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ANALYSIS OF TEMPERATURE CHANGES IN JANUARY AND JULY IN CHINA

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ABSTRACT: The temperature change trends in January and July are analyzed and the results show that the trends descend in July but ascend in January except in South China and Southwest China. The relation between the temperature in January and July are discussed by using the wavelet. The results show that the trend phase in July and January are nearly in-phase in Southwest and South China, but are out-of-phase in other regions. Reconstruction of original temperature series in each of the regions indicates that their change trends are consistent with the original temperature series.

Key words: temperature in January; temperature in July; wavelet analysis

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1 INTRODUCTION

One of the significant features of global climate change over the past century is the increasing of temperature over contemporary times. Ding et al report generally similar warming trends in China as across the Northern Hemisphere[1]. Studying the variation of temperature changes in China over the past 100 years and comparing variations in the Northern Hemisphere and China, Wang[2] suggests basically consistent overall trends of climate change in China as across the globe. As shown in some studies[3], there are clear rising trends of annual mean temperature across the globe and minimum temperature over most parts of the world; correspondingly, warming trends also appear in most parts of China. Studies[4] also show that major contemporary warming events occurred in areas north of 35°N, mostly with the increasing of minimum temperature while there was a cooling area between 23°N and 35°N and east of 100°E, mostly with the decrease of maximum temperature.

More work on temperature changes in China is needed and in more detail. For instance, against the general background of global climate warming, how does change take place in different regions of China, seasons and months? Are there any similarities and differences? For the purpose, the current work uses the wavelet method to discuss temperature changes in January (the coldest month of the year) and July (the hottest one) in all parts of China and their relationship. It is of great significance for more understanding of fine details of temperature changes in China over the past century.

2 METHODS AND DATA

Basic principles of the wavelet analysis are described in detail in [5] and [6]. The method includes wavelet transform and reversed transform. The first approach is to reveal the location of the abrupt change of the original series and shows local features of drastic changes that are not

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easily recognized in complex series, i.e. the phenomenon of abrupt changes. The latter approach is to restore transformed results to individual series on various time scales, i.e. with different degrees of smoothness. It is used to analyze trends of evolution on different layers of climate.

The MaxHat and Haar wavelet functions are used here as basic wavelets. The former is expressed by

$$Y\ (t) = (1 - t^2)\frac{1}{\sqrt{2\eth}} e^{-t^2/2} \qquad -\infty < t < \infty \tag{1}$$

Eq.(1) is derived from the second order of the Gaussian function. The ascending abrupt change point for $f(t)$ of the original function in the transform curves diagram, which is obtained by the MaxHat wavelet function, corresponds to the zero-crossing point (which cuts across the abscissa axis) and the descending abrupt change point corresponds to the zero-crossing point that goes downwards.

The Haar wavelet function is expressed by

$$\Psi(t) = \begin{cases} 1 & 0 \le t < \frac{1}{2} \\ -1 & \frac{1}{2} \le t < 1 \\ 0 & \text{others} \end{cases} \tag{2}$$

Eq.(2) is a simplified form of the spline function. The ascending abrupt change point for $f(t)$ of the original function in the transform curves diagram, which is obtained by the Haar wavelet function, corresponds to the peak point of W_f and the descending abrupt change point corresponds to the valley point.

A binary wavelet is introduced in the work. It is

$$a = 1 \times 2^j \qquad (j = 1, 2, \cdots\cdots) \tag{3}$$

By substituting $f(t)$ and the value of a in Eq.(3) into the wavelet transform equation (omitted) for discrete limited series, we can plot wavelet transform diagrams with different time scale (a). Graded temperature data for seven regions of China from 1911 to 1998 are used, with data for Xinjiang covering the period from 1951 to 1998. Mean temperature is divided into five grades, denoted with numerals 1, 2, 3, 4 and 5 (all data are assigned with two effective digits). Specifically, Grade 1 is for warm mean temperature, Grade 2 for less warm, 3 for normal, 4 for less cold and 5 for cold. To remove large disturbances of the boundary during wavelet transform, we first apply a wavelet analysis of the 1988 data by extending forward and backward a length of sample and after calculation the extended part is eliminated and the central part is retained to reduce the boundary effect[6]. The following sections will be devoted to presentation of wavelet analyses of temperature changes in January and July in the country.

