Observation of Wintertime Clouds and Precipitation in the Arctic Canada (POLEX-North)

Part 2: Characteristic Properties of Precipitation Particles

By Katsuhiko Kikuchi, Shigeyuki Tsuboya*, Noboru Sato
and Yoshio Asuma

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

Takao Takeda and Yasushi Fujiyoshi**

*Water Research Institute, Nagoya University, Nagoya 464, Japan
(Manuscript received 17 April 1982, in revised form 17 September 1982)*

Abstract

One of the subprograms of the Polar-Experiment North (POLEX-North), "Observation of Wintertime Clouds and Precipitation" was carried out at Inuvik ($68^{\circ}22'N$, $133^{\circ}42'W$), Northwest Territories, Arctic Canada, from December 1, 1979 to January 5, 1980. When the warm air from the Pacific Ocean advected over the observation station, dendritic crystals were observed as rimed and snowflakes, and at times, graupel particles. Corresponding to these snow crystals, a PPI radar echo showed convective type. On the other hand, when the polar air masses covered over the observation station, as expected from the temperature condition, the prevailing shapes of snow crystals were combination of bullets, columns and crossed plates. Corresponding to these air masses, a PPI radar echo was a stratiform type. The maximum precipitation intensities in a successive snowfall during the observation period were in the order of 10^{-3} to $10^0 \text{ mm} \cdot \text{hr}^{-1}$. Calculating the mass using the number flux and the maximum precipitation intensity, they fell into the range between $1 \times 10^{-3} \text{ mg}$ and $1 \times 10^{-2} \text{ mg}$. The equivalent diameters corresponding to these masses were from 0.12 mm to 0.27 mm. The $Z-R$ relation, $Z=13R^{1.2}$ and $Z=9R^{1.1}$ were obtained for crossed plates and column type snow crystals, respectively. These relations were nearly equal to $Z=10R^{1.0}$ for ice crystals introduced by Sato et al. (1981) for the light precipitation intensity during the summer season at the South Pole. About the relation between the maximum size and number flux, the increase in number flux increased the maximum size when the cloud thickness was thick and the increase in number flux decreased the maximum size when the cloud thickness was very thin. Based on the relation above described, a correlation between cloud thickness, maximum and minimum temperatures in clouds, weather conditions of synoptic scale and the shapes of snow crystals was summarized in Fig. 15.

1. Introduction

In recent years, there has been an increasing interest in the precipitation phenomena in the polar areas, for instance, the water budget, the

condition of snowfall and precipitation intensity and so on. As the air temperature in the polar areas is generally very low, water vapor in the free atmosphere would be extremely small. Therefore, the amount of precipitation in these areas is very small.

Klinov (1960), Shimizu (1963), Kikuchi (1969, 1970) and Kikuchi and Yanai (1971) reported the shapes of snow crystals in the polar areas.

* Present affiliation: Sekine Gakuen Senior High School, Joetsu, Niigata Prefecture.

** The Institute of Low Temperature Science, Hokkaido University, Sapporo.

Especially, Kikuchi and Hogan (1976) carried out the observation of the peculiar shapes of snow crystals consisting of prism planes extending abnormally sideways by means of a polarization microscope in temperatures colder than -25°C at the South Pole Station, Antarctica. Furthermore, Kikuchi and Hogan (1979) discussed some properties of diamond dust type ice crystals which are the most typical precipitation phenomena in the polar areas.

Recently, Sato et al. (1981) discussed the precipitation intensity, size distribution of ice crystals and the relation between radar reflectivity factor and precipitation intensity using the data obtained during four seasons in the Antarctica by one of the authors (K.K.) and his co-workers. On the other hand, Magono (1978) and his co-workers conducted an expedition to observe snow crystals in mid-winter in Arctic Canada under the title of "The Scientific Research on Snow Crystals of Cold Temperature Type in Canada".

Based on the back ground of these observations, one of the subprograms of the Polar-Experiment North (POLEX-North), "Observation of Wintertime Clouds and Precipitation" was carried out at Inuvik ($68^{\circ}22'\text{N}$, $133^{\circ}42'\text{W}$), Northwest Territories, Arctic Canada, from December 1, 1979 to January 5, 1980. In this paper, the characteristic properties of precipitation particles in the Arctic Canada will be mainly described.

