INTERNATIONAL JOURNAL OF CLIMATOLOGY
Int. J. Climatol. **30**: 153–158 (2010)
DOI: 10.1002/joc.1876

Short Communication

Effect of the climate shift around mid 1970s on the relationship between wintertime Ural blocking circulation and East Asian climate

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ABSTRACT: Blocking variability over the Ural Mountain region in the boreal winter and its relationship with the East Asian winter climate is investigated. The climate shift around mid 1970s has been shown to exert a significant influence on the blocking pattern. In contrast with the years before 1976/1977, the Ural blocking signal after 1976/1977 is found to propagate less into the stratosphere and more eastward in the troposphere to East Asia, which therefore exerts more influence on the East Asian winter climate. This enhanced Ural blocking–East Asian climate relationship amplifies the impact of Ural blocking on East Asia and, with the background of decreasing Ural blocking, contributes to the higher frequency of warm winters in this region. Further analyses suggest that the NAM-related stratospheric polar vortex strength and its modulation on the propagation of atmospheric stationary waves can account for this change, with the key area being located in the North Atlantic region. Copyright © 2009 Royal Meteorological Society

KEY WORDS climate shift; blocking; Siberian High; East Asian winter climate; polar vortex

Received 18 June 2008; Revised 6 November 2008; Accepted 21 January 2009

1. Introduction

In the mid-1970s, the atmospheric circulation underwent significant changes in many regions of the world (Trenberth and Hurrell, 1994; Nakamura *et al*., 1997; Wang *et al*., 2007). One of the most important components of the East Asian climate system, the Siberian High (SH), is found to have an obvious weakening trend since then (e.g. Gong and Ho, 2002; Panagiotopoulos *et al*., 2005), which is accompanied with more frequent warm winters in East Asia (Gong and Ho, 2002). Several studies have pointed the long-term trend of Northern Annular Mode/North Atlantic Oscillation (NAM/NAO) as a partially responsible mechanism of the weakened SH and the increased frequency of warm winters (Gong *et al*., 2001; Panagiotopoulos *et al*., 2005). However, the role played by other atmospheric circulation patterns was relatively less discussed.

Wintertime blocking over the Ural Mountain is of great importance for the climate of downstream regions such as East Asia, as blocking events in this region are usually followed by the amplification of the SH (Takaya and Nakamura, 2005) and subsequent outbreaks of cold air in East Asia (Joung and Hitchman, 1982; Ding and Krishnamurti, 1987). Climatologically, persistent positive height anomalies over the Urals and the associated intensified SH is also found to be one of the most important features of a stronger East Asian winter monsoon (Lau and Li, 1984; Chan and Li, 2004). Understanding the East Asian winter climate therefore requires a thorough investigation of the Ural blocking variability. Some studies (e.g. Li, 2004) have focused on this topic in early winter. However, not much attention has been paid to the midwinter situation.

The objective of this study is therefore to investigate the circulation patterns associated with Ural blocking as well as its relationship with the downstream East Asian winter climate in midwinter during the last four decades. The focus will be on the effect of the climate shift around mid 1970s and the possible mechanism.

2. Data and method

Daily and monthly mean ERA40 reanalysis data with 2.5° latitude by 2.5° longitude resolution from the European

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Centre for Medium-Range Weather Forecasts (Uppala *et al.*, 2005) are used in this study. An Ural blocking index (UBI) is employed to measure the resemblance of a particular circulation pattern with the Ural blocking regime (Liu, 1994):

$$\mathrm{UBI} = \frac{\langle \Delta Z_b, \Delta Z_m \rangle}{\langle \Delta Z_b, \Delta Z_b \rangle}$$

