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Typical severe dust storms in northern China during 1954—2002

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Abstract **Based on China's available daily observation data from 681 national meteorological stations from 1954 to 2002, a time series of typical severe dust storms in northern China is constructed in terms of the weather process, and the temporal and spatial distribution, and their evolution tendency is analyzed. The results indicate that there were 223 relatively typical severe dust storms in northern China from 1954 to 2002, among which the event on April 10—12, 1979 had the largest affected area. Closely associated with the geographical distribution of deserts, sandy lands and the tracks of strong cold air outbreaks, severe dust storms mainly occurred in the Tarim Basin, the eastern part of Northwest China and the northern part of North China. The season with the most frequent severe dust storms was spring, in which the frequency accounts for 82.5% in the whole year, while the least occurrence was in summer and autumn. During the past 49 years, the highest frequency of severe dust storms occurred in the 1950s and the lowest was in the 1990s with a general descending tendency, but during 2000—2002 the occurrence was relatively increasing. On the average, the duration of severe dust storms was shortest in the 1990s, about 0.5—1 h shorter than that in the other 4 decades.**

Keywords: northern China, typical severe dust storms, temporal and spatial distribution, weather process.

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Compared with the general dusty weather, severe dust storms are more harmful, and often cause enormous losses to both ecological environment and human society because of their strong wind, poor horizontal visibility and high dust concentration[1—3]. Joseph[4] and Middelton[5] classified dust storms in India based on nature of variation of visibility and wind speed, which can be taken as the general classifying criterion of severe dust storms. Referring to this criterion, Xu[6] has put forward instantaneous wind velocity not less than 20 m/s and horizontal visibility less than 200 m as the criterion of severe dust storms for a single station in Northwest China, and furthermore defined the events with instantaneous wind velocity not less than 25 m/s and horizontal visibility less than 50 m as super severe dust storms. Qian[7], Lu[8], Sun[9] et al. have attempted to present the case spectrum of severe dust storms or the number of those in Northwest China, but have not achieved satisfying results due to the lack of objective observation data, especially missed a lot of events in the 1950s and the 1960s, or sometimes mistaken gales for severe dust storms[10]. Therefore, those results cannot completely reflect the facts of severe dust storms in northern China during the past 5 decades and are greatly needed to be further studied and completed by using more objective observation data.

Recently, after collecting and compiling the original daily record of dust storms and relevant data of gale and visibility from 681 national meteorological stations from 1954 to 2002, we have performed an experiment and got some new conclusions on reconstructing time series of severe dust storms with examples of eastern part of Northwest China in 1954—2001 and the whole country in 2000—2002[11—13]. On the base of the experiment, in this paper we expand the investigated area to the whole country, and attempt to give a more complete time series of typical severe dust storms in northern China according to weather process, and analyze their temporal and spatial distribution characteristics and evolution tendency.

1 Data

The data of dust storms and relevant gale and visibility adopted here are mainly derived from *Surface Meteorological Monthly Bulletin* and *Wind-recorder's Paper* covering the period of 1954—2002. All the data have been checked and confirmed record by record, so the data set is of high quality and integrity. The time resolution of dust storms and gales in the raw data set is one minute. As for visibility, limited by meteorological observation system, only 4 times observation values per day can be obtained (i.e. the time interval is 6 h) in most of the years, but since 1987 one observation value for each hour can be provided at some stations because of the successive establishment of national basic climate stations in China. Among 681 stations, in 49 years, there are 469 stations with the record of dust storms, accounting for 68.9%, which accumulate 64922 original records of dust storms altogether.

2 Criterion of typical severe dust storms

Previous experiment by us[13] showed that Xu's criterion of severe dust storms for a single station is applicable to northern part of China, but the criterion of super severe dust storms cannot be suitable everywhere because of lack of the coherent and systematic observation data. In the meteorological observational system in China, the visibility was marked by 0—9 grades before 1980, among which grade 0 means the visibility less than 50 m and grade 1 indicates the visibility not less than 50 m and less than 200 m etc. Since 1980, the visibility was marked by meters, and with the minimum resolution of 100 m. From then on the scale of 50 m did not exist any more, therefore so-called super severe dust storms cannot be determined

with Xu's criterion. For this reason, the super severe dust storms are not within the discussion here.

