SOME CHARACTERISTICS OF DRIFTING SNOW AT MIZUHO STATION, EAST ANTARCTICA, 1982

Shuhei TAKAHASHI[1], Hirokazu OHMAE[2], Masao ISHIKAWA[2], Takayoshi KATSUSHIMA[3] and Fumihiko NISHIO[4]

[1]*Kitami Institute of Technology, 165, Koen-cho, Kitami 090*
[2]*The Institute of Low Temperature Science, Hokkaido University, Kita-19, Nishi-8, Kita-ku, Sapporo 060*
[3]*Faculty of Science, Hokkaido University, Kita-10, Nishi-8, Kita-ku, Sapporo 060*
[4]*National Institute of Polar Research, 9-10, Kaga 1-chome, Itabashi-ku, Tokyo 173*

Abstract: Several measurements on drifting snow were carried out at Mizuho Station (70°42′S, 44°20′E, 2230 m, above sea level)) East Antarctica, in 1982.

Visibility was correlated to wind velocity on a logarithmic plot; it was proportional to about the −8 power of wind velocity over a year. This is explained by the reciprocal relation of visibility to drift density and the power relation of drift density to wind velocity. Moreover, visibility changed with the seasonal variation of daylight.

The repose angle of drifting snow particles was observed by measuring the inclination of a cone shape deposit formed in sub-surface chamber. The repose angle was more than 80° in the case of snow falling and less than 80° in the case of no precipitation. The angle in the case of no precipitation showed a temperature dependence.

The fall velocity of drifting snow particles in still air was observed. The fall velocity was between 0.3 and 0.9 m/s and depended on wind velocity and snow particle shape. This dependence is explained by the change of particle size or drag coefficient.

1. Introduction

Several measurements of drifting snow were carried out at Mizuho Station in Antarctica (70°42′S, 44°20′E, 2230 m above sea level) in 1982 in addition to the observation of snow drift flux (TAKAHASHI *et al.*, 1984). In this paper we will report on measurements of visibility, repose angle of drifting snow particles and fall velocity of particles.

At Mizuho Station, visibility is closely correlated with wind velocity (KOBAYASHI *et al.*, 1983). This is because a lowering of visibility is mainly caused by drifting snow which in turn depends on wind velocity. The visibility also depends on the daylight which has a large seasonal variation at this latitude. To examine the effect of daylight change, the correlation between visibility and wind velocity was calculated by month.

In a katabatic wind slope region, precipitation is difficult to estimate owing to the strong drifting snow. The repose angle, the inclination of the cone shape deposit, was measured every day at Mizuho Station to examine its possibility of being an indicator of precipitation, because the angle would depend on snow particle shape.

The fall velocity of drifting snow particles, which is an important variable for drift density, has rarely been observed, whereas many reports has been published on the fall velocity of precipitation particles (*e.g.*, LANGLEBEN, 1954; KAJIKAWA, 1975). 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. In our observation, we obtained fall velocity by a direct method at Mizuho Station in December 1982.

2. Visibility

At Mizuho Station, visibility was observed with a series of drums at distances of 0.05, 0.1, 0.2, 0.3, 0.5, 0.8, 1, 1.5, 2 and 5 km as a visual objects. Wind velocity was observed by a windmill type anemometer at a height of 6.9 m. Data at 15 h local time were used for calculating the correlation between visibility and wind velocity (Table 1). When precipitation was observed (marked by "×" in Fig. 1), visibility relatively decreased, and the data were excluded from the correlation calculation to eliminate this effect. To examine the effect of drifting snow, data were also excluded at wind velocity below 8 m/s, at which drifting snow was negligible.

Visibility closely correlated with wind velocity and decreased with increasing wind

Table 1. Correlation between visibility (Vis) and wind velocity (V) on a logarithmic plot.

1982	r	A	B	Vis (10 m/s) (km)
January*	−0.83	−5.8	6.5	4.3
Februay	−0.72	−6.3	7.4	12.9
March	−0.87	−11.2	11.7	3.0
April	−0.93	−7.0	7.1	1.3
May	−0.82	−8.5	8.8	2.0
June	−0.89	−6.6	6.5	0.85
July	−0.85	−5.5	5.3	0.63
August	−0.78	−5.7	5.8	1.3
September	−0.87	−8.2	8.8	3.9
October	−0.92	−9.7	10.6	8.3
November	−0.75	−7.5	8.3	6.6
December	−0.74	−5.3	6.4	11.5
Jan.–Dec.	−0.77	−7.9	8.4	3.4

r: Correlation coefficient, A: regression coefficient, B: intercept on logarithmic paper given by the regression equation

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

and Vis (10m/s): the visibility at a wind velocity of 10m/s given by 10^{A+B}.

