NOTES AND CORRESPONDENCE

Characteristics of Intense Rainfalls over Southwestern Japan in the Baiu Season in the CMIP3 20th Century Simulation and 21st Century Projection

Kozo NINOMIYA

Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology, Yokohama, Japan

(Manuscript received 26 April 2011, in final form 25 August 2011)

Abstract

This study examined features of intense rainfalls over southwestern Japan in the Baiu season (June and July) in the 20th Century Climate in Coupled Models (20C3M) and 21st Century projection (Special Report on Emission Scenarios [SRES] A1B) used by 18 climate models that contributed to the World Climate Research Programme's Coupled Model Intercomparison Project phase 3 (CMIP3).

Characteristics of daily precipitation over an area of $5^{\circ} \times 5^{\circ}$ within 30°N – 35°N and 130°E – 135°E obtained by 20th century climate simulation were compared with observed precipitation data for a 3-year period (1997–1999). The studied area includes four meshed subareas of $2.5^{\circ} \times 2.5^{\circ}$. The four-area averaged daily precipitation and the maximum precipitation in the four areas were analyzed. The order statistics of the maximum precipitation indicated a very wide difference from model to model. To measure the temporal and spatial concentration of precipitation, “concentration ratio,” defined as (the average of the first- to sixth-largest maximum precipitation)/(time–area averaged precipitation) was examined. Although a few models reproduced a reasonable concentration ratio comparable to observations, many other models did not reproduce a reasonable ratio. Models of medium and high horizontal resolution with the Arakawa–Schubert cumulus scheme tended to reproduce a reasonable concentration ratio. Models that simulate a realistic Baiu frontal precipitation zone were able to simulate a proper concentration ratio.

Features of the intense rainfalls in the 21st century climate projection by the models were examined for June and July over a 3-year period (2097–2099). The characteristics of the models in regard to the intense rainfalls in the 20th century simulation were commonly found in the 21st century projections. Because the difference among the models was too large with respect to the intense rainfalls, the change in intense rainfalls under the climate changes in the 21st century cannot be definitely determined by CMIP3 models.

1. Introduction

Several climate model simulation studies have examined the precipitation in the summer monsoon rainy season over East Asia (Baiu season in Japan and Meiyu season in China). Kang et al. (2002) assessed simulations by 10 models that participated

in the CLIVAR/Monsoon GCM (general circulation model) Intercomparison Project and concluded that none of the models realistically reproduced the observed Meiyu and Baiu rain band. Now, owing to the progress of climate models, many models can simulate the rain bands to a certain extent. Kimoto et al. (2005) analyzed the difference between a high (T106 atmosphere) and a medium (T42) horizontal resolution version for the present-day climate. The comparison showed that the higher resolution version better represented both the mean and the frequency distribution of precipitation. The climate projection for the 21st century by the high-

Corresponding author: Kozo Ninomiya, Research Institute for Global Change, JAMSTEC, 3173-25 Showa-machi, Kanazawa-ku, Yokohama 236-0001, Japan.
E-mail: nmiya@jamstec.go.jp
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resolution version showed that precipitation in the warm season around 35°N will increase by approximately 10% in 100 years from the present. They also noted significant increases in the frequencies of non-precipitation and heavy rainfall days and decreases in relatively weak rainfall days. Kitoh and Uchiyama (2006) analyzed the changes in intensity and duration of Meiyu/Baiu rain by global warming using data of 15 models under the SRES A1B scenario. They demonstrated a delay in Meiyu/Baiu rainy season withdrawal. In a comparison study of 18 coupled climate models in 20C3M, Dai (2006) stated that most models reproduce the observed broad patterns of precipitation amount and year-to-year variability. He also stated that the models reproduce the percentage of the contribution and frequency of moderate precipitation, but underestimate the contribution and frequency of heavy precipitation ($>20 \text{ mm d}^{-1}$). Tu et al. (2009) evaluated the output of 25 models in CMIP3 with a focus on summer precipitation in eastern China for the last 40 years of the 20th century. Most models failed to reproduce rainfall associated with the East Asian summer monsoon (EASM) and hence the seasonal cycle in eastern China. The Meiyu phenomenon was underestimated in general. The seasonal northward shift of the rain belt from early to late summer was completely missed by most models. The annual extremes were grossly underestimated in the monsoon-dominated regions. Li et al. (2011) analyzed potential changes in precipitation extremes over China in July–August based on the output of 24 coupled climate models in the 20C3M experiment and the 1% per year CO_2 increase experiment of the CMIP3. The majority of models fairly reproduced the broad spatial pattern of observed precipitation. However, all of the models underestimated extreme precipitation by approximately 50%. The CO_2 increase experiment indicated a relatively robust change in extremes because the ratio between the multi-model ensemble average (MEA) extreme precipitation change and the model spread was larger than that for total precipitation.

