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VALIDATION BY A NEW GAUGE-BASED DAILY GRID PRECIPITAION DATASET OF DAILY PRECIPITATION CLIMATOLOGY OVER MONSOON ASIA SIMULATED BY MRI/JMA 20-KM-MESH AGCM

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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. 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 (Yatagai et al., 2006). High-resolution atmospheric general circulation models (AGCMs) or RCMs have horizontal resolutions of less than 1º, sometimes as small as 20 km, but there are few datasets to validate such high-resolution model results. In addition, there is 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 2.5º. 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.

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Gauge-based data, including the Climate Research Unit (CRU; New et al. 1999) and the Precipitation REConstruction over Land (PREC/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, 2006) described a 26-year gauge-based dataset of daily precipitation on a 0.5^{o} latitude/longitude grid over East Asia (5–60ºN, 65–155ºE). The domain encompassed monsoon Asia and included South Asia and most of Southeast Asia. The 0.05º 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 was used to validate precipitation climatology in a global model with a 20-km mesh (Yatagai et al., 2006).

The primary purpose of the present study is to validate MRI/JMA 20km mesh (TL959) model by using the new gauge-based daily dataset over eastern Asia. The present study also 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 (0.05º) horizontal resolution that includes orographic effects. EA clim can be used to evaluate seasonal variations in the daily time series. 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

2.1 *East Asia rain-gauge-based analysis*

The new algorithm to make a gauge-based

precipitation dataset is described in Xie et al. (2004, 2006). This section briefly describes how EA clim was constructed.

Gridded analyses of daily precipitation were produced for all 365 calendar days. 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 0.05º grid through Shepard (1965).

Then the 365-day gridded time series was adjusted against the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Daly et al. 1994) monthly climatology over China and Mongolia, so that the magnitude of the adjusted daily climatology matched that of the monthly climatology, and the patterns of temporal variation in the original daily climatology were retained. The adjustment augments the orographic effects in the precipitation fields that are not accounted for in the interpolation of the station climatology.

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. Details of the development of EA clim is described in Xie et al. (2006) and Yatagai et al. (2005).

A 26-year (1978-2003) East Asia rain-gauge-based daily analysis (hereafter EA analysis, Xie et al., 2006) has been released to scientific community. Only GTS data is used outside of China in the current version (V0409) of the EA analysis. Xie et al. (2004) showed the impact of additional rain gauge data over South and Southeast Asia those are available from GEWEX Asian Monsoon Experiment (GAME)-Tropics data archive. We call the EA analysis with additional GAME-T archive data for the year 1998 as GAME enhanced version in this paper.

2.2 *Model Data*

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 20km. Hereafter we call this model as “TL959”. Mizuta et al. (2006) 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. The resolution is at TL159 and TL95, which corresponds to a horizontal resolution of 110km and 180km, respectively. Conventionally, grid precipitation data sets such as GPCP or CMAP with 2.5º 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 total annual precipitation from the 10-year averaged (a) MRI/JMA model (TL959) and (b) EA clim. 10-year averaged annual precipitation patterns from the coarse models are also shown in Fig.1 (c) and (d) for comparison. Comparisons are shown only over land. TL959 captures the overall precipitation pattern well and successfully simulates narrow precipitation region along the windward of the mountains, namely qualitative characteristics of orographic precipitation along the Himalayas and Western Ghats. These sharp patterns are not clearly observed in the results of the coarse models (Figs.1c and 1d).

Over central and southern China, the area of maximum rainfall is located around 115E/27N, which is north or northwest of that in EA clim (southeastern coast). The coarse models (TL159 and TL95) also underestimate of precipitation over the southern coastal region, namely, this model bias is commonly observed for the three of MRI/JMA model outputs. The precipitation totals over the land areas of 65-150E/5-55N are overestimated for the three models compared to that of EA clim. Average

