—研究論文—
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Atmospheric Water Vapor Measurements at Mizuho Camp, East Antarctica in 1976–1977

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みずほ観測拠点における水蒸気量観測

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要旨: 1976年11月30日から1977年1月21日まで，みずほ観測拠点において水蒸気量の測定を行った．測定期間中，相対湿度は30～80%の値を示し，低気圧の影響を受けている期間は，斜面下降風に支配されている気象状況のときよりも高い相対湿度が観測された．水蒸気量が測定された気温範囲は，−6.5°Cから−22.8°Cであった．水蒸気量の測定結果から，この測定期間中の雪面からの昇華量が計算された．計算結果は雪尺測定による消耗量の2～3倍になった．

Abstract: The measurement of air humidity at the height of 1.5 meters above the snow surface was made at Mizuho Camp, East Antarctica, several times a day during the summer in 1976–1977, with the Karl Fisher method and the Assmann ventilated psychrometer method. The values of air humidity obtained by these two methods agreed within approximately 5% error. Water vapor pressure was estimated from the air humidity at temperatures between −6.5 and −22.8°C. The water vapor pressure obtained showed daily variation similar to air temperature.

During the measurement no supersaturation of water vapor with respect to ice was detected and no ice fog was observed. The relative air humidity was between 30 and 80%. It was lower under a condition of predominant katabatic winds than under an influence of cyclones. The daily mean amount of sublimation estimated from the water vapor pressure obtained was between 1.3 and 1.9 millimeters per day and it was nearly two or three times larger than the amount of sublimation obtained by a direct measurement, snow stake measurement.

1. Introduction

Since the transfer of water vapor near the snow surface is sensitive to the gradient of air humidity and radiation is mainly absorbed by water vapor, air humidity is one of the most important meteorological elements for the understanding of mass and heat budget.

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The Japanese Antarctic Research Expedition)JARE) has measured air humidity at Syowa Station. However, in order to investigate the heat and mass budget in the Enderby Land region it is necessary to measure air humidity at Mizuho Camp located in an inland area as well as at Syowa Station in a coastal area. JARE has used a dewcel type dew-point meter and a carbon resister hygrometer at Syowa Station for the measurement of air humidity near the surface and in the upper air, respectively. But, it is impossible to detect air humidity accurately in such a low temperature area as Mizuho Camp by the same instruments as those used at Syowa Station because of a small amount of absolute humidity.

Then, I considered the following methods to measure air humidity at Mizuho Camp; (1) a simple and handy method in which the Assmann ventilated psychrometer was used and (2) a complicated but accurate method in which a sampled air was analyzed chemically. The second chemical method was reported previously by THUMAN and ROBINSON (1954) and it has been believed that the method gives the most accurate air humidity at very low temperatures.

In this paper, the result of the measurement of air humidity at Mizuho Camp using these methods will be described in detail. In addition, the sublimation rate of the snow surface will be calculated and compared with a direct measurement using snow stakes.

2. Experimental Apparatus and Field Operation

The measurement of water vapor at Mizuho Camp was carried out during the summer from November 30, 1976 to January 21, 1977. Mizuho Camp (latitude 70°41.9′S and longitude 44°19.9′E) is located about 300 km southeast of Syowa Station and at an elevation of 2,230 meters (Fig. 1).

At Mizuho Camp the mean annual temperature was about −33°C in 1976 and the monthly mean temperature was −43.8°C in August and −15.7°C in December, 1976. The direction of the prevailing wind during the period of the measurement was generally in the quadrant between northeast and southeast.

The point for the measurement was east of the camp facilities and about 50 meters upwind of artificial sources of water vapor. The measurement of air humidity using the Assmann ventilated psychrometer was performed several times a day as daily routine observations at the same times as the observation of other surface meteorological elements. The Assmann ventilated psychrometer was carefully handled in such a way that the surface of a sensor of wet-bulb thermometer was wet before every humidity measurement. Every measurement took about 10 minutes to obtain humidity data.

