# ESTIMATION OF PRECIPITATION FROM DRIFTING SNOW OBSERVATIONS AT MIZUHO STATION IN 1982

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***Abstract:*** Precipitation at Mizuho Station, East Antarctica, in 1982 was estimated in two ways. From the drift flux at a 1 m height, the daily precipitation was estimated by assuming that an increase of the drift flux compared with an empirical formula is all due to precipitation. On the other hand, the precipitation was estimated from the drift density at a 30 m height, where the drift density is assumed all due to precipitation.

The estimated precipitation by the both ways was small in summer, large in winter, and especially large in June. The annual precipitation in 1982 was estimated as 230 mm from the drift flux at the 1 m height, and 260 mm from the drift density at the 30 m height. Taking accuracy into account, these are in the range between 100 and 300 mm. The estimated precipitation is considerably larger than the net accumulation of 70 mm obtained from accumulated snow by NARITA and MAENO (Nankyoku Shiryô, **67**, 18, 1979).

## 1. Introduction

In a katabatic wind slope region in Antarctica, drifting snow occurs throughout the year, where precipitation is the important factor for mass balance of the antarctic ice sheet but difficult to observe owing to the drifting snow. Changes of the snow surface level measured by the snow stakes method do not represent the precipitation, and even a visual observation of precipitation is often impossible in heavy drifting snow.

Continuous observation of drifting snow was carried out at Mizuho Station (70°42′S, 44°20′E), East Antarctica, between March 1982 and January 1983 by the 23rd Japanese Antarctic Research Expedition (TAKAHASHI *et al.*, 1983, 1984a, b). In this paper, estimation of precipitation based on the drifting snow observation is attempted in two ways: from the drift flux at 1 m height and from the drift density at 30 m height. So far, KOBAYASHI *et al.* (1985) has obtained 140 mm (water equivalent; the same thereafter) as the annual precipitation in 1980 at Mizuho Station in a similar way.

## 2. Estimation of Precipitation from Drifting Snow at 1 m Height

### *2.1. Relation between the drift flux and the wind speed*

At Mizuho Station, the snow drift flux from the snow surface to 30 m height was observed in 1982 by three types of drift collectors: a slit type collector, four cyclone type collectors and four rocket type collectors (TAKAHASHI *et al.*, 1984a). The drift flux at exactly 1 m height was obtained everyday by the four cyclone type collectors from a drift flux profile between 0.3 and 2 m.

Discrimination of precipitation phenomena was made mainly by visual observations, but it was frequently difficult in heavy drifting snow at Mizuho Station. In such a case, the repose angle of drifting snow particles was useful for the discrimination. The repose angle, a slope inclination of cone-shaped deposit of drifting snow formed in a subsurface chamber, was more than 85° in the case of snow fall and less than 80° in the case of no precipitation; it was a good indicator of precipitation even in heavy drifting snow (TAKAHASHI *et al.*, 1984b).

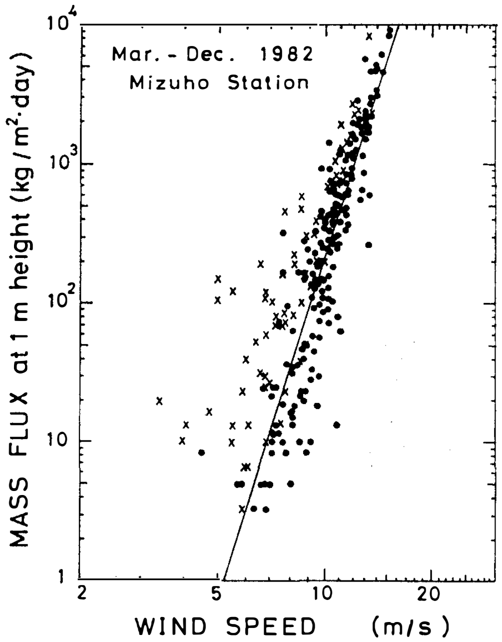


*Fig. 1. Relation between drift flux and wind velocity at 1 m height. Crosses are the data in the case of precipitation, solid circles are the data of no precipitation, and a solid line is a regressive line of no precipitation.*

In the case of no precipitation, the drift flux at 1 m height correlated to the wind speed adequately. In Fig. 1, daily drift flux at 1 m height versus wind speed is plotted on the logarithmic graph paper. The data in the case of no precipitation (marked by solid circles in Fig. 1) were approximately on a straight line, which gives the following empirical formula between the drift flux and the wind speed (TAKAHASHI *et al.*, 1984a);

$$F_1 = 1.61 \times 10^{-6} V_1^{8.1}, \tag{1}$$

where $F_1$ is drift flux at 1 m height (kg/m²·day) and $V_1$ is wind speed at 1 m height (m/s). The coefficinet $1.61 \times 10^{-6}$ and the power 8.1 are for the 1 m height. They were different at another height; the coefficient decreased with height, and the power decreased with height below 1 m but was constant above 1 m (TAKAHASHI, 1985). The power and the coefficient tended to vary seasonally (TAKAHASHI *et al.*, 1984a), but here we use the constants of eq. (1) throughout the year.

