Changes of Baiu (Mei-yu) Frontal Activity in the Global Warming Climate Simulated by a Non-hydrostatic Regional Model

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Abstract

The Baiu (Mei-yu) front over East Asia in the global warming climate as well as that in the present one, is studied using outputs of a non-hydrostatic regional model with a horizontal grid size of 5 km (NHM). The NHM was run in June and July for ten years, applying a spectral boundary coupling method to reduce the horizontal phase differences of large-scale disturbances using the outputs of a global climate model with a grid size of 20 km. In the global warming climate, the Baiu front is likely to stay over the southern Japan Islands around the latitudes of 30°N–32°N and will not move northward. Therefore, the activity of the Baiu front maintains longer than that in the present climate, and the precipitation increases. On the other hand, the precipitation decreases over the northern Japan Islands and the northern Korean Peninsula. Years with no end of the Baiu season are often seen, and the frequency of occurrence of heavy rainfall greater than 30 mm h\(^{-1}\) increases over the Japan Islands.

1. Introduction

Global warming is an urgent and important problem that is threatening humans and the terrestrial environment; thus, its impact must be quantitatively and scientifically estimated. In order to study global warming, super-high-resolution global and regional climate models were developed from 2002. In this project, there are two objectives; (1) to develop two high-resolution atmospheric models, i.e., a global climate model with a horizontal grid of 20 km (AGCM) and a non-hydrostatic regional model (NHM) with a grid size of a few km; and (2) to study the changes of severe weather activities in the global warming climate, such as typhoons and the Baiu front. Here, Baiu refers to rainy phenomena observed over East Asia in the early summer. It is called Mei-yu in China and Changma in Korea. In the project, the calculations and data handling were performed using the Earth Simulator (ES).

In order to pursue these objectives, there are two research subgroups: AGCM and NHM. First, the AGCM subgroup made global-scale simulations in the present and global warming climates using the AGCM. Second, the NHM subgroup made regional simulations using the outputs of the AGCM as the initial and lateral boundaries of the NHM. Third, the outputs of both models in the present climate were compared with the observations, and the similarities and differences between the present and global warming climates were discussed.

Noda et al. (2004) presented a general introduction of the project and the results of the AGCM subgroup.

Therefore, the main purpose of this study is to examine the changes in the Baiu frontal activities in June and July in the global warming climate using the outputs of the NHM. In Section 2, brief explanations of the AGCM results are shown. The Baiu frontal activity in the present and global warming climates simulated by the NHM is examined in detail in Section 3. Monthly-mean precipitation, the onset and end of the Baiu season, and precipitation amounts and frequency of heavy rainfall over the Japanese regions are studied. In Section 4, the NHM precipitation in the present climate is compared with the observations. Conclusions are presented in Section 5.

2. AGCM results in the present and global warming climates

In this study, it is assumed that the global changes of CO\(_2\) emission follow Scenario A1B. This is characterized by a future world of very rapid economic growth, global population that peaks in middle of the 21st century and declines thereafter, and by a balanced introduction of new and more efficient technologies of all energy supply (IPCC 2001). CO\(_2\) increases about twice in concentration around 2080–2099. Since the models treat only atmospheric parts in detail, the sea surface temperature (SST) and the soil temperature at the lowest ground grid points are obtained from the outputs of an atmosphere-ocean coupled model (AOGCM) with a horizontal grid size of about 270 km (Yukimoto and Noda 2002). The SST distributions are assumed to have only a seasonal variation but have no year-to-year variation.