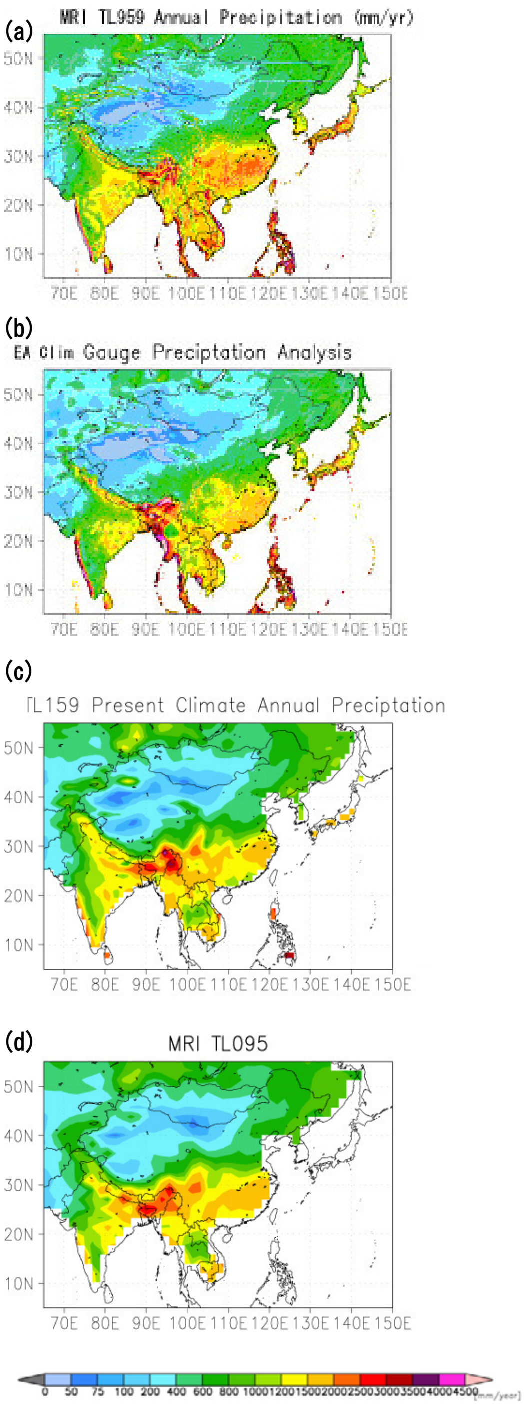

Fig. 1. (a) 10-year mean annual precipitation (mm/year) from MRI/JMA Tl959 (20-km) model. (b) East Asia rain gauge analysis (Xie et al., 2004) of climatological annual precipitation (mm/year). (c) Same as (a) but for TL159 (about 110km grid size at latitudes of 30 degrees), and (d) TL95 (180km).

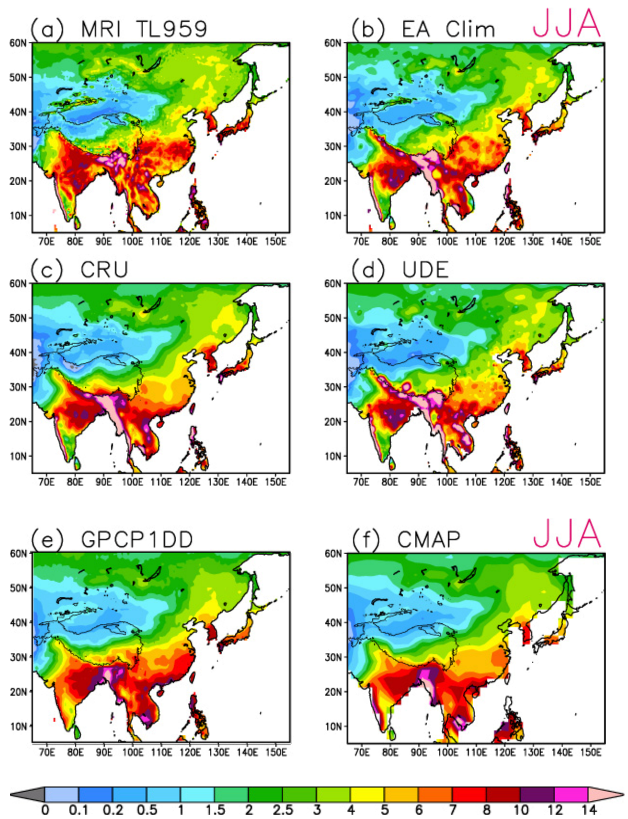

Fig. 2. Summer (JJA) precipitation (unit: mm/day). a) MRI model (TL959), b) EA clim, c) Climate Research Unit (CRU) precipitation, d) climatology by Willmott and Matsuura (1995) of the University of Delaware, e) GPCP 1DD and f) CMAP.

