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Interdecadal Variation of Wintertime Blocking Frequency over the Siberia

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Abstract: The interdecadal variation of wintertime blocking frequency over the Siberia (60°E-140°E) is examined using the ECMWF/NCEP-NCAR re-analysis data for the period 1958-2006. The wintertime blocking frequency over the Siberia significantly decreased for the period 1986-2006, compared to the period 1958-1985, which is mainly due to the anomalous circulation of 500-hPa geopotential height field. During the period 1986-2006, there was enhancement in both the anomalous cyclonic flow over the western Siberia and the anomalous anticyclonic flow over the east Asia. These anomalous circulation patterns, which might be associated with changes in surface temperatures over the Asian continent, are suspected to play a possibly important role as an obstacle to the formation of blocking flow over the Siberia.

Keywords: interdecadal variation, blocking

Introduction

In recent years, unusual weather extremes, which are often associated with the occurrence of atmospheric blocking, are frequently observed in all parts of the world (Hansen et al., 1993; Easterling et al., 2000; Carrera et al., 2004). The blocking is defined as a persistent and recurrent flow system which interrupts the regular westerly flow at mid- and high-latitudes by the high-amplitude ridge (Rex, 1950; Renwick and Wallace, 1996). The research for the climatic variability of blocking has been mainly conducted in terms of interannual variations in relation to the ENSO (Renwick and Wallace, 1996; Chen and Yoon, 2002; Carrera et al., 2004). Nonetheless, there are only a few studies for the interdecadal variation of blocking over the specific area. Chen and Yoon (2002) showed that the North Pacific winter blocking underwent a noticeable interdecadal change in the period before and after 1978 due to the PDO (Pacific Decadal Oscillation): blocking days increased, while blocking highs migrated eastward. In addition, Luo and Wan (2005) suggested that the wintertime blocking activities over the North Atlantic and North Pacific sectors exhibited a salient decadal variability which is likely controlled by a decadal change in the basic-state baroclinicity associated with the large-scale atmosphere-ocean coupling in the mid-latitudes. Thus, previous researches primarily focus on the climatic variability of blocking over the Pacific or Atlantic ocean. Apart from these regions, Lee and Jhun (2006) investigated the relationship between two types of blocking over the Asian continent and the east Asian winter monsoon (EAWM). They mainly discussed the interannual variations of two types of blocking and their contribution to the intensity of the EAWM. The main objective of this study is to show observational evidence for the interdecadal change in the wintertime blocking frequency over the Siberia. In addition, we attempted to investigate corresponding changes of circulation patterns.

Data and Methods

The $2.5^\circ \times 2.5^\circ$ ECMWF reanalysis data (ERA-40, http://data.ecmwf.int/data) for 1958-2002 and the NCEP-NCAR reanalysis data (Kistler et al., 2001) for 1958-2006 are used in this study. The $2^\circ \times 2^\circ$ NOAA Extended Reconstructed sea surface temperature (SST) data provided by the NOAA-CIRES Climate Diagnostics

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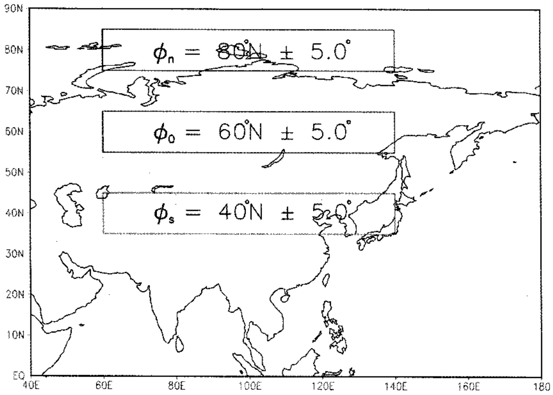

Fig. 1. The areas used to define blocking index over the Siberia.

Center (http://www.cdc.noaa.gov) are also used for 1854-2006.

