Future Changes in the Baiu Rain Band Projected by a 20-km Mesh Global Atmospheric Model: Sea Surface Temperature Dependence

Shoji Kusunoki¹ and Ryo Mizuta²
¹Meteorological Research Institute, Tsukuba, Japan
²Advanced Earth Science and Technology Organization, Tsukuba, Japan

Abstract

Global warming projection experiments were conducted using a 20-km mesh global atmospheric model (the 20-km model), focusing on the change in the rain band of the East Asian summer monsoon (the Baiu rain band in Japan). To quantify the dependence of the projected change on the sea surface temperature (SST) prescribed to the 20-km model, we have taken different SSTs given by the two Atmospheric-Ocean General Circulation Models (AOGCMs) of MRI-CGCM2.3.2 and MIROC(hires). In the future climate simulations, the Intergovernmental Panel on Climate Change (IPCC) A1B emission scenario was assumed. The future climate simulations show that precipitation and its intensity increase over the Yangtze River valley of China and Western Japan. The termination of the Baiu season tends to be delayed until August. These changes were consistently found in the simulations regardless of different SSTs.

1. Introduction

The rainy season or the rain band observed over Japan from June to July is called the Baiu. Kusunoki et al. (2006) indicated the realistic reproduction of the Baiu rain band needs an atmospheric model with a higher horizontal resolution. They investigated the future change in the Baiu rain band with the 20-km model, using the time-slice method (Bengtsson et al. 1996) which prescribes SST simulated by an AOGCM. It is widely recognized that global warming projections include a wide range of uncertainty arising from many factors such as differences in the future emission scenario, the model performance, the internal natural variability of the climate system. Therefore, the evaluation and the quantification of the uncertainty in global warming projection are strongly required to obtain more robust and reliable information on future climate changes (IPCC 2007). Although the time-slice experiments of the 20-km model are largely affected by prescribed SST, Kusunoki et al. (2006) have used only one set of SSTs for the present-day and future climate simulations. The purpose of this study is to evaluate and quantify the uncertainty of the projected change in the Baiu originating from the differences in SSTs prescribed to the 20-km model.

2. Model

The 20-km model used in this study was jointly developed by the Japan Meteorological Agency (JMA) and the Meteorological Research Institute (MRI). The model has a horizontal spectral truncation of TL959 corresponding to an about 20-km horizontal grid spacing and has 60 levels with a 0.1 hPa (altitude of about 65 km) top. The details are described in Mizuta et al. (2006). The integration of the 20-km model and the data processing were performed on the Earth Simulator (Habata et al. 2004).

3. Experimental design

Table 1 summarizes the specification of SSTs. For the present-day climate simulations, three different SSTs were prescribed to the 20-km model. Simulation PC used the observed climatological SSTs (Reynolds and Smith 1994) averaged for 12 years from 1982 to 1993. The SST of PC has no year-to-year variability, but has seasonality. We have integrated the 20-km model for 20 years. The general performance of the simulation...
Changes in the Baiu Rain Band for the first 10 years of simulation PC is discussed in detail by Mizuta et al. (2006). PY used the SST from 1979 to 1998 simulated by MRI-CGCM2.3.2 (Meteorological Research Institute - Coupled General Circulation Model Version 2.3.2; Yukimoto et al. 2006b) in the climate of the 20th Century experiment (20C3M) of IPCC Fourth Assessment Report (AR4; IPCC 2007). The SST of PY has year-to-year variability and was taken from one of the 5-member ensemble simulations for 20C3M. PR used the climatological SST (1979–1998 average) simulated by MIROC(hires) in the 20C3M experiment of IPCC AR4. MIROC(hires) is the high resolution version of a coupled model by the University of Tokyo, National Institute for Environmental Studies and Frontier Research Center for Global Change (K-1 Model Developers 2004). The ensemble size of MIROC(hires) simulation for 20C3M is one. The SST of PR has no year-to-year variability, but has seasonality.

