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TAO, Vol. 15, No. 5, 999-1018, December 2004

A Composite Study of the Synoptic Differences between Major and Minor Dust Storm Springs over the China-Mongolia Areas

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(Manuscript received 1 June 2004, in final form 9 December 2004)

ABSTRACT

In order to improve the understanding of the mean circulations of and the differences between major and minor dust storm springs over the China-Mongolia area, multiple-cases, multiple-element circulation composite analyses were conducted utilizing the NCEP/NCAR reanalysis gridded data. The main conclusions are: 1) Based on the differences in the dust storm-inducing system, dust origin, route of cold air and main dust storm-hit areas, the China-Mongolia dust storms regime can be divided into west, east and Southwest China-Mongolia sub-regimes; 2) During the major dust storm springs in Western China-Mongolia, circulations on the mid-and lower-levels are characterized by a deeper and stronger Siberian high, dominant troughs or cyclones in and around Mongolia, and intensified westerly winds around the China-Mongolia border, with cold air moving frequently along northwestern or northern routes into China. During minor dust storm springs in Western China-Mongolia, the pattern is altered toward lesser cold air intrusions; 3) During major dust storm springs in Eastern China-Mongolia, circulations on the mid- and lower-levels are characterized by the dominant China-Mongolia ridges and troughs or cyclones in and around the Japan Sea, with cold air moving frequently along northeast routes into China; 4) The inter-annual and inter-decadal variations in dust storm occurrences in the last five decades are related closely to the changes in synoptic circulations; and 5) Warming in Mongolia and Southwest Siberia are

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accompanied with a weakening of the Siberian cold air mass and intensification of the Xingjiang ridges since the 1980's. These conditions are unfavorable for the initiation of major dust storms. Hence, if warming in this region continues in phase with the current global warming trend, dust storm activities will decrease in the future.

(Key words: China Mongolia dust storm, Composite study, Synoptic circulation)

1. INTRODUCTION

According to the WMO's definition, when the surface visibility is reduced below 1000 m by strong dust-raising winds, this dusty weather phenomenon is logged as a dust storm. Dust storms are generated mainly in windy, dust-rich arid and semiarid environments, such as in North Africa, Southwest Asia, Southwest US and the China-Mongolia areas. (Thomas 1997). The violent winds and obscured visibility heavily influence traffic, aviation, construction, and can even cause great loss of human life and property damage (Fang et al. 1997). The entrainment, transport and deposition of aeolian dust can lead to soil erosion and degradation of terrestrial, aquatic and air environments, causing climatic modifications on a global scale (Goudie and Middleton 1992).

The dust phenomena can range within a wide meteorological spectrum, from dust haze, blowing dust, weak- to strong- and to very strong-dust storms. For simplicity, in this context we designate strong and very strong-dust storms, with a minimum visibility of less than 200 m and a maximum wind speed of more than 20 m s^{-1} (Qian et al. 1997), as a major dust storm. Locally, major dust storms are referred to as "black wind" or "yellow wind" in Northwestern China and "ugalz" in Mongolia. Downwind of the dust storm origin, it weakens into a weak dust storm or dust haze, called "yellow sand" in Japan and Korea. Naturally, people concern more on major dust storm events.

Recently, issues concerning China-Mongolia dust storm have received growing attention in the world (Fang et al. 1997; Yeh et al. 2000; Chun et al. 2001; Niu et al. 2001; Qian and Song et al. 2002; Qian and Quan et al. 2002; Shi et al. 2003; ACE-Asia Special issue 2003). Qian et al. (2004) pointed out that in North China, major dust storms often occur in the Gansu Corridor with the highest frequency occurring at Minqin; on the southern edge of the South Xingjiang Basin, centered at Hetian; Western Inner Mongolia, centered at Guaizihu; Central Inner Mongolia, centered at Yikwusu and Zhurihe (as marked in Fig. 1). Most deserts in Northern China are surrounded by mountains. Only airflows with a specific direction passing through deserts are capable of initiating dust storms of different intensity scales. Figure 1 shows that there are four major routes for cold air coming from Siberia into China: west (W), northwest (NW), north (N) and northeast (NE) routes. Among them, the north route consists of two branches. Clearly, dust storms appear mainly on the cold air intrusion route.

Since 1952 the major dust storm activities in Northern China have exhibited a variation in wavy ways. The first trend intensified from the 1950's to 1960's, reaching its peak frequency in the 1970's, weakened from the 1980's to late 1990's, intensified in 2000 and 2001, then weakened after 2002 (Fig. 2). Li et al. (2003) took the weak dust storm cases into account to study the temporal and spatial distributions of dust storm cases in Northern China. They revealed that the cores and axes of the maximum dust storm frequency, and the inter-decadal frequency variation pattern were in accord with those obtained by analyzing only the major dust storm dataset. Qian et al. (2004) concluded that the climatological characteristics of major dust storms were representative enough for that of all dust storm events.

Qian and Quan et al. (2002) studied the variations in dust storms in China during 1948~1999 and its climatic control through statistical correlation analyses. They pointed out that the frequency of dust storms was strongly related to the high-frequency cyclone activity in the spring season for most parts of Eastern China. Based on this relationship, they suggested that warming in Mongolia and cooling in Northern China after the 1980's has reduced the meridional temperature gradient, resulting in reduced cyclone frequency in Northern China and hence less frequent dust weather after the mid-1980s in the eastern part of China. There have not