In general, either the persistent positive anomaly method (Dole and Gordon, 1983; Carrera et al., 2004) or the meridional gradient method (Lejenäs and Økland, 1983; Tibaldi and Molteni, 1990; Chen and Yoon, 2002) for 500-hPa geopotential height has been used to detect the blocking. In this study, the blocking index of Tibaldi and Molteni (1990) modified from that of Lejenäs and Økland (1983) was introduced to detect the blocking flow. After the application of a five-day running mean to the daily-mean 500-hPa geopotential heights, the blocking index is calculated from the southern and northern geopotential height gradients (GHGS and GHGN):

$$\mathrm{GHGS} = \frac{Z(\phi_o) - Z(\phi_s)}{\phi_o - \phi_s}, \quad (1a)$$

$$\mathrm{GHGN} = \frac{Z(\phi_n) - Z(\phi_o)}{\phi_n - \phi_o} \quad (1b)$$

where $\phi_n = 80°\mathrm{N} + \Delta$, $\phi_o = 60°\mathrm{N} + \Delta$, $\phi_s = 40°\mathrm{N} + \Delta$, $\Delta = -5°, 0°, 5°$. A given longitude is considered to be blocked if the following conditions are satisfied for at least one value of Δ:

$$\mathrm{GHGS} > 0 \text{ and } \mathrm{GHGN} < -10 \text{ m/(deg.latitude)} \quad (2)$$

For the respective longitude, each blocking frequency is defined as the ratio of the blocked days to the number of DJF winter season days (90 days). In this study, we focus on the blocking frequency over the Siberian region (60°E-140°E), indicated by the small boxes in Fig. 1. The duration of one blocking event is equal to or longer than five days.

Results

The area-averaged blocking frequency over the Siberia for the period 1958-2006 is shown in Fig. 2. In terms of data consistency between ECMWF and NCEP reanalysis, the advantages of the blocking detection method proposed by Tibaldi and Molteni (1990) are explained in Lee and Jhun (2006). Although blocking frequencies obtained from these

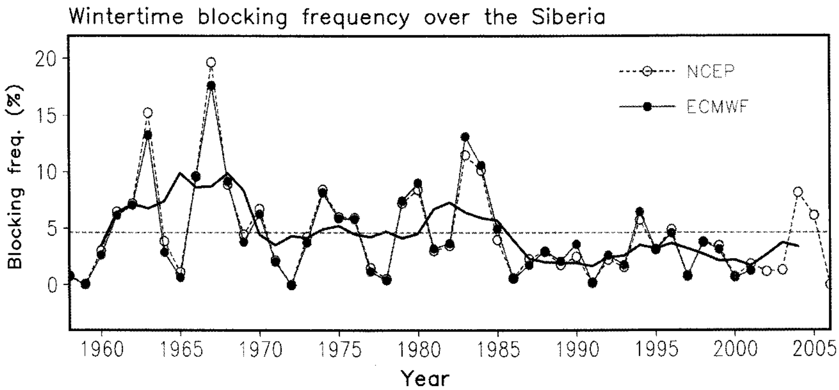

Fig. 2. Time series of area-averaged (60°E-140°E) blocking frequency over the Siberia during each winter. Closed (open) circles are calculated from ECMWF (NCEP) reanalysis data. The thick solid line is the five-year moving-averaged blocking frequency over the Siberia; its mean value is indicated by the dotted line.

Table 1. Mean values and standard deviations of blocking frequency over the Siberia for each period

Period (DJF)	Mean ± standard deviation (%)
1958/59-2006/07	4.5 ± 4.1
1958/59-1985/86	5.8 ± 4.6
1986/87-2006/07	2.6 ± 2.1

two datasets are in good agreement with each other, the NCEP reanalysis data before the late 1970s are underestimated in the Asian region (Wu et al., 2005; Lee and Jhun, 2006). Therefore, we used the ECMWF reanalysis data for the period 1958/59-2001/02 and NCEP reanalysis data for the period 2002/03-2006/07 in the following composite analyses.

