Theoretical and Applied Climatology
https://doi.org/10.1007/s00704-018-2522-5

ORIGINAL PAPER

Spatial and temporal stability of temperature in the first-level basins of China during 1951–2013

Yuting Cheng[1] · Peng Li[1] · Guoce Xu[1] · Zhanbin Li[1] · Shengdong Cheng[1] · Bin Wang[1] · Binhua Zhao[1]

Received: 4 February 2018 / Accepted: 20 May 2018

Abstract

In recent years, global warming has attracted great attention around the world. Temperature change is not only involved in global climate change but also closely linked to economic development, the ecological environment, and agricultural production. In this study, based on temperature data recorded by 756 meteorological stations in China during 1951–2013, the spatial and temporal stability characteristics of annual temperature in China and its first-level basins were investigated using the rank correlation coefficient method, the relative difference method, rescaled range (R/S) analysis, and wavelet transforms. The results showed that during 1951–2013, the spatial variation of annual temperature belonged to moderate variability in the national level. Among the first-level basins, the largest variation coefficient was 114% in the Songhuajiang basin and the smallest variation coefficient was 10% in the Huaihe basin. During 1951–2013, the spatial distribution pattern of annual temperature presented extremely strong spatial and temporal stability characteristics in the national level. The variation range of Spearman's rank correlation coefficient was 0.97–0.99, and the spatial distribution pattern of annual temperature showed an increasing trend. In the national level, the Liaohe basin, the rivers in the southwestern region, the Haihe basin, the Yellow River basin, the Yangtze River basin, the Huaihe basin, the rivers in the southeastern region, and the Pearl River basin all had representative meteorological stations for annual temperature. In the Songhuajiang basin and the rivers in the northwestern region, there was no representative meteorological station. R/S analysis, the Mann-Kendall test, and the Morlet wavelet analysis of annual temperature showed that the best representative meteorological station could reflect the variation trend and the main periodic changes of annual temperature in the region. Therefore, strong temporal stability characteristics exist for annual temperature in China and its first-level basins. It was therefore feasible to estimate the annual average temperature by the annual temperature recorded by the representative meteorological station in the region. Moreover, it was of great significance to assess average temperature changes quickly and forecast future change tendencies in the region.

1 Introduction

Over the last 100 years, the most prominent feature of global climate change has been the significant rise in temperature. The fifth Intergovernmental Panel on Climate Change (IPCC) report pointed out that the average global surface temperature has risen by about 0.85 °C over the past 130 years. During 1983–2012, the rate of increase in global temperature has been the highest in the last 1400 years. The rate and extent of climate warming are becoming drastic as never before (IPCC 2013). The second National Assessment Report on Climate Change stated that the average land surface temperature rose by 1.38 °C during 1951–2009 in China. Hence, the climate variation trend in China is stronger than the average warming rate all over the world (Compilation Committee of the Second National Assessment Report on Climate Change 2011). The main reason for rapid global warming is enhancement of the greenhouse effect caused by increasing greenhouse gas content (Liu et al. 2005; Peng et al. 2009; Wang et al. 2011). However, at different regional and temporal scales, obvious differences exist in the temperature change trend. The temperature change range in winter is larger than that in summer (Fang et al. 2010; Yu et al. 2011) and is related to latitude; the higher the latitude, the faster is the warming rate (Lu et al. 2006; Song et al. 2012). The spatial pattern of global temperature change during 1979–2005 quarter-by-quarter shows an obvious rising trend for seasonal

✉ Guoce Xu
xuguoce_x@163.com

[1] State Key Laboratory of Eco-hydraulics in Northwest Arid Region of China, Xi'an University of Technology, Xi'an, Shaanxi 710048, People's Republic of China

Published online: 31 May 2018

temperature in some regions, such as Western North America, Northern Europe, and China in winter and Europe, Eastern Asia, and Northern Asia in summer. In parts of certain regions, a downtrend appears, for example, in the mid-latitude region of the Southern Hemisphere and Eastern Canada in spring (Trenberth et al. 2007). The geographical distribution and regional characteristics of temperature change in China during 1951–2010 show that temperatures in all regions of China are on the rise, but that the warming processes in various regions are out of sync (Han et al. 2013). In the past 10 years, research on historical climate change in China has achieved certain successes in alternative evidence collection and analysis, reconstruction series and change feature analysis, numerical simulation and mechanism diagnosis, and the effect of climate change on the social economy (Hao et al. 2012; Shi et al. 2012; Yao et al. 2013; PAGES 2013). However, the observed facts of climate change and the reasons underlying them are a very complex problem. It is still necessary to carry out further research on many aspects. Moreover, temperature changes play an important and unique role in the development of agriculture and social economy (Lorenzoni et al. 2000; Shi et al. 2009; Moral et al. 2016; Sun et al. 2017). Many public policies including agriculture, social economy, and energy at present China are based on the past data to today's forecast, and in the new weather conditions, these are not appropriate anymore. So, we must readjust the related policy in order to adapt the external changes, which directly affects the social economy. Therefore, climate change is a hot topic at the moment (Río et al. 2007; Savić et al. 2015).

The concept of temporal stability was proposed by Vachaud et al. in 1985 for the first time, citing the relatively stable spatial pattern of soil moisture with time. They held that a specific position could represent the average value in a region over a period of time (Vachaud et al. 1985). Later, other researchers verified the phenomenon (Grayson and Western 1998; Brocca et al. 2009; Hu et al. 2010; Xu et al. 2016). The concept of temporal stability can greatly reduce the number of samples required to characterize soil moisture content. It also provides the main upscaling method to estimate soil moisture and can interpolate missing data (Vanderlinden et al. 2012). Some researchers have applied the concept of temporal stability to other soil characteristics. For example, Douaik (2006) and Castrignanò et al. (1993) found that soil salinity and soil electric conductivity also had excellent temporal stability characteristics. Xu et al. (2015) showed that the conductivity of underground water in the Luohui irrigation district possessed strong temporal stability and periodicity. The representative variable of groundwater conductivity can be used to confirm irrigation time in the irrigated area quickly and accurately. Because the spatial distribution of temperature data in the historical period is relatively sparse, in a research study on temperature problems, some researchers apply data from a station with records to a neighboring region without records. The year-round change process is indicated by the seasonal temperature; otherwise, the temperature change in the climatic zone is reconstructed by the alternative temperature series of a single station (Ge et al. 2003; Ge et al. 2006; Wang et al. 2007; Yan et al. 2012). However, at present, there have been few reports on the temporal stability of temperature. In particular, a representative meteorological station for temperature confirmed on the basis of temporal stability has not been reported. Therefore, the results of this study can provide a reasonable argument for reconstruction of a temperature series using one or several stations inside the region, especially to the regional average temperature.

