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Oxygen isotope composition of surface snow collected along the traverse route from Zhongshan Station toward Dome A, Antarctica

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Abstract: Oxygen isotope composition of surface snow sampled in the austral summer of 1998/1999 along the traverse route from Zhongshan Station toward Dome A, Antarctica is measured with the conventional mass spectrometer technique. The results of measurement show that oxygen isotope composition of surface snow varies in a wide range from -22.51‰ to -50.67‰ , and has a tendency that isotopic values gradually decrease with increase of distance from Zhongshan Station and altitude. Linear regression analysis indicates that there exists good correlation between oxygen isotope composition of surface snow and distance from Zhongshan Station, altitude and/or latitude, which actually reflects the close relation between stable isotope composition and air temperature.

1. Introduction

The Chinese Antarctic Inland Traverse Party carried out a glaciological survey along the traverse route from Zhongshan Station toward Dome A three times in the austral summers 1996/1997, 1997/1998 and 1998/1999, and a 1106 km-long traverse route was established for comprehensive glaciological investigations. As part of the field work, four 50–100 m ice cores were retrieved at 300 km, 500 km, 800 km and 1076 km far from Zhongshan Station, and a series of surface snow and snow pit samples were collected along the traverse route.

Reconstruction of climate and environmental changes within the past 200 years recorded in snow/ice are priority research topics at present, which are part of international cooperation projects such as GLOCHANT (The role of Antarctica in Global Change) and ITASE (International Trans-Antarctic Scientific Expedition). As indispensable aspect of polar glaciological studies, the isotopic composition of snow/ice reveals information about the precipitation process and palaeoclimatic change. This paper is devoted to the spatial variation of oxygen isotope of present precipitation based on isotopic analyses of surface snow collected along the traverse route from Zhongshan Station toward Dome A.

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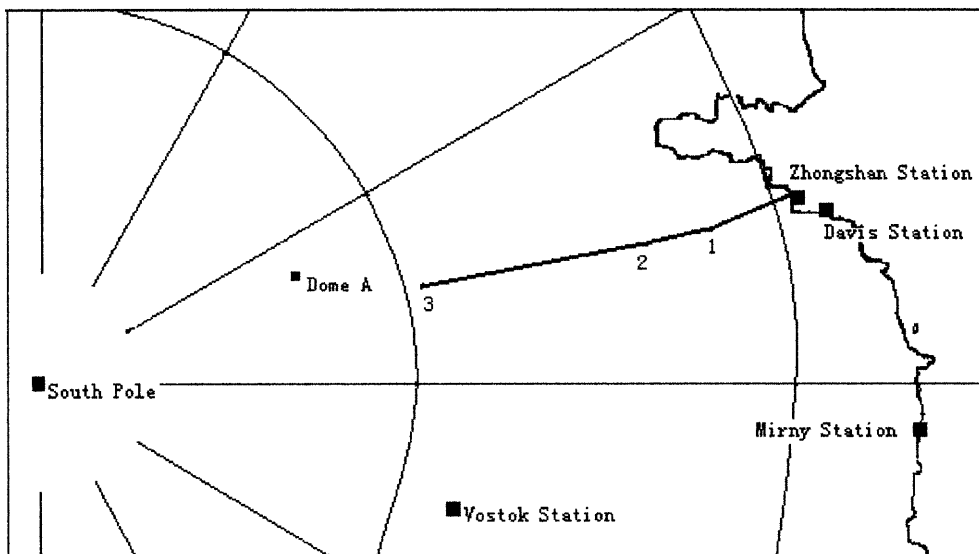


Fig. 1. The route of the three Chinese inland ice-sheet traverses from Zhongshan Station toward Dome A. 1, 2 and 3 stand for the terminations of the first, second and third Chinese inland traverses, respectively.

2. Sampling and analyses

The terminations of the three Chinese inland traverses are showed in Fig. 1. They are 304 km, 464 km and 1128 km from Zhongshan Station, respectively. Their altitudes are 2320 m, 2577 m and 3900 m, respectively, and geographical coordinates are $71^{\circ}52'59''\text{S}$, $77^{\circ}56'60''\text{E}$; $73^{\circ}22'03''\text{S}$, $77^{\circ}00'50''\text{E}$ and $79^{\circ}16'47''\text{S}$, $76^{\circ}59'46''\text{E}$. In the austral summer of 1998/1999 we sampled surface snow along the traverse route from Zhongshan Station toward Dome A every 10 km, a total of 101 samples. Surface snow in this study means fresh snow or drifting snow, which represents the composition of the last precipitation (snowfall). Strict measures were taken to prevent isotopic change of sampled snow during transport and storage. All of the oxygen isotope measurements were made at the Department of Geophysics, University of Copenhagen, at a rate of 115 double measurements per day. Samples were melted a few hours before analyses, and the standard CO_2 equilibrium method was employed for isotopic measurements, using 5-mL water samples and two sets of secondary working standards for each batch of samples. All the secondary standards were calibrated regularly against V-SMOW and SLAP (standard low Antarctic precipitation). The routine measuring accuracy is $\pm 0.07\text{‰}$ ($\delta^{18}\text{O}$, the per mil deviation of the $^{18}\text{O}/^{16}\text{O}$ ratio in a sample from the $^{18}\text{O}/^{16}\text{O}$ value in standard mean ocean water (SMOW), hereinafter denoted by δ).