The five-year moving-averaged blocking frequency over the Siberia shows a prominent interdecadal variation (Fig. 2 and Table 1). That is, the blocking frequency considerably decreased for the period 1986-2006 compared to the period 1958-1985. We have performed the significant test based on the Lepage (1971). The Lepage test is a non-parametric test that investigates significant difference between two samples, even if the distributions of the parent populations are unknown. If the Lepage statistic is greater than 5.99 (9.21), the mean change between two samples is significant at the 95 (99) % confidence level. The Lepage statistic between our two periods is about 8.5, which is significant at the 95% confidence level. Thus, the test statistics indicate a significant variation of wintertime blocking frequency over the Siberia before and after 1985/86.

To isolate the pressure and wind structure corresponding to the increase of blocking frequency, we first shows the composite 500-hPa geopotential heights and height anomalies averaged for the duration of all blocking events over the Siberia during the period 1958-2006 in Fig. 3a. There are strong positive anomalies and the accomanying ridge over the Siberia. The strengthened ridging by the blocking activity contributes to the occurrence of cut-off low over the northeast Asia and the subsequent strong negative anomalies over the east Asia covering eastern China, Korea, and Japan. This meridional dipole structure originated from the blocking activity plays a crucial role in a strong EAWM (Lee and Jhun, 2006).

Fig. 3b displays the difference in composite 500-hPa geopotential heights for all blocking events between two periods. Considering that the central latitude of strong positive anomalies associated with blocking high over the Siberia is primrily located in 60°N-70°N as shown in Fig. 3a, the intensity of blocking over the Siberia is likely to be weakened, centering around the western part of the Siberia, for the period 1986-2006.

DJF-mean 500-hPa geopotential height and 500-hPa wind vector differences between the periods 1958-1985 and 1986-2006 are shown in Fig. 3c. The most striking features are the existence of the negative anomaly over the western Siberia, the significant positive anomaly over the east Asia, and a strong negative anomaly over the North Pacific. The characteristic over the North Pacific is not the scope of this study. The interdecadal change of circulation patterns over the Siberia is closely associated with the decrease of blocking frequency over the Siberian region. The cyclonic flow anomaly over the western Siberia induces the negative GHGS in Eq. (1) and act as a brake on the formation of blocking high. In addition, the anticyclonic flow anomaly over the east Asia, which is primarily located in 30°N-50°N, leads to the negative GHGS. Thus, the interdecadal variation of mean field over the Siberia is likely to significantly contribute to the interdecadal decrease of blocking frequency and the weakening of blocking intensity over that area.

According to Lee and Jhun (2006), negative anomaly over the east Asia during the blocking period (Fig. 3a) contributes to a strong EAWM by the cold northwesterly flow. In this sense, positive anomalies of 500-hPa geopotential height over the east Asia as shown in Figs. 3b and 3c are correlated with a weak EAWM. The east Asian winter monsoon index (EAWMI) by Jhun and Lee (2004) is used to investigate the difference of the intensity of EAWM between two periods. Here, the EAWMI is defined as the difference in the area-averaged zonal wind speed