*: Data in January 1982 were obtained by JARE-22, and the criteria of visibility were partially different from those of JARE-23 taken in other months.

velocity (Fig. 1), which are shown in Table 1 as high negative correlation coefficients on a logarithmic plot. The relation is explained as follows. Visibility is inversely proportional to drift density (BUDD *et al.*, 1966), and drift density can be expressed as

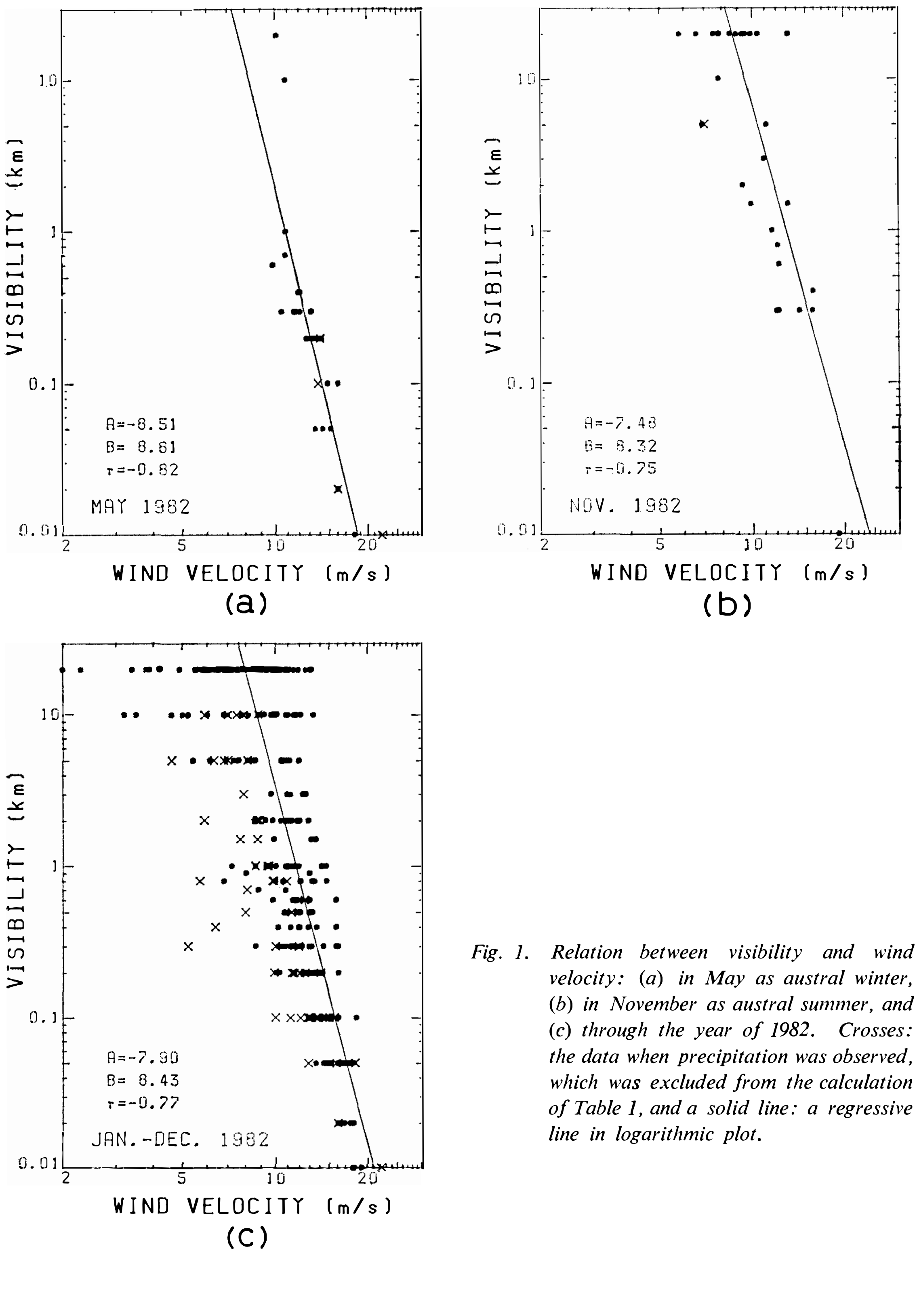

Fig. 1. Relation between visibility and wind velocity: (a) in May as austral winter, (b) in November as austral summer, and (c) through the year of 1982. Crosses: the data when precipitation was observed, which was excluded from the calculation of Table 1, and a solid line: a regressive line in logarithmic plot.

a power of wind velocity because drift flux is expressed as a power of wind velocity (TAKAHASHI *et al.*, 1984). Therefore visibility is expressed as a power of wind velocity.

