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Research Article

Drought Risk Assessment in Yunnan Province of China Based on Wavelet Analysis

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A wavelet transform technique was used to analyze the precipitation data for nearly 60 years (1954–2012) in Yunnan Province of China. The wavelet coefficients and the variance yield of wavelet were calculated. The results showed that, in nearly 60 years, the spring precipitation increased slightly; however, the linear trend of other seasonal and annual precipitations showed a reducing trend. Seasonal and annual precipitation had the characteristics of multiple time scales. Different time scales showed the different cyclic alternating patterns. Overall, in the next period of time, different seasons and the annual precipitation will be in the periods of precipitation-reduced oscillation; high drought disaster risks may occur in Yunnan province. Particularly, by analyzing large area of severe drought of Yunnan province in 2009–2012, the predicted results of wavelet were verified. The results may provide a scientific basis for guiding agricultural production and the drought prevention work for Yunnan Province and other places of China.

1. Introduction

China is a typical monsoon climate country and is an agricultural country. The instability of monsoon climate leads to frequent flood and drought, causing 55% of total natural disasters loss in China [1, 2]. Drought has become the key obstacle factor constraining China's agriculture and sustainable development. During the last decade, the severe drought in southwest China has resulted in tremendous losses, including crop failure, a lack of drinking water, and ecosystem destruction [3]. From July 2009, Yunnan Province of China has been hit with the worst droughts in a century. The drought has affected about 2.1 million hectares of farmland or about 85 percent of wheat producing areas of Yunnan province until March 2010 [4]. From 2009 to 2012, Yunnan province has suffered a continuous severe drought. Most parts of China's Yunnan Province have been gripped by drought since early December 2011 as rainfall has been 50%–80% less than the long-term average [5]. Some attempts have been made to explore the causes and variability of drought in southwest China [6–10]. However, it is unclear and even disputable as to what and how precipitations and circulation oscillation patterns affect the drought risk.

Droughts are caused by a depletion of precipitation over time [11]. It is well known that precipitation is one of the most important aspects related to climate change and, in recent years, droughts and also floods have been experienced with higher peaks and severity levels [12]. The wavelet transform is a mathematical tool that provides a time scale representation of a signal in the time domain [13]. It could be applied to meteorological data to bring up distinct patterns that might be hidden within the original data [14]. It also could be used to identify the location of the mutation point in nonstationary signals. Currently, wavelet analysis research mainly focused on the multiple time scales characteristics of temperature and precipitation [15–17]: connections' definition between hydrometeorological variables [18–21], short-term climate prediction [22–24], and so on. In China, based on statistical methods, some scholars have studied the relationship between precipitation and drought in Yunnan Province [25–27].

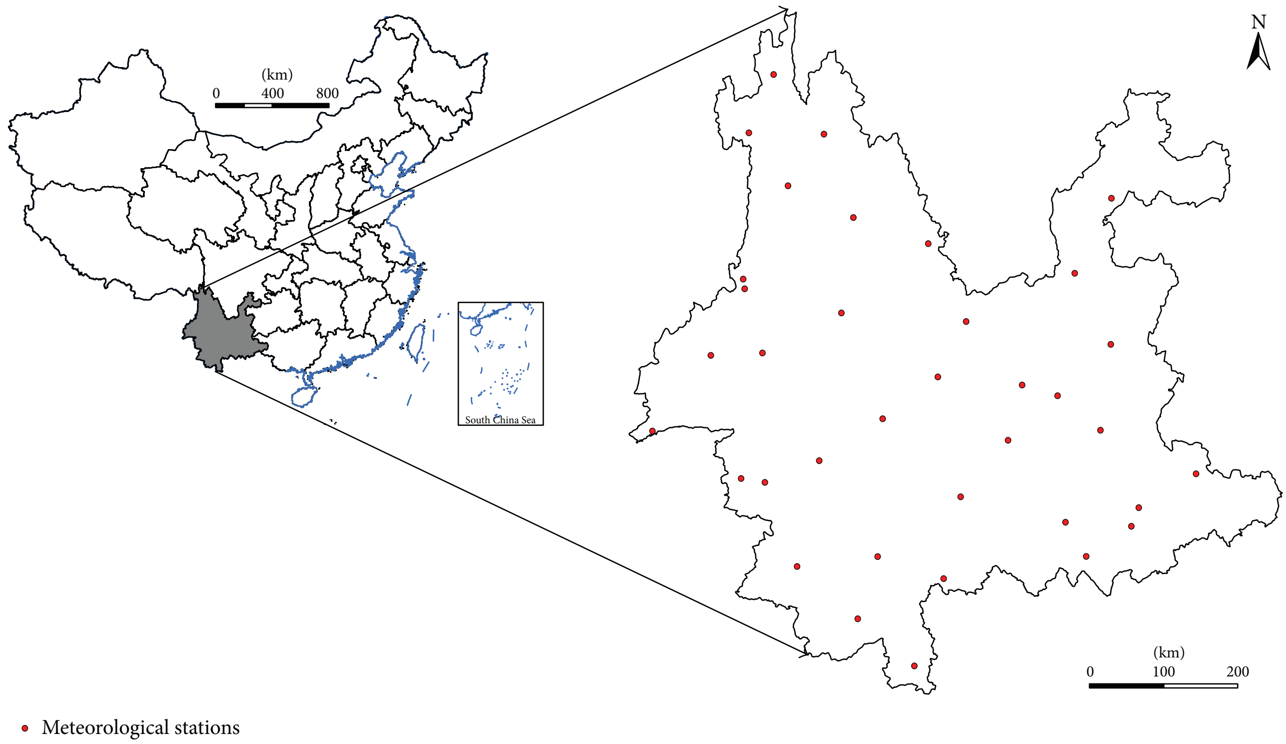


Figure 1: Study area and the distribution of meteorological stations in Yunnan Province.

