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Observed climatic changes in Shanghai during 1873–2002

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Abstract: Variation characteristics of temperature and precipitation in January and July and annual mean temperature and annual precipitation are analyzed with the help of cumulative anomalies, Mann-Kendall analysis and wavelet analysis. The research results indicate that January precipitation presents an increasing trend after 1990, wavelet analysis result suggests that this increasing trend will continue in the near future. The changes of July precipitation present different features. During 1900-1960, July precipitation is in a rising trend, but is in a declining trend after 1960. Wavelet analysis shows that this declining trend will go on in the near future. Temperature variations in Shanghai are in fluctuations with 2 to 3 temperature rising periods. Mann-Kendall analysis indicates that temperature variations have the obvious abrupt change time when compared with precipitation changes in Shanghai during the past 100 years. The abrupt change time of January temperature lies in 1985, and that of July temperature lies in 1931-1933 and annual mean temperature has the abrupt change time in 1923-1930. Except July precipitation, the precipitation in January, temperature in January, July and annual mean temperature, and annual precipitation are also in a rising trend in the near future. The research results in this paper may be meaningful for future further climatic changes of Shanghai and social mitigation of climatic disasters in the future.

Key words: Shanghai; climatic change; wavelet analysis; Mann-Kendall analysis
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Global warming and its possible influences on human society have received increasing concerns from academic circles (Yao *et al*., 1996; Chen, 1987; Zhang *et al*., 2004; Zhang *et al*., 2000). Some scholars paid much more attention to climatic changes during the past 100 years, which are taken as the fundamental factor for predicting future climatic changes (Wang, 1998). Xie *et al*. (2000) preformed wavelet analysis on seasonal temperature and precipitation of Beijing during 1870-1994 and obtained interesting results. Deng *et al*. (1997) analyzed monthly mean temperature and monthly precipitation in Xi'an during 1939-1988 with the help of Morlet analysis.

Shanghai city has a longer and consistent time series of climatic changes of more than 100 years (1873-2002), which provides valuable materials for climatic research in Shanghai region. Many researches concerning Shanghai climatic changes were carried out (Wang, 1962; Xu, 1999), Xu Jialiang (2000) studied two apparent warming periods (1937-1953 and 1987-1999) by analyzing the instrumental data of temperature during 1873-1999 and 1961-1999, and temperature variation characteristics have also studied separately (Xu, 1993). Zhou and Yang (2001) analyzed characteristics of spatial and temporal distributions of precipitation changes of Shanghai region with the precipitation data from Longhua gauging station of Shanghai and those from its neighbouring areas. However, the above mentioned researches just studied one aspect of climatic changes, e.g. temperature or precipitation. Furthermore, climatic conditions are changing over time, esp. the present global warming. Therefore, it is necessary to perform research on Shanghai climatic changes with the help of multiple analysis methods and with data of longer time series of climatic changes. Accumulative difference, Mann-Kendall analysis and wavelet

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analysis will be used to detect the climatic changes in Shanghai, providing good evidences for climatic changes in the Shanghai region and its neighbouring areas.

1 Data and methodology

Data used in this paper are the monthly mean temperature and monthly precipitation during 1873-2002. Temperature and precipitation data during 1873-1950 were provided by the Meteorological Bureau of Shanghai, and those data during 1951-2002 were provided by Chinese Meteorological Administration.

Accumulative difference (Wei, 1999), Mann-Kendall analysis and wavelet analysis were used in this paper. Accumulative difference results were tested for significance at 95% confidence level (Claudia Libiseller, 2002).

Mann-Kendall method assumes the time series under research is stable, independent and random with equal possibility distribution. We assume the time series under study is x_1, x_2, $x_3 \cdots x_n$, m_i denotes the accumulative total of samples that $x_i > x_j$ $(1 \leq j \leq i)$, n is the number of the samples.

