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Regional characteristics of dust events in China

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The regional characteristics of dust events in China has been mainly studied by using the data of dust storm, wind-blown sand and floating dust from 338 observation stations through China from 1954 to 2000. The results of this study are as follows: (1) In China, there are two high frequent areas of dust events, one is located in the area of Minfeng and Hotan in the South Xinjiang Basin, the other is situated in the area of Minqin and Jilantai in the Hexi Region. Furthermore, the spatial distributions of the various types of dust events are different. The dust storms mainly occur in the arid and semiarid areas covering the deserts and the areas undergoing desertification in northern China. Wind-blown sand and floating-dust not only occur in the areas where dust storms occur, but also extend to the neighboring areas. The range of wind-blown sand extends northeastward and southeastward, but floating-dust mainly extends southeastward to the low-latitude region such as the East China Plain and the area of the middle and lower reaches of the Yangtze River. Compared with wind-blown sand, the floating-dust seldom occurs in the high latitude areas such as North Xinjiang and Northeast China. (2) The affected areas of dust storms can be divided into seven sub-regions, that is, North Xinjiang Region, South Xinjiang Region, Hexi Region, Qaidam Basin Region, Hetao Region, Northeastern China Region and Qinghai-Xizang (Tibet) Region. The area of the most frequent occurrence of dust storms and floating-dust is in South Xinjiang Region, and of wind-blown sand in the Hexi Region. In general, the frequency of dust events in all the seven regions shows a decreasing tendency from 1954 to 2000, but there are certain differences between various dust events in different regions. The maximum interannual change and variance of dust events during this time happened in South Xinjiang Region and Hexi Region. The dust events generally occur most frequently in April in most parts of China. The spring occurred days of dust events occupied 60-70% of the whole year in Hetao Region and Northeastern China Region. However, in South Xinjiang Region and North Xinjiang Region, which was less affected by monsoon climate, dust events may occur at any time of the year, less than 50% of the events in this region occur during spring. In the remaining three regions 50-60% of the dust events occur in spring of a year.

Regional characteristics of dust events in China WANG Shigong1, WANG Jinyan1, ZHOU Zijiang2, SHANG Kezheng1, YANG Debao1, ZHAO Zongsuo3 (1. Department of Atmospheric Science, College of Resources & Environment, Lanzhou University, Lanzhou 730000, China; 2. National Meteorological Center, Beijing 100081, China; 3. 93864 Army 75 Unit Xinjiang, Changji 831112, China) Abstract: Key words: CLC number: A severe dust storm occurred over East Asia in the middle ten days of April 1998. After one week, its dust plume affected the continent of North America. This attracted the attention of many scientists in the related countries to dust storms. In recent years the number of dust storms has been increasing in China. It is not only an important symptom of desertification from slower change to faster change, but also a reflection of the synthesis of environmental states, including climate, ecosystem and soil, which are all deteriorating to some degrees. According to the definition of Meteorological Observing Criterion (National Weather Bureau of China, 1979), dust storms, wind-blown sand and floating dust belong to a category called dust events. Among them, the dust storm is generally defined as a storm that carries a great deal of dust and sand and is formed by strong winds which blow up a lot of dust and sand into the boundary layer or lower troposphere. This severe weather phenomenon makes air seriously polluted and reduces horizontal visibility to less than 1,000 m. A severe dust storm with maximal destructive force can reduce surface horizontal visibility to less than 50 m, even 0 m, which is then called a "Black Storm". Wind-blown sand is generally defined as a weather phenomenon that is caused by strong winds carrying a lot of dust and sand, and reduce horizontal visibility to 10,000-1,000 m. Floating dust is generally defined as another weathe r phenomenon for which fine dust suspends in lower troposphere with horizontal visibility of less than 10,000 m. It occurs usually when dust is transported by air flow from the mid and lower troposphere, or when fine dust still suspends in air after a dust storm. These classifications show that the dust storm is the most severe of the three kinds of dust events. Especially a severe dust storm can cause a great loss of lives and property damage (Zhao, 1993). The investigation of spatial and temporal distribution characteristics of dust storms as a basis began to be studied early. The effort has been made to understand spatial distribution characteristics of dust storms in South and Central America and in the Sahara Desert of Africa since the 1930s. The distribution of dust storms in Mexico City was systematically studied (Jauregui, 