

Spatiotemporal Variation Characteristics of Extreme Temperature in Hami City over the Past 60 Years: Postprint

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Date: 2023-07-19T00:00:00+00:00

Abstract

Using daily maximum and minimum temperature data from the Hami National Meteorological Reference Station from 1961 to 2019, methods including simple linear regression, 10-year moving average, Mann-Kendall test, sliding t-test, and principal component analysis were employed to analyze the spatiotemporal variation characteristics of extreme temperatures in Hami City, providing a basis for predicting future temperature change trends, enhancing the capacity to respond to extreme temperature events, and mitigating the hazards of meteorological disasters on agricultural production in Hami City. The results show that: (1) The changes in extreme temperature indices in Hami City exhibit asymmetry, with cold and warm indices showing opposite trends, and the warming magnitude of night indices being greater than that of day indices. Seasonally, most extreme temperature indices show greater changes in summer and autumn. (2) Over the past 60 years, the frequency of extreme low-temperature events in Hami City has decreased significantly, with frost days showing the most pronounced decline at a rate of $-4.59 \text{ d} \cdot (10\text{a})^{-1}$; the frequency of extreme high-temperature events has increased and their intensity has significantly strengthened; the changes in growing season length and warm spell duration index tend to be consistent, while the cold spell duration index shows opposite changes. (3) Cold extreme temperature indices are more sensitive to climate change, with abrupt changes occurring in the mid-1980s and late 1990s, while the abrupt change time for warm indices and duration indices was the late 1990s. (4) The cumulative variance contribution rate of the two principal components is 76.453%, the changes in extreme temperature events are highly correlated with temperature warming, cold and warm indices are negatively correlated, and cold nights, cold days, frost days, warm nights, and warm days are the main factors contributing to temperature increase in Hami City.

Full Text

Spatial and Temporal Variation Characteristics of Extreme Temperatures in Hami City in the Past 60 Years

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Abstract

Using daily maximum and minimum temperature data from Hami National Meteorological Reference Station from 1961 to 2019, this study analyzed the spatiotemporal variation characteristics of extreme temperature in Hami City through univariate linear regression, 10-year moving average, Mann-Kendall test, moving t-test, and principal component analysis. This provides a basis for predicting future temperature trends, enhancing the city's capacity to respond to extreme temperature events, and reducing meteorological disaster impacts on agricultural production. The results show: (1) Extreme temperature index changes exhibit asymmetry, with cold and warm indices trending in opposite directions, and nighttime indices warming more than daytime indices. Seasonally, most extreme temperature indices show greater variation in summer and autumn. (2) Over the past 60 years, the frequency of extreme low-temperature events decreased significantly, with frost days showing the most pronounced decline at $-4.59 \text{ d} \cdot (10\text{a})^{-1}$. The frequency and intensity of extreme high-temperature events increased significantly. The growing season length and warm spell duration index showed consistent trends, while the cold spell duration index changed in the opposite direction. (3) Cold indices are more sensitive to climate change, with abrupt changes occurring in the mid-1980s and late 1990s, while warm and persistent indices showed abrupt changes in the late 1990s. (4) The cumulative variance contribution of two principal components reached 76.453%, indicating high correlation between extreme temperature events and temperature warming, with negative correlation between cold and warm indices. Cold nights, cold days, frost days, warm nights, and warm days were the main factors contributing to temperature increase in Hami City.

Keywords: extreme temperature index; temporal and spatial variation; mutation test; Hami City

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report indicates that global mean surface temperature has risen by 1.07°C , and projects that global surface temperature will increase by $1.5\text{--}2.0^\circ\text{C}$ within the next 20 years. In China, temperature changes over the past century show a

significant upward trend, with annual mean surface temperature rising by approximately $0.20\text{--}0.52^{\circ}\text{C} \cdot (10\text{a})^{-1}$. Under global warming, climate change is affecting every region on Earth in multiple ways. Extreme climate events such as extreme temperatures, heavy rainfall, and floods have significant impacts on human society, economy, and agriculture.