Definition of the statistic parameter of d_k is as follows: $d_k = \sum_i^k m_i$ $(2 \leq k \leq N)$. On the condition that the original time series was random and independent, free from correlations between items. The variance and the mean of d_k are defined as follows: $E[d_k] = \frac{k(k-1)}{4}$ and $Var[d_k] = \frac{k(k-1)(2k+5)}{72}$ $(2 \leq k \leq N)$.

Under the above assumption, the definition of statistic index of Z_1 is shown in the following equation: $Z_1 = \frac{d_k - E[d_k]}{\sqrt{\mathrm{var}[d_k]}}$ $(k = 1, 2, 3, \cdots, n)$. Where Z_1 satisfies the normal distribution, given significance level of a, when $|Z_1| > U_a$ (U_a is the value determined by the significance level of a), the time series are determined to have the obvious trend of changes. Computation of Z will be done again based on the adverse sequence of the above mentioned, which means that the m_i is the accumulative total of samples that $x_i > x_j$ $(1 \leq j \leq i)$, n is the number of the samples, but the sequence is from x_n to x_1, then Z_2 will be got.

Wavelet analysis is a kind of powerful tool for digital signal analysis on temporal and frequency field, being the great progress in Fourier Transform (Claudia Libiseller, 2002). The definition of the wavelet in this paper is as follows: suppose $\Psi(t)$ in the following equation is a random one, which has the following characteristics: $\int_R \Psi(t)dt = 0$; $\int_R \frac{|\hat{\Psi}(\omega)|^2}{|\omega|} d\omega < \infty$. Here $\hat{\Psi}(\omega)$ and $\Psi(t)$ are the frequency spectrums, let $\Psi_{a,b}(t) = |a|^{-1/2} \Psi\left(\frac{t-b}{a}\right)$ be the continuous wavelet, and Ψ is the mother wavelet. The continuous wavelet transformation should be: $\omega_f(a, b) = |a|^{-1/2} \int_R f(t)\overline{\Psi}\left(\frac{t-b}{a}\right)dt$. The wavelet used in the present paper is Mexico hap: $\Psi(t) = (1 - t^2) \frac{1}{\sqrt{2\pi}} e^{-t^2/2} - \infty < t < \infty$.

2 Accumulative difference analysis

During the past 120 years, the January temperature in Shanghai is in a rising trend in the three

