Article ID: 1006-8775(2010) 03-0221-10

POSSIBLE RELATIONSHIP BETWEEN ENSO AND BLOCKING IN KEY REGIONS OF EURASIA

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Abstract: Using reanalysis data provided by the U.S. National Centers for Environmental Prediction/National Center for Atmospheric Research, the potential relationship between the El Niño-Southern Oscillation (ENSO) cycle and blocking highs in three key regions of Eurasia (Ural, Baikal, and Okhotsk) from 1950 to 2008 is analyzed. Composite analysis of 500 hPa geopotential height field during different stages of ENSO reveals that in the winters of El Niño (EN) years, there is significant negative anomaly of geopotential height in the three key regions. In the winters of La Niña (LN) years, on the other hand, significant positive anomaly of geopotential height is observed in Eastern Ural, Baikal, and Okhotsk. In summer, Okhotsk exhibits positive anomaly, which is significant at a confidence level of 90% by Student's *t*-test during the developing stage of an LN year. In the developing stage of an EN year, geopotential height field at 500 hPa manifests positive (negative) anomaly in Baikal (Ural and Okhotsk), while the geopotential height field at 500 hPa exhibits positive (negative) anomaly in Ural and Okhotsk (Baikal) during the decaying stage of both EN and LN years. However, these abnormities are insignificant in a developing EN year, decaying EN year, and the summer of a decaying LN year. By analyzing 500 hPa geopotential height field during different phases of the ENSO cycle, it is observed that results of the case study are consistent with those of composite analysis.

Annual average blocking is likewise examined during the different stages of ENSO from 1950 to 2008. Combined with composite analysis and case study, results indicate that blockings in the three key regions are suppressed (enhanced) during the winters of EN (LN) years. In summer, the influence of ENSO on the blockings in the three key regions is not as significant as that in winter. Evidently, developing LN may enhance blockings in Okhotsk.

Influence factors on blockings are various and complex. This paper indicates that the influence of ENSO on blockings cannot be neglected, and that it is crucial to related operational forecasting as a potential signal.

Key words: blocking highs; ENSO; relation; composite analysis

CLC number: P466 **Document code:** A **doi:** 10.3969/j.issn.1006-8775.2010.03.003

1 INTRODUCTION

Blocking highs persist in the westerly mid-high latitudes as a large-scale circulation system[1, 2]. Their onset and decay are often accompanied by sizeable circulation adjustment, even in the large hemispheric scale, resulting in widely abnormal weather and climate. Influential blockings on the weather and climate of China are mainly located in three key regions of Eurasia: Ural, Baikal, and Okhotsk[3]. Many related studies have indicated that blockings in these regions significantly influence not only the winter cold wave, but also the summer persistent precipitation in China[4-8]. Therefore, studies on blocking, especially those that occur in these three key Eurasian regions, will be essential to operational forecasting.

As a strong signal of vital temperature fluctuations in surface waters of the tropical eastern Pacific Ocean, formation and development of El Niño-Southern Oscillation (ENSO) may cause anomaly to global

Received date: 2009-09-16; **revised date:** 2010-04-23

Foundation item: Key project of national science and technology support program (2007BAC29B03); Key project of the medium-range forecasting technology of the destructive weather (freezing temperatures, rains, snows and cold damages) from China Meteorological Administration (CMATG20092D02); Operational medium-range weather forecasting system based on ensemble predictions (2nd period) (2200508)

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atmospheric circulations. Thus, it can affect global climate change. They can even cause climate disasters in various regions. In recent years, a significant number of studies have focused on the relationship between ENSO and blocking variation. Results have revealed that blocking variation is dominated by ocean-atmosphere variability associated with ENSO. Renwick and Wallace[9] observed that blocking activity tends to be suppressed during the cold season of El Niño (EN) years in the North Pacific. Chen and Dool[10] discovered that winter blocking frequency increased (decreased) during the cold (warm) phase of ENSO in the North Pacific and North America. In addition, Wiedenmann and Lupo[11] examined the interannual average variability of blocking with respect to ENSO-related variability and learned that blocking events in the northern/southern hemisphere (NH/SH) were stronger and more frequent during LN/EN years. Because of different local topographic features, ENSO influences different regions differently in terms of manner, intensity, and stability; its effect has a prominent local character[12]. Summarizing the above-mentioned studies, it was observed that despite investigations conducted on the Pacific[9, 10], North America[10], and other regions across the globe[11], blockings in the three key regions of Eurasia have rarely been studied from the perspective of their relationship with ENSO. Although numerous studies have been carried out in China on the influence of ENSO on weather and climate, a majority of these have emphasized the relationship between ENSO and precipitation or droughts/floods in the middle and eastern parts of China[13]. Only a handful of research works have focused on the relationship between blocking variation and ENSO. While there are extensive studies on the influence of ENSO on weather and climate in the local regions of China[14-17], these studies cannot directly relate ENSO with meteorological elements or synoptic phenomena as the ENSO cycle is global in scale. A link between ENSO and the weather and climate can be obtained by examining the possible relationship between ENSO and blockings in the three regions of Eurasia. Through this investigation, the mechanism by which ENSO affects weather and climate will be recognized more clearly, and this understanding will play an important role in operational forecasting of related weather and climate in China. Blocking highs in the three key regions of Eurasia are denoted in this paper by the PV- θ blocking index provided by Pelly and Hoskins[18]. The relationship of blocking highs with ENSO is examined to confirm the influence on blocking activity in the said three key regions. Potential information for scientific forecast will be provided to recognize this influence on related weather and climate in China.