The “time-slice” simulation is defined as the two-tier global warming projection approach using an AOGCM and an AGCM whose horizontal resolution is higher than that of atmospheric part of the AOGCM. Such time-slice experiments for ten years in the present and global warming climates were performed using the AGCM. The precipitation patterns and intensities in the present climate showed good agreements with the observations (e.g., Global Precipitation Climatology Project). The surface air temperature, T\(_s\), in the global warming climate shows large differences from that in the present climate, especially over the high-latitude land areas. The global-mean T\(_s\) rises about 2.5 K. The precipitation patterns and intensities do not change directly following the SST distributions. Tropical cyclones, including typhoons and hurricanes, are also examined. In the global warming climate, the total number of their occurrences decreases globally, although their wind intensity increases.
3. Baiu frontal activities in the present and global warming climates simulated by the NHM

3.1 Brief description of the NHM

Since our focus is on the Baiu frontal activities in East Asia, NHM simulations in June and July in the present and global warming climates were performed for ten years. The initial and lateral boundary conditions of the NHM were obtained from the outputs of the AGCM in an one-way nesting manner. In order to couple the AGCM and NHM smoothly, it is necessary to reduce the horizontal phase differences of propagating large-scale cyclones between both models. A spectral boundary coupling (SBC) method was adopted. In this method, large-scale modes from the AGCM are combined with small-scale ones from the NHM using the wave-number decomposition (separation wave number; \(K_s\)) (Kida et al. 1991; Yasunaga et al. 2004a). The SBC method is applied to the fields of horizontal winds and temperature above a height of 5 km for every 20 minutes, and the inverse \(K_s\) was selected to be about 1000 km (Yasunaga et al. 2004a). A two-moment parameterization of cloud water and rain for the mixing ratio and number concentration was also introduced for the cloud physics of the NHM to express fine precipitation patterns (Hashimoto et al. 2003). No cumulus-cloud parameterization is included in the NHM. The treatment of cumulus clouds is much different from the AGCM among various physical processes. Such NHM with small grid sizes is sometimes called a cloud-resolving model.

The horizontal resolution of the NHM was set to be 5 km. The model domain was 800×600 horizontal grids (4000 km×3000 km) and 48 vertical layers (top height: 22 km). The polar stereo map projection was utilized (Fig. 1). The 40-day simulation, which is a unit of calculation, required about 64 hours using 30 nodes of the ES. The detailed specification of the NHM was shown in Muroi et al. (2004).

3.2 Monthly-mean precipitation in July

Ten years precipitation data for the month of June and July were obtained by using the NHM. The precipitation in June and July is brought by Baiu fronts as well as synoptic-scale disturbances. However, we simply consider that the Baiu frontal activity produces all precipitation in both months hereafter. The changes of Baiu frontal activities in June were small compared with those in July in the present and global warming climates, and, therefore, only the changes in July are discussed here.

Figure 2 shows the horizontal distributions of (a) monthly-mean daily accumulated precipitation in July in the present climate and (b) differences of the global warming climate from the present one. Units are mm day\(^{-1}\).

3.3 Onset and end of the Baiu season

In East Asia, the onset and end of the Baiu season represent valuable information because they are indicators of remarkable seasonal changes. Figure 3 shows time-latitude sections of precipitation averaged in 130 E–135 E in the present and global warming climates. Here, the Baiu front is defined by examining temperature gradients and wind shears near the surface, and wind jets at 850 hPa. Usually the Baiu front moves northward gradually and disappears in the middle of July. In the global warming climate, meanwhile, the onset of the Baiu season is found at around similar dates, but its end is not seen even until the end of July. Also the northward shift of the Baiu front is not seen. The year in Fig. 3 was selected arbitrarily, but such years with no end of the Baiu season are often seen.

In order to study the physical mechanisms for the longer duration of the Baiu season in the global warming climate, Kanada et al. (2004) and Yasunaga et al. (2004b) investigated the spatial distributions of pressure, winds, temperature, and water vapor as well as daily changes of these variables.

3.4 Precipitation amounts and frequency of heavy rainfall over the Japanese regions

Here, the NHM precipitation in the present and global warming climates is compared over the Japanese regions. The validation of precipitation was conducted over the Japan Islands (all) and five separated regions; SW (Southwest), KS (Kyushu), CJ (Central Japan), EJ (Eastern Japan), and NJ (Northern Japan) (Fig. 4c).
Figure 4a shows the mean precipitation amounts in June and July. See the green and orange columns. Solid lines denote the rates of increase of the global warming climate from the present one. It is noteworthy that the precipitation in the global warming climate increases by 10% on average. The rate of increase is 30% larger in the KS region, while 10% smaller in the NJ region from average precipitation. These features are consistent with the previous results, in which more precipitation is found in the southern Japan Islands and less in the northern Japan Islands (Fig. 2b).