2. Data acquisition

To obtain the information of horizontal and vertical distribution of precipitating clouds, a short-range PPI weather radar of 3.2 cm in wave length was used. A parabolic type antenna of 1.2 m in diameter was set up on a flat roof of the Inuvik Scientific Resource Centre and a main indicator and transmitter/receiver equipments were set up on the third floor in the same resource centre. The scanning time of the antenna was 15 seconds and a display of the main indicator was photographed by a motor driven camera at 5 or 10 minute intervals automatically.

Ice and snow crystal observations were carried out in a storage hut located in a lot on the premises of the resource centre. This hut was unheated and hoar frost grew on the steel wall, further, the floor was covered packed snow. This did not allow sublimation or melting during the short period between collection and examination. A polarization microscope, Formvar solution method (replica) and the snow crystal

measuring system (SCMS) designed for this experiment by Kikuchi et al. (1982) were used for the measurement of number flux, shapes and size of precipitation particles. A polarization microscope with double cameras was used to take photographs of the shapes of snow crystals, and to determine the principal axis of the crystals, at approximately 10 minute intervals or on random occasions: one of the cameras was for reversal film and the other was for monochrome film. Simultaneously, falling snow crystals were collected by sedimentation and replicated on 25×75 mm glass slides coated with a 0.5% Formvar solution at 5 or 10 minute intervals. As for small "diamond dust" type ice crystals and ice fog, these were collected by the interception technique. These replicas were used to estimate the relative rate of precipitation intensity and the ratio of number concentration of peculiar shapes to ordinary shapes of snow crystals. A SCMS consists of a collector, controller, television monitor and video tape recorder. The collector consists mainly of a turn table receiving falling snow crystals entering from an intake and a television camera for recording the crystals. The collector was set up in front of the storage hut and it was controlled by the controller which was set up in the observation room with a monitor and recorder. The SCMS was operated at the same time with a vertical pointing radar (Takeda et al. 1982, Fujiyoshi et al. 1982). Therefore, the place collecting falling snow crystals was the same in all techniques, that is, the polarization microscope, Formvar solution method and SCMS. Measurements of atmospheric electric field on the ground surface and electric charges on precipitation particles were carried out at the same place obtaining the informations of electric features of precipitating clouds and precipitation particles as an aid for the experiments.

3. Results

3.1 General description of the meteorological conditions and the shapes of snow crystals during the observation period

Fig. 1 shows a time height cross section of air temperature and cloud layers from the surface up to 400 mb level from November 29, 1979 to January 6, 1980 at Inuvik. The isotherms are drawn at interval of 5°C .

Striped histograms show cloud layers which are defined to be layers of more than 90% in relative humidity with respect to water. Short

Fig. 1 Time-height cross section of air temperature, cloud layers, and shapes of snow crystals.

horizontal bars with spikes at both ends above the time height cross section, show the observation period of snow crystals. Typical shapes of snow crystals observed during the periods were sketched by graphic symbols and additional characteristics, for instance, rimed and flake crystals based on the classification of solid precipitation agreed upon by the International Commission on Snow and Ice in 1949 (Mason, 1971). As may be clearly seen, the classification does not include crossed plates (formerly side planes) type snow crystals which are typical shapes growing in cold temperature regions. Thus we added this shape depicted by a graphic symbol (∇) to the classification. The discovery and frequency of the peculiar shapes of snow crystals are the most interesting and they now are very familiar in

lower temperature regions, for instance, below -25°C , and we added these shapes depicted by a graphic symbol ($\diamond$) to the classification. This graphic symbol indicates a tetragonal shape which is formed by two prism planes from two columns or bullets. Therefore, the diagonal line shows the grain boundary between both prism planes. "Seagull" shaped snow crystals reported by Kikuchi and Kajikawa (1979) in the former expedition at the same place is highly interesting and we added the crystal as a graphic symbol (∇). Fig. 2 shows these snow crystals photographed by polarization microscope.

During the observation period, the surface air temperature recorded was approximately from 0°C to -40°C . This temperature range was nearly the same with the previous expedition.

Fig. 2 Typical shapes of snow crystals photographed by polarization microscope.
(a), (b): Crossed plates; (c), (d): Gohei type; (e), (f): Seagull type.