2 DATA AND METHODS

2.1 *Data*

The daily dataset employed in this study is obtained from the U.S. National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR), covering the period of January 1, 1950 to December 31, 2008. The 1200 UTC NCEP/NCAR reanalysis used for calculations is global 2.5° latitude by 2.5° longitude. Variables used in this study are geopotential height at 500 hPa, temperature, and zonal and meridional winds from 1 000 hPa to 10 hPa. Niño 3 sea surface temperature (SST) anomalies (5°S–5°N, 150°W–90°W) of the equatorial Pacific were downloaded from a website[1] to confirm the phase of ENSO. Detailed description of the dataset can be obtained at another website[2].

2.2 *Methods*

The PV- θ blocking index[18] used in this study was based on the assumption that the potential temperature on the poleward side of dynamic tropopause is higher than that on the equatorward side in a blocking sector. This index is defined on the dynamic tropopause of PV=2 pvu, where each synoptic feature in the geopotential height field is illustrated more clearly in the θ on the PV = 2 field and Lagrangian behavior is more apparent[18]. Both dynamic and thermodynamic characters of the atmosphere can be represented as well[19]. The PV- θ blocking index represents a new breakthrough for blocking indices that previously used only geopotential height and character of circulation. Its ability to quantify occurrence of blocking may likewise satisfy the need for applying a consistent definition. In the following, the PV- θ blocking index will be employed to examine blockings in the three key regions of Eurasia: Ural (40–80°E), Baikal (80–120°E), and Okhotsk (120–160°E).

The method earlier presented by Quan et al.[20] is adopted to confirm the phase of ENSO. EN (LN) year is considered when winter (DJF) sea surface temperature (SST) index exceeds (+/-) 1 standard deviation. In general, an ENSO event develops in the spring and summer, tends to mature in winter, and decays in the next summer[21, 22]. As ENSO during different stages will assume different roles for the

[1] http://www.cdc.noaa.gov/ClimateIndices/
[2] http://www.cdc.noaa.gov/data/reanalysis/reanalysis.shtml

summer weather and climate in China[23, 24], character of blockings should also be analyzed in different stages of ENSO. Different ENSO phases in summer and winter are shown from 1950 to 2008, as illustrated in Table 1.

Table. 1. Different ENSO phases in summer and winter

Winter	EN		1957/1958, 1965/1966, 1968/1969, 1972/1973, 1982/1983, 1986/1987, 1991/1992, 1994/1995, 1997/1998, 2002/2003, 2006/2007
	LN		1950/1951, 1954/1955, 1955/1956, 1967/1968, 1970/1971, 1973/1974, 1975/1976, 1984/1985, 1988/1989, 1998/1999, 1999/2000, 2007/2008
Summer	Developing stage	EN	1957, 1965, 1968, 1972, 1982, 1986, 1991, 1994, 1997, 2002, 2006
		LN	1950, 1954, 1955, 1967, 1970, 1973, 1975, 1984, 1988, 1999, 2007
	Decaying stage	EN	1958, 1966, 1969, 1983, 1987, 1992, 1995, 1998, 2003
		LN	1951, 1956, 1968, 1971, 1974, 1976, 1985, 1989, 2000, 2008

3 COMPOSITE ANALYSIS

3.1 *In winter*

Figure 1a demonstrates that in the mid-high latitudes during the winter of EN years, there is a clear teleconnection relationship in the central Pacific-Northern Pacific-Northern America (PNA) pattern in the western hemisphere. This character is consistent with the investigation of Horel et al.[25], which indicated that teleconnection relationship of the PNA pattern can be identified easily during EN years. Negative anomaly of 500 hPa geopotential height located in the northern Pacific extends to the west and up to Ural. Mid-high latitudes of the eastern hemisphere are nearly entirely controlled by significant (at 90% confidence level by Student’s *t*-test) negative anomaly of geopotential height, approximately 30 gpm less than that in the northern Pacific. In the winter of LN years, distribution of geopotential height anomaly at 500 hPa is different from that of EN years. In mid-high latitudes of NH during LN winter, reversed teleconnection relationship of PNA pattern is manifested in the central Pacific, northern Pacific, and North America. Positive anomaly of geopotential height over the northern Pacific likewise extends to the northwest, up to Ural, which is dominant at 90% confidence level by Student’s *t*-test in eastern Ural, Baikal, and Okhotsk. This indicates that a significant positive anomaly from eastern Ural to Okhotsk can easily occur in the winter of LN years. Compared to anomaly in the northern Pacific, this anomaly is approximately 10 gpm less and north of 20° latitudes.

