ChinaRxiv

AI translation · View original & related papers at
chinarxiv.org/items/chinaxiv-202109.00045

Variation Characteristics of Summer Extreme Heat in Ningxia and Its Relationship with Arctic Sea Ice (Postprint)

Authors: Wang Dai

Date: 2021-09-14T00:00:00+00:00

Abstract

Based on summer daily maximum temperature data from 20 meteorological stations in Ningxia, NCEP/NCAR reanalysis data, and Arctic sea ice data for the past 57 years, this study employs climatic statistical diagnostic methods to analyze the climatic anomaly characteristics of summer extreme high temperature in Ningxia and its relationship with Arctic sea ice. The results indicate that the total intensity, event frequency, and maximum duration of summer extreme high temperature in Ningxia have exhibited an overall increasing trend since 1961, with the period from the late 1990s to the mid-2000s representing the fastest interdecadal increase. In years with anomalously strong total intensity of extreme high temperature, Ningxia is situated to the south of the positive center of the 500 hPa geopotential height field, where cold air from the north is less likely to intrude, thereby favoring stronger summer extreme high temperature in Ningxia. When sea ice concentration is higher in the Greenland Sea, Barents Sea, and Kara Sea regions during the preceding spring, it excites alternating positive and negative wave trains on the 500 hPa geopotential height anomaly field that propagate stably from north to south and from west to east toward the Eurasian region, causing weakening of the Ural high-pressure ridge and resulting in zonal circulation dominance in the mid-high latitude regions of Eurasia, which leads to stronger intensity of summer extreme high temperature in Ningxia. The findings of this study aim to provide a theoretical basis for the prediction of summer extreme high temperature in Ningxia.

Full Text

Preamble

Arid Zone Research
ChinaXiv Partner Journal

Vol. 38 No. 5 Sep. 2021

Characteristics of Summer Extreme High Temperature Variation in Ningxia and Its Relationship with Arctic Sea Ice

WANG Dai[1],[2], WANG Suyan[1],[2], WANG Fan[1],[2], LI Xin[1],[2], YANG Jianling[1],[2]
[1] Key Laboratory for Meteorological Disaster Monitoring and Early Warning and Risk Management of Characteristic Agriculture in Arid Regions, China Meteorological Administration, Yinchuan 750002, Ningxia, China
[2] Ningxia Key Laboratory of Meteorological Disaster Prevention and Reduction, Yinchuan 750002, Ningxia, China

Abstract: Based on daily maximum temperature data from meteorological stations in Ningxia, NCEP/NCAR reanalysis data, and Arctic sea ice data from 1961 to 2017, this study analyzes the climatic characteristics of summer extreme high temperature in Ningxia and its relationship with Arctic sea ice using statistical diagnostic methods. The results show that the total intensity, frequency, and longest duration of summer extreme high temperature events in Ningxia have generally increased since 1961, with the most rapid interdecadal increase occurring during the mid-1990s to 2000s. In years with strong extreme high temperature intensity, Ningxia is located south of the positive center of the 500 hPa geopotential height field, preventing cold air from the north from invading and favoring intense summer extreme high temperatures. When sea ice concentration in the Greenland Sea, Barents Sea, and Kara Sea is high in the preceding spring, it excites a wave train of alternating positive and negative anomalies in the 500 hPa geopotential height field that propagates stably from north to south and west to east toward Eurasia, causing the Ural Mountain ridge to weaken and resulting in zonal circulation dominating the mid-high latitudes of Eurasia, which leads to stronger summer extreme high temperature intensity in Ningxia. These findings aim to provide a theoretical basis for predicting summer extreme high temperatures in Ningxia.

Keywords: Ningxia; summer; extreme high temperature; Arctic sea ice

Introduction

Global climate change has attracted increasing attention, and the frequency of extreme weather and climate events has risen dramatically against the backdrop of global warming, causing enormous economic losses to human society. The IPCC Fifth Assessment Report indicates that global mean surface temperature has increased by approximately 0.85°C, with extreme climate events becoming more frequent and intense worldwide. China' s northwest region is a typical inland arid area, representing the core of the mid-latitude arid zone in Asia and a transitional zone between westerly and monsoon climates. This region is sensitive to global climate change and provides corresponding feedback to regional and global climate systems.

Research on extreme high temperatures in Northwest China shows that the frequency of extreme high temperature events exhibits a significant positive response to regional warming, with greater warming rates corresponding to increased extreme high temperature days and decreased extreme low temperature days. The reduction in extreme low temperature days exceeds the increase in extreme high temperature days, showing an asymmetric warming pattern. Atmospheric circulation anomalies are the direct cause of high temperature and heatwave events. The Western Pacific Subtropical High and South Asian High are closely related to high temperature weather in China. For northern China, the main cause of extreme high temperature events is the potential height anomaly in the middle and upper troposphere. In years with more high temperature days in Ningxia, the subtropical high is positioned further west with greater intensity, while in years with fewer high temperature days, the ridge shifts eastward and the subtropical high retreats.

Polar sea ice serves as a cold source for the atmosphere and has global-scale impacts on atmospheric circulation and climate. It can excite global atmospheric teleconnection patterns, demonstrating importance comparable to equatorial Pacific sea temperature anomalies and, in some cases, even exceeding their influence. China is located downstream of Greenland, so sea ice changes near Greenland can alter the properties of polar air masses and affect China' s weather and climate through circulation anomalies. When spring sea ice in the Greenland and Barents Seas is abnormally high, the Baikal Lake region and the Mongolian Plateau to its southwest are typically controlled by large-scale anomalous high pressure, which favors near-surface temperature increases. Simultaneously, the weakened Ural blocking high reduces the southward movement of polar cold air, facilitating temperature increases in the East Asian mid-latitude region.

Against the backdrop of climate warming, extreme high temperature events have occurred frequently in Ningxia since 2000, often clustering together and adversely affecting public life, production safety, urban operations, agricultural production, and ecological construction. The summer of 2016 saw record-breaking intensity, spatial extent, and duration of extreme high temperature events, causing severe drought in the central arid belt and sharply increasing pressure on urban electricity and water supplies. Previous studies on summer extreme high temperatures in Ningxia primarily focused on periods before 2000, with limited subsequent analysis and few investigations into external forcing factors affecting Ningxia' s extreme high temperatures. As Arctic sea ice represents an important external forcing factor influencing China' s temperature, its impact on summer high temperatures in Ningxia warrants in-depth exploration. This paper focuses on analyzing the anomalous characteristics of extreme high temperatures in Ningxia and their relationship with Arctic sea ice, aiming to provide a theoretical basis for summer extreme high temperature prediction.

1 Data and Methods

1.2 Data Sources

Temperature data consist of daily maximum temperature records from 25 meteorological stations in Ningxia, obtained from the Ningxia Meteorological Information Center. Atmospheric circulation data are derived from the NCEP/NCAR 500 hPa geopotential height reanalysis dataset with a horizontal resolution of 2.5°$×2.5°, *sourcedfromtheNOAAPhysicalSciencesLaboratory.Seaicedatacomprisemonthlyseaiceconcentr*
obtained from the UK Hadley Centre (HadISST).

1.3.1 Definition of Extreme High Temperature Indices

The analysis period covers summer months (June–August). Following the World Meteorological Organization' s definition for single-station extreme temperature and improvements based on Russo et al. [22], the threshold, intensity, frequency, and duration of summer extreme high temperature are defined as:

Single-station extreme high temperature threshold: For a given calendar day, the 90th percentile of daily maximum temperatures within a 31-day window centered on that day during the study period (1961–2017) is defined as the high temperature threshold, provided the daily maximum temperature $ $25°C.

Single-station extreme high temperature day: A day when the daily maximum temperature exceeds the high temperature threshold for that day.

Single-station extreme high temperature intensity: The sum of differences between the daily maximum temperature and the extreme high temperature threshold across all extreme high temperature days in a summer.

Single-station extreme high temperature event frequency: If a station experiences extreme high temperature days for three or more consecutive days, this is counted as one extreme high temperature event.

Single-station longest extreme high temperature duration: The maximum number of consecutive extreme high temperature days.

1.3.2 Statistical Methods

Using summer extreme high temperature index time series, we employed regression analysis to identify circulation signals. For each grid point in the circulation field (y), a univariate linear regression was established with the extreme high temperature index series (x). The regression coefficient for each grid point was calculated as:

$$b = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

where b represents the regression coefficient at each grid point, x is the extreme high temperature index series, y is the circulation field series, and n is the number of years. The F-test was used to assess the significance of regression coefficients, with the null hypothesis that the population regression coefficient equals zero. The F-statistic is calculated as:

$$F = \frac{(n-2) \cdot r^2}{1 - r^2}$$

At a given significance level α, when $F > F\alpha$, the regression equation is considered significant. Correlation analysis used the t-test, where if $|t| > t\alpha$, the correlation coefficient is significant at level α. All time series used in the analysis represent averages across the 25 stations in Ningxia.

2 Results

2.1 Characteristics of Summer Extreme High Temperature Variation

Time series of extreme high temperature event frequency, total intensity, and longest duration in Ningxia from 1961 to 2017 show significant increasing trends with consistent variation characteristics (Fig. 2). All three indices exhibit pronounced interdecadal variability: changes were relatively gradual before the 1990s with small interannual variability; the period from the late 1990s to mid-2000s showed the most significant increasing trend, representing the fastest interdecadal growth; since the late 2000s, the increasing trend has slowed but with larger interannual variability, reaching historical extremes in 2016 and 2017.

Spatial decadal evolution reveals distinct patterns (Figs. 3-5). In the 1960s, extreme high temperature event frequency ranged from 0.3 to 0.9 occurrences, slightly increasing in the 1970s (0.3-1.3) with greater increases in the north than the south. The 1980s saw a slight decrease (0-0.7), followed by persistent increases in the 1990s (0.6-1.2), 2000s (1.4-2.7), and 2010s (2.5-8.9), with higher frequencies in the north than in the central-southern regions. Similarly, total intensity was 2.5-8.9°C in the 1960s, weakening slightly in the 1970s (1.0-7.4°C), increasing in the 1980s (1.4-3.4°C), rising substantially in the 1990s (4.0-11.4°C), and reaching 7.0-20.6°C in the 2000s and 14.7-40.4°C in the 2010s, with northern intensities significantly exceeding those in central-southern areas. Longest duration showed consistent increases across the region: 0.7-2.7 days in the 1960s, decreasing to 0.3-2.1 days in the 1970s, then increasing progressively to 2.1-4.7 days in the 1980s, 3.7-6.7 days in the 1990s, 2.5-4.3 days in the 2000s, and 3.6-5.0 days in the 2010s.

2.2.1 500 hPa Height Field Characteristics in Extreme High Temperature Years

Regression analysis between the extreme high temperature intensity series and concurrent 500 hPa geopotential height field shows that in years with strong extreme high temperature intensity, positive height anomalies dominate northern China and regions to its north, with negative anomalies west of West Siberia, placing Ningxia in a positive correlation region (Fig. 6). This "negative north, positive south" pattern favors high temperatures. Years with the highest standardized intensity values (top 8 years) were classified as strong years, and those with the lowest values (bottom 8 years) as weak years. Composite analysis of 500 hPa height anomaly fields for these years reveals that in strong years, the continent is controlled by a warm high-pressure system, with Ningxia located south of the positive height center. The Western Pacific Subtropical High expands westward with its northern boundary shifting north of 40°N, intensifying the continental warm high and favoring extreme high temperatures in Ningxia (Fig. 6a). In weak years, a "west high, east low" pattern over Ningxia facilitates southward intrusion of high-latitude cold air, which is unfavorable for extreme high temperatures (Fig. 6b).

2.3.1 Relationship Between Arctic Sea Ice and Summer Extreme High Temperature

Analysis of the relationship between preceding spring Arctic sea ice and summer extreme high temperature intensity in Ningxia reveals a significant positive correlation with sea ice concentration in the Greenland Sea, Barents Sea, and Kara Sea (after removing linear trends) (Fig. 7, shaded areas). Higher spring sea ice concentration in these key regions favors stronger summer extreme high temperature intensity in Ningxia. A regional average sea ice concentration series was calculated for the key area. Figure 8 shows that when sea ice concentration is high, extreme high temperature intensity is also strong, with a significant correlation ($r = 0.38$ for 1961-2017, significant at the 0.01 level). The correlation reaches 0.58 after 1990, indicating a strengthening relationship.

Comparison of extreme high temperature years and sea ice anomaly years shows consistency: 7 of the top 8 sea ice high years correspond to strong extreme high temperature years, and 6 of the bottom 8 sea ice low years correspond to weak extreme high temperature years.

2.3.2 Mechanism of Sea Ice Impact on Summer Extreme High Temperature in Ningxia

Regression of the spring key region sea ice concentration series onto the summer 500 hPa geopotential height field shows that high sea ice concentration corresponds to lower geopotential heights near the Ural Mountains (Fig. 9a), indicating a weakened blocking high and zonal circulation dominance in mid-high latitudes. The opposite pattern occurs when sea ice concentration is low (Fig. 9b). Composite analysis of high and low sea ice years confirms these patterns: in high sea ice years, the Ural Mountain ridge and the low trough to its east are anomalously weak, with a stable "positive-negative-positive" pattern maintaining zonal circulation and weak cold air activity (Fig. 9c); low sea ice years show the reverse pattern (Fig. 9d).

Regression of the spring key region sea ice concentration series onto the concurrent summer 500 hPa height field (Fig. 9a) and the extreme high temperature intensity series onto the summer 500 hPa height field (Fig. 6) reveal similar circulation systems at mid-high latitudes (60°-100°E), with significant negative correlations over the Ural Mountains, indicating that high sea ice concentration weakens the Ural ridge. The Ural Mountain high-pressure ridge index, calculated as the regional average 500 hPa height over 60°-100°E, 55°-80°N, shows a strong inverse relationship with sea ice concentration (r = -0.42, significant at the 0.01 level) (Fig. 10).

The physical mechanism involves increased sea ice concentration enhancing surface albedo, which reduces ocean-atmosphere heat exchange and decreases energy income, leading to lower geopotential heights. This sea ice anomaly excites a Rossby wave teleconnection pattern with equivalent barotropic structure that propagates along specific waveguides. The wave train from the key sea ice region to low latitudes propagates stably southward and eastward toward Eurasia, weakening the Ural ridge. Additionally, increased Arctic sea ice enhances the thickness gradient between polar and mid-latitude regions, blocking the southward propagation of polar cold air and contributing to extreme summer high temperatures in northern China.

3 Discussion

Previous studies have demonstrated that polar sea ice is linked not only to local high-latitude atmospheric circulation but also to mid-low latitude and global atmospheric circulation. Variations in Arctic sea ice area can excite teleconnection wave trains that influence atmospheric circulation and climate. Wu et al. [16] found that when sea ice is abundant (scarce), the Asian continental thermal low deepens (weakens), the 500 hPa Western Pacific Subtropical High shifts northward (southward) with stronger (weaker) intensity, the South Asian High weakens (strengthens), and the East Asian summer monsoon tends to be stronger (weaker). This study focuses on how key polar sea ice regions influence mid-high latitude circulation systems affecting Ningxia' s summer extreme high temperatures, without discussing impacts on mid-low latitude circulation systems. However, composite analysis of sea ice anomaly years indicates that the Western Pacific Subtropical High (5880 gpm contour) differs significantly between high and low sea ice years, suggesting sea ice does influence the subtropical high.

The relationship between key region sea ice density and Ningxia summer extreme high temperature intensity exhibits distinct decadal characteristics. The correlation was weak before 1990 ($r < 0.3$) but strengthened dramatically after 1990, reaching 0.58. This may be related to climate warming, which has made the connection between Ningxia extreme high temperature events and sea ice increasingly significant. Since the late 2000s, the increasing trends in total intensity, longest duration, and event frequency have all slowed, but interannual variability has increased. Extreme high temperature days, intensity, and duration have generally increased and intensified across Ningxia, with greater increases in the north than in the central-south.

4 Conclusions

1) The total intensity, frequency, and longest duration of summer extreme high temperature events in Ningxia have shown increasing trends since 1961, with pronounced interdecadal variability. The period from the late 1990s to mid-2000s was the fastest growing interval. After the late 2000s, the increasing trend slowed but interannual variability remained high.
2) In years with strong extreme high temperature intensity in Ningxia, the 500 hPa height field shows northern China under the control of positive height anomalies, with Ningxia located south of the positive center. This configuration prevents cold air from the north from invading, favoring strong extreme high temperatures. In weak years, a "west high, east low" pattern over Ningxia facilitates southward intrusion of high-latitude cold air, which is unfavorable for extreme high temperatures.
3) When sea ice concentration is high in the preceding spring in the Greenland Sea, Barents Sea, and Kara Sea, it excites a wave train of alternating positive and negative anomalies in the 500 hPa geopotential height field that propagates stably from north to south and west to east toward Eurasia. This weakens the Ural Mountain ridge, causing zonal circulation to dominate the mid-high latitudes of Eurasia and resulting in stronger summer extreme high temperature intensity in Ningxia.

References

[Sun Jianqi, Wang Huijun, Yuan Wei. Decadal variability of the extreme hot event in China and its association with atmospheric circulations[J]. Climatic and Environmental Research, 2011, 16(2): 199-208.]

IPCC. Climate Change 2013: The Physical Science Basic Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panelon Climate Change[M]. Cambridge: Cambridge University Press, 2013.

[Wang Jinsong, Chen Fahu, Jin Liya, et al. The response to two global warming periods in the 20th century over the Arid Central Asia[J]. Journal of Glaciology and Geocryology, 2008, 30(2): 224-323.]

[Yang Xia, Zhao Yizhou, Li Yuanyuan, et al. Extreme weather events in Urumqi and their relation with regional climate change[J]. Arid Land Geography, 2009, 32(6): 867-873.]

[Hu Yichang, Dong Wenjie, He Yong. Progress of the study of extreme weather and climate events at the beginning of the twenty first century[J]. Advances in Earth Science, 2007, 22(10): 1066-1075.]

[Gao X J, Zhao Z C, Filippo G. Changes of extreme events in regional climate simulations over East Asia[J]. Advances in Atmospheric Sciences, 2002, 19(5): 927-942.]

[Wang Haiyan, Fang Shibo, et al. Variation characteristics of extreme climate events in Northwest China during 1961-2010[J]. Journal of Arid Meteorology, 2015, 33(6): 963-969.]

[Chen Nan, Peng Weigeng. Analysis on features of average circulation and OLR field during the years with more and less high temperature weather in Ningxia[J]. Journal of Arid Meteorology, 2004, 22(2): 23-27.]

[Yang Jing, Jia Hongyuan, Yang Baoling, et al. Abnormal characteristics and causes of extreme high temperature events in summer of Ningxia[J]. Ningxia Engineering Technology, 2015, 14(1): 10-15.]

[Li Bo, Chen Ting, Wang Nan, et al. Extremely high temperature and circulation features in Xi'an in 2017 and 2014[J]. Arid Zone Research, 2019, 36(3): 645-656.]

[Chen Ying, Shao Weiling, Cao Meng, et al. Variation of summer high temperature days and its affecting factors in Xinjiang[J]. Arid Zone Research, 2020, 37(1): 58-66.]

[Wu Yao, Tang Hongyu, Jiang Xingwen, et al. Diagnosis of a regional severely high temperature weather process in Chongqing[J]. Journal of Arid Meteorology, 2019, 37(5): 817-826.]

[Liu Jiahuimin, Zheng Ran, Lou Panxing, et al. Causes of heat wave weather in Shanxi in July 2017 and preceding signals[J]. Journal of Arid Meteorology, 2019, 37(2): 233-242.]

[Huang Shisong, Yang Xiuqun, Jiang Pengxiang. The effects of the polar sea ice on climate[J]. Journal of the Meteorological Sciences, 1995, 15(4): 46-56.]

[Wu Bingyi, Huang Ronghui, Gao Dengyi. The impact of variation of sea ice extent in the Kara sea and the Barents sea in winter on the winter monsoon over East Asia[J]. Chinese Journal of Atmospheric Sciences, 1999, 23(3): 267-275.]

[Bai Jingyu, Xu Xiangde, Miao Qiuju. The Arctic sea strong signal region[J]. Acta Meteorologica Sinica, 2000, 58(4): 485-491.]

[Wu Lei, Chen Haishan, Zhou Yang. Indicative role of interannual variations of Arctic sea ice on summer land surface thermal anomalies in the mid latitude of East Asia and its possible cause[J]. Journal of the Meteorological Sciences, 2019, 39(4): 427-436.]

[Chen Luyao. Impact of Declining Arctic Sea Ice on the Summer Air Temperature in Northern Hemisphere Mid-latituede[D]. Nanjing: Nanjing University, 2019.]

[Fang Rong, Yang Xiuqun. Summer maximum air temperature variability in China and its association with the Arctic sea ice concentration[J]. Meteorological

Monthly, 2009, 35(3): 81-86.]

[Fang Zhifang, Tan Youbang, Sui Xuehai. Teleconnection pattern between the Arctic ice area and the 500 hPa geopotential height field during the Northern Hemispheric summer[J]. Chinese Journal of Atmospheric Sciences, 1991, 15(1): 53-60.]

[Russo S, Dosio A, Graversen R G, et al. Magnitude of extreme heat waves in present climate and their projection in a warming world[J]. Journal of Geophysical Research, 2014, 19(22): 12500-12512.]

[Wei Fengying. Modern Climate Statistical Diagnosis and Prediction Technology[M]. Beijing: China Meteorological Press, 2007.]

[Wu Bingyi, Huang Ronghui, Gao Dengyi. Numerical simulations on influence of sea ice thickness and extent variation in arctic on atmospheric circulation[J]. Acta Meteorologica Sinica, 2001, 59(4): 414-428.]

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

Source: ChinaXiv —Machine translation. Verify with original.