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Microparticle content records of the Dunde ice core and dust storms in northwestern China

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Abstract

Dust storms are important atmospheric phenomenon in central Asia, particularly in the regions bordering deserts, arid and semi-arid regions. Dust storms occur quite often in northwestern China. There are some research results about past dust storm events using historical archives in China. However, the archives used cover limited time and area. Microparticle concentrations in the Dunde ice cap, Qilian mountain of northwestern China, represent a continuous record of past dust storms. Comparison between dust rain frequency reconstructed from historical archives and the ice core record from the Dunde ice cap demonstrate that the microparticle record in the Dunde ice core is a good indicator of dust storms in northwest China. According to the ice core records, we can reconstruct the dust storm chronology for historical time. During the past 700 years, the dust content fluctuated with time, and lower frequency variations existed. Although the linear trend increased over the past 700 years, dust content was decreasing since the early 1700s. During the Little Ice Age, it was slightly higher corresponding to the cold period.

Keywords: Micropartical concentration; Dunde ice core; Historical archive; Dust storm; Northwest China

1. Introduction

Dust storms are important atmospheric phenomenon in central Asia, particularly in the regions bordering deserts, arid and semi-arid regions. It was found that dust in central Asia was mainly derived from dust storms, while dust haze, blowing dust and dust devils are important forms of dust (Goudie and Middleton, 1992). Dust storms occurring in central Asia are the major phenomenon of dust events. Large quantities of dust during the dust storms in central Asia, particularly on the Tibetan Plateau, occur in spring and early summer. Dust from the deserts in northwest China not only fall to the source area in China (Liu et al., 1981), but also accumulate in eastern China (Gao et al., 1992a), Japan (Iwasaka et al., 1983), the Pacific Ocean (Parrington et al., 1983; Gao et al., 1992b), Hawaii (Shaw, 1980) and the Canadian Arctic (Rahn et al., 1981; Welch et al., 1991).

Satellite imagery (Middleton, 1986) and meteorological data (Goudie, 1983) are powerful methods for monitoring present dust events. Various types of glaciers on earth are unique mediums not only for recording present dust events, but also for recording past dust events. The longest ice core dust record was retrieved from the Vostok ice core in Antarctica (Petit et al., 1990) through analysis of insoluble particle concentrations. On the Tibetan Plateau, dust records in ice cores were achieved from the Dunde Ice Cap and the Gulya Ice Cap (Fig. 1) by analyzing the contents of microparticles and calcium (Thompson et al., 1989; Yao et al., 1994). In addition to the Dunde ice core, the Guliya ice core (Yao et al., 1995a; Thompson et al., 1995) and the Tanggula ice core (Yao et al., 1995b) were recovered

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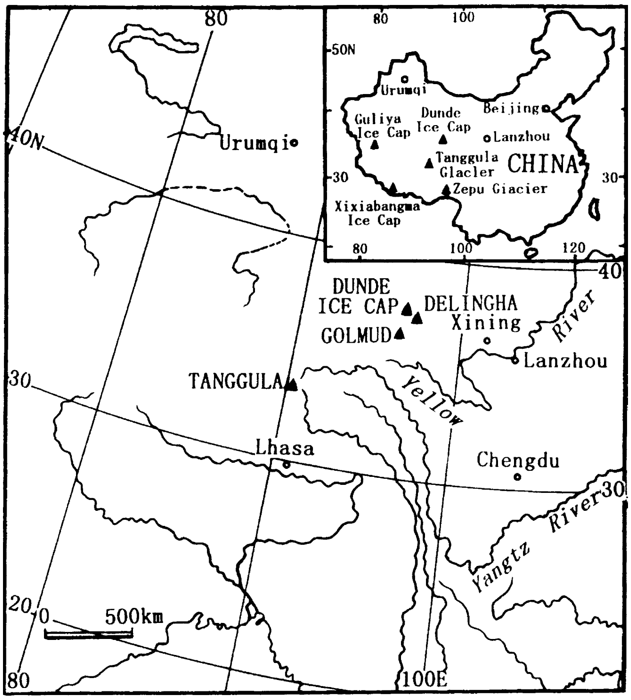

Fig. 1. Location of the Dunde ice Cap. It is located in northwest China near Delingha and Golmud.

recently (Fig. 1). Although some researchers have examined the frequency of the dust storm in China based on historical records (Zhang, 1982, 1984; Huang, 1997), such information is not enough and is limited by the number of records. This paper aims to discuss the microparticle records of the Dunde ice core and the dust storms in northwest China.