3.2 *In summer*

Statistical result reveals that ENSO occurs during the developing stage in the summer of certain years, while it can be present during the decaying stage in other years. Composite departure fields of geopotential height at 500 hPa are illustrated in Fig. 2 and Fig. 3 for the summer during different stages of ENSO.

Influence of ENSO on geopotential height field in summer is not as significant as that in winter, as demonstrated in Figs. 2 & 3. During the developing stage of EN years in summer, negative anomaly of geopotential height controls the mid-high latitudes of NH. For the three key regions in Eurasia, positive (negative) anomaly is observed in eastern Europe and Baikal (Ural and Okhotsk), which has yet to be significant at a confidence level of 90% by Student’s *t*-test. During the developing stage of LN years in summer, the three key regions (especially Okhotsk) are controlled by positive anomaly. However, only the anomaly in the Okhotsk is significant at a confidence level of 90% by Student’s *t*-test. This indicates that developing LN may be related to positive anomaly of the three key regions, especially in Okhotsk.

Figure 3 demonstrates that the decaying ENSO has slight influence on the geopotential height field at 500 hPa in summer. During the decaying stage of EN years, there is positive (negative) anomaly in Ural and Okhotsk (Baikal), indicating that decaying EN may be related to the positive (negative) anomaly in Ural and Okhotsk (Baikal). With an opposite character to the composite departure of geopotential height during the developing stage of LN years, composite departure of geopotential height is mainly negative at 500 hPa. For the three key regions, there is small positive anomaly (nearly zero) in Ural and Okhotsk, while Baikal is mainly controlled by negative anomaly. Negative anomaly in the north of Baikal is highly significant. This anomaly indicates that decaying LN may be mainly related to the small positive (negative) anomaly in Ural and Okhotsk (Baikal).

4 500 hPa GEOPOTENTIAL HEIGHT DURING DIFFERENT ENSO PHASES

Geopotential height at 500 hPa is analyzed for

January and July of the representative EN year (1998) and LN year (2008) to examine the different characters of geopotential height in winter and summer during different ENSO phases.

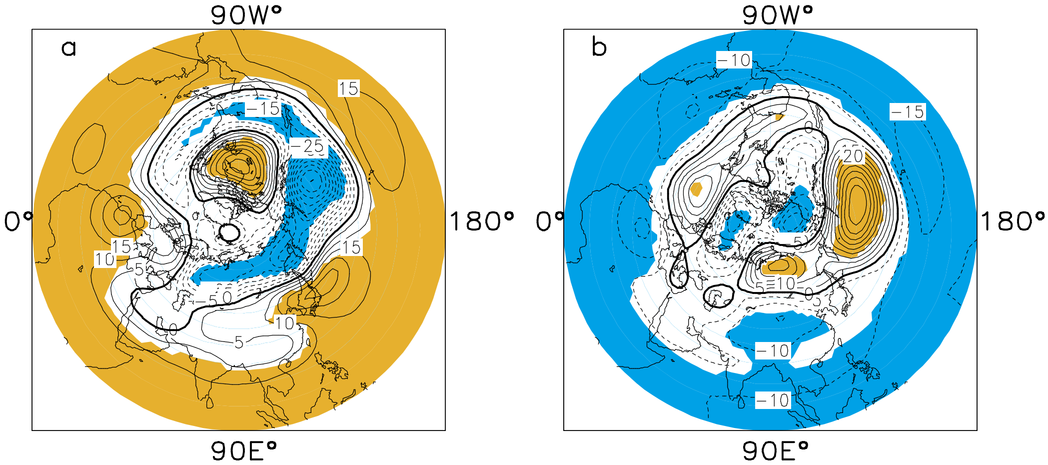

Fig. 1. Composite difference between the mean of geopotential height at 500 hPa in EN (a) and LN (b) years and its climatological mean in winter (DJF) from 1950 to 2008. Unit: gpm. The confidence level of shading is 90% (Student's *t*-test is used). Contour interval is 5 gpm.

