

Development of Super High Resolution Global and Regional Climate Models

Project Representative

Akira Noda Meteorological Research Institute

Authors

Akira Noda ^{*1}, Shoji Kusunoki ^{*1} and Masanori Yoshizaki ^{*1}

^{*1} Meteorological Research Institute

A time-slice global warming projection was conducted using a very high horizontal resolution atmospheric general circulation model (AGCM) with 20-km grid. In a future climate simulation, the number of tropical cyclones (TCs) generally decreases in most of regions except for North Atlantic Ocean. The number of TC generation is conspicuously diminished in the globe, but the locations of generation and tracks are not greatly changed. In the rainy season, Baiu, over East Asia in June and July, precipitation increases over Yangtze river valley of China, the East China Sea, western part of Japan and to the south of Japan archipelago. On the contrary, precipitation decreases over the Korean peninsula and the Northern Japan. Termination of the Baiu tends to delay until August. The Baiu front is also studied using outputs of a non-hydrostatic regional model with a horizontal grid size of 5 km (NHM). This model was run in June and July for ten years, applying a spectral boundary coupling method to the outputs of the global climate model with a grid size of 20 km. Although the changes of the Baiu front are similar to those of the AGCM, the NHM more realistically simulates precipitation amount and structures of clouds. It is found that the frequency of occurrence of heavy rainfalls greater than 30 mm h⁻¹ increases over the Japan Islands.

These results will contribute to the Fourth Assessment Report of the IPCC to be published in 2007.

Keywords: global warming projection, high resolution global model, non-hydrostatic cloud resolving model, Baiu, tropical cyclone

1. Subproject 1: Development of a global climate model with a horizontal resolution of 20 km

1.1. Model and experimental design

High horizontal resolution AGCM experiments were realized by adopting so-called the "time-slice" method (Bengtsson et al. 1996; IPCC 2001). This method is defined as the two-tier global warming projection approach using an atmospheric ocean general circulation model (AOGCM) and an AGCM whose horizontal resolution is higher than that of atmospheric part of the AOGCM.

AOGCM used in the first step of the time-slice experiment is MRI-CGCM2.3 (Yukimoto and Noda 2002). The atmospheric part of this model has a horizontal spectral truncation of T42 corresponding to about a 270 km horizontal grid spacing, and has 30 levels with a 0.4 hPa top. The flux adjustment was used for heat and freshwater globally, and for wind stress near the equator.

The 20-km mesh AGCM used in the second step of the time-slice experiment has a horizontal spectral truncation of TL959 corresponding to about a 20 km horizontal grid spacing, and has 60 levels with a 0.1 hPa top (Mizuta et al. 2005). The time integration is accelerated by introducing a

semi-Lagrangian scheme (Yoshimura and Matsumura 2005). The calculation of the 20-km AGCM and data processing were performed on the Earth Simulator.

Observed climatological sea surface temperature (SST) average from 1982 through 1993 (Reynolds and Smith 1994) was used for the present climate simulation with the 20-km mesh AGCM. The SST change from the present (1979-1998, 20 year mean taken from 20th century climate simulations) to the future (2080-2099, 20 year mean) was obtained from a climate change simulation with the MRI-CGCM2.3 based on the Intergovernmental Panel on Climate Change (IPCC) A1B emission scenario (IPCC 2000). The SST differences between present and future SSTs were added to the observed SSTs for a warmer future climate simulation. In the future simulation with the 20-km mesh AGCM, concentration of greenhouse gas and emission of aerosols were assumed as values in year 2090 specified by A1B scenario. Then, the model was integrated for ten-year period each by forcing the SSTs as lower boundary condition.

1.2. Tropical cyclone

We performed an objective tracking of tropical cyclones

(TCs) in the model outputs, basically following the criteria used in a previous study (Sugi et al. 2002). Six-hourly data of 20-km mesh between 45°S and 45°N were used in this tracking. Initial position of each TC was restricted to the oceanic grid points between 30°S and 30°N. For the purpose of comparison to the observation, we used global TC data (1979–1998) obtained from a website of Unisys Corporation (<http://weather.unisys.com/hurricane>). Table 1 shows the annual mean number of tropical cyclone (TC) formation in the observational data, and in the present and future climate simulations for different regions. In the present climate, global number of TC reproduced by the model (78.3) is almost

comparable to that of observation (83.7). In the future warmer climate, number of TC generally decreases in most of regions except for North Atlantic Ocean. Figure 1 shows TC tracks of observation and those of the present and future climate simulations. In the present climate simulation, the model realistically reproduces the locations of generation and tracks. In the future climate simulation, number of generation is conspicuously diminished in the globe, but the locations of generation and tracks are not greatly changed.

