Spatio-Temporal Analysis of Precipitation Patterns in Xinjiang Using TRMM Data and Spatial Interpolation Methods: A Comparative Study

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Abstract : In the context of global warming, changes in precipitation patterns and the increase in extreme weather events have had a serious impact on regional development. In order to grasp the temporal and spatial distribution characteristics and trend changes of precipitation in Xinjiang, this paper uses TRMM3B43v7 data to interpolate with radial basis function method, inverse distance weighting method, ordinary kriging method and ANUSPLIN interpolation method, and uses evaluation indicators to determine the best interpolation method. The results show that the applicability of TRMM data in Xinjiang is good, but it is overestimated, and the average monthly scale is 1.30mm higher. Precipitation in Xinjiang is mainly concentrated in the north of the Tianshan Mountains, and less in the south. From 1998 to 2019, the precipitation trend in Xinjiang showed an increasing trend, with more than 63.64% of the total area of Xinjiang showing an increasing trend, and the western region showed a significant increase, while the eastern region showed a slight decreasing trend.

Keywords: TRMM; spatiotemporal variation of precipitation; Interpolation; Xinjiang

1. Introduction

According to the sixth report of the IPCC, the global average precipitation and evaporation are increasing with the global surface warming, and the tropical rain belt is moving in a polar direction, and extreme weather events are frequent [1,2]. Changes in precipitation patterns will have a serious impact on regional water resources, agriculture, ecology and urban development. Therefore, it is of great significance to grasp the spatial and temporal distribution characteristics and trends of regional precipitation.

At present, the main sources of precipitation data are ground-based rain gauges, radar, and satellite observations [3]. However, in some remote areas, due to environmental constraints, it is not possible to establish extensive and uniformly distributed ground observation stations, and satellite precipitation data can provide reliable precipitation reference values for these areas [4]. Satellite precipitation data are

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often biased, and precipitation interpolation can improve the accuracy of the data. At present, many scholars have adopted the method of multi-satellite precipitation data fusion to improve the accuracy and resolution of satellite precipitation data, such as Shen Zhehui [5] to study the applicability of precipitation data from different satellites in Chinese mainland. Lang Lichen [6] studied the interpolation reliability of MPRISM considering multiple terrain features. Bian Wei [7] compared the applicability of TRMM (The Tropical Rainfall Measuring Mission) and GLDAS data in the southern slope of the Tianshan Mountains in Xinjiang, and the results showed that the overall performance of TRMM data was better. Wei Linyong [8] also compared the applicability of various satellite products in different regions of China, and the results showed that the TRMM data had better performance on both monthly scale and season.

In summary, although satellite precipitation data can fill the problem of insufficient ground sites, and the use of interpolation method is conducive to improving the accuracy of satellite precipitation data, for Xinjiang region with complex terrain, the method of interpolation with TRMM data has not been studied in detail. In this paper, the optimal interpolation method is determined by comparing the four commonly used interpolation methods, and the temporal and spatial distribution and trend changes of precipitation in Xinjiang are analyzed.

2 Data and analysis

2.1 Overview of the study area and data sources

2.1.1 Overview of the study area

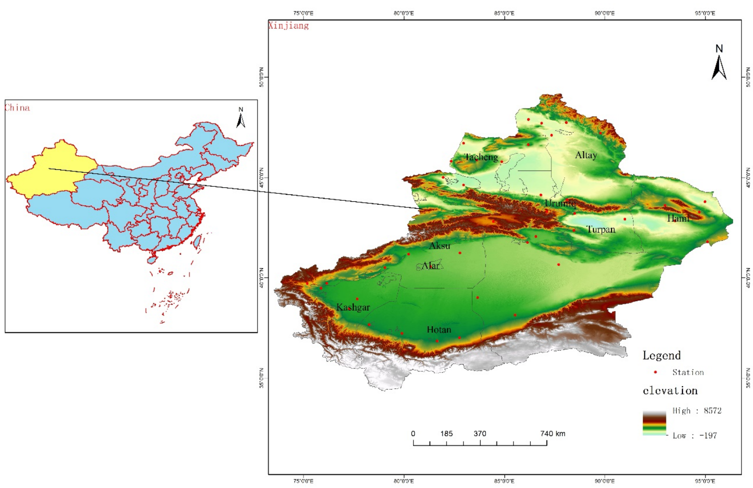

Figure 1. Location of the study area and site distribution.

