Spatiotemporal Variation Characteristics of Temperature During the "Shu-Jiu" Period in Shanxi Province, 1960–2015 (Postprint)

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Abstract

Based on daily maximum, minimum, and mean temperature data from 24 meteorological stations in Shanxi Province from 1960 to 2016, this study employs linear trend estimation, Mann-Kendall non-parametric test, Morlet wavelet analysis, and other methods to analyze the spatiotemporal variation characteristics of temperature during the "Shu Jiu" period in Shanxi over the past 56 years. The results show that: (1) Temperatures during the "Shu Jiu" period in Shanxi have all exhibited an upward trend over the past 56 years, with the average maximum temperature showing the largest increase at approximately 0.5 ℃·(10 a)^{1}. In terms of mean temperature changes, the "Wu Jiu" period demonstrates the greatest trend at approximately 0.703 ℃·(10 a)^{1}. Regarding distribution, the "Si Jiu" period exhibits the lowest values, warming begins during "Wu Jiu", and the "Liu Jiu" period shows the largest warming magnitude. Comparison of mean temperatures for each "Jiu" before and after the 1990s reveals that the lowest values are delayed, the warming time is advanced, and the cold period of "Shu Jiu" is shortened. (2) High-temperature areas during the "Shu Jiu" period are mainly concentrated in the intermontane basins and river valleys of southern Shanxi, most notably the Yuncheng Basin, while low-temperature areas are primarily distributed in the mountainous and hilly regions centered around Mount Wutai in northeastern Shanxi, with the distribution of warming magnitude being roughly opposite to this pattern. (3) An abrupt warming change occurred in temperatures around 1990, with the average maximum temperature showing the largest change before and after the mutation at approximately 1.73 ℃. (4) Temperature periodic variations are evident, with short-time scale cycles of 4–8 a present in all cases. This study fills the research gap regarding temperature changes during the "Shu Jiu" period in Shanxi Province and provides a scientific basis for climate resource evaluation and agricultural production layout in Shanxi.

Full Text

Preamble

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Title: Temporal and Spatial Variations of Temperature During the "Jiu"Periods in Shanxi Province from 1960 to 2015

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Abstract

In recent years, global climate change has become a widely concerned topic. Air temperature, as one of the important climate factors, has a strong influence on production and living worldwide. Previous studies on climate change indicated that air temperature variation in China had remarkable periodicity, spatial differentiation, and abrupt change characteristics. There have been some researches on temporal and spatial variations of air temperature in Shanxi Province, a typical inland province of China. However, those works normally focused on analyzing air temperature data at fixed time scales such as year, season, month, etc. While this may be useful for understanding temperature variation characteristics from a macroscopic perspective, few studies in Shanxi Province concern the temporal and spatial variations of air temperature in a distinct time or special season. "Jiu" means nine days in the traditional Chinese calendar and has a long history of application in traditional agricultural production and daily life in China. It begins from the winter solstice and ends after eighty-one days, divided into nine "Jiu" periods. In China, the "Jiu" periods represent the coldest days of the whole year. Based on daily air temperature data from 24 meteorological stations in Shanxi Province from 1960 to 2015, this study used linear trend estimation, Mann-Kendall nonparametric test, and Morlet wavelet analysis methods to analyze the temporal and spatial variations of air temperature during the "Jiu" periods over the past 56 years. The results indicate: (1) The air temperature during the "Jiu" periods shows an increasing trend over the past 56 years, especially the mean maximum temperature increased by 0.5℃ · (10a) [1]. From a temporal perspective, the fourth "Jiu" period had the lowest temperature, and temperatures started to increase from the fifth "Jiu" period with sharp warming in the sixth period. After 1990, the number of cold days during the "Jiu" periods became smaller. (2) Higher temperatures usually appeared in the basins and river valleys of South Shanxi such as Yuncheng Basin, while lower temperatures normally occurred in the mountain and hill regions of Northeast Shanxi such as Wutai Mountain. However, the distribution of regions with temperature increase range at the same time displayed reverse variation. (3) After 1990, the air temperature during the "Jiu" periods presented a warm abrupt change, particularly the mean maximum temperature increased by 1.73℃. (4) There is a distinct air temperature cycle in this area with a 4-8 year cycling period. This study provides additional information for the evaluation of climate resources and distribution of agricultural production in this area by covering the special "Jiu" periods.

Keywords: "Jiu" period; air temperature; Shanxi Province; temporal and spatial changes; numerical analysis

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1. Introduction

Shanxi Province (110°14 -114°33 E, 34°34 -40°43 N) is located in the central part of China, on the eastern edge of the Loess Plateau. The province has a total area of 156,700 km², characterized by a temperate continental monsoon climate. Based on daily air temperature data from 24 meteorological stations in Shanxi Province from 1960 to 2015, this study employed linear trend estimation, Mann-Kendall nonparametric test, and Morlet wavelet analysis methods to analyze the temporal and spatial variation characteristics of air temperature during the "Jiu" periods over the 56-year period.

[Figure 1: see original paper]

The "Jiu" periods begin from the winter solstice, with each "Jiu" representing nine days. The entire period spans 81 days divided into nine segments: "Yi Jiu" (first nine days), "Er Jiu" (second nine days), through "Jiu Jiu" (ninth nine days). According to traditional Chinese climate classification, the "San Jiu" and "Si Jiu" periods (third and fourth nine-day periods) typically represent the coldest time of year.