precipitation from TL959, TL159, TL95 and EA clim are 2.271, 2.227, 2.030 and 1.994, mm/day, respectively. That implies high-resolution model reduced bias in total precipitation over Monsoon Asia. The bias in annaual precipitation of TL959 from EA clim is the smallest among the biases between TL959 and other datasets. Detailed statistics comparing the three models and EA clim and other observations are shown in Supplement-1 of Yatagai et al. (2005).

Figure 2 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) 0.05º (5.5 km), (c) 0.5º, (d) 0.5º, (e) 1º, and (f) 2.5º, respectively. Temporal resolutions are (b) daily, (c) monthly, (d) monthly, (e) daily, and (f) monthly and pentad. In Figure 1, the products were interpolated on a 0.5º grid except for GPCP1DD (1º) and CMAP (2.5º). Comparisons are shown only over land.

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.2c–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 maximum rainfall over central and southern China is near 27ºN, 115ºE 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 of Yatagai et al., 2005) 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 (25–30ºN, 100–110ºE, east of the Tibetan Plateau), TL959, EA clim, and UDE all shows similar precipitation patterns enhanced by orography.

Figure 3 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 (30-32ºN, 75-80ºE), and a strong single band at about 28ºN, 85ºE. These spatial patterns match the patterns in the EA clim and in rain rates observed by TRMM/Precipitation Radar (PR) composited to 0.05 º grid precipitation in JJA season (Yatagai 2001). A rainfall maximum appears at about 27ºN, 90E in EA clim. Such maximum also occurs in TL959. These three data (TL959, EA clim, TRMM/PR) represents the characteristics of the precipitation over this region very well. However, quantitative validation should be necessary in the near future.

Over Southeast Asia (Fig. 2), there are large variations in the observation datasets (hereafter “observations”) over the eastern coast (in Vietnam). Precipitation minima in Myanmar (20ºN, 95ºE) and Thailand (15ºN, 100ºE) 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.

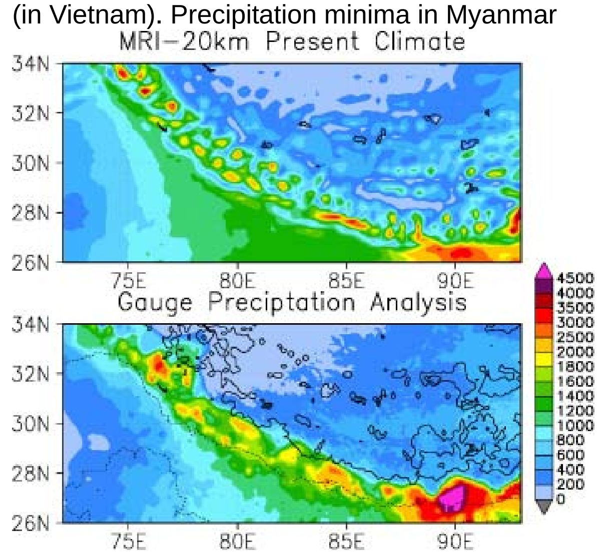

Fig. 3 Annual precipitation (unit: mm year^{-1}) from MRI model (TL959; upper panel) and EA clim at 0.05º (lower panel). Black solid (thick) contour and dashed (thin) contour lines (lower panel) represent the elevations at 4,800 and 250 m, respectively. Red arrows in and outside of the maps indicate the double rain band.

