MCI-Based Analysis of Spatiotemporal Characteristics of Drought in Xinjiang over the Past 60 Years: Postprint

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Abstract

Using daily meteorological data from 99 meteorological stations in Xinjiang from 1961-2020, the daily Meteorological Drought Composite Index (MCI) sequences for each station were calculated according to the latest revised national standard "Grades of Meteorological Drought". The spatiotemporal variation characteristics of drought intensity in Xinjiang over the past 60 years were analyzed using correlation analysis, linear trend analysis, abrupt change detection, Empirical Orthogonal Function (EOF) decomposition, and other methods. The results indicate: (1) MCI monitoring results in Xinjiang exhibit good consistency with precipitation anomaly percentage and drought disaster records. (2) Drought intensity underwent an abrupt change around 1987. Since 1988, drought in Xinjiang has been generally mild overall, with drought intensity in spring, summer, and autumn all showing a significant decreasing trend. Spatially, with the Tianshan Mountains as the boundary, the pattern generally shows that northern Xinjiang is more severe than southern Xinjiang, and pastoral areas are more severe than agricultural areas. (3) Drought is relatively severe across the entire region in spring, the western regions of northern and southern Xinjiang experience intense drought in summer, and drought is generally mild across the entire region in autumn. (4) The first mode of the EOF decomposition reflects the average state of drought variation across the entire region, while the second mode reflects the spatial distribution characteristic of anti-phase drought variation between northern and southern Xinjiang. The spatiotemporal variation of drought intensity in Xinjiang over the past 60 years exhibits overall consistency, yet with local differences.

Full Text

Abstract

Based on daily meteorological data from 99 stations in Xinjiang from 1961 to 2020, the daily meteorological drought composite index (MCI) was calculated according to the latest revised national standard "Grades of Meteorological Drought." The temporal and spatial variation characteristics of drought intensity in Xinjiang over the past 60 years were analyzed using correlation analysis, linear trend analysis, mutation tests, and empirical orthogonal function (EOF) methods. The results show that: (1) The MCI monitoring results are in good agreement with precipitation anomaly percentages and drought disaster records in Xinjiang. (2) The degree of drought underwent an abrupt change around 1987, and since 1988, drought has been generally lighter across Xinjiang. (3) Drought intensity in spring, summer, and autumn all showed significant decreasing trends. Spatially, with the Tianshan Mountains as the boundary, northern Xinjiang experienced more severe drought than southern Xinjiang, and pastoral areas were more severely affected than agricultural areas. (4) Spring drought was severe across the entire region, summer drought was severe in western areas of both northern and southern Xinjiang, while autumn drought was generally lighter. (5) The first EOF mode reflected the average state of drought variation across the region, while the second mode reflected the out-of-phase relationship between northern and southern Xinjiang. Overall, the spatiotemporal variation of drought intensity in Xinjiang showed consistency across the region while exhibiting local differences.

Keywords: drought; meteorological drought composite index (MCI); temporal and spatial characteristics; Xinjiang

1.1 Study Area Overview

Xinjiang is located in the hinterland of the Eurasian continent (Fig. 1), in the northwestern border of China. Its geographical location far from the ocean and unique topography have created a strongly continental temperate arid climate. The annual average evaporation in Xinjiang is as high as approximately 1775 mm, while the annual average precipitation is only 68.5 mm. The water vapor flowing into the upper atmosphere over Xinjiang during a year is only 11540×10^{8} m^3, with the maximum in summer and minimum in winter. Combined with land surface evaporation within Xinjiang, the total annual water vapor content in the upper atmosphere is 13797×10^{8} m^3. This is equivalent to 1/5 of the Yangtze River basin and 1/3 of the Yellow River basin. Moreover, the precipitation formation rate from water vapor is only 17.6%, which fundamentally determines that Xinjiang is an arid region with scarce precipitation, and drought is a basic attribute of Xinjiang' s climate.

1.2 Data Sources

The data used in this study were uniformly published by the National Climate Center, including daily meteorological data from 105 stations in Xinjiang. After excluding stations with extensive missing data, 99 stations were finally selected for analysis (Fig. 1). The data span from 1961 to 2020.

1.3.1 Meteorological Drought Composite Index (MCI)

The MCI was calculated according to the national standard "Grades of Meteorological Drought" (GB/T 20481-2017) using the following formula:

$$MCI = K_a \times (SPIW_{60} + MI_{30} + SPI_{90} + SPI_{150})$$

where $SPIW_{60}$ is the standardized weighted precipitation index for the past 60 days, MI_{30} is the 30-day moisture index, and SPI_{90} and SPI_{150} are standardized precipitation indices for 90 and 150 days, respectively. The coefficients a, b, c, and d are weight coefficients, with values of 0.3, 0.3, 0.3, and 0.4, respectively, for northern and western China. K_a is a seasonal adjustment coefficient determined based on drought conditions and plant growth characteristics in Xinjiang, with monthly values as shown in Table 1. This study focuses on monitoring meteorological drought from April to September (Table 1). The calculation methods for each component are detailed in the literature.

The drought classification standard based on MCI is shown in Table 2. When daily MCI $\leq$ -0.5, light drought or more severe drought is identified. The drought intensity during a certain period is represented by the cumulative value of drought events at or above the light drought level. The smaller the MCI value, the stronger the drought intensity, and vice versa.

Table 1. Ka values in different months in Xinjiang

Month	Ka
4	0.9
5	1.0
6	1.1
7	1.2
8	1.1
9	0.9

Table 2. Drought classification standard of MCI

Grade	MCI Value
Light drought	MCI $\leq$ -0.5

Grade	MCI Value
Moderate drought	MCI ≤ -1.0
Severe drought	MCI ≤ -1.5
Extreme drought	MCI ≤ -2.0

1.3.2 Empirical Orthogonal Function (EOF) Analysis

Empirical orthogonal function (EOF) analysis, also known as eigenvector analysis or principal component analysis, is commonly used in meteorological and climate research to analyze various meteorological element fields. This method can decompose a time-varying variable field into a spatial function part that does not change with time and a time function part that depends only on time. The spatial function part indicates the regional distribution characteristics of the field, while the time function part is formed by the linear combination of variables at spatial points, called the principal component. This method can extract the main characteristic quantities of the data without losing original information.

1.3.3 Other Analysis Methods

For trend analysis of meteorological drought indices, a linear regression model was used to estimate the trend tendency. The least squares method was applied to the 60-year MCI sequence to calculate its linear growth trend (climate tendency rate). Temporal change analysis employed the Mann-Kendall (M-K) test. The spatial distribution characteristics of drought intensity were analyzed using ArcGIS.

2.1 Applicability Analysis of MCI

The annual MCI values in Xinjiang from 1961 to 2020 showed an extremely significant correlation with precipitation anomaly percentages, with a correlation coefficient of -0.78 ($P < 0.001$). This indicates that the MCI and precipitation anomaly percentage are basically consistent in reflecting the deviation of precipitation from the average state (Fig. 2). The comparison of drought disaster records shows that the spatial distribution of cumulative drought intensity values for light drought and above has a high degree of 吻合 with the actual occurrence of drought conditions (Table 3). Taking the severe drought events in Xinjiang in 1997 and in northern Xinjiang in 2020 as examples, the daily variation of MCI and precipitation during the drought periods was analyzed (Fig. 3). The results show that each drought event evolves with MCI values gradually decreasing as precipitation remains consistently low, and rising again when large precipitation occurs. When the average meteorological drought degree in Xinjiang approaches moderate drought (MCI ≤ -1.5), the MCI index is relatively more sensitive to precipitation. The MCI shows fewer abnormal jump phenomena during drought development and has good applicability in Xinjiang.

2.2 Temporal Variation Trends

The annual MCI in Xinjiang showed an overall fluctuating upward trend from 1961 to 2020, with a significant linear trend and a climate tendency rate of $2.7 \cdot (10a)^{-1}$. Additionally, comprehensive testing using the M-K test and cumulative anomaly method identified a mutation in 1987. Taking 1987 as the boundary, Xinjiang's drought can be divided into two periods: before 1987, the MCI showed obvious fluctuations with smaller values, indicating a relatively dry period; after 1987, the drought trend continued to weaken, with MCI values showing an increasing trend, indicating that drought was generally lighter.

The analysis of seasonal drought intensity shows that the MCI index in spring, summer, and autumn all showed significant upward trends, with climate tendency rates of $1.0 \cdot (10a)^{-1}$, $2.7 \cdot (10a)^{-1}$, and $1.5 \cdot (10a)^{-1}$, respectively, indicating a weakening trend in drought intensity. Spring drought (Fig. 4b) showed no obvious mutation point, with MCI values ranging from -42.2 to -7.2 and the maximum in 1974. Summer drought (Fig. 4c) showed a significant mutation in 1993 when the UF and UB curves intersected and crossed the critical line at the 0.05 significance level, indicating a significant weakening of summer drought intensity. After 1993, the UF curve declined slightly, and summer drought intensified during this stage, but the trend weakened again after 2000 and turned to intensification again after 2010. Autumn drought (Fig. 4d) showed that after the mutation in 1987, the UF curve continued to rise, crossing the critical line at the 0.05 significance level, indicating a significant weakening of autumn drought intensity. Since 2000, drought intensity has begun to increase again.

2.3 Spatial Variation Characteristics

The annual average MCI at each station in Xinjiang ranged from -91.6 to -25.0, with the minimum at Horgos in Yili Prefecture and the maximum at Ruoqiang in southern Bayingolin. The spatial difference was significant, with more severe drought in mountainous areas and lighter drought in plains. The annual average MCI values in the Yili River Valley and western Bortala were less than -65, indicating severe drought. In northern Altay, eastern Changji, eastern Aksu, and northern Bayingolin, the values were between -55 and -45. Most areas in eastern Xinjiang and southern Xinjiang had annual average MCI values greater than -45, indicating relatively light drought. Overall, annual drought intensity in Xinjiang was generally heavier in northern Xinjiang than in southern Xinjiang, and heavier in pastoral areas than in agricultural areas.

Spring drought MCI values ranged from -30.7 to -1.2, with the minimum at Yining County in Yili Prefecture and the maximum at Anding River in eastern Hotan. The entire region tended to experience consistent drought, with more severe drought in northern Xinjiang, the Tianshan Mountains area, and parts of western southern Xinjiang, while most areas in southern Xinjiang and eastern Xinjiang had relatively light drought. Summer MCI values ranged from -70.5 to -26.5, with significant spatial differences, showing severe drought in western areas of both northern and southern Xinjiang and lighter drought in eastern areas. Autumn MCI values ranged from -32.3 to -11.8, indicating generally weak drought across the region.

2.4 Comprehensive Spatiotemporal Characteristics of Drought in Xinjiang

To further understand the spatial distribution characteristics of drought in Xinjiang, EOF analysis was performed on the annual MCI values. The results show that the first two eigenvectors are major components with large variance contributions of 34.8% and 15.1%, respectively, with a cumulative variance contribution rate of 49.9%. Eigenvectors after the second have small variance contributions and can be ignored.

The first eigenvector (Fig. 6a) shows positive values across Xinjiang, representing consistent drought variation across the region—either universally severe or light. However, the intensity of this variation differs by region, with major value zones in western northern Xinjiang and the northern Tianshan slopes, making these the main control areas of the first mode. The corresponding time coefficient (Fig. 6c) shows negative values dominating before 1987, indicating severe drought across the region during this period, with the lowest coefficient in 1974 representing extreme drought. After 1987, positive values dominate, indicating lighter drought overall. This is consistent with the interannual variation characteristics of drought intensity shown in the time series analysis. The correlation coefficient between the first eigenvector time coefficient and the MCI time series is as high as 0.92.

The second eigenvector (Fig. 6b) shows significant differences from the first, with positive values in northern Xinjiang and negative values in southern Xinjiang, reflecting an out-of-phase spatial distribution pattern of drought intensity between the two regions. The time coefficient (Fig. 6d) shows positive and negative fluctuations from 1961 to 2020, reflecting alternating severe and light drought in northern and southern Xinjiang. The minimum coefficient in 2020 accurately reflects the severe drought event in northern Xinjiang that year, with significant differences between the north and south. According to historical disaster records, in 2020, severe drought occurred in northern Xinjiang, particularly in Altay, Tacheng, Yili River Valley, Bortala, Changji, and Urumqi, with nearly 2.2$\times10^{5}$ hm^{2} of crops affected and grain production reduced by approximately 1.5$\times10^{8}$ kg.

3 Conclusions

(1) The annual MCI values in Xinjiang from 1961 to 2020 showed high consistency with precipitation anomaly percentages and drought disaster records documented in "China Meteorological Disasters (Xinjiang Volume)." The MCI index is more sensitive to precipitation when meteorological drought

reaches moderate levels or above, shows fewer abnormal jumps during drought development, and has good applicability in Xinjiang.

(2) Before 1987, Xinjiang experienced a relatively drier period. After 1987, the drought trend continued to weaken, and drought has been generally lighter since 1988. The MCI in spring, summer, and autumn all showed significant upward trends, indicating weakening drought intensity. No obvious mutation point was found in spring. Summer drought intensity showed a significant weakening mutation in 1993, intensified during 1993–2000, weakened again after 2000, and turned to intensification after 2010. Autumn drought showed a significant weakening mutation after 1987, but drought intensity began to increase again after 2000.

(3) Spatial variation of drought intensity in Xinjiang was significant, with heavier drought in mountainous areas than in plains, and heavier in pastoral areas than in agricultural areas. Annual drought intensity was generally heavier in northern Xinjiang than in southern Xinjiang. Spring drought tended to be consistent across the region, with severe drought in northern Xinjiang, the Tianshan Mountains, and western southern Xinjiang, while most areas in southern and eastern Xinjiang had lighter drought. Summer drought showed large spatial differences, with severe drought in western areas of both northern and southern Xinjiang and lighter drought in eastern areas. Autumn drought was generally weak across the region.

(4) EOF analysis of drought intensity in Xinjiang revealed two main patterns: regionally consistent drought and opposite-phase drought between northern and southern Xinjiang. The first mode reflected the average state of drought change across the region, while the second mode reflected the out-of-phase spatial distribution characteristics of drought between northern and southern Xinjiang.

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Figures

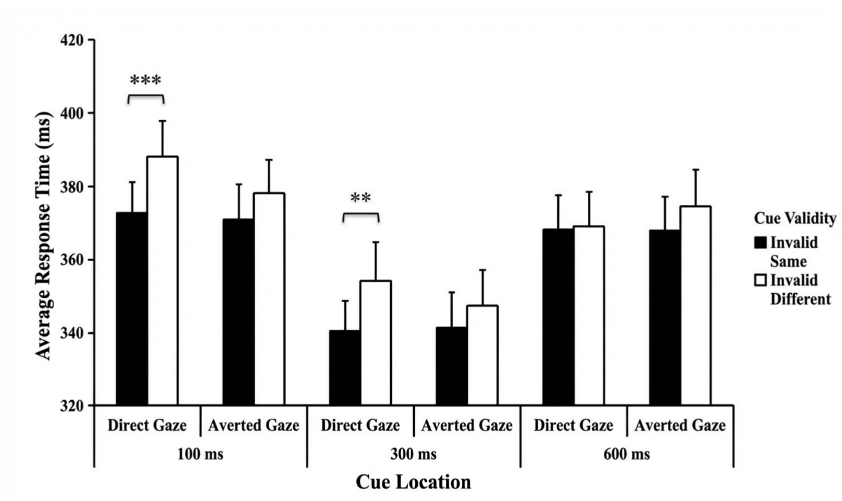

Figure 1: Figure 1

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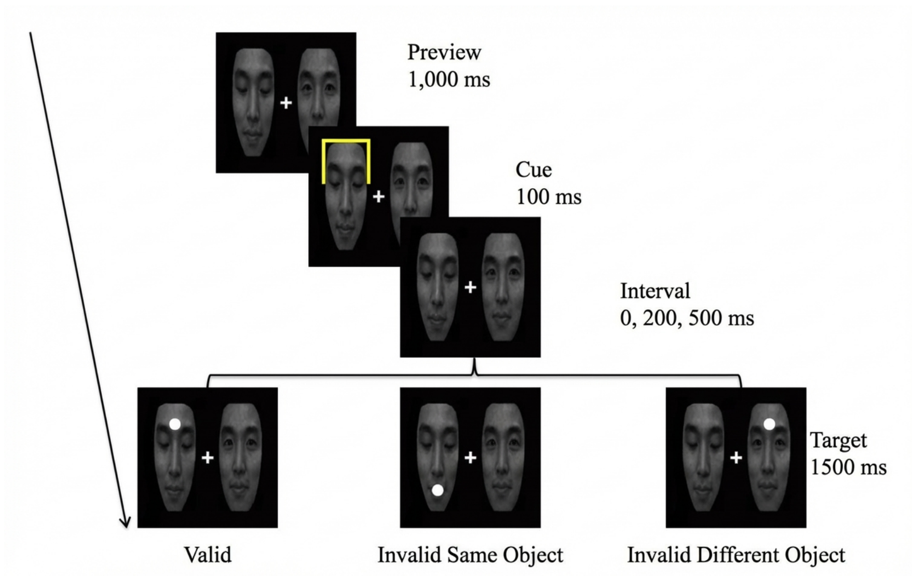

Figure 2: Figure 2

Figure 3: Figure 5