Dynamical Downscaling of JRA-25 Precipitation over Japan
Using the MRI-Regional Climate Model

Kazuyo Murazaki, Kazuo Kurihara, and Hidetaka Sasaki
Meteorological Research Institute, Tsukuba, Japan

Abstract

To study regional climate change over Japan, we conducted continuous 26-year dynamical downscaling of JRA-25 (Japanese Re-Analysis 25 years) data using a 20 km-mesh Regional Climate Model (RCM20). The accuracy of the results of downscaling were examined using the observed precipitation data. We found that the downscaled precipitation data reproduce well at both monthly and daily time scales, as well as for extreme events. The data also correlate well with observed inter-annual variability of daily precipitation frequencies for heavy rain events over Japan. These results demonstrate that RCM20’s ability for dynamical downscaling is quite strong and that the data are useful for investigating regional climate change.

1. Introduction

People worldwide recognize that climate change seriously affects natural ecosystems, human life and industries (IPCC 2007), and demand a better understanding of its mechanisms and trends (e.g., Meehl et al. 2000).

Climate change not only influences long term climatic patterns on a regional scale but also short timescale phenomena, such as the intensity and frequency of extreme events. Recent climate change research has studied changes in the frequency and severity of extreme events over time using observation station data (e.g., Fujibe et al. 2006). However, these observation station data do not allow a sufficient understanding of the mechanisms and causes of regional extreme events. To effectively study regional phenomena, it is essential to use fine resolution three-dimensional atmospheric models, which include ocean areas. Relying on data from observation stations is fraught with difficulty, because higher-resolution observation data are limited in their scope, covering only land areas and are very sparse in upper atmospheric layers and over ocean areas.

In this study, we produced a downscaled dataset from global re-analysis data, JRA-25, using a Regional Climate Model of 20 km resolution over Japan (RCM20) developed by the Meteorological Research Institute (MRI) (Sasaki et al. 2000; Sasaki et al. 2006). JRA-25 is a re-analysis data covering the period from 1979 to 2004. It was produced by the Japan Meteorological Agency (JMA) and the Central Research Institute of Electric Power Industry (CRIEPI) and the Japan Meteorological Agency (JMA) and the Central Research Institute of Electric Power Industry (CRIEPI) (Onogi et al. 2007) and is a useful tool for investigating patterns of climate change. However, JRA-25’s resolution (1.25 degrees of longitude by 1.25 degrees of latitude) is too coarse to investigate the fine structure of Japanese regional climate change.

The goal of this study is to obtain detailed dynamical down-scaled data over Japan from global re-analysis data, in order to study the regional climate over Japan. We performed a 26-year continuous time integration initialized at 0000UTC, 1 January 1979, using RCM20 with initial and boundary conditions provided by six-hourly data from JRA-25. In this study, we focused specifically on precipitation and evaluated the performance of RCM20 model against actual weather data.

2. Model description

RCM20 is based on a regional spectral model originally developed by the JMA as a short-range forecast model (NPJ/JMA 1997). The model used in this study has a 20 km horizontal mesh with 36 hybrid vertical levels and covers Japan in the same way as described by Sasaki et al. (2006). The model employs two cumulus convection schemes, a scheme based on Arakawa and Shubert (1974) and convective adjustment scheme. To improve modeling of land areas, the land surface process by Takayabu et al. (2004) was introduced to RCM20. For long-term simulations, the model adopted the Spectral Boundary Coupling (SBC) method proposed by Kida et al. (1991) and Sasaki et al. (2000). In this method, the large-scale component of outer coarse-mesh data and the small-scale component of inner nested model results are joined in wave number space. It has an advantage for smooth, long-term integration because there is no contradiction between the outer coarse-mesh data and the nested model with respect to large-scale fields. In this study, RCM20 uses the SBC method for both wind and temperature fields over 500 hPa. Figure 1 illustrates the topography of JRA-25 and RCM20. In RCM20 (Fig. 1b), altitudes of mountains in central Japan are closer to the real altitudes than in JRA-25; although there is still a discrepancy in altitude between RCM20 and the real topography.

3. Quality of downscaled data

To compare the model results with observations, we used the data sets obtained from Automated Meteorological Data Acquisition System (AMeDAS) stations and the Radar-AMeDAS composite data. The AMeDAS stations are located at an average interval of 17 km apart throughout Japan and the spatial grid resolution of Radar-AMeDAS data sets is 5 km. To evaluate climate distribution of precipitation, we also used 1-km mesh climatic data developed by the JMA. This dataset is based on multivariate analysis of weather observation data, with topographical factors as explanatory variables. For comparison, precipitation data from JRA-25 were interpolated on the RCM20 grid.

