CLIMATIC ABRUPT CHANGE IN THE NORTHERN HEMISPHERE FOR 1920s AND 1950s

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Received August 18, 1993; revised May 18, 1994

ABSTRACT

In recent years, a large number of papers on the climatic sudden change have been presented. From the viewpoint of climatic sudden change, two methods of studying climatic sudden change are applied in this paper. The Northern Hemisphere land temperature (NHLT) during 1851—1984, China temperature (CT) during 1873—1990 and the Northern Hemisphere sea-level pressure (NHSLP) at each grid point during 1899—1987 are analyzed by the moving T-test. The results show that there exist two climatic sudden changes in the 1920s and the 1950s during the past 100 years, and then features of circulation for the two sudden changes are discussed by the NHSLP data.

Key words: climate, climatic sudden change, the NHSLP (the Northern Hemisphere sea-level pressure)

I. INTRODUCTION

In recent years, the frequent climatic abnormality, the discontinuity and jump of climatic variation have been attracting many scientists' attention. The conception of the climatic sudden change is preliminarily formed, meaning that there exists a turning mode between two stable climatic types.

The phenomena of jump have been put forward in an analysis of synoptic and seasonal scale changes. Yeh et al. (1958) first noted the seasonal jump of the atmosphere circulation in Asia monsoon region. Later, Zhang et al. (1983) discovered the stages of the long-term variation of the atmospheric active centers; its turning point was in the 1930s. Lin (1986) also discovered the stages of the long-term variation of the ultra-long waves, and the turning point was in the 1920s. In Japan, several climatic elements, such as sea-level pressure (SLP) in summer, temperature and precipitation in spring, exist two jumps in the 1920s and 1950s in the past 100-years (Yamamoto et al. 1986). Fu and Wang (1991) found the sudden change of the southern Asia monsoon abrupt change in the 1920s, which occurred almost simultaneously with the jump of the global temperature warming. Yan (1990a; 1990b) discussed the space-time distributions of precipitation, temperature, SLP and 500 hPa height variations in the Northern summer for the period of 1951—1980. All above mentioned shows that the study of climatic jump has reached a considerably high level.

In this paper, Section I is to discuss the method of examining climatic abrupt change. Section II is to analyze the data of the Northern Hemisphere land temperature (NHLT) from 1851 to 1984, China temperature (CT) from 1873 to 1990, and the climatic series of more than twenty single stations. Section III is to discuss the circulation features before and after the abrupt change of the Northern Hemisphere sea-level pressure (NHSLP) (1899—1986).

II. METHODS OF DETERMINING THE CLIMATIC SUDDEN CHANGE

There are many methods in detecting jumps of climatic series, but only two of them are used commonly: Mann–Kendall Rank Statistic (abbreviated to M–K) and T–test. A prerequisite for using the M–K method is that the climatic series must be stable and random, and the probability distribution must keep unchanged. The details of the M–K calculation method refer to Fu and Wang (1992). The T–test method is a classic statistic method. It can be used to test the significant difference between two sample averages. So we have designed the moving T–test to examine the significant difference between two adjacent subseries in a time series Y_i ($i=1, 2, 3, \cdots, N$), and to determine the climatic sudden change points.

Given a hypothesis (H_0): $\mu_1-\mu_2=0$, this means that the mean values of two subseries have no difference. A statistic is defined:

$$T_{j2}=\frac{\dfrac{\overline{X}_{j1}-\overline{X}_{j2}}{\sqrt{\dfrac{(n_1-1)S_{j1}^2+(n_2-1)S_{j2}^2}{n_1+n_2-2}}}}{\sqrt{\dfrac{1}{n_1}+\dfrac{1}{n_2}}},$$

where

$$\overline{X}_{j1}=\frac{1}{n_1}\sum_{i=1}^{n_1}Y_{i+j_1-1}, \qquad S_{j1}^2=\frac{1}{n_1}\sum_{i=1}^{n_1}(Y_{i+j_1-1}-\overline{X}_{j1})^2,$$

$$\overline{X}_{j2}=\frac{1}{n_2}\sum_{i=1}^{n_2}Y_{i+j_2-1}, \qquad S_{j2}^2=\frac{1}{n_2}\sum_{i=1}^{n_2}(Y_{i+j_2-1}-\overline{X}_{j2})^2,$$

$$j_1=1, 2,\cdots, N-n_1-n_2-b,$$

$$j_2=j_1+n_1+b,$$

where j_2 denotes the second j point in the series, n_1, $\overline{X}_{j1}$ and S_{j1} are the length, mean value and variance of the first subseries; n_2, $\overline{X}_{j2}$ and S_{j2} are those of the second subseries, respectively. b is the number of years between the two adjacent subseries. Then T_{j2} defers to T (n_1+n_2-2) distribution.