2 Data sources and methods

2.1 Data sources

In 2002, a hierarchical data set of a first-level basin at a scale of 1:25 ten thousand in China was obtained from the Earth System Science Data Sharing Platform-Lake Catchment Science Data Sharing Platform. Based on the basic geographic data at 1:25 ten thousand scale in China in 2002, the data for first-level basins, such as name and codification, were extracted by the data set. The first-level basins in China were divided into ten: the Songhuajiang basin, the Liaohe basin, the Haihe basin, the Huaihe basin, the rivers in the southeastern region, the Yellow River basin, the Yangtze River basin, the Pearl River basin, the rivers in the northwestern region, and the rivers in the southwestern region (Fig. 1).

The temperature data were derived from the data set of annual surface climate data in China and the Chinese meteorological data sharing service system. The data set was the annual data set of climatic data recorded by 756 basic and standard ground-based meteorological stations and automatic stations in China since 1951.

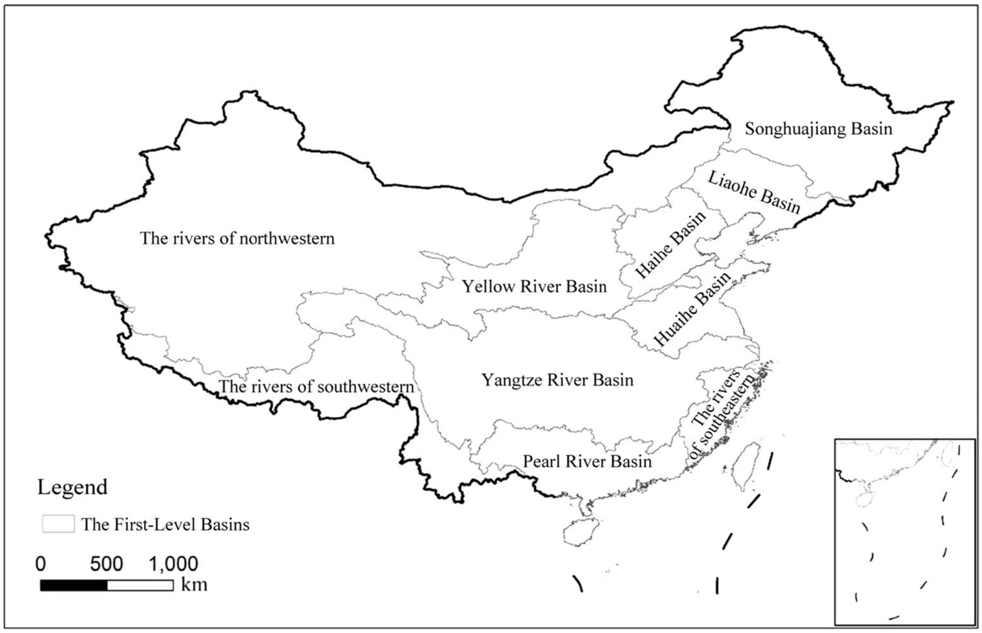
2.2 Analysis method

Spearman's rank correlation is a correlation analysis method that can explain the temporal stability of annual average temperature with numerous sampling locations (Vachaud et al. 1985; Xu et al. 2015). Spearman's nonparametric test has been widely used to evaluate the temporal persistence of spatial patterns (Martínez-Fernández and Ceballos 2005). Spearman's rank correlation coefficient (r_s) was calculated as follows (Vachaud et al. 1985):

$$r_s = 1 - \frac{6\sum_{i=1}^{n}\left(R_{ij}-R_{ik}\right)^2}{n\left(n^2-1\right)} \quad (1)$$

where R_{ij} is the rank of temperature measured at location i at

Fig. 1 The first-level basin in China



time j, R_{ik} is the rank of temperature measured at the same location i at time k, and n is the total number of meteorological stations. The value of r_s ranges from − 1 to 1; the closer the r_s value to 1, the stronger the temporal stability of the average annual temperature spatial pattern, and the closer the r_s value to 0, the weaker the temporal stability (Douaik 2006).

The relative difference δ_{ij} at location i ($i = 1,\ldots, n$) at time j ($j = 1951,\ldots, 2013$) was introduced to assess temporal stability, and δ_{ij} was expressed as

$$\delta_{ij} = \frac{P_{ij} - \overline{P_j}}{\overline{P_j}} \quad (2)$$

The mean relative difference (MRD) and the standard deviation of relative difference (SDRD) for each location were used to determine the representative location of the mean temperature and the most temporally stable location. Locations with MRD near zero and low SDRD were usually selected as representative locations to evaluate the annual average temperature of the region, and the value of MRD can be regarded as close to 0 and ± 0.05 (Gao and Shao 2012). The t-test was used to test whether the difference between the annual temperature of the representative location and the regional average temperature was significant.

The Hurst coefficients can reveal the trend of the time series of climatic elements (Feng et al. 2009). When $0.5 < H < 1.0$, the long-term correlation of the time series is persistent, indicating that future climate change will be consistent with past trends, and the closer the H value to 1, the stronger the persistence. When $0.0 < H < 0.5$, the long-term correlation of the time series is anti-persistent, indicating that the general trend of climate change in the future is contrary to the past, and the closer the H value to 0, the stronger the anti-persistence. When H is equal to 0.5, the trend is diffusive; that is, the climate elements are completely independent, and climate change is random. The Hurst coefficient values were calculated by rescaled range (R/S) analysis in this study. To analyze the changes and trends of annual average temperature, the nonparametric Mann-Kendall trend test was used.

Wavelet analysis is an effective method for analyzing the multiple-timescale variation of annual temperature. Wavelet analysis was used here to analyze the multiscale characteristics of the data. The Morlet wavelet transform was used to analyze the periodicity of annual temperature. The Morlet wavelet function is defined as (Grossman and Morlet 1984)

$$g(t) = e^{s2\pi f_0|t|} \cdot e^{-|t|^2/2} \quad (3)$$

where s is an imaginary unit, f_0 is the wavelet function center frequency, and t is time.

3 Results and analysis

3.1 Temporal change characteristics of annual average temperature in China

Table 1 shows the statistical characteristics of annual average temperature in China and its first-level basin during 1951–2013. The average temperature was 11.1 °C in China during 1951–2013. The maximum temperature in China occurred on a coral island in Hainan in 1998, whereas the minimum occurred in Tianchi, Xinjiang, in 1969. According to the classification system of Nielsen and Bouma (1985), defining weak

Table 1 The statistical characteristics of the annual average temperature (°C) in China and its first-level basin during 1951–2013