On the other hand, the air temperature at 400 mb was recorded to be lower than -50°C during several periods. This upper air condition was lower by 5°C than the previous expedition period. Therefore, the frequency of the peculiar shapes as shown in Fig. 2(c)~(f) was larger than the results obtained in the previous expedition (Kikuchi and Magono, 1978). Fig. 2(c) and (d) shows typical examples of "Gohei" and (e) and (f) shows "Seagull" type crystals (Kikuchi and Kajikawa, 1979), respectively. However, at times very warm air masses invaded into the layer below 700 mb level. Especially, at the beginning of December, graupel particles were observed mingled with dendrites and spatial dendrites and

at times rimed crystals and flakes appeared. Corresponding to this period, a PPI radar echo was convective and was 3 km in width and 15 km in length as shown in Fig. 3(a). However, needle type crystals, ice pellets and frozen rain drops reported in the previous expedition (Magono and Kikuchi, 1980) were not observed in this observation. When the polar air masses covered over the observation station, as expected from the temperature conditions, the prevailing shapes of snow crystals were combination of bullets, columns and crossed plates. Corresponding to these snow crystals, a PPI radar echo was stratiform as shown in Fig. 3(b). Temperature conditions on or about December 9, 1979 and from

Fig. 3 Photographs of PPI radar echoes. (a) Convective, (b) Stratiform.

January 2 to 4, 1980 were isothermal from the surface to 700 mb level. "Seagull" type crystals as shown in Fig. 2(e) and (f) were observed during this time.

3.2 Precipitation intensity

To estimate the precipitation intensity in the polar areas is highly important to understand the precipitation mechanism, properties of precipitating clouds, and the water budget in the areas. Fig. 4 shows an example of the time variation of the precipitation intensity of rimed crossed plates at times flakes, columns and combination of bullets on December 21, 1979. In this case, a cloud layer was very thick from 950 mb to 550 mb level. The maximum precipitation intensity was greater than $1 \text{ mm} \cdot \text{hr}^{-1}$. On the other hand, in the case on December 7, 1979, the prevailing crystal shape was column and a few percentage of crossed plates. The intensity was very weak in a range between 3×10^{-4} and $9 \times 10^{-3} \text{ mm} \cdot \text{hr}^{-1}$ as shown in Fig. 5

Throughout the observation period, a relationship between the maximum precipitation intensity and the temperature at cloud base obtained from sounding data is shown in Fig. 6. Each black dot showed the maximum precipitation intensity in a successive snowfall. The letters B, C, D, and S stand for the shapes of snow crystals of bullet and combination of bullets, column, dendrite and crossed plates (formerly side planes), respectively. Although the data are widely scat-

Fig. 4 Time variation of the precipitation intensity of rimed crossed plates, column and combination of bullets on December 21, 1979.

tered, it appears that the maximum precipitation intensity of the bullet and combination of bullets was larger than other crystals. This is the reason why the combination of bullets prevailed throughout the observation period. Fig. 7 shows the rela-

Fig. 5 Same as Fig. 4 except of columns on December 7, 1979.

Fig. 6 Relation between the maximum precipitation intensity and temperature at cloud base to individual shapes of snow crystals (B: Bullet and Combination of bullets, C: Column, D: Dendrite, S: Crossed plates).

Fig. 7 Relation between the maximum precipitation intensity and number flux of snow crystals.

tion between number flux of precipitation particles by the replica method and the maximum precipitation intensity.

The number flux of precipitation particles ranged from an order of $10^{-2} \text{ cm}^{-2} \cdot \text{sec}^{-1}$ to $10^1 \text{ cm}^{-2} \cdot \text{sec}^{-1}$. Calculating the mass using the number flux and the maximum precipitation intensity, they fell into a range between $1 \times 10^{-3} \text{ mg}$ and $1 \times 10^{-2} \text{ mg}$, except for a few samples. The equivalent diameters (D_e) corresponding to these masses were from 0.12 mm to 0.27 mm.

