Annals of Glaciology 35 2002

Indian monsoon and North Atlantic Oscillation signals reflected by Cl^- and Na^+ in a shallow ice core from Dasuopu glacier, Xixabangma, Himalaya

WANG Ninglian,[1] YAO Tandong,[1] Lonnie G. THOMPSON,[2] Mary E. DAVIS[2]
[1]*Laboratory of Ice Core and Cold Regions Environment, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou 730000, China*
E-mail: nlwang@ns.lzb.ac.cn
[2]*Byrd Polar Research Center, The Ohio State University, 1090 Carmack Road, Columbus, OH 43210-1002, U.S.A.*

ABSTRACT. Information about past atmospheric circulation and climate change can be revealed by the chemical constituents of ice cores. Based on the analytical results of Cl^- and Na^+ concentrations in an 18.5 m ice core, which contains 14 annual layers, from the Dasuopu glacier, central Himalaya, a significant correlation is found between Cl^- and Na^+ concentrations. This, along with the average Cl^-/Na^+ weight ratio of 1.9, indicates that moisture at the drilling site came mostly from oceans. Furthermore, there was a high positive correlation between the Cl^-/Na^+ ratio in the summer monsoon layers and the monsoon rainfall in northeast India, and there exists a teleconnection between the Cl^- and Na^+ concentrations in this shallow ice core and the North Atlantic Oscillation.

INTRODUCTION

Soluble impurities in ice cores have been used to study past changes in atmospheric chemistry conditions and climatic and environmental conditions. Information on past changes in atmospheric circulation, ocean ice cover, volcanic eruptions, marine and terrestrial aerosols, forest evolution, biomass burning and human activities has been revealed by chemical records of ice cores from the bipolar ice sheets and mountain glaciers (Hammer and others, 1980; Neftel and others, 1985; Legrand and Delmas, 1987; Legrand and others, 1988, 1995; Wagenbach and others, 1988; Mayewski and others, 1990, 1994; Delmas, 1992; Hansson, 1994; Zielinski and others, 1994; O'Brien and others, 1995; Thompson and others, 1995; Taylor and others, 1996; Cole-Dai and others, 1997; Legrand and Mayewski, 1997; Stager and Mayewski, 1997). In order to better understand the climatic and environmental information preserved in the major soluble constituents of ice cores from the Himalaya and adjacent areas, some researchers have investigated the spatial and temporal variations of the major ions in snow and ice (Mayewski and others, 1983, 1984, 1986; Wake and others, 1990, 1993) and the correlation between the constituents of the atmospheric aerosol and snow (Wake and others, 1994; Sun and others, 1998). It has been found that monsoon and dust signals are recorded by the chemical records of the Asian glaciers (Wake and others, 1993; Yao and others, 1995; Kang and others, 2000; Thompson and others, 2000), and changes in atmospheric chemistry could also be reflected by snow chemistry (Wake and others, 1994; Sun and others, 1998). These connections heighten our confidence in the reconstruction of past atmospheric and environmental changes using glaciochemical data from the Tibetan Plateau. Here, we examine the signals of Indian monsoon rainfall and the North Atlantic Oscillation (NAO) from the Cl^- and Na^+ concentrations in a shallow ice core from Dasuopu glacier, Himalaya.

THE ICE CORE

Dasuopu glacier (28°23′ N, 85°43′ E) is located on the northern slope of Xixabangma peak, central Himalaya, and its snowline lies at 6300–6500 m a.s.l. In 1996, three firn cores (6.1, 18.5 and 19.2 m) were recovered from a broad flat plain near the col at 7100 m a.s.l. The borehole temperature was about −14°C at 10 m depth, which indicates that this is a cold glacier. According to the measurements of a 12-stake accumulation network near the drilling sites, the annual net accumulation is about 1.5–1.8 m snow, i.e. about 750–1000 mm w.e. Here, we try to explain the variations in Cl^- and Na^+ concentrations recorded in the 18.5 m long ice core. This will help us understand the climatic and environmental information contained in the chemical records of the deep ice cores drilled in 1997.