The continuous wavelet analysis on Yunnan meteorological data is a new research for studying periodicities and long-term variability. Different temporal levels of precipitation (such as the seasonal and annual levels) in the structure and characteristics of abnormal variation should be revealed. In this study, based on Yunnan meteorological data, the precipitation characteristics in long-term drought and interdecadal changes were analyzed. Decreasing trends found in previous studies of precipitation were also clarified by using wavelet transforms. The objective of this study is twofold: (1) to explore the periodical fluctuations and the relationship between precipitation and drought risk in Yunnan Province and (2) to predict the seasonal precipitation in Yunnan Province and the trend of the annual precipitation. The results from this study will be of important reference value and significance to understand the precipitations characteristics, agricultural production, and the drought prevention work in Yunnan Province.

2. Data and Methods

2.1. Study Area. Yunnan, located in the southwest China (Figure 1), has a vast territory, magnificent mountains and rivers, and abundant natural resources. With an area of 390,000 square kilometers, Yunnan is the eighth largest province in China. It is an inland province, with Guizhou Province and Guangxi Zhuang Autonomous Region in the east, Tibet Autonomous Region in the northwest, and the Qinghai-Tibet Plateau in the southwest. The regional climate is classified as subtropical monsoonal, with annual average precipitation of 1100 mm and mean annual temperature between 5°C and 24°C from north to south.

Daily precipitation records of 36 stations in Yunnan Province from 1954 to 2012 were provided by the National Climate Centre of China Meteorological Administration (CMA). Based on the daily records, we calculated annual, monthly, and seasonal data series to assess responses of precipitation to drought disaster. We use the wavelet transform technique to analyze the precipitation data for nearly 60 years in Yunnan Province. The wavelet coefficients and the variance yield of wavelet were calculated to study the characteristics of abnormal variation. From the precipitation-reduced oscillation information, we can judge the trend of precipitation in different seasons and local drought disaster may occur in some areas.

2.2. Methods. The wavelet transform is a useful mathematical tool that can provide information about both time and frequency simultaneously and enable a separation to be made between features associated with different characteristic length scales, so they have some advantages over traditional Fourier transforms. At present, there are a large number of wavelet transforms available for various applications. In this study, we selected the Morlet wavelet [28] to analyze the multiple time scales inherent in our data series; it is a complex nonorthogonal continuous wavelet; the basis of a Morlet wavelet (ψ) consisting of a plane wave modulated by a Gaussian function can be defined as

