NOTES AND CORRESPONDENCE

Relationship between Springtime Surface Temperature and Early Summer Blocking Activity over Siberia

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Abstract

Influence of springtime surface condition over Siberia upon subsequent summertime blocking activity over northeastern Siberia, and the Okhotsk sea is examined. It is found that when the surface temperature over Siberia is high in April (the *high years*), blocking events over northeastern Siberia, and the Okhotsk sea in May and June, occur more frequently than climatology. In the *high years*, a jet stream over the north of Siberia is formed in the upper troposphere, corresponding to the enhanced meridional temperature gradient, and the polar frontal jet is observed from April to the beginning of July over East Asia. During this period, the meridional gradient of potential vorticity is more gradual, between this high-latitude jet stream and a subtropical jet, consistent with the more frequent occurrences of blocking. Associated with the enhancement of blocking activity, is the intensification of the surface Okhotsk high and cold anomaly to its south over the northern part of Japan during the early summer season of the *high years*. The finding of this study suggests monitoring the springtime surface condition over northern Siberia as one of the promising predictors for the early-summer climate over East Asia.

1. Introduction

Over the Okhotsk sea, quasi-stationary anticyclones, which are called the Okhotsk high, are observed in summer. Many studies pointed out that the Okhotsk high has an equivalent barotropic structure, except for near-surface levels, and is accompanied by blocking anticyclones at upper tropospheric levels over northeastern Siberia and the Okhotsk sea.

There are two kinds of formation mechanism of blocking anticyclones; the principal formation factor of blocking anticyclones, which develops in May, is synoptic eddy forcing, and those develop in July is formed from Rossby wave, that propagate over the Eurasia Conti-

nent (Wang and Yasunari 1994; Nakamura et al. 1997; Nakamura and Fukamachi 2004). Moreover, it is well-known that activities of the Okhotsk high are related to the Baiu/Meiyu front (e.g., Kurashima 1969; Wang 1992). Thus, the summertime blocking anticyclone over northeastern Siberia and the Okhotsk sea is one of the keys to understand the inter-annual variability of the summertime climate of East Asia.

On the other hand, it has been pointed out that, using monthly mean data, summertime geopotential field over the Okhotsk sea has a good correlation with springtime Eurasian snow cover; when snow cover extent is large over western Siberia in April, negative anomalies of the 500 hPa geopotential height over the Okhotsk Sea is observed in June (Kodera and Chiba 1989). This relationship between the springtime snow cover and summertime geopotential field was also supported by a numeri-

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cal experiment, with a general circulation model (Yasunari et al. 1991). Recently, Ogi et al. (2003) and Ogi et al. (2004) pointed out that springtime Eurasian snow cover, and surface temperature, are affected by the North Atlantic Oscillation (NAO) in the previous winter, and when NAO is in the positive phase, the spring and summertime snow cover extent becomes smaller, and the summertime Okhotsk high is amplified. It is also pointed out by Tachibana et al. (2004), that the summertime warmth of eastern Siberia influences the interannual variation of the Okhotsk high, which has vertically deep structure, namely it is accompanied by a blocking anticyclone.

However, these studies could not discuss in detail the formation of blocking anticyclones accompanied by the Okhotsk high beneath, which has sub-month timescale since they used the monthly mean dataset for analyses. On the other hand, Nakamura and Fukamachi (2004) found that the difference of the zonal and meridional gradient of surface air temperature over the Far East and the Okhotsk sea between May and July, leads the formation mechanism of blocking to the different way. Their discussion is based upon the climatological seasonal march, and did not mention the key factor of the interannual variation of the blocking formation.

In this study, we aim to clarify the effect of springtime surface condition over Siberia upon summertime Asian climate, using daily atmospheric datasets, in order to focus the interannual variability of inter-seasonal time scale evolution of blocking activity over northeastern Siberia and the Okhotsk sea. Since springtime snow cover data tends to emphasize snow-edge regions, we use surface temperature data to characterize the springtime land surface condition. The dataset used in this study is the European Centre for Medium-Range Weather Forecasts, 40 year Re-Analysis (ECMWF ERA-40), for the time period 1958–2001, except for the last section of this article.