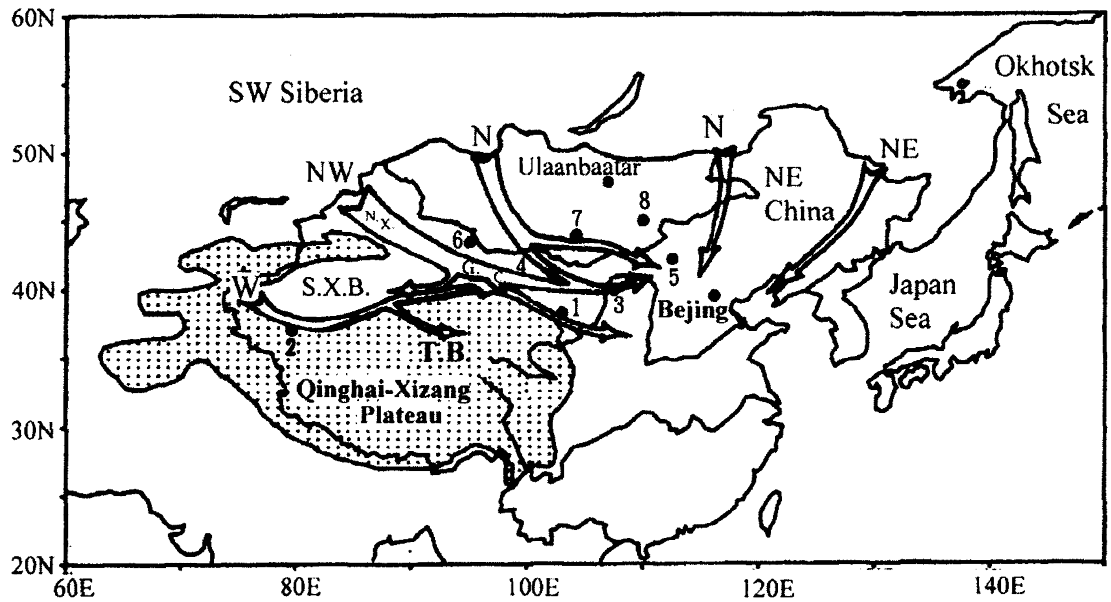

Fig. 1. Map of China-Mongolia (CM) area and four major dust tracks of cold air coming from Siberia into China. In the figure, W, NW, N and NE stand for the western, northwestern, northern and northeastern route, respectively. S.X.B. and T.B. stand for the Southern Xinjiang Basin and the Tsaidam Basin, respectively. N.X. and G.C. stand for northern Xinjiang and Gansu Corridor, respectively. SW Siberia stands for Southwest Siberia. Stations 1, 2, 3, 4, 5, 6, 7 and 8 refer to Minqin, Hetian, Yikwusu, Guaizihu, Zhurihe, Naomaohu, Danlandzadgad and Sainshada, respectively.

studied the reasons why the variation in cyclonic activity is vital to dust storm occurrences and what the synoptic circulation pattern over China-Mongolia is during active and non-active dust storm periods in Qian and Quan et al. (2002).

Other attempts were made to explain the causes of the inter-decadal changes in dust storm in China-Mongolia. Brown et al. (2002) suggested that China would have 100 major dust storms events during the 2000 decade judging from the nonlinear development of desertification in Northern China. Clearly, they overestimated the impact of desertification on dust storm occurrences. With no suitable synoptic conditions and the right airflow to initiate desert dust storms, the dust storm occurrence frequency has been the lowest in the 1990's, with desertification activities in Northern China going on as usual (Qin 2002) during a record drought period (Fu and Wen 2002).

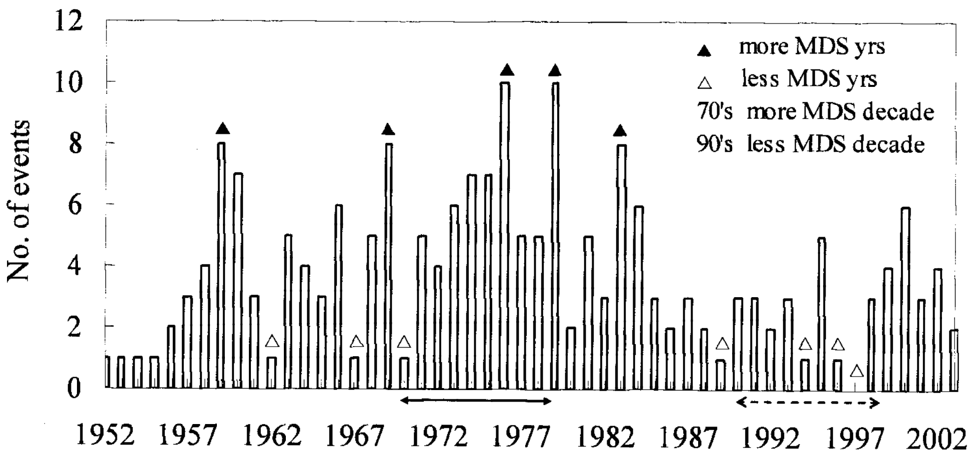

Fig. 2. Yearly change of the No. of spring Major Dust Storm (MDS) events in West and Southwest CM (defined in Table 1) during 1952~2003.

Natsagdorj et al. (2003) analyzed dust storms in Mongolia and showed that the number of dusty days tripled from the 1960s to the 1990s but decreased since the 1990s, with the greatest occurrence of drifting dust arising around the Mongol Els area of West Mongolia. Analyses done by Mandakh et al. (2002) indicated that dust storms in Mongolia occur mainly in the southern and western parts, with a yearly mean frequency of more than 30 days at Danlanzadgad and Sainshanda. The yearly occurrence days of the dust storm in southeast Mongolia, Korea and Japan have been increasing since the mid- 1990's or mid-1980's (Yoshino et al. 2002; Chun and Lee 2002), as opposed to the decrease in Northern China (Qian et al. 2004). This poses another interesting subject: whether the climatological factors affecting dust storms in Western China-Mongolia are different from those affecting Eastern China-Mongolia.

In this paper, we analyze and compare the composite circulation features in major and minor dust storm springs. Here, the composite approach is to obtain an averaged condition of springs with many major dust storms, i.e., the major dust storm springs, and that of springs with less major dust storm events, i.e., the minor dust storm springs. The dataset used is the NCEP/NCAR reanalysis gridded data from 1950 to 2003 (Kalnay et al 1996). The images were downloaded from the NOAA-CIRES Climate Diagnostics Center web site.

2. MAJOR AND MINOR DUST STORM SPRING AND DECADE SELECTION

The major dust storm frequency data come from the Data Center of the China Meteorological Administration. Although dust storm events appear all year round, most occur in the spring. According to Qian and Song et al. (2002), 63% of the major dust storm events occur in the spring. Events reported in other seasons are considerably less and more sporadic. For simplicity, we decided to concentrate only on major dust storms occurring in the spring (Fig. 2). The spring months are March, April and May.

Figure 2 shows the major dust storm frequency variations during the spring in Western and Southwestern China-Mongolia (defined in Table 1) from 1952 to 2003. On average, there were four major dust storm events every spring. In some years, like 1959, 1969, 1976, 1979 and 1983, 8~10 events were reported. This is more than normal, and hence these years were chosen as major dust storm years. Years like 1962, 1967, 1970, 1989, 1994, 1996 and 1997, with as few as 0~1 events reported were chosen as minor dust storm years. Note that all of

Table 1. Summary of characteristics of three sub-regimes of China-Mongolia dust storm area.