The frequency of heavy rainfalls is shown in Fig. 4b. Here, heavy rainfalls are defined as those with the precipitation intensity greater than 30 mm h\(^{-1}\). It is found that the frequency of heavy rainfall increases over all regions in the global warming climate. The KS region shows the highest rate of increase of precipitation, reaching 70%. However, the frequency of heavy rainfalls simulated in the NJ region is not shown, because numbers of occurrence of heavy rainfalls are very few.

In order to examine precipitation properly, the frequency to rainfall rates is examined (Fig. 5). See the green and orange lines, too. Here, all, SW, KS, and CJ regions are considered. The area of frequency and rainfall rate is the precipitation amount. It is found that all rainfall intensity increase in the global warming climates.

Detailed comparisons of the NHM results in the present climate with those in the global warming climate were conducted by Wakazuki et al. (2004).

4. Comparison of the observations with the NHM precipitation in the present climate

In order to examine whether the NHM can simulate the precipitation realistically, the NHM results in the present climate were compared with the observations. Here, radar-AMEDAS analyzed rainfall, estimated by meteorological radars and calibrated by AMeDAS precipitation data, was used for the validation of the NHM precipitation. AMeDAS means an Automated Meteorological Data Acquisition System of the Japan Meteorological Agency (JMA), and observes temperature, wind, and precipitation on the surface over land.
Let’s compare the observations with the NHM precipitation in the present climate. Hereafter, see the blue and green columns and lines in Figs. 4 and 5, respectively. It indicates in Fig. 4a that the simulated precipitation is, on average, 30% less than the observations. When the dependence of precipitation over the regions is examined, considerable differences are found about 60% less in the SW region. On the other hand, the heavy rainfalls greater than 30 mm h⁻¹ were simulated well (Fig. 4b), differently from the precipitation amounts. When the rainfall rates are examined in Fig. 5, it is found that most differences come from the underestimate of the precipitation intensity between 1 and 25 mm h⁻¹; especially, in the SW and KS regions. This may come from that the 5km-NHM could not well simulate convective cells, which produce moderate precipitation. The present NHM did not include the cumulus-cloud parameterization. On the other hand, an operational NHM of JMA with a grid size of 10 km includes a Kain-Fritch (1990) parameterization, and shows larger precipitation amounts than the observations, differently from the present results (Numerical Prediction Division 2004). It suggests that the cumulus-cloud parameterization is necessary even for the NHM with a horizontal size of 5 km.

It is also found that the present NHM has a trend of negative temperature/moisture deviations near the surface, because of insufficient surface fluxes from the ocean, and the accumulation of errors with time. These deficits may lead to weaker precipitation, too.

In order to get quantitative precipitation, further development and improvement of the NHM are required, such as higher horizontal resolution as well as physical processes of cloud physics, PBL, and surface fluxes.

5. Conclusions

The Baiu (Mei-yu) front over East Asia in the global warming climate as well as the present one is studied using the NHM. Main results of the NHM in the global warming climate are summarized as follows. The Baiu front is more active over the southern Japan Islands, and precipitation amounts increase there. Meanwhile, they decrease over the northern Japan Islands and northern Korean Peninsula. Years with no end of the Baiu season are often seen, and the frequency of occurrence of heavy rainfall greater than 30 mm h⁻¹ increases over the Japan Islands.

There are some differences in precipitation, when the observations are compared with the NHM results in the present climate. One reason may be due to that the present NHM contained no cumulus-cloud parameterization. Therefore, the development of NHM, such as a higher horizontal resolution, is necessary as a next step.

Toward the end of the 21st century, mesoscale convective systems are expected to become more active and form more frequently over the southern Japan Islands. Thus, more attention than ever needs to be paid to severe weathers.

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References


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