ADVANCES IN ATMOSPHERIC SCIENCES, VOL. 24, NO. 1, 2007, 15–23

Dust Storms in North China in 2002: A Case Study of the Low Frequency Oscillation

FAN Ke*[1,2,3] (范 可) and WANG Huijun[2] (王会军)

[1] *Nansen-Zhu International Research Centre, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing* 100029

[2] *Department of Atmospheric Science, Yunnan University, Kunming* 650091

[3] *Graduate University of the Chinese Academy of Sciences, Beijing* 100039

(Received 15 December 2005; revised 5 June 2006)

ABSTRACT

The low frequency oscillation in both hemispheres and its possible role in the dust weather storm events over North China in 2002 are analyzed as a case study. Results show that the Aleutian Low is linked with the Circumpolar Vortex in the Southern Hemisphere on a 30–60-day oscillation, with a weak Circumpolar Vortex tending to deepen the Aleutian Low which may be helpful for the generation of dust storm events. The possible mechanism behind this is the inter-hemispheric interaction of the mean meridional circulation, with the major variability over East Asia. The zonal mean westerly wind at high latitudes of the Southern Hemisphere in the upper level troposphere may lead that of the Northern Hemisphere, which then impacts the local circulation in the Northern Hemisphere. Thus, the low frequency oscillation teleconnection is one possible linkage in the coupling between the Southern Hemisphere circulation and dust events over North China. However, the interannual variation of the low frequency oscillation is unclear.

Key words: dust storm events, low frequency oscillation, mean meridional circulation and local circulation, relationship

DOI: 10.1007/s00376-007-0015-z

1. Introduction

Dust storms occur in boreal spring (March–April–May) over North China due to both the regional atmospheric circulation and the special geographical environment. The dust weather includes dust haze, blowing dust, and dust storms according to the wind speed and visibility. Since 2000, strong dust weather has frequently occurred in this region resulting in serious environmental problems and disruption of social and economic activities. In particular, the dust episode of 19-21 March 2002 was the strongest and most widespread dust event in North China since the 1990s. The Korean Peninsula and Japan were affected and schools were closed on 21–22 March. The weather factors related to dust storms include strong wind, thermal instability, and sand sources. Therefore, many studies on Asian dust storms have been made through large-scale field observation, remote sensing, numerical modeling, and land-surface processes (Merrill et al., 1989; Gillette and Hanson, 1989; Shao et al., 2003).

We will focus on dust-related atmospheric circulations in this paper. Many weather and climatic reasons for dust storms in North China are explored in the literature (Wang et al., 2000; Zhou, 2001; Qian et al., 2002; Zhao et al., 2004), such as the anomalous cold air activity climatic factors, the state of ENSO, the polar vortex in the Northern Hemisphere and so on (Zhang et al., 2002; Zhao et al., 2004). These studies mostly focus on the atmospheric circulation in the Northern Hemisphere (NH) and emphasize the cold weather anomalies over Asia.

As is well known, the mean large-scale circulation of the SH extratropics is strongly zonally symmetric. A major component of the seasonal to interannual variability in the SH is the high-latitude AAO-mode, representing a zonally symmetric exchange of mass between mid and high southern latitudes. Thus, a pos-

*E-mail: fanke@mail.iap.ac.cn

itive Antarctic Oscillation (AAO) is concurrent with a deepened circumpolar Low and a strengthened Subtropical High, as well as with an enhanced westerly at high latitudes in the SH. Several studies show that the AAO has important impacts on the SH mid-high latitude surface temperature and precipitation fields (Rogers and van Loon, 1982; Kindson, 1988; Gong and Wang, 1999; Thompson and Wallace, 2000). Fan and Wang (2004) studied the interannual variability of the dust weather frequency (DWF) in North China and its relationship to the SH atmospheric circulation at high latitudes. In their work, DWF denotes the number of days of dust weather events including dust haze, blowing dust and dust storms throughout the year in North China recorded by a Beijing station. Their results show that the AAO and dust weather frequency (DWF) in North China correlate well, with a positive AAO tending to decrease the DWF in North China. Two possible mechanisms for AAO-DWF coupling are identified, one is related to a meridional teleconnection from the Antarctic to the Arctic, the other is related to a regional circulation pattern over the Pacific Ocean.

The low frequency oscillation (LFO) in a 30–60-day range has been detected in various datasets and by various methods in the Tropics since Madden and Julian (1971). Many studies show that the 30–60-day oscillation exists in both the extratropics and the Tropics (Weickmann et al., 1985; Simmons et al., 1983; Ghil and Mo, 1991). Some investigations have also demonstrated that both tropical-extratropical interactions and inter-hemispheric interactions are associated with LFO (Liebmann and Hartmann, 1984; Li, 1990; Krishnamurti and Subrahamanyam, 1982; Webster and Holton, 1982). In addition, it has been indicated that the LFO significantly influences both the winter monsoon and the summer monsoon in Asia, Australia, North America and South America (Yasunari, 1979; Lau and Chan, 1986; Mo, 2000; He and Song, 1992). Since the DWF is directly related to cold weather anomalies in Asia, the LFO may play an important role in atmospheric circulation related to DWF.

