Characteristic Analysis of Extreme Temperature and Drought Events in Different Grassland Type Regions of Inner Mongolia over the Past 60 Years: Postprint

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Abstract

Based on the relative moisture index and non-parametric percentile method, combined with linear trend analysis, Mann-Kendall non-parametric test, and cumulative anomaly test, we analyzed temperature and precipitation, as well as the variation characteristics of extreme climate events in four grassland type regions of Inner Mongolia (Duolun, Xilinhot, Hailar, and Siziwang Banner) from 1955 to 2015. The results show that: (1) The annual mean temperature in all four regions increased significantly, with a warming rate of approximately 0.40~0.47℃ • $(10a)^{-1}$. The temperature change exhibited asymmetric warming characteristics; the increasing rate of minimum temperature was 1.61, 1.86, 2.73, and 1.65 times that of maximum temperature in Duolun, Xilinhot, Hailar, and Siziwang Banner, respectively. The temperature increase rate in spring and winter was higher than that in summer and autumn. (2) The annual precipitation in Duolun, Hailar, Siziwang Banner, and Xilinhot was 381.6mm, 350.5mm, 318.6mm, and 283.6mm, respectively; the number of precipitation days increased significantly, whereas precipitation showed no significant change, with Duolun and Xilinhot exhibiting a slight decreasing trend and the other two regions showing a slight increasing trend. (3) The frequency of extreme high temperature events increased significantly in all four regions, with abrupt change points occurring in the 1990s; the frequency of extreme low temperature events decreased significantly, with abrupt change points occurring in the late 1970s. (4) All four regions exhibited a warming-drying trend. Drought events were most prominent in Xilinhot; Siziwang Banner was dominated by moderate drought, while Hailar and Duolun were mainly drought-free. After 2000, the frequency of drought events increased significantly in all four regions. The non-significant change in precipitation, combined with significant increases in temperature and potential evapotranspiration, may be the main cause of the

continuous aridification in the four regions.

Full Text

Preamble

This study analyzes temperature, precipitation, and extreme climate event characteristics in four grassland regions of Inner Mongolia—Dolun, Xilinhot, Hailar, and Siziwang Banner—using the relative humidity index and non-parametric percentile method, combined with linear trend analysis, Mann-Kendall mutation testing, and cumulative anomaly testing. The results indicate: (1) Annual average temperatures increased significantly at rates of 0.40–0.47℃ · $(10a)^{-1}$, with asymmetric trends where minimum temperature rose 1.61–2.73 times faster than maximum temperature; (2) While the number of precipitation days increased significantly, precipitation amounts showed mixed trends; (3) Extreme high temperature events increased significantly while extreme cold events decreased; (4) Over the past 60 years, the climate has exhibited warming and drying trends, with extreme drought events becoming more frequent after 2000.

2. Data and Methods

Meteorological data from 1955–2015 were obtained from the China Meteorological Administration, including daily temperature, precipitation, sunshine hours, wind speed, and relative humidity. The linear trend method was applied using the equation $y = at + b$, where y represents the meteorological element, t is time, a denotes the trend rate, and b is the intercept. The decadal trend rate was calculated as $a \times 10$.

2.1 Mann-Kendall Trend Test

The Mann-Kendall (M-K) test is a non-parametric method for detecting trends in time series data. The test statistic UF follows a standard normal distribution: when $UF > 0$, the series shows an upward trend; when $UF < 0$, a downward trend is indicated. The critical value for significance testing at the 95% confidence level is $UF_{0.05} = \pm 1.96$.

2.2 Potential Evapotranspiration Calculation

Potential evapotranspiration (PET_{TH}) was calculated using the Thornthwaite method:

$$PET_{TH} = 16.0 \times \left(10\frac{T_i}{H}\right)^A$$

where PET_{TH} is monthly potential evapotranspiration (mm · mon^{-1}), T_i is mean monthly temperature (℃), H is the annual heat index, and A is a coefficient calculated as:

$$A = 6.75 \times 10^{-7} H^3 - 7.71 \times 10^{-5} H^2 + 1.792 \times 10^{-2} H + 0.49$$

When $T \leq 0$℃, the heat index H is set to 0 and evapotranspiration is 0 mm · mon^{-1}.

2.3 Drought Classification

Drought events were classified using the relative humidity index based on the national standard "Classification of Meteorological Drought" (GB/T 20481–2006). The index M was calculated as:

$$M = \frac{P - PET_{TH}}{PET_{TH}} \times 100\%$$

where P is monthly precipitation (mm). Drought severity was categorized as: no drought ($M > -20\%$), mild drought ($-35\% < M \leq -20\%$), moderate drought ($-50\% < M \leq -35\%$), and severe drought ($M \leq -50\%$).

3. Results

3.1 Temperature Trends (1955-2015)

From 1955-2015, annual average temperatures in all four grassland regions increased significantly ($P < 0.05$) at rates of 0.40-0.47℃ · (10a)$^{-1}$. Minimum temperatures rose 1.61-2.73 times faster than maximum temperatures, demonstrating pronounced asymmetric warming. Seasonal analysis revealed higher warming rates in spring and winter compared to summer and autumn.

The growing season length (defined as days with daily average temperature ≥ 5℃) increased significantly at rates of 1.4-4.7 days · (10a)$^{-1}$ across the regions. The number of precipitation days also increased significantly (5.6-5.9 days · (10a)$^{-1}$), while precipitation amounts showed regional variation: slight decreases in Dolun and Xilinhot, and minor increases in Hailar and Siziwang Banner.

3.2 Extreme Climate Events

Extreme high temperature events increased significantly while extreme low temperature events decreased significantly across all regions. After 2000, the frequency of drought events increased markedly, particularly in Xilinhot which experienced the highest frequency of extreme drought. Siziwang Banner was dominated by moderate drought events. This intensification likely resulted from significant temperature increases and rising potential evapotranspiration without corresponding significant changes in precipitation.

The asymmetric warming pattern—where minimum temperatures increased 0.50-0.60℃ per decade compared to lower rates for maximum temperatures—has substantially altered the thermal regime. The growing season extended by

18-20 days in meadow steppe and typical steppe regions, and up to 27 days $\cdot$ a^{-1} in desert steppe areas, with three grassland types showing 17-19 days $\cdot$ a^{-1} extensions.

5. Discussion

The significant warming trend of 0.40-0.47℃ $\cdot$ $(10a)^{-1}$ across Inner Mongolia grasslands has profound ecological implications. The asymmetric nature of this warming, with minimum temperatures rising faster than maximums, alters the diurnal temperature range and affects ecosystem processes. Increased precipitation days without substantial changes in total precipitation suggest more frequent but less intense rainfall events.

The lengthening growing season and increased drought frequency, particularly post-2000, indicate a clear warming-drying trend. These changes affect grassland productivity and carbon cycling, with potential evapotranspiration playing a key role in drought intensification. The differential responses among grassland types—meadow steppe, typical steppe, and desert steppe—highlight the need for region-specific adaptation strategies.

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