ON THE PRECIPITATION INTENSITY AT SYOWA STATION, ANTARCTICA

Katsuhiro KIKUCHI, Noboru SATO

Department of Geophysics, Faculty of Science, Hokkaido University, Sapporo 060

and

Goro KONDO

Nagoya Local Meteorological Observatory, Nagoya 464

Abstract: Precipitation intensities of snow crystals grown from sublimation and condensation processes in the free atmosphere at Syowa Station, Antarctica (69°00′S, 39°35′E) were calculated by using the data of 550 glass slides in 1968 and 300 glass slides in 1969 obtained with the replica solution method. The peak value of the maximum precipitation intensity was 1.5 mm·hr^{-1} in 1968 and 7.2 mm·hr^{-1} in 1969. Therefore, the maximum precipitation intensity ranged from 10^{-2} to 10^{0} mm·hr^{-1}, and the peak values of the intensity ranged from 10^{0} to 10^{1} mm·hr^{-1}. Next, the peak values of the maximum precipitation intensities at Syowa Station, Inuvik (68°22′N, 133°42′W), N.W.T., Canada in December 1979 (midwinter), and South Pole Station (90°S) in January 1975 (austral midsummer) and in November 1978 (end of winter) were compared. The order of the maximum precipitation intensity at Syowa Station, Inuvik, and South Pole Station was regarded as 10^{1}, 10^{0}, and 10^{-1} mm·hr^{-1}, respectively. Further, using the average maximum precipitation intensity and the duration of precipitation at Syowa Station, the annual amount of precipitation by snowfalls and snow storms except drifting and blowing snow was estimated and an approximate value of 430 mm was obtained.

1. Introduction

In recent years, observations of the field of cloud physics have been made in the arctic and antarctic areas. And various questions concerning the precipitation phenomena have been brought forth, for example, the actual conditions of snowfall, the precipitation mechanism in the relatively lower temperature regions, the water budget, and so on. As an attempt to estimate the water budget in Antarctica, the depth of snow cover was measured mainly by means of snow stakes. For instance, at Syowa Station, Antarctica (69°00′S, 39°35′E), the first measurement of the depth of snow cover was carried out in 1957 by a wintering member of the 1st Japanese Antarctic Research Expedition (JARE-1) (MURAKOSHI, 1958). Since then, some members of JARE have made measurements of the depth of snow accumulation.

Owing to the influences of drifting and blowing snow due to relatively strong winds which prevail in the long winter season in Antarctica, it is thought that the measured values by means of snow stakes do not give the true amount of precipitation of snow crystals grown from the sublimation and condensation processes of water vapor in the free atmosphere. Therefore, the precipitation intensity at Syowa Station, Antarctica was estimated by using the data of snow crystals replicated.

2. Analytical Method

Snow crystal observations with the replica solution method to estimate the precipitation intensity were made in 1968 by KIKUCHI who was one of the wintering members of JARE-9 and in 1969 by KONDO who was one of the wintering members of JARE-10 at Syowa Station, Antarctica. During the observations snow crystals were collected by sedimentation on 6×9 cm glass slides coated with 1.0% Formvar solution, and they were replicated. The number of replicated glass slides obtained was 550 in 1968 and 300 in 1969, respectively.

As expected from the air temperature at the station, the shapes of the greater part of the precipitating snow crystals were bullets, combination of bullets, columns, crossed-plates, and dendrites (KIKUCHI, 1969, 1970). The specimens of snow crystals replicated on glass slides by the replica solution method were inserted directly into a photographic enlarger and were enlarged about ten times on printing papers and the size of individual snow crystals was measured by a scale. In order to estimate the mass of individual snow crystals, the following empirical formulae for each shape of snow crystals were used:

Graupel	$m=0.065d^3$	(1)
Crystals with cloud droplets	$m=0.027d^2$	(2)
Powder snow and spatial dendritic crystals	$m=0.010d^2$	(3)
Plane dendritic crystals	$m=0.0038d^2$	(4)
Columns	$m=1.3a^2l$	(5)

where m is the mass in milligrams, d, diameter of circle which envelopes the crystal given in millimeters, a, radius and l, length of the column in millimeters. The empirical formulae of (1) to (4) were after NAKAYA and TERADA (1935) and the formula (5) was after HIGUCHI (1956). For single bullets and combination of bullets, the empirical formula of (5) was used. For the snow crystals whose shapes were numerous combinations of bullets, crossed-plates, aggregated and uncertain ones, the formula (3) was used. An upper air sounding at Syowa Station was made once a day as a routine operation of JARE at 0300 LMT (00Z). In order to determine the height of the ice saturation layer, the sounding data were used. The height where ice saturation was reached was regarded as the height of the cloud base for convenience' sake.

Further, the temperature at this height was regarded as the air temperature of the cloud base.

3. Results

3.1. Precipitation intensity

Since a great number of specimens of snow crystals were replicated, we calculated the maximum precipitation intensity during the period of a series of successive precipitations. On the other hand, since other meteorological elements at Syowa Station were recorded as routine work of JARE, the maximum precipitation intensity was compared with the atmospheric pressure (a.s.l.) as one of the elements.