where the brackets denote a squared norm inner product (the normalized projection), ΔZ_m is the monthly 500-hPa height anomaly field for every winter month and year, and ΔZ_b is the winter blocking anomaly pattern in 500-hPa geopotential height derived by compositing daily 500-hPa height anomaly fields for those winter blocking days detected over the Ural sector (30 °E–90 °E) for the full period. Blocking days were previously identified following an automatic method of blocking diagnosis developed by Barriopedro *et al.* (2006a), which in turn is based on a modified version of the well-known Tibaldi and Molteni (1990) zonal index. As a consequence, ΔZ_b can be regarded as the mean regional anomaly signature of the blocked regime and provides information on the shape, location, extension, and intensity of the blocking structure (Vautard, 1990). UBI time series are then obtained by projecting the ΔZ_m for every winter month and year onto the blocking anomaly pattern ΔZ_b, the projection area being of 180° in longitude centred in the Ural sector (i.e. −30 °W–150 °E) and from 30 °N to 90 °N in latitude. This method was also used previously in Garcia-Herrera and Barriopedro (2006), and was proved to well represent the regional blocking activities. In addition, a SH index (SHI) is defined as the area-averaged sea level pressure (SLP) in the region between 40°–65 °N and 80°–120 °E (Panagiotopoulos *et al.*, 2005) to measure the intensity of SH. The normalized SHI is then used in this study. The principal component-based winter mean NAM index is downloaded from http://www.cgd.ucar.edu/cas/jhurrell/indices.html. As a diagnostic tool, the quasi-geostrophic version three-dimensional Eliassen-Palm (EP) flux defined by Plumb (1985) is used to indicate the stationary wave activities associated with Ural blocking.

Seasonal mean data are used throughout this paper. The analysis period spans 44 winters from 1957 to 2000, with the winter of 1957 referring to December of 1957 and January and February of 1958 (DJF). When comparing the differences of Ural blocking-related circulations before and after mid 1970s (Figure 3–6), the linear trends are removed from all the indicates and data to avoid the possible influence of the long-term trend.

3. Results

3.1. Observations

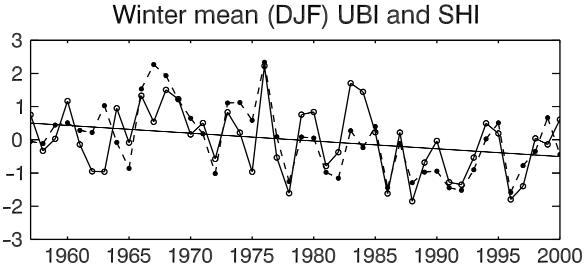

Figure 1. The normalized winter mean (DJF) UBI (solid line with open circle) and its linear trend, and the normalized winter mean SHI (dashed line with filled circle) for the period 1957–2000.

The normalized winter mean UBI for the period 1957–2000 suggests a large interannual variation of the blocking activity over the Urals, and a significant (confidence level above 99%) decrease of the frequency of blocking activity during the data period (Figure 1). The circulation anomalies associated with high Ural blocking occurrence reveal a positive geopotential height anomaly near the Kara Sea, with two negative anomalies over coastal Europe and East Asia (Figure 2(a)). This wave–train-like structure is quasi-barotropic and extends from the surface (Figure 2(b)) to the lower stratosphere (Figure 2(c)). It exerts a strong impact on the East Asian winter climate, namely, the drop (increase) of lower tropospheric air temperature over the East Asia (northern Siberia) with the 99% confidence level (Figure 2(d)), which results from the cold (warm) air advection downstream (upstream) of the blocking high. These signals are consistent with previous studies, and resemble those obtained in early winter (Li, 2004).

Takaya and Nakamura (2005) have pointed out that the Ural blocking may cause a synoptic amplification of the SH with the leading period of about 1 week. This leads to simultaneous variations between SH and Ural blocking on seasonal timescale. Figure 1 reveals that the interannual variation of winter mean SH is closely related to that of Ural blocking, with the correlation coefficient between the UBI and SHI time series being 0.69 for the 44 winters from 1957 to 2000, which exceeds the 99% confidence level. In addition, the circulation anomalies associated with the Ural blocking (Figure 2(a) and (b)) quite resemble those related to the SH in the lower troposphere (Panagiotopoulos *et al.*, 2005). This means that the blocking occurrence over the Ural region is generally accompanied by a strong SH, with about 45% of the interannual SH variance being related to that of the Ural blockings. This ratio is much higher than that related to any other single teleconnection investigated in Panagiotopoulos *et al.*, (2005). In the following, we will focus on the effect of famous climate shift around mid-1970s, and examine the change of Ural blocking circulation and its relation to the East Asian winter climate. In order to avoid the possible influence of the long-term trend (e.g. Figure 1), the following analyses are performed with detrended data.