2. Summertime blocking activity over northeastern Siberia and the Okhotsk sea

The region of a high standard deviation of springtime (March, April and May) surface temperature is largely spread over Siberia, and

the maximum is located around (80°E, 60°N). Therefore, for the concise expression of the interannual variation of springtime surface condition over Siberia, we define a ‘Siberian index’ as an average of surface temperature anomaly, over an area 60°E–140°E, 50°N–70°N. The following results are not critically modified by a slight shift of the area that is used to define the Siberian index.

On the other hand, in order to extract blocking events, we used the definition proposed by Tibaldi and Molteni (1990) for the grid points of the 10-day low-pass filtered 500 hPa geopotential field, in a region downstream of the key area for the surface temperature index, between 110°E and 160°E, where blocking anticyclones are most frequently observed over East Asia in early summer (Wang 1992). A blocking event is identified when the following conditions are met;

$$\frac{Z(\phi_0) - Z(\phi_s)}{\phi_0 - \phi_s} > 0 \quad (1)$$

and

$$\frac{Z(\phi_n) - Z(\phi_0)}{\phi_n - \phi_0} < \Delta Z, \quad (2)$$

where $Z(\phi_0)$ is the 500 hPa geopotential height for the latitude ϕ_0 . Because the original definition by Tibaldi and Molteni (1990) is designed for wintertime blocking, the values for ϕ_0 , ϕ_n , ϕ_s and ΔZ , are altered to detect summertime blocking over northeastern Siberia and the Okhotsk sea as follows;

$$\left. \begin{aligned} 65^\circ\text{N} &\leq \phi_n \leq 85^\circ\text{N}, \\ 50^\circ\text{N} &\leq \phi_0 \leq 70^\circ\text{N}, \\ 35^\circ\text{N} &\leq \phi_s \leq 55^\circ\text{N}, \\ \Delta Z &= -8\text{m/deg.} \end{aligned} \right\} \quad (3)$$

If the conditions (1) and (2) are satisfied simultaneously for more than 6 days, a blocking event is said to have occurred at that longitude.

To understand the relationship between springtime surface condition and blocking activity in detail, we make a composite map in which the Siberian index averaged over 1–30 April, is adopted as the key period. Correlations of number of blocking days in June, with surface temperature over Siberia in May (0.286)

and April (0.192), are much better than that with surface temperature over Siberia in June, which is 0.042. Although both of these scores exceed the 90% level of confidence, these correlation is not large. This is partly from monthly statistics. In fact, the correlation coefficient between the time series of Siberian index in April, and blocking frequency in May and June is 0.355, whose significance evaluated from t -test exceeds 98%. Therefore, we use daily dataset for the following analysis. The following results are not sensitive to the averaging period for the Siberian index between April and May.

Using the daily dataset, we pick up years when the Siberian index in April exceeds one standard deviation: 1967, 68, 75, 77, 81, 82, 95, 97 and 2000, which are referred to as the *high years*. These years include most of the years when the timing of snow disappearance was earlier over central-eastern Siberia (Shinoda et al. 2001).

Blocking frequency for each calendar date is defined as the number of blocking days during the 20-day period centered on that date. Composite time series of blocking frequency for the *high years*, is shown in Fig. 1(a). Composite blocking frequency (solid red line) is considerably higher than that of the 44-year average (broken dark red line), from April to June. It is remarkable that the tendency of the high blocking frequency has a longer time scale than the surface temperature (solid black line) itself. By contrast, in a similar composite, but for the *low years*, when the surface temperature over Siberia in April is less than one standard deviation, blocking frequency falls to the minimum value, as less than one third of that of the 44-year average in the beginning of April, and still less than the climatology in the beginning of June (Fig. 1(b)). The situation is roughly opposite between the *high* and *low years*, although the signal in blocking frequency in the *high years*, appears more consistent.

It is found that the springtime surface temperature over Siberia exerts influence, not only on blocking frequency, but also on characteristics of individual events. Figure 2 shows composite time evolution of the maximum value of the 500 hPa geopotential height anomalies during blocking events, which are observed in the *high* and *low years* (solid and broken lines, respectively).

Fig. 1. a: Composite time series of blocking frequency, which is defined as the number of blocking days for 20 days centered in the date (unit is day; solid red line) and surface temperature anomaly over Siberia (solid black line) for the *high years*. Blocking frequency averaged for 44 years is also depicted as broken dark red line with one standard deviation as the shades. b: Same as (a), but for the *low years*.

To make the composite of Fig. 2, 15 events are used for each of the *high* and the *low years*. To avoid picking up abnormal blocking events, 15 events are selected from events that are close to the median of the maximum value of the 500 hPa geopotential height anomaly, during a blocking episode. Duration of the blocking event is simply estimated by the length of days, which exceeded the threshold; the average of the maximum value of the 500 hPa geopotential height anomaly of blocking anticyclones, indicated by a horizontal line in Fig. 2. The amplitude of blocking anticyclones is larger, and duration of blocking events is longer in the *high years*. These facts demonstrate that springtime surface temperature over Siberia has a influence on the subsequent blocking activity over northeastern Siberia and the Okhotsk sea.

Fig. 2. Composite time series of the maximum value of the 500 hPa geopotential height anomaly of blocking anticyclones, which are observed over northeastern Siberia and the Okhotsk sea region (110–160°E, 50–70°N) for the *high years* (solid line) and the *low years* (broken line). The day when the blocking anticyclones are mostly amplified is set to 0. The average of the maximum value of blocking anticyclones are indicated by a horizontal line.

3. Composite analysis of the upper-air circulation

We examined further how the springtime high surface temperature anomaly over Siberia could be responsible for the intensification of summertime blocking activity over northeastern Siberia and the Okhotsk sea. In this section, the sequence of anomaly, from springtime surface condition, to the summertime upper level circulation is investigated.

Over the Eurasian Continent, a polar frontal jetstream is climatologically formed from early June, owing to the summertime large temperature gradient, between the continent and the Arctic Ocean. This polar jetstream works as a Rossby wave guide, and the breaking of the wave packet causes a blocking event over the Okhotsk sea (Nakamura and Fukamachi 2004). The left-hand panel of Fig. 3, shows the composite time series of 250 hPa zonal wind (contour), and zonal wind anomaly (shade), averaged between 110°E and 160°E, where blocking anticyclones over northeastern Siberia and the Okhotsk sea are predominantly observed. To eliminate the transient component, the composite and the climatology of zonal wind are experienced, with a 11-day running mean.

Fig. 3. Left-hand panel: Composite time series for the *high years* of zonal wind anomaly (shade) and the climatological zonal wind (contour; contour intervals are 4.0 m/s) on the 250 hPa surface, zonally averaged from 110°E to 160°E. Right-hand panel: Time averaged potential vorticity on the 250 hPa level from May to June (between the two vertical lines in the Left-hand panel). Solid line is composite for the high years and broken line is the 44-year climatology.

When the surface temperature over Siberia is higher in April, greater-than-normal meridional temperature gradient with its northern area, should develop the zonal wind anomaly. This enhancement of the zonal wind can also be seen in eastern Siberia, as large westerly anomaly and northern extension of 8 m/s contour line of the zonal wind between 70°N–80°N in April, in the left-hand of Fig. 3. The zonal wind anomaly remains positive around 70°N until June, and the polar frontal jetstream over eastern Siberia, clearly appears between 65°N and 70°N from the beginning of May. This amplification of the polar jet lasts until June, while the subtropical jet is weaker than climatology (see shades in the left-hand of Fig. 3).

Potential vorticity on the 250 hPa surface (PV_{250}) used in the right-hand panel of Fig. 3, is evaluated approximately as $PV_{250} \simeq (\zeta_{250} + f) \cdot \left(-g \frac{\theta_{300} - \theta_{200}}{p_{300} - p_{200}} \right)$, where ζ is relative vorticity, f the planetary vorticity, θ and p the potential temperature and pressure, respectively. The subscripts denotes the pressure level at which the variable is defined. The value of PV, between these two westerly jet streams, (40°N–70°N) for the *high years* (solid line), are located in higher latitude than that for the 44-year average (broken line), from May to July. This means that

the meridional PV gradient for the high years, is more gradual than the 44-year average over northeastern Siberia and the Okhotsk sea.

This gradual meridional gradient of PV, is clearly a reflection of the enhanced meridional stirring by the frequent blockings, but, at the same time, it may provide a condition to facilitate subsequent occurrence of another blocking. It is often observed that a parcel with low PV, that originated from lower latitude moves to higher latitude at the onset of a blocking event (Hoskins et al. 1985; Nakamura et al. 1997; Pelly and Hoskins 2003). Such movement may be facilitated in the presence of the gradual meridional gradient in the background PV. The band of homogenized PV could well be the consequence of high blocking activity, but it might also provide a preferable condition for blocking occurrences.

