Decadal change of the spring dust storm in northwest China and the associated atmospheric circulation

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[1] The decadal variations of spring dust storms in Northwest China and the associated circulation changes are investigated by using the station observations of dust storm frequency data of China and the NCEP/NCAR reanalysis data for the period 1960–2003. The domain-averaged, spring dust storm frequency index (DSFI) in Northwest China exhibits a decadal change, with a sharp decrease after the mid-1980s. The decreased frequency of spring dust storms in Northwest China after the mid-1980s is concurrent with enhanced geopotential height over the Mongolian plateau and Middle Siberia (MPMS) as well as an anomalous shift in the phase and intensity of the stationary wave over Eurasia. In addition, an increase in precipitation in the western region of Northwest China also contributed to the decrease in spring dust storms.
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1. Introduction

[2] Dust storms are a special type of natural disaster that frequently occurs in deserts and their surrounding areas. A significant literature exists regarding the climatology and influences of dust storms [*Littmann*, 1991; *Derbyshire et al.*, 1998; *Huang and Gao*, 2001; *Ogunjobi et al.*, 2003]. The Loess Plateau and the deserts in the arid and semiarid regions of Northwest China (see Figure 1), are one of the largest and most persistent dust sources in the Northern Hemisphere [*Prospero et al.*, 2002]. Dust storms occurring over Northwest China may extend to North Pacific, Japan and Korea [*Duce et al.*, 1980]. Particularly severe dust storms can even go across the Pacific and reach the Western Coast of North America as was the case for the April 18, 1998, dust storm [*Wang et al.*, 2003]. Recent studies have documented the spatial and temporal distribution characteristics of dust storms occurring over Northwest China including their sources and paths [*Zhou and Wang*, 2002; *Wang et al.*, 2003]. The occurrence of dust storms has been found to be closely associated with an anomalous atmospheric circulation pattern [*Westphal et al.*, 1988; *Fan and Wang*, 2004], however, up to now, few investigations have been carried out concerning the connections between the decadal-scale variations of dust storms and the accompanying anomalous atmospheric circulation. The aim of this study is to investigate decadal-scale variations of dust storm occurrence in Northwest China and to shed light on possible relationships with the associated atmospheric circulation changes.

[3] The data on dust storm occurrence used in this analysis are mainly derived from the records from 1960 to 2003 from 338 meteorological observing stations located throughout China [*Wang et al.*, 2003]. Among the 338 stations, 48 stations are located in Northwest China. The reanalysis data from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) (1958–2003), the monthly precipitation data from China's 160-station network [*Nan and Li*, 2003] (1951–2001), the Arctic Oscillation index (AOI) [*Li and Wang*, 2003] (1873–2003) and Antarctic Oscillation index (AAOI) [*Nan and Li*, 2003] (1948–2003) are also used. The winter and spring in this paper refer to the boreal winter and spring.

2. Results

[4] We first define a dust storm frequency index (hereafter DSFI) by averaging the 48-station observations of total occurring days of dust storms for spring (March–May). Spring is chosen because dust storms mainly occur during the period from March to May [*Littmann*, 1991; *Zhou and Wang*, 2002]. Figure 2 illustrates the normalized series of the spring DSFI in Northwest China and its 9-yr running mean series. It is shown that the spring DSFI undergoes a distinct decadal change during the mid-1980s. Compared with earlier period (1960–1985), the spring DSFI in the period 1988 to 2003 is significantly lower, in agreement with the studies of *Wang et al.* [2003].

[5] To investigate the atmospheric circulation changes associated with this decrease of spring dust storm frequency, Figure 3 shows the correlation map between the spring DSFI in Northwest China and spring (March–May average)

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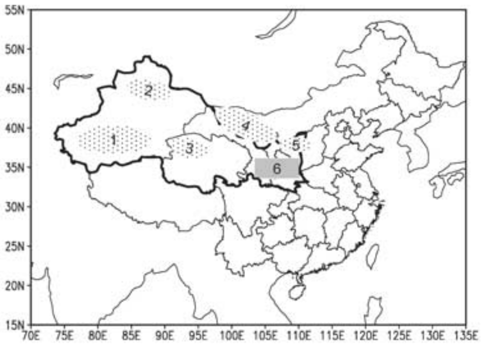

Figure 1. The distribution of dust sources located in Northwest China, the region that bold curve encompassing. Several major dust sources located in Northwest China are shown as follows: 1 Taklamakan desert; 2 Gurbantonggut desert; 3 Kumtag desert; 4 Badain Juran desert; 5 Maowusu desert; 6 Loess Plateau.