1.3. Baiu

Geographical distribution of observed climatological precipitation and 850 hPa wind for July is shown in Fig. 2a. The model well reproduces observed large rainfall over the western part of Japan and the Korean peninsula associated with clockwise 850 hPa level wind over the subtropical high to the south of Japan (Fig. 2b). It is noteworthy that the model succeeded in simulating the concentration of precipitation over the western part of Japan and the Korean peninsula as well as the seasonal march. The change of precipitation and 850 hPa wind due to the warming is illustrated in Fig. 2c. Precipitation increases over the Yangtze River valley of China, the East China Sea, western Japan, and south of the Japan archipelago. Conversely, precipitation decreases over the Korean peninsula and Northern Japan. Strengthening of clockwise circulation is evident over subtropical high (20°N, 120-150°E), which means the intensification of subtropical high.

2. Subproject 2: Development of non hydrostatic models (NHMs) with horizontal resolutions of several km

2.1. Brief description of the NHM

Initial and lateral boundary conditions of the NHM were obtained from the outputs of the global climate model with a horizontal resolution of 20 km (GCM) in a one-way nesting manner. In order to couple the GCM and NHM smoothly

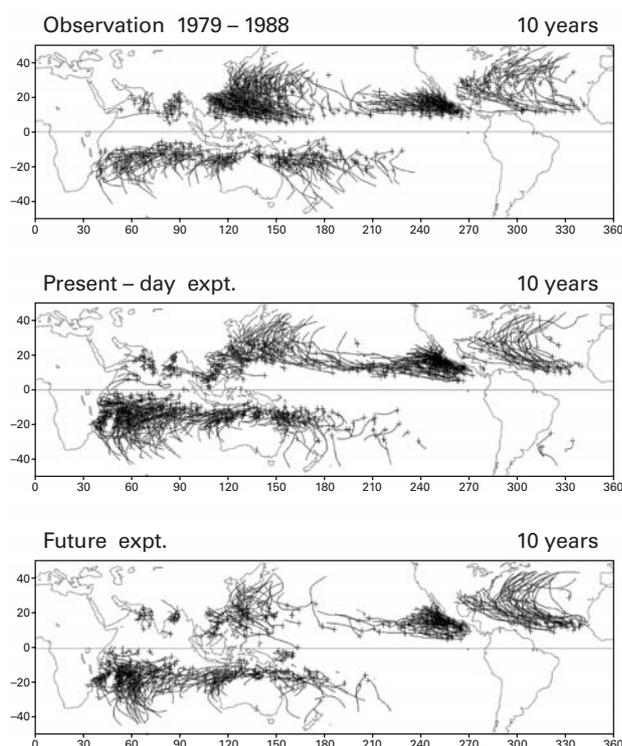


Fig. 1 TC tracks of the observational data (top), and the present climate simulation (middle) and future climate simulation (bottom). Initial positions of TCs are indicated by + marks.

Table 1 Annual mean number of tropical cyclone (TC) formation in the observational data, and in the present and future climate simulations for different regions.

| Region | Latitude | Longitude | Observation 20 years | Present 10 years | Fututre 10 years |
|-----------------------------|----------|-----------|-------------------------|---------------------|---------------------|
| Global | 45S-45N | ALL | 83.7 | 78.3 | 54.8 |
| Northern Hemisphere | 0 -45N | ALL | 58.0 | 42.8 | 30.8 |
| Southern Hemisphere | 0 -45S | ALL | 25.7 | 35.5 | 24.0 |
| North Indian Ocean | 0 -45N | 30E-100E | 4.7 | 4.5 | 2.2 |
| Western North Pacific Ocean | 0 -45N | 100E-180 | 27.0 | 12.7 | 7.6 |
| Eastern North Pacific Ocean | 0 -45N | 180 - 90W | 18.1 | 20.2 | 14.2 |
| North Atlantic Ocean | 0 -45N | 90W- 0 | 8.3 | 5.4 | 6.8 |
| South Indian Ocean | 0 -45S | 20E-135E | 15.5 | 26.1 | 18.9 |
| South Pacific Ocean | 0 -45S | 135E- 90W | 10.2 | 9.2 | 5.1 |

