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Reproducibility of AGCM20 Precipitation Output and Its Dependency on Topography

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Synopsis

This study provides evaluation results on the precipitation output of the AGCM20 by comparing the present climate condition (1979~2003) output with the AMeDAS observation. Amount and spatial pattern of annual mean precipitation from the AGCM20 showed considerably good match with the AMeDAS observation. However, the clear spatial pattern of the observed precipitation was presented in smoothen way in the AGCM20 precipitation output. It is mainly because of topographic information in the AGCM20, which also has 20-km averaged elevation values. The effect of the averaged elevation in the AGCM20 was also investigated by using the GTOPO30 topographic data.

Keywords: AGCM20, reproducibility, precipitation, topography

1. Introduction

Rapid evolution of general circulation models (GCMs) in the last three decades allows us to expect reasonable hydrologic dataset from the model output. In 2007, Japan's Ministry of Education, Culture, Sports, Science, and Technology launched the Innovative Program of Climate Change Projection for the 21st Century (Kakushin21), and have developed a super-high-resolution atmospheric model having 20-km spatial and 1-hour temporal resolution (hereafter AGCM20). The AGCM20 provides two terms of future projection run output based on the A1B climate change scenario (IPCC, 2007; Nakicenovic et al., 2000), which are near-future term (2015~ 2039) and future term (2075~2099). The controlled run using an observed sea surface temperature (SST) provides the present term (1979~2003) atmospheric data.

This paper provides basic analysis results on the reproducibility of the AGCM precipitation output. First, the controlled simulation output from the AGCM20 was evaluated using the AMeDAS observed precipitation data. The AMeDAS data has long enough duration to provide reliable precipitation pattern over the Japan with its very fine observation network. The evaluation was carried out in two aspects; spatial distribution pattern of seasonal amount and reproducibility of extreme events such as hourly and daily maximum precipitation amount. Understanding the characteristics and limits of the AGCM20 precipitation output, topographic effects on the simulated precipitation was also investigated.

The next section describes in more detail this evaluation procedure, introducing the AGCM20 and its output. The third and fourth section illustrates the analysis results on the model reproducibility and topographic effects on the precipitation output, respectively. The last section summarizes this study and offers conclusions.

2. Data and Methodology

AGCM20

The Japan Meteorological Agency (JMA) and Meteorological Research Institute (MRI) of Japan have developed a prototype of the next generation of global atmospheric models for use in both climate simulations and weather predictions (Mizuta et al., 2006). AGCM20 is the state-of-the-art atmospheric general circulation model with super-fine resolution.

The model conducts simulations using triangular truncation at wave number 959 with a linear Gaussian grid (TL959) in the horizontal based on 1920 × 960 grid cells about 20 km in size and 60 levels in vertical, and provides hourly precipitation output. AGCM20 uses the HadISST1 dataset (Rayner et al., 2003) for observed monthly mean climatologic sea surface temperature (SST) for a boundary condition of controlled simulation. The HadISST1 provides global sea ice and sea surface temperature (GISST) datasets from 1871, uniquely combining monthly, globally complete fields of SST and sea ice concentration on a 1° latitude × 1° longitude grid. Test run output during the model development showed advantages in simulating orographic rainfall and frontal rain bands, as a result of its very fine spatial resolution. Refer to Mizuta et al. (2006), Kitoh and Kusunoki (2007) and Kusunoki and Mizuta (2008) for more details on the model description and its characteristics.

AMeDAS Observation

Automated Meteorological Data Acquisition System (AMeDAS) is a high-resolution surface observation network developed by JMA for gathering regional weather data and verifying forecast performance. Point gauged AMeDAS precipitation data have converted into spatial averaged values that is equivalent type of the AGCM20 output as following procedures.

1) Define the center of the 20km resolution grid of the AGCM20 output, and also define four other points that apart ±5km from the center of the grid.
2) Estimate rainfall amount of each point from the nearest three AMeDAS station using the inverse distance method, at every time step.
3) Get an arithmetic mean of the five points in the grid box at every time step.
4) If there is missing data at a certain station, next nearest station value is adopted.
5) If the nearest one is over 30km apart, the value of the point is excluded.
6) If all the five points' values are not available, the value of the grid is marked as "missing".