Given the significance level $\alpha=0.05$, we can obtain a critical value T_α ($T_{0.05}=\pm 1.96$), when $|T_{j2}|$ is less than $|T_\alpha|$, the hypothesis H_0 is accepted. When $|T_{j2}|$ is greater than or equal to $|T_\alpha|$, H_0 is not true. This means that there exists a significance difference between the mean values of two subseries. If two subseries are regarded as two different stable climatic states, the climatic sudden change requires that the lengths of the two adjacent subseries, n_1 and n_2, should be far greater than the transition time (i.e. b). The trend of series can be determined by the sign of T_{j2}. In this paper, n_1, n_2 and b are 20, 20 and 1, i.e. $n_1, n_2 \gg b$; these values are consistent with the definition of climatic abrupt change.

Another statistic method Yamamoto (1986) used is similar to T–test. We defined a signal–to–noise ratio $J=S/N$, which is similar to T_{j2}. When $|J|\gg 1$, the occurrence of jump is possible; when $|J| \gg 2$, the strong jump will happen. From here we see that the significance level of this method is less than that of the moving T–test.

Figure 1 shows the time series curves of NHLT during 1851—1984 (Jones et al. 1986), the 10–year moving average value and the moving T value, and the M–K test, respectively. The curves indicate that an abrupt increase of the temperature occurred in the 1920s, and an abrupt decrease of the temperature occurred in the 1950s. The greatest negative and positive values of the moving T occurred in 1924 and 1954, respectively. Their significance levels exceed 0.01 and 0.05, respectively. As to the M–K test curve, only one cross–over point occurred in 1918—1919 between the confidence intervals of 0.05. Therefore, the M–K test has the significant reaction to the NHLT increase in the 1920s, and no reaction to the decrease in the 1950s.

Moreover, the temperature series is divided into three different length series. First, we discuss how the abrupt change point is influenced by the series length change. Table 1 shows that the abrupt change points obtained by using the M–K method are different. Li et al.

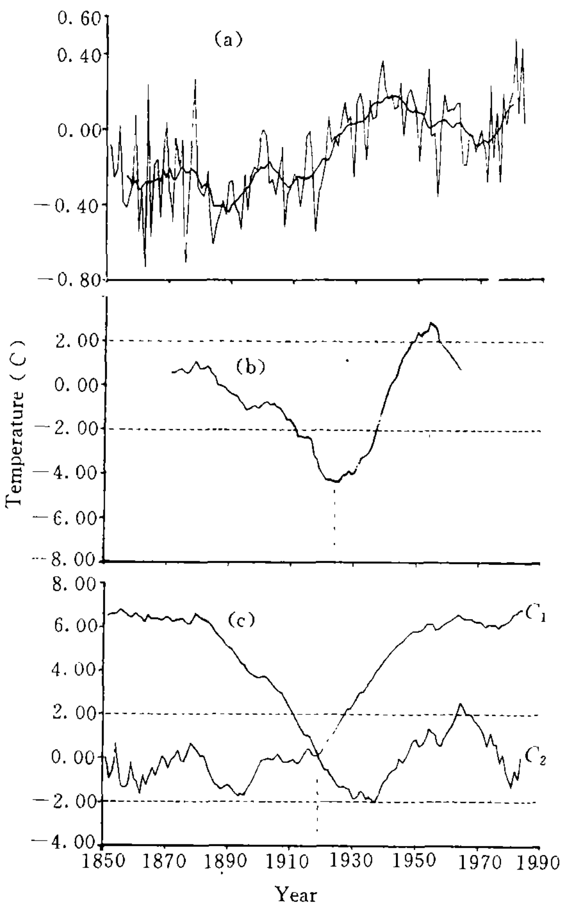


Fig.1. The time series of NHLT during 1851—1984. (a) the 10–year moving average value; (b) moving T value; (c) M–K value.