Sub-regimes	dust storm-inducing system	dust origin	cold air intrusion route (referring to Fig.1)	dust storm-hit areas
East	Japan Sea troughs or cyclones	east Mongolia	NE route	east Mongolia, Beijing, northeast China, Korea, Japan, and Taiwan
West	Mongolia troughs or cyclones	border of China-Mongolia	NW or N route	most areas of China-Mongolia, Korea, Japan, and Taiwan
South-west	south Xingjiang heat lows	south Xingjiang	W route	South Xingjiang, west Gansu Corridor, Tsaidam Basin

these case years were randomly scattered over past decades. The number of major dust storms counted in the 50's, 60's, 70's, 80's and 90's were 21, 44, 60, 35, and 25, respectively. Fifteen events occurred during 2000~2003. Hence, the 1970's (1970~1979) were chosen as the major dust storm decade, while the 1990's were the minor dust storm decade.

Note that the major and minor dust storm year selection was based on major dust storms events occurred in West and Southwest China-Mongolia. According to Yoshino et al. (2002), in Eastern China-Mongolia most major dust storms occurred in 2000 and 2001.

3. COMPOSITE CIRCULATION FEATURES OF MAJOR DUST STORM SPRINGS

Most dust storm studies analyzed the circulation patterns in the lower troposphere (Xu et al. 1997; Yang et al. 2001; Liu and Zheng 2003) and the dust initialization and transport (Chen and Chen 1987; Cai et al. 2000; Yoshino et al. 2002) for selected cases throughout an event period. In this section, composite plots of selected elements on 850 hPa and 500 hPa are analyzed for the five major dust storm springs.

In the five major dust storm springs, a large-scale negative anomaly region dominated the 850 hPa spring composite geopotential height anomaly field (Fig. 3a), which covers China-Mongolia, Southwestern Siberia and Eastern Kazakhstan with a center of -20 gpm over Central Mongolia. This negative region stretches vertically up to 500 hPa, tilting northwestward with height due to its cold air property, with a 500 hPa anomaly center of -40 gpm over Siberia (about 60°N, 90°E) (Fig. 4a). This negative anomaly region can be regarded as an active trough-developing region. Keeping in mind, in spring there should generally be a Xingjiang ridge on the mid- and lower-levels. Hence judging from the dominant negative anomaly in major dust storm springs, the seasonal ridges over China-Mongolia must have weakened dramatically, while the Mongolian troughs or cyclones intensify.

In the meantime, a negative temperature anomaly region covers Southwestern Siberia and Mongolia on 850 hPa (Fig. 3b) and over southwest Siberia on 500 hPa (Fig. 4b) with a core of about -1.4°C and -1°C, respectively. Since the center of the so-called Siberia-Mongolia cold high sits in general at the same location in winter and spring (Tang et al. 1995), a deeply-developed and colder Siberia air mass (or stronger cold high) often occupies the region that is usually the top part of the Xingjiang ridge. The steering flow at the rear of the Mongolian troughs or cyclones will frequently bring fresh cold air from Southwestern Siberia into Western China-Mongolia to initiate a dust storm. Along the China-Mongolia borders and between Mongolia and Russia, a strong southward meridional temperature anomaly gradient suggests a strong and active mid- and lower-level frontal development zone, which is favorable for efficient dust particle lifting.

It is worthwhile to note that a cyclonic wind anomaly pattern appears at 850 hPa (Fig. 3c) and 500 hPa (Fig. 4c) with centers over Mongolia and Southwest Siberia. This finding is in accord with the point raised by Qian and Quan et al. (2002) that more cyclone activities are favored over Mongolia during major dust storm years. Westerly winds are intensified around the China-Mongolia border, near Guaizihu, Mingqin, Yikwusu and Zhurihe stations, to favor dust storm initiation.