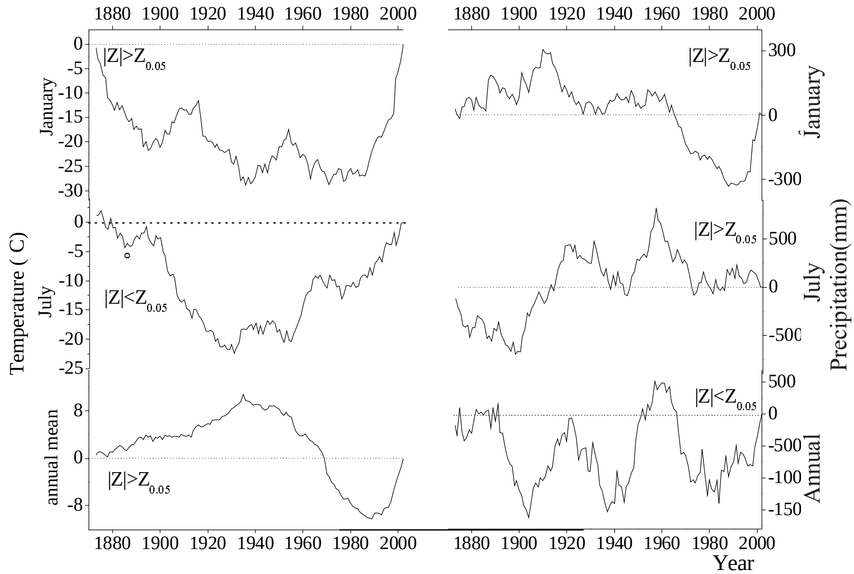

Figure 1 Accumulative anomalies of temperature and precipitation in Shanghai

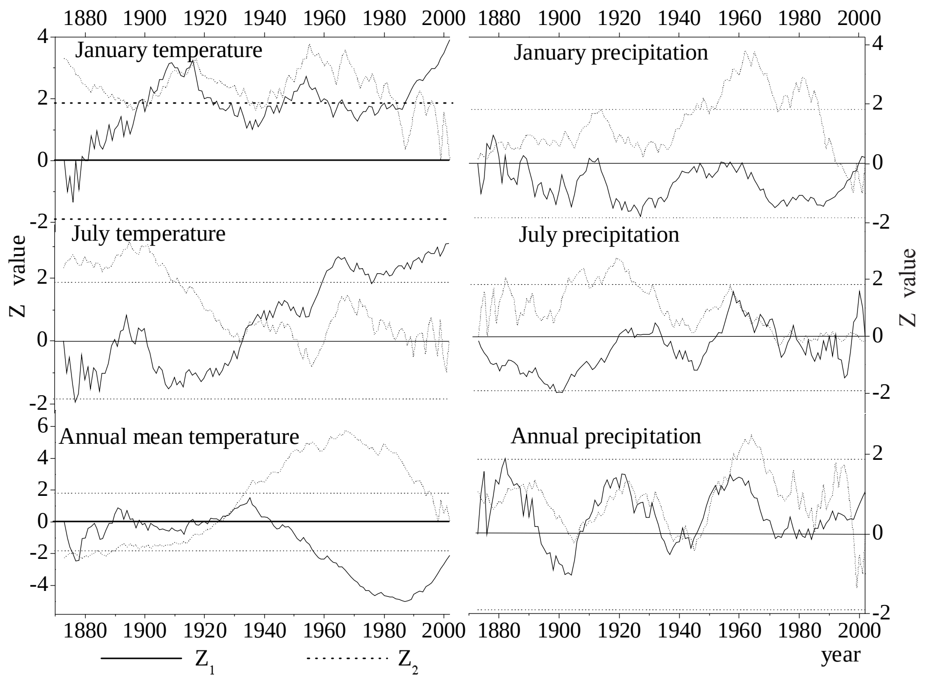

Figure 2 The abrupt changes of temperature and precipitation in Shanghai during 1973-2002

periods of 1900-1905, 1940-1950 and 1990-present. However this rising trend during recent 10 years is significant (at > 95% confidence level). The July temperature however is in a declining trend before 1940 and in a rising trend after 1940, but these trends are not significant at > 95% confidence level. The annual mean temperature is different from January and July temperature variations. The annual mean temperature is in a rising trend before 1935 and during 1990-present and the annual mean temperature is in a declining trend (at > 95% confidence level) during

1935-1990.

It can also be seen from Figure 1 that annual and January precipitation in Shanghai is in a rising trend after 1980 but no trends were detected for July precipitation. As for temperature variations, similar trend changes occur in January and July temperature. Abrupt changes occur during ca. 1900, 1940 and 1980. The July temperature fluctuations are not obvious. While the annual mean temperature shows different changing patterns, there are altogether two periods showing the rising temperature trends, one starting after 1870 and another after 1990.

3 Analysis of abrupt changes

Figure 3 indicates that temperature variations have more obvious patterns when compared with precipitation changes. The abrupt change time of January temperature variations is ca. 1985, and that for July temperature is ca. 1930, and that for annual mean temperature is ca. 1920. Another, Z curve indicates that, after 1990, significant rising trend occurred in January and July temperature (at > 95% confidence level), which is in good line with accumulative difference analysis results of temperature variations (Figure 1). No significant trend changes occur to precipitation changes (Figure 2).

