Analysis of Extreme Temperature Variation Characteristics and Their Influencing Factors in Tacheng Region, Xinjiang (Postprint)

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Abstract

Using daily temperature data from 7 national meteorological observation stations in the Tacheng region from 1961 to 2018, and selecting 10 internationally recognized extreme temperature indices, the spatiotemporal variation characteristics of extreme temperatures in the Tacheng region and their influencing factors were analyzed. The results show: (1) The extreme temperature indices in the Tacheng region exhibit a clear warming trend, with the minimum temperature extreme value increasing significantly at a trend rate of 0.97 ℃·(10a)-1, while the maximum temperature extreme value increased insignificantly at a trend rate of 0.09 ℃·(10a) -1; cold days, cold nights, frost days, and ice days decreased at rates of 1.75, 5.24, 4.07, and 1.84 d·(10a)-1, respectively, while warm days, warm nights, summer days, and tropical nights increased significantly at rates of 1.79, 5.89, 2.18, and 2.08 d·(10a)-1, respectively; the future variation trends of all 10 selected extreme temperature indices are consistent with those of the past 58 years, showing strong persistence. (2) The variation amplitudes of cold and warm indices show significant asymmetry, with the magnitude of change in minimum temperature extreme values being greater than that of maximum temperature extreme values, and the magnitude of change in night indices being greater than that of day indices; most extreme temperature indices exhibit greater warming magnitudes in the northern part of the region than in the southern part. (3) Minimum temperature extreme values, cold days, and cold nights experienced a warm shift in the early 1980s; warm days, warm nights, summer days, tropical nights, and frost days experienced a warm shift in the mid-1990s. (4) Overall, changes in atmospheric circulation have a greater influence on cold indices than on warm indices, wherein cold days, cold nights, frost days, and ice days are positively correlated with the winter Northern Hemisphere and Asian polar vortex area indices, positively correlated with the Pacific, North American, and Atlantic-European polar vortex area indices and the Eurasian and Asian meridional circulation indices, and negatively correlated with the Eurasian and Asian zonal circulation indices and the Tibetan Plateau index; warm days, warm nights, summer days, and tropical nights are positively correlated with the summer Northern Hemisphere, Western Pacific subtropical high area, and Tibetan Plateau indices. (5) Cold and warm indices exhibit differences in their response to sea surface temperature variations in the Atlantic and tropical Pacific regions; night indices show a more pronounced response to sea surface temperature than day indices.

Full Text

Analysis of Variation Characteristics of Extreme Temperature and Its Influencing Factors in Tacheng Prefecture, Xinjiang

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Abstract

Based on daily temperature data from seven national meteorological stations in Tacheng Prefecture, sea surface temperature (SST) data from the Physical Sciences Laboratory of the National Oceanic and Atmospheric Administration (NOAA), and atmospheric circulation indices from the National Climate Center of China Meteorological Administration covering the period 1961-2018, this study analyzes the spatiotemporal variation characteristics of extreme air temperature indices and their influencing factors using the least-squares method, R/S analysis, Mann-Kendall tests, and Pearson correlation analysis. The results show that the annual maximum daily maximum temperature indices increased at a rate of 0.09 per decade (insignificant), whereas the annual minimum daily minimum temperature indices warmed at a rate of 0.97 per decade. Cool indices (cool days, cool nights, frost days, and icing days) decreased at rates of 1.75, 5.24, 4.07, and 1.84 $d \cdot (10a)^{-1}$, respectively, while warm indices (warm days, warm nights, summer days, and tropical nights) significantly increased at rates of 1.79, 5.89, 2.18, and 2.08 $d \cdot (10a)^{-1}$. Future trends of the ten extreme temperature indices are projected to continue the patterns observed over the past 58 years, with strong persistence. The variation between cool and warm indices exhibits pronounced asymmetry: the magnitude of change in the coldest daily minimum temperature exceeds that of the warmest daily maximum temperature, and the amplitude of night indices (cool nights, warm nights) is greater than that of day indices (cool days, warm days). Most extreme temperature indices show greater warming magnitude in northern Tacheng Prefecture than in the south. The annual minimum daily minimum temperature, cool days, and cool nights underwent abrupt warming changes in the early 1980s, while warm days, warm nights, summer days, tropical nights, and frost days shifted abruptly in the mid-1990s. Overall, atmospheric circulation exerts a stronger influence on cool indices than on warm indices. Cool days, cool nights, frost days, and icing days are positively correlated with winter Northern Hemisphere and Asian polar vortex area indices, Pacific, North American, and Atlantic-European polar vortex area indices, and Eurasian and Asian meridional circulation indices, but negatively correlated with Eurasian and Asian zonal circulation indices and the Tibetan Plateau index. Warm days, warm nights, summer days, and tropical nights are positively correlated with summer Northern Hemisphere and Western Pacific subtropical high area indices and the Tibetan Plateau index. Cool and warm indices respond differently to SST variations in the Atlantic and tropical Pacific, with night indices showing more pronounced responses to SST than day indices.