Numerous scholars have analyzed extreme climate events across different regions. At the global scale, Alexander et al. [?] found that over 70% of land areas experienced significantly fewer cold nights and more warm nights. In China, Zheng et al. [?] documented multiple extreme cold winters and exceptionally warm periods exceeding 20th-century records. Wang et al. [?] found that overall, extreme temperatures show warming slowdown or cooling phenomena, with regional and seasonal differences. For northwestern China, Qi et al. [?] showed that temperatures rose overall, with negative correlation between extreme high- and low-temperature event frequencies. Qu et al. [?] found increasing extreme high-temperature events in northwest China, concentrated in Xinjiang, Qinghai, Gansu, and Ningxia.

Xinjiang's unique geographical location and fragile ecological environment make it highly sensitive to climate change. Zhang et al. [?] analyzed extreme climate events in northern Xinjiang using data from 22 meteorological stations, finding significant increases in both high- and low-temperature event intensity and frequency. Gao et al. [?] analyzed 16 extreme temperature indices in Tacheng, finding greater warming in northern than southern regions and asymmetric changes between cold and warm indices. While many studies have focused on large-scale regions in Xinjiang, research on smaller-scale areas remains limited.

Hami City, located in eastern Xinjiang at the center of the Eurasian continent with the Tianshan Mountains traversing it, exhibits climate characteristics of both northern and southern Xinjiang. With a typical temperate continental arid climate, Hami is one of China's hottest and driest regions and an important base for animal husbandry and fruit production. Extreme climate events significantly impact local agricultural development. This study uses daily maximum and minimum temperature data from six meteorological stations in Hami City and the RCLimDex 1.0 software to analyze 16 extreme temperature indices, providing a basis for predicting future temperature trends and mitigating meteorological disaster impacts on agricultural production.

2. Data and Methods

Data were obtained from six national meteorological ground reference stations in Hami City (Barkol, Hami, Hongliuhe, Naomao Lake, Shisanjianfang, and Yiwu). Based on principles of data continuity and maximum time span, daily maximum and minimum temperature data from 1960–2019 were selected. Seasons were defined according to Xinjiang's unique geography: spring (March–May), summer (June–August), autumn (September–November), and winter (December–February). Meteorological data underwent quality control for missing values,

outliers, and errors (such as daily maximum temperature < daily minimum temperature), which accounted for 0.142% of the data.

The study employed univariate linear regression, 10-year moving average, Mann-Kendall test, moving t-test, inverse distance weighting interpolation, and principal component analysis to examine temporal trends, abrupt changes, spatial variations, and correlations of extreme temperature indices in Hami City. Sixteen extreme temperature indices were calculated using RClimDex 1.0 software .

3. Results

3.1 Temporal Variation Characteristics

3.1.1 Trend Analysis From 1960–2019, extreme temperature cold indices in Hami City showed decreasing trends, except for daily minimum temperature extremes (TNn) and daily maximum temperature extremes (TXn) [Figure 2: see original paper]. The absolute trend rates from high to low were: frost days (FD0) at $-4.59 \text{ d} \cdot (10\text{a})^{-1}$, ice days (ID0) at $-1.90 \text{ d} \cdot (10\text{a})^{-1}$, cold days (TX10P) at $-1.16 \text{ d} \cdot (10\text{a})^{-1}$, and cold nights (TN10P) at $-1.09 \text{ d} \cdot (10\text{a})^{-1}$. TNn and TXn showed large fluctuations with increasing trends of $0.30^\circ\text{C} \cdot (10\text{a})^{-1}$ and $0.65^\circ\text{C} \cdot (10\text{a})^{-1}$, respectively. TNn showed large fluctuations before 1985, then smaller fluctuations with an increasing trend; TXn showed a slight increase before 1990, then a decreasing trend at $-1.10 \text{ d} \cdot (10\text{a})^{-1}$.

Warm indices showed consistent increasing trends. Summer days (SU25), warm nights (TN90P), and warm days (TX90P) increased significantly at rates of $3.85 \text{ d} \cdot (10\text{a})^{-1}$, $5.35 \text{ d} \cdot (10\text{a})^{-1}$, and $4.06 \text{ d} \cdot (10\text{a})^{-1}$, respectively—more than double the rates of TN90P. Tropical nights (TR20), daily minimum temperature maximum (TNx), and daily maximum temperature maximum (TXx) showed slight increases at $0.53^\circ\text{C} \cdot (10\text{a})^{-1}$, $0.49^\circ\text{C} \cdot (10\text{a})^{-1}$, and $0.46^\circ\text{C} \cdot (10\text{a})^{-1}$, respectively, all passing the 0.05 significance test.