3. Reproducibility of AGCM20

Seasonal Pattern AGCM20 Output

Reliance on GCM output, especially on the projection run output can be achieved through an evaluation of the model reproducibility for the current climate condition. Before the projection output was analyzed in this paper, the 25 years of controlled run output of AGMC20 was evaluated using the AMeDAS observation data. For a reasonable comparison, the point-gauged AMeDAS data was converted into the 20-km grid-based spatially averaged data as the AGCM20 output format. Inverse-distance weighting factor method was adopted for the AMeDAS data conversion.

First of all, annual mean precipitation was estimated from the converted AMeDAS observation data and the AGCM20 output data (see Fig. 1). According to the AMeDAS observation, annual mean precipitation during 1979 and 2003 is 1684.3 mm, and the AGCM20 output shows 1703.8 mm of annual mean for the same duration, which shows very good consistency. Spatial distribution pattern of the annual mean precipitation also shows considerably good match between the AGCM20 output and the AMeDAS observation, showing 0.78 of pattern correlation.

Winter precipitation such as heavy snowfall in Hokuriku mountainous area along the northern seashore of Kanto and Tohoku region is showing successful reproducibility. Summer heavy rainfall in Kyushu, Shikoku and Kansai region, which is mostly due to frontal rain-band and Typhoon, is also well presented in the model output.

However, it is noticeable that the clear spatial pattern of the observed precipitation is presented in somewhat smoothen way in the AGCM20 precipitation output. It is mainly because of topographic information in the AGCM20, which also has 20-km spatially averaged elevation values. The averaged topographic data would have rather flattened shape comparing to the original topography. Even though there is several physical parameterization schemes are applied in the AGCM20 to properly consider the influence of flattened sub-grid scale topographic data, the performance of the atmospheric model still shows some limitations.

The AGCM20 output for the present shows smoothen rainfall concentration in both winter season (see Fig. 2) and summer season (see Fig. 3). It seems that the characteristics of the AGCM20 precipitation output is related to topographic data used in the atmospheric model. Although there are several physical parameterization schemes are applied in the AGCM20 (Mizuta et al., 2006) to properly consider the influence of flattened sub-grid scale topographic data, the atmospheric model still shows noticeable limits on a rough geographic shape.

Extreme Events

Reproducibility of daily and hourly maximum precipitation of each grid was evaluated by checking maximum precipitation of the AGCM20 controlled run output and the AMeDAS observed one within the same period. The 100 maximum values of daily and hourly precipitation were selected by choosing 4 maximum values of each year during 25 years. As shown in Fig. 4, a regression coefficient was calculated using one pair of 100 maximum values on each grid. Desirable reproducibility on the extreme value will be showing 1.0 regression coefficient. If it is less than 1.0, it means that the AGCM20 output has generally underestimated extreme values compared to the observation and vice versa. Regression coefficient is depending on the choosing sample numbers however, this simple evaluation method

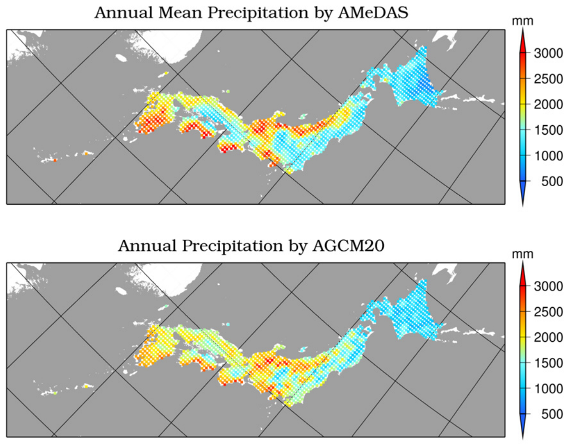

Fig. 1 Annual mean precipitation of 1979~2003 in Japan, observed by the AMeDAS (up) and simulated by the AGCM20 (down).