Therefore, the purpose of this paper is to analyze the 30–60-day oscillation in 2002 as a case study to explore the interaction between the two hemispheres in dust storm events over North China. The paper is organized as follows. In section 2, the datasets and the analysis techniques are described. Results are presented in section 3, and conclusions follow in section 4.

2. Data and methods

The NCEP-NCAR reanalysis datasets from September 2001 to August 2002 are employed in the study. To obtain the 30–60 day oscillation features, the annual average and seasonal cycle are removed in the daily datasets and the Lanczos method is used for filtering. The observed wind data are derived from the 325-m high meteorological tower located at the Institute of Atmospheric Physics (IAP), which represents Beijing Station. The Meteorology Tower site is at 39°58′N, 116°22′E with a base altitude of 48.632 m. Data is collected at 15 levels: 9 m, 15 m, 32 m, 47 m, 65 m, 80 m, 103 m, 120 m, 140 m, 160 m, 180 m, 200 m, 240 m, 270 m and 320 m. The wind data at 320 m is utilized in this paper.

Table 1 is from the China Meteorological Administration (CMA). There are many dust events in North China in 2002. Most flowing dust events occur in February whereas the dust storm events occur in March and April. The period of 15 March–24 April has the number of dust weather events accounting for 86%–98% of all of March–April. In particular, the dust storm episode occurring during the period of 18–22 March was most noticed by the public, therefore we focus on the continuance of dust storm events from the period of 15 March–1 April.

Table 1. Dust weather events in February, March and April 2002. BD, DS and SDS are defined as blowing dust, dust storm and strong dust storm, respectively.

Event	Date (2002)	Class	Wind speed ($m\ s^{-1}$)
1	9–10 Feb.	BD	7–12
2	22–23 Feb.	BD	7–12
3	1–2 Mar.	BD	7–12
4	15–17 Mar.	DS	9–15, up to 20
5	18–22 Mar.	SDS	9–15, up to 22
6	24–25 Mar.	SDS	9–15
7	28–30 Mar.	DS	9–15
8	30–31 Mar.	DS	9–15
9	1–3 Apr.	DS	7–12
10	5–9 Apr.	SDS	9–15
11	11 Apr.	DS	9–15
12	13–17 Apr.	DS	9–15, up to 20
13	19–20 Apr.	DS	9–15, up to 22
14	21–24 Apr.	SDS	9–15

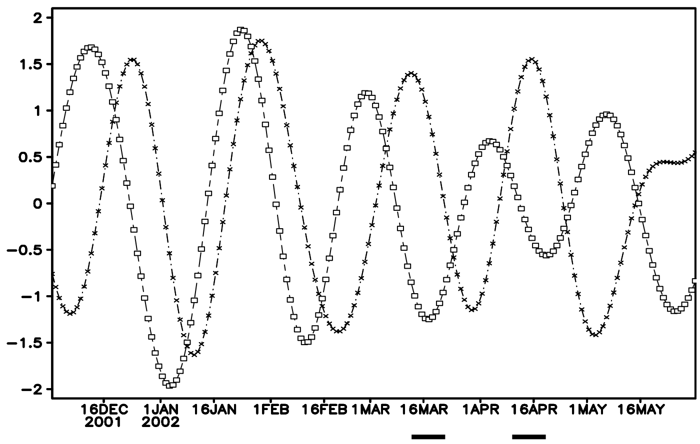

Fig. 1. Time series of 30–60-day filtered velocity (denoted by ×) and Aleutian Low (denoted by □). The short solid lines under the time axis indicate the periods of dust storm events occurring in Beijing (18–22 March, 16–24 April), y-axis indicates normalized values.

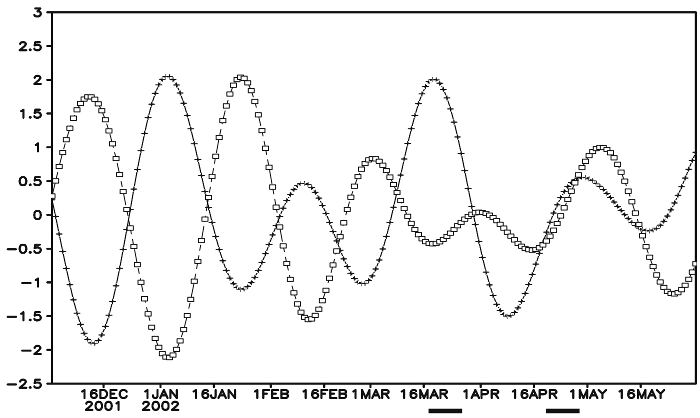

Fig. 2. Time series of 30–60-day filtered Aleutian Low (denoted by □) and Circumpolar Vortex (denoted by +). The short solid lines under the time axis represent the active periods of dust storm events (18–22 March, 16–24 April), y-axis indicates normalized values.