3.1 Regional climate

Figure 2 presents the monthly precipitation for January. Comparison with the observed climate data clearly demonstrates an apparent precipitation peak on the Sea of Japan side, which is on the windward side of the Japan islands, (Fig. 2c). This climatic distribution is not clear in Fig. 2b. However, some problems still remain. RCM20 results show an unrealistic wavy pattern in Fig.
the efficacy of the model in capturing these climatic differences, statistical evaluation was performed with seven climatic areas using the methods from Sasaki’s paper (2006), as shown in Fig. 4.

Figure 5 compares the model bias and root mean square error (RMSE) of monthly mean precipitation periods from 1979 to 2004 for the seven climatic areas. RCM20 significantly improves RMSE over these areas. For the bias, JRA-25 shows overestimation in area 7 and large underestimation in the remaining areas, while RCM20 has significantly improved performance in all areas apart from area 7. RCM20 performs better because it more accurately represents topography and uses a more realistic precipitation distribution. However, for area 7, RCM20’s bias is even larger than that of JRA-25. The negative bias of surface temperature in this area is likely to suppress convection and is possibly caused by errors in radiation balance calculations (not shown). This is a future issue to be solved.

2c as a result of the characteristics of the spectral atmospheric model. Furthermore, the precipitation peaks are sensitive to topography effects, which cause irregular distributions of precipitation over areas close to the Sea of Japan.

Figure 3 depicts monthly precipitation for July. The Bonin high is usually accompanied by a moisture rich, southwesterly wind, so the precipitation peak appears over the western part of the Japan islands (Fig. 3a). This feature is represented in both results (Figs. 3b and 3c), but the RCM20 results provide a more detailed distribution than those of JRA-25.

The climate of Japan varies widely from region to region with the southern areas of Japan having subtropical climates, while the northern areas experience sub-frigid climates. In order to evaluate

Fig. 2. Monthly precipitation in January. (a) Mesh climatic data from 1971 to 2000. (b) JRA-25 (c) RCM20.

Fig. 3. Same as Fig. 2 except for July.

Fig. 4. Climatic areas for analysis. Area 1: cold, snowfall in winter; cool in summer; area 2: cold and dry in winter, cool in summer; area 3: heavy snowfall in winter; area 4: dry in winter, wet in summer; area 5: rain or occasionally snowfall in winter, much rain in summer; area 6: dry in winter, much rain in summer; area 7: oceanic type of climate, warm and humid during all seasons.

Fig. 5. Statistical scores of monthly precipitation averaged over seven climatic areas. Bias (column) and RMSE (squares and circles) between AMeDAS and both RCM20 (red) and JRA-25 (blue). “All” on horizontal axis means averaged all over Japan. Units are mm precipitation per month.
### 3.2 Successful and failure cases

The timing and intensity of precipitation on a daily scale are also important for downscaling climate data. Figures 6 and 7 represent typical failure and success examples of extreme events. Figure 6 represents a model failure example. It shows the amount of precipitation on September 11, 2000 (a), along with the data from JRA-25 (b) and simulation from RCM20 (c). On this day, a stationary front extended eastward over Japan. The front increased its activity with time because of a typhoon located at approximately 500 km southwest of Japan and produced more than 400 mm day\(^{-1}\) of rainfall at Tokai area as indicated by the arrow in Fig. 6a. As shown in Fig. 6b, the precipitation peak of JRA-25 is approximately 100 km northwest from the actual peak in the observation data. RCM20 simulates a similar precipitation distribution to JRA-25 (Fig. 6c). The similarity in precipitation distributions shared by both JRA-25 and RCM20 indicates that any apparent discrepancies between the outer data (JRA-25) and the observations at a large scale, such as the location of a front, are difficult to improve by the downscaling using RCM20.

Figure 7 shows an example, where the models accurately simulated the precipitation distribution that occurred on August 21, 2001. A typhoon struck the Pacific side of central Japan and heavy rain peak can be seen on the southeast side of western Japan in Fig. 7a. RCM20 significantly improves these rain peaks compared to JRA-25. For a geopotential height of 850 hPa, the RCM20 result is quite similar to that of JRA-25, suggesting that the large-scale characteristics of the free atmosphere are quite similar to JRA-25. Although the simulated large-scale phenomena are similar in RCM20 and JRA-25, RCM20 presents a more realistic precipitation.