Region	Number of sites	The annual average temperature	Maximum value (site/year)	Minimum value (site/year)	CV (%)
The national level	735	11.1	27.9 (Coral Island/1998)	− 8.6 (Tianchi/1969)	61
Songhuajiang basin	65	2.4	7.7 (Changchun/2007)	− 6.9 (Tuli River/1969)	114
Liaohe basin	40	7.5	12.3 (Dalian/2007)	1.2 (Changbai/1965)	24
Haihe basin	38	10.4	15.5 (Xinxiang/2006)	− 5.3 (Wutai Mountain/1956)	35
Huaihe basin	46	14.0	17.2 (Luan/2006)	10.0 (Chengshantou/1969)	10
Yellow River basin	90	7.5	15.8 (Jinghe River/2013)	− 5.5 (Mardo/1965)	55
Yangtze River basin	180	14.2	23.2 (Yuanmou/1960)	− 7.3 (Toto river/1985)	36
The rivers in the northwestern region	111	6.0	16.3(Turpan/2007)	− 6.4 (Bayanbulak/1984)	68
The rivers in the southwestern region	57	10.1	24.8 (Yuanjiang/2012)	− 3.4 (Naqu/1963)	72
The rivers in the southeastern region	36	17.7	22.6 (Zhangzhou/2007)	8.1 (Tianmu Mountain/1976)	15
Pearl River basin	72	20.7	27.0 (Sanya/1998)	13.1 (Anshun/1976)	13

CV is the mean value of coefficient of variation for annual average temperature

variability as CV ≤ 10%, intermediate variability as 10% < CV < 100%, and strong variability as CV ≥ 100%, the variation coefficient of temperature in the national level was 61%, which belongs to the intermediate variability class. In China, the lowest average temperatures occurred mainly in the Songhuajiang basin, the annual average temperature was 2.4 °C, and the variation coefficient was 114%, which is in the strong variability class. In the Pearl River basin, the annual average temperature was the highest (21.6 °C), and the variation coefficient was 13%, which belongs to the intermediate variability class. In the Yangtze River and Yellow River basins, the average temperatures were 14.2 and 7.5 °C, respectively, and the maxima appeared in the Jinghe River and in Yuanmou, respectively. In the two basins, the variation coefficients of annual temperature both belong to the intermediate variability class. Among the first-level basins, the largest variability coefficient is 114% in the Songhuajiang basin, and the smallest is 10% in the Huaihe basin, which belongs to the weak variability class.

3.2 Analysis of spatial and temporal stability of annual average temperature in China

Spearman's rank correlation coefficient can confirm the similarity of the spatial patterns of annual temperature at the meteorological stations of China in different months and strongly reflects the continuity and similarity of the spatial patterns of annual temperature over time. Figure 2 shows Spearman's rank correlation coefficients of annual temperature at the meteorological stations of China during 1951–2013. In China, Spearman's rank correlation coefficients of annual temperature range from 0.97 to 0.99, and at the level of $p < 0.01$, all r_s values are significantly related and relatively close to 1. This suggests that the spatial distribution pattern of annual temperature in China presents extremely strong temporal stability characteristics. However, some variability still exists in the spatial annual temperature distribution pattern in China. Low values of r_s mainly occurred during 1951–1954, indicating relatively larger temperature changes and worse temporal stability in China in the early 1950s. The Mann-Kendall trend test shows an increasing trend for the spatial distribution pattern of temperature during 1951–2013 in China ($p < 0.05$).

3.3 Recognition of representative position for annual average temperature

Figure 3 shows the MRD values of annual temperatures and the corresponding standard deviations in China and the first-level basins. The main goal of temporal stability analysis of annual

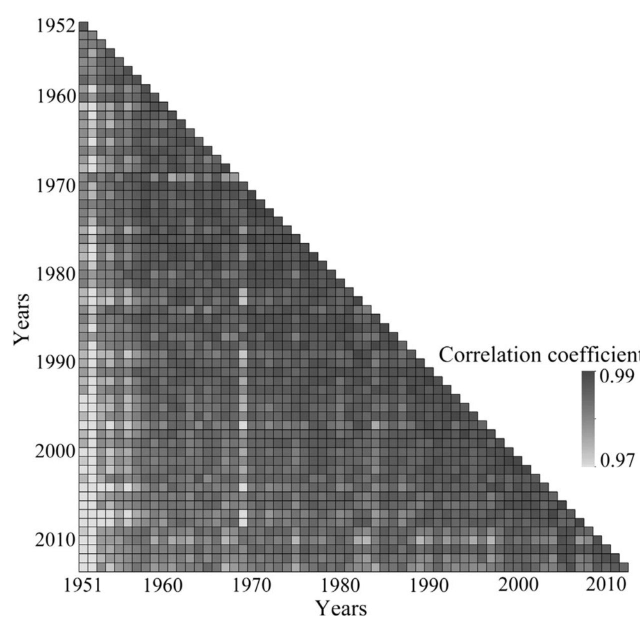


Fig. 2 Spearman's rank correlation coefficients of the annual average temperature of China during 1951–2013

