Wavelet analysis for seasonal precipitation variations of Yuanmou dry-hot valley in recent 50 years

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सार - हेंगडोन पर्वतों में शुष्क-गर्म घाटी एक विशेष प्रकार का गिरावटी परिस्थितिकी तंत्र क्षेत्र है। मौसमी वर्षा के परिवर्तनों से इसकी भू-भाग संरचना और कृषि क्रियाकलापों पर महत्वपूर्ण प्रभाव पड़ता है। इस शोध पत्र में 1956 से 2006 तक के मासिक और वार्षिक वर्षा आँकड़े के आधार पर मेयर वेवलेट विश्लेषण का प्रयोग करके पिछले 50a में वर्षा के मौसमी और वार्षिक परिवर्तनों की बहु समय पैमानों पर विशेषताओं का युआनमाऊ काउंटी में विश्लेषण किया गया है। वर्षा परिवर्तन का आवर्ती दोलन और विभिन्न पैमानों पर समय श्रेणियों के साथ अचानक बदलाव के बिन्दुओं को खोजा गया है और प्रत्येक श्रेणी की मुख्य अवधि की पुष्टि हुई है। यह देखा गया कि मौसमी और वार्षिक वर्षा परवर्तन के लिए 8-12a और 4-6a का आवर्ती दोलन स्पष्ट है। मेयर वेवलेट विश्लेषण के समय आवृत्ति स्थानीय परिवर्तन विशेषता वर्षा की अच्छी संरचना का प्रदर्शन कर सकते हैं और यह विधि जलवायु के बहु समय पैमानों पर विशेषताओं और लघु अवधि जलवायु के पूर्वानुमान के विश्लेषण में नया तरीका उपलब्ध कराती है। वेवलेट विश्लेषण के लिए समय आवृत्ति की स्थानीय विशेषताएं वर्षा की संरचना ब्यौरे को पदर्शित कर सकती है। वेवलेट विश्लेषण जलवायु बहु समय पैमानों पर विशेषताएं और लघु अवधि जलवायु परिवर्तनों के पूर्वानुमान के लिए एक वैकलिपक पहुँच हो सकती है। शुष्क गर्म घाटी क्षेत्र में मौसमी वर्षा का लगातार शोध कृषि पैदावार और बाढ़ रोकने में लचीलेपन के लिए अच्छे मार्गदर्शन का अभिप्राय है।

ABSTRACT. The dry-hot valley is a special kind of degradation ecosystem region in Hengduan Mountains. Variations of seasonal precipitation have important influnces on its landscape patterns and agricultural activities. Based on the monthly and annual precipitation data from 1956 to 2006, the multi-time scales characteristics of seasonal and annual variations of precipitation in the past 50a in the Yuanmou County had been analyzed using Meyer wavelet analysis in this paper. The periodic oscillation of precipitation variation and the points of abrupt change at different time scales along the time series are discovered and the main periods of every serial are confirmed. It was showed that the periodic oscillation of 8-12a and 4-6a for the seasonal and annual precipitation variation are obvious. The time-frequency local change characteristic of Meyer wavelet analysis can demonstrate the fine structures of precipitation and the method provides a new way in analyzing climate multi-time scales characteristics and forecasting short-term climate. The localization characteristics of time -frequency for wavelet analysis can demonstrate the detailed structures of rainfall. The wavelet analysis can be an alternative approach to analyze climate multi-time scales characteristics and forecast short-term climate variations. The research on the regularity of seasonal precipitation variation in the dry-hot valley region has a great guidance meaning to the agriculture production and resilience in flood prevention.

Key words – Precipitation, Wavelet transform, Yuanmou county, Wavelet variance.

1. Introduction

The dry-hot valley is a special kind of natural geography region in Hengduan Mountains. In this area, the spatial distribution and annual variations of precipitation are recognized as the significant driving forces of shaping landscape pattern characteristics of the valley and the most important limiting factors to agroforestry ecosystem productivity. The dry-hot valley has a typical non-zonal climate, not only is the precipitation variation of many years on the basis of atmospheric circulation and global climatic change background, but also it is closely related to the underlying surface changes. For the agricultural activities, the seasonal variation of precipitation is often more practical than annual variation. The dry-hot valley, as a typical

ecological degradation region and an important agricultural production base, its seasonal precipitation variation trend of time series for many years is analyzed and the driving factors are investigated. This exploration is helpful to understand the properties of underlying surface and the effect of human activities. Meanwhile, it also provides the evidence for decision making of development in cropping system, exploitation in local biological resources and promotion the ecological restoration. Furthermore, it is a scientific problem that needs to be solved when the relevant authorities formulate the regional sustainable development strategy. It is noteworthy that statistical methods for extracting oscillation period of time series have developed very rapidly for the past few years, transitioning from discrete periodogram, analysis of variance to continuous spectral analysis. However, both periodogram and variance analysis are the methods to research the periodical oscillation in the climatic series from the time domain. They have their own limitations to regard the periodicity in the climatic series as sine wave. Although the spectral analysis is a method to analyze time series in the frequency domain, such as power spectral analysis and maximum entropy spectral analysis, its application is limited because it can only reflect the average condition in the whole time domain, but cannot reflect the local multiple time scale features.

