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CHARACTERISTICS OF DRIFTING SNOW AT MIZUHO STATION, ANTARCTICA

by

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ABSTRACT

Observations of drifting snow were carried out at Mizuho Station (70°42'S, 44°20'E, 2230 m above sea level), East Antarctica, in 1982. Drift flux was proportional to about the 8th power of wind velocity above 1 m and about the 4th power below 0.1 m, while snow drift transport rate was proportional to about the 5th power. For drift flux at 1 m height, the power had a temperature dependence, decreasing above -20°C. Visibility was proportional to about the -8th power of wind velocity; this is explained by the power relation between drift flux and wind velocity. The repose angle of drifting snow particles was observed by the inclination of a cone-shaped deposit on a disk; it was more than 80° when snow was falling and less than 80° without precipitation. The fall velocity of drifting snow particles, obtained by time-marked trajectories of particles, was between 0.3 and 0.9 m/s, and depended on wind velocity and snow particle shape.

INTRODUCTION

In the region of Mizuho Station, East Antarctica, drifting snow occurs by katabatic winds throughout the year and plays an important role in the redistribution of snow on the ice sheet surface. Mass transportation of drifting snow is enormous, and was estimated at 10^9 kg/km year at the Station (Kobayashi 1978). Many investigators have examined the drifting snow in this region and clarified its behaviour. However, there still remain problems; for example temperature dependence, effect of precipitation, and fall velocity of drifting snow particles. From January 1982 to January 1983, the 23rd Japan Antarctic Research Expedition studied transport rate, snow drift flux, visibility, repose angle of drifting snow particles and fall velocity of the particles in drifting snow.

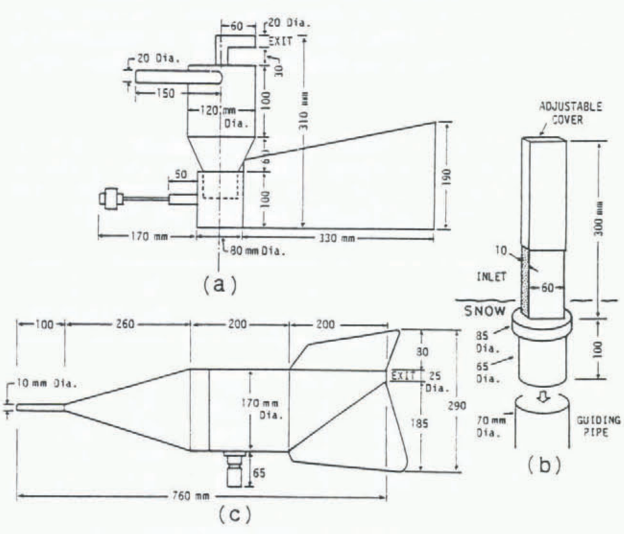

Fig.1. Snow drift collectors: (a) cyclone type with vanes, (b) slit type, and (c) rocket type.

SNOW DRIFT FLUX

Measurements of snow drift flux

Snow drift flux was observed by a slit type collector (surface - 0.1 m in height), four cyclone type collectors (0.3, 0.5, 1, 2 m), and four rocket type collectors (4, 8, 15, 30 m). Snow particles collected by the slit and cyclone collectors fell into an observation chamber 4 m under the snow surface, and were weighed once a day. The rocket collectors were installed on a 30 m high tower and the stored snow was weighed at 5 or 10 day intervals. The cyclone collector was pointed toward the wind direction by vanes (Figure 1a). Its collection efficiency is about 0.6, according to a wind-tunnel calibration (Kobayashi 1978). The slit collector was positioned to measure the drift flux close to the snow surface; it has a narrow slit inlet 1 cm in width and about 10 cm in height (Figure 1b). Its collection efficiency was estimated to be the same as that of the cyclone collector, based on calibration by extrapolation of the drift flux obtained by the cyclone type. Its inlet had to be pointed manually toward the wind, usually a constant katabatic wind. The rocket collector was shaped like that of Budd and others (1966) (Figure 1c); its collection efficiency was estimated to be the same as the cyclone, on which it was calibrated.