3. Results

3.1 *The change of LOF circulations in 2002*

The cold air activity in North China provides an important dynamic condition for dust weather. The intensity of the Aleutian Low may represent the cold air activity in East Asia in boreal winter and spring; it is called the Atmospheric Activity Center (AAC). Fang and Wang (2003) suggested that the East Asian Trough deepened frequently to cause the high frequency of dust storm events in March–April in North China in 2002. Consequently, we define the intensity of the Aleutian Low as the normalized 850 hPa geopotential height averaged over the region (45°–60°N, 150°E–150°W) and it is used as an index for the cold air activity that is directly related to the dust events in North China.

Firstly, the observed wind speed as revealed by the 325-m Beijing Meteorological Tower (an Urban Flux Networked Station) and the Aleutian Low in a 30–60-day oscillation are depicted in Fig. 1. It is noticed that they have a negative correlation. A deep Aleutian Low correlates well with the strong wind speed at the Beijing station, especially during March–April. The Aleutian Low is deep while the wind speed is strong when the dust events occur frequently. Therefore, the intensity of the Aleutian Low is a good indicator for cold air activity associated with both strong wind and dust storm events.

The Southern Hemisphere Circumpolar Vortex index is defined as the 850 hPa geopotential height averaged over the region (60°–70°S, 0°–360°E). The time series of the 30–60-day band-filtered circumpolar vortex and Aleutian low in 2002 (Fig. 2) show a significant

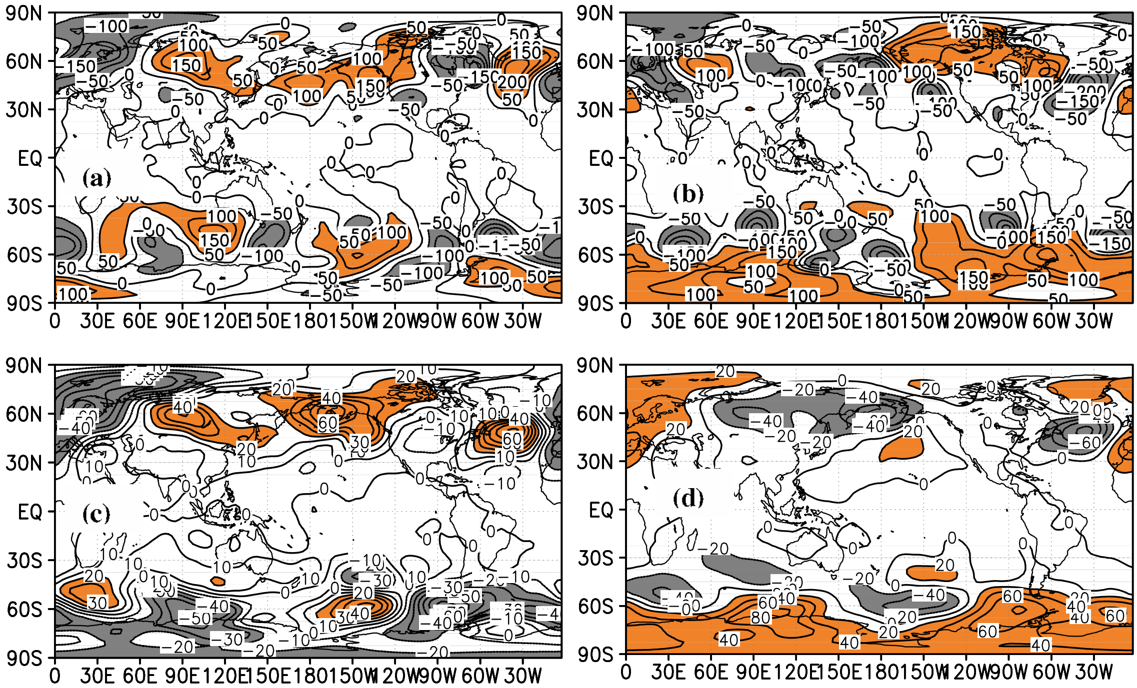

Fig. 3. Unfiltered and filtered geopotential height anomaly field at 850 hPa (Unit: gpm): (a) unfiltered for 0000 UTC 1 March 2002; (b) unfiltered for 0000 UTC 20 March 2002; (c) filtered for 0000 UTC 1 March 2002; (d) filtered for 0000 UTC 20 March 2002.

correlation of −0.79 (where the significance level is above 99%). It suggests there are linkages between the LFO circulations in both hemispheres. The positive phase of the SH Circumploar Vortex coincides well with the dust storm events during both 15 March–1 April and 16–24 April, which are indicated in Fig. 2. It shows that the positive SH Circumploar Vortex correlates with the negative Aleutian Low better in the 15 March–1 April period than in the 16–24 April period. The plausible reason for this is that the SH Circumpolar Vortex is a small positive anomaly which then causes a small negative anomalous Aleutian Low in the 16–24 April event but not in the 15 March–1 April event (see Fig. 1 and Fig. 2). It suggests that significant change in the SH Circumpolar Vortex may cause significant change in the Aleutian Low. To some degree, a weaker Circumpolar Vortex tends to increase dust storm episodes in 2002. SH atmospheric circulation at high latitudes may impact dust-related circulations not only on interannual timescales but also on 30–60-day timescales in 2002.