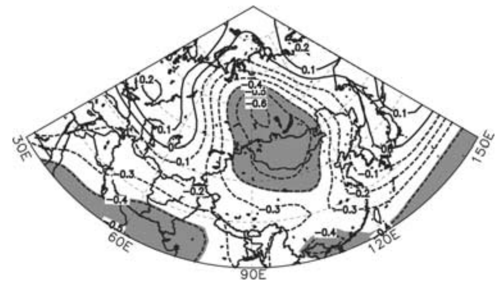

Figure 3. Correlations between the spring DSFI in Northwest China and 500 hPa geopotential height for the period 1960–2003. The correlation coefficients that are significant at the 99% confidence level are shaded. The latitude lines are at 10 degree intervals starting with 20°N at the outer edge. The contour interval is 0.1.

500 hPa geopotential height. Figure 3 shows that there is an area over the Mongolian plateau and Middle Siberia (MPMS) with significant negative correlation, implying that the above- (below-) normal occurrence of springtime dust storms in Northwest China is closely associated with the negative (positive) 500 hPa height anomalies over the region. The correlation distribution between the DSFI and 500 hPa geopotential height for each of spring months (March, April and May) (not shown) is similar to that for spring.

[6] Based on the above analysis, 1960–1985 and 1988–2003, respectively, are chosen as periods of high- and low-frequency occurrence of springtime dust storms in Northwest China. The pattern of the composite differences in spring 500 hPa geopotential height between the low- and high-frequency periods (not shown) looks like that in Figure 3. North of Northwest China, there is a region with strong anomalous positive geopotential height, with the center over the MPMS, which is nearly coincident with the area of significant negative correlation between the spring DSFI in Northwest China and 500 hPa geopotential height field (Figure 3). The enhanced geopotential height over the MPMS, corresponding to a strong anomalous anticyclone, causes anomalous northerly winds to occur over the eastern part of China and anomalous southerly winds over the western part of China that tend to weaken the intensity of northwest cold air flow from higher latitudes to Northwest China (Figure 4). This process appears to be responsible for the springtime decrease in the frequency of strong winds in Northwest China since the mid-1980s, which is the most important change in atmospheric circulation contributing to the decreased frequency of dust storms in Northwest China [*Zhou*, 2001].

[7] If the domain-averaged 500 hPa geopotential height over the region (85°–110°E, 40°–65°N) is defined as an atmospheric circulation index (ACI) over the MPMS, this index in spring has a significant negative correlation with the spring DSFI in Northwest China (Figure 2). The correlation coefficient between the two records is −0.64, which is significant at the 99.9% confidence level. Because of the high correlation, the springtime variation of 500 hPa geopotential height over the MPMS can be used as a good indicator of spring dust storm occurrence in Northwest China. The spring 500 hPa geopotential height over the MPMS has been persistently enhanced since the mid-1980s (Figure 2), which provides a basic large-scale circulation background for continuous low-frequency spring dust storms in Northwest China. The AO and AAO are major

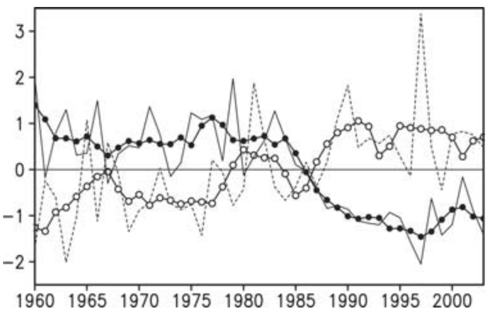

Figure 2. Normalized time series of the spring DSFI (light solid line) in Northwest China and the circulation index (light dashed line) over MPMS which is defined as the 500 hPa geopotential height averaged over the domain (85°–110°E, 40°–65°N). Their 9-yr running mean series are indicated by closed circle line and open circle line, respectively.

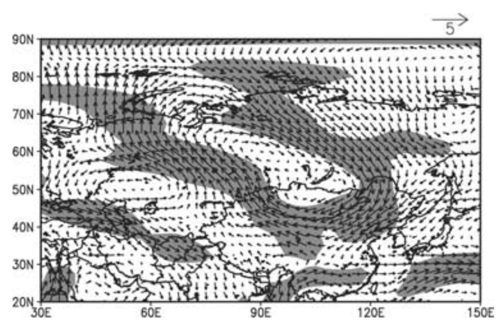

Figure 4. Composite difference in the spring 500 hPa horizontal wind field (in m s^{-1}) between the low- and high-frequency periods (1988–2003 and 1960–1985, respectively) of springtime dust storm occurrence in Northwest China. The values in the shaded areas are significant at the 95% *t*-test confidence level.