METHODS

The 18.5 m ice core was cut into 144 samples with a clean stainless-steel knife just after being retrieved, and its outside was carefully processed. The samples were kept in clean plastic bags, and then poured into distilled-water-rinsed polyethylene bottles after they melted. All these samples were transported to the Laboratory of Ice Core and Cold Regions Environment, Chinese Academy of Sciences, and Byrd Polar Research Center, The Ohio State University, U.S.A., for analyses. The anion analyses of all 144 samples were performed using a DX-300 ion chromatograph; the cations were analyzed via flame atomic absorption spectrometry using a PE-2380 system; and $\delta^{18}O$, which was used for the ice-core dating, was measured using a Finnigan MAT-252 Spectrometer.

Wake and others (1992) found that there was no significant difference in the concentration of major ions between

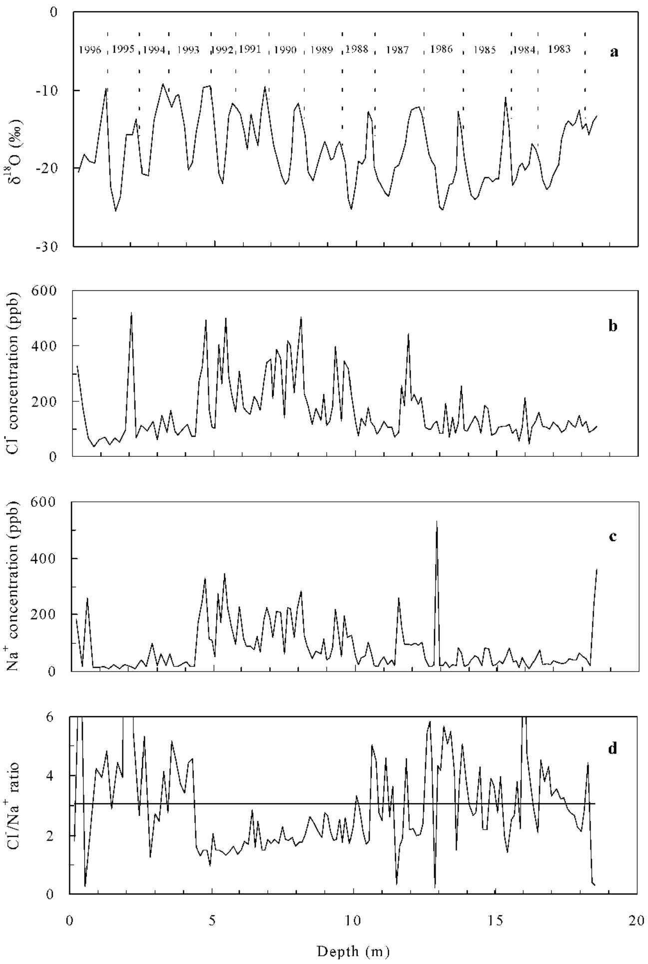

Fig. 1. The variations of $\delta^{18}O$ (a), Cl^- (b) and Na^+ (c) concentrations and Cl^-/Na^+ ratio (d) along an 18.5 m ice core from Dasuopu glacier.

