Adaptability evaluation of TRMM over the Tianshan Mountains in central Asia

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सार – जल विज्ञान संबंधी प्रक्रियाओं और परिस्थितिकी समस्याओं का आकलन करने के लिए पर्वतीय क्षेत्र में सही वर्षा का होना अत्यंत महत्वपूर्ण है। गत कुछ दशकों में व्यापक रूप से प्रयुक्त किए गए उपग्रह ऑकड़ों सहित अनुकूलनीय मूल्यांकन करना प्रमुख समस्या बन गया है। इस अध्ययन में मध्य एशिया के पर्वतीय क्षेत्र में TRMM 3B43 की अनुकूलनशीलता का विश्लेषण किया गया। 2000-2006 की अवधि के लिए प्रेक्षित ऑकड़ों के साथ TRMM उत्पाद की तुलना की गई। सांख्यिकीय विश्लेषण सिद्धांत के आधार पर चार सांख्यिकीय प्राचल प्रस्तुत किए गए। प्राप्त हुए परिणामों से पता चला है कि पूरे क्षेत्र में बायस -13.93% पहुँच गया और 70% से अधिक स्टेशनों में सहसंबंध गुणांक 0.70 से अधिक थे। TRMM के सटीक विश्लेषण के अनुसार हमने समय और स्थान में महत्वपूर्ण भिन्नताओं में त्रुटियाँ देखी है। कुल मिलाकर परिशुद्धता शीत ऋतु की अपेक्षा उष्ण ऋतु में अधिक रही। स्थानिक रूप में अन्य क्षेत्रों की अपेक्षा दक्षिणी और पूर्वी क्षेत्रों में परिशुद्धता अधिक रही। इसके अतिरिक्त अवयव सहित TRMM की सटीकता अत्यंत उल्लेखनीय स्तर पर स्वीकार्य थी। इस अध्ययन में पता चलता है कि मध्य एशिया में तियानशन पर्वतों में TRMM 3B43 से प्राप्त वर्षा प्रयुक्त की जा सकती है। इससे पर्वतीय क्षेत्र में नए ऑकड़ों के स्रोतों के प्रयोग के लिए संदर्भ उपलब्ध हो सकेंगे।

ABSTRACT. Accurate precipitation in mountain area is very important for evaluating the hydrological process and ecological problem. With the satellite data having been widely used in the past few decades, adaptability evaluation becomes the principle problem. The adaptability of TRMM 3B43 in mountain area of Central Asia was analyzed in this study. The TRMM product was compared with the observed data for the period of 2000-2006. Four statistic parameters were introduced based on the statistical analysis theory. The results show that the bias reached -13.93% over the entire regions, and the correlation coefficients over 70% of stations were greater than 0.70. According to the accuracy analysis of TRMM, we found the errors have significant differences in time and space. On the whole, the precision in the warm seasons is much higher than that in the cold seasons. The precision of the southern and eastern areas is higher than the other areas in space. Additionally, the accuracy of TRMM with elevation was acceptable at very significant level. This study indicates that the precipitation from TRMM 3B43 could be applied in the Tianshan Mountains in Central Asia. It could provide reference for the use of new data source in the mountain area.

Key words – Remote sensing, Precipitation, Adaptability evaluation, TRMM.

1. Introduction

Precipitation is one of the most important variables in the hydrological cycle, which is very difficult to measure for its great variability (Jaagus, 2009). Adaptability evaluation of the precipitation from ungauged source is very necessary for hydrological simulation, flood forecast and water resource management (Tarnavsky *et al.*, 2012; Mair and Fares, 2011; Min *et al.*, 2011).

Weather station is not well equipped in mountainous areas, especially for the developing countries.

Interpolation of precipitation is necessary when areal data is needed. But the accuracy depends on the distribution and numbers of weather stations (Mair and Fares, 2011; As-Syakur *et al.*, 2011). How to improve the accuracy of precipitation is meaningful for water resources management and hydrological research.

