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Preliminary research on the transmission path of nssSO_4^{2-} and NO_3^- in Antarctic ice sheet

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Abstract The main sources of nssSO_4^{2-} and NO_3^- were summarized in this paper. By analyzing the spatial distribution features of major ions in Antarctic ice sheet and studying on the different time of the same volcanic event recorded by different ice cores from different regions in Antarctica, this paper intends to study the transmission path of nssSO_4^{2-} and NO_3^-. Results show that nssSO_4^{2-} and NO_3^- are transmitted to the ice sheet through long distance and high altitude. The procedure of the transmission is that nssSO_4^{2-} and NO_3^- are transmitted to the level between the top of troposphere and the bottom of stratosphere, then subsided to the ice sheet surface and spread to other regions.

Key words Antarctic ice sheet, nssSO_4^{2-}, NO_3^-, transmission path.

1 Introduction

The study on the Antarctic ice cores has obtained great achievements since Bader proposed to sample ice cores by drilling successively in Polar Regions for scientific research in 1954 (Bader 1958). As one of the frontier research fields in global change research, the results significantly improve people's understanding of the reflection and the contribution of Antarctica to global change. The ultimate object of studying ice cores is to learn the history and to predict the future environmental change. To explain the ice core records quantitatively and to establish reliable models are necessary to obtain this object. However, it is still difficult to interpret all kinds of parameters quantitatively obtained from analyzing the ice cores, because we do not know exactly the main sources, transmission paths and depositional processes of major ions.

Lots of studies show that the sea-salt ions in Antarctic ice sheet mainly come from Sub-Antarctic Ocean (Qin 1995; Li *et al*. 1999). Some studies also point out that the cyclones from Sub-Antarctic Ocean bring sea-salt ions into the ice sheet, when they invade south region and frequently enter the inland of Antarctica (Van Loon 1966). However, there is little studies on the transmission path of the important ions in Antarctic ice sheet, such as nssSO_4^{2-} and NO_3^- which sources are considered to be complicated. By summarizing the main sources of nssSO_4^{2-} and NO_3^- and by analyzing the spatial distribution features of major ions in Antarctic ice sheet and studying on the different time recording the volcanic eruptions in different regions, this paper intends to give a preliminary study on the transmission path of nssSO_4^{2-} and NO_3^-.

2 Main sources of nssSO_4^{2-} and NO_3^-

Generally speaking, SO_4^{2-} in Antarctic ice sheet can be divided into sea-salt (ss) SO_4^{2-} and non-sea-salt (nss) SO_4^{2-}, of which the former comes from sea-salt aerosols and the latter mainly comes from marine organisms in the low and middle latitudes and volcanic eruptions (Qin 1995). In the previous works, 13 sources of NO_3^- have been recorded in Antarctic ice sheet (Zeller and Parker 1981). The sources of NO_3^- in Antarctic ice sheet are considered to be complicated, but recent studies show that most of NO_3^- in Antarctic ice sheet comes from lighten in the low and middle latitudes and various atmospheric processes in the high altitudes of Antarctica (Legrand and Delmas 1986). By summarizing the sources of nssSO_4^{2-} and NO_3^- in Antarctic ice sheet, two points must be emphasized: (1) Long distance; (2) High altitude.

3 Transmission path of nssSO_4^{2-} and NO_3^-

Our studies show that nssSO_4^{2-} and NO_3^- are transmitted to the ice sheet through long distance and upper air. The procedure of nssSO_4^{2-} and NO_3^- transmission is that nssSO_4^{2-} and NO_3^- are transmitted to the ice sheet at the level between the top of troposphere and the bottom of stratosphere, then nssSO_4^{2-} and NO_3^- subsided to the ice sheet surface and spread to other regions. Reasons are as follows:

3.1 Analyzing the spatial distribution features of major ions in Antarctic ice sheet

The glaciochemical data of the snow samples collected during the 1990 International Trans-Antarctic Expedition (ITAE) by Qin Dahe are rather good to study the spatial distribution features of major ions in Antarctic ice sheet. Concentrations of Cl^-, Na^+, Mg^{2+}, SO_4^{2-}, nssSO_4^{2-}, ssSO_4^{2-} and NO_3^- over the ITAE route, as well as their fluxes in section M (multi-year snow), are shown in Fig. 1. It is clear that the sea-salt ions (Cl^-, Na^+, Mg^{2+} and ssSO_4^{2-}) displaying a similar distribution pattern decrease from west to east along the ITAE route. Enough evidences show that the sea-salt ions in Antarctic ice sheet derived from the vapor channel from the Ross-Bellingshausen-Weddell Seas towards the interior, especially from the Weddell Sea section (Qin *et al*. 1999). At the same time, it is also clear in Fig. 1 that SO_4^{2-}, nssSO_4^{2-} and NO_3^- display a different pattern comparing to those of sea-salt ions (nssSO_4^{2-} dominates SO_4^{2-}, so SO_4^{2-} and nssSO_4^{2-}

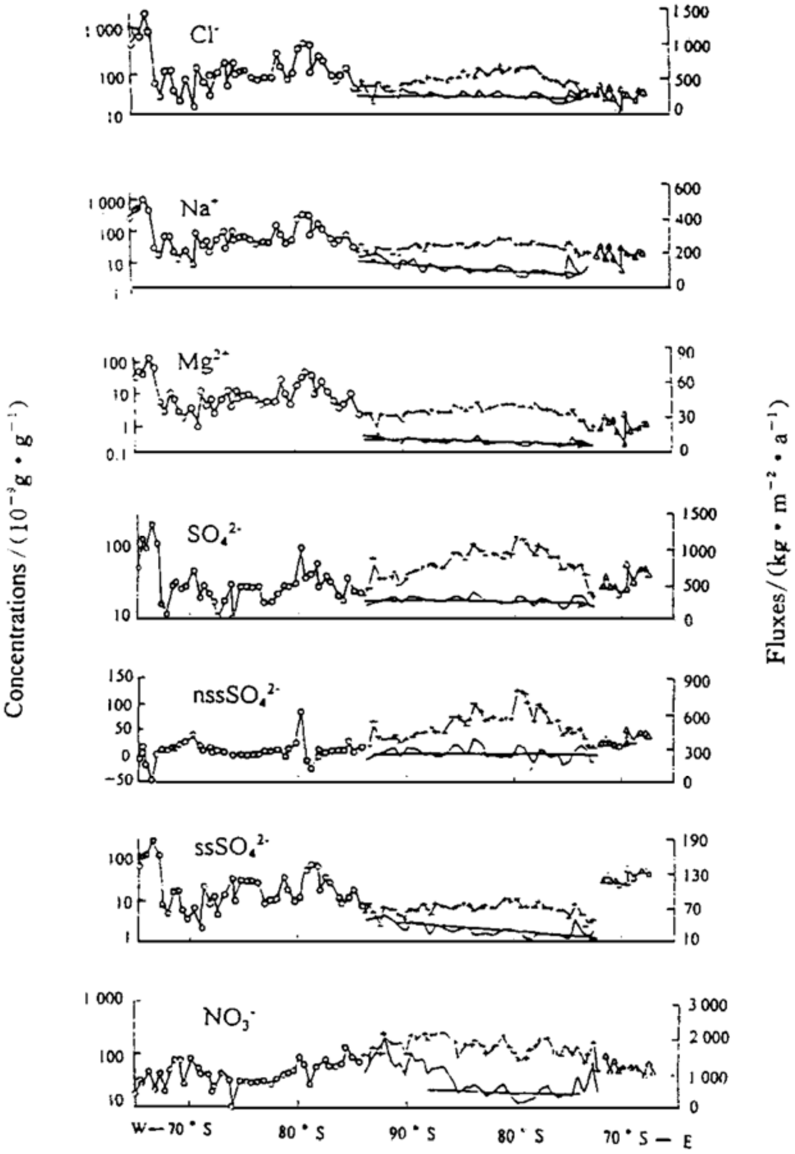

Fig. 1. Distribution of the concentrations and fluxes of Cl^-, Na^+, Mg^{2+}, SO_4^{2-}, $nssSO_4^{2-}$, $ssSO_4^{2-}$ and NO_3^- along the ITAE route. Circles represent the section mainly of winter snow; crosses the multi-year snow; and triangles the section mainly of summer snow. Left ordinate: the measured concentration (in exponent) of surface snow. Right ordinate: the calculated fluxes ($kg \cdot m^{-2} \cdot a^{-1}$) for multi-year snow only. Abscissa: the latitudes of the sample sites.

show a similar pattern while $ssSO_4^{2-}$ display a pattern similar to that of sea-salt ions). That is the concentrations of SO_4^{2-}, $nssSO_4^{2-}$ and NO_3^- showing high values at 80°S, then decreasing towards both sides, which support our point that $nssSO_4^{2-}$ and NO_3^- are transmitted to the ice sheet through long distance and upper air. The transmission process is that $nssSO_4^{2-}$ and NO_3^- are transmitted to the level between the top of troposphere and the bottom of stratosphere, then subsided to the ice sheet surface and spread to other regions.

3.2 Studying on the different time of the same volcanic event recorded by different ice cores from different regions in Antarctica

If the above-mentioned point is correct, different ice cores from different regions in

