Reproducibility of Present Climate in a Non-Hydrostatic Regional Climate Model
Nested within an Atmosphere General Circulation Model

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Abstract

A 20-year-integration of a non-hydrostatic regional climate model (NHRCM) was conducted to reproduce the present climate. The annual mean surface temperature and precipitation of Japan are well simulated in NHRCM. There was one conspicuous outlier in the verification of the model’s annual precipitation with observations. An even finer grid spacing than 5 km would be required to reproduce the precipitation at this observation point. The regional model successfully simulated heavy precipitation that a general circulation model could not reproduce. This model reproduced snow depth well in most of Japan, except in the north on the coast of the Sea of Japan, where the depth was underestimated.

1. Introduction

Both scientists and policymakers are asking for high-resolution projections of global warming and its impacts, in order to map the changes and impacts in detail. One useful technique for obtaining detailed projections of regional climate changes due to global warming is to dynamically downscale the output of global climate models. For example, Kurihara et al. (2005) projected the future climate in and around Japan with a regional climate model (RCM) having a grid spacing of 20 km. However, even at the grid spacing, this model did not simulate extreme events well and did not resolve the main mountain ranges or main river basins, both of which must be depicted if the climate projections are to be useful for adapting to a changing climate in water resource and flood planning, agriculture, and so forth. To cope with these problems, Sasaki et al. (2008) developed a non-hydrostatic regional climate model (NHRCM or hereafter the model) having a grid spacing of 4 km, and carried out a simulation for 5 years with perfect boundary conditions. They showed that the model performed well in reproducing climatic temperature and precipitation fields. Kanada et al. (2010) conducted long-term integrations with a 5-km grid model nested within a 20-km atmospheric general circulation model (AGCM). The precipitation biases of the 5-km model were smaller than the biases of the AGCM, but their calculations were done only for June to October. In this study, we nested our model within results of present climate experiment of an AGCM and integrated it for all four seasons over 20 years and investigated its performance, in order to make good use of the model for projections of global warming around Japan.

We present the results in the following sections as follows. Section 2 explains the nesting method; Section 3 gives results of the simulations; and our summary and concluding remarks are in Section 4.

2. Nesting method

A multiple nesting method is used in this study as shown in Fig. 1. Outer most data is results of present climate experiments using an AGCM whose grid spacing is 20 km (Kitoh et al. 2009). The AGCM is based on the operational model for numerical weather prediction of the Japan Meteorological Agency (JMA) (Mizuta et al. 2006). A regional model, the first NHRCM, with a grid spacing of 15 km, is nested within the AGCM. The AGCM does not have variables of cloud water, cloud ice, and other cloud properties, so the 15-km NHRCM grid is included to generate such variables for the lateral boundary of a smaller domain having a 5 km grid spacing. Sasaki et al. (2008) describes the specifications of NHRCM used in this study. The domain of the 5-km inner grid is slanted from northeast to southwest. By skewing the inner domain, calculations are reduced, and the inner domain still covers almost all of the Japanese Archipelago. See Table S1 (Supplement 1) for outline of NHRCM used in this study.

Time slice integration method is used in this study. Each integration is conducted from July 21st to September 1st in the next year. The results of the first 42 days are abandoned for spin up. This cycle is repeated 20 times since 1980.

3. Simulation results

3.1 Temperature

We verified the model by comparing the observed data of the Automated Meteorological Data Acquisition System (AMeDAS) to the results at the closest model grid point on land to each observation station. The differences between the modeled climate variables and observed climate data are shown in Fig. 2. Since the elevation of each model grid point generally differs from the elevation of the nearest AMeDAS station, both temperatures are adjusted to sea-level values by using the temperature lapse rate of 0.0065°C m⁻¹. For annual means, the modeled temperature differed from the observed temperature by less than 1°C at most of the observation points, except at several points in mountainous regions, where the model temperatures were 2 to 3°C lower than those at AMeDAS stations.

The NHRCM05 reproduced seasonal changes of surface
temperature rather well (see Fig. 3). KAKUSHIN05 in this figure indicates the results of present climate experiments conducted by Kanada et al. (2010) under Kakushin Program (hereafter called Kakushin). The model had a cool bias in winter in comparison to observations, whereas in summer, modeled surface temperatures were almost the same as the results of the Kakushin and the AMeDAS observations. Because the model underestimated temperatures in winter, its annual mean temperature bias is negative, but the bias value is small, only −0.3°C. The annual mean of daily maximum temperature in the model was also lower than in the AMeDAS observations, by 1.2°C (not shown). The model reproduced maximum temperature well in the summer, but it underestimated by about 2°C in the winter. The daily minimum temperature was somewhat underestimated in winter and overestimated in summer (not shown), giving an annual bias of +0.7°C for this measure.

For annual mean surface temperature, the correlations between the model results and AMeDAS observations were 0.99 for NHRCM05 but 0.82 for the AGCM. The biases for NHRCM05 and AGCM were −0.3°C and −0.6°C, and the root mean square errors (RMSE) were 0.7°C and 2.8°C, respectively. Therefore, the nested model reproduced the spatial details of surface temperature better than the AGCM did.