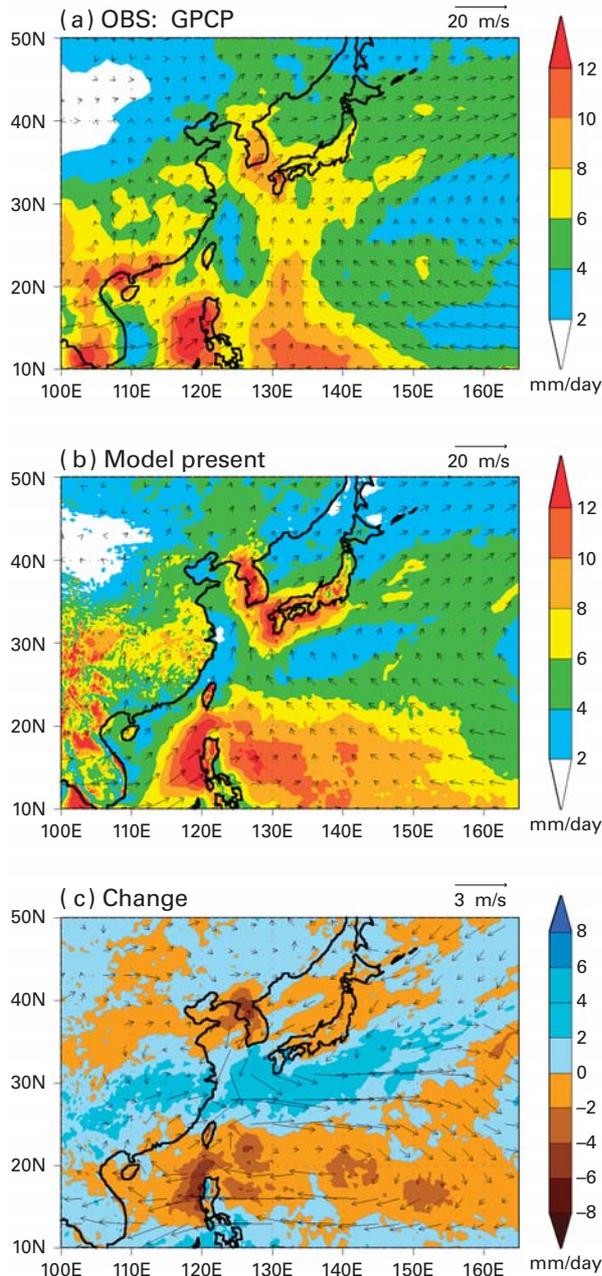


Fig. 2 Distributions of climatological precipitation (color, mm/day) and 850 hPa wind vector (arrow, m/s) for July. (a) Observed precipitation by GPCP data (Huffman et al. 2001) for 7 years from 1997 to 2003. Observed wind by ERA-40 data (Simmons and Gibson, 2000) for 30 years from 1971 to 2000. (b) Model's present climate simulation. (c) Change as future minus present climate simulation.

and to reduce the horizontal phase differences of propagating large-scale cyclones, a spectral boundary coupling (SBC) method was adopted (Yasunaga et al. 2004). 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. 2004). No cumulus-cloud parameterization was included in the NHM. The horizontal resolution of the NHM was set to be 5 km. The model domain was 800×600 horizontal grids ($4000 \text{ km} \times 3000 \text{ km}$) and 48 vertical layers (top height: 22 km). The 40-

