On the Vertical Distribution of Blowing Snow

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Abstract

Movement of snow in the snow storm has been measured in the air layer up to 6 m with snow collectors attached to a mast and with collecting boxes placed on the snow surface in the northern part of Honshū, and a vertical distribution of blowing snow was chiefly obtained and results were discussed in conjunction with a vertical distribution of wind velocity. As the density of blowing snow was far less than that of the air even in the air layer close to the surface of snow, snow particles were assumed to be floating by the action of turbulence of the wind. An analytical expression of a vertical distribution of concentration of blowing snow was obtained and it agreed nearly with measured values. The values of falling velocities of snow particle were calculated and results were discussed.

I. Introduction

It is important to know the amount of drifting snow by winds in the snow storm for designing facilities of prevention of snow drifts and establishing traffic controls in wintertime. We have made a great deal of experiments on snow fences and snow storm prevention forests by changing their sizes, materials, species, distributions of trees and widths of forests. While making these experiments, we have taken the opportunity to examine movements of snow in the northern part of Honshū in 1952, 1957 and 1960. We could not obtain the amount of drifting snow in relation to wind velocity and air temperature. We merely found a vertical distribution of blowing snows in moderate and strong snow storms. Some of these results were already published in 1953 (Arai, Shiotani and Ogasawara, 1953; Shiotani, 1953). Here, we made farther analysis on the same problems by adding data taken afterwards.

II. Method of Measurement

Many devices were made to catch snow particles flying in the air. First, a simple circular pipe was used by turning one end to the wind and wrapping other end with gauze. Sometimes, were tried complicated devices, which inhaled mixture of snow and air in a cyclone and separated the snow from the air or measured absorption of light passing through the air laden by snow with photoelectric cell. Finally we used snow collectors as snown in Fig. 1 (A) and (B) because of their easiness of treatment and cheapness. To know the efficiency of snow collection, we installed the collector in the wind tunnel and measured a rate of collection with powders of alminium oxide. We obtained satisfactory results, but, owing to differences between powder and snow, we could not find a true rate of collection. We tentatively used 25 cm² in (A)-type collector and 70 cm² in (B)-type one as an effective cross section of collection in the analysis.

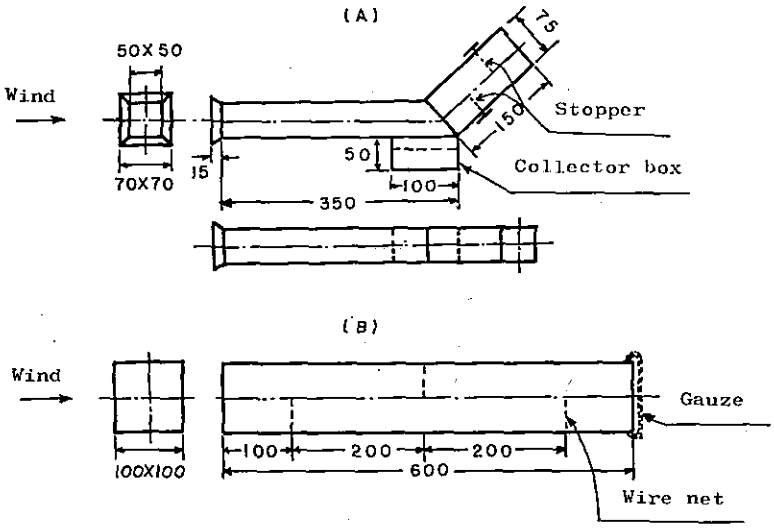

Fig. 1. Collectors of blowing snow (Size in mm)

Together with snow collectors mentioned above, we used boxes of 50 cm long, 30 cm wide and 30 cm deep, burying in the snow so that their upper brims may just lay the surface of the snow, and 50 cm edges may be parallel to the wind. We put lids at 10 cm above the snow surface, in order to collect snow particles moving in the proximity to the surface.

