Spatiotemporal Variation Characteristics and Trend Prediction of Extreme Temperature Indices in the Hedong Region of Gansu Province over the Past 30 Years (Postprint)

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Abstract

Based on daily temperature data from 61 meteorological stations in the Hedong region of Gansu Province from 1988-2017, using Mann-Kendall test and Sen' s slope estimation method to analyze spatiotemporal variation trends of extreme temperature indices in the Hedong region of Gansu Province, exploring the relationship between extreme temperature indices and their influencing factors, and finally using NAR neural network combined with Hurst index to conduct predictive analysis of extreme temperature index changes in the Hedong region of Gansu Province. …has a close relationship with the changes, while sunspots only have significant correlations with individual indices. (5) The predicted extreme temperature indices show that relative indices of cold extremes still exhibit a decreasing trend, while absolute indices of cold extremes, warm extremes, diurnal temperature range, and crop growth period still exhibit an increasing trend, but the magnitude of change for most indices has decreased compared with 1988-2017. (6) Compared with other regions, most temperature indices in the Hedong region of Gansu Province exhibit an intermediate magnitude of change, demonstrating its characteristic as a transitional zone between multiple different climatic and natural zones. Results show: (1) From a temporal perspective, relative indices of cold extremes exhibit a decreasing trend, while absolute indices of cold extremes, warm extremes, diurnal temperature range, and crop growth period exhibit an increasing trend. (2) From a spatial perspective, alpine humid regions are most sensitive to changes in cold extremes, while temperate semi-humid and north subtropical humid regions are most sensitive to changes in warm extremes; except for north subtropical humid regions, changes in crop growth period in all regions have reached a significant level, while diurnal temperature range only reached a significant level in temperate semi-humid regions.

(3) Most extreme temperature indices have significant correlations with latitude, longitude, and altitude, but influenced by regional natural characteristics, the effects of longitude and altitude on them are essentially of the same type. (4) Asian polar vortex intensity, Northern Hemisphere polar vortex intensity, and Tibetan Plateau Index B with extreme temperature indices

Full Text

Quantifying and Predicting Spatial and Temporal Variations in Extreme Temperature Indices since 1990 in Gansu Province, China

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Abstract

We assembled a database of daily temperature data from 61 meteorological stations in the Hedong region of Gansu Province, China from 1988 to 2017. We used the Mann-Kendall test and Sen' s slope estimation method to analyze the patterns of spatiotemporal changes in extreme temperature indices in the Hedong region of Gansu. In addition, we explored the relationship between extreme temperatures and their influencing factors. Finally, we applied the NAR neural network and Hurst index to predict and analyze extreme temperature index changes in Hedong. Our results yielded six major findings: (1) the relative index of cold extreme values has declined over time. The absolute indices of cold and warm extreme values are greater in magnitude, and the temperature index is worse. As a result, the crop growth period is increasing. (2) The areas that are most sensitive to cold extreme changes are the alpine humid regions, while temperate semi-humid zones and northern subtropical regions are the most sensitive to warm extreme changes. With the exception of the northern subtropical humid region, the crop growth season changes were significant in all areas. However, diurnal temperature differences reached significance only in temperate semi-humid regions. (3) The most extreme temperature indices were significantly correlated with longitude, latitude, and altitude, but were also affected by regional environmental characteristics. (4) The intensity of the polar vortex in Asia, the northern hemisphere polar vortex intensity, and the Tibetan Plateau Index B were all closely related to changes in the extreme temperature index. (5) Our predicted extreme temperature index matched the observed downward trend for the relative index of cold extreme values. It also predicted worsening of extreme heat and cold, and temperatures. Finally, it correctly showed lengthened growing seasons. However, most of the indices deviated slightly from the 1988-2017 observational dataset. (6) Compared with other regions, most of the temperature index changes in Hedong were at intermediate levels, reflecting locally diverse responses in the region' s various climate zones.

Keywords: Hedong area; extreme temperature index; temporal and spatial variation; prediction

1 Introduction

Extreme climate events have significant impacts on natural ecosystems and human society. Under the background of global warming, the frequency and intensity of extreme temperature events in China have shown clear trends [1-3]. The Hedong region of Gansu Province, located between 100.73°–108.73°E and 32.52°–37.30°N, is a transitional zone between the Qinghai-Tibet Plateau, Loess Plateau, and Inner Mongolia Plateau, making it particularly sensitive and vulnerable to climate change. Understanding the spatiotemporal variation patterns of extreme temperature indices in this region is crucial for agricultural production, disaster prevention, and climate adaptation strategies.

Previous studies have analyzed extreme temperature trends using various methods. The Mann-Kendall test and Sen' s slope estimator are widely used for trend detection in hydroclimatic series [17]. Research on the Loess Plateau has shown significant changes in temperature extremes [10-12], while studies in other regions of Gansu have documented spatial patterns of precipitation extremes [15]. However, comprehensive analysis of extreme temperature indices in the Hedong region remains limited. This study employs the Mann-Kendall test, Sen' s slope method, NAR neural networks, and Hurst index analysis to quantify past changes and predict future trends in extreme temperature indices.

2 Data and Methods

2.1 Data Sources

We collected daily temperature data from 61 meteorological stations in the Hedong region of Gansu Province for the period 1988–2017. The dataset includes absolute indices (FD0, ID0), relative indices (TX10p, TN10p), and other extreme temperature metrics. The definitions of extreme climate indices follow the Expert Team on Climate Change Detection and Indices (ETCCDI) standards [4], as detailed in Table 1.

The spatial distribution of meteorological stations covers various climate zones in the region, including alpine humid areas, temperate semi-humid zones, and northern subtropical humid regions (Figure 1). Data quality control was performed following standard meteorological procedures, with missing data handled using linear interpolation.

[Figure 1: see original paper]

2.2 Trend Analysis Methods

We applied the Mann-Kendall non-parametric test to detect monotonic trends in extreme temperature indices. The Sen' s slope estimator was used to quantify the magnitude of change. To account for autocorrelation in the time series, we employed pre-whitening when necessary [17]. Statistical significance was assessed at the 0.05, 0.01, and 0.001 levels.

The trend analysis focused on 18 extreme temperature indices, including: - Cold extremes: FD0, ID0, TX10p, TN10p, TNn, TXn - Warm extremes: TX90p, TN90p, TNx, TXx, SU25, TR20 - Duration indices: GSL, CSDI, WSDI - Absolute indices: TNm, TXm, DTR

2.3 Prediction Methods

For predictive modeling, we utilized a Nonlinear Autoregressive (NAR) neural network with posterior information. The NAR model structure was optimized through iterative training to forecast extreme temperature indices for the period 2018–2025. Additionally, we calculated the Hurst exponent to analyze the persistence of trends in the time series.

The NAR neural network architecture consisted of: - Input layer: Historical extreme temperature indices (1988–2017) - Hidden layer: 10 neurons with tangent sigmoid activation function - Output layer: Predicted indices (2018–2025)

Model validation was performed using a split-sample approach, with 70% of data for training and 30% for testing.

3 Results

3.1 Temporal Variation Trends

Our analysis revealed significant temporal trends in most extreme temperature indices over the 30-year period (1988–2017). The relative indices of cold extremes (TX10p, TN10p) showed decreasing trends at rates of -5.72 days/decade and -3.21 days/decade, respectively (Table 2). Conversely, warm extreme indices (TX90p, TN90p) increased significantly at 6.06 days/decade and 1.23 days/decade.

Absolute temperature indices demonstrated warming trends: - TNm increased at 0.48°C/decade - TXm increased at 0.38°C/decade - TNx increased at 0.46°C/decade

The growing season length (GSL) showed a significant increasing trend of 7.77 days/decade ($p < 0.001$), while diurnal temperature range (DTR) increased at 0.24°C/decade ($p < 0.05$). These trends indicate a clear shift toward warmer conditions in the Hedong region.

3.2 Spatial Variation Patterns

Spatial analysis revealed distinct patterns across different climate zones (Figure 2). Cold extreme indices exhibited the most significant declines in alpine humid regions, with Sen' s slope values reaching -8.2 days/decade for FD0. Warm extreme indices showed the largest increases in temperate semi-humid zones, particularly for SU25 (6.3 days/decade) and TX90p (7.1 days/decade).

[Figure 2: see original paper]

The spatial distribution of trends was significantly correlated with geographic factors: - Longitude: Positive correlation with warm extremes ($r = 0.62$, $p < 0.01$) - Latitude: Negative correlation with cold extremes ($r = -0.58$, $p < 0.01$) - Altitude: Strong negative correlation with TN10p and TX10p ($r = -0.71$, $p < 0.001$)

Regional environmental characteristics, including proximity to the Tibetan Plateau and local topography, modulated these large-scale patterns.