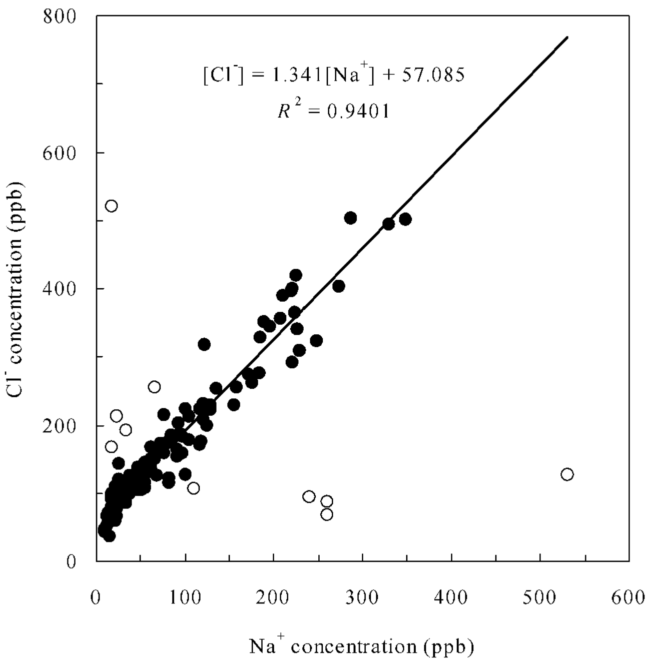

Fig. 2. Correlations between the Cl^- and Na^+ concentrations. The open circles represent the samples with the extreme Cl^-/Na^+ ratios beyond 2σ.

samples that were melted in the field and those that were kept frozen until just prior to analysis. This suggests that the ion-concentration data presented in this paper were little influenced by the procedure of melting samples in the field. The chemical species at depth in a firn core can easily be rearranged by leaching processes, which occur mainly in temperate glaciers (Eichler and others, 2001). The cold climate inhibited snowmelt at our drilling site. Stratigraphic analysis showed that the total thickness of ice layers was only 6.9% of the whole core length (Yao and others, 1998). This suggests that the influence of ion-elution processes on the distribution of ion concentration along our firn core may be negligible. Thus, the analytical results of the snow chemistry along the core may reflect the changes in atmospheric conditions and precipitation chemistry.

ANALYTICAL RESULTS AND DISCUSSION

Figure 1 shows the variations in $\delta^{18}O$ and Cl^- and Na^+ concentrations along the 18.5 m ice core. It can clearly be seen that $\delta^{18}O$ shows strong seasonality, low (depleted) in summer and high (enriched) in winter. According to the seasonal variations of $\delta^{18}O$, 14 annual layers are easily recognizable in this ice core. Most of the peaks in Cl^- and Na^+ concentrations occur in winter and spring, coinciding with high aerosol concentrations observed in the Nepal Himalaya in those seasons (Shrestha and others, 2000). The high winter and spring concentrations result from reduced precipitation and more productive (drier) source regions (such as the Near East, northwestern India, and the Tibetan Plateau) from where westerlies transport dust to the drilling site. During the period 1988–92, Cl^- and Na^+ concentrations were high. This was a result of low precipitation, as shown by thinner annual layers. However, the weight ratio of Cl^- to Na^+ (Cl^-/Na^+ ratio) was low and with small amplitude during that period.

A very good correlation was found between Cl^- and Na^+ concentrations for the 144 samples ($R^2 = 0.4192$, sig. = 99.9%; when 10 extreme samples were removed, $R^2 = 0.9401$, sig. = 99.9%; see Fig. 2). This suggests that Cl^- and Na^+ had a common source. Moreover, the Cl^-/Na^+ ratio of 1.92, which was calculated from the average Cl^- concentration (166.6 ppb) of all the samples divided by the average Na^+ concentration (86.8 ppb), is close to the weight ratio of sea water (1.8, reported by Keene and others, 1986), which indicates that the vapor at the drilling site may have come from oceans. Bao (1985) analyzed the data of satellite cloud photographs and found that one of the major paths of the vapor transported from the Bay of Bengal to the Tibetan Plateau during the monsoon season is across the central Himalaya where our drilling site is located. Dai (1990) pointed out that the weather in the Himalaya is controlled by the southern branch of the westerlies from September through May. This suggests that the vapor that arrives at the drilling site came from the Bay of Bengal during the monsoon season, and possibly from the North Atlantic Ocean during the non-monsoon season (September–May). Thus, we should investigate the information about atmospheric circulation that may be reflected by Cl^- and Na^+ concentrations and Cl^-/Na^+ ratio in different seasons.

