Wavelet Analysis on Temperature and Precipitation Changes in Dabie Mountain of West Anhui

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Abstract: The wavelet analysis method is applied to analysis of multi-level time change characteristics of temperature and precipitation in Dabie Mountain based on the meteorological observation data of five stations in Dabie Mountain from 1960 to 2013. According to results, the temperature shows oscillation periods of 22 years and 10 years in Dabie Mountain, West Anhui. While the precipitation shows an oscillation period of 26 years. The change relationships of temperature and precipitation are not the same based on different time scales. From the scale of 3 years, to 10 years and 20 years, the out-of-phase becomes weaker. The tendency of consistence appears gradually.

1. Introduction

Wavelet analysis, also known as multi-resolution method, is a popular cutting-edge field globally in recent years. It is believed as the breakthrough of the Fourier analysis. Owing to special advantage of wavelet analysis for signal processing, it attracts attention of meteorologists soon. Many noticeable research findings have been made when applying time-frequency structure analysis to meteorological and climatic sequences [1-10].

Dabie Mountain in west Anhui is located between Yangtze River and Huai River at 115.20°E~117.14°E, 31.05°N~32.40°N. This area is high in southwest and low and flat in the northeast. Under the background of global warming, what are the changes of climate elements in Dabie Mountain, West Anhui Province? Few studies focus on climate in this area as one of the old revolutionary base areas. This paper, based on former research findings, carries out periodic analysis on temperature and precipitation in Dabie Mountain, West Anhui, and will provide important theoretical and practical significance.

2. Materials and methodology

2.1 Data processing

According to the meteorological observation data of five observation stations in Dabie Mountain, West Anhui (Huoshan, Huoqiu, Jinzhai, Liuan, Shucheng) from 1960 to 2013, anomaly analysis is applied to temperature and precipitation and wavelet analysis method is adopted to analyze periods of temperature and precipitation.
2.2 Wavelet analysis

The wavelet analysis introduces window function based on Fourier transformation; the wavelet transformation is based on the invariance of affine group (invariance of translation and stretching), and allows to break one time sequence to contribution to time and frequency. It is effective for acquiring the adjustment rules of a complex time sequence, diagnosing internal hierarchical structure of climate changes, and distinguishing evolution characteristics of time sequence based on different scales. The wavelet function may be defined as: Suppose \( \varphi(t) \) is an integral function of 1 square meter, i.e., if the Fourier transformation \( \hat{\varphi}(\omega) \) meets the admissible conditions:

\[
C_{\varphi} = \frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} \left| \frac{\hat{\varphi}(\omega)}{\omega} \right| d\omega
\]

(1)

Then, \( \varphi(t) \) is a basic wavelet or wavelet generating function; dilating and translating the wavelet function , the following continuous wavelet will be acquired

\[
\varphi_{\alpha, \tau}(t) = \frac{1}{\sqrt{\alpha}} \varphi\left(\frac{t-\tau}{\alpha}\right), \alpha, \tau \in R, \alpha > 0
\]

(2)

For any function , the continuous wavelet transform shall be:

\[
W_{f}(\alpha, \tau) = (f(t), \varphi_{\alpha, \tau}(t)) = \frac{1}{\sqrt{\alpha}} \int_{R} f(t) \varphi\left(\frac{t-\tau}{\alpha}\right) dt
\]

(3)

In the formula, \( \alpha \) is the scale factor, \( \tau \) is the translation factor and \( W \) is the wavelet function. The common Mexican Hat wavelet function is applied to continuous wavelet transform of precipitation time sequence in the Yellow River catchment, and the wavelet function is as follows:

\[
\varphi(t) = (1-t^2)e^{-t^2/2}
\]

(4)

In order to judge main periods of each sequence, i.e., the period playing the leading role in precipitation sequence change, the following calculation formula is adopted as follows for wavelet variance test:

\[
W_p(\alpha) = \frac{1}{\sqrt{\alpha}} \int f(t) \varphi\left(\frac{t}{\alpha}\right) dt
\]

(5)

In the formula, \( W_p(\alpha) \) is wavelet variance, and \( W_{f}(\alpha, \tau) \) is wavelet coefficient.

3. Analysis on temperature change:

The temperature in Dabie Mountain of West Anhui is unstable. The temperature anomaly from 1960-2013 can be seen in Table 1. According to Table 1, the temperature anomaly in 1960s, 1970s and 1980s is negative, which means the weather is cold at that time; while the value in 1990s and the dozens of years after 2000 is positive, which means the weather is warmer. However, the anomaly percentage is -2.936%~3.3401%, approaching to the the average value. However, the temperature is rising as a whole, and the temperature is rising at present.

Table 1. The decadal anomaly of temperature in Dabie Mountain of West Anhui during 1930-2013

| Year       | Anomaly | Anomaly percentage (%) |
|------------|---------|------------------------|
| 1960-1969  | -0.072  | -0.459                 |
| 1960-1969  | -0.324  | -2.068                 |
| 1960-1969  | -0.46   | -2.936                 |
| 1960-1969  | 0.18602 | 1.1874                 |
| 1960-1969  | 0.52326 | 3.3401                 |
| 1960-1969  | 0.31443 | 2.0071                 |
According to data analysis, the temperature during 1960-2013 is increasing, with temperature tendency rate of 0.16°C/10 years. The weather is warm (Fig. 1 (a)). Fig. 1 (a) shows the periodic oscillation of temperature in Dabie Mountain of West Anhui Province during 1960-2013 based on different time scales. The strength of signal is represented by the size of wavelet coefficient in the figure; the full line means the positive contour, representing high temperature; dotted line means the negative contour, representing low temperature; the catastrophe point is for zero wavelet coefficient. According to Fig. 1 (b),

