

Spatiotemporal Characteristics of Wind Speed Variation in the Wind Erosion Region of Northern China (Postprint)

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Abstract

Utilizing average wind speed data from 155 meteorological stations in the northern wind erosion zone from 1971 to 2015, climate trend analysis, spatial interpolation, and wavelet analysis were employed to analyze the spatiotemporal variation trends of average wind speed in the northern wind erosion zone. The results show that over the past 45 years, the annual average wind speed in the northern wind erosion zone was $2.70 \text{ m} \cdot \text{s}^{-1}$, exhibiting a significant decreasing trend with a decline rate of $0.017 \text{ m} \cdot (\text{s} \cdot \text{a})^{-1}$ ($\alpha=0.001$). Wind speed decreased most rapidly in the 1980s, most slowly in the 1990s, and showed an increasing trend in the 2010s; the average wind speed in all four seasons in the northern wind erosion zone of China displayed a decreasing trend, with the decline rate ordered as spring > summer > autumn > winter ($\alpha=0.001$). There were substantial differences in seasonal wind speed variations across different decades; in the 2010s, wind speed showed an increasing trend in all seasons except spring. Spatial distribution reveals clear differences in the magnitude of wind speed changes across the region: within the northern wind erosion zone, northwestern and southeastern Xinjiang, Qinghai, central and northeastern Inner Mongolia, Heilongjiang, and Jilin were areas with relatively rapid wind speed reduction, while southeastern Gansu, Ningxia, northern Shaanxi and Shanxi, as well as northeastern and western Xinjiang were areas where wind speed reduction was not significant. The area of regions with rapid wind speed reduction expanded in spring and summer, while the area of regions with slow wind speed reduction expanded in winter and autumn. The average wind speed exhibited periodic structural characteristics at multiple time scales, with a primary period of approximately 28 a for wind speed variation and an average variation period of 18 a.

Full Text

Preamble

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1 Introduction

Wind erosion is a major environmental problem in arid and semi-arid regions, affecting land degradation, dust storm formation, and ecological security. Understanding the spatiotemporal characteristics of wind speed changes in wind erosion regions is crucial for disaster prevention, ecological restoration, and wind energy resource development.

2 Data and Methods

2.1 Data Collection

To analyze wind speed changes in northern China's wind erosion region, we selected annual and seasonal wind speed data from 155 evenly distributed meteorological stations covering the period 1971-2015. The study area spans 33°-53°N latitude and 74°-125°E longitude, encompassing the wind erosion region of northern China with a total area of approximately 340×10^4 km². The region includes various land cover types such as grassland, farmland, desert, and Gobi areas.

Data quality control was performed following standard meteorological procedures. After screening for completeness and consistency, 11 stations with missing data exceeding 5% were excluded, leaving 144 stations for the final analysis. The continuous wavelet transform method was applied to detect periodicities in the wind speed time series.

2.2 Methods

2.2.1 Wavelet Analysis Wavelet analysis is an effective tool for examining multi-scale temporal characteristics of climate variables. The Morlet wavelet function was selected as the mother wavelet due to its good balance between time and frequency localization. For a given time series $f(t) \in L^2(\cdot)$, the continuous wavelet transform (CWT) is defined as:

$$W_f(a, b) = |a|^{-1/2} \int_{\mathbb{R}} f(t) \bar{\psi} \left(\frac{t-b}{a} \right) dt$$

where $W(a, b)$ represents the wavelet coefficient, a is the scale parameter (dilation), and b is the translation parameter. The wavelet power spectrum, calculated as the squared modulus of the wavelet coefficients, reveals the dominant periods of variability in the time series.

Significance testing was performed using the red noise spectrum at the 95% confidence level ($\alpha = 0.05$). The cone of influence was identified to distinguish between reliable and edge-affected regions in the wavelet spectrum.

3 Results

3.1 Temporal Trends of Wind Speed

The annual average wind speed in northern China's wind erosion region was $2.70 \text{ m} \cdot \text{s}^{-1}$ during 1971-2015, decreasing significantly at a rate of $0.017 \text{ m} \cdot \text{s}^{-1} \cdot \text{a}^{-1}$ ($\alpha = 0.001$). The decreasing trend was most pronounced in the 1980s and weakest in the 1990s, with a slight increase observed only in the 2010s.

Seasonal analysis revealed significant declining trends in all seasons (Fig. 3): - **Spring:** Average wind speed was $3.29 \text{ m} \cdot \text{s}^{-1}$, decreasing at $0.023 \text{ m} \cdot \text{s}^{-1} \cdot \text{a}^{-1}$ ($\alpha = 0.001$). The maximum spring wind speed occurred in 1971 ($4.01 \text{ m} \cdot \text{s}^{-1}$), while the minimum occurred in 2014 ($2.86 \text{ m} \cdot \text{s}^{-1}$), representing a reduction of $1.15 \text{ m} \cdot \text{s}^{-1}$ over the study period. - **Summer:** Average wind speed was $2.72 \text{ m} \cdot \text{s}^{-1}$, decreasing at $0.017 \text{ m} \cdot \text{s}^{-1} \cdot \text{a}^{-1}$ ($\alpha = 0.001$). The maximum occurred in 1972 ($3.39 \text{ m} \cdot \text{s}^{-1}$) and the minimum in 2012 ($2.44 \text{ m} \cdot \text{s}^{-1}$). - **Autumn:** Average wind speed was $2.33 \text{ m} \cdot \text{s}^{-1}$, decreasing at $0.014 \text{ m} \cdot \text{s}^{-1} \cdot \text{a}^{-1}$ ($\alpha = 0.001$). The maximum occurred in 1979 ($2.87 \text{ m} \cdot \text{s}^{-1}$) and the minimum in 2012 ($1.98 \text{ m} \cdot \text{s}^{-1}$). - **Winter:** Average wind speed was $2.72 \text{ m} \cdot \text{s}^{-1}$, decreasing at $0.017 \text{ m} \cdot \text{s}^{-1} \cdot \text{a}^{-1}$ ($\alpha = 0.001$). The trend was statistically significant across all seasons.

Interdecadal variations showed distinct patterns (Fig. 4). The 1980s experienced the fastest decline in wind speed, with a rate of $-0.46 \text{ m} \cdot \text{s}^{-1} \cdot (10\text{a})^{-1}$ ($\alpha = 0.001$). The 1990s showed a weaker decreasing trend of $-0.09 \text{ m} \cdot \text{s}^{-1} \cdot \text{a}^{-1}$. Notably, the 2010s exhibited a reversal with a slight increase of $0.017 \text{ m} \cdot \text{s}^{-1} \cdot \text{a}^{-1}$ ($\alpha = 0.001$), though this trend was not statistically significant at all stations.

3.2 Spatial Variation of Wind Speed Trends

The spatial distribution of wind speed trends revealed significant heterogeneity across the region (Fig. 5). The most rapid decreases occurred in the central-east, central-west, northwest, and eastern parts of northern China. Areas with

non-significant trends included the southeastern part of Gansu, Ningxia, northern Shanxi and Shaanxi, Liaoning, and the northeastern and western parts of Xinjiang.

Seasonal spatial patterns varied considerably. In spring and summer, the area experiencing rapid wind speed reduction expanded significantly, while in autumn and winter, the area of slowly decreasing wind speed extended. The spatial variability was closely related to topography, land cover type, and regional climate patterns.

3.3 Wavelet Analysis of Wind Speed Periodicity

Wavelet analysis revealed quasi-periodic oscillations in wind speed with two dominant timescales (Fig. 6). The average wind speed exhibited significant periodicities of approximately 28 years and 18 years. The 28-year cycle was prominent throughout the entire study period, while the 18-year cycle showed stronger signals during 1971-1980, 1988-1997, and 2006-2015.

The wavelet power spectrum indicated that the 28-year periodicity passed the 95% significance test, suggesting a robust multi-decadal oscillation pattern. This long-term cycle may be associated with large-scale atmospheric circulation patterns such as the Pacific Decadal Oscillation and Arctic Oscillation. The 18-year cycle showed intermittent significance, with enhanced power during certain decades.