Wind velocity was measured at 6.9 m height by a windmill anemometer. Wind velocity at 1 m was estimated at 16% less than that at 6.9m, according to previous observations of wind velocity profiles.

Snow drift tranport rate

Snow drift transport rate was obtained 41 times between March 1982 and January 1983 by integrating drift flux from the surface to a height of 30 m. The relationship of drift transport rate with wind velocity was close to the empirical relationship of maximum transport rate to wind velocity given by Kobayashi (1978) (Figure 2), though drift collectors gave different results.

Proportional to about the 5th power of wind velocity, the rate was greater than the 3rd or 4th power reported from other districts (eg Kobayashi 1972). This difference can be explained as follows. In drifting snow transportation, two transport mechanisms are distinguished: "saltation" prevails near the surface and "suspension" is predominant in the air. As for the drift flux, the power was a function of height; it was about 4 below 0.1 m and about 8 above 1 m (Figure 3). The small power at the low height would be related to the saltation; it is close to the theoretical power of 3 indicated for the saltation by Bagnold (1941). The large power above 1 m would be related to suspension, though its value has not been explained theoretically. Since the observed transport rate is a vertical integral of the drift flux from the surface to 30 m, the overall power will depend on the ratio of suspension to saltation. In astrong-wind region as at Mizuho Station, suspension is predominant, and the transport rate will be proportional to the larger power of wind velocity.

Relation between snow drift flux and wind velocity

Snow drift flux at 1 m adequately correlated with

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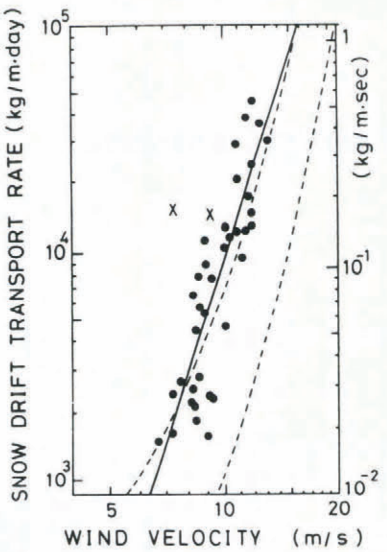

Fig.2. Relation between snow drift transport rate and wind velocity at 1 m height. A solid line: a regressive line on a logarithmic plot; crosses: data when much precipitation was observed; and two dashed lines: the maximum and the minimum transport rate empirically given by Kobayashi (1978).

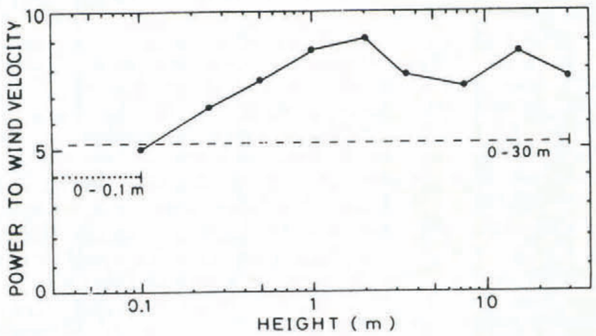

Fig.3. The power, by which drift flux is related to wind velocity, as a function of height. A dotted line: the power below 0.1 m, a dashed line: the power for drift transport rate up to 30 m height.