The occurrence, development and transportation of dust storms are closely associated with weather process. Therefore, study on the uniqueness and harmfulness of severe dust storms much relies on the weather process to examine whether severe dust storms have a regional group feature. Different from ref. [13], considering the change of study area, this paper improves the determining criterion of typical severe dust storms in China as the following: (1) During the same weather process, there are 3 or more stations where severe dust storms break out together. (2) During the same weather process, there are 2 stations where severe dust storms break out, and there are 3 or more stations where moderate dust storms break out together. (3) During the same weather process, there is only one station where severe dust storms break out, and there are 5 or more stations where moderate dust storms break out together. The criterion of severe and moderate dust storms for each single station can be referred to ref. [13].

3 Results and analysis

(ⅰ) Time series of typical severe dust storms in North China. After the check of the above 64922 original dust storm reports record by record according to the weather process, it can be found that there were 223 relatively typical severe dust storms altogether which have broken out in northern China (Table 1), with the average frequency of ~4.6 times each year during the period of 1954—2002. But it should be noted that the start-end date listed in Table 1 implies the peak period of the severe dust storms, not including the accessory period of the blowing and drifting dusts. Additionally, northern China covers a large area and in the same day there may be two weather systems that would cause dust storms in eastern and western parts respectively. The latter case may start before the end of the former one. This kind of cases is studied respectively by regional division in accordance with the system location of daily *Surface Synoptic Chart*. Because of this reason, there exist a lot of coherence or intersection of the beginning and ending dates of neighboring events, such as the case during April 5—7 and that during April 7—9 in 2001.

Depending on the number of stations with severe and moderate dust storms and all kinds of dust storms simply, it can be seen that the event occurring during April 10—12 in 1979 is the most outstanding one because there were 117 stations altogether where dust storms brook out simultaneously. In addition, among 117 stations, 27 stations in Xinjiang, Gansu, Qinghai, Ningxia, Shanxi and Inner Mongolia reached the criterion of severe dust storms and 35 other stations reached the criterion of moderate dust storms. The other more outstanding severe dust storm events were on April 27—28 of 1983, April 25—26 of 1984 and April 7—9 of 2001, with more than 20 stations