3.2 *Analysis of the different dust storm phases*

We chose the middle to end of March 2002 as a case study to explore further the interaction of the hemispheres via the 30–60-day oscillation by comparing the circulation between the broken (1 March) and active (20 March) dust storm phases. Firstly, in order to identify the 30–60-day oscillation, we compare the difference between the original and filtered height fields at 850 hPa in the dust storm phase (Fig. 3). A similar pattern of the 850 hPa geopotential height fields can be found in the two periods. As for the broken dust storm phase (1 March), both Fig. 3a and Fig. 3c show a positive anomalous height in North China and a negative anomalous height in high latitudes in the SH, indicating a weaker Mongolian Cyclone and a deeper Circumpolar Vortex, respectively, associated with the strong AAO. Comparatively, Fig. 3b and Fig. 3d (for the active phase) show that the negative anomalous height is located in large parts of Asia representing both a strengthened Mongolian Cyclone and a deepened Aleutian Low that may cause cold air activity and strong winds on the surface in North China, with dust storms moving eastward, corresponding to the eastward motion of the cyclone and the regime of the strong northwesterly wind. At the same time, the positive anomalous height is in the high latitudes and the negative anomalous height is in the middle latitudes in the SH, and these just represent the negative Antarctic Oscillation (AAO). Little difference between the filtered and unfiltered 500 hPa geopotential height anomaly for each phase is found. As far as the active dust storm phase (20 March) is concerned, there is a

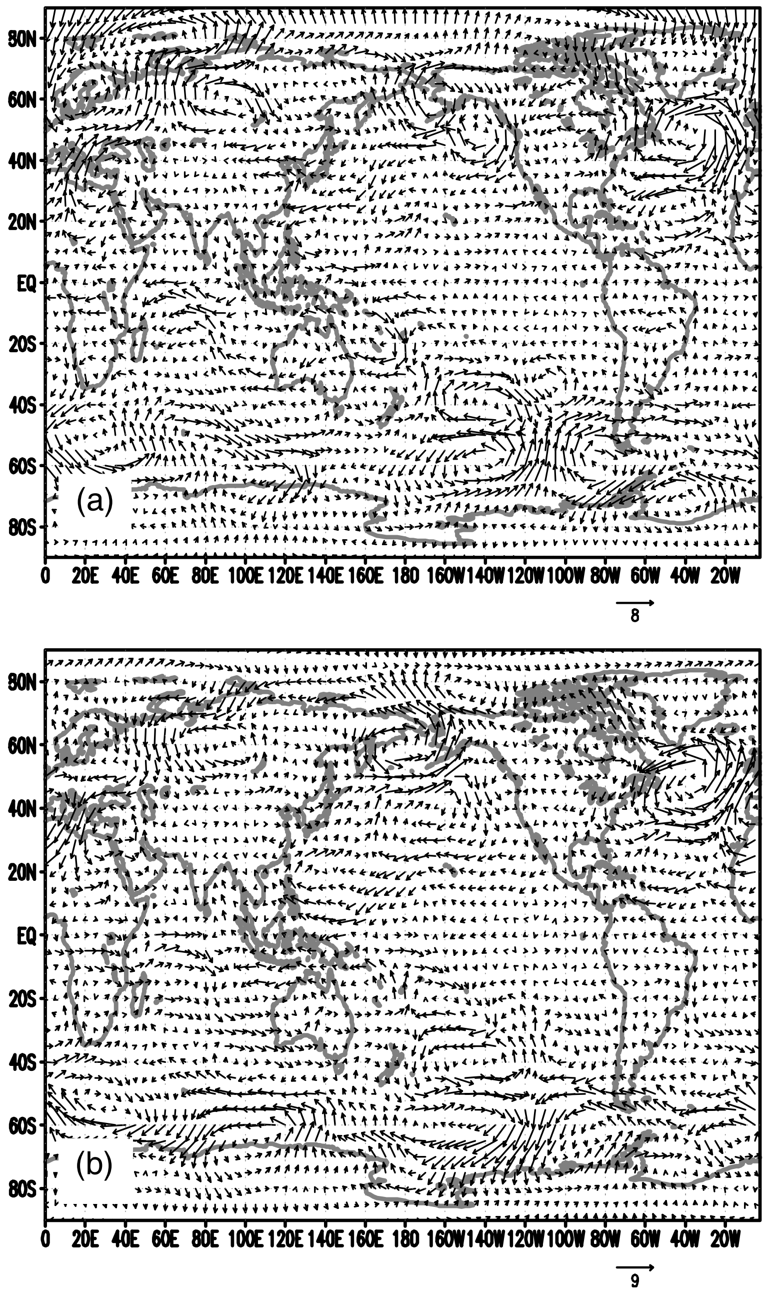

Fig. 4. 30–60-day bandpassed wind anomaly field at 850 hPa (unit: m s^{-1}). (a) 0000 UTC 1 March 2002; (b) 0000 UTC 20 March 2002.