Precipitation data from satellite is very useful for mountainous areas (Heidinger *et al.*, 2012; Kidd and Levizzani, 2011). Tropical Rainfall Measuring Mission (TRMM) is an integral part of the National Aeronautics and Space Administration (NASA) Earth Science Enterprise [Huffman *et al.*, 2007; Kummerow *et al.*, 1998]
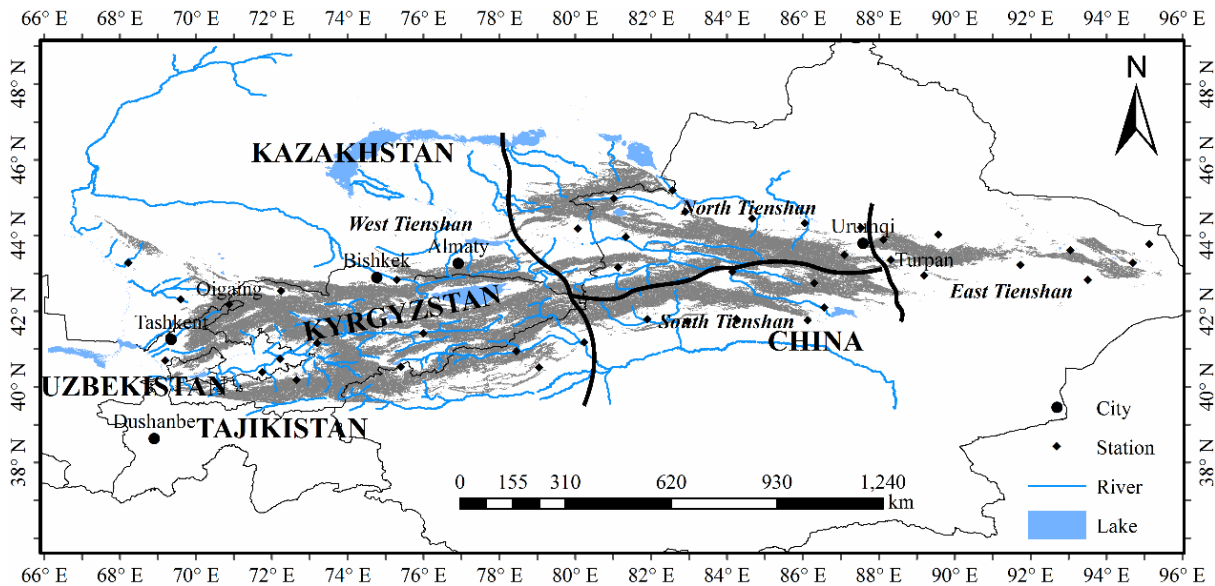
Fig. 1. Location of Tianshan Mountains

which has make the precipitation precision significantly improved since 1997 (Robinson *et al*., 2000).

Some researchers have been done for testing the adaptability of TRMM precipitation data (TRMM Version 6) in many areas (Adeyewa and Nakamura, 2003; Dinku *et al*., 2007; Beighley *et al*., 2011; Karaseva *et al*., 2011; Vila *et al*., 2009). Most of results showed that the observed data could be replaced with the TRMM (Villarini and Krajewski, 2007; Scheel *et al*., 2011). However, some reports indicated that TRMM is not so accuracy in those complex topography regions (Sandoval, 2007; Krishnamurti *et al*., 2009). So adaptability evaluation of TRMM in the local region is a critical issue in these regions, especially in the mountain areas.

Reliable precipitation data is very lack in most of the Tianshan Mountains (Huffman *et al*., 2007). In order to evaluate the adaptability of satellite precipitation data, the TRMM 3B43 (V7) in this region was analyzed and compared with the observed data from 2000 to 2006. The evaluation includes the data in different space, time, climate zones and elevation.

2.   Description of the study area

Tianshan Mountains, the largest mountains in central Asia, stretch from east to west with a length of 2500 km (Fig. 1). The north-south distance varies from 250 km to 350 km. The elevation ranges from -192 m to 7435 m (Bolch, 2007). The climate is dominated by the zonal

westerlies (Yao *et al*., 2012). Being blocked by the Tianshan Mountains, four climatic zones have formed (Hu, 2004) with 16.8 mm to 814.5 mm of annual precipitation in space. About 40% of the precipitation occurs in the summer and 12% in the winter.

3.   Data and methodology

3.1. *Climate data*

The observed climate data from 42 rain gauges were used for adaptability evaluation (Fig. 1). Thirty sites distribute in China, and the other 12 stations are located in Kazakhstan, Kyrgyzstan and Uzbekistan (Feng *et al*., 2004). They were provided by the National Climatic Centre of China (NCCC), the China Meteorological Administration, and the Global Historical Climatology Network-Daily (GHCN-Daily) dataset (http://www1.ncdc.   noaa.gov/pub/data/ghcn/daily/) (Menne *et al*., 2012). The period of all data is from 1 January, 2000 to 31 December, 2006. They have been widely proven to be reliable (Li *et al*., 2012; Peterson *et al*., 2008).

