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Distribution of δ^{18}O in surface snow along a transect from Zhongshan Station to Dome A, East Antarctica

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Surface snow samples were collected during the 14th (1997/1998) and 24th (2007/2008) Chinese National Antarctica Research Expeditions along a transect from Zhongshan Station to Dome A. The stable oxygen isotope ratios of these samples were measured to investigate their relationships with temperature and geographical parameters (latitude, longitude, altitude and distance to the coast). The results reveal a strong positive correlation (R=0.945) between δ^{18}O and mean annual temperature, with a gradient of 0.84‰°C^{-1}, which is a little higher than that in Terre Adelie Land. Regression analyses also show that the δ^{18}O of surface snow is strongly correlated with distance to the coast (R=0.942), latitude (R=0.942), and altitude (R=0.941). But no significant correlation was found between δ^{18}O and longitude in study area. Altitude should be the most important factor influencing the δ^{18}O distribution because of distinctive topography. The δ^{18}O-altitude and T-altitude gradients along this transect are determined to be −1.1‰/100 m and 1.31°C/100 m, respectively.

Antarctica, ITASE, isotope, Dome A, δ^{18}O, CHINARE

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Since Dansgaard [1–3] first reported positive correlations between stable isotopes in precipitation and temperature, oxygen and hydrogen isotopic variations preserved in ice cores have been widely used to trace past climate changes. Firn temperature measurement was used as an indicator of annual average surface temperature. Studies in polar areas have demonstrated that the stable hydrogen and oxygen isotopic compositions in precipitation are strongly correlated with local temperature [3,4]; these relationships have been applied to reconstruct paleoclimate records in ice cores in Antarctica and Greenland. But these studies of δ^{18}O-T and δD-T were established in specified areas. It has been observed that δ^{18}O-T and δD-T relationships differ in different areas [5]. Masson-Delmotte et al. [6] also found that the δ values vary with altitude, latitude and distance to the coast based on ~1000 surface snow samples in Antarctica.

As part of International Trans Antarctic Scientific Expedition, the Chinese National Antarctica Research Expedition (CHINARE) has carried out seven traverses from Zhongshan Station (ZS) to inland since 1996/1997; and arrived the summit of East Antarctic ice sheet, Dome A (80°22′00″S, 77°21′11″E, 4093 m) in Jan. 2005. Additionally, several firn cores and 124 surface snow samples were drilled/collected along the route during 14th (1997/1998, 462 km inland) and 24th (2007/2008, also arrived at Dome A, 1248 km) CHINARE.

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1 Snow sampling and δ measurement

The CHINARE traverse route starts at the ZS and ends at Dome A, with a distance of 1248 km (Figure 1). The transect is on the east side of the Lambert Glacier Basin (LGB), approximately along the 77°E longitudinal line. The Lambert Glacier lies in a deep rift valley in the East Antarctic ice sheet, with the ice flows converging into the glacier and draining into the Amery Ice Shelf. Surface snow samples were collected from the top 5 cm at 4 km intervals during 1997/1998 and 10 km intervals during 2007/2008 (both austral summer). All procedures like preparation, fieldwork and sealed transportation were carried very carefully to prevent adverse environmental impacts and contamination.

Samples were prepared using the standard CO_2 equilibration method [7] and the oxygen isotopic compositions were analyzed using a stable isotope ratio mass spectrometer (Finnigan MAT-252) in the State Key Laboratory of Cryospheric Sciences, Chinese Academy of Sciences. Each sample was measured two rounds and one round four times. The oxygen isotopic composition was reported in terms of the standard δ^{18}O value representing the difference in the ^{18}O/^{16}O ratios between the sample and the standard V-SMOW. The measurement accuracy was estimated into ±0.15‰.

2 Discussion

It shows that in the spatial distribution graph (Figure 2), although the two groups of surface snow samples have a little difference with each other, the variations are in the same order; so we just discussed the data derived from 2007/2008 in the following sections. The δ values are between –23.61‰ and –57.06‰, averaged to –42.35‰, the standard deviation is 7.90. The samples may come from different precipitation processes with variables, so there is a relative high coefficient of variation, 18.65%. For example, in areas below 2500 m a.s.l., the wind regime and local climate are controlled by the morphology of Lambert Glacier Basin [8]; the snow accumulation rate near coast could be 68 cm m^{-2} a^{-1} [9], but there is only ~10 cm m^{-2} a^{-1} at Dome A [10]. Qin et al. [5] have forecasted that the stable isotope ratios in precipitation at Dome A should be the lowest in East Antarctic ice sheet; Xiao et al. [11] studied the oxygen isotope ratio in snow pit and ice core, it showed a value of –58.4‰. The lowest δ^{18}O we observed is lower than Dome C and Dome Fuji [12,13], but higher than Vostok (–58.4‰) [5].