The study area selected in this paper is Xinjiang Uygur Autonomous Region (73°40′-96°18′E, 34°25′-48°10′N) in the northwest border of China, with a total area of

1,660,400 square kilometers, accounting for the total land area of China1/6。 Xinjiang is located in the hinterland of the Eurasian continent, deep inland, and has a typical continental arid climate with less precipitation, with an average annual precipitation of 100 mm ~ 300 mm, mainly concentrated in summer, and due to the complex topography, the spatial distribution pattern of precipitation is extremely uneven, and the precipitation gradually decreases from northern Xinjiang to the south [9–11]. The topographic map and station distribution of Xinjiang are shown in Figure 1.

2.1.2 Data sources

The TRMM3B43_V7 used in this study was derived from NASA (National Aeronautics and Space Administration),http://www.earthdata.nasa.gov/), the precipitation product has a spatial resolution of 0.25°×0.25°, the raw data unit is mm/h, covering the global region from 50°S to 50°N. The data of 42 national reference stations and ground stations are from the China Meteorological Data Sharing Service Center (http://cdc.cma.gov.cn). The time range of the study area data is from January 1998 to December 2019, and the distribution of sites is shown in Figure 1 above

2.2 Research methodology

2.2.1 Spatial interpolation and evaluation indicators

In order to obtain information on the spatial distribution of precipitation in a large area, spatial interpolation of precipitation has become an important means for the change of precipitation pattern in the study area [12,13]. Through spatial interpolation, the measurement data of discrete points can be transformed into a continuous data surface to better understand and predict precipitation distribution and change trends. In this paper, four precipitation interpolation methods are selected to interpolate and compare the TRMM data.

The radial basis function method (RBF) is based on the method of radial basis function, and the commonly used radial basis functions include Gaussian function, multiple Gaussian function, multiple cubic function, etc. This method has certain adaptability to areas with uneven distribution of observation points and complex topography, and the expression formula is described in Ref. [14].

Inverse Distance Weighting (IDW), one of the most common interpolation methods, is based on the principle of similarity, i.e. the closer you are to the interpolation point, the greater the weight. It is more suitable for mountainous areas or areas with low concentration of precipitation stations, but the influence of topography is not taken into account, and the expression formula is described in Ref. [15].

Ordinary Kriging (OK), which is a statistically based interpolation method, has good applicability to the amount of change that satisfies the second-order stationarity hypothesis. The advantages are that the spatial autocorrelation is considered, the interpolation accuracy is high, and the smoothness of the interpolation results can be adjusted, and the expression formula is described in Ref. [16].

ANUSPLIN, an interpolation method developed by scholars at the Australian National University, is based on the theory of thin disk splines, which allows the introduction of linear covariate submodels in addition to the usual spline independent variables, and the expression formula is described in Ref. [17] [18].

Firstly, the accuracy of the TRMM data was verified, and the correlation coefficient R, the determinism coefficient R2 and the root mean square error RMSE, as well as the mean deviation MBE and the relative deviation BIAS were used to evaluate the TRMM data. The above evaluation indicators were used to compare and evaluate the results of the interpolation method. The expression formulas for each evaluation index are described in Ref. [19,20].

2.2.2 Theil-Sen Median slope estimation and Mann-Kendall trend analysis

In this study, the Theil-Sen median trend method combined with Mann-Kendall trend analysis (M-K test) was used to visualize the spatial variation trend of annual precipitation in Xinjiang. The Theil-Sen median trend method is often used in conjunction with the M-K test to detect trends in long-term series data. The median ß , the test statistic Z are used to determine the trend change of precipitation, and the detailed formula is described in Ref. [21–24].