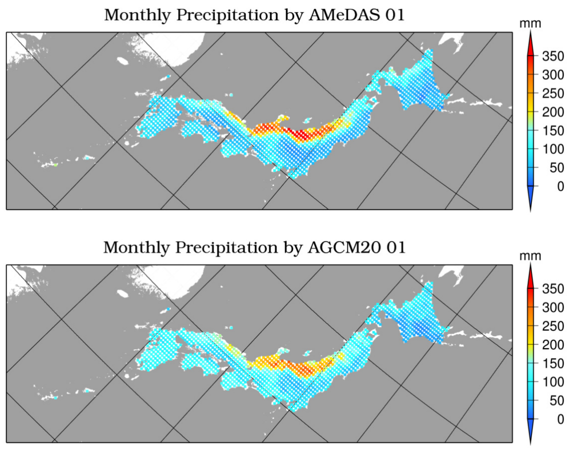

Fig. 2 Monthly mean precipitation (January), observed by the AMeDAS (up) and simulated by the AGCM20 (down).

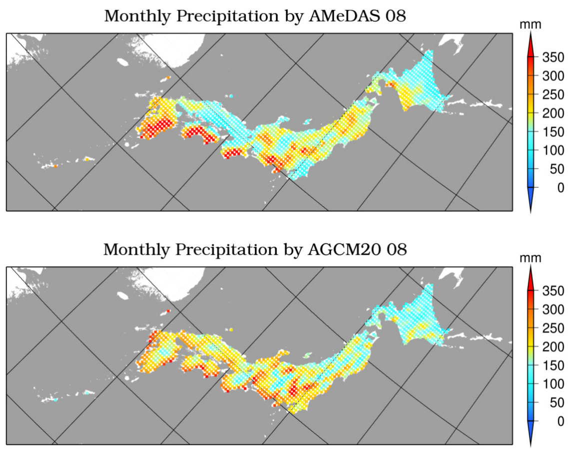

Fig. 3 Monthly mean precipitation (August), observed by the AMeDAS (up) and simulated by the AGCM20 (down).

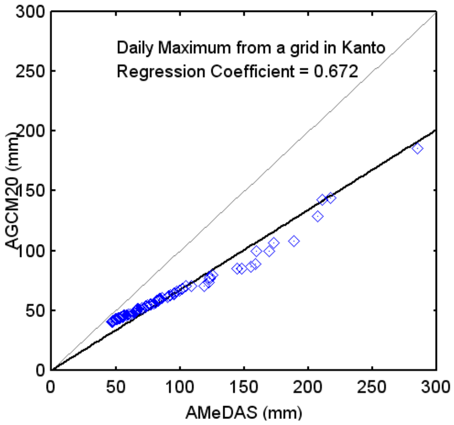

Fig. 4 Examples of the regression coefficient calculation with daily maximum precipitation values of AGCM20 output and AMeDAS.

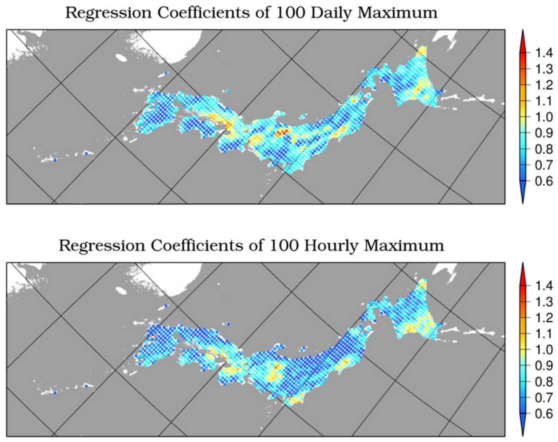

Fig. 5 Regression coefficient of daily (up) and hourly (down) maximum precipitations of the AGCM20 output to the AMeDAS observation.

provides direct and clear understanding on the overall model performance related to extreme values.

In Fig. 5, which expresses the regression coefficients on each grid, it is clear that the AGCM20 output has underestimated daily and hourly maximum in most part of Japan. The same characteristics on the controlled run output of the AGCM20 was also found in the precipitation analysis of Takara et al. (2009) and river flow reproducibility analysis of Kim et al (2010) over the Tone River basin. This underestimation on the extreme precipitation values reveals that the 20-km spatial resolution might be still insufficient to simulate sophisticated sub-grid scale orographic rainfall.