Based on previous studies (Trenberth and Hurrell, 1994; Nakamura *et al.*, 1997; Panagiotopoulos *et al.*, 2005), the data period is divided into two subperiods: 1957–1976 and 1977–2000. The circulation patterns associated with the Ural blocking are quite different

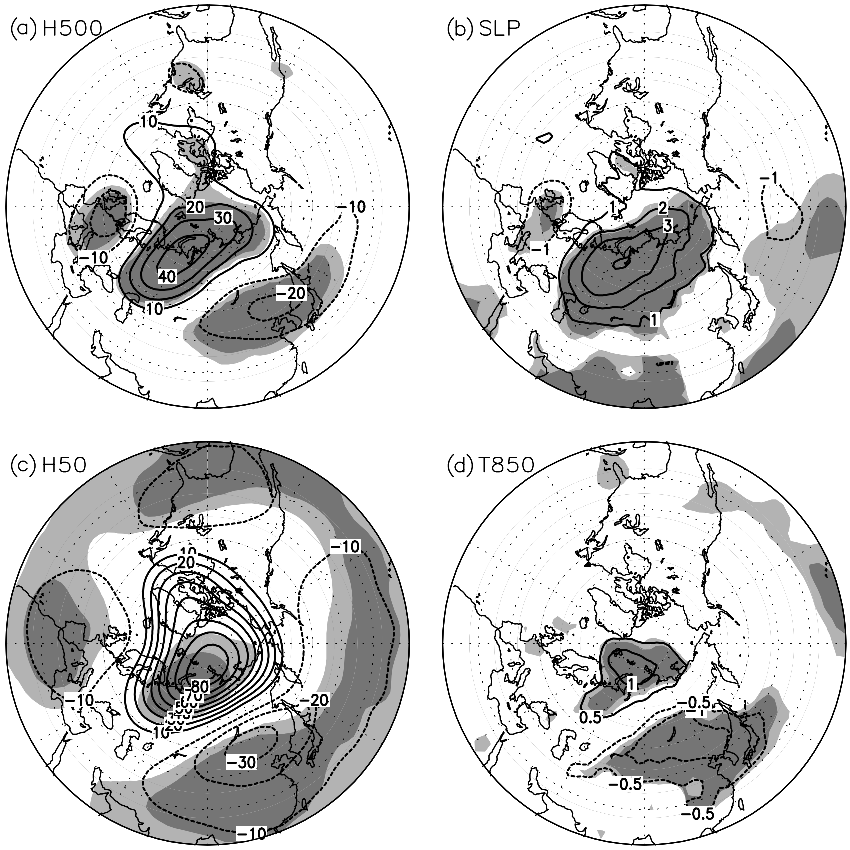

Figure 2. The regression (contour)/correlation (shading) of winter mean (a) 500-hPa geopotential height, (b) SLP, (c) 50-hPa geopotential height, and (d) 850-hPa air temperature with UBI for the period 1957–2000. Contour intervals are 10 gpm, 1 hPa, 10 gpm and 0.5 °C in (a)–(d). Dark and light shading indicates the 99% and 95% confidence level, respectively.

between them (Figure 3). The centers of the 500-hPa wave–train-like anomalies are strong over Europe and relatively weak over East Asia in the first subperiod (Figure 3(a)), but strong over East Asia and weak over Europe in the second subperiod (Figure 3(b)). This feature can be seen more clearly in the SLP field (Figure 3(c) and (d)). It implies that the signal of Ural blocking tends to propagate more eastward in the latter period and influence the climate over East Asia more to the southeast. The UBI-associated 850-hPa air temperature anomalies over East Asia are mainly located to the north of 40°N in the first subperiod (Figure 3(e)) and extend southeastward to about 25°N in the second subperiod (Figure 3(f)). Hence, these results suggest an expanded influence of Ural blocking on the East Asian winter climate after the mid-1970s.

The intensity of SH can be used to represent the East Asian winter climate (Gong *et al.*, 2001). The correlation coefficients between UBI and SHI are 0.60 and 0.74 for the first and the second subperiod, respectively. Although both values exceed the 99% confidence level, the Ural blocking can only explain about 36% of the SH variance for the former period, but over 55% for the latter period. A sliding correlation with a 21-year moving window between UBI and SHI (Figure 4) also suggests that the correlation coefficient increases gradually from about 0.6 in the late 1960s to about 0.8 in the mid-1980s. The variation of Ural blocking can thus explain a larger variance (up to about 60%) of the recent SH variability. Therefore, with the background of a decreasing frequency of Ural blocking, this intensified UBI–SHI relationship amplifies the influence of Ural blocking on the East Asian winter climate, and contributes to the frequent warm winters over East Asia in recent years.

