Analysis of Characteristics of Temperature Changes in Heilongjiang River Basin

Bo Yan$^{1,2}$, Zhe Yuan$^{1,2}$, Jiqiong Li$^3$, Liqiang Yao$^{1,2}$, Li Song$^{1,2}$, Yanyi Liu$^4$, Xiao Zhang$^5$, Ligang Zhang$^6$

$^1$Changjiang River Scientific Research Institute, Changjiang Water Resources Commission of the Ministry of Water Resources of China, Wuhan 430010, China
$^2$Hubei Key Laboratory of Water Resources & Eco-Environmental Sciences, Wuhan 430010, China
$^3$Wuhan Changjiang Kechuang Technology Development Co.Ltd, Wuhan 430010, China
$^4$Jiangxi Provincial Water Conservancy Planning Design and Research Institute, Nanchang 330029, China
$^5$Bureau of Hydrology, Changjiang Water Resources Commission of the Ministry of Water Resources of China, Wuhan 430010, China
$^6$School of Natural Resources, University of Nebraska-Lincoln, Lincoln, NE 68588, USA

*correspondence: yuanzhe_0116@126.com(Z Yuan)

Abstract. As an international river, the climate change research in Heilongjiang River Basin can provide references for sino-Russia cooperation in tackling climate change. Using the long-term daily measured data from 44 meteorological stations in the Heilongjiang River Basin, the spatial-temporal characteristics of the temperature in the past 59 years were analyzed. The results show that the temperature in the Heilongjiang River Basin has increased significantly and passed the significance test of 0.99. The abrupt change occurred in 1986. The climate change also showed multiple cyclical changes of 16-years, 8-years, and 4-years. The spatial distribution of the annual average temperature of the river basin is generally gradually decreasing from the south to the north as the latitude rises. There is also a spatial difference in the annual temperature increase, but all of the basin have passed the significance test of 99%.

1. Introduction

Heilongjiang is a world-famous international river, and its watershed is located in the mid-high latitudes and cold regions. The climate of the watershed is extremely sensitive to global climate change[1]. In recent years, there have been many studies on the characteristics of temperature changes, but articles on international rivers are relatively few. Few scholars have studied climate change in Heilongjiang River Basin. A related report from IPCC states that global warming not only affects extreme temperatures and extreme precipitation, but also accelerates the change of the frequency of extreme events such as high temperature, flood, drought, heavy rain, etc[2]. Against the backdrop of global warming, the impact of climate change on water resources in the basin is also particularly
significant. Therefore, it is necessary to analyze the characteristics of climate change in Heilongjiang river basin under global warming.

2. Study area, data and methodology

2.1 Study area
Heilongjiang River Basin is located in the cold temperate zone and temperate zone, and the monsoon climate is obvious. In winter, the dry and cold air from Siberia brings sunny and dry weather with strong frost. In summer, the warm and humid sea breeze brings heavy rain to improve the water level of the basin and its main tributary. The Heilongjiang River Basin involves China, Russia, Mongolia, and North Korea, and is an important international river.

2.2 Study data
Daily temperature data series of 44 meteorological stations in the Heilongjiang River Basin from 1954 to 2012 was collected. The complete long-term data is very important for the statistical analysis of the trend, breakout and periodic characteristics of climate change in Heilongjiang River Basin. Data in this paper have all passed the uniformity test of RHtestV.3 [3, 4] software. This software was developed by Environment Canada’s Climate Research Center. It includes the maximum penalty F test (PMFT) and maximum penalty T test (PMT). Considering the lagging first-order autocorrelation of time series, it can be used for the uniformity test of time series on different time scales. Location of 44 stations selected in the temperature analysis can be seen in Figure 1.

Figure 1. Location of selected meteorological stations for temperature analysis in Heilongjiang River Basin

2.3 Methodology
As a common time series trend assessment and breakout diagnosis method, the Mann-Kendall (M-K) test is commonly used in meteorology and hydrology [5-7]. This paper uses the M-K test to quantitatively evaluate the temperature trends and breakout diagnosis in the Heilongjiang River Basin. The Morlet wavelet analysis method [8] is used to analyze the periodicity of temperature changes. The inverse distance weighting method [9] is employed to display the spatial distribution of temperature changes.