Using a two-sided trend test, given the significance level a=0.05, when the absolute values of Z are greater than 1.65 , 1.96, and 2.58 , the trends passed the significance tests with 90%, 95%, and 99% reliability, respectively, test criteria are shown in Table 1.

Table 1. Trend checklist.

Classification criteria	Trend characteristics
$ß>0$ and $2.58<Z$	Extremely significant increase
$ß>0$ and $1.96<Z\leq2.58$	Significant increase
$ß>0$ and $1.65<Z\leq1.96$	A slightly significant increase
$ß>0$ and $Z\leq1.65$	No significant increase
$ß = 0$ and $Z = 0$	No change
$ß<0$ and $Z\leq1.65$	No significant reduction
$ß<0$ and $1.65<Z\leq1.96$	Slightly significantly reduced

ß<0 and 1.96<Z≤2.58	Significantly reduced
ß<0 and 2.58<Z	Dramatically reduced

3 Results and Analysis

3.1 TRMM Data Accuracy Validation Analysis

The measured precipitation data provided by 42 meteorological stations in Xinjiang were used to verify the accuracy of TRMM precipitation data, and the monthly average precipitation of 42 stations was used as the verified data value due to the large amount of data. The measured data measured by each meteorological station were used as the independent variable, and the TRMM data was used as the dependent variable for univariate linear fitting (as shown in Figure 2).

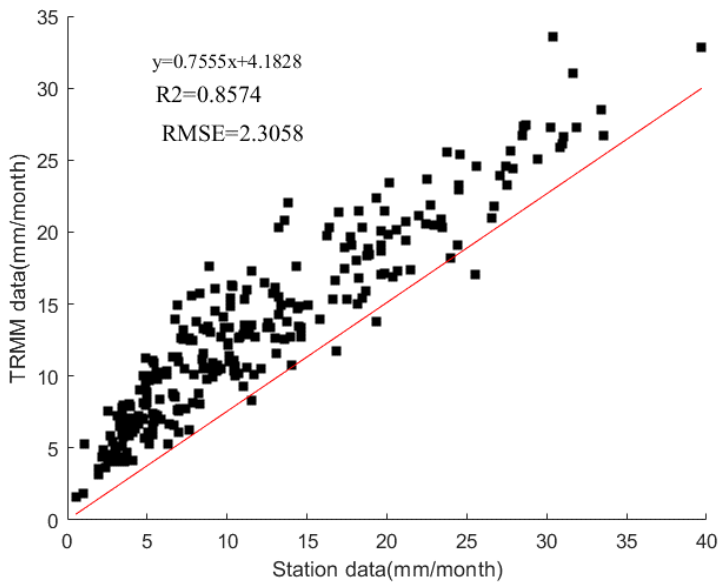

Figure 2. Comparison of site-measured precipitation data with TRMM precipitation data.

It can be seen from Figure 2 that on the monthly scale, the goodness-of-fit R2 between the TRMM data and the station data is 0.8574, but the scatter points are mainly concentrated above the regression fitting line, indicating that the TRMM data overestimate the precipitation in Xinjiang. The average monthly deviation MBE is about 1.30mm, i.e. the TRMM data is 1.30mm higher on a monthly scale. The Pearson correlation coefficient R is 0.9356, which proves that the TRMM data has a high correlation with the precipitation data measured by surface stations in Xinjiang, indicating that the TRMM data are sufficient for statistics and analysis.

3.2 Comparison of Four Interpolation Methods Based on Precipitation Data

Firstly, ArcGIS 10.7 software was used to analyze four kinds of precipitation data, and then the interpolation accuracy was evaluated by ANUSPLIN4.4 software for ANUSPIN interpolation. In this paper, the TRMM precipitation data in Xinjiang from 1998 to 2019 were summarized as the average annual precipitation and the average precipitation of each month, and the spatial interpolation analysis was carried out to obtain the spatial interpolation accuracy evaluation table for each year and each month, and the results are shown in Table 2 and Table3：:

Table 2. Assessment of spatial interpolation accuracy for mean annual precipitation.