For the future climate simulations, the concentrations of greenhouse gas and aerosols in the 20-km model were assumed as those for the year 2090 prescribed by the IPCC Special Report on Emission Scenarios (SRES) A1B scenario (IPCC 2000). Four different SSTs were prescribed to the 20-km model. In FC, the changes from the present SSTs (1979–1998, 20-year mean taken from 20C3M) to the future SSTs (2080–2099, 20-year mean) simulated by MRI-CGCM2.3.2 (Yukimoto et al. 2006a) were superposed on the observed SSTs (PC) for each grid point and each month. The change of SST was calculated by the ensemble averages of the 5-member simulations for 20C3M and a future climate. FY used the SST from 2080 to 2099 projected by MRI-CGCM2.3.2 (Yukimoto et al. 2006a). The SST of FY has year-to-year variability and was taken from one of the 5-member ensemble simulations. FR is the same as PR, except for the average period from 2080 to 2099. The ensemble size of the MIROC(hires) simulation for the future climate is one. FR2 is the same as FC, except for the model MIROC(hires). Due to the limitation of computer resources, the integration time for PR, FR and FR2 was restricted to less than 20 years.

The present-day climate simulation PC was used for reference climatology to calculate a future change in the simulations FC and FR2. The future change in the simulation FR was calculated relative to the simulation PR. Student’s t-test is applied using interannual variances.

Fig. 1. Sea surface temperature (SST) prescribed to the 20-km model for July. (a–d) Future climate simulations. Contour interval is 1°C. (e–h) Differences relative to the reference SST for respective present-day climate simulations. Contour interval is 0.5°C. (b) is for year 2080. (f) is SST difference between year 2080 and 1979. (g) and (h) is identical.

Fig. 2. Precipitation (mm day⁻¹) for July. (a) Observation by GPCP (2.5 degree, 1979–1998; Adler et al. 2003). (b–d) Present-day climate simulations. (e–h) Changes relative to the reference present-day climate simulations. Contours show 90% significance level. The box in (a) shows the target region for Fig. 3. Student’s t-test is applied using interannual variances.
sensitivity of MIROC(hires), the SST changes by MIROC(hires) (g, h) are much larger than those by MRI-CGCM2.3.2 (e, f). Therefore, the prescribed SSTs projected by MIROC(hires) (c, d) are higher than those by MRI-CGCM2.3.2 (a, b). Similar tendencies are also found in the June case (supplement Fig. S1). The spatial structure of the SST change over the tropical Pacific resembles an El-Niño-like response both for MRI-CGCM2.3.2 and MIROC(hires) (figure not shown).

4. Verification of the present-day climate simulations, and future changes

4.1 Geographical distribution

Figure 2a–d show the precipitation in July for the present-day climate. The observational data of the Global Precipitation Climatology Project (GPCP; Adler et al. 2003) with 2.5 degree resolution in longitude and latitude are averaged from 1979 to 1998 (a). Simulation PC (b) overestimates the precipitation over the Yangtze River valley, Taiwan, the Korean peninsula and Western Japan, but the comparison with the higher-horizontal-resolution observations (Fig. S3b, d, e) suggests that discrepancies are within the range of uncertainty in observations. Simulation PY (c) underestimates the precipitation over Japan and overestimates that over the region south of 25°N. Simulation PR (d) overestimates the precipitation over Japan. The errors in simulations PY and PR are partly due to the errors in the SSTs given by AOGCMs. Similar tendencies of PY and PC are also found in the June case (supplement Fig. S2a–d). Excessive precipitation of PR in July is also confirmed by the time-series of the area average over Japan (supplement Fig. S4a).

Figure 2e–h show the changes in precipitation in July for a future climate. In Fig. 2e and h, the reference simulation for the present-day climate is PC with observed SST. In Fig. 2f, both FY and PY use SST with year-to-year variability of MRI-CGCM2.3.2. In Fig. 2g, both FR and PR use climatological SST of MIROC(hires). Figure 2e–h show a common tendency that precipitation increases over the Yangtze River valley of China (not statistically significant in 2h), the East China Sea, Western Japan, and over the ocean to the south of Japan archipelago. This is also confirmed by the latitudinal profile of precipitation changes (Fig. S5). These changes are due to the intensification of clockwise moisture transport over Ogasawara high (Fig. S6). The geographical distribution of the changes and their mechanism is consistent with the previous results by Kusunoki et al. (2006) which analyzed the first ten years of simulations PC and FC. Over the region south of 25°N, precipitation decreases in Fig. 2e–g but increases in Fig. 2h. In the June case, only the increases of precipitation over the Yangtze River valley of China were common among three pairs of simulations (supplement Fig. S2e, f, h).