In the measurement, snow collectors shown in Fig. 1 were attached to the mast of 5 m in height, separating each other by nearly equal interval in logarithmic scale. Durations of measurement were varied by judging the amount of collected snow in the lowest collector. The duration was only five minutes in a strong snow storm in which wind velocity attained 14 m/sec. Accordingly, attention was paid to fix up and take away collectors to the mast as rapid as possible. A vertical distribution of wind velocity above the snow was measured with small cup anemometers during the snow storms.

III. Measurement of Blowing Snow

A vertical distribution of blowing snow was measured over flat snow surface at Higashinoshiro and Kado in Akita Prefecture, and Jōko in Fukushima Prefecture. There were a few irregularities on the snow surface at Higashinoshiro. At Kado and Jōko, snow surface was almost flat to a distance of a few kilometers except for scattered trees and houses, and it was seen to be in good conditions for the experiment.

The collections of blowing snow were carried out by ten times with (A)-type collector and by two times with (B)-type collector. They are shown in Table 1. The range of wind velocity was 6 to 14 m/sec at 1 m above the snow surface and that of air temperature was -2 to -8°C. The results are plotted in Fig. 2, which shows the amount of drifting snow is large in the neighbourhood of snow surface and is very small above 100 cm. Judging from the amount of snow collected in the box put in the snow surface, we have estimated that the concentration of blowing snow, that means the amount of snow in unit volume of the air, may be the order of 10^{-5} g/cm^3 and is fairly smaller than the density of air even in the strong snow storm.

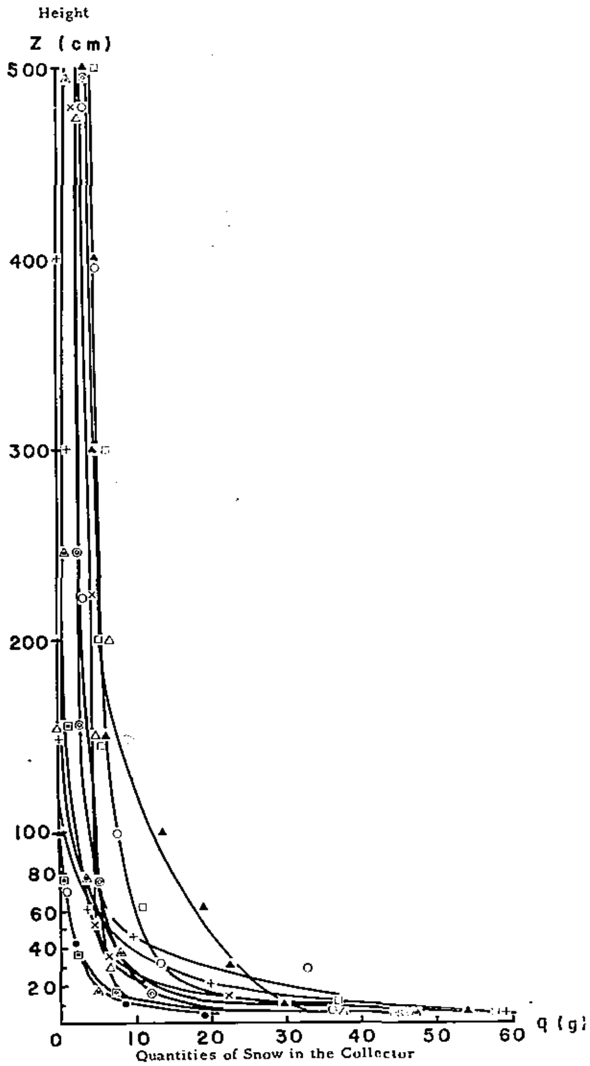

Fig. 2. Vertical distribution of collected snow

Table 1. Summary of data in measurements of amount of blowing snow with collectors