2. Dunde ice core and the microparticle analysis

2.1. Dunde ice core

The Dunde Ice Cap (38°06′N, 92°24′E, see Fig. 1) is located in a desert environment between the Qaidam Basin, the highest desert in China, and the Gobi desert. This relatively large ice cap has a summit elevation of 5325 m and a total area of 60 km^2. This glacier is about 140 m thick and the underlying bedrock is flat. About 0.4 m of water equivalent snow accumulates on the ice cap each year, and the firn–ice transition occurs at a depth of ~25 m (Thompson et al., 1989). The ice temperature at a depth of 10 m is −7.3 and −4.7 °C at the base, 139.8 m below surface (Yao and Thompson, 1992). Three cores to bedrock were recovered from the ice cap summit: Core D-1 (139.8 m), Core D-2 (136.6 m) and Core D-3 (138.4 m). Thompson et al. (1989, 1990), Xie et al. (1989) and Yao et al. (1990) have already reported the field sampling, analytical procedure, and major results of the core analyses.

Thompson et al. (1989) and Yao et al. (1990) described how to date the upper part of an ice core recovered from high elevation and region of high dust concentration in the Tibetan Plateau using a combined method of counting dirt layers and comparing them with the δ^{18}O seasonal cycle.

Dating of the ice core is a very important aspect in ice core studies. Many methods are, therefore, applied to ice core dating. The dating of the Dunde ice core was made by counting the seasonal cycles of δ^{18}O referring to the variations of microparticle concentrations (MPC) and electrical conductivity (EC). The basic principle is to take δ^{18}O as an indicator of annual variation in the ice core since there is a big difference in values between winter and summer snowfall.

On middle and low latitude glaciers, a dirt layer is formed during the period between spring and summer. A microparticle concentration peak appears in this layer, and EC is generally proportional to MPC. As discussed by Yao et al. (1991) for the Dunde ice core, there is a good relationship in annual variations between MPC, δ^{18}O, and EC. For example, during a seasonal cycle a high MPC approximately corresponds to less negative δ^{18}O value and low EC. This does not mean, however, that less negative δ^{18}O definitely corresponds to high MPC and low EC. This depends on the formation processes of δ^{18}O, MPC, and EC. In the Dunde Ice Cap, less negative δ^{18}O values generally appear in the winter snow layer while high MPC appears in the snow layer between spring and summer. There is, therefore, a phase difference between δ^{18}O peak and MPC peak. The variation of EC is not only influenced by MPC, but also by salt and other chemical components. Because of these reasons, the dating of the Dunde ice core since 1600 AD was mainly based on δ^{18}O referring to MPC. When both δ^{18}O and MPC were not effective for dating, EC was employed.

2.2. Microparticle measurement

The visible stratigraphy of each core was photographed immediately after drilling. Core D-1 was then cut into 3585 samples and melted in closed containers by passive solar heating in a laboratory tent. Samples were then poured into polyethylene bottles, sealed in wax, and shipped to BPRC (Byrd Polar Research Center). Samples were divided so that MPC, δ^{18}O and EC could be measured on the same sample. The concentrations of three inorganic anions and pH were measured for the entire length of D-3 while crystal sizes were measured for selected sections (Thompson et al., 1990).

Core D-1 was analyzed along the entire length for MPC, δ^{18}O and EC. MPC was measured at BPRC under Class 100 Clean Room conditions. The concentrations of microparticles with diameters ≥2 μm/ml sample were measured using a model TA-II Coulter Counter (Thompson, 1977), fitted with a 100 μm aperture tube. Most of the samples necessitated diluting 36 times due to very high microparticle concentrations for the Coulter Counter method, and up to 7000 times in extreme cases, to avoid problems with coincident passage through the aperture tube. Only the samples for dust measurement were diluted. EC of liquid samples was measured with a Beckman model RC-16C conductivity bridge and pH was measured with a Beckman model ϕ40 pH meter (Thompson et al., 1990).