3.2. *TRMM (3B43 V7)*

Tropical Rainfall Measuring Mission (TRMM) Version 7 was released on 26th July, 2012. The parameters, products, metadata, and data structures all have changed. For example, several popular Level-3 products have been added in the parameters. The TRMM Rainfall Product Version 7 (TRMM 3B43 V7) has the

TABLE 1

Station-wise comparision statistical parameters and fitting equation between TRMM 3B43 and observed data

| Station	R	R^2	RMSE	PBAIS (%)	Regression Equation
Baluntai	0.98	0.97	4.80	-2.22	$y = 0.83x + 3.69$
Tashkent	0.98	0.96	9.50	-44.75	$y = 1.3x + 5.57$
Kokaral	0.98	0.96	6.60	-0.09	$y = 0.94x + 1.9$
Andizhan	0.96	0.91	6.78	-34.72	$y = 1.05x + 6.06$
Turkestan	0.95	0.91	10.31	67.55	$y = 1.54x + 2.59$
Aheqi	0.94	0.89	6.72	11.37	$y = 0.66x + 4.92$
Urumqi	0.94	0.88	5.35	23.30	$y = 0.72x + 1.08$
Qitai	0.91	0.83	3.51	13.09	$y = 0.71x + 2.42$
Fergana	0.91	0.83	7.26	-35.42	$y = 0.96x + 6.64$
Kuerle	0.91	0.82	3.00	-38.29	$y = 1x + 1.73$
Yining	0.89	0.79	10.26	-17.55	$y = 0.8x + 10.89$
Baybulk	0.89	0.78	12.35	-20.10	$y = 0.82x + 9.41$
Kuche	0.89	0.78	4.08	-45.89	$y = 0.89x + 3.75$
Almaty	0.89	0.78	14.93	-14.40	$y = 0.68x + 11.24$
Oigaing	0.87	0.75	21.23	2.66	$y = 0.73x + 16.26$
Tianchi	0.86	0.75	18.50	21.46	$y = 0.67x + 5.52$
Xiaoquzi	0.84	0.71	9.58	51.00	$y = 0.37x + 5.53$
Zhaosu	0.84	0.70	13.68	12.13	$y = 0.56x + 14.49$
Panfilov	0.83	0.69	10.66	60.37	$y = 1.14x + 8.59$
Keping	0.83	0.68	6.95	-14.46	$y = 0.73x + 3.85$
Yiwu	0.81	0.66	6.83	-23.01	$y = 0.92x + 2.55$
Jinghe	0.81	0.66	5.58	-64.77	$y = 0.9x + 7.72$
Qijiaojing	0.80	0.65	3.24	-123.97	$y = 1.11x + 2$
Baicheng	0.80	0.64	7.66	-18.56	$y = 0.84x + 4.43$
Balitang	0.79	0.63	7.08	24.75	$y = 0.47x + 5.08$
Dabancheng	0.78	0.61	7.80	-59.16	$y = 0.65x + 7.85$
Caijiahu	0.78	0.61	7.22	-20.74	$y = 1.08x + 1.49$
Hami	0.76	0.58	5.09	-76.24	$y = 1.02x + 3.25$
Alashankou	0.72	0.52	5.41	0.50	$y = 0.45x + 6.78$
Yanqi	0.70	0.49	15.10	-142.39	$y = 1.65x + 5.12$
Chuomaohu	0.67	0.45	5.53	-175.55	$y = 1.09x + 3.88$
Shihezi	0.67	0.45	8.07	16.74	$y = 0.51x + 6.3$
Luntai	0.63	0.40	8.86	-55.32	$y = 0.84x + 4.73$
Torugart	0.63	0.40	12.10	-22.23	$y = 0.48x + 16$
Aksu	0.62	0.38	9.02	-49.27	$y = 0.74x + 5.86$
Kirgizata	0.59	0.35	18.50	16.76	$y = 0.58x + 9.41$
Wusu	0.56	0.31	9.07	-25.35	$y = 0.54x + 10.64$
Turpan	0.55	0.30	5.47	-408.06	$y = 1.4x + 5.14$
Naryn	0.54	0.30	16.20	-141.35	$y = 0.68x + 19.8$
Tokmak	0.48	0.23	23.01	-128.93	$y = 0.46x + 34.46$
Wenquan	0.31	0.09	19.17	-27.92	$y = 0.27x + 24.09$
Dzhalalaba	0.28	0.08	32.46	-519.67	$y = 0.57x + 50.69$
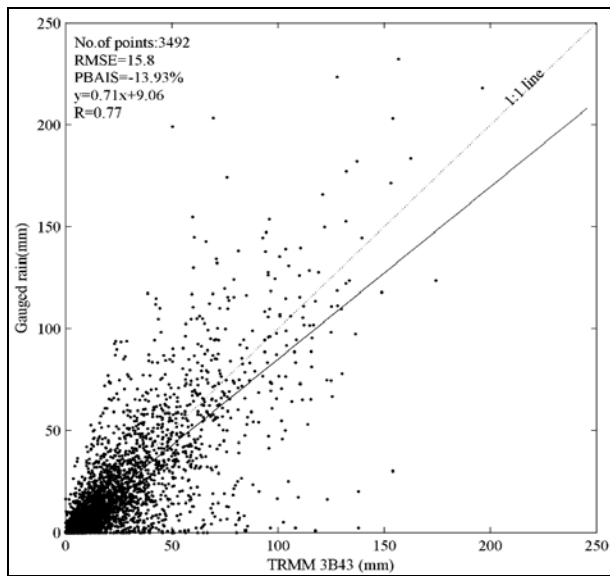
Fig. 2. Scatter plots between TRMM 3B43 V7 precipitation and observed data in the Tianshan Mountain (2000-2006)

