

Evaluation of TRMM Precipitation Product for Meteorological Drought Monitoring in Hai Basin

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Abstract. Due to spatial coverage, data availability and cost efficiency, this paper focused on studying the potential to apply the satellite rainfall product to monitor meteorological drought. Standard Precipitation Index (SPI) is widely used around the world for research and operational applications on meteorological and agricultural drought monitoring and early warning. SPI was designed to be calculated for any location that has a long-term precipitation record. Therefore, the accuracy of monthly precipitation data of TRMM (the Tropical Rainfall Measurement Mission) 3B43, was firstly investigated through comparison with rainfall data of forty ground stations in Hai Basin from 1998 to 2010. The significant correlations between the two sources were found during different durations of months, seasons and years, and the decision coefficients (R^2) are separately 0.84, 0.52-0.82 and 0.60. A single parameterized correction equation was presented to calibrate the TRMM rainfall data to formulate the series rainfall dataset of 30 year from 1981 to 2010. Based on this dataset, the corrected TRMM rainfall data from 2000 to 2004 were used to calculate Standard Precipitation Index (SPI) pixel by pixel for Hai Basin. It was found that 3-month SPI was the best to depict the meteorological drought, which agreed well with the statistical drought information from 2000 to 2004.

1. Introduction

Hai Basin is located in northeast China, between the longitudes and latitudes of 112.0° - 119.8°E and 35.0° - 42.8° N. The basin has a total area of 318,000 km². Hai Basin belongs to the temperate zone continental monsoon climate, and droughts occur frequently in the spring and winter season because about 80% of the annual precipitation concentrates in the flood season from June to September.

Traditionally, the precipitation data observed from the meteorological stations are often used for monitoring drought conditions in China. The spatial resolution of these stations is coarse so that the representative and reliability are often questioned by people. Remote sensing technology which provides spatial information becomes new source for precipitation data. TRMM (the Tropical Rainfall Measuring Mission) 3B43 monthly precipitation product has been used with good results over distinct parts of the world by e.g. [1-9], who compare or improve *on-site* rainfall land data. Zeng et al. (2011) found that TRMM 3B43 product had a higher accuracy in a monthly scale for Langcang River Basin in China [10]. Xiong *et al.* (2009) noted that the spatial interpolation of the gauge data can't reflect the spatial and temporal dynamics of rainfall over Hai basin, and found the encouraging results of using the TRMM data in basin-scale hydrology analysis in long term [11].

Standardized Precipitation Index (SPI), is widely used to monitor meteorological drought in the world [12][13][14]. The SPI, developed by McKee et al., is calculated by standardizing the probability



of observed precipitation for any duration of months or years. A probability density function and an inverse normal (Gaussian) function are applied to the long-term precipitation data. SPI is a popular index because of its simplicity and versatility. Durations of months can be used to apply the SPI for agricultural or meteorological purposes, and the longer durations can be used for hydrological and water management purposes [15].

This paper focuses on the feasibility and adaptability of using remote sensing data monitor meteorological drought. TRMM precipitation data are evaluated by comparison with rainfall data of stations. SPI results of different durations for the period from 2000 to 2004 are analyzed to find out the reasonable SPI product to depict meteorological drought.

2. Data and Methods

2.1. Data

The Version 7 Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA) products released by the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC), consists of three products at different temporal resolutions: 3-hourly (3B42), daily (3B42 derived), and monthly (3B43). The monthly precipitation data from 1998 to 2010 were processed, including format transformation from HDF to GEOTIFF, clipping and re-projection. The spatial resolution of the data is 25km*25km covering Hai Basin.

Multiyear observations of rainfall are being recorded on meteorological 40 stations in Hai Basin. The daily rainfall data for the years 1984 to 2010 are collected and accumulated to monthly data.