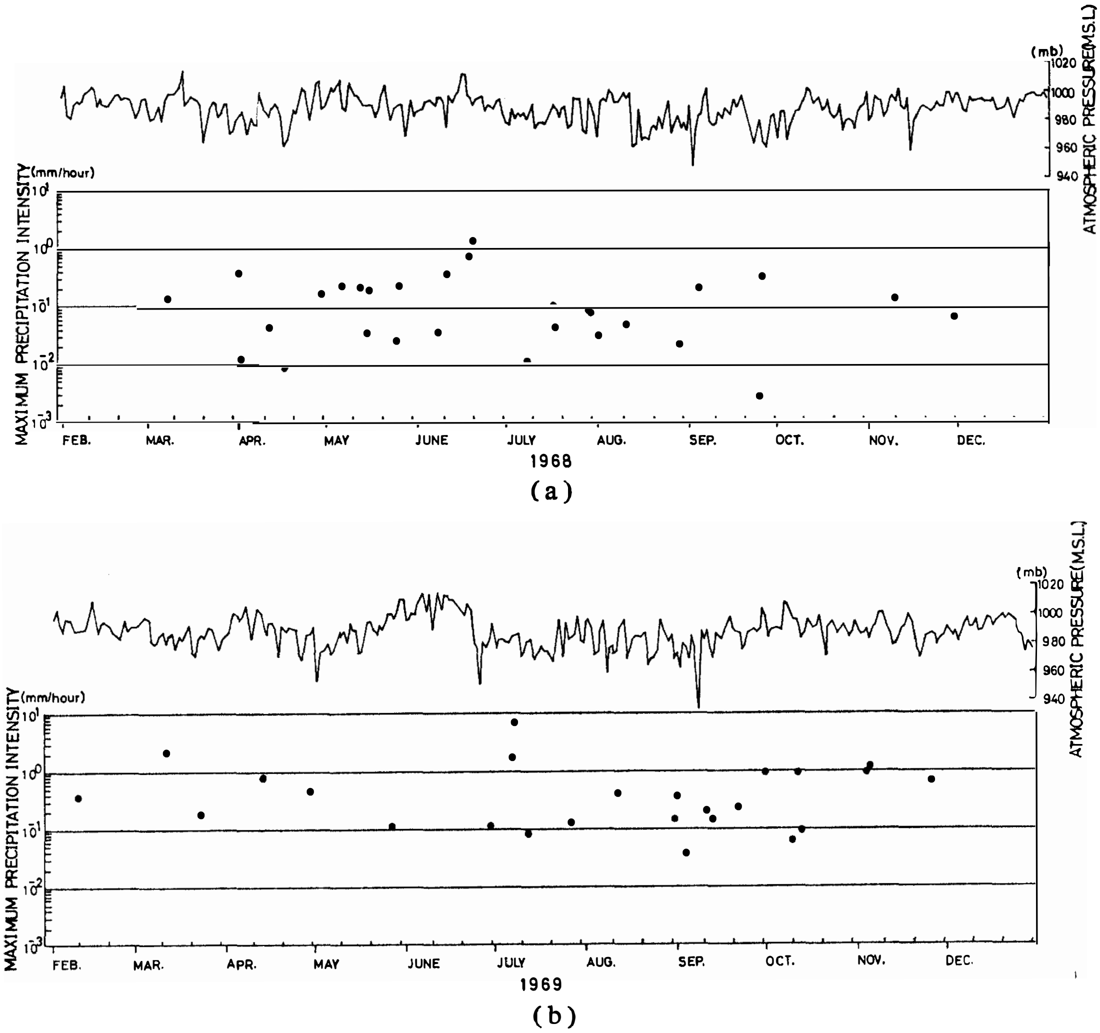

Fig. 1. Daily change of atmospheric pressure and calculated maximum precipitation intensity in 1968 (a) and 1969 (b) at Syowa Station, Antarctica.

Figure 1 shows the variations of the maximum precipitation intensity and the atmospheric pressure in 1968 and 1969, respectively. The variation of the atmospheric pressure was employed as a standard of atmospheric disturbances. As seen in Fig. 1, the greater part of precipitations were recorded when the pressure was relatively lower than other days. It was thought, therefore, that the precipitation occurred mainly as a result of the cyclonic disturbances. A relationship between the maximum precipitation intensity and the cloud base temperature is shown in Fig. 2. The ordinate and abscissa show the maximum precipitation intensity ($mm \cdot hr^{-1}$) and the cloud base temperature (°C), respectively. In this figure, open and solid circles show the results of 1968 and 1969, respectively. As seen in this figure, the cloud base temperature was in a range from −30° to −5°C in both years of 1968 and 1969. The peak value of the maximum precipitation intensity was 1.5 $mm \cdot hr^{-1}$ in 1968 and 7.2 $mm \cdot hr^{-1}$ in 1969. When these peak values were recorded, a snow storm was raging according to the surface observation of routine data. The predominant shapes of precipitating snow crystals were mainly bullets and combination of bullets.

The result of analysis in the two years of 1968 and 1969 at Syowa Station, Antarctica showed that the maximum precipitation intensity was in a range from

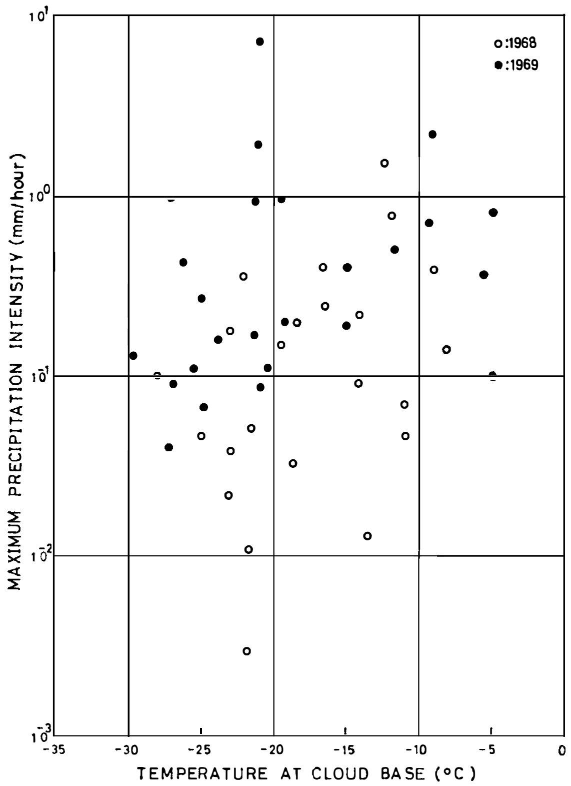

Fig. 2. Calculated maximum precipitation intensity vs. temperature at cloud base at Syowa Station, Antarctica.

