CONTROLLING FACTORS OF DRIFTING SNOW

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Abstract: A series of observations of drifting snow was carried out at Mizuho Camp, East Antarctica, during the wintering of the 13th Japanese Antarctic Research Expedition (1972–1973). The collectors used in this work were a box-type drift gauge and MELLOR's saltation gauges, whereby measurements were made on the amount of snow drift transport, the saltation length of snow particles and their rebound mass under different condition of snow surface.

The amount of snow drift transport Q (g/m·s) was represented by the relation $\log Q = (0.17\text{–}0.22)\ V - (0.2\text{–}0.4)$, where V represents the wind speed in m/s, from the results measured by these drift gauges. The saltation length was less than 75 cm on a soft snow surface with dunes, barchans, etc., and more than 100 cm on a hard snow surface with sastrugi, glazed surface. It was also found that the saltation length became longer and the amount of snow drift transport increased as temperature decreased.

1. Introduction

Observations of drifting snow have been performed in Mizuho Plateau by several investigators; NARUSE (1970), S. KOBAYASHI (1976) and INOUE (1976). During the wintering of the 13th Japanese Antarctic Research Expedition 1972–1973 (JARE-13), the present author also had a chance to observe drifting snow at Mizuho Camp which was one of the subjects of the Glaciological Research Programs in Mizuho Plateau.

S. KOBAYASHI (unpublished) made a rough estimation of the amount of snow drift transport across a unit width, 1 km along the contour line, per year at Mizuho Camp, by the use of 1) distribution of wind speed throughout the year, 2) probability of occurrence of snow drifting against the wind speed (both were obtained from the field observation at Mizuho Camp), and 3) an empirical relation between the snow drift transport and the wind speed. He gave a value of 1×10^9 kg/km·year for the amount of snow drift transport at Mizuho Camp.

However, snow drifting is controlled not only by wind speed, but also by snow surface condition, particle shape of snow, and air temperature. Therefore, the author investigated the effects of the snow surface condition, particle shape of snow and air temperature, on snow drifting based on the data of the measurements obtained at Mizuho Camp by using a box-type drift gauge and four

MELLOR's saltation gauges. The box-type drift gauge (D. KOBAYASHI, 1972) was originally designed to observe the saltation phenomena of drifting snow, whereas four MELLOR's saltation gauges were used to measure the amount of blowing snow transport.

Mizuho Camp (70°42′S, 44°20′E) is situated in the area where the strong katabatic wind prevails in winter with a mean speed of 11 m/s. In this season, snow surfaces in this area are featured mainly by glazed surfaces, sastrugi, dunes and barchans.

2. Instruments and Methods

The instruments used in this observation were a box-type drift gauge and four MELLOR's saltation gauges as described below.

The box-type drift gauge made up by a combination of 10 small cabinets in series, as shown in Fig. 1 (D. KOBAYASHI, 1972) was placed on the snow surface

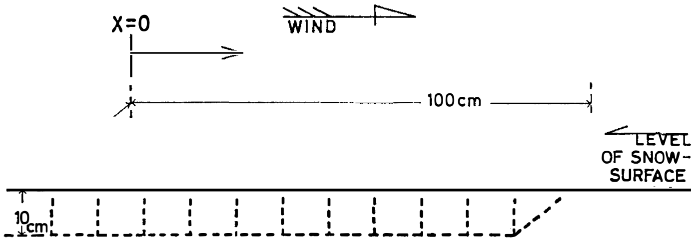

Fig. 1. Box-type drift gauge.

