P3.33 How often does it rain?

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1. Introduction

The distribution of worldwide precipitation has been the focus of many studies (e.g., Legates and Willmott 1990; Xie and Arkin 1997; Adler et al. 2003), but other characteristics relevant to climate research such as the frequency of occurrence, intensity and the contribution of heavy rainfall to total amount, are also attracting increasing attention. For example, Trenberth et al. (2003) argued that in a warmer climate, where the amount of atmospheric moisture is expected to rise faster than the total precipitation amount, increases in precipitation intensity must be offset by decreases in precipitation frequency. However, these characteristics have been subject to limited analysis using observations and models. Evaluating the global distribution of these parameters from observations and testing how well climate models deal with these characteristics of precipitation is the focus of this paper.

2. Data, models, and analysis methods

The observational data used in this study is the daily precipitation data set (1840-2001) compiled at the National Climatic Data Center (NCDC) (NCDC 2002). The daily data are station records of varying length (only years with >300 day records are used, and stations with <5 year records are shown as open triangles in the figures).

The models' daily precipitation data are extracted from CMIP2+ (the second phase of Coupled Model Intercomparison Project, see Covey et al., 2003) datasets, which are stored at the National Energy Research Supercomputer Center (NERSC).

In this study, precipitation is classified into two categories based on daily rates: light (1-10 mm day^{-1}) and heavy (>10 mm day^{-1}) precipitation. Because drizzle contributes little to total precipitation amounts over most areas (Dai 2001), the days with precipitation < 1mm day^{-1} were not counted. Precipitation frequency was calculated by dividing the number of days with light or heavy precipitation by the number of total days, with data expressed as a percentage. The mean precipitation intensity was calculated from the mean precipitation rates over days with light or heavy precipitation.

We also developed a simple index to evaluate models' performance in reproducing how frequently precipitation occurs that dominates the total annual accumulation. This variable is the average number of days that make up most (selected cutoff of 67%) of the total annual precipitation, $\overline{N}_{67}$. The specific calculation method is as follows: for each year we sort the daily precipitation data from the heaviest to the lightest. We then count the heaviest precipitation days that are required to accumulate 67% of the total precipitation for each year, N_{67}. Then the climatological mean $\overline{N}_{67}$ of N_{67} were calculated. Different from the conventional precipitation frequency and intensity, the number of days contributing 67% of the total precipitation provides a complementary and simple way to quantify how many precipitation events typically dominate the local precipitation budget over different regions, since it makes no assumption of any particular intensity (e.g., 1-10 versus >10 mm day^{-1}, etc.).

3. Precipitation frequency

a. Light precipitation

Because the limited space, the observed and simulated mean frequency for light precipitation are not shown. The analyses show that most of the models considerably overestimate the frequency of light precipitation in the Northern Hemisphere. And the GFDL model produces the most realistic patterns of light precipitation frequency.

b. Heavy precipitation

Our results show that most of the models simulate the heavy precipitation frequency better than the light precipitation frequency, and they generally reproduce the large-scale pattern (not shown). These results suggest that these climate models have too many days with light precipitation, but perform rather well in simulating the heavy precipitation frequency.

4. Precipitation intensity

a. Light precipitation

Also because the limited space, the observed and simulated precipitation intensities for light precipitation (1-10 mm day^{-1}) are not shown. However, our results indicate that the biases in the light precipitation intensity are less severe than in the light precipitation frequency.

b. Heavy precipitation

Figure 1 compares the observed and simulated mean intensity of heavy (> 10 mm day^{-1}) precipitation for JJA. In the observations, high precipitation intensity (>25 mm day^{-1}) is found in the central and eastern U.S., the Asian monsoon regions, and northern South America, where summer moist convection is intense. In high latitudes, where the atmosphere contains less moisture, the precipitation intensity is much weaker than that at mid- and low-latitudes. In dry regions, such as Africa and the Middle East, observed precipitation never exceeds 10 mm day^{-1} (indicated by the black open circles in Fig. 1a).

The simulated heavy precipitation intensity shows large discrepancies from the observations for most of the models (Fig. 1). Except for the GFDL model, all of the other models underestimate the heavy precipitation intensity over most of the land areas, especially over the mid- and low-latitudes, where the simulated intensity is only ~10-15 mm day^{-1}, which is less than half of that observed (Fig. 1a). Again, the GFDL model performs best in simulating the heavy precipitation intensity.

5. Number of days dominating total precipitation

Figure 2 compares the observed and simulated global distributions of the number of days contributing 67% of total precipitation, $\overline{N}_{67}$. The observations show large regional differences. For many regions in northern high latitudes, most of the annual precipitation occurs in more than

30 days (Fig. 2a), and in parts of Europe the number is more than 40 days, indicating that rainfall in these regions occurs frequently but with relatively low intensity. In many regions at lower latitudes, such as the Southeast U.S., northern South America and southeastern Asia, most of the annual precipitation falls in less than 30 days, indicating that precipitation there is more concentrated and intense. In many dry regions, such as northern and southern Africa, most of Australia, the Southwest U.S., and central Asia, most of annual precipitation falls in only a few days. In these areas, each locally heavy-rain day is critical for annual rainfall. Thus regions where most of the annual precipitation occurs in fewer than about 10-15 days are likely to be vulnerable to droughts.