The chemical method was nearly the same as the one reported by THUMAN and ROBINSON (1954), but there is the following difference between the two methods. In the method of THUMAN and ROBINSON, the sampled air was bubbled through absolute meth-

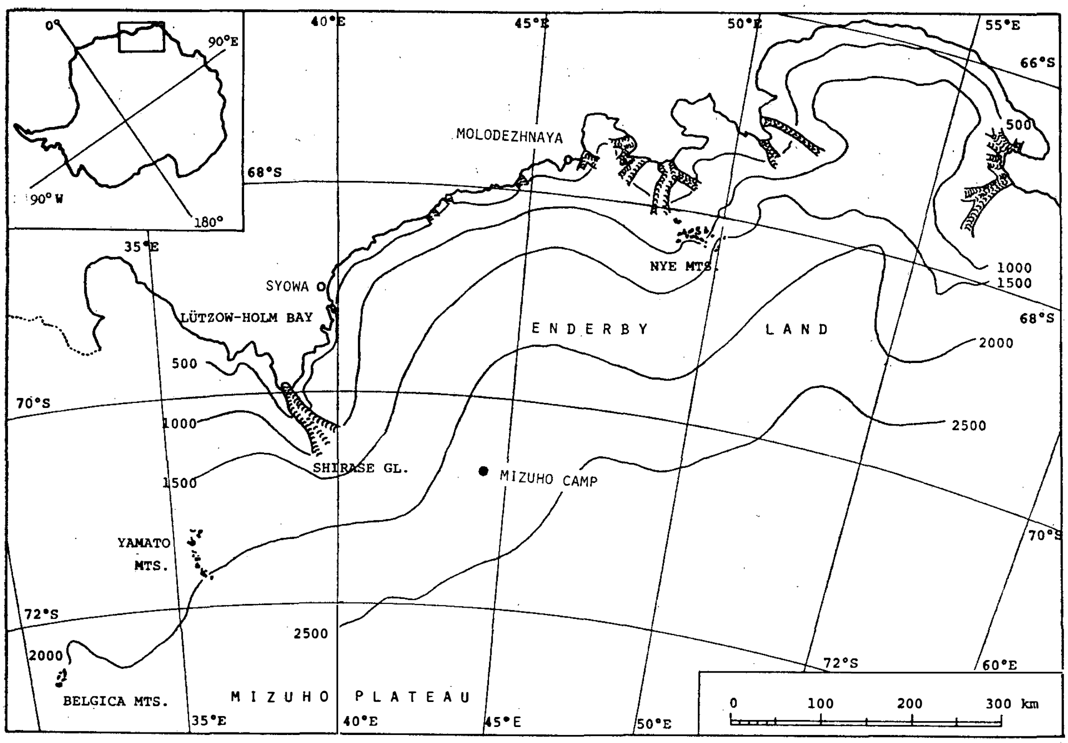

Fig. 1. Location map of Mizuho Camp and Syowa Station.

anol which absorbed all of the water in the air and the amount of absorbed watei in the methanol was determined by titration to a visual end-point with the Karl Fisher reagent. In the present measurement, on the other hand, an apparatus for air sampling was a specially designed syringe of 500 m*l* in volume with a syringe needle and a cock. The procedure of measurement consisted of two principal steps: (1) Before sampling the air the syringe was washed out with absolute methanol, dried at 120°C for two or three hours in an electric oven and subsequently put in a desiccator till it cooled to room temperature. The syringe was brought outside for the measurement and back to the desiccator after sampling the air. Air temperature was also measured with a calibrated thermometer at the same time of sampling the air. The syringe in the desiccator was brought indoors and left for about 30 minutes till it warmed to almost room temperature, which prevented moisture in the room air from entering the sampled air through the syringe wall. (2) For the titration of water content in the sampled air a syringe needle was inserted through the rubber stopper on the top of the titration cell, and the sampled air in the syringe was transferred to the titration cell.

The titration apparatus used in the measurement was worked electrically and automatically. The quantity of water content was represented on Hiranuma digital aquacounter, model AQ-2 type (Hiranuma Sangyo Co., Ltd, Tokyo). This analytical device could measure water content in a range from 10 mg to 10 μg. The accuracy of measured values was between 0.3 and 1%. The reagent used for measuring a small quantity of water content was the generator solution for coulometry (Aquaent A: Mitsubishi) and counter solution for coulometry (Aquaent C: Mitsubishi).

The water content (unit: grams per cubic meter) of air was calculated in the following way: (1) The volume of air in the 500 m*l* syringe was reduced to the value under the standard conditions of temperature and pressure using measured air temperature and pressure at the station level at a time; (2) The total weight of water per cubic meter of air was determined from the calculated volume of air at standard conditions and the measured values of water content.

Relative air humidities were calculated by dividing the actual weight of water per unit volume of air by the weight of water in air saturated with respect to water at the average ambient air temperature at the time of air sampling.