$$\psi(\eta) = \pi^{-1/4} e^{i\omega\eta - \eta^2/2}, \quad (1)$$

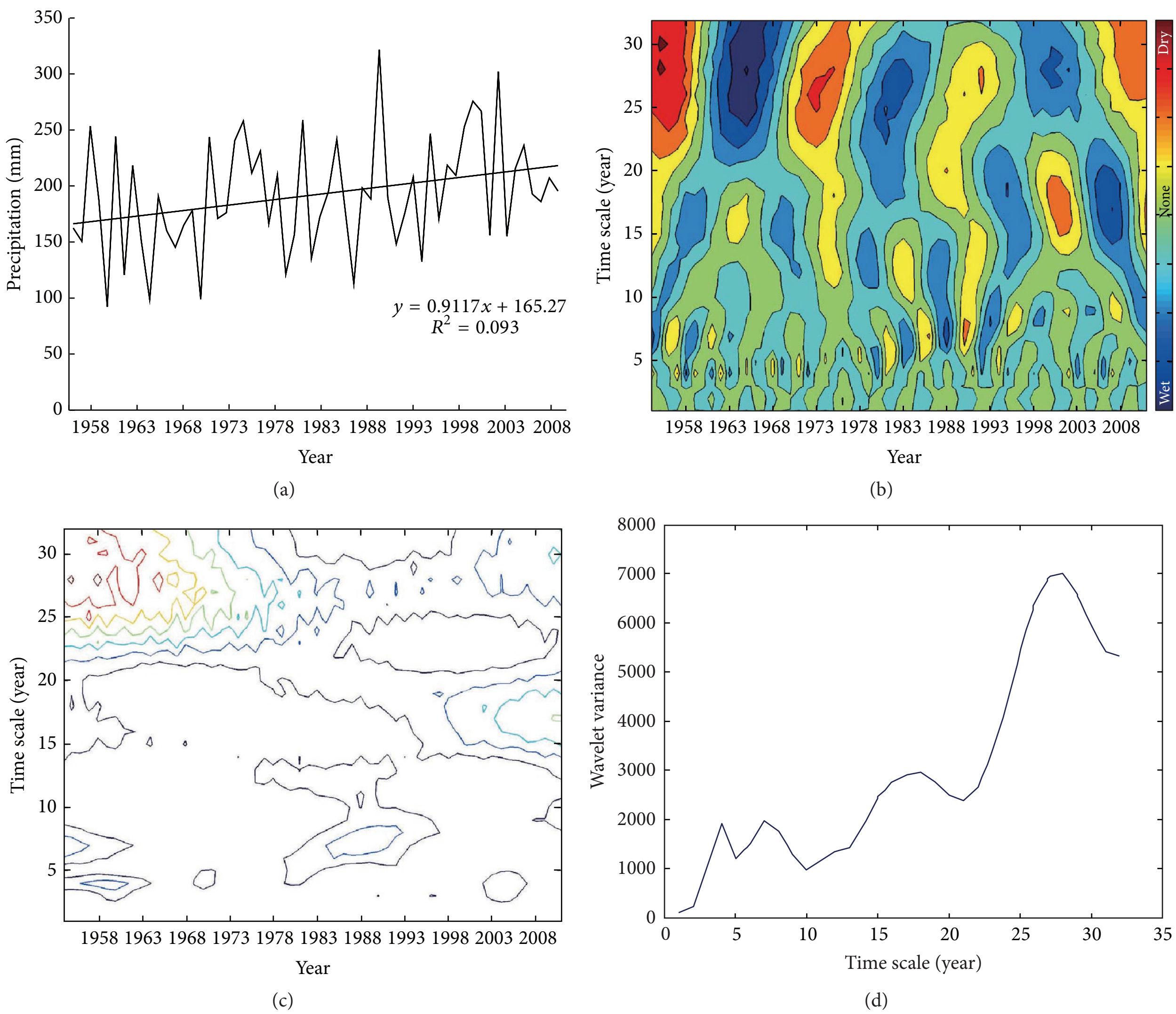


FIGURE 2: (a) Spring precipitation interannual change of Yunnan. (b) Spring precipitation wavelet transform of Yunnan. (c) Spring precipitation wavelet coefficients contour of Yunnan. (d) Spring precipitation wavelet variance of Yunnan.

where ω is the dimensionless frequency and η is the dimensionless time parameter. The continuous wavelet transform (CWT) has an ability to detect significant cycles and their occurrence time in the observation period. The CWT is defined as

$$W(a,b) = \frac{1}{\sqrt{a}} \int f(t) \cdot \psi^{*} \left(\frac{t-b}{a}\right) dt, \quad (2)$$

where a and b are scale and translation parameters, respectively, and ψ^{*} is the complex conjugate of ψ.

The wavelet variance ($W(a)$) used to detect the main periods contributing to a signal can be expressed as

$$W(a) = \frac{1}{\sqrt{a}} \int \left|W_x(b,a)\right|^2 db. \quad (3)$$

Since the precipitation data sets used in this paper are of finite length and the Morlet wavelet is not completely localized in time, errors will occur at the beginning and at the end of the wavelet power spectrum. To reduce the edge effects, we carried out a symmetry extension at both ends of the precipitation time series before undertaking the wavelet transform and then removed them.

3. Results and Analysis

3.1. Analysis of Spring Precipitation Variation Characteristics. As seen from Figure 2(a), the spring precipitation of Yunnan Province presented an upward trend in recent 60 years. The annual precipitation increased in the linear inclined rate which was 9.117 mm/10 years, but in recent five years it presented a downward trend. Figure 2(b) showed that a periodic oscillation is obvious under the scale of 18 years. With the increase of time scale, above the scale of 18 years, a gentle periodic oscillation was indicated for 7 cycles. Until year 2012, the contours of decreased precipitation were still not closed, indicating that spring drought may occur within the next