### 2.2. *Increase of the drift flux due to precipitation*

Compared with the case of no precipitation, the drift flux at 1 m height increased owing to precipitation. As shown in Fig. 1, the drift flux when precipitation was observed (marked by crosses in Fig. 1) was larger than that of no precipitation (marked by solid circles). The regressive line in the figure was the relation of no precipitation expressed by eq. (1).

From the increase of the drift flux, the precipitation intensity can be estimated as follows: the increase of drift flux $dF(z)$ at a height of $z$ is assumed equal to the horizontal mass flux of the precipitation. Considering that precipitation particles have the speed with a horizontal component equal to wind speed $V(z)$ and with a vertical component of fall velocity $W$, the spatial density of precipitation $Np$ is expressed as follows;

$$Np = dF(z)/V(z). \tag{2}$$

Since precipitation intensity $P$ is a product of fall velocity $W$ and density $Np$,

$$P = W\ Np = W\ dF(z)/V(z). \tag{3}$$

By this equation, the precipitation intensity can be estimated from the increase of the drift flux, if the relation between the drift flux and the wind speed in the case of no precipitation is known.

*2.3. Precipitation estimated from the drift flux at 1 m height*

Precipitation can be estimated from the drift flux increase at 1 m height by eq. (3), but a problem for the estimation is accuracy of the drift flux. Since the drift flux increases abruptly as the wind speed increases, the absolute error of the drift flux increases together. By the increasing error, the increase of the drift flux due to precipitation becomes difficult to observe at a high wind speed, which is examined below.

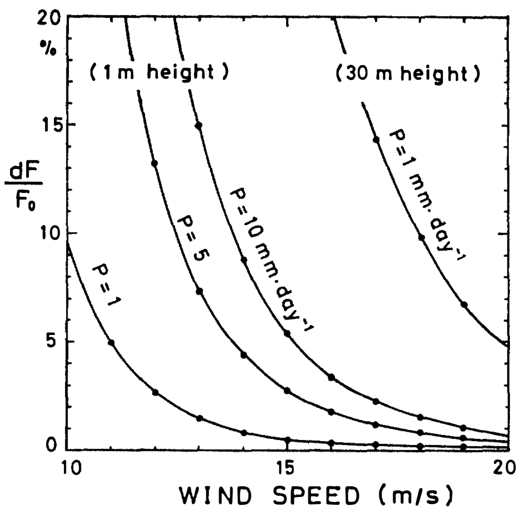


*Fig. 2. Ratio of the drift flux increase due to precipitation dF to the drift flux in the case of no precipitation $F_0$ versus wind speed with parameter of precipitation intensity.*

In Fig. 2, the ratio of the horizontal flux of precipitation to the drift flux by eq. (1) is shown against the wind speed in parameter of precipitation (1, 5, 10 mm/day). The drift flux is proportional to about 8 power of wind speed (eq. (1)) while the horizontal flux of precipitation is linearly proportional to the wind speed. Therefore, the ratio becomes small at a high wind speed, which concernes with the difficulty of precipitation observation. In the case of 1 mm/day precipitation, the ratio is less than 5% at wind speed more than 10 m/s. Since the accuracy of drift flux measurement is considered about 5 to 10%, the condition for observing 1 mm/day precipitation is limited to wind speed less than 10 m/s at 1 m height (equivalent to about 12 m/s at the routine observation height of 6.9 m). For reference, the ratio at 30 m height for 1 mm/day precipitation is shown in Fig. 3; the ratio is much larger than that of 1 m height, which means that the precipitation would largely contribute to horizontal flux at 30 m height.