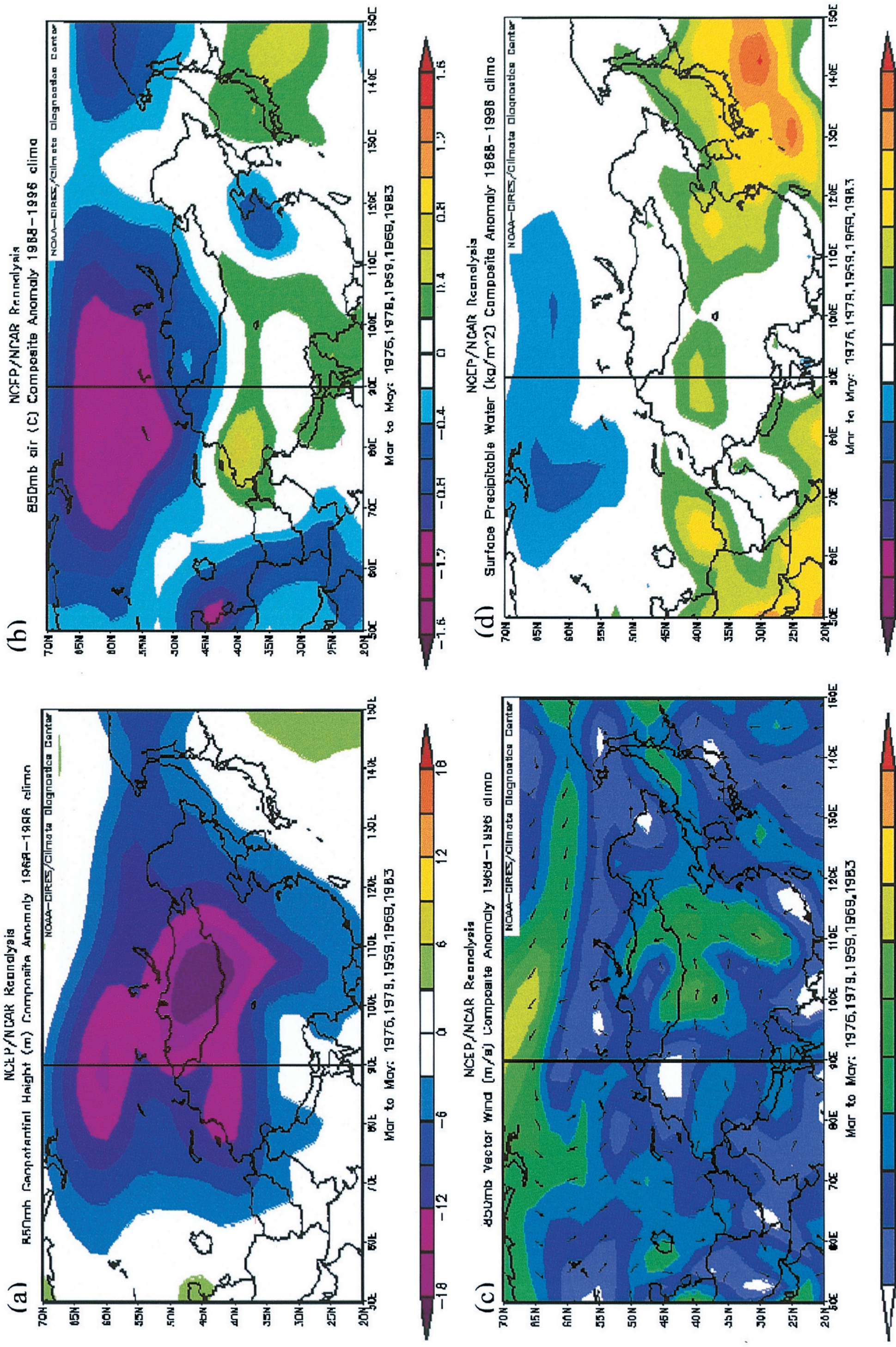

Fig. 3. Composite plots of the anomaly of (a) geopotential height, (b) temperature, (c) wind on 850 hPa and (d) precipitable water in springs of five more MDS years.

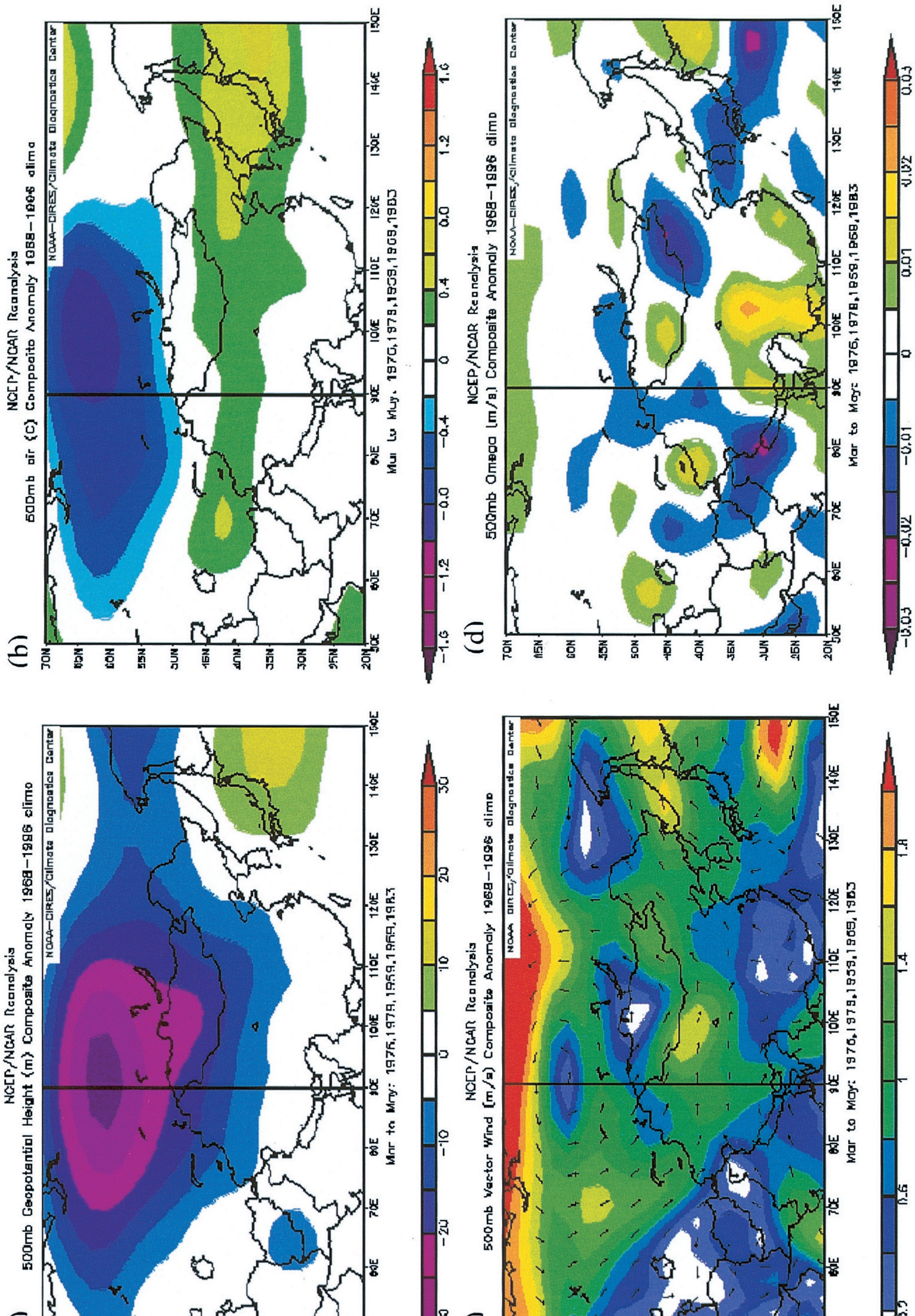

Fig. 4. Composite plots of the anomaly of (a) geopotential height, (b) temperature, (c) wind and (d) omega on 500 hPa in springs of five more MDS years.

Perhaps due to the stronger southerly wind on the eastern side of the Qinghai Xizang Plateau and ahead of the Mongolian cyclones, a column of precipitable water over the South Xingjiang and Gansu Corridor is above-normal (Fig. 3d), and the 500 hPa rising motion at Sanshanda and Zhurihe is stronger than normal (Fig. 4d).

To confirm the findings stated above, we analyzed the data of the spring of 1976. A noteworthy strong west southwest- east northeast oriented trough with an innermost contour of 1420 gpm over Mongolia appears at the mean geopotential height of 850 hPa, moving 10 longitudes further eastward than expected (Xu et al. 1997). This trough is accompanied with an anomaly center of -40 gpm, a cold core of -2.5°C and a cyclonic wind anomaly. Along the China-Mongolia border, a westerly wind speed of 3~5 m s^{-1} stronger than normal appears. Not surprisingly, this favorable synoptic environment for Mongolian troughs or cyclones brought frequent fresh cold air from Southwestern Siberia southward into China along the NW- and N-routes (Fig. 1) and initiated 10 major dust storms events.