Table 1 Typical severe dust storms in northern China in 1954—2002

Order	Date	N_1	N_2	N_3	Order	Date	N_1	N_2	N_3	Order	Date	N_1	N_2	N_3
1	1954-03-18—19	5	10	64	2	1954-03-25—26	2	5	32	3	1954-04-30—05-01	1	7	32
4	1954-05-05	4	4	35	5	1954-05-17—18	3	3	37	6	1955-03-11—12	2	3	23
7	1955-03-16—17	6	14	91	8	1955-04-07—08	2	6	60	9	1955-04-12—14	9	5	40
10	1955-08-14—15	4	3	21	11	1956-02-07	2	4	18	12	1956-02-24	3	3	20
13	1956-03-20—21	7	18	57	14	1956-04-13—14	7	19	94	15	1956-04-22	1	7	58
16	1956-04-29	1	5	36	17	1956-12-03	2	3	26	18	1957-03-06—7	15	12	78
19	1957-04-01	1	8	33	20	1957-04-08	6	10	53	21	1957-05-12—14	3	6	41
22	1957-12-16—17	2	3	34	23	1958-02-20—21	7	21	51	24	1958-02-22—23	9	18	85
25	1958-03-11—13	1	5	50	26	1958-03-17—20	6	11	62	27	1958-03-22—23	4	5	70
28	1958-04-04—05	7	18	101	29	1958-04-22—23	3	6	61	30	1958-04-28	9	9	49
31	1959-01-11	2	5	31	32	1959-01-13—14	2	3	40	33	1959-03-07—08	1	7	26
34	1959-03-16—17	3	1	27	35	1959-03-25—26	4	6	49	36	1959-04-07	3	6	33
37	1959-04-08—09	4	5	60	38	1959-04-11	3	3	30	39	1959-04-15—16	6	12	56
40	1959-05-02—03	2	3	31	41	1959-06-06—07	4	3	22	42	1960-02-24—25	3	10	71
43	1960-03-07—09	3	0	30	44	1960-03-15—16	1	6	31	45	1960-03-22—23	6	10	50
46	1960-04-09—10	3	10	70	47	1960-04-18	2	4	31	48	1960-05-27—28	2	5	29
49	1960-12-10	1	6	20	50	1961-04-02—03	3	4	43	51	1961-04-05—07	3	3	37
52	1961-04-18—19	4	4	29	53	1961-05-09—10	3	8	37	54	1961-05-14—16	3	6	30
55	1961-05-31—6.2	6	12	80	56	1962-03-19—20	3	5	33	57	1962-04-20—21	3	1	54
58	1963-01-28	2	13	54	59	1963-04-03—04	2	10	49	60	1963-04-14—16	11	17	91
61	1964-03-14	1	6	29	62	1964-03-26	2	4	34	63	1964-03-31—4.1	7	11	58
64	1964-04-16—17	1	8	26	65	1965-04-15	2	3	35	66	1965-04-25—26	3	15	47
67	1965-11-27—28	7	8	40	68	1965-12-13	7	6	32	69	1966-02-01—02	4	14	75
70	1966-02-26—28	5	5	29	71	1966-03-04—05	2	5	37	72	1966-03-17	8	17	75

(*To be continued on the next*)

(*Continued*)