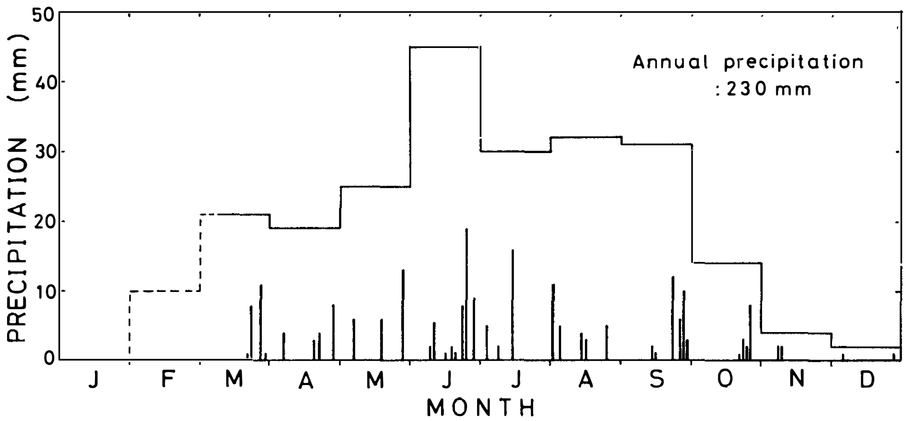


*Fig. 3. Precipitation at Mizuho Station in 1982 estimated from drift flux at 1 m height. Dashed line is the estimation by interpolation.*

The daily precipitation was calculated from the drift flux at 1 m height by eq. (3), as shown in Fig. 3. The fall velocity for the estimation was assumed 0.5 m/s according to the measurement of fall velocity at Mizuho Station (TAKAHASHI *et al.*, 1984a). In the estimation, the data at wind speed more than 10 m/s were excluded for the given reason; the number of the days when snow or ice prisms were observed was 99 days in 1982, 21 days of which had the daily mean wind speed more than 10 m/s (TAKAHASHI *et al.*, 1983). Therefore, the estimation should be undervalued.

As shown in Fig. 3, the estimated precipitation at Mizuho Station was small in summer from October to next February, large in winter from April to September, and especially large in June, about 50 mm. The annual precipitation in 1982 was estimated as 230 mm, which includes the interpolated estimation during the absence of observation from January to March.

## 3. Estimation of Precipitation from Drifting Snow at 30 m Height

### *3.1. Vertical profiles of snow drift density*

Assuming that diffusivity is constant with height, KOBAYASHI *et al.* (1985) expressed the snow drift density $n$ at height $z$ in the case of precipitation $P$ as follows;

$$n=P/W+(n-P/W)\exp(-zW/K), \qquad (4)$$

where $n_0$ is snow drift density at snow surface and $W$ is fall velocity of precipitation particles. According to this equation, the vertical profile of drift density is a curved profile on the semilogarithmic graph paper, but it can become a linear profile by subtracting an adequate amount (equivalent to $P/W$) from the drift density $n$. In Fig.

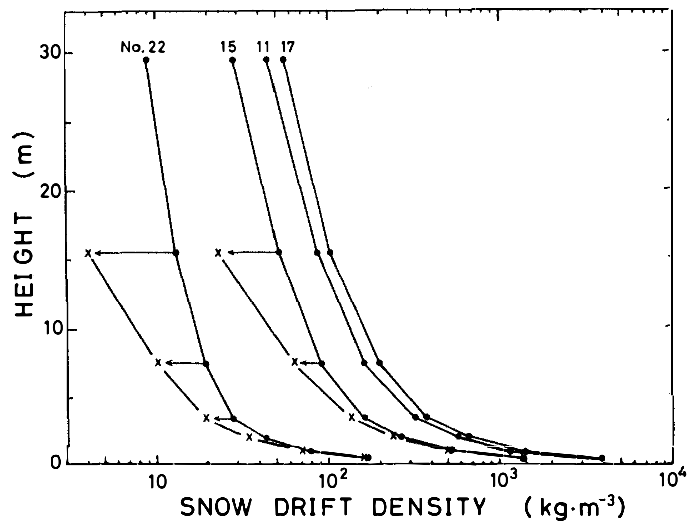


*Fig. 4. Vertical profiles of drift density on semilogarithmic graph paper. Crosses are the data subtracted by the density at 30 m height.*

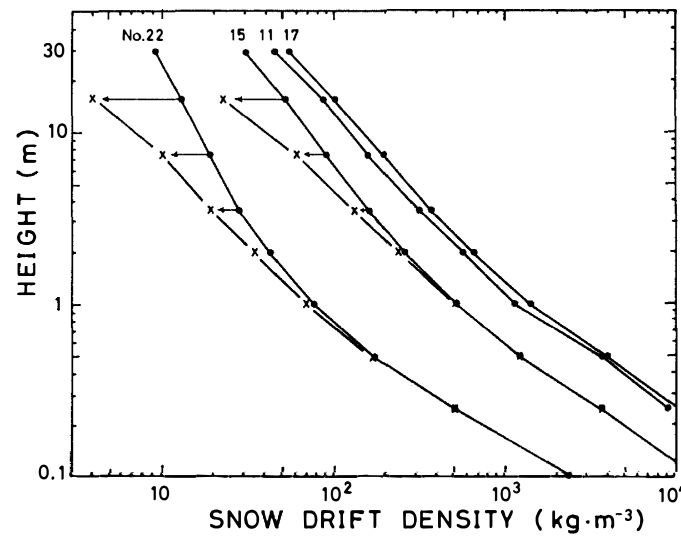


*Fig. 5. Vertical profiles of drift density on logarithmic graph paper. Data are the same as those of Fig. 4.*