3. Results and discussion

3.1 Temporal variation characteristics of temperature

3.1.1 Trend analysis of temperature changes
The process of annual mean temperature anomaly changes in Heilongjiang River Basin can be seen in Figure 2. It can be seen from the figure that the annual mean temperature of Heilongjiang River Basin showed an obvious upward trend from 1954 to 2012 and it can be estimated that its upward range is 0.34°C/10a according to the linear trend. Although 0.34 is not a big number, an increase of 0.34°C per decade is also a quantity that cannot be ignored for annual mean temperature and it is higher than the global and northern hemisphere average temperature growth rates. The results of M-K test shows that its upward trend has passed the significance test of 0.99. The M-K statistic of annual mean temperature of Heilongjiang River Basin in China is 5.45 and it has passed the significance test of 99% reliability by M-K test, which has a significant upward trend. This significant upward trend of annual mean temperature will inevitably affect the water cycle process in its basin and it also has a certain impact on the utilization of water resources and the water ecological environment in the basin.

Figure 2. The process of annual mean temperature anomaly changes in Heilongjiang River Basin

Figure 3. Breakout Diagnosis of annual mean temperature in Heilongjiang River Basin by M-K test

3.1.2 Breakout diagnosis of temperature changes

Figure 3 is a breakout diagnosis chart of annual mean temperature in Heilongjiang River Basin from 1954 to 2012, it is found that 1986 was a change point of the average temperature series by the M-K test, which means that the temperature trend has changed the most in the years around 1986 and the breakout has reached a significance level of 95% (in fact, it has exceeded the significance level of 99%). Therefore, there was a significant temperature change in the late 1980s, which means that, it has experienced a transition from cold to warm. This sudden change in temperature has brought the annual mean temperature in Heilongjiang River basin to a new level since the late 1980s, which will inevitably affect each link in the hydrological cycle in the basin, thus affecting ecological hydrology situation in the basin.

3.1.3 Periodic analysis of temperature changes

The annual mean temperature series of 59 years from 1954 to 2012 in Heilongjiang River Basin was used as the periodic analysis data of temperature changes. The data was preprocessed by symmetric extension method to eliminate the boundary effect of wavelet transform.
Figure 4. Real part of complex Morlet wavelet coefficients of annual mean temperature in Heilongjiang River Basin

Figure 5. Complex Morlet wavelet variance of annual mean temperature in Heilongjiang River Basin

Figure 4 is a diagram of the real part of wavelet coefficients by wavelet transform using the annual mean temperature series in Heilongjiang River Basin. It can be clearly seen from Figure 4 that the periodic oscillations and mutation characteristics of the temperature in the region over the past 59 years on different time scales. The strength of the signal oscillations in the figure is represented by the size of the gray scale, and the larger the gray scale, the lower the temperature is. The smaller the gray scale, the higher the temperature is. In general, the annual mean temperature in the basin has a small scale of about 4-16 years, a mesoscale of about 8-16 years and a large scale of about 16-4 years. There is a strong signal of the change throughout the period on the scale of about 16-years. It clearly exists that the cycle process of low-high-low-high-low-high in the temperature change from 1954 to 2012, and it shows a slight increasing trend in large-scale cycles, which is very stable on the whole. The cycle process of high-low-high-low-high-low-high is obvious on the mesoscale about 8-years from 1971 to around 1995, and it shows an increasing trend in the scale change. Mesoscale cycles of about 8 years disappear in the signal after 1995. For small scales of about 4-years, the changes are more complicated, and they constantly shake around 4-years. In summary, there is a complex nested structure on multiple time period scales in the temperature series in Heilongjiang River Basin. The small scale change is nested in the change on the larger scale.

Figure 5 is a diagram of wavelet variance of the annual mean temperature series in Heilongjiang River Basin. It can be clearly seen from Figure 5 that there are three peaks, which are 16, 8 and 4 respectively, indicating that the oscillation periods in the region are 16-years, 8-years and 4-years respectively and the main oscillation period is 4-years. It can be seen from the main oscillation period that the higher temperature isoline is about to close, indicating that it may be in a period of lower temperature in the future.

Based on the analysis of the breakout and periodicity of the temperature time series, despite the periodic fluctuations in the temperature series, it is still difficult to conceal the fact that the overall temperature has risen.

3.2 Spatial change characteristics of temperature

Figure 7 is the diagram of the spatial distribution of the annual mean temperature, and Figure 8 is the diagram of the spatial distribution of the annual mean temperature trend change in Heilongjiang River Basin. The annual mean temperature in Heilongjiang River Basin decreases roughly from south to north as the latitude rises in space and the regional differences are obvious. The annual mean temperature in the basin is generally -5.03 °C ~ 5.61 °C. The temperature in the northern and western parts of the basin is lower, which is below 0 °C. The annual mean temperature in the Shilka River, the Arun River, the upstream of the Heilongjiang River, the Zeya River, the Bureya River, the upstream of Nenjiang River and other river basins is lower, which is below 0 °C. Among them, the temperature in the Shilka River, the area where the Argun River flows into the main stream of Heilongjiang River and the upstream areas of the Zeya River and the Bureya River is the lowest, ranging from -5.03 °C to -
3.42 °C. The temperature is higher in the southern part of the basin, ranging from 1.17 °C to 5.61 °C.

Figure 6. Spatial distribution of annual mean temperature in Heilongjiang River Basin

Figure 7. Spatial distribution of annual mean temperature trend change in Heilongjiang River Basin

In order to analyze the change trend of the annual mean temperature in different regions of the basin, a linear trend distribution diagram of the annual mean temperature was drawn (Figure 7). It can be seen that the annual mean temperature of the entire basin has been increasing in the past 59 years, but there is a spatial difference in the annual temperature increase in various regions of the basin. The annual temperature increase in various regions of the basin is 0.16°C~0.53°C/10a. In the southwestern regions, central regions and northern regions, the temperature increases greatly, with an increase of 0.47°C to 0.53°C/10a. The M-K method shows that the Z value of the annual temperature in each area of the basin is 3.114 ~ 5.180, which have passed the significance test of 99% , indicating that there is a extremely significant upward trend of the annual temperature all of the basin.

4. Conclusions
By analyzing the trend, breakout and periodicity characteristics of temperature changes in the Heilongjiang River Basin, and the analysis of the spatial distribution, the following conclusions can be drawn:

a. The temperature increase in the Heilongjiang River Basin was obvious, and a significant abrupt change occurred around 1986.

b. Through wavelet analysis, there are multi-scales periodic changes in the temperature of the Heilongjiang River Basin (16-years, 8-years, and 4-years), and large-scale nesting of small-scales presents more complex periodic changes.

c. The Heilongjiang River Basin has a relatively regular phenomenon with the increase of latitude and the annual average temperature decreases. The whole river basin also shows a significant temperature increase trend, but the temperature increase is irregular in space, showing a phenomenon of high and low staggering.

d. The phenomenon of increasing climate in the Heilongjiang River Basin is in line with the background of global warming. However, as an international river in the high latitudes and cold regions, how to deal with climate change and potential changes in water resources is a problem that countries in the basin, especially China and Russia, must face.

Acknowledgments
This work is funded by the National Key R&D Program of China (2017YFC1502404, 2016YFC0502201), National Public Research Institutes for Basic R&D Operating Expenses Special Project (CKSF2017061, CKSF2017057), Jiangxi Provincial Natural Science Foundation Project (20181BAA208043). Special thanks are given to the anonymous reviewers and editors for their constructive comments.
References

[1] Bo Y, Ziqiang X, Feng H, et al. Climate Change Detection and Annual Extreme Temperature Analysis of the Amur River Basin[J]. Advances in Meteorology, 2016, 2016:1-14.

[2] Henderson-Sellers A, Zhang H, Berz G, et al. Tropical Cyclones and Global Climate Change: A Post-IPCC Assessment[J]. Bulletin of the American Meteorological Society, 1998, 79(1):19-38.

[3] Wang X L. Accounting for autocorrelation in detecting mean shifts in climate data series using the penalized maximal t or F test[J]. Journal of Applied Meteorology & Climatology, 2008, 47(9):2423-2444.

[4] Wang X L. Penalized Maximal F, Test for Detecting Undocumented Mean Shift without Trend Change[J]. Journal of Atmospheric & Oceanic Technology, 2008, 25(3):368-384.

[5] Lins, Harry F, Slack, James R. Streamflow trends in the United States[J]. Geophysical Research Letters, 26(2):227-230.

[6] Ullah S, You Q, Ullah W, et al. Observed changes in precipitation in China-Pakistan economic corridor during 1980–2016[J]. Atmospheric Research, 2018, 210:1-14.

[7] Malakar S, Goswami S, Chakrabarti A. An Online Trend Detection Strategy for Twitter Using Mann–Kendall Non-parametric Test[J]. 2018..

[8] Bolton, Edward W, Maasch, Kirk A, Lilly, Jonathan M. A wavelet analysis of Plio-Pleistocene climate indicators: A new view of periodicity evolution[J]. Geophysical Research Letters, 22(20):2753-2756.

[9] Zimmerman D, Pavlik C, Ruggles A, et al. An Experimental Comparison of Ordinary and Universal Kriging and Inverse Distance Weighting[J]. Mathematical Geology, 1999, 31(4):375 to 390.