Antarctic ice sheet may show different detected time as to the same volcanic event. It also can be expressed as follows, when detecting a volcanic event using ice cores from Antarctic ice sheet, the detected time appearing in the ice cores from the region of 80°S may be earlier than that of ice cores from fringe area of Antarctica under precision dating condition. In order to prove the hypotheses, we studied with special attention on the galciochemical data of the two snow pits recovered during Chinese First Antarctic Inland Expedition. The traces (the increased nssSO_4^{2-} concentrations) of the June 1991 Pinatubo eruption in Philippines and the August 1991 Cerro Hudson eruption in Chile were detected by the data of the two snow pits (Zhang *et al*. 1999, 2000a). The detected time in the two snow pits of the two volcanic events is 1995/1994 and 1994/1993, respectively. In the meanwhile, the detected time of the same two volcanic events in the two snow pits in South Pole is 1994/1993 and 1993/1992, respectively (Dai *et al*. 1997a). There exists apparent time difference between the records. Since the two volcanic events occurred in 1990s, ice core dating should not be a problem. So it can be regarded as a proof to our point. However, the time difference between the records is as long as one year, which is affected by the precision of the ice core dating, in fact, if we can date the snow pits month by month, then the time difference may be far less than that of one year. At the same time, lots of studies show that the signals of volcanic events in Antarctic ice sheet are more obvious in low accumulation regions than those in high accumulation regions (Legrand and Delmas 1987). Dai *et al*. (1997b) consider it to be the result of the dilution in high accumulation regions. However, we found that the concentrations of major ions in the atmosphere in Princess Elizabeth Land, East Antarctica are independent of snow accumulation rate, which shows that the dilution effect did not occur in the ion concentrations of this region (Zhang *et al*. 2000b). The study of Mulvaney also shows that the concentrations of major ions in Antarctic ice sheet do not vary with the accumulation rate (Mulvaney and Wolf 1994). From our study, this phenomenon can be considered as the result the SO_4^{2-} transmission. Detailedly SO_4^{2-} came from volcanic eruptions and were transmitted to the ice sheet, which passed through the level between the top of troposphere and the bottom of stratosphere, then subsided to the ice sheet surface and spread to other regions. In addition, the accumulation rate in the fringe region of Antarctica is higher than that in the interior land. So it is self-evident to understand that the signals of volcanic events in Antarctic ice sheet are more obvious in low accumulation regions than those in high accumulation regions.