4 Wavelet analysis

Precipitation in Shanghai makes 12 years as its main period, the high-frequency fluctuation with period less than 12 years is more complex (Figure 3). Low-frequency oscillation with a period over 12 years is more regular, with changing patterns of positive and negative time intervals. If we take difference analysis, accumulative difference analysis and abrupt change analysis and wavelet transform into consideration, we can see that the positive wavelet coefficient corresponds to the rising precipitation changes and the minus wavelet coefficient corresponds to the declining precipitation changes, and dense wavelet coefficient contours correspond to time series with intense changes, and vice versa.

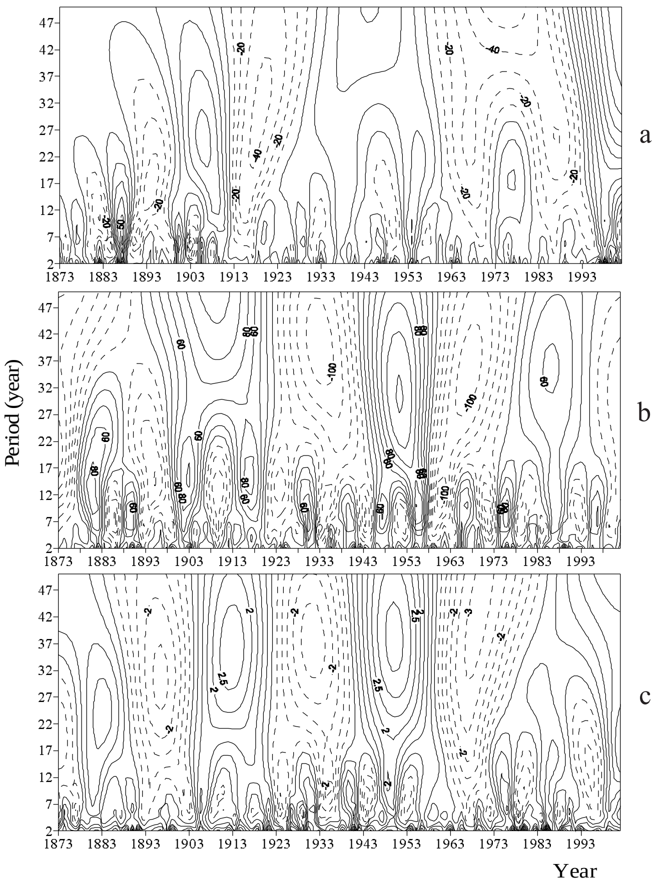

Figure 3 Wavelet analysis of precipitation in January (a), July (b) and annual (c) in Shanghai during 1873-2002

Figure 3A indicates that, during 1886-1888 and 1995-1997, the figures show dense wavelet coefficient contours with the largest wavelet coefficient, showing the intense changes of precipitation, which present as intersection points of Z_1 and Z_2 curves. Figure 3B indicates that changes of July precipitation are dominated by low-frequency fluctuations with alternative positive and negative wavelet coefficient regions (Figure 3B). During 1943-1958, the dense wavelet coefficient contours show a strong rising precipitation trend, and during 1900-1918 and 1978-1990, the rising precipitation trend is not strongly reflected by sparse wavelet coefficient contours. Changes of annual precipitation show different changing patterns. High-frequency fluctuations indicate shorter periods over time, that means the precipitation has the rising trend if viewing from shorter periodicity. Wavelet transform of January and annual precipitation shows that there is a positive wavelet coefficient region after 2000, showing a continuous rising trend of precipitation after 2000.

Wavelet transform of temperature variations shows that strong fluctuations occur in a short period relating to temperature variations (Figure 4). No obvious low-frequency oscillations occur in July and annual mean temperature variations . Low-frequency wavelet coefficient contours of January temperature are sparse, showing no intense changes of high-frequency temperature variations occur, similar phenomenon also occurs in low-frequency variations. If viewing from longer periodicity, after 1996-1998, stronger rising trend occurs in temperature variations. For if this positive wavelet coefficient region is not closed, then the rising trend will continue in the future. July temperature variations have the stronger rising or declining trend when compared with January temperature variations with obvious high-frequency oscillations. July temperature is in rising trend most of the time during the past 100 years, having longer period of rising trend alternated with shorter period of declining trend.