so that the upper side (open side) of cabinets was properly level with the surrounding snow surface without a gap between the gauge and the snow surface, and the front side of the gauge was directed perpendicularly to the wind direction, and the lengthwise side of the gauge was directed in parallel with the wind direction. The amount of snow drift transport Q (g/m·s), the average saltation length $\bar{L}$ (cm), and the rebounding mass G (g/m^2·s) of drifting snow were calculated as follows (KAWAMURA, 1951): the x-axis was taken in parallel to the wind direction with the origin at the windward edge of the gauge, as shown in Fig. 1: then the amount of deposited snow $F(x)$ is given by,

$$F(x)=G\left\{\int_0^\infty g(l)dl-\int_0^x g(l)dl\right\},$$
$$=G\left\{1-\int_0^x g(l)dl\right\},$$

where $F(x)$: amount of deposited snow per unit area and unit time (g/m^2·s), the center of which is located at x,

G: rebound mass of drifting snow, $G=F(x)_{x=0}$(g/m^2·s),

l: saltation length of a snow particle (cm), and

$g(l)$: distribution function of saltation length.

The amount of snow drift transport Q is given by,

$$Q=\int_0^\infty F(x)\cdot dx=\bar{L}\cdot G, \tag{1}$$

where Q: mass of drifting snow which passes through unit width perpendicular to the wind direction in unit time (g/m·s), and

$\bar{L}$: mean length of saltation of drifting snow particles (cm).

The measured and calculated values are given in JARE Data Reports (YAMADA and NARITA, 1975).

Four MELLOR's saltation gauges used had the dimensions as shown in Fig. 2.

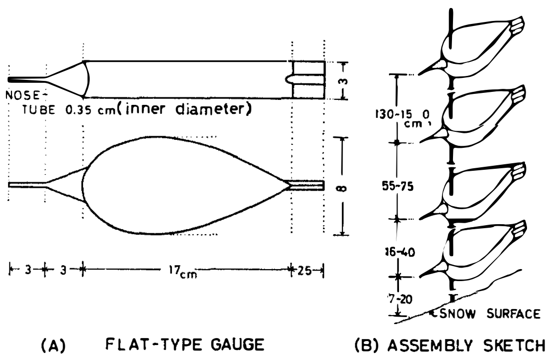

Fig. 2. MELLOR's saltation gauge (from MELLOR, 1960)

They were exactly similar to MELLOR's type (MELLOR, 1960). MELLOR designed his drift gauge, named "saltation gauge", to measure the amount of the mass transport of snow in a saltation layer. However, the present author used this gauge to measure the amount of mass transport of snow above the saltation layer. The inner diameter of the inlet tube of this MELLOR's saltation gauge, nose tube,

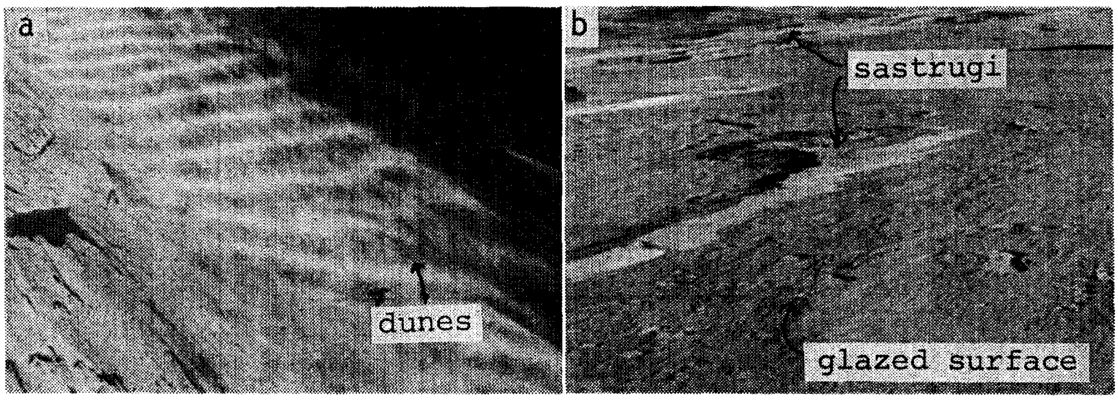

Fig. 3. Snow surface features at the observation sites.
a: soft surface b: hard surface

was 0.35 cm, and the collection factor was estimated at 0.72 for a wind speed of 12.0 m/s. Four of MELLOR's gauge were used to measure the vertical distribution of mass-flux of drifting snow ($g/m^2 \cdot s$), then the amount of flux per unit time from the snow surface to the given height was calculated.