Owing to the change in precipitation in different areas and the change in monthly distributions of precipitation at one site in different years, it is difficult to estimate the monthly net accumulation rate in each annual layer, and it is therefore impossible to calculate the monthly variations in Cl^- and Na^+ concentrations. But we can approximately

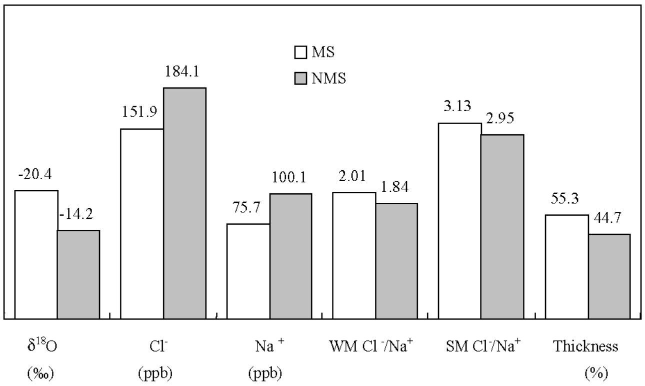

Fig. 3. The average values of $\delta^{18}O$, Cl^- and Na^+ concentrations, and Cl^-/Na^+ ratio in MS and NMS layers in the 18.5 m ice core. The large difference in $\delta^{18}O$ indicates that its seasonal variation is quite marked. WM and SM indicate the methods by which the average Cl^-/Na^+ ratios were computed (see text). The MS and NMS thicknesses are described by percentages of their respective total thicknesses in the whole depth of the core.

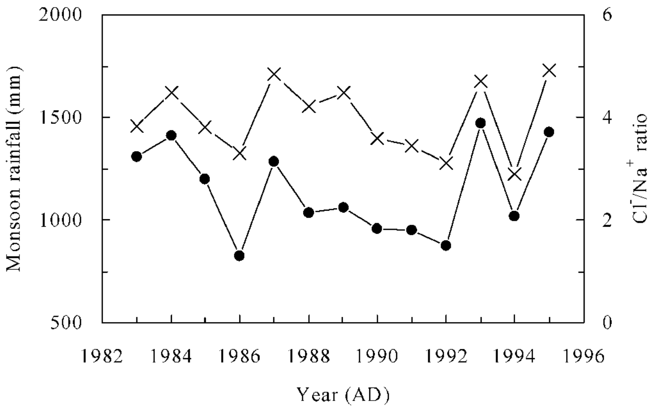

Fig. 4. Comparison of the variations in Cl^-/Na^+ ratio (line with circles) in MS layers with the variations in monsoon rainfall (line with crosses) in northeast India.

separate each annual layer into a monsoon-season (MS) layer and a non-monsoon-season (NMS) layer according to the seasonal variations of $\delta^{18}O$ (low value in summer monsoon season and high value in non-monsoon season). To this end, we regard the depth at which $\delta^{18}O$ decreases abruptly as the beginning of the MS layer, and the depth at which $\delta^{18}O$ increases abruptly as the end of MS layer. Figure 3 displays the mean values of $\delta^{18}O$, Cl^- and Na^+ concentrations and Cl^-/Na^+ ratios in the MS and NMS layers. In the 18.5 m ice core, the total thickness of the MS layers is larger than that of the NMS layers, which means that the annual precipitation at the drilling site is concentrated in the summer Indian monsoon season. This phenomenon is also observed at meteorological stations near Dasuopu glacier (e.g. summer rainfall (June–August) accounts for about 67% of annual precipitation at the Kathmandu Airport station, Nepal (27°70′ N, 85°30′ E; data available at http://www.worldclimate.com/cgi-bin/). The high precipitation in the MS layer should be responsible for the low Cl^- and Na^+ concentrations, while the converse should apply to the NMS. Thompson and others (2000) used the variations in Cl^- concentrations to study the variability of the Indian monsoon. The average Cl^-/Na^+ ratio in the MS or NMS layers, computed by means of the Cl^-/Na^+ ratio in each sample (this is called the sample method (SM) here), was different from that computed by means of the average Cl^- concentration in the whole MS or NMS layers divided by the average Na^+ concentration (called the whole method, (WM) here). Nevertheless, the results of both methods show that the Cl^-/Na^+ ratio was higher in the MS layers than in the NMS layers. This suggests that the Cl^-/Na^+ ratio was larger in the rainy monsoon season, and smaller in the dry non-monsoon season.

This kind of variation in Cl^-/Na^+ ratio with precipitation is also supported by the spatial variations in Cl^-/Na^+ ratio in snow and ice and precipitation. The chemical data of snow and ice over the Tibetan Plateau (see Wake and others, 1993, table 1) show that the Cl^-/Na^+ ratio decreases with the increases in aridity. This may reflect the spatial variations in the Cl^-/Na^+ ratio in summer precipitation to a large extent, since about 80% of annual precipitation occurs in the summertime over the Tibetan Plateau (Dai, 1990). Sequeira and Kelkar (1978) also found that Cl^-/Na^+ ratios in summer monsoon rainwater over India decrease inland. The loss of Cl^- from sea-salt nuclei upon entry inland, and the increase of Na^+ from soil might be responsible for the spatial variations in Cl^-/Na^+ ratio in summer precipitation over the large area from the Indian subcontinent to the Tibetan Plateau. We can use these spatial variations in Cl^-/Na^+ ratio in summer precipitation to examine the temporal variations in Cl^-/Na^+ ratios in the MS layers of our ice core. In other words, the variations in Cl^-/Na^+ ratios in the summer layers might reflect the variations in monsoon precipitation. By analyzing the correlations between the Cl^-/Na^+ ratios in the MS layers and the summer monsoon rainfalls (Sontakke and Singh, 1996) in different parts of India, we found that a very good positive correlation (Fig. 4) exists between the Cl^-/Na^+ ratio (R_{MS}) in the MS layers and the monsoon rainfall (P, in mm) in northeast India:

$$P = 150.84 R_{MS} + 1104 \ (R^2 = 0.6117, \text{sig.} = 99.5\%) . \quad (1)$$

If a long series of Cl^-/Na^+ ratios in the MS layers is obtained from the deep ice core from Dasuopu glacier, the past changes in monsoon rainfall in northeast India can be roughly reconstructed using Equation (1).

Many studies of the Arctic ice-core records have tried to reveal the past atmospheric circulation and North Atlantic Oscillation (NAO) (Mayewski and others, 1994; Stager and Mayewski, 1997; Rogers and others, 1998). In the north Tibetan ice-core records, we found that changes in accumulation rate were influenced strongly by variations in the strengths of the westerlies and the Indian monsoon (Wang and others, 2000). During the NMS period, the southern branch of the westerlies exerts an important influence on the weather and climate of southern Tibet and the Himalaya. This process could leave an imprint on our ice-core records. Considering this atmospheric circulation mode and the vapor transfer mostly from oceans to the drilling site during the NMS period, it is speculated that the ultimate origin during that season might be the North Atlantic Ocean. Generally, stronger westerlies are linked with lower precipitation in this region. This could result in a relatively high concentration of chemical species in the snow. Moreover, the NAO index is always a descriptor of the strength of the westerlies