best-estimated precipitation rate (mm/hr) and root-mean-square error (RMSE). The spatial resolution is 0.25° × 0.25° extending from 50° N to 50° S (Huffman *et al*., 2007). These data obtained from the NASA Goddard Space Flight Centre (http://mirador.gsfc.nasa.gov).

3.3. *Evaluation method*

Correlation coefficient (R), determination coefficient (R^2), root mean square error (RMSE) and percent bias (PBIAS) were selected to evaluate the TRMM 3B43 V7 precipitation (Van *et al*., 2003; Moriasi *et al*., 2007; Li *et al*., 2008; Gupta *et al*., 1999). In this study, we think the evaluation is excellent if the absolute value of PBIAS is less than 20%; it is good if between 20% and 40% and else is poor (Liew *et al*., 2005).

4. Results and discussion

4.1. *Spatial accuracy evaluation of TRMM*

In order to investigate the accuracy of TRMM 3B43 V7 product over the Tianshan Mountains, the scatter plots of monthly gauged precipitation have been drawn (Fig. 2). The fitted equations also have been calculated for all 42 stations (Table 1).

Fig. 2 shows that the correlation coefficient is 0.77, and RMSE is 15.8 mm. This indicates that there is a good linear correlation and consistency between the TRMM 3B43 and the gauged data. In addition, the PBAIS

is -13.93%, whose absolute value is less than 20%. All indicate that the precipitation from TRMM 3B43 V7 data had been slightly underestimated over the Tianshan Mountains, but it is still acceptable.

Table 1 shows that the average correlation coefficients (R) have arrived at excellent level, ranging from 0.28 (Dzhalalaba) to 0.98 (Baluntai). The determination coefficients varied from 0.08 to 0.97, with a mean of 0.62. RMSE ranged from 3.00 mm to 32.64 mm, with an average of 10.11 mm. PBAIS differed from -19.67% to 67.55%, and the average value is -48.30%. In addition, the regression slopes change from 0.27 to 1.65, and the interceptions change from 1.08 to 50.69. Furthermore, the determination coefficients (R^2) in 29 stations were greater than 0.50, which shows that more than 70% of stations are acceptable. Also, the absolute percent biases in 25 stations value between 20% and 40%, that is to say, sixty percent of the stations have arrived at good level.

But the data accuracy in some places doesn't reach good level. The reason is that the frontal surface causes more precipitation. On the other hand, it is absent in the interior areas. Their locations, most in the valley, are deemed to the reason of the disturbing of signal.

4.2. *Temporal accuracy evaluation of TRMM*

In order to evaluate the accuracy of TMMM 3B43V7 at different temporal resolutions, the statistical parameters and fitting equation have been calculated (2000-2006). The results were listed in Table 2.

The evaluation results (Table 2) indicate the accuracy gradually improved with the timescale. First, the different time-scale series were calculated, which included monthly, seasonal, cold-warm-season and annual scale. The correlation coefficient was greater than 0.72 in the study area. The determination coefficient was greater than 0.52. The slope of the regression equations varied from 0.72 to 1.26. And the PBAIS change from -19.06% to 48.90%. The accuracy of TRMM 3B43 V7 in most periods belongs to good level. The correlation coefficient (R) and the determination coefficient (April to September) were less than that in the other months. The accuracy changed obviously with temporal resolutions.

The absolute PBIAS values in warm season were less than 20%. Also the slope of regression equations was close to 1 in this period. The correlation coefficient and the PBIAS all show that the accuracy of TRMM 3B43 V7 is better during warm season than that during cold season.

