J3.9 Orographic Enhancements in Precipitation: Construction of a Global Monthly Precipitation Climatology from Gauge Observations and Satellite Estimates

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1. Introduction

Accurate representation of the long-term mean precipitation is important for a number of applications including global change studies, climate model evaluations, and examinations of energy and water cycle. Over the past 20 years, several sets of long-term precipitation climatology have been constructed through objective analysis of gauge observations over global land areas (e.g. Legates and Willmott 1990; New et al. 1990; and Chen et al. 2002). While, these gauge-based climatologies present very similar spatial distribution patterns of precipitation, differences exist in smaller scale features and in magnitude, especially over mountainous areas (Chen et al. 2004). One problem common to all of these climatologies is the under-estimation of mean precipitation over mountainous areas (Nijsen et al. 2001). In general, gauge stations tend to be placed in areas with low elevation where less precipitation is observed than that over nearby mountainous regions. Orographic effects in precipitation must be included to improve the quantitative accuracy of the global land precipitation climatology.

A monthly precipitation climatology with orographic consideration has been constructed for several regions including CONUS, China and Mongolia (PRISM; Daly et al. 1994). This sophisticated technique defines analyzed fields of monthly precipitation climatology through interpolation of observed station long-term means from a dense gauge network using a locally established empirical relationship between precipitation and elevation. Two limitations of this technique are the dense gauge network required to establish the precipitation – elevation relationship and the manual operations involved to select the best combination of models and parameters region by region, making it difficult for global applications.

We have started a project to construct a monthly precipitation climatology over global land areas with orographic consideration. Our final goal is to define analyzed fields over 1961-1990 of long-term mean precipitation on a 0.25^{o} lat/lon grid over the global land areas by combined use of gauge observations, satellite estimates and a simplified orographic precipitation model. In this paper, we report the preliminary results of this project on data collection and algorithm development.

2. Gauge Data

In order to improve the quantitative accuracy of climatological precipitation analyses, special efforts have been made to collect station observations from several individual data sources. These include:

1) Global Historical Climatology Network (GHCN) of NCDC/NOAA. GHCN contains monthly precipitation reports from mid 1800 to present for 20,590 stations. The number of gauge stations reporting precipitation varies through the data period, with reports from a maximum of ~17,000 stations available during 1960s and 1970s.
2) Climate Anomaly Monitoring System (CAMS) of CPC/NOAA. CAMS contains monthly precipitation observations from about 2,000 stations before 1982 and from about 4,000 stations afterward.
3) Daily precipitation for the former USSR from NCDC. This data set contains daily precipitation time series from a total of 2,178 stations over 15 former USSR counties. For our applications, monthly

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precipitation totals are first accumulated from the daily records for stations with no more than one day missing daily reports during the month. Monthly climatology is then defined by averaging the corresponding monthly values for stations with 20 years or longer records during the 30-year period from 1961 to 1990. Monthly precipitation climatology at a total of 2016 stations was defined from the daily data set.

4) Station monthly precipitation normals over Canada and Australia. The Canadian monthly precipitation normals, available at 2,646 stations, are defined for stations with 10 years or longer reports through a period from 1971 – 2000, while the Australian station normals are available for 7,284 stations with at least 10 years records from 1961 – 1990 and continuing operations after 1990.
5) The United Nations (UN) Food and Agriculture Organization (FAO) monthly precipitation data set. Monthly precipitation climatology representing the mean state of 1961 – 1990 is available for about 27,000 stations covering most countries of the world.
6) Precipitation data sets for several regions over East Asia, South America and Africa made available through various CPC activities.

Station monthly precipitation climatological data are collected from the above-mentioned individual sources , duplicate reports are eliminated, and the data are combined. For stations that are located within 10km of each other, the data are combined. The elimination of duplications is done by examining the WMO station IDs and comparing the original time series. The combination of nearby station is done to make the station climatology more representative of the mean status over the region. As a result, a monthly precipitation climatology is defined for a total of 49,745 station locations and used in this study to construct the analyzed fields of monthly precipitation climatology.

Figure 1 shows the spatial distribution of the stations. Many of the global land areas, including Western Europe, India, East Asia, the east and west coastal areas of Australia, Canada, and the United States, are covered by very dense gauge networks, while precipitation is sampled by sparse networks of gauges over several areas over North Africa and mid-West Australia. In general, the gauge station network density represents a substantial improvement compared to that used in previous studies (e.g. Chen et al. 2002, Legates and Willmott 1990), establishing the foundation upon which a better precipitation climatology may be constructed.