Run No.	Date	Observation site	Duration (min)	Amount of blowing snow q versus height z											Wind velocity at 1 m (m/s)	Air temp. (°C)	Type of collector
1	18, Jan. 1952	Higashi-noshiro	60	z (cm)	12	33	52	222	480						8.9	−5.0	A
				q (g)	22.6	6.7	5.2	4.4	2.1								
2			30	z (cm)	7	27	58	222	480						8.7	−5.0	A
				q (g)	36.7	32.7	6.4	3.5	3.4								
3			20	z (cm)	5	30	78	150	480						8.2	−5.0	A
				q (g)	37.2	6.6	3.8	4.8	2.9								
4			10	z (cm)	5	10	20	40	70	100	200				5.5	−2.0	A
				q (g)	19.5	9.0	4.3	2.2	0.8	0.2	0						
5	2, Feb. 1952	Kado	60	z (cm)	5	20	45	60	100	150	200	300	400	500	14.0	−5.0	A
				q (g)	58.95	20.35	9.80	4.40	0.60	0.40	0.30	1.45	0.40	0.60			
6			30	z (cm)	5	10	30	60	100	150	200	300	400	500	11.7	−6.0	A
				q (g)	57.61	37.03	13.05	10.80	7.86	5.93	5.77	6.50	5.75	4.02			
7			5	z (cm)	5	10	30	60	100	150	200	300	400	500	14.0	−8.0	A
				q (g)	54.26	29.60	22.40	19.32	13.60	6.51	6.57	4.67	5.47	3.74			
8	23, Feb. 1957	Jóko	5	z (cm)	5	15	35	75	155	245	495				10.0	−5.0	A
				q (g)	45.5	12.0	8.2	5.2	3.0	2.3	3.6						
9			5	z (cm)	5	15	35	75	155	245	495				9.7	−5.0	A
				q (g)	47.2	5.2	7.6	3.9	0.3	1.0	1.5						
10	24, Feb. 1957		60	z (cm)	5	15	35	75	155	245	495				12.4	−2.5	A
				q (g)	45.2	7.5	2.4	0.6	0.6	Traces							
11	12, Feb. 1960	Higashi-noshiro	10	z (cm)	8	23	72	104	137	172					8.8	−4.0	B
				q (g)	71	21	12	10	8	8							
12			60	z (cm)	17	35	65	98	131	165					8.3	−2.0	B
				q (g)	40	24	16	14	12	6							

Vertical distributions of wind velocities for three minutes are shown in Fig. 3, with mean velocity as abscissa and logarithm of height as ordinate. The wind velocity increases linearly upwards with logarithm of height, and a kink of velocity distribution curve which has been pointed out in the movement of sand is not noticed in the range of height between 20 and 600 cm.

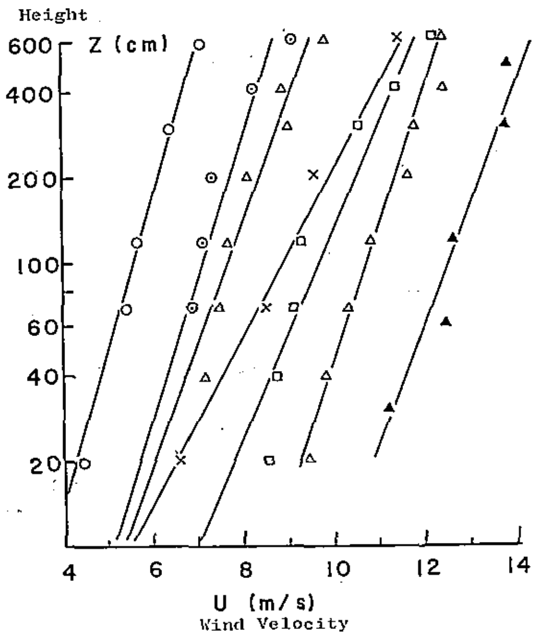

Fig. 3. Variation of wind velocity with height

IV. Analysis of the Measured Results

Let us denote snow quantity taken in a collector be q, duration of snow collection be t, and wind velocity at the height of collector be U. Then, the concentration of blowing snow m is given as follows:

$$m = q/UtS, \tag{1}$$

where S is an effective cross section of the collector. The wind velocity U at height z is expressed as follows:

$$U = \frac{u_*}{k} \ln \frac{z}{z_0} = 5.75 u_* \log \frac{z}{z_0}, \tag{2}$$

where u_*, k and z_0 denote friction velocity, Kármàn constant (=0.4) and roughness length of the snow surface, respectively. In Fig. 3, value of z_0 scatters in the range of 0.2 to 0.002 cm and we can not obtain an accurate value. However, we have estimated it about 0.005 cm on an average and have taken z_0 as 0.005 cm in farther analysis.

