

Isotopic fractionation and profile evolution of a melting snowcover

ZHOU Shiqiao (周石礪)¹, M. NAKAWO (中尾正义)²,
S. HASHIMOTO (桥本重将)², A. SAKAI (坂井亚规子)²,
H. NARITA (成田英器)³ & N. ISHIKAWA (石川信敬)³

1. College of Land and Resources, Hunan Normal University, Changsha 410081, China;

2. Institute for Hydrospheric-Atmospheric Sciences, Nagoya University, Nagoya 464-8601, Japan;

3. Institute of Low Temperature Science, Hokkaido University, Sapporo 060-0819, Japan

Correspondence should be addressed to ZHOU Shiqiao (email: zhoushq@mail.hunnu.edu.cn)

Received August 20, 2000

Abstract Successive snow pits were dug intensively in a melting snowcover. Water was successfully separated from snow grains in the field for the first time. By measuring $\delta^{18}\text{O}$ values of water and snow grain samples as well as comparing isotopic profiles, it is found that meltwater percolating down in snow develops quick and clear isotopic fractionation with snow grains, but exerts no clear impact on the $\delta^{18}\text{O}$ profile of the snowcover through which the meltwater percolates.

Keywords: snowcover, melt, isotopic fractionation, $\delta^{18}\text{O}$.

1 Introduction

Heavy water isotope method is commonly used in climatic reconstructions by interpreting cores from polar ice sheets, ice caps and glaciers^[1,2]. However, it has always been questioned when applied to cores taken from rather warm sites^[3]. The reason is that there is heavy summer melting at these sites. Summer melting causes not only the absence of surface snow layers of a snowpack, but also the change of densification rate. More important is that the meltwater, in the process of percolating down and refreezing, may disturb the isotopic profile of the snowpack and thus increase the uncertainty of ice core interpretation. Therefore, it is of great importance in environmental reconstructions to study the metamorphosing process of melting snowpack, especially the isotopic fractionation of oxygen and hydrogen.

A melting snowcover consists of three components: solid ice grains, liquid water and air. Experiments^[4] have shown that, in the water-saturated snow, isotopic ratios ($\delta^{18}\text{O}$, δD) of ice grains and water change with time, namely, there are isotopic exchange and fractionation between them. Nevertheless, a melting snowcover is water-unsaturated. According to our measurements, its voluminal water content is usually less than 13%. Moreover, its meltwater is always percolating down, and thus experiences a short time in it. In order to understand its isotopic process, we separated water from ice grains in the field for the first time, and then measured their isotopic ratios of oxygen ($\delta^{18}\text{O}$) respectively indoors. This paper is to clarify whether there is perceivable isotopic

fractionation in the process of water percolating and make clear the isotopic profile evolution of the snowcover.

2 Methods

The field work was conducted at Snow Melting Research Station of Hokkaido University, Moshiri (44°23' N, 142°17' E), in the northern part of Hokkaido, Japan, where the snowcover was as thick as 180.1cm on February 14 and its recorded lowest temperature was -173°C on February 7, 1998. The snowcover began to melt close to the end of the March. Both the records of snow temperature and the measurements of snow water content showed that the whole snowcover had not reached the state in which ice grains and water co-existed at a temperature of 0°C until March 25, and the surface layer re-froze in the following most nights. The field work included: ① Inserting 8 temperature sensors into the snowcover at different heights in the period of dry snow to automatically record the temperature variations in the whole field period. ② Digging successive pits almost everyday in the plain plot of the station, then recording stratigraphic observations, measuring snow temperatures by a portable sensor, sampling snow by a $4\times 6\times 7\text{ cm}^3$ sampler with a thickness of 4 cm continuously from the surface to the bottom of pit wall, and taking grain photos of each sample by using a camera with a magnifying lens for grain size measurements. ③ Separating water from snow grains with a hand-driven centrifuge and two cylinder-shaped polythene boxes which was 9.5cm high and 9cm in diameter of the cross section (Its inner cover was fitted with a cup-shaped mesh with 6cm in height and 7.9cm in diameter of the upper cross section. The diameter of the holes of the mesh was 0.6mm. It was proved, both in pre-experiments and field work, that the device was very effective in separating water even for the snow with grain size less than 0.5mm, and that sufficient sampling water could be obtained at a time), and then sampling separated water and snow grains respectively. ④ Continuously collecting, weighing and sampling the bottom discharge obtained by a $90\times 90\text{ cm}^2$ lysimeter. ⑤ Continuously collecting, weighing and sampling precipitation. ⑥ Measuring snow water content at different heights with a dielectric moisture meter (made by Innsbruck University, Austria). ⑦ Collecting meteorological data obtained by an automatic station, including radiation, air temperature, humidity as well as wind velocity. After the field work, all the samples were transported to the Institute for Hydro-spheric-Atmospheric Sciences, Nagoya University, Japan for the measurements of isotopic ratios of oxygen ($\delta^{18}\text{O}$) by a MAT-250 spectrometer having an accuracy of $\pm 0.5\%$.