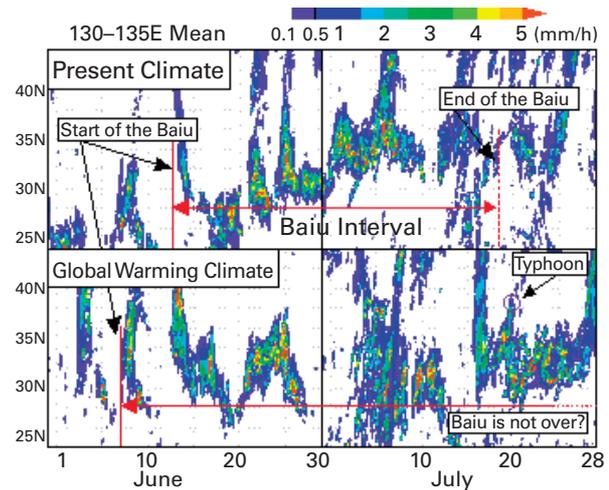


Fig. 3 Time-latitude sections of precipitation averaged in 130E-135E in the present climate (upper) and in the future warmer climate (lower).

day simulation, which is a unit of calculation, required about 64 hours using 30 nodes of the Earth Simulator.

2.2. Numerical results - Baiu frontal activities in the present climate and in the future warmer climate

2.2.1. 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. Usually the Baiu front moves northward gradually and disappears in the middle of July (the upper panel in Fig. 3). In the future warmer 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 (the lower panel in Fig. 3). 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 (Yoshizaki et al. 2005). Such features are similar to those of the AGCM. However, the NHM more realistically simulates precipitation amounts and structures of clouds.

2.2.4. Precipitation amounts and frequency of heavy rainfall over the Japanese regions

The NHM precipitation in the present and future warmer 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. It is noteworthy that the precipitation in the future warmer 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

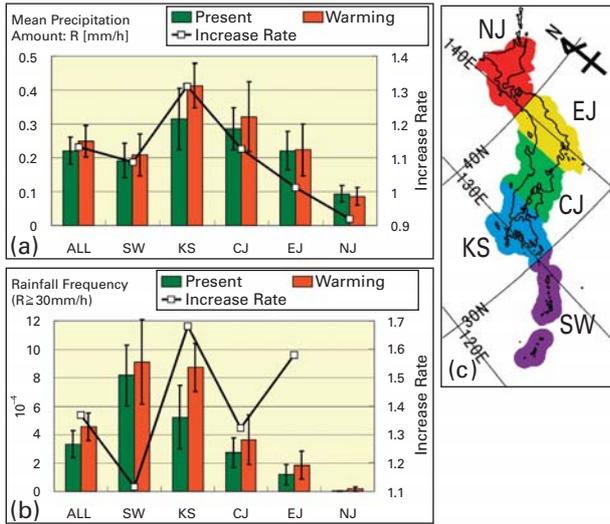


Fig. 4 (a) Mean precipitation amounts (mm h^{-1}) and (b) frequency of heavy rainfall over the Japan Islands (all) and five regions in June and July. Five regions denoted by SW, KS, CJ, EJ, and NJ are shown in (c). In (a) and (b), green and orange columns denote the NHM results in the present climate and the NHM results in the future warmer climate, respectively. Root mean square errors (bars) and rates of increase of the future warmer climate from the present one (solid lines) are also shown.

the northern Japan Islands (Fig. 3b).

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

future warmer climate. The KS region shows the highest rate of increase of precipitation, reaching 70%.

Bibliographies

- Bengtsson et al. 1996: *Tellus*, 48A, 57-73.
- Hashimoto, A., M. Murakami, T. Kato, C. Muroi, M. Yoshizaki, and S. Hayashi, 2004: *Research Activities in Atmospheric and Oceanic Modelling/WMO*, 34, 4-11 - 4-12.
- Huffman et al. 2001: *J. Hydrometeor.*, 2, 36-50.
- IPCC (Intergovernmental Panel on Climate Change), 2000: *Special Report on Emissions Scenarios*.
- IPCC, 2001: *Climate Change 2001: The Scientific Basis*.
- Mizuta et al. 2005: *J. Meteor. Soc. Japan*, Submitted.
- Reynolds et al. 1994: *J. Climate*, 7, 929-948.
- Simmons et al. 2000: *ERA-40 Project Report Series No. 1*.
- Sugi et al. 2002: *J. Meteor. Soc. Japan*, 80, 249-272.
- Yasunaga, K., T. Kato, Y. Wakazuki, H. Sasaki, C. Muroi, K. Kurihara, Y. Sato, M. Yoshizaki, S. Kanada, and A. Hashimoto, 2004: *Research Activities in Atmospheric and Oceanic Modelling/WMO*, 34, 7-43 - 7-44.
- Yoshimura, H. & T. Matsumura, 2005: *J. Meteor. Soc. Japan*, Submitted.
- Yoshizaki, M., C. Muroi, S. Kanada, Y. Wakazuki, K. Yasunaga, A. Hashimoto, T. Kato, K. Kurihara, A. Noda, and S. Kusunoki, 2005: *SOLA*, 1, 25-28.
- Yukimoto, S. & A. Noda, 2002: CGER's Super Computer Activity Report Vo 10-2001, CGER-1054-2002, 37-44.

