Prospect for TRMM in rainfall estimates: a case study in the Laohahe basin, China

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Abstract Four years (2002–2005) of data from the Tropical Rainfall Measuring Mission (TRMM) 3B43 (V6) and 52 monthly raingauge measurements over the Laohahe basin in northeastern China were compared. The distribution of rainfall estimated from TRMM and raingauges showed the same spatial trend: a strong north–south gradient in rainfall. The time sequence patterns of the rainfall determined by both processes were remarkably similar (the correlation coefficient is 0.99). Analysis of rain climatology in different seasons and at 52 stations showed that the calculation period and site are important factors in estimating rainfall from TRMM. In the rainy season, the degree of accuracy of the TRMM estimate is more than 46%, while in the dry season, it is only about 12%. At the annual scale, only 23.1% of station data were accurately estimated, 0.2% underestimated and 75% overestimated. Therefore, in the Laohahe basin, TRMM is useful for estimating the average values of rainfall and good for long-term climatology with application to strategic water resource management.

Key words rainfall; TRMM 3B43; raingauges; Laohahe basin, China

INTRODUCTION

Precipitation is a major driving force in the water cycle and accurate data with sufficient spatial detail are of key importance in assessing basin-scale hydrology. It is common practice that hydrological models are run with precipitation data acquired from a limited number of gauges (Goodrich *et al.*, 1995). Recent studies showed that the spatial resolution greatly influences model outcomes and that models using raster based precipitation data outperform models that use precipitation derived from point measurements (raingauges) (Guo *et al.*, 2004). Schuurmans & Bierkens (2007) also showed that spatial patterns of precipitation are essential in characterizing the behaviour of a catchment.

Satellite remote sensing is a better source of spatial rainfall data. Such data are generally readily available over longer periods, and cover large areas. The Tropical Rainfall Measuring Mission (TRMM), cosponsored by the National Aeronautics and Space Administration (NASA) of the USA and the Japan Aerospace Exploration Agency (JAXA, previously known as the National Space Development Agency, or NASDA), is the first coordinated international satellite mission to study tropical and sub-tropical rain systems (Kummerow *et al.*, 2000). The TRMM provides visible, infrared, and microwave observations of tropical and subtropical rain systems, as well as lightning, cloud and radiation measurements. The satellite observations are complemented by ground radar and raingauge measurements to validate satellite rain estimation algorithms (Simpson *et al.*, 1988). The TRMM satellite was launched on 27 November 1997 and flew in the direction 35°N–35°S. It was boosted on 24 August 2001 from its original 350-km altitude to 402 km, helping to extend the mission life. Since then, the TRMM satellite spans the globe from 50° N to 50°S.

In the Laohahe basin (41°–42.5°N; 117°–119.8°E), raingauge data are the only representation of precipitation. Inadequate raingauge networks throughout the basin sometimes provide incomplete information on the distribution of rainfall. Thus, the use of remote sensing data in estimating rainfall offers an exciting opportunity. Neither raingauges nor satellite-based estimates are perfect indicators of rainfall (Nicholson *et al.*, 2003). Morrissey & Greene (1993) and Xie & Arkin (1995, 1996) show in their studies that all satellite estimates have non-negligible biases when compared with concurrent *in situ* observations. With raingauges, biases are introduced by gauge type, maintenance and placement (Legates & Willmott, 1990), as well as by spatial sampling (Huffman *et al*., 1997). However, these are small when compared with the bias in satellite estimates. In this study, the raingauge is used to provide a ground-based rainfall measurement.

Information about the distribution of rainfall and the structure of precipitation systems from medium-latitude areas of China, such as the Laohahe basin, is important for TRMM data validation. Unfortunately, so far, there has been no research done to validate TRMM data over the Laohaohe basin. In this work, attempts have been made to compare the rainfall determined by TRMM 3B43 products with the data of ground-based raingauges throughout the study area.

STUDY AREA

The Laohaohe basin is located in the northeast of China (Fig. 1). It covers 1.86×10^4 km^2, with an elevation range of roughly between 427 and 2054 m a.m.s.l.. There is an apparent W–E gradient in elevation with highest points in the northwest of the study area. Daily rainfall data from 52 raingauges have been available since 1970. The statistical results from nearly 30 years of rainfall data showed that this region is characterized by seasonal climatic conditions: a rainy season (June–September) and a dry season (January–May and October–December). In the Laohaohe basin, about 73% of the annual rainfall (433.5 mm) occurs during the rainy season.