Order	Date	N_1	N_2	N_3	Order	Date	N_1	N_2	N_3	Order	Date	N_1	N_2	N_3
73	1966-04-01	2	5	51	74	1966-04-13—15	17	27	113	75	1966-05-05	1	12	34
76	1966-05-13	3	3	38	77	1966-06-21	7	1	37	78	1967-02-05	2	3	23
79	1967-04-01—2	1	9	33	80	1968-04-01—02	3	2	29	81	1968-04-23	3	18	70
82	1968-05-11	2	6	45	83	1969-03-14	2	3	30	84	1969-03-25—27	8	26	73
85	1969-04-02—03	6	11	52	86	1969-04-06	3	24	89	87	1969-04-13—14	1	15	61
88	1969-04-18—19	1	5	40	89	1969-09-14—16	2	4	18	90	1970-04-01—02	3	7	63
91	1970-04-09—10	1	5	29	92	1970-05-23—24	1	6	22	93	1971-02-14—15	1	8	42
94	1971-03-16	2	5	39	95	1971-04-04	3	2	20	96	1971-04-05—06	7	26	104
97	1971-04-11—12	2	9	60	98	1971-04-21	2	9	45	99	1971-04-22—23	3	3	38
100	1972-02-24—25	3	0	34	101	1972-03-30	1	7	54	102	1972-04-02—03	2	7	30
103	1972-04-17—18	2	12	72	104	1972-04-30	4	21	65	105	1973-04-01	1	7	36
106	1973-04-08	1	7	54	107	1974-02-04—05	2	3	23	108	1974-04-29	5	8	46
109	1975-03-05—06	3	4	17	110	1975-04-06—07	1	13	88	111	1975-04-16—17	5	9	40
112	1975-04-24	3	7	44	113	1975-07-17	4	10	27	114	1976-02-26	1	5	27
115	1976-03-27—28	2	18	59	116	1976-04-04—05	1	4	29	117	1976-04-21	2	7	56
118	1976-05-24	2	4	30	119	1976-12-17	3	14	45	120	1977-02-20—21	5	12	80
121	1977-03-13	8	10	61	122	1977-03-21	2	8	52	123	1977-04-22	4	10	48
124	1978-04-13—15	4	17	82	125	1978-05-25	2	4	20	126	1978-06-09	1	4	14
127	1979-02-20	1	8	37	128	1979-03-19	3	2	30	129	1979-04-10—12	27	35	117
130	1979-05-13—14	2	5	34	131	1979-05-21	1	10	56	132	1979-05-25—26	2	6	13
133	1979-06-11—12	2	3	16	134	1980-01-24—25	3	1	22	135	1980-04-11	1	6	29
136	1980-04-17—18	8	22	91	137	1980-05-03—04	3	7	34	138	1980-05-15—16	2	4	24
139	1980-06-03	1	6	15	140	1981-04-22—23	3	6	34	141	1981-04-30—05-02	12	14	86
142	1981-05-09—11	8	9	55	143	1981-05-30—31	2	3	16	144	1982-04-05	4	3	27
145	1982-05-01	3	11	51	146	1982-05-04	3	2	57	147	1982-05-10	3	6	29
148	1982-12-20—21	2	6	30	149	1983-03-15	6	10	47	150	1983-03-31	3	3	27
151	1983-04-02	2	3	27	152	1983-04-13	5	4	31	153	1983-04-17	7	3	23
154	1983-04-27—28	26	21	108	155	1983-05-18	3	1	28	156	1983-05-19—21	9	13	70
157	1984-04-02	2	3	13	158	1984-04-19—20	10	9	70	159	1984-04-25—26	24	41	118
160	1984-05-09—10	1	6	18	161	1984-11-04—05	2	6	48	162	1985-04-18—19	2	5	36
163	1985-04-23—24	2	5	46	164	1985-05-25	4	4	16	165	1985-06-10—11	4	4	16
166	1986-03-06	2	3	20	167	1986-03-15	4	2	17	168	1986-04-18	1	8	38
169	1986-04-22—23	3	10	46	170	1986-05-18—20	13	6	42	171	1987-05-07	3	3	19
172	1987-05-15	3	3	32	173	1988-01-21—22	2	7	40	174	1988-04-03—04	3	3	12
175	1988-04-10	2	8	68	176	1988-04-16	3	9	65	177	1988-04-19	1	7	35
178	1989-04-19	3	6	39	179	1989-05-24—25	3	3	16	180	1990-03-12—13	5	3	33
181	1990-04-05—06	2	11	57	182	1990-04-24—25	3	1	26	183	1990-05-27	2	5	23
184	1990-06-03—04	2	4	13	185	1991-05-05	4	4	32	186	1992-04-28	3	4	31
187	1992-05-02—03	3	7	20	188	1993-03-14—15	3	2	13	189	1993-04-20	1	8	41
190	1993-04-23	3	4	23	191	1993-05-05	11	9	42	192	1994-04-06—08	10	8	26
193	1994-04-29—05-01	4	6	26	194	1995-03-10	5	4	27	195	1995-05-16	4	5	30
196	1995-05-18	5	5	22	197	1996-04-16	1	5	19	198	1996-04-22—23	1	7	25
199	1996-05-29—30	14	6	30	200	1997-05-08—09	3	3	13	201	1997-07-10	3	1	7
202	1998-03-17—18	3	12	28	203	1998-04-15	4	13	40	204	1998-04-18	4	9	39
205	1998-04-22	2	5	19	206	1998-05-20	2	5	17	207	1999-04-23—24	5	6	27
208	1999-05-13	4	3	20	209	2000-04-12	4	5	27	210	2000-04-19	5	12	39
211	2000-04-28	2	7	30	212	2000-05-10—11	4	5	24	213	2000-12-31—01-01	2	4	13
214	2001-03-04—05	2	7	33	215	2001-03-21	3	0	23	216	2001-04-02—03	3	4	16
217	2001-04-05—07	17	15	62	218	2001-04-07—09	20	31	79	219	2001-04-28—29	11	17	56
220	2001-05-03	4	4	17	221	2002-03-19—21	7	20	83	222	2002-04-06—08	11	7	35
223	2002-04-21—22	1	6	17										

N_1, Number of stations with severe dust storm; N_2, number of stations with moderate dust storms; N_3, number of stations with all kinds of dust storms.

meeting the criterion of severe dust storms.