Figure 4 is a Taylor-style diagram (Taylor, 2001) of annual and seasonal pattern correlation and standard deviations, and can clarify the complicated statistics. EA clim is used as an “observation.” The root mean square (RMS) difference between each of two patterns is shown as the distances between “observation” and each point. Clear superiority of TL959 (denoted as “1”) compared to TL159

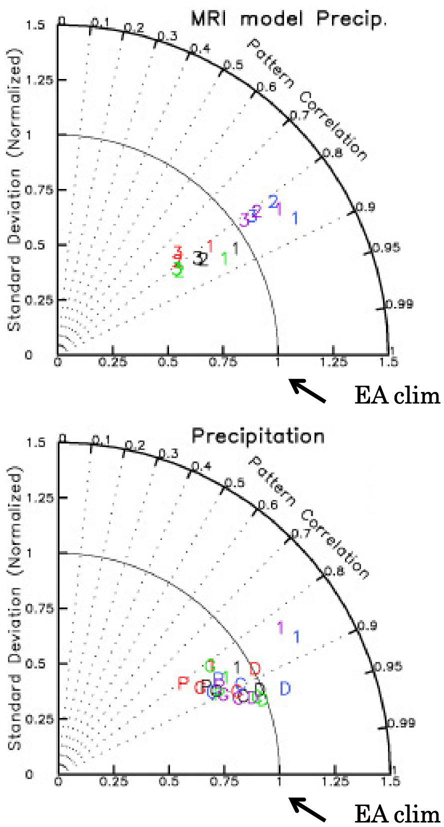

Fig. 4 Taylor-style diagram for annual and seasonal mean precipitation over the land areas in the 65E-155E, 5N-60N. “EA clim” is the observed reference data. Upper panel: Black “1”, “2” and “3” show the pattern correlation and normalized standard deviation between annual precipitation of EA clim and MRI /JMA TL959, TL159 and TL95, respectively. Color letters indicate the same with black letters but for seasonal precipitation. Blue: DJF, Purple: MAM, Red: JJA and Green: SON. Lower panel: Marks “C”, “D”, “G”, “P” and “1” show the pattern correlation and normalized standard deviation between precipitation of EA clim, and observationally based precipitation (CRU, UDE, GPCP1DD, CMAP) and TL959, respectively. Colors are the same with that of in the upper panel.

and TL095 (denoted as “2” and “3” respectively) is represented in the upper panel of Fig.4. MRI TL959 represents patterns of SON (September, October, November, or autumn) precipitation best among the four seasons.

As mentioned above, observations based on rain gauges (CRU and UDE) show higher correlation with EA clim than TL959. CMAP or GPCP1DD show almost comparative correlation and small standard deviation than those of TL959 for some seasons. If observational estimates were equally believable, then one should not expect the RMS differences between the models and the reference observational data set to be smaller than the differences between the two observational data sets (Taylor, 2001). Here, we think climatological precipitation of CRU and UDE are more believable than that of GPCP1DD and CMAP. However they are monthly product. Hence, high temporal resolution grid observation based on rain gauges is important for validating model precipitation.

3.2 *Seasonal variation*

Figure 5 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 28ºN), precipitation is too heavy during spring and summer. TL959 does not reproduce the rainfall maximum over southern coastal China.

Figure 6 shows area-averaged seasonal variations of EA clim and MRI/JMA TL959 (red). For comparison, GPCP1DD (blue), TL159 (green) and TL95 (orange) are also plotted. All data were truncated. As shown in the previous section, MRI TL959 reproduces the spatial pattern of the strong orographic precipitation well. TL959 underestimates (~2mm/day) precipitation over the Himalayas in summertime, although it shows seasonal change very well.

TL159 and TL95 do not simulate simulate the seasonal cycle well. The rainfall peak of TL159 comes earlier and that of TL95 has two peaks. In regions outside China, the representation of orographic effects relies heavily on the gauge network and PREC/L.