3. Microparticle records preserved in the Dunde ice cap

Microparticle records of the Dunde ice core for the past 20 ka show that the microparticle content was high during the Last Ice Age. For the Holocene, the record of microparticle content is low. Fig. 2a shows the annual variations and its corresponding linear trend of the microparticle content during the past 700 years. It demonstrates that the content fluctuates with time but the linear increasing trend is not significant. When the 11-point (year) running average records were used (Fig. 2b), we found that the linear increasing trend ($y=0.5717x+2860.5\times10^3$, $R^2=0.01$) was significant ($\alpha=0.01$) over

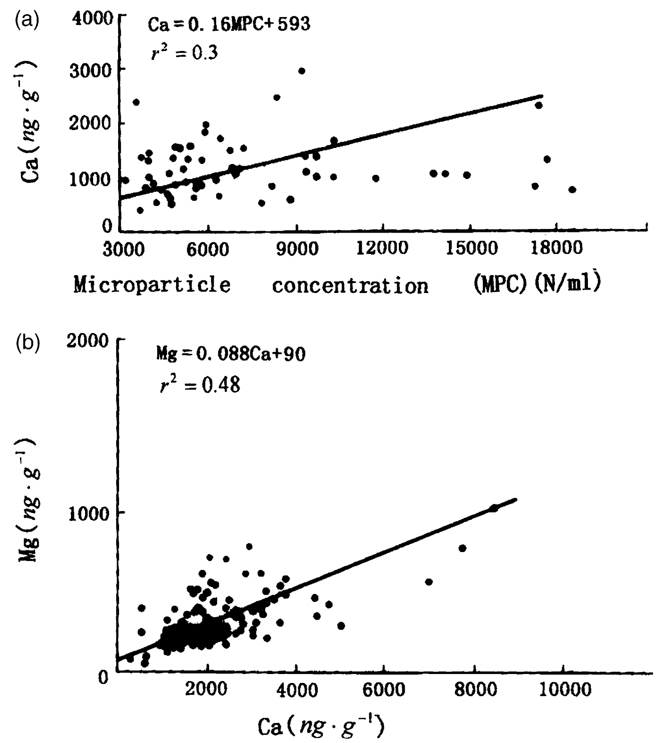

Fig. 3. Correlations between microparticle and calcium (a), and between calcium and magnesium (b) of the Dunde ice core.

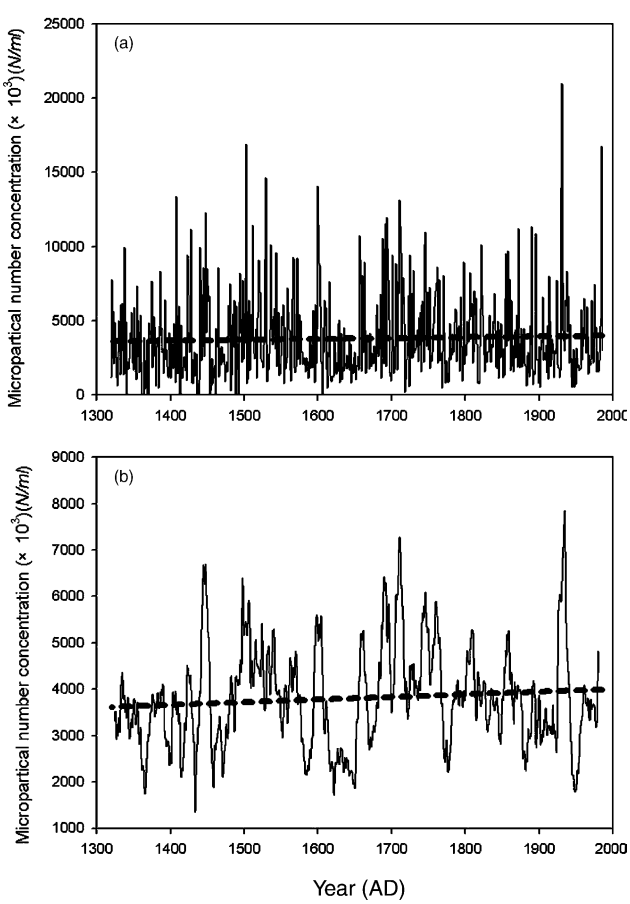

Fig. 2. Variations of microparticle concentration records in the Dunde ice core from 1320 AD to 1986 AD. The data here are the total particles (diameter >2.0 μm). (a) The annual records (thin line) and its corresponding linear trend (dashed line). (b) The 11-point (year) running average (thin line) and its corresponding linear trend (dashed line).

the past 700 years. However, it was decreasing since the early 1700s. During the Little Ice Age, it was slightly high, corresponding to the cold period.