Most of the models are able to reproduce the small number of $\overline{N}_{67}$ over many dry regions, such as Australia and northern Africa (Fig. 2). However, the simulation over wet regions is poor, especially in northern South America, tropical Africa and Indonesia, where the simulated $\overline{N}_{67}$ values exceed 160, which is 4-5 times larger than the observed. These regional biases are consistent with the precipitation frequency biases shown in Fig. 3. Similar to the frequency, the GFDL model performs best in simulating the $\overline{N}_{67}$; all of the other models substantially overestimate the number of the days dominating the precipitation over most regions.

6. Summary

Precipitation characteristics are a key issue in climate research. Our results provide important further quantification of the model simulations not just of total amounts but also precipitation frequency, intensity, and heavy-precipitation events.

For light precipitation (1-10 mm day^{-1}), most of the models simulate the observed intensity rather well but overestimate the frequency. In contrast, for heavy precipitation (>10 mm day^{-1}), the models approximately reproduce the observed frequency patterns but underestimate the intensity. The GFDL model tends to perform best in simulating the frequency and intensity for both light and heavy precipitation.

Consistent with the biases in precipitation frequency and intensity, we found that most of the models overestimate the annual number of the days contributing 67% of total precipitation over most land areas, particularly in wetter regions. Again, the GFDL model performs best in simulating this statistic, although it also requires too many rainy days to accumulate most of annual precipitation over Europe, Canada, Alaska, and some other regions.

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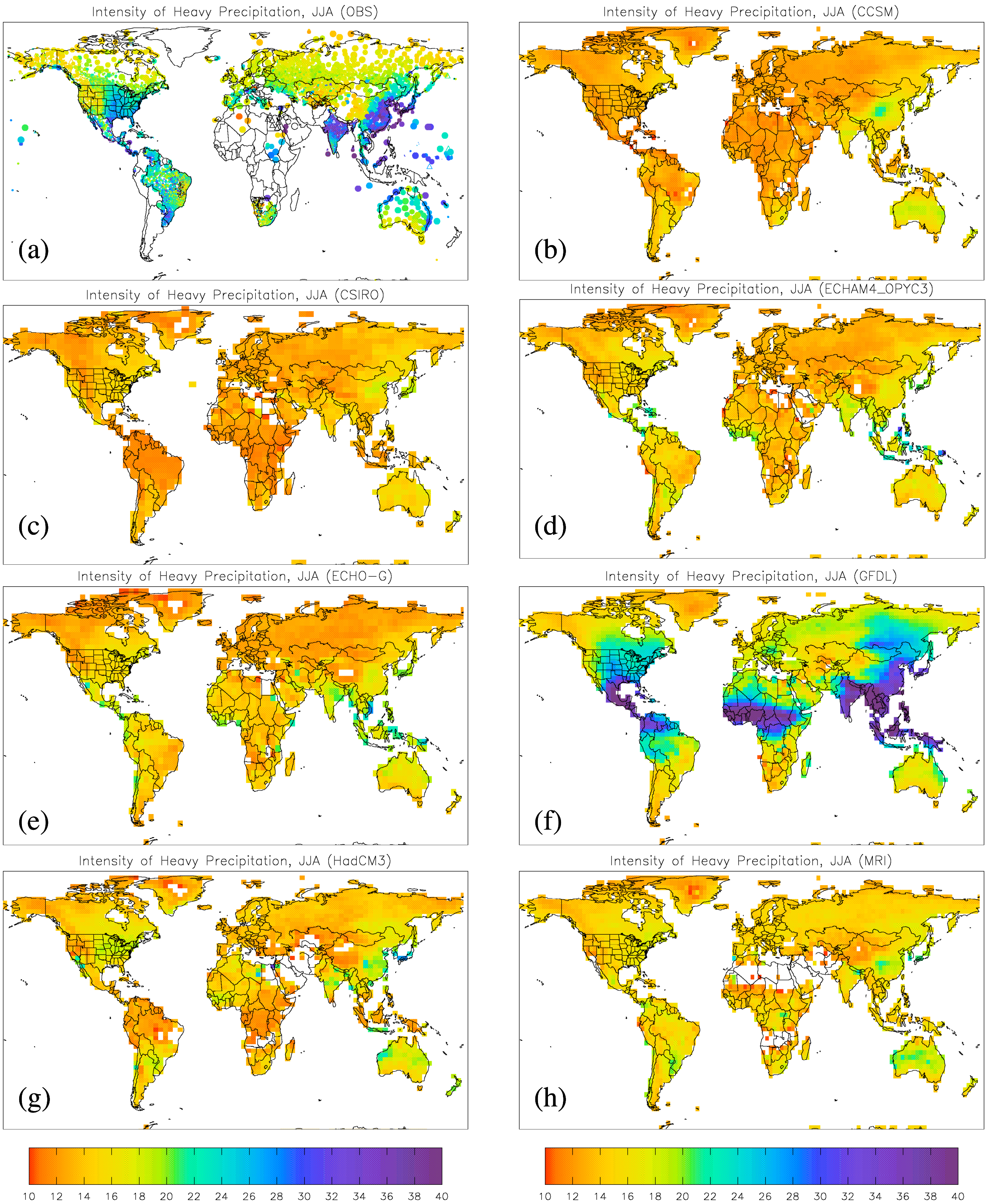

