Spatiotemporal Variation of Extreme Climate Events in the Hulunbuir Grassland, 1960–2017: Postprint

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Abstract

Based on daily meteorological data from six meteorological stations in the Hulunbuir Grassland from 1960 to 2017, 13 climate change indices closely related to regional drought, flood, cold, and heat were calculated. Using methods including linear fitting, Mann-Kendall test, Sen' s slope estimator, and wavelet analysis, the occurrence trends and spatiotemporal patterns of extreme climate events in the Hulunbuir Grassland were analyzed. The results indicate: The extreme high temperature indices, including summer days, warm nights, warm days, and warm spell duration, increased significantly at rates of 3.53 d • (10a) ^{1}, 4.09 d • (10a) ^{1}, 3.1 d • (10a) ^{1}, and 2.67 d • (10a) ^{1}, respectively ($P<0.01$); while the extreme low temperature event indices, including frost days and cold nights, decreased significantly at rates of 3.22 d • (10a) ^{1} and 2.9 d • (10a) ^{1}, respectively ($P<0.05$). The abrupt change in extreme temperatures began in the 1990s, with the region of fastest warming located in the northeastern part of the study area. On the 58-year time scale, the significant periods of various extreme temperature indices were concentrated in 2–9 years. The maximum 5-day precipitation and consecutive wet days index in the study area showed significant decreasing trends at rates of 5 mm • (10a) ^{1} and 0.2 d • (10a) ^{1}, respectively ($P<0.01$), while the consecutive dry days index showed a slight increase. Annual total precipitation and precipitation intensity exhibited decreasing trends, but these were not significant. The indices characterizing extreme precipitation events (simple daily intensity index, annual total wet-day precipitation, aridity index, and maximum 5-day precipitation) showed a north-south division along the central axis of the study area: in the eastern region, the aridity index decreased and annual total precipitation increased significantly, indicating a wetting trend; in the western region, the consecutive dry days index increased and the consecutive wet days index decreased significantly, showing a drying trend. No uniform pattern was found in the distribution of precipitation index change points, with significant periods concentrated in 2–7 years.

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Full Text

Spatiotemporal Variation of Extreme Climatic Events in the Hulunbuir Grasslands during 1960–2017

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Abstract: Thirteen extreme climatic indices related to regional meteorological disasters and vegetation growth were calculated based on daily meteorological data from six meteorological stations in the Hulunbuir Grasslands and its surrounding area during 1960–2017. The linear trend method, Mann–Kendall test, Sen' s slope estimator, and wavelet analysis were used. The results showed that: (1) Summer days (SU25), warm nights (TN90P), warm days (TX90P), and consecutive warm days (CWD) used to characterize extreme high temperature increased significantly ($P < 0.01$) with rates of 3.53 d·(10a) ^{1}, 4.09 d·(10a) ^{1}, 3.1 d·(10a) ^{1}, and 2.67 d·(10a) ^{1}, respectively. Frost days (FD0) and cold nights (TN10P) used to characterize extreme cold events decreased significantly with rates of 3.22 d·(10a) ^{1} and 2.9 d·(10a) ^{1} ($P < 0.05$). (2) The abrupt change of extreme temperature began from the 1990s. The region with the highest warming rate was located in the northeastern part of the study area. The significant period of extreme high temperature index was concentrated on the scale of 2–9 years. (3) The maximum 5-day precipitation (RX5D) and consecutive wet index (CWD) in the study area were in a significantly decreasing trend ($P < 0.01$) with rates of 5 mm·(10a) ^{1} and 0.2 d·(10a) ^{1}, respectively. The consecutive dry index (CDD) was in a slight increase, and the annual wet day precipitation (PRCPTOT) and precipitation intensity were in a slight decrease trend. (4) The indices used to characterize extreme precipitation events (common daily intensity index, wet day precipitation, consecutive dry index, and maximum 5-day precipitation) were delimited along the central axis of the study area in a north-south direction. The drying index in the eastern region was in a decrease trend. Annual precipitation increased significantly. In the western region, the consecutive dryness index (CDD) increased, and the consecutive wetness index (CWD) decreased significantly.

Keywords: extreme climate; extreme precipitation; spatiotemporal variation; Mann–Kendall test; wavelet analysis; Hulunbuir grasslands

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1 Introduction

Climate change and its impacts have become a major concern in global change research. Extreme climate events, as an important component of climate change, have significant effects on natural ecosystems and socio-economic systems. According to IPCC reports, from 1880 to 2012, the global average surface temperature increased by 0.85°C, and the frequency and intensity of extreme climate events showed significant changes. Under the background of global warming, the spatiotemporal variation characteristics of extreme climate events in the Hulunbuir Grasslands have undergone profound changes, affecting regional vegetation growth and ecosystem stability. Studying the variation trends of extreme climate events in this region is of great significance for understanding regional climate change impacts and adaptation strategies.

2 Data and Methods

2.1 Data Sources

Daily meteorological data from six meteorological stations in the Hulunbuir Grasslands and surrounding areas from 1960–2017 were used, including daily maximum temperature, minimum temperature, and precipitation. The data were obtained from the China Meteorological Data Service Center (http://data.cma.cn). NDVI data were used to analyze vegetation growth conditions. Based on previous studies, 13 extreme climate indices were selected, including temperature extremes and precipitation extremes (Table 1).

2.2 Methods

2.2.1 Extreme Climate Indices The extreme climate indices were calculated following the definitions recommended by the ETCCDI (Expert Team on Climate Change Detection and Indices). The indices include absolute indices, threshold indices, duration indices, and other metrics that characterize extreme temperature and precipitation events.

Table 1 Definitions of extreme climate indices

Index	Name	Definition	Unit
FD0	Frost days	Annual count of days with daily minimum temperature < 0°C	d
TN10p	Cold nights	Percentage of days with daily minimum temperature < 10th percentile	%

Index	Name	Definition	Unit
TX10p	Cold days	Percentage of days with daily maximum temperature < 10th percentile	%
CSDI	Cold spell duration indicator	Annual count of days with at least 6 consecutive days of minimum temperature < 10th percentile	d
TN90p	Warm nights	Percentage of days with daily minimum temperature > 90th percentile	%
TX90p	Warm days	Percentage of days with daily maximum temperature > 90th percentile	%
SU25	Summer days	Annual count of days with daily maximum temperature > 25°C	d
WSDI	Warm spell duration indicator	Annual count of days with at least 6 consecutive days of maximum temperature > 90th percentile	d
PRCPTOT	Annual wet day precipitation	Annual total precipitation from days with precipitation 1 mm	mm
SDII	Simple daily intensity index	Annual total precipitation divided by number of wet days	mm · d ^{1}
RX5D	Maximum 5-day precipitation	Annual maximum consecutive 5-day precipitation	mm
CDD	Consecutive dry days	Maximum number of consecutive days with precipitation < 1 mm	d
CWD	Consecutive wet days	Maximum number of consecutive days with precipitation 1 mm	d

2.2.2 Trend Analysis Methods The linear trend method was used to analyze the temporal variation of each extreme climate index. The Mann-Kendall test and Sen' s slope estimator were applied to detect trend significance and magnitude. Wavelet analysis was employed to identify periodic characteristics of the time series. All analyses were performed using Matlab 2015b.

3 Results

3.1 Temporal Variation Characteristics

The extreme high temperature indices (SU25, TN90P, TX90P, CWD) showed significant increasing trends ($P < 0.01$) with rates of 3.53 d · (10a) ^{1}, 4.09 d · (10a) ^{1}, 3.1 d · (10a) ^{1}, and 2.67 d · (10a) ^{1}, respectively. The extreme low temperature indices (FD0, TN10P) showed significant decreasing trends with rates of 3.22 d · (10a) ^{1} and 2.9 d · (10a) ^{1} ($P < 0.05$). TX10P and CSDI showed no significant trends.

The Mann–Kendall test revealed that the abrupt change of extreme temperature indices began in the 1990s. The mutation points for TX90P, SU25, TN90P, and WSDI were significant at the 0.01 level, indicating a significant warming shift in the region.

The wavelet analysis showed that the significant periods for extreme temperature indices were concentrated at 2–9 year scales. The extreme precipitation indices RX5D and CWD showed significant decreasing trends ($P < 0.01$) with rates of 5 mm · (10a) ^{1} and 0.2 d · (10a) ^{1}, respectively. The consecutive dry index (CDD) showed a slight increasing trend, while precipitation intensity (SDII) and annual wet day precipitation (PRCPTOT) showed slight decreasing trends. The significant periods for precipitation indices were concentrated at 2–7 year scales.

3.2 Spatial Variation Characteristics

The extreme precipitation indices (SDII, PRCPTOT, CDD, RX5D) showed a north-south differentiation pattern along the central axis of the study area. In the eastern region, the drying index showed a decreasing trend while annual precipitation increased significantly. In the western region, the consecutive dry index (CDD) increased and the consecutive wet index (CWD) decreased significantly ($P < 0.05$), indicating a drying trend.

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