3.3 Size distribution and $Z-R$ relation of snow crystals

The size distribution and $Z-R$ relation of snow crystals were considered. In general, the size distribution of precipitation particles is represented by the well known Marshall and Palmer's exponential equation (1948), $N_D = N_0 \exp(-AD)$, where D is the melted diameter, $N_D dD$ is the number of snow crystals having a melted diameter between D and $D+dD$ in a unit volume of space, and N_0 is the value of N_D for $D=0$. Parameters for precipitation particles, $N_0 (\text{m}^{-3} \cdot \text{mm}^{-1})$, $A (\text{mm}^{-1})$, $M (\text{mg} \cdot \text{m}^{-3})$ as the precipitation content and $D_0 (\text{mm})$ as the median volume diameter were calculated as a function of $R (\text{mm} \cdot \text{hr}^{-1})$ in cases of Figs. 4 and 5. In a case of Fig. 4, the calculation was done to the falling snow crystals of crossed plates type between 2100 and 2200 LST. The calculated values were $\sim 10^7$, $18.3 R^{-0.18}$, $525 R^{0.80}$ and $0.20 R^{0.16}$ in a range of precipitation intensity 0.11~0.71

$\text{mm} \cdot \text{hr}^{-1}$ in Fig. 4 and $10^4 \sim 10^7$, $2.0 R^{-0.39}$, $290 R^{0.81}$ and $0.32 R^{0.14}$ in a range of precipitation intensity $0.00065 \sim 0.0078 \text{ mm} \cdot \text{hr}^{-1}$ in Fig. 5, respectively.

The calculated values of the $Z-R$ relation for snow crystals corresponding to the Figs. 4 and 5 are shown in Figs. 8 and 9. The ordinate and abscissa show the radar reflectivity factor $Z (\text{mm}^6 \cdot \text{m}^{-3})$ and precipitation intensity $R (\text{mm} \cdot \text{hr}^{-1})$, respectively. Generally, the $Z-R$ relation is represented as $Z = BR^\beta$. The results of these analyses were $B=13$, $\beta=1.2$ in the case of Fig. 8 and $B=9$, $\beta=1.1$ in the case of Fig. 9. These values of $B=13$ and 9 and $\beta=1.2$ and 1.1 were nearly equal to $Z=10 R^{1.0}$ for ice crystals introduced by Sato et al. (1981) for the light precipitation intensity during the summer season at the South Pole, Antarctica.

3.4 Relation between number flux and maximum size of precipitation particles

A strong temperature inversion near the ground surface is very common in winter season, especially, in polar areas. In such cases, the cloud layers were very thin and the size of precipitation particles was very small such as seen in "diamond dust" or "ice fog". The content of water vapor in the free atmosphere was extremely small under cold temperature conditions. It is very interesting to study the relation between number flux and maximum size of precipitation particles. Data obtained by SCMS were used for this study. Fig. 10 shows a case of den-

Fig. 8 Relation between the radar reflectivity factor $Z (\text{mm}^6 \cdot \text{m}^{-3})$ and precipitation intensity $R (\text{mm} \cdot \text{hr}^{-1})$ on December 21, 1979.

Fig. 9 Same as Fig. 8 except on December 7, 1979.

Fig. 10 Relation between the maximum size and number flux of dendrite.

driftic crystals. In the figure, the ordinate and abscissa show the maximum size (mm) and number flux ($\text{n}\cdot\text{cm}^{-2}\cdot\text{sec}^{-1}$) of precipitation particles, respectively. Each open circle shows a non-rimed dendrite and the solid circle shows a rimed one. Although the relation is seen scattered widely as shown in the open circle since the number flux of dendrite is generally very small, there seems to be a positive correlation, that is to say, an increase in number flux of non-rimed dendrites increases the maximum size. However, in a case of rimed dendrites as seen in solid circles, there seems to be a negative correlation, an increase in number flux decreases the maximum size. As seen in Fig. 1, the thickness of cloud layer in the afternoon on December 2 was very thin.

Fig. 11 shows the case of bullet type crystals which is one of the most typical shape of snow crystals in cold temperature conditions. As seen in Fig. 1, the height of cloud top defined as more than 90% in relative humidity with respect to water was 500 mb and the thickness of the cloud layer defined as more than ice saturation was 4,700 m. A positive correlation was clear as seen in a straight line indicating both relations. Nearly the same example in the afternoon on December 10 is shown in Fig. 12. In this case, the main shapes of snow crystals were bullet, combination of bullets and column. During the observation period from 1610 to 2150 LST, bullet and combination of bullets, and column prevailed alternatively. In Fig. 12, solid circles show the prevailing of bullet type crystals and open circles show another case. As the combination of bullets is composed of several bullets, the maximum

Fig. 11 Same as Fig. 10 except for bullet and combination of bullets.

Fig. 12 Same as Fig. 10 except for bullet and column.

size and number flux are smaller than column type crystals as expected.

