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A Composite Study of Synoptic Differences between More and Less Major Dust Storms Springs over China-Mongolia Areas

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Abstract

To comprehensively understand the mean circulations and their differences between more and less major dust storms (MDS) springs over China-Mongolia (CM) and to improve the short-range prediction of MDS inter-annual changes, multi-cases, multi-elements composite analyses of circulations between more and less MDS over CM are exercised, utilizing the NCEP/NCAR reanalysis gridded data. The main conclusions are as follows: 1) Due to differences in the DS-inducing system, dust origin, route of cold air and main DS-hit areas, the CM DS regime can be divided into the West, East and Southwest CM sub-regimes. 2) During springs of more MDS in West CM, circulations on the mid-and lower-levels are characterized by a deeper and stronger Siberia high, dominated troughs or cyclones in and around Mongolia, and intensified westerly wind around the border of CM, with cold air moving frequently along the Northwest or North routes into China. During springs of less MDS in West MDS, the pattern is altered toward lesser cold air intrusions. 3) During springs of more MDS in East CM, circulations on the mid- and lower-levels are characterized by the dominated CM ridges and the troughs or cyclones in and around Japan Sea, with cold air moving frequently along the Northeast routes into China. 4) The inter-annual and inter-decadal variations of DS occurrences in the last five decades are related closely to the changes of synoptic circulations. 5) Warming in Mongolia and Southwest Siberia is accompanied with the weakening of Siberia cold air mass and the intensification of the Xingjiang ridges in springs since 1980's, which are unfavorable for a frequent initiation of MDS. Hence, if warming in this region continues as in phase with the current global warming trend, DS activities would get weaken in the near future.

Key words: China Mongolia dust storm, composite study, synoptic circulation.

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1. **Selection of More and Less MDS Years and Decades**

CM DS issue receive a growing attention in the world recently (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) point out that in North China, the MDS often occurs in Gansu Corridor with the highest occurring frequency centered at Minqin; southern edge of South Xingjiang Basin, centered at Hetian; west Inner Mongolia (IM), centered at Guaizihu; middle IM, centered at Yikwusu and Zhurihe (Fig. 1). Most deserts in North China are surrounded by mountains; only air flows with specific direction passing through deserts are capable of initiating dust storms of different scale of intensity. Fig. 1 shows that there are four major routes of cold air coming from Siberia into China: west (W), northwest (NW), north (N) and northeast (NE) routes. Among them north route consists of two branches. Clearly, dust storms appear mainly on the route of cold air intrusion.

In this paper, we have analyzed and compared the composite circulation features in springs of more and less MDS years. The dataset used is the NCEP/NCAR reanalysis gridded data from 1950 to 2003 (Kalnay et al, 1996), while the images are downloaded from the web site of NOAA-CIRES Climate Diagnostics Center.

The MDS frequency data come from the Data Center of China Meteorological Administration. Although DS events appear all year round, most occurs in spring. According to Qian and Song et al., (2002), 63% of MDS events have happened in spring, while events reported in other seasons are considerably less and sporadic. For simplicity, we have decided to concentrate only on MDS happened in spring (Fig. 2). The spring months refer to March, April and May (MAM).

Fig. 2 shows the spring MDS frequency variations in West and Southwest CM sub-regimes (defined in Table 1) from 1952 to 2003. On the average, there are about four MDS events every spring, but in some years, like 1959, 1969, 1976, 1979 and 1983, 8~10 events are reported, which is more than normal, and hence these years are chosen as the more MDS years; some like 1962, 1967, 1970, 1989, 1994, 1996 and 1997, as few as 0~1 events only, are chosen as the less MDS years. Note that all these case years scattered randomly in past decades. In addition, MDS counted in 50's, 60's, 70's, 80's and 90's are 21, 44, 60, 35, and 25, respectively. Total events happened during 2000 ~ 2003 are 15. Hence, 1970's (1970 ~ 1979) is chosen as the more MDS decade, while 1990's the less MDS decade.

It must be noted that the selection of more or less MDS years are based on MDS events happened in West and Southwest CM, while according to Yoshino et al (2002), most MDS happened in years 2000 and 2001 were in East-CM.

2. Discussions and Conclusions

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In this paper, we discover that the circulation patterns of more and less MDS springs are just opposite to each other. Colder Siberia air mass, stronger and longer stayed troughs or cyclones in and around Mongolia, and stronger mid- and lower-level westerly wind around the border of CM are key features leading to more MDS in West CM spring. Meanwhile, in less MDS springs the mean circulation on the mid- and lower-levels over CM and SW Siberia are characterized by weak Siberia cold air mass (or cold high), broad CM ridge and weakened westerly wind speed around the border of CM. In other words, there is no favorable condition for NW- or N-route cold air into NW China. To further check the differences over up- and down-stream areas, we have analyzed the element of 1000hPa potential temperature which remains constant in a non-saturated, adiabatic process and is useful when tracing a moving air parcel. In springs of more MDS decade of 1970’s, area of negative anomaly tilted from the Yamal Peninsula (about 68ºN, 70ºE) toward Northeast China (Fig. 3a), however it becomes a warm tongue covering even wider area in springs of 1990’s (Fig. 3b). Consequently a NW-SE (northwest-southeast) oriented axis of maximum difference extends from Yamal Peninsula via Lake Baigal to Northeast China then turns southward to Taiwan (Fig. 3c). This phenomenon suggests that cold air originated from Siberia moves much more efficiently south-eastward toward NE Asia in springs of more MDS than those of less MDS and hence spreading dust particles further southward and eastward.