TABLE 2

**Monthwise comparison statistical parameters and fitting equation between
TRMM 3B43 and observed data at different temporal resolutions**

Month	R	R^2	RMSE	PBAIS (%)	Regression Equation
Jan	0.81	0.65	11.38	48.90	y = 0.73x - 1.02
Feb	0.83	0.69	10.75	41.34	y = 0.78x - 1.28
Mar	0.83	0.69	14.62	22.19	y = 0.80x + 0.36
Apr	0.79	0.62	19.99	6.32	y = 0.85x + 2.52
May	0.73	0.53	22.41	1.26	y = 0.82x + 4.56
Jun	0.72	0.52	21.14	-6.26	y = 1.03x + 0.86
Jul	0.74	0.55	22.36	-7.07	y = 1.18x - 2.91
Aug	0.73	0.54	19.37	-14.67	y = 1.15x + 0.41
Sep	0.74	0.55	11.63	-19.06	y = 1.22x + 0.14
Oct	0.82	0.67	16.74	10.83	y = 0.98x - 1.58
Nov	0.79	0.62	13.66	33.60	y = 0.72x + 0.56
Dec	0.84	0.71	12.11	46.05	y = 0.81x - 2.66
Spring	0.85	0.72	37.05	19.29	y = 0.83x + 0.28
Summer	0.77	0.59	52.33	-4.16	y = 1.15x - 8.63
Autumn	0.79	0.62	33.25	-7.58	y = 1.25x - 8.75
Winter	0.84	0.70	21.94	39.90	y = 0.81x - 3.90
Cold	0.86	0.74	53.84	26.55	y = 0.84x - 5.42
Warm	0.78	0.62	76.58	-5.49	y = 1.26x - 26.87
Annual	0.81	0.65	116.45	8.74	y = 0.95x - 8.00

4.3. *Accuracy comparison of TRMM in different climatic zones*

To compare the accuracy of the precipitation in different climatic zones, regression analysis has been used [Figs. 3(a-d)].

The scatter plots [Figs. 3(a-d)] shows that there is significantly corresponding relationship between the two data resources in the four climate zones. The highest correlation coefficient (R) (0.88) appeared in the South Tianshan, and the smallest (0.65) presented in the North Tianshan. R in the East Tianshan and West Tianshan were 0.81 and 0.78, respectively. RMSE in West Tianshan is almost twice of the other three zones. The slope of the regression lines varied from 0.44 to 0.79.

All absolute PBIAS in the four climate zones were less than 20%. However, the PBIAS in North and East Tianshan was greater than zero and that in South and West Tianshan was less than zero. It indicates the monthly TRMM precipitation has been overestimated in North and East Tianshan, and underestimated in South and West Tianshan.

4.4. *Accuracy difference of TRMM with elevation*

Four elevation zones has been classfied to evaluate the accuracy of TRMM [Figs. 4(a-d)].

Fig. 4 shows that there is a significant linear relationship between the gauged data and the TRMM. The highest correlation coefficient (R) appeared in the area above 2000 m elevation. The minimum is
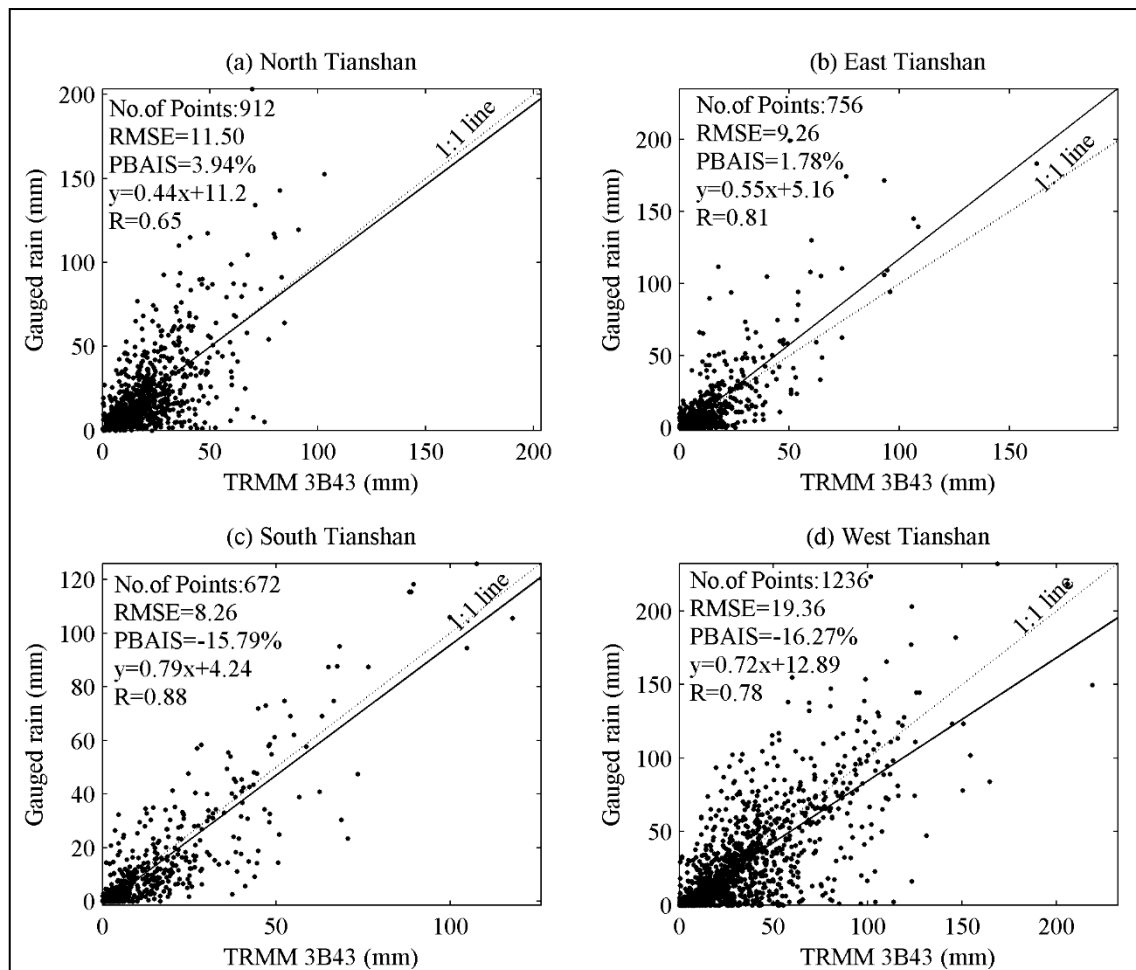
Figs. 1(a-d). Scatter plots between TRMM 3B43 V7 precipitation and observed data in different climate zones

in the area below 1000 m elevation. The slope of the regression line ranges between 0.53 and 0.69. Also, the PBIAS in the area below 1500 m elevation was less than zero. They were -12.74%, -15.48% between 0-1000 m elevation and 1000-1500 m elevation, respectively. On the other side, the PBIAS was positive if the elevation is greater than 1500 m. They were 11.82% and 4.05% with 1500-2000 m and above 2000 m elevation, respectively. In summary, the TRMM shows a good consistency when the elevation is above 2000 m.

5.   Conclusions

The TRMM 3B43 V7 precipitation data was adaptable after comparison with the observed data from 42 rain gauges over the Tianshan Mountains. More than 60% of stations have arrived at good level.

The accuracy gradually improved with the timescale. The accuracy of TRMM 3B43 V7 in most periods belongs to good level. The accuracy of TRMM data is better during warm season than that during cold season.

The accuracy has significantly responding relationship with aspect of area. The highest correlation coefficient appeared in the South Tianshan and the smallest presented in the North Tianshan. In addition, the monthly TRMM precipitation has been overestimated in North & East Tianshan and underestimated in South and West Tianshan.

There is a significant linear relationship between the gauged data and the TRMM at different elevation. That is to say, the higher the elevation is, the greater the correlation coefficient is. Also, the PBIAS was negative in the area below 1500 m elevation and it was positive in
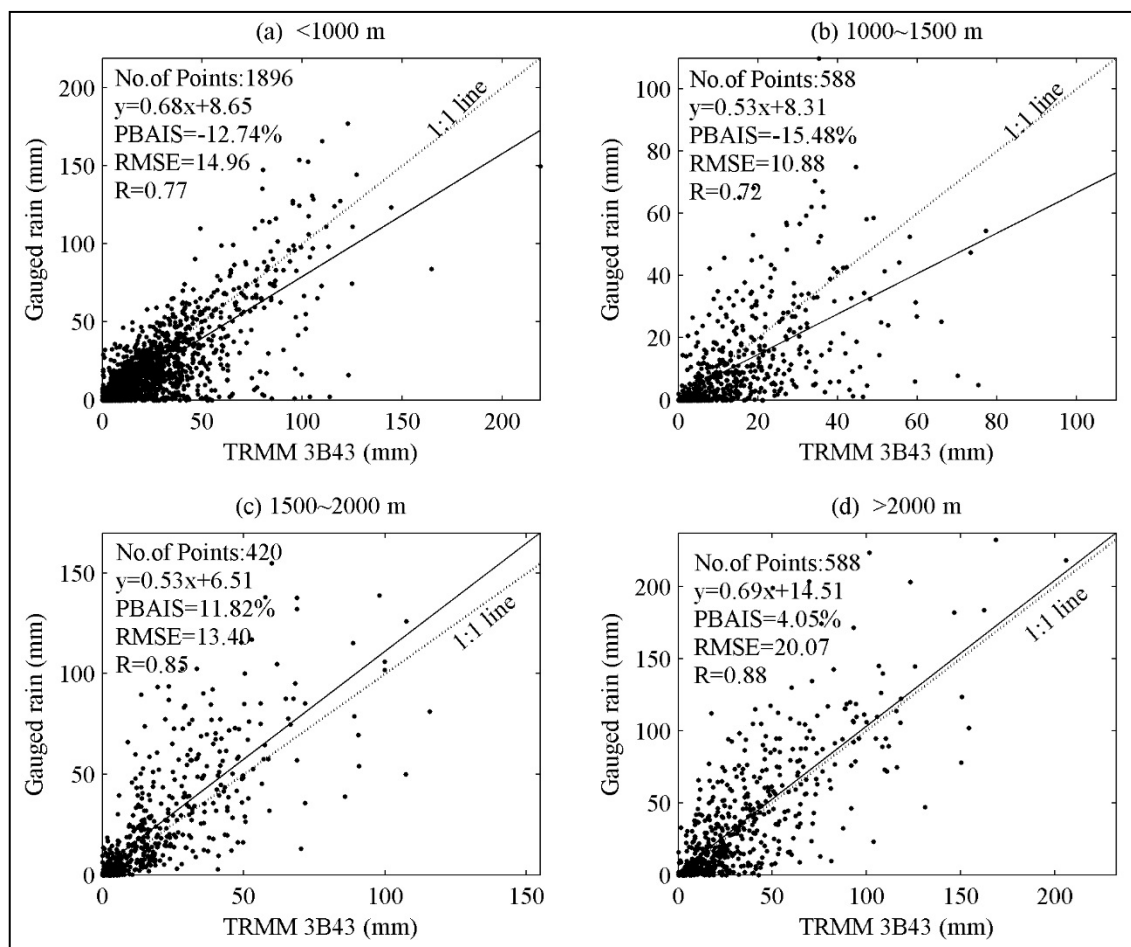
Figs. 2(a-d). Scatter plots between TRMM 3B43 V7 precipitation and observed data in different elevation zones

the other area. The TRMM shows a good consistency when the elevation is above 2000 m.

Above all, the TRMM 3B43 V7 data could be applied for the Tianshan mountains area. This evaluation could provide reference for the use of new data source.

Acknowledgment

References

Adeyewa, Z. D. and Nakamura, K., 2003, "Validation of TRMM radar rainfall data over major climatic regions in Africa", *Journal of applied meteorology*, **42**, 331-347.