In recent years, the wavelet analysis as a new method to study the periodic phenomena and time-frequency structure analysis, its appearance brings a new leap in the technology of extracting the climatic series period. The wavelet analysis is able to reflect the local variation characteristics and it can show the location of every moment in each period. Furthermore, it not only can clearly display the implicit various periodic oscillation in the series but can reflect the trend of its variation. This is very important for analyzing the future development of series. For hydrological factors, the periodic transformation is very complicated and the variation period is not fixed. Moreover, it contains the periodic variations of various time scales in the same time interval, which displaying the multiple time scale features. Hence, the wavelet analysis becomes a very important tool to study the long-term variations of hydrological factors, which can do multi-scale refinement analysis to the function or signal series by dilation, translation and other operations with it and can research the evolution of different scales (periods) over time. In addition to multi-scale refinement analysis of signal, the wavelet analysis has the ability to diagnose the abrupt change points strictly in mathematical sense, so that it has been widely applied in the study of multi-scale analysis of climate, which has achieved very obvious results in researching the multi-scale structure and characteristics of abrupt climate variation. This provides a new method to objectively study the hierarchical structure and characteristics of climate variation.

In research on precipitation time series, the traditional methods are mostly based on statistical theory, such as conceptual model (Datta *et al.*, 1980; Barbulescu and Maftei, 2012), ESMD method (Lei *et al.*, 2016), discriminant function analysis (Aditya *et al.*, 2012), trend analysis (Varikoden, 2013), DCCA analysis (Liu *et al.*, 2017), data mining model (Meganathan and Sivaramakrishnan, 2015), self-organized criticality (Liu *et al.*, 2014a), Multifractal (Liu *et al.*, 2014b) and so on. But the statistical methods have some limitations. Especially for the precipitation in different periods, they consider them isolated and have no mutual impact and they do not take into account the underlying nonlinear effect of them. Therefore, some researchers have explored the nonlinear methods with chaos, fractal, spectral analysis, DFA, etc. and have obtained a series of achievements in recent years. For example, Kumar and Foufoular-Gegious (1993) using using Haar wavelet transform researched space and oscillation characteristics of the scale of the precipitation and the results showed that precipitation has self similarity scale and time scale of a variety of ingredients. Venugopal and Foufoula-Georgiou (1996) using wavelet packet theory was adopted to improve the precipitation of wavelet decomposition by Venckp and Foufoular-Gegious and opened a new way of precipitation formation mechanism research. Wang *et al.* (2002) summarizes the application of wavelet analysis in hydrological subject status and anticipated the future research direction. Guo *et al.* (2005) put forward the hydrological time series prediction method, based on of wavelet fuzzy neural network, forecasted the water volume for 10 years into Zhejiang's source reservoirs and its effect was good. Sang and Dong (2008) analyzed 54 wavelet of hydrology sequences of discrete wavelet transform and established the basis and method of reasonable choice of wavelet function. In the same year, Lv *et al.*, 2008 and other researchers analyzed the precipitation sequence from 1954 to 2003 in Hotan, using wavelet transform and the non-detrended fluctuation to explore the correlation of the sequence and combined with wavelet analysis to extract the precipitation of the main cycle. Sang *et al.* (2009) combined wavelet analysis, neural network and hydrological frequency analysis and set up a medium and long term hydrological forecast model. The model was then applied to the Yellow River estuary area. Compared with the traditional method, the model's forecast results are more reasonable. Zhang *et al.* (2010) applied Morlet wavelet transform, made the analysis on the Chinese mainland in recent 54 of rainfall time series, revealed the annual precipitation's time and frequency characteristics, scale and main cycles changes in different time scales.

The classical wavelet functions include Mexican Hat (Mi *et al.*, 2005), Marr (Mei and Yang, 2005), Daubechies (Partal and Kişi, 2007), Morlet (Cui *et al.*, 1998) and Meyer (Liu *et al.*, 2010). The wavelet basis function determines the wavelet self-similarity principle, discriminant function, the support length, etc.. The properties of Meyer continuous wavelet-compact support, orthogonality, infinite differentiability, etc., are more suitable to analyze the regional precipitation variation. Hence in this paper, we adopted the Meyer continuous wavelet as a new attempt to analyze the variation characteristics and regularity of the precipitation time series in the dry-hot valley of Yuanmou County, Yunnan province for the past 50a. The paper adopts wavelet analysis (wavelet analysis) method which introduces the window function on the basis of Fourier transform and contributes to the division of the time sequence into time and frequency. It is very effective to obtain a complex adjustment rule of time sequence, diagnose the internal hierarchy of climate change, determine the evolution of time series in different scale feature (Ye *et al.*, 2017). This study pinpoints the periodic characteristics and abrupt change points of the precipitation variation and reveals the precipitation structures at different levels and abnormal variation regularity. It also provides the technical support and scientific basis for research on the critical problems of water-saving agriculture such as short period of climate prediction and can further understand the impact of the global climate change on regional climate.

