Spatio-temporal variations of temperature and precipitation in Northwest China across multiple time scales (Preprint)

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Abstract

To investigate the spatiotemporal variation patterns of temperature and precipitation in Northwest China, this study utilizes a 1 km resolution monthly temperature and precipitation grid dataset from 1960 to 2023. Linear regression, Theil-Sen median trend analysis, the Mann-Kendall test, and Morlet wavelet transform were employed to quantitatively analyze the spatiotemporal variation characteristics of temperature and precipitation in Northwest China.

The results indicate that: (1) Over the past 64 years, both the annual mean temperature and precipitation in Northwest China have shown a significant increasing trend, with rising rates of 0.28 ℃ • $(10a)^{-1}$ and 3.46 mm • $(10a)^{-1}$, respectively; on a seasonal scale, the warming rate is highest in spring, while the increasing trend in precipitation is most significant in summer. (2) On a spatial scale, the annual mean temperature and temperatures in all four seasons show a significant increasing trend, with the area of extremely significant warming accounting for more than 94% of the total region; annual and seasonal precipitation are dominated by an increasing trend, but fewer areas passed the significance test, with annual precipitation accounting for only 34.96%, and winter (35.59%) being relatively the highest. (3) Wavelet transform analysis shows that temperature and precipitation exhibit periodic variations across multiple time scales, with the primary periods for annual mean temperature and precipitation being 10–16 a and 33–47 a, respectively. The research findings provide a scientific basis and data support for Northwest China to respond to climate change and ensure ecological security and sustainable development.

Full Text

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Abstract

To investigate the spatiotemporal variation patterns of temperature and precipitation in Northwest China, this study utilizes a 1-km resolution monthly grid dataset covering the period from 1960 to 2023. By employing linear regression, Theil-Sen median trend analysis, the Mann-Kendall test, and Morlet wavelet transform, we quantitatively analyze the spatiotemporal characteristics of climate changes in the region. The results indicate: (1) Over the past 64 years, both the annual mean temperature and precipitation in Northwest China have shown significant increasing trends, with rising rates of $0.28^{\circ}\mathrm{C} \cdot (10\mathrm{a})^{-1}$ and $3.46\ \mathrm{mm} \cdot (10\mathrm{a})^{-1}$, respectively. On a seasonal scale, the warming rate is highest in spring, while the increasing trend in precipitation is most significant in summer. (2) Spatially, the annual mean temperature and temperatures across all four seasons exhibit significant increasing trends, with areas showing highly significant warming exceeding 94% of the total region. While annual and seasonal precipitation primarily show increasing trends, the areas that passed the significance test are relatively limited; significant increases in annual precipitation cover only 34.96% of the region, with winter showing the highest proportion of significant change at 35.59%. (3) Wavelet transform analysis reveals multi-time-scale periodic fluctuations in both temperature and precipitation, with the primary periods for annual mean temperature and precipitation identified as 10–16 years and 33–47 years, respectively. These findings provide a scientific basis and data support for addressing climate change, ensuring ecological security, and promoting sustainable development in Northwest China.

Keywords: temperature; precipitation; temporal characteristics; spatial characteristics; periodic characteristics; Northwest China

1. Introduction

Climate change has become an indisputable fact. According to the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6), global surface temperatures have increased significantly since the industrial revolution, primarily driven by anthropogenic greenhouse gas emissions. Northwest China, characterized by its vast arid and semi-arid regions, is highly sensitive to global climate change. Recent studies indicate that the traditional "warm and dry" climate of Northwest China is shifting toward a "warm and wet" trend, a phenomenon that carries profound implications for regional ecological stability, water resource management, and agricultural sustainability.

The complexity of these climatic shifts is further compounded by unique topographical features, including the Qinghai-Tibet Plateau and vast inland basins. These features interact with large-scale atmospheric circulations, such as the East Asian Monsoon and the Westerlies, creating intricate feedback loops. While global warming has led to an increase in atmospheric water vapor content, altering the global hydrological cycle, regional climate change in Northwest China still exhibits significant discrepancies in current research due to data limitations and methodological differences. This study aims to analyze multi-scale variations of temperature and precipitation using high-resolution gridded data to provide a comprehensive understanding of regional climate dynamics.

2. Data and Methods

2.1 Study Area

Northwestern China is located in the central part of the Eurasian continent ($31°35' \sim 49°15'N$, $73°25' \sim 111°15'E$). The region encompasses Xinjiang, Ningxia, Qinghai, Gansu, and Shaanxi. This vast territory is characterized by significant topographic relief and diverse geomorphological types. With the exception of certain areas with a temperate monsoon climate, the majority of the region is characterized by a temperate continental climate or a cold highland climate.