3. Gauge-Based Analysis of Monthly Precipitation Climatology

Analyzed fields of monthly precipitation climatology of precipitation are constructed on a 0.25^{o} lat/lon grid over the global land by interpolating the corresponding station climatology at over 49,000 stations described in section 2 through the technique of Shepard (1965). The Shepard method defines the analyzed value at a grid point through interpolating gauge observations at 4 to 10 nearby stations with a weight that is inversely proportional to the station-grid distance.

Figure 2 presents a comparison of the analyzed monthly precipitation climatology for July over East Asia with that of Chen et al. (2002) that is based on a less dense gauge network. Good agreement is observed between the two climatologies in overall magnitude and large-scale spatial distribution patterns. As expected, the new gauge-based field, based on a denser gauge network and generated on a finer spatial resolution, depicts more details of precipitation distributions compared to that of Chen et al. (2002). Some problems, however, remain in this gauge-based climatology. One such example is the northward extension of heavy rainfall from Indian and Nepal across the Himalaya into the Tibet high plain, an artifact caused by the distance-based interpolation over the gauge-sparse region. Additional information, such as that from satellite observations, is needed to correct the problems and further improve the quality of the precipitation climatology over these gauge sparse areas.

4. Combining with Satellite Observations

a. Satellite Data

We try to improve the monthly precipitation climatology by taking advantage of the information from precipitation estimates derived from satellite observations. Although satellite estimates contain both bias and random error, they are capable of depicting the spatial distribution of precipitation reliably.

In this preliminary study, monthly precipitation estimates derived from the TRMM Precipitation Radar (PR, TRMM Product 3A25) are used to combine with the gauge-based analysis described in section 3. Satellite-based precipitation climatology fields are computed on a 0.5°lat/lon over global land using the TRMM data for an 8-year period from 1998 to 2005. The TRMM PR-based monthly precipitation climatology for July is shown in Figure 3b. Compared with that derived from the gauge observations (Fig.3a), the TRMM-based precipitation climatology presents very similar spatial patterns but with significant biases over many areas. The artificial extension of the heavy rainfall into Tibet seen in the gauge-based climatology is not visible in the satellite-based climatology.

b. Combining the Gauge and Satellite Data

A two-step approach is taken to combine the gauge and satellite data to define the analyzed fields of monthly climatology with improved quantitative accuracy. The first step of this approach involves the correction of the bias inherent in the raw TRMM-based precipitation climatology. This is done by adjusting the TRMM data against the gauge observations. Ratio between the gauge-based climatology and the TRMM-based values are first calculated at grid boxes with at least one gauge. Analyzed values at all grid boxes are then computed by interpolating the ratio values at the gauge locations through the Optimal Interpolation (OI) method of Gandin (1965). The bias in the raw TRMM precipitation climatology is then corrected by multiplying the analyzed ratio fields with the raw TRMM climatology. As shown in Figure 3c, the bias in the raw TRMM climatology is reduced substantially through this procedure.

The second step of the gauge-satellite combination is to merge the bias-corrected TRMM data with the gauge-based analysis through the OI technique. Here, the gauge-based analysis is taken as the first guess and the bias-corrected TRMM data is employed as observation to correct the gauge-based analysis over regions with less-reliable accuracy. Error fields are defined for both the satellite and gauge-based fields to best take advantage of each input information source. In particular, error for the gauge-based analysis (the first guess field) is defined as a function of the number of gauges available within the grid box so that the combined analysis will be dominated by the gauge data over gauge dense areas while the satellite data will play more roles in areas of sparse networks. An example of the combined climatology for July is shown in Figure 3d. We can see that the artificial extension of rain belt of the south of the Himalayas has been reduced. The magnitude and pattern of large scale precipitation are kept well in the combined analysis. However, there are detailed features need to be improved.

5. Summary and Future Work

Preliminary development work has been performed towards the construction of a gauge-satellite merged monthly precipitation climatology with improved representation of orographic effects. Through accumulated efforts in recent years, gauge-observed monthly precipitation climatology data have been collected from near 50,000 stations around the globe. A prototype algorithm has been developed to combine the gauge-based and satellite-derived monthly precipitation climatology over the global land areas, Preliminary examinations revealed improved quantitative accuracy of the merged precipitation climatology compared with that based on gauge observations or satellite estimates alone. More work is underway to improve the merging algorithm and to taking account of the orographic effect in the merged analysis.