The concentration of blowing snow is the order of 10^{-5} g/cm^3 in the air layer up to 10 cm above the snow surface, and is 10^{-5} to 10^{-6} g/cm^3 over 10 cm. Accordingly, in the air layer above 10 cm, where our measurement has chiefly been carried out, we might assume that snow particles are suspending in the air by the action of turbulence of the wind. Then, in a steady state, the concentration of blowing snow m is expressed by a following equation:

$$-K\frac{\mathrm{d}m}{\mathrm{d}z}=wm\,, \tag{3}$$

where (Sutton, 1953) K denotes eddy viscosity of the turbulent wind and w denotes falling velocity of snow particles. K is expressed as follows:

$$K=l^2\frac{\mathrm{d}U}{\mathrm{d}z}\,, \tag{4}$$

where l is mixing length and is equal to kz in the range of the air layer where our measurements have been taken place. Using eq. (2), we obtain,

$$K=ku_*z=0.4u_*z\,. \tag{5}$$

Inserting eq. (5) in eq. (3), we obtain

$$m=Cz^{-\frac{w}{0.4u_*}}\,, \tag{6}$$

where C is a constant. Or, taking the concentration of blowing snow as m_1 at reference height z_1, we replace eq. (6) as follows:

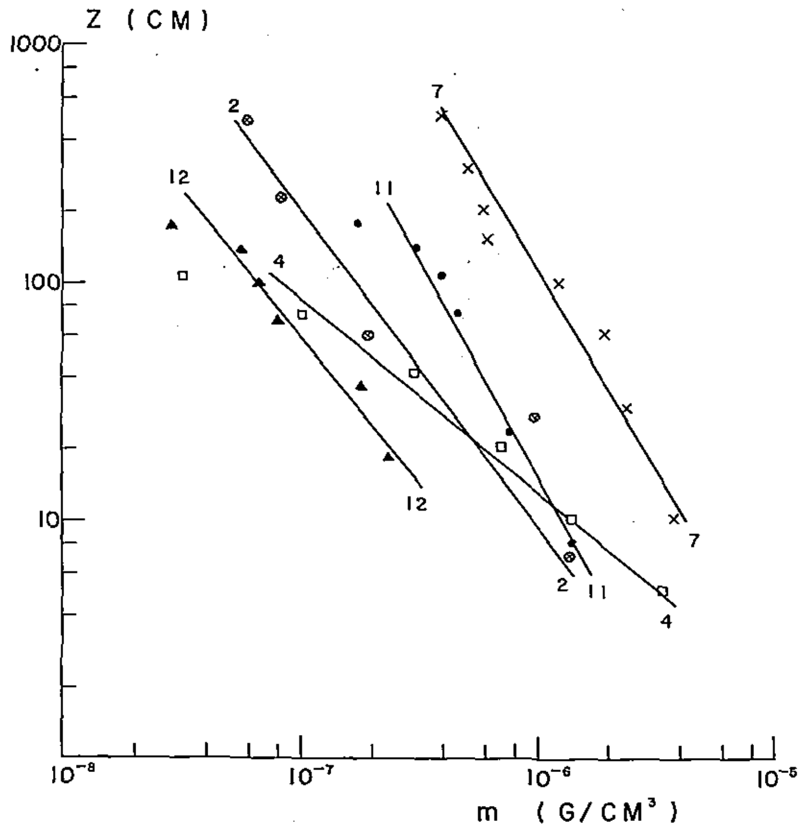

Fig. 4. Variation of the concentration of blowing snow with height

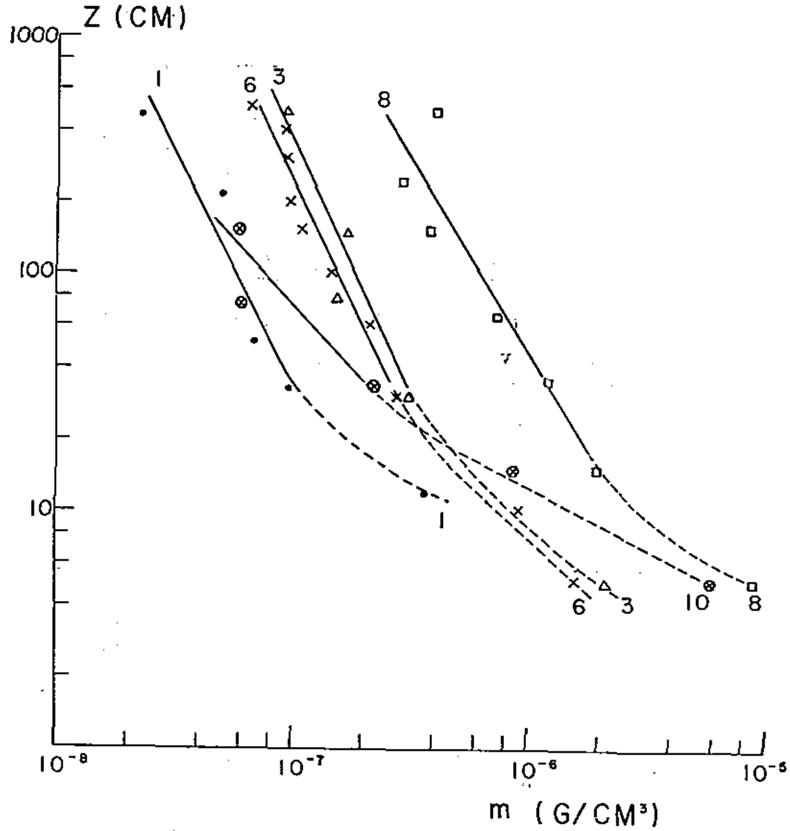

Fig. 5. Variation of the concentration of blowing snow with height

$$m/m_1 = (z/z_1)^{-\frac{w}{0.4u_*}} . \tag{7}$$

The relation between m and z is shown in Figs. 4 and 5 with both axes of graph by logarithmic scale (see Fig. 4). In five cases out of twelve, straight lines turn up a from the height of 20 or 30 cm above the snow. In the air layer corresponding to the upper straight part of the curve, snow particles may move in suspention by wind turbulence. Inclination of a straight line in the figures is $-0.4u_*/w$. In the curved section of the line, a movement of snow can not be governed only by wind turbulence.