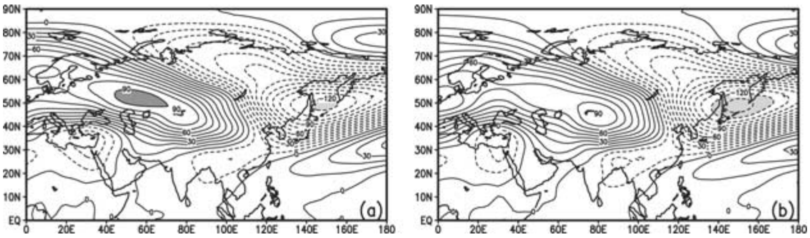

Figure 5. The spring geopotential-height stationary wave (in gpm) at 500 hPa over Eurasia for (a) the high-frequency period (1960–1985) and (b) low-frequency period (1988–2003) of springtime dust storm occurrence in Northwest China. The positive (negative) stationary perturbation center is shaded dark (light).

modes of low-frequency variability in the Northern and Southern Hemispheres, respectively [*Thompson and Wallace*, 1998; *Li and Wang*, 2003; *Nan and Li*, 2003]. The correlation coefficient between the previous winter AOI (AAOI) and the spring ACI over the MPMS is 0.41 (0.11), and that between the spring AOI (AAOI) and the spring ACI over the MPMS is 0.39 (0.13). It is implied that the previous winter AO and spring AO may contribute to the variability of spring atmospheric circulation over the MPMS.

3. Further Analysis

[8] The decadal anomaly of geopotential height field is related to the changes in the stationary wave over the mid-latitude westerlies, while the change of phase and intensity of stationary wave can affect the occurrence of dust storms in Northwest China. Compared with the geopotential-height stationary wave in the high-frequency period (1960–1985) of dust storm occurrence in Northwest China (Figure 5a), that in the low-frequency period (1988–2003) shows a systematic eastward migration in phase and a distinct movement of the positive stationary perturbation center from west of Balkhash Lake to the east (Figure 5b). These changes cause conditions over Northwest China to shift from the ahead-of-ridge and back-of-trough region in the high-frequency period (1960–1985) to the ridge region of the stationary wave during the low-frequency period (1988–2003), leading directly to the weakening of northwest air flow over Northwest China. Moreover, the decrease in amplitude of the positive stationary perturbation region (i.e., ridge region) further weakens northwest winds over Northwest China (Figure 5), thereby also contributing to the decrease of springtime dust storms.

[9] In addition to the dependence on atmospheric circulation, the variability of dust storm occurrence in China has also been found to be associated with fluctuations of climatic factors such as precipitation, soil moisture conditions and snow cover et al. [*Liu et al.*, 2004; *Zhao et al.*, 2004; *Kurosaki and Mikami*, 2004; *Zhang et al.*, 2003; *Gong et al.*, 2004]. It seems quite plausible that these changes may be result of decadal variations of atmospheric circulation. The composite difference of annual total precipitation (not shown) between the low- and high-frequency dust storm periods as mentioned above indicates that annual total precipitation is significantly enhanced in the later period in the western region of Northwest China. As a result of this change, the ecological environment is likely to have correspondingly improved, which would also contribute to a decrease of dust storms in this region [*Qian et al.*, 2002].

4. Discussion

[10] The decadal variations of springtime dust storms in Northwest China and associated circulation changes are investigated in this study. The results show that the springtime dust storm frequency in Northwest China has undergone a distinct decrease since the mid-1980s. This decrease has been found to be closely associated with enhanced geopotential height over the MPMS as well as with anomalous changes in stationary wave pattern over Eurasia. The increase in springtime intensity of 500 hPa geopotential height over the MPMS since the mid-1980s has shifted the basic large-scale circulation toward conditions conductive to a reduction in the frequency of springtime dust storms in Northwest China. In addition, the increase in precipitation in the western region of Northwest China has likely also, to some degree, contributed to the decrease of dust storms in Northwest China. Gaining further understanding of the causes of changes in DSFI will require further study of the mechanisms determining decadal variations in the atmospheric circulation over the MPMS, and more generally about the shift in the stationary wave pattern over Eurasia and changes in precipitation in the western region of Northwest China.

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