Kusunoki et al. (2006) showed that compared with lower resolution models, a very high horizontal resolution atmospheric general circulation model (AGCM) with a 20-km grid size (20-km model) reproduced a realistic Baiu rain band in June and July under present-day climate conditions in terms of geographical distribution and northward seasonal march. Kusunoki and Mizuta (2008)

also conducted a global warming projection experiment using the 20-km model, focusing on the changes in the Baiu rain band. To quantify the dependence of the projected change on the sea surface temperature (SST) prescribed by the model, they took different SSTs given by the two atmospheric–ocean general circulation models. They showed precipitation increases over the Yangtze River valley and western Japan and found that the termination of the Baiu season tended to be delayed until August. These changes were consistently found in the simulations regardless of different SSTs. Feng et al. (2011) studied the future precipitation change over China based on the output of a global AGCM, ECHAM5 (T319). In the present-day simulation, the spatial distributions of both mean and extreme precipitation were reasonably reproduced. A weakness of the model was the overestimation of precipitation over northern and western China. Analysis of the potential change in the precipitation projection under the A1B scenario showed that both annual mean precipitation intensity and extreme precipitation would increase significantly over southeastern China.

Several observational studies (e.g., Ninomiya and Murakami 1987; Ding 1991; Ninomiya and Akiyama 1992; Ninomiya 2004) have shown that the most distinct feature of Baiu/Meiyu season is a long and narrow Meiyu/Baiu frontal rain zone (MFZ and BFZ) extending along the northern rim of the North Pacific subtropical anticyclone (NPSA). The frontal rain zone is characterized by a strong moisture gradient with a weak thermal gradient. Ninomiya (2011) evaluated models' ability to reproduce MFZ and BFZ in the present climate (1980–1999) using a “CMIP3 multi-model dataset” (Meehl et al. 2007). He concluded that the models did not necessarily reproduce the latitudes of the zones. He also noted that the characteristics of the projected MFZ and BFZ in 2080–2099 were similar to the characteristics of the simulated MFZ and BFZ in 1980–1999. That is, the models that simulate MFZ and BFZ in the northern (southern) latitude project the zones in the northern (southern) latitude, and the models that simulate the large (small) “precipitation in FZ” project large (small) precipitation. According to the projections, MFZ and BFZ shift slightly northward from 1980–1999 to 2080–2099, and the precipitation in FZ decreases slightly from 1980–1999 to 2080–2099. However, the change of latitude and “precipitation in FZ” from the 20th century simulation to the 21st

Table 1. Models of CMIP3 used for the present study.

