Spatiotemporal Variation Characteristics of Sunshine Duration in the Qinghai Plateau from 1961 to 2020 (Postprint)

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Abstract

Solar radiation is the primary energy source for the Earth system and is closely related to human life. By utilizing monthly sunshine duration data from 50 meteorological observation stations across the Qinghai Plateau from 1961 to 2020, this study analyzes the spatiotemporal variation characteristics of sunshine duration for the entire plateau, as well as for different latitudinal and altitudinal regions. The results indicate: (1) From 1961 to 2020, the annual sunshine duration on the Qinghai Plateau exhibited a significant decreasing trend, with an abrupt reduction occurring in 2004. From a spatial perspective, with the exception of a few stations in the southern region where sunshine duration remained stable or slightly increased, all other areas showed a significant decreasing trend in annual sunshine duration, with the most pronounced declines observed in the Qaidam Basin and the eastern agricultural zones. (2) The decreasing trend in annual sunshine duration in high-latitude regions of the Qinghai Plateau was significantly greater than that in low-latitude regions. During spring, the variation trends in sunshine duration across different latitudinal regions were relatively minor; in summer and winter, the decreasing trend was significantly more pronounced in relatively high-latitude regions compared to low-latitude regions; in autumn, both low-latitude and high-latitude regions exhibited significantly greater decreasing trends than mid-latitude regions. (3) The decreasing trend in annual sunshine duration in relatively low-altitude regions of the Qinghai Plateau was significantly greater than that in relatively high-altitude regions. In spring, the variation trends in sunshine duration across different altitudinal regions were relatively small, remaining essentially stable or slightly decreasing; in summer and winter, the decreasing trend was significantly more pronounced in relatively low-altitude regions compared to high-altitude regions; in autumn, sunshine duration exhibited a decreasing trend across all altitudinal regions, though the significance levels of these decreasing trends varied considerably.

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Spatiotemporal Variation Characteristics of Sunshine Hours in the Qinghai Plateau from 1961 to 2020

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Abstract

Solar radiation is the primary energy source of the Earth' s system and is closely related to human life. By selecting monthly sunshine hour data from 50 meteorological observation stations in the Qinghai Plateau from 1961 to 2020, this study analyzes the spatiotemporal variation characteristics of sunshine hours across the entire plateau, different latitude zones, and different altitude zones. The results show that: (1) Annual sunshine hours in the Qinghai Plateau exhibited a significant decreasing trend from 1961 to 2020, with an abrupt decline occurring in 2004. Spatially, except for a few southern stations where sunshine hours remained stable or slightly increased, all other regions showed significant decreases, with the most pronounced reductions in the Qaidam Basin and eastern agricultural areas. (2) The decreasing trend in high-latitude regions was significantly greater than in low-latitude regions. Seasonally, spring showed minimal variation across latitudes, while summer and winter displayed significantly greater decreases at higher latitudes compared to lower latitudes. In autumn, both low and high latitudes showed greater decreasing trends than mid-latitudes. (3) Lower-altitude regions exhibited significantly greater decreasing trends than higher-altitude regions. Spring showed minimal variation across altitudes, while summer and winter displayed significantly greater decreases at lower altitudes. Autumn showed decreasing trends across all altitudes, but with varying significance levels.

Keywords: Qinghai Plateau; sunshine hours; spatiotemporal variation characteristics; Mann-Kendall mutation test

1. Introduction

Over the past century, global climate has undergone significant warming. Multiple indicators and observations of the climate system demonstrate that the warming trend continues. The IPCC Fifth Assessment Report indicates that global average surface temperature increased by approximately 0.85°C. Global warming leads to changes in climatic factors, and solar radiation, as the primary energy source of the Earth' s system, is closely related to human life and represents an important climatic factor. Sunshine hours are a characteristic quantity representing solar radiation, influenced not only by geographic parameters but also by solar constants, cloud cover, water vapor, and atmospheric aerosols. Under global warming, exploring and researching the spatiotemporal variability of sunshine hours and their influencing factors is significant for human industrial and agricultural activities and provides references for Earth system science research.

Stanhill and Cohen analyzed global solar radiation variations from 1958 to 1992, finding that solar radiation reaching the Earth' s surface decreased significantly, with an average global reduction of 0.46–0.56 $W \cdot m^{-2}$ per decade. The most likely factors causing this reduction are aerosols and air pollution. Chinese scholars have conducted extensive research on sunshine hour variation characteristics and influencing factors in different regions of China. The China Meteorological Administration Climate Change Center found that China' s average annual sunshine hours showed a significant decreasing trend, with an average reduction rate of 32.8 $h \cdot (10a)^{-1}$. Xiao et al. analyzed spatiotemporal variation characteristics and influencing factors of sunshine hours in different regions of China from 1961 to 2016, revealing a significant decreasing trend nationwide, with abrupt changes occurring in 1981 in Southwest China, 1990 in Northwest China, and 1995 in Northeast China. Zhou et al. studied temporal and spatial variations of sunshine hours in Northeast China from 1961 to 2009 using data from 94 meteorological stations, finding a significant decreasing trend with an average reduction rate of 40.5 $h \cdot (10a)^{-1}$. Dai et al. analyzed spatiotemporal variation characteristics of agricultural climate resources in southern China under global warming, showing that total annual radiation presented a "low-high-low" pattern while sunshine hours decreased at an average rate of 40.2 $h \cdot (10a)^{-1}$. Chen et al. analyzed sunshine hour data from 1960 to 2006 in Northwest China, finding that most areas showed significant decreases with a regional average reduction rate of 19.92 $h \cdot (10a)^{-1}$, primarily caused by increased relative humidity and cloud cover.

The Qinghai Plateau, located in the northeastern part of the Tibetan Plateau, is the source of the Yellow River, Yangtze River, and Lancang River, and serves as both a "National Park Province" and the "Water Tower of China." The terrain is complex and diverse, with elevations ranging from 1500–6000 m and spanning 8 latitude zones. The plateau has long sunshine hours and abundant solar energy resources, making it an important national clean energy industry base. In March 2021, President Xi Jinping emphasized during the review of the Qinghai delegation at the Fourth Session of the 13th National People's Congress the need to leverage Qinghai' s advantages and resources to build a national clean energy industry highland. In July 2021, the provincial government and the National Energy Administration jointly issued the "Qinghai Action Plan for Building a National Clean Energy Industry Highland," aiming to contribute to achieving carbon peak and carbon neutrality goals. Consequently, changes in sunshine hours over the Qinghai Plateau have attracted considerable scholarly attention.

Fu et al. analyzed sunshine hour variation characteristics in the Qilian Mountains from 1960 to 2014, finding an overall decreasing trend in multi-year average sunshine hours. He et al. analyzed sunshine hour variation characteristics in the Yellow River source region from 1961 to 2016, revealing an increasing trend at a rate of 26.0 $h \cdot (10a)^{-1}$. These studies indicate that sunshine hour variation characteristics differ across different regions of the Qinghai Plateau. Therefore, this paper selects monthly sunshine hour data from 50 meteorological observation stations in the Qinghai Plateau from 1961 to 2020, along with related meteorological element data, to analyze spatiotemporal variation characteristics across the entire plateau, different latitude zones, and different altitude zones. The aim is to provide a scientific basis for understanding climate resource changes in the Qinghai Plateau and scientific references for rational agricultural and pastoral production layout and clean energy development.

2. Study Area

The Qinghai Plateau (89°35 -103°04 E, 31°09 -39°19 N) is located in the northeastern part of the Tibetan Plateau, stretching approximately 1200 km from east to west and 800 km from north to south. It is the source of the Yellow River, Yangtze River, and Lancang River, and serves as both a "National Park Province" and the "Water Tower of China" [Figure 1: see original paper]. The terrain is complex and diverse, with elevations ranging from 1500-6000 m. The plateau has a typical continental plateau climate, far from the ocean, with large regional differences in precipitation (100-550 mm annually) and annual average temperatures ranging from -5.0 to 9.0°C. Located in the mid-latitude zone, the plateau has long sunshine hours and strong radiation, with total annual radiation of 690.8-753.6 $kJ \cdot cm^{-2}$, of which direct radiation accounts for 60-70%.

Based on research requirements, the 50 meteorological observation stations in the Qinghai Plateau were divided into 8 latitude bands (32-33°N, 33-34°N, 34-35°N, 35-36°N, 36-37°N, 37-38°N, 38-39°N) and 5 altitude bands (2000-2500 m, 2500-3000 m, 3000-3500 m, 3500-4000 m, 4000-4500 m) . Geographically, the plateau can be divided into the Qaidam Basin, the area around Qinghai Lake, the eastern agricultural area, and the southern pastoral area.

3. Data and Methods

Sunshine hours refer to the duration when solar radiation intensity on a plane perpendicular to the sun' s rays exceeds or equals 120 $W \cdot m^{-2}$. Sunshine hour variation is influenced not only by large-scale climate change but also by local atmospheric environment and anthropogenic factors.

This study selected monthly sunshine hour data from 50 meteorological observation stations in the Qinghai Plateau from 1961 to 2020, obtained from the China Meteorological Science Data Sharing Service Network. Due to various anthropogenic factors, the data exhibit non-uniformity, so the RHtest method was used to identify and correct obvious breakpoints in the 50-station dataset. Breakpoints in data sequences may reflect either non-uniformity in climate data or climate mutation signals. By calculating ratio or difference sequences between the test sequence and a reference sequence with high correlation, breakpoints can be identified and corrected. Data sequence testing includes the difference method and ratio method, with correction primarily using correlation coefficient adjustment. After correction, the 50-station dataset shows good continuity.

The Mann-Kendall test is a non-parametric statistical method widely used for trend analysis and significance testing of runoff, climate, and hydrological sequences. Its advantages include not requiring specific distributions, being unaffected by outliers, and identifying mutation timing and regions. This study primarily uses the Mann-Kendall test for mutation analysis.

4. Results

4.1 Overall Variation Characteristics of Sunshine Hours in the Qinghai Plateau Using the climate tendency rate method, the variation trend of sunshine hours in the Qinghai Plateau from 1961 to 2020 was analyzed [Figure 2: see original paper]. The results show that annual sunshine hours exhibited a significant decreasing trend, with a rate of -30.1 $h \cdot (10a)^{-1}$, and passed the 0.01 significance test. Interdecadal variation shows that sunshine hours remained between 2765.0–2805.0 $h \cdot a^{-1}$ from the 1960s to the 1990s, with small interdecadal changes (rates of -0.9% and -0.4%). From 2000 onward, sunshine hours decreased rapidly, with the 2000s average at 2713.8 $h \cdot a^{-1}$ and the 2010s at 2621.9 $h \cdot a^{-1}$, showing significant interdecadal changes (rates of -1.9% and -3.4%).

Spatial distribution of sunshine hour change rates from 1961 to 2020 [Figure 3: see original paper] shows that except for a few southern stations where sunshine hours remained stable or slightly increased, all other regions exhibited significant decreases. The most significant reductions occurred in the Qaidam Basin and eastern agricultural area, with Xining in the eastern agricultural area showing a rate of -65.0 $h \cdot (10a)^{-1}$. Stations including Minhe, Ledu, Nuomuhong, Xiazaohuo, Mangya, Delingha, Lenghu, and Dulan in the Qaidam Basin all showed rates reaching -50.0 $h \cdot (10a)^{-1}$.

Mann-Kendall mutation analysis of sunshine hours [Figure 4: see original paper], combined with moving T-test analysis, shows that the UF and UB curves intersect in 2004 and pass the 0.05 significance test, indicating an abrupt decrease in sunshine hours in 2004. Pre-mutation (1961–2003) average sunshine hours were 2778.7 $h \cdot a^{-1}$, while post-mutation (2004–2020) average was 2646.6 $h \cdot a^{-1}$, representing a 4.6% decrease.

4.2 Variation Characteristics by Latitude

4.2.1 Interannual Variation by Latitude The 50 stations were divided into 8 latitude bands for analysis [Figure 5: see original paper]. Results show that the decreasing trend in high-latitude areas is significantly greater than in low-latitude areas. Change rates for each latitude band were: 32–33°N: -2.72 $h \cdot a^{-1}$; 33–34°N: -0.52 $h \cdot a^{-1}$; 34–35°N: -1.13 $h \cdot a^{-1}$; 35–36°N: -2.16 $h \cdot a^{-1}$; 36–37°N: -3.84 $h \cdot a^{-1}$; 37–38°N: -3.81 $h \cdot a^{-1}$; 38–39°N: -3.28 $h \cdot a^{-1}$. All rates except 33–34°N and 34–35°N passed the 0.05 significance test.

Mann-Kendall mutation analysis for different latitude bands shows that the 32–33°N, 36–37°N, 37–38°N, and 38–39°N bands intersected in 2004 and passed the 0.05 significance test, indicating abrupt decreases in 2004. The 35–36°N band intersected in 2005, while 33–34°N and 34–35°N showed no significant mutations.

4.2.2 Seasonal Variation by Latitude Seasonal variation trends show that spring had minimal variation across latitudes, with only the 37-38°N band showing a significant decrease. Summer displayed significantly greater decreases at higher latitudes than lower latitudes, with rates of -0.59, -0.38, -0.59, -0.64, -0.21, -0.06, and -0.21 $h \cdot a^{-1}$ for each band respectively, with higher latitudes passing significance tests. Autumn showed decreasing trends across all latitudes, but with varying significance: low and high latitudes showed greater decreases than mid-latitudes, with bands below 35°N and above 37°N passing 0.01 significance tests. Winter patterns were similar to summer, with higher latitudes showing significantly greater decreases than lower latitudes, and bands above 36°N passing significance tests .

4.3 Variation Characteristics by Altitude

4.3.1 Interannual Variation by Altitude Stations were divided into 5 altitude bands for analysis [Figure 6: see original paper]. Lower-altitude regions showed significantly greater decreasing trends than higher-altitude regions. Change rates were: 2000–2500 m: -4.60 $h \cdot a^{-1}$; 2500–3000 m: -3.28 $h \cdot a^{-1}$; 3000–3500 m: -4.19 $h \cdot a^{-1}$; 3500–4000 m: -2.43 $h \cdot a^{-1}$; 4000–4500 m: -1.70 $h \cdot a^{-1}$. All rates except the 4000–4500 m band passed the 0.05 significance test.

Mann-Kendall mutation analysis shows that the 2000–2500 m and 2500–3000 m bands intersected in 2004 and passed the 0.05 significance test, indicating abrupt decreases. The 3000–3500 m band intersected in 2005, while higher altitude bands showed no significant mutations.

4.3.2 Seasonal Variation by Altitude Seasonal analysis shows that spring had minimal variation across altitudes, with only slight decreases. Summer displayed significantly greater decreases at lower altitudes, with rates of -0.64, -0.27, -0.53, -0.45, and -0.69 $h \cdot a^{-1}$ respectively, with lower altitude bands passing significance tests. Autumn showed decreasing trends across all altitudes, but with varying significance: 2500–3000 m and 3500–4000 m bands passed 0.05

tests, while 2000–2500 m passed 0.01 test. Winter patterns were similar to summer, with lower altitudes showing significantly greater decreases .

5. Conclusions

This study analyzed monthly sunshine hour data from 50 meteorological stations in the Qinghai Plateau from 1961 to 2020, examining spatiotemporal variation characteristics across the entire plateau, different latitudes, and different altitudes. The main conclusions are:

1) Annual sunshine hours in the Qinghai Plateau showed a significant decreasing trend from 1961 to 2020, with a rate of -30.1 $h \cdot (10a)^{-1}$, and experienced an abrupt decrease in 2004. Spatially, except for a few southern stations where sunshine hours remained stable or slightly increased, all other regions showed significant decreases, with the most pronounced reductions in the Qaidam Basin and eastern agricultural area.

2) High-latitude regions exhibited significantly greater decreasing trends than low-latitude regions. Seasonally, spring showed minimal variation across latitudes; summer and winter displayed significantly greater decreases at higher latitudes; and autumn showed greater decreases at both low and high latitudes compared to mid-latitudes.

3) Lower-altitude regions showed significantly greater decreasing trends than higher-altitude regions. Seasonally, spring showed minimal variation across altitudes; summer and winter displayed significantly greater decreases at lower altitudes; and autumn showed decreasing trends across all altitudes with varying significance levels.

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