The same circulation patterns dominate in the 1970's. At 850 hPa (Figs. 5a, b and c), a negative height anomaly with center of -20 gpm and a strong cyclonic wind anomaly over Mongolia and a cold core over Southwestern Siberia exists. Similar features also appear at 500 hPa (not shown). These phenomena suggest that the prevalence of Mongolian dust storm-inducing troughs or cyclones on mid- and lower-levels are keys to the westerly wind speed increasing by 2 m s^{-1} or so along the China-Mongolia border with the initiation of 60 major dust storm events in this decade.

In summary, the colder Siberia air mass, stronger and longer troughs or cyclones in and around Mongolia, and stronger mid- and lower-level westerly winds around the China-Mongolia border are key features leading to more major dust storms in western China-Mongolia in the spring.

4. COMPOSITE CIRCULATION FEATURES OF MINOR DUST STORM SPRINGS

In the springs of the seven minor dust storm years, the mid- and lower-level circulation patterns have changed in opposite ways from those in the major dust storm springs. First, the 850hPa height manifests a dipole pattern of positive anomalies in the north and negative values in the south around 50°N (Fig. 6a). The temperature anomaly field shows a warm core over Southwest Siberia (Fig. 6b). These patterns suggest that the Xingjiang ridge becomes stronger, while the Southwest Siberia cold air mass and mid- and lower-level meridional height and temperature gradient weaken considerably. An anticyclonic wind anomaly with a core over Southwest Siberia covers Mongolia and the areas north of 45°N (Fig. 6c). This further supports a stronger Mongolia ridge. It also results in an easterly wind speed anomaly of 1.2 m s^{-1} or so around the China-Mongolia border (Fig. 6c). The reversed patterns from major dust storms exist at 500 hPa (not shown), and with a much larger change in positive anomaly of 30 gpm over (60°E, 60°N) with a 1°C warmer anomaly over Southwest Siberia and Mongolia, and an easterly anomaly of 2 m s^{-1} over the China-Mongolia border. Needless to say, the weakened cold air activities are unfavorable for major dust storm development in Western China-Mongolia.

To confirm these findings, we analyzed the data for the spring of 1997. A broad, strong

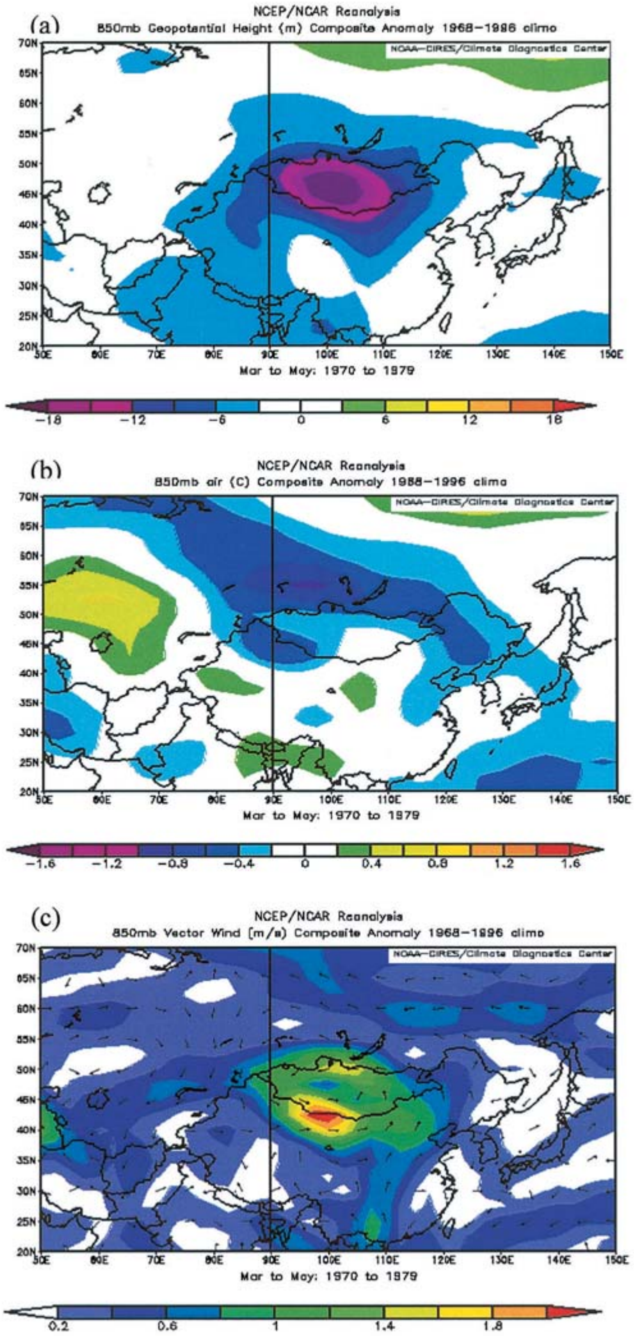

Fig. 5. Composite plots of the anomaly of (a) geopotential height, (b) temperature, and (c) wind on 850 hPa in springs of more MDS decade of 1970's.