3. Weather Condition during Measurements

The weather during the present measurement was not greatly changed by a very strong snow storm. During a period of the prevalence of katabatic wind, it was generally clear, the drifting snow was observed, the daily variation of wind speed and air temperature was large, and the wind direction was mainly east. But when a cyclonic disturbance developed around Lützow-Holm Bay and influenced the weather of the Mizuho Camp area, a stratus overcast, stormy weather, northerly winds, frequent snow fall and higher air temperature than under the predominance of katabatic wind were observed.

Around November 30, December 6 and 16–17, cyclonic disturbance developed in the Mizuho Camp area and snow fall was observed with a stratus overcast. The air humidity showed lower values during the prevalence of katabatic wind than those under the influence of cyclonic disturbances. When the relative humidity was high, stratus overcast, snow fall, slightly northerly winds and an increase in air temperature were observed. The relative air humidity showed about 70 to 80% even though snow fall occurred. Therefore, no supersaturation with respect to ice took place and no ice fog was observed during the period of the measurement.

4. Results

The values of relative air humidity obtained by the Assmann ventilated psychrometer agree approximately with those obtained by the chemical method within error of 5% as shown in Fig. 2 and tabulated in Table 1. When air temperature is −22.8°C, the difference of the humidity between the two methods is extraordinarily large compared with that at other temperatures. The weight of water vapor is 200 μg in the syringe of 500 m*l* at air temperature of −22.8°C and it is possible to measure 10 μg

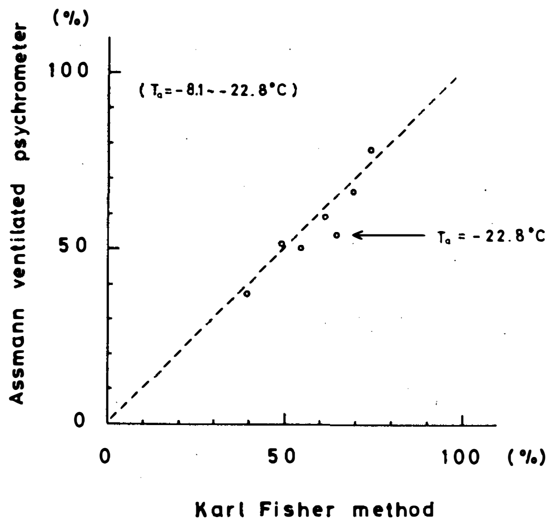

Fig. 2. Relation of the relative air humidity obtained by the Assmann ventilated psychrometer and the Karl Fisher method. (When air temperature is −22.8°C, it is a special case.)

Table 1. Water vapor observations by the Assmann ventilated psychrometer and the Karl Fischer method.

Date	Sample time	Weather	Wind speed (m/s)	Wind dir. (36)	Air temp. (°C)	Pressure (mb)	Water vapor conc. (g/m^3)	Relative humidity (%)	Relative humidity by Assmann ventilated psychrometer (%)
1976 Dec. 1	1125–1140	Cloudy Drifting snow	12.0	07	−9.3	762.0	1.862	75	78
1	2250–2305	Clear Drifting snow	12.0	10	−18.0	761.5	0.691	55	50
1	2305–2320	Clear Drifting snow	12.0	10	−18.0	761.5	0.691	55	54
2	1545–1600	Clear Drifting snow	16.9	09	−10.0	756.0	1.289	55	58
2	1600–1615	Clear Drifting snow	16.9	09	−10.0	756.0	1.367	58	54
4	1750–1800	Clear	6.8	09	−14.5	755.0	0.831	50	51
4	2112–2130	Clear	4.9	09	−19.0	756.0	0.724	62	59
5	0045–0105	Clear	7.2	10	−23.0	756.0	0.536	64	54
7	1523–1530	Cloudy	4.8	02	−8.0	755.0	1.099	40	37
7	2233–2250	Clear	4.8	08	−15.9	756.0	1.046	70	66

Relative humidity is over water surface.

by our instrument, so it is most likely that the difference of the humidity is caused by entering of water vapor in the room air into the sampled air in the syringe through its wall although the instrument is closely packed to prevent the outside air from entering. However, in the present measurement it is not clear whether such a leak of air takes place under the condition of low temperatures below about −20°C or this is a special case.