2.   Study area

The Yuanmou dry-hot valley is located in the north of Central Yunnan Plateau, Yunnan province, the lower reaches of Longchuan River, a tributary of the Jinsha River (Fig. 1). The range in latitude is between 25°23′ N and 26°06′ N and in longitude between 101°35′ and 102°06′ E. The central Yuanmou basin is a fault basin, the elevation of which is 980-1400 m and Longchuan River runs south to north through the basin; the eastern mountainous region is about 1200-1400 m above the basin, which descends with ladder form from the mountaintop to the basin; the western region is mostly the hills, which has round flat hilltops and long ridges in parallel arrays and the elevation of hilltops is 1300-   1500 m; the southern mountainous region has an elevation of 1400-2600 m; the northern mountainous region is over 1800m in elevation. The Yuanmou formation strata, which are widespread in the area, are divided into 4 Members and 28 Beds. And they are fluvial, limnetic and fluvial-limnetic sediments and the formation is sand, silt, clay, mild-clay and sand-gravel interbed. The lithology is loose for the strata and they are susceptible to erosion. In the region, the climate is hot and the wet and dry seasons are distinct.
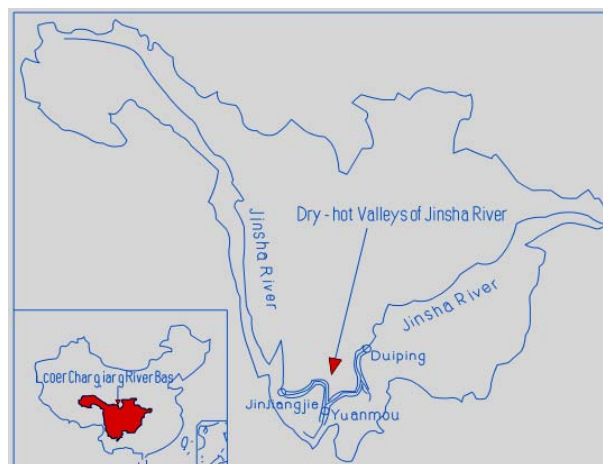

Fig. 1. The dry hot valleys area of Jinsha River and the location of Yuanmou County

The average annual temperature here is 21.9 ℃, while the average temperature in the coldest month (December) is 14.9 ℃ and the average temperature in the hottest month (May) is 27.1 ℃; the average annual precipitation is 6138 mm and the precipitation in rainy season (from May to October) accounts for more than 90% of the annual precipitation; the average annual evaporation is 3640.5 mm, which is 5.9 times the amount of average annual precipitation; the average annual relative humidity is 53%. Below the elevation of 1600 m mainly grow shrub savanna, in which herbs account for the most part with coverage more than 90% and there are very few shrubs and more rare trees; above the elevation of 1600 m mainly are shrubby grassland with small patches of forest. The zonal soil in the region is dry-red soil and red soil. Because of special geographical location and natural environment and interference of human activities, the ecosystem of dry-hot valley has degraded severely.

3.   Data and methodology

3.1. *Wavelet analysis method*

The wavelet analysis is a time-scale (time-frequency) signal analysis method developed from the beginning of 1980s, which studies the evolution of different scales (periods) over time. The method has the characteristics of good localization quality and multi-resolution analysis at both time domain and frequency domain. Wavelet analysis is based on Fourier transform by introducing window function. Based on invariance of the affine group (invariance of translation and dilation), the wavelet transform allows to decompose a time series into time and frequency contribution and it is very effective to obtain the adjustment law of a complex time series, to diagnose
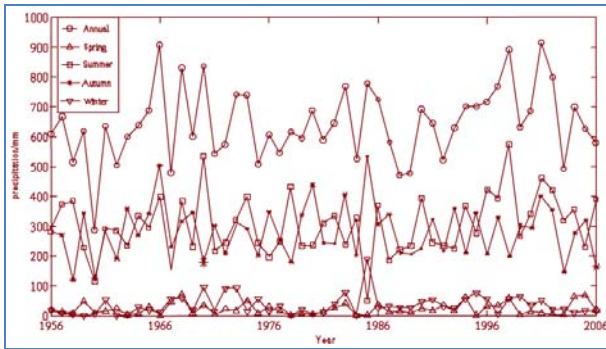
Fig. 2. Time series of annual and seasonal precipitation in Yuanmou County during 1956-2006

the internal hierarchical structure of climate variation , to distinguish the evolution characteristics of time series on different scales. So far the ideal tool of dealing with the stable and unchanging signals is also Fourier analysis. However, in actual applications, most signals are unstable and wavelet analysis is just the processing tool suitable for the unstable signals. Compared with the traditional time-frequency analysis, the wavelet analysis has the advantage of decomposing the signal at any time-frequency resolution and it also has good multi-resolution analysis capabilities as well as adaptive features. Hence, it can focus on any details, so as to observe the changes in different time scales.

If $\psi(t) \in L^2(R)$ satisfies the admissibility condition

$$C_\psi = \int_R \frac{\left|\hat{\psi}(\omega)\right|^2}{\left|\omega\right|} d\omega < \infty$$

then $\psi(t) \in L^2(R)$ is called admissibility wavelet (integral wavelet, basis wavelet), where $\hat{\psi}(\omega)$ is Fourier transform of $\psi(t)$. To dilate and translate the basis wavelet function $\psi(t)$, we obtain the continuous wavelet:

$$\psi_{a,b}(t) = \left|a\right|^{-1/2} \psi\left(\frac{t-b}{a}\right)$$

where, a, $b > R$, $a > 0$. For any function $f(t) \in L^2(R)$, the continuous wavelet transform of the admissibility wavelet function $\psi_{a,b}(t)$ is:

$$W_f(a,b) = \left\langle f(t), \psi_{a,b}(t) \right\rangle = \left|a\right|^{-1/2} \int_R f(t) \psi\left(\frac{t-b}{a}\right) dt$$

where, a is a dilation scale factor, b is a translation scale factor and $W_f(a, b)$ is called wavelet coefficient.