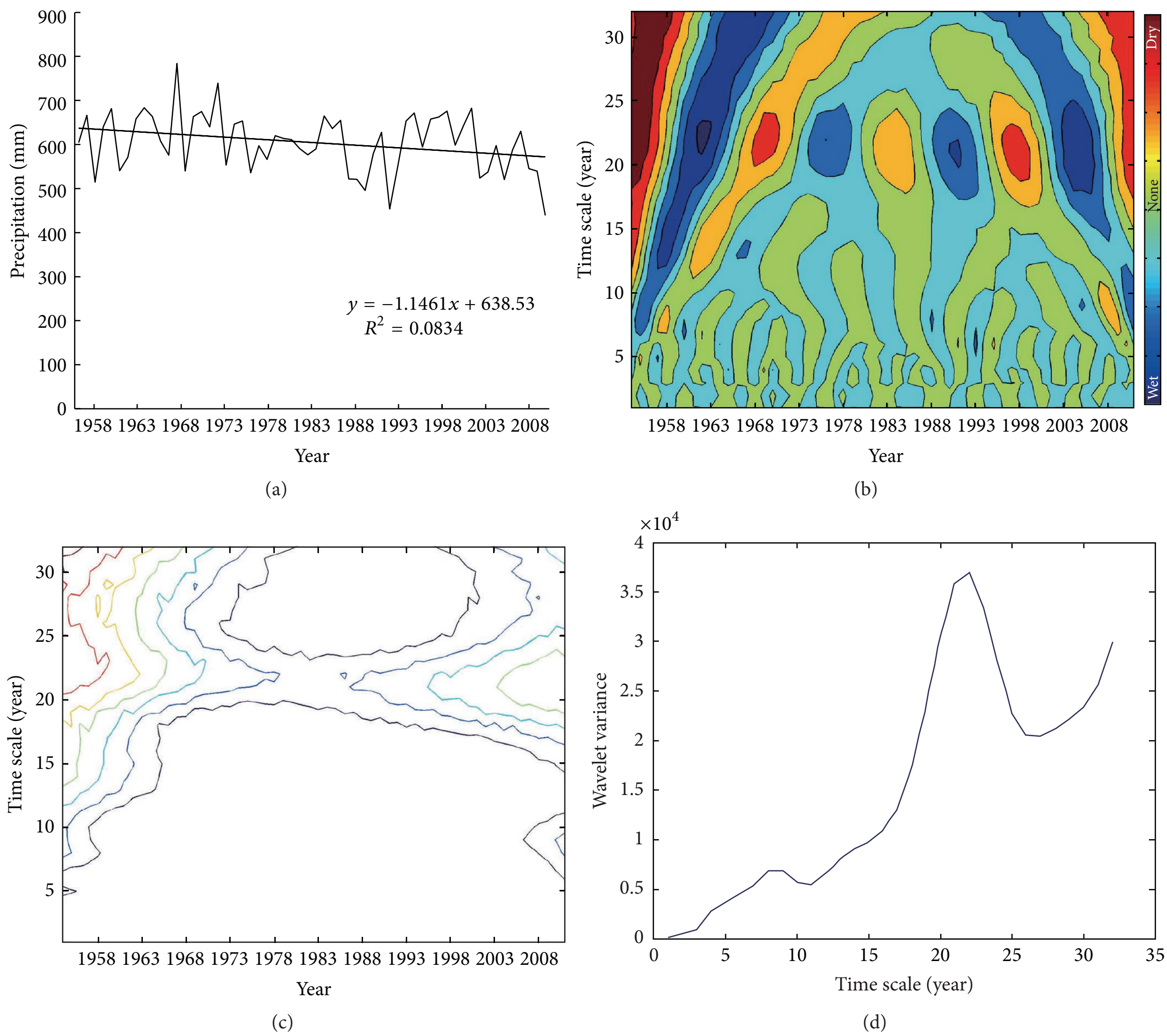


Figure 3: (a) Summer precipitation interannual change of Yunnan. (b) Summer precipitation wavelet transform of Yunnan. (c) Summer precipitation wavelet coefficients contour of Yunnan. (d) Summer precipitation wavelet variance of Yunnan.

few years. The fact of spring Yunnan drought event in 2009, 2011, and 2012 has proved the results of the analysis. From Figure 2(c) we can see that a precipitation wavelet energy spectrum is strong at time scale of 25~32 years, but the cycle changes have a localization characteristic (before 1980). The wavelet energy spectrum is weaker at time scale of 10~22 years, but more obvious cycle distribution occupies the entire study time domain (1954~2012). Figure 2(d) showed that wavelet variance of spring rainfall has four peaks, corresponding to time scales of 28 years, 18 years, 7 years, and 4 years (correlation coefficient is 0.82 and coefficient is significant at 0.05 level). The largest peak value corresponds to the time scale of 28 years indicating that the period oscillation of 28 years fluctuated most; it could be considered as the first major period in spring precipitation change.

3.2. Analysis of Summer Precipitation Variation Characteristics. From Figure 3(a) we can see that the summer precipitation of Yunnan Province presented a downward trend in recent 60 years. The annual precipitation decreased in the linear inclined rate which was −11.461 mm/10 years. Figure 3(b) showed that a periodic oscillation is gentle at the scale of above 22 years; the regular pattern is obvious. Until 2012, the contour of decreased precipitation has not closed, indicating that summer drought may continue to occur. As seen from Figure 3(c), we can see that a precipitation wavelet energy spectrum is strong at time scale of 20~32 years, but the cycle changes have a localization characteristic (before 1970). The wavelet energy spectrum is weaker at time scale of 6~18 years, but more obvious cycle distribution occupies the entire study time domain (1954~2012). Figure 3(d) showed that wavelet variance of summer rainfall has two peaks, corresponding to time scales of 22 years and 8 years (correlation coefficient is 0.85 and coefficient is significant at 0.05 level).

3.3. Analysis of Autumn Precipitation Variation Characteristics. From Figure 4(a) we can see that the autumn precipitation of Yunnan Province presented a nondistinct fluctuation