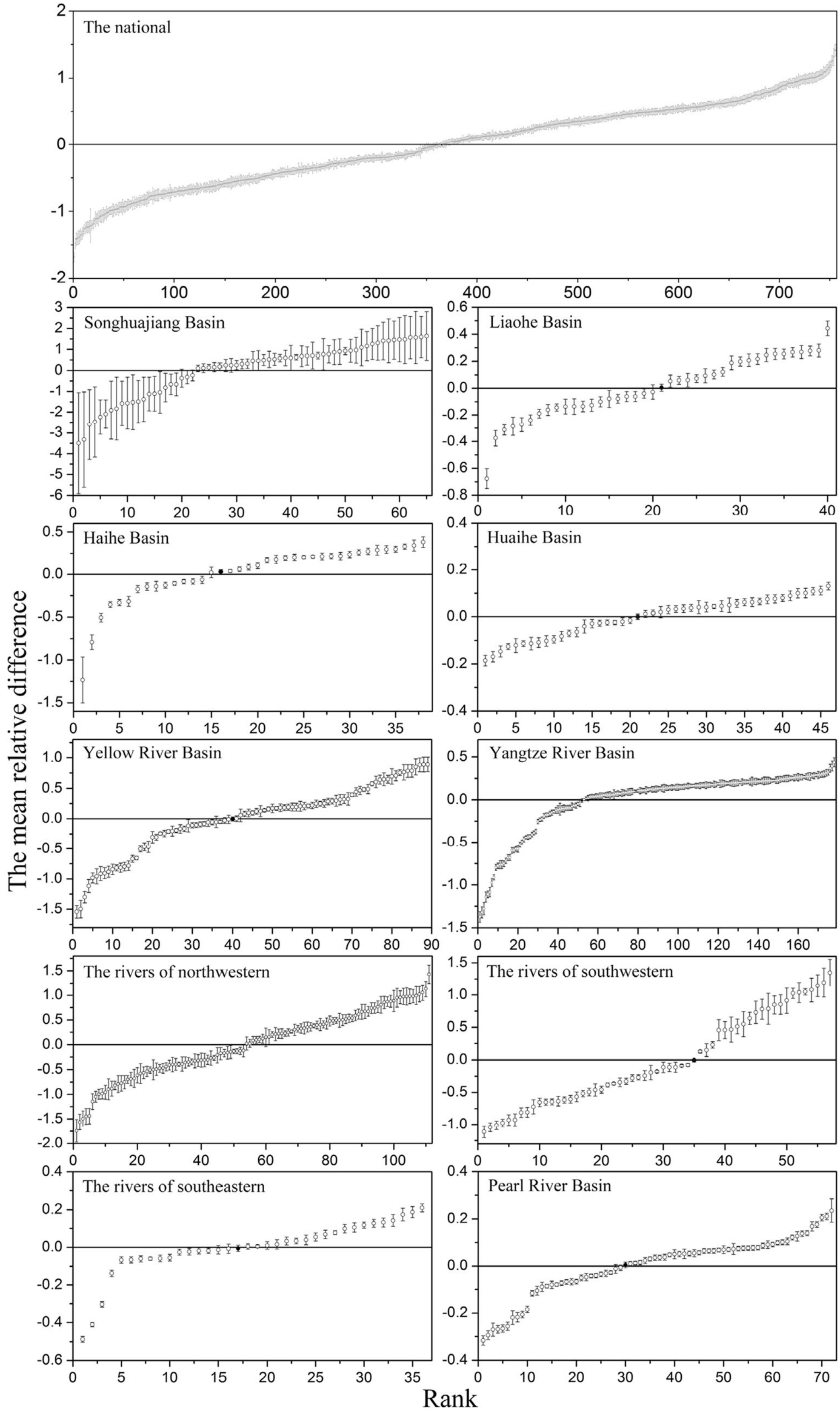


Fig. 3 Mean relative difference of annual temperature in China and the first-level basins

temperature is to confirm quantitatively the most representative position for annual temperature in the region. In the national level, for the Songhuajiang basin, the Liaohe basin, the Haihe basin, the Huaihe basin, the rivers in the southeastern region, the Yellow River basin, the Yangtze River basin, the Pearl River basin, the rivers in the northwestern region, and the rivers in the southwestern region, the range of MRD of annual temperature was 3.10, 5.13, 1.12, 1.62, 0.32, 0.70, 2.57, 1.90, 0.55, 3.17, and 2.46 and the range of SDRD was 0.23, 2.31, 0.05, 0.25, 0.02, 0.03, 0.14, 0.06, 0.04, 0.20, and 0.22, respectively. The ranges of MRD and SDRD reached their maximum in the Songhuajiang basin and their minimum in the Huaihe basin. This is identical with the change trends of the variation coefficient of annual temperature in the basins. The range of MRD of annual temperature is related to the basin area on the one hand and to the relatively small spatial variability of basin terrain and vegetation on the other.

Using the relative difference method, the representative meteorological stations in China and its first-level basins were identified. In other words, for each basin, the meteorological station with MRD equal or close to 0 and a relatively small SDRD was selected as the representative station to estimate the annual average temperature in the whole basin (Bai and Shao 2011). Under this condition, the average relative difference deviates by 5% from the mean value. Starks et al. (2006) claimed that when the SDRD of a sample was lower than 5%, the point could be considered to be temporally stable. In accordance with this principle, in the national level, the Liaohe basin, the rivers in the southwestern region, the Haihe basin, the Yellow River basin, the Yangtze River basin, the Huaihe basin, the rivers in the southeastern region, and the Pearl River basin each contain most representative meteorological stations for annual temperature, and their numbers are 19, 2, 1, 2, 1, 10, 19, 14, and 16, respectively. Among the representative monitoring stations, the meteorological stations with MRD closest to 0 and smallest SDRD were selected as the best representative meteorological stations. In the national level, the Liaohe basin, the rivers in the southwestern region, the Haihe basin, the Yellow River basin, the Yangtze River basin, the Huaihe basin, the rivers in the southeastern region, and the Pearl River basin were all found to have best representative meteorological stations for annual temperature, which are Tikanlik, Zhangwu, Gajah, Leting, Haiyuan, Jinggangshan, Heze, Wuyishan, and Liuzhou. The MRD of annual temperature was − 0.01, 0.00, − 0.01, 0.03, 0.00, 0.00, 0.00, 0.01, and 0.00, and the SDRD was 0.03, 0.03, 0.02, 0.03, 0.03, 0.01, 0.01, 0.01, and 0.01, respectively. However, there is no representative meteorological station for temperature in the Songhuajiang basin or among the rivers in the northwestern region. This indicates that the number of representative meteorological stations for annual temperature is independent of the number of regional meteorological stations, but it should be associated with the location of the meteorological station. The location of the representative meteorological station for annual temperature should possess regional average characteristics.

3.4 Estimation accuracy of the most representative position

To test the estimation accuracy of the best representative meteorological station for annual temperature in China and its first-level basins, the root-mean-square error (RMSE), mean absolute error (MAE), and coefficient of determination (R^2) were used (Fig. 4). The coefficient of determination (R^2) in China and its first-level basin ranges from 0.70 to 0.93, and the fitting equations are all extremely significantly correlated with each other at the level of $p < 0.01$. MAE and RMSE vary in the 0.09–0.31 range and the 0.00–0.41 range, respectively. The first-level basin with the maximum MAE and RMSE is the Haihe basin. The *t*-test shows that the annual temperatures of representative meteorological stations in China and its first-level basins have no significant difference from the annual average temperatures in the region ($p > 0.05$). This indicates that it is feasible to estimate the annual average temperature in a region by the annual temperature of its representative meteorological station.

3.5 Change trend analysis of annual average temperature

Table 2 shows the Hurst coefficient and Mann-Kendall test results for the national-level and the first-level basins and for the best representative meteorological stations. There is little difference between the Hurst coefficients at the best representative meteorological stations and in their corresponding regions. In the regions and stations, H values are all greater than 0.5. This shows that the overall trend of annual temperature change in the future will be similar to that in the past; the closer the H value to 1, the stronger the continuity.

The Mann-Kendall trend test was carried out for the national-level and the first-level basins and for the best representative meteorological stations. The results show that the annual temperature in Heze, Yangtze River basin, and the best representative meteorological station in the Jinggangshan changes significantly ($p < 0.05$) and shows an extremely significant change relative to the other first-level basins and their best representative meteorological stations ($p < 0.01$). According to the significance results for the Hurst coefficient and the Mann-Kendall trend test, aside from the decreasing trend in the rivers in the northwestern region, the future annual temperature shows an increasing trend in the other first-level basins and their best representative meteorological stations. From the anomaly variation of annual temperature in the first-level basins (Fig. 5), it can be concluded that a certain difference and fluctuation exist in the anomaly of each first-