weaker Circumpolar Vortex in the SH and a deeper trough over the northeast over Asia at 500 hPa, and behind it the northwesterly flow is very strong which is helpful to move both the cold flow and the dust particles southward (not shown). Meanwhile, the enhanced northwesterly jet at 40°N over North China is also clearly seen at 200 hPa, which is linked to the low-level cyclogenesis (Uccellini, 1986) (not shown).

Therefore, in terms of the 30–60-day oscillation in the circulation related to dust storm events over North China, a negative correlation between the Circumpolar Vortex and the Aleutian Low is found and this relationship may be closely linked to the dust storm events.

The difference in the wind field in the troposphere between the two dust storm phases is analyzed. In the broken dust storm phase (1 March) in Fig. 4a, there is an anticyclonic anomaly at 850 hPa over the area from Siberia to Northeast Asia and the Aleutian Islands that reflects that both the Mongolian Cyclone and the Aleutian Low are weaker, implying a weaker than normal intensity of cold weather anomalies over

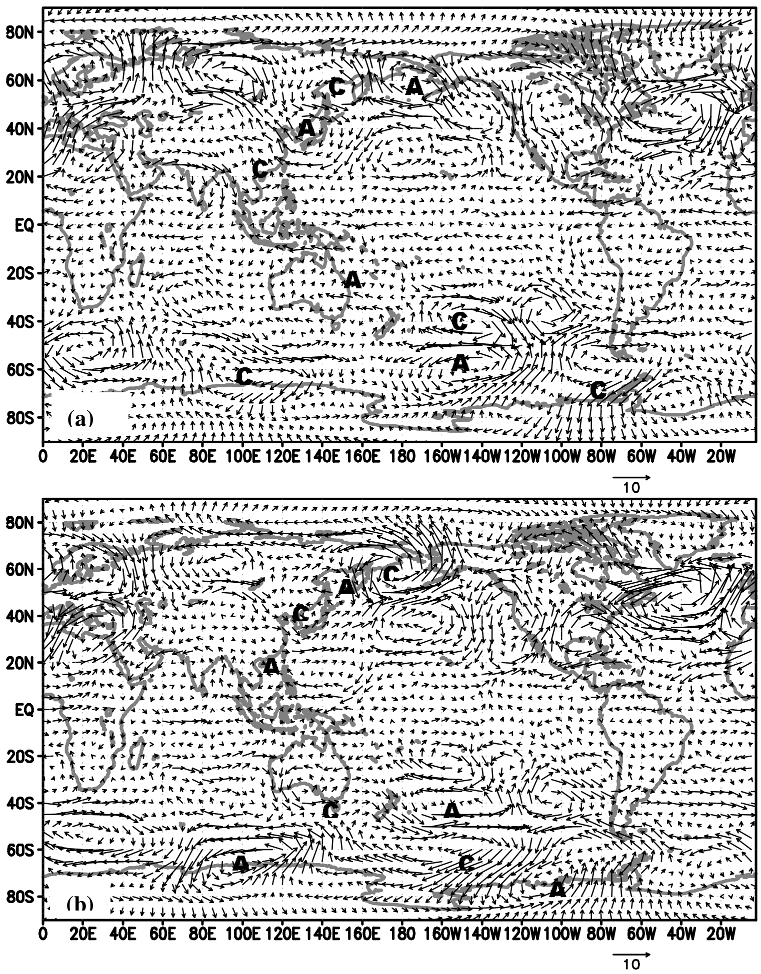

Fig. 5. 30–60-day bandpassed wind anomaly field at 200 hPa (unit: m s^{-1}) (a) 0000 UTC 1 March 2002; (b) 0000 UTC 20 March 2002 (b) 0000 UTC 20 March 2002.

East Asia. Meanwhile, there is an enhanced westerly south of 60°S and an easterly wind at middle latitudes in the SH indicating both a stronger AAO and a deeper Circumpolar Vortex. Conversely, the distribution of the wind field in the dust storm phase (20 March) is opposite to that in the broken dust storm phase in Fig. 4b. The distribution of the wind field at 500 hPa is similar to that at 850 hPa, but the features are much more remarkable. We analyze the 200 hPa wind fields for the two dust storm phases in Fig. 5a and Fig. 5b respectively. Both show alternating teleconnection patterns along the Antarctic, Australia, and coastal East Asia to the North Pacific Ocean. The upper level teleconnection is more remarkable than that of the low level which suggests that the implied inter-hemispheric interaction may begin with the upper level and that the SH Circumpolar Vortex may influence the circulation at high latitudes in the NH such as the Aleutian Low, in terms of this teleconnection. Therefore, the 30–60-day filtered teleconnection may account for the relationship between the Circumpolar Vortex and the Aleutian Low and hence may explain why this relationship consists well with the dust storm events in 2002, as Fig. 2 has shown.