10^{-2} to 10^{0} mm·hr^{-1}, and the peak values of the intensity was in a range from 10^{0} to 10^{1} mm·hr^{-1}.

3.2. Comparison of the data at Syowa Station with those at South Pole Station and Inuvik, Arctic Canada

The maximum precipitation intensities calculated from the data obtained at Syowa Station (69°00′S, 39°35′E) were compared with those calculated from the data obtained at South Pole Station (90°S) and at Inuvik (68°22′N, 133°42′W), N.W.T., Arctic Canada. The result is shown in Fig. 3. In this figure, solid circles, white squares, and white triangles show the results calculated at Syowa Station, South Pole, and Inuvik, respectively. The results obtained at Syowa Station include both years of 1968 and 1969. On the other hand, the results obtained at South Pole are based on the data of January 1975 which is the austral midsummer season and of November 1978 which is the end of winter or the beginning of the austral summer season (SATO *et al.*, 1981). The results obtained at Inuvik are based on the data of the midwinter season from the beginning of December 1979 to the beginning of January 1980 when the observation was carried out as a part of Polar-Experiment North (POLEX-North)

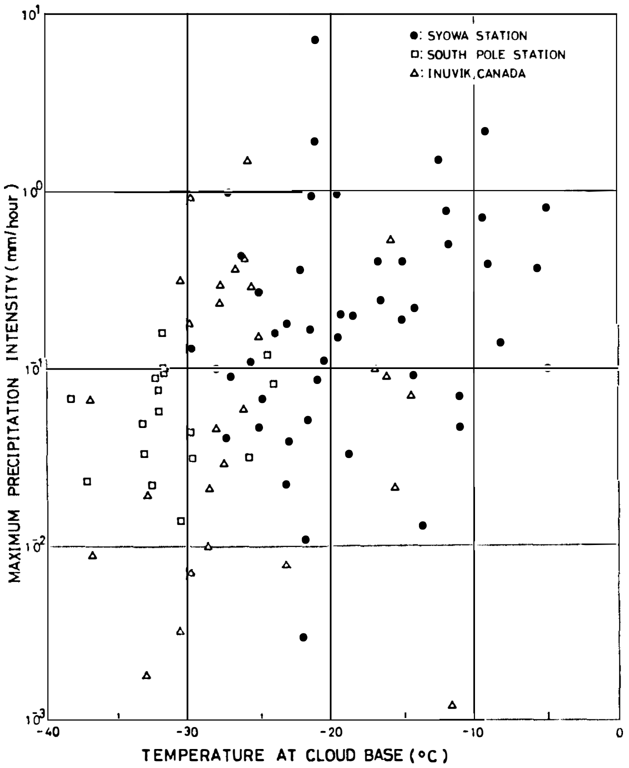

Fig. 3. Calculated maximum precipitation intensity vs. temperature at cloud base at Syowa Station (solid circle), South Pole Station (white square), and Inuvik, Canada (white triangle).

(KIKUCHI *et al.,* 1981). As a matter of course, the temperature of the cloud base measured at Syowa Station ranged from $-30°$ to $-5°C$, which was warmer by 10°C than the temperature at Inuvik which ranged from $-40°$ to $-15°C$. On the other hand, at South Pole Station, although the observation was carried out during the summer season, the temperature of the cloud base ranged from $-40°$ to $-25°C$. This might be due to the altitude of the station which was approximately 2800 m (a.s.l.).

Regarding the peak values of the maximum precipitation intensities at the abovementioned three stations, the order of them at Syowa Station, Inuvik, and South Pole will be regarded as 10^1, 10^0, and 10^{-1} $mm \cdot hr^{-1}$, respectively. However, the average maximum precipitation intensities at three stations were in the order of the range from 10^{-2} to 10^0 $mm \cdot hr^{-1}$.