### 3.3 Statistics on heavy rainfall

In order to statistically compare observation data with model results, we established 0.5 by 0.5 degree grid boxes that covered Japan. We then took into account the grid boxes that had two or more AMeDAS stations and two or more grid points of the RCM20. Daily precipitation amounts were calculated for each box. We defined the averaged station precipitation value in a box as the ‘observed grid box value’, and the averaged RCM20 (JRA-25) grid point value in a box as the ‘RCM20 (JRA-25) grid box value’. The number of boxes that met each criterion for daily precipitation amount were summed up as specific area for 26 years (9497 days) and normalized by the total number of boxes. We defined this value as the Precipitation frequency Coverage Rate (PCR), which relates to the frequency and spread of a given precipitation intensity.

Figure 8 presents the PCR categorized by daily precipitation intensity. We classified the PCR according to climatic differences, as shown in Fig. 4, then grouped the data into four regions: the Sea of Japan side (area 1 and 3); the Pacific side (area 2 and 4); Western Japan (area 5 and 6); and the Nansei islands (area 7). On the Sea of Japan side, the PCR from RCM20 (Fig. 8a) corresponds well to that from the AMeDAS. On the Pacific side (Fig. 8b), there is a discrepancy in PCR between RCM20 and AMeDAS at high precipitation intensity exceeding 150 mm day\(^{-1}\). A similar result can be seen in Western Japan, (Fig. 8c). Both RCM20 and AMeDAS PCRs in Western Japan and on the Pacific side (Fig. 8b and Fig. 8c) show relatively high daily precipitation intensities compared to the Sea of Japan side (Fig. 8a). The PCR values from JRA-25 (Figs. 8a, 8b, and 8c) are consistently low, with daily precipitation intensity rarely exceeding 50 mm day\(^{-1}\). There are no clear climatic differences in the precipitation distributions simulated by JRA-25 in Figs. 8a, 8b, and 8c. It is only in Fig. 8d, which shows the PCR of the Nansei islands region, that JRA-25 shows a different precipitation range and one that matches quite closely to the daily precipitation range of 100 mm day\(^{-1}\) from...
AMeDAS. This area is covered by ocean dotted with islands. Therefore, we cannot expect the improvement of the simulations by the orographic effect of RCM20. Furthermore, as previously mentioned, RCM20 has a cold bias, which adversely affects convection in the model. Despite the bias, the PCR from RCM20 is still more accurate than that from JRA-25 for precipitation intensities greater than 150 mm day$^{-1}$. These results indicate that RCM20 can simulate longer term trends in daily precipitation intensity quite accurately and only fails systematically, when faced with extreme rainfall events of greater than 150 mm day$^{-1}$.

The year-to-year variations in PCR with daily precipitation exceeding 50 mm day$^{-1}$ and 200 mm day$^{-1}$ are evaluated in Fig. 9. Figure 9a shows that RCM20 accurately simulates PCRs with precipitation intensity exceeding 50 mm day$^{-1}$. For example, the heavy rain years of 1993, 1998 and 2004 are well simulated. The correlation coefficient between the PCRs from RCM20 and AMeDAS is 0.91, which is considerably stronger than the JRA-25 result of 0.48. However, RCM20 is less robust when it comes to heavy rainfall events, when daily precipitation exceeds 200 mm day$^{-1}$. Indeed, Fig. 9b indicates that RCM20 underestimates the number of these high rainfall days with the correlation coefficient of 0.67. Nevertheless, this result is still better than that of JRA-25.

4. Conclusions

We performed 26-years using the regional climate model, RCM20, which is nested within the global re-analysis data, JRA-25, and obtained downscaled climate data over Japan. We evaluated RCM20 by assessing the accuracy of its precipitation intensity simulations. The results show that RCM20 is superior to JRA-25 in simulating both daily precipitation intensity and its year-to-year variations. However, RCM20 is biased towards lower rainfall events and fails to accurately simulate extreme events, where daily precipitation intensity exceeds 200 mm day$^{-1}$. Higher-resolution models would be required to more accurately represent extreme heavy rain events.

It has been shown that RCM20 is useful for downsampling coarse-resolution global climate data to fine-resolution regional climate data. The downscaled data is helpful to investigate regional climate change. For example, the data help us to understand the mechanisms behind increases in the frequency of heavy rains. Further research is needed on other atmospheric factors relating to precipitation. In future work, we plan to examine climatic variability that causes extreme events, such as the relationship between water vapor flux over the Sea of Japan and extreme weather events over Japan.

Acknowledgments

This study was conducted as part of the Japan Meteorological Agency’s special project on regional climate projection over Japan incorporating global warming. It was also partly supported by the Global Environment Research Fund (S-5-3) of the Ministry of the Environment, Japan. We thank anonymous reviewers and Dr. Takayabu who provided carefully considered feedback and valuable comments. We also thank Mr. Tsuguchi for support with observation data.

References


Manuscript received 26 August 2010, accepted 7 December 2010.

SOLA: http://www.jstage.jst.go.jp/browse/sola/