3.3 *Zonal mean meridional circulation and dust storm events*

The zonal mean fields at middle-high latitudes at the upper level reflect not only planetary-scale circulation features but also the mean meridional circulation to some degree. We analyze the evolutions of the 200 hPa daily zonal mean westerly wind both at 60° latitude (Fig. 6a) and 40° latitude (Fig. 6b) for the two hemispheres. As Fig. 6 illustrates, the zonal winds of two hemispheres show coherent change, where sometimes the SH may lead the NH. During the active periods of dust storms (15 March–1 April), the zonal mean westerly wind at 60° (40°) latitude is weaker (stronger)

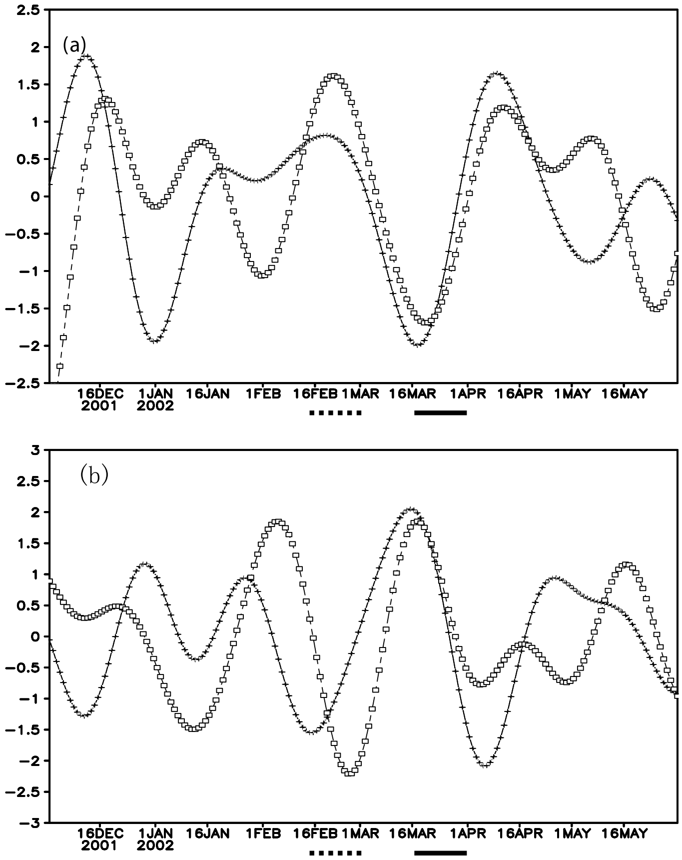

Fig. 6. Time series of the 30–60-day filtered zonal mean westerly at 60° and 40° latitude respectively (unit: m s^{-1}). (a) 60°N (denoted by □) and 60°S (denoted by +); (b) 40°N (denoted by □) and 40°S (denoted by +). The short dashed line under the time axis represents the quiet period of dust storm events (16 February–1 March); the short solid line represents the active period of dust storm events (16 March–1 April).

in both hemispheres. On other hand, the zonal mean westerly wind at 60° (40°) latitude is stronger (weaker) during the broken period of dust storms (16 February–1 March). It is clear that there is a seesaw change in the extratropical circulation of both hemispheres on a 30–60-day timescale.

How do the local zonal winds over North China that are associated with dust storm events respond to inter-hemispheric zonal winds? Based on previous research (Uccellini, 1986), the westerly jet may impact the Mongolian Cyclogenesis. So, we investigate the key circulation factors related to dust storms to go further into the change of local zonal winds over East Asia. One is the upper level westerly jet near 40°N; the other is the low level Mongolian Cyclone. We plot the daily westerly wind averaged over 90°–110°E at 40°N at 200 hPa in Fig. 7a. It is found that the westerly is weaker during the broken period of dust storms, viz. 16 February–1 March. Conversely, the strong westerly jet is associated with the active period of dust storms, viz. 15 March–1 April. Figure 7b shows the daily change in the intensity of the Mongolian Cyclone, which is defined as the 850 hPa geopotential height averaged over the region (40°–50°N, 100°–140°E). It is clear that a strong (weak) Mongolian Cyclone is concurrent with the active (broken) period of dust storms. Therefore, the above results illustrate further that the inter-hemispheric mean zonal circulation interaction with the local circulation over East Asia may impact the dust storm events in North China.