3.3. Estimation of the amount of precipitation

Although the measurements of the depth of snow cover in the arctic and antarctic areas have been carried out mainly by means of snow stakes so far, but owing to the influences of drifting and blowing snow caused by relatively strong winds which prevail in the long winter season especially in the Antarctic, the measured values by means of snow stakes do not give the true amount of precipitation of snow crystals grown from the sublimation and condensation processes of water vapor in the free atmosphere. On the other hand, in the cases of ice fog and ice prisms (diamond dust), the amount of precipitation was so small that it was recorded only as "trace". Therefore, no attempt has been made until the present to estimate the amount of precipitation in millimeters in Antarctica based on falling ice and snow crystals.

If both the maximum precipitation intensity during a period of a series of successive precipitations and the duration of precipitation were known, the maximum amount of precipitation of snow crystals grown in the free atmosphere could be estimated. Because the maximum precipitation intensity in the case of 1968 was calculated as described in the preceding section, we must know the duration of precipitation for each precipitation phenomenon. Fortunately, the data from the journal of observations at Syowa Station can be utilized. Figure 4 shows the duration of precipitation divided by the types of precipitation, namely, snowfalls in black ribbons, snow storms in dotted ribbons, and drifting or blowing snow in white ribbons, respectively. The upper and lower halves for each month indicate the former and latter parts of the month, respectively. As seen clearly in this figure, snowfalls predominate from February in austral summer to July in winter. On the other hand, from August to December, snow storms and drifting or blowing snow predominate. A series of successive precipitations during which the maximum precipitation intensity was observed is marked by open circles in Fig. 4. In the corresponding Fig. 1 to Fig. 4, the amount of precipitation was estimated. The result of the estimations is shown in Fig. 5. The maximum amount of precipitation converted from the maxi-

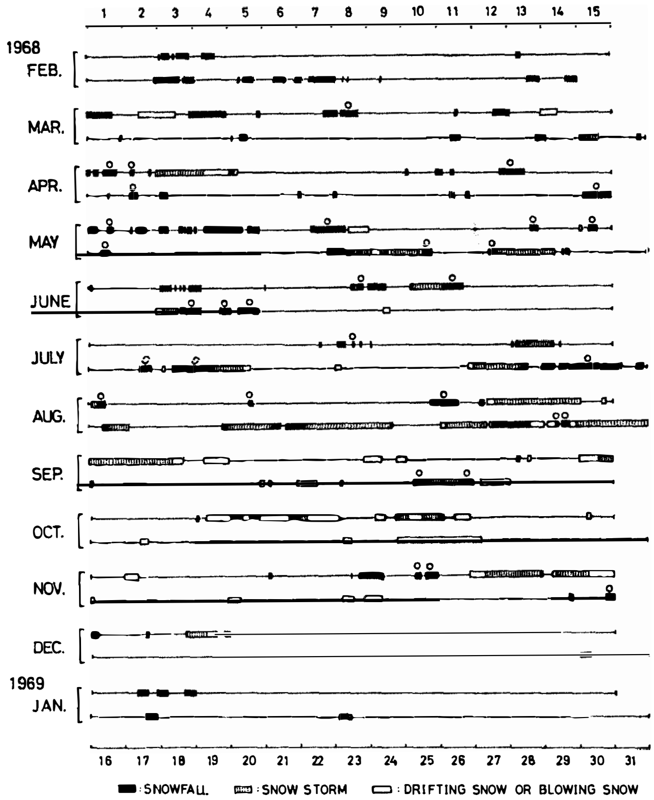

Fig. 4. Duration of precipitation from February 1968 to January 1969 at Syowa Station.