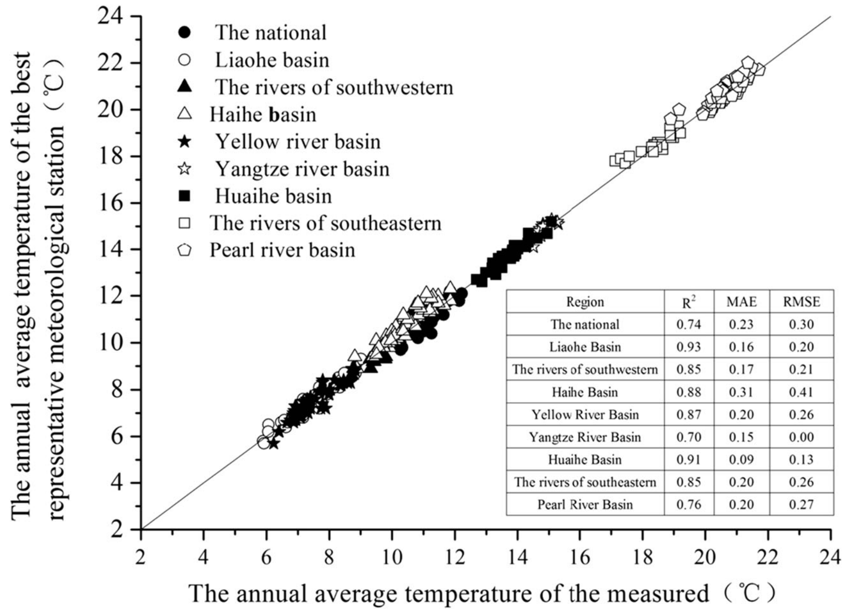


Fig. 4 Plots of estimates at the best representative locations versus measured average annual temperature for China and its first-level basins

level basin year by year, whereas most anomalies fluctuate in the range of ± 20%. Except for the decreasing trend in the rivers in the northwestern region, the anomaly variation of annual temperature shows a rising trend in the rest of the first-level basins. This is consistent with the analytical results of the trend test. In the rivers in the southwestern region and its best representative meteorological station in Gajah, some differences exist in the temperature trend change, which are mainly due to different temperature time series in the rivers in the southwestern region. Therefore, the best representative meteorological station can reflect the change trend of annual temperature in the region.

Table 2 The Hurst coefficient and Mann-Kendall test results and future trends (1951–2013)

Region	H	R^2	Historical trends	The temperature mutation year	Future trends
The national level	0.9847	0.9925	Increasing (extremely significant)	1997	Increasing
Tikanlik	0.9664	0.8917	Increasing (extremely significant)	1989	Increasing
Songhuajiang basin	0.9561	0.8242	Increasing (extremely significant)	1985	Increasing
Liaohe basin	0.9183	0.9189	Increasing (extremely significant)	1981	Increasing
Zhangwu	0.8387	0.8851	Increasing (extremely significant)	1982	Increasing
Haihe basin	0.8878	0.8711	Increasing (extremely significant)	1987	Increasing
Leting	0.9766	0.9287	Increasing (extremely significant)	–	Increasing
Huaihe basin	0.8255	0.9034	Increasing (extremely significant)	1988	Increasing
Heze	0.6513	0.8554	Increasing (significant)	1990	Increasing
Yellow River basin	0.9717	0.2393	Increasing (extremely significant)	1997	Increasing
Haiyuan	0.9701	0.9545	Increasing (extremely significant)	1993	Increasing
Yangtze River basin	0.9852	0.9941	Increasing (significant)	2000	Increasing
Jinggangshan	0.9861	0.9833	Increasing (significant)	1999	Increasing
The rivers in the northwestern region	0.9321	0.9722	Increasing (extremely significant)	1995	Increasing
The rivers in the southwestern region	0.9441	0.9908	Decreasing (extremely significant)	–	Decreasing
Gajah	0.8101	0.8802	Increasing (extremely significant)	–	Increasing
The rivers in the southeastern region	0.8771	0.9233	Increasing (extremely significant)	1994	Increasing
Wuyishan	0.9983	0.9873	Increasing (extremely significant)	1995	Increasing
Pearl River basin	0.7815	0.9144	Increasing (extremely significant)	–	Increasing
Liuzhou	0.8441	0.9075	Increasing (extremely significant)	–	Increasing