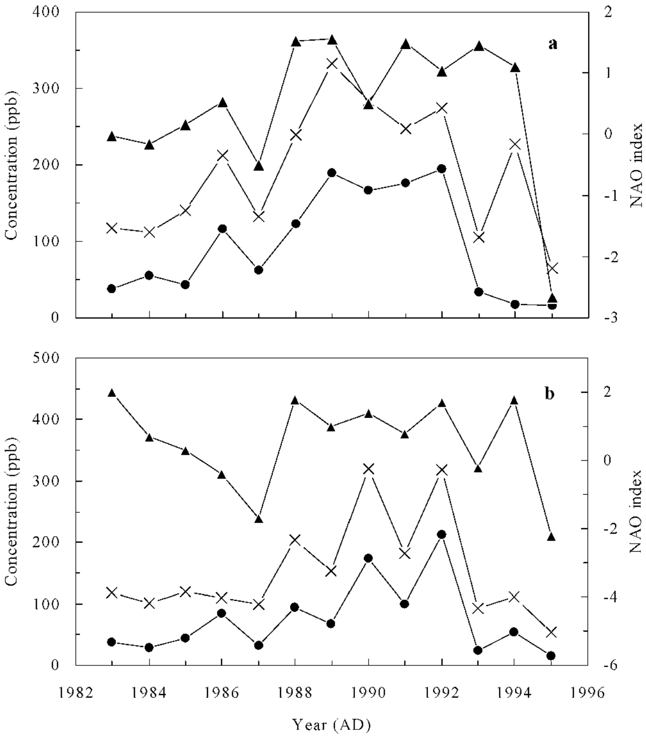

Fig. 5. Comparison of Cl^- (line with crosses) and Na^+ (line with circles) concentrations with NAO index (line with triangles): (a) for non-monsoon seasons (September–May); (b) for monsoon seasons (June–August). The normalized seasonal series of the NAO index used here have been updated by J. Rogers of The Ohio State University, and are available at http://www-bprc.mps.ohio-state.edu/NAO/index.html.

over the North Atlantic. Therefore, this index is useful for investigating the teleconnections between the NAO and the Himalayan Cl^- and Na^+ concentrations. Analytical results show that there indeed exist reliable positive correlations (sig. >90%) between the Cl^- and Na^+ concentrations in our ice core and the NAO index, during both the NMS and MS periods (Fig. 5). It can be seen from Figure 5 that the westerlies were strong (high NAO index) from 1988 through 1992, which might account for high Cl^- and Na^+ concentrations and low Cl^-/Na^+ ratios (because the westerlies can transport much more Na^+ from drier regions to the drilling site, as reflected by the low Cl^-/Na^+ ratio in the NMS period). Comparison of Figures 4 and 5b shows a negative correlation between the monsoon rainfall and the NAO index during the summertime. The correlation coefficient between Cl^-/Na^+ ratio in the MS layers (an index of Indian monsoon precipitation) and the NAO index is 0.4986, with sig. >90%. This indicates that the records of deep ice cores from Dasuopu glacier could be used to study the interaction between the Indian monsoon and the NAO, a connection that needs further study.

CONCLUSIONS

Here we present preliminary studies on the climatic and environmental significances of Cl^- and Na^+ concentrations recorded in an 18.5 m long ice core from Dasuopu glacier, central Himalaya. Snow chemistry and meteorological data suggest that the vapor arriving at this high drilling site comes mostly from the Bay of Bengal during the monsoon season, and possibly from the North Atlantic Ocean during the non-monsoon season. The high Cl^- and Na^+ concentrations reflect the influence of the strong westerlies on the high central Himalaya. The trend of variations in the Cl^-/Na^+ ratio in the MS layers was similar to that of the Indian summer monsoon rainfall. Consequently, the comprehensive analyses tell us that the records of deep ice cores from this glacier could be used to study the impact of the Indian monsoon on climate change over the Tibetan Plateau, and the interaction between the variations in the Indian monsoon and the NAO or the westerlies.

ACKNOWLEDGEMENTS

We thank Pu Jianchen, Tian Lide and Duan Keqin for help with the fieldwork. Special thanks are extended to Huan Cuilan for chemical analyses, and to B. R. Koci and Zhang Yongliang. We are grateful to T. D. van Ommen and two anonymous reviewers for their comments on the manuscript. This research was supported by the National Science Foundation of China (NSF grant 49801004), the Chinese National Committee of Science and Technology (CN grant G1998040800), the Chinese Academy of Sciences (CAS grant KZCX1-10-02) and the U.S. National Science Foundation–Environment, Safety and Health Program.

REFERENCES

Bao Yuzhang. 1985. [Analyses of the satellite cloud photographs over the Tibetan Plateau.] *[Sci. Technol. Tibet]*, **10**(4), 27–42. [In Chinese.]

Cole-Dai, J., E. Mosley-Thompson and L. G. Thompson. 1997. Annually resolved Southern Hemisphere volcanic history from two Antarctic ice cores. *J. Geophys. Res.*, **102**(D14), 16,761–16,771.

Dai Jiaxi, *ed.*. 1990. *[Climate on the Tibetan Plateau.]* Beijing, Meteorological Press. [In Chinese.]