4. Dependency on Topography

Smoothen Orographic Effects

Orographic effect is well known phenomena, especially in mountainous area of Japan (Oki et al., 1991). AGCM20 output shows a limitation to simulate clear orographic effects mainly due to its 20-km resolution topographic data. This characteristic of the AGCM20 output can also be founded in the elevation dependency of the simulated precipitation amount.

Fig. 6 shows the annual mean precipitation of each 20-km grid in Kyushu area that is corresponding to the topographic information of its own grid; the mean and standard deviation of elevation of the GTOPO30 in the 20-km grid window. First of all, annual mean precipitation amount of AMeDAS which was spatially averaged in each 20-km grid was plotted with the mean elevation of its own grid to see the elevation dependency of the precipitation amount. For a comparison, annual mean precipitation amount from the AGCM20 output was also plotted in the same scatter-gram (see the upper scatter gram of Fig. 6).

Even though it is not very clear to see the elevation dependency in the figure, it was able to see the difference between the observed and simulated annual precipitation amount; the observed one shows more dependant behavior to the elevation. High elevation has more precipitation amount. This elevation dependency can be more clearly found in the scatter-gram with the summer season precipitation amount (the upper one of Figure. 7)

Elevation Variance and Precipitation

The precipitation amount may be related not only to the elevation itself, but also to the variation of elevation in the 20-km grid window. Here, the variation of elevation was simply measured by calculating the standard deviation of elevation in each 20-km grid. The original topographic information data comes from the GTOPO30 data (global DEM data provided by the U.S. Geological Survey), which offers 1-km fine resolution data of elevation.

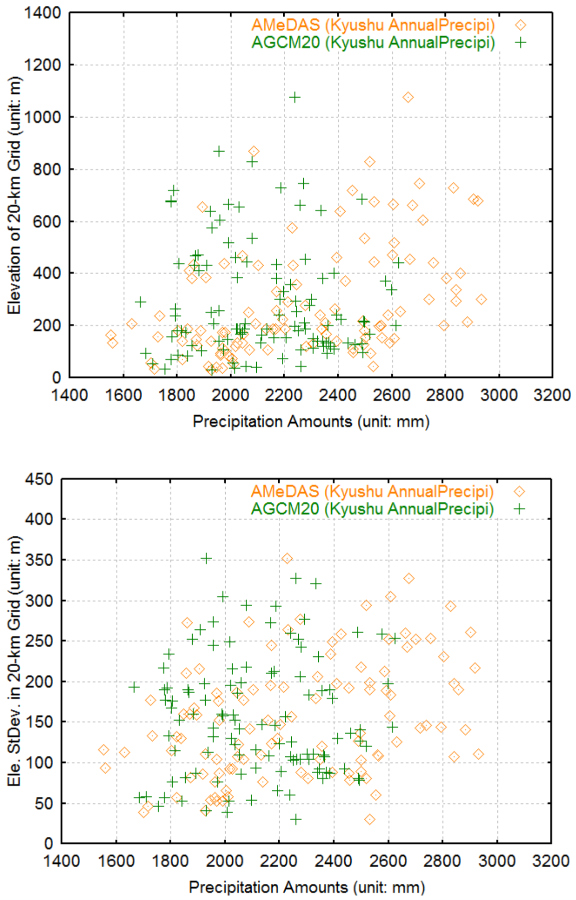

Fig. 6 Annual mean precipitation of each 20-km grid in Kyushu area, corresponding to the topographic information of the own grid; mean elevation (up) of the GTOPO30 in the 20-km grid window and standard deviation (down) of the elevation in the window.