4. Summary

The relationship between the circulation on the 30–60-day oscillation timescale and the dust storm events in 2002 has been described. The main results of this study can be summarized as follows:

(1) In the year 2002, the extratropical circulations in both hemispheres are coincident on a 30–60-day timescale. The Circumpolar Vortex in the SH has a

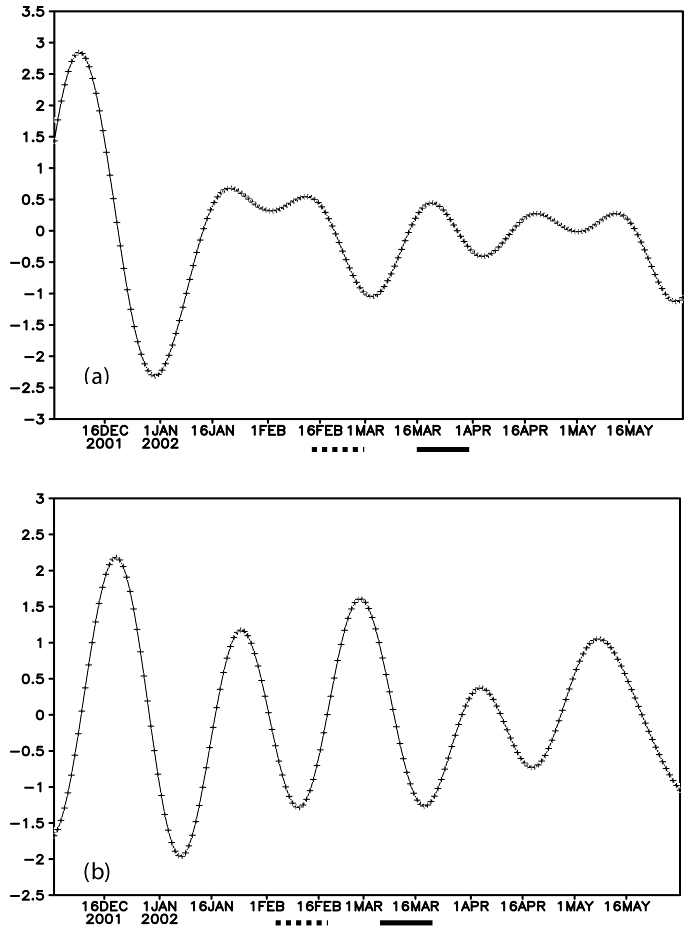

Fig. 7. (a) Time series of the 30–60-day filtered zonal mean westerly along 90°–110°E at 40°N at 200 hPa (unit: m s^{-1}). (b) Time series of the 30–60-day filtered Mongolian Cyclone defined as the geopotential height average over the region (40°–50°N, 100°–140°E) at 850 hPa (unit: gpm). Time axis markers as in Fig. 6.

significant negative correlation with the Aleutian Low in the NH. A deeper Circumpolar Vortex tends to weaken the Aleutian Low, resulting in the strong cold air activity over East Asia in boreal spring and further providing increasing dynamic conditions for the active period of dust storms.

(2) The 30–60-day filtered meridional teleconnection pattern associated with dust storms occurs over the Antarctic, Australia, and the coast of East Asia to the Aleutian Islands. The Circumpolar Vortex in the SH may impact the Aleutian Low in terms of teleconnection and then influence the cold air activity over East Asia by the dissipation of energy in the NH. In addition, the teleconnection pattern is more remarkable in the upper level, which indicates that the inter-hemispheric circulation coupling begins in the upper level.

(3) In the case study, the zonal mean circulations of both hemispheres have prominent coherence. The SH mean circulation tends to lead that of the NH.

(4) The inter-hemispheric zonal mean circulation interaction through teleconnection with local circulations over East Asia plays an important role in the dust storm events in North China.

In this paper, the case study of the 30–60-day oscillation of dust events in North China was conducted and the dust storm events were analyzed. However, the interannual variability of low frequency oscillations related to dust storms has not been discussed yet and many unsolved problems remain with respect to the physical processes behind the inter-hemispheric coupling.

Acknowledgements. This research was jointly supported by the Chinese Academy of Sciences key program under Grant KZCX3-SW-221 and the National Natural

Science Foundation of China under Grant Nos. 40125014 and 40475037. We thank Huizhi Liu, Aiguo Li and Yunyun Li for providing the observational wind data of the Beijing 325-m Meteorological Tower.

REFERENCES

Fan K., and H. J. Wang, 2004: Antarctic Oscillation and the dust weather frequency in North China. *Geophys. Res. Lett.*, **31**, L10201, doi: 10.1029/2004GL019465.

Fang Zongyi, and Wang Wei, 2003: Characteristic Analysis of China dust storm in 2002. *Journal of Applied Meteorological Science*, **14**, 513–521. (in Chinese)

Ghil, M., and K. Mo, 1991: Intraseasonal Oscillations in the global atmosphere. Part I: Northern Hemisphere and Tropics. *J. Atmos. Sci.*, **48**, 752–779.