### 3.2 Precipitation

The differences in precipitation were less than 20% at most points (Fig. 4). Large differences occurred along the coast of the Japan Sea and in the Nansei Archipelago, where the model underestimated annual precipitation by 20% to 40%. At some inland points, the model overestimated precipitation by more than 40%.

The model reproduced fairly well seasonal change in Japan (Fig. 5). There are two annual peaks of precipitation, one from June to July associated with the Baiu (or Mei-yu) front and the other in September due to typhoon landfalls. Although the model gave almost the same temperatures as the Kakushin simulations, its precipitation values differed about 10%. In Kakushin program, the nesting method is different from in NHRCM05: NHM with larger domain than this study is directly nested in AGCM. However, the physical processes are quite the same as in this study. Different nesting methods may bring about the difference of precipitation amount.

Scatter plots of annual precipitation totals of the NHRCM05 and AGCM models at the locations of all AMeDAS observations are depicted in Fig. 6. See Fig. S1 (Supplement 2) for the scatter plots of NHRCM15. The NHRCM05 reproduced the spatial features of precipitation well as compared to the AGCM. As indicators of the difference in scatter, bias, RMSE and correlation against AMeDAS is shown in Table 1. NHRCM05 is best in all the scores. This means that it is important to use high resolution model for reproducing better local features. We thus conclude that the downscaling methods by NHRCM are effective.
3.3 Snow depth

We evaluated the performance of the model in capturing the climatic characteristics of snow depth in the same way that Sasaki et al. (2006) did. Snow depth was not observed in two of the seven regions in this study, so we analyzed statistics of snow depth in five regions as follows: the Japan Sea side (NJJ) and the Pacific Ocean side (NJP) of northern Japan; the Japan Sea side (EJJ) and the Pacific Ocean side (EJP) of eastern Japan; and the Japan Sea side (WJJ). The maximum daily snow depths from both observations and the model were averaged over the regions (Fig. 8). The model almost well reproduced the seasonal change of snow depth in each region. However, it underestimated the depth more than 20 cm at the peak season in the NJJ region. The snow depth was also underestimated in NJJ on plots of the inter-annual variability of maximum snow depth, averaged over each region (Fig. 9), but in other regions the model reproduced maximum depth rather well. The range of inter-annual variability was narrower in the model than it was in observations in each region.

In Japan, snow depth generally reaches an annual peak from February to March. Figure 10 shows maximum snow depth in March. Around the region where snow depth exceeds 10 cm on mainland Japan, the model well reproduced the snow depth distribution along the western and southern boundaries, but in the central mountainous part of this region, the model reproduced too much snow in comparison to observations, because it over-estimated precipitation and gave temperatures somewhat colder than observed. On the other hand, on Hokkaido, the model put the peak snow depth in the center of that island although observations located the peak on the west coast. This is due to that the model has a bias in overestimating precipitation in central Hokkaido in March.

In May, snow remains only on Hokkaido Island and in the central mountains of the mainland (not shown). The model depicted snow remaining over a somewhat wider area than was observed. Snow was gone in June from all points in the model and the observations. The model is thought to have sufficient reproducibility at this stage, but we are going to try some further improvements in the representation of precipitation and temperature.

4. Summary and concluding remarks

We ran the NHRCM for a 20-year integration of the present climate using an inner nested grid with a spacing of 5 km. In mountainous regions, the model calculated surface temperatures 2–3°C lower than AMeDAS observations at several points. Along the coast of the Japan Sea and the Nansei Archipelago, the model underestimated precipitation from 20% to 40% compared with observed amounts. At some inland points, the model overestimated precipitation by more than 40%.

However, the model reproduced the spatial distribution and seasonal changes of annual mean temperature and precipitation well. The verification of annual mean surface temperature was much more favorable in the model than in the AGCM. Similarly, the model’s mean annual precipitation exhibited much less scatter than equivalent results of an AGCM did (Fig. 6), and its correlations with ground truth data are higher, and its RMS errors lower, than those of the AGCM. The model reproduced fine-scale spatial
features of precipitation and temperature distributions better than the AGCM did. There is one conspicuous outlier in the scatter plot of annual precipitation in the model (Fig. 6). Precipitation might be correctly modeled at this mountainous location only by using a smaller grid spacing.

The AGCM underestimated the frequency of hourly precipitation, especially when precipitation was heavy. The NHRCM05 underestimated it slightly but reproduced the observed frequencies better. It reproduced intense precipitation (more than 80 mm h\(^{-1}\)) much better than the AGCM and NHRCM15 did. It is necessary for reproducing the heavy rain to use the fine grid spacing. The basic performance of the NHRCM05 is good enough for it to be used for downscaling from an AGCM.

The NHRCM05 simulated well the daily change of snow depth, and the inter-annual variability of snow depth, except on the western coast of northern Japan. The model did not correctly locate the point of maximum snow depth (situating it in the center of Hokkaido rather than on the west coast, the AMeDAS location). Although there remain some defects, the NHRCM05 otherwise reproduced the distribution of snow depth around Japan. Because it simulates the present climate well, we will make use of the NHRCM for analyzing the details of future projected global warming and related climate changes around Japan.

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Supplements

Model description is shown in Supplement 1. Scatter plots of 20-year-mean annual precipitation amount from NHRCM15 vs. observed values are shown in Supplement 2. The distribution of precipitation calculated by the model around Yakushima Island is shown Supplement 3.

References


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