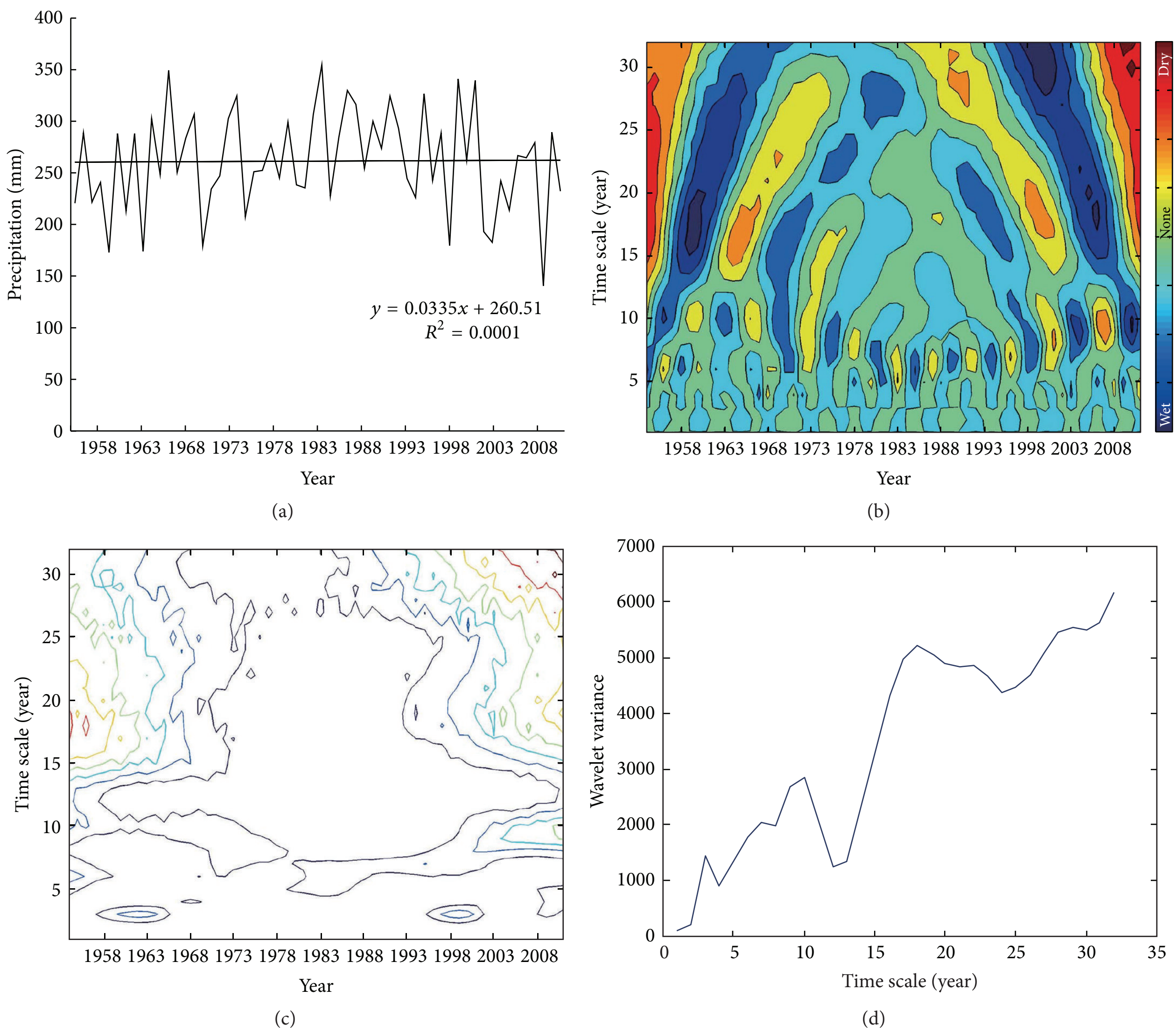


FIGURE 4: (a) Autumn precipitation interannual change of Yunnan. (b) Autumn precipitation wavelet transform of Yunnan. (c) Autumn precipitation wavelet coefficients contour of Yunnan. (d) Autumn precipitation wavelet variance of Yunnan.

in general. The linear inclined rate was 0.335 mm/10 years. Figure 4(b) showed that a periodic oscillation is obvious under the scale of 15 years, performing no obvious law. With the increase of time scale, above the scale of 15 years, a gentle periodic oscillation was distinct and represented 7 cycles. Precipitation was relatively more in the period of 1970–2000. Autumn rainfall went into the dry season after 2003. The year of 2012 located in the middle of reduction period of oscillation; autumn drought may continue within the next few years. From Figure 4(c) we can see that a precipitation wavelet energy spectrum is strong at time scale of 15~32 years, but the cycle changes have a localization characteristic (before 1960 and after 2000). The wavelet energy spectrum is weaker at time scale of 8~13 years, but more obvious cycle distribution occupies the entire study time domain (1954~2012). Figure 4(d) showed that wavelet variance of autumn rainfall has three peaks, corresponding to time scales of 18 years, 10 years, and 3 years (correlation coefficient is 0.90 and coefficient is significant at 0.05 level).

3.4. Analysis of Winter Precipitation Variation Characteristics. Figure 5(a) showed that the winter precipitation of Yunnan Province presented a little downward trend in recent 60 years. The annual precipitation decreased in the linear inclined rate which was −0.929 mm/10 years. Figure 5(b) showed that a periodic oscillation is obvious under the scale of 17 years. With the increase of time scale, above the scale of 17 years, a gentle periodic oscillation represented 10 cycles. Until 2012, the contour of increased precipitation has not closed, indicating that the trend of precipitation increase in winter will continue within the next few years. From Figure 5(c) we can see that a precipitation wavelet energy spectrum is strong at time scale of 15~20 years, but the cycle changes have a localization characteristic (1985–1995). The wavelet energy spectrum is