Visibility was proportional to the -7.9 power of wind velocity through the year, as shown by the regression coefficient A in Table 1. The result is explained as follows. When drift flux is proportional to the n power of wind velocity, drift density is proportional to the $(n-1)$ power. Hence visibility is proportional to the $(1-n)$ power of wind velocity, owing to the reciprocal relation between visibility and drift density. Since the average value of n was about 8 from the simultaneous observations of drift flux (TAKAHASHI *et al.*, 1984), visibility is considered to have been proportional to the -7 power of wind velocity. This value agrees with the values in Table 1, though there is some difference. As for the seasonal variation of the power in Table 1, the low negative values for January, February and December in summer are explained by the seasonal change of n, which was small in summer (TAKAHASHI *et al.*, 1984). However, the low negative values from June to August and the high negative value in March cannot be explained except by error due to winter twilight or perhaps experimental error.

Visibility at a reference wind velocity showed a seasonal change. The magnitude of visibility at a reference wind velocity changed seasonally (Figs. 1a and 1b) and therefore the plots of data over a whole year were scattered in the graph (Fig. 1c). In Table 1, this seasonal variation shows up in the visibility at a wind velocity of 10 m/s, which is close to the average wind velocity over the year; it was less than 1 km in winter and more than 10 km in summer. The relation between drift density and wind velocity was comparatively constant throughout the year except above -20°C (TAKAHASHI *et al.*, 1984). Therefore the main cause of the seasonal change does not exist in this relation, but in the relation between visibility and snow density, in which optical factors must be contained. Hence, from the period and phase of the visibility change, the main cause is considered to be daylight brightness, which changes seasonally at this latitude of 70°S.

3. 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 a slit type collector were dropped into an observation chamber 4 m under the snow surface and guided onto a disk 20 cm in diameter to make a cone shape deposit. The inclination of the cone shape slope is the repose angle. Though the cone shape was usually more or less asymmetric, the maximum inclination among the three or four values around the cone shape was adopted as the repose angle.

As shown in Fig. 2, the repose angle clearly increased when precipitation was observed. In Table 2, the frequency of the repose angle is shown as a function of precipitation. The repose angle was generally more than 80° with snow falling, whereas it was less than 80° with no precipitation. In the case of ice prism falling, the frequency showed a distribution between the cases of no precipitation and snow falling. The snow crystal type observed in Mizuho Station is column or bullet type through a year and sometimes hexagonal plate and others (SATOW, 1983). Since all

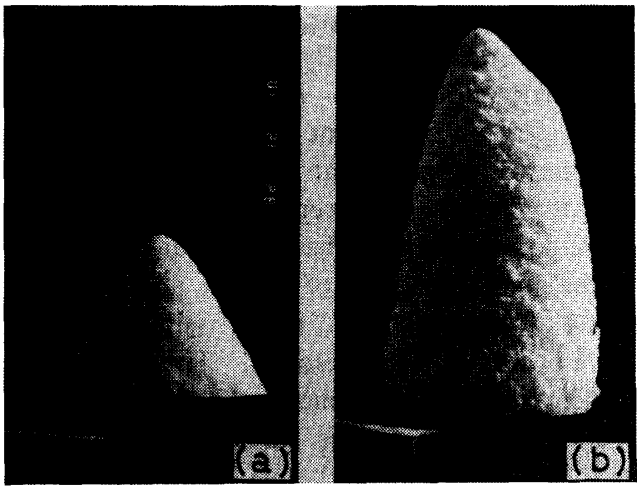

Fig. 2. A cone-shaped deposit for the measurement of the repose angle: (a) in the case of no precipitation and (b) in the case of snow falling.

Table 2. Frequency of repose angle as a function of precipitation from June 26, 1982 to January 3, 1983 at Mizuho Station.

