also depicted using GCM precipitation estimation. The drought season is represented by a centroid of annual minimum accumulated precipitation months frequency and the difference between a centroid of present period and that of future period represent the future drought season shift. The maps seem to indicate that 1 month time interval drought season will shift by 4 to 6 months in Latin America, southern Africa, and Australia. In addition, Short term droughts, such as 3 and 6 months time intervals may shift by 1 to 4 months earlier in middle Europe. On the other hand, future drought season shift may not appear in most part of Asia.

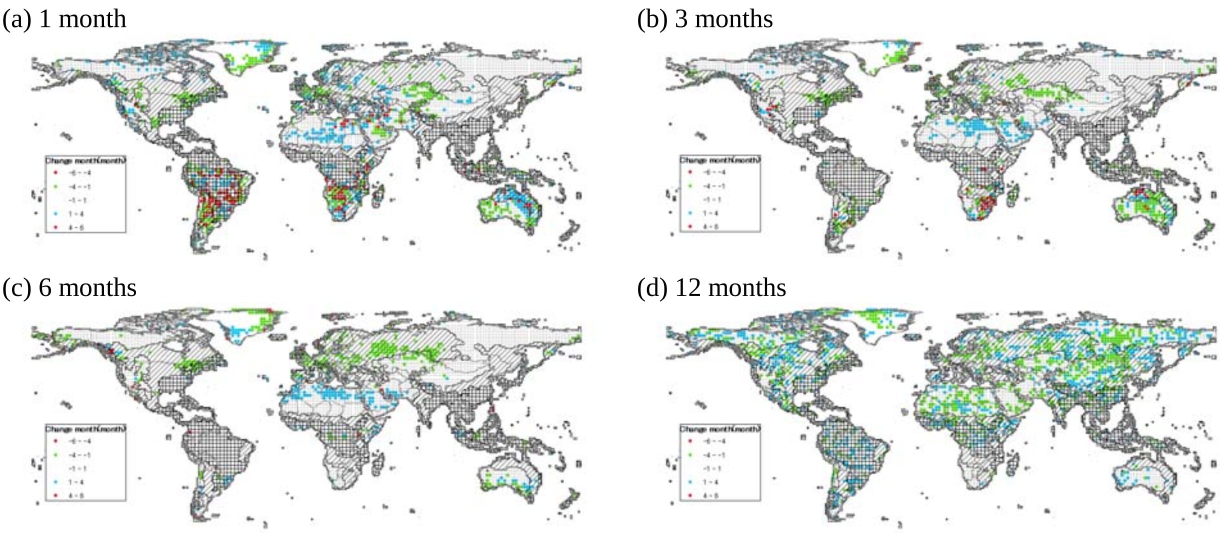

Figure 5 Future drought season shit estimated by GCM20 precipitation data

Interregional comparison of future change of extreme events in different time intervals using FDC & DDC: 6 target regions are selected based on the result of the global future drought level change assessment and based on the area of food production. A PPCC test is applied and it is clear that these distributions cannot apply for all dataset of moving averaged precipitation in different intervals. Therefore, it is assumed that Weibull distribution is suitable for the all dataset of minimum moving averaged precipitation and Gumbel distribution is suitable for the all dataset of maximum moving averaged precipitation. Figure 6 shows 10 year return period FDC & DDC using GCM20 precipitation estimation. From the comparison of FDC & DDC between present and future period at the 6 regions, it seems to indicate that there is no significant future change in 10 year return period maximum and minimum precipitation in the 6 regions. However, several future changes are pointed out. It is likely that future drought levels in short terms, such as 1 to 6 months time intervals, will increase at the selected regions in Mexico and Brazil, whereas those in long terms will not have big change. In contrast, future drought levels will increase not only in short terms but also in long terms at the selected regions in Spain and Australia.

(a)Mexico (b)Brazil (c)Spain (d)South Africa (e)India (f)Australia

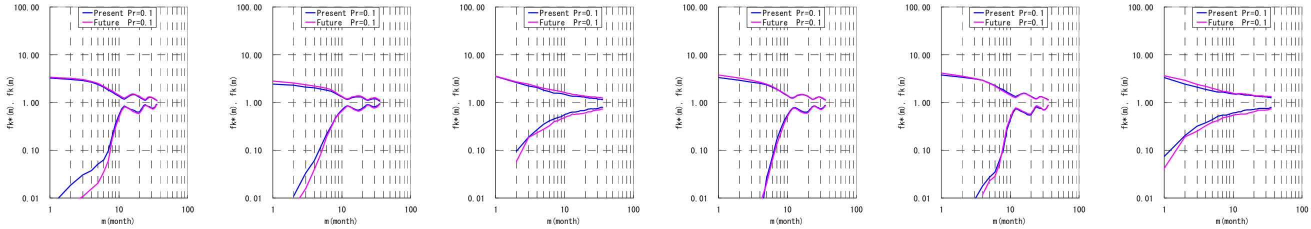

Figure 6 FDC & DDC of 10 year return period at the selected 6 regions

CONCLUSION AND RECOMMENDATION

GCM20 precipitation was validated and it seems to have a good reproducibility in terms of drought level and drought season. In addition, interregional comparisons of climate change impacts on drought were drawn through the assessments of FDC & DDC, drought level change, and drought season shift. Particularly in the assessment of drought level change, global maps of future drought level change with confidence level were depicted.

In this study, only precipitation data is used to assess future change of drought. Changes of extreme weather events such as drought are not explained simply by changes in precipitation. For future study, other hydrological variables, such as temperature, evapotranspiration, and river discharge, should be considered to be able to actualize more reliable climate change impacts assessment on drought. Moreover, the multi-GCM ensemble analysis should be used in all assessments to reduce the uncertainties which the future projection of GCMs contain.

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