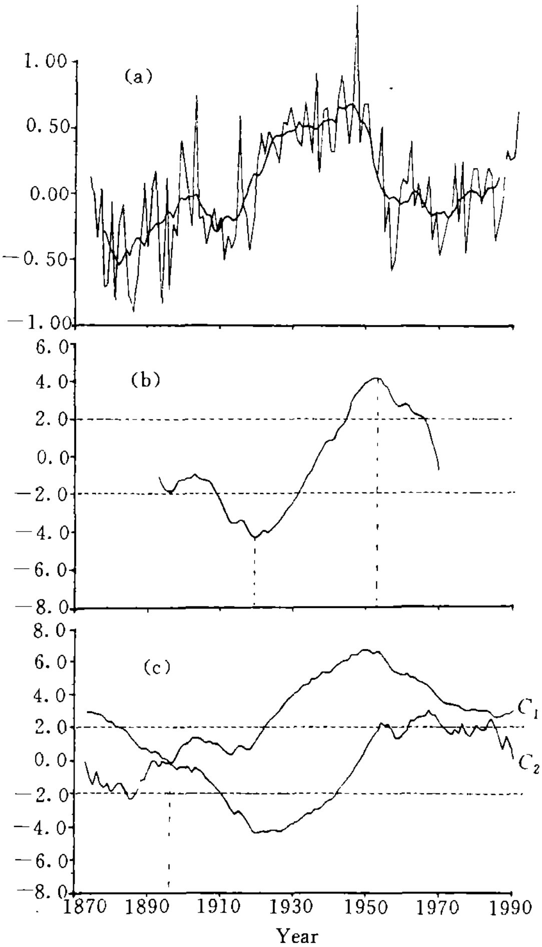


Fig.2. The temperature in China during 1873—1990. (a) the 10–year moving average value; (b) the moving T value; (c) M–K value.

Table 1. Results of Two Methods

	M–K method				Moving–*T* test			
Phases	1851—1930	1891—1950	1901—1984	1851—1984	1851—1960	1891—1960	1891—1984	1851—1984
Abrupt change points	1921	1923	1919	1918	1924	1924	1924, 1954	1924, 1954

(1991) found that the temperature series of Beijing and Shanghai calculated by using the M–K method have abrupt changes from cool to warm in 1919 and 1932, respectively. The results in Table 2 calculated by using the moving *T* method indicate that climatic abrupt changes from cool to warm in Shanghai occurred only in 1913, and in Beijing in 1931. But, in Beijing, another abrupt change from warm to cool occurred in 1947. Compared with the moving *T* method, the M–K method is sensitive to the first abrupt change point, not sensitive to the second. So in this paper, the moving *T*–test is applied to analyze climatic series.

III. ANALYSIS OF SINGLE STATION SERIES

According to the division of the temperature grade, the trend of temperature in China is almost consistent with that of NHLT (Wang 1990). The temperature variation in China during 1873—1990 is shown in Fig.2a (Lin et al. 1995). We can see that there is a small wave before the 1920s. But in the 1920s, the temperature increased rapidly and a high temperature period came; in the 1950s, it decreased rapidly and a lower temperature period came. The maximum negative and positive moving *T* values are in 1919 and 1953, respectively (see Fig.2b). They exceed the significance level of 0.01. It means that there exist two abrupt changes in the CT series in the 1920s and the 1950s. Only one cross–over point is shown in Fig.2c. A small wave obtained by using the moving *T* values can not reach the significance level of 0.05. From the abrupt change points and trends, CT change is almost similar to that of NHLT, and slightly earlier.

Moreover, more than twenty series, such as several cities' temperature series in China, the number of broken days of South Asian summer monsoon (Parthasarathy and Pant 1985), the number of west wind days in Great Britain Island (Lamb 1977) and the annual precipitation in more than ten regions of India (Parthasarathy et al. 1987), etc. are tested by using the moving *T* method (see Table 2).

The variation of the number of west wind days in Great Britain is considered as an index of global circulation energy change (Lamb 1977). The energy abruptly increased in the early 1890s, abruptly decreased in the 1940s. The number of broken days suddenly decreased in the 1920s and a relative active period came, which is consistent with the result obtained by using the M–K method (Fu and Wang 1992); in the 1960s, the number of broken days of South Asian summer monsoon suddenly increased along with an inactive period, which can not be obtained by the M–K method. As NHLT, the time of abrupt change (the number of broken days of South Asian summer monsoon) lags behind that of the global circulation energy, but their trends are the same. Temperatures of two cities in Southwest China have been dropping in recent 100 years and have two abrupt change points in the 1950s and the 1960s (becoming cooler). But the two abrupt changes in Shengyang in Northeast China are turning to warmer.