3.3 Theoretical discussion

In order to further prove the point, the theoretical discussion can be made. As have been noted, nssSO_4^{2-} mainly comes from marine organisms in the low and middle latitudes and volcanic eruptions. SO_4^{2-} comes from marine organisms which can be transmitted to high altitude due to the strong air convection in the low and middle latitudes. Explosive volcanic eruption introduce large amounts of dust and gaseous materials into the atmosphere and often directly into the stratosphere (Dai *et al*. 1997b). Therefore, SO_4^{2-} comes from marine organisms or SO_4^{2-} comes from volcanic eruptions, they all can be transmitted to the high altitude between the top of troposphere and the bottom of stratosphere or to the upper air over the Antarctic ice sheet according to three-circle atmospheric-circulation, then subsided to the ice sheet surface and spread to other regions. Because NO_3^- in Antarctic ice sheet mainly comes from various atmospheric processes in the high altitude, it is transmitted to Antarctic ice sheet according to three-circle atmospheric-circulation, similar to the transmission of $nssSO_4^{2-}$. So, $nssSO_4^{2-}$ and NO_3^- are transmitted to Antarctic ice sheet by atmospheric-circulation in a large scale, such as three-circle atmospheric-circulation.

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References

Bader H (1958): United States polar ice and snow studies in the International Geophysical Year. Geophys Monong, 2: 177 – 181.

Dai J, Mosley-Thompson E, Thompson LG (1997a): Quantifying the Pinatubo volcanic signal in South Pole snow. Geophysical Research Letters, 24(21): 2679 – 2682.

Dai J, Mosley-Thompson E, Thompson LG (1997b): Annually resolved southern hemisphere volcanic history from two Antarctic ice cores. J. Geophys. Res., 102: 16761 – 16771.

Legrand MR, Delmas RJ (1986): Relative contributions of tropospheric and stratospheric sources to nitrate in Antarctic snow. Tellus, 38B: 236 – 249.

Legrand MR, Delmas RJ (1987): A 220-year continuous record of volcanic H_2SO_4 in the Antarctic ice sheet. Nature, 327: 672 – 676.

Li ZQ, Zhang MJ, Qin DH, Xiao CD, Tian LD, Kang JC, Li J (1999): Primary research on the seasonal variations of $\delta^{18}O$, Cl^-, Na^+, NO_3^- and Ca^{2+} in the snow and firn recovered from Princess Elizabeth Land, Antarctica. Chinese Science Bulletin, 44 (24): 2270 – 2274.

Mulvaney R, Wolf EW (1994): Spatial variability of the major chemistry of the Antarctic ice sheet. Annals of Glaciology, 20: 440 – 447.

Qin DH (1995): The physical procedure, contemporary climate and environmental records in the surface firn of Antarctic ice sheet. Beijing: Science Press (in Chinese).

Qin DH, Mayewski PA, Ren JW, Xiao CD, Sun JY (1999): The Weddell Sea region: an important precipitation channel to the interior of the Antarctic ice sheet as revealed by glaciochemical investigation of surface snow along the longest trans-Antarctic route. Annuals of Glaciology, 29: 55 – 60.

Van Loon H (1966): The half yearly oscillations in middle and high southern latitudes and the coreless winter. J. Atmos. Sci., 24: 472 – 486.

Zeller EJ, Parker BC (1981): Nitrate ion in Antarctic firn as a marker for solar activity. Geophysical research Letter, 8(8): 895 – 898.

Zhang MJ, Li ZQ, Qin DH, Li J (1999): The primary research on the environmental climatic records of the two snow pits recovered from Princess Elizabeth Land, Antarctica. Chinese Journal of Polar Science, 10(1): 61 – 66.

Zhang MJ, Li ZQ, Qin DH, Xiao CD, Kang JC, Li J (2000a): A continuous 250 a record of volcanic activity from Princess Elizabeth Land, Antarctica. Progress in Natural Science, 10(10): 920 – 924 (in Chinese).

Zhang MJ, Li ZQ, Qin DH, Xiao CD, Kang JC, Li J (2000b): The study on the depositional style of major ions and the climatic effect of $nssSO_4^{2-}$ in Princess Elizabeth Land, Antarctica. Chinese Journal of Polar Science, 11(2): 107 – 112.