3 Results and discussion

Figure 1 shows the discharge variations of the snowcover in the whole field period. The thickness of the snowcover decreased from 122.5 cm on March 25 to 46 cm on April 14. Although the sampling frequency was not large, it can be seen that, from April 3 to April 15, the daily variation of the discharge is very clear except for raining, and that all the lowest values at nights are

about $500 \text{ g} \cdot \text{h}^{-1} \cdot \text{m}^{-2}$. This indicates that the entire meltwater amount in the daytime had flowed out of the snowcover before the next morning. According our observations and model calculations^[5](refs. [6—8]), the meltwater before the summit flux of a surface melt curve (ref. [8]) would flow out of the snowcover in about 2 to 3 hours. For example, on April 7, both the measured net radiation and the calculated heat flux consumed for surface melting^[9] reached their peak values from 11 : 00 to 13 : 00 (The former accounted for 86%—97% of the later, which was consistent with Ishikawa's data^[10]), and the peak discharge values appeared from 13 : 00 to 15 : 00. Since the sampling work began from surface downward between 10 : 00—11 : 00, about 2 hours after the melt beginning, and finished with the bottom sample at about 16 : 00 (15 : 00 in the late period), all the water samples should come from the surface melt of the day. For the period of March 30 to April 2, we can't see the above daily variation. Since the discharge on March 30 was larger than $500 \text{ g} \cdot \text{h}^{-1} \cdot \text{m}^{-2}$ and it was also large on March 29, the water content of the snowcover was high at the time of melt beginning on March 30, and thus the water samples of March 30 should also come from the surface melt of the day. Snow fell on March 31, there was no melting. To April 1, the discharge had become very small and thus the water content of the snowcover was low, which, along with the light melting (The positive net radiation on April 1 was just 26% of that for April 7), made the percolating water flow slowly^[6] and the discharge become smaller. Although the melt amount was not small on April 2 (The positive net radiation of the day was 54.8% of that for April 7), most of it did not flow out of the cover in that day because the water content had been very small before, thus the flow velocity was still low and much water was kept in the cover. Therefore, part of the sampling water obtained on April 1 and on April 2 might come from the meltwater before.

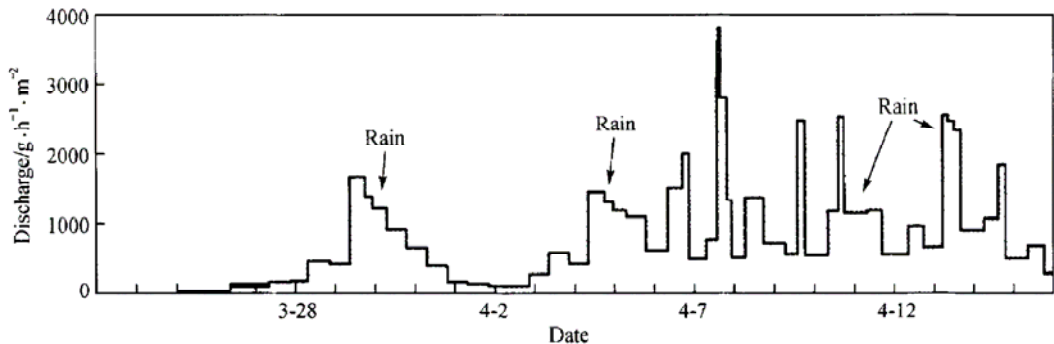


Fig. 1. Discharge variations of the snowcover.

As the solar short wave radiation attenuates very quickly in snow, melt occurs only in several centimeters of the surface^[11]. This was confirmed by the everyday stratigraphic observations. Thus it should be true that all the meltwater of each day was produced in the surface 10 cm. Then the $\delta^{18}\text{O}$ value of the first or the second snow grain sample from the surface was the original $\delta^{18}\text{O}$ value of the downward water samples obtained in the same day. In fact, the stratigraphic records

show that, although the density of the surface layer differed, the daily melt thickness was not larger than 5 cm in the whole period except April 3 (6.5 cm), April 6 (6.0 cm) and April 8 (5.5 cm). Considering this and the sampling order in time, it can be safely regarded that all the water samples of each day originated from the uppermost 5 cm, namely, the $\delta^{18}\text{O}$ value of the first snow grain sample from the surface was the original $\delta^{18}\text{O}$ value of the water samples obtained in the same day.