	60–65°	-70°	-75°	-80°	-85°	-90°	Total	Average
No precipitation	3	14	35	52	1		105	74.6°
Uncertain	1	1	2	20	4		28	77.9°
Ice prism falling		1	1	10	2		14	78.5°
Snow falling				10	20	5	35	82.7°
Total	4	16	38	92	27	5	182	77.0°

these shapes of falling snow crystal are more angular than the drifting snow particles in the case of no precipitation, the repose angle shows a large value in the case of snow falling.

The repose angle can be a good indicator of snow precipitation; a repose angle of more than 80° means snow falling as mentioned above. In a katabatic wind slope region as around Mizuho Station, where drifting snow occurs throughout the year, mass balance measured by the snow stake method does not directly represent precipitation, and even visual observation of precipitation is often unreliable, because strong drifting snow hides the falling precipitation. In this condition, examining the shape of sampled snow particles with a microscope was reliable. However, observation in this way should be done several times a day to monitor precipitation. On the other hand, in the observation of repose angle, one measurement a day was sufficient to discriminate falling snow, because the large repose angle in the case of snow falling was conserved in an unsymmetrical cone-shaped deposit even if the snowfall stopped.

Temperature dependence of the repose angle was found in the case of no precipitation. As shown in Table 3, the repose angle was large, about 77°, between −30 and −40°C and small, about 72°, above −20°C. The cohesion of snow particles,

Table 3. Frequency of repose angle in the case of no precipitation as a function of temperature.

Angle	$T<-20°C$	$T<-30°C$	$T<-40°C$	$T<-50°C$	$T<-60°C$
65°	2			1	
66°		1		2	1
67°				2	
68°	3				
69°					
70°	3			1	1
71°	2	5		1	1
72°	2	3	1		
73°			1		
74°		3	2	3	
75°		2	2	4	3
76°			1	6	2
77°	3	2	1	10	1
78°	1	2	7	3	
79°	1	1	1	4	
80°			5	1	
81°		1			
Total	17	20	21	38	9
Average	71.6°	74.0°	77.2°	75.0°	73.4°

which decreases with decreasing temperature, can explain the low repose angle below −40°C, but cannot explain the small repose angle at high temperature, especially above −20°C. This small angle is explained as follows. In summer at Mizuho Station (above −20°C), active sublimation causes particles to have a round shape, and then the round particles produce a small repose angle.

4. Fall Velocity

The fall velocity of drifting snow particles in still air was observed every day at Mizuho Station in December 1982. Drifting snow particles collected by a slit type collector were guided into a closed dark box in a chamber under the snow surface (Fig. 3). The effect of descending air flow on the observation was negligible. 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 and particle diameter were obtained. A hundred trajectories were chosen at random for one measurement.

Correlation between fall velocity and diameter, in a measurement, was not seen in the ordinary case of irregular shape particles (Fig. 4a), except in the case of round shape particles during periods of fine weather in summer (Fig. 4b). This difference is explained as follows. According to investigations of fall velocity of precipitation particles (*e.g.*, KAJIKAWA, 1974), the fall velocity depends mainly on the melted diameter which is related to particle mass, and on particle shape which affects the drag coefficient. In the case of irregular shape particles, the observed diameter, which is obtained from the particle trajectory width, does not directly represent the melting diameter and, moreover, the drag coefficient would be random; therefore the fall velocity does not show a significant correlation to the diameter. On the other hand, the correlation can be seen in the case of round shape particles, because the observed diameter is close to the melted diameter and the drag coefficient would be constant owing to its homogeneous shape.

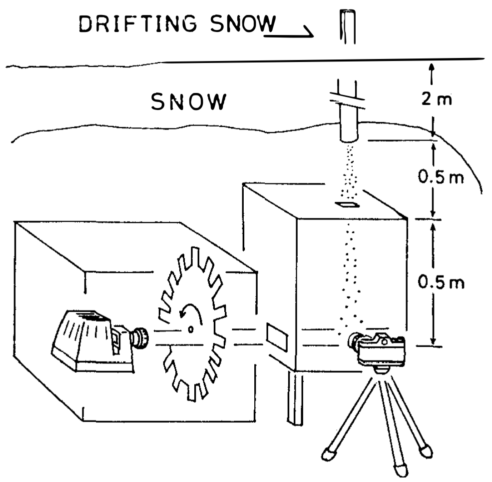

Fig. 3. Measurement system for fall velocity of drifting snow particles.

