Utilization of a New Gauge-based Daily Precipitation Dataset over Monsoon Asia for Validation of the Daily Precipitation Climatology Simulated by the MRI/JMA 20-km-mesh AGCM

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Abstract

Using new gauge-based gridded daily precipitation climatology over monsoon Asia (5–60°N, 65–155°E) with a grid resolution of 0.05°, we validate the precipitation climatology simulated by a global 20-km resolution atmospheric model of the Meteorological Research Institute of the Japan Meteorological Agency. The new gauge-based precipitation climatology explicitly expresses orographic precipitation over the East Asia. The model has the highest resolution of all atmospheric general circulation models currently in use to study global warming. It successfully simulates orographically enhanced precipitation patterns presented in the East Asia climatology (hereafter, EA clim). The model overestimates precipitation averaged over land areas of monsoon Asia, and bias is larger over India and central China. Difference in annual precipitation between the model and EA clim exceeds those between other well-known grid precipitation climatological datasets. EA clim can be used to validate seasonal changes in monsoon precipitation over the domain, including mountainous regions. The 20-km resolution model reproduces seasonal cycles in precipitation over northern China and the Himalayas. However, large biases and seasonal cycle differences occur over India and central and southern China. As the model resolution improves, gridded daily precipitation datasets based on dense rain-gauge networks should be prepared to validate the model results.

1. Introduction

Climate model resolution is improving, and the motivating factor behind such high-resolution super computing is to project the impact of global warming on local environments. Regional climate models (RCMs) and statistical methods can be used as downscaling tools. In contrast, the Earth Simulator is a parallel-vector supercomputer system in Japan that simulates realistic global climate with a general circulation model (GCM) run at very high resolution. Mass is conserved, and there are no lateral boundary conditions.

A reliable interpretation of the impact of global warming on local environments hinges on the ability to use a high-resolution precipitation dataset as a validation tool and as a reference dataset for statistical downscale methods. High-resolution atmospheric general circulation models (AGCMs) or RCMs have horizontal resolutions of less than 1°, sometimes as small as 20 km, but there are few datasets to validate such high-resolution model results. In addition, there is a great demand for accurate simulations of the frequency of extreme events, and thus a daily grid precipitation dataset is warranted.

Model precipitation has conventionally been evaluated against “observations” with a horizontal resolution of about 2.5°. Such observations also have monthly or a pentad mean temporal resolution. For example, the Global Precipitation Climatology Project (GPCP) monthly precipitation (Huffman et al. 1997) and CPC Merged Analysis of Precipitation (CMAP; Xie and Arkin 1997) are two precipitation datasets that are widely used to verify global model simulations. GPCP 1 degree daily (1DD) data (Huffman et al. 2001) and some satellite-derived products can validate results from high-resolution models. The Tropical Rainfall Measuring Mission (TRMM) produces high-resolution rainfall estimates over the tropics, but it has sampling biases. In addition, rain gauge networks yield more accurate precipitation amounts than satellite-derived estimates, especially over land.

Gauge-based data, including the Climate Research Unit (CRU; New et al. 1999) and the Precipitation REConstruction over Land (PRECL/L; Chen et al. 2002), have been used to validate models and to study climatology or hydrology over land. However, gauge-based data have been monthly products. In contrast, Xie et al. (2004) described a 20-year gauge-based dataset of daily precipitation on a 0.5° latitude/longitude grid over East Asia (5–60°N, 65–155°E). The domain encompassed monsoon Asia and included South Asia and most of Southeast Asia. Here, the 0.05° grid of daily precipitation climatology over the domain (hereafter the East Asia climatology [EA clim]) that was produced as an intermediate product for the East Asia rain-gauge-based analysis is used to validate precipitation climatology in a global model with a 20-km mesh. The present study demonstrates the utility of the EA clim dataset. It has several advantages. A dense rain gauge network is used to produce EA clim over China, and EA clim has a fine (0.05°) horizontal resolution that includes orographic effects. EA clim can be used to validate seasonal changes in the daily time series. Here, the EA clim is used to validate a model on a 20-km mesh run by the Meteorological Research Institute of the Japan Meteorological Agency (MRI/JMA). The model biases to the new “observation” dataset (EA clim) are compared with those biases between many “observations”.