Climatologically, the CM DS regime can be divided into West, East and Southwest sub-regimes. For comparison, table 1 lists the DS-inducing system, DS origin, cold air intrusion route and DS hit areas of each sub-regime (Qian et al, 2002; Qian et al, 2004). The characteristics of West and East CM sub-regimes have been discussed previously. As to DS originated from Southwest CM, the major DS-inducing system is a heat low over South Xingjiang with the cold air rear of it coming into South Xingjiang along the W-route track. Among these three sub-regimes, the West CM sub-regime is certainly the most dominate one.

In this paper, we also note that the characteristics of circulation patterns in springs of more or less MDS years are preserved in springs of more or less MDS decade. This is helpful to study the inter-decadal change of DS activities. Here, we have analyzed the 850hPa geopotential height anomaly field of springs of each decade. In 1950's, a negative anomaly field covers almost the whole Asia continent. This negative region gradually shrinks in 1960’s, then in 1970’s, with a largest negative core centered over Mongolia. Later on, the isobaric surface on the lower-level over Mongolia has been rising since 1980's. In 1990s’, positive height anomaly centered over Mongolia appears. Hence, the intensification of Mongolia cyclones has resulted in active DS break out from 1950's to 1970's, while warming in Mongolia (Qian et al., 2002) which is in phase with the global warming trend since 1980’s, has caused the Mongolia cyclones weakened and therefore lesser activities of DS in West CM from 1980's to 1990's.

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In all, we conclude that:

1. Due to the differences in the DS-inducing system, dust origin, intrusion track of cold air and DS-hit areas, the DS activities over CM area can be divided into three sub-regimes (Table 1): West, East and Southwest CM. The first one is the most dominated sub-regime.

2. Stronger and more frequent cold air intrusions into CM along NW- or N-routes (Fig. 1) in association with the existence of stronger Siberia cold air mass, stronger and longer-stayed Mongolia troughs or cyclones, along with the much stronger westerly wind in Middle and West IM and Gansu Corridor, are important dynamic factors causing more MDS activities in West CM.

3. In contrast, weaker and lesser frequent cold air intrusion into CM in association with the existence of warmer Siberia air mass, stronger and longer-stayed Xingjiang ridges, along with the weaker westerly wind in Middle and West IM and Gansu Corridor, are important dynamic factors causing lesser MDS activities in West CM.

4. Synoptic circulation characteristics of more or less MDS springs are well kept in springs of a decade long. The inter-annual and inter-decadal variations of DS occurrences in the last five decades are resulted mainly from the change of synoptic circulations, while desertification may aid some flavor into the scene but definitely not a crucial factor.

5. In springs of more MDS happened in East CM, CM ridges and Japan Sea troughs or cyclones dominate, which causes frequent DS along the NE route of cold air intrusion (Fig. 1).

6. Warming in Mongolia and Southwest Siberia is very likely causing the weakening of Siberia cold air mass and intensification of the Xingjiang ridges in springs since 1980's. If global warming continues, we can almost certain that 2000's will not be a more MDS decade.

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Table 1：Summary of characteristics of three sub-regimes of China-Mongolia(CM) duststorm(DS) area.

Sub-Regimes	DS-inducing system	dust origin	cold air intrusion route (referring to Fig.1)	DS-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 CM	NW or N route	most areas of CM, Korea, Japan, and Taiwan
South-west	South Xingjiang heat lows	South Xingjiang	W route	South Xingjiang, west Gansu Corridor, Tsaidam Basin

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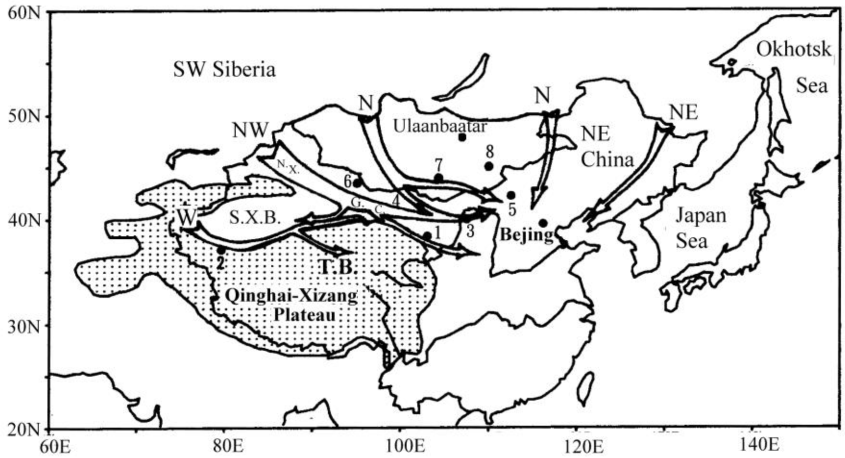