Table 2 shows that the abrupt change points of all time series mostly gathered in the 1920s (1916—1926) and the 1950s (1945—1955).

Table 2. Abrupt Change Points of Single Station Series

	1890—1899	1900—1909	1910—1919	1920—1929	1930—1939	1940—1949	1950—1959	1960—1969	1970—1979
Guiyang *T*							1955	1967	
Chongqing *T*						1949		1967	
Shengyang *T*			1916						1970
Shanghai *T*					1931				
Beijing *T*			1913			1947			
NH *T*				1924			1954		
China *T*			1919				1953		
BD*				1920				1960	
WD*	1890					1940			
Circulation W		1900			1932				
Circulation E				1926			1950		
Circulation C		1902			1932	1947			
R SD 03*		1902					1954		
R SD 04							1958		
R SD 05						1940			
R SD 06						1947			
R SD 07				1926				1963	
R SD 20							1950	1962	
R SD 26					1932		1950		
R SD 11	1899								
R SD 18	1896					1942			
R SD 19	1895					1940			
R SD 23	1899					1945			
R SD 30		1918				1947			
R SD 32		1918				1946			
R SD 13							1957		
R SD 14						1945	1958		
R SD 25					1939				
R SD 27						1947			
R SD 28						1945			
Total	5	2	5	4	5	14	10	5	1

Note: BD represents the number of broken days of South Asian monsoon. WD represents the number of west–wind days in Great Britain Island. R SD *N* represents the rainfall in the *N*th subvision of India.

IV. ANALYSIS OF THE ABRUPT CHANGE OF THE NORTHERN HEMISPHERE CIRCULATION

The aim of analysis of the single station time series is to analyze circulation patterns. As one of the most active climatic systems, atmosphere circulation attracts more and more scientists' attention. The each grid of SLP time series of the Northern Hemisphere (20—80°N, 504 grid points) during 1899—1986 is analyzed by the moving *T* method so as to find out the variation of the lower layer circulation.

First, the point numbers at which *T* values of the NHSLP per year exceed the significance level of 0.05 are calculated. Figure 3 shows the year when the point number reaches the maximum is in 1923. Moreover, the other two peak values are in 1944 and in 1954, but the duration of the peak value in 1944 is shorter than that in 1954. According to the variation of the curve, the peak around 1944 can be considered as a small wave in the descending section after 1923. Compared the abrupt change points of NHLT (1924 and 1954) with those of CT (1919 and 1953), the main abrupt changes of the NHSLP occurred in 1923 and in 1953, and the region of the abrupt change occurred in the 1920s is larger than that in the 1950s. The positive and negative T values above the significance level of 0.05 are calculated respectively. The results show that the number of positive T points reaches the maximum in the 1920s, and the number of negative T points reaches the maximum in the 1950s, and the year when the maximum positive T point number occurred is just the year when the minimum negative T point number occurred, and vice versa. So it can be obtained that there exist two climatic abrupt changes in the 1920s and 1950s, respectively; the former is the pressure descend and the later is the pressure rise. The region of the former is larger than that of the later.

Variation of NHLT is related to that of NHSLP. Their abrupt changes occurred in the 1920s and in the 1950s. In general, the increase of land temperature is usually accompanied by the decrease of SLP and the decrease of temperature is accompanied by the increase of SLP. On the basis of the abrupt change time of NHLT, CT and SLP (Fig.3), the NHSLP time series is divided into three stable phases. The first phase is in 1873—1918, the second in 1924—1952 and the third in 1956—1990. They represent three stable climatic stages before and after two abrupt change points, respectively. Then the difference of SLP among three phases can be detected.

The mean pressure anomaly of every phase is calculated (see Fig.4). In the first phase (see Fig.4a), the positive predominates over the negative. The positive center is located around the pole and extends to Asia and America. The negative center lies around the Urals. Europe, Northern Africa and the high–mid latitudes of the Pacific and the Atlantic are negative regions. In the second phase (Fig.4b), only the middle–southern North America, the Atlantic, the Urals and North Africa are positive areas; the pole, Asia and North America become negative centers. In the third phase (Fig.4c), the positive region predominates over the negative one again. The positive region almost forms a zone round the mid–latitudes. The negative region is still located around the pole and the low–latitudes. Comparing Fig.4a with Fig.4b, the region where the sign of anomaly changed is around the pole, Asia, the Urals, the low–latitudes of the Pacific and the Atlantic Oceans. Comparing Fig.4b with Fig.4c, in regions of East Asia, the middle–southern North America, mid–southern Europe and Northwest Africa the signs of the anomalies differ.

Figure 5 shows the difference of T value at each grid between adjacent two phases; hatched areas and cross–hatched areas denote negative and positive regions which exceed the significance level of 0.05, respectively. So the regions where NHSLP abrupt changes occurred in the 1920s and in the 1950s are clearly displayed. Figure 5a shows the regions where abrupt changes occurred in the 1920s are in the pole, Asia land, the mid–low latitudes of the Pacific and the Atlantic Oceans. SLP in these regions abruptly fell. The abrupt change regions of increasing SLP are only in the Urals, North Africa and North America. Figure 5b shows that the regions where abrupt change occurred in the 1950s are less than those of the 1920s. The T values that reach the significance level of 0.05 are in the Asia Continent, South Europe, South America and so on. SLP in Middle Asia, Europe and the northeastern America rose abruptly and dropped abruptly in the low–latitudes of America, the Atlantic, North Africa and South–East Asia.

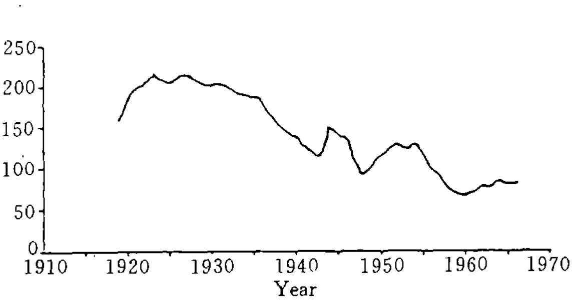
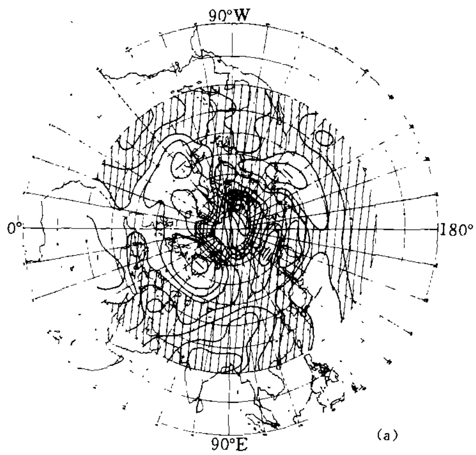
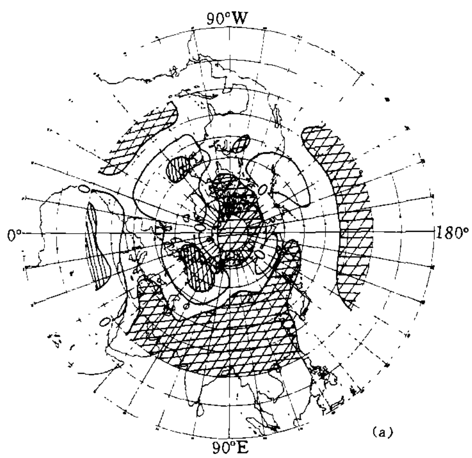
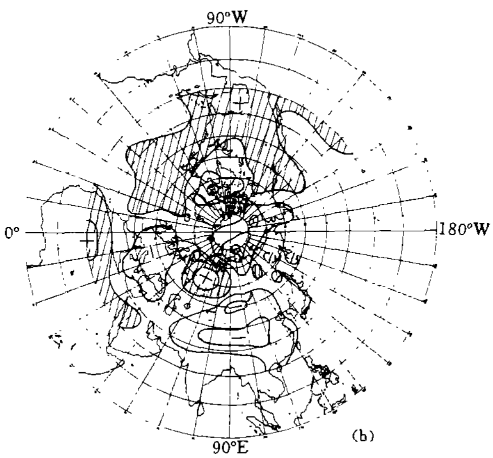
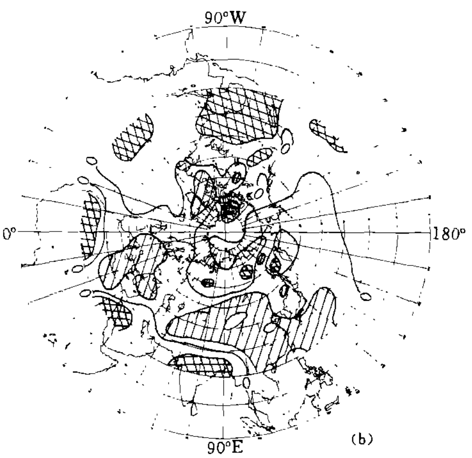


Fig.3. The point number of T value of NHSLP per year above the significance level of 0.05.