Evaluation coefficient	RBF	IDW	OK	ANUSPLIN
R^2	0.5957	0.6146	0.6064	0.4923
RMSE	74.89	76.75	75.73	86.31
MBE	15.58	9.77	15.60	15.57
BIAS	7.92%	7.47%	7.52%	8.03%

Table 3. Assessment of spatial interpolation accuracy for monthly mean precipitation.

Evaluation coefficient	RBF	IDW	OK	ANUSPLIN
R^2	0.6141	0.6146	0.6115	0.4907
RMSE	6.248	6.250	6.270	7.178
MBE	1.303	1.299	1.300	1.436
BIAS	7.48%	7.48%	7.48%	8.26%

Considering R2, RMSE, MBE and BIAS, the four interpolation methods are combined with TRMMTHE ACCURACY PRIORITY AFTER DATA COMBINATION AND INTERPOLATION IS: IDW>OK>RBF>ANUSPLIN. In addition, the spatial distribution of precipitation obtained by the four interpolation methods, this paper takes the average precipitation of each month as an example to show the interpolation effect of the spatial interpolation method in Xinjiang, and the results are shown in Figure 3.

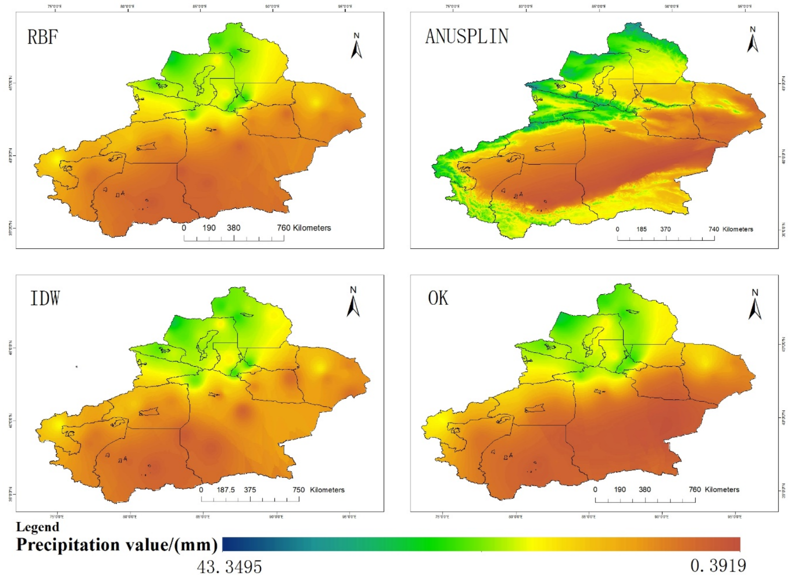

Figure 3. Spatial interpolation of monthly average precipitation.

Both Tables 2 and 3 show that inverse distance-weighted interpolation of IDW has the highest coefficient of certainty and the smallest mean deviation, making it the most suitable of the four methods for interpolation in combination with TRMM data. Among them, the RMSE and MBE of the annual average precipitation interpolation accuracy evaluation are higher than the monthly average precipitation interpolation accuracy, which proves that the monthly average precipitation interpolation has higher interpolation accuracy. In addition, compared with the spatial interpolation maps, RBF interpolation, IDW interpolation and OK interpolation all showed the spatial precipitation distribution characteristics of high and low in northern Xinjiang, while ANUSPLIN interpolation not only showed high precipitation in northern Xinjiang, but also showed slightly higher precipitation in southern Xinjiang, mainly in the inner basin of Xinjiang and eastern Xinjiang.