In this paper, the Meyer wavelet analysis method is chosen to analyze the seasonal and annual variations of precipitation in the past 50a in Yuanmou County. The Meyer continuous wavelet transform is defined in the frequency domain and its expression and auxiliary function are defined as:

$$\phi(\omega) = \begin{cases} (2\pi)^{\frac{1}{2}} e^{\frac{i\omega}{2}} \sin\left[\frac{\pi}{2} v\left(\frac{3}{2\pi}|\omega|-1\right)\right], \frac{2\pi}{3} \le |\omega| \le \frac{4\pi}{3} \\ (2\pi)^{\frac{1}{2}} e^{\frac{i\omega}{2}} \cos\left[\frac{\pi}{2} v\left(\frac{3}{4\pi}|\omega|-1\right)\right], \frac{4\pi}{3} \le |\omega| \le \frac{8\pi}{3} \\ 0, \quad |\omega| \in \left[\frac{2\pi}{3}, \frac{8\pi}{3}\right] \end{cases}$$

$$v(a) = a^4\left(35 - 84a + 70a^2 - 20a^3\right), a \in [0,1]$$

In addition, the Meyer wavelet is very smooth and has very good localization properties both in time domain and frequency domain. In order to determine the main periods of series, we can do the wavelet variance test:

$$Wp(a) = \int_R \left|W_f(a,b)\right|^2 db$$

where, $W_p(a)$ is the wavelet variance, which reflects the distribution of energy with time scale (a). It can determine the relative intensity of various scale disturbances in a time series. The main time scale of the series, identified as the scale with peak value, is used to reflect the main period of time series.

3.2. *Data source and preprocessing*

According to the precipitation information from meteorological stations in Yuanmou County, the data range was from 1956 to 2006. The seasons were divided as follows: spring (from March to May), summer (from June to August), autumn (from September to November) and winter (from December to February).

The paper fits straight lines with the average precipitation series of spring, summer, autumn, winter and annual and ten times the slope of fitting line is the climate tendency rate which represents variations of precipitation per 10a. Besides, in order to eliminate the seasonal variation, the 10a average anomaly of each precipitation time series is calculated so as to be compared with the results of wavelet analysis. The calculation formula of decadal anomaly is:

$$p = x - y$$

where, x is the average value of decadal data and y is the average value of the data series.

4. Study result

4. 1. *Time distribution of precipitation*

From Fig. 2, we can find that the distribution of precipitation in Yuanmou County is extremely uneven. Specifically, summer precipitation is slightly higher than that in autumn, summer and autumn precipitation is significantly higher than that in winter and spring; and winter precipitation is the least in four seasons. The average annual precipitation is 642.9 mm, while the average precipitation in spring, summer, autumn and winter are accordingly 34.9 mm, 303.8 mm, 281.7 mm and 21.9 mm, accounting for 13.9%, 42%, 33.7% and 10.4% of the precipitation in the whole year respectively. In the time series, the annual and seasonal precipitation has obvious fluctuations and its fluctuation will be greater if the season has more abundant precipitation.

Using the least square method to fit annual precipitation and each season's precipitation in spring, summer, autumn and winter (the fitting line is not indicated in the Fig. 2), after fitting we can obtain the slope of the line and they are respectively 1.948, 0.1811, 1.414, 0.0714, 0.3249. This indicates that the amount of annual and seasonal precipitation overall is on the increase and the rising trend is weak in autumn while obvious in summer. The precipitation tendency rates are respectively 19.48 mm/10a, 1.811 mm/10a, 14.14 mm/10a, 0.714 mm/10a, 3.249 mm/10a, but it cannot reveal the more detailed and real fluctuations.

### 4.2. *Variation characteristics of annual precipitation*

The interannual variation of precipitation in Yuanmou County is extremely disparate and the ratio between the maximum value and minimum value of annual precipitation is 3.2. In Fig. 3(a), we can clearly see that the annual precipitation anomalies in Yuanmou has a strong increasing trend and it shows that the annual average precipitation in the overall trend is increasing year by year and the increase amplitude is larger. The precipitation anomalies are negative from 1950s to 1980s, which means the precipitation is slightly less during the time. But the slope of the precipitation anomaly is positive and shows a rising trend, which indicates the precipitation decreasing trend has been weakening. The anomaly is positive until 1990s to 2006 and the change is great, which indicates that the value of average annual precipitation in Yuanmou County is much higher than that of normal since 1990s.
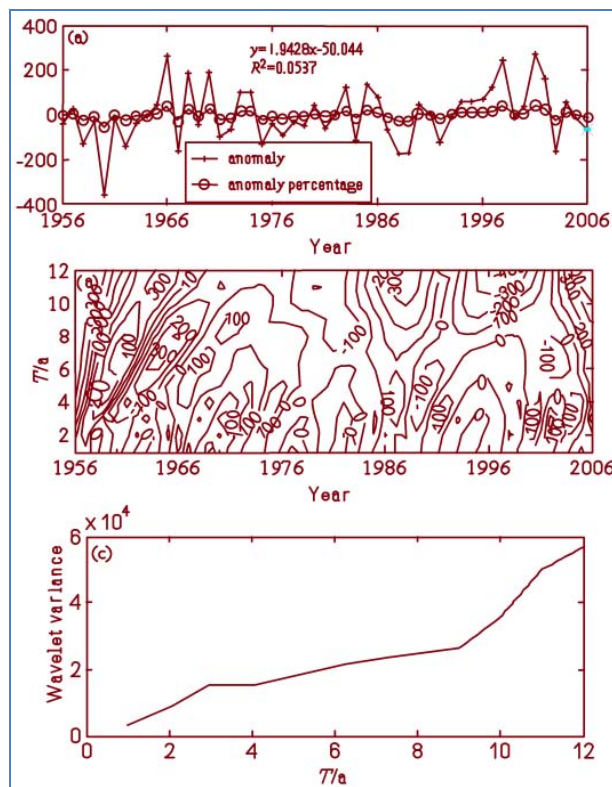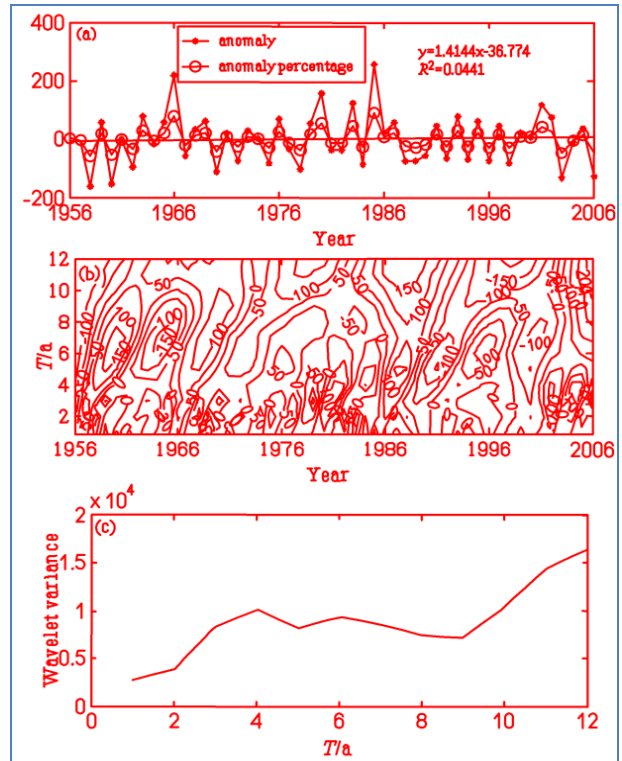

Figs. 3(a-c). (a) Decadal anomaly (mm) of average annual precipitation in1956-2006 and its anomaly percentage, (b) wavelet transform (c) as well as wavelet variance

Fig. 3(b) shows the periodic oscillation of average annual precipitation on different time scales in Yuanmou Country during recent 50 years. In this figure, the contour lines are positive representing that the precipitation is more; the contour is negative meaning that the precipitation is less; the wavelet coefficient is zero corresponding to the abrupt change point and the signal strength is expressed by the wavelet coefficients. What's more, we also can see that the precipitation structures on different time scales are different and the periodic oscillation of annual precipitation on the long time scale of 8-12a is very significant. During the period, the average annual precipitation has experienced 6 alternate cycles of "less→more→less→more→less→more", with little precipitation before 1959, 1968-1982, 1994-1996 and more precipitation during 1960-1967, 1983-1993 and after 1997.

On the medium scale of 4-6a, there are many abrupt change points. It has experienced the same 6 alternate cycles of "little →more →little →more →little →more", with little precipitation before 1957, 1962-1965, 1991-1992 and more precipitation during 1958-1961, 1966-1990 and after 1993. The contour line is not closed until 2006, which means that the precipitation is more during a
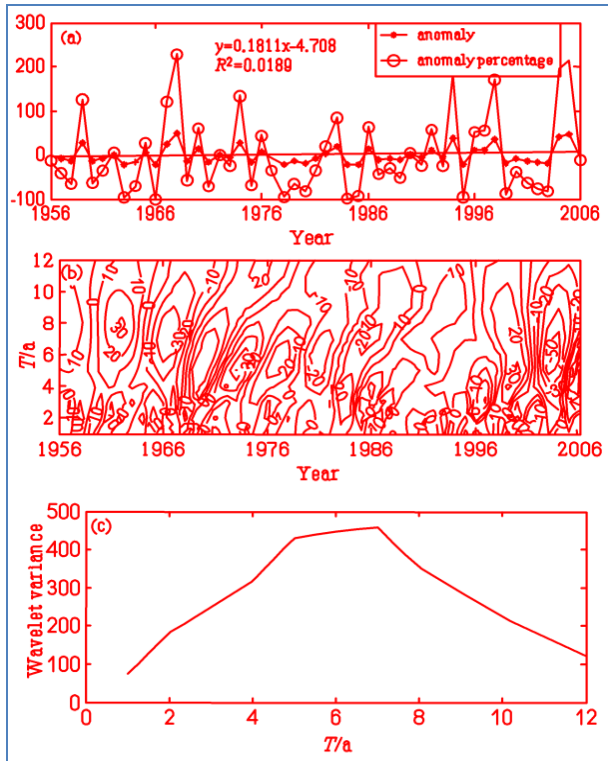
Figs. 4(a-c). (a) Decadal anomaly(mm) of spring precipitation in1956-2006 and its anomaly percentage, (b) wavelet transform (c) as well as wavelet variance

Figs. 5(a-c). (a) Decadal anomaly (mm) of summer precipitation in1956-2006 and its anomaly percentage (b) wavelet transform (c) as well as wavelet variance

period after 2006, while its increasing trend is not obvious in the 1966-1990 stage.