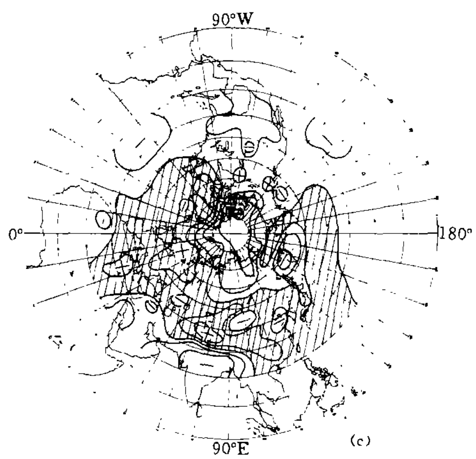


Fig. 4. Mean pressure anomaly of three phases (shaded areas show positive regions). (a) the first phase (1899—1918); (b) the second (1924—1952); (c) the third (1956—1986).

Fig. 5. The difference of T value at each grid between adjacent two phases. (a) the difference between the first phase and the second phase; (b) the difference between the second and the third phases.

The atmospheric active centers have the characteristics of varying by stages (Zhang et al. 1983). The mean pressure anomaly values of several atmospheric active centers during the three phases are calculated from Fig.4 and Fig.5. The figures in Table 3 show that the differences between the pole high and the Asia land high are significant before and after the first phase. The particularly significant changes of the pole high mean that the cold air comes into an inactive period after the first abrupt change. After the second abrupt change, the Asia land high slightly increases, but cannot return to the level before the first abrupt change, and its trends are in correspondence with CT trends during the three phases. The polar high, the Pacific high and the Atlantic high have been falling. According to the NHSAT and NHSST curves which were calculated by Ellsaesser et al. (1986) using COADS ship data from 1860 to 1980, trends of the curves keep falling from the end of last century to the beginning of this century. After the 1920s, the trends of NHSAT and NHSST turn to rise, and after the 1950s they almost keep unchanged around the mean value. Although the division of three phases is not on the basis of the trends of SAT and SST, the figures in Table 3 are almost consistent with the trends of SAT and SST.

Table 3. The Mean Pressure Anomaly Values of Four Atmospheric Active Centres during Three Phases

	1899—1918	1924—1952	1956—1986
Polar high (hPa)	3.00	−0.21	−1.75
Asia land high (hPa)	1.04	−0.90	0.36
Pacific high (hPa)	0.72	−0.12	−0.34
Atlantic high (hPa)	0.59	−0.05	−0.46

V. CONCLUSIONS

On the basis of climatic abrupt change, the data of the NHLT during 1851—1984 and CT during 1873—1990 are analyzed by two methods. After the results are carefully compared, it can be found that the moving *T* method is superior to the M−K method. Then NHSLP during 1899—1986 is studied. Several conclusions are as follows:

(1) The moving *T*−test method has two advantages over the M−K method. First, the M−K method is sensitive to the first abrupt change point of series, and even no reaction to the second abrupt change point. By using the M−K method, only one abrupt change point of series is obtained. But by the moving *T* method we can obtain all abrupt change points of series. Second, the abrupt change point obtained by the M−K method has some drift when lengths of the series vary. For the moving *T* method, the abrupt change points have no drift. So the moving *T* method is chosen to test climatic abrupt change.

(2) NHLT has two abrupt changes in the past 100 years. One is temperature increasing in 1924, another is temperature decreasing in 1954. The former is stronger in intensity than that of the later. CT also has two abrupt changes in the past 100 years. One is temperature increase in 1919. The other is temperature decrease in 1953. The abrupt change time of CT is a little earlier than that of NHLT. More than twenty climatic series are tested. It is found that their abrupt change points relatively concentrate in two phases, 1916—1926 and 1945—1955.

(3) The peak values of points at which *T* value of NHSLP per year exceeds the significance level of 0.05 are in 1923 and in 1954. That is to say the NHSLP has two abrupt changes in the

1920s and in the 1950s, and its trends correspond to that of NHLT and CT.

(4) According to the abrupt change time of NHLT and CT, SLP time series is divided into three phases. Features of the mean SLP in the three phases are that the polar high, the Pacific high and the Atlantic high keep weakening, and the Asia land high considerably weakens after the first abrupt change, and strengthens after the second abrupt change, but does not restore to its original condition.

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