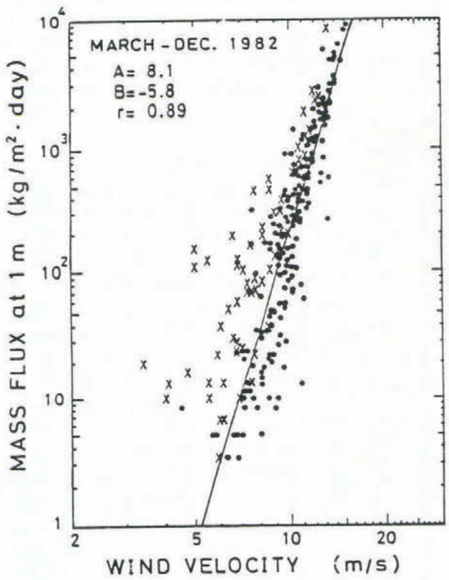

Fig.4. Relation between drift flux and wind velocity at 1 m height from March to December 1982. A solid line: a regressive line on a logarithmic plot; and crosses: data when precipitation was observed.

TABLE 1. CORRELATION BETWEEN MASS FLUX F (KG/M^2DAY) AND WIND VELOCITY V (M/S) AT 1 M HEIGHT ON A LOGARITHMIC PLOT; N: DATA NUMBER; R: CORRELATION COEFFICIENT; A: REGRESSION COEFFICIENT; B: INTERCEPT GIVEN BY THE REGRESSION EQUATION

$\log F = A \log V + B \quad (F = 10^B V^A)$,

V AND F: MONTHLY AVERAGE OF V AND F RESPECTIVELY.

Month 1982	n	r	A	B	V (m/s)	F (kg/m^2d)
Mar.	15	0.90	6.2	-3.7	8.7	112
Apr.	19	0.87	6.0	-3.4	10.3	453
May	30	0.87	8.3	-5.9	10.9	563
Jun.	14	0.97	8.1	-5.8	10.3	313
Jul.	23	0.96	8.1	-5.7	11.3	780
Aug.	22	0.90	8.1	-5.7	10.3	307
Sep.	21	0.80	8.2	-6.0	10.5	302
Oct.	23	0.92	9.4	-7.2	10.8	325
Nov.	24	0.88	8.0	-6.0	9.4	63
Dec.	19	0.79	5.3	-3.5	8.3	20
Total	210	0.89	8.1	-5.8	10.1	234

wind velocity, and was proportional to about the 8th power (Figure 4). The threshold wind velocity for occurrence of drifting snow with no precipitation was 6 or 7 m/s, as shown in Figure 4. In Table 1, the correlation between daily snow drift flux and wind velocity at a height of 1 m, is shown monthly from March to December 1982. When precipitation of snow or ice prisms was observed, the drift flux increased relatively: to eliminate effects of precipitation the data were not included in the correlating calculations in Table 1. The correlation coefficient had a high value of 0.8 or 0.9; the regression coefficient, equal to the power of wind velocity, was 8.1 through the observation period. The power showed a seasonal change; it was above 8 between May and November and below 8 in other months.

Temperature dependence of drift flux

The seasonal change of the power by which drift flux is related to wind velocity is explained by the temperature dependence of the power. In Table 2, the correlation between drift flux and wind velocity on a logarithmic plot is shown as a function of temperature. The power showed a maximum of 8.0 at temperatures

TABLE 2. CORRELATION BETWEEN MASS FLUX F (KG/M^2DAY) AND WIND VELOCITY V (M/S) ON A LOGARITHMIC PLOT AS A FUNCTION OF TEMPERATURE. NOTATION IS SAME AS TABLE 1.

Temperature T (C°)	n	r	A	B	V (m/s)	F (kg/m^2d)
-10>T>-20°C	21	0.73	4.4	-2.7	8.3	21
T>-30°C	39	0.87	7.3	-5.1	9.2	85
T>-40°C	53	0.89	7.8	-5.4	10.8	480
T>-50°C	88	0.92	8.0	-5.6	10.6	389
T>-60°C	14	0.84	7.5	-5.2	9.7	143
Total	215	0.89	8.0	-5.8	10.1	218

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ranging between -40°C and -50°C and decreased at higher temperatures; it was 4.4 above -20°C.