2.2. Method

The comparison of TRMM rainfall data with observation data was implemented. The evaluation indices include Pearson correlation coefficient (R), the coefficients of determination (R^2), the root mean square error (RMSE) and the relative error (RE). The equations for these indices are illustrated as follow.

$$R = \frac{n(\sum_{i=1}^n P_i O_i) - (\sum_{i=1}^n P_i)(\sum_{i=1}^n O_i)}{\sqrt{[n \sum_{i=1}^n P_i^2 - (\sum_{i=1}^n P_i)^2][n \sum_{i=1}^n O_i^2 - (\sum_{i=1}^n O_i)^2]}} \quad (1)$$

$$R^2 = \frac{[\sum_{i=1}^n (P_i - \bar{P})(O_i - \bar{O})]^2}{\sum_{i=1}^n (P_i - \bar{P})^2 (O_i - \bar{O})^2} \quad (2)$$

$$RMSE = \sqrt{\frac{1}{n} \times \sum_{i=1}^n (P_i - O_i)^2} \quad (3)$$

$$RE = \frac{\sum_{i=1}^n (P_i - O_i)}{\sum_{i=1}^n O_i} * 100\% \quad (4)$$

Where, P_i is the TRMM rainfall at month i , O_i is the *on-site* rainfall at month i , \bar{P} is the average TRMM rainfall, \bar{O} is the average *on-site* rainfall, n is sample numbers.

The Multiyear observations of rainfall are being recorded on forty meteorological stations in Hai Basin. The daily rainfall data for the years 1984 to 2010 are collected and accumulated to monthly data.

The inverse distance weighting method (IDW) was used to produce the grid monthly SPI result from *on-site* SPI data.

3. Comparison of TRMM and Observation Rainfall Data

In order to compare TRMM rainfall (3B43 product) and *on-site* rainfall data, the evaluation indices for different durations of rainfall were calculated (Table 1).

Table1. Statistics of TRMM rainfall and *on-site* rainfall data

Durations	R	R ²	RMSE	RE
Annual	0.773	0.60	96.26	0.07
Spring	0.828	0.68	24.20	0.08
Summer	0.721	0.52	74.72	0.05
Autumn	0.904	0.82	26.01	0.10
Winter	0.816	0.67	9.46	0.41
Month	0.914	0.84	631.54	0.82

Correlation coefficients are mostly significant ($\alpha = 0.001$) with better values in Hai Basin for different durations. The coefficients of determination results showed the similar information. It indicated that the change trends of TRMM rainfall data for different durations agreed well with observation data and TRMM monthly rainfall product can be used to depict the process of drought.

The evaluation indices of RMSE and RE showed significant differences for different durations. The RMSE and RE of monthly rainfall data were not well if the difference of seasons was ignored. It would draw the conclusion that TRMM data was not feasible to monitor drought. However, the indices of four seasons provided new information. The RMSE values in spring, autumn and winter were relatively lower. The overestimation of TRMM rainfall data were found in summer and this condition may be caused by the high intensity storms and high frequency rain. The relative error value of the winter season was showed highest than other three seasons, and this condition was caused by the lower rainfall. The statistics of rainfall from two sources showed TRMM data had a higher R², lower RMSE and RE in spring and autumn. Droughts were easy to occur in the winter and spring season for Hai Basin according to the historical records. It indicated that the monthly TRMM rainfall data can be applied to monitor drought for spring season.

4. Meteorological Drought Result and Analysis

4.1. TRMM-based SPI Results in Hai Basin

The long time series rainfall data was firstly required for application of SPI algorithm on TRMM rainfall dataset. Wu et al. [16] reported that the SPI was strongly influenced by record length, and the minimum precipitation record for SPI was 30 years. Based on the correlation analysis result of TRMM data and observation data, linear regression equations were built to calibrate TRMM data for all stations. Hereafter, the observation rainfall data from 1980 to 1997 was interpolated using IDW method to produce the comparable dataset with corrected TRMM dataset from 1998 to 2010.

According to the statistical drought data, the five years from 2000 to 2004 were chosen to analyse the drought change. The SPI for the time period of 1-month, 3-month, 6-month, 9-month, 12-month and 24-month intervals were calculated from 2000 to 2004. Figure 1 showed the change process of these results for Hai Basin. SPI classification was used for different time periods: -0.5 is the threshold of mild drought and normal; -1.0 is the threshold of moderate drought and severe drought, and -1.5 is the threshold of severe drought and extreme drought [12].