(ⅱ) Temporal and spatial distribution characteristics of typical severe dust storms

(1) Spatial distribution. Figure 1 indicates the geographical distribution of typical severe dust storms in northern China. It can be seen that the Tarim Basin, the eastern part of Northwest China and the northern part of North China are the main areas influenced by severe dust storms, where there are more than 5 events in the recent 49 years. Among them Ruoqiang and Minfeng in Xinjiang are the place with most frequent occurrences of severe dust storms as many as 33 and 32 events respectively, followed by Hetian and Qiemo in Xinjiang with 25 and 23, Minqin and Anxi in Gansu with 27 and 20, Yanchi in Ningxia with 28 and Zhurihe in Inner Mongolia with 24 events respectively. Centered round the above places, many areas with high frequency occurrence have formed. Obviously the main areas influenced by severe dust storms are related to deserts and sandy lands. At the same time, those areas are just on the main paths of strong cold air outbreaks influencing China. These further prove that the invasion of strong cold air outbreaks is the main dynamical source of dust storms, while the bare deserts and sandy lands are the dominant source regions of dust, and the effective combination of the two aspects has composed the basic form of spatial distribution of severe dust storms in China.

It should be noticed that at Raoyang, in central Hebei Province, 9 severe dust storms occurred from the 1950s to the 1970s. The latest occurring date was April 15, 1978. Besides, in Zhengzhou, Kaifeng, Xuchang of Henan Province, Heze of Shangdong Province and their fringes, one or two severe dust storms also brook out in the 1960s, which is the area influenced by severe dust storms with the lowest latitude in eastern China. Through investigation, it is found that the reason may be related with local sandy lands, bare dry land or bare alluvial sands of dried riverbed.

(2) Seasonal distribution. The monthly distribution of 223 typical severe dust storms (Table 2) indicates that the severe dust storms occurred mainly in spring (March, April, May), with a total number of 184, occupying 82.5% of the whole year, among which in April there are 99 events, accounting for 44.4% of the whole year. This is because during spring, temperature in northern part of China is ascending quickly, surface is quite bare and dust can be easily entrained to high level through upward air motion. The second season of frequent severe dust storms is winter (December, January, February). Because of the seasonal improvement of the surface cover, there are only a few severe dust storms occurring in summer and autumn, altogether 13 events from June to November in the 49 years, less than 6% of the total number. It is worth mentioning that the severe dust storm event in Minqin of Gansu, Mandula of Inner Mongolia and other places from December 31 of 2000 to January 1 of 2001 is both the earliest and the latest one in seasonality.

(3) Variation in recent 49 years. Figure 2 is the annual variation of typical severe dust storms in the northern part of China from 1954 to 2002. Apparently severe dust storms in the 1950s occurred more frequently, in which period almost each year the frequency was higher than the average. In 1959 there were 11 events, which was the highest value in the recent 49 years. Although there existed a relatively large annual fluctuation from the 1960s to the 1980s, the tendency was not obvious. In the 1990s there were relatively fewer severe dust storms and the occurrences in eight years were lower than the average level, among which in 1991 only one event was observed, which was the lowest in the recent 49 years. In 2001 the number increased to 7, which was the largest number after 1983. To be brief, in the 49 years the number of typical severe dust storms in northern China tended to descend, but recently there was a relatively increasing tendency.