The growing season length (GSL) and warm spell duration index (WSDI) showed consistent increasing trends, while the cold spell duration index (CSDI) showed the opposite trend. GSL increased significantly at $3.52 \text{ d} \cdot (10\text{a})^{-1}$ with large fluctuations, while WSDI increased slightly at $2.85 \text{ d} \cdot (10\text{a})^{-1}$. CSDI showed large fluctuations before 1990, then slight fluctuations with a decreasing trend at $-0.77 \text{ d} \cdot (10\text{a})^{-1}$.

Seasonally, most indices showed greater variation in summer and autumn. Cold indices TX10P and TN10P passed significance tests in all seasons, with winter showing the largest increase for TNn ($0.70^\circ\text{C} \cdot (10\text{a})^{-1}$) and summer the largest for TXn ($0.57^\circ\text{C} \cdot (10\text{a})^{-1}$). Warm indices TX90P and TN90P showed significant increases in all seasons, with summer rates of $6.88 \text{ d} \cdot (10\text{a})^{-1}$ and $5.30 \text{ d} \cdot (10\text{a})^{-1}$, respectively, and winter rates of $3.41 \text{ d} \cdot (10\text{a})^{-1}$ and $2.54 \text{ d} \cdot (10\text{a})^{-1}$.

3.1.2 Abrupt Change Characteristics Mann-Kendall and moving t-tests detected abrupt changes in extreme temperature indices. Cold indices TN10P, TX10P, FD0, and ID0 showed significant decreasing trends after 1985 [Figure 3: see original paper]. TN10P exceeded the 0.01 significance level ($\pm \$2.88$) in 1988, with the intersection point within the moving t-test range ($N=10$), indicating an abrupt change around 1988. TX10P exceeded the threshold in 1997, with the intersection point within the 1995–1999 range, indicating a 1997 abrupt change. FD0 and ID0 showed similar patterns with abrupt changes in 1997 and 1996, respectively.

Warm indices TN90P and TX90P showed significant upward trends after 1995, with abrupt changes in the late 1990s. TN90P exceeded the threshold in 1998, with the intersection point within the 1996–2000 range. TX90P showed multiple intersection points; moving t-test confirmed an abrupt change in 1998. Persistent indices GSL and WSDI showed abrupt changes in the late 1990s, while CSDI showed no significant abrupt change.

3.2 Spatial Variation Characteristics

From 1960–2019, extreme low-temperature event frequency decreased significantly across Hami City. FD0 showed the most significant decline, decreasing from east to west, with 33–50% of stations passing significance tests. Extreme high-temperature event frequency and intensity increased significantly, with TN90P and TX90P showing the most pronounced increases. High-value areas were in Shisanjianfang and Naomao Lake, while low-value areas were in Barkol, Hami, Yiwu, and Hongliuhe [Figure 4: see original paper].

Extreme temperature intensity indices TNn and TXx showed smaller variation ranges between stations, with warm indices changing more than cold indices. TN90P and TX90P increased significantly at all stations, with the largest increases in Shisanjianfang ($6.88 \text{ d} \cdot (10\text{a})^{-1}$) and $5.30 \text{ d} \cdot (10\text{a})^{-1}$, respectively). Barkol showed the most significant decrease in CSDI ($-2.14 \text{ d} \cdot (10\text{a})^{-1}$). Most stations with large variation trends are located near or surrounded by the Tianshan Mountains, indicating close relationships between terrain, elevation, and extreme temperature changes.

3.3 Regional Differences in Extreme Temperature Indices

To clarify differences between Hami and other regions, Table 3 compares extreme temperature index trends. Hami's extreme temperature changes are generally consistent with Xinjiang, global, and national trends but show notable differences. Cold index changes in Hami are significantly greater than in other Xinjiang regions and globally, particularly FD0 ($-4.59 \text{ d} \cdot (10\text{a})^{-1}$) and TN10P ($-2.06 \text{ d} \cdot (10\text{a})^{-1}$), which exceed levels in the Tianshan region, Xinjiang, and the Qinghai-Tibet Plateau. TX10P changes are slightly lower than in the Tianshan region but higher than in Xinjiang, indicating that mountainous areas are more sensitive to temperature changes than valleys and plains.

