Annals of Glaciology 6 1985

EFFECTS OF PRECIPITATION ON THE ISOTOPIC COMPOSITION OF FALLING SNOW PARTICLES

by

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ABSTRACT

Observation on the isotopic composition of falling snow particles was carried out at two points 30 km apart in the coastal area of the Sea of Japan, between 20 January to 25 February 1983. Sampling periods of snow particles were from 10 minutes to several hours. Time variation of 6 hours running mean of $\delta^{18}O$ values showed good correlation with the variation of surface air temperature. The $\delta^{18}O$ value is maximal at the beginning of a snowfall, except when large graupels were observed at the beginning. Comparison of the results between the two observation points showed that the differences in the $\delta^{18}O$ values are great when precipitation is plentiful and precipitation cells are small.

INTRODUCTION

Moser and Stichler's 1980 review showed that oxygen isotopic composition ($\delta^{18}O$) of snow particles is related to annual mean air temperature, monthly air temperature and upper air temperature; accumulation rates on glaciers and ice sheets can thus be determined from seasonal $\delta^{18}O$ cycles of snow and ice. However, few studies have been made on possible mechanisms controlling the relationship. This note describes detailed observations on the $\delta^{18}O$ of falling snow particles, conducted in the Hokuriku Region of Central Japan.

OBSERVATIONS

Sampling of falling snow particles and meteorological observations were carried out at Tsurugi (100 m a.s.l.) and Shirakawa (460 m) near the coast area of the Sea of Japan (137°E 36°N), between 20 January and 25 February 1983. The predominant direction of wind in winter is NW. Shirakawa and Tsurugi are separated by 30 km with the Hakusan mountain range (highest peak 2700 m) between them. Falling snow was collected in a tray, over periods ranging from 10 minutes to several hours, depending on the intensity of the snowfall. Isotopic composition was shown in values of $\delta^{18}O$ (‰) on the basis of the value of Standard Mean Ocean Water. The accuracy of the analysis was ± 0.2 ‰. Observations by the meteorological radar at Fukui, which is 50 km WNW of Tsurugi, indicate that snowfalls during the observation period were mainly of the convective type with rimed snowflakes and graupels.

RESULTS

Hourly variation of the $\delta^{18}O$ values

Time variation of 6 hours running mean of the $\delta^{18}O$ values of snow particles at Tsurugi and Shirakawa, together with 6 hours running mean of surface air temperature and hourly precipitation at Tsurugi, are shown in Figure 1. In the case of Tsurugi, hourly variation of the $\delta^{18}O$ values showed good correlation with variation of surface air temperature, namely, smaller $\delta^{18}O$ values in the colder condition. Time variation of the $\delta^{18}O$ values at Shirakawa is similar to that at Tsurugi, with lower values of 1 to 3‰ and a time lag of 30 to 60 minutes. The time lag corresponds with the time taken by precipitation cells in moving between the two points.

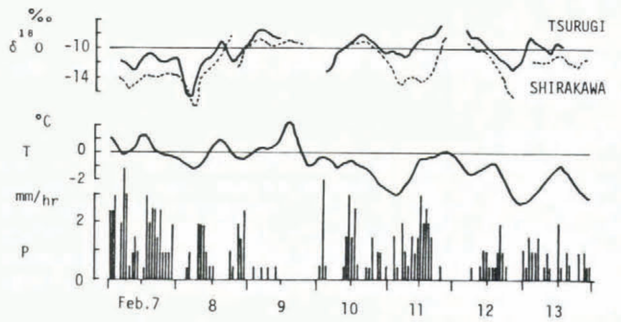

Fig.1. Hourly variation of the oxygen isotopic composition of falling snow particles at Tsurgi and Shirakawa ($\delta^{18}O$), surface air temperature (T) and hourly precipitation (P) at Tsurugi.