1989); the spatial and temporal distribution of dust caused by wind erosion in the United States was also investigated by Gillette (1990); the spatial and temporal distribution of dust storms occurred in New Mexico of USA was studied by using detailed observational data (Snow, 1990). Up to now it has been found that there are mainly four high frequency regions of dust events which are associated with the large desert and its surrounding areas, such as Central Asia, North America, Central Africa and Central Australia (Yan, 1993). In China, dust storms began to be studied in the 1970s (Xu, 1979). Great advances have been achieved to identify spatial and temporal distribution characteristics of dust storms including their sources and paths (Wang et al., 1995-1996; Xu et al., 1997; Zhou, 2001; Qiu, 2001). However, few investigations have been carried out concerning wind-blown sand and floating dust, especially about regional characteristics of dust events in China. On the basis of the compilation of the 47-year data of dust events, this paper emphasizes the analyses of the regional characteristics of dust storms, wind-blown sand and floating dust in China, so that a scientific basis will be provided for preventing and reducing their disastrous consequences. 1 Data and methods 1.1 Data For this investigation, the data of dust storms, wind-blown sand and floating dust that occurred, were compiled from 338 meteorological observing stations throughout China from 1954 to 2000, are used. (During 1951-1953, the observing standards of dust event´s data were different from those of 1954 and after, and the number of the observing stations was smaller, thus we omitted the data during 1951-1953. In addition, because of sparsity of observing stations and data degradation in southwestern Qinghai-Xizang Region, this area has not been analyzed for this study). The monthly occurred days of dust storms, wind-blown sand and floating dust were regarded as token indexes. All of these data came from the National Center for Climatological Data in Beijing. 1.2 Methods A method of clustered analysis was used to investigate the regional division of dust events in China. The monthly days of dust storms that occurred were regarded as the main factors. We made use of the method of stratified cluster by which each occurrence is classified into appropriate categories. Detailed steps were: (1) the original data were first standardized; (2) each variable was regarded as one kind and calculated correlation coefficient; (3) two variables were united to a new kind according to the maximum correlation coefficient; (4) the correlations between new kinds and other kinds were calculated; and (5) the steps (2)-(4) were repeated until all kinds united to one big kind. To study the changes of dust events in each region, a mean interannual variability was calculated. Expressions of mean interannual variation: Mean interannual variability (D - D), where Di is the annual number of days for which any type of dust events was observed at any meteorological observing station for any given year, n is the number of years, i = 1, 2, 3, ... n-1. The unit is days per year. In addition, the data of dust events in the whole country had been standardized before the variance was calculated, then the variances of dust events in various regions were respectively calculated. In this paper, the methods for standardization and calculation of variance and correlation coefficient were adopted, and the conventional calculation methods from The Methods of Statistical Analysis and Forecasting in Meteorology (Huang, 1979) were applied. 2 Spatial distribution characteristics of dust events 2.1 Spatial distributions of various types of dust events in all of China and their climatic characteristics 2.1.1 The spatial distributions of various types of dust events The data of dust events observed by 338 meteorological observing stations in China during 1954-2000 have statistically been analyzed (Figure 1). To reveal further the spatial distribution differences between these three types of dust events, we drew the spatial distribution of the areas in which only the wind-blown sand or floating dust occurred without the occurrence of dust storms (Figure 2). Figure 1a shows that the spatial distribution of the dust storms is basically similar to that of the desert and the areas undergoing desertification (Zhu et al., 1994). This reflects that both the surface characteristics and the distribution of dust sources play an important role in the formation of dust storms. Figure 1a also indicates that South Xinjiang Basin, Hexi Region, and northeastern Qinghai-Xizang Plateau are the places where the 47-year mean annual days for which dust storms that occurred is more than 10 days. These regions all lie in the deserts and their neighboring areas. Of these three areas, the bulls eye for the highest annual mean days of dust storms with 35.8 days is at Minfeng (37o04´N, 82o43´E) in South Xinjiang Basin, the second one with 28.1 days is located at Minqin (38o38´N, 103o05´E) in the northeastern Hexi Region. Figure 1b shows that the spatial distribution of high frequency areas of wind-blown sand is basically consistent with tha t of dust storms, and is also located in South Xinjiang Basin and