2. The new validation data and the model data

The new algorithm to make a gauge-based precipitation dataset over East Asia was designed to assess the change of the hydrological environment over the Yellow River. The analysis strategy for gauge-based daily analyses of precipitation is a modification of that found in Chen et al. (2002), as described in Xie et al. (2004). This section briefly describes how EA clim was constructed. Gridded analyses of daily precipitation were produced for all 365 calendar days. Analyses were of 20-year (1978–1997) average daily precipitation defined for all stations at which reporting rates exceed 90% during the period. The first six harmonic components were then summed from the 365-day time series of the 20-year mean values to get smoothed daily climatology expressing monsoon onsets. Analyzed fields of daily precipitation were subsequently determined by interpolating the station climatology to a 0.05° grid through Shepard (1968). Then the 365-day gridded time series was adjusted against the Global Precipitation Climatology Project (GPCP; Huffman et al. 1997) and CPC Merged Analysis of Precipitation (CMAP; Xie and Arkin 1997) are two precipitation datasets that are
The PRISM, digital monthly climatology of precipitation, has created over the United States, China, and Mongolia, and it originally had a resolution of 4 km. Data used in their creation included observations from more than 2,500 rain gauges over China and digital elevation map (DEM) information. Chen et al. (2004) compared PREC/L climatology to that of PRISM, and noted improvements in the PRISM dataset. They showed underestimates of precipitation in PREC/L compared to PRISM over the western (mountainous) part of the United States (3–50° N, 110–125° W). The two products more closely matched at the grid boxes where PREC/L had more than two stations in a grid box in the mountainous region. Therefore the PRISM is considered to be more reliable than grid datasets which do not account for orographic enhancements.

Monthly climatologies based on PREC/L (Chen et al. 2002) were used outside of China and Mongolia, where PRISM is unavailable. The seasonal pattern of daily climatology was determined by the station precipitation data in the Global Telecommunication System (GTS) daily summary files. The daily rain-gauge data network by GTS is not as dense as that used in China, but PREC/L yields better monthly climatologies because it contains more rain gauge data (see Fig. 2 of Chen et al. 2002). Thus, the horizontal pattern of the climatological average was estimated from the denser station network than from the time series stations.

Model results in this study are from the MRI/JMA AGCM. The simulations were performed at a resolution of TL959, which corresponds to a horizontal grid size of about 20 km. Hereafter we call this model as “TL959”. Mizuta et al. (2005) described details of the model, which has the highest resolution of AGCM currently used to study global warming. Results are shown from a 10-year present climate simulation using observed climatological sea surface temperatures (SSTs) as a boundary condition. A result from 10-year present-day climate simulations using MRI/JMA coarser models is also shown in Supplement 1. The resolution is at TL159 and TL95, which corresponds to a horizontal resolution of 110 km and 180 km, respectively. Conventionally, grid precipitation data sets such as GPCP or CMAP with 2.5° resolution have been used to validate the model results at a resolution of 100 km to 300 km.

3. Results

3.1 Mean annual and seasonal distribution of precipitation

Figure 1 compares summertime (June, July, and August (JJA)) precipitation from (a) the 10-year averaged TL959, (b) EA clim, (c) CRU, (d) the precipitation climatology by Willmott and Matsuura (1995) of the University of Delaware (UDE), (e) GPCP 1DD, and (f) CMAP. Horizontal resolutions of the original datasets are (a) 20 km, (b) 0.05° (5.5 km), (c) 0.5°, (d) 0.5°, (e) 1°, and (f) 2.5°, respectively. Temporal resolutions are (b) daily, (c) monthly, (d) monthly, (e) daily, and (f) monthly and pentad. In Fig. 1, the products were interpolated on a 0.5° grid except for GPCP1DD (1°) and CMAP (2.5°). Comparisons are shown only over land. Similar distributions in annual and seasonal precipitation are shown in Supplement-1. CRU precipitation pattern is smooth and resembles that of GPCP1DD. CMAP, CRU, and UDE underestimate EA clim over central China. EA clim over China was adjusted by PRISM and included more rain gauge data than the other datasets. It therefore shows larger precipitation amounts than the other four precipitation datasets (Fig. 1c–f) over China.

The model (TL959) results reproduce overall precipitation patterns well, but do not include a precipitation maximum that occurs on the southern coast of China during summer. The area of heavy rainfall over central China and in the southern China near 27° N, 115° E in the model results, which is located north or northwest of the maximum rainfall of EA clim on the southeastern coast. The coarser-resolution models (TL159 and TL95 in Supplement 1) likewise underestimate the precipitation along the southern coast. This model bias is common to all three of the MRI/JMA model outputs.

The model (TL959) successfully simulates narrow precipitation bands windward of the mountains, or qualitative characteristics of orographic precipitation along the Himalayas and Western Ghats. The coarser-resolution datasets (GPCP1DD and CMAP) do not show such sharp horizontal changes. Near the Sichuan basin (25°–30° N, 100–110° E, east of the Tibetan Plateau), TL959, EA clim, and UDE all show similar precipitation patterns enhanced by orography.

Figure 2 shows a closer comparison of the annual precipitation patterns over the Himalayas between TL959 and EA clim. The model simulates two rain bands along the southern slopes (4,000–4,500 m a.s.l.) and foothills (500–1,000 m a.s.l.) of the Himalayas (30°–32° N, 75°–80° E), and a strong single band at about 28° N, 85° E. These spatial patterns match the patterns in the EA clim and in rain rates observed by TRMM/Precipitation Radar (PR) composited to 0.05° grid precipitation in JJA season (Yatagai 2001). A rainfall maximum appears at about 27° N, 90° E in EA clim. Such maximum also occurs in TL959.

