OXYGEN ISOTOPIC COMPOSITION OF THE SURFACE SNOW IN MIZUHO PLATEAU

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Abstract: Oxygen isotopic compositions of new-fallen snow collected at Syowa Station, and drifting snow at Mizuho Camp and various stations in Mizuho Plateau were determined. Daily variation of oxygen isotopic composition of new snow at Syowa Station is caused mainly by the supply of ^{18}O-rich water vapor according to the approach of a cyclone. Seasonal variations of oxygen isotopic compositions of new snow at Syowa Station and of drifting snow at Mizuho Camp are controlled not only by the seasonal variation of atmospheric temperature, but also by that of transportation process of water vapor to Syowa Station and Mizuho Camp varying with the distance from the coast of open sea. Oxygen isotopic compositions of drifting snow at the stations at elevations below 1000 m are almost independent of elevation. At elevations between 1000 and 2900 m, oxygen isotopic compositions of drifting snow against elevation show a fairly linear relationship. At elevations between 3200 and 3300 m, a large anomaly is found in the variation with elevation of oxygen isotopic composition of drifting snow. The area where the anomaly is found is considered to be the boundary between the spheres of influence of maritime cyclone and Antarctic anticyclone. The drifting snow does not reflect the daily variation of meteorological condition and is of relatively local origin.

1. Introduction

Antarctic ice sheet is the largest body of water in a solid state on the earth and is concerned strongly in the global circulation of water and also in the global climate. The investigation of the process of transportation of water vapor to the Antarctic ice sheet is important.

The knowledge of the magnitude and nature of variation of isotopic composition of surface snow is, as KATO and WATANABE (1977) pointed out, essential to the interpretation of isotope relationships in firn and ice. The isotope relationships provide useful informations for the understanding of the Antarctic environment and its history as DANSGAARD *et al.* (1973) summarized.

No systematic study has been made on the isotopic composition of surface snow in the Antarctic ice sheet. So, the serial sampling of surface snow was made in Mizuho Plateau and the oxygen isotopic composition of the samples was determined. The process of transportation of water vapor was discussed through the consideration of the factors controlling the oxygen isotopic composition of surface snow.

2. Experimental

Snow samples collected for the oxygen isotope determination (KATO, 1977) are as follows:

1) New snow collected on different dates in February–December 1974 at Syowa Station

2) Drifting snow collected on different dates in January 1974–February 1975 at Mizuho Camp

3) Drifting snow collected at various stations along the traverse routes (shown in Fig. A) of the 15th Japanese Antarctic Research Expedition 1973–1975 (JARE-15).

All the samples were put in polyetylene bottles and transported to the refrigerator at the Water Research Institute, Nagoya University. The samples were melted just before the oxygen isotope determination.

The oxygen isotope determination of these snow samples was performed by following the technique of EPSTEIN and MAYEDA (1953). The $^{18}O/^{16}O$ ratio of CO_2 equilibrated with a water sample was measured with a double collector mass spectrometer (Varian Mat CH-7 at Department of Earth Sciences, Faculty of Science, Nagoya University). Analytical results are given in $\delta^{18}O$ notation (CRAIG, 1961) as follows,

$$\delta^{18}O=\frac{(^{18}O/^{16}O)_{sample}-(^{18}O/^{16}O)_{SMOW}}{(^{18}O/^{16}O)_{SMOW}}\times 1{,}000\ (‰)$$

SMOW: Standard Mean Ocean Water

and analytical error is ± 0.2‰.

3. Results and Discussion

3.1. Oxygen isotopic composition of snow at Syowa Station and Mizuho Camp

Fig. 1 shows the variations of oxygen isotopic composition of snow and meteorological condition (JAPAN METEOROLOGICAL AGENCY, 1977, 1978; KAWAGUCHI,