Factors affecting this temperature dependence include the following. The seasonal change of snow particle shape, which is suggested by the observation of repose angles below, can explain the dependence; when particles are round during fine weather in summer, saltation prevails over suspension, and drift flux is proportional to the low power of wind velocity, as mentioned above. Narita (1978) reported an increase of saltation path length with decreasing temperature; this would cause an increase of drift flux at low temperatures. Schmidt (1980) examined the temperature dependence of the threshold wind velocity for transport of snow, which would also affect the power.

Increase of drift flux due to precipitation

Drift flux increased when precipitation was present, as mentioned above. The effect of precipitation appeared as a vertical profile variation of the snow drift flux. Plotted logarithmically, the drift flux profile lost linearity when precipitation was observed; its variation was greater at height, (profile of 23 June 1982, Figure 5). This is explained as follows. The increase of horizontal mass flux due to precipitation is proportional to wind velocity and therefore increases with height, whereas ordinary drift flux with no precipitation is about inversely proportional to height. Hence the ratio of the increase to the ordinary drift flux, shown in the logarithmic plot, increases with height.

Precipitaiton intensity P can be estimated from the increase of horizontal mass flux, as the product of snow fall velocity W and precipitation density. The precipitation density at a height of z is the ratio of flux increase Fp(z) to wind velocity V(z), thus P is given by

$$P = W\ Fp(z)/V(z)$$

For example, on 23 June 1982 (Figure 5), precipitation intensity was evaluated as 7 kg/m^{2}day from Fp (1 m) of 80 kg/m^{2}day, V(1 m) as 5.5 m/s, and W as 0.5 m/s, (from observations of fall velocity, see below).

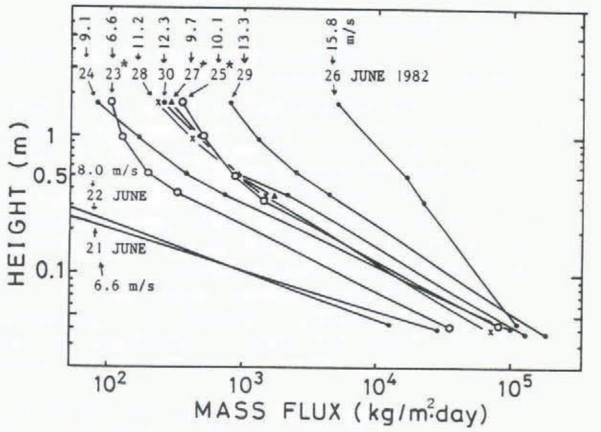

Fig.5. Vertical profiles of daily drift flux from 21 to 30 June 1982. "*" is attached to the date when precipitation was observed.

VISIBILITY

Visibility decreased with increasing wind velocity at Mizuho Station (Figure 6), because of drifting snow. It depended also on daylight, which has a large seasonal variation at this latitude; at a wind velocity of 10 m/s visibility was less than 1 km in winter and more than 10 km in summer.

The visibility was proportional to the -7.9th power of wind velocity through the year. This power is explained by that for drift flux. Drift flux above 1 m height is porportional to about the 8th power of wind

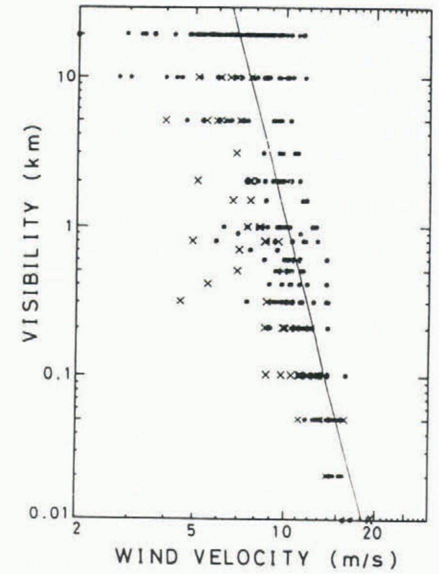

Fig.6. Relation between visibility and wind velocity at 1 m height through 1982. Crosses: data when precipitation was observed; and a solid line: a regressive line on a logarithmic plot.

velocity (see above) and therefore drift density is proportional to the 7th power. When visibility is considered to be inversely proportional to drift density (cf Budd and others 1966), the visibility would be proportional to the -7th power of wind velocity; this power agrees roughly with the observed one. Taking into account the vision persistence effect of human eyes, Takeuchi (1980) showed that visibility is correlated with drift flux rather than with drift density. From this relation, the visibility would be proportional to the -8th power of wind velocity; this power is closer still to the observed power.