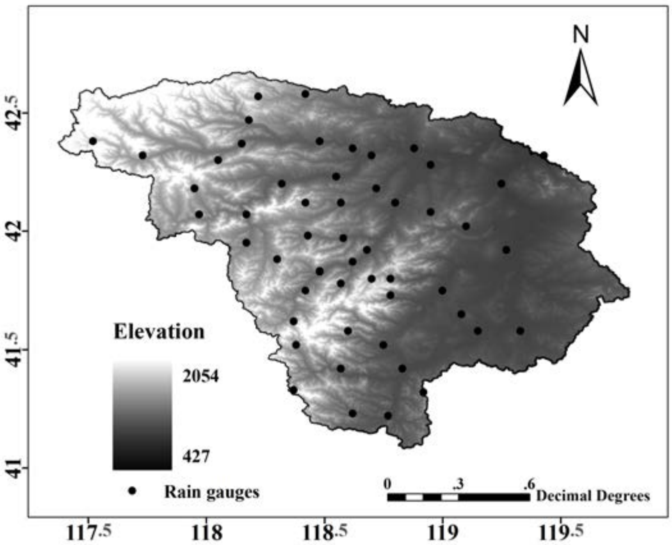

Fig. 1 Digital elevation map, illustrating the spatial layout of raingauges across the Laohahe basin.

DATA AND METHODS

In this paper, the TRMM data set 3B43 V6 with a 0.25° grid was used to obtain satellite rainfall estimates. The TRMM satellite product 3B43, "Tropical Rainfall Measuring Mission (TRMM) and Other Source Monthly Rainfall" was selected and downloaded from the Goddard Distributed Active Archive Center (see ftp://disc2.nascom.nasa.gov/data/TRMM/Gridded/3B43_V6). Daily rainfall measurements were provided by the Hydrological Bureau of Inner Mongolia. Monthly raingauge data (RNG) are the totals of daily rainfall per month. The RNG and TRMM data have the same monthly resolution, and span the period January 2002–December 2005.

The data from the TRMM 3B43 data set were resampled using the bilinear weighted interpolation technique to match the spatial location of the raingauge (Ud Din *et al*., 2008). The accuracy of TRMM estimation was described by two indices: correlation coefficient and bias (= TRMM – RNG). The performance of the TRMM data was characterized into three categories (Islam & Uyeda, 2007): underestimation, overestimation and approximately equal (within ±10%).

RESULTS AND DISCUSSION

Several comparisons were made of RNG rain intensities and satellite retrievals from the TRMM 3B43.

Comparison of rainfall distribution from TRMM and RNGs

Figure 2(a) and (b) shows, respectively, the monthly accumulated rainfall estimated from the TRMM data and the RNG total rainfall kriged map, for the 2002–2005 period, throughout the Laohahe basin. Comparing Fig. 2(a) and (b), it is apparent that there is a strong N–S gradient in rainfall, and the RNG kriged map seems to capture the orographic precipitation in the northwestern part of the basin, while the TRMM does not. Rainfall estimated from the TRMM is lowest in the north and highest in the south, while RNG rainfall is the lowest in the northeast and highest in the southwest and northwest. This can be partially explained by Table 1. In the Laohahe basin, rainfall determined by RNG is significantly correlated with latitude in both rainy and dry seasons (Table 1). The RNG is also significantly correlated with elevation in the rainy season and at the annual averaged scale. Thus, we conclude that the spatial distribution of rainfall in the Laohahe basin is mainly influenced by latitude, and elevation is a secondary factor (Fig. 2(b)).