Fig. 3(c) displays the wavelet variance for relative intensity of scale disturbance about the average annual precipitation on various time scales in Yuanmou County in recent 50 years. The corresponding peak value is called main time scale of the series, which is used to reflect the main period of time series. Fig. 3(c) also presents that there are 3 peaks for the wavelet variance diagram of average annual precipitation corresponding to the time scales with 11a, 8a and 3a respectively. It means that the periodic oscillation is the strongest in the time scale 11a for annual precipitation, which is the first main period of average annual precipitation variations, thus the second and the third main period is 8a and 3a.

4.3. *Variation characteristics of spring precipitation*

Fig. 4(a) shows the slope of spring precipitation anomaly in Yuanmou County is positive, that is, there is a weak increasing trend for the anomaly and the spring precipitation is increasing year by year in general. From

late 1950s to 1980s, the precipitation anomaly is positive, which means that the precipitation during the period is more. From 1960s to 1980s, the precipitation anomaly is negative and it shows a downward trend, which indicates the decreasing trend of precipitation has been reinforcing. But by 1990s, the precipitation anomaly is positive and varies greatly and it is 32.98, 41.3, 55.35 percentage points higher than in 1960s, 1970s and 1980s respectively, which means that spring precipitation is much higher than the normal value since 1990s. By 2000s, the precipitation anomaly is still positive, but compared with 1990s, it decreased by 9.82 percentage points, which means that the precipitation is increasing in Yuanmou County during the early period of 2000s , but the increase amplitude is not drastic as 1990s.

Fig. 4(b) shows a regular periodic oscillation on a long time scale of 8-12a, in which there is 9 alternate cycles of "little →more →little →more →little →more → little→more→little" for spring precipitation, but by 2006, the contour line has been closed, which indicates that the precipitation after 2006 is more. On a medium time scale of 4-6a, there is 12 alternate cycles of "little →more → little→more→little→more→little→more→little", which the precipitation is more during 1960-1964 , 1969-1971,
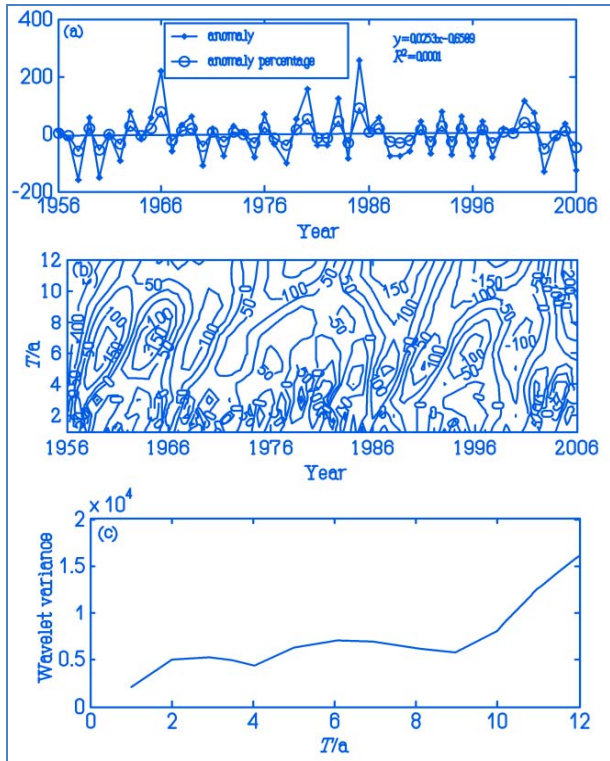
Figs. 6(a-c). (a) Decadal anomaly (mm) of autumn precipitation in 1956-2006 and its anomaly percentage (b), wavelet transform (c) as well as wavelet variance

1975-1979, 1984-1986, 1994-2001 and after 2005 and the precipitation is little in the remaining years. But whether on the long time scale of 8-12a or on the medium time scale of 4-6a, the contour line has been closed by 2006, which indicates that the precipitation is more after 2006. For small scale below 4a, it shows repeated alternating change of precipitation with more and little and the abrupt change points of precipitation are more.

Fig. 4(c) displays that the wavelet variance of spring precipitation has 3 peaks, which respectively correspond to the time scales of 2a, 5a and 7a. The first peak is 7a, which means that the periodic oscillation is the strongest in the time scale 7a for spring precipitation, that is the first main period of spring precipitation variations, then the second period is 5a and the third period is 2a.