Currently, the wind erosion region of northern China is experiencing a low wind velocity stage, consistent with the descending phase of the 28-year cycle. This suggests that wind speeds may remain relatively low for the next decade before potentially increasing as the cycle enters its ascending phase.

4 Conclusions

- (1) During 1971-2015, the annual average wind speed in northern China's wind erosion region decreased significantly at a rate of $0.017 \text{ m} \cdot \text{s}^{-1} \cdot \text{a}^{-1}$ ($\alpha = 0.001$), with the most rapid decline in spring ($0.023 \text{ m} \cdot \text{s}^{-1} \cdot \text{a}^{-1}$) and the slowest in winter ($0.014 \text{ m} \cdot \text{s}^{-1} \cdot \text{a}^{-1}$). The decreasing trend was strongest in the 1980s and weakest in the 1990s, with a slight increase observed only in the 2010s.
- (2) Significant spatial differences existed in wind speed trends. The central-east, central-west, northwest, and eastern regions experienced the fastest decreases, while parts of Gansu, Ningxia, Shanxi, Shaanxi, Liaoning, and Xinjiang showed non-significant trends. Seasonal spatial patterns varied, with spring and summer showing expanded areas of rapid decline.
- (3) Wavelet analysis revealed quasi-periodic variations of approximately 28 years and 18 years, with the region currently in a low wind velocity stage.

These findings improve our understanding of wind speed changes and provide a scientific basis for predicting future trends, which is crucial for disaster prevention, ecological improvement, and wind energy planning in northern China' s wind erosion region.

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Abstract: In order to research the temporal and spatial characteristics of wind speed changes in the wind erosion region of northern China, annual and seasonal wind speed data from the 155 meteorological stations evenly distributed in the study area were selected from 1971 to 2015, and the methods of climate trending rate, spatial interpolation and wavelet analysis method were used. The annual and seasonal wind speed characteristics, spatial variability of the range of wind speed variety and the period of wind speed changes were analyzed. The results showed as follows that the annual average wind speed was $2.70 \text{ m} \cdot \text{s}^{-1}$ in the wind erosion region of northern China and reduced significantly at a rate of $0.017 \text{ m} \cdot \text{s}^{-1} \cdot \text{a}^{-1}$ ($\alpha = 0.001$) in the last 45 years. Furthermore, the seasonal

wind speed trend rate were $-0.023 \text{ m} \cdot \text{s}^{-1} \cdot \text{a}^{-1}$ (spring), $-0.017 \text{ m} \cdot \text{s}^{-1} \cdot \text{a}^{-1}$ (summer), $-0.016 \text{ m} \cdot \text{s}^{-1} \cdot \text{a}^{-1}$ (autumn), $-0.014 \text{ m} \cdot \text{s}^{-1} \cdot \text{a}^{-1}$ (winter) ($\alpha = 0.001$), respectively. Wind speed decreased fastest and slowest were in 1980s and 1990s respectively, and wind speed increased only in 2010s. There were significant differences in different decades and seasons. The change range of wind speed had different spatial distribution in the wind erosion region of northern China. The wind speed decreased quickly in the central east, central west, northwest and east part of northern China. The southeastern part of Gansu, Ningxia, northern parts of Shanxi and Shaanxi, Liaoning and northeastern and western parts of Xinjiang provinces were areas where wind speed were not significantly decreasing. In spring and summer, the area of wind speed reduced quickly has extended, and the area of wind speed reduced slowly has extended in winter and autumn. Morlet wavelet analysis revealed that average wind speed exhibited quasi-periodic variations of around 28 year, and the average change period was about 18 years. At present, the wind erosion region of northern China is experiencing a low wind velocity stage. This paper used the latest time series data to analyze the temporal and spatial analysis of wind speed in the whole wind erosion region of northern China to improve the overall and forward understanding of wind speed changes and lay the foundation for predicting the future trend of wind speed, which is of far-reaching significance for preventing the disasters and improving the ecology and environment of the wind erosion region of northern China, and provide reference and scientific basis for the nation to develop and make plans for wind energy resources.

Keywords: wind speed change; wavelet analysis; the wind erosion region of northern China

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