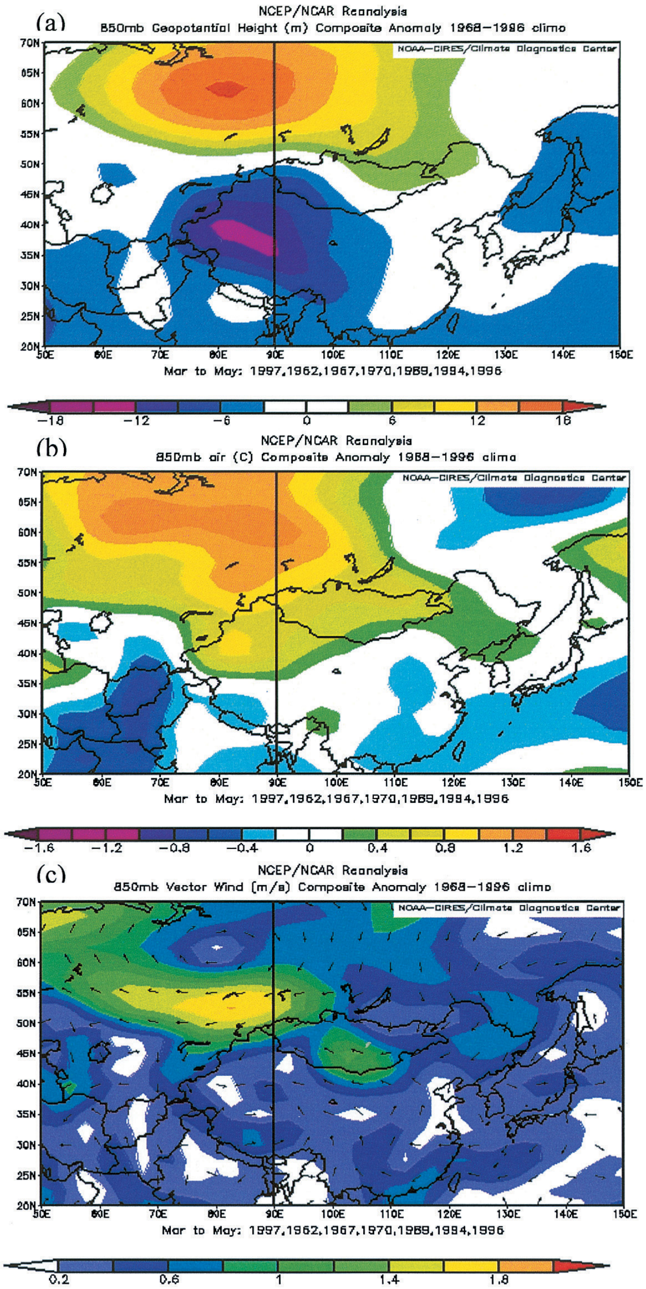

Fig. 6. Composite plots of the anomaly of (a) geopotential height, (b) temperature, (c) wind on 850 hPa in springs of seven less MDS years.

mean ridge coving China-Mongolia and Southwest Siberia appears at the mean geopotential height of 850 hPa (not shown). The spring mean 850 hPa height over Mongolia was 80 gpm higher in 1997 than in 1976. This strong ridge is accompanied by a weakened Southwest Siberian cold air mass characterized by a warm anomaly core of 5°C over Southwest Siberia and directly linked to a warming trend in Mid-Mongolia over the last 20 years. A strong anticyclonic wind anomaly appears over Southwest Siberia and Mongolia from 850 hPa to 500 hPa, associated with an easterly wind anomaly of 5 m s^{-1} around the China-Mongolia border which is unfavorable for dust storm initiation, resulting in no major dust storm event in the spring of 1997.

Similar circulation patterns are identified in the composite plots for the minor dust storm 1990's decade (Figs. 7a, b and c). A positive Mongolia height anomaly with a core of 16 gpm, a warm anomaly with a core of 1.2°C, and an anticyclonic wind anomaly over Southwest Siberia and Mongolia with about 2 m s^{-1} decreasing in westerly wind speed around the China-Mongolia border, all unfavorable for major dust storm initiation, dominate the 1990's and result in only 25 major dust storms events.

Briefly speaking, in minor dust storm springs the mean circulation at the mid- and lower-levels over China-Mongolia and Southwest Siberia are characterized by a weak Siberian cold air mass (or cold high), broad China-Mongolia ridge and weakened westerly wind speed around the China-Mongolia border. In other words, there were no favorable conditions for the NW- or N-route cold air route into NW China.

5. DISCUSSIONS AND CONCLUSIONS

In this paper, we discovered that the circulation patterns for major and minor dust storm springs were opposite to each other. Hence these differences show an intensified Siberian cold air mass over China-Mongolia and Southwest Siberia, dominant dust storm inducing troughs or cyclones over Mongolia, and a strong cyclonic wind anomaly with intensified westerly wind around the China-Mongolia border, especially on the China side. To further check the differences in the up- and down-stream areas, we analyzed the 1000 hPa potential temperature, which remains constant in a non-saturated, adiabatic process and is useful when tracing a moving air parcel. In the springs of the major dust storm 1970s decade, a negative anomaly area tilted from the Yamal Peninsula (about 68°N, 70°E) toward Northeast China (Fig. 8a). However, it became a warm tongue covering an even wider area in the 1990's (Fig. 8b). Consequently a northwest-southeast oriented axis of maximum difference extended from the Yamal Peninsula via Lake Baigal to Northeast China that then turned southward to Taiwan (Fig. 8c). This phenomenon suggests that cold air originating from Siberia moves much more efficiently south-eastward toward Northeast Asia in the springs of major dust storm years than in minor dust storm years, and hence spreads dust particles further southward and eastward.

We must note that the major dust storm events that occurred in the springs of the years 2000 and 2001 were something special. Most dust storms occur in Eastern Mongolia and the northern part of North China (Gao and Ren 2002), but not in Western China-Mongolia. Figure 9 shows composite plots at 850 hPa for these two springs. Compared with those of 1990's (Fig. 7),

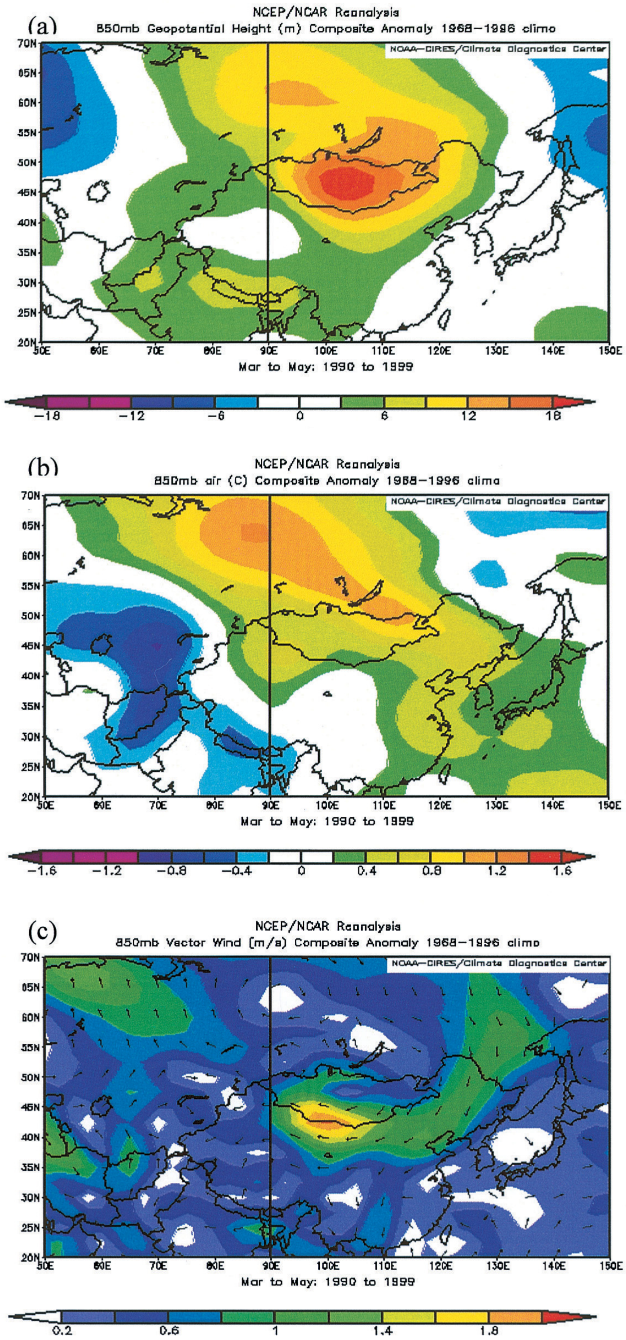

Fig. 7. Composite plots of the anomaly of (a) geopotential height, (b) temperature, and (c) wind on 850 hPa in springs of less MDS decade of 1990's.