4.4. *Variation   characteristics   of   summer   precipitation*

Fig. 5(a) shows the summer precipitation anomaly and its percentage in Yuanmou Country during 1956-2006. From Fig. 5(a), we can find that the summer precipitation anomaly is positive and there is a strong trend of increasing, which means that the summer precipitation is

increasing year by year in general. Besides, the fluctuation of summer precipitation anomaly is very large: from early1950s to 1990s, it's in an alternation of "positive→negative", with a large variation, especially, the precipitation anomaly of 1990s is 89.53 percentage points higher than that of 1980s and precipitation value of summer precipitation in 1990s is much higher than that in 1980s. On the other hand, summer precipitation continued to increase in early 2000s as the trend in 1990s.

Fig. 5(b) presents 6 alternate cycles of "little→more→little→more→little→more" on the long time scale of 8-12a, which the more precipitation appeared during 1983-1992, 1960-1966 and after 1998, while the little precipitation appeared during 1967-1982 , 1993-1997 and before 1959. On the medium time scale of 4-6a, the abrupt change points surge and summer precipitation has experienced 10 alternate cycles of "little→more→little→ more→little→more→little→more→llittle→more".   The precipitation is more during 1958-1961, 1965-1987, 1995-2001 and after 2004, while the precipitation is little during 1962-1964, 1988-1994, 2002-2003 and before 1957. The contour line is not closed until 2006, which means that the precipitation is more after 2006. There are more alternating cycles between pluvial period and brief rain period on the small time scale of 1-4a. Therefore, Summer Precipitation of Yuanmou Country will be more than that of normal in a period after 2006 and the increase of precipitation in summer is bound to affect the annual rainfall.

Fig. 5(c) displays that the wavelet variance of summer precipitation has 3 peaks and they respectively correspond to the time scale of 11a, 4a and 6a. The first peak is 11a, which means that 11a is the first main cycle and the second and third main period is respectively 4a and 6a.

4.5. *Change characteristics of autumn precipitation*

From Fig. 6(a), we can find that there is a weak increasing trend for the anomaly of summer precipitation in Yuanmou County, which indicates summer precipitation is gradually increasing with small amplitude year by year in general. Autumn rainfall anomaly is in an alternation of "negative →positive" from late 1950s to early 2000s and it shows that autumn precipitation is in an alternation of "less →more". The anomaly percentage age of autumn precipitation is 32% in 1980s and it is significantly higher than that of other years, which means that the autumn precipitation is much higher than normal value during the period. But from late 1980s to early 2000s, the anomaly of autumn precipitation is negative, which means that the precipitation is little, but the trend has been weakening, until it rises close to the

normal value, therefore, it cannot indicate that autumn precipitation is little or increased in Yuanmou after 2006.

From Fig. 6(b), we can find that the periodic oscillation on the larger scale of 8-12a is significant and the autumn precipitation has experienced 8 alternate cycles of "less →more →less →more →less →more → less→more" during the period. The more precipitation appeared during 1961-1974, 1982-1991, 1997-2001 and after 2004, while the little precipitation appeared during 1975-1981, 1992-1996, 2002-2003 and before 1957. On the 4-6a time scale, autumn precipitation has experienced 12 alternate cycles of "less →more →less →more →less →more →less →more →less →more →less →more", The precipitation is less in the six stages of 1963-1965, 1972-1974, 1984-1986, 1991-1993, 2000-2002 and before 1957 and the precipitation is more in six stages of 1958-1962, 1966-1971, 1975-1983, 1987-1990, 1994-1999 and after 2003. The contour has not closed until 2006, which indicates that the precipitation is more in a period after 2006. There are more alternate cycles between pluvial period and brief rain period on the small time scale of less 1-4a and the abrupt change points increase.

Fig. 6(c) displays that the first main period of precipitation change in autumn is 6a and the second and third main period is respectively 7a and 3a.

4.6. *Variation characteristics of winter precipitation*

From Fig. 7(a), we can find that there is a weak increasing trend for the anomaly of summer precipitation in Yuanmou County, which means that winter precipitation is increasing year by year in general. From late 1950s to 1960s, the anomaly of winter precipitation is negative, which indicates that the precipitation is less, but the decrease trend is weakened. The anomaly of winter precipitation is positive until 1970s and it continues to 1990s, which means that winter precipitation of Yuanmou Country is higher than normal value in recent 30 years. Then the anomaly of precipitation has turned negative in early 2000s and the precipitation is less.