Hexi Region. However, compared with sand storms, the 47-year mean annual occurred days of the wind-blown sand increases remarkably. For example, there are 81.1 (versus 35.8 days) days at Minfeng of South Xinjiang Basin and 97.2 days at Jilantai (39o50´N, 105o24´E) in the Hexi Region. In addition, the spatial distribution range of wind-blown sand extended noticeably to Northeastern China and the East China Plain, and reached the Yangtze Valley beyond the area where the dust storms generally occur (Figure 2a). In comparison with dust storms and wind-blown sand, the mean annual days of the floating dust that occurred are the highest; for example, the 47-year mean annual days for which floating dust that occurred are 209 days at Hotan (37o08´N, 79o56´E) of South Xinjiang Basin and are 70 days at Jilantai of Hexi Region. It is obviously seen by comparing both Figures 1a and 1c with Figure 2b carefully that floating dust seldom occurred in the high latitude areas such as North Xinjiang and Northeastern China. And the influenced ranges of the floating-dust mainly extended southeastward, and reached the lower-latitude regions such as the East China Plain and the area of the middle and lower reaches of the Yangtze River. This shows that not only dust storms and wind-blown sand harmed their local areas, but also the dust swept off by them could be transported to downwind regions, where floating dust was formed and affected a larger range. 2.1.2 Climatic characteristics in various dust events´ areas in China In order to understand the differences of the climatic states among dust storms, wind-blown sand, and floating dust, we analyzed the climatic elements such as annual precipitation and annual mean surface air temperature in the occurred area of dust storms, the extended area of wind-blown sand without dust storm, and the extended area of floating dust without dust storm respectively. The analytical results (Table 1) indicates that the 47-year mean annual precipitation in the region of dust storm was 198.5 mm, a little lower than the annual precipitation critical value (200 mm) between arid and semiarid area according to the routine index of divided climate. The maximum of 47-year mean annual precipitation in the region susceptible of dust storms was 648.7 mm, which is within the range of annual precipitation in the transitional area from semi-arid area to sub-humid area. The minimum of 47-year mean annual precipitation in the region of dust storms was 17.5 mm, which is within the range of mean annual precipitation in most arid areas. The range of 47-year mean annual precipitation in the extended area of wind-blown sand was from 192.2 mm to 1188.7 mm, that is, from arid areas to humid areas; and its mean was 589.1 mm, belonging to the range of annual precipitation in the sub-humid area. The range of 47-year mean annual precipitation in the extended area of floating dust was from 434.3 mm to 1274.2 mm, that is, from semiarid area to humid area; and its mean was 708.2 mm, being close to the range of annual precipitation in the humid area. In addition, Table 1 also shows that the 47-year mean temperatures in the areas of dust storms, extended areas of wind-blown sand, and of floating dust increased progressively in turn. 2.2 Regional division of dust events and their changes in various regions 2.2.1 Regional division of dust events It is necessary that the dust events are divided and studied according to their regional characteristics, since their spatial distributions are closely associated with vegetation coverage, specific geographical conditions, surface ecological environmental status, and synoptic and climatic systems. The regions of desert and the regions undergoing desertification in northern China were divided into six sub-regions, and there were certain differences in temperature, precipitation and moisture degree among these six sub-regions (Shang et al., 2001). These results provided a basis for the regional division of dust events. Additionally two conceptions need to be clarified: one is that the source regions of dust events are mainly coincident with the areas of dust storms, the other is that the influenced regions of dust events are only the areas directly affected to some extent by wind-blown sand and/or floating dust. According to the days and time of occurrences of dust storms in the last 47 years, the regional division of dust events was done by means of cluster analysis. The results are as follows: The Xinjiang Region is divided by the Tianshan Mountains into North Xinjiang Region and South Xinjiang Region; both the Hexi Region and the Hetao Region are divided by the Helan Mountain Range which are generally regarded as the boundary line between arid and semiarid areas; both Hetao Region and Northeastern China Region are divided by the Taihang Mountain Range which are generally regarded as the boundary line between semiarid and sub-humid areas. In addition, the Qaidam Basin Desert is separated from the Qinghai-Xizang Plateau. Thus the areas of dust events in China are divided into seven sub-regions (Figure 3): (1) North Xinjiang Region (from the north side of the Tianshan Mountain Range to the south side of the Altay Mountain Range, including the Gurbantunggut Desert); (2) South