The wind speed was measured with a BIRAM's vane anemometer at a level of 1 metre above the snow surface. These drift gauges were placed on a soft snow surface and a hard snow surface, as shown in Fig. 3a and b.

3. Measurements and Results

3.1. Measurements by the box-type drift gauge

3.1.1. Distribution function $F(x)$

The box-type drift gauge (Fig. 1) was set on the snow surface in the manner described in Section 2. The mass of the snow deposited in each cabinet was weighed after a period of 1 to 2 minutes.

The plots of the distribution function $F(x)$ obtained from the above are shown in Fig. 4. Snow drifting was classified into three types by a combination

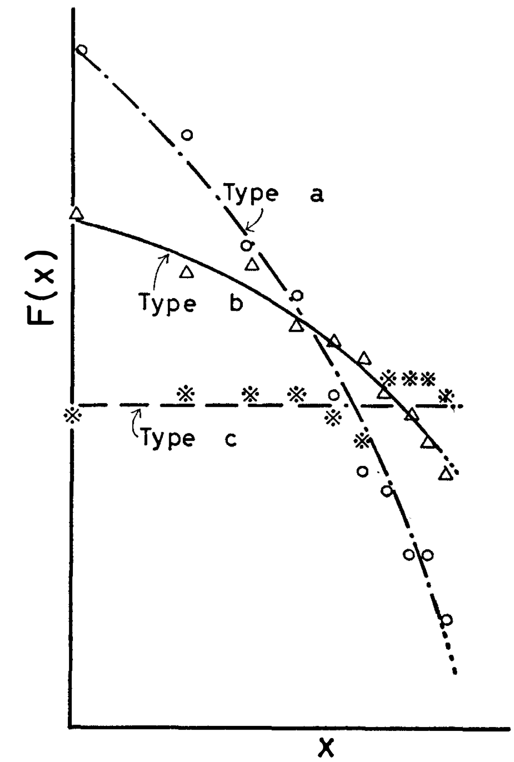

Fig. 4. Conceptual representation of snow deposition distribution by a box-type drift gauge (○, △, ※: See Table 1).
F(x): Mass of deposited snow.
x: Distance from the windward end of the drift gauge.

of snow surface condition and particle shape of drifting snow, as follows: type a, denoted by ○, was observed when the drifting snow particles were in rounded shape, as illustrated in Fig. 5a, and type b, denoted by △, when those were in angular shape, mainly fresh snow crystals, as in Fig. 5b; both for a soft snow surface. While type c, denoted by ※, was a mixture of round-shaped and angular-shaped particles of drifting snow on the hard snow surface. The hardness of the soft surface was less than $200\ g/cm^2$ in KINOSITA's hardness. The snow particles which constituted these deposits of snow did not seem to have been sintered into each other sufficiently; the measured places were on moving barchans