Fig. 7(b) shows that, on the 8-12a time scale, there is 7 alternate cycles of "more →less →more →less → more →less →more" for winter precipitation. The more precipitation appeared during 1972-1979, 1986-1991, before 1966 and after 1997 and the precipitation is less in other years. The contour is not closed until 2006, which shows that the precipitation will be more in a period after 2000. On the 4-6a time scale, there is 5
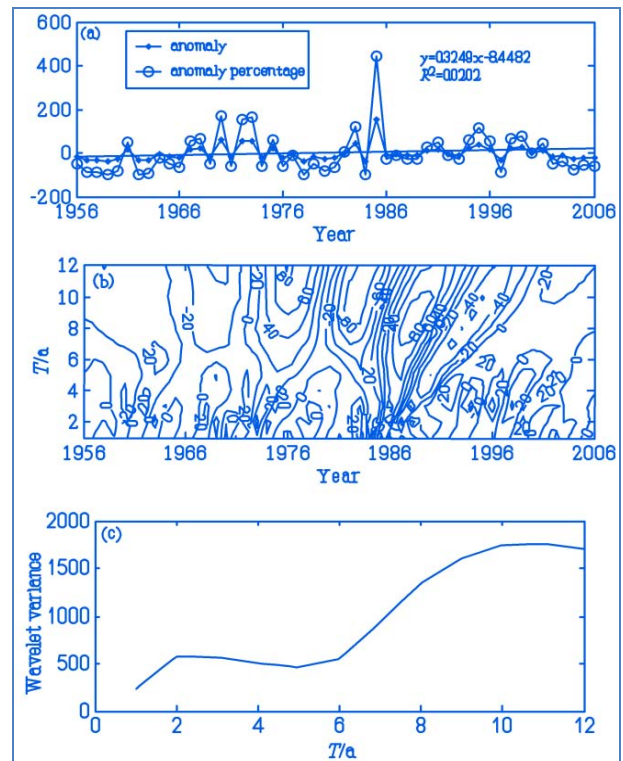
Figs. 7(a-c). (a) Decadal anomaly (mm) of winter precipitation in 1956-2006 and its anomaly percentage (b), wavelet transform (c) as well as wavelet variance

alternate cycles of "more →less →more →less →more" for autumn precipitation. The precipitation is more during 1986-1988, before 1982 and after 1997 while the precipitation is less during 1983-1985 and 1989-1991. In the 25a during 1956- 1981with general more precipitation, there are 5 alternate cycles between more precipitation and normal values. There is a slight increase for the winter precipitation during 2004-2006 and the contour is not closed, which means that the winter precipitation is becoming slightly more in a period time after 2006 in Yuanmou County and the variation will not be great. The fluctuation is still not strong on small scale of 1-4a and the annual variation is small.

Fig. 7(c) displays that the first main period of winter precipitation variation is 10a, followed by 8a and 6a.

5. Conclusions

Through analyzing the anomaly of seasonal and annual precipitation series as well as continuous wavelet transform in the past 50a, the complex structure of seasonal and annual precipitation variations on multi-time

scales in Yuanmou County was studied. The results are as follows:

(*i*)   It shows a rising trend for the annual and seasonal precipitation for nearly 50a in Yuanmou County, but this increase has a fluctuate characteristic: in summer and winter, the alternate cycle between precipitation abundance and poor is long (11a and 10a respectively) and the change is relatively slow; while in spring, autumn and all the year the alternate cycle between precipitation abundance and poor is short (7a and 6a respectively) and the change is relatively fast. Whether on the long or medium-short time scale, Yuanmou County is in the second half of abundant precipitation so far, which shows that it is entering a fluctuation period of more precipitation in the next few years. The time-frequency local change characteristic of Meyer wavelet analysis can demonstrate the fine structures of precipitation and the method provides a new way in analyzing climate multi-time scales characteristics and short-term climate forecast as well as other problems about the water-saving of agriculture, thus it can be used to forecast the short-term precipitation in the region.

(*ii*)   The wavelet transform analysis of precipitation series in Yuanmou County shows that the structures of precipitation on different time scales are varied. How many changes of small scales are represented by how many complex structures nested within the larger scales. There are more in the small time scales and the abrupt change points are becoming more. There is such a law that the more the abrupt change points, the smaller the scales. Both the average annual precipitation and the precipitation in spring, summer, autumn have obvious periodic characteristics of 8-12a. The annual and summer precipitation have experienced 6 alternate cycles of "less →more →less →more →less →more"; the spring precipitation has experienced 9 alternate cycles of "less →more →less →more →less →more →less →more →less"; the autumn precipitation has experienced 8 alternate cycles of "less →more →less →more →less →more →less →more". In the second, the periodic characteristics on 4-6a time scale are quite obvious. The precipitation series in spring and autumn have experienced 11 alternate cycles of "less →much →less →much →Less →much →less →much →less →much →less" and the precipitation series in summer has experienced 10 alternate cycles of "less →much →less →much →less →much →less →much →less →much". So far, the county is in a period of more precipitation. The precipitation in winter is also obvious at 8-12a and 4-6a scales, it has experienced 7 alternate cycles of "much →less →much →less →much →less →much" and 5 alternate cycles of "much →less →much →less →much". Furthermore, the precipitation in winter becomes

somewhat more for a period of time after 2006 in Yuanmou Country, but the variation is not great.

(*iii*) From the decadal and interannual variations in Yuanmou County, we can see that the average decadal anomaly of seasonal precipitation is positive, especially the anomaly slope of summer precipitation is bigger, which indicates that there is an increasing trend after 2006 for the summer precipitation, so we need to pay more attention on flood prevention in summer and autumn, in order to ensure the safety of people lives and property as well as the growth of crops (such as rice).

Above all, the method of wavelet analysis is mainly used for the analysis of the cycles of time series change and paroxysmal diagnosis, multiple time scale analysis, trend prediction and correlation analysis. Using the scale and position of the scale of the wavelet analysis method, we can make multi-scale refinement analysis on the function or signal sequence. It not only can reveal the cycle of change over time in a sequence of vibration but also can determine the location of the precipitation mutation and can also estimate the evolution trend of the time series. Therefore, wavelet analysis has become a very important tool to study the effects of meteorological elements of long-term variation and paved the solid ground for further hydrology calculation and hydrological forecasting.

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