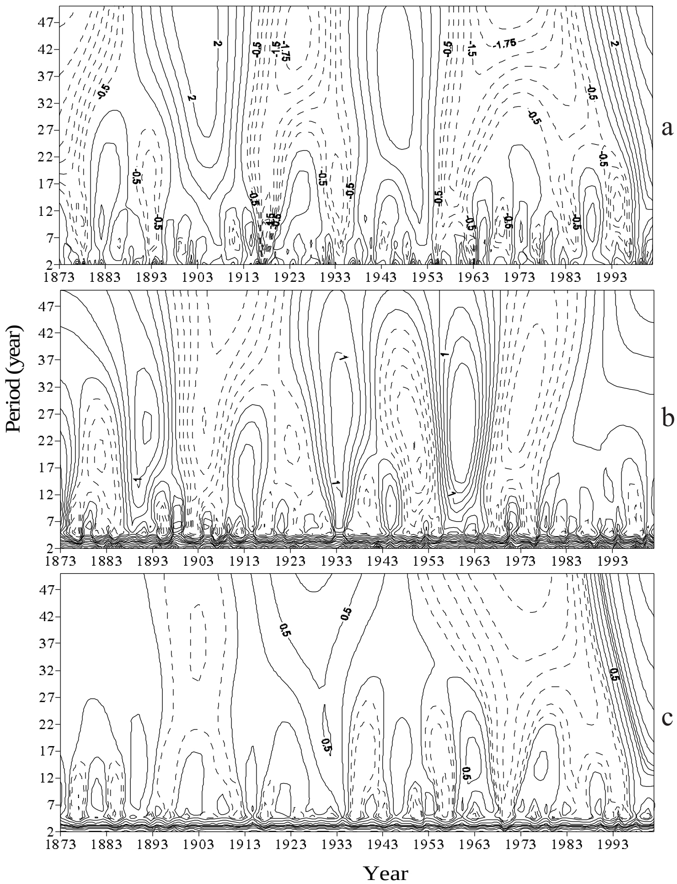

Figure 4 Wavelet analysis of the mean temperature in January (a), July (b) and annual (c) in Shanghai during 1873-2002

Less intense changes occurred in annual mean temperature when compared to January and July temperature variations, represented by sparse wavelet coefficient contours. After 1995-1997, more significant rising trends occurred in annual mean temperature variations in open positive wavelet coefficient region, showing this rising trend will continue in the future.

5 Summary

Some viewpoints were drawn from the above mentioned research:

(1) January precipitation is in a declining trend during 1900-1990 with minor rising changes. After 1990, wavelet transform of January precipitation changes shows open wavelet coefficient regions, suggesting continuous rising precipitation trend in the future. July precipitation shows

different changing patterns. During 1900-1960, July precipitation is in a rising trend; after 1960, it is in a declining trend. Relatively complex changing patterns occurred in annual precipitation, showing greater changes. Climate change analysis indicates that precipitation in Shanghai shows no obvious abrupt change time.

(2) January temperature variations show three periods with a rising trend: 1) in ca. 1900; 2) in ca. 1940; 3) in ca. 1980. July temperature variations show no obvious changing patterns. July temperature shows significant rising trend after 1960. While annual mean temperature shows different changing patterns if compared with January and July temperature, with two periods characterized by rising trends: 1) after 1870; 2) after 1990, and during 1940-1990, annual mean temperature in Shanghai is in slight declining trend. Another temperature variations have the obvious abrupt change time: the abrupt change time for January temperature is ca. 1985, the abrupt time for July temperature is during 1931-1933, and that for annual mean temperature is during 1923-1930.

(3) Based on the limited climatic data, January, July and annual precipitation, January, July and annual mean temperature were analyzed. However, the research results will be helpful for further understanding climatic changes in the Shanghai region and also for its neighbouring areas.

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