Delmas, R. J. 1992. Environmental information from ice cores. *Rev. Geophys.*, **30**(1), 1–21.

Eichler, A., M. Schwikowski and H.W. Gäggeler. 2001. Meltwater-induced relocation of chemical species in Alpine firn. *Tellus*, **53B**(2), 192–203.

Hammer, C. U., H. B. Clausen and W. Dansgaard. 1980. Greenland ice sheet evidence of post-glacial volcanism and its climatic impact. *Nature*, **288**(5788), 230–235.

Hansson, M. E. 1994. The Renland ice core: a Northern Hemisphere record of aerosol composition over 120 000 years. *Tellus*, **46B**(5), 390–418.

Kang Shichang, C. P. Wake, Qin Dahe, P. A. Mayewski and Yao Tandong. 2000. Monsoon and dust signals recorded in Dasuopu glacier, Tibetan Plateau. *J. Glaciol.*, **46**(153), 222–226.

Keene, W. C., A. A. P. Pszenny, J. N. Galloway and M. E. Hawley. 1986. Sea-salt corrections and interpretation of constituent ratios in marine precipitation. *J. Geophys. Res.*, **91**(D6), 6647–6658.

Legrand, M. R. and R. J. Delmas. 1987. A 220-year continuous record of volcanic H_2SO_4 in the Antarctic ice sheet. *Nature*, **327**(6124), 671–676.

Legrand, M. and P. Mayewski. 1997. Glaciochemistry of polar ice cores: a review. *Rev. Geophys.*, **35**(3), 219–243.

Legrand, M. R., C. Lorius, N. I. Barkov and V. N. Petrov. 1988. Vostok (Antarctica) ice core: atmospheric chemistry changes over the last climatic cycle (160,000 years). *Atmos. Environ.*, **22**(2), 317–331.

Legrand, M., M. de Angelis, H. Cachier and A. Gaudichet. 1995. Boreal biomass burning over the last 80 years recorded in a Summit–Greenland ice core. *In* Delmas, R. J., *ed. Ice core studies of global biogeochemical cycles.* Berlin, etc., Springer-Verlag, 347–360. (NATO ASI Series I: Global Environmental Change 30.)

Mayewski, P. A., W. B. Lyons and N. Ahmad. 1983. Chemical composition of a high altitude fresh snowfall in the Ladakh Himalayas. *Geophys. Res. Lett.*, **10**(1), 105–108.

Mayewski, P. A., W. B. Lyons, N. Ahmad, G. Smith and M. Pourchet. 1984. Interpretation of the chemical and physical time-series retrieved from Sentik Glacier, Ladakh Himalaya, India. *J. Glaciol.*, **30**(104), 66–76.

Mayewski, P. A., W. B. Lyons, M. J. Spencer and J. L. Clayton. 1986. Correspondence. Snow chemistry from Xixabangma Peak, Tibet. *J. Glaciol.*, **32**(112), 542–543.

Mayewski, P. A., W. B. Lyons, M. J. Spencer, M. S. Twickler, C. F. Buck and S. Whitlow. 1990. An ice core record of atmospheric response to anthropogenic sulphate and nitrate. *Nature*, **346**(6284), 554–556.

Mayewski, P. A. *and 13 others.* 1994. Changes in atmospheric circulation and ocean ice cover over the North Atlantic during the last 41,000 years. *Science*, **263**(5154), 1747–1751.

Neftel, A., J. Beer, H. Oeschger, F. Zürcher and R. C. Finkel. 1985. Sulphate and nitrate concentrations in snow from south Greenland, 1895–1978. *Nature*, **314**(6012), 611–613.

O'Brien, S. R., P. A. Mayewski, L. D. Meeker, D. A. Meese, M. S. Twickler and S. I. Whitlow. 1995. Complexity of Holocene climate as reconstructed from a Greenland ice core. *Science*, **270**(5244), 1962–1964.

Rogers, J. C., J. F. Bolzan and V. A. Pohjola. 1998. Atmospheric circulation variability associated with shallow-core seasonal isotopic extremes near Summit Greenland. *J. Geophys. Res.*, **103**(D10), 11,205–11,219.