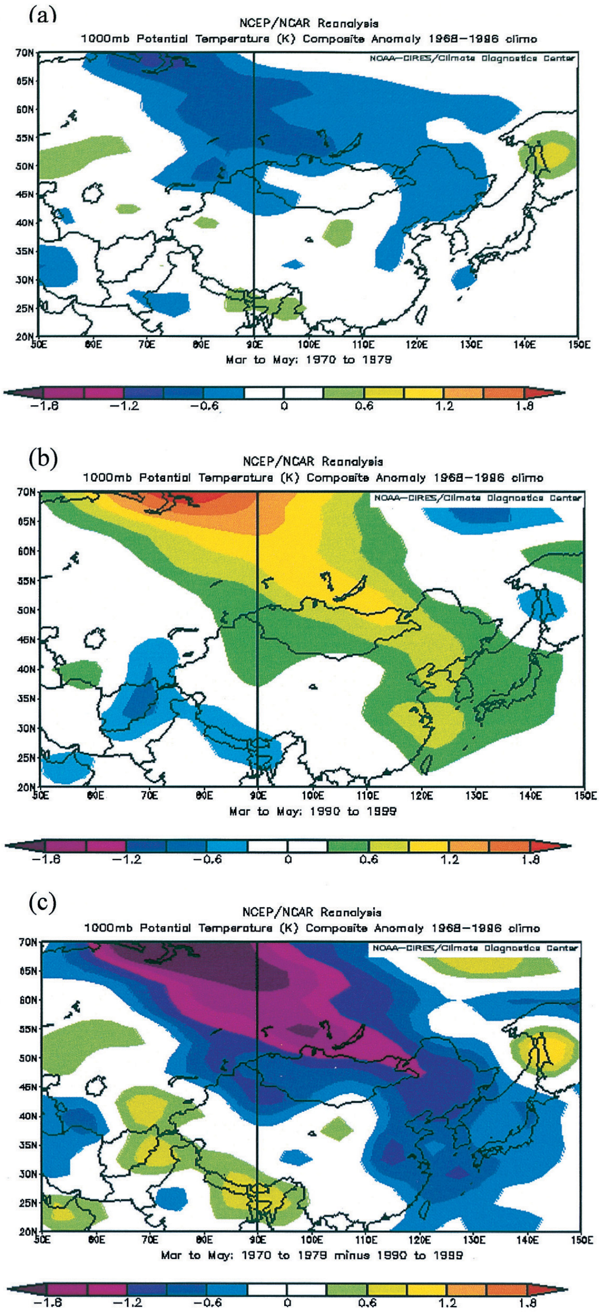

Fig. 8. Composite plots of the anomaly of 1000 hpa potential temperature in springs of (a) 1970's, (b) 1990's and (c) the differences of the latter from the former.

the positive height anomaly over China-Mongolia and a warm core over Southwest Siberia indicate that the China-Mongolia ridge remains strong. However, some vital differences exist. The differences are the negative height anomalies in and around the Japan Sea in association with a cyclonic wind anomaly over the same area. These phenomena suggest that Japan Sea troughs or cyclones were active during these two springs, but not the Okhotsk Sea cyclones as Qian et al. (2002) and Yoshino et al. (2002) suggested. Meanwhile, a northerly wind anomaly of 2 $m\ s^{-1}$ appears over Eastern Mongolia and the northern part of North China, producing favorable conditions for cold air to move into China along the NE-route (shown in Fig. 1) as Yoshino et al. (2002) indicated. This resulted in frequent dust storm events in these areas. At the same time, owing to an intensified westerly wind anomaly over Korea and a northerly wind anomaly over East China, dust particles were transported down-stream to Japan, Taiwan (Lin 2001), etc. Just as the importance of the Mongolia trough or cyclones are to dust storm initiation in Western China-Mongolia, the Japan Sea troughs or cyclones form the dust storm-inducing system for Eastern Mongolia and the northern part of North China. Therefore, these areas can be regarded as the Eastern China-Mongolia sub-regime with major dust storms occurring along the NE-route of cold air into China (Table 1). This is an important finding. Since there are more observation sites in Western China-Mongolia than in Eastern Mongolia, most researches in the past concentrated only on dust storms originating from Western China-Mongolia.

Climatologically, the China-Mongolia dust storm regime can be divided into west, east and southwest sub-regimes. For comparison, Table 1 lists the dust storm-inducing system, dust storm origin, cold air intrusion route and dust storm hit areas for each sub-regime (Qian et al. 2002; Qian et al. 2004). The characteristics of the Western and Eastern China-Mongolia sub-regimes have been previously discussed. Dust storms originating from Southwest China-Mongolia are induced by a warm low over Southern Xingjiang with cold air at the rear coming into Southern Xingjiang along the W-route track. Among these three sub-regimes, the Western China-Mongolia sub-regime is certainly the most dominant.

In the above, we deduce the circulation pattern characteristics in the springs of major and minor dust storm years or decades. This allows determining the inter-decadal change in dust storm activities. We have analyzed the 850 hPa geopotential height anomaly field for each decade. In the 1950's, a negative anomaly field covered nearly the entire Asian continent. This negative region gradually shrank in the 1960's. In the 1970's, with a large negative core centered over Mongolia (Fig. 5a), the isobaric surface on the lower-level over Mongolia rose until the 1980's. In the 1990's, a positive height anomaly centered over Mongolia appeared (Fig. 7a). Hence, the intensification of Mongolian cyclones resulted in increasing dust storm activities from the 1950's to the 1970's. Warming in Mongolia (Qian et al. 2002), especially in China-Mongolia border, which is in phase with the global warming trend since the 1980's, has caused the Mongolian cyclones to weaken, causing less dust storm activity in Western China-Mongolia from the 1980's to 1990's.