No.	Model	S or G	Approx. resolution Lon. $\times$ Lat. deg	Convection scheme	Flux adjustment
1	BCCR_bcm2_0	S	2.8×2.8	MF	None
2	CCCma_cgcm3_1	S	3.8×3.8	MC	HW
3	CCCma_cgcm3_t63	S	2.8×2.8	MC	HW
4	CNRM_cm3	S	2.8×2.8	MF	None
5	CSIRO_mk3_0	S	1.9×1.9	MC	None
6	GFDL_cm2_0	G	2.5×2.0	AS	None
7	GFDL_cm2_1	G	2.5×2.0	AS	None
8	GISS_aom	G	4.0×3.0	MF	None
10	IAP_fggoalsl_0_g	S	2.8×2.8	MF	None
12	INMcm3_0	G	5.0×4.0	MC	W
13	IPSL_cm4	G	3.8×2.5	MC	None
14	MIROC3_2_h	S	1.1×1.1	AS	None
15	MIROC3_2_m	S	2.8×2.8	AS	None
16	MIUB_echo_g	S	3.8×3.8	MF	None
17	MPI_echam5	S	1.9×1.9	MF	None
18	MRI_cgcm2_3_2a	S	2.8×2.8	AS	HWM*
19	NCAR_ccsm3_0	S	1.4×1.4	MF	None
20	NCAR_pcm1	S	2.8×2.8	MC	None

S or G: Spectral or Grid model.

Convection scheme: MF = Mass flux, MC = moist convective adjustment, AS = Arakawa and Schubert.

Flux adjustment: H = heat, W = water vapor, M = momentum, *: In tropical zone.

century projection are significantly smaller than the respective standard deviation (STD) from the MEA.

However, the ability of models of the “CMIP3 multi-model dataset” to reproduce the daily intense precipitation in the Baiu season has not yet been evaluated. This article demonstrates the models’ ability to reproduce the daily intense precipitation over the southwestern parts of Japan in the Baiu season using data of 20C3M in the “CMIP3 multi-model dataset”* and studies the changes in daily precipitation under global warming, using the 21st century projection (SRES A1B) dataset.

2. Procedure of the analysis

Of 22 models that contributed to 20C3M, 18 presented the daily precipitation data in an agreed-upon format. The sequential numbers, abbreviations, and characteristics of these 18 models are listed in Table 1. The model intercomparison in the present climate is made for the daily precipitation in June (1–30) and July (1–30) during a 3-year

period between 1997 and 1999 (a total of 180 days in 6 months). Global Precipitation Climatology Project (GPCP) (Adler et al. 2003) daily precipitation data (in a $1^\circ \times 1^\circ$ grid) are used as the observational verification data. The studied period is limited to the 3-year period because daily GPCP data are available only during this 3-year period within the 20-year period of the CMIP3 simulation. The area (30°N – 35°N and 130°E – 135°E) studied in the present report is shown in Fig. 1. This area was selected for the analysis because intense Baiu rainfalls occur most frequently over the southwestern part of Japan (Ninomiya and Mizuno 1987). Because the horizontal resolutions of the models and GPCP are not identical, all data are interpolated into the $2.5^\circ \times 2.5^\circ$ grid. As shown in Fig. 1, there are four $2.5^\circ \times 2.5^\circ$ subareas within the area of 30°N – 35°N and 130°E – 135°E . The data are given at the center of each $2.5^\circ \times 2.5^\circ$ area.

The daily precipitation thus defined is noted by

$$R_{i,j}. \quad (1)$$

Here, i ($= 1$ – 4) indicates the subarea, and j ($= 1$ – 180) indicates the time series that started on June 1, 1997 and ended on July 30, 1999.

* Detailed explanations on these models, “CMIP3 Climate Model Documentation, Reference, and link” are available at http://www-pcmdi.llnl.gov/ipcc/model_documentation/ipcc_model_documentation.php.

Fig. 1. Analysis in the present article was conducted for the rectangular area shown in Fig. 1. There are four sub-areas of $2.5^\circ \times 2.5^\circ$ within the area in 30°N – 35°N and 130°E – 135°E .

The area average daily precipitation on each day is defined by

$$R_j = \left(\sum_i R_{i,j} \right) / 4. \quad (2)$$

The maximum daily precipitation in the area on each day is defined by

$$mR_j = \text{maximum of } R_{i,j}. \quad (3)$$

The temporal average of R_j and mR_j are noted, respectively, by

$$[R] = \left(\sum_j R_j \right) / 180 \quad \text{and} \\ [mR] = \left(\sum_j mR_j \right) / 180. \quad (4)$$

Given a set of data mR_j ($j = 1$ – 180), the order statistics of the sample consists of the same numbers (180) sorted in descending order from largest to smallest, which is indicated by

$$mR_k, \quad (k = 1$$
– $180). \quad (5)$

That is, mR_1 indicates the largest maximum precipitation, and mR_{180} indicates the smallest maximum precipitation during 180 days.