3.3 Characteristics of Spatial and Temporal Distribution

3.3.1 Spatial Distribution characteristics

Precipitation in Xinjiang gradually decreased from north to south (Figure 4). The annual precipitation is roughly in the range of 10-350mm, and the precipitation is seriously insufficient, which is a typical arid zone. The precipitation in northern Xinjiang is mainly concentrated in Tacheng, Altay and Urumqi. The eastern part of Xinjiang has the second highest precipitation, while the southern part of Xinjiang is severely drought, with an average annual precipitation of less than 100 mm. Due to the blocking of water vapor from the northwestern mouth of Xinjiang, precipitation is higher below the northern slope of the Tianshan Mountains, such as in Urumqi, while the southern slope is in a dry state. Also due to the topography is the concentration of precipitation in the northernmost region of Altay.

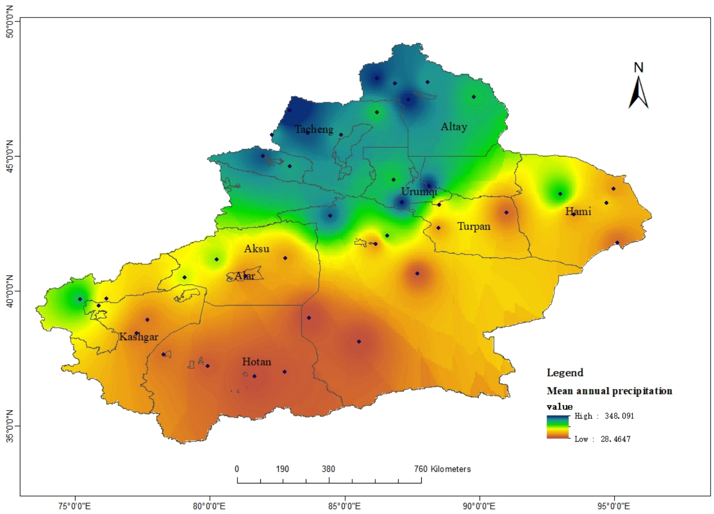

Figure 4. 1998-2019 average precipitation map for xinjiang region.

3.3.2 Interannual Precipitation Distribution Characteristics

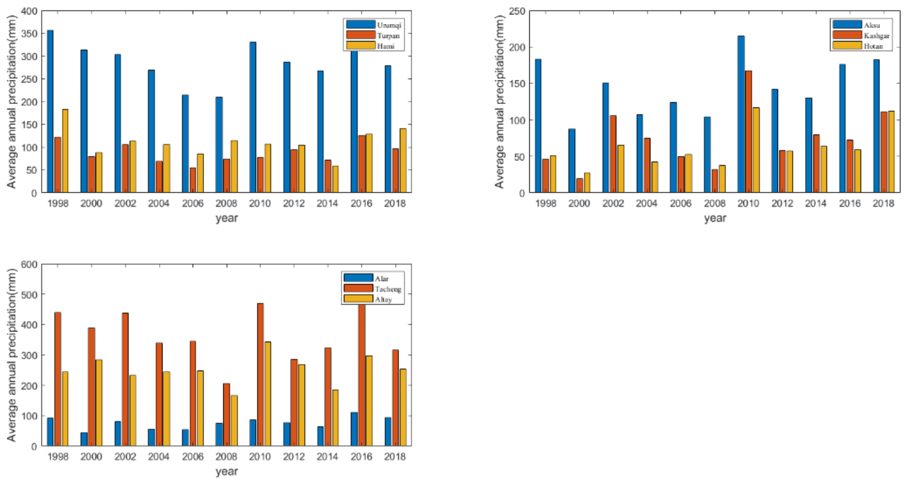

Figure 5. 1998-2019 precipitation changes in Xinjiang region.

In this paper, the distribution characteristics of interannual precipitation in Xinjiang from 1998 to 2019 were analyzed, and the histograms of annual precipitation in nine municipal areas of Xinjiang were obtained, and the results are shown in Figure 5. It can be seen from the figure that the annual precipitation in Xinjiang has a certain fluctuation law, which generally changes in a wave-like manner. /b14>From 1998 to 2019, the annual precipitation in Xinjiang was generally on an increasing trend, for example, the annual precipitation in Aksu, Kashgar, Hotan and Alar areas increased significantly. Overall, the increase trend was most pronounced in 2015 and 2016.