4. Concluding remarks

In this study, the influence of springtime high surface temperature anomaly over Siberia, upon summertime blocking activity over northeastern Siberia and the Okhotsk sea, is examined by observational datasets for the recent 44 years. When the springtime surface temperature over Siberia is high, blocking events are more frequently observed than the 44-year average, during the subsequent early summer.

Mechanism of such a long duration of influence from the surface temperature anomaly in Siberia, are to be clarified. A candidate for this persistence is a positive feedback between the meridional gradient of PV and blocking events; the gradual meridional gradient of PV helps to form a blocking anticyclone, and a blocking event makes a more gradual PV gradient. This process have to be examined by various analyses, including numerical experiments. Another reason of the long duration, is the springtime long memory of the surface condition over the Eurasia Continent. The snow cover over Siberia begin to melt in April, so that there is large variation of the surface condition, and a surface temperature anomaly survives during a few months (Yasunari et al. 1991; Ogi et al. 2003). This longlasting memory of the springtime surface temperature anomaly, influences the upper circulation and subsequent early summer blocking activities.

Fig. 4. Left-hand panel: Composite map for the *high years* of surface temperature (shade: by CRU over the land; colored contour: by ECMWF over the oceans), sea level pressure (contour) and wind field anomaly (vector) in early summer (May and June). Right-hand panel: Composite map for the *high years* of precipitation anomaly (by CRU) over the East Asia in early summer.

In order to illustrate the influence of springtime high surface temperature over Siberia, other than summertime blocking activity, composite maps are drawn by using the monthly mean anomaly fields of surface temperature, sea level pressure, surface wind and precipitation in May and June (Fig. 4). Note that the period of data for this figure is 50 years, from 1950 to 1999. In the left-hand panel of Fig. 4, the Okhotsk high is amplified, and the surface temperature decreases over the Pacific coastal region of northeastern Japan, due to the northeasterly winds from the Okhotsk sea in the *high years*. These characteristics coincide well with typical pattern of anomalously cold summer in northeastern Japan (e.g., Ninomiya and Mizuno 1985a, b; Kodama 1997).

The left-hand panel of Fig. 4 also indicates the warm anomaly over eastern Siberia in the *high year*. This fact means that a memory of the springtime surface condition remains until early summer. The surface temperature over northern Siberia for the *high years*, does not seem to keep its warm anomaly more than a month from Fig. 1. However, a high temperature anomaly over the entire of northern Siberia in April, tends to move northeastward with the seasonal march, and the high temperature anomaly is confined over eastern Siberia in

June. Thus, the area that has warm anomaly in June, is located in the east of the area that is used for the definition of the Siberian index. It is possible that the survived warm anomaly over eastern Siberia until June, causes the enhancement of the polar jet in Fig. 3.

Moreover, the warm anomaly over eastern Siberia, the amplified Okhotsk high, as shown in Fig. 4, and enhancement of blocking activity, correspond with the finding of Tachibana et al. (2004), which shows the positive correlation between the summertime surface temperature over eastern Siberia, and the intensity of the Okhotsk high that has a deep vertical structure. Furthermore, this warm anomaly in early summer makes not only the meridional temperature gradient that, mentioned in section 3 of this article, but also a zonal temperature gradient with the Okhotsk sea, from the difference of thermal inertia between the cold ocean and the warm land masses. Nakamura and Fukamachi (2004) indicated that blocking anticyclones over the Okhotsk sea which develop in July, is characterized from the summertime meridional and zonal temperature gradient over east Siberia and the Okhotsk sea, or the Arctic Sea. Therefore, the springtime warm anomaly over Siberia, causes earlier development of the zonal and meridional temperature gradient, and might influence the interannual variation of blocking activity in early summer.

However, the impact on the Baiu front, which is influenced by the Okhotsk high or blocking activity over the Okhotsk sea, as mentioned by Okawa (1973), is not very clearly shown. A wet tendency along the northern Pacific coast of Japan, is indicated in the right-hand panel of Fig. 4, that is drawn by the monthly precipitation data, compiled by the Climate Research Unit of the University of East Anglia (CRU). The exact position and strength of the Baiu front is determined, not only by the intensity of the Okhotsk high, the influence from the north, but also by the western Pacific subtropical high to the south of Japan. The finding of this study, the precursory signal in North Siberian surface, is hoped to offer the potential for early summer predictability over East Asia.

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