Spatiotemporal Variation of Extreme Temperature in the Hedong Region over the Past 30 Years: Postprint

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Abstract

Using daily maximum temperature, minimum temperature, and mean temperature data from 61 meteorological stations during 1988–2017, and employing linear trend estimation, Mann-Kendall test, moving t-test, and correlation analysis methods, the spatiotemporal variation characteristics of extreme temperature events in the Hedong region were investigated. The results indicate that: In the Hedong region over the past 30 years, the maximum (minimum) values of daily maximum temperature, maximum (minimum) values of daily minimum temperature, annual mean maximum (minimum) temperature, summer days, tropical nights, warm days (nights), diurnal temperature range, warm spell duration, and biological growing season exhibit increasing trends, while frost days, ice days, cold days (nights), and cold spell duration exhibit decreasing trends. The warming magnitude of warm indices is greater than that of cold indices, the warming magnitude of daytime indices is greater than that of nighttime indices, with the largest warming magnitude occurring in the Longdong Plateau region and the smallest in the Gannan Plateau region. The abrupt change points of most indices occurred in the mid-to-late 1990s and the early 21st century. Most extreme temperature indices are significantly correlated with longitude and altitude, and the changes in extreme temperature indices in the Hedong region are closely associated with regional warming.

Full Text

2. Data and Methods

2.1 Data Sources

Daily maximum, minimum, and mean temperature data from 61 meteorological stations in the Hedong region were used for the period 1988–2017 [Figure 1: see original paper]. The data were provided by the National Meteorological

Information Center of China. Quality control procedures included removal of missing values and outliers. According to the World Meteorological Organization (WMO) recommendations and the Climate Variability and Predictability (CLIVAR) project, the Expert Team on Climate Change Detection and Indices (ETCCDI) defines 27 core extreme climate indices, of which 16 temperature indices were selected for this study (Table 1). These indices can be categorized into four types: absolute indices, relative indices, extreme value indices, and duration indices [12, 26–27].

The 16 extreme temperature indices include: frost days (FD0), ice days (ID0), summer days (SU25), tropical nights (TR20), warm days (TX90P), warm nights (TN90P), cold days (TX10P), cold nights (TN10P), maximum daily maximum temperature (TXx), maximum daily minimum temperature (TNx), minimum daily maximum temperature (TXn), minimum daily minimum temperature (TNn), mean daily maximum temperature (TXam), mean daily minimum temperature (TNam), diurnal temperature range (DTR), growing season length (GSL), warm spell duration indicator (WSDI), and cold spell duration indicator (CSDI).

2.2 Definition of Extreme Temperature Indices

The extreme temperature indices were calculated using the RClimDex software package. Table 1 provides detailed definitions of each index. Absolute indices are based on fixed threshold values (e.g., FD0: days with daily minimum temperature < 0°C). Relative indices are based on percentiles (e.g., TX90P: percentage of days when daily maximum temperature $>$ 90th percentile). Extreme value indices represent the highest or lowest values within a given period. Duration indices measure the length of warm or cold spells.

2.3 Analysis Methods

Linear regression analysis was used to calculate trends in extreme temperature indices over time. The Mann-Kendall (M-K) test was applied to detect monotonic trends and their significance levels [29–30]. The sliding T-test was employed to identify abrupt changes in the time series [31]. Spatial distributions of trends were generated using the Inverse Distance Weighted (IDW) interpolation method in ArcGIS 10.2. Pearson correlation analysis was conducted to examine relationships between extreme temperature indices and geographic parameters (longitude, latitude, altitude) [16].

The M-K test is a non-parametric statistical test that detects whether a time series has a monotonic upward or downward trend. The test statistic follows a standard normal distribution, with significance levels of 0.05 and 0.01 used to determine statistical significance. The sliding T-test compares the means of two sub-periods within the time series to identify potential abrupt change points.

3. Results

3.1 Temporal Trends of Extreme Temperature Indices

Over the past 30 years (1988-2017), significant warming trends were observed across most extreme temperature indices in the Hedong region [Figure 2: see original paper]. Warm indices showed increasing trends while cold indices showed decreasing trends. The trend magnitudes varied among different indices and sub-periods (Table 2).