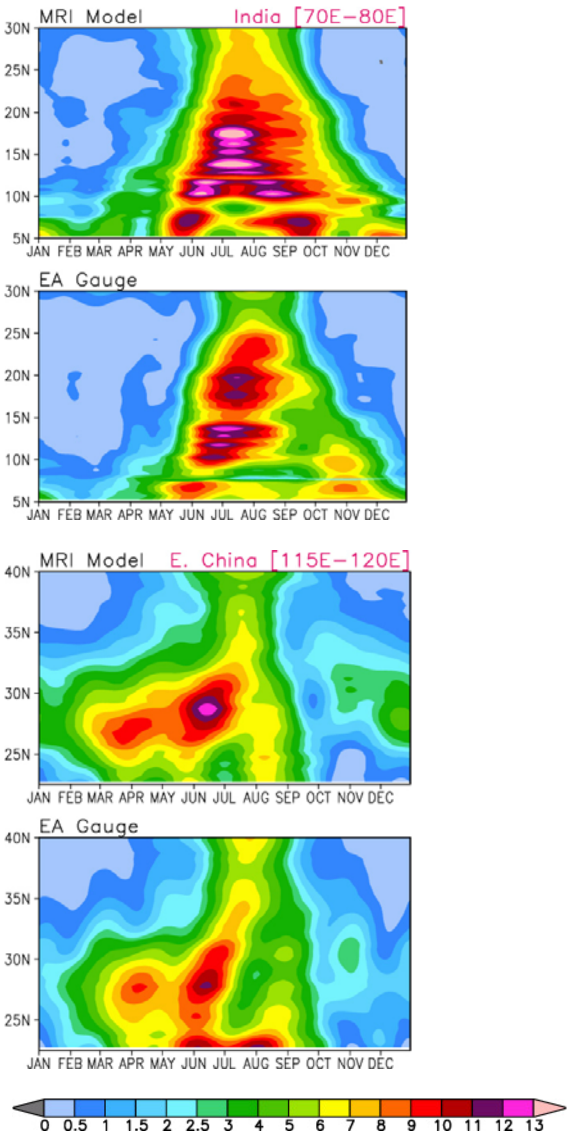

Fig.5. Latitude–time section of daily precipitation climatology over India (upper panels, averaged between 70 and 80ºE) and eastern China (lower panels, 115–120ºE; unit: mm/day).

Xie et al. (2004) showed the impact of additional rain gauge data over South and Southeast Asia. A dense network of gauges in Nepal caused a significant increase in precipitation estimates along Himalayas. Therefore, even EA clim in (a) likely underestimates the real area-avaraged precipitation. In contrast, the GPCP1DD significantly underestimated EA clim. Rain-gauge-based daily precipitation dataset are, therefore, necessary for such regions to develop fine resolution models.

Over the North China, TL959 simulates the amount of peak precipitation and seasonal cycle very well, although it overestimates (~1mm/day) precipitation from April to June. Over the Central and South China, GPCP1DD match EA clim in terms of both magnitude and seasonal cycle. TL959 simulates precipitation amount well from July to October, however, it significantly overestimate EA clim from December to June. The difference between TL 959 and EA clim (~2mm/day) is larger than that of TL159 (or TL95) and EA clim (~1mm/day).

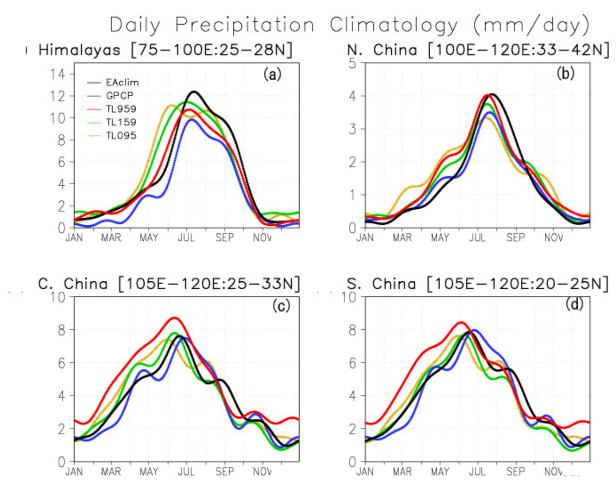

Fig. 6. Comparison of daily precipitation climatology (truncated). Black: EA clim, Blue: GPCP1DD, Red: MRI/JMA TL959, Green:TL159, Orange: TL95. (a) Himalayas, (b) North China (around the Yellow River), (c) Central China (d) South China. Each domain (latitude and longitude boundary) is shown on the top of each panel.

Figure 7 shows area-averaged seasonal variations of observational monthly precipitation data. EA anaysis (black), GAME enhanced version of EA analysis, TRMM/PR3A25 (blue), TRMM/PR3A25 averaged over land (green), and PREC/L (orange) are plotted. Additional rain gauge data of Nepal clarifies the EA analysis underestimated (~2mm/day). It is clear that TRMM/PR has a systematic negative bias to the rain-gauge based precipitation dataset during summer monsoon season. This bias was found throughout the observation period of TRMM (December 1998-2005, manuscript is under preparation). Since TRMM/PR has a strong advantage of depicting orographic precipitation patterns, PR data is expected to be used for model validation and for developing orographic precipitation. In order to use the full benefit of TRMM/PR to represent orographic precipitation and used for model validation, it is inevitably important to acquire rain-gauge-based precipitation dataset for their retrieval algorithm development.