From the value of mean wind velocity U_1 at 1 m above the snow, we can obtain from eq. (2) as follows:

$$u_* = 0.040U_1 , \tag{8}$$

where we take z=0.005 cm as mentioned before. In Table 2, we show the values of friction velocity u_* and falling velocity w at each measurement.

We can not find available data of falling velocity of snow particles suspending in the air in the snow storm. In the falling snow under calm weather the falling velocity is 100 to 150 cm/sec when size of snow is greater than 10 mm, and it becomes less than 50 cm/sec when size of snow is less than 5 mm. The value of falling velocity shown in Table 2 seems to be smaller than the value we have expected before.

Table 2. Values of friction velocity at snow surface and falling velocity of snow

Run No.	1	2	3	4	6	7	8	10	11	12
u_* (cm/s)	36	35	33	22	47	56	40	50	36	34
w (cm/s)	8	11	6	11	9	14	10	19	8	11

V. Farther Discussions

We have obtained turbulent properties of the wind from a vertical distribution of mean wind velocity above the snow as shown in eq. (2). Having been pointed out by Bagnold (1954), the velocity distribution is not expressed by eq. (2) when the snow is moving, but is expressed by following equation:

$$U = U_t + \frac{u'_*}{k} \ln \frac{z}{z'_0}, \tag{9}$$

where U_t means velocity corresponding to momentum sink due to snow movement. z'_0 may be roughness length of ripple heights of snow surface and u'_* denotes a new friction velocity (see Fig. 6). We could not find definite values of U_t and z'_0 from our velocity distribution curves. However, we guessed these values as follows: We have found during our measurement that a critical wind velocity U_c for the occurrence of snow storm is about 5.0 m/sec at 1 m above the snow surface. It is the velocity at which all snow particles on the snow surface begin to move, and which is connected with another critical velocity U'_c, below which any snow particle does not move, by following relation (Dyunin, 1954),