Except the case of −22.8°C, though the cause of error in the chemical method was not clear, the measurement of water vapor concentration was repeated many times during the measurement and the accuracy of the measurement was found to be 3%. The same kind of the measurement using the Assmann ventilated psychrometer was

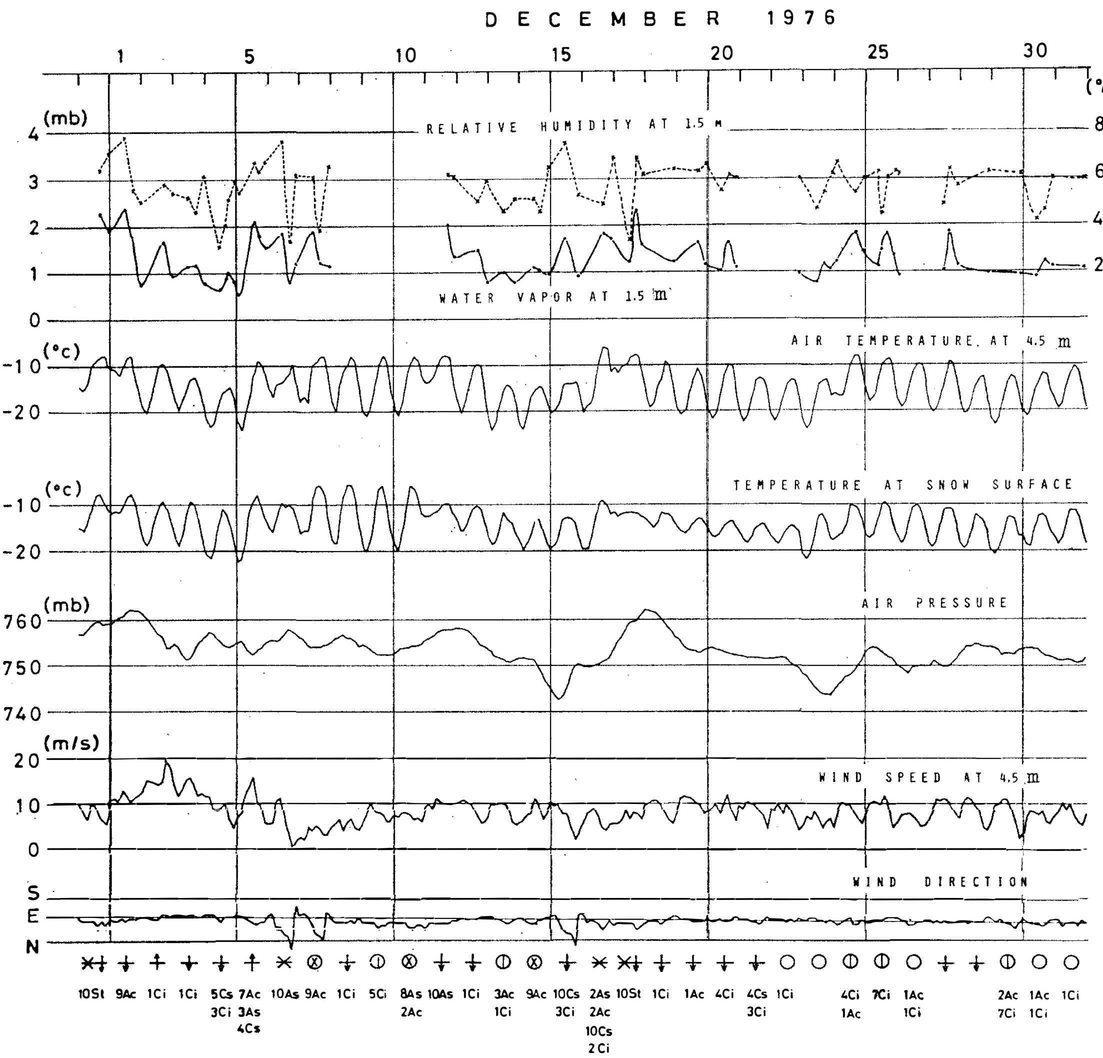

Fig. 3. Graphs showing the relative air humidity, water vapor pressure and other surface meteorological elements at Mizuho Camp between November 30 and December 31, 1976.

made and this showed that the error of the measurement was approximately 4%. Therefore, it may be reasonable to consider that the fluctuation of the relation between the results obtained by the two methods was within 5% as described above and we can conclude that the values of humidity obtained in the present measurement are considerably precise.

The results of the measurement of air humidity during a period from November 30 to December 31 are shown in Fig. 3.

5. Discussion

Using snow stakes, the measurement of ablation was made and the results are shown in Fig. 4. From this figure it can be seen that ablation occurred in the middle of November, 1976 and continued until the end of observation in January, 1977. The ablation in this area is caused only by sublimation which is enhanced by the transport of water vapor from the snow surface into air as shown in Fig. 5, because the water

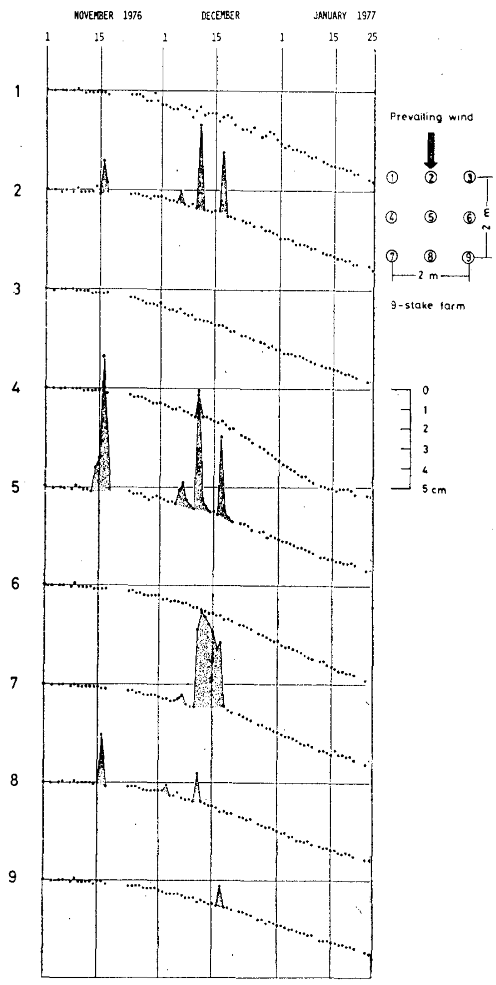

Fig. 4. Ablation by 9-snow stakes farm at Mizuho Camp between November 1, 1976 and January 25, 1977. Dotted area shows deposited snow around the snow stakes.

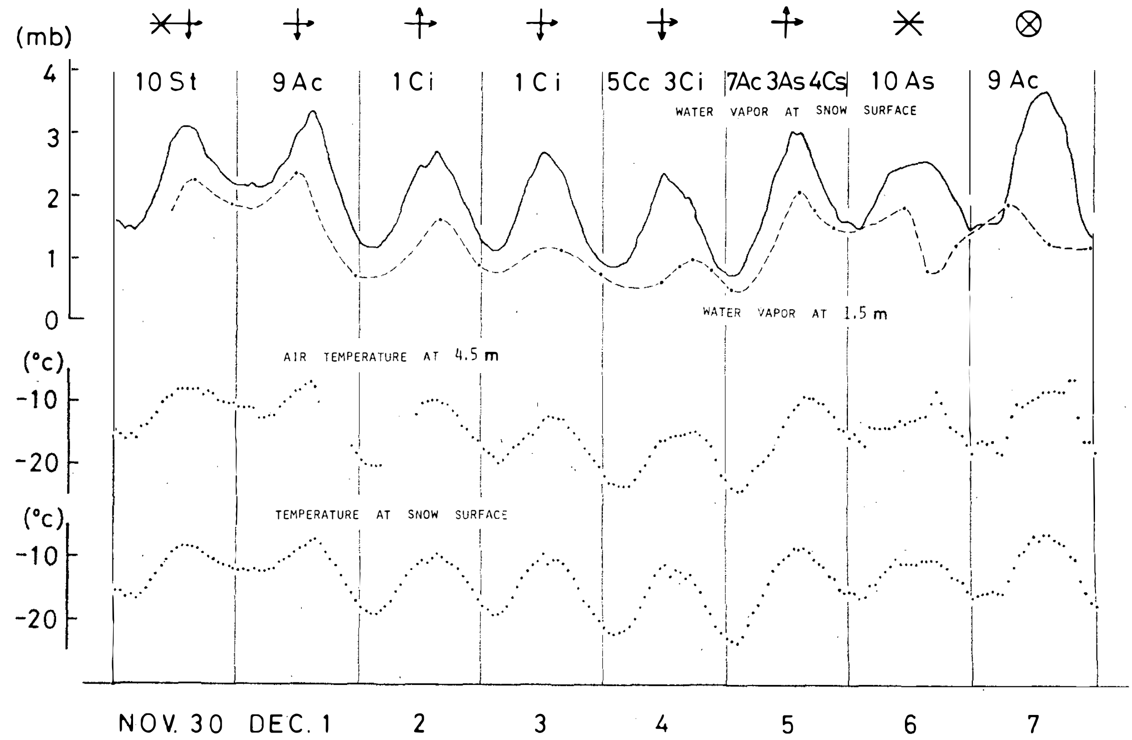

Fig. 5. Graphs showing the water vapor pressures at the snow surface and at a height of 1.5 meters, air temperature at a height of 4.5 meters and snow surface temperature at Mizuho Camp between November 30 and December 7, 1976.

vapor at the snow surface is higher than above it.