Xinjiang Region (including the Taklimakan Desert, the Kumutage Desert and its neighboring areas); (3) Hexi Region (from the north side of the Qilianshan Mountain Range to the west side of the Helan Mountain Range, including the Badain Jaran Desert and the Tengger Desert); (4) Qaidam Basin Region (from the south side of the Qilian Mountain Range to the north side of the Bayan Xar Mountain Range, including the Qaidam Basin Desert); (5) Hetao Region (from the east side of the Helan Mountain Range to the west side of the Taihang Mountain Range, including the Ulan Buh Desert, the Hobq Desert and the Mu Us Desert); (6) Northeastern China Region (from the east side of the Taihang Mountain Range to semiarid areas in No rtheastern China, including the sandy lands of Houshang, Horqin and Hulun Buir); and (7) Qinghai-Xizang Region (from southern Qinghai to northeastern Xizang, i.e.,starting from the southern Bayan Xar Mountain Range to the northern Himalayan Mountain Range). The divisions of dust events are basically consistent with the normally accepted divisions of climate in China. 2.2.2 The states of dust events in each region and their interannual changes The 47-year changes of various dust events in each region were statistically analyzed according to the given regional divisions of dust storms above. The regional mean results showed that the maximum of the mean annual days for dust storms that occurred was 13.6 days in South Xinjiang Region, the second was 12.8 days in Hexi Region, and the minimum was 1.6 days in Northeastern China Region; the maximum of the mean annual days for which wind-blown sand occurred was 47.1 days in Hexi Region, the second was 41.4 days in South Xinjiang Region, and the minimum was 5.1 days in North Xinjiang Region; the maximum of the mean annual days for floating dust that occurred was 94.4 days in South Xinjiang Region, the second was 21 days in Hexi Region, and the minimum was 1.3 days in North Xinjiang Region. The statistical results concerning the occurred days of various dust events changed from 1954 to 2000 in each region are as follows: The maximum of 47-year mean descending rate of dust storms was 0.53 days per year in the Qinghai-Xizang Region, the second was 0.42 days per year in South Xinjiang Region. The maximum of 47-year mean descending rate of wind-blown sand was 0.67 days per year in the Qaidam Basin Region, the second was 0.62 days per year in South Xinjiang Region. The maximum of 47-year mean descending rate of floating dust was 0.85 days per year in Hexi Region, the second one was 0.66 days per year in the Qaidam Basin Region. In order to contrast directly the differences between various dust storms in different regions, the Nanjiang Region, Hexi Region, Qaidam Basin Region and Northeastern China Region are chosen as four representative regions, and the curves of interannual variation of mean annual occurred days of various dust events in the four regions have been drawn (Figure 4). Figure 4a shows that, in general, mean annual occurred days of dust storms monotonously decreased with fluctuation in the four regions from 1954 to 2000. Among them, the maximum of annual occurred days of dust storms existed in the mid-1950s. After that it began to decrease, especially from the mid-1970s to the mid-1990s it decreased quickly in South Xinjiang Region and Hexi Region. It reached the minimum in 1997, since 1998 it has been increasing. Figures 4b and 4c show that the interannual variation of regional mean annual occurred days of wind-blown sand and floating dust are different slightly from that of the dust storm, they increased with fluctuation from the mid-1950s to the mid-1970s and reached their peaks in the mid-1970s, then decreased until 1997. The annual occurred days of wind-blown sand in the four regions have been increasing again since 1998, but those of floating dust do not evidently reveal this phenomenon. Table 2 showed that the maximum variances of days of both dust storms and wind-blown sand existed in South Xinjiang Region, while those of floating dust occurred in Hexi Region. These are consistent with the distributions of 47-year mean maximum days of them and indicated that the maximum interannual variabilities of dust events occurred in the source areas of them. Furthermore, Table 2 showed that, of the three kinds of dust events, both interannual variabilities of dust storms in the same region and their differences between different regions were all maximum. This indicated that the effects of the factors of climate and surface conditions on dust storm´s occurrence were primary, their influences on wind-blown sand were the secondary, and the effects on floating dust were tertiary. 