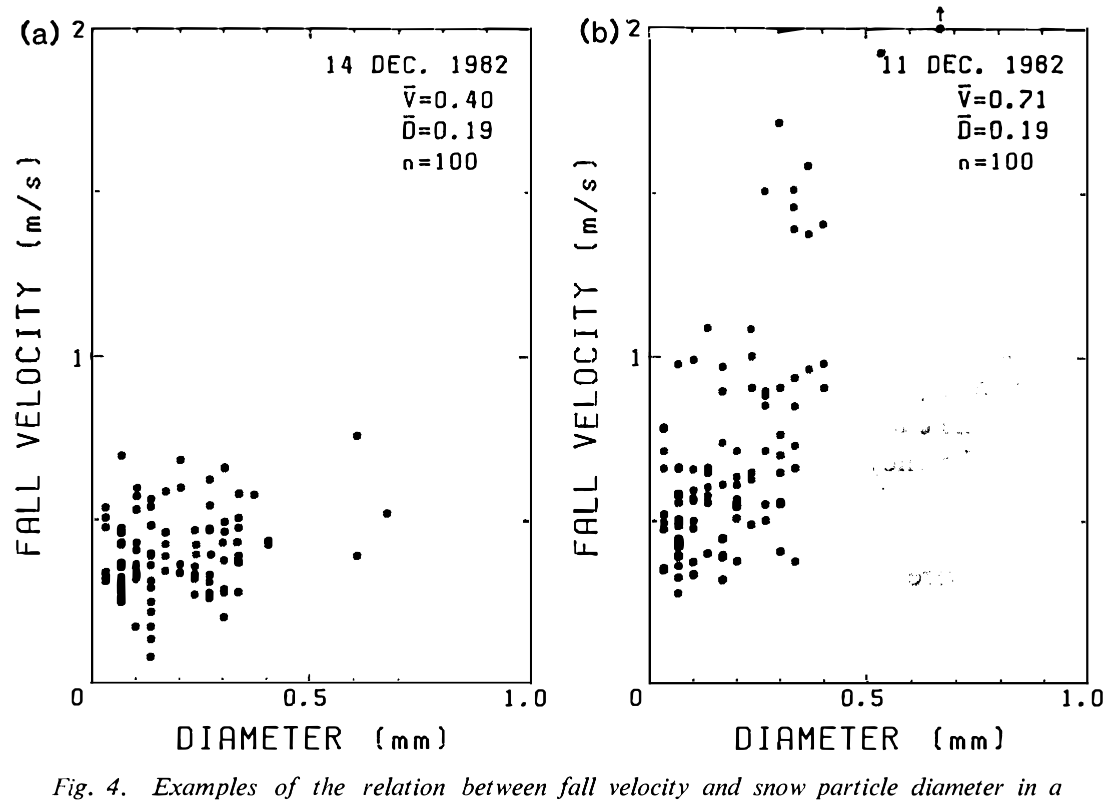

Fig. 4. Examples of the relation between fall velocity and snow particle diameter in a measurement: (a) in the ordinary case of irregular shape particles and (b) in the case of round shape particles.

The fall velocity was between 0.3 and 0.9 m/s and tended to increase with increasing wind velocity, as shown in Fig. 5. This tendency is explained as follows. The threshold wind velocity, at which particle motion just begins, mainly depends on particle diameter, drag coefficient and cohesive force on a snow surface (*e.g.*, SCHMIDT, 1980); it will be large in the case of large diameter or small drag coefficient, if the cohesive force is constant. Conversely, particles which begin to move at a large wind velocity will have a large diameter or small drag coefficient, which means a large fall velocity in either case. Hence, at large wind velocity, particles having large fall velocity will increase in drifting snow, and the average fall velocity will increase. As for cohesive force, variation with temperature is expected as discussed by SCHMIDT (1980), who discussed the force which breaks cohesive bonds.

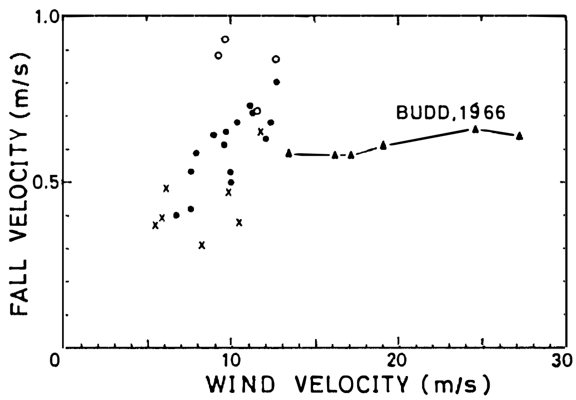

Fig. 5. Relation between fall velocity and wind velocity at a height of 6.9 m. Open circles: data during fine weather, and crosses: the data when precipitation was observed. The solid line is from BUDD *(1966).*

Snow particle shape is related to the fall velocity; fall velocity decreased in the case of angular particles when precipitation was observed, and increased in the case of round particles during fine weather. This difference can be explained by the change of drag coefficient.

From drift density profiles, BUDD (1966) obtained a fall velocity of about 0.6 m/s and a slight variation with wind velocity, though the observed fall valocity is an apparent one in air turbulence determined by SHIOTANI and ARAI (1953). 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 relationship between fall velocity and wind velocity is different than that of BUDD (1966) (Fig. 5). The reason for this difference is in the different measurement method, or in the different observation height; one is close to the snow surface and the other is several meters high. 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.

5. Concluding Remarks

Visibility was correlated to wind velocity at Mizuho Station on a logarithmic plot with a high negative correlation coefficient of −0.7 or −0.9; it was proportional to the −5 to −11 power of wind velocity each month and to the −7.9 power over the year. This is explained by the reciprocal relation between visibility and drift density and the power relation between drift density and wind velocity. Moreover the visibility changed with the seasonal variation of daylight.

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

The fall velocity of drifting snow particles in still air was observed. The fall velocity was between 0.3 and 0.9 m/s and increased with increasing of wind velocity. Moreover the fall velocity depended on snow particles shape; it decreased in the case of angular particles of precipitation, and increased in the case of round particles during fine weather. These are explained by the change of particle size or drag coefficient.

Acknowledgments

The authors wish to express their sincere thanks to Dr. S. KOBAYASHI, the Institute of Low Temperature Science, Hokkaido University, who offered meteorological data at Mizuho Station with valuable comments. Many thanks are due members of the wintering party of JARE-23 for their kind support in drifting snow measurements at Mizuho Station.

References

BUDD, W. (1966): Glaciological studies in the region of Wilkes, Eastern Antarctica, 1961. ANARE Sci. Rep., Ser, A, **88**, 149 p.

BUDD, W. F., DINGLE, R. J. and RADOK, U. (1966): The Byrd snow drift project; Outline and basic results. Studies in Antarctic Meteorology, ed. by J. RUBIN. Washington, D. C., Am. Geophys. Union, 71–134 (Antarct. Res. Ser., Vol. 9).

KAJIKAWA, M. (1974): Kôsui ryûshi no rakka sokudo ni tsuite (On the falling velocity of precipitation particles). Tenki, **21**, 317–332.

KAJIKAWA, M. (1975): Experimental formula of falling velocity of snow crystals. J. Meteorol. Soc. Jpn., **53**, 267–275.

KOBAYASHI, S. (1978): Snow transport by katabatic winds in Mizuho Camp area, East Antarctica. J. Meteorol. Soc. Jpn., **56**, 130–139.

KOBAYASHI, S., ISHIKAWA, N. and OHATA, T. (1983): Nankyoku ni okeru kyôfû-ji no fubuki (Snow storm with strong wind in Antarctica). Teion Kagaku, Butsuri-hen (Low Temp. Sci., Ser. A, Phys. Sci.), **42**, 65–79.

LANGLEBEN, M. P. (1954): The terminal velocity of snow flakes. Q. J. R. Meteorol. Soc., **80**, 174–181.

LOEWE, F. (1956): Etudes de Glaciologie en Terre Adélie, 1951–1952. Paris, Hermann, 159 p.

RADOK, U. (1968): Deposition and erosion of snow by the wind. CRREL Res. Rep., **230**, 23 p.

SATOW, K. (1983): Observations on the shapes of snow crystals in the summer season in Mizuho Plateau, Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **29**, 103–109.

SCHMIDT, R. A. (1980): Threshold wind-speeds and elastic impact in snow transport. J. Glaciol., **26**, 453–467.

SHIOTANI, M. and ARAI, H. (1953): A short note on the snow storm. Second National Congress for Applied Mechanics, Science Council of Japan.

TAKAHASHI, S., OHMAE, H., ISHIKAWA, M., KATSUSHIMA, T. and NISHIO, F. (1984): Observation of snow drift flux at Mizuho Station, East Antarctica, 1982. Mem. Natl Inst. Polar Res., Spec. Issue, **34**, 113–121.

(*Received May 17, 1984; Revised manuscript received September 12, 1984*)