The amount of sublimation rate F_e is calculated using the bulk formula based on the eddy diffusion theory, written in the form:

$$F_e = 0.622 \frac{\rho U_*^2}{P} (e_0 - e_1)/\bar{U}_1 \tag{1}$$

where ρ (g/cm^3) is the density of air, P (mb) atmospheric pressure at the station level, U_* (cm/s) friction velocity, e_0 (mb) water vapor pressure at the roughness height Z_0 above the snow surface, e_1 (mb), $\bar{U}_1$ (cm/s) water vapor pressure and wind velocity at the height of 1.5 meters above the snow surface, respectively. In eq. (1) it is assumed that the coefficient of turbulent diffusion of momentum is approximately equal to that of water vapor. Involving the inversion conditions, an empirical relation between U_* and $\bar{U}_1$ was given by KOBAYASHI (private communication) at Mizuho Camp in the following equation:

$$U_* = 0.0455\ \bar{U}_1 \tag{2}$$

Substituting eq. (2) into eq. (1) and assuming that ρ is the density of the air at temperature of -15°C, P is the pressure at the station level of 750 mb and the density of snow at the surface is 0.45 g/cm^3, then the sublimation rate F_e is given by:

$$F_e = 2.50 \frac{\bar{U}_1}{P} (e_s - e_1) \qquad \text{mm/day} \tag{3}$$

where the water vapor pressure e_0 at the roughness height is assumed to be nearly equal to the water vapor pressure e_s at the snow surface under saturation condition over ice obtained by the measurement of snow surface temperature.

Fig. 5 shows that the water vapor pressure in air is closely related with the diurnal change of air temperature. Though water vapor pressure at the snow surface is equal to the saturation water vapor pressure on ice at the temperature of the snow surface, the difference between water vapor pressures in the air and at the snow surface depends upon the radiation balance at the snow surface. When the snow surface is heated, sublimation at the snow surface and upward water vapor transport occur and result in a relatively moist mid-day air mass. During a period of low sun and clear sky night the snow surface is cooled by radiation, but sublimation at the snow surface still continues because of higher water vapor pressure at the snow surface than at the height of 1.5 meters.

At Mizuho Camp, the average difference of the both water vapor pressures during the period of the measurement is expected to reach about 1 mb and in this case the amount of sublimation from the snow surface is estimated to be 2 millimeters per day.

Ten-days average of the amount of sublimation in snow depth is estimated and shown in Table 2. From this table it is clearly seen that the sublimation rate estimated is two or three times larger than the ablation rate measured using snow stakes.

Table 2. Ten-days average of sublimation rate.

Period	Air temper-ature (°C)	Wind speed (m/s)	Air pressure (mb)	Water vapor pressure difference (e_s–e_1) (mb)	Subli-mation rate (mm/day)	Latent heat (ly/day)	Ablation rate by 9-snow stakes farm (mm/day)
11/30–12/7	−14.7	6.4	754.6	0.85	1.8	55	0.6
12/11–12/20	−14.8	7.0	753.9	0.60	1.4	42	0.6
12/22–12/31	−15.7	6.4	751.1	0.61	1.3	40	0.8
1/ 1– 1/10	−14.7	7.1	746.8	0.78	1.9	57	0.8
1/12– 1/21	−17.1	7.1	746.6	0.69	1.6	50	0.7

The measurement of snow stakes was carried out on the snow surface called the glazed surface (WATANABE, 1978). As shown in Fig. 4 deposition of snow takes place on occasion but the snow deposited is blown off by wind a few days after. Therefore, it is considered that no deposition and erosion of snow occurs on the snow surface.

The measurement of snow surface temperature was made in a few millimeters of the snow under the snow surface. Then it might be possible that the measured temperature of the snow surface was estimated higher than the true temperature of the snow surface during a period of low sun and clear sky night.

The cause of the difference between the sublimation rates obtained by two methods is not clear in the present study and it might be a very important problem to be solved in a future study.

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