Time variation of the $\delta^{18}O$ values during snowfall

Figure 2 shows the case of 7 February, 1983 at Tsurugi, when small graupels and rimed snowflakes were observed. The $\delta^{18}O$ value was large at the start of a snowfall, and decreased with the rate depending on the intensity of snowfall. However, when large graupels (diameter nearly 1 cm) were observed at the start of a snowfall, the $\delta^{18}O$ values were low to begin with and increased later.

Comparison of $\delta^{18}O$ values at two observation points

As described above, time variation in $\delta^{18}O$ values was similar at the two observation points. Radar observation at Fukui showed that the same convective precipitation cells passed over the two observation points in seven snowfalls, and the relation between horizontal variation of the $\delta^{18}O$ values and precipitation was examined in these cases. Figure 3 shows the differences of $\delta^{18}O$ values between Tsurugi and Shirakawa ($\Delta\delta^{18}O$), related to precipitation amount at Tsurugi (R), horizontal size (L) and height (H) of the precipitation cells, estimated from radar observations. Differences are greater

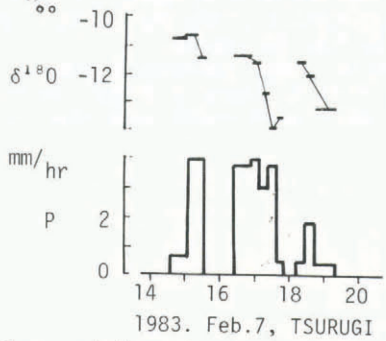

Fig.2. Time variation of oxygen isotopic composition of falling snow particles ($\delta^{18}O$) and the precipitation intensity (P) during a snowfall.

https://doi.org/10.3189/1985AoG6-1-261-262 Published online by Cambridge University Press

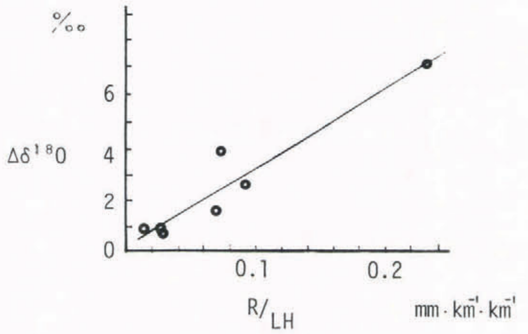

Fig.3. Difference of $\delta^{18}O$ values ($\Delta\delta^{18}O$) between Tsurugi and Shirakawa, total amount of precipitation at Tsurugi (R), horizontal size (L), and the height (H) of a precipitation cell.

when precipitation is heavier and precipitation cells are smaller.

DISCUSSION

We conclude that $\delta^{18}O$ values of snow are correlated with air temperature not only over longer periods of a month or year (Dansgaard 1964), but also for periods as short as a few hours. Since $\delta^{18}O$ values are smaller in colder conditions, this relation cannot be explained by temperature dependency of the isotope fractionation factor.

As seen in Figure 1, decrease in $\delta^{18}O$ values of snow is about 4°/oo, corresponding to a temperature drop of about 2.5°C. This can be explained by theoretical estimation for the case of moist adiabatic cooling at vapor-ice equilibrium on the basis of Rayleigh process, if the precipitation cell can be assumed to be 1500 m higher in colder air. But since the hourly precipitation rate was not higher in colder air (Figure 1), such an assumption is unreasonable. Another possible explanation is that the $\delta^{18}O$ values of water vapor in colder air are smaller because of the kinetic effect in a high evaporation rate, due to a large temperature difference between the air and sea surface. This assumption is supported by measurement of the δD value of the same snow samples. Details will be published in the near future.

As seen in Figure 3, the difference in $\delta^{18}O$ values of snow between the two observation points can be explained by a decrease in the $\delta^{18}O$ of water vapour after condensation of water vapour with large $\delta^{18}O$ value during snowfall between the two points. The rate of horizontal variation of the $\delta^{18}O$ values was 3 to 10 °/oo/ 100 km. As discussed by Higuchi (1982), higher rates can be explained in terms of snowfall from convective clouds with large vertical velocity.

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https://doi.org/10.3189/1985AoG6-1-261-262 Published online by Cambridge University Press