Sequeira, R. and D. Kelkar. 1978. Geochemical implications of summer monsoonal rainwater composition over India. *J. Appl. Meteorol.*, **17**(9), 1390–1396.

Shrestha, A. B. *and 6 others.* 2000. Seasonal variations in aerosol concentrations and compositions in the Nepal Himalaya. *Atmos. Environ.*, **34**(20), 3349–3363

Sontakke, N. A. and N. Singh. 1996. Longest instrumental regional and all-India summer monsoon rainfall series using optimum observations: reconstruction and update. *Holocene*, **6**(3), 315–331.

›Stager, J. C. and P. A. Mayewski. 1997. Abrupt early to mid-Holocene climatic transition registered at the Equater and the Poles. *Science*, **276**(5320), 1834–1836.

Sun Junying *and 6 others.* 1998. Soluble species in aerosol and snow and their relationship at Glacier 1, Tien Shan, China. *J. Geophys. Res.*, **103**(D21), 28,021–28,028.

Taylor, K. C., P. A. Mayewski, M. S. Twickler and S. I. Whitlow. 1996. Biomass burning recorded in the GISP2 ice core: a record from eastern Canada? *Holocene*, **6**(1), 1–6.

Thompson, L. G. *and 7 others.* 1995. Late glacial stage and Holocene tropical ice core records from Huascarán, Peru. *Science*, **269**(5220), 46–50.

Thompson, L. G., T. Yao and E. Mosley-Thompson. 2000. A high-resolution millennial record of the south Asian monsoon from Himalayan ice cores. *Science*, **289**(5486), 1916–1919.

Wagenbach, D., K. O. Münnich, U. Schotterer and H. Oeschger. 1988. The anthropogenic impact on snow chemistry at Colle Gnifetti, Swiss Alps. *Ann. Glaciol.*, **10**, 183–187.

Wake, C. P., P. A. Mayewski and M. J. Spencer. 1990. A review of central Asian glaciochemical data. *Ann. Glaciol.*, **14**, 301–306.

Wake, C. P., P. A. Mayewski, Wang Ping, Yang Qinzhao, Han Jiankang and Xie Zichu. 1992. Anthropogenic sulfate and Asian dust signals in snow from Tien Shan, northwest China. *Ann. Glaciol.*, **16**, 45–52.

Wake, C. P., P. A. Mayewski, Xie Zichu, Wang Ping and Li Zhongqin. 1993. Regional distribution of monsoon and desert dust signals record in Asian glaciers. *Geophys. Res. Lett.*, **20**(14), 1411–1414.

Wake, C. P., J. E. Dibb, P. A. Mayewski, Z. Li and Z. Xie. 1994. The chemical composition of aerosols over the eastern Himalayas and Tibetan Plateau during low dust periods. *Atmos. Environ.*, **28**(4), 695–704.

Wang Ninglian, Yao Tandong and L. G. Thompson. 2000. A preliminary study on correlationship between accumulation rates in ice cores from the northern Qinghai–Tibetan Plateau and atmospheric action centers. *In* Zheng Du and Zhu Liping, *eds. Formation and evolution, environmental changes and sustainable development on the Tibetan Plateau. Proceedings of International Symposium on the Qinghai–Tibetan Plateau, Xining, 1998.* Beijing, Academy Press, 166–174.

Yao Tandong, Jiao Keqin, Huang Cuilan, Li Yuefang and L. G. Thompson. 1995. [Environmental records in ice cores and their spatial coupling feature.] *[Quat. Res.* (China)*]*, **15**(1), 23–31. [In Chinese with English summary.]

Yao Tandong, Pu Jianchen, Wang Ninglian and Tian Lide. 1998. [A new type of ice formation in China.] *[Chin. Sci. Bull.]*, **43**(1), 94–97. [In Chinese.]

Zielinski, G. A. *and 8 others.* 1994. Record of volcanism since 7000 B.C. from the GISP2 Greenland ice core and implications for the volcano–climate system. *Science*, **264**(5161), 948–952.