Figure 2 presents the isotopic data of the separated snow grain and water samples obtained

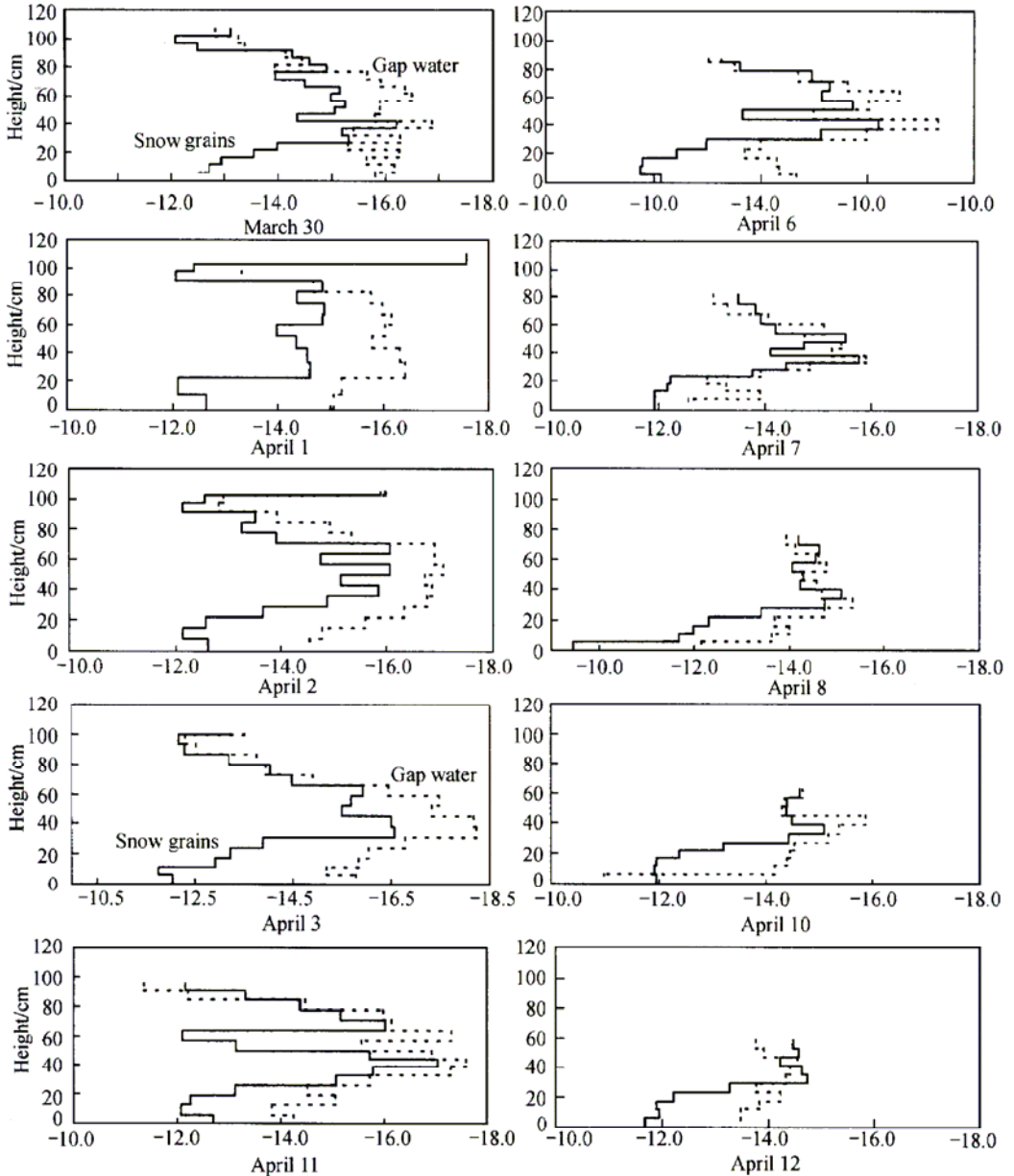


Fig. 2. $\delta^{18}\text{O}$ (‰) profile evolution of the snowcover.

from March 30 to April 12. It shows: ① $\delta^{18}\text{O}$ values of the gap water vary from the top to the bottom in all profiles except one or two (e.g. those in April 11 and April 12) in which the variation is difficult to judge. ② All the $\delta^{18}\text{O}$ values of the gap water, except several ones, are lower than those of the corresponding snow grain samples, and the difference in lower profiles is larger than that in upper profiles. ③ Two lines are similar in shape, namely, in most profiles, when the $\delta^{18}\text{O}$ value of snow grains is high, the corresponding value for gap water is also high, and *vice versa*. ④ There is no clear change in the shape of the $\delta^{18}\text{O}$ profile lines for snow grains (comparable parts) in the whole period. From the above, it can be concluded that meltwater percolating down in snow develops quick (According to the model calculations, the time interval is less than 10 minutes for the interstitial water passing through an average sampling thickness of 5 cm.) and clear isotopic fractionation (The fractionation factor for $\delta^{18}\text{O}$ is 1.0028 in a ice-water system^[12]), but exerts no clear impact on the $\delta^{18}\text{O}$ profile of the snow layers through which the meltwater percolates.