3. Results and discussion

Oxygen isotope values of surface snow range from -22.51 to -50.67‰ , and their mean value, standard deviation and variation coefficient are -40.14‰ , 5.19‰ and

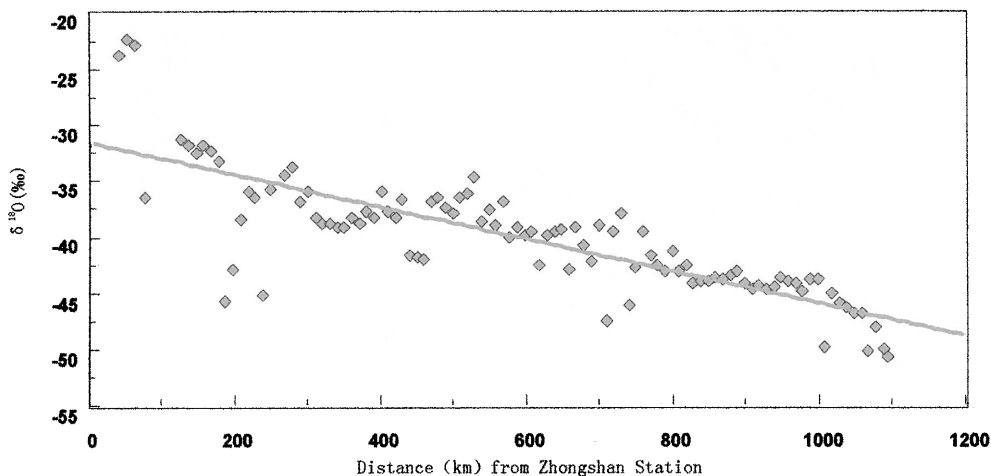


Fig. 2. The variability of the oxygen isotope composition of surface snow collected along the traverse route from Zhongshan Station toward Dome A with distance from Zhongshan Station.

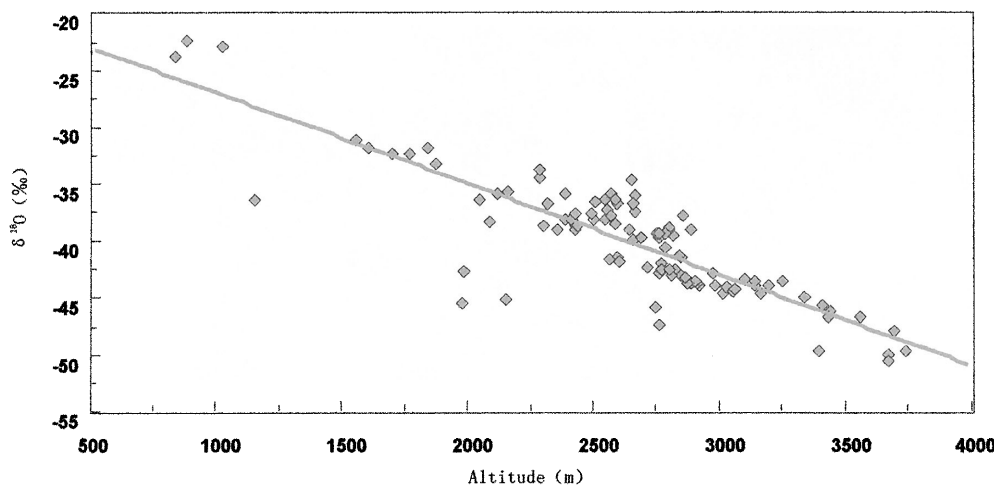


Fig. 3. The variability of the oxygen isotope composition of surface snow collected along the traverse route from Zhongshan Station toward Dome A with altitude.

12.93%, respectively. The reason for the high variation coefficient is probably that surface snow samples did not originate from the same precipitation process, and/or surface snow in low altitude area was redistributed by strong katabatic wind. Surface snow samples collected within 300 km from Zhongshan Station or below 2300 m a.s.l. have more scattered oxygen isotope composition than others.