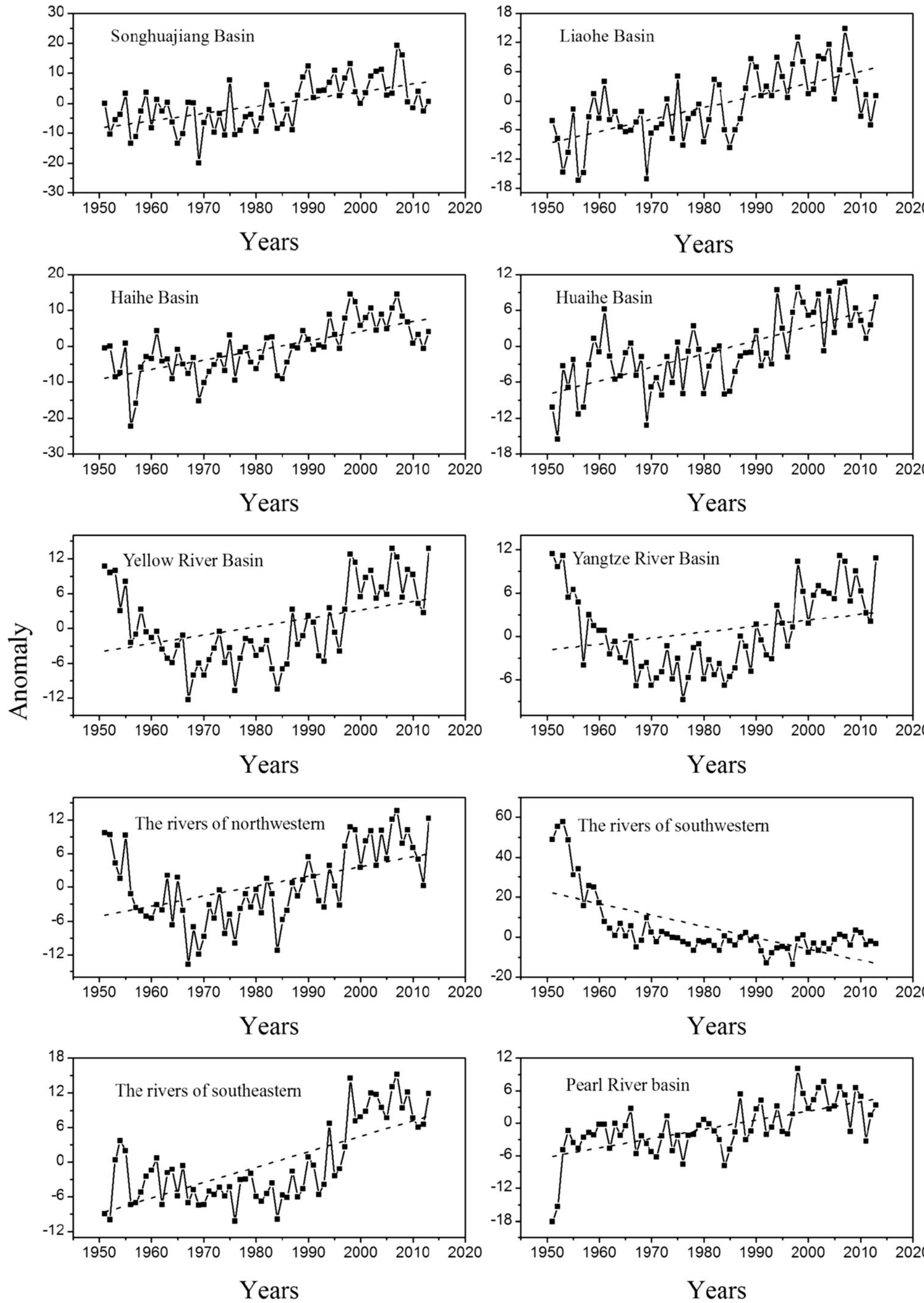


Fig. 5 Anomaly variation of annual temperature in the first-level basins

3.6 Timescale characteristics of annual average temperature change

Based on the Morlet wavelet transform, the periodicity of annual temperature series in the national-level and the first-level basins and their best representative meteorological stations was analyzed. With the timescale as abscissa and the wavelet variance as ordinate, a wavelet variance diagram of the annual temperature series was obtained (Fig. 6). The wavelet variance diagram reflects the variation of annual temperature series with timescale and can confirm the primary period of the change in the annual temperature series. In the national-level and the first-level basins, two obvious peaks exist for all the annual temperature series: 1974–1977 and 1991–1995. The maximum peak of wavelet variance appeared during 1991–1995. This shows that the periodicity of annual temperature was the strongest during this period, which was the first primary period of change in the annual temperature series in the national-level and the first-level basins. The minimum peak of wavelet variance was during 1974–1977, which

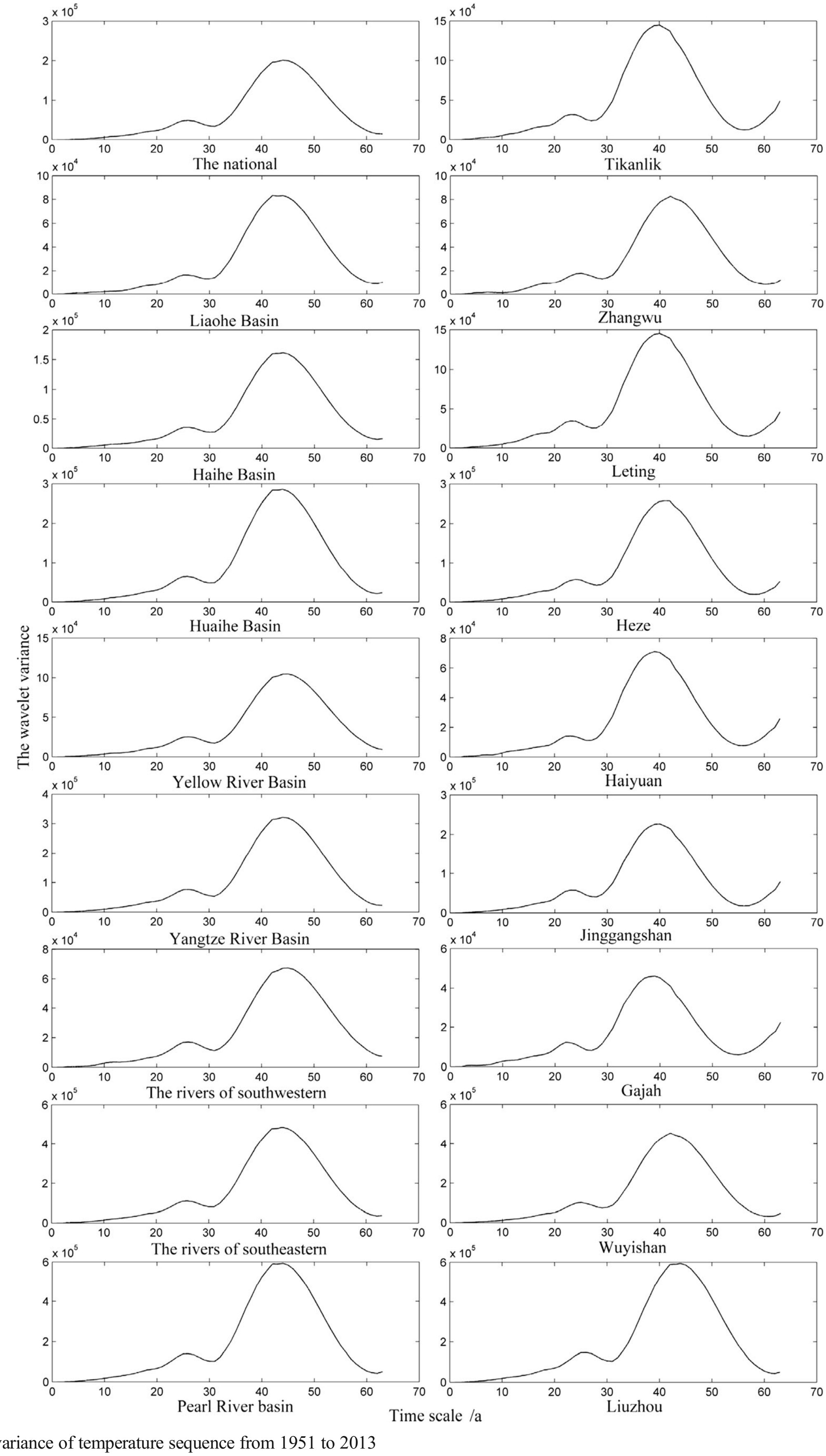


Fig. 6 Wavelet variance of temperature sequence from 1951 to 2013

was the second primary period of the change in the annual temperature series. In the national-level and the first-level basins, the first and second primary periods of the best representative meteorological stations were 1989–1993 and 1972–1975, respectively. There was some difference between the first and second primary periods and the primary period in the national-level and the first-level basins, but the difference was smaller. Therefore, the best representative meteorological station can well reflect the main periodic change of annual temperature series in the corresponding region.

4 Discussion

The temperature data were derived from 756 basic and standard ground-based meteorological stations and automatic stations, but during the annual temperature analysis in the national level, several stations far away from the land were not used, and only 735 meteorological stations were included. Spearman's rank correlation analysis showed a relatively large change in the spatial distribution pattern of annual temperature in some years in the national level, but the proportion of the change in temporal stability of annual temperature was less than 20%. Overall, the spatial distribution pattern of annual temperature presents extremely strong temporal stability characteristics in the national level. In an effort to recognize representative positions in the national-level and the first-level basins, it was found that a representative position does not exist in all ten first-level basins; the rivers in the northwestern region and the Songhuajiang basin had no representative position. This suggests that the representative meteorological station is closely associated with spatial position. The more uniform the spatial distribution of stations, the greater the probability that a representative meteorological station exists and the higher the estimation accuracy for the best representative meteorological station. In the national level and at the best representative meteorological stations of the Yangtze River and Pearl River basins, the coefficients of determination are lower ($0.7 < R^2 < 0.8$). This does not necessarily mean that the best representative meteorological station cannot represent the annual temperature in the region (Cosh et al. 2008). Rather, it is related to the range of variation in annual temperature. If the coefficient of determination is lower but the range of variation of annual temperature is smaller, it is still acceptable to represent the accuracy of annual temperature by the best representative meteorological station in the region.