Fig. 13 shows the case of column type crystals observed on December 7, 1979. As seen in Fig. 1, the thickness of cloud layer was 1,000 m approximately. The maximum sizes were independent of the number flux of the range from 0.01 to $0.4 \text{ cm}^{-2}\cdot\text{sec}^{-1}$ throughout the observation period. On the other hand, in the case of crossed plates type crystals observed in the afternoon on December 18 as shown in Fig. 14, the relation between the maximum size and number flux was distinctly negative. The thickness of cloud layer was very thin, amounting to only a few hundred meters, as shown in Fig. 1. As above described examples of Figs. 10 to 14, the relation between the number flux and the maximum size of precipitation particles was positive as shown in cases

Fig. 13 Same as Fig. 10 except for column.

Fig. 14 Same as Fig. 10 except for crossed plates.

of non-rimed dendrites of Fig. 10. bullet and combination of bullets of Fig. 11, and bullet and column of Fig. 12. Contrary to them, a negative correlation was recognized in a case of crossed plates type crystals of Fig. 14, and no correlation was recognized in a case of column type crystals as shown in Fig. 13. Considering these results, it will be concluded that the relation between the number flux and the maximum size of precipitation particles depends on the thickness of cloud layers, that is, water vapor content in cloud layers, in the lower temperature conditions. In the case of Fig. 14, the cloud was lacking water vapor and a number of crossed plates type crystals could not grow enough. Therefore, when the number flux of the crystals increased the maximum size decreased. The sky condition in such case was clear and no visible clouds were present. At times we could see the

Fig. 15 Relation between cloud thickness, maximum and minimum temperatures in clouds, weather conditions of synoptic scale and shapes of snow crystals.

moon and stars through the falling precipitation particles. These conditions are nearly the same as "clear sky precipitation" reported at Amundsen-Scott South Pole Station, Antarctica, (Kikuchi and Hogan, 1976).

Fig. 15 summarizes the relation between the maximum size and number flux of all data obtained in this observation period. In the figure, the cloud thickness which was defined as more than ice saturation and the maximum and minimum temperatures in clouds as parameters are given. In the figure, horizontal lines with open circles at both ends show the maximum and minimum temperatures in clouds and the letters of B, C, D, and S indicate the shapes of snow crystals of bullet and combination of bullets, column, dendrite and crossed plates, respectively. Arrows drawn on the right side of each letter shows the correlation between the maximum size and the number flux which was described previously, namely, arrows directed to upper right, horizontal and lower right show positive, no and negative correlations, respectively. Classifying these tendencies by means of the weather charts of the synoptic scale of 850 mb (A, B and C) and the vertical temperature profiles in cloud layers by sounding data from the surface up to

400 mb (I, II, III and IV) (Takeda et al. 1982), they were classified from A-I to C-III type. These types, furthermore, were classified corresponding to the shapes of snow crystals of bullet type crystals, column and crossed plates. Although the relation between maximum size and number flux of diamond dust were not obtained by SCMS, it is possible to estimate the cloud thickness of a few hundred meters less and the maximum temperature of approximately -25°C . However, dendritic crystals were not classified clearly for the sake of only two cases in this observation period. It is roughly seen the following tendencies from this figure; in the cases that the cloud thickness is 4.5 km or more, the correlation between the maximum size and the number flux is positive, the synoptic situation is classified as the C-II type and the main shape of snow crystals is combination of bullets. In the cases that the cloud thickness is approximately 4 km, the correlation between both parameters is positive except rimed crystals, the synoptic situation is A-IV type and the main shape of snow crystals is crossed plates. When the cloud thickness is approximately 3 km, positive or no correlation presents in both parameters, and the column shape crystals prevail under the synoptic situations of B-II and C-II types. Although the crossed plates crystals prevail when the cloud thickness is approximately 2 km, the synoptic situation is A-I and II types and the correlation between both parameters is no or negative. Notwithstanding the synoptic situation is C-II type and the main shape of snow crystals is column, in the cases that the cloud thickness is very thin such as 1 km, there is no correlation between both parameters. Synoptic situations in the cases of snow crystals of minute columns and minute plates so called diamond dusts will be limited to A-III and C-III types. As the most typical shapes of snow crystals in the mid-winter season in cold temperature regions are combination of bullets, columns and crossed plates, it is understood that the Fig. 15 expresses properties of these crystal shapes sufficiently under the condition of synoptic situations and cloud thickness.