REPOSE ANGLE OF DRIFTING SNOW PARTICLES

The repose angle of drifting snow particles was observed every day from June 1982 to January 1983. Drifting snow particles collected by the slit collector dropped into the sub-surface chamber and were guided onto a disk 20 cm in diameter to make a cone-shaped deposit (Figure 7). The slope of the cone is the repose angle. This angle increased from less than 80° with no precipitation to above 80° when snow was falling (Table 3). This was because snow crystals are more angular than drifting snow particles. Ice prisms caused further variation in the angle of slope, and so did temperature in the absence of precipitation.

The angle was largest (about 77°) between -30° and -40°C (Table 4). The cohesion of snow particles, which decreases with decreasing temperature, may explain the low repose angle below -40°C, but cannot

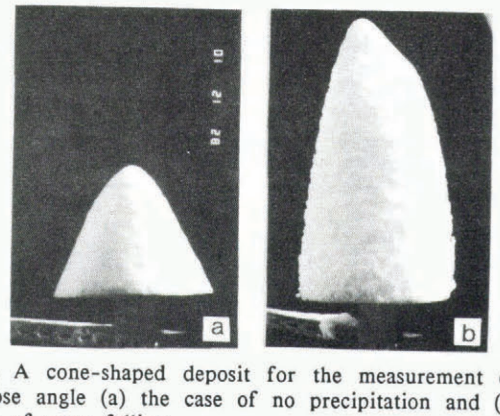

Fig.7. A cone-shaped deposit for the measurement of the repose angle (a) the case of no precipitation and (b) the case of snow falling.

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TABLE 3. FREQUENCY OF REPOSE ANGLE AS A FUNCTION OF PRECIPITATION BETWEEN 26 JUNE 1982 AND 3 JANUARY 1983 AT MIZUHO STATION; A: THE CASE OF NO PRECIPITATION, B: THE CASE WHEN PRECIPITATION WAS UNCERTAIN, C: THE CASE WHEN ICE PRISM OBSERVED, D: THE CASE WHEN SNOW OBSERVED.

Angle	A (nothing)	B (uncertain)	C (ice prism)	D (snow)
60°- 65°	3	1		
- 70°	14	1	1	
- 75°	35	2	1	
- 80°	52	20	10	10
- 85°	1	4	2	20
- 90°				5
Total	105	28	14	35
Average	75°	78°	79°	83°

explain the small repose angle at high temperature (eg 72° above -20°C). The small angle at high temperature is explained by the round particle shape, which is formed by active sublimation in summer at Mizuho Station (above -20°C).

FALL VELOCITY

Fall velocity of drifting snow particles is an important variable for drift density and for drift flux. Shiotani and Arai (1953) and Loewe (1956) expressed drift density as a function of fall velocity; they considered that the amount of snow descending is balanced by the amount spread upwards by turbulent diffusion. With this concept, Budd (1966) and Kobayashi (1978) obtained fall velocity from drift density profiles and Radok (1968) discussed the drift density of non-uniform fall velocity.

At Mizuho Station, the fall velocity of particles was observed every day in December 1982. Drifting snow particles collected by a slit collector were guided into a closed dark box through a perpendicular shaft 2.5 m in length. In the dark box, the snow particles were photographed using a slit light source flashed at 380 Hz by a rotating shutter. From the time-marked trajectories of particles in the photographs, the fall velocity of a particle was obtained. A hundred trajectories were chosen at random for one measurement.

The fall velocity was between 0.3 and 0.9 m/s and tended to increase with increasing wind velocity (Figure 8). This tendency is explained by the threshold wind velocity, at which particle motion just begins. Threshold wind velocity (cf Schmidt 1980) varies like fall velocity; large diameter or small drag coefficient give rise to high threshold wind velocity and large fall velocity. Hence, as wind velocity increases, particles with large fall velocity will increase in relation to the respective threshold wind velocity, and therefore the average fall velocity increases also.

TABLE 4. FREQUENCY OF REPOSE ANGLE WITH NO PRECIPITATION AS A FUNCTION OF TEMPERATURE.

Angle	T<-20°C	<-30°C	<-40°C	<-50°C	<-60°C
60° - 65°	2			1	
- 70°	6	1		5	2
- 75°	4	13	6	8	4
- 80°	5	5	15	24	3
- 85°		1			
Total	17	20	21	38	9
Average	72°	74°	77°	75°	73°

Related to snow particle shape, fall velocity decreased when particles were angular during precipitation and increased when they were round during fine weather (Figure 8). This difference can be explained by the change of drag coefficient.

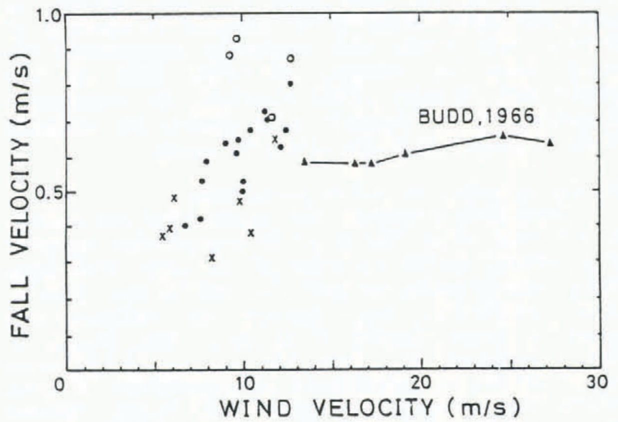

Fig.8. Relation between fall velocity and wind velocity. Open circles: data during fine weather; crosses: data when precipitation was observed; and a solid line: data from Budd (1966).

From drift density profiles, Budd (1966) obtained a fall velocity of about 06. m/s and a slight variation with wind velocity. In the same way, Kobayashi (1978) obtained a fall velocity between 0.35 and 0.40 m/s at Mizuho Station. Our results do not contradict these values. However, the change of fall velocity with increasing wind velocity is larger than that of Budd (1966) (Figure 8). In either case, the dependence of fall velocity on wind velocity, which would be caused by change of particle diameter or drag coefficient, should be taken into account when considering the relation between drift density and wind velocity.

CONCLUDING REMARKS

Observations of drifting snow were carried out at Mizuho Station, East Antarctica, in 1982.

Drift flux was proportional to about the 8 power of wind velocity above 1 m and to about the 4 power below 0.1 m, these powers are considered to be related to "suspension" and "saltation" respectively.

Drift transport rate was proportional to about the 5 power of wind velocity; this large power, compared with other districts, is explained by the large ratio of suspension to saltation at Mizuho Station.

The power relation between drift flux at 1 m height and wind velocity showed a temperature dependence; the power was about 8 throughout the year below -20°C and decreased at high temperature, above -20°C.

When precipitation was observed, the drift flux increased and the drift flux profile lost linearity on logarithmic paper. From the increase of drift flux, the precipitation intensity can be estimated.

Visibility was proportional to the -7.9 power of wind velocity. This power is explained by the power for the drift flux.

The repose angle of drifting snow particles was observed; it was more than 80° in the case of snow falling and less than 80° with no precipitation. The angle with no precipitation showed a temperature dependence; it had a large value between -30°C and -40°C.

The fall velocity of drifting snow particles in still air was observed; it was between 0.3 and 0.9 m/s and increased with increasing wind velocity, which is explained by the threshold wind velocity for particle motion. Moreover the fall velocity was related to snow

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particle shape because of the change of drag coefficient.

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