Over Southeast Asia (Fig. 1), there are large variations in the observation datasets (hereafter “observations”) over the eastern coast (in Vietnam). Precipitation minima in Myanmar (20° N, 95° E) and Thailand (15° N, 100° E) are present in EA clim and in UDE. In contrast, TL959 does not show the Thailand minimum, and CRU and CMAP do not clearly show the Myanmar minimum. Rain-gauge data for southern Asia was sparse compared to other areas (Chen et al. 2002), so care must be taken when considering precipitation patterns over this region. Improvement of the climatology data over Southeast Asia in the future is warranted.

Table 1 compares statistics of annual (ANN) and JJA precipitation in TL959 and EA clim with the other four (CRU, UDE, GPCP1DD, and CMAP) data sets. As mentioned earlier, estimation of the regional precipitation varies between the “observations” used for model validation. Therefore, TL959 model biases from EA clim are compared to those from the other four “observations.” Comparisons are also made between the spatial
Table 1. Areal mean annual (ANN) and summer (JJA) precipitation (mm/day) from (1) MRI TL959 and EA clim. Biases between (1) and TL959, EA clim, CRU, UDE, GPCP1DD, and CMAP, and the spatial correlation coefficients between (1) and TL959, EA clim, CRU, UDE, GPCP1DD, and CMAP are shown. Statistics were computed after all data were interpolated to a 0.5° grid.

<table>
<thead>
<tr>
<th></th>
<th>Precip (mm)</th>
<th>Bias (mm)</th>
<th>Correlation between (1) and</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)-EA</td>
<td>(2)-CRU</td>
</tr>
<tr>
<td>Ann</td>
<td>2.271</td>
<td>0.277</td>
<td>0.301</td>
</tr>
<tr>
<td></td>
<td>1.994</td>
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<td>0.024</td>
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<td>JJA</td>
<td>3.949</td>
<td>0.097</td>
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<td></td>
<td>3.847</td>
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</table>

3.2 Seasonal variation

Figure 3 shows latitude-time sections of truncated MRI TL959 and EA clim over India and eastern China. EA clim is comprised of the first six harmonics, so the 10-year average climatological time series from TL959 is also truncated (the first six harmonic components of the daily time series are summed). Comparing TL959 with EA clim, precipitation is too heavy over India from August to October. Monsoon onset occurs over both regions one-half or one month earlier than observed. Over central China (around 28°N), precipitation is too heavy during spring and summer. TL959 does not reproduce the rainfall maximum over southern coastal China.

4. Conclusion and remarks

A reliable interpretation of the impact of global warming on local precipitation hinges on the availability of the quantified observation dataset. This study used new gauge-based...
daily precipitation climatology (EA clim) on a 0.05° grid over monsoon Asia (5–60°N, 65–159°E). The new data explicitly
expresses orographic precipitation over East Asia and can be
used to validate precipitation climatology produced by the
MRI 20-km resolution (TL959) model. EA clim allows valida-
tion of seasonal changes in monsoon precipitation including
precipitation over mountains. Spatial distribution differences
between TL959 and EA clim, i.e., model biases, were compared
to differences between EA clim and other well-known gridded
precipitation products (observations).

The MRI model (TL959) rain totals exceeded those in EA
clim, especially over India and central China. The model bias
was larger compared to differences between EA clim and other
“observations” in most cases, spatial correlations between
“observations” exceeded those between TL959 and EA clim.

The model precipitation from August to October was too
heavy over India, where TL959 monsoon onset was too early.
Over China, TL959 did not capture the precipitation maximum
over the southern coastal regions. This model bias was
common to the coarser-resolution models (TL159 and TL959)
simulated by the same MRI/JMA model except for the resolu-
tion.

The model qualitatively represented the characteristics of
orographically induced precipitation. For example, the narrow
precipitation bands along the Himalayas were detected. These
bands were also present in EA clim. Over the Himalayas,
TL959 accurately simulated the seasonal variations but under-
estimated the amounts from July to September.

CMAP and GPCP have often been used as “observations”
to evaluate precipitation derived from climate models. In
some cases in which model precipitation overestimated the
“observations,” model precipitation was adjusted to the “obser-
vation” by tuning the model parameters. However, the esti-
mates of regional precipitation used to validate climate model
results vary among the “observations.” This paper shows the
real possibility that “observations” have underestimated the
real values over the land areas. It is therefore necessary to
develop better “observations” by augmenting the rain gauge
network. Satellite-derived products such as TRMM/PR can
represent the characteristics of orographic rainfall, but those
products must be validated before they are used to verify
model precipitation quantitatively. Modeled precipitation
should be reevaluated against those more complete “observa-
tions” in the future.

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Supplements

Supplement-1 shows the distributions of seasonal precipitation
from EA clim, MRI TL959, CRU, UDE, GPCP1DD, CMAP,
TL159, and TL95.

Supplement-2 includes statistics comparing EA clim to MRI
TL959, CRU and UDE TL159, and TL95, and their Taylor
diagrams.

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