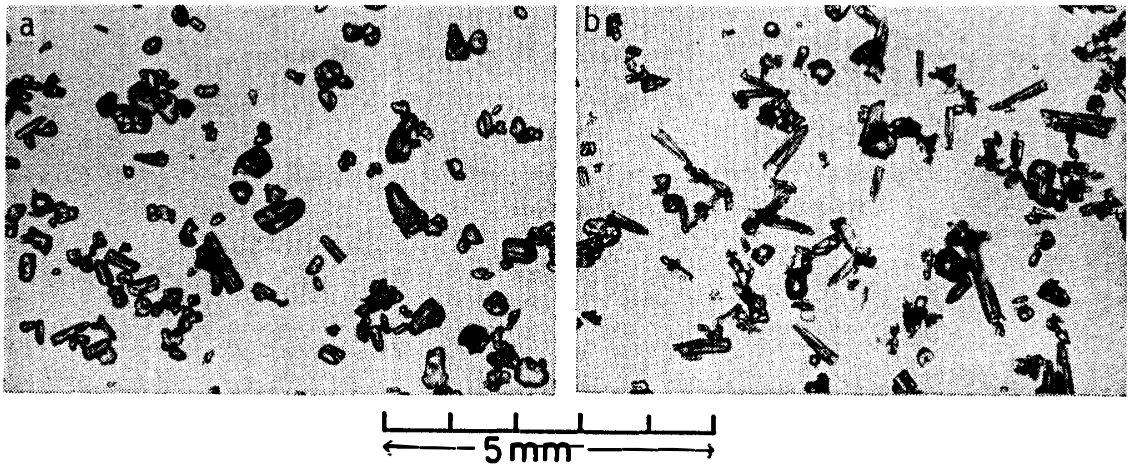

Fig. 5. Shapes of drifting snow particles.
a: Drifting snow composed mostly of rounded particles.
b: Drifting snow composed mostly of fresh snow crystals.

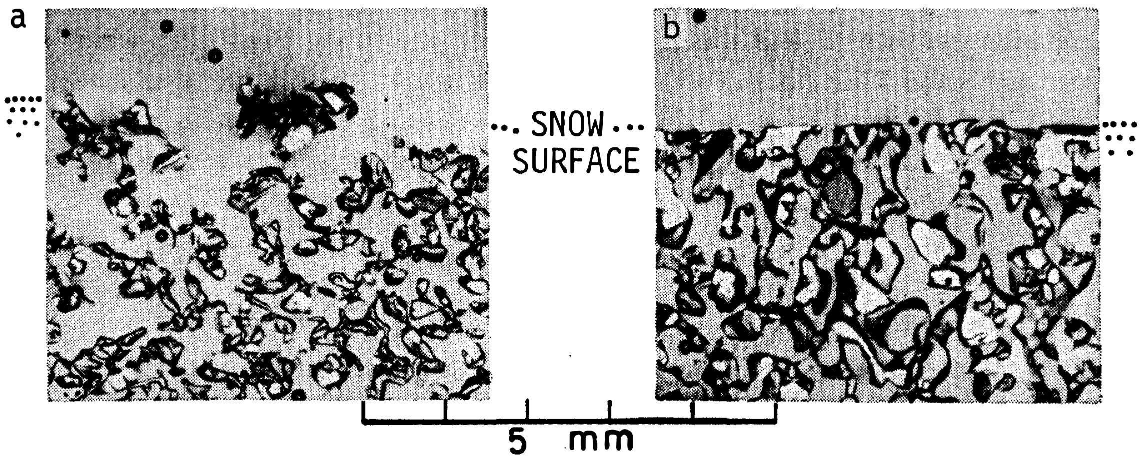

Fig. 6. Vertical thin sections of snow surface.
a: Soft surface (dunes; barchans).
b: Hard surface (sasturgi; glazed surface).

and dunes, as shown by Fig. 3a. The vertical cross-section of the soft snow surface was irregular, as shown by Fig. 6a. As for type c, the data were obtained on the hard surface, the hardness of which was larger than 2000 g/cm^2 in KINOSITA's hardness. The surface of the measured places had an appearance of a smooth ice sheet as shown by Fig. 6b. Table 1 shows the grouping of the foregoing types of snow drifting against the combination of the surface condition and snow particle shape.

Table 1. Classification of snow drifting by the combination of snow surface condition and snow particle shape.

Classification of snow drifting	Particle shape	Surface
type a ○	rounded	soft
type b △	angular	
type c ※	rounded +angular	hard

The curves of distribution function $F(x)$ of types a and b decreases exponentially as x increases, but that of type c remains almost at a level regardless of changes of x. There is a strong suspicion that the use of the box-type drift gauge is limited on the hard surface.