Fig. 1. Mean JJA precipitation intensity for heavy precipitation (>10 mm day^{-1}) from (a) observations (open triangles represent stations with records less than 5 years) and models: (b) CCSM, (c) CSIRO, (d) ECHAM4_OPYC3, (e) ECHO-G, (f) GFDL, (g) HadCM3, and (h) MRI. Black colors (including open triangles and circles) in (a) indicate that heavy precipitation has not been observed. White regions in land areas in (b-e) and (g-h) indicate that light precipitation never occurs there in the model.

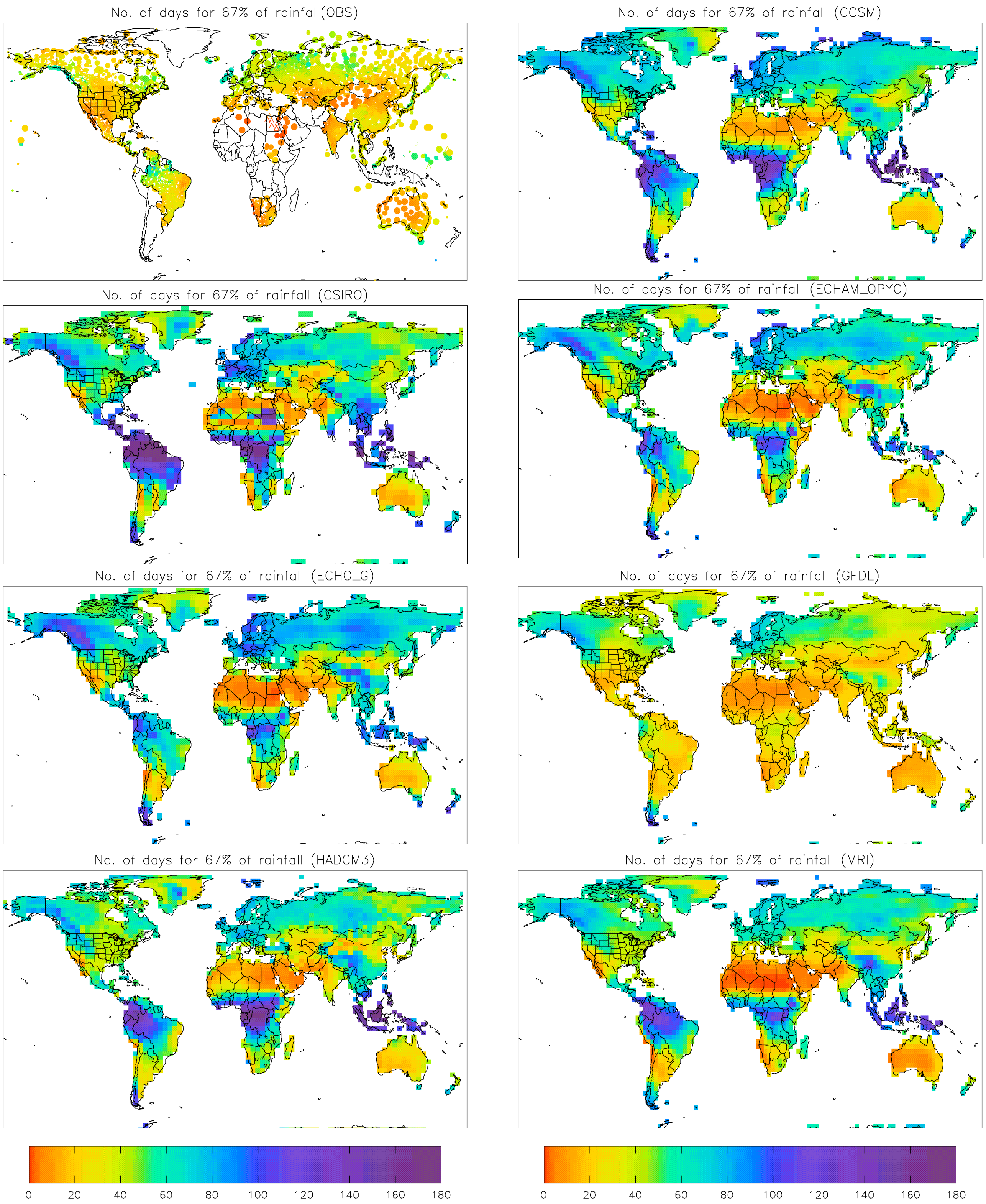

Fig. 2. The number of days contributing 67% of total precipitation from (a) observations (open triangles represent stations with records less than 5 years) and models: (b) CCSM, (c) CSIRO, (d) ECHAM4_OPYC3, (e) ECHO-G, (f) GFDL, (g) HadCM3, and (h) MRI.