As-Syakur, A. R., Tanaka, T. and Prasetia, R., 2011, "Comparison of TRMM multisatellite precipitation analysis (TMPA) products and daily-monthly gauge data over Bali", *International Journal of Remote Sensing*, **32**, 8969-8982.

Beighley, R. E., Ray, R. L. and He, Y., 2011, "Comparing satellite derived precipitation datasets using the Hillslope River Routing (HRR) model in the Congo River Basin", *Hydrological Processes*, **25**, 3216-3229.

Bolch, T., 2007, "Climate change and glacier retreat in northern Tien Shan (Kazakhstan / Kyrgyzstan) using remote sensing data", *Global and Planetary Change*, **56**, 1-12.

Dinku, T., Ceccato, P. and Grover-Kopec, E., 2007, "Validation of satellite rainfall products over East Africa's complex topography", *International Journal of Remote Sensing*, **28**, 1503-1526.

Feng, S., Hu, Q. and Qian, W., 2004, "Quality control of daily meteorological data in China, 1951-2000, a new dataset", *International Journal of Climatology*, **24**, 853-870.

Gupta, H. V., Sorooshian, S. and Yapo, P. O., 1999, "Status of automatic calibration for hydrologic models, Comparison with multilevel expert calibration", *Journal of Hydrologic Engineering*, **4**, 135-143.

Heidinger, H., Yarleque, C. and Posadas, A., 2012, "TRMM rainfall correction over the Andean Plateau using wavelet multi-resolution analysis", *International Journal of Remote Sensing*, **33**, 4583-4602.

Hu, R., 2004, "Physical geography of the Tianshan mountains in China". *Beijing, China Environmental Science Press* (in Chinese).

Huffman, G. J., Bolvin, D. T. and Nelkin, E. J., 2007, "The TRMM multisatellite precipitation analysis (TMPA), Quasi-global, multiyear, combined-sensor precipitation estimates at fine scales", *Journal of Hydrometeorology*, **8**, 38-55.

Jaagus, J., 2009, "Regionalisation of the precipitation pattern in the Baltic Sea drainage basin and its dependence on large-scale atmospheric circulation", *Boreal Environment Research*, **14**, 31-44.