The average of the largest six cases ($k = 1$ – 6) is defined by

$$mR_{1-6} = \text{average of } mR_k \text{ for } k = 1$$
– $6. \quad (6)$

The “temporal and spatial concentration ratio of intense rainfall” is then defined by

$$mR_{1-6} / [R]. \quad (7)$$

3. Intense rainfalls simulated in 1997–1999

Table 2 shows $[mR]$, $[R]$, $[mR]/[R]$, mR_{1-6} , and $mR_{1-6}/[R]$ obtained by each model and GPCP.

The MEA and the standard deviation (STD) from the respective MEA of $[mR]$, $[R]$, $[mR]/[R]$, mR_{1-6} , and $mR_{1-6}/[R]$ obtained by the models are shown in Table 2. Large differences can be seen among the models. $[R]$ varies from 2.8 mm d^{-1} (model #20) to 8.7 mm d^{-1} (model #14), and mR_{1-6} varies from 16.5 mm d^{-1} (model #20) to 84.6 mm d^{-1} (model #13). The concentration ratio

Table 2. Characteristics of precipitation in models of CMIP3 20C3M.

Model	$[mR]$ mm/d	$[R]$ mm/d	$[mR]/[R]$	mR_{1-6} mm/d	$mR_{1-6}/[R]$
01	8.7	6.9	1.26	55.0	8.0
02	6.5	3.4	1.91	46.8	13.8
03	8.3	5.1	1.63	59.9	11.8
04	12.4	7.7	1.61	59.5	7.2
05	8.1	4.9	1.65	42.2	8.6
06	10.2	5.7	1.79	50.6	8.9
07	9.4	5.7	1.65	59.0	10.4
08	9.8	6.4	1.53	32.9	5.1
10	9.0	7.1	1.39	29.8	4.2
12	6.9	4.8	1.44	27.6	5.8
13	12.3	6.9	1.78	84.6	12.3
14	15.9	8.7	1.83	62.9	7.2
15	9.0	5.9	1.53	46.3	7.9
16	5.9	3.8	1.55	35.0	9.2
17	14.6	8.2	1.78	66.9	8.2
18	12.8	7.9	1.62	48.6	6.2
19	9.0	5.6	1.61	40.0	7.1
20	4.2	2.8	1.50	16.5	5.9
MEA	9.6	6.0	1.61	48.0	8.2
STD	3.0	1.7	0.16	16.5	2.6
GPCP	21.6	10.9	1.98	75.9	7.0

Fig. 2. Order statistics of mR_k obtained by models #08, 10, 02, 03, 14, and GPCP.

$mR_{1-6}/[R]$ also varies widely from 4.2 (model #10) to 13.8 (model #02).

The order statistics of mR_k also shows large differences among the models. As examples, Fig. 2 shows the order statistics of mR_k obtained by models #08, 10, 02, 03, and 14 and GPCP. Models #08 and #10 (top panel, Fig. 2) show typical order statistics with moderate $[R]$ and small $mR_{1-6}/[R]$. Models #02 and #03 (middle panel) show typical order statistics with the smaller $[R]$ and larger $mR_{1-6}/[R]$. Model #14 (bottom left panel) shows the relatively large $[R]$ and large $mR_{1-6}/[R]$. The order statistics simulated by model #14 show features consistent with GPCP (bottom right panel).

The differences seen in the order statistics among the models are examined in relation to the horizontal distribution of precipitation and the sea level pressure (SLP) field simulated by the respective models. For this, the case of the second largest

maximum precipitation (i.e., mR_2) is examined because the first case is significantly different from the second to sixth cases.