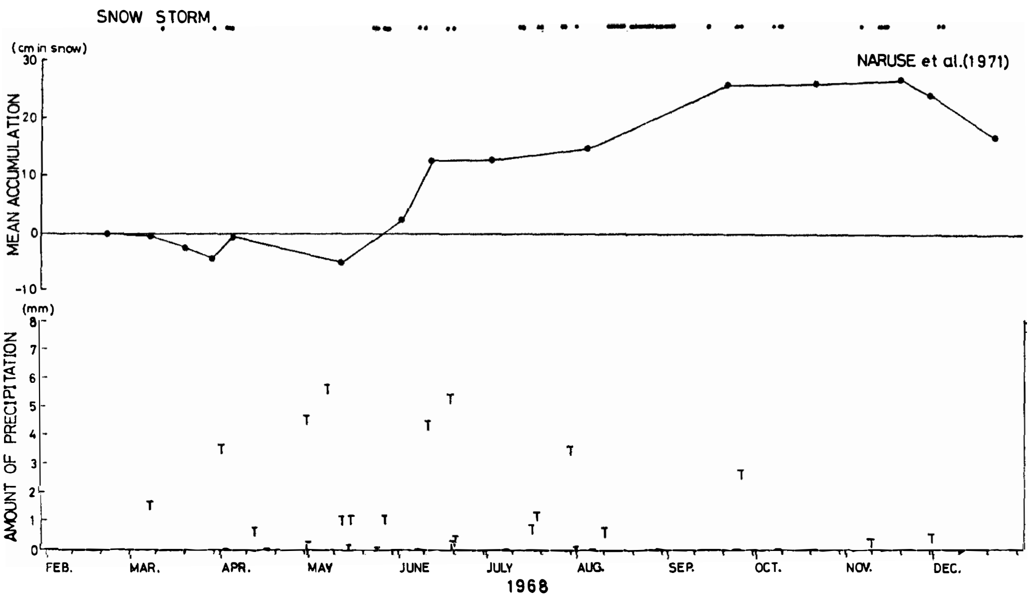

Fig. 5. Calculated amount of precipitation and mean accumulation in 1968 at Syowa Station.

mum precipitation intensity in each precipitation phenomenon is indicated by T. The maximum amount of each precipitation was 5.8 mm which was observed in the first part of May 1968. The summation of these maximum amounts of precipitation was only 42.8 mm. As the total duration of snowfalls at Syowa Station in 1968 is approximately 800 hrs, if we assume 0.1 $mm \cdot hr^{-1}$ to the average maximum precipitation intensity, the annual amount of precipitation becomes 80 mm. This amount corresponds to the depth of snow cover of approximately 80 cm to 20 cm, assuming that the densities of fresh snow and snow cover are 0.1 $g \cdot cm^{-3}$ and 0.4 $g \cdot cm^{-3}$, respectively, and that all snowfalls change into the snow cover without drifting, melting and subliming. Further, as the total duration of snow storms at Syowa Station in 1968 is approximately 700 hrs, if we assume 0.5 $mm \cdot hr^{-1}$ to the average maximum precipitation intensity, the annual amount of precipitation of snow storms alone would be 350 mm. Therefore, the annual amount of precipitation by snowfalls and snow storms, except drifting and blowing snow, comes to be 430 mm.

On the other hand, the measurements of the depth of snow cover by means of of snow stakes were carried out on the sea ice near Syowa Station by the wintering members of JARE-9 (NARUSE *et al.,* 1971). The measurements were made with fifteen stakes, revealing that the depth of snow cover differed remarkably among the stakes. NARUSE *et al.* (1971) attributed this remarkable difference to the effects of islands around Syowa Station in relation to the prevailing wind systems and the properties of sea ice surface composed of pure and glazy ice. A cummulative curve (mean accumulation) of the average value for all fifteen stakes is represented in the upper half of Fig. 5 (Fig. 5 in the report of NARUSE *et al.,* 1971). As clearly seen in this figure and as described in the preceding section, in spite of the predominant snowfalls from February to July, the mean accumulation of snow was below zero until the former half of June, 1968. But during August and September, the mean accumulation increased. Also during these months, the snow storms dominated as marked by solid circles in the upper row of Fig. 5 and by dotted ribbons in Fig. 4, and the mean accumulation reached the maximum. In contrast, the amount of precipitation was very small from July to December as seen in Fig. 5. Although during this period the number of glass slides of replica of precipitation particles was small, replicated particles were mostly those of blowing snow and snow storms. Therefore, the increase of the mean accumulation was ascribed mainly to blowing snow and snow storms. However, there still remains the problem of how to differentiate the falling snow crystals from the blowing snow particles during snow storms.