Karaseva, M. O., Prakash, S. and Gairola, R. M., 2011, "Validation of high-resolution TRMM-3B43 precipitation product using rain gauge measurements over Kyrgyzstan", *Theoretical and Applied Climatology*, **108**, 147-157.

Kidd, C. and Levizzani, V., 2011, "Status of satellite precipitation retrievals", *Hydrology and Earth System Sciences*, **15**, 1109-1116.

Krishnamurti, T. N., Mishra, A. K., Simon, A. and Yataga, A., 2009, "Use of a dense rain-gauge network over India for improving blended TRMM products and downscaled weather models", *Journal of the Meteorological Society of Japan*, **87**, 393-412.

Kummerow, C., Barnes, W. and Kozu, T., 1998, "The tropical rainfall measuring mission (TRMM) sensor package", *Journal of Atmospheric and Oceanic Technology*, **15**, 809-817.

Li, L., Hong, Y. and Wang, J., 2008, "Evaluation of the real-time TRMM-based multi-satellite precipitation analysis for an operational flood prediction system in Nzoia Basin, Lake Victoria, Africa", *Natural Hazards*, **50**, 109-123.

Li, X. H., Zhang, Q. and Xu, C. Y., 2012, "Suitability of the TRMM satellite rainfalls in driving a distributed hydrological model for water balance computations in Xinjiang catchment, Poyang lake basin", *Journal of Hydrology*, **426-427**, 28-38.

Liew, M. W., Van, J. G., Arnold, D. and Bosch, D., 2005, "Problems and potential of autocalibraring a hydrological model", *Transactions of the ASAE*, **48**, p16.

Mair, A. and Fares, A., 2011, "Comparison of Rainfall Interpolation Methods in a Mountainous Region of a Tropical Island", *Journal of Hydrologic Engineering*, **16**, 371-383.

Menne, M. J., Imke, D. and Russell, S. V., 2012, "An Overview of the Global Historical Climatology Network-Daily Database", *Journal of Atmospheric and Oceanic Technology*, **29**, 897-910.

Min, S. K., Zhang, X. and Zwiers, F. W., 2011, "Human contribution to more-intense precipitation extremes", *Nature*, **470**, 378-81.

Moriasi, D. N., Arnold, J. G. and Van Liew, M. W., 2007, "Model evaluation guidelines for systematic quantification of accuracy in watershed simulations", *Transactions of the ASABE*, **50**, 885-900.

Peterson, T. C., Zhang, X. and Brunet-India, M., 2008, "Changes in North American extremes derived from daily weather data", *Journal of Geophysical Research-All Series*, **113**, p7113.

Robinson, M., Kulie, M. S. and Silberstein, D. S., 2000, "Evolving improvements to TRMM ground validation rainfall estimates", *Physics and Chemistry of the Earth Part B-Hydrology Oceans and Atmosphere*, **25**, 971-976.

Sandoval, M., 2007, "Spatial and temporal rainfall gauge data analysis and validation with TRMM microwave radiometer surface rainfall retrievals", International Institute for Geo-Information Science and Earth Observation (ITC), Enschede, The Netherlands.

Scheel, M. L. M., Rohrer, M. and Huggel, C., 2011, "Evaluation of TRMM Multi-satellite Precipitation Analysis (TMPA) performance in the Central Andes region and its dependency on spatial and temporal resolution", *Hydrology and Earth System Sciences*, **15**, 2649-2663.

Tarnavsky, E., Mulligan, M. and Husak, G., 2012, "Spatial disaggregation and intensity correction of TRMM-based rainfall time series for hydrological applications in dryland catchments", *Hydrological Sciences Journal-Journal Des Sciences Hydrologiques*, **57**, 248-264.

Van, L. M., Arnold, J. and Garbrecht, J., 2003, "Hydrologic simulation on agricultural watersheds, choosing between two models", *Transactions of the ASAE*, **46**, 1539-1551.

Vila, D. A., De Goncalves, L. G. G. and Toll, D. L., 2009, "Statistical Evaluation of Combined Daily Gauge Observations and Rainfall Satellite Estimates over Continental South America", *Journal of Hydrometeorology*, **10**, 533-543.

Villarini, G. and Krajewski, W. F., 2007, "Evaluation of the research version TMPA three-hourly 0.25 degrees × 0.25 degrees rainfall estimates over Oklahoma", *Geophysical Research Letters*, **34**, L05402.

Yao T., Thompson, L. and Yang, W., 2012, "Different glacier status with atmospheric circulations in Tibetan Plateau and surroundings", *Nature Climate Change*, **2**, 663-667.