Figure 1: Map of China-Mongolia (CM) area and major dust tracks. In the figure, W, NW, N and NE stand for the western, northwestern, northern and northeastern route, respectively. S.X.B. and T.B. stand for the Southern Xinjiang Basin and the Tsaidam Basin, respectively. N.X. and G.C. stand for northern 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.

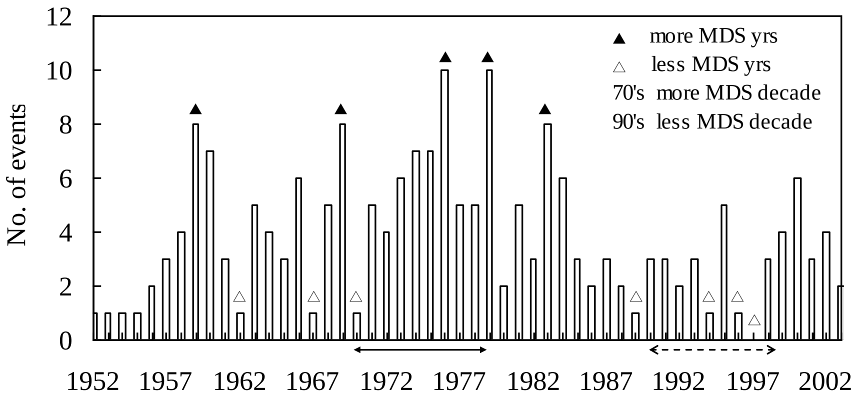

Figure 2: Yearly change of the No. of spring Major Dust Storm (MDS) events in West and Southwest CM (defined in Table 1) during 1952 ~2003.

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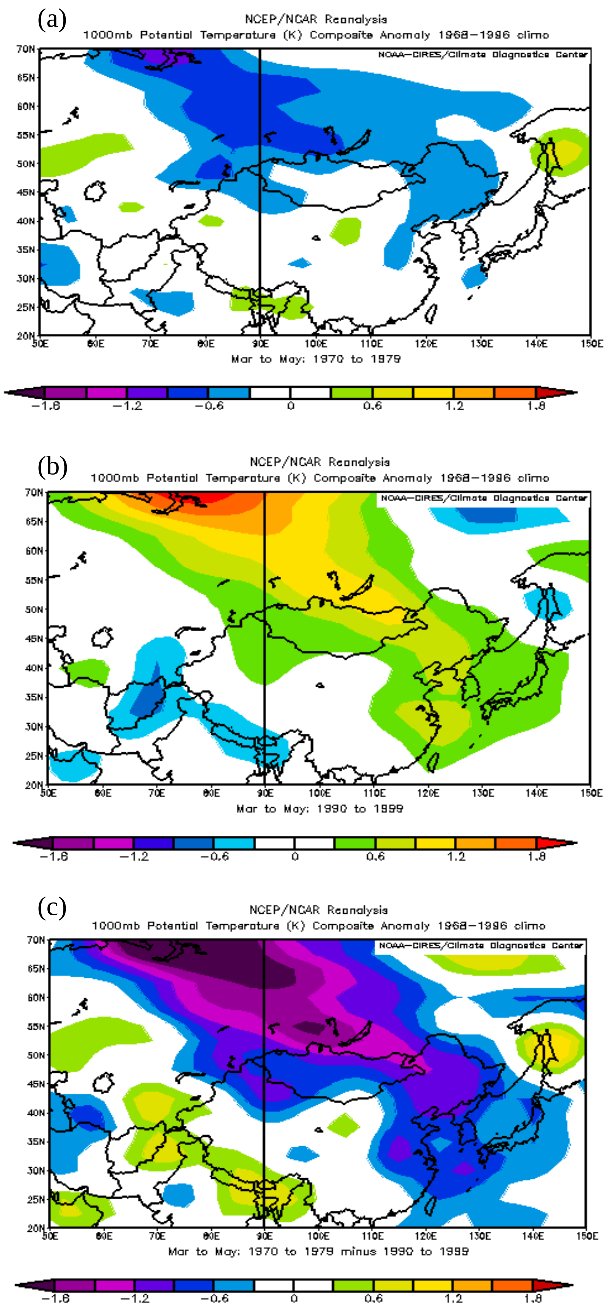

Figure 3: Composite plots of the anomaly of 1000hpa potential temperature in springs of (a) 1970's, (b) 1990's and (c) the differences of the latter from the former.