It can be seen from Fig. 2 that oxygen isotope values of surface snow gradually decrease with increase of distance from Zhongshan Station. Linear regression analysis shows that there is good correlation between isotopic composition and distance from Zhongshan Station: $y = -0.0141x - 31.72$, $r^2 = 0.66$, confidence level 99%, where y is

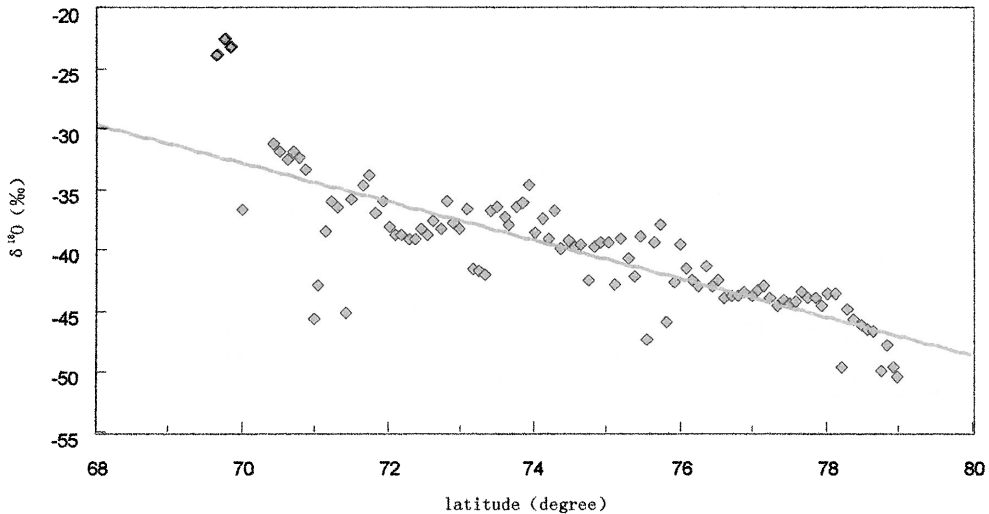


Fig. 4. The variability of the oxygen isotope composition of surface snow collected along the traverse route from Zhongshan Station toward Dome A with latitude.

oxygen isotope composition (‰) of surface snow, and x is distance (km) of sampling site from Zhongshan Station.

This same exercise is repeated with the altitude of the sampling site (Fig. 3). The linear regression equation is: $y = -0.00794x - 19.22$, $r^2 = 0.73$, confidence level 99%, where y is oxygen isotope composition (‰) of surface snow, and x is the altitude (m) of the sampling site. The correlation coefficient (r) in this equation is higher than the previous one.

Linear regression analysis between oxygen isotope values of surface snow and sampling site latitudes (Fig. 4) gives $y = -1.6x + 79.1$, $r^2 = 0.66$, confidence level 99%, where y is still oxygen isotope composition (‰) of surface snow, and x is latitude (south latitude, degree) of the sampling site.

In polar regions, the geographical variance of stable isotope composition of precipitation is determined mainly by the parameter $T_c - T_c^\circ$, *i.e.* the difference between the condensation temperature, T_c , at a given location and T_c° at the first stage of the precipitation process, although it is influenced by many other parameters. None of these temperatures are generally known, and therefore one has to tentatively replace $T_c - T_c^\circ$, by $T_m - T_m^\circ$, *i.e.* the mean air temperature difference at ground level, or even by T_m itself, assuming the temperature T_m° at the early stage of the condensation to be essentially the same for all stations (Dansgaard *et al.*, 1973; Johnsen *et al.*, 1997). For this reason the mean annual $\delta^{18}\text{O}$ of snow at middle and high latitudes is related closely to the mean annual surface temperature at the precipitation (*i.e.* snow deposition) site, which is also demonstrated clearly by the simple Rayleigh-type distillation models and general circulation models (Jouzel *et al.*, 1997). This linear relationship is further supported effectively by observations of present and past precipitation in Greenland and Antarctica (Dansgaard *et al.*, 1973; Johnsen *et al.*, 1989; White *et al.*, 1997; Jouzel *et al.*, 1997).