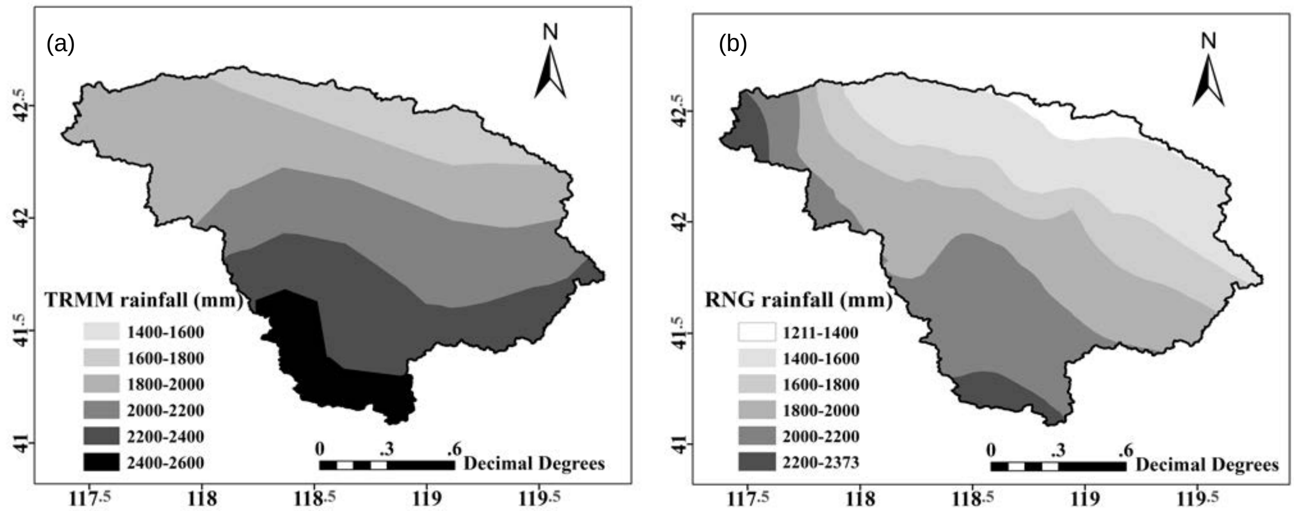

Fig. 2 Distribution in the Laohaohe basin of: (a) monthly TRMM 3B43 accumulated rainfall (January 2002–December 2005), and (b) monthly RNG accumulated rainfall using ordinary the kriging method from 2002 to 2005.

Table 1 Correlations between RNG accumulated rainfall from 2002 to 2005 and respective longitude, latitude and elevation at 52 stations in the Laohahe basin.

Correlation coefficient	Rainy season	Dry season	Annual averaged
Latitude (°)	–0.690*	–0.458*	–0.650*
Longitude (°)	–0.196	–0.207	–0.218
Elevation (m)	0.418*	0.226	0.372*

* correlation is significant at the 0.01 level (2-tailed).
Rainy season means: June–September; dry season means: January–May and October–December.

Rain climatology obtained from TRMM and RNG

Long-term rain climatology derived from TRMM The comparison of the satellite rainfall data following bilinear weighted interpolation and the gauge measurements averaged from 52 stations over the Laohahe basin is presented in Fig. 3(a). It is obvious, from the plot, that the

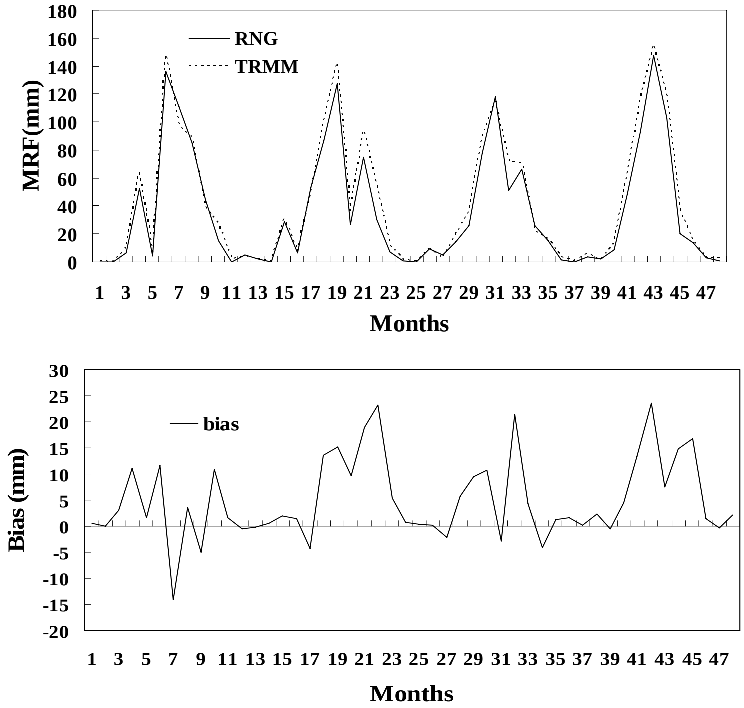

Fig. 3 (a) Monthly rainfall (MRF) measured by RNG and TRMM; and (b) monthly bias (= TRMM – RNG) averaged from 52 raingauges, 2002–2005, in the Laohaohe basin.

measured and estimated rainfall data are highly correlated (the correlation coefficient is 0.99). The monthly rainfall (MRF) patterns between the RNG and TRMM values have good similarity during the observed period. Fig. 3(b) shows the variation of the averaged biases calculated from 52 stations in the study period. The minimum, maximum and mean bias is –14.1, 23.5 and 5 mm, respectively. On average, rainfall determined from the TRMM data overestimated RNG data by 5 mm per month. In general, the comparison is much better for the average sites and over the long term.

Rain climatology in different seasons over the Laohahe basin The monthly average rainfall determined by TRMM and RNG from 52 locations during the rainy and dry seasons was compared, and the annual averaged scale is described below.

In the rainy season, monthly rainfall measured by TRMM had almost the same amount—the bias ratio (= (TRMM – RNG)/RNG)) is within ±10%—as RNGs at 24 locations; overestimated (bias ratio > 10%) the RNG rainfall at 26 locations, and underestimated (bias ratio 11–20%) the RNG rainfall at two locations (Table 2). The TRMM accurately detected about 46% of the analysed stations at the monthly time scale.