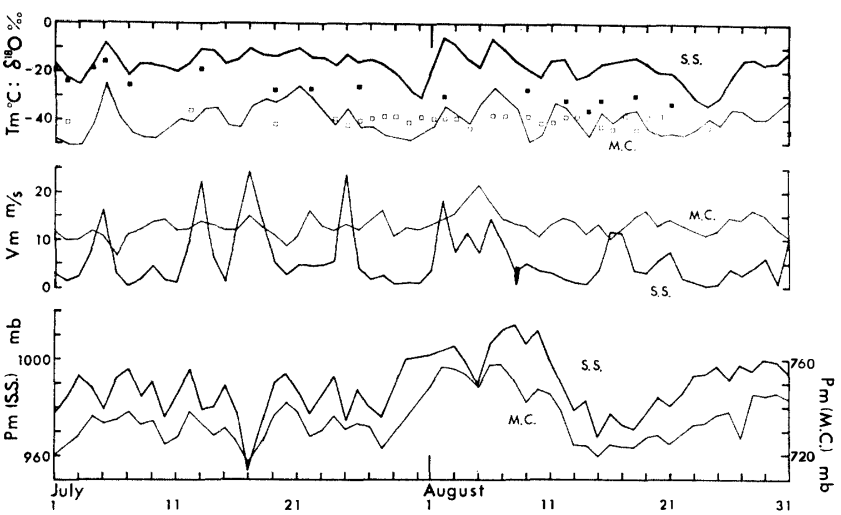

Fig. 1. Variations of oxygen isotopic composition of snow ($\delta^{18}O$; Syowa Station ■ and Mizuho Camp □), daily mean surface air temperature (Tm), daily mean wind velocity (Vm) and daily mean atmospheric pressure at station level (Pm) in the period of 1 July to 31 August 1974 at Syowa Station (S.S.) and Mizuho Camp (M.C.), East Antarctica.

1975) from 1 July to 31 August 1974 at Syowa Station and Mizuho Camp. The variation of oxygen isotopic composition ($\delta^{18}O$) of new snow on 1–7 July and 12–21 August at Syowa Station follows faithfully that of daily mean surface air temperature: $\delta^{18}O$ of snow increases and decreases with increasing and decreasing temperature, respectively. This fact seems to suggest that the oxygen isotopic composition of new snow is controlled mainly by the temperature of its formation.

The surface inversion layer exists in the air on the Antarctic ice sheet. The strong wind destroys the surface inversion and causes the mixing of the surface cold and the upper warm. This mixing results in an increase in the surface air temperature but not in the upper air temperature. In the above two periods, a cyclone passed far off the coast. And the wind velocity and temperature increased simultaneously with decreasing atmospheric pressure, and decreased simultaneously with increasing atmospheric pressure. The $\delta^{18}O$ of snow increased both under the cyclone and under the strong wind. Accordingly, the fact that the variation of oxygen isotopic composition of new snow at Syowa Station follows that of daily mean temperature in the above two periods would not mean that the oxygen isotopic composition of snow is controlled mainly by the temperature of its formation.

The factors increasing the $\delta^{18}O$ of snow are considered to be 1) the mixing of the surface and the upper atmospheres and 2) the supply of ^{18}O-rich water vapor, according to the approach of the cyclone.

Both on 13 July and on 2 August, the wind velocity and temperature were increased. It seems, however, that the $\delta^{18}O$ of snow collected on 13 July is increased, but that on 2 August is not increased, though snow samples were collected before and after those days. These facts show that the $\delta^{18}O$ of snow is not increased by the mixing of the surface and the upper atmospheres, and also show that the daily variation of $\delta^{18}O$ of snow is not controlled mainly by its formation temperature. The pressure on 13 July was decreased, while that on 2 August was increased over 1,000 mb. The $\delta^{18}O$ of snow is always increased when a cyclone passes, while it is not increased even under the high wind velocity and high temperature when no cyclone passes. Accordingly, the daily variation of $\delta^{18}O$ of new snow collected at Syowa Station is considered to be caused mainly by the supply of ^{18}O-rich water vapor according to the approach of a cyclone.

The variation of $\delta^{18}O$ of drifting snow at Mizuho Camp is out of relation to the variations of daily mean temperature, wind velocity and pressure. The daily mean temperature and pressure at Mizuho Camp vary as greatly as those at Syowa Station, while the $\delta^{18}O$ of snow at Mizuho Camp does not vary so greatly as that at Syowa Station. These facts show that the daily variation of $\delta^{18}O$ of snow drifted by the katabatic wind with a fairly constant velocity of about 10 m/s is not obviously affected by snowfall.

