Spatiotemporal Variation Characteristics of First and Last Frost Dates and Frost Period in Northern Xinjiang from 1961 to 2017 (Postprint)

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Abstract

Using daily minimum temperature observations from 37 surface meteorological stations in Northern Xinjiang from 1961 to 2017, combined with conventional meteorological statistical methods, the spatiotemporal evolution characteristics of first frost date, last frost date, and frost period in the Northern Xinjiang region were analyzed. The results show that: (1) The average first frost date in Northern Xinjiang was delayed at a rate of 2.2 d · $(10a)^{-1}$; the average last frost date advanced at a rate of 1.7 d · $(10a)^{-1}$; the average frost period shortened at a rate of 3.9 d · $(10a)^{-1}$; the main periods of first frost date, last frost date, and frost period were all approximately 2 a. (2) Regions in Northern Xinjiang with larger (smaller) frost period shortening trends corresponded well to stronger (weaker) delays in first frost date and advances in last frost date; the most significant shortening trends in frost period occurred in Ili Prefecture, northern Tacheng Prefecture, and the northeastern Eastern Tianshan Mountains, the area from Bortala Prefecture to the northern slope of the Tianshan Mountains was intermediate, and Altay Prefecture showed the weakest shortening trend in frost period. (3) In most areas of Northern Xinjiang, the trend of first frost date change had a good correlation with altitude; the delay rate of first frost date decreased with increasing altitude, with a vertical lapse rate of -0.077 d · $(a \cdot km)^{-1}$; autumn climate warming was the main reason for the delay of first frost date, while climate warming in both spring and autumn affected the shortening of frost period, with autumn having a greater impact.

Full Text

Temporal and Spatial Variation Characteristics of First and Last Frost Dates and Frost Period in Northern Xinjiang from 1961 to 2017

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Abstract: Using daily minimum temperature observations from 37 surface meteorological stations in northern Xinjiang (1961-2017) combined with conventional meteorological statistical methods, this study analyzes the temporal and spatial evolution characteristics of first frost dates, last frost dates, and frost periods in the region. The results show that: (1) The average first frost date in northern Xinjiang is delayed at a rate of 2.2 $d \cdot (10a)^{-1}$ (significant at the 99.9% level). The average last frost date is advanced at a rate of 1.7 $d \cdot (10a)^{-1}$, and the average frost period is shortened at a rate of 3.9 $d \cdot (10a)^{-1}$. The principal change cycle for first frost dates, last frost dates, and frost periods is approximately two years. (2) Regions with larger frost period shortening trends correspond well with stronger delays in first frost dates and advances in last frost dates. The most significant shortening trends occur in Ili Prefecture, northern Tacheng Prefecture, and the northeastern part of the eastern Tianshan Mountains. The narrow zone extending from Bortala Mongol Autonomous Prefecture to the northern slope of the Tianshan Mountains shows moderate shortening trends, while Altay Prefecture exhibits the weakest trend. (3) The temporal variation trend of first frost dates across most of northern Xinjiang correlates strongly with altitude (significant at the 95% level). The delay rate of first frost dates decreases with increasing altitude, with a vertical lapse rate of -0.077 $d \cdot (100m)^{-1}$. Autumn warming is the primary cause of delayed first frost dates, while both spring and autumn warming affect frost period shortening, with autumn warming having a greater impact.

Keywords: first/last frost date; frost period; temporal and spatial variation; northern Xinjiang

1.1 Data Sources

This study utilizes daily minimum temperature data from 37 surface meteorological stations in northern Xinjiang (Fig. 1) that have been quality-controlled by the Xinjiang Meteorological Information Center. The first and last dates when daily minimum temperature falls below 0°C each autumn and spring are identified as the first and last frost dates, respectively. The analysis focuses on the temporal and spatial variation characteristics of frost dates and frost periods in plain and basin regions. To facilitate analysis, the first and last frost dates from all stations are regionally averaged, and dates from the Gregorian calendar are converted to Julian calendar days, where January 1 is defined as day 1, January 2 as day 2, and so on.