For the entire study period (1988-2017), TX90P increased at a rate of 6.36 days per decade, TN90P increased by 1.85 days per decade, TX10P decreased by 2.25 days per decade, and TN10P decreased by 1.95 days per decade. The warming trends were more pronounced in the diurnal indices (TX90P, TX10P) compared to nocturnal indices (TN90P, TN10P). Summer days (SU25) increased by 6.52 days per decade, while frost days (FD0) decreased by 5.40 days per decade. Tropical nights (TR20) increased by 3.51 days per decade, and ice days (ID0) decreased by 2.61 days per decade.

The growing season length (GSL) showed a significant increasing trend of 7.66 days per decade, while the cold spell duration indicator (CSDI) decreased by 0.27 days per decade. The warm spell duration indicator (WSDI) increased by 1.95 days per decade. The mean daily maximum temperature (TXam) increased by 0.64°C per decade, and the mean daily minimum temperature (TNam) increased by 0.41°C per decade.

3.2 Abrupt Changes in Extreme Temperature Indices

Abrupt changes in most extreme temperature indices occurred in the mid-1990s and early 2000s [Figure 3: see original paper]. The sliding T-test identified significant abrupt changes around 1997 for FD0, 1994 for ID0, 1995 for TX90P, 1997 for TX10P, and 2000 for CSDI (Table 3). These change points correspond to a period of accelerated warming in the region.

For warm indices, SU25 showed an abrupt increase in 1997, while TR20 increased sharply after 1994. TX90P exhibited a significant upward shift in 1995, and TN90P increased abruptly in 1996. Cold indices generally showed abrupt decreases around the same period, with TX10P decreasing significantly after 1997 and TN10P after 1999.

3.3 Spatial Distribution of Trends

The spatial distribution of trends revealed significant regional variations across the Hedong region [FIGURE:4-7]. Warming trends were generally more pronounced in the eastern Loess Plateau area, while the Gannan Plateau in the southwest showed relatively weaker trends.

For absolute indices, FD0 showed decreasing trends across 71.43% of stations, with the largest decreases in the central region at rates up to -12.82 days per decade (significant at $p < 0.01$). ID0 decreased at 39.34% of stations, primarily in the central and eastern areas. SU25 increased at 96.72% of stations, with the highest increases in the eastern Loess Plateau reaching 9.51 days per decade. TR20 increased at 59.02% of stations, mainly in the central region.

Relative indices showed TX90P increasing at 77.05% of stations, with the most significant increases in the eastern region at 7.63 days per decade. TN90P increased at 91.80% of stations, with rates up to 8.23 days per decade in the central area. TX10P decreased at 75% of stations, particularly in the central and eastern regions at -5.10 days per decade. TN10P decreased at 32.79% of stations, mainly in the eastern Loess Plateau.

Extreme value indices exhibited TXx increasing at 51.67% of stations, with the highest increases in the central region at 2.71°C per decade. TNx increased at 27.87% of stations, primarily in the central area at 2.21°C per decade. TXn increased at 14.75% of stations, while TNn increased at 19.67% of stations.

Duration indices showed GSL increasing at 75% of stations, with the largest increases in the eastern region at 15.51 days per decade. WSDI increased at 59.02% of stations, while CSDI decreased at 27.87% of stations, mainly in the central region.

3.4 Correlation with Geographic Parameters

Correlation analysis revealed significant relationships between extreme temperature trends and geographic parameters (Table 5). Longitude showed positive correlations with TX90P ($r = 0.30$, $p < 0.05$) and TN90P ($r = 0.28$, $p < 0.05$), indicating stronger warming trends in the eastern part of the region. Altitude showed negative correlations with most cold indices, suggesting that higher elevation areas experienced less pronounced warming trends for cold extremes.

