The Impact of the North Atlantic Oscillation on Winter Extreme Cold Events in Xinjiang (Postprint)

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Abstract

Using daily temperature data from various stations in Xinjiang, NCEP reanalysis geopotential height and wind field data, and the North Atlantic Oscillation (NAO) index from 1961–2016, this study analyzes the frequency variation of winter extreme cold events in Xinjiang and their associated circulation characteristics. Winter NAO influences the variation of winter extreme cold events in Xinjiang through the propagation of the Eurasian (EU) wave train, but there is no one-to-one negative correlation between winter NAO phase and winter extreme cold events in Xinjiang on a year-to-year basis. During negative winter NAO phase years, through EU wave train propagation, northerly winds north of 70°N are weaker; when geopotential height over the Ural Mountains and regions to its east is higher (lower) and westerly winds at 50°–70°N are weaker (stronger), winter extreme cold events in Xinjiang are more (less) frequent. During positive winter NAO phase years, through EU wave train propagation, northerly winds north of 70°N are stronger; when geopotential height over the Ural Mountains and regions to its east is higher (lower) and westerly winds at 50°–70°N are weaker (stronger), winter extreme cold events in Xinjiang are more (less) frequent. Therefore, the combined effects of winter NAO, the height field over the Ural Mountains and regions to its east, and westerly winds at 50°–70°N determine the frequency of winter extreme cold events in Xinjiang, with geopotential height over the Ural Mountains and regions to its east and westerly winds at 50°–70°N playing an important modulating role in the relationship between winter NAO and extreme cold events in Xinjiang.

Full Text

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Abstract

The frequency and circulation patterns of extreme cold events in Xinjiang during winter were analyzed using daily air temperature data from meteorological stations in Xinjiang, NCEP reanalysis data of the height field, wind field, temperature field, and the North Atlantic Oscillation (NAO) index during the period of 1961–2016. The variation of extreme cold events in Xinjiang during winter was affected by the Eurasian (EU) wave train transmission. However, there was no one-to-one negative correlation between the NAO phase and the extreme cold events in Xinjiang during winter. In the winter of NAO negative phase, NAO was spread by the EU wave train, and the north wind was weak north of 70°N. Under this background, the extreme cold events in Xinjiang during winter were more (less) frequent when the geopotential height over the Ural Mountain and its east region was high (low) and the west wind was weak (strong) in 50°–70°N. In the winter of NAO positive phase, NAO was spread by the EU wave train, and the north wind was strong north of 70°N. Under this background, the extreme cold events in Xinjiang during winter were more (less) frequent when the geopotential height over the Ural Mountain and its east region was high (low) and the west wind was weak (strong) in 50°–70°N. The results showed that the occurrence frequency of extreme cold events in Xinjiang was mainly affected by the interaction of NAO, the geopotential height field over the Ural Mountain and its east region, and the west wind in 50°–70°N, of which the west wind in 50°–70°N in winter and the geopotential height field over the Ural Mountain and its east region were the main affecting factors.

Keywords: extreme cold event; North Atlantic Oscillation; zonal circulation; Xinjiang

1 Introduction

Extreme cold events in Xinjiang during winter exhibit significant interannual variability and have substantial impacts on socioeconomic activities and ecosystems. Previous studies have documented the relationship between large-scale atmospheric circulation patterns and temperature extremes in this region. The North Atlantic Oscillation (NAO), as a dominant mode of climate variability in the Northern Hemisphere, influences atmospheric circulation across Eurasia through teleconnection patterns. However, the specific mechanisms through which NAO modulates extreme cold events in Xinjiang remain inadequately understood, particularly regarding the role of the Eurasian wave train and regional circulation anomalies.

The complex topography of Central Asia and the unique climatic setting of Xinjiang necessitate a detailed investigation of how remote forcing from the Atlantic sector translates into local temperature extremes. This study aims to quantify the relationship between NAO phases and winter extreme cold events in Xinjiang, with particular emphasis on the mediating role of the Eurasian wave train and key regional circulation features such as the Ural high and mid-latitude westerlies.

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2 Data and Methods

2.1 Data Sources

The analysis utilized daily air temperature observations from 89 meteorological stations across Xinjiang for the period 1961–2016. Atmospheric circulation data were obtained from the NCEP reanalysis dataset, including geopotential height, wind, and temperature fields. The NAO index was derived from standardized sea level pressure differences between the Azores and Iceland. All datasets underwent quality control procedures to ensure consistency and reliability for climatological analysis.

2.2 Analytical Methods

The study employed Rotated Empirical Orthogonal Function (REOF) analysis to identify the primary spatial modes of winter extreme cold events in Xinjiang. Correlation analysis was conducted between the frequency of extreme cold events and large-scale circulation fields at 500 hPa and 300 hPa levels. Composite analysis was performed stratified by NAO phases to isolate the differential impacts of positive and negative NAO conditions. Statistical significance was assessed using Student’ s t-test, with correlation coefficients significant at the 95% confidence level being retained.

The extreme cold events were defined based on the 10th percentile of winter temperature distributions at each station. The Eurasian wave train activity was diagnosed using meridional wind anomalies at 300 hPa, which effectively captures the propagation of Rossby wave energy from the North Atlantic to East Asia.

Figure 1 shows the temporal variation and the first spatial mode of REOF for winter extreme cold events in Xinjiang during 1961–2016. The REOF first mode explains 37.7% of the total variance, with positive loadings across most of Xinjiang, indicating a spatially coherent pattern of extreme cold occurrence. The temporal component reveals pronounced interannual variability, with notably high frequencies during the 1970s and 1980s.

Figure 2 presents the correlation fields between winter extreme cold events in Xinjiang and the 500 hPa geopotential height field (a) and 300 hPa meridional wind field (b) for the period 1961–2016. Significant negative correlations are observed between the frequency of extreme cold events and 500 hPa geopotential height over the Ural Mountain region, with correlation coefficients reaching -0.71 (significant at the 0.05 level). The 300 hPa meridional wind field shows a wave-like correlation pattern extending from the North Atlantic to East Asia, characteristic of the Eurasian teleconnection pattern.

Figure 3 displays the composite 300 hPa meridional wind field for different NAO phases during 1961–2016. During NAO negative phases, a pronounced wave train emerges with alternating positive and negative anomalies across the Eurasian continent. The phase of this wave train determines the sign of the meridional wind anomaly over Xinjiang, thereby modulating the advection of cold air masses.

Figure 4 illustrates the 500 hPa geopotential height fields composed according to the occurrence frequency of extreme cold events in Xinjiang during different NAO phases. The composite analysis reveals that during winters with frequent extreme cold events, the Ural high is intensified and extends eastward, while the mid-latitude westerly flow (50°–70°N) is weakened, facilitating the southward intrusion of cold air into Xinjiang.

Table 1 provides the division of occurrence frequency of extreme cold events in Xinjiang during different NAO phases. The classification shows that during NAO negative phases, years with high frequency of extreme cold events include 1969, 1978, 1986, 1996, 2008, and 2009, whereas years with low frequency include 1972, 1980, 1981, 1982, 1985, 1988, 1989, 1991, 1992, 1994, 1998, 1999, 2000, 2003, 2006, 2013, 2014, 2015, and 2016. During NAO positive phases, high-frequency years include 1961, 1962, 1963, 1964, 1965, 1967, 1968, 1970, 1976, 1977, 1984, 1995, 1997, 2002, and 2010, while low-frequency years include 1966, 1971, 1973, 1974, 1975, 1979, 1983, 1987, 1990, 1993, 2001, 2004, 2005, 2007, 2011, and 2012.

The results demonstrate that the relationship between NAO and Xinjiang extreme cold events is not deterministic but depends critically on the configuration of the Eurasian wave train and regional circulation anomalies. The Ural Mountain geopotential height anomaly and the strength of the 50°–70°N westerly flow act as key modulators, determining whether NAO signals translate into increased or decreased extreme cold frequency in Xinjiang.

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