3 TRENDS OF TEMPERATURE CHANGES IN JANUARY AND JULY IN ALL PARTS OF CHINA

Fig.1 gives the curves of temperature changes in January and July in different parts of China, which are plotted based on graded data. Temperature changes in a way so randomly and irregularly that it is impossible to know how it varies.

The univariate regression is used to determine the linear trends of temperature change in all parts of China

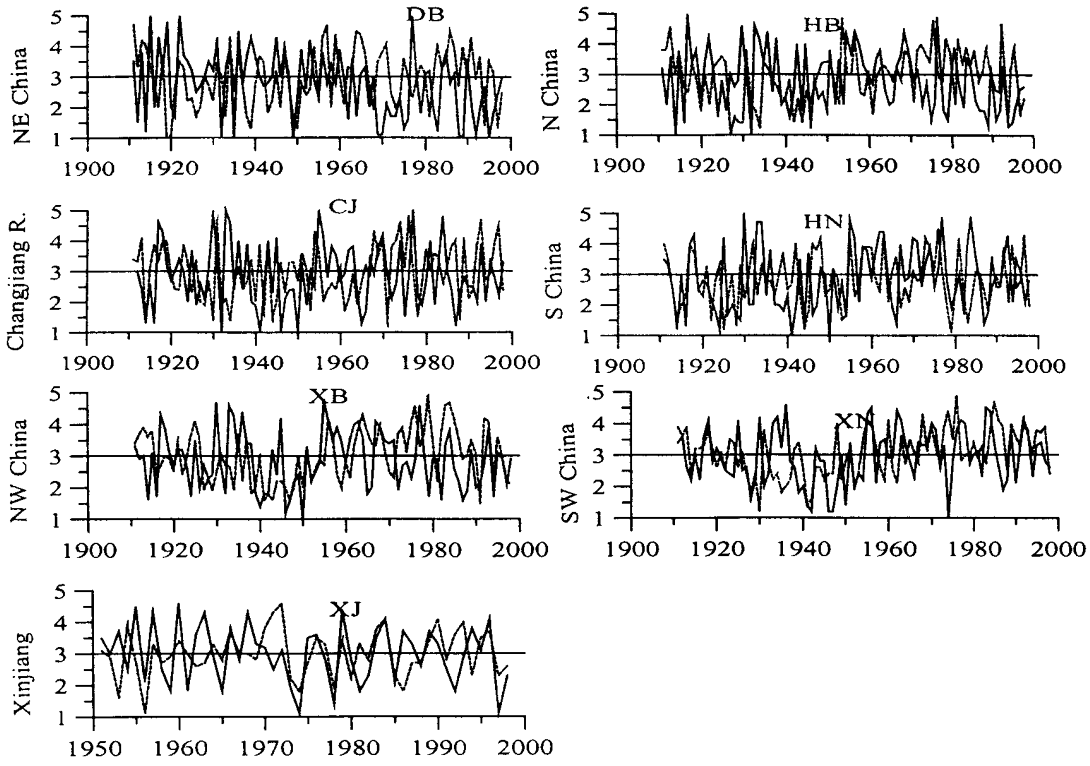

Fig.1 Variation curves of temperature in January and July in the seven regions. The solid lines stand for January and the dashed lines for July. The abscissa is the year.

$$\hat{y}_i = bt_i + b_0 \qquad i=1,\ 2,\ \cdots\cdots,\ n \tag{4}$$

b is the trend of temperature change, $b > 0$ is the ascending trend of temperature and $b<0$ the descending trend. The higher the grade of temperature for the data used in the current work, the lower the temperature is and vise versa. It shows that $b < 0$ suggests a rising trend of temperature while $b > 0$ a falling trend.

Tab.1 gives the trends of temperature change and the evaluation of regression effects. It shows that the coefficient for July $b > 0$ all over the country, i.e. temperature shows a trend of falling while the coefficient for January $b >0$ except in South China and Southwest China, i.e. temperature shows a trend of rising. It suggests an increasing trend in the coldest month but a decreasing trend in the hottest month.