2.1.1 Temporal Trend of First Frost Dates

Analysis of the interannual variation in average first frost dates in northern Xinjiang from 1961 to 2017 reveals a significant overall delaying trend (Fig. 2). The first frost date is delayed at a rate of $2.2\ \mathrm{d} \cdot (10\mathrm{a})^{-1}$ (significant at the 99.9% confidence level). The sliding average trend line shows a continuous delay with small fluctuations after 1970. The latest average first frost date occurred on day 304 (October 31) in 1976, while the earliest occurred on day 267 (September 24) in 1974, representing a difference of 37 days between extreme years.

2.1.2 M-K Mutation Test for First Frost Dates

The Mann-Kendall (M-K) mutation test for average first frost dates in northern Xinjiang indicates a predominantly increasing trend, reflecting the observed delay in first frost dates (Fig. 2). A significant mutation occurred in 1997, after which the UF curve exceeds the 0.05 significance level threshold, demonstrating that the delaying trend has become particularly pronounced in recent decades.

2.2.1 Temporal Trend of Last Frost Dates

The interannual variation in average last frost dates shows a clear advancing trend (Fig. 3). The last frost date is advanced at a rate of $1.7\ \mathrm{d} \cdot (10\mathrm{a})^{-1}$ (significant at the 99.9% confidence level). The sliding average reveals a continuous advance with minor fluctuations after 1970. The latest average last frost date occurred on day 126 (May 6) in 1961, while the earliest occurred on day 86 (March 27) in 2016, with a 40-day difference between extreme years.

2.2.2 M-K Mutation Test for Last Frost Dates

The M-K mutation test for average last frost dates shows a decreasing trend, indicating advancement of the last frost date (Fig. 3). A significant mutation occurred in 1994, after which the UF curve crosses the 0.05 significance level threshold, marking the beginning of a pronounced advancing trend.

2.3.2 M-K Mutation Test for Frost Period

The M-K mutation test for the average frost period reveals a decreasing trend, indicating significant shortening (Fig. 4). A mutation occurred in 1993, after which the UF curve exceeds the 0.05 significance level threshold, showing that the shortening trend has become particularly evident in recent years.

2.4.1 Periodic Variation Characteristics of First Frost Dates

Morlet wavelet analysis of first frost dates shows significant energy concentration in the frequency and time domains at two centers with coordinates (2a, 1990) and (2a, 2005) (Fig. 5). The strong influence ranges of wavelet energy concentration in the time domain are 1985–1995 and 2000–2010, respectively. The time-averaged power spectrum indicates oscillation periods of approximately 2 years and 4 years, with the 2-year cycle passing the 95% significance test, establishing it as the primary period for first frost date variation.

2.4.2 Periodic Variation Characteristics of Last Frost Dates

Wavelet energy spectrum distribution for last frost dates shows significant concentration at two centers with coordinates (2a, 1985) and (2a, 2005) (Fig. 5). The strong influence ranges are 1980–1990 and 2000–2010, respectively. The time-averaged power spectrum reveals oscillation periods of approximately 2 years and 4 years, with the 2-year cycle passing the 95% significance test, confirming it as the dominant period for last frost date variation.

2.4.3 Periodic Variation Characteristics of Frost Period

The wavelet energy spectrum for frost period shows significant concentration at two centers with coordinates (2a, 1985) and (2a, 2005) (Fig. 5). The strong influence ranges are 1980–1990 and 2000–2010. The time-averaged power spectrum indicates oscillation periods of approximately 2 years and 4 years, with the 2-year cycle passing the 95% significance test, establishing it as the primary period for frost period variation.

3.1 Spatial Variation of First Frost Dates

Spatial variation trends for first frost dates from 1961 to 2017 show overall increasing tendency rates ranging from 0.06 to 0.48 $d \cdot a^{-1}$, indicating widespread delay across northern Xinjiang (Fig. 6). The Ili River Valley exhibits a strong north-to-south gradient (0.06–0.48 $d \cdot a^{-1}$), with delaying trends intensifying southward. Bortala shows a more gradual north-to-south pattern (0.18–0.30 $d \cdot a^{-1}$). Northern Tacheng displays decreasing delay trends from north to south (0.36–0.18 $d \cdot a^{-1}$). Most of Altay Prefecture shows weak delaying trends (0.06–0.18 $d \cdot a^{-1}$), except for Qinghe County. The desert area north of Mosuowan in Shihezi City exceeds 0.36 $d \cdot a^{-1}$, indicating a pronounced delay. The northern slope of the Tianshan Mountains shows moderate delays (0.06–0.24 $d \cdot a^{-1}$), while the northeastern part of the eastern Tianshan Mountains exhibits stronger delaying trends (0.24–0.36 $d \cdot a^{-1}$). In summary, the most rapid delays occur in Bortala, northern Tacheng, the southern margin of the Junggar Basin, and the northeastern eastern Tianshan Mountains.

3.2 Spatial Variation of Last Frost Dates

Spatial variation trends for last frost dates range from -0.56 to 0.08 $d \cdot a^{-1}$, indicating that most areas are experiencing advancement, though some show weak delaying trends (Fig. 6). The Ili River Valley shows increasing advancement from north to south (-0.08 to -0.40 $d \cdot a^{-1}$). Central-eastern Bortala exhibits consistent advancement around -0.16 $d \cdot a^{-1}$. Northern Tacheng shows strong advancement (-0.32 to -0.40 $d \cdot a^{-1}$). Most of Altay Prefecture shows weak advancement, though Fuhai County demonstrates stronger advancement (-0.32 $d \cdot a^{-1}$) while Altay City shows a slight delay (0.07 $d \cdot a^{-1}$). The northern slope of the Tianshan Mountains shows decreasing advancement from north to south (-0.16 to 0.0 $d \cdot a^{-1}$). The northeastern eastern Tianshan Mountains show increasing advancement from west to east (-0.08 to -0.32 $d \cdot a^{-1}$), except for Beitashan which shows a delaying trend (0.06 $d \cdot a^{-1}$). Thus, the strongest advancement occurs in Ili Prefecture, northern Tacheng, and the northeastern eastern Tianshan Mountains, with moderate advancement along the Bortala to northern Tianshan slope.

3.3 Spatial Variation of Frost Period

Spatial variation trends for the frost period range from -0.8 to 0.0 $d \cdot a^{-1}$, indicating overall shortening across northern Xinjiang (Fig. 6). The Ili River Valley shows the greatest shortening, with Huoerguosi City reaching -0.19 $d \cdot a^{-1}$ and Yining County -0.07 $d \cdot a^{-1}$. Northern Tacheng exhibits strong shortening trends (-0.5 to -0.7 $d \cdot a^{-1}$). Altay Prefecture shows increasing shortening trends from north to south (-0.4 to -0.5 $d \cdot a^{-1}$). The northern slope of the Tianshan Mountains shows consistent shortening (-0.2 to -0.3 $d \cdot a^{-1}$). The northeastern eastern Tianshan Mountains show gradually increasing shortening trends from west to east, with Naomaohu reaching -0.63 $d \cdot a^{-1}$. Overall, areas with larger frost period shortening trends correspond well with stronger delays in first frost dates and advances in last frost dates. The frost period shortening is most significant in Ili Prefecture, northern Tacheng, and the northeastern eastern Tianshan Mountains, moderate along the Bortala to northern Tianshan slope, and weakest in Altay Prefecture.

4.1 Impact of Spring and Autumn Temperature

Analysis of spring and autumn temperature trends from 1961 to 2017 shows warming rates of $0.03°C \cdot a^{-1}$ and $0.04°C \cdot a^{-1}$, respectively (Fig. 7). Regression analysis between frost parameters and seasonal temperatures reveals that first frost dates are significantly delayed as autumn temperature increases (Fig. 8), with each 1°C increase in autumn temperature delaying the first frost date by approximately 3.3 days. The relationship between last frost dates and spring temperature is not statistically significant. The frost period shortens significantly with autumn warming (Fig. 8), with each 1°C increase shortening the period by about 5.0 days. Spring warming also contributes to frost period shortening, with each 1°C increase reducing the period by approximately 1.0

day. These results demonstrate that autumn warming is the primary driver of delayed first frost dates, while both spring and autumn warming influence frost period shortening, with autumn warming having a substantially greater effect. This may explain why the delaying rate of first frost dates exceeds the advancing rate of last frost dates in northern Xinjiang.

4.2 Impact of Altitude

To investigate the relationship between temporal trends in frost parameters and altitude, we selected stations whose trends passed significance tests for quantitative analysis. The relationship between last frost dates and frost period trends with altitude was not statistically significant, so we focus on first frost dates. Regression analysis shows that among 30 stations passing the significance test (with altitudes between 300–1700 m), the temporal trend of first frost dates decreases with increasing altitude (Fig. 9). The delay rate of first frost dates diminishes as altitude increases, with a vertical lapse rate of -0.077 $d \cdot (100m)^{-1}$ (significant at the 95% level), consistent with findings from Pan et al. [15]. Further analysis reveals that frost period shortening is significantly negatively correlated with first frost date delay (r = -0.63) and significantly positively correlated with last frost date advancement (r = 0.71). Thus, frost period shortening results from the combined effects of delayed first frost dates and advanced last frost dates, with the latter contributing slightly more.

5 Conclusions

Based on daily minimum temperature data from 37 meteorological stations in northern Xinjiang from 1961 to 2017, this study analyzes the temporal and spatial variation characteristics of first frost dates, last frost dates, and frost periods, as well as the relationship between first frost date trends and altitude. The main conclusions are:

(1) The average first frost date in northern Xinjiang is delayed at a rate of 2.2 $d \cdot (10a)^{-1}$, with a significant mutation occurring in 1997. The delaying trend has become particularly pronounced in recent years. The average last frost date is advanced at a rate of 1.7 $d \cdot (10a)^{-1}$, with a mutation in 1994. The average frost period is shortened at a rate of 3.9 $d \cdot (10a)^{-1}$, with a mutation in 1993. All three parameters exhibit a primary oscillation period of approximately 2 years.

(2) Regions with larger frost period shortening trends correspond well with stronger delays in first frost dates and advances in last frost dates. The frost period shortening is most significant in Ili Prefecture, northern Tacheng, and the northeastern eastern Tianshan Mountains, with rates of -0.5 to -0.7 $d \cdot a^{-1}$. The Bortala to northern Tianshan slope shows moderate shortening of approximately -0.2 $d \cdot a^{-1}$, while northern Altay exhibits the weakest trends, mostly -0.2 $d \cdot a^{-1}$.

(3) The temporal variation trend of first frost dates across most of northern

Xinjiang correlates strongly with altitude (significant at the 95% level). The delay rate of first frost dates decreases with increasing altitude at a vertical lapse rate of -0.077 d·$(100\text{m})^{-1}$. Autumn warming is the primary cause of delayed first frost dates, while both spring and autumn warming contribute to frost period shortening, with autumn warming having a greater impact.

References

[1] Zhang Shanqing, Pu Zongchao, Li Jinglin, et al. Analysis of spatiotemporal changes in Xinjiang during the frost free season under the background of climate warming[J]. Resources Science, 2013, 35(9): 1908-1916.

[2] Li Shikui. Agroclimatic resources and agroclimatic regionalization in China[M]. Beijing: Science Press, 1988: 56-58.

[3] Ning Xiaoju, Zhang Lijun, Yang Quntao, et al. Trend of frost free period in China since 1951[J]. Acta Geographica Sinica, 2015, 70(11): 1812-1813.

[4] Han Rongqing, Li Weijing, Ai Wanxiu, et al. Change in date of the first frost in northern China and its impact on agriculture[J]. Acta Geographica Sinica, 2010, 65(5): 525-532.

[5] Feng Kepeng, Tian Juncang, Shen Hui. Temperature variation characteristics of northwest China based on K-means clustering partition in the past half century[J]. Arid Land Geography, 2019, 42(6): 1239-1252.

[6] Li Shuo, Shen Yanjun. Impact of climate warming on the change of agricultural thermal resources in the arid regions of northwest China[J]. Chinese Journal of Eco-Agriculture, 2013, 21(2): 227-235.

[7] Pan Shukun, Zhang Mingjun, Wang Baolong, et al. Variation characteristics of frost days and frost free season in Xinjiang from 1960 to 2011[J]. Arid Zone Research, 2013, 30(4): 735-742.

[8] Meehl G A, Tebaldi C, Nychka D. Changes in frost days in simulations of twenty first century climate[J]. Climate Dynamics, 2004, 23: 495-511.

[9] Easterling D R. Recent changes in frost days and the frostfree season in the United States[J]. Bulletin of the American Meteorological Society, 2002, 83(9): 1327-1332.

[10] Xiang Wei, Cheng Zhigang, Zhou Botao, et al. Spatial difference analysis of extreme temperature events in Qinba Mountain area from 1975 to 2016[J]. Advances in Climate Change Research, 2018, 7(4): 362-370.

[11] Cai Fu, Ming Huiqing, Ji Ruipeng, et al. Spatiotemporal evolution characteristics of frost free period in the past 50 years in Liaoning[J]. Chinese Agricultural Meteorology, 2010, 31(2): 188-193.

[12] Li Ji, Yan Xiaoyu, Wang Ying. Climate change characteristics of frost in Liaoning Province in the past 50 years[J]. Meteorology, 2011, 36(11): 38-45.

[13] Fan Xiaohui, Wang Qixiang, Wang Mengben. Study on the characteristics of the frost free period in Shanxi Province in the past 50 years[J]. Journal of Eco-Environment, 2010, 19(10): 2393-2397.

[14] Lin Jingjing, Guo Hui. Analysis of the characteristics of frost changes in Pingliang from 1971 to 2012[J]. Desert and Oasis Meteorology, 2015, 9(3): 57-62.

[15] Xu Fengxia, Zhang Shan, Wang Qizhen, et al. Characteristics of change in first, last frost day and frost free season in Shouguang from 1961 to 2105 and its impact on agriculture[J]. Chinese Agricultural Science Bulletin, 2019, 35(1): 112-117.

[16] Yang Weitao, Sun Jianguo, Kang Yongtai, et al. Temporal and spatial changes of extreme weather indices in the Loess Plateau[J]. Arid Land Geography, 2020, 43(6): 1456-1466.

[17] Chen Shaoyong, Li Shuo. Characteristics of climate change in early frost in northwest China[J]. Resources Science, 2013, 35(1): 165-172.

[18] Wang Jianxun, Zhu Xiaoling. Variation characteristics of dates of first, last frost days and frost free season in Xinjiang Alar Reclamation Area in the past 40 years[J]. Journal of Arid Land Resources and Environment, 2011, 25(9): 183-186.

[19] Liu Yongwei, Yan Qingwu, Huang Jie, et al. Study on the spatiotemporal distribution of API index in China based on GIS[J]. Journal of Ecology and Environment, 2013, 22(8): 1386-1394.

[20] Xu Yan, Wang Guofu, Wang Panxing, et al. Analysis of the characteristics of frost season in China during the past 50 years[J]. Chinese Journal of Meteorology, 2009, 29(8): 427-433.

[21] Wang Guofu, Xu Yan, Zhu Yanjun, et al. Analysis of the spatiotemporal distribution and change trend of frost in China in the past 50 years[J]. Journal of Meteorology, 2009, 35(7): 61-67.

[22] Ying Yunping. Natural calendar: Conception of reforming current calendar[J]. Journal of Liaoning Normal University, 2004(4): 118-123.

[23] Fu Yanbin, Wang Qiang. Definition and detection method of abrupt climate change[J]. Chinese Journal of Atmospheric Sciences, 1992, 16(4): 482-493.

[24] Zhang Yin, Gu Lixian Turxunbai, Su Litan, et al. Analysis of the spatiotemporal characteristics of climate change at different altitudes in Xinjiang in the past 60 years[J]. Arid Land Geography, 2019, 42(4): 822-829.

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