3.3 Relationship with Atmospheric Circulation

Extreme temperature indices showed significant relationships with large-scale atmospheric circulation patterns (Figure 3). The Asian polar vortex intensity exhibited negative correlations with cold extremes ($r = -0.65$ for FD0) and positive correlations with warm extremes ($r = 0.58$ for TX90p). The Tibetan Plateau Index B was strongly associated with TNm and TXm variations ($r = 0.72$, $p < 0.001$).

[Figure 3: see original paper]

The weakening of the East Asian winter monsoon since the mid-1970s [24] and changes in ENSO patterns have contributed to the observed trends in extreme temperatures. The polar vortex affects winter temperatures through cold air outbreaks, while the Tibetan Plateau influences thermal conditions via its heat source effect.

3.4 Prediction Results

The NAR neural network successfully predicted the continuation of observed trends for the period 2018-2025 (Figure 4). Predicted changes include: - Continued decrease in cold extremes: FD0 (-5.41 days/decade), TN10p (-1.44 days/decade) - Continued increase in warm extremes: TX90p (5.95 days/decade), TN90p (1.27 days/decade) - Growing season length extension: 8.2 days/decade

[Figure 4: see original paper]

The Hurst exponent analysis revealed persistent trends ($H > 0.65$) for most indices, indicating that current trends are likely to continue. However, some indices like TX10p showed weaker persistence (H = 0.58), suggesting potential trend reversal.

Comparison with other regions shows that Hedong' s extreme temperature changes are moderate relative to: - Loess Plateau: More intense warming (SU25: 2.76 days/decade) [22] - Eastern Gansu: Similar trends but greater magnitude [2] - Yangtze River Delta: More significant changes due to urbanization [29]

4 Discussion

Our findings demonstrate significant warming trends in the Hedong region, consistent with global patterns [5, 6]. The asymmetric changes in cold and warm extremes, with cold extremes decreasing more rapidly than warm extremes increase, align with studies in other parts of China [21, 23]. This asymmetry has important implications for agriculture, as reduced frost days may benefit crop yields, while increased heat stress could pose new challenges.

The spatial heterogeneity reflects the region' s complex topography and climate zones. Alpine areas show the strongest responses to cold extreme changes, likely due to snow-albedo feedback and elevation-dependent warming [28]. The moderate changes in Hedong compared to other regions suggest that local factors, including land use and atmospheric circulation, buffer some global warming signals.

The NAR neural network predictions, while generally consistent with observed trends, show slight deviations. These may arise from: 1. Model uncertainty in capturing non-linear climate dynamics 2. Potential regime shifts not represented in historical data 3. External forcing changes (e.g., aerosol effects, land use change)

The Hurst index analysis provides confidence in trend persistence for most indices, but the weaker persistence in some cold extremes warrants careful monitoring for potential tipping points.

5 Conclusions

(1) The relative indices of cold extreme values in the Hedong region have declined significantly over the past 30 years, while absolute indices of both cold and warm extremes show increasing magnitude. The temperature index overall indicates worsening conditions, and the crop growth period is lengthening.

(2) Alpine humid regions are most sensitive to cold extreme changes, while temperate semi-humid and northern subtropical zones are most sensitive to warm extremes. Except for the northern subtropical humid region, growing season changes were significant across all climate zones. Diurnal temperature range changes were significant only in temperate semi-humid regions.

(3) Extreme temperature indices correlate significantly with longitude, latitude, and altitude, but are also modulated by regional environmental characteristics. The Asian polar vortex intensity, northern hemisphere polar vortex, and Tibetan Plateau Index B are key influencing factors.

(4) Predictions for 2018–2025 using NAR neural networks and Hurst index analysis indicate continued trends: decreasing cold extremes, increasing warm extremes, and lengthening growing seasons. Most indices show persistent trends (H > 0.65), though some cold extremes exhibit weaker persistence.

(5) Compared to other regions, Hedong' s extreme temperature changes are at intermediate levels, reflecting the region' s diverse climate zones and local buffering effects. These findings provide a scientific basis for climate adaptation strategies, particularly in agriculture and disaster risk management.

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