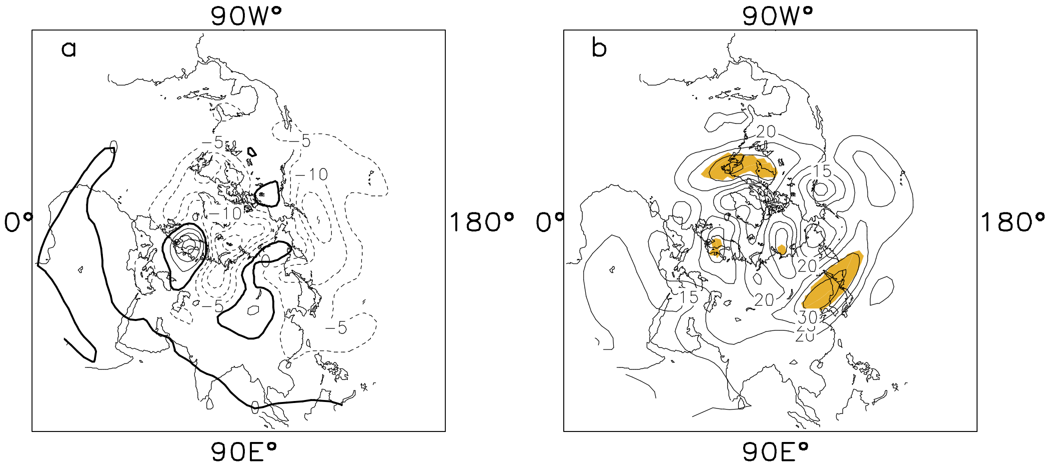

Fig. 2. Same as Fig. 1 but during the developing stage of ENSO in summer (JJA)

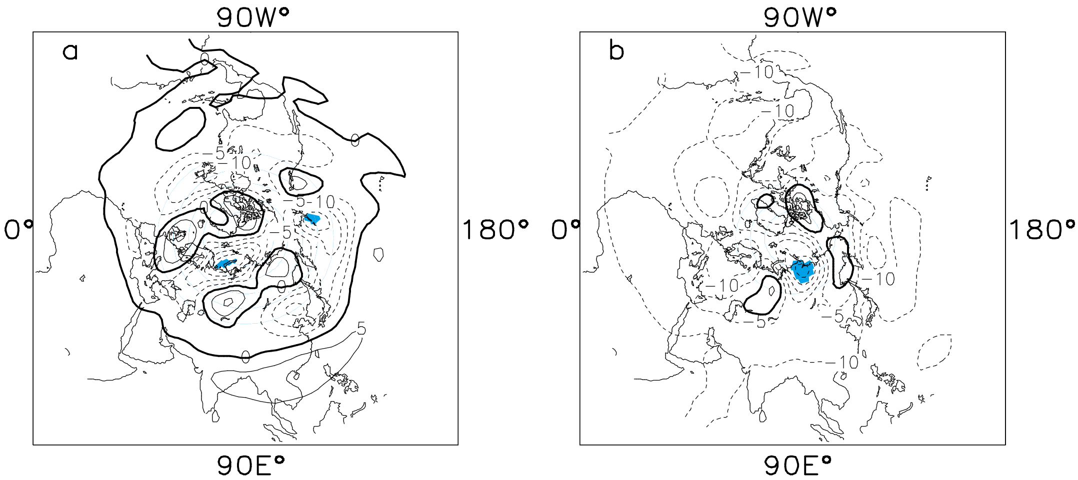

Fig. 3. Same as Fig. 1 but during the decaying stage of ENSO in summer (JJA)

Figure 4 indicates that in January 1998 (EN), there was high-index circulation in the mid-low latitudes of the NH. Meanwhile, in the mid-high latitudes, there was almost all negative departure of the 500 hPa geopotential height (Fig. 5a). Positive departure merely existed over the north of Ural and Okhotsk. However, negative departure extending from the North Pacific to Ural may weaken or even withdraw (persistent) blockings in Ural and Okhotsk; this validates as well as indicates that blockings do not easily appear over the three key regions of Eurasia in January of EN winter. In January 2008 (LN), an area of low trough spanned from the Aral Sea-Caspian Sea to the west of Balkhash in 500 hPa geopotential height field. Positive departure above 40 gpm over areas surrounding Ural and the East Asia indicates that blockings easily occur in NH during January of LN winter (Fig. 5c). Persistent blocking highs in the west of Baikal (Ural) can be associated with destructive weather as well, including low temperatures, snowfall, and anomalous freezing from January 1 to February 2, 2008 in the south of China[26].