Keywords: extreme temperature events; variation characteristics; atmospheric circulation index; sea surface temperature; Tacheng Prefecture

1. Data and Methods

1.1 Data Sources

Tacheng Prefecture (82°16 ~87°21 E, 43°25 ~47°15 N) is located in the northwesternmost part of Xinjiang. Daily temperature data from seven national meteorological observation stations for the period 1961–2018 were obtained from the Xinjiang Meteorological Information Center. Atmospheric circulation indices for 1961–2018, including monthly Atlantic multidecadal oscillation (AMO), tropical North Atlantic SST index, tropical South Atlantic SST index, North tropical Atlantic SST index, Caribbean SST index, and tropical Pacific region SST indices (Niño3, Niño1+2, extreme eastern tropical Pacific SST, eastern tropical Pacific SST, Niño4, central tropical Pacific SST, Niño3.4), were sourced from the Earth System Research Laboratory of the National Oceanic and Atmospheric Administration (NOAA).

1.2 Research Methods

Given the complexity of extreme cold and warm events and their interactions with global and regional climate variability, further investigation of spatiotemporal variation characteristics and influencing factors in Tacheng Prefecture is essential for improving predictive capabilities and providing scientific support for disaster prevention and mitigation. Extreme temperature indices were calculated and quality-controlled using ClimDex software. Temporal and spatial variation characteristics were analyzed using linear regression, moving average, and R/S analysis. Pearson correlation analysis was employed to examine relationships between extreme temperature indices and geographical location, atmospheric circulation, and sea surface temperature, thereby revealing underlying mechanisms. Based on geographical location and climatic features, Tacheng Prefecture was divided into two zones: the northern region (Tacheng, Emin, Yumin, Toli, and Hoboksar—abbreviated as Hoboksar) and the southern region (Wusu and Shawan).

2. Results

2.1 Temporal Variation of Extreme Temperature Indices

2.1.1 Climate Tendency Rate From 1961 to 2018, the annual mean temperature in Tacheng Prefecture increased significantly at a rate of 0.40 ℃ $\cdot$ $(10a)^{-1}$, with an abrupt warming shift in the mid-1980s and particularly pronounced warming after 1985. Under this warming background, extreme temperature indices exhibited clear trends (Table 2). The extreme value index (maximum daily maximum temperature) increased at an insignificant rate of 0.09 ℃ $\cdot$ $(10a)^{-1}$, while the minimum daily minimum temperature rose significantly at 0.97 ℃ $\cdot$ $(10a)^{-1}$. Relative indices showed that TX10p (cool days) and TN10p (cool nights) decreased at rates of 1.75 d $\cdot$ $(10a)^{-1}$ and 5.24 d $\cdot$ $(10a)^{-1}$, respectively, while TX90p (warm days) and TN90p (warm nights) increased at rates of 1.79 d $\cdot$ $(10a)^{-1}$ and 5.89 d $\cdot$ $(10a)^{-1}$, respectively. Absolute indices revealed that frost days (FD0) and icing days (ID0) decreased at 4.07 d $\cdot$ $(10a)^{-1}$ and 1.84 d $\cdot$ $(10a)^{-1}$, respectively, while summer days (SU25) and tropical nights (TR20) increased at 2.18 d $\cdot$ $(10a)^{-1}$ and 2.08 d $\cdot$ $(10a)^{-1}$, respectively. All ten selected extreme temperature indices are projected to maintain their past trends with strong persistence.