3.1.2. The relation between the rebound mass G and the wind speed V

The rebound mass of drifting snow G is obtained as the value of $F(x)_{x=0}$. A relation between G and the wind speed V is shown by Fig. 7, in which the upper and lower limit lines of values of D. KOBAYASHI (1972) are also shown by lines A and B, together with a heavy line representing the following equation.

As for the data of type a, G increases as V increases. The relation between G and V for type a is represented by the following equation:

$$\log G = 0.15V + 0.87,$$

where G is represented by g/m$^2\cdot$s, V by m/s and $7.0 < V < 12.0$. For type b, however, no empirical formula was obtained, because measurements of G of type b were obtained only for a narrow range of wind speed.

The data of type b show the same tendency as the one described above, but the values of type a is eight to nine times as large as that of type b.

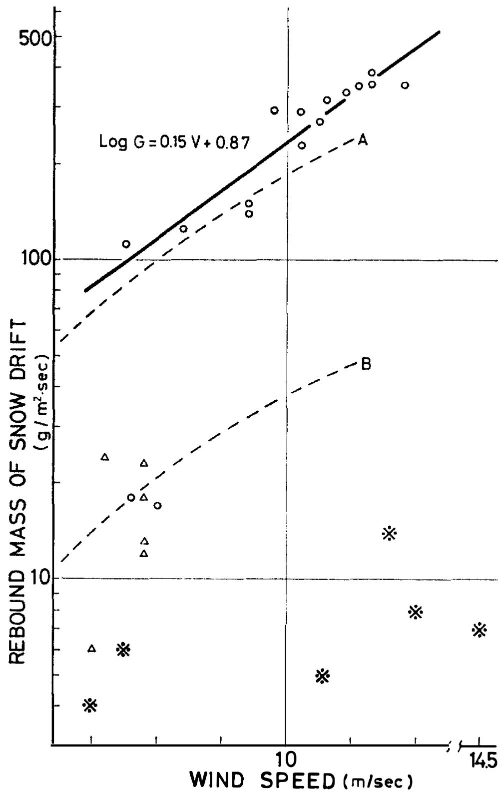

Fig. 7. Relation between the rebound mass G of snow drift and the wind speed at height of 1 m.

3.1.3. The relation between the amount of snow drift transport Q and the wind speed V

The amount of snow drift transport Q is obtained by eq. (1), $Q=\int_0^{\infty} F(x)\cdot dx$. The length of the instrument was 1 m. The fact that there was some amount of snow particles deposited in the 10th cabinet of the gauge, shows that they could be collected at a location further leeward. Hence, the distribution curve was extrapolated to 1.5 m on the x-axis and the amount of snow drift transport Q was calculated by eq. (1), $Q=\int_0^{1.5m} F(x)\cdot dx$. The relation between Q and V is shown in Fig. 8. The upper and lower lines which are represented respectively by A and B in Fig. 8 show D. KOBAYASHI's data (1972). As for the values of G treated in the previous section, types a and b had values near D. KOBAYASHI's values, but as for the values of Q, type a had values 5 to 6 times as large as D. KOBAYASHI's value.

The relation between Q and V for the data of type a is represented by:

$$\log Q = 0.22V - 0.41,$$

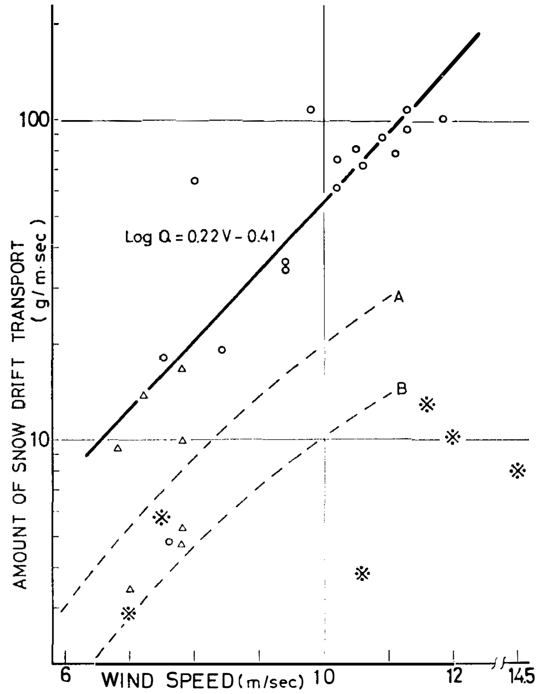

Fig. 8. Relation between the amount of snow drift transport Q measured by a box-type drift gauge and the wind speed at a height of 1 m.

where Q is represented by g/m·s, V by m/s and $7.0<V<12.0$.

The amount of snow drift transport denoted by △ in Fig. 8 is smaller than the value obtained from the above equation giving the relation between Q and V.

3.1.4. The relation between the mean length of saltation parths $\bar{L}$ and wind speed V

The mean length of saltation paths can be calculated from eq. (1). The relation between $\bar{L}$ and V is shown in Fig. 9. As seen from the figure, there is no consistency in the distribution of the data as a whole, regardless of the types of snow drifting. Lines A and B are the upper and lower limits of the data of D. KOBAYASHI (1972) respectively. In Fig. 9, the values denoted by ○, △, and ※ represent types a, b and c, respectively, as shown in Table 1. The figure shows that the mean length of saltation paths on the hard snow surface, that is, those denoted by ※, is longer than those on the soft surface, namely those denoted by ○ and △. From eq. (1), the calculated values of the mean length of saltation on the hard snow surface are in a range from 75 to 125 cm. As for the values on the soft snow surface denoted by ○ and △, they are less than 75 cm, in which those denoted by △ are longer than those denoted by ○ at a given wind speed. The values of the former are in a range of 40 to 75 cm, and the latter 9 to 40 cm. As to the values of the former, they are longer than D.

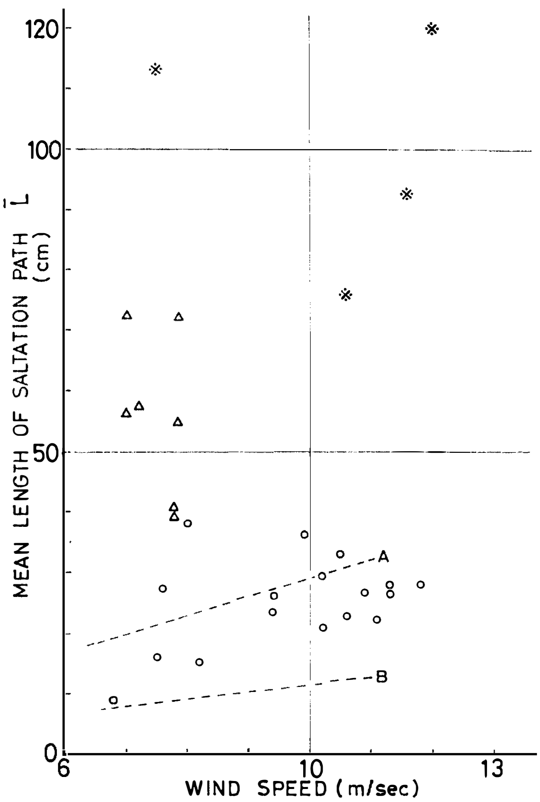

Fig. 9. Relation between the mean length of saltation path $\bar{L}$ and the wind speed at a height of 1 m.

KOBAYASHI's values. Such a difference of the value might be ascribed to the difference in the basic condition of snow drifting, air temperature, surface condition and particle shape between NARITA's record in Antarctica and D. KOBAYASHI's record in Japan.

3.1.5. The temperature dependency of drifting snow

The author selected, from the data of NARITA and D. KOBAYASHI, the ones which were obtained on the soft surface in the same conditions, including the angular particles in drifting snow, and the wind speed in the region of 7.2–7.8 m/s.