Figure 3 shows the precipitation and SLP of the second largest maximum precipitation case simulated by models #08 and #10. These models do not simulate a realistic BFZ. Model #08 reproduced relatively large precipitation over southwestern Japan associated with a weak northeast–southwest-extending surface trough over the Korean Peninsula, whereas model #10 reproduced relatively large precipitation over southwestern Japan associated with a weak west–east-extending surface trough over the East China Sea. The simulated features are not consistent with the observed features shown by GPCP and European Center for Medium-Range Weather Forecasts 40-year reanalysis data (ERA40; Uppala 2005) in the right panel of Fig. 5.

Fig. 3. Precipitation (isohyets; 10-mm d^{-1} interval) and SLP (isobars; 2-hPa interval) of the second largest maximum precipitation case simulated by models #08 (left panel) and #10 (right panel).

Figure 4 shows the precipitation and SLP of the second largest maximum precipitation case simulated by models #02 and #03. These models do not simulate BFZ and reproduced intense precipitation over southwestern Japan associated with respective synoptic-scale depressions. The simulated features are not consistent with the observed features shown by GPCP and ERA40.

The left panel in Fig. 5 shows the precipitation and SLP of the second largest maximum precipitation case simulated by model #14. This model simulates the intense precipitation in BFZ, which extends along the northwestern rim of the North Pacific subtropical anticyclone. The features simulated by model #14 are consistent with the observed features shown by GPCP and ERA40 (right panel). This model, which is able to simulate realistic BFZ, is also able to simulate the proper order statistics of the intense precipitation and “concentration ratio.”

The influence of horizontal resolution and the cumulus parameterization scheme on the simulation of intense rainfalls is next examined. Table 3 shows $\text{mR}_{1-6}/[\text{R}]$ and $[\text{R}]$ obtained by the models. In this table, high, medium, and low resolution indicate resolutions of approximately 1° , $2-3^\circ$, and $3-5^\circ$, respectively. MC, MF and AS show the moist convective adjustment scheme, the mass-flux scheme, and the Arakawa–Schubert scheme, respectively. The low- and medium-resolution models with MC give the large variation range of the “concentration ratio” from 5.8 to 13.8, whereas models with MF give a smaller variation range from 4.2 to 9.2. Medium- and high-resolution models with the AS scheme give a variation range from 6.2 to 10.4.

Figure 6 shows the dependence of $\text{mR}_{1-6}/[\text{R}]$ and $[\text{R}]$ on horizontal resolution and the cumulus parameterization scheme. In this figure, L, M, and H indicate the low-, medium-, and high-resolution

Fig. 4. Precipitation and SLP of the second largest maximum precipitation case simulated by models #02 (left panel) and #03 (right panel).

models, respectively. The cumulus scheme is indicated by the symbols. Medium- and high-resolution models with the AS scheme tend to yield a concentration rate consistent with GPCP. Because the large and small concentration ratios reproduced by the models are canceled out in MEA, the MEA concentration rate (8.2) does not largely deviate from the ratio obtained from GPCP (7.0).

4. Features of intense precipitation projected for 2080–2099

Features of intense precipitation projected for June and July in 2097–2099 are examined with the same procedure used to evaluate the 20th century simulation in the previous section. Table 4 shows $mR_{1-6}/[R]$ and $[R]$ obtained by the models for this period. Table 4 shows that the low- and medium-resolution models with MC give a large range of

variation in the concentration ratio, from 3.9 to 14.5, whereas models with MF give a smaller variation range from 4.1 to 10.5. Medium- and high-resolution models with the AS scheme give the smaller variation range from 5.3 to 10.8.

Figure 7 compares the “concentration ratio” simulated for 1997–1999 (in the x-axis) with those projected in 2097–2099 (in the y-axis). The regression line and the correlation coefficient between the two time periods are shown in Fig. 7. The models that simulate a large (small) concentration ratio project the large (small) concentration ratio. Because the change in the concentration ratio from the 20th century simulation to the 21st century projection is very small compared with the differences in the simulated concentration ratio among models, the change in the concentration ratio from the 20th to 21st century cannot be satisfactorily clarified using CMIP3 data.

Fig. 5. Precipitation and SLP of the second largest maximum precipitation case simulated by model #14 are shown in the left panel. Precipitation of the second largest maximum GPCP precipitation case and corresponding ERA40 SLP are shown in the right panel.

Table 3. Dependency of $mR_{1-6}/[R]$ and $[R]$ on models, in the 20th century simulation (20C3M).

Resolution Cum. Param.	Low			Medium			High		
	Model	$mR_{1-6}/[R]$	$[R]$ mm/d	Model	$mR_{1-6}/[R]$	$[R]$ mm/d	Model	$mR_{1-6}/[R]$	$[R]$ mm/d
MC	#02	13.8	3.4	#03	11.8	5.1			
	#12	5.8	4.8	#05	8.6	4.9			
	#13	12.3	6.9	#20	5.9	2.8			
MF	#08	5.1	6.4	#01	8.0	6.9	#19	7.1	5.6
	#16	9.2	3.8	#04	7.2	7.7			
				#10	4.2	7.1			
				#17	8.2	8.2			
AS				#06	8.9	5.7	#14	7.2	8.7
				#07	10.4	5.7			
				#15	7.9	5.9			
				#18	6.2	7.9

Fig. 6. Dependence of $mR_{1-6}/[R]$ and $[R]$ on horizontal resolution and the cumulus parameterization scheme. L, M, and H indicate the low-, medium-, and high-resolution models, respectively. The cumulus scheme is indicated by the symbols.

5. Appearance frequency of days with large rainfalls in June and July

In this section, the appearance frequency of days with a large mR_k of the first to sixth rank (i.e., total

Fig. 7. Comparison of “concentration ratio” simulated by the 18 models for 1997–1999 (in the x -axis) with these projected for 2097–2099 (in the y -axis). The numeral attached to the small circle indicates the sequential number of the models shown in Table 1.

of 6 days for each model) in June and July, simulated in 1997–1999 and projected for 2097–2099, are examined. Table 5 shows days with a large mR_k simulated and projected by each model. GPCP data in 1997–1999 (bottom line in Table 5) show that 3 days appear in June and 3 days appear in July among 6 days of the largest mR_k . Meanwhile, the MEA simulates approximately 4 days in June and 2 days in July. Table 5 also shows large differences among the models in terms of the occur-

Table 4. Dependency of $mR_{1-6}/[R]$ and $[R]$ on models, in the 21st century simulation (A1B).

Resolution Cum. Param.	Low			Medium			High		
	Model	$mR_{1-6}/[R]$	$[R]$ mm/d	Model	$mR_{1-6}/[R]$	$[R]$ mm/d	Model	$mR_{1-6}/[R]$	$[R]$ mm/d
MC	#02	13.7	3.7	#03	14.5	5.3			
	#12	3.9	5.9	#05	6.3	5.8			
	#13	12.4	8.0	#20	5.6	3.7			
MF	#08	6.1	5.9	#01	7.3	7.3	#19	6.1	5.2
	#16	8.5	5.3	#04	10.5	6.1			
				#10	4.1	8.7			
				#17	8.1	9.5			
AS				#06	7.6	8.7	#14	10.2	8.7
				#07	10.8	6.1			
				#15	6.7	8.0			
				#18	5.3	9.1			

MEA: $mR_{1-6}/[R] = 8.2$, STD = 3.2.

Table 5. Appearance of days of mR_{1-6} in 1997–1999 and 2097–2099.