Comparison with other regions (global [28], China [29], Northwest China [30], Xinjiang [31], and the northern Tianshan slope [18]) shows that Tacheng Prefecture exhibits greater warming magnitude than global, national, and regional averages, particularly for night indices (TN10p, TN90p), confirming it as a highly sensitive region to extreme temperature change and corroborating findings that northwestern Xinjiang is among the fastest-warming areas in the region.

2.1.2 Interannual and Interdecadal Variations To eliminate geographical and underlying surface effects, the arithmetic mean of anomalies at all stations was used as the regional anomaly series. The R/S analysis method, first proposed by British scientist H.E. Hurst, effectively reveals trend persistence in time series. Hurst exponent (H) indicates persistence strength: $H = 0.50$ suggests no persistence; $0.50 < H < 1.0$ indicates positive persistence (future trends consistent with past), with stronger persistence as H approaches 1.0; $0 < H < 0.50$ indicates anti-persistence (future trends opposite to past). Table 3 shows that all extreme temperature indices in Tacheng Prefecture exhibit persistence, with H values ranging from 0.65 to 0.91. Except for TXx showing weaker persistence, all other indices demonstrate moderate to extremely strong persistence, with night indices (TN10p, TN90p) reaching the highest persistence levels.

2.1.4 Abrupt Change Analysis Mann-Kendall tests were applied to detect abrupt changes in the ten extreme temperature indices (Table 4). Abrupt changes occurred for all indices except TXx. Cold indices (TNn, TX10p, TN10p) shifted in the early 1980s, earlier than the regional mean temperature shift in 1988, consistent with reported cold index shifts in Xinjiang during the mid-to-late 1980s. Warm indices (TX90p, TN90p, FD0, ID0, SU25, TR20) shifted in the mid-1990s, earlier than warm index shifts in Xinjiang reported for the late 1990s. These abrupt changes align with the global warming acceleration period, indicating Tacheng Prefecture' s pronounced response to global climate change. Post-shift mean values for night indices changed more dramatically than day indices, with TN90p increasing by 67.8% and TN10p decreasing by 33.0%, demonstrating the heightened sensitivity of night indices to climate change.

2.2 Spatial Distribution of Extreme Temperature Indices

2.2.1 Extreme Value Indices Spatial distribution of extreme value indices (Fig. 3) shows a south-high, north-low pattern. The multi-year average maximum daily maximum temperature (TXx) ranges from 36.4 ℃ in the north to 39.1 ℃ in the south (Wusu). The minimum daily minimum temperature (TNn) ranges from -31.5 ℃ in Hoboksar to -26.2 ℃ in the south. Trend analysis reveals that TXx increased significantly at all stations except Shawan (which showed a slight decrease), with Hoboksar showing the strongest warming trend [0.25 $℃ \cdot (10a)^{-1}$]. TNn increased significantly at all stations, with Hoboksar again showing the most pronounced warming [0.35 $℃ \cdot (10a)^{-1}$].