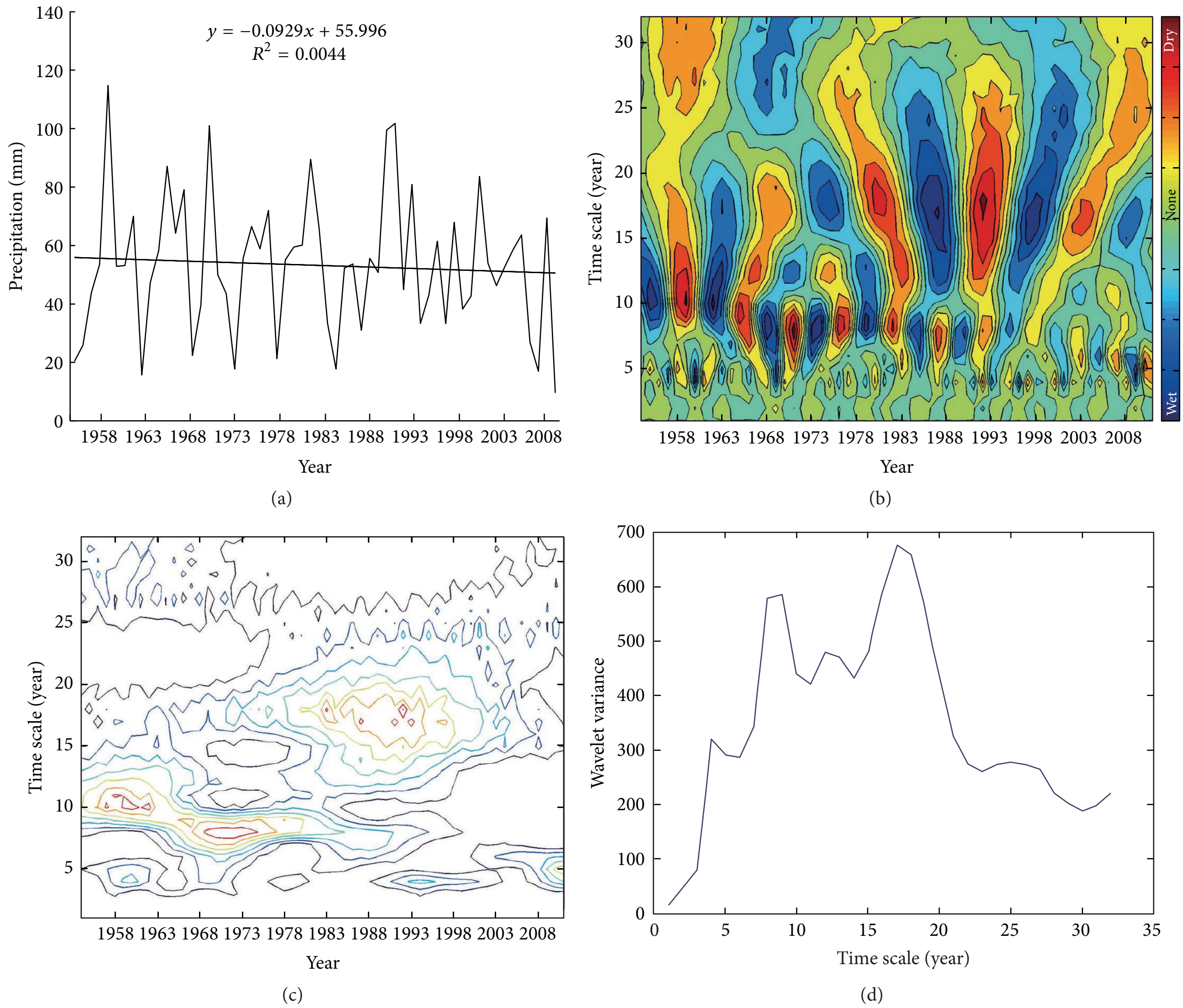


Figure 5: (a) Winter precipitation interannual change of Yunnan. (b) Winter precipitation wavelet transform of Yunnan. (c) Winter precipitation wavelet coefficients contour of Yunnan. (d) Winter precipitation wavelet variance of Yunnan.

weaker at time scale of 10~22 years, but more obvious cycle distribution occupies the entire study time domain (1954~2012). Figure 5(d) showed that wavelet variance of winter rainfall has three peaks, corresponding to time scales of 17 years, 9 years, and 4 years (correlation coefficient is 0.88 and coefficient is significant at 0.05 level).

3.5. Analysis of Annual Precipitation Variation Characteristics. Figure 6(a) showed that the annual precipitation of Yunnan Province presented a little downward trend in recent 60 years. The annual precipitation decreased in the linear inclined rate which was −3.323 mm/10 years. The descending trend of recent 5 years is obvious. Figure 6(b) showed that a periodic oscillation has a nondistinct law under the scale of 22 years. With the increase of time scale, above the scale of 22 years, a gentle periodic oscillation represented 7 cycles. The year of 2012 located in the middle of reduction period of oscillation; annual precipitation reduction may continue within the next few years. From Figure 6(c) we can see that a precipitation wavelet energy spectrum is strong at time scale of 20~32 years but mainly before 1960. The wavelet energy spectrum is weaker at time scale of 7~22 years, but more obvious cycle distribution occupies the entire study time domain (1954~2012). Figure 6(d) showed that wavelet variance of annual rainfall has two peaks, corresponding to time scales of 22 years and 10 years (correlation coefficient is 0.76 and coefficient is significant at 0.05 level).