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3. Results

3.1 Spatial Distribution Characteristics

Figure 5 shows the spatial distribution of average temperature during the "Jiu" periods in Shanxi Province over the past 56 years. The spatial pattern reveals that higher temperatures during the "Jiu" periods were concentrated in the basins and river valleys of southern Shanxi, particularly the Yuncheng Basin, while lower temperatures were primarily distributed in the mountainous and hilly regions of northeastern Shanxi, especially the Wutai Mountain area.

[Figure 5: see original paper]

The temperature increase range showed an inverse spatial distribution pattern compared to the temperature itself. The spatial distribution of temperature trend during the "Jiu" periods (Figure 6) indicates that the warming trend was more pronounced in the northern and central regions of Shanxi, while the southern regions exhibited relatively weaker warming.

[Figure 6: see original paper]

3.2 Temporal Variation Characteristics

Figure 3 illustrates the average temperature of each "Jiu" period in Shanxi Province over the past 56 years. The fourth "Jiu" period ("Si Jiu") exhibited the lowest average temperature at -11.28℃. Temperatures began increasing from the fifth "Jiu" period, with particularly sharp warming observed in the sixth period. The average temperature of "Er Jiu" (second nine days) was -10.14℃, "San Jiu" -10.94℃, "Si Jiu" -11.28℃, "Wu Jiu" -10.06℃, "Liu Jiu" -8.99℃, "Qi Jiu" -9.59℃, "Ba Jiu" -10.20℃, and "Jiu Jiu" -5.26℃.

[Figure 3: see original paper]

Table 2 shows the interdecadal variation of average temperature during the "Jiu" periods. The 1960s had an average temperature of -5.28℃, the 1970s -5.15℃, the 1980s -4.03℃, the 1990s -3.59℃, and the 2000s -4.02℃.

3.3 Abrupt Change Analysis

Using the Mann-Kendall test for abrupt change detection, significant temperature mutations were identified around 1990. Figure 7 shows the Mann-Kendall mutation discriminant curve for the average temperature during the "Jiu" periods. The analysis revealed that after 1990, the average temperature during the "Jiu"periods experienced a significant abrupt warming, with the mean maximum temperature increasing by 1.73℃.

[Figure 7: see original paper]

Table 3 lists the possible abrupt change years for each "Jiu" period' s average temperature. The results show that most "Jiu" periods experienced abrupt warming changes in the 1990s, particularly between 1990–1995.

Figure 8 displays the spatial distribution of potential abrupt temperature change points during the "Jiu" periods across Shanxi Province. The spatial pattern indicates that abrupt changes occurred earlier in the northern regions (late 1980s) compared to southern regions (early 1990s).

[Figure 8: see original paper]

3.4 Periodic Characteristics

Morlet wavelet analysis revealed distinct periodic characteristics in the temperature series during the "Jiu" periods. Figure 9 shows the wavelet coefficient real part contour map of the average temperature during the "Jiu" periods in Shanxi Province over the past 56 years.

[Figure 9: see original paper]

The analysis identified significant periodicities of 4–8 years and 15–20 years in the temperature variation. The 4–8 year cycle was particularly prominent, corresponding to the quasi-biennial oscillation of atmospheric circulation. Table 4 summarizes the main cycles of average temperature during each "Jiu" period, showing that most periods exhibited primary cycles of 4–8 years and secondary cycles of 15–20 years.

The periodic analysis also revealed that the temperature variation during the "Jiu" periods was influenced by large-scale climate factors such as ENSO events, particularly the strong ENSO episodes during 1982–1983 and 1997–1998, which corresponded to significant temperature anomalies in Shanxi Province.

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4. Discussion and Conclusions

Based on the analysis of temporal and spatial variations of temperature during the "Jiu" periods in Shanxi Province from 1960 to 2015, the following conclusions can be drawn:

(1) **Temporal trend:** The air temperature during the "Jiu" periods showed a significant increasing trend over the past 56 years, with the mean maximum temperature increasing at a rate of 0.5℃·(10a)^{1}. The fourth "Jiu" period was the coldest, and temperatures began rising from the fifth period onward. After 1990, the number of cold days during the "Jiu" periods decreased substantially.

(2) **Spatial pattern:** Temperatures were higher in the basins and valleys of southern Shanxi (e.g., Yuncheng Basin) and lower in the mountainous regions of northeastern Shanxi (e.g., Wutai Mountain). However, the spatial distribution of warming rates showed an inverse pattern, with northern and central regions warming more rapidly than southern regions.

(3) **Abrupt change:** A significant warm abrupt change occurred around 1990, with the mean maximum temperature increasing by 1.73℃ after this point. The Mann-Kendall test identified 1990–1995 as the primary mutation period for most "Jiu" periods.

(4) **Periodic characteristics:** The temperature variation exhibited distinct cycles, with a primary period of 4–8 years and secondary periods of 15–20 years and 25–30 years. These cycles are likely associated with large-scale atmospheric circulation patterns and ENSO events.

This study provides valuable information for understanding the characteristics of winter temperature variation in Shanxi Province and offers a scientific basis for agricultural planning, disaster prevention, and climate resource evaluation during the coldest periods of the year.

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Note: Figure translations are in progress. See original paper for figures.