4.2 Seasonal marching

In Fig. 3, the seasonal marching of precipitation is shown for the longitudinal sector including Japan. Simulation PC (b) well reproduces the observed seasonal
marching of precipitation, but overestimates the precipitation in August. However, the comparison with higher-horizontal-resolution observational data of GPCP 1DD (Fig. S7b) suggests that discrepancies are within the range of uncertainty in observations. Simulation PY (c) underestimates precipitation. PR (d) overestimates precipitation. Figure 3e–h show a common tendency that the precipitation in the future climate increases around 30°–35°N from July to the middle of August. The increase of precipitation suggests a delay in the termination of the Baiu season. However, a statistically significant region in Fig. 3g is missing mainly due to the short period (5 years) of simulations PR and FR. Due to larger interannual variances in pentad data than those in monthly data, significant areas in Fig. 3e are generally less than those in Fig. 3a–h. The delay in retreat of the rainy season is confirmed by the time-series of the area averaged over Japan (supplement Fig. S3b) and by the change in the retreat time on the grid point base analysis (supplement Fig. S4e, f). The change in the onset of the rainy season has no clear and consistent tendency. The delay in the termination of the Baiu season in this study is consistent with the previous results by Kusunoki et al. (2006).

4.3 Intensity of precipitation
Figure 4 shows the intensity of precipitation in June and July in terms of the number of heavy rain days (precipitation ≥ 30 mm day\(^{-1}\)). In the present-day climate, simulations PC and PY underestimate the intensity, whereas PR overestimates the intensity over the Yangtze River valley and the East China Sea. Figure 4e–h show a common tendency that the intensity of precipitation increases over the Yangtze River valley and Western Japan. This is consistent with the previous results by Kusunoki et al. (2006).

5. Summary and discussion
Global warming projection experiments were conducted using a 20-km mesh global atmospheric model (the 20-km model), focusing on the change in the rain band of the East Asian summer monsoon (the Baiu rain band in Japan). The IPCC SRES A1B emission scenario (IPCC 2000) was assumed in the future climate simulations. The experiments using the 20-km model were conducted by adopting the time-slice method, in which future changes in SST were predicted by AOGCMs. One of the major uncertainties in time-slice experiments originates in the differences of SSTs prescribed to the 20-km model. To quantify the dependence of the projected change in the Baiu rain band on SSTs, we have taken different SSTs from the two AOGCMs; MRI-CGCM2.3.2 and MIROC(hires). The effective climate sensitivity of MIROC(hires) is higher than that of MRI-CGCM2.3.2, so that the future increase of SSTs projected by MIROC(hires) is larger than that of MRI-CGCM2.3.2.

The future climate simulations show that precipitation and its intensity increase over the Yangtze River valley of China and Western Japan. The termination of the Baiu season tends to be delayed until August. These changes were consistently found in simulations regardless of different SSTs. The changes in the Baiu rain band found in this study are more robust and reliable than those found in the previous time-slice experiments prescribed with a single set of SSTs given by a specific AOGCM.

Uncertainty arising from performance of the atmospheric model and internal variability of the atmosphere should be evaluated by the ensemble simulations. These topics should be pursued in future works.

Acknowledgments
This study was conducted under the research project of “Kyosei-4” and the “KAKUSHIN” funded by Ministry of Education, Culture, Sports, Science and Technology (MEXT).

Comments and supplements
Figure S1 : Same as Fig. 1 except for June. S2 : Same as Fig. 2 except for June. S3 : Multiple precipitation observations for July. S4 : Time series of precipitation averaged over Japan. S5 : Latitudinal profile of precipitation changes for July. S6 : Changes in vertically integrated moisture flux for July. S7 : Multiple precipitation observations of seasonal march. S8 : Onset and retreat time of the rainy season for the present-day climate on grid-point base. S9 : Changes in onset and retreat time on grid-point base.

References
Bengtsson, L., M. Botzet, and H. Esch, 1996: Will greenhouse gas-induced warming over the next 50 years lead to higher frequency and greater intensity of hurricanes? Tellus, 48A, 57–73.

Manuscript received 12 May 2008, accepted 19 August 2008 SOLA: http://www.jstage.jst.go.jp/browse/sola/