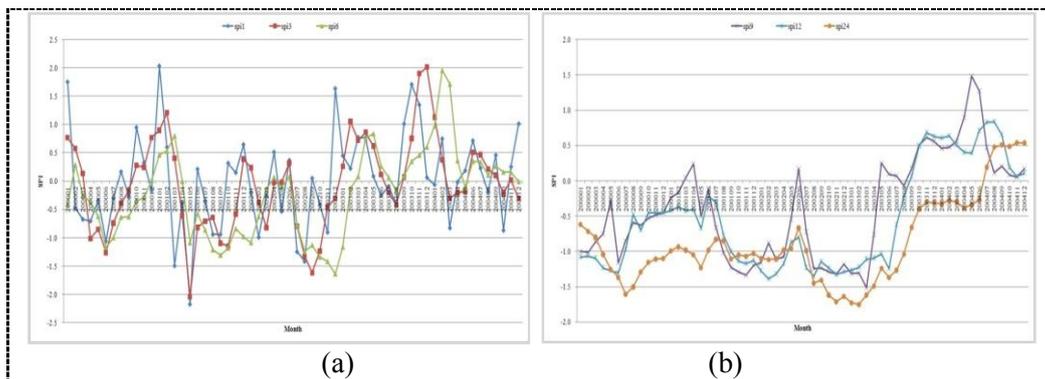


Figure 1. SPI of different durations from 2000 to 2004 for Hai Basin.(a) are the SPI change curves for the time period of 1-month, 3-month and 6-month; (b) are the SPI change curves for the time period of 9-month, 12-month and 24-month;

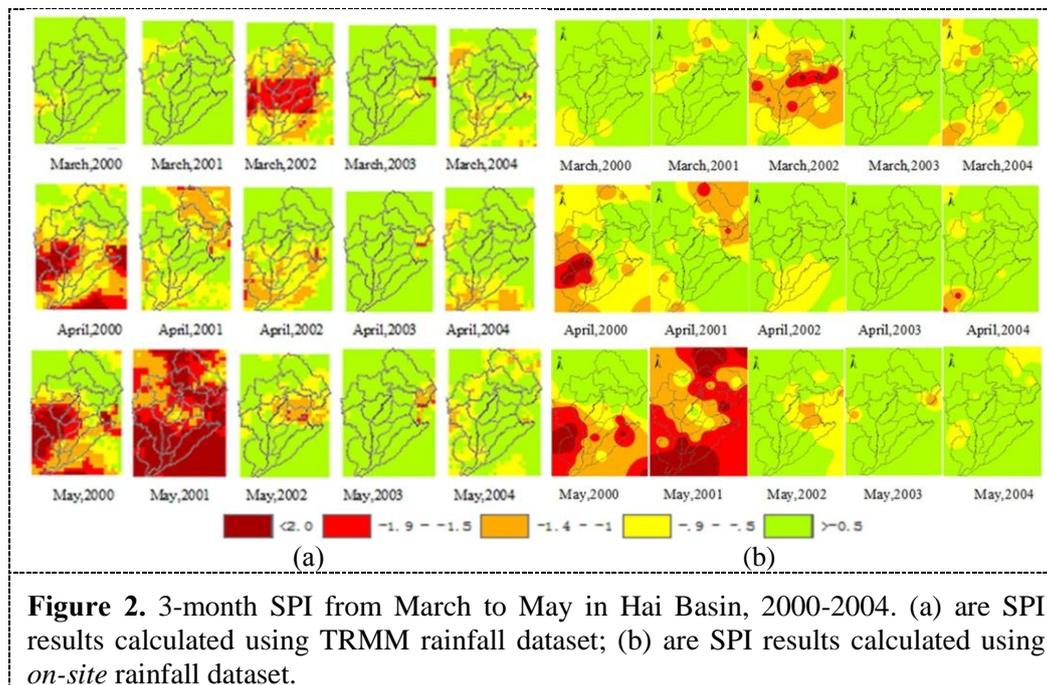
24-month SPI result showed that drought occurred from January of 2000 to September of 2003, and severe drought was detected during the period from October of 2002 to April of 2003; 12-month SPI result showed that drought occurred from January to September of 2000, and August of 2001 to July of 2003, and no severe drought was detected; 9-month SPI result showed that drought occurred from January to April of 2000, June to October of 2000, July 2001 to May 2002, July of 2002 to April of 2003, and no severe drought was detected; 6-month SPI result showed that drought occurred from May to September of 2000, May of 2001 to February of 2002, July of 2002 to January of 2003, and severe drought was detected in December of 2002; 3-month SPI result showed that drought occurred from April to July of 2000, April to November of 2001, March of 2002, July to October of 2002, and severe drought was detected in May of 2001 and September of 2002; 1-month SPI result showed that drought occurred from March to June of 2000, March, May, August and September in 2001, February, July, August and November in 2002, and March of 2004, and severe drought was detected in May of 2001. From above analysis SPI changes for periods were significantly different. 1-month SPI variance was the most violent due to the strong influence of monthly rainfall, and contrarily 24-month SPI was the most gentle because the drought was impacted by the previous total precipitation. Compared with the historical recorded drought data, the drought occurrence expressed by 3-month SPI was most consistent than SPI result of other periods. Therefore, 3-month SPI was best to depict drought for Hai Basin.