Latitude exhibited mixed relationships, with positive correlations for some warm indices and negative correlations for cold indices. The diurnal temperature range (DTR) showed a significant negative correlation with altitude ($r = -0.48$, $p < 0.01$), indicating that higher elevation stations experienced smaller changes in DTR.

3.5 Regional Variations

The Hedong region was divided into four sub-regions for detailed analysis: the eastern Loess Plateau, central region, western region, and Gannan Plateau. Table 4 shows the average values and trends of extreme temperature indices for each sub-region.

The eastern Loess Plateau exhibited the most pronounced warming, with TX90P increasing at 6.20 days per decade and TN90P at 2.53 days per decade. The Gannan Plateau showed the weakest trends, with TX90P increasing at only 0.67 days per decade. Frost days decreased most rapidly in the central region (-6.44 days per decade) and most slowly in the Gannan Plateau (-0.67 days per decade).

The growing season length increased by 9.45 days per decade in the eastern Loess Plateau but only by 1.68 days per decade in the Gannan Plateau. These regional differences reflect the complex topography and varying climate sensitivity across the Hedong region.

4. Discussion

The significant warming trends in extreme temperature indices observed in the Hedong region are consistent with global warming patterns [34-38]. The more pronounced warming in diurnal indices compared to nocturnal indices suggests asymmetric warming, which may be related to local land cover changes and urbanization effects [27, 32].

The abrupt changes detected in the mid-1990s and early 2000s align with the accelerated warming period observed across northwestern China [14, 15]. The spatial heterogeneity of trends, with stronger warming in the eastern Loess Plateau and weaker trends in the Gannan Plateau, reflects the influence of topography and elevation on climate change patterns [33].

The significant correlations between extreme temperature trends and geographic parameters indicate that longitude and altitude are important controlling factors. The eastern part of the region, at lower elevations, experienced more rapid warming, possibly due to stronger human activities and land use changes [39-41].

5. Conclusions

Based on the analysis of daily temperature data from 61 meteorological stations in the Hedong region during 1988-2017, the following conclusions were drawn:

1. Most extreme temperature indices showed significant warming trends over the past 30 years. Warm indices (TX90P, TN90P, SU25, TR20, WSDI, GSL) increased significantly, while cold indices (TX10P, TN10P, FD0, ID0, CSDI) decreased. The warming magnitude of diurnal indices exceeded that of nocturnal indices.

2. Abrupt changes in most extreme temperature indices occurred in the mid-1990s and early 2000s, with 1994-1997 being a critical transition period for many indices.

3. Spatial distribution of trends showed significant regional variations, with the strongest warming in the eastern Loess Plateau and the weakest in the Gannan Plateau. Warming trends were more pronounced in the eastern and central parts of the region.

4. Extreme temperature trends were significantly correlated with geographic parameters, particularly longitude and altitude. Higher elevation areas generally showed weaker warming trends for most indices.

These findings provide important insights into climate change impacts in the Hedong region and can inform adaptation strategies for agriculture and water resource management.

Abstract: The methods of linear regression, Mann-Kendall test, sliding T-test, and correlation analysis were used to analyze the spatiotemporal variation of extreme temperature events in the Hedong region based on daily temperature (maximum, minimum, and average) data from 61 meteorological stations in the study area during the period of 1988–2017. The results showed that: In recent 30 years, the daily maximum and minimum temperature values, annual mean maximum and minimum temperature values, summer duration, tropical nights, warm days, warm nights, daily temperature range, warm-day duration, and growing season were in an increase trend. Whereas the frost days, ice days, cold days, cold nights, and cold-day duration were in a decrease trend; The change ranges of warming indices were obviously higher than those of cold ones. The warming ranges of diurnal indices were higher than those of nocturnal ones. The warming range was the highest in the Loess Plateau in east Gansu Province but the lowest in the Gannan Plateau; Abrupt change of the most temperature indices occurred in the mid-1990s and early 21st century; Most extreme temperature indices were closely related to the longitude and altitude. The variation of extreme temperature indices in the Hedong region was closely related to the regional warming.

Keywords: extreme temperature; cold (warm) index; spatiotemporal variation; Hedong region; Gansu Province

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