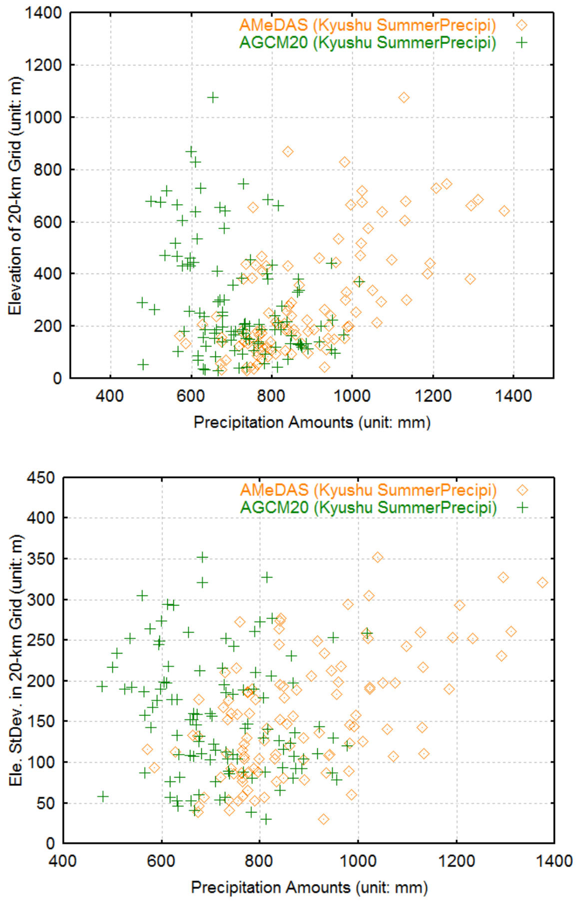

Fig. 7 Summer precipitation of Kyushu area, corresponding to the topographic information of the own grid; mean elevation (up) and standard deviation (down) of the elevation in the window.

The standard deviation was calculated using the original 1-km elevation values of the GTOPO30 data for a 20-km grid window. Higher standard deviation values stands for a severe change of elevation in a given window. And the severe change of elevation in a certain area can provides more chance of existing steep topography, which may cause an abrupt boosting the atmosphere.

Under this consideration, we can imagine a positive correlation between precipitation amount and the degree of variance in elevation, which was quantified the standard deviation in a 20-km grid window in this study. As shown in the lower scatter-gram in Fig. 6 and Fig. 7, which is showing the annual precipitation and summer precipitation amount to the standard deviation of each grid in Kyushu area, a grid of higher variance of elevation has a tendency to have more precipitation amount, especially in the summer season. While the summer precipitation amount in Kyushu area shows very strong relationship with the elevation variance, the elevation dependency of precipitation was not clearly expressed in the AGCM20 precipitation output.

The AGCM20 conducts its simulation on a TL959, which has about 20-km grid resolution topographic data. The model adopts various parameterization schemes to compensate its rough resolution and to provide realistic rainfall generation. However, the model output certainly shows some limitation on a simulation of extreme events and it was also not able to show proper elevation dependency of summer precipitation.

5. Concluding Remarks

The precipitation output of the AGCM20 was evaluated using the AMeDAS observed data, and reproducibility of the model was discussed in two aspects, seasonal and spatial pattern of precipitation and extreme events. Firstly, AGCM20 precipitation output for the present term was evaluated with a comparison to the AMeDAS observation over the Japan Island. Annual mean of precipitation shows very good match, however, spatial distribution of annual precipitation amount from the AGCM20 output shows smoothened spatial pattern comparing to the observation one.

The topographic data having 20-km resolution, which was based on the AGCM20 has rather flattened topographic information while detailed topographic information is spatially averaged within the 20-km grid. The precipitation output of the AGCM20 shows some limitation on a simulation of extreme events and it was also not able to show proper elevation dependency of summer precipitation.

Further research is under going to figure out a proper bias correction method to improve the accuracy of the precipitation output, especially considering the sub-scale orographic effects to precipitation amount.

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地形の影響を考慮したAGCM20降水出力の再現性に関する考察

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要　旨

GCMから出力された降水量の再現性の検証を行うために，アメダスの観測データーとの比較し評価を行った。アメダスの地点観測をGCM出力の形式である20kmグリットの空間平均に変換した後,GCMの再現期間25年間（1979～2003）の出力データと比較した。検証の結果，GCMからの降水量の計算結果は地域毎の降水量の分布はおおむね表現出来たが，降水量の空間分布は緩慢な変化を見せている。これはGCMでモデリングに用いた20kmメッシュの地形が実際の地形を緩慢に表現するため，モデルの地形では降水の発生が低減されている可能性があると考える。

キーワード:超高解像度大気モデル，再現性，降水出力，地形依存性