4. Conclusion

Precipitation intensities of snow crystals grown from the sublimation and condensation processes in the free atmosphere at Syowa Station, Antarctica (69°00′S, 39°35′E) were calculated by using the data of 550 glass slides in 1968 and 300 glass slides in 1969 obtained by the replica solution method. In 1968, snowfall predominated from February in austral summer to July in winter, whereas from August to December, snow storms and drifting or blowing snow predominated. In the case of snowfalls, the cloud base temperature was in the range of $-30°$ to $-5°C$ in both years of 1968 and 1969. The predominant shapes of precipitating snow crystals were mainly bullets, combination of bullets, columns, and crossed-plates. The peak value of the maximum precipitation intensity was $1.5\ mm \cdot hr^{-1}$ in 1968 and $7.2\ mm \cdot hr^{-1}$ in 1969. Therefore, the maximum precipitation intensity ranged from 10^{-2} to $10^{0}\ mm \cdot hr^{-1}$, and the peak values of the intensity ranged from 10^{0} to $10^{1}\ mm \cdot hr^{-1}$. Next, the peak values of the maximum precipitation intensities at Syowa Station, Inuvik, and South Pole Station were compared. The order of them was regarded as 10^{1}, 10^{0}, and $10^{-1}\ mm \cdot hr^{-1}$, respectively. Further, by the use of the average maximum precipitation intensities and the duration of precipitation at Syowa Station, an annual amount of precipitation by snowfalls and snow storms except drifting and blowing snow was estimated and the value obtained was approximately 430 mm.

Acknowledgments

The data used in this paper were obtained during the wintering of JARE-9 and -10.

References

HIGUCHI, K. (1956): A new method for the simultaneous observation of a large number of falling snow particles. J. Meteorol., **13**, 274–278.

KIKUCHI, K. (1969): Unknown and peculiar shapes of snow crystals observed at Syowa Station, Antarctica. J. Fac. Sci., Hokkaido Univ., Ser. VII, **3**, 99–116.

KIKUCHI, K. (1970): Peculiar shapes of solid precipitation observed at Syowa Station, Antarctica. J. Meteorol. Soc. Jpn, **48**, 243–249.

KIKUCHI, K., TSUBOYA, S., SATO, N., ASUMA, Y. and TAKEDA, T. (1981): Characteristic properties of precipitation particles in the winter season at Inuvik, N.W.T., Arctic Canada. Observations of Clouds and Precipitation in the Arctic Canada, ed. by K. HIGUCHI *et al.* Tokyo, Organizing Committee for POLEX, 27–50.

MURAKOSHI, N. (1958): Dai-1-ji ettôtai kishô bumon hôkoku (Meteorological observations at the Syowa Base during the period from March, 1957 to February, 1958). Nankyoku Shiryô (Antarct. Rec.), **4**, 1–22.

NAKAYA, U. and TERADA, T., JR. (1935): Simultaneous observations of the mass, falling velocity and form of individual snow crystals. J. Fac. Sci., Hokkaido Univ., Ser. II, **1**, 191–200.

NARUSE, R., ENDO, Y., ISHIDA, T. and AGETA, Y. (1971): Observations of snow accumulation and sea ice at Syowa Station, Antarctica. Nankyoku Shiryô (Antarct. Rec.), **40**, 57–64.

SATO, N., KIKUCHI, K., BARNARD, S. C. and HOGAN, A. W. (1981): Some characteristic properties of ice crystal precipitation in the summer season at South Pole Station, Antarctica. J. Meteorol. Soc. Jpn, **59**, 772–780.

(Received May 11, 1981)