4, several vertical profiles of the snow drift density at Mizuho Station are shown on the semilogarithmic graph. The drift density subtracted by that at 30 m height would become a linear profile if the horizontal flux at 30 m height is all due to precipitation, or would become an inversely curved profile if the subtracting is too much. However, the subtracted data (marked by crosses in Fig. 4) did not show this tendency at all. Therefore, the drift density profiles should be expressed by another equation.

Considering that the diffusivity in $ku_*z$, SHIOTANI and ARAI (1953) expressed the snow drift density as follows;

$$\frac{n_2}{n_1}=\left(\frac{z_2}{z_1}\right)^{-\frac{W}{ku_*}}, \qquad (5)$$

where $n_1$ and $n_2$ are drift density at the height of $z_1$ and $z_2$, $k$ is Karman constant and $u_*$ is friction velocity. Assuming that the density of precipitation is added uniformly to this drift density profile, eq. (5) is transformed as follows;

$$\frac{n_2+n_0}{n_1+n_0}=\left(\frac{z_2}{z_1}\right)^{-\frac{W}{ku_*}}. \qquad (6)$$

According to this equation, the drift density profile would become a linear profile on the logarithmic graph paper by subtracting a certain amount (equivalent to $n_0$) from the drift density $n$. Conversely, the precipitation can be estimated from the subtracter. In Fig. 5, the same data of drift density as those of Fig. 4 are plotted on the logarithmic graph paper. The profiles subtracted by the density at 30 m height (marked by crosses) became approximately linear, or rather inversely curved. This suggests that the drift density at 30 m height was mostly due to precipitation. Comparing the two graphs of Figs. 4 and 5, eq. (6) represents the observed drift density profiles rather than eq. (4).

According to eq. (6), the precipitation can be estimated from the subtraction for making a linear drift density profile. The measurement of drift density, however, was not very high in accuracy and the accurate subtraction was difficult to obtain. Nevertheless, Fig. 5 shows that the drift density at 30 m height was mostly due to precipitation, and the precipitation is estimated from the drift density at 30 m height in the next section.

### *3.2. Precipitation estimated from the drift density at 30 m height*

Assuming that the drift density at 30 m height $n_{30}$ is all derived from precipitation, the precipitation $P$ can be estimated by the following equation:

$$P=n_{30}W, \qquad (7)$$

where $W$ is fall velocity of precipitation particles. By this assumption, the estimated precipitation would be more or less overestimated.

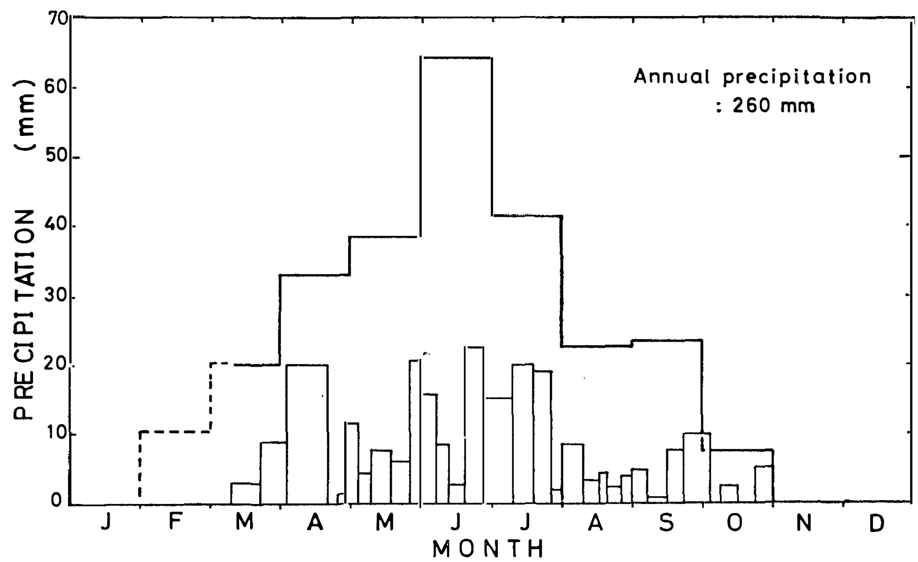


*Fig. 6. Precipitation estimated from drift density at 30 m height.*

The estimated precipitation at Mizuho Station is shown in Fig. 6, for which the fall velocity was assumed 0.5 m/s, as in Section 2. The annual precipitation at Mizuho Station was estimated as 260 mm, which was not much different from the estimation at 1 m height of 230 mm. Moreover, the seasonal change is almost the same as that at 1 m height; the precipitation was small in summer, large in winter, and especially large in June.