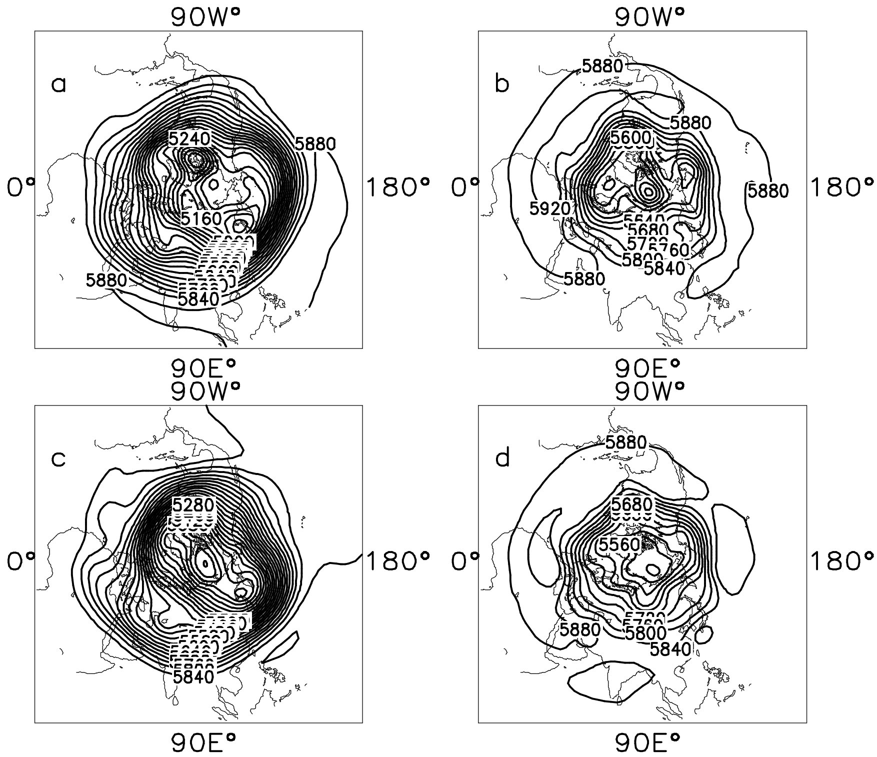

Fig. 4. The 500 hPa geopotential height field in January 1998 (a), July 1998 (b), January 2008 (c), and July 2008 (d). Unit: gpm. Contour interval is 40 gpm.

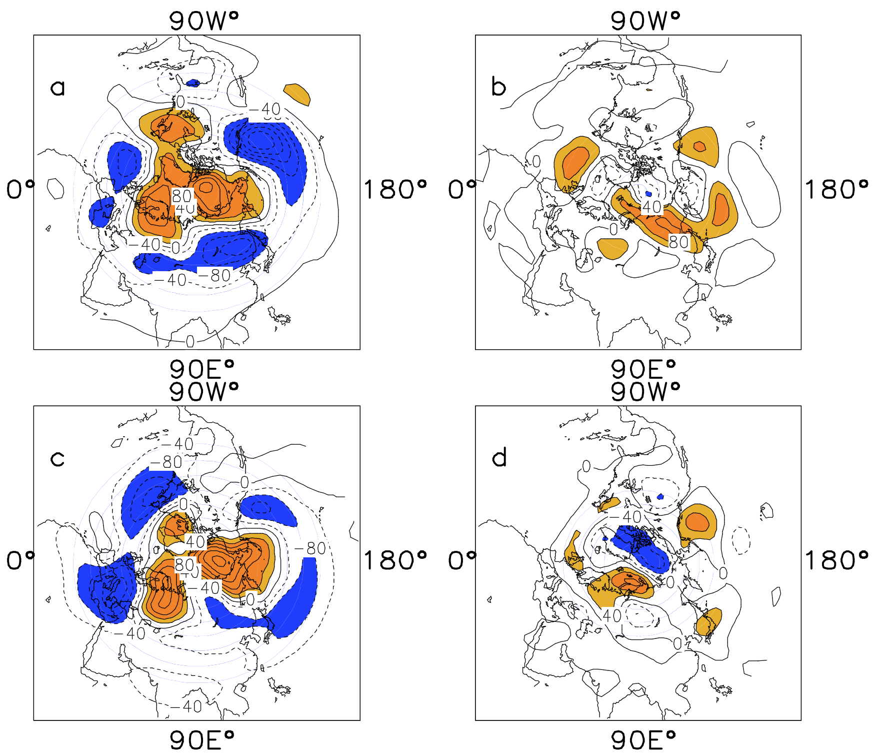

Fig. 5. The departure of 500 hPa geopotential height in January 1998 (a), July 1998 (b), January 2008 (c), and July 2008 (d). Unit: gpm. Contour interval is 40 gpm.

Geopotential height at 500 hPa in NH revealed a different character in July during different ENSO phases. To illustrate, in July 1998 (EN), there was a pressure ridge (departure is approximately 20–80 gpm) over 60°E around Ural and 130°E around Okhotsk; this recalls the conclusion of composite analysis that positive anomaly of 500 hPa geopotential height appears over Ural and Okhotsk during the summer of decaying EN. Decaying EN may enhance blockings over Ural and Okhotsk. In July 2008 (LN), circulation was mainly zonal in mid-high latitudes of NH. A high pressure ridge was located over 60°E around Ural and 140°E around Okhotsk, where positive departure of geopotential height likewise appeared with a relatively smaller value (Fig. 5d). Double blockings over Ural and Okhotsk in July 2008 are consistent with the result of composite analysis as well, indicating positive anomaly of the 500 hPa geopotential height over Ural and Okhotsk during the summer of decaying LN years. Further, the case study of 500 hPa geopotential height during other developing stages of EN (1997) and LN (1973) years demonstrates results consistent with the abovementioned composite analysis (figures not shown).