The Hurst coefficient and the Mann-Kendall trend test showed that annual temperature change exhibited an increasing trend in China during 1953–2013. This is consistent with the second National Assessment Report on Climate Change, Zhou et al. (2013) also indicate that the climate presents a linear increasing trend in recent 60 years. Among the first-level basins, except for the decreasing trend in the rivers in the southwestern region, the annual temperature presents a rising trend in the rest of the first-level basins. Because China is a vast territory and affected by terrain and monsoons, researchers, by much statistical analysis, have found that the temperature change trends in all the regions are different. The temperature changes are out of sync in different regions (Tang and Zhai 2005; Zhang et al. 2006). Against the background of overall warming, the annual average temperature has shown a declining trend in Southwestern China (Ren et al. 2005). There exist differences in the temperature change trend in the rivers in the southwestern region and at their representative meteorological station in Gajah. The main reason is that the temperature time series was obtained during 1953–2013 for the rivers in the southwestern region, but during 1991–2013 in Gajah. There is a great difference in the temperature time series between these two time periods, Song et al. (2014) showed that different temporal series (scales) had an obvious influence on the temperature change trend check result; hence, the trend change is inconsistent. Under the same time series, the trend test was performed for temperature change in the rivers in the southwestern region and at Gajah, and the changes were found to be consistent. This indicates that the temperature in Gajah can reflect the trend of annual temperature change in the region, provided that the consistency of the two time series is maintained. Wavelet analysis showed a clear difference between the first and second primary periods in the national-level and the first-level basins and the primary period of their representative meteorological stations, but the difference was smaller. This was also due to the use of different time series for annual temperature. Given the consistent annual temperature series in a representative meteorological station and its corresponding region, such as Zhangwu and Liuzhou, the first and second primary periods of annual temperature series are identical with the corresponding first-level basin and accurately represent the primary period of annual temperature series in the region. Therefore, the best representative meteorological station can reflect the change trend and main period of annual temperature in the region, but the annual temperature series in the representative meteorological station and its corresponding region is inconsistent. This will cause a certain difference in the change trend, mutation point, and primary period of annual temperature between the station and the region (Song et al. 2014).

Annual temperature is always involved in the study of hydrology, sediment, and rainfall, and due to different processing methods for annual temperature data, there are important differences in the analytical results obtained for surface temperature change (Li et al. 2015). The homogeneity problem in the measured data has not been solved, and this has a certain effect on analyzing average temperature series in a region (Mamara et al. 2015). Based on the analysis of the representative meteorological station in a basin, the homogeneity problem for annual temperature data, the interpolation of missing annual temperature data, and the data assimilation issue in the hydrological model can be solved. On the basis of the representative meteorological station, the change in average temperature in the basin can be assessed quickly, without spending time carrying out a statistical analysis of mass data for all stations. Therefore, recognition of the representative meteorological station for annual temperature plays an important role in rapidly analyzing the average temperature of the basin.

5 Conclusions

The spatial distribution pattern of annual average temperature change in China and the first-level basins during 1951–2013 was analyzed, and the following conclusions were drawn: (1) the spatial variation of annual temperature in the Songhuajiang basin was strong, and in the Huihe basin, this was weak. In the rest of the first-level basins and in the national level, the spatial variation of annual temperature was intermediate, but the extents were different. In China, the spatial distribution pattern of annual temperature showed an increasing trend during 1951–2013 ($p < 0.05$). (2) In the national level, the Liaohe basin, the rivers in the southwestern region, the Haihe basin, the Yellow River basin, the Yangtze River basin, the Huaihe basin, the rivers in the southeastern region, and the Pearl River basin all had the best representative meteorological stations for annual temperature. However, in the Songhuajiang basin and the rivers in the northwestern region, there was no representative meteorological station. And, it was feasible to estimate the annual average temperature in a region by the annual temperature of the best representative meteorological station. (3) The Hurst coefficient, the Mann-Kendall trend test, and the anomaly analysis suggested that, except for the inconsistent change trend of future annual temperature in the rivers in the northwestern region and its best representative meteorological station in Gajah, the future annual temperature in the rest of the first-level basins and their best representative meteorological stations all showed an increasing trend. In the national-level and the first-level basins and their best representative meteorological stations, two obvious periods were observed; moreover, the best representative meteorological station could accurately reflect the main periodic changes in annual temperature series in the corresponding region.

Acknowledgements The authors thank the reviewers for their useful comments and suggestions.

Funding information This research was supported by the National Key Research and Development Program (2016YFC0402404), the National Natural Science Foundations of China (nos. 41330858, 41401316, and 41471226), the New Star Foundation on Shaanxi Province Youth Science and Technology (2016KJXX-68), and the School Foundation of Xi'an University of Technology (310-252071604).

References

Bai Y, Shao M (2011) Temporal stability of soil water storage on slope in rain-fed region of Loess Plateau. Transactions CSAE 27(7):45–50

Brocca L, Melone F, Moramarco T, Morbidelli R (2009) Soil moisture temporal stability over experimental areas in Central Italy. Geoderma 148(3/4):364–374

Castrignanò A, Lopez G, Stelluti M (1993) Temporal and spatial variability of electrolytic conductivity, Na content and sodium adsorption ratio of saturation extract measurements. Eur J Agron 3(3):221–226

Compilation Committee of the Second National Assessment Report on Climate Change (2011) The second national assessment report on climate change. Science, Beijing

Cosh MH, Jackson TJ, Moran S, Bindlish R (2008) Temporal persistence and stability of surface soil moisture in a semi-arid watershed. Remote Sens Environ 112:304–313

Douaik A (2006) Temporal stability of spatial patterns of soil salinity determined from laboratory and field electrolytic conductivity. Arid Land Res Manag 20:1–13

Fang XQ, Zhang XZ, Dai YJ et al (2010) Regionalization of winter temperature change over mainland of China during 1951-2005. Sci Geogr Sin 30(4):571–576

Feng XL, Luo LC, Feng ZL (2009) Hurst index experiment on precipitation change trend and mutation of China in the near 50 years. Arid Land Geography 32(6):859–866

Gao L, Shao MA (2012) Temporal stability of shallow soil water content for three adjacent transects on a hillslope. Agric Water Manag 110: 41–54

Ge QS, Zheng JY, Man ZM et al (2003) Winter half-year temperature reconstruction for the middle and lower reaches of the Yellow River and Yangtze River, China, during the past 2000 years. The Holocene 13(6):933–940

