Postprint: Analysis of Spring Cold Wave Frequency and Influencing Factors in the Hexi Corridor, 1966–2018

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Abstract

Based on daily minimum temperature data for spring (March–May) from 15 national benchmark basic stations in the Hexi Corridor of Gansu from January 1, 1966, to December 31, 2018, this study investigates the variation in spring cold wave frequency and its influencing factors in the Hexi Corridor region from 1966 to 2018 using linear regression analysis, Spline spatial interpolation, and Mann-Kendall trend and abrupt change tests. The results indicate: (1) From 1966 to 2018, spring (March–May) single-station cold wave frequency in the Hexi Corridor region exhibited an overall decreasing trend [-0.098 times · (10 a)$^{-1}$], with a significant decreasing trend during 1980–2010; after 2010, the decreasing trend slowed and failed the significance test; regional cold wave frequency over the 53 years showed a slowly decreasing trend overall [-0.015 times · (10 a)$^{-1}$]. (2) Over the past 53 years in the Hexi Corridor region, among the three spring months, the total single-station cold wave frequency was April > March > May, with no significant decrease in April and May, but a significant decrease in March. (3) Spatially, roughly bounded by the Beida River and the main stream of the Heihe River, the area between the two rivers had low spring cold wave frequency, while the area north of the Beida River and east of the Heihe River main stream was a high cold wave frequency zone; peripheral areas of the corridor had higher cold wave frequency, mostly showing a significant decreasing trend, with a significant negative correlation between cold wave frequency and temperature anomaly; trends in interior areas were not significant. (4) Spring cold wave frequency in the Hexi region is influenced by climate warming, topography, and atmospheric circulation, with regional differences in cold wave frequency change trends. This study can enhance understanding of cold wave evolution processes in the Hexi Corridor of Gansu and lay a foundation for further research on climate change in the Hexi Corridor.

Full Text

Abstract

Based on daily minimum temperature data from 15 national reference meteorological stations in the Hexi Corridor of Gansu Province during spring (March–May) from 1966 to 2018, this study employs linear regression analysis, spline spatial interpolation, and Mann-Kendall trend and mutation testing to investigate the spatiotemporal variation characteristics of spring cold wave frequency and their influencing factors. The results reveal that: (1) The frequency of single-station spring cold waves in the Hexi Corridor exhibited a significant decreasing trend from 1966 to 2018, with a rate of -0.46 times per decade ($\alpha = 0.05$). The decline was particularly pronounced during 1980–2010, after which the trend slowed and failed to pass significance testing. Regional cold wave frequency showed a slow overall decline at a rate of -0.015 times per decade, which was not statistically significant. (2) Among the three spring months, April had the highest single-station cold wave frequency (0.59 times/year), accounting for 32.45% of the spring total, followed by March (0.46 times/year, 25.90%) and May (0.38 times/year, 41.65%). The decreasing trend in March was significant, while those in April and May were not. (3) Spatially, the area between the Beida River and the main stream of the Heihe River had relatively low spring cold wave frequency, whereas regions north of the Beida River and east of the Heihe River constituted high-frequency zones. Peripheral areas of the corridor generally showed significant decreasing trends in a semicircular pattern, while interior regions exhibited no clear trend. (4) Cold wave frequency demonstrated a significant negative correlation with temperature anomalies. The frequency reduction is closely related to climate warming, with topographic effects and atmospheric circulation contributing to regional differences in variation trends. This study enhances understanding of cold wave evolution processes in the Hexi Corridor and provides a foundation for further climate change research in the region.

Keywords: Hexi Corridor; cold wave; frequency change; influencing factors

1 Introduction

Extreme climate events refer to occurrences where climatic elements deviate significantly from their mean states, reaching or exceeding statistical thresholds [1]. Regional cold waves are defined as events where more than 30% of meteorological stations within a region experience cold wave conditions during a single cold air outbreak [2]. Compared to average climate conditions, extreme events exhibit greater randomness and abruptness, responding more sensitively to climate change while exerting widespread and profound impacts on natural ecosystems and human society [3]. As a primary extreme climate event in winter half-year, cold waves significantly affect weather systems [4] and pose substantial hazards to regional industrial and agricultural production as well as daily life, thus attracting considerable research attention.

According to China' s national standard "Cold Wave Grade" (GB/T21987-2008) and "Air Temperature Grade" (GB/T20484-2006), a single-station cold wave is defined as a process where daily minimum (or mean) temperature drops by \$ \$10°C within 24 hours or \$ \$12°C within 48 hours, resulting in a daily minimum temperature \$ \$4°C. Early research on East Asian cold waves by Li Xianzhi [8] classified them into three categories. Tao Shiyan [9] subsequently investigated the source regions and paths of cold air affecting China. Yu Yang [10] conducted in-depth studies on southward cold wave paths in East Asia, proposing that cold air is primarily blocked by transverse troughs over Mongolia, accumulating near Lake Baikal before rapidly moving southward as troughs turn vertical. Ding Yihui and Zhang Peizhong et al. [11,12] further confirmed three primary pathways: (1) from Scandinavia southward to central Europe, merging with western high pressure before moving northeast; (2) from Novaya Zemlya southward, merging with Black Sea high pressure and moving eastward; and (3) from the Taymyr Peninsula southward to merge with the aforementioned paths near 100°E. Wang Zunya et al. [13] found that regional cold wave frequency decreased nationwide, particularly in northern China, possibly due to weakening Mongolian-Siberian high pressure and East Asian winter monsoon intensity.

Climate projection studies indicate that by 2030, the Hexi Corridor may experience fewer cold wave days but more extreme low-temperature events [14], suggesting potentially increased cold wave frequency around 2030. As a major commercial grain base and important ecological barrier in China, the Hexi Corridor (35°36 -45°19 N, 85°02 -114°25 E) spans approximately 1,000 km east-west, covering about 400,000 km^2 (nearly 30% of Gansu Province). The region includes Wuwei, Jinchang, Zhangye, Jiuquan, and Jiayuguan prefecture-level cities, plus parts of Jingtai County in Baiyin City [19]. Topographically, the area slopes from high in the south (Qilian Mountains) to low in the north, with a flat central corridor, scattered mountains in the east and north, and extensive deserts and gobi. The climate is temperate continental, controlled by the westerlies with prevailing subsidence, characterized by aridity and long sunshine duration [20]. All rivers are inland, mostly seasonal, with high permeability, low runoff depth, and high sediment content. Vegetation coverage is low, dominated by drought-resistant deep-rooted shrubs such *Calligonum*, *Alhagi*, and *Tamarix* [21].

The Hexi Corridor represents a primary pathway for cold air masses moving southward, with spring cold waves particularly damaging to agriculture and animal husbandry [7]. However, research on spring cold wave frequency and influencing factors in this region remains limited. This study analyzes spring cold wave frequency and influencing factors from 1966 to 2018 to provide guidance for disaster prevention and mitigation.

2 Data and Methods

2.1 Data Sources

Minimum temperature effectively reflects relative cooling amplitude [22]. Data were obtained from 15 national reference meteorological stations in the Hexi Corridor (Fig. 1), comprising daily minimum temperature values for spring (March–May) from 1966 to 2018. Data for Wutonggou and Jinta stations covered 1966–1988 and 1966–1989, respectively, while the remaining 13 stations provided complete records. Statistically, this length of time series yields reliable regional results.

2.2 Research Methods

2.2.1 Mann-Kendall Test

The Mann-Kendall test is a nonparametric statistical method for detecting long-term trends in meteorological, precipitation, and hydrological time series. It does not require normal distribution and is insensitive to outliers, making it suitable for non-normally distributed variables. The method offers simple calculation, wide detection range, and high quantification [23,24].

2.2.2 Cold Wave Frequency Statistics

Single-station cold wave frequency is calculated as the ratio of total cold wave occurrences at each station during a decade to the number of stations:

$$S = \frac{\sum_{i=1}^{n} X_i}{n}$$

where S is single-station cold wave frequency (times), X is the total number of cold waves at station i during a decade (times), and n is the number of stations.

Regional cold wave frequency counts events where >30% of stations experience cold waves, summed over a decade:

$$T = \sum_{j=1}^{m} Y_j$$

where T is regional cold wave frequency (times), Y is the number of regional cold wave events in year j, and m is the number of years.

3 Results and Analysis

3.1 Decadal Variations of Spring Cold Waves

From 1966 to 2018, single-station spring cold wave frequency in the Hexi Corridor showed an overall decreasing trend (Table 1). The 1960s–1970s represented a "low period" with far fewer events than other decades. The 1980s–1990s showed a significant increase compared to the 1970s but remained substantially lower than the 1960s, averaging 0.52 times/year. The overall declining trend aligns with research showing large fluctuations and reductions in extreme low-temperature days after the mid-1980s [14]. Regional cold wave frequency exhibited minimal interdecadal variation, though events showed a temporal advance, indirectly reflecting climate warming (Table 2).

3.2 Monthly Variations of Spring Cold Waves

Single-station spring cold wave frequency from 1966 to 2018 decreased significantly at -0.46 times per decade ($\alpha = 0.05$), with 1980 identified as the mutation year (Fig. 2). Monthly analysis reveals: March frequency was 0.46 times/year (25.90% of spring total), decreasing significantly at -0.29 times per decade; April frequency was 0.59 times/year (32.45% of spring total), decreasing at -0.12 times per decade without significance; May frequency was 0.38 times/year (41.65% of spring total), decreasing at -0.05 times per decade without significance. Thus, April contributes most to spring cold waves, while March shows the most significant decline.

Regional cold wave frequency decreased overall at -0.015 times per decade, passing significance testing ($\alpha = 0.05$), with 1979 as the mutation year (Fig. 3). The decline is extremely significant, likely related to cold wave pathways.

3.3 Spatial Distribution and Regional Differences

3.3.1 Spatial Distribution Characteristics

Spatial distribution of single-station spring cold waves (Fig. 4) shows clear spatial heterogeneity. Frequency is higher at both north and south ends, with lower values in the central region. Most areas of Jiuquan, Wuwei, and Jinchang have high frequency, peaking near Mazong Mountain in Subei County. The central Zhangye region shows overall low frequency, with the lowest center near Gaotai County. Bounded roughly by the Beida River and Heihe River main stream, the area between these rivers has low frequency, while regions north of the Beida River and east of the Heihe River constitute high-frequency zones.

3.3.2 Regional Differences

Peripheral stations including Dunhuang, Mazong Mountain, Jinta, Dingxing Town, Shandan, and Minqin show significant decreasing trends, forming a semicircular pattern around the central corridor stations. Central corridor stations show no clear trend. Notably, high-frequency zones largely overlap with areas of significant decline, indicating that regions with higher cold wave frequency also experienced greater reductions.

3.4 Influencing Factors

3.4.1 Climate Warming

The number of days with minimum temperature $ 0°*ChasdecreasedintheHexiCorridor.Coldwavefrequencyin*
= 0.05). Spring mean temperature is rising while winter warming trends indicate overall climate warming, synchronous with cold wave frequency reduction.

Figure 5 shows the interannual evolution of spring temperature anomalies and cold wave frequency. Both linear and polynomial trends reveal a strong inverse relationship: higher temperatures correspond to fewer cold waves, and vice versa. A temperature mutation occurred in 1997, coinciding with the cold wave frequency mutation in 1998, confirming their close relationship [25].

3.4.2 Topographic Effects

Topography redistributes regional hydrothermal conditions and blocks/diverges invading cold air. Cold air from Mongolia–Siberia is slowed by the Beishan Mountains, causing accumulation and forming high-frequency zones near Mazong Mountain and Wushao Ridge. In Minqin, cold air is partially diverted by the Helan Mountains, increasing local cold wave frequency.

3.4.3 Atmospheric Circulation

During regional cold wave events, the 500 hPa circulation field shows a "one ridge, one trough" pattern: a ridge with positive height anomalies over the Ural Mountains and a northeast–southwest oriented trough with negative height anomalies over Lake Baikal–eastern Xinjiang. The Hexi Corridor lies under northwest flow ahead of the ridge. During March–May, Ural ridge development peaks, guiding high-latitude cold air into the low trough [26], causing eastward intrusion into the Hexi Corridor. Additionally, Asian polar vortex influences cold wave activity. After forming in winter, the vortex center moves southward to northern Siberia, creating a high-pressure system that channels cold air southward to affect Xinjiang and the Hexi Corridor, forming large-scale persistent low temperatures [27].

4 Conclusions

(1) From 1966 to 2018, single-station spring cold wave frequency in the Hexi Corridor showed a significant decreasing trend of -0.46 times per decade, with the decline slowing after 2010. Regional cold wave frequency decreased slowly at -0.015 times per decade, without statistical significance.

(2) Among spring months, April had the highest single-station cold wave frequency (0.59 times/year), accounting for 32.45% of the spring total, followed by March (0.46 times/year, 25.90%) and May (0.38 times/year, 41.65%). March showed a significant decreasing trend, while April and May did not.

(3) Spatially, bounded by the Beida River and Heihe River main stream, the area between rivers had low cold wave frequency, while regions north of the Beida River and east of the Heihe River were high-frequency zones.

Peripheral areas showed significant decreasing trends in a semicircular pattern, whereas interior regions showed no clear trend.

(4) Cold wave frequency exhibited a significant negative correlation with temperature anomalies. The frequency reduction is closely related to climate warming, with topography and atmospheric circulation causing regional differences in variation trends and spatial distribution.

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