As a result, the relation between the mean length of saltation paths and the air temperature based on the data of NARITA and D. KOBAYASHI under the same condition fell on a straight line as shown in Fig. 10, indicating a strong dependence between them. The line representing the relation is given by the following equation:

$$\bar{L}=1.16T+6.1$$

where $\bar{L}$ and T are represented by cm and °C, respectively.

Likewise, the relation between the amount of snow drift transport and the

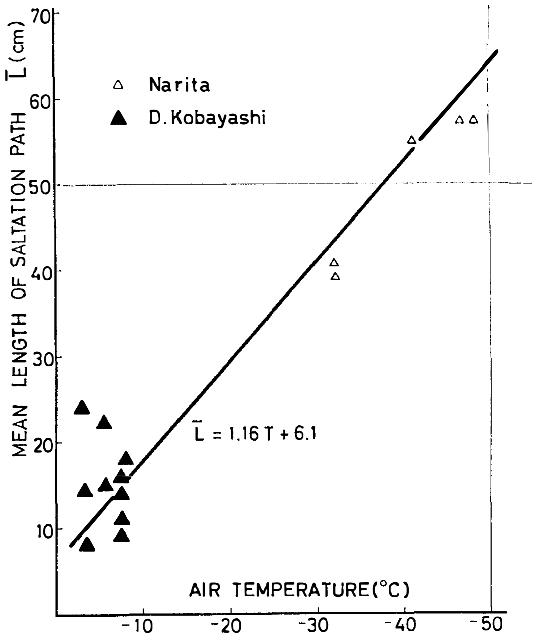

Fig. 10. *Mean length of saltation path $\bar{L}$ of snow particles of type b (angular particles) as a function of air temperature T. Wind speed: 7.2~7.8 m/s.*

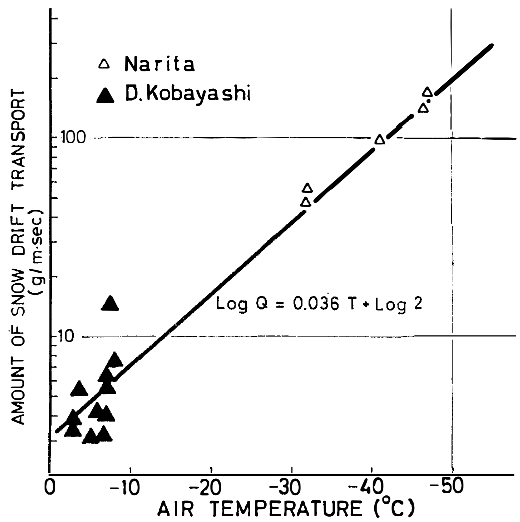

Fig. 11. *Relation between the amount of snow drift transport Q and the air temperature T.*

air temperature is shown in Fig. 11. In the figure, a linear relation between the logarithm of the amount of snow drift transport log Q and the air temperature T can be seen. The line representing the relation is given by the following equation:

$$\text{Log}\, Q = 0.036T + \log 2,$$

where Q and T are represented by g/m · s and °C, respectively.

Therefore, it is clear that the snow drifting was controlled not only by wind speed, but also by snow surface condition, particle shape of drifting snow, and air temperature.

D. KOBAYASHI (1972) obtained an experimental result that the restitution coefficient of a small ice sphere on a thick ice plate increased as the temperature decreased. While TAKEUCHI *et al.* (1975) carried out a series of experiments on friction between various shapes of snow particles and snow surface under various temperatures. They obtained a result that the friction coefficient between snow particle and snow surface decrease with increase of roundness of snow particle and decrease of temperature. These experimental results in the laboratory supported the observational results at Mizuho Camp.