On the Greenland Ice Sheet, the present-day spatial oxygen isotope/surface temperature gradient ($d\delta/dT_s$) is $0.62\text{‰}/^\circ\text{C}$ (Dansgaard *et al.*, 1973), and is further corrected to $0.67\text{‰}/^\circ\text{C}$ (Johnsen *et al.*, 1989). But the isotopic latitude or altitude effect appears to be relatively complicated in Antarctica, mainly due to low accumulation rates and high storminess which make wind erosion, snow drift etc. more effective in disturbing the isotopic distribution pattern. It is known that the spatial oxygen isotope/surface temperature gradient at Adelie Land, Antarctica is $0.76\text{‰}/^\circ\text{C}$ (Lorius and Merlivat, 1977), which is similar to oxygen isotope/surface temperature gradient ($0.74\text{‰}/^\circ\text{C}$) obtained at Collins Ice Cap, King George Island, Antarctica (Yan, 1997). Satow and Watanabe (1992) analyzed the good linear relationship between the $\delta^{18}\text{O}$ values of surface snow layers and the 10m snow temperature (T in $^\circ\text{C}$, close to mean annual surface temperature) in Enderby Land-East Queen Maud Land, East Antarctica, and obtained the equation $\delta^{18}\text{O}=0.834T-8.7$ in the temperature range from -20 to -55°C . Satow *et al.* (1999) modified the above equation to $\delta^{18}\text{O}=0.852T-7.92$ based on new data and further discussed the relationship among accumulation rate, stable isotope ratio and surface temperature on the plateau of East Dronning Maud Land, Antarctica.

Due to the extremely limited temperature data available for the traverse route from Zhongshan Station toward Dome A, it is difficult to discuss the relationship between the oxygen isotope composition of surface snow and the mean annual surface temperature at the precipitation (or sampling) site. According to the oxygen isotope values and Automatic Weather Station temperature data of both LGB69 and LGB66, which are Australian observation sites situated along the traverse route from Zhongshan Station toward Dome A (Higham and Craven, 1997), we can acquire the spatial oxygen isotope/surface temperature gradient of $0.80\text{‰}/^\circ\text{C}$ by direct comparison. Although the topography of the Lambert Glacier basin controls the katabatic wind regime and strongly influences the surface climate of the slope region to at least 2500 m elevation and up to nearly 1000 km inland (Allison, 1998), and the oxygen isotope composition of 2 m firn cores has much lower correlation with 10-m firn temperature (T_{10}) than with elevation, Higham and Craven (1997) established a regression of $\delta^{18}\text{O}=0.81T_{10}-8.3$, with a correlation coefficient of 0.96. This regression formula reveals that spatial oxygen isotope/10 m-firn temperature gradient for the Lambert Glacier basin is $0.81\text{‰}/^\circ\text{C}$.

The systematic decrease of oxygen isotope composition of surface snow collected along the traverse route from Zhongshan Station toward Dome A with altitude, latitude and distance from Zhongshan Station (or the coast), actually reflects the close relationship between stable isotope composition and air temperature. The isotopic altitude/inland and latitude effects (lower $\delta^{18}\text{O}$ values at higher altitudes, latitudes and/or further inland) are due to preferential removal of heavy components from precipitation clouds moving toward higher latitude, which causes gradual depletion of heavy components in remaining vapor and precipitation (Dansgaard and Oeschger, 1989; Jouzel *et al.*, 1996). The isotopic altitude effect on precipitation, defined as the change of δ per 100 m increasing altitude, often includes both a latitude effect and an inland effect (decreasing δ inland from the coast at unchanged altitude). From the above-mentioned regression equation between oxygen isotope composition of surface snow and altitude, we can define the isotopic altitude effect along the traverse route from

Zhongshan Station to Dome A as $-0.79\text{‰}/100\text{ m}$, which is much lower than the isotopic altitude effect in temperate regions of the order of $-0.2\text{‰}/100\text{ m}$ (Dansgaard, 1973). Combining the isotopic altitude effect ($-0.79\text{‰}/100\text{ m}$) with the spatial oxygen isotope/surface temperature gradient ($0.80\text{‰}/^{\circ}\text{C}$), we obtain the lapse rate of surface temperature along the traverse route from Zhongshan Station toward Dome A, *i.e.* $0.99^{\circ}\text{C}/100\text{ m}$.

4. Conclusions

The results of measurement of oxygen isotope composition of surface snow sampled in the austral summer of 1998/1999 along the traverse route from Zhongshan Station toward Dome A indicate that the isotopic composition of surface snow varies in a wide range from -22.51‰ to -50.67‰ , and has a relatively high variation coefficient (12.93%). Linear regression analysis shows that the oxygen isotope composition of surface snow has strong correlation with altitude, latitude and distance from Zhongshan Station, called altitude/inland and latitude effects, which actually reflects the close relation between stable isotope composition and air temperature. The spatial oxygen isotope/surface temperature gradient along the profile from Zhongshan Station toward Dome A is, based on direct comparison, $0.80\text{‰}/^{\circ}\text{C}$, and the isotopic altitude effect is $-0.79\text{‰}/100\text{ m}$, obtained through linear regression analysis. The induced lapse rate of surface temperature along the profile from Zhongshan Station to Dome A is $0.99^{\circ}\text{C}/100\text{ m}$.

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References

- Allison, I. (1998): Surface climate of the interior of the Lambert Glacier basin, Antarctica, from automatic weather station data. *Ann. Glaciol.*, **27**, 515–520.
- Dansgaard, W. and Oeschger, H. (1989): Past environmental long-term records from the Arctic. The Environmental Record in Glacier and Ice Sheets, ed. by H. Oeschger and C.C. Langway. J. Wiley, 287–317.
- Dansgaard, W., Johnsen, S.J., Clausen, H.B. and Gundestrup, N. (1973): Stable isotope glaciology. *Medd. Grøn.*, **197** (2), 1–53.
- Higham, M., and Craven, M. (1997): Surface mass balance and snow surface properties from the Lambert Glacier Basin Traverse 1990–94. Cooperative Research Centre for the Antarctic and Southern Ocean

- Environment, Research Report No. 9, 1–129.
- Johnsen, S.J., Dansgaard, W. and White, J.W. (1989): The origin of Arctic precipitation under present and glacial conditions. *Tellus*, **41**, 452–469.
- Johnsen, S.J., Clausen, H.B., Dansgaard, W., Gundestrup, N.S., Hammer, C.U., Andersen, U., Andersen, K., K., Hvidberg, C.S., Dahl-Jensen, D., Steffensen, J.P., Shoji, H., Sveinbjornsdottir, A.E., White, J., Jouzel, J. and Fisher, D. (1997): The $\delta^{18}\text{O}$ record along the Greenland Ice Core Project deep ice core and the problem of Eemian climate instability. *J. Geophys. Res.*, **102**, 26397–26410.
- Johnsen, S.J., Clausen, H.B., Jouzel, J., Schwander, J., Sveinbjornsdottir, A.E. and White, J. (1999): Stable isotope records from Greenland Deep Ice Cores: the climate signal and the role of diffusion. *Ice Physics and the Natural Environment*, ed. by J.S. Wettlaufer *et al.* Berlin, Springer, 89–107 (NATO ASI Series, Vol. 156).
- Jouzel, J., Alley, R.B., Cuffey, K.M., Dansgaard, W., Grootes, P., Hoffmann, G., Johnsen, S.J., Koster, R.D., Peel, D., Shuman, C.A., Stievenard, M., Stuiver, M. and White, J. (1997): Validity of the temperature reconstruction from water isotopes in ice cores. *J. Geophys. Res.*, **102**, 26471–26487.
- Jouzel, J., Hammer, C., Lorius, C., Johnsen, S., Grootes, P., Stievenard, M. and White, J. (1996): Abrupt climate changes: A global perspective from ice cores. *Clouds, Chemistry and Climate*, ed. by P.J. Crutzen and V. Ramanathan. Berlin, Springer, 83–108 (NATO ASI Series, Vol. 135).
- Lorius, C. and Merlivat, L. (1977): Distribution of mean surface stable isotope values in East Antarctica: Observed changes with depth in a coastal area. *Isotopes and Impurities in Snow and Ice. Proceedings of the Grenoble Symposium Aug./Sept. 1975.* Bartholomew, IAHS, 125–137 (IAHS-AISH Publ. No. 118).
- Satow, K. and Watanabe, O. (1992): Distribution of mean $\delta^{18}\text{O}$ values of surface snow layers and their dependence on air temperature in Enderby Land-East Queen Maud Land, Antarctica. *Polar Meteorol. Glaciol.*, **5**, 120–127.
- Satow, K., Watanabe, O., Shoji, H. and Motoyama, H. (1999): The relationship among accumulation rate, stable isotope ratio and surface temperature on the plateau of East Dronning Maud Land, Antarctica. *Polar Meteorol. Glaciol.*, **13**, 43–52.
- White, J.W.C., Barlow, L.K., Fisher, D., Grootes, P., Jouzel, J., Johnsen, S.J., Stuiver, M. and Clausen, H. B. (1997): The climate signal in the stable isotopes of snow from Summit, Greenland: Results of comparisons with modern climate observations. *J. Geophys. Res.*, **102**, 26425–26439.
- Yan, M. (1997): A preliminary study on oxygen isotope of ice cores of Collins Ice Cap, King George Island, Antarctica. *Chin. J. Polar Sci.*, **8** (1), 65–71.

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