3.6. Case Verification. Water scarcity and bad water quality are the basic reasons which lead to drinking difficulties (hereafter referred to as "PDWDD"). Severe drought has led to problems of difficulty in accessing drinking water. In China,

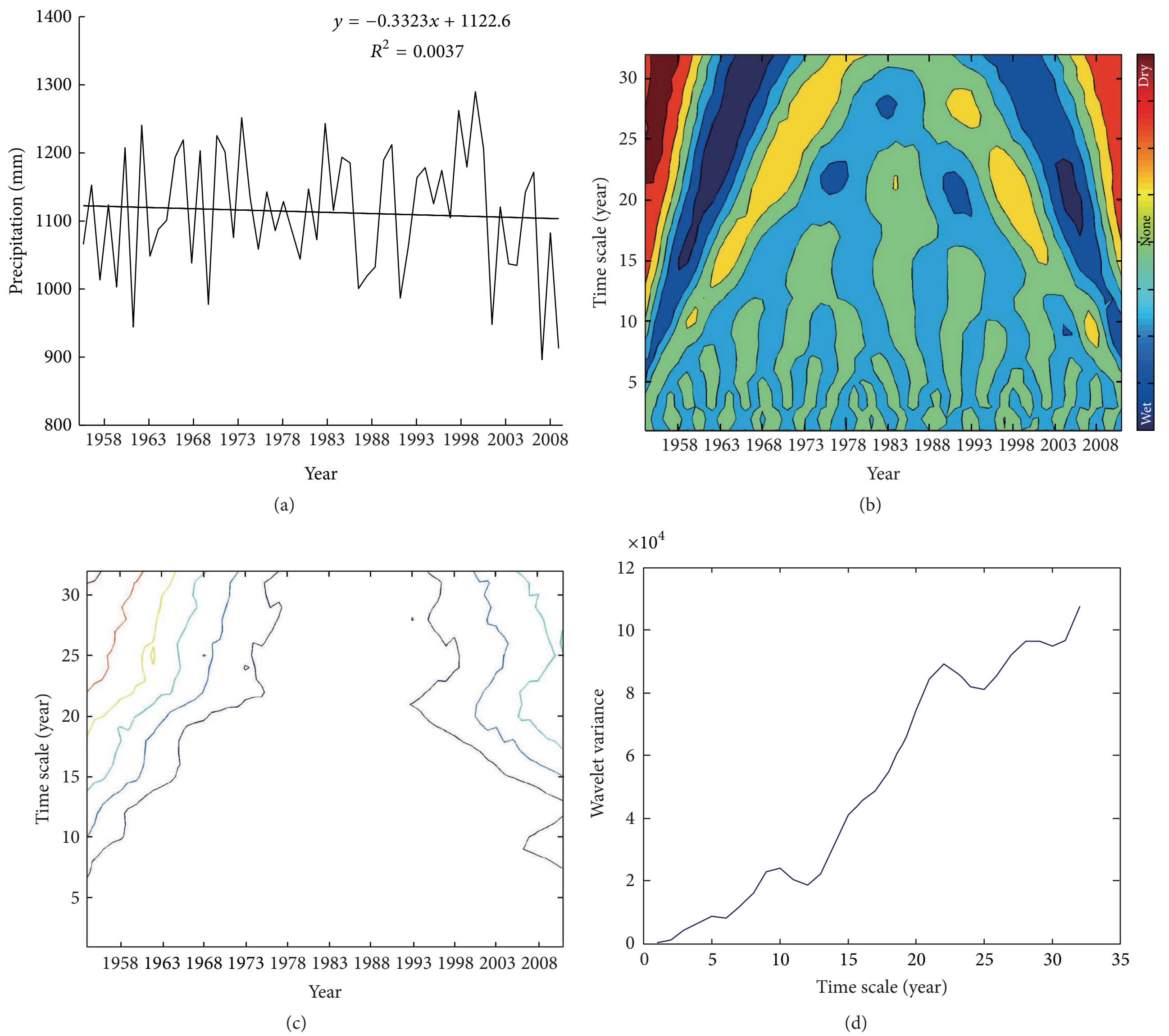


Figure 6: (a) Annual precipitation interannual change of Yunnan. (b) Annual precipitation wavelet transform of Yunnan. (c) Annual precipitation wavelet coefficients contour of Yunnan. (d) Annual precipitation wavelet variance of Yunnan.