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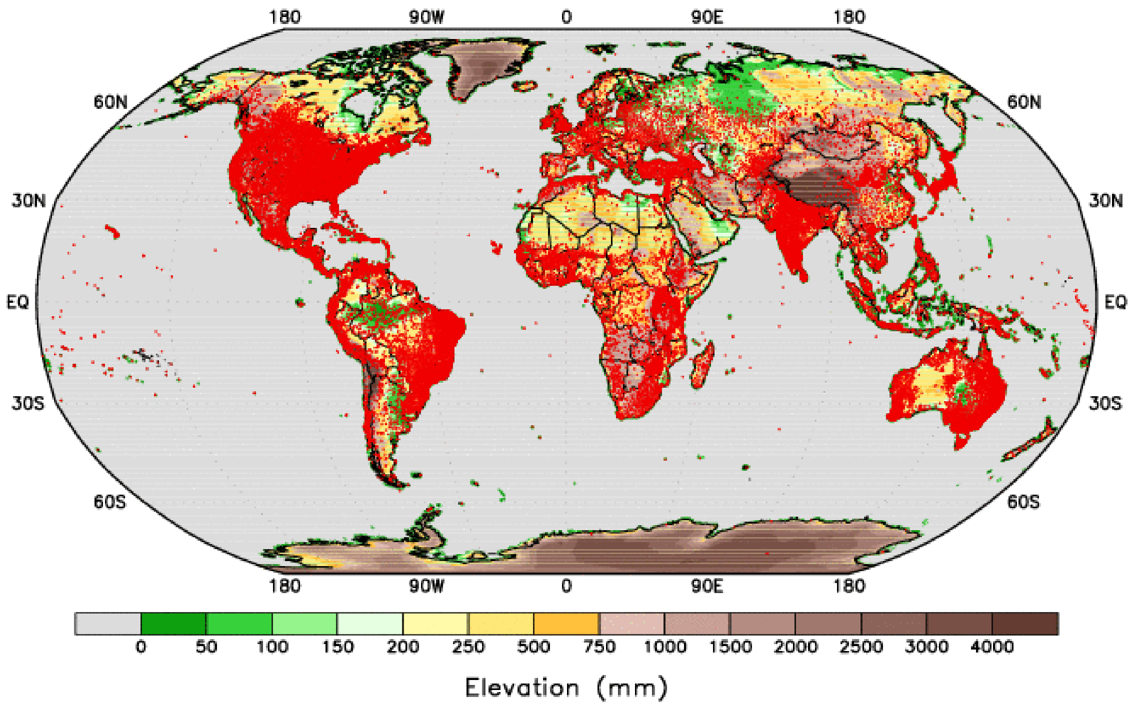

Fig. 1 Spatial distribution of 49,745 stations complied in our new monthly climatology of precipitation database.