Figure 3 is a comparison of the discharge with the surface snow grains on the variations of the $\delta^{18}\text{O}$ values. The surface snow grains refer to the surface-most sample of each day. In addition, four times' rain data were added. From the figure, It can be found that the $\delta^{18}\text{O}$ values for the snow grains and rain are larger than those for the discharge as a whole with the former having large variations and the latter not. The especially noticeable is the heavy raining ($25463.46 \text{ g} \cdot \text{m}^{-2}$) in the morning (about 0 : 00—8 : 00) of April 13. The difference of the two values reaches to 5%—7%. These further reveal the rapid isotopic fractionation between gap water and snow grains.

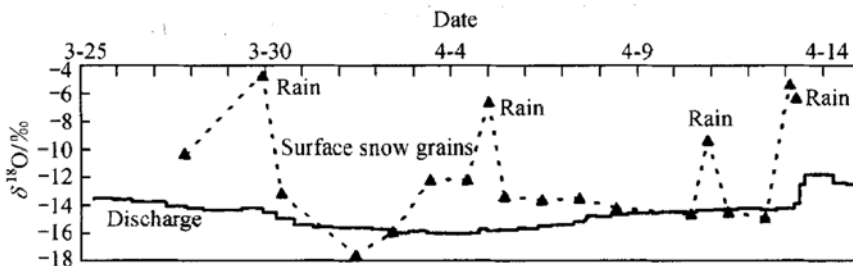


Fig. 3. $\delta^{18}\text{O}$ variations of the discharge and surface snow grains.

Additionally, compared with others, the $\delta^{18}\text{O}$ profiles of April 1 and April 2 show no clear difference.

The isotopic fractionation, between percolating water and snow grains, would certainly lead to less isotopic difference among snow layers. Nevertheless the above profile comparisons among different dates show no clear change. This can only be explained by saying that the site differences among the snow pits are larger than those from the isotopic fractionation. Since the field work was conducted in a large plain plot and the distance between two successive pits was usually less than one meter, the site differences should be very small.

4 Conclusion

Meltwater percolating down in snow develops quick and clear isotopic fractionation with snow grains, but exerts no clear impact on the $\delta^{18}\text{O}$ profile of the snowcover through which the meltwater percolates.

Acknowledgements This work was supported by the Ministry of Education, Science, Sports and Culture of Japan, and the Research Foundation of Hunan Normal University, China.

References

1. Dansgaard, W. et al., Evidence for general instability of past climate from a 250-kyr ice-core record, *Nature*, 1993,364: 218—220.
2. Lorius, C. et al., A 150,000-year climatic record from Antarctic ice, *Nature*, 1985,316: 591—596.
3. Koerner, R. M., Some comments on climatic reconstructions from ice cores drilled in areas of high melt, *Journal of Glaciology*, 1997,43: 90—97.
4. Nakawo, M. et al., Isotopic fractionation during grain coarsening of wet snow, *Annals of Glaciology*, 1993,18: 129—134.
5. Zhou Shiqiao et al., Mathematical modeling of water percolation in snow, *Journal of Hydraulic Engineering*, 2001,1: 6-10(In Chinese with English abstract).
6. Colbeck, S. C., A theory of water percolation in snow, *Journal of Glaciology*, 1972,11: 369—385.
7. Shimizu, H., Air permeability of deposited snow, *Contrib. Inst. of Low Temp. Sci.*, 1970,A22: 1—32.
8. Colbeck, S. C., Anderson, E. A., The permeability of a melting snow cover, *Water Resources Research*, 1982,18: 904.
9. Zhou Shiqiao et al., Verification of different empirical formulas for the calculation of turbulent heat on the snow surface, *Journal of Hunan Normal University*, 2000, 23(2): 88—92, 96(In Chinese with English abstract).
10. Kono, N. et al, Hydrological phenomena of snow and ice, Kokin shoen press, 1994, 36(In Japanese).
11. Nakawo, M., Hayakawa, N., ed. Snow and Ice Science in Hydrology, IHAS, Nagoya University and UNESCO, 1998, 71.
12. Suzuki, T., Kimura, T., D/H and $^{18}\text{O}/^{16}\text{O}$ fractionation in ice-water system, *Mass Spectroscopy*, 1973,21: 229—233.