Spatiotemporal Variation Characteristics of Crop Heat Stress in Xinjiang (Postprint)

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Abstract

With the continuous rise in global temperatures and the frequent occurrence of extreme climates, crop heat stress has become increasingly common, severely affecting regional food production. Based on the China Meteorological Forcing Dataset, this paper employs three heat stress indicators—Accumulated Heat Stress Days (AHSD), Heat Stress Intensity (HSI), and Heat Degree Days (HDD)—and utilizes the Mann-Kendall trend test, Sen' s slope analysis, and spatial autocorrelation methods to systematically analyze the spatiotemporal variation characteristics of crop heat stress in the cultivated areas of Xinjiang from 1979 to 2020.

The results indicate that the level of crop heat stress in Xinjiang has intensified significantly, with AHSD, HSI, and HDD increasing at rates of 12.3 $\mathrm{d} \cdot (10\mathrm{a})^{-1}$, 0.3 $^\circ\mathrm{C} \cdot (10\mathrm{a})^{-1}$, and 60.2 $^\circ\mathrm{C} \cdot \mathrm{d} \cdot (10\mathrm{a})^{-1}$, respectively. Overall, HSI and HDD in Northern Xinjiang are higher than those in Southern Xinjiang, while AHSD is longer in Southern Xinjiang. There are significant differences in the spatial distribution of heat stress; the Turpan region is most severely affected by heat stress (AHSD reaching 162.8 d, HDD reaching 710.6 $^\circ\mathrm{C} \cdot \mathrm{d}$), while the Ili River Valley and Altay region are the least affected (AHSD ranging from 0.2 to 49.1 d, HDD ranging from 0.3 to 85.4 $^\circ\mathrm{C} \cdot \mathrm{d}$).

Concentrated cultivated areas, such as the border between Shihezi City and Tacheng Prefecture, the Turpan Basin, and the Hami Oasis, exhibit high heat stress intensity and a significant upward trend. The global Moran' s I index indicates a significant positive spatial correlation for heat stress ($P < 0.001$), with clusters of high-high and low-low heat stress values. The research results provide a scientific basis for Xinjiang' s agriculture to adapt to climate change, optimize crop layout, and formulate stress-resistant cultivation measures.

Full Text

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Abstract

As global temperatures continue to rise and extreme climate events occur more frequently, crop heat stress has become increasingly prevalent, severely impacting regional food production. Based on the China Meteorological Forcing Dataset (CMFD), this study employs three heat stress indicators—Accumulated Heat Stress Days (AHSD), Heat Stress Intensity (HSI), and Heat Degree Days (HDD)—to systematically analyze the spatiotemporal variations of crop heat stress in the cultivated areas of Xinjiang from 1979 to 2020. The analysis utilizes Mann-Kendall trend tests, Sen' s slope estimator, and spatial autocorrelation methods.

The results indicate that crop heat stress levels in Xinjiang have intensified significantly, with AHSD, HSI, and HDD increasing at rates of 12.3 d $\cdot$ $(10a)^{-1}$, 0.3 °C $\cdot$ $(10a)^{-1}$, and 60.2 °C $\cdot$ d $\cdot$ $(10a)^{-1}$, respectively. Overall, HSI and HDD values in Northern Xinjiang are higher than those in Southern Xinjiang, whereas Southern Xinjiang exhibits longer AHSD durations. Significant spatial heterogeneity exists in the distribution of heat stress: the Turpan region is most severely affected (with AHSD reaching 162.8 d and HDD reaching 710.6 °C $\cdot$ d), while the Ili River Valley and Altay regions experience the mildest impacts (with AHSD ranging from 0.2 to 49.1 d and HDD from 0.3 to 85.4 °C $\cdot$ d). In concentrated agricultural zones, such as the border between Shihezi City and the Tacheng region, the Turpan Basin, and the Hami Oasis, the intensity of heat stress is high and shows a significant upward trend. Global Moran' s I analysis reveals a significant positive spatial autocorrelation ($P < 0.001$), characterized by the clustering of High-High and Low-Low heat stress values. The findings provide a scientific basis for agricultural adaptation to climate change in Xinjiang, the optimization of crop distribution, and the formulation of stress-resistant cultivation measures.

Keywords: crops; heat stress; cropland; spatiotemporal variation; Xinjiang

1. Introduction

Global warming has led to a marked increase in extreme temperature events. Agriculture, being highly dependent on climatic conditions, is one of the sectors most vulnerable to these changes. Heat stress, defined as the rise in temperature beyond a threshold level for a period sufficient to cause irreversible damage to plant growth and development, has become a major limiting factor for crop yields worldwide. When temperatures exceed critical crop thresholds, every 1°C increase can lead to yield reductions of 6.0% for wheat, 3.2% for rice, and 7.4% for maize [**?**].

Xinjiang, covering an expansive area of 166×10^4 km^2, serves as a vital base for cotton, grain, and fruit production in China. However, the region' s inland location and arid environment make it particularly susceptible to high-temperature anomalies. In 2020, the annual average temperature warming rate in Xinjiang was 0.33 $^\circ\mathrm{C} \cdot (10\mathrm{a})^{-1}$, significantly higher than the national average of 0.28 $^\circ\mathrm{C} \cdot (10\mathrm{a})^{-1}$ ($P < 0.001$). Understanding the spatiotemporal evolution of heat stress on Xinjiang' s cropland is crucial for adapting to climate change and ensuring regional food security.

2. Materials and Methods

2.1 Study Area

The study area encompasses the Xinjiang Uygur Autonomous Region. The region is divided by the Tianshan Mountains into Northern and Southern Xinjiang. Agriculture in Xinjiang is primarily oasis-based, relying heavily on irrigation. The cultivated land area is 1.06×10^8 hm^2, accounting for 5.5% of the total national cultivated land area.

2.2 Data Sources

- **Land Use Data:** Cultivated land data were obtained from the 30 m resolution land-use dataset released by the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (2020).
- **Meteorological Data:** The China Meteorological Forcing Dataset (CMFD) was obtained from the National Tibetan Plateau Data Center. It features a temporal resolution of 3 hours and a spatial resolution of $0.1^\circ \times 0.1^\circ$ [**?**]. Daily maximum temperature (T_{max}) was extracted for the period 1979–2020.

2.3 Research Methods

2.3.1 Heat Stress Indicators This study adopts 30 ℃ as the threshold (T_h) for heat stress for major crops (maize, wheat, and soybeans). - **Accumulated Heat Stress Days (AHSD):** The total number of days where $T_{max} > T_h$. - **Heat Stress Intensity (HSI):** The average T_{max} during days where $T_{max} >$

T_h. - **Heat Degree Days (HDD):** The cumulative sum of $(T_{max} - T_h)$ for all days where $T_{max} > T_h$.

2.3.2 Statistical Analysis

- **Mann-Kendall (M-K) Test:** Used to analyze temporal trends and identify mutation points. A $|Z| \geq 1.96$ indicates a significant trend at the 95% confidence level.
- **Sen' s Slope Estimator:** Used to quantify the magnitude of the trend:

$$\text{Slope} = \text{median}\left(\frac{x_j - x_i}{j - i}\right)$$

- **Spatial Autocorrelation:** Global Moran's I and Local Indicators of Spatial Association (LISA) were used to evaluate spatial clustering. The spatial weight matrix was constructed using the K-nearest neighbors (KNN) method ($K = 10$).

3. Results and Analysis

3.1 Temporal Variation and Mutation Analysis

The AHSD in Xinjiang ranged from 15.0 to 96.6 days, with an average of 55.6 days. The M-K test identified a mutation point in 2004 ($P < 0.05$), after which the upward trend became significant [FIGURE:2]. The HSI fluctuated between 31.8 and 33.4 °C, with a mutation point in 2002. The HDD ranged from 23.0 to 381.1 °C · d, with an average of 170.1 °C · d and a mutation point in 2004.

[FIGURE:2]

3.2 Intra-annual Variation

Heat stress is primarily concentrated between May and September. AHSD and HDD peak in July, with July AHSD accounting for 33.39% of the annual total and July HDD (75.4 °C · d) accounting for 45.66% of the annual total.

[FIGURE:3]

3.3 Regional Comparison: Northern vs. Southern Xinjiang

Southern Xinjiang exhibits a longer duration of heat stress (average AHSD of 58.3 days) compared to Northern Xinjiang (52.5 days). However, Northern Xinjiang experiences higher intensity (average HSI of 32.7 °C) and higher cumulative heat (average HDD of 178.6 °C · d) compared to Southern Xinjiang (HSI 32.1 °C, HDD 149.8 °C · d).

[FIGURE:4]

Figure 1

Figure 1: Figure 1

Figure 6

Figure 2: Figure 6

3.4 Spatial Distribution and Autocorrelation

The Turpan region is the most severely affected, with AHSD reaching 162.8 days, HSI at 34.9 °C, and HDD at 710.6 °C · d. The Ili and Altay regions experience the mildest stress. Global Moran' s I values for AHSD (0.86), HSI (0.91), and HDD (0.93) all indicate significant positive spatial correlation ($P < 0.001$).

[FIGURE:5], [FIGURE:7]

4. Discussion and Conclusion

4.1 Discussion

The warming rate in Xinjiang ($0.33\ ^{\circ}\mathrm{C} \cdot (10\mathrm{a})^{-1}$) exceeds the national average, making heat stress a critical threat. This study' s use of three complementary indicators (AHSD, HSI, HDD) provides a more comprehensive characterization than single-indicator studies. The concentration of heat stress in oases and its significant upward trend since 2000 necessitate urgent adaptation strategies.

4.2 Conclusion

1. Crop heat stress in Xinjiang has intensified significantly from 1979 to 2020, with mutation points occurring around 2000–2004.
2. Southern Xinjiang has longer stress durations, while Northern Xinjiang faces higher stress intensity and cumulative heat.
3. The Turpan Basin, Hami Oasis, and the northern slopes of the Tianshan Mountains are high-risk "High-High" clustering zones.
4. Adaptation measures should include adjusting sowing dates in Southern Xinjiang and promoting heat-tolerant varieties in Northern Xinjiang and the Turpan region.

Figures

Source: ChinaXiv —Machine translation. Verify with original.