2.1 The relationship between δ^{18}O and annual average temperature

The CHINARE and ANARE (Australian National Antarc-

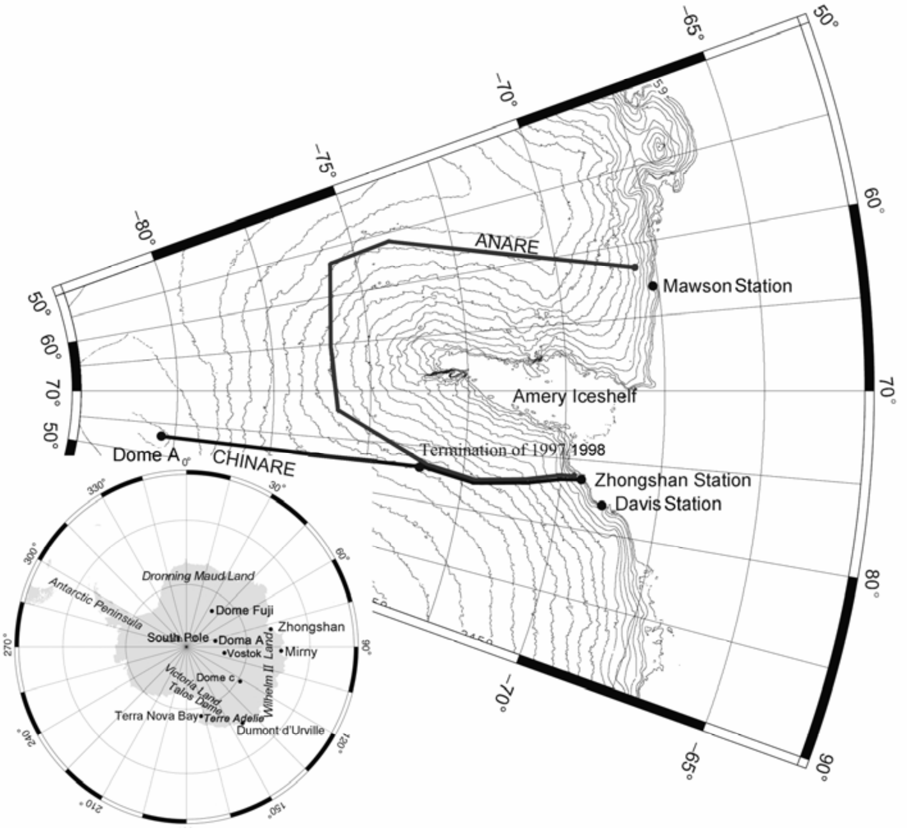

Figure 1 The traverse route of Chinese National Antarctica Research Expedition (CHINARE).

tica Research Expedition) measured the annual average temperature at 14 sites by bore-hole method or automatic weather station observation (Table 1). In this study, we used multiple regression plus Kriging method [14], interpolated these data in the region of 60°–81°S and 76°–78°E at a 0.00001° spatial resolution, and then picked up annual average temperature at the sampling sites. Accuracy analysis of the method for the annual average temperature showed that the correlation coefficient is 0.980, and the average relative error is 1.2°C or less.

The δ^{18}O-T relationship established at Terre Adelie Land by Lorius and Merlivat [4] is widely used in paleoclimatic reconstruction in East Antarctica ice sheet. Figure 3 demonstrates a strong positive correlation between δ^{18}O and annual average temperature along the whole transect. The linear regression of the data yielded the following equation:

$$\delta^{18}\mathrm{O}(‰)=0.842T-9.118, \quad R=0.945. \tag{1}$$

The above equation shows that the δ^{18}O-T gradient is 0.842‰°C^{-1} (the result during 14th CHINARE is 0.837‰°C^{-1}, R=0.864), which is a little higher than that in the Terre Adelie Land (0.755‰°C^{-1}) [4] and Dronning Maud Land (0.77‰°C^{-1}) [15], but similar to that in the Victoria Land (0.81‰°C^{-1}) [16]. It is lower than observed by Qin et al. [5] and Proposito et al. [12], along Mirny to Vostok route (0.971‰°C^{-1}) and Terre Nova Bay to Dome C route (0.99‰°C^{-1}). The main reason is that these snow samples occupied different season; the vapor sources also have influence on this variation. The precipitation in our study area is mainly from the low-middle zone of western Indian Ocean [17].