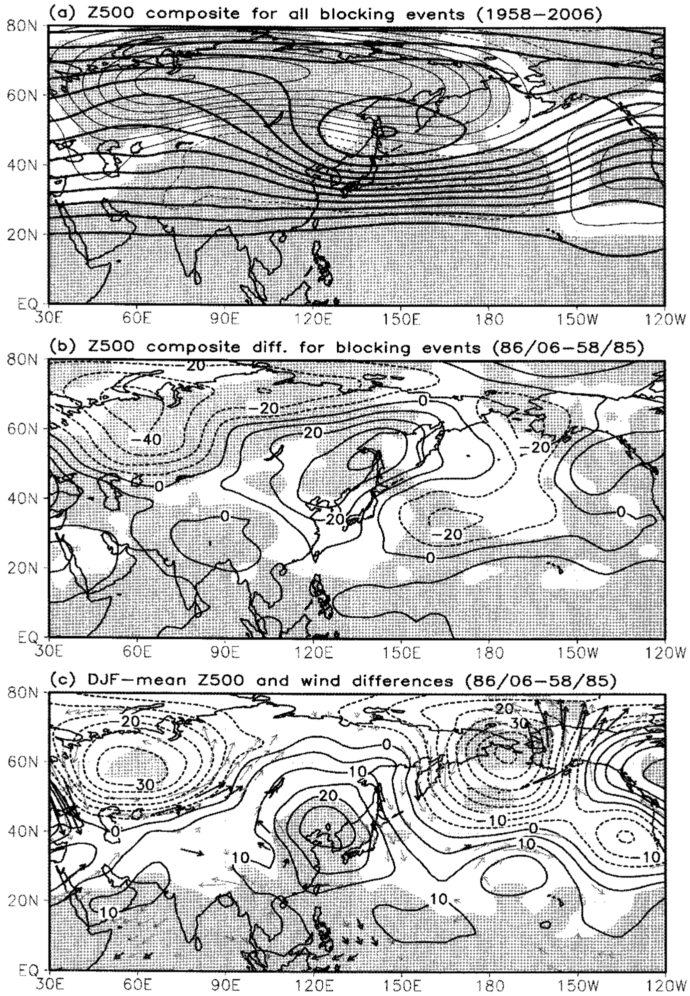

Fig. 3. (a) Composite 500-hPa geopotential heights (thick solid lines with a contour interval of 60 m) and height anomalies (thin lines with a contour interval of 20 m) averaged over the duration of all blocking events over the Siberia during the period 1958-2006. The thin solid (dashed) lines represent positive (negative) anomalies. The areas exceeding the 95% significance level are shaded. (b) Difference of each composite 500-hPa height anomalies for only blocking events in between two periods. (c) Differences of DJF-mean 500-hPa geopotential heights and wind vectors in between two periods. Shaded area denotes the 95% confidence level by Lepage test. Thin and thick arrows, which are wind differences, are significant at the 95% and 99% confidence levels, respectively.

at 300-hPa level between two boxed regions:

$$EAWMI = U_{300}\ (27.5^{\circ}N - 37.5^{\circ}N,\ 110^{\circ}E - 170^{\circ}E) - U_{300}\ (50^{\circ}N - 60^{\circ}N,\ 80^{\circ}E - 140^{\circ}E) \qquad (3)$$

A positive (negative) EAWMI indicate a strong (weak) monsoon. The averaged EAWMI during the period 1958-1985 is 0.81 and that during the period 1986-2006 is -1.32. Therefore, it is suggested that there is a difference in the intensity of EAWM between two periods.

It is known that the heat source due to surface heating plays an important role in mid-latitude quasi-stationary circulations (Hoskins and Karoly, 1981; Held, 1993). According to these studies, an isolated region of heating may excite a propagating wave train and influence the extratropical standing wave, and thus produce blocking events. Fig. 4a shows the interdecadal difference of DJF-mean surface temperature between the periods 1958-1985 and 1986-2006. Although there are regions with decreasing temperature