Gillette, D. A., and K. J. Hanson, 1989: Spatial and temporal variability of dust production caused by wind erosion in the United States. *J. Geophys. Res.*, **94**, 2197–2206.

Gong, D. Y., and S. W. Wang, 1999: Definition of Antarctic oscillation index. *Geophys. Res. Lett.*, **26**, 459–462.

He Jinhai, and Yang Song, 1992: Meridional propagation of East Asian low frequency mode and mid latitude low frequency waves. *Acta Meteorologica Sinica*, **50**, 190–197. (in Chinese)

Higgins, R. W., and W. Shi, 2001: Intercomparison of the principal modes of interannual and intraseasonal variability of the North American monsoon system. *J. Climate*, **14**, 403–417.

Kindson, J. W., 1988: Indices of the Southern Hemisphere zonal wind. *J. Climate*, **1**, 183–194.

Krishnamurti, T. N, and D. Subrahamanyam, 1982: The 30–50 day mode at 850 mb during Monex. *J. Atmos. Sci.*, **39**, 2088–2095.

Lau, K. M., and P. H. Chan, 1986: Aspects of the 40–50 day oscillation during the northern summer as inferred from outgoing longwave radiation. *Mon. Wea. Rev.*, **114**, 1354–1367.

Liebmann, B., and D. L. Hartmann, 1984: An observational study of tropicalmidlatitude interaction on intraseasonal time scales during winter. *J. Atmos. Sci.*, **41**, 3333–3350.

Li Chongyin, 1990: Seasonal Oscillation in atmosphere. *Scientia Atmospheric Sinica*, **14**, 32–44. (in Chinese)

Madden, R. A., and P. R. Julian, 1971: Detection of a 40–50 day oscillation in the zonal wind in the tropical Pacific. *J. Atmos. Sci.*, **28**, 702–708.

Merrill, J. T., M. Uematsu, and R. Bleck, 1989: Meteorological analysis of long range transport of mineral aerosols over the North Pacific. *J. Geophys. Res.*, **94**, 8584–8598.

Mo, K. C., 2000: Intraseasonal modulation of summer precipitation over North America. *Mon. Wea. Rev.*, **128**, 1490–1505.

Qian, W. H., L. S Quan, and S. Y. Shi, 2002: Variations of the dust storm in China and its climatic control. *J. Climate*, **15**, 1216–1229.

Rogers, J. C., and H. van Loon, 1982: Spatial Variability of sea level pressure and 500 mb height anomalies over the Southern Hemisphere. *Mon. Wea. Rev.*, **110**, 1375–1392.

Shao, Y. P., Y. Yang, J. J. Wang, Z. X. Song, Lame M. Leslie, C. H. Dong, Z. H. Zhang, Z. H. Lin et al., 2003: Northeast Asian dust storms: Real-time numerical prediction and validation. *J. Geophys. Res.*, **108**(d22), 4691, doi: 1-.1029/2003Jd003667.

Simmons, A. J., J. M. Wallace, and G. W. Branstator, 1983: Barotropic wave propagation and instability and atmospheric teleconnection patterns. *J. Atmos. Sci.*, **40**, 1363–1392.

Thompson, D. W. J., and J. M. Wallace, 2000: Annular modes in the extratropical circulation: Part I: Month to month variability. *J. Climate*, **13**, 1000–1016.

Uccellini, Louis W., 1986: The possible influence of upstream upper-level baroclinic Processes on the development of the AEII storm. *Mon. Wea. Rev.*, **114**, 1019–1026.

Wang Shigong, Dong Guangrong, Chen Huizhong, Li Xiliang, and Jin Jiong, 2000: Advances in Studying sand-dust Storms of China. *Journal of Desert Research*, **20**, 349–356. (in Chinese)

Webster, P. J., and J. R. Holton, 1982: Cross-equatorial response to middle-latitude forcing in a zonally varying basic state. *J. Atmos. Sci.*, **39**, 723–733.

Weickmann, K. M., G. R Lussky, and J. E. Kutzbach, 1985: Intraseasonal (30–60 day) fluctuations of outgoing longwave radiation and 250 mb streamfunction during northern winter. *Mon. Wea. Rev.*, **113**, 941–961.

Yasunari, T., 1979: Cloudiness fluctuations associated with the Northern Hemisphere summer monsoon. *J. Meteor. Soc. Japan*, **57**, 225–229.

Zhang Renjian, Han Zhiwei, Wang Mingxing, and Zhang Xiaoye, 2002: Dust storm weather in China: New characteristics and origins. *Quaternary Sciences*, **22**, 374–380. (in Chinese)

Zhao C. S, X. Dabu, and Y. Li, 2004: Relationship between Climatic factors and dust storm frequency in Inner Mongolia of China. *Geophys. Res. Lett.*, **31**, L01103 doi:10.1029/2003Gl018351.

Zhou Zijiang, 2001: Blowing-sand and sandstorms in China in recent 45 years. *Quaternary Sciences*, **21**, 9–16. (in Chinese)