2.2.2 Relative Indices Spatial patterns of relative indices (Fig. 4) show that TX10p (cool days) decreased across the region, with significant reductions in northern stations (Tacheng, Emin, Toli) at rates of 2.53–3.18 $d \cdot (10a)^{-1}$ ($P < 0.05$). TN10p (cool nights) exhibited consistent significant decreases throughout the region, with larger reductions in the north, particularly at Toli [8.42 $d \cdot (10a)^{-1}$]. TX90p (warm days) and TN90p (warm nights) showed significant increasing trends, especially in the north. TN90p trends reached highly significant levels at all stations except Wusu, with Emin showing the largest increase [9.03 $d \cdot (10a)^{-1}$] and Wusu the smallest [1.71 $d \cdot (10a)^{-1}$]. The amplitude of night index changes is approximately three times that of day indices, highlighting the asymmetry between daytime and nighttime warming.

2.2.3 Absolute Indices Absolute indices (Fig. 5) show that frost days (FD0) decreased significantly across the region, with the largest reduction at Toli [5.75 $d \cdot (10a)^{-1}$] and the smallest at Wusu [2.17 $d \cdot (10a)^{-1}$]. The multi-year average ranges from 185.4 days in the north to 142.2 days in the south. Icing days (ID0) also decreased significantly, with Toli showing the greatest reduction [3.08 d·$(10a)^{-1}$] and Hoboksar the smallest [0.23 d·$(10a)^{-1}$]. Summer days (SU25) increased significantly at all stations, with Tacheng showing the largest increase [4.52 d·$(10a)^{-1}$] and Wusu the smallest [0.91 d·$(10a)^{-1}$]. Tropical nights (TR20) increased significantly in the north (Tacheng, Yumin, Emin, Toli) but insignificantly in the south, with Shawan showing the largest increase [5.73 d·$(10a)^{-1}$] and Hoboksar the smallest [0.12 d·$(10a)^{-1}$]. Overall, warming trends are more pronounced in the north, consistent with findings that higher latitudes experience more significant temperature changes.

2.3 Influencing Factors

2.3.1 Latitude, Longitude, and Altitude For analysis convenience, TX10p and TN10p are collectively termed cold indices, while TX90p and TN90p are warm indices. Correlation analysis between climate tendency rates and geographical parameters (Table 5) reveals significant relationships. TX10p and TN10p show significant positive correlation with longitude: for every 1° decrease in longitude, the tendency rate increases by 0.48 d·$(10a)^{-1}$ and 1.29 d·$(10a)^{-1}$, respectively. TX90p and TN90p exhibit significant negative correlation with longitude and latitude: for every 1° decrease in longitude, the rates increase by 0.95 d·$(10a)^{-1}$ and 1.81 d·$(10a)^{-1}$, respectively; for every 1° decrease in latitude, the rates increase by 1.75 d·$(10a)^{-1}$ and 2.08 d·$(10a)^{-1}$, respectively. Altitude shows no significant correlation with most indices, differing from findings in other regions where altitude effects are prominent. This may be attributed to Tacheng' s diverse topography and local climate features, such as Hoboksar's location in a valley on the lee slope of the Sawuer Mountains, which creates distinct local characteristics in cold index variations.

2.3.2 Atmospheric Circulation Global atmospheric energy transport occurs primarily through horizontal sensible and latent heat transfer, including mean meridional circulation and transient eddy fluxes. The polar vortex, a large-scale cold vortex system in the upper troposphere, is the primary indicator of cold air activity. Over the past 58 years, the Northern Hemisphere polar vortex area has decreased significantly, while the Asian polar vortex area shows an insignificant decreasing trend. Winter (December–February) Northern Hemisphere and Asian polar vortex area indices correlate significantly with cold indices (Table 6): TX10p and TN10p are positively correlated with polar vortex areas and meridional circulation indices, but negatively correlated with zonal circulation and Tibetan Plateau indices. This indicates that larger polar vortex areas, stronger meridional circulation (greater trough-ridge amplitude), and lower Tibetan Plateau geopotential heights (more plateau trough activity) favor increases in cold indices.