What can we expect for dust storm activities in the 2000 decade? Previous discussions indicated that active dust storm events in the springs of 2000 and 2001 were mainly in the Eastern China-Mongolia sub-regime and not in Western China-Mongolia. The intensification of Japan Sea cyclones plays a crucial role. However, in the springs of 2002 and 2003, the

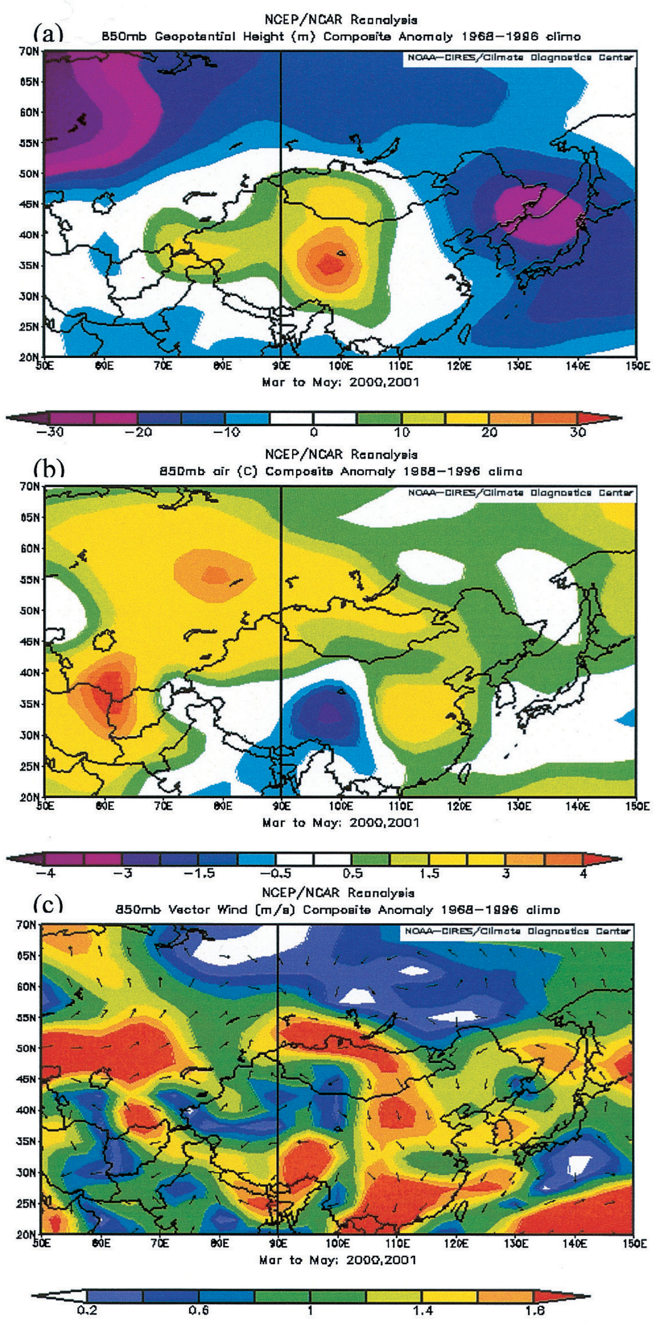

Fig. 9. Composite plots of the anomaly of (a) geopotential height, (b) temperature and (c) wind on 850 hPa in springs of years 2000 and 2001.

Japan Sea cyclones were weakened, resulting in weaker dust storm activities. Hence, if warming in the Northern part of China and Mongolia continues as predicted by the global warming trend (IPCC 2002), the China-Mongolia ridge will continue to rise and suppress Mongolian cyclones and dust storm activities in Western China-Mongolia. There is a trend towards positive height anomalies over the Japan Sea. The dust storm activities in Eastern China-Mongolia are not likely to strengthen. Certainly, desertification has been blamed for initiating dust storms. The fact that the desert area in North China has been expanding since the 1950's (Qin at al 2002) still cannot explain the gradually decreasing dust storm trend in Western China-Mongolia in the 1980's and the abrupt changes in recent years. Hence, the change of synoptic circulation is far more important than desertification. It is not likely that the 2000 decade will be an active dust storm period.

We conclude that:

1. Due to the differences in the dust storm-inducing system, dust origin, cold air intrusion track and dust storm areas, the dust storm activities over the China-Mongolia area can be divided into three sub-regimes (Table 1): West, East and Southwest China-Mongolia. The first western track is the most dominant sub-regime.

2. Stronger and more frequent cold air intrusions into China-Mongolia along NW- or N-routes (Fig. 1) in association with a stronger Siberian cold air mass, stronger and longer-stayed Mongolian troughs or cyclones, along with a much stronger westerly wind in Central and Western Inner Mongolia and the Gansu Corridor, are important dynamic factors causing major dust storm activities in Western China-Mongolia.

3. In contrast, weaker and less frequent cold air intrusions into China-Mongolia in association with a warmer Siberia air mass, stronger and longer remaining Xingjiang ridges, along with a weaker westerly wind in Central and Western Inner Mongolia and the Gansu Corridor, are important dynamic factors causing fewer major dust storms in Western China-Mongolia.

4. The synoptic circulation characteristics of major and minor dust storm spring periods tend to last over a decade long. The inter-annual and inter-decadal variations in dust storm occurrences in the last five decades resulted mainly from the change in synoptic circulations. While desertification may play some roles, it is not a crucial factor.

5. In the springs of more major dust storms in Eastern China-Mongolia, China-Mongolia ridges and Japan Sea troughs or cyclones became dominant which caused frequent dust storms along the NE cold air intrusion route (Fig. 1).

6. Warming in the Northern part of China and Mongolia and Southwest Siberia very likely causes weakening in the Siberian cold air mass and intensification of the Xingjiang ridges in the springs since 1980. If global warming continues, we can be almost certain that the 2000 decade will not be a major dust storm decade.

Acknowledgments This research is supported by the National Science Council, R.O.C. under grants NSC91-2621-Z-002-007 and NSC92-2621-Z-002-026. Support from the Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Science, Lanzhou, China, are also appreciated. The authors thank the NOAA-CIRES Climate Diagnostics Center, Boulder Colorado, USA for providing needed images from their Web site at http://www.cdc.noaa.gov/. Also, we appreciate the encouragement and suggestions from Prof. Shaw C. Liu. Many thanks to Dr. Y Cai for her help in preparing this manuscript.

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