Temperature structures corresponding to different time scales are different. The change of small scale is nested to a more complicated structure based on large scales. The periodic scale is obvious based on the 22-year time scale; the temperature experienced five cyclic alternation of low-high-low-high-low. The three low-temperature periods are 1960-1970, 1975-1980 and 2010-2013; the two high-temperature periods are 1973-1975 and 1980-2010. The contour is closed in 2013, which means the temperature is rising in the later period. On the time scale of 10 years, the temperature experienced seven cycles of high-low-high-low-high-low-high. The four high-temperature periods are 1960-1965, 1970-1980, 1990-2005 and 2010-2013; the four low-temperature periods are 1965-1970, 1980-1990 and 2005-2010. The contour is closed in 2013, which means the temperature is rising in the later period.
Fig. 2: Wavelet variance of annual average temperature in Dabie Mountain of West Anhui Province

According to Fig. 2, the peak values of two wavelet variance are corresponding to 10 and 22. It means the temperature change in 22 years during 1960-2013 is the largest in Dabie Mountain of West Anhui Province, which is the first period; the second period is 10 years.

4. Analysis on precipitation change

The precipitation anomaly in Dabie Mountain of West Anhui Province during 1960-2013 can be seen in Table 2; the anomaly value in 1960s is negative, which means the precipitation is little; the anomaly value in 1970s and 1980s is positive, which means the precipitation is much. Particularly in 1980s, the anomaly percentage reached 9.5162%, showing higher precipitation level. The anomaly in 1990s and the first thirteen years in the 21st century is negative, showing little precipitation; particularly the anomaly percentage during 2011-2013 reached -8.148%, which means the precipitation is too little.

Table 2: Decadal anomaly of precipitation in Dabie Mountain, in West Anhui during 1960-2013

| Year       | Anomaly | Anomaly percentage (%) |
|------------|---------|-------------------------|
| 1960-1969  | -43.19  | -3.733                  |
| 1970-1979  | 16.7039 | 1.4438                  |
| 1980-1989  | 110.098 | 9.5162                  |
| 1990-1999  | -32.518 | -2.811                  |
| 2000-2009  | -13.384 | -1.157                  |
| 2010-2013  | -94.274 | -8.148                  |
According to Fig. 3 (a), the annual precipitation during 1960-2013 is on a declining curve, with tendency rate of -12.73mm/10years. The weather is warm. Fig. 3 (b) Oscillation period of precipitation in Dabie Mountain, in West Anhui during 1960-2013 The oscillation period in 26 years is obvious. It experienced five cycles of less rainfall- much rainfall- less rainfall - much rainfall- less rainfall. The three periods with less rainfall are 1960-1975, 1985-1990 and 2000-2013; the two periods with much rainfall are 1975-1985 and 1990-2000. It is approximately consistent with the analysis on precipitation anomaly, and the value is different only during 1970-1975 and 1990s. The problem that whether the influence of small cycle is added to large ones will not be discussed in this paper. After 2013, since the contour is not closed, the rainfall is less.
Fig. 4 shows the peak value of wavelet variance is corresponding to 26 years, which means the first cycle of precipitation change in Dabie Mountain in 26 years.

5: Scale change relationships of temperature and precipitation

By comparing Fig.1b to 3b, the wavelet coefficient distributions of temperature and precipitation are greatly different on entire time scale. The corresponding relationship of temperature and precipitation in this period will be analyzed below.

Fig. 5a, b and c respectively show the wavelet coefficient change of temperature and precipitation based on scales of 10 years and 20 years; various characteristics are for different time scales.

Fig. 5 shows the change trend of temperature (dotted line) and precipitation based on time scale of 3 years (a), 10 years (b) and 20 years (c).

The temperature and precipitation based on 3-year scale shows an out-of phase relationship. It means on that scale the precipitation is high when the weather is cold and precipitation is low when the weather is warm. The out-of phase relationship of temperature and precipitation is shown in different time periods based on the 10-year scale, 1960-1965 and 1980-2013. However, the temperature during 1966-1980 is changed sharply, and the precipitation is almost consistent. Based on
20-year scale, the out-of phase of precipitation only exists in a short period (1966-1970 and 1995-2003). The temperature changes rapidly in other time periods, and precipitation is constant and stable (1970-1995). Moreover, the precipitation and temperature change during 1960-1965 and 2005-2013 is on the same trend, but precipitation is lagged behind.

6. Conclusions
The following main conclusions are drawn through the wavelet analysis on temperature and precipitation changes in Dabie Mountain of West Anhui:

(1) Temperature structures corresponding to different time scales are different. The change of small scale is nested to a more complicated structure based on large scales. On the 22-year time scale, the temperature experienced five cycles of low-high-low-high-low. On the time scale of 10 years, the temperature experienced seven cycles of high-low-high-low-high-low.

(2) Precipitation experienced five cycles of less rainfall - much rainfall - less rainfall - much rainfall - less rainfall.

(3) Temperature shows the first main cycle of 22 years and the second cycle of 10 years. The precipitation shows the first cycle of 26 years.

(4) The scale relationship of temperature and precipitation shows opposite scale on the scale of 3 years. Most values show out-of phase on the scale of 10 years, and few show fierce temperature change and gentle precipitation change. On the scale of 22 years, most values show fierce temperature change and gentle precipitation change, and few show consistent precipitation and temperature change, but the precipitation is lagged behind temperature in phase.

(5) The future temperature and precipitation change may be predicted according to warmth or coldness of wavelet coefficient curve, dry-wet alternations as well as analysis on corresponding periods.

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