Adaptability evaluation of TRMM over the Tianshan Mountains in central Asia

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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].
which has made 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 (Boich, 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
| Station     | R    | R²   | 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   |
| Qitaif     | 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   |
| Baybalk    | 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   |
| Xiaoungzi  | 0.84 | 0.71 | 9.58 | 51.00     | y = 0.37x + 5.53   |
| Zhaoou     | 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    |
| Qiiaoting  | 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   |
| Baltang    | 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   |
| Caijiabu   | 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   |
| Chuoamaohu | 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 (R²), root mean square error (RMSE) and percent bias (PBAIS) 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 PBAIS 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 (R²) 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 TRMM 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 PBAIS 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 PBAIS all show that the accuracy of TRMM 3B43 V7 is better during warm season than that during cold season.
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 classified 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
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...
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.

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