Model#	Resolution	Cum. parameterization	1997–1999		2097–2099	
			Jun	Jul	Jun	Jul
01	med	MF	4	2	5	1
02	low	MC	2	4	2	4
03	med	MC	4	2	1	5
04	med	MF	6	0	5	1
05	med	MC	6	0	1	5
06	med	AS	4	2	5	1
07	med	AS	4	2	6	0
08	low	MF	5	1	4	2
10	med	MF	3	3	2	4
12	low	MC	6	0	4	2
13	low	MC	3	3	3	3
14	high	AS	5	1	5	1
15	med	AS	4	2	3	3
16	low	MF	2	4	6	0
17	med	MF	6	0	5	1
18	med	AS	4	2	5	1
19	high	MF	6	0	4	2
20	med	MC	2	4	4	2
MEA			4.2	1.8	3.9	2.1
STD			1.4	1.4	1.6	1.6
GPCP			3	3		

rence of the days with large mR_k . For example, models #04, 05, 12, 17, and 19 simulate all 6 days in June. This may be related to the fact that the models tend to simulate Baiu rainfall in June compared with July (Ninomiya 2011).

A few models produce large changes from 20th century simulation to 21st century projection. For example, model #05 projects a decrease in days with large mR_k in June and an increase in July, whereas model #16 projects a decrease in July. Because the differences among the models are very large with regard to the occurrence of days with large mR_k , the changes in days with a large mR_k from the 20th to the 21st century cannot be discussed with certainty using CMIP3 data.

6. Concluding remarks

This study examined features of intense rainfalls over southwestern Japan in the Baiu season (June and July) in the 20th Century simulation (20C3M) and 21st Century projection (SRES A1B) obtained by 18 climate models that contributed to CMIP3.

Characteristics of daily precipitation over an area of $5.0^\circ \times 5.0^\circ$ within 30°N – 35°N and 130°E – 135°E obtained by the 20th century climate simulation were compared with observed precipitation data for June and July during a 3-year period (1997–1999). The studied area includes four subareas of $2.5^\circ \times 2.5^\circ$. The four-area averaged daily precipitation and the maximum precipitation in the four areas was analyzed. The order statistics of the maximum precipitation indicated a wide difference from model to model. To measure the temporal and spatial concentration of precipitation, the “concentration ratio” was examined, which is defined by (the average of the first to sixth-largest maximum precipitation)/(time and area-averaged precipitation). While a few models reproduce a reasonable concentration ratio comparable with the observation, many other models did not reproduce a reasonable ratio. The high- and medium-resolution models with the AS scheme tend to simulate a concentration ratio consistent with GPCP because these models properly simulate intense rainfalls in the Baiu frontal rainfall zone.

Features of the order statistics of intense rainfalls and the concentration ratio in the 21st century climate projection by the models were examined for June and July over a 3-year period (2097–2099). The characteristics of the models with regard to the concentration ratio in the 20th century simulation were commonly found in the 21st century projection. That is, models that reproduce a large (small) concentration ratio in the 20th Century tend to project a large (small) concentration ratio in the 21st Century. Because the difference among the models in regard to the intense rainfalls is too large, the change in the concentration ratio under the climate changes in the 21st century cannot be definitely concluded by CMIP3 models.

In the present study, we discussed features of daily precipitation. To evaluate the models’ ability to reproduce the intense Baiu precipitation, an examination of hourly precipitation is also needed. Ninomiya et al. (2008) stated that the high-resolution (T106) model “Miroku-high” (model #14 in this report) simulated the daily intense Baiu

rainfalls well. However, this model does not necessarily simulate the intense rainfalls when hourly rainfalls are considered.

Acknowledgment

This work was partially supported by the Global Environment Research Fund (S-5-2) of the Ministry of the Environment, Japan. I acknowledge the modeling groups, the Program for Climate Model Diagnosis and Intercomparison (PCMDI), and the WCRP's Working Group on Coupled Modelling (WGCM) for their roles in making available the WCRP CMIP3 multi-model dataset. Support of this dataset is provided by the Office of Science, US Department of Energy. I also acknowledge to the "Data Integration and Analysis System Fund for National Key Technology" from the Ministry of Education, Culture, Sports, Science and Technology, Japan, for providing us with an invaluable environment for mass data handling. I express my sincere thanks to Dr. Y. Kawatani of JAMSTEC for his various forms of support. I also thank the members of S-5-2 project and two anonymous referees for informative comments.

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