3.2. Possible mechanism

Austin (1980) has shown that the stationary planetary waves in the atmosphere, which can propagate vertically into the stratosphere, can influence the variation of blockings. The polarity of NAM and associated stratospheric polar vortex strength can in turn change the stratosphere–troposphere coupling process (Perlwitz and Graf, 2001) and associated tropospheric circulation (Thompson and Wallace, 2001; Wallace and Thompson, 2002; Graf and Walter, 2005) by modulating the vertical propagation of atmospheric waves and related wave-flow interactions. As the Ural blocking is related to the stratospheric polar vortex (Figure 1(c)), in this section, we will explore why the signal of Ural blocking propagates more eastward to East Asia after mid-1970s from the perspective of NAM-related stratospheric polar vortex and associated atmospheric stationary waves.

The 50-hPa geopotential height anomalies associated with Ural blocking for the two subperiods show the

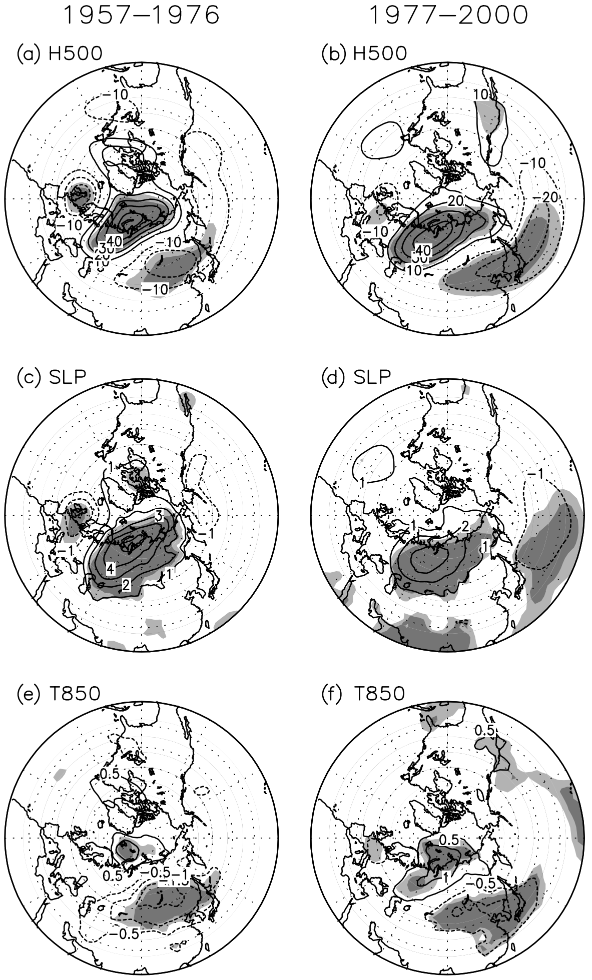

Figure 3. The regression (contour)/correlation (shading) of detrended winter mean (a) 500-hPa geopotential height, (c) SLP, and (e) 850-hPa air temperature on detrended winter mean UBI for the period 1957–1976. (b), (d), (f) are the same as (a), (c), (e), but for the period 1977–2000. Contour intervals are 10 gpm in (a) and (b), 1 hPa in (c) and (d), and 0.5 °C in (e) and (f). Dark and light shading indicates the 99% and 95% confidence level, respectively.

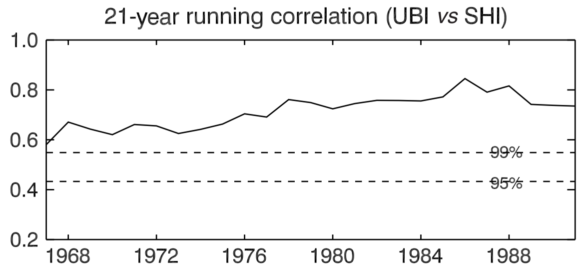

Figure 4. The sliding correlations between detrended winter mean UBI and detrended winter mean SHI with a 21-year moving window. The x-label indicates the central year of the moving window.

common feature that the Ural blocking is accompanied by positive height anomalies in the polar region and negative ones in the midlatitudes (Figure 5). Clearly, this midlatitude-polar sign reverse covers the entire Northern Hemisphere in the first subperiod with a high significance level (Figure 5(a)), but is much weaker and covers only the East Asia in the second subperiod (Figure 5(b)). The correlation coefficients between UBI and NAM index, which can represent the intensity of stratospheric polar vortex, are −0.54 and −0.47 for the first and the second subperiods, respectively. These results suggest that the interannual variation of Ural blocking is closely related with that of the lower stratospheric polar vortex in the first but not in the second subperiod. Combining this result with those in Figure 3 and Figure 4, it suggests that when the eastward propagation of Ural blocking signal in the troposphere is weak (Figure 3(a) and (c)), the stratospheric blocking signal is strong (Figure 5a), and vice versa (Figures 3(b) and (d), and 5(b)). Chen *et al.* (2003) identified a seesaw between the planetary wave activities propagating into the stratosphere and those into the troposphere, i.e. when more waves propagate vertically into the stratosphere, fewer will propagate horizontally to the lower latitudes in the troposphere, and vice versa. Here, our result seems to indicate that a similar seesaw also exists between the stratospheric upward-propagating and tropospheric eastward-propagating Ural blocking signals.

Such a seesaw can be explained further by examining the stationary wave activities associated with Ural blocking. Figure 6 presents the quasi-geostrophic EP flux (Plumb, 1985) associated with the Ural blocking. In the first subperiod, the Ural blocking-related upward-propagating stationary waves into the stratosphere are very strong while horizontally propagating waves in the troposphere are relatively weak (Figure 6(a)), with the upward wave propagation into the stratosphere mainly occurring in the Atlantic region (Figure 6(b)). During this subperiod, the stratospheric polar vortex is in its weak regime (Christiansen, 2003), which favors the upward propagation of planetary waves and the stratosphere–troposphere coupling (Perlwitz and Graf, 2001). As a consequence, the Ural blocking signal tends to propagate more upward into the stratosphere and less eastward to East Asia, and Ural blocking is less related to the SH and East Asian winter climate in the downstream regions. In the second subperiod, however, the Ural blocking-related stationary waves barely propagate into the stratosphere and more wave activities are confined in the troposphere (Figure 6(c)). This feature can also be seen in the longitude-altitude plot, with hardly any upward-propagating waves in the Atlantic region (Figure 6(d)). During this subperiod, the stratospheric polar vortex is much stronger than that in the former one (Christiansen, 2003), which suppresses the upward propagation of planetary waves and the stratosphere–troposphere coupling (Perlwitz and Graf, 2001). The Ural blocking signal tends to propagates more eastward to East Asia in the troposphere and barely upward into the stratosphere. Therefore, Ural blocking is more closely related to the downstream SH and East Asian winter climate. These results appear to explain the seesaw between stratospheric and tropospheric Ural blocking signals, and are consistent with those of Chen *et al.* (2003). In addition, these results also echo previous studies which show that certain tropospheric weather regimes can be determined by the

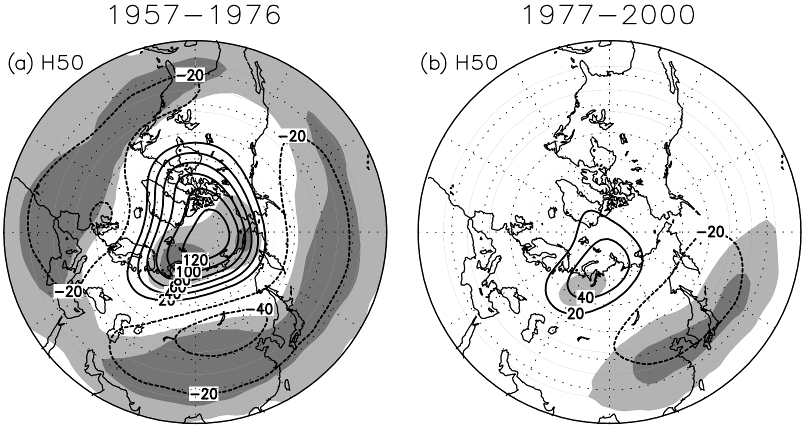

Figure 5. The regression (contour)/correlation (shading) of detrended winter mean 50-hPa geopotential height on detrended winter mean UBI for the period (a) 1957–1976 and (b) 1977–2000. Contour intervals are 20 gpm. Dark and light shading indicates the 99% and 95% confidence level, respectively.