Warm index changes in Hami are greater than most other regions, with TN90P ($5.35 \text{ d} \cdot (10\text{a})^{-1}$) and TX90P ($4.06 \text{ d} \cdot (10\text{a})^{-1}$) significantly exceeding values for Xinjiang, Bayingolin Mongol Autonomous Prefecture, and the Loess Plateau. TX90P is slightly lower than in the Tianshan region. Persistent index changes are also significantly greater than most other regions. Overall, Hami City shows distinct extreme temperature index changes that are generally more pronounced than other Xinjiang and national regions, indicating high sensitivity to extreme temperature changes.

3.4 Principal Component Analysis of Extreme Temperature Indices

Principal component analysis yielded $KMO = 0.826$ and Bartlett's test significance < 0.01 , indicating suitability for factor analysis. The first two principal components had cumulative variance contribution of 76.453%, meeting analysis requirements .

The first principal component (60.614% variance) had high loadings for all indices except TX90P, with cold indices loading above 0.85 and warm indices above 0.70. The second principal component (15.839% variance) had high loadings for TX90P, TNx, and TXx. Correlation analysis shows warm indices are positively correlated ($P < 0.01$) and negatively correlated with cold indices (TN10P, TX10P). Cold indices are positively correlated with each other and negatively correlated with warm and persistent indices. Cold nights, cold days, frost days, warm nights, and warm days are the main factors driving temperature increase in Hami City.

4. Discussion and Conclusion

4.1 Discussion

Hami's extreme temperature trends are consistent with Xinjiang and national patterns, though most indices show lower magnitudes, possibly due to different study periods. Temperature changes are influenced by multiple factors, with atmospheric circulation being primary. Ding et al. [?] found that Arctic Oscillation (AO), North Atlantic Oscillation (NAO), and Southern Oscillation Index (SOI) significantly affect extreme temperatures in northern Xinjiang, with AO showing significant correlation and co-variation with surface temperature anomalies. Increased AO leads to fewer cold waves in northern China, promoting winter warming in Hami.

Terrain significantly influences extreme temperatures. The Tianshan Mountains traverse Hami from east to west, creating complex topography. Xu et al. [?] demonstrated close relationships between extreme temperature indices and terrain/elevation. In this study, areas with significant extreme temperature changes (Shisanjianfang, Hami) are located on the southern Tianshan slopes, clearly influenced by slope effects. Urbanization also impacts extreme temperatures [?]. With population growth and industrialization, environmental

degradation and increased greenhouse gas emissions contribute to rising temperatures. Solar activity [?] and cloud cover [?] also affect extreme temperature changes.

Extreme temperature events (extreme cold, extreme heat) severely damage society and ecosystems. Studying Hami's past extreme temperature trends and predicting future frequencies and intensities is crucial for effective adaptation. This study provides detailed spatiotemporal analysis, but further research is needed on influencing factors due to limited data.

4.2 Conclusion

- (1) **Temporal characteristics:** Hami's extreme temperature index changes are asymmetric, with opposite trends in cold and warm indices. Cold indices (except TN_n and TX_n) decreased while warm indices increased, with nighttime indices warming more than daytime indices. Seasonally, most indices show greater variation in summer and autumn, indicating increasing frequency of hot summer events.
- (2) **Spatial characteristics:** Over the past 60 years, extreme low-temperature event frequency decreased significantly, with FD₀ showing the most pronounced decline spatially decreasing from east to west. Only 33–50% of stations passed significance tests for intensity enhancement. Extreme high-temperature event frequency and intensity increased significantly, with TN_{90P} and TX_{90P} showing the most notable increases. High-value areas are in Shisanjianfang and Naomao Lake, while low-value areas are in Barkol, Hami, Yiwu, and Hongliuhe. Extreme persistent events show opposite trends: GSL and WSDI are consistent, while CSDI is opposite.
- (3) **Abrupt changes:** Cold indices are more sensitive to climate change, with abrupt changes around the mid-1980s. Warm indices (TN_{90P}, TX_{90P}) and persistent indices had abrupt changes in the late 1990s.
- (4) **Principal component analysis:** Two principal components explained 76.453% of variance. Correlation analysis shows high correlation between extreme temperature events and warming, with negative correlation between cold and warm indices. TN_{10P}, TX_{10P}, FD₀, TN_{90P}, and TX_{90P} are the main factors driving Hami's temperature increase.

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