4. Concluding remarks

As the temperature condition throughout the observation period, on the average, was lower by approximately 5°C than the previous observation carried out at Inuvik by the Hokkaido

University team in 1977, a number of peculiar shapes of snow crystals such as "Gohei" and "Seagull" were observed. When the warm air from the Pacific Ocean advected over the observation station, however, dendritic crystals were observed as rimed and snowflakes, and at times, graupel particles. Corresponding to these snow crystals, a PPI weather radar showed convective type echoes. On the other hand, when the polar air masses covered over the observation station, as expected from the temperature conditions, the prevailing shapes of snow crystals were combination of bullets, columns and crossed plates. Corresponding to these snow crystals, a PPI radar echo was a stratiform type. The maximum precipitation intensities in a successive snowfall during the observation period were in the order of 10^{-3} to $10^0 \text{ mm}\cdot\text{hr}^{-1}$. Calculating the mass using the number flux and the maximum precipitation intensity, they fell into the range between $1\times 10^{-3} \text{ mg}$ and $1\times 10^{-2} \text{ mg}$. The equivalent diameters corresponding to these masses were from 0.12 mm to 0.27 mm. The $Z-R$ relation, $Z=13 R^{1.2}$ and $Z=9 R^{1.1}$ were obtained for crossed plates and column type snow crystals, respectively. These relations were nearly equal to $Z=10 R^{1.0}$ for ice crystals introduced by Sato et al. (1981) for the light precipitation intensity during the summer season at the South Pole. About the relation between the maximum size and number flux, the increase in number flux increased the maximum size when the cloud thickness was thick, and the increase in number flux decreased the maximum size when the cloud thickness was very thin. Based on the relation above described, a correlation between cloud thickness, maximum and minimum temperatures in clouds, weather conditions of synoptic scale and the shapes of snow crystals was summarized in Fig. 15.

Acknowledgements

The expense of this research was supported by the Special Funds for Scientific Research from the Ministry of Education, Science and Culture, Japan.

We would like to express our thanks to Mr. C. P. Lewis, Scientist-in-Charge, and Mr. J. D. Ostrick, Operations Manager, Inuvik Scientific Resource Centre, Northwest Territories, Canada for their supports and the supply of facilities. We also wish to express our thanks to Dr. G. G. Goyer, Head and staffs, Alberta Research Coun-

cil, Canada for their help in performing the radar observations at Inuvik, and to Inuvik Airport Weather Station and Inuvik Upper Air Station.

References

- Fujiyoshi, Y., T. Takeda and K. Kikuchi, 1982: Observation of wintertime clouds and precipitation in the Arctic Canada (POLEX-North). Part 3: Radar observations of precipitating clouds. *J. Meteor. Soc. Japan*, **60**, 1227-1237.
- 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. Meteor. Soc. Japan*, **48**, 243-249.
- Kikuchi, K. and A. W. Hogan, 1976: Snow crystal observations in summer season at Amundsen-Scott South Pole Station, Antarctica. *J. Fac. Sci., Hokkaido Univ., Ser. VII*, **5**, 1-20.
- Kikuchi, K. and A. W. Hogan, 1979: Properties of diamond dust type ice crystals observed in summer season at Amundsen-Scott South Pole Station, Antarctica. *J. Meteor. Soc. Japan*, **57**, 180-190.
- Kikuchi, K. and M. Kajikawa, 1979: Comments on V-shaped snow crystals observed in Arctic Canada. *J. Meteor. Soc. Japan*, **57**, 484-487.
- Kikuchi, K. and C. Magono, 1978: General description of the meteorological conditions and shapes of snow crystals during the observation period at Inuvik, N.W.T., Canada. Snow Crystals in the Arctic Canada. Hokkaido Univ., Japan, 172 pp. (Edited by C. Magono).
- Kikuchi, K., S. Tsuboya, Y. Asuma and K. Inatsu, 1982: A new method for measuring snow crystals (Snow Crystal Measuring System) *J. Fac. Sci., Hokkaido Univ., Ser. VII*, **7**, 159-168.
- Kikuchi, K. and H. Uyeda, 1979: On snow crystals of spatial dendritic type. *J. Meteor. Soc. Japan*, **57**, 282-287.
- Kikuchi, K. and K. Yanai, 1971: Observation on the shapes of snow crystals in the south pