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The Response of Climatic Jump in Summer in North China to Global Warming①

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ABSTRACT

To reveal climatic variation over North China, the climatic jumps in summer in Beijing are analyzed using the data of precipitation of summer (June, July, August) during the period of 1841–1993, in which those missed before 1950 were reconstructed by the stepwise regression method with minimum forecast error.

The climatic jumps at different scales are analyzed using different diagnostic methods with different decade (10–100 years) windows. Some new methods and ideas are proposed. The variance difference, the linear tendency difference, and the difference of power spectral distribution between the samples before and after the period at the moving point in the center of the series are compared with other methods (for example, Mann–Kendall test, t–test, and accumulative anomaly etc.).

Considering the differences among the statistics above, a synthetic jump index is also proposed in order to get the definite jump points in the moving series.

The results show that the climatic jumps in the area occurred in the 1890s, the 1910s and the 1920s, and mostly in the 1920s, which suggests that the local climatic jumps in North China have a simultaneous response to the global warming in the hundred–year scales.

Key words: Climatic jump, New diagnostic statistics, Synthetic jump index, Response to global warming

1. Introduction

Being the center of politics, economy and culture of China, Beijing has an increasing demand for water with its rapid development in industry and agriculture. However, a series of worldwide droughts started in the 1980s affected North China and caused lower water levels in the rivers and reservoirs of this area in recent years. The drought brought disastrous consequences by serious water deficiency especially in the growing season of crops in summer. In such a background, some questions were put forward: Will the summer drought continue? How can we improve the water supply in this area? In this paper, we try to answer whether the long–term variations of the summer dryness / wetness phenomena in the area are associated with the global warming.

It is well known that the global warming started in the 1920s, which means that there was a sudden change in the climatic change at global scale in the 1920s (Jones, et al., 1989). Was there a similar jump in the same period in local climatic variation, for example in North China, as a response to the global warming? A study like this will be meaningful in theoretical

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aspect as well as practical field. Moreover, since the longest meteorological element data are available from 1840 to 1993, it is long enough to apply to the investigation of climatic change at the hundred–year scale.

There are several methods for the analysis of jump phenomena in a time series, such as t–test, Mann–Kendall test, accumulative anomaly and wavelet analysis etc. (Salstein et al., 1986; Cooper et al., 1989; Lozowski et al., 1989; Nasrallah et al., 1990; Bardossy et al., 1990; Boroneant et al., 1992). The t–test, in which paired samples are applied to different temporal points, is often used in the detection of climatic jumps (Yamamoto, et al., 1986) or linear tendency with two–phase regression (Solow, 1987). Demaree (1990) found the climatic change in the rainfall data of Mauritania using Mann–Kendall test. This kind of comparison is focused on the difference between the averages and linear tendencies in the paired periods so that they can only be used to detect some variations of average value or tendency in the paired samples at a temporal point. However, there is another different feature in the variation at a point in series. For example, the difference between two sample series exists not only in the averages but also in the variances. They should be detected to demonstrate it. It is well known that climatic jump has more complicated contents due to the climatic change on the earth. The climatic jump should include the jump of the variance and the distribution of the spectral contribution in the climatic series except for the average and the tendency. Specially, the distribution of the spectral contribution in a period in the series can be representative of the features in different oscillations in different periods. Their difference of the spectral distribution in paired samples at a divide point in the series represents the variation on the periodic fluctuations. They should also be considered in measuring the difference of the paired samples. Therefore, the ratio of variance and difference of spectral distribution in a paired sample are proposed in this paper as new diagnostic statistics on the research of climatic jump.

2. Data and method

In order to analyze the climatic jump at the scale longer than a decade, the data need to be prolonged as long as possible. The observations of the precipitation in Beijing have lasted for a long period, which is longer than 150 years (1841–1993) (see Fig.1). Though there are some missing data in 1859–1868, 1884–1889, 1900–1903, 1926–1929 and 1937–1939, they are reconstructed by means of the stepwise regression method with minimum forecast error (Huang et al., 1990). It is focused for the minimum prediction error on independent sample rather than the dependent sample. The selective predictors were taken from the data of precipitation 12 months before the target years.

The series of precipitation in Beijing will be divided into two samples with decade scales at some temporal points, named moving windows. In order to analyze the climatic jump, we use several statistics to measure the change of average, variance, tendency and spectral distribution in this paper. The forms of the statistics are given as follows.

The first is the measurement of the difference of average in paired samples.

$$T=\frac{\bar{x}_1-\bar{x}_2}{s(1/n_1+1/n_2)}, \tag{1}$$

where s is the synthesis standard deviation of the paired sample (with the size of n_1 and n_2, respectively), $\bar{x}_1$ and $\bar{x}_2$ are the averages of the paired sample. Its square is expressed by

$$s^2=((n_1-1)s_1^2+(n_2-1)s_2^2)/(n_1+n_2-2),$$

where s_1 and s_2 are the standard deviations of one sample and the other, respectively. The second is the measurement of the difference of variance in paired samples. It is

$$F=s_1^2/s_2^2 \qquad (s_1>s_2), \tag{2a}$$

or

$$F=s_2^2/s_1^2 \qquad (s_1<s_2). \tag{2b}$$

The third is the measurement of the difference of tendency in paired samples.

$$T_d=b_1-b_2, \tag{3}$$

where b_1 and b_2 are the slopes of the linear equation of the paired periods. The fourth is the measurement of the difference of spectral distribution in paired samples.

$$P_d=(1000\sum_{k=1}^{m}(P_{s1k}-P_{s2k})^2)^{1/2}. \tag{4}$$

where P_{s1k} and P_{s2k} are the standardized power spectral densities of the fluctuation at the $k-th$ wave number in the paired samples, m is the total number of waves selected by one third of sample size. They can be calculated from autocorrelation coefficients (Huang et al., 1984).

The probable jump will occur at a divide temporal point (year) in the paired periods if the absolute value of the statistics is great. Moving windows with different scales yield the paired, for example 140, 120, 100, 80, 60, 40 and 20 years in the period of 1841—1993. The divide point is at the center of the window and it splits the window period into two samples. Our attention will be paid on the scale of hundred years. Therefore, we select moving windows of 140, 120 and 100 years. The maximum jump should be represented by the maximum value in

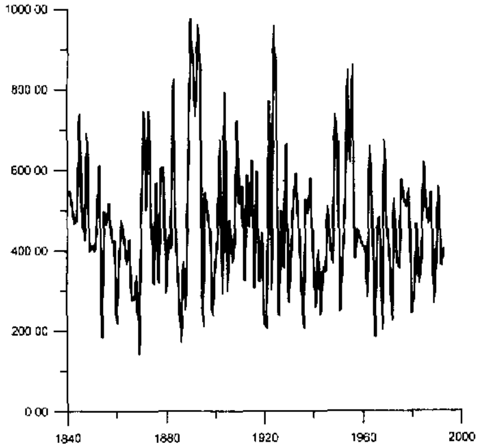

Fig. 1. The series of the precipitation in Beijing.

the series of the moving statistics on the hundred–year scale.

Different statistics will give out different jump points, though they may be very close to the same year. So we use the synthesis index series to identify the climatic jumps, which are yielded by the principal factor analysis (Huang, 1990) of the four moving values of the statistics. The first principal factor (PF1) is representative of the main feature of the differences among the moving divide points given by the individual statistics. The peak point in the curve of PF1 represents the synthesis jump point in the climatic variation. Similarly, the variation of the second principal factor (PF2) is representative of another main feature of the statistics. The significant jump points in the series will fall into the expectation of the absolute value 1.96 (2.0 being taken), because the principal factors are the standardized variables under the hypothesis of Gaussian distribution.

3. The climatic jump on different scale

The statistics of T, F, T_d and P_d are calculated using Eqs. (1)–(4) and the data of summer precipitation on the scale of 140 years (corresponding to the window length of 70 years). The maximum values of the statistics are listed in Table 1 with the sign (*).

Table 1. The comparisons of maximum statistics in the jump year on the scale of 140 years

Year	T	F	T_d	P_d
1913	0.685	1.207	1.667	1.797 *
1914	0.711 *	1.204	1.720	1.759
1920	0.318	1.254	1.905 *	1.248
1922	0.389	1.394 *	1.789	1.486

It is found that the possible jump points are in 1913–1914 and 1920–1922. From Table 2, the average value is 486.2 mm before 1913, thereafter the average value (462.7 mm) dropped about 26 mm.The variance varied from 45152.1 to 37405.1. The tendency represents a process from positive to negative. The power contribution of the fluctuations on the long periods (surpass 46–year) build up and the ones on 9–15–year periods have a reduced tendency. Another jump point is in 1922. The dry tendency is also significant. The average drops a little but the variance drops more. The power contribution of the fluctuations at the scale of 9–15 years reduced more rapidly at the jump point of 1913, which implies that the differences of averages and spectral distribution at the jump point of 1913 were more significant than those at the jump point of 1922. The significant differences were in 1922 with the variance and linear tendency.

Table 2. The comparisons of statistics in the paired samples in the jump year on the size of 70 years

Year	1913		1922	
	before	after	before	after
Average (mm)	486.2	462.7	478.3	464.9
Variance	45152.1	37405.1	47925.8	34392.1
Tendency	1.4	−0.3	1.1	−0.7
>46 yr	0.712	0.742	0.714	0.742
9–15 yr	0.067	0.017	0.055	0.022

Obviously, if the number of the statistics increases, the number of jump points will increase as well. If the traditional t–test is used, the jump point will be the one in 1914 on the 140–year scale. The diagnostic series of t statistics is similar to the series of statistics P_d with the correlation coefficient of 0.78. But statistics P_d can represent the difference on the fluctuation distributions of the paired samples. The statistics of F and T_d are useful for describing the other jump points. Their series show the lag phase difference with the series of t (their correlation coefficients are −0.65 and −0.28 respectively). Their correlation matrix (listed in Table 3) shows that they can detect different features.

Table 3. Correlations among statistics of T, F, T_d and P_d

statistics	T	F	T_d	P_d
T	1.000	−0.645	−0.277	0.779
F	−0.645	1.000	0.267	−0.368
T_d	−0.277	0.267	1.000	−0.277
P_d	0.779	−0.368	−0.277	1.000

On the scale of 120 years, the maximum values in the statistics are listed in Table 4(I) with the sign (*). It is found that the possible jump points are in the 1900s and the 1920s. There are three statistics that indicate the occurrence of climatic jump in the 1920s. Table 4(II) shows that most of the jump points of the statistics occur in the 1920s on the scale of 100 years. The others occur in the 1890s. The difference of spectral distribution is similar to that on the scale of 140 years. Their variance contribution of the fluctuations on long period declines and that on 10–30–year period has a strengthening tendency.

Table 4. The comparisons of maximum statistics in the jump year on the scale of 120 years (I) and 100 years (II)

	Year	T	F	T_d	P_d
(I)	1908	−0.045	1.195	2.449 *	1.684
	1925	1.155	1.771	0.832	2.451 *
	1926	1.024	1.825 *	0.302	2.359
	1929	1.481 *	1.745	−1.019	2.154
(II)	1890	−1.150	1.928 *	4.085	1.732
	1894	1.097	1.732	5.749	3.690 *
	1898	0.818	1.771	6.807 *	2.329
	1925	1.311 *	1.688	−1.184	2.627

The result suggests that most of the jump points occur in the 1920s on the scale of 100 to 140 years. In fact, the jump is found in Beijing's summer precipitation series with the moving average window of 30 years. The average of precipitation was about 500 mm before the 1920s and declined to 400 mm thereafter. The jump point of the average series occurred in 1921 with a significant change from 501.0 mm to 462.4 mm. A great difference in frequency is observed between the anomalous dry and wet stages of 1870–1919 and 1920–1989. The frequency occurred in grade 1 (very wet) and grade 5 (very dry) was 0.04 and 0.14 at the former stage and 0.14 and 0.08 at the latter stage, respectively. They are greater than the climatic probability of the difference in two successive stages.

4. Synthetic index for climatic jump

To represent the common features of the four statistics, the principal factor analysis (PFA)(Huang, 1990) is employed on the standardized matrix consisting of the four statistics. To strengthen the difference among them, the statistics are transformed into their absolute values before the PFA being complete. The first common factor (PF1) represents the main feature as a synthesis index. The second common factor (PF2) represents another synthesis feature. Table 5 displays their variance contributions (V.C.) and maximum values on the scales of 140 years, 120 years and 100 years. Their variance contributions (V.C.) in the PF1s all surpass 80% and the variance contributions for two factors are more than 90%. We can see from the PF1's in Table 5 that there is a maximum in 1914 with the standardized value of 3.746 on the 100–year scale. There is a maximum in 1895 with the standardized value of 2.526 on the 100–year scale (see Fig. 2). The jump points occurred in the 1890s, the 1910s and the 1920s, respectively. The jump points occurred only in the 1920s in the PF2s. In order to get a

Table 5. The comparisons of maximum statistics in some years on PF1 and PF2 curve on the scales of 140 years (I), 120 years (II) and 100 years (III)

	PF1			PF2		
Year	(I)	(II)	(III)	(I)	(II)	(III)
V.C.	0.974	0.857	0.887	0.023	0.124	0.080
1895			2.526			
1914	3.746					
1921				−8.112		
1925						3.278
1927					3.756	
1929		2.893				

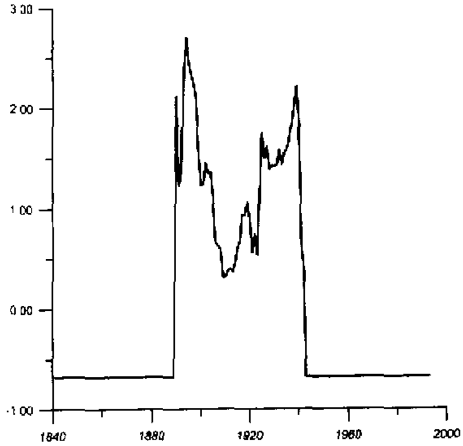

Fig. 2. The curve of synthetic index on the 100–year scale.

synthesis index, we calculate the sum of the absolute values of PF1 and PF2. They represent the synthesis jump of the two common factors. It is found that the maximum values occurred in 1921, 1929 and 1925 on the scales of 140, 120 and 100 years, respectively.

Generally speaking, the climatic jump points of precipitation on the hundred–year scale occurred in the 1890s and the 1920s. The significant jumps in the 1920s have the highest values of the synthetic index.

5. Comparison with other methods

In order to compare the above result with the results of other methods, for example, Mann–Kendall test, *t*–test, and accumulative anomaly, the climatic jump points detected in the same series by those methods are given below.

The Mann–Kendall test is based on the calculation of the rank statistics with forward and backward directions in the series. If the two series of the statistics cross a point within the significant confidence, the point will be a climatic jump point. There is one cross point in 1898 in the summer precipitation series. Its value is −0.168 and within the confidence and is the minimum of the cross values of the two curves.

There are potential climatic jump points occurring at the peak of the curve of accumulative anomaly series. The jump points are in 1894, 1915 and 1925 in the accumulative anomaly series of precipitation series. Their values are 6.262, 5.794 and 6.622, respectively.

Therefore, the results show that the climatic jump points on the hundred–year scale given in Section 3 and Section 4 are similar to the ones detected with other methods.

6. Response to global warming

There is a significant relationship between summer precipitation in Beijing and the Northern Hemisphere temperature (Jones et al., 1989). The correlation coefficient is −0.155 on the sample size of 132 in the period of 1860–1991 and is significant at the level of 5%.

In order to study the relationship of the climatic jump between summer precipitation in Beijing and the Northern Hemisphere temperature, the analysis of jump points for the data of Northern Hemisphere temperature (1860–1991) will follow the same procedure in previous sections. The temporal scale is taken from 120 and 100 years for comparison.

Table 6 shows the variance contributions (V.C.) and maximum values of the first and second principal factors on the scales of 120 years and 100 years. It can also be observed that the variance contributions (V.C.) on 120–year and 100–year scales in PF1s all exceed 90% and the variance contributions for the two factors are more than 99%, which means that the oscillation on the two scales is more prominent in the series of the Northern Hemisphere temperature than in that of precipitation of Beijing. There are maximum values in 1912–1914 on the 100–year scale. They would be the probable jump points. Other jump points are found in 1920–1924 on the 120–year scale. They are very similar to the jump points in the precipitation series. It appears therefore that the local climatic jumps in North China have a simultaneous response to the global warming on the hundred–year scale.

It should be pointed out that the value of P_d statistic series in 1914 and 1921 is 2.009 and 2.415, which represent the maximum difference on 100–year and 120–year scales, respectively. It means that the new statistics of P_d that is proposed in this paper as a representative of the synthetic index is more effective for the detection of the climatic jump. The comparison of the statistics of P_d between summer precipitation in Beijing and the Northern

Hemisphere temperature shows that the fluctuations on long and short scales are reverse. The contribution of the fluctuations on the long scale is enhanced after the jump point in the precipitation series and is alleviated in the Northern Hemisphere temperature series. The distribution of wave numbers in the P_d analysis on the precipitation series and the Northern Hemisphere temperature series is very similar. Their correlation coefficient is 0.76.

Table 6. The comparisons of maximum statistics in some years on PF1 and PF2 curve on the scales of 120 years (I) and 100 years (*II*) using the data of the Northern Hemisphere temperature

	PF1		PF2	
Year	(I)	(II)	(I)	(II)
V.C.	0.980	0.946	0.019	0.050
1912		2.217		
1914				−2.881
1920			−5.258	
1924	3.371			

7. Conclusion

The climatic jumps on different scales are analyzed for the precipitation in Beijing of China in this paper using different decade windows (100–140 years) with different diagnostic methods. New statistics of the difference in variance and spectral distribution in paired samples for detecting climatic jump are proposed. The variance difference, the linear tendency difference, and the difference of power spectral distribution between the period before and after the moving point at the center of the series are compared. The maximums of their absolute value are the probable climatic jump points. The jump points were found in the 1890s, the 1910s and 1920s, and mostly in the 1920s. The synthetic jump indices composed of the moving series of the differences of those diagnostic statistics for precipitation are also proposed. PFA is applied to extracting their common factors. The jump points were also found in the 1890s, the 1910s and 1920s, and mostly in the 1920s. The results are confirmed by comparing with other methods of the detection of climatic jump, such as Mann–Kendall test, t–test, and accumulative anomaly etc.. The results show that the climatic maximum jump in the area occurred mostly in the 1920s. From the results given above, we can draw the conclusion that the local climatic jumps in North China have a simultaneous response to the global warming in the hundred–year scale.

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