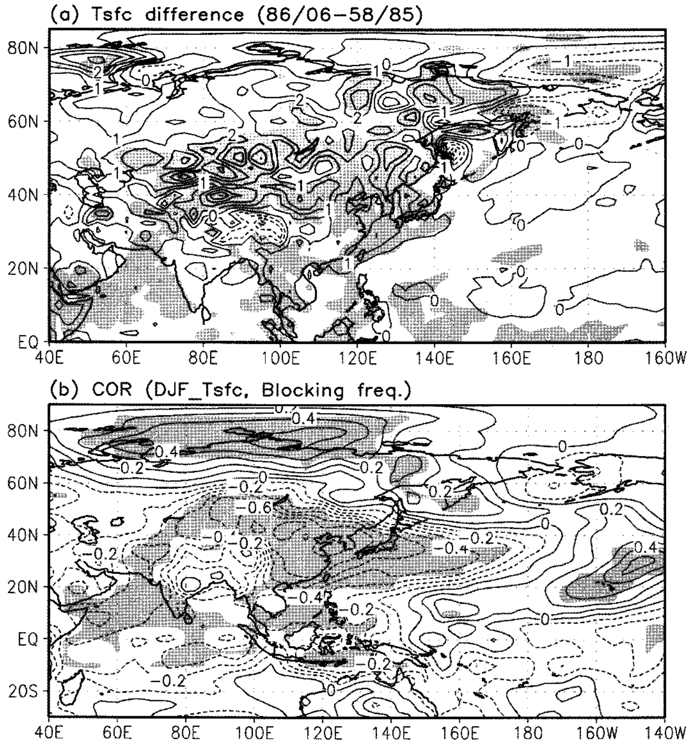

Fig. 4. (a) Differences of surface temperature anomalies between two periods. Shaded area indicates the 95% confidence level by Lepage test. (b) Correlation between the blocking frequency over the Siberia and DJF-mean surface temperature. The areas exceeding the 95% significance level are shaded.

between two periods, most regions have underwent the increase of temperature during the period 1986-2006. Especially, compared to the ocean SST, the surface temperature over the Asian continent has greatly increased with priority given to the latitudinal range of 35°N-55°N. In addition, the correlation map between the blocking frequency over the Siberia and the DJF-mean surface temperature shows that the correlation pattern over the Asian continent is very similar to the meridional dipole structure in 500-hPa geopotential height anomalies as shown in Fig. 3a (Fig. 4b). That is, the positive correlation area over the latitude 65°N-85°N and the negative correlation area over the latitude 20°N-55°N are closely associated with the positive and negative anomaly regions in 500-hPa geopotential height field during the blocking period, respectively.

The possible mechanism for the variation of blocking frequency induced by the interdecadal change of surface temperature over the Siberia can be roughly explained. In general, atmospheric blocking is characterized by the split jet and recurrent flow system which interrupt the regular westerly flow at mid- and high-latitude region (Rex, 1950). As meridional surface temperature gradient is enhanced over the Asian continent (primarily for the regions 60°E-120°E and 50°N-70°N) as shown in Fig. 4a, the zonal wind in the upper layer over the blocking high region (55°N-65°N) is increased by thermal wind relationship, which is an obstacle to a formation of blocking flow. Although these features do not accurately explain the detailed mechanism, significant regional changes in the meridional surface temperature gradient is likely to contribute to the interdecadal variation of blocking frequency over the Siberia.

Summary and Discussion

It has been found that the wintertime blocking frequency (intensity) over the Siberia significantly decreased (weakened) for the period 1986-2006 compared to the period 1958-1985. This interdecadal variation is closely associated with the change of circulation patterns over the Siberia. The anomalous cyclonic flow over the western Siberia plays as an obstacle to the formation of blocking high. In addition, the anomalous anticyclone over the east Asia is located in the relatively lower latitudes of 30°N-50°N and do not favor the blocking detection over the eastern Siberia. Thus, these anomalous circulation patterns play an important role in impeding the formation of blocked flow over the Siberia, and appear to be significantly influenced by the interdecadal and regional changes in the surface temperature over the Asian continent.

In this study, the primary focus has been on the interdecadal decrease of blocking frequency over the Siberia and the subsequent change of circulation patterns. However, it is not easy to understand how thermal effects contribute to the decrease of blocking frequency over the Siberia. Henceforth, the detailed further study is required for a more complete understanding of dynamic processes which are associated with surface conditions. It may be recommended that the atmospheric general circulation model (AGCM) should be applied to do so.

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