3.2. *Measurement by the MELLOR's saltation gauge*

After the drift gauge was set up, it was allowed to stand for 1 to 2 hours; the snow mass deposited in the drift gauge was weighed. The vertical distribution of mass flux of snow through a unit area, perpendicular to the wind direction, per unit time is shown in Fig. 12. The relation between the wind speed and the mass

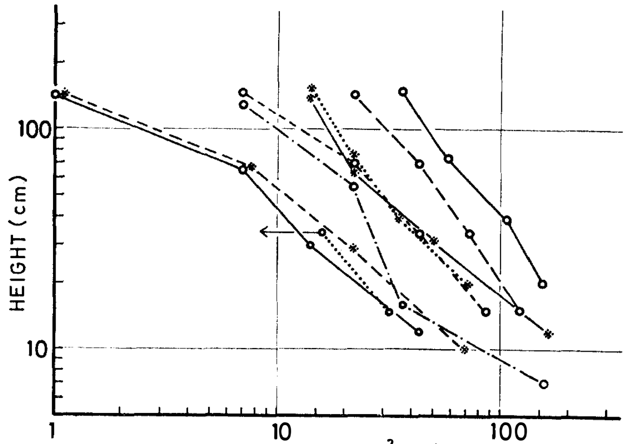

Fig. 12. Vertical profiles of horizontal mass flux obtained by a MELLOR's saltation gauge.

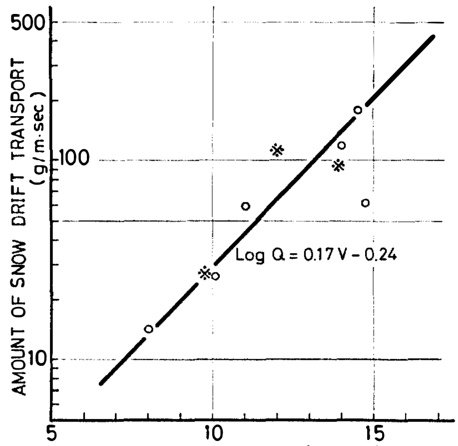

Fig. 13. Relation between the amount of snow drift transport Q and the wind speed V at a height of 1 m.

flux is linear on a log-log diagram. As the height of blowing snow was practically up to several meters the lines shown in Fig. 12 were extrapolated to the snow surface and also to a height of 10 m on the assumption that the upper limit of the height of drifting snow was 10 m; the amount of snow drift transport was calculated by integrating these lines from the snow surface to a height of 10 m. The relation between these results and the wind speed measured at a height of 1 m are plotted in Fig. 13, regardless of hardness of the snow surface. The plots are aligned on a line represented by the following equation:

$$\log Q = 0.17V - 0.24,$$

where Q is represented by g/m·s and V by m/s. The marks, ○ and ※, indicate the values measured on the soft and the hard snow surface, respectively.

4. Conclusion

It has been found from the measurements by the box-type drift gauge that the phenomena of drifting snow varied remarkably with the condition of snow surface, soft or hard, with the shapes of snow particles, angular or rounded, and with the temperatures. Now, let us summarize the effects of the controlling factors (hardness of snow surface, shape of particle and air temperature) on the snow drifting (G, Q and $\bar{L}$).

When the snow surface is soft:

(1) The rebound mass G of the rounded particle shape is larger as much as 8 to 9 times that of the angular particle shape (Section 3.1.2).

(2) The amount of snow drift transport Q has a tendency to increase with wind speed, and Q of the rounded particle is slightly bigger than that of the angular particle (Section 3.1.3).

(3) The mean length of saltation path $\bar{L}$ of the angular particle is longer than that of the rounded particle (Section 3.1.4).

(4) The snow drift transport Q and the mean length of saltation parth $\bar{L}$ increase remarkably with decrease of air temperature (Section 3.1.5).

When the snow surface is hard:

(5) The mean saltation path $\bar{L}$ is longer than 1 m (Section 3).

From those results it would be concluded that the principal controlling factors of snow drifting are the condition of snow surface and the shape of drifting snow particles; both are strongly affected by air temperature.

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