By evaluating results of composite analysis and case study of 500 hPa geopotential height, it is observed that blockings in the three key regions are suppressed (enhanced) during winter of EN (LN) years. In LN winter, enhanced blockings in Ural do not only favor precipitation in eastern China on the background of atmospheric circulation with mainly meridional circulation in the mid-high latitudes of Eurasia, calm and straight westerly winds in the backward eastern Asia, and frontal zone farther to the south. Also, they bring low temperature and even cold waves to most areas of China as well[27, 28]. Enhanced blocking in Baikal may cause temperature in north and south China to drop, but appears to produce no effect on precipitation in China[8]. Temperature and rainfall in China appear to be unrelated to blockings over Okhotsk during winter of LN years. These conclusions confirm the previous investigation, verifying "the cold waves of Eastern Asia are enhanced in the winter of LN years and vice versa"[29].

Influence of ENSO on geopotential height at 500 hPa in summer are not as significant as that in winter, especially in Ural and in the developing stage of EN year, decaying EN year, and LN year. However, developing LN is closely correlated to positive anomaly of the geopotential height at 500 hPa in Okhotsk, indicating that developing LN can enhance blockings in Okhotsk; it is not only highly related to the Mei-Yu in the East Asia[30, 31], but a main reason for greater precipitation over the Nen River and Songhua River valleys of China as well[32]. Furthermore, the stronger the high pressure over Okhotsk, the lower the temperature of northeast China, and vice versa[33]. By this token, ENSO during different stages in summer may have a certain influence on blockings in the three key regions of Eurasia, and this influence will assume an important role in the weather and climate of China[5-7, 23, 30-36]. In particular, the influence of developing LN is extremely prominent in Okhotsk.

The potential relationship between ENSO and blockings in the three key regions is indicated by the above composite analysis and case study of the 500 hPa geopotential height during different stages of EN and LN years. This relationship will be validated by examining annual average blocking frequency (AABF) during different ENSO phases.

5 BLOCKING CHARACTER OVER KEY REGIONS DURING DIFFERENT ENSO PHASES

Character of blocking frequency is examined in different ENSO phases from 1950 to 2008, as illustrated in Fig. 6. In the following, analysis will mainly focus on the three key regions of Eurasia.

As illustrated in Fig. 6, regardless of the stage of ENSO, preferred blocking areas are located in the Atlantic and Pacific[1, 2, 37]. In Fig. 6a, AABF is significantly low (high) in the winter of EN (LN) years in the Pacific, consistent with investigations conducted by Renwick and Wallace[9] and Chen and Dool[10]. In the three key regions of Eurasia, AABF is significantly low (high) in the winter of EN (LN) years, consistent with composite analysis stating that LN in winter is associated with positive anomaly of geopotential height in the three key regions.

During the developing stage of EN years (Fig. 6b) in summer, AABF is relatively high (low) in Baikal (Ural and Okhotsk). During the developing stage of LN years in summer, AABF is relatively high in all three key regions, especially in Okhotsk (where it is higher in developing LN summer than in any other period). Figure 6c demonstrates that in the decaying ENSO summer, AABF is high in EN years over 40°E–60°E around the west of Ural. Likewise, AABF is high in LN years over 60°E–80°E around the east of Ural, except around 70°E, where blocking frequency is high in EN years. In Baikal, AABF is lower in the decaying ENSO summer than in other neutral summers. On the other hand, AABF in Okhotsk is slightly higher in the decaying ENSO summer than in the neutral summer.