高精度・高分解能気候モデルの開発

プロジェクト責任者

野田 彰 気象研究所

著者

野田 彰^{*1}, 楠 昌司^{*1}, 吉崎 正憲^{*1}

*1 気象研究所

平成16年度は、前年度までに開発を行った20 kmメッシュ全球気候モデル及び5 kmメッシュ雲解像モデル各々のプロトタイプモデルを用いて、タイムスライス法による地球温暖化予測実験を行った。

先ず、現在気候の気候値SST (1982-1998年平均)を20 km格子全球モデルに与え、現在気候の10年間の再現実験を行った。次に、気象研究所大気海洋結合モデルMRI-CGCM2.3によりIPCCのSRES A1Bシナリオに基づいて計算された将来(2080-2099年平均)のSSTと過去歴史実験(1979-1998年平均)のSSTの差を、現在気候の気候値SSTに加え、温暖化時のSST(年々変動なし)とした。これを20 km格子全球モデルに与え、2090年頃に相当する温暖化時の10年間の予測を行った。一方、東アジア域の梅雨前線を対象にして、現在気候と温暖化気候における6-7月の10年間について、水平解像度5 kmの雲解像大気モデル(5 km-NHM)を20 kmメッシュ全球大気モデルにネステイングさせて長時間シミュレーションを行った。

熱帯低気圧の全球的な発生数は、現在気候実験において年平均84個であったのに対し、温暖化実験では年平均58個であり、30%程度減少した。地理的な分布には大きな変化は見られなかった。また、熱帯低気圧の強度(最大風速)別の出現頻度を調べたところ、850 hPa面の最大風速が65 m/sを超えるような非常に強い熱帯低気圧の出現数については、逆に温暖化にともなって増加する傾向があることが分かった。熱帯低気圧にともなう降水も、温暖化実験の方が強くなる傾向があった。

梅雨については、中国大陸の揚子江付近、東シナ海、西日本にかけて降水量が増加した。逆に、朝鮮半島から北日本では降水量が減少した。フィリピン付近では850 hPa風ベクトルの変化が時計回りの循環を示しており、これは亜熱帯高気圧の強化を示唆している。同時に大気中の水蒸気量も増えており、水蒸気収束が増加して東シナ海や日本の南海上で降水量が増加することがわかった。

極端な現象に関する様々な指標の変化を計算した。例えば、日本では夏日(日最高気温が30°C以上)は本州では30日以上増加し、冬日または霜日(日最低気温が0°C以下)は本州を中心に20日以上減少した。温暖化により、夏は厳しい暑さの日が増え、冬は厳しく冷え込む日が減ることが予想される。

5 km-NHMに関して、平成16年度は、東アジア域の梅雨前線を対象にして、現在気候と温暖化気候における6-7月の10年間について、20 kmメッシュ全球大気モデルにネステイングさせて長時間シミュレーションを行った。梅雨前線の活動の変化に関しては20 km全球モデルの結果と同様であるが、5 kmNHMは降水量や雲の構造についてはよりリアリスティックである。NHMの結果から、日本列島では30 mmh⁻¹以上の豪雨の頻度が増加することが分かった。5 km-NHMでこのような広領域で長期間シミュレーションを行ったのは世界で初めての試みである。また雲解像大気モデルの開発・最適化を引き続いて行った。

キーワード: 地球温暖化予測, 高分解能全球大気モデル, 雲解像モデル, 梅雨, 台風