2.2 Data Sources and Preprocessing

The meteorological data used in this study were obtained from the National Tibetan Plateau Data Center (https://data.tpdc.ac.cn/). These data feature a spatial resolution of 1 km and a monthly temporal resolution from 1960 to 2023. Digital Elevation Model (DEM) data were obtained from the Geospatial Data Cloud platform (https://www.gscloud.cn). Data processing was conducted using Python, ArcGIS, Origin, and Matlab. Monthly NetCDF data were batch-extracted and integrated into annual scales (mean for temperature, cumulative sum for precipitation).

2.3 Statistical Methods

2.3.1 Linear Regression To quantify variations, linear regression analysis was performed:

$$y = ax + b$$

where a is the regression coefficient (slope) indicating the rate of change.

2.3.2 Theil-Sen Trend Analysis and Mann-Kendall Test Theil-Sen trend analysis is a robust non-parametric method used to calculate the slope of the trend:

$$\beta = \text{median}\left(\frac{x_j - x_i}{j - i}\right), 1 < j < i < n$$

The Mann-Kendall (M-K) test was used to determine the statistical significance of these trends and to detect mutation points in the time series.

2.3.3 Wavelet Analysis Morlet wavelet analysis was applied to identify periodicities across multiple time scales. The wavelet variance was utilized to identify the intensity of oscillations, where the time scales corresponding to peaks represent the primary periods of the sequence.

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3. Results and Analysis

3.1 Spatiotemporal Characteristics of Temperature and Precipitation

From 1960 to 2023, the average temperature in Northwest China was 3.92°C. Spatially, temperatures are higher in plain basins and lower in mountainous areas [Figure 2: see original paper]. The annual mean temperature has exhibited a highly significant upward trend ($P < 0.01$) at a rate of $0.28^{\circ}\text{C} \cdot (10\text{a})^{-1}$. Seasonally, the warming rates for spring, summer, autumn, and winter were 0.34, 0.23, 0.24, and $0.33^{\circ}\text{C} \cdot (10\text{a})^{-1}$, respectively.

The multi-year average precipitation was 226.72 mm, showing a distinct decreasing trend from the southeast toward the northwest. Annual precipitation has shown a significant upward trend at a rate of $3.46\ \text{mm} \cdot (10\text{a})^{-1}$. Summer precipitation contributes most significantly to the annual total, increasing at $1.87\ \text{mm} \cdot (10\text{a})^{-1}$ ($P < 0.05$), while winter precipitation shows a highly significant increase of $0.42\ \text{mm} \cdot (10\text{a})^{-1}$ ($P < 0.01$).

3.2 Spatial Variation Trends

The area passing the significance test for temperature warming reaches 99.99% of the region [Figure 5: see original paper]. In contrast, while 85.89% of the region showed an increase in annual precipitation, only 34.96% passed the significance test, primarily distributed in western Xinjiang and most of Qinghai. Winter showed the highest proportion of significant precipitation increase (35.59%).

3.3 Periodic Variation Characteristics

Wavelet analysis revealed that the annual mean temperature exhibits three distinct periodic oscillation scales: 2–8 years, 10–16 years, and 26–38 years. The 10–16 year cycle is identified as the primary period [Figure 6: see original paper]. Annual precipitation exhibits periodicities of 4–9 years, 10–16 years, 20–31 years, and 33–47 years, with the 33–47 year scale identified as the first primary period.

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4. Discussion

The results confirm that Northwest China is undergoing a "warming and wetting" transition. The warming rate of $0.28^{\circ}\mathrm{C} \cdot (10\mathrm{a})^{-1}$ is significantly higher than the national average of $0.12^{\circ}\mathrm{C} \cdot (10\mathrm{a})^{-1}$. While winter was historically the fastest-warming season due to the weakening of the Siberian High, recent data suggests spring warming has become more pronounced.

The increase in precipitation is likely driven by atmospheric circulation shifts, including the strengthening of the Indian Ocean Basin Mode and changes in the Westerlies. However, the "warm-wet" phenomenon represents an improvement in moisture within an inherently arid zone and has not fundamentally altered the region's water-scarce characteristics. Future projections suggest a continued warming trend, though the transition to a "warm-dry" pattern remains a risk under high-emission scenarios.

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5. Conclusion

1. From 1960 to 2023, the annual mean temperature in Northwest China was 3.92°C, and the average precipitation was 226.72 mm. The region is characterized by hot, rainy summers and cold, dry winters.
2. The annual mean temperature exhibited a highly significant upward trend at $0.28^{\circ}\mathrm{C} \cdot (10\mathrm{a})^{-1}$. Annual precipitation increased at $3.46\ \mathrm{mm} \cdot (10\mathrm{a})^{-1}$. A precipitation regime shift occurred between 2001 and 2002.
3. Warming is spatially ubiquitous (99.99% of the area), while significant precipitation increases are more localized (34.96% of the area).
4. The primary periods for annual temperature and precipitation are 10–16 years and 33–47 years, respectively. These cycles provide a basis for future climate predictions in the region.

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