Summer (June–August) Northern Hemisphere and Western Pacific subtropical high area indices correlate positively with warm indices, particularly TN90p, with correlation coefficients passing significance tests in most months (Table

6). The subtropical high, a warm high-pressure system, plays a crucial role in heat, moisture, and energy transport between low and mid-high latitudes. Its expansion and intensification contribute significantly to increases in warm indices.

2.3.3 Sea Surface Temperature (SST) Heat transport and exchange occur primarily through global atmospheric circulation and ocean currents. The upper ocean is experiencing significant warming, with the fastest warming near the surface. The 1980s–1990s represent the period of most significant SST increase, coinciding with the fastest global surface temperature rise, demonstrating strong ocean-atmosphere coupling. SST directly affects sea surface sensible heat flux and is a crucial factor influencing air temperature.

Analysis of extreme temperature index responses to SST (Table 8) reveals distinct patterns. Cold indices show negative correlations with Atlantic and tropical Pacific SST indices (Niño3, Niño4, Niño1+2, Niño3.4), with 77.8% of correlation coefficients passing significance tests. Warm indices, particularly TN90p, show positive correlations with Atlantic SST indices, with 80.0% of coefficients being significant. Night indices demonstrate stronger SST responses than day indices, which may partly explain why night index trends are more pronounced.

2.3.4 Urbanization Effects Urbanization represents concentrated human activity and has measurable impacts on extreme temperature indices. Studies using demographic, economic, remote sensing, and meteorological data consistently show that urban stations exhibit more significant changes than rural stations, with suburban stations intermediate, and minimum temperatures being more affected than maximum temperatures. All seven meteorological stations in Tacheng Prefecture were established in the 1960s within county seats, making their records susceptible to urban development.

Since the 1980s, urban areas have expanded, accelerating in the 2000s with increasing population density, economic activity, greenhouse gas emissions, and anthropogenic heat release. Land use changes have altered surface radiative properties, increasing daytime solar radiation absorption and nighttime longwave radiation emission, thereby raising near-surface temperatures, especially at night. Tacheng' s urban land use and industrial/transportation land have increased by 245.13% and 1120.94%, respectively, the highest rates in Xinjiang. While urbanization' s contribution to extreme temperature warming is evident, its precise magnitude requires further investigation.

3. Conclusions

(1) Extreme temperature indices in Tacheng Prefecture show significant warming trends from 1961 to 2018. The minimum daily minimum temperature increased significantly at 0.97 ℃ · $(10a)^{-1}$, while the maximum daily maximum temperature rose insignificantly at 0.09 ℃ · $(10a)^{-1}$. Cold indices

(TX10p, TN10p, FD0, ID0) decreased significantly, while warm indices (TX90p, TN90p, SU25, TR20) increased significantly. R/S analysis indicates that future trends will continue past patterns with strong persistence.

(2) Daytime and nighttime indices exhibit marked asymmetry, with nighttime warming (TN10p, TN90p) significantly exceeding daytime changes (TX10p, TX90p). Minimum temperature warming is more pronounced than maximum temperature warming, indicating that nighttime warming dominates the overall warming process.

(3) Abrupt warming shifts occurred during the period of accelerated global warming, with most indices shifting earlier than reported for Xinjiang as a whole. Cold indices shifted in the early 1980s, while warm indices shifted in the mid-1990s.

(4) Decreases in Eurasian and Asian polar vortex areas, weakening of Eurasian and Asian meridional circulation, and increases in Atlantic and tropical Pacific SST are primary drivers of cold index warming. Expansion of Northern Hemisphere and Western Pacific subtropical high areas and Atlantic SST warming significantly contribute to warm index increases.

(5) Spatial distribution of extreme temperature trends is influenced by latitude, altitude, topography, atmospheric circulation, and SST. Accelerated urbanization and increased greenhouse gas emissions have amplified warming trends, though their precise contribution requires further study.

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