3.3.3 Characteristics of Monthly Seasonal Precipitation Distribution

Distribution of seasonal precipitation in Xinjiang (from December to February of the following year, March to May in spring, June to August in summer, and September to November in autumn) in Xinjiang) As shown in Figure 6, precipitation in Xinjiang is mainly concentrated in summer, followed by spring, and the least in autumn and winter, and summer precipitation accounts for 39% of the annual precipitation. For example, the summer precipitation in Urumqi can reach up to 127.36mm, while the winter precipitation is only 33.11mm. Xinjiang is rich in summer precipitation resources, which is a valuable season for water reserves in Xinjiang.

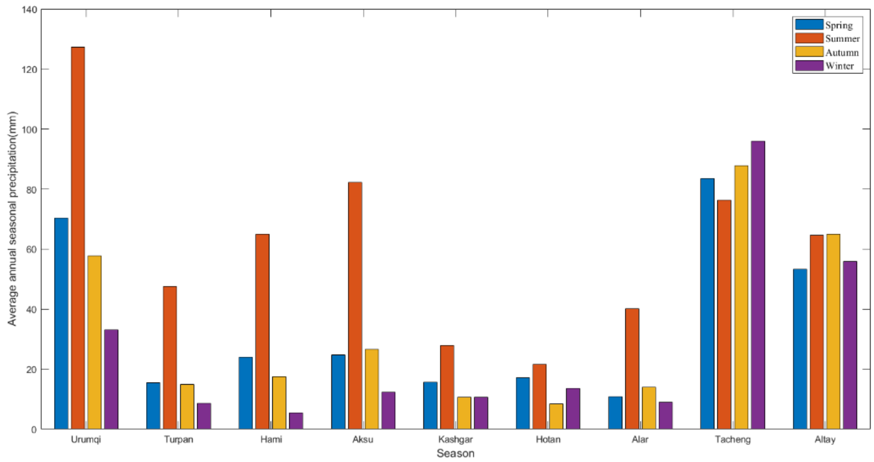

Figure 6. Seasonal precipitation variation in Xinjiang region, 1998-2019.

As can be seen from Figure 7, the most precipitation months in Xinjiang are concentrated in June, July and August, while the least precipitation months are in March, October and December. This corresponds to the above-mentioned seasons with the highest precipitation in summer and the least in autumn and winter. Urumqi, Turpan and Hami all have high peaks of precipitation in November, December and January, and their precipitation is relatively concentrated in summer and winter.

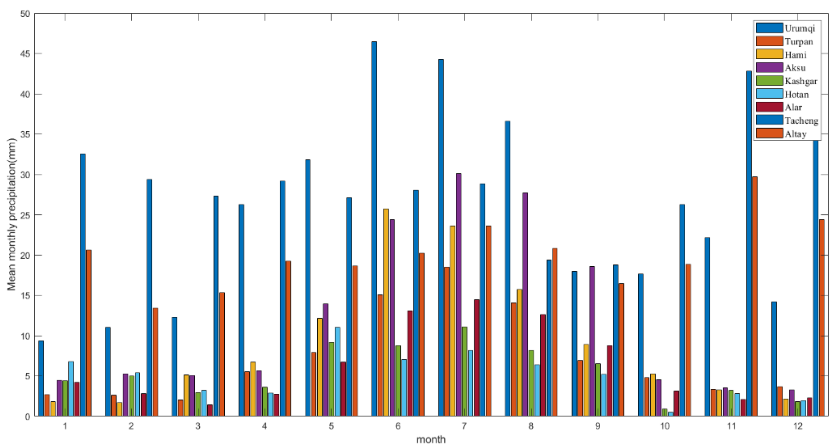

Figure 7. Monthly precipitation variations in prefecture-level cities of Xinjiang region, 1998-2019.

3.4 Results of the characterization of the spatial variability of annual precipitation

In this paper, the annual precipitation data of the processed TRMM were used to analyze the trend and significance of annual precipitation in Xinjiang by combining Theil-Sen median trend analysis and Mann-Kendall test MATLAB software, and the results are shown in Figure 8.

From 1998 to 2019, the annual precipitation in Xinjiang mainly showed an increasing trend. More than 63.64% of the total area of Xinjiang showed an increasing trend, of which 2.22% was extremely significant and 20.87% was significantly increased, mainly distributed in Alar, Aksu, Tacheng and Kashgar. The areas with reduced precipitation accounted for 36.36% of the total area of Xinjiang, of which only 1.30% were slightly or significantly reduced, and most of the areas showing a decrease were in a non-significant decreasing trend.

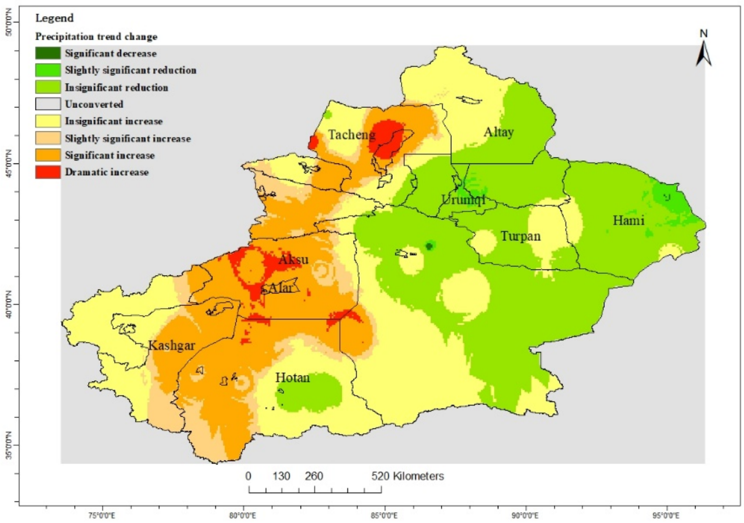

Figure 8. Maps of sudden change analysis of annual precipitation.

4 Conclusion

In this study, the TRMM data were selected to comprehensively study the spatial and temporal distribution characteristics and trends of precipitation in Xinjiang, and four interpolation methods were evaluated, so as to select the most suitable method for precipitation interpolation in Xinjiang. The results of the study show that:

(1) The applicability of TRMM data in Xinjiang is good, although the precipitation value in Xinjiang is overestimated in general, and it is speculated that the reason may be that the TRMM satellite altitude is high, and some small precipitation events may be missed, and other non-precipitation clouds and fog are also included in the precipitation. This leads to overestimation.

(2) The spatial distribution of precipitation in Xinjiang is mainly more in the north and less in the south, and the precipitation in the northern region is mainly due to the influence of water vapor from the Atlantic Ocean and the Arctic Ocean, and due to the obstruction of the Tianshan Mountains and the Altai Mountains, some topographic rain is formed, but it also makes it difficult for water vapor to enter the southern part of Xinjiang, and because the southern region is deep inland, and there is also the blocking of water vapor from the Indian Ocean by the Himalayas. Therefore, the precipitation in the southern region is low.

(3) The trend characteristics of annual precipitation in Xinjiang generally showed an increasing trend, and the precipitation showed an increasing trend mainly in the western part of Xinjiang, while the precipitation in the eastern part showed a slight decreasing trend. Geographical location and topographical factors are the main reasons for this result. In addition, due to climate change, global warming has accelerated glacial meltwater, and precipitation and evaporation have become more intense, and ice and snow meltwater from the Qinghai-Tibet Plateau may have an impact on precipitation changes in western Xinjiang.

In summary, with the continuous improvement of the accuracy and resolution of satellite precipitation data, the role of satellite precipitation data in the field of climate research will play an important role in the future, including the improvement of monitoring accuracy, the vertical structure analysis of precipitation, and the monitoring and early warning of severe precipitation.

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