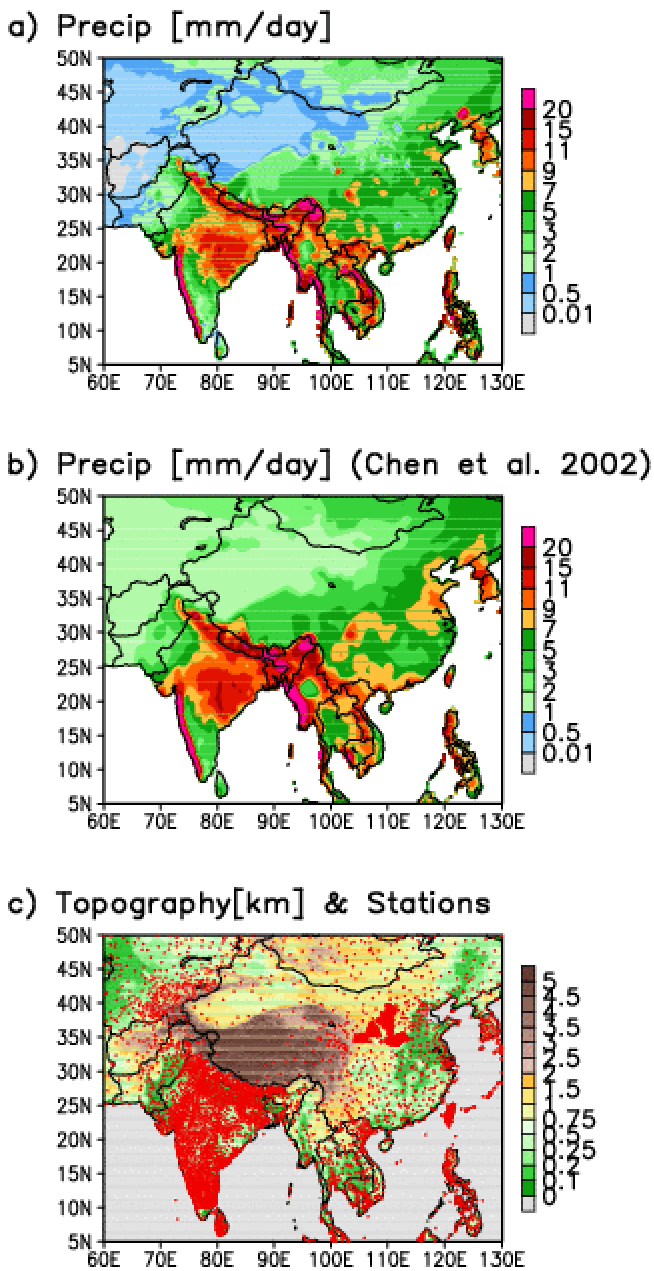

Fig. 2: a) The Spatial distribution of gauge based analysis over the region of East Asia for the month of July based on the new data set; b) the same as a) except for the previous version; c) The topography and locations of stations from the new data set.

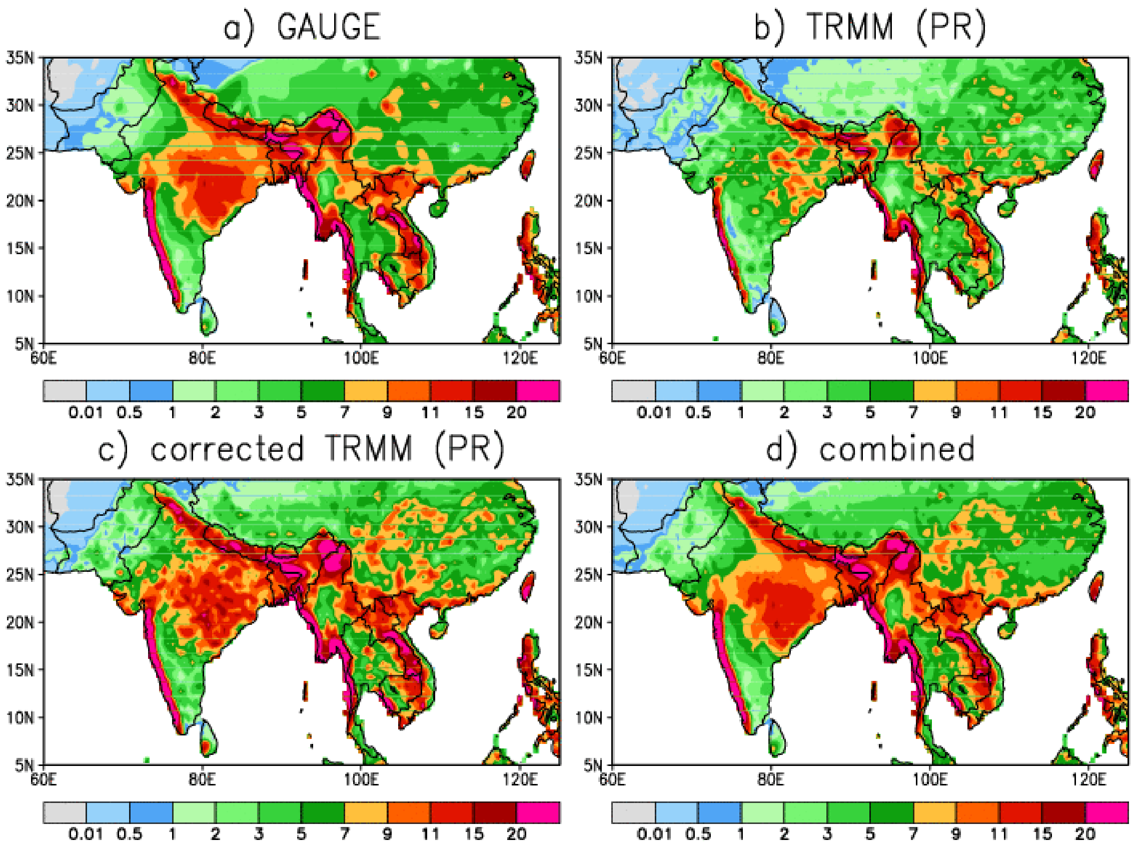

Fig. 3: Spatial distribution of monthly precipitation climatology for July (unit = mm/day). a) the gauge-based analysis; b) the original TRMM PR; c) the bias corrected TRMM PR; and d) the combined analysis.