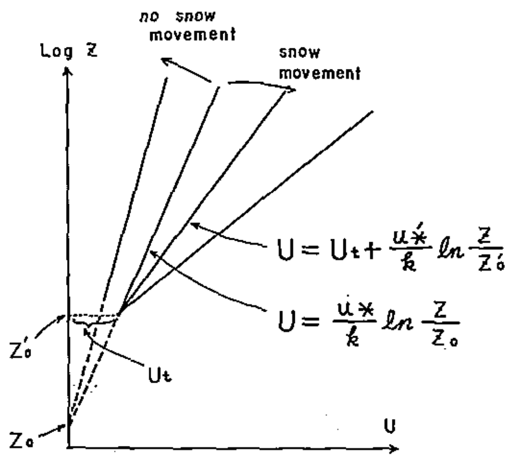

Fig. 6. Velocity profiles over snow surface

$$U_c = 1.56 U'_c.$$

Then, at the height of z'_0 which we tentatively take as 0.3 mm following the sand movement, the value of U'_c becomes 1.5 m/sec, which should be equal to U_t in eq. (9).

From eq. (9) we obtain new friction velocities u'_* and falling velocities w of snow particles. They are shown in Table 3. The values of falling velocities become larger.

Table 3. Values of friction velocity from velocity profile eq. (9) and falling velocity of snow

Run No.	1	2	3	4	6	7	8	10	11	12
u_* (cm/s)	55	50	46	28	70	87	59	75	50	47
w (cm/s)	14	16	9	15	17	25	15	37	15	17

We have assumed snow particles move as the air does. In reality, snow particle can not follow accurately rapid fluctuations of air movement. This makes the eddy viscosity of mixture of air and snow smaller than that of the air and eventually comes to smaller value of falling velocity.

We have also assumed in obtaining an analytical expression of vertical distribution of the concentration of snow, that size of snow particles are same in the air layer above the snow. However, as pointed out by Ōura (1966) and Budd (1964), sizes of snow are not uniform. We might say in the snow storm light snow particles are carrying in the state of suspension, heavier ones are in the state of saltation and heaviest ones in the state of rolling. Accordingly, the values of falling velocities shown in Tables 2 and 3 are something like the average of different sizes of snow particles and in the air layer. Judging from measured values of falling velocity by Budd in Antarctica (Budd *et al.*, 1964, Budd, 1964), the values shown in Tables 1 and 2 seem to be allowable magnitudes.

References

1) ARAI, H., SHIOTANI, M. and OGASAWARA, T. 1953 On the snow storm. *J. Japan. Soc. Snow and Ice*, **15**, No. 1, 1–5.*

2) BAGNOLD, R. A. 1954 Physics of Blown Sand and Desert Dunes, Methuen and Co., London, 265 pp.

3) BUDD, W. 1964 The drifting of nonuniform snow particles. *Antarctic Research Series*, **9**, 59–70.

4) BUDD, W., DINGLE, R. and RADOK, V. 1964 The Byrd snow drift project: Outline and basic results. *Antarctic Research Series*, **9**, 71–134.

5) DYUNIN, A. K. 1954 The mechanical conditions of snow erosion. *Trudy Transportno-Energeicheskogo Instituta*, (4), 59–69.

6) ÔURA, H. 1966 Studies of blowing snow. I. *In* Physics of Snow and Ice, Part 2 (H. ÔURA, *ed.*), Inst. Low Temp. Sci., Sapporo, 1085–1097.

7) SHIOTANI, M. 1953 Note on the vertical distribution of density of blowing snow in the snow storm. *J. Japan. Soc. Snow and Ice*, **15**, No. 1, 6–9.*

8) SUTTON, O. G. 1953 Micrometeorology, McGraw Hill, New York, 333 pp.

* In Japanese.