In the dry season, monthly rainfall measured by TRMM was almost the same amount as RNGs at six stations, overestimated the RNG rainfall at 45 stations, and underestimated it at one

Table 2 Comparison of TRMM and RNG performances for different seasons and stations, 2002–2005.

	Bias ratio	Rainy season	Dry season	Annual averaged
Approximately equal	(±10%)	24	6	12
Overestimation	11–20%	13	12	23
	20–30%	9	16	12
	> 30%	4	17	4
Underestimation	11–20%	2		
	> 30%		1	1
Total stations		52	52	52

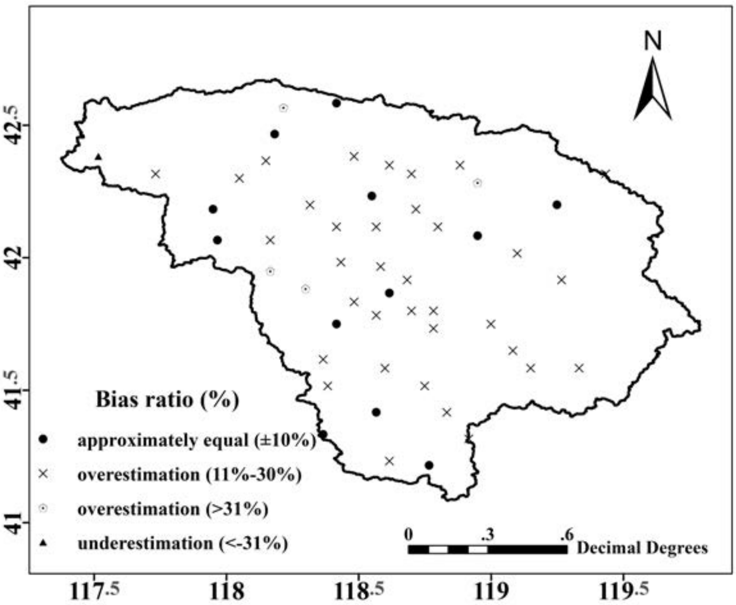

Fig. 4 The distribution of monthly rainfall bias ratio (= (TRMM – RNG)/RNG) averaged from 2002–2005 at 52 stations over the Laohaohe basin.

location (Table 2). Only about 12% of the analysed stations could be detected precisely by the TRMM.

It is clearly seen that the performance of TRMM is better during the rainy season than the dry season. Whether in the rainy or dry period, TRMM overestimated the rainfall as a whole, and this was more evident in the dry period. Hence, it is noticeable that magnitude of the errors in rainfall determined from TRMM data is largely dependent on the calculation period, or on the season in which the precipitation occurred.

Figure 4 shows the bias ratio distribution of TRMM estimation averaged from annual rainfall in the period 2002–2005 in the Laohahe basin. The four-year averaged rainfall at 12 stations was correctly estimated by TRMM. At only one station (gauge name SDG), the rainfall was underestimated by TRMM, while at the remaining 39 stations, the rainfall was overestimated by TRMM. This is in accordance with the results of Table 2. For the SDG gauge, TRMM always underestimated rainfall whether in the rainy or the dry season. This can be explained by the topography: the SDG gauge is located in the northwest corner of the basin with elevation as high as 1350 m (Fig. 1).

CONCLUSIONS

The spatial distribution of rainfall determined by TRMM 3B43 V6 and raingauges (RNG) all displayed strong variation with latitude. Elevation seems to be the secondary factor in the Laohahe basin. The patterns of monthly rainfall determined by both TRMM and RNG showed good agreement in the amounts, as well as in the variation of the average rainfall. The correlation coefficient was 0.99. Long periodic analysis showed that TRMM data could be used to better understand rain climatology in mid-altitude zones, such as the Laohahe basin. Analysis of rain climatology in different seasons and at 52 stations showed that the calculation period or the season of the occurrence of precipitation and site were important factors in estimating rainfall from the TRMM 3B43. In the rainy season, the accurate ratio of TRMM estimate was more than 46%, while in the dry season, it was only about 12%. On the annual scale, only 23.1% of the stations were accurately estimated; 0.2% were underestimated and 75% were overestimated by the TRMM product. Overall, in the Laohahe basin, TRMM 3B43 is good for long-term climatology with application to strategic water resource management, but it may not be so good for short-term hydrological application such as flood forecasting. Therefore, investigation of the TRMM 3B42 3-hour data is suggested for further study.

Acknowledgements This study was undertaken by the National Key Basic Research Programme of China (Grant no. 2006CB400502) and the Natural Science Foundation of China (Grant no. 40871230).

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