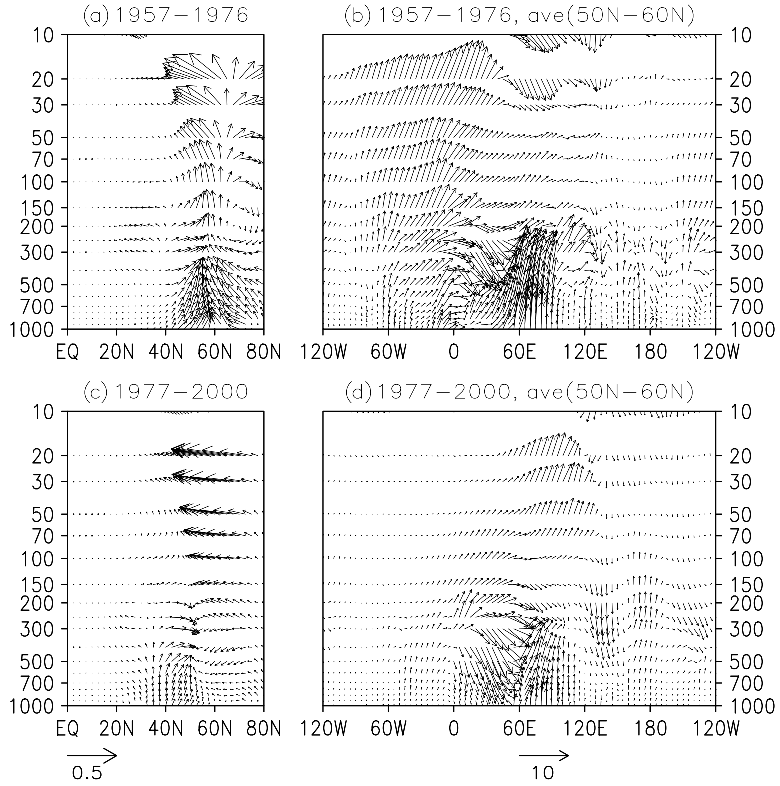

Figure 6. (a) Zonal mean latitude-altitude plot, and (b) longitude-altitude plot (averaged between 50°N and 60°N) of the winter mean quasi-geostrophic EP flux for stationary waves associated with detrended winter mean UBI for the period 1957–1976. (c) and (d) are the same as (a) and (b), but for the period 1977–2000. EP fluxes are scaled by the inverse of the air density and with the unit $m^2 s^{-2}$.

stratospheric harbingers (e.g., Baldwin and Dunkerton, 2001). Moreover, it should be pointed out that the North Atlantic region seems to be a key area in determining the coupling process (Figure 6(b) and (d)).

4. Summary and discussions

The interannual variation of Ural blocking activity is found to be strongly related to that of the SH and the East Asian winter climate. This relationship has been influenced much by the climate shift around mid 1970s. After the mid-1970s, the Ural blocking signal propagates more eastward to East Asia and tends to exert more influence on the East Asian winter climate. The stronger coupling between UBI and SH amplifies the impact of Ural blocking on East Asia, which contributes to the higher frequency of warm winters in this region. Further analyses reveal that the NAM-related stratospheric polar vortex and its modulation on the propagation of atmospheric stationary waves are likely responsible for this change, with the key area being located in the North Atlantic region. This result is similar to the seesaw of planetary wave activities found by Chen *et al*. (2003), and echoes previous studies which show that certain tropospheric weather regimes can be determined by the stratospheric harbingers (e.g., Baldwin and Dunkerton, 2001).

Besides the internal dynamical processes, external factors may also contribute to the change in blocking's variability and its influence. For example, previous studies (Li, 2004) suggested that the North Atlantic sea surface temperature(SST) anomalies could affect the interannual variation of Ural blocking in early winter. The Eurasian snow cover was also found to be able to exert important influences on the regional blocking and associated atmospheric circulation (e.g., Garcia-Herrera and Barriopedro, 2006; Barriopedro *et al*., 2006b). In addition, the changes of the relationship between East Asian winter climate and other factors may also be related to the basic state of the external forcing (e.g., Wang *et al*. 2008). However, no SST signal can be found for the midwinter in this work, and further study is needed in the future.

Acknowledgements

This work is supported jointly by the National Natural Science Foundation of China (Grant 40775035) and City University of Hong Kong (Grants 7002136 and 9610021).

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