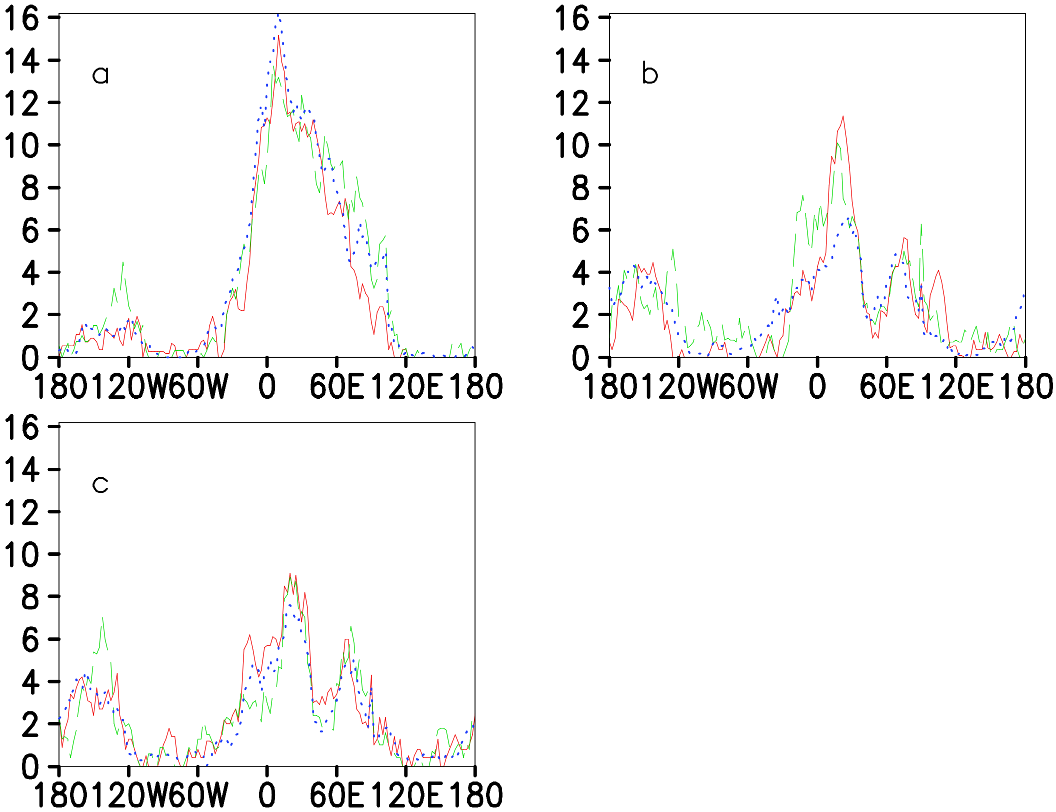

Fig. 6. AABF during the mature stage in the winter (a), developing stage (b) and decaying stage in the summer (c) from 1950 to 2008. The red solid curve shows the AABF in EN years, the green dashed curve shows the AABF in LN years, and the blue dotted curve shows the AABF in neutral years.

Composite analysis reveals that the influence of ENSO on Ural is almost all in the east of Ural. This influence of topography can be seen in Fig. 6. Figure 6a indicates that AABF is lower in the west but higher in the east of Ural during EN than in the neutral winter, with 60°E as the middle boundary. Figure 6c illustrates that in decaying EN summer, the area with a higher AABF is around 40°E–60°E. In decaying LN summer, the area with a higher AABF is enveloped from 60°E to 80°E. As Ural is located around 60°E, the above phenomenon indicates that a large-scale terrain such as Ural is not only important to the formation of blockings[38], but also plays a significant role in identifying the influence of ENSO on the blockings.

Potential effect of ENSO on blockings in the three key regions has been demonstrated. However, blocking character in certain years may not always coincide with the above conclusion. For example, atmospheric circulation in 1985 (LN) is an exception (Fig. 7).

Figure 7 demonstrates that in January and July 1985, negative departure of 500 hPa geopotential height controls the mid-high latitudes of NH; there is no dominant positive departure of geopotential height over the three key regions. This indicates that even during the cold phase of ENSO, blocking does not easily occur in the key regions in both the winter and the summer of 1985. The reason may be that the factors influencing blocking are various and complex. In addition to ENSO, other factors such as Arctic oscillation, north Atlantic oscillation, PNA pattern, and Eurasia pattern (EU) may have additional effects on blockings. The influence of ENSO may be prominent in certain years, while other large-scale circulation systems may play more important roles in blockings in other years. However, response of atmospheric circulations to ENSO is generally in agreement with the results of the current study.

By evaluating the results of composite analysis, case study, and statistical analysis of the annual average blocking frequency, the influence of ENSO on blocking cannot be neglected. Findings that blockings from eastern Ural to Okhotsk are enhanced in LN winter and that developing LN in summer is in favor of blockings in Okhotsk may assist in forecasting large-scale weather in China. This is because blockings around Ural assume an important role in the formation of cold waves over eastern Asia in winter[4, 8], while double blockings (in Ural and Okhotsk), especially those over Okhotsk, are highly related to abnormal precipitation during the summertime Mei-yu period in Eastern Asia[32, 39]. From another point of view, this study indicates that ENSO influences large-scale weather processes such as the summertime Mei-yu, not only by affecting the east Asian summer monsoon[40], but also by affecting large-scale atmospheric systems such as blocking. These results may provide an important basis for related operational forecasting.