Tab.1 Trends of temperature change in January and July in all parts of China

Regions	Trend coefficients *b* (Jan.)	Trend coefficients *b* (Jul.)
Northeast China	-0.0144	0.0046
North China	-0.0082	0.0065
Changjiang R.	-0.0010	0.0050
South China	0.0068	0.0020
Northwest China	-0.0022	0.0073
Southwest China	0.0046	0.0100
Xinjiang	-0.0353	0.0064

4 WAVELET ANALYSIS OF TEMPERATURE CHANGE IN JANUARY AND JULY IN ALL PARTS OF CHINA

4.1 *Results of wavelet analysis using MaxHat*

Fig.2 gives the Maxhat wavelet transform of temperature change in January and July in the seven regions of China with a time scale $a=32$. Take Northeast China for example. The point of abrupt temperature change for January and July happens to be right near the intersection of two curves, i.e. around year 1960. On the time scale, temperature was lower (higher) before 1960 but higher (lower) after it, for January (July). It is then clear that the time around 1960 is a turning point of trend for the two curves of warmer and colder temperatures. In addition, the two wavelet transform curves are just the opposite in January and July. Similar to Northeast China, they also show opposite trends in the regions of Changjiang R., Northwest China and Xinjiang but basically the same trends in the regions of Southwest and South China, with the point of abrupt temperature change near the intersection of the two curves.

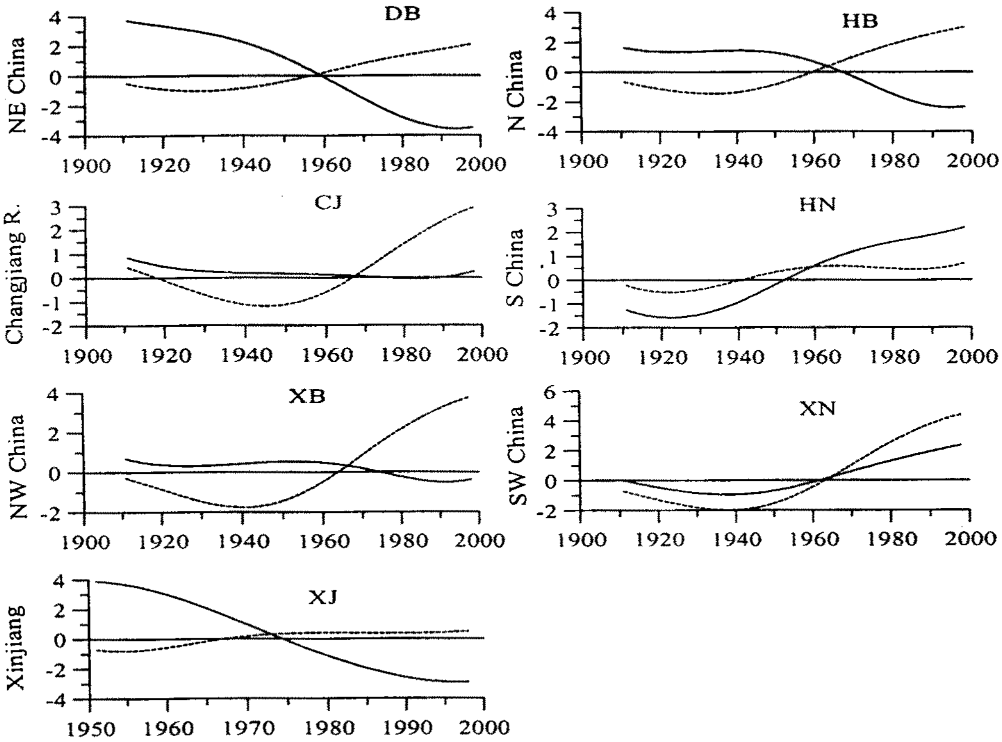

Fig.2 The MaxHat wavelet transform of temperature changes in January and July in the seven regions. The abscissa is the year.

Summarizing the analysis above, we note that what is same about the wavelet structure for the seven regions is that the point of abrupt change is all near the intersection of the transform curves for January and July. At present, temperature in July stays within a lower range; what is different is that the wavelet structure look much similar for the regions of Northeast and North China, Changjiang R., Northwest China and Xinjiang and temperature changes have basically the opposite trends in January and July. The current temperature in January stays within a higher range, with the transform curves for the two months in almost the same phase for Southwest and South China. The fact that temperature is relatively cold for both January and July shows that the latter two regions are dominated by the same center of temperature change, which is consistent with the result of [4].

4.2 *Results of wavelet analysis using Harr*

On the diagram of transform curves determined with the Haar wavelet function, we note that peaks are numerically over places where there is the point of abrupt ascending change and valleys over places where there is the point of abrupt descending change. The higher the temperature grade for the data used in this work, the lower the temperature and otherwise is true. It is then known that in terms of temperature change the peak is where the abrupt change point appears for temperature descending while the valley is where the point appears for temperature ascending.

Fig.3 gives the result of Haar wavelet analysis with the time scale $a = 32$. It shows that the peaks for temperature change in July in the regions of Northeast China, North China, Changjiang R., Northwest China and Xinjiang appear near 1955, 1950, 1965, 1965 and 1966; the valleys for temperature change in January in the above regions appear near 1965, 1985, 1985, 1985 and 1960. For South China, the peaks of July and January temperature change appear near 1945 and 1955; for Southwest China, the peaks appear near 1955.

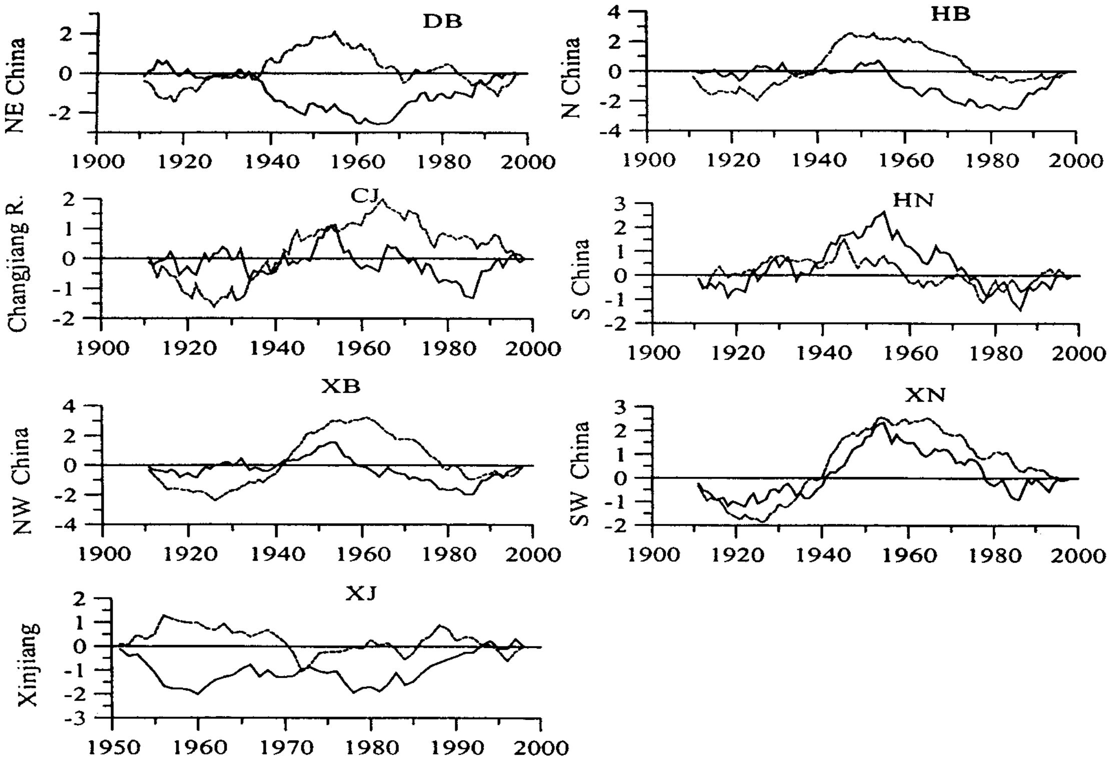

Fig.3 The Haar wavelet transform of temperature changes in January and July in the seven regions. The abscissa is the year.