This estimation is an overestimation in principle, but was counted smaller in summer because of vapor evaporation. As shown in Fig. 6, the estimated precipitation was zero in November and December, while the precipitation phenomenon was visually observed and the estimation from the drift flux at 1 m height was possible. This defect of precipitation at 30 m height was caused by the vapor evaporation of collected snow particles. At Mizuho Station, the strong solar radiation in summer causes evaporation of snow particles in the rocket-type drift collectors during 5 to 10 days of measuring interval. On the other hand, the drift flux at 1 m height was measured in a subsurface chamber everyday and was not affected by the solar radiation. Taking account of this evaporation, the precipitation estimation from the drift density at 30 m height should be counted larger.

## 4. Discussion

Estimation of the annual precipitation at Mizuho Station in 1982 was 230 mm from the drift flux at 1 m height and 260 mm from the drift density at 30 m height. However, these estimated values have several problems and involve errors, so that the validity of this estimation is examined as follows.

In the estimation at 1 m height, the precipitation is estimated under the limitation of wind speed less than 10 m/s and the estimation would be undervalued. Moreover, the estimation would involve some error. The error of precipitation would be about 1 mm/day, for which the limitation of wind speed was decided. Since the average precipitation in a day was about 5 mm, the relative error is considered 20%. Therefore, the estimation of annual precipitation of 230 mm would have the error of $\pm 50$ mm, and a minimum estimation can be considered 150 mm.

The estimation at 30 m height was to be overvalued, because the drift density at this height was assumed to be all derived from precipitation. On the other hand, since the drift density was underestimated in summer owing to evaporation of snow particles in a drift collector, the precipitation in summer was counted small. So, the annual precipitation as a maximum estimation would be 300 mm.

A common problem for the two estimations is the validity of fall velocity of precipitation particles; the estimation of precipitation by the two ways is proportional to the fall velocity of snow particles. The adopted fall velocity of 0.5 m/s was according to the observation in summer at Mizuho Station (TAKAHASHI *et al.*, 1984b). The velocity does not contradict the observation of column-type snow crystals (KAJIKAWA, 1976) and of plane-type snow crystals (KAJIKAWA, 1975), both of which were ordinarily observed at Mizuho Station. In winter, on the other hand, small snow particles or ice crystals (ice prisms) were often observed (TAKAHASHI *et al.*, 1983). The small particles would have a small fall velocity; the crystals with dimensions less than 0.1 mm have a velocity less than 0.1 m/s (KAJIKAWA, 1973). Taking account of the small snow particles in winter, the average fall velocity may be smaller than 0.5 m/s. If the fall velocity were assumed 0.3 m/s, the mentioned estimation should be reduced to 3/5. Hence, the annual precipitation as a minimum estimation can be 100 mm for this fall velocity.

KOBAYASHI *et al.* (1985) obtained 140 mm as the annual precipitation in 1980 by the drift flux observation in a similar way, who adopted fall velocity of 0.5 m/s. This value is rather smaller than the estimation of 1982 ranging between 150 and 300 mm which is based on the fall velocity of 0.5 m/s. However, this difference may be explained by year-to-year variation of precipitation.

NARITA and MAENO (1979) obtained the annual net accumulation on a snow surface of 70 mm from the growth rate of crystal grains in snow. The precipitation estimations of this paper and of KOBAYASHI *et al.* (1985) are both considerably larger than this net accumulation. The difference would be caused by the vapor evaporation from the snow surface and the surface erosion due to horizontal divergence of drifting snow. However, its quantitative explanation requires further studies of the mass balance on a snow surface.

## 5. Concluding Remarks

Assuming the fall velocity of precipitation particles as 0.5 m/s, the annual precipitation at Mizuho Station in 1982 was estimated as 230 mm from the drift flux at 1 m height, and as 260 mm from the drift density at 30 m height. However, taking account of the accuracy of measurement and the possibility of small fall velocity of particles in winter, the annual precipitation is considered in the range between 100 and 300 mm. This annual precipitation is considerably larger than the reported annual accumulation on a snow surface.

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