Variations of unweighed monthly mean oxygen isotopic composition of snow and monthly mean surface air temperature in January 1974 to January 1975 at Syowa Station and Mizuho Camp are shown in Fig. 2. Unweighed monthly mean $\delta^{18}O$ of snow denotes the mean value of unweighed 10 day mean $\delta^{18}O$ of snow, because snow samples were not collected every day. The variation of unweighed

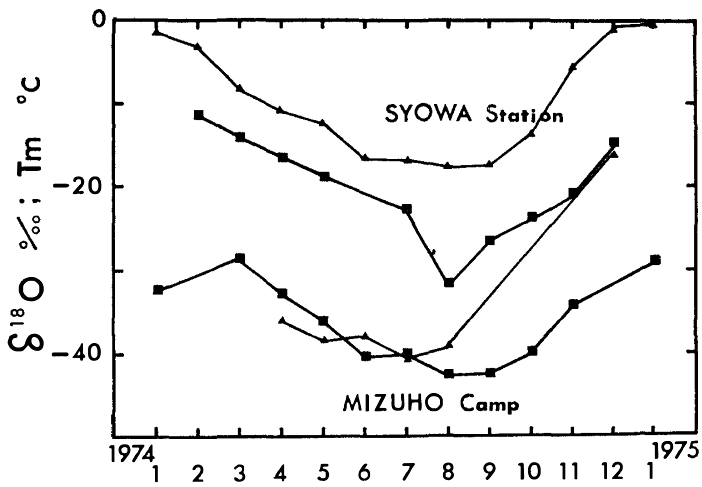

Fig. 2. Variations of unweighed monthly mean oxygen isotopic composition of snow ($\delta^{18}O$ ■) and monthly mean surface air temperature (Tm ▲) in January 1974 to January 1975 at Syowa Station and Mizuho Camp, East Antarctica.

monthly mean $\delta^{18}O$ of drifting snow at Mizuho Camp seems to follow that of monthly mean temperature one month behind the latter, although no remarkable relation is found between the variations of the $\delta^{18}O$ of snow and of daily mean temperature, wind velocity and pressure, as described previously. The variation of unweighed monthly mean $\delta^{18}O$ of new snow at Syowa Station also seems to follow that of monthly mean temperature one month behind the latter, except August: the unweighed monthly mean $\delta^{18}O$ of snow in August is extraordinarily low. The monthly mean pressure at station level at Syowa Station and Mizuho Camp during June–October are as follows:

	Syowa Station	Mizuho Camp
June	987.3 mb	735.6 mb
July	984.0	731.5
August	993.5	738.2
September	977.3	—
October	980.4	—

The monthly mean pressure is very high in August. These facts support that the $\delta^{18}O$ of new snow collected at Syowa Station is increased by the supply of ^{18}O-rich water vapor according to the approach of a cyclone. It is considered that the amount of ^{18}O-rich water vapor supplied by the cyclone was smaller in August than in the other months. Nevertheless, the unweighed monthly mean $\delta^{18}O$ of drifting snow collected at Mizuho Camp is not extraordinarily low in both August and September. This means that water vapor supplied to Mizuho Camp correspondingly to the approach of a cyclone is not so ^{18}O-rich.

The variations of unweighed monthly mean $\delta^{18}O$ of snow with monthly mean temperature at Syowa Station and Mizuho Camp in February–July are different from those in August–December. This fact shows that supplied water vapor is ^{18}O-richer in February–July than in August–December, even at same temperatures. This can be explained by that the distance of transportation of water vapor from the coast of open sea is shorter in February–July than in August–December. The seasonal variations of oxygen isotopic composition of snow at Syowa Station and Mizuho Camp are controlled not only by the seasonal variation of atmospheric temperature, but also by that of process of transportation of water vapor to Syowa Station and Mizuho Camp.

3.2. Oxygen isotopic composition of drifting snow of inland area

The variation with elevation of oxygen isotopic composition of drifting snow collected at the stations along Route S-H-Z-Y-I of JARE-15 (shown in Fig. A) in the period of 30 September to 11 November, 1974 is shown in Fig. 3. The $\delta^{18}O$ values of snow collected at the stations below 1,000 m in elevation are almost independent of elevation, showing little elevation effect as Lorius *et al.*

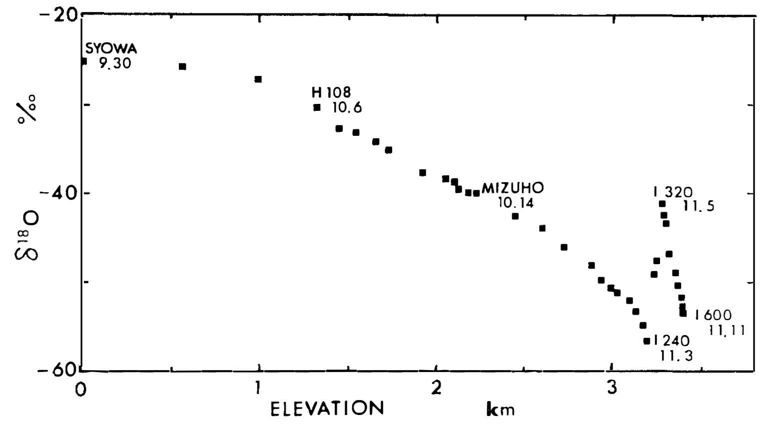

Fig. 3. Relation between oxygen isotopic composition of drifting snow ($\delta^{18}O$) and elevation along the travers route S-H-Z-Y-1 (shown in Fig. A) of JARE-15 in the period of 30 September to 11 November 1974.