With the Haar wavelet transform, the magnitude of positive and negative values reflects how sharp the rising and falling trends are. It is known from Fig.3 that temperature in July does not change much over the regions of South China and Xinjiang while it generally rises before 1960 (around the peak) but falls after it over the other regions. It also shows that temperature in January generally rises over the regions of South China and Southwest China before 1950 (around the peak) but falls after it. For the regions of North China, Changjiang R. and Northwest

China, the valley for which temperature changes the most in January appears near 1985, with the trend falling before the year but rising after it. For the regions of Northeast China and Xinjiang, there is a falling trend of temperature after the 1960's (near the valley). In addition, the trends are basically similar for both January and July in South China and Southwest China while diverse almost to the opposite in other regions.

Fig.4 gives the results of 15-year running mean of the temperature series for each of the regions. They are clearly reflected in the figure. For instances, the trend is falling after the 1960's over the regions of Northeast China, North China, Changjiang R. and Northwest China, with the values of temperature grades rising.

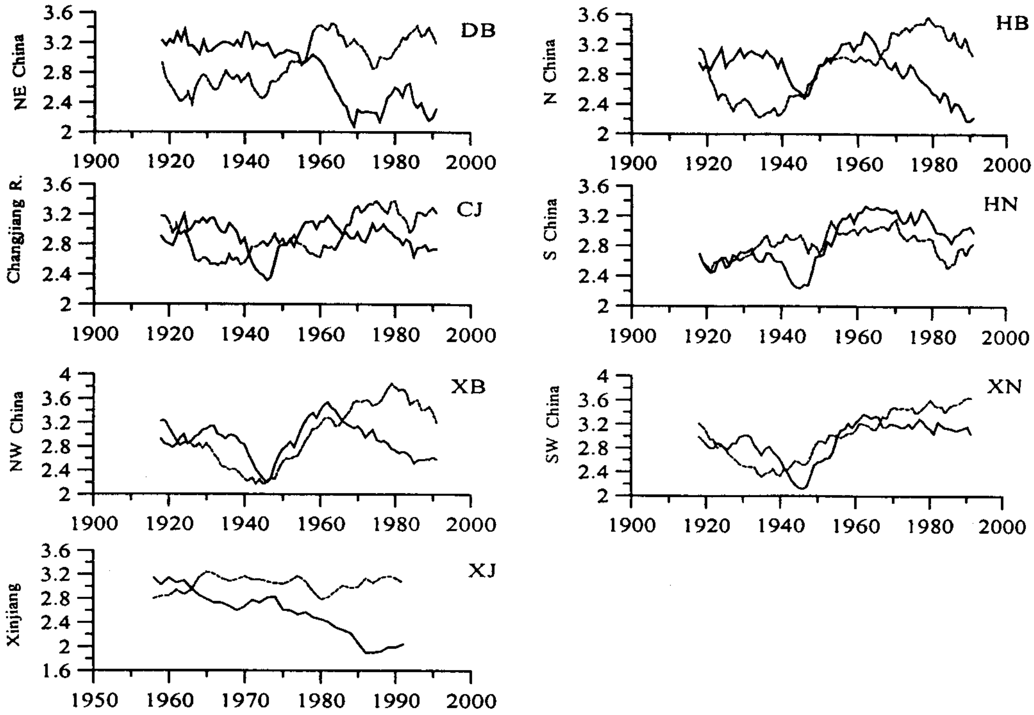

Fig.4 Running mean curves of temperature changes in January and July in the seven regions. The abscissa is the year.

4.3 *Comparison of results with the two wavelet analysis methods*

Tab.2 gives a point of abrupt climatic change obtained with the MaxHat and Haar wavelet analysis methods when a = 32 is set. It is known that differences are quite large in the point of abrupt climatic change obtained by the two methods. The Yamamoto method and Man-Kendall method are then used to verify the points.

With the Yamamoto method, a 5-year running mean of the original series is used to calculate the signal / noise ratio (S/N) and the root-mean-square error $|Y_b - Y_a|$. It is expressed as

$$\frac{S}{N}=\frac{|Y_b-Y_a|}{S_b+S_a} \tag{5}$$

where a and b are periods of 10 points before and 10 points after a particular point of time, and Y_a, Y_b, S_a and S_b are the mean values and standard deviation of sampled data for corresponding periods of time. Given specific levels of confidence, an abrupt change point is defined when

S/N is larger than 0.5 at a particular point of time. Fig.5 gives the S/N curves calculated and Tab.3 gives the points of abrupt climatic change obtained with the method.

Then the Man-Kendall method[7] is used to verify the abrupt change point of climate. Fig.6 is the M-K calculation chart of all regions for January (results of July omitted). Tab.3 gives the abrupt climate change points for January and July with the same method (except for the initial part).

Tab.2 Abrupt climate change points obtained with the two wavelet analysis methods (year)

Regions	MaxHat wavelet (a = 32)		Haar wavelet (a=32)	
	January	July	January	July
Northeast China	1960	1960	1965	1955, 1980
North China	1965	1960	1985	1950
Changjiang R.	1980	1920, 1970	1955, 1985	1925, 1965
South China	1955	1945	1955	1930, 1945
Northwest China	1975	1965	1950, 1985	1930, 1960
Southwest China	1960	1960	1955	1925, 1965
Xinjiang	1975	1970	1960, 1975	1955, 1990

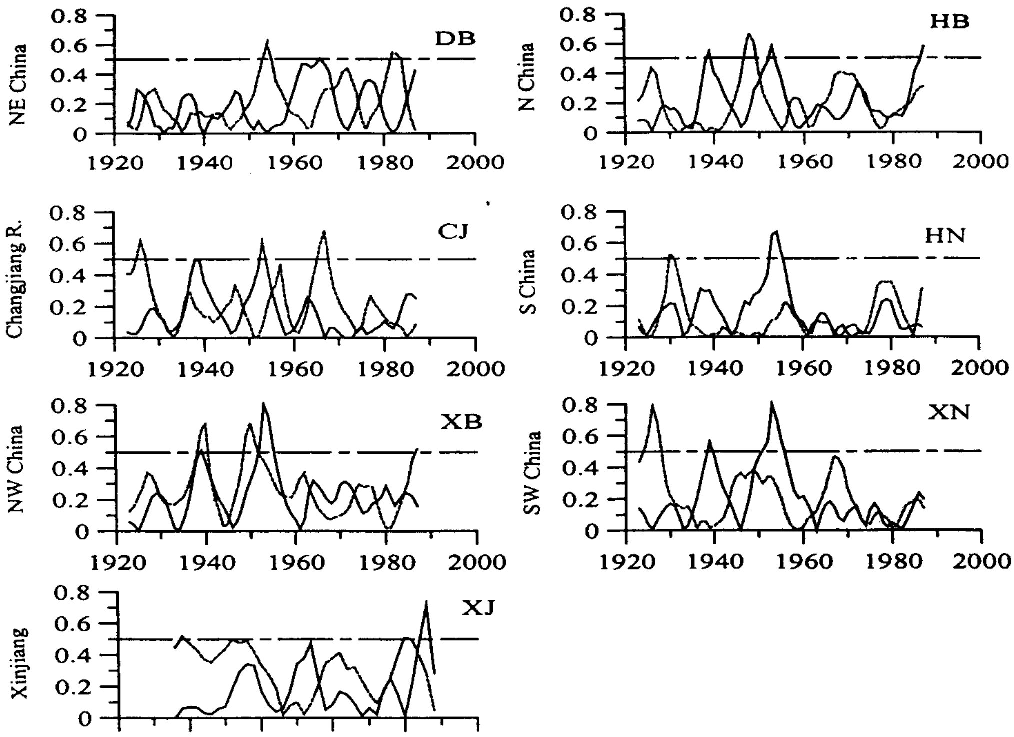

Fig.5 Signal / noise ratio curves as determined with the Yamamoto method. The dotted and dashed lines stand for signal / noise ratios equal to 0.5; The abscissa is the year.

Every diagnostic method for abrupt climatic change has its own limitation. With the Yamamoto method, it is sometimes difficult to locate the exact abrupt change point as the length is artificially given for two continuous sub-series so that constant adjustment is needed in the smoothening. In this work, the Yamamoto method fails to diagnose the abrupt change point near the year 1985 for January over the regions of Changjiang and Northwest China. When the point does not appear in the middle of the series or there are a number of abrupt change points, the method sometimes yield errors. Comparing Tab.2 with Tab.3, for an abrupt climate change point identified with the Harr wavelet analysis, consistent results can also be found either with the Man-Kendall or Yamamoto methods, if the error varies within a range of ±5 years. In contrast, the point determined with the MaxHat wavelet analysis has too large a drift for the January in North China and Northwest China that no similar results can be found in Tab.3. It also indicates that the Haar is more accurate than the MaxHat on the diagnosis of abrupt climatic change points. Some of the points located with the Yamamoto or Man-Kendall methods do not appear in Tab.2, but they are present when the wavelet analysis is done on finer time scale.

Tab.3 Reference points of abrupt climatic change as verified with the Yamamoto method and Man-Kendall method (year)

Regions	Man-Kendall method		Yamamoto method	
	January	July	January	July
Northeast China	1925,1940,1950	1940,1960	1965	1955,1980
North China	1925,1940	1955	1940,1955,1985	1950
Changjiang R.	1940,1960,1990	1920,1950	1940,1955	1925,1965
South China	1920,1935,1960	1920,1930,1940,1955	1955	1930
Northwest China	1940,1960,1990	1930,1940,1960	1940,1955	1940,1950,1985
Southwest China	1940,1960	1955	1940,1955	1925,1965
Xinjiang	1965	1960	1975,1992	1960,1965,1990

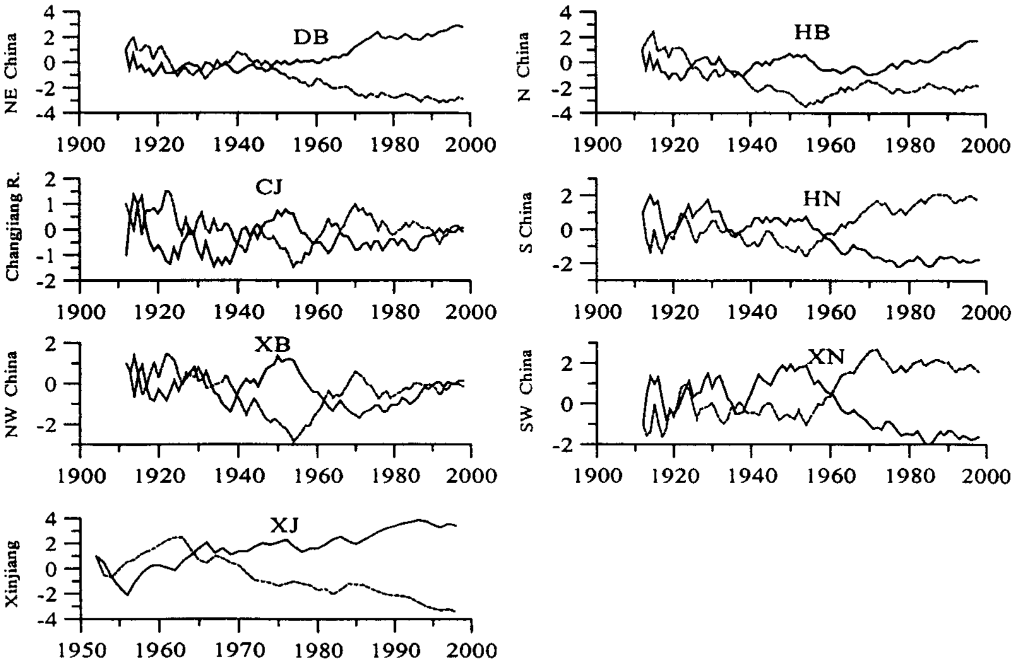

Fig.6 Curves of Man-Kendall verification of temperature changes in January in China. The abscissa is the year.

5 RECONSTRUCTION OF TEMPERATURE CHANGE CURVES IN JANUARY AND JULY IN INDIVIDUAL REGIONS OF CHINA

The Maxhat and Harr wavelets are separately used to reconstruct the curves of temperature change in January and July in individual regions of China The time scale is j =1, 2, 3, 4, 5 and j = 2 ~ 5, respectively. Fig.7 gives reconstructed curves for j = 5 (or a = 32) calculated with the MaxHat wavelet (j = 4 or a = 16 for the region of Xinjiang). It is known that the reconstructed curves for the seven regions have almost consistent tendency as their wavelet transform curves on the same time scale. It is also the characteristic of the MaxHat function which is used as the parent function of wavelets, though it is entirely different numerically.