Ge QS, Wang SB, Zheng JY (2006) Temperature reconstruction for China during the past 5000 years. Prog Nat Sci 16(6):689–696

Grayson RB, Western AW (1998) Towards areal estimation of soil water content from point measurements: time and space stability of mean response. J Hydrol 207(1/2):68–82

Grossman A, Morlet J (1984) Decomposition of Hardy functions into square integrable wavelets of constant shape. SIAM J Math Anal 15(4):723–736

Han CH, Hao ZX, Zheng JY (2013) Regionalization of temperature changes in China and characteristics of temperature in different regions during 1951-2010. Prog Geogr 32(6):887–896

Hao ZX, Zheng JY, Ge QS, Wang WC (2012) Winter temperature variations over the middle and lower reaches of the Yangtze River since 1736 AD. Clim Past 8(3):1023–1030

Hu W, Mingan S, Kluas R (2010) Using a new criterion to identify sites for mean soil water storage evaluation. Soil Sci Soc Am J 74(3): 762–773

IPCC (2013) Climate change 2013: the physical science basis. Cambridge University Press, Cambridge, pp 5–6

Li Y, Wang X, Zhang G X (2015) The characteristic analysis of rainfall and temperature between 1956 and 2013 in the Hanjiang River basin. J Water Resour Res 04(4):345–352

Liu J, Von Storch H, Chen X et al (2005) Simulated and reconstructed winter temperature in the eastern China during the last millennium. Chin Sci Bull 50(24):2872–2877

Lorenzoni I, Jordan A, Hulme M, Kerry Turner R, O'Riordan T (2000) A co-evolutionary approach to climate change impact assessment: part I. Integrating socio-economic and climate change scenarios. Glob Environ Chang 10(1):57–68

Lu AG, Pang DQ, He YQ et al (2006) Impact of global warming on latitudinal temperature gradients in China. Sci Geogr Sin 26(3): 345–350

Mamara A, Argiriou AA, Anadranistakis M (2015) Recent trend analysis of mean air temperature in Greece based on homogenized data. Theor Appl Climatol 121(3–4):1–31

Martínez-Fernández J, Ceballos A (2005) Mean soil moisture estimation using temporal stability analysis. J Hydrol 312(1):28–38

Moral FJ, Rebollo FJ, Paniagua LL, García A, de Salazar EM (2016) Application of climatic indices to analyse viticultural suitability in Extremadura, South-Western Spain. Theor Appl Climatol 123(1–2): 277–289

Nielsen DR, Bouma J (1985) Soil spatial variability. PUDOC, Wageningen, pp 2–30

PAGES k Consortium (2013) Continental-scale temperature variability during the past two millennia. Nat Geosci 6(6):339–346

Peng YB, Xu Y, Jin LY (2009) Climate changes over eastern China during the last millennium in simulations and reconstructions. Quat Int 208(1):11–18

Ren GY, Guo J, Xu MZ et al (2005) Climate changes of China's mainland over the past half century. Acta Meteor Sin 63(6):942–956

Río SD, Fraile R, Herrero L et al (2007) Analysis of recent trends in mean maximum and minimum temperatures in a region of the NW of Spain (Castilla y León). Theor Appl Climatol 90(1–2):1–12

Savić S, Milovanović B, Lužanin Z, Lazić L, Dolinaj D (2015) The variability of extreme temperatures and their relationship with atmospheric circulation: the contribution of applying linear and quadratic models. Theor Appl Climatol 121(3–4):591–604

Shi YS, Wang YZ, Chi JC et al (2009) Impact of climate change on winter wheat production in the Hebei Plain. Chin J Eco-agric 16(6):1444–1447

Shi F, Yang B, Von Gunten L (2012) Preliminary multiproxy surface air temperature field reconstruction for China over the past millennium. Sci China Earth Sci 55(12):2058–2067

Song C, Pei T, Zhou CH (2012) Research progresses of surface temperature characteristic change over Tibetan Plateau since 1960. Prog Geogr 31(11):1503–1509

Song YH, Yue XY, Liu LX et al (2014) Comparative analysis of air temperature changes between coastal and inland areas of the Shandong Peninsula from 1972 to 2012. Mar Sci 38(6):65–69

Starks PJ, Heathman GC, Jackson TJ, Cosh MH (2006) Temporal stability of soil moisture profile. J Hydrol 324:400–411

Sun XS, Long ZW, Song GP et al (2017) Effects of climate change on cropping pattern and yield of summer maize-winter wheat in Huang-Huai-Hai Plain. Sci Agric Sin 50(13):2476–2487

Tang HY, Zhai PM (2005) Comparison of variations of surface air temperatures in eastern and western China during 1951-2002. Chin J Sin 48(3):526–534

Trenberth KE, Jones PD, Ambenje PR et al (2007) Observations: surface and atmospheric climate change//IPCC. Climate change 2007: the physical science basis. Cambridge University Press, Cambridge

Vachaud G, De Silans AP, Balabanis P et al (1985) Temporal stability of spatially measured soil water probability density function. Soil Sci Soc Am J 49(4):822–828

Vanderlinden K, Vereecken H, Hardelauf H et al (2012) Temporal stability of soil water contents: a review of data and analyses. Vadose Zone J 11(4):280–288

Wang SW, Wen XY, Luo Y et al (2007) Temperature reconstruction for China of the nearly 1000 years. Chin Sci Bull 52(8):958–964

Wang HL, Liu J, Wang ZY, Wang SM, Kuang XY (2011) Simulated analysis of summer climate on centennial time scale in eastern China during the last millennium. Chin Sci Bull 56(21):2229–2235

Xu G, Haibo L, Zhenzhou S et al (2015) Temporal stability of groundwater electrical conductivity in Luohuiqu irrigation district. Transactions of the Chinese Society of Agricultural Engineering (TCSAE) 31(10):115–121

Xu GC, Ren ZP, Li P et al (2016) Temporal persistence and stability of soil water storage after rainfall on terrace land. Environ Earth Sci 75(11):1–11

Yan JH, Ge QS, Zheng JY (2012) Reconstruction and analysis on the series of winter-half-year temperature change during the Qing Dynasty in the Northern China region. Prog Geogr 31(11):1426–1432

Yao TD, Masson- Delmotte V, Gao J et al (2013) A review of climatic controls on δ18O in precipitation over the Tibetan Plateau: observations and simulations. Rev Geophys 51(4):525–548

Yu HY, Liu SH, Zhao N et al (2011) Characteristics of air temperature and precipitation in different regions of China from 1951 to 2009. J Meteorol Environ 27(4):1–11

Zhang JJ, Chen S, Zhao XY (2006) Spatial divergency of temperature change during 1951-2000 in China and its correlation with global climate change. Journal of Arid Land Resources and Environment 20(4):1–6

Zhou X, Wang F, Wu Y et al (2013) Analysis of temperature change characteristics of Heilongjiang Province, Northeast China and whole country in recent 60 years. Journal of Natural Disasters 22(2):124–129