2.2.3 Annual variations of dust events in each region The percentages of 47-year mean days for dust storms, wind-blown sand and floating dust that occurred in different regions in every month in China are given (Tables 3-5). It is showed that the maximum percentages of 47-year mean occurred days of dust events as a whole occurred usually in April in most parts of China. But in Qinghai-Xizang Region, the month in which dust storm and wind-blown sand occurred with the most frequency was February, and the month in which floating dust occurred with the most frequency was March. However, the month in which wind-blown sand occurred with the most frequency was May in the whole Xinjiang Region including North Xinjiang Region and South Xinjiang Region, but dust storms occurred with the most frequency in May in South Xinjiang Region only. The statistics (Tables 3-5) also indicated that, of the seven different sub-regions, both Hetao Region and Northeastern China Region were obviously affected by monsoon climate. The months in which dust events occurred with high frequency were relatively centralized and mainly concentrated in the spring (March, April and May). The spring occurred days of dust events occupied 60-70% of the whole year. However, in Xinjiang Region, which was less affected by monsoon climate, dust events may occur at any time of the year, less than 50% of the events in this region occur during the spring. In the remaining three regions, 50-60% of the dust events for one year occur in the spring. 3 Conclusions and discussion In this paper, the main conclusions can be drawn as follows: (1) In China, there are two high frequent centers of dust events: One lies in the region of Minfeng and Hotan in the South Xinjiang Basin, the other is located in the region of Minqin and Jilantai in Hexi Region. In South Xinjiang Region, the maximum of 47-year mean annual days of dust storms was 35.8 days; wind-blown sand, 81.1 days; and floating dust, 209 days. In the center of Hexi Region, their maximums were 28.1 days, 97.2 days and 70 days respectively. Fu

rthermore, the spatial distributions of the various types of dust events were different. The dust storms mainly occurred in the arid and semiarid areas covering the deserts and desertification lands in northern China. The wind-blown sand and floating-dust not only occurred in the areas where dust storms occurred, but also extended to its neighboring areas. The influenced range of wind-blown sand extended northeastward and southeastward. But floating-dust mainly extended southeastward to the low-latitude regions such as the East China Plain and the area of the middle and lower reaches of the Yangtze River. Compared with wind-blown sand, the floating-dust very seldom occurred in the high latitude areas such as North Xinjiang and Northeastern China. (2) The areas in which dust storms occurred can be divided into seven sub-regions by cluster analysis with reference to the division of arid climate in China; These are North Xinjiang Region, South Xinjiang Region, Hexi Region, Qaidam Basin Region, Hetao Region, Northeastern China Region and Qinghai-Xizang Region. The dust storms and floating dust occurred with the most frequency in South Xinjiang Region, while wind-blown sand occurred with the most frequency in Hexi Region. The spatial averages of the 47-year mean annual occurred days of them in the three areas were 13.6 days, 94.4 days, and 47.1 days respectively. The occurrences of dust events generally decreased with fluctuation in all the seven regions from 1954 to 2000, but there are certain differences between various dust events in different regions. Among them, the maximum of annual occurred days of dust storms existed in each region in the mid-1950s. After that it began to decrease, especially from the mid-1970s to the mid-1990s it decreased quickly in the Nanjiang Region and Hexi Region. It reached the minimum in 1997, then has been increasing since 1998. The interannual variations of regional mean annual occurred days of wind-blown sand and floating dust are different slightly from that of the dust storm, they increased with fluctuation from the mid-1950s to the mid-1970s and reached their peaks in the mid-1970s, then decreased until 1997. The annual occurred days of wind-blown sand in four regions have been increasing again since 1998, but those of floating dust do not evidently reveal this phenomenon. The maximum variances of days of both dust storms and wind-blown sand existed in South Xinjiang Region, while those of floating dust occurred in Hexi Region. The dust events generally occur most frequently in April in most parts of China. The spring occurred days of dust events occupied 60-70% of the whole year in Hetao Region and Northeastern China Region, which were obviously affected by monsoon climate. However, in Xinjiang Region, which was less affected by monsoon climate, dust events may occur in any time of the year, less than 50% of the events in this region occur during the spring. In the remaining three regions 50-60% of the dust events for one year occur in the spring. In addition, there are two problems to be resolved: (1) Although the occurred days of dust storms and floating dust were more in South Xinjiang Region than in Hexi Region, the annual occurred days of wind-blown sand and its variance were less in South Xinjiang Region than in Hexi Region. This problem needs to be researched further. Maybe there are other influencing factors besides the obvious occurrence of high surface wind speed in Hexi Region owing to the role of its special terrain. (2) Although the dust storms and wind-blown sand occurred more in the high latitude areas of North Xinjiang Region and in Northeastern China Region, why did the floating dust occur there very seldom? References

关键词： dust events; regional characteristics