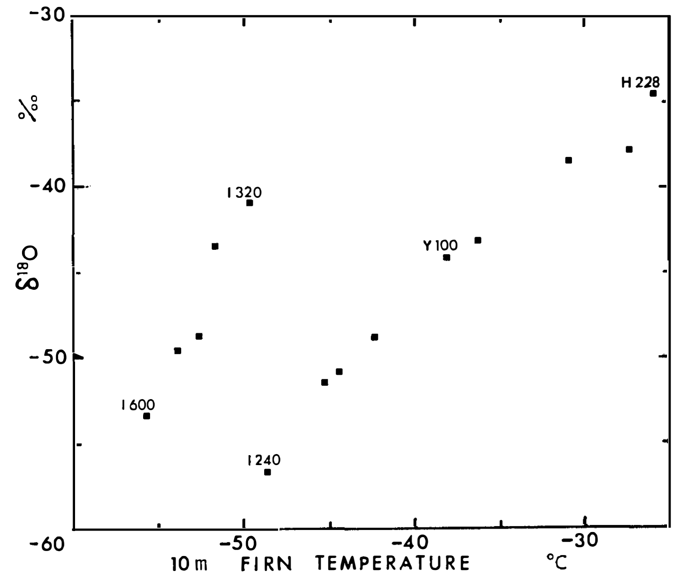

Fig. 4. Relation between oxygen isotopic composition of drifting snow ($\delta^{18}O$) and 10 m snow temperature along the traverse route S-H-Z-Y-1.

(1969) pointed out the δD of firn. The $\delta^{18}O$ values of snow at elevations between 1,000 and 2,900 m decrease fairly linearly with increasing elevation. This fact shows that the drifting snow does not reflect the daily variations of meteorological conditions, because these samples were collected on 5–24 October. And also it suggests that the drifting snow is of a relatively local origin, as GONFIANTINI and PICCITTO (1959) and PICCIOTTO *et al.* (1960) pointed out about the snow collected at King Baudouin Base, East Antarctica, which is opposed to the conclusion of the study on the drifting snow at Little America, West Antarctica, by EPSTEIN *et al.* (1963).

A large anomaly is found in the variation with elevation of $\delta^{18}O$ of snow collected at the stations at elevations above 2,900 m (KATO *et al.*, 1977). The $\delta^{18}O$ of snow decreases greatly with increasing elevation up to I240. However, the $\delta^{18}O$ of snow abruptly increases from $-56.7‰$ at I240 to $-41.0‰$ at I320 and again decreases greatly inland with increasing elevation. Furthermore, the $\delta^{18}O$ at I600, -53.7 is still higher than that at I240.

Fig. 4 shows the relation between oxygen isotopic composition of drifting snow and 10 m snow temperature given by SATOW (1977) at the stations along the traverse route. The 10 m snow temperature gives approximate mean annual air temperature (DALRYMPLE, 1966). H228 to I240 fall almost on one straight line and I320 to I600 fall almost on another straight line. The slopes of the two straight lines are different. These facts suggest that the area where the $\delta^{18}O$ anomaly of drifting snow is found is a boundary between the different spheres of atmospheric influence. They also support that the drifting snow is of a relatively local origin, as above mentioned.

Fig. 5 shows the variations of oxygen isotopic compositions of drifting snow and snow from the wall of 2 m pits (KATO, 1977), 10 m snow temperature and elevation at the stations from Mizuho Camp to I600 along Route Y-I in the period of 14 October to 11 November. The trends of the variations of $\delta^{18}O$ values of snow from the wall of 2 m pits, 10 m snow temperature and elevation change around I240 and I320. These changes are considered not as the causes of the

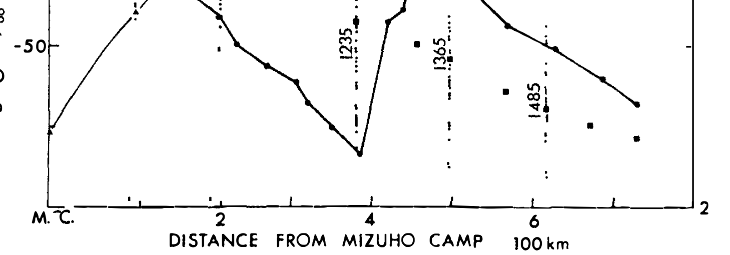

Fig. 5. Variations of oxygen isotopic composition of snow ($\delta^{18}O$; drifting snow ● and snow from the wall of 2 m pits ·), 10 m snow temperature (T_{10m}) and elevation along the traverse route Y-I in the period of 14 October to 11 November 1974.