4.2. Comparison of 3-month SPI of two sources

In order to compare the TRMM-based SPI and *on-site* SPI, the series precipitation dataset from 1980 to 2010 were also applied to calculate 3-month SPI for 40 stations, and then interpolated to grid results.

According to the records, the period from March to May for the years from 2000 to 2004 was the high-incidence season, Figure 2 showed the spatial maps of two sources. Whenever March, April, or May for five years was, the drought maps from two sources showed the high consistency. The result based on TRMM data showed the smooth transition, while the result based on *on-site* rainfall data showed the mutation feature.

The average SPI for the months from March to May was stated for water resource districts. Eight water resources districts belong to the plain area and the other seven districts belong to the mountain area. The correlation analysis method was used to analyze the relations between TRMM-based SPI and SPI data calculated using *on-site* rainfall data for the plain and mountain areas. The results showed that R of SPI values from two sources are 0.93 in the plain area ($\alpha=0.05$, $n=40$) for three months, and 0.94 for March, 0.95 for April and 0.97 for May respectively ($\alpha=0.05$, $n=35$) in the mountain area. It indicated that the SPI calculated using TRMM had good relations with the SPI using *on-site* rainfall data in spatial and temporal scales. It can be concluded that monthly TRMM rainfall data can be a replaceable data source of *on-site* rainfall data to calculate SPI, and then monitor drought.



5. Conclusions

The rainfall data from 40 meteorological stations were used to evaluate the accuracy of monthly precipitation data of TRMM 3B43. The four evaluation indices were used for the comparisons of monthly rainfall data from 1998 to 2010. The result showed that the significant correlations between the two sources were found during different durations of months, seasons and years. The decision coefficient (R^2) for months is 0.84, while the RMSE and RE are relatively lower. The results showed that RMSE values in the spring, autumn and winter were lower, and RE values in the spring, summer and autumn seasons was lower. It can be concluded that the involvement of rainfall data in summer and winter made the lower RMSE and RE for month.

The linear regression equations for forty stations were used to correct the TRMM rainfall data in order to be comparable with *on-site* rainfall data for Hai Basin. To formulate the series rainfall dataset of 30 year from 1981 to 2010, the grid rainfall data before 1998 was generated using *on-site* data. This paper didn't focus on the interpolation method, so the common interpolation method-IDW was used, and other method may be considered such as Kriging, Taison polygon method to meet the requirement of study.

SPI was calculated from TRMM rainfall data for different durations. The result was found that 3-month SPI was the best to depict the meteorological drought, which agreed well with the statistical drought information from 2000 to 2004. The 3-month SPI was accordance with the interpolation result based on the *on-site* SPI. The correlation results of SPI in the water resource districts of Hai Basin showed that the good relationships between the two source. TRMM rainfall data was a replaceable data source to calculate SPI and monitor drought for Hai Basin.

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