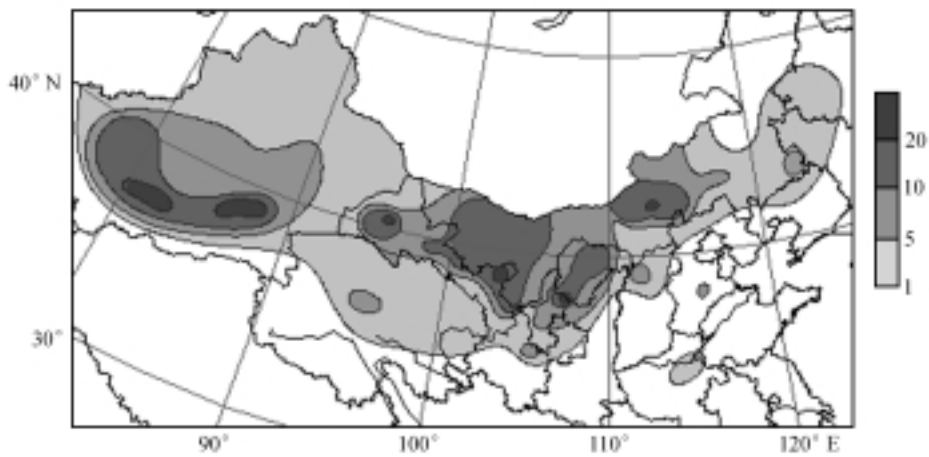

Fig. 1. Spatial distribution of typical severe dust storms in northern China in 1954—2002.

Table 2 Monthly mean number of typical severe dust storms in northern China

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
No. of severe dust storm	5	14	41	99	44	7	2	1	1	0	2	7
Percentage (%)	2.2	6.3	18.4	44.4	19.7	3.1	0.9	0.5	0.5	0.0	0.9	3.1

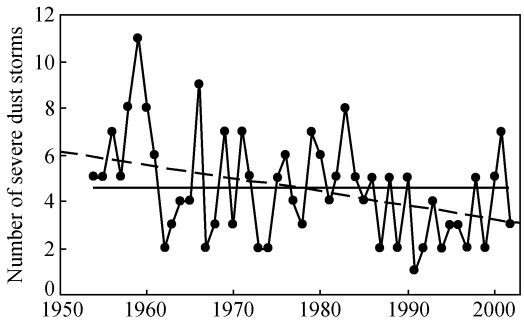

Fig. 2. Annual variation of typical severe dust storms in northern China in 1954—2002. Broken line: Variation of typical severe dust storms, horizontal line: the average value in 49 years, dotted line: linear trend.

Table 3 gives the occurring number of typical severe dust storms and their average duration during different periods of the 49 years in northern China. It indicates that during seven years in the 1950s, there were 49 severe dust storms with an average of 7 events per year, which was relatively frequent. The annual change of severe dust storms was not obvious in the 1960s, 1970s and 1980s, with an average of 4.3—4.7 times per year. In the 1990s there were relatively fewer events with an average of 2.9 times per year, not as many as half of that in the 1950s. But during the three years from 2000 to 2002, 15 events occurred with the annual average of 5 times, higher than the average value of the 1990s but fewer than those in the 1950s. The average duration of sever dust storms indicates that the mean value of the 1990s was the shortest, about 0.5—1 h shorter than that in other 4 decades.

Table 3 Decadal variation of typical severe dust storms in northern China in 1954—2002

	1954—1960	1961—1970	1971—1980	1981—1990	1991—2000	2000—2002
No. of severe dust storm	49	43	47	45	29	15[a)]
Mean duration[b)]/h	8.556	8.235	8.143	8.574	7.568	8.090

a) It includes 5 times in 2000, in order to indicate the whole circumstance of the recent 3 years. b) It is the average value of the events listed in line one which meet the criterion of severe dust storms.

4 Conclusion

In the period of 1954—2002, there were 223 events of typical severe dust storms in northern China, among which the case in April 10—12, 1979 had the largest affected area. Closely associated with the geographical distribution of deserts and sandy lands and the routes of strong cold air outbreaks coming into China, the severe dust storms mainly occurred in the Tarim Basin, eastern part of Northwest China and northern part of North China. Severe dust storms occurred mainly in spring (March, April, May), with a total number of 184, occupying 82.5% of the whole year, among which in April there are 99 events, accounting for 44.4% of those of the whole year. During the later half of 20th century, severe dust storms occurred most frequently in the 1950s, lowest frequently in the 1990s with a general descending tendency, but they suddenly increased from 2000 to 2002 and 2001 is the year with most severe dust storms since 1983. The average duration of severe dust storms in the 1990s was the shortest, about 0.5—1 h shorter than that in other 4 decades.

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