$\delta^{18}O$ anomaly of drifting snow but rather as the results of the different atmospheric influence.

It is worth noticing that the situation of $\delta^{18}O$ of drifting snow in the range of $\delta^{18}O$ of snow from the wall of 2 m pits at the stations between Mizuho Camp and I240 is in marked contrast to that at the stations between I320 and I600. This fact is favorable for a conception that the area from Syowa Station to I240 is under the influence of maritime cyclone, while the inland area beyond I320 is under the influence of Antarctic Anticyclone. Because the seasonal variations of snow accumulation differ significantly between the above two areas (EPSTEIN, *et al.,* 1965; YAMADA *et al.,* 1978), it is reasonable that the situation of $\delta^{18}O$ of drifting snow in the range of $\delta^{18}O$ of snow from the wall of 2 m pits in the area under the influence of Antarctic Anticyclone is in marked contrast to that in the area under the influence of maritime cyclone.

The meteorological condition changed around I240 and I320 (INOUE, 1977). The drifting snow samples at I240 and I320 were collected on 3 and 5 November, respectively. On these days, snowfall was seen occasionally and the surface air temperature increased by 8°C. The sky was covered with stratus on 4 and with altostratus on 5 November, respectively. After 6 November it was fine. After 4 November the wind velocity was decreased below 5 m/s. It is doubtless that fallen snow is very ^{18}O-rich. This means that the transportation process of water vapor supplied for this very ^{18}O-rich snowfall differs significantly from that of water vapor supplied to Syowa Station and Mizuho Camp. The change of the meteorological condition is also considered to be caused by the different atmospheric influences.

From the standpoint of oxygen isotopic composition of snow, the area where the $\delta^{18}O$ anomaly of drifting snow is found is considered to be the boundary between the spheres of influence of maritime cyclone and Antarctic Anticyclone. This conclusion is supported by the results of glaciological observations: abrupt changes around the above area of direction and velocity of katabatic wind, of microrelief of snow surface (WATANABE, 1978a), and of process and degree of depth-hoar formation (WATANABE, 1978b).

4. Conclusions

The oxygen isotopic compositions of new snow collected at Syowa Station, and drifting snow at Mizuho Camp and various stations along the traverse routes of JARE-15 were determined. The process of transportation of water vapor to the Antarctic ice sheet was discussed through the consideration of the factors controlling the oxygen isotopic compositions.

A remarkable relation was observed between the daily variations of $\delta^{18}O$ of new snow and meteorological condition at Syowa Station. The daily variation of $\delta^{18}O$ of new snow is caused mainly by the supply of ^{18}O-rich water vapor according to the approach of a cyclone. While, no significant relation was found between the variations of $\delta^{18}O$ of drifting snow and meteorological condition at Mizuho Camp. The daily variation of drifting snow is fairly little and not obviously affected by snowfall.

The seasonal variations of $\delta^{18}O$ of new snow at Syowa Station and of drifting snow at Mizuho Camp are controlled not only by the seasonal variation of atmospheric temperature, but also by that of process of transportation of water vapor to Syowa Station and Mizuho Camp due to the difference of distance from the coast of open sea.

The $\delta^{18}O$ values of drifting snow at the stations at elevations below 1,000 m are almost independent of elevation, showing little elevation effect below 1,000 m. The $\delta^{18}O$ values of drifting snow against elevation show a fairly linear relationship at elevations between 1,000 and 2,900 m. The drifting snow does not reflect the daily variation of meteorological condition and is of a relatively local origin. A large anomaly is found in the variation with elevation of $\delta^{18}O$ of drifting snow at the stations at elevations between 3,200 and 3,300 m. The area where the $\delta^{18}O$ anomaly of drifting snow is found is considered to be the boundary between the spheres of influence of maritime cyclone and Antarctic Anticyclone. This is supported by the results of glaciological and meteorological observations.

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