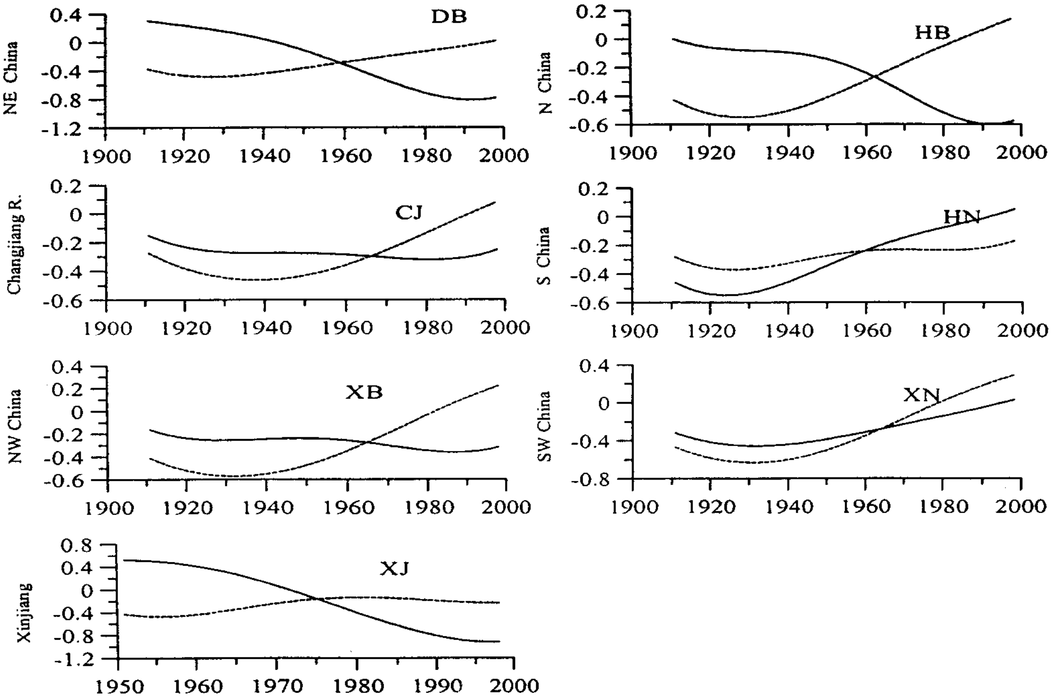

Fig.7 Curves of temperature changes in January and July as reconstructed with the MaxHat wavelet reverse transform for the seven regions of China. The abscissa is the year.

Trends are calculated of the temperature change in all parts of China in January and July reconstructed with the MaxHat wavelet that sets a = 32 (Table omitted). The coefficient is known to be $b > 0$, which is consistent with the analysis results of Tab.1. In contrast, the trend coefficients $b < 0$ in all regions but South China and Southwest China where $b > 0$. It suggests that the change trend of temperature series reconstructed with the time scale with a = 32 can reflect the tendency of the variation of temperature series. On smaller time scales (like a = 8 or a = 4), the variation trends of the reconstructed series are not entirely the same as those of the original series.

For the reconstructed curves of individual regions determined with the Haar wavelet and j = 5 (i.e. a = 32) but j = 4 (i.e. a = 16) for the Xinjiang region, the original series so reflected is in greater detail than in Fig.7. The trends of temperature change in January and July as reconstructed with the Haar wavelet and a = 32 are consistent with the results analyzed in Tab.1. It further suggests that the change trend of temperature series reconstructed with the time scale with $a = 32$ can reflect the tendency of the variation of temperature series.

6 CONCLUDING REMARKS

a. Applying wavelet transform of temperature in January and July in all regions of China, we note that the two monthly curves are generally out of phase for Northeast China, North China, Changjiang R., Northwest China and Xinjiang, which is sign that temperature is rising in the coldest month but falling in the hottest month in these regions. The transform curves are almost in phase in the regions of Southwest and South China, indicating that temperature is decreasing in both the hottest and coldest months of the year over these regions, being consistent with the conclusions of [4].

b. A number of methods are used to verify the abrupt change points by the MaxHat and Haar wavelets to show that the abrupt change point is more accurately analyzed by the Haar wavelet method.

c. Examining regional series curves reconstructed with reverse wavelet transform, we note that larger time scale ($a = 32$) can reflect general tendencies in the original series that are not easily recognized.

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