4. CONCLUSION

Using new gauge-based gridded daily precipitation climatology over monsoon Asia (5–60ºN, 65–155ºE) with a grid resolution of 0.05º, we validate the precipitation climatology simulated by a global 20-km resolution atmospheric model of the Meteorological Research Institute of 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

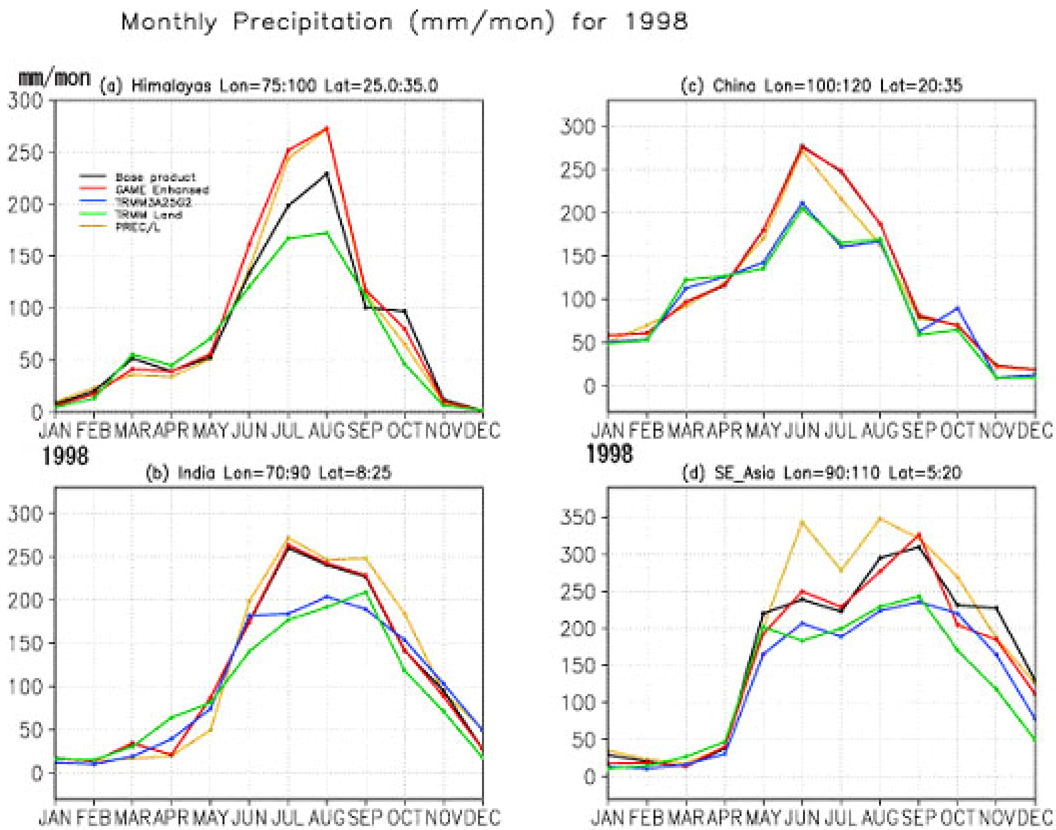

Fig. 7. Comparison of seasonal change of monthly precipitation for the year 1998. Black: EA analysis, Red: GAME enhanced version of EA analysis, Blue: TRMM/PR ver.5, Green:TRMM/PR averaged over land, Orange: PREC/L. (a) Himalayas, (b) China, (c) India (d) Southeast Asia. Each domain (latitude and longitude boundary) is shown on the top of each panel.

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. Some satellite-derived product, for example, TRMM/PR can represent the characteristics of orographic rainfall. However, we still need to validate them before verify model precipitation quantitatively. We have compared area averaged TRMM/PR monthly product (3A25) by using this East Asia analysis dataset, and found that PR3A25 systematically underestimate summertime precipitation.

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