2.2 The spatial distribution of δ^{18}O

There are many factors affecting the distribution of δ^{18}O. The surface snow stable isotope ratios decrease with distance to the coast, altitude and latitude [6,18]. Surface inversion layer and its changes, cyclones and cyclone paths [5,19], surface climate such as wind could disturb the redistribution of surface snow [20], will also change the surface snow stable isotope ratios. The altitude increases rapidly within the initial 300 km to the coast, with an average slope of 7 m km^{-1} (Figure 2). Marine air masses induce more precipitation near coast because of topography, and there are variable vapor sources toward inland area. Especially in Dome A, which has the similar distance to East Antarctic coasts (Weddell coast, Ross coast and the others), it is almost impossible to identify where the precipitation comes from.

This study analyzed the relationship between geographical parameters and δ^{18}O along ZS to Dome A traverse, it shows that the regression model is

$$\delta^{18}\mathrm{O}(‰)=0.408\sin\mathrm{Lat.}-0.004\,\mathrm{Elev.}-0.013\,\mathrm{Dist.}-21.658, \quad R=0.954. \tag{2}$$

Significant level is listed in Table 2. eq. (2) demonstrates that Lat., Elev. and Dist. have a linear relationship with δ^{18}O. But actually, latitude and distance to the coast is positively correlated with elevation, so it can say altitude is the most important factor. The analysis in the initial 500 km can display this result more clearly (not shown). Figure 2 also demonstrates the relation between slope and δ^{18}O.

If longitude is included as a variable, the following equation will be obtained:

$$\delta^{18}\mathrm{O}(‰)=0.633\sin\mathrm{Lat.}-2.958\sin\mathrm{Lon.}-0.004\,\mathrm{Elev.}-0.014\,\mathrm{Dist.}-25.506, R=0.955. \tag{3}$$

The R does not show obvious change, and it suggests

Table 1 The locations along CHINARE where annual average temperature data are available

Position	Lat. (°S)	Lon. (°E)	Elev. (m a.s.l.)	Dist.	10-m-deep firn temperature (°C)	Time
LGB69	70.8353	77.0747	1854	172	–27.2	2005–2006
LT925	71.0954	77.2886	1996	202	–28.5	1994
LT910	71.3606	77.5112	2135	233	–30.7	1994
LT895	71.6205	77.7305	2214	263	–31.7	1994
LT880	71.8808	77.9509	2325	294	–33.1	1994
LT865	72.1505	77.9494	2351	324	–33.3	1994
LT850	72.4106	77.7231	2424	354	–34.7	1994
LT835	72.6712	77.4936	2468	384	–34.5	1994
LT805	73.1914	77.0268	2581	444	–36.1	1994
LT790	73.452	76.7877	2537	474	–36.1	1994
LT743	74.2595	76.1687	2476	564	–35.6	1994
LT730	74.4793	75.8756	2468	594	–35.5	1994
EAGLE	76.4197	77.0239	2830	801	–43.1	2005–2008
Dome A	80.3675	77.3439	4093	1248	–58.2	2005–2008

a) Lat., Latitude; Lon., longitude; Elev., elevation; Dist., distance to the coast.

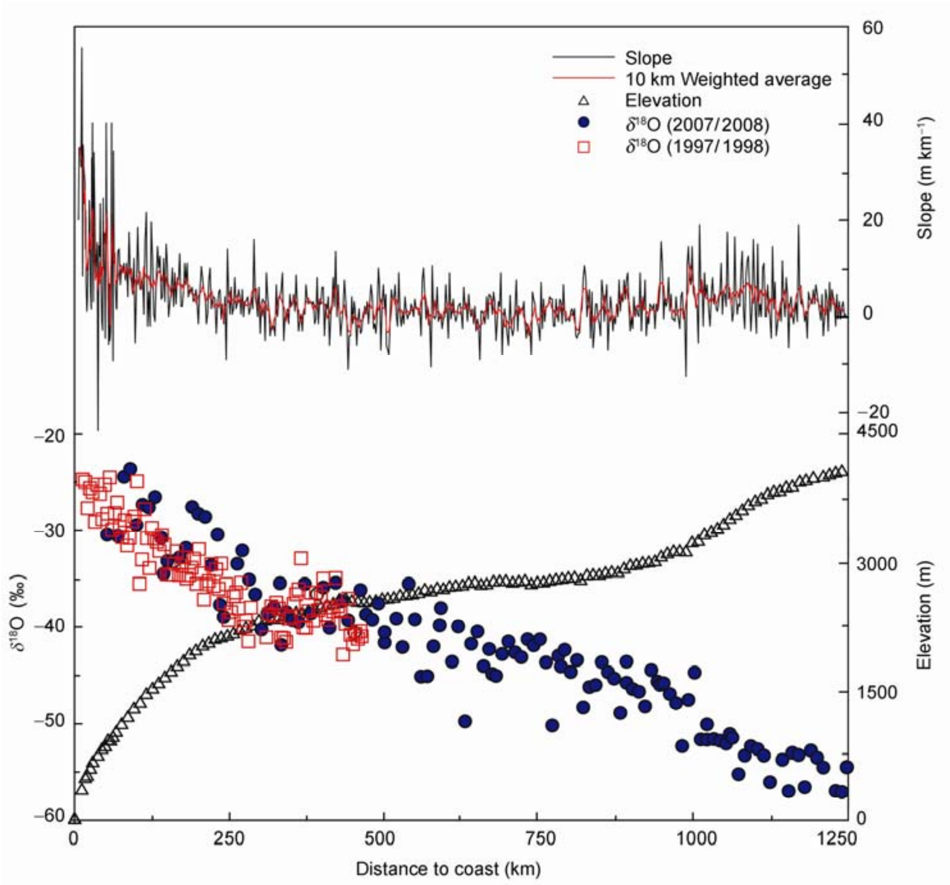

Figure 2 The variability of δ^{18}O along ZS to Dome A route.

Table 2 The regression analysis and correlated test between δ^{18}O and geophysical parameters (Lat., Elev., Dist. and Lon.) along CHINARE route

		Sin (Lat.)	Sin (Lon.)	Elev. (m)	Dist. (km)	δ^{18}O (‰)
Sin (Lat.)	*R*	1				
	Sig.					
Sin (Lon.)	*R*	0.005	1			
	Sig.	0.042				
Elev. (m)	*R*	–0.468 $^{a)}$	–0.391 $^{a)}$	1		
	Sig.	0.999	0.999			
Dist. (km)	*R*	–0.274 $^{a)}$	–0.393 $^{a)}$	0.954 $^{a)}$	1	
	Sig.	0.998	0.999	0.999		
δ^{18}O (‰)	*R*	0.365 $^{a)}$	0.419 $^{a)}$	–0.941 $^{a)}$	–0.942 $^{a)}$	1
	Sig.	0.999	0.999	0.999	0.999	

a) Significant at the 0.01 level; Sig., significant.

longitude has no influence on the variability of stable oxygen isotopic composition.

Figure 4 displays the relationship between δ^{18}O and these factors respectively. The linear regression equations are

$$\delta^{18}\mathrm{O}(‰) = -2.458\ \mathrm{Lat.} + 142.181 \quad R = 0.942, \tag{4}$$

$$\delta^{18}\mathrm{O}(‰) = 7.446\ \mathrm{Lon.} - 613.616 \quad R = 0.561, \tag{5}$$

$$\delta^{18}\mathrm{O}(‰) = -0.011\ \mathrm{Elev} - 12.275 \quad R = 0.941, \tag{6}$$

$$\delta^{18}\mathrm{O}(‰) = -0.022\ \mathrm{Dist.} - 28.144 \quad R = 0.942, \tag{7}$$

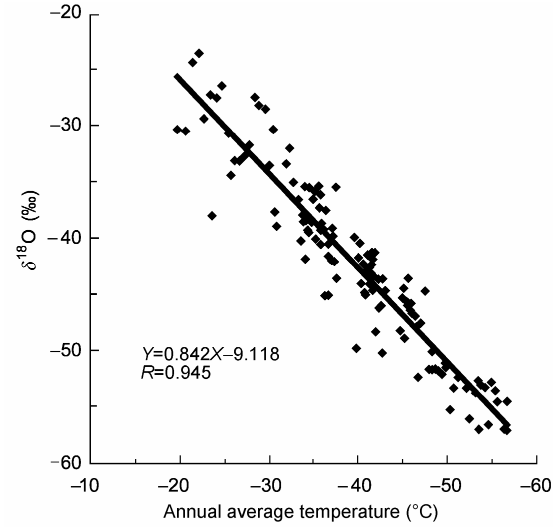

Figure 3 The relationship between δ^{18}O and annual average temperature along ZS to Dome A route.

In eqs. (4), (6), (7), latitude, elevation and distance to the coast have the same order of *R*. Both δ^{18}O-Lat. and δ^{18}O-Elev. effects are due to the preferential removal of the heavy isotope ^{18}O in precipitation when air masses move to inland [21,22]. We can find in eq. (6) that the δ^{18}O-altitude

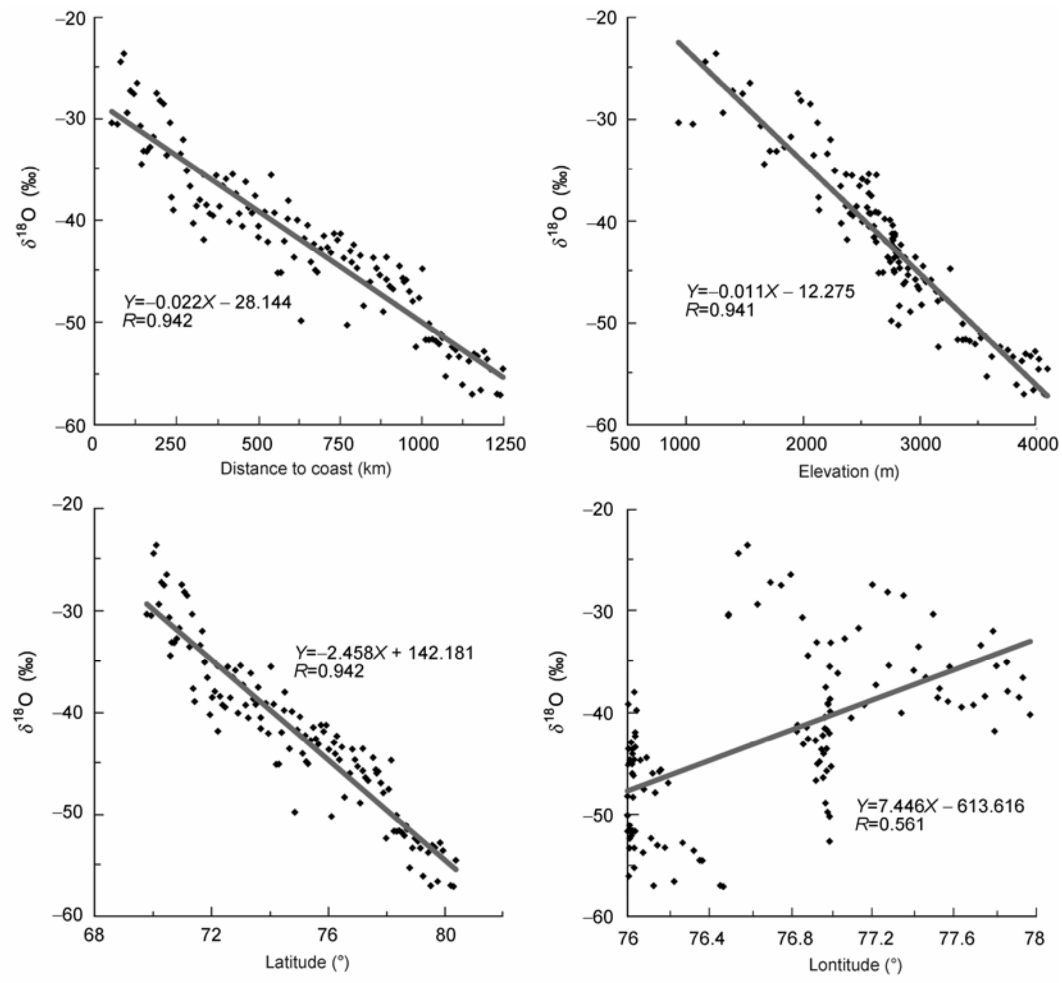

Figure 4 The relationships between δ^{18}O and geographical elements along ZS to Dome A route.

gradient is –1.1‰/100 m. Previous studies showed that there are different δ^{18}O-Elev. ratios in East Antarctica. These gradients are –1.7‰/100 m along Mirny to Vostok route [5], –1.5‰/100 m along the initial half route of Dumont d'Urville to Dome C [23], –1.3‰/100 m at Talos Dome [23], –1‰/100 m along Terra Nova Bay to Dome C route [12], and –0.8‰/100 m in the Wilhelm II Land [24].

These differences were mainly due to the variability of temperature declining with altitude rise, which differs isotope fractionation rates. We can also calculate the T-Elevation gradient along ZS to Dome A transect, which is –1.31°C/100 m.

3 Conclusions

This study shows that significant relationships exist between surface snow oxygen isotopic composition and altitude, latitude, and also distance to the coast. The δ^{18}O-Elev. and δ^{18}O-T gradients are –1.1‰/100 m and 0.84‰°C^{-1}, respectively. This result provides the basis to explain the climate record from ice cores along Zhongshan station to Dome A route.

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