Several indices can be used for dust reconstruction. Among them microparticle is a direct measure of dust, whereas calcium and magnesium ions are indirect indices. Fig. 3a and b shows the relationships between microparticle and calcium ion concentration, and between calcium ion and magnesium ion concentration. These figures clearly indicate the close relationship among microparticle, calcium and magnesium. Fig. 4 shows long-term variations of the Mg^{2+} record from the Guliya ice core and dust record from the Dunde ice core (Yao et al., 1995c). Because Mg^{2+} and MPC are both indicators of dust, the records of Mg^{2+} in the Guliya ice core and MPC in the Dunde ice core show the history of dust fluctuations at each site. Since dust is an indicator of terrestrial material (Yao et al., 1990; Thompson, 1997; Yao and Thompson, 1992; Petit and Royer, 1981) and terrestrial material mainly originated from deserts, arid and semi-arid regions around the Guliya and Dunde ice Caps; it is reasonable to study the frequency and intensity of dust storms at these two sites by using these dust indicators. Two features are important in the figure. First, both records show three dust peaks. The first peak occurred around the early 16th century, the second around the 1730s and the third around the 1870s (although the second and third peaks of the Guliya ion are not as high compared with the Dunde microparticle concentrations). Secondly, dust records in

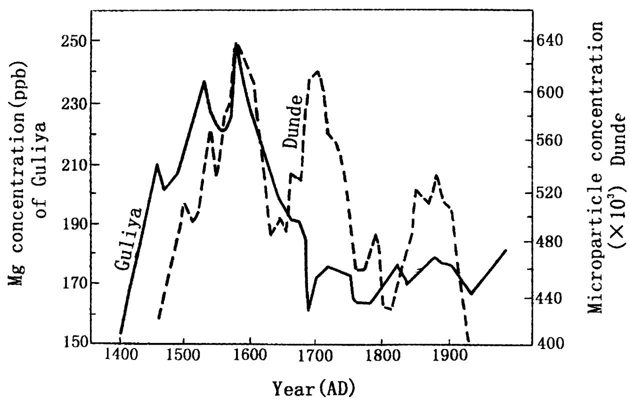

Fig. 4. The Mg^{+2} record reconstructed from the Guliya ice core and the microparticle concentration (diameter is >5.04 μm) of the Dunde ice core. Both are indicators of dust.

both cores show strong intensity and large amplitudes from the 16th to 17th century.

4. The dust storm occurred in northwestern China

Dust storms occur quite often in northwestern China and can cause many problems for the local society. A dust storm can destroy traffic and communication systems, agricultural activities, and the people's daily life. The dust storm has been observed at meteorology stations over the past several decades. But there are no direct records in pre-instrumental period. However, it is important to know the historical frequency and strength of the dust storms. Based on archives, researchers can obtain some knowledge about the dust storms during pre-instrumental time. The dust storms were described as dust rain in historical archives. Zhang (1982) examined the dust rain records in the historical archives and established the dust rain chronology. However, the number of years that dust rain occurred increased with time. This is mainly due to better archive records. Furthermore, most of the dust rain records were archived in eastern China, where human activity was more intense (Fig. 5). Zhang (1984) examined the annual dust storms and the days of dust haze observed at 498 meteorological stations in China from 1951 to 1980 and published their 30-year averaged results. She found that the dust storms mainly occurred in northwest China (Fig. 6).

Some researchers also tried to collect the dust-storm records archived in northwest China (Huang, 1997). Huang (1997) concluded that, according to the archived records, there were a total of 140 dust storm events from the 3rd century BC to 1990 (a dust storm that occurred in one period or surrounding areas during the same period was considered one dust storm). He also concluded that the number of dust storm occurrences was significantly large during the 20th century. Whether this is related to better record-keeping due to culture development from the 18th century onward or not needs to be examined further.

5. The relationship between dust storm events in northwest China and the microparticle content records of Dunde ice core, Qilian mountain, China

Zhang et al. (1984) reconstructed dust rain frequencies in east China by using historical records. Comparison between the dust rain frequency record and ice core dust record from the Dunde ice cap (Fig. 7) indicates a similar fluctuation trend. In particular, three peaks in these two records are almost identical. However, the ice core dust record decreases from the Little Ice Age to present while the number of historical dust records increases over the same

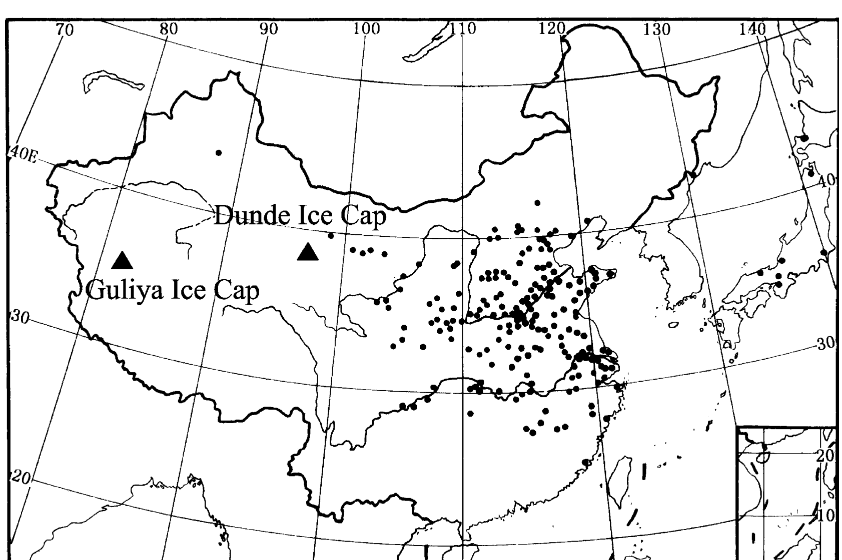

Fig. 5. The locations where dust rain was archived in the historical literature from the 3rd century BC to the early 20th century AD in China (Zhang, 1982).

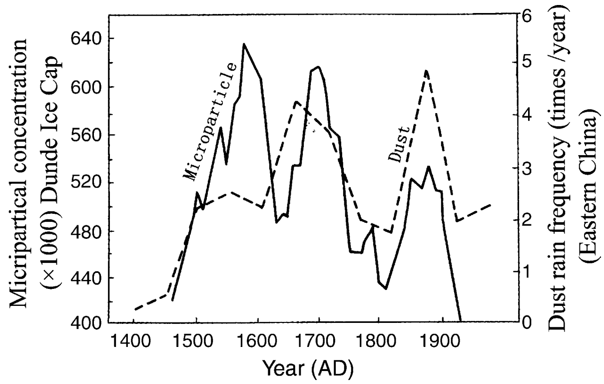

Fig. 6. The source area of the dust haze and dust storm in China (Zhang, 1984). The dotted region is the dust haze area and the region outlined with the italic line is the dust storm area where dust storms occurred more than 30 days each year. The dashed line is the border of the area where the dust haze occurred more than 5 days each year.

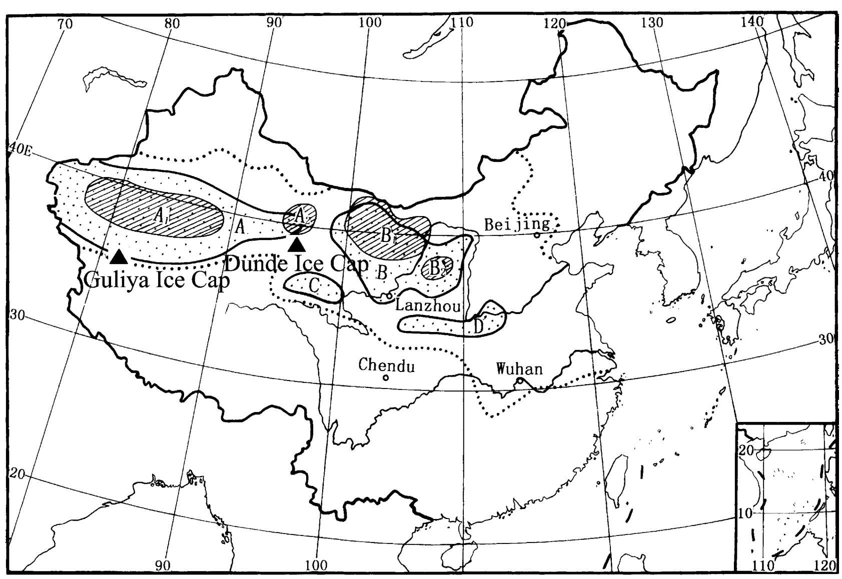

Fig. 7. A comparison of dust records between the Dunde ice core (diameter is >5.04 μm) and the historical records in eastern China (Zhang, 1984).

time period. One possible explanation is that the increasing trend of historical dust records from the Little Ice Age to present is an artifact of increased literature records. Another possibility is that the amount of dust in these two regions was different. Of course, variations in the accumulation rate of snow can also affect the MPC.

The dust storm records archived in historical documents are limited to the observation sites and amount of literature. There are more literature archives in eastern China. Therefore, most of the dust rain records were found there. Although there are some records in northwestern China, they are not as complete. Some dust storms were not recorded. However, the microparticle record of the Dunde Ice Cap is a good natural archive that recorded dust storms activity in the surrounding area. Using ice core records, we can establish the dust storm chronology for historical time.

6. Conclusions

Because dust storm records (such as dust rain) in archives depend on the number of the literature records and local civilizations, it is difficult to use them for determining the number of actual dust storm occurrences. The literature records are also influenced by the frequency of wars and other factors. Some places where the dust rain and dust storm were observed are far from the source areas. Therefore, natural records of dust storms would be very useful indicators for examining the frequency of dust storms in the past. Fortunately, the ice core recovered from the Dunde Ice Cap in Qilian Mountain, northwestern China, provides a dust record for the past 20 ka. Because the Qaidam Basin and Gobi Desert are relatively close to the Dunde Ice Cap, the dust record is considered a good natural archive for past dust storm events in the surrounding areas. Comparison between the dust rain frequency reconstructed from historical archives and the ice core record from the Dunde ice cap indicates a similar fluctuation trend. In particular, three peaks in these two records are almost identical. Therefore, the microparticle record of the Dunde Ice Cap is a good natural archive of dust storms that occurred in the surrounding area. Using ice core records, we can reconstruct the dust storm chronology for historical time. During the past 700 years, it fluctuated with time. Although the linear trend increased over the past 700 years, it was decreasing since the early 1700s. During the Little Ice Age, the microparticle content was slightly higher corresponding to a cold period.

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Further Reading

Fiacco, R.J., 1991. Microparticles as paleovolcanic indicator in the 1989 GRIP2 firn and ice core. Ms Thesis. University of New Hampshire, Durham, NH, USA, pp. 138.

Hammer, C.U., Clausen, H.B., Dansgarrd, W., Neftel, A., Kristinsdottir, P., Johnson, E., 1985. Continuous impurity analysis along the Dye 3 deep core, In: Greenland ice Core Geophysics, Geochemistry and the Environment. Geophysical Monograph 33. American Geophysical Union, Washington, DC, pp. 90–94.

Palais, J.M., Germani, M.S., Zelinski, G.A., 1992. Inter Hemisphere transport of volcanic ash from a 1259AD volcanic eruption to the Greenland and Antarctic ice sheet. Geophys. Res. Lett. 19, 801–804.

References

Gao, Y., Arimoto, R., Duce, R.A., Lee, D.S., Thou, M.Y., 1992a. Input of atmospheric trace elements and mineral matter to the yellow sea during the spring of a low dust year. J. Geophys. Res. 97, 3767–3777.

Gao, Y., Arimoto, R., Thou, M.Y., Merill, J.T., Duce, R.A., 1992b. Relationship between the dust concentration over the east Asia and the remote north Pacific. J. Geophys. Res. 97, 9867–9872.

Goudie, A.S., 1983. Dust storms in space and time. Prog. Phys. Geography 7, 502–530.

Goudie, A.S., Middleton, N.J., 1992. The changing frequency of dust storms through time. Climatic Change 20, 197–225.

Huang, Z.H., 1997. The dust storm in northwest China in historical period. In: Zongyi, Fang, Fukang, Zhu, Jiangjixi, Zhenan, Qian (Eds.), Dust Storm Study in China (in Chinese).

Iwasaka, Y., Minoura, H., Nagaya, K., 1983. The transport and special scale of Asian dust storm clouds: a case study of the dust storm event of April, 1979. Tellus B 35, 189–196.

Liu, T.S., Gu, X.F., An, Z.S., Fan, Y.X., 1981. The dust fall in Beijing, China on April 18, 1980. In: Pewe, T.L. (Ed.), Desert Dust: Origin, Characteristics and Effect on Man Geological Society of American, Special Paper, 186, pp. 149–157.

Middleton, N.J., 1986. Dust storms in the Middle East. J. Arid Environ. 10, 83–96.

Parrington, J.R., Zoller, W.H., Aras, N.K., 1983. Asian dust: seasonal transport to the Hawaiian islands. Science 220, 195–197.

Petit, M., Royer, A., 1981. Ice age aerosol content from East Antarctic ice core samples and past wind strength. Nature 293, 391–394.

Petit, M., Mounier, L., Jouzel, M., Korotkevich, Y.S., Kotlyakov, V.I., Lorius, C., 1990. Paleoclimatological and chronological implications of the Vostok core dust record. Nature 343, 56–58.

Rahn, K.A., Borys, R.D., Shaw, G.E., 1981. Asian desert dust over Alaska, Anatomy of an Arctic haze episode, In: Desert Dust: Origin, Characteristics and Effect on Man. Special Paper, 186. Geological Society of American, Boulder, CO, pp. 37–70.

Shaw, G.E., 1980. Transport of Asian desert aerosol to the Hawaiian island. J. Appl. Meteorol. 19, 1254–1259.

Thompson, L.G., 1977. Microparticles, Ice Sheets and Climate. Ohio State University, Institute of Polar Studies, Report, pp. 64.

Thompson, L.G., Thompson, E.M., Davis, M.E., Bolzan, J.F., Dai, J., Yao, T., Gundestrup, N., Wu, X., Klein, L., Xie, Z., 1989. Holocene–Late Pleistocene climatic ice core records form the Qinghai–Tibetan plateau. Science 246, 474–477.

Thompson, L.G., Thompson, E.M., Davis, M.E., Bolzan, J.F., Dai, J., Klein, L., Gundestrup, N., Yao, T., Wuand, X., Xie, Z., 1990. Glacial stage ice-core records form the subtropical Dunde ice core. Ann. Glaciol. 14, 288–297.

Thompson, L.G., Thompson, E.M., Davis, M.E., Lin, P.N., Dai, J., Bolzan, J.F., 1995. 1000 year climate record from the Guliya ice cap China, its relationship to global climate variability. Ann. Glaciol. 21, 175–181.

Welch, H.E., Muir, D., Billeck, B.N., Lockhart, W.L., Brunskill, G.K., Ling, H.J., Olson, M.P., Lemoine, E.M., 1991. Brown snow: a long-range transport event in the Canadian Arctic. Environ. Sci. Technol. 25, 280–286.

Xie, Z., Wu, X., Yao, T., Thompson, L.G., 1989. A primary study of paleoclimate and paleoenvironment from Dunde ice core. Quat. Sci. 2, 135–142 (in Chinese with English abstract).

Yao, T.D., Thompson, L.G., 1992. Trends and features of climatic changes in the past 5000 years recorded by the Dunde ice core. Ann. Glaciol. 16, 21–24.

Yao, T.D., Xie, Z., Thompson, L.G., 1990. Little ice age recorded by Dunde ice Cap. Sci. China 11B, 1197–1201.

Yao, T.D., Xie, Z., Wu, X., Thompson, L.G., 1991. Climatic change since little ice age recorded by Dunde ice cap. Sci. China (series B) 34 (6), 760–767.

Yao, T.D., Qin, D.H., Huang, C.L., Jiao, K.Q., Xie, Z.C., 1994. Cations in the Guliya ice core and their implication to environmental changes since the little ice age. Proceedings of Qinghai–Xizang Plateau Symposium, pp. 1–10.

Yao, T.D., Jiao, K.Q., Tian, L.D., Li, Z.Q., Liu, Y., Liu, J., Huang, C., Xie, C., 1995a. Climatic and environmental records in the Guliya ice cap. Sci. China (Series B) 38 (2), 228–237.
Yao, T.D., Thompson, L.G., Jiao, K.Q., Thompson, E.M., Yang, Z., 1995b. Recent warming as recorded in the Qinghai–Tibetan cryosphere. Ann. Glaciol. 21, 323–329.
Yao, T., Jiao, K., Huang, C., Li, Y., Thompson, L.G., 1995c. Environmental records in ice cores and their spatial coupling features. Quat. Sci. 1, 23–31.
Zhang, D., 1982. The analysis of the dust rain in historical period in China. Chin. Sci. Bull. 5, 294–297 (in Chinese).
Zhang, D., 1984. The preliminary synoptic analysis of the dust deposition in historical period in China. Sci. China 3, 278–288 (in Chinese).