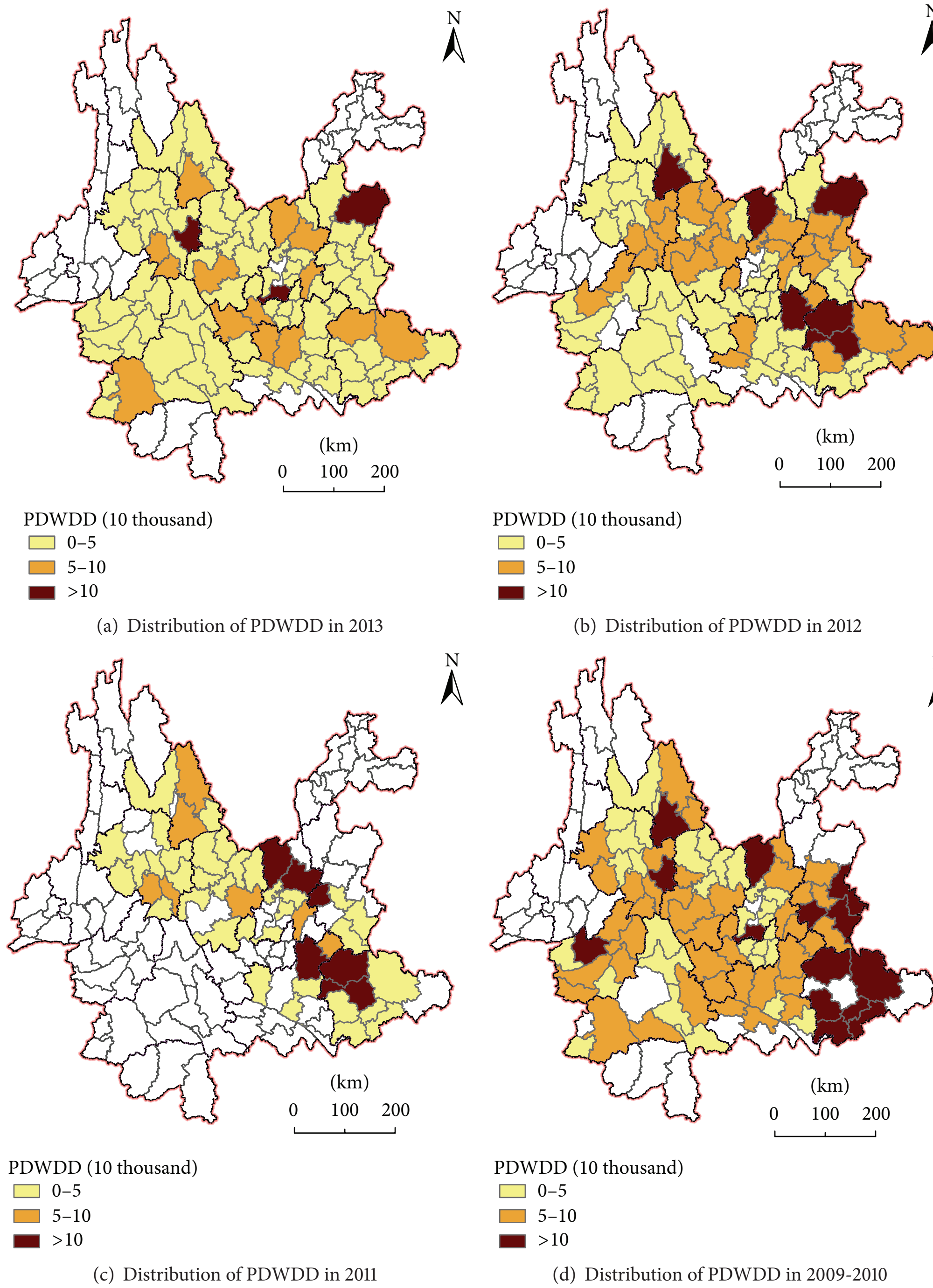
PDWDD is an important indicator of drought disaster. The reported drought disaster statistic data [29] in 2009–2013 of Yunnan province was selected as basis for a case validation.

From the point of view of meteorological precipitation statistics, since the year of 2009, drought has occurred four times in Yunnan Province [30]: from September 2009 to May 2010, across autumn, winter, and spring seasons; from June to September 2011, lasting for 4 months, from December 2011 to May 2012, lasting for 6 months, and from October 2012 to May 2013, lasting for 8 months. The four processes have significant correspondence with the four wavelet seasonal changes (Figures 7(a), 7(b), 7(c), and 7(d)).

From the perspective of disaster statistics, the four consecutive occurrences of drought, continuous heavy drought across autumn, winter, and spring seasons in 2009-2010, continuous drought from summer to autumn in 2011, continuous drought from winter to spring in 2012, and continuous drought from winter to spring in 2013, the cumulative effects of the disaster were very obvious. Under a comparative analysis of PDWDD of the four processes of Yunnan Province, the drought process in 2013 was a light drought, the counties' (cities and districts) number of heavier drinking population problems (>50,000) is 17. Respectively, it accounted for 10% and 37% of the total heavier county numbers of the 2009-2010 drought process and the 2012 drought process. Severely affected counties of PDWDD (>100,000) were least for the past four years. Currently Yunnan province is in a dry period of precipitation wavelet analysis, with the likelihood of frequent droughts occurrence being greater.

4. Conclusions

Based on the Morlet wavelet method, this paper used the precipitation data for nearly 60 years (1954–2012) to study



(a) Distribution of PDWDD in 2013

(b) Distribution of PDWDD in 2012

(c) Distribution of PDWDD in 2011

(d) Distribution of PDWDD in 2009-2010

Figure 7: Distribution of populations in drinking water access difficulties because of drought of Yunnan province in 2009–2013.

the characteristics of the periodic variation of precipitation in Yunnan Province. The results showed some conclusions which are given as follows.

In the recent 60 years, all the seasons except for spring and annual precipitation showed a decreasing trend. Seasonal and annual precipitation had a characteristic of multiple time scales. A periodic oscillation is significant at the scale of 17~28 years. Secondly, oscillations of time scale of 7~10 years are obvious. The periodic variation on a large scale contains the periodic variation on a small scale.

Wavelet and energy spectrum in summer is the closest to that of annual. It indicated that annual precipitation is mainly affected by summer precipitation. From perspective of multiple time scales, summer precipitation has a similar trend and phase to annual precipitation; that is, when there is more summer rainfall, annual precipitation is greater.

According to the main cycle of summer and the annual rainfall, precipitation of Yunnan is in the decreased oscillation period; local drought may also occur in the next future times.

Time-frequency localization properties of wavelet analysis can show the fine structure of precipitation time series not only to dig out information hidden in the sequence of periodic oscillations over time but also to determine the approximate location of the mutation point of precipitation and qualitatively estimate the time sequence evolution trend. These results can provide a new way for the analysis of multiple time scale climate variations and short-term climate prediction.

Disclosure

This work was completed in Key Laboratory of Digital Earth Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, China.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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