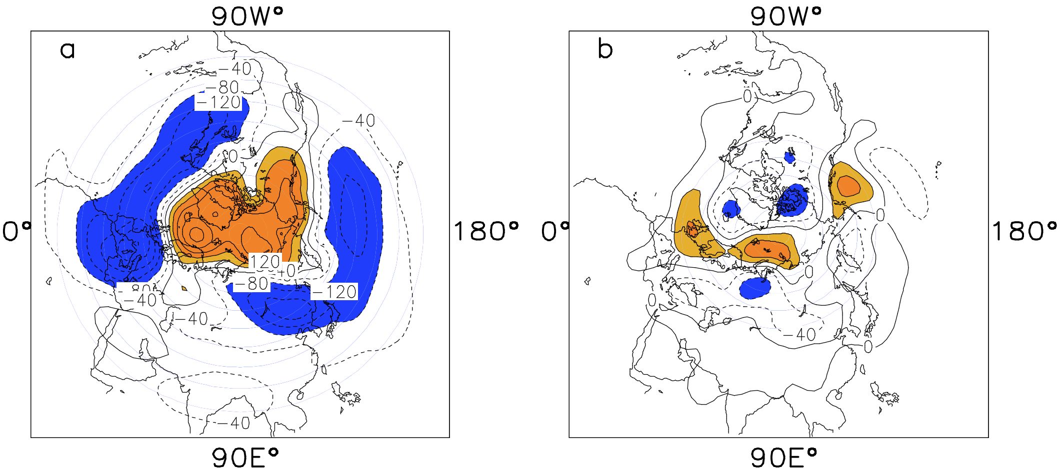

Fig. 7. The departure of 500-hPa geopotential height in January (a), and July (b) 1985. Unit: gpm. Contour interval is 40 gpm.

6 SUMMARY

Using NCEP/NCAR reanalysis data during 1950 to 2008, possible relationships between blockings in the three key regions of Eurasia and ENSO cycle are examined. The results are as follows:

(1) Composite analysis of geopotential height at 500 hPa indicates positive anomaly of the geopotential height during the winter of EN years in the three key regions of Eurasia. In the winter of LN years, anomaly of geopotential height tends to be negative from Eastern Ural to Okhotsk. In summer, geopotential height field at 500 hPa demonstrates positive (negative) anomaly in Baikal (Ural and Okhotsk) during the developing stage of EN years. In the developing stage of LN years, positive anomaly exists in the three key regions, especially in Okhotsk. Composite geopotential height field at 500 hPa manifests positive (negative) anomaly in Ural and Okhotsk (Baikal) during the decaying stage of both EN and LN years. However, the amplitude of positive (negative) anomaly in Ural and Okhotsk (Baikal) during the decaying stage of LN years is smaller (larger) compared with that of EN years.

(2) By analyzing 500 hPa geopotential height filed and examining AABF during different phases of the ENSO cycle, results are consistent with the above composite analysis.

(3) Blockings in the three key regions are suppressed (enhanced) during the winter of EN (LN) years. In summer, LN during the developing stage can enhance blockings in Okhotsk. Relatively, the influence of ENSO on blockings in the three key regions is not apparent during the developing EN year, decaying EN year, and LN year. EN during the developing stage may enhance (suppress) blockings in Baikal (Ural and Okhotsk); however, decaying EN and LN in summer may play an enhancing (suppressing) role in blockings in Ural and Okhotsk (Baikal).

In mid-high latitudes, factors influencing blocking are various and complex. In addition to ENSO, other large-scale systems can also influence blocking activity. However, the current study indicates that the influence of ENSO on blocking in the three key regions appears to be representative, and can play an important role in operational forecasting.

ENSO is a tropical phenomenon, while blocking is a mid-latitude event. Their correlation hints at interactions between mid- and low-latitude systems, and between air and ocean. As for possible mechanisms of ENSO influencing the blockings, Mullen[41] conducted sensitivity experiments with a perpetual January version of a low-resolution general circulation model to investigate the influence of Pacific SST anomalies on blockings in NH. However, mechanism on the blocking characteristics of the model has not been presented because the version of community climate model analyzed in the said study lacked a potentially important feedback mechanism: the dynamic coupling of the ocean and atmosphere. Addressing this issue, Wiedenmann et al.[11] indicated that increased NH blocking frequency in LN years may correspond to LN year increase in cyclone activity over the mid-latitude NH, as more cyclones may provide greater opportunities for blocking formation. As an upstream cyclone develops because of dynamic (e.g., cyclonic vorticity advection or flux) and thermodynamic forcing processes, forcing mechanisms contributing to cyclone development and downstream ridging are synergistically enhanced, resulting in anticyclonic vorticity transport into the developing or strengthening blocking event. The aforementioned studies provide a possible mechanism of ENSO influencing blockings. As interaction is highly complex between the air and ocean, the possible influence mechanism of ENSO on blockings over the three key regions of Eurasia must be further explored.

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Citation: LI Yan, JIN Rong-hua and WANG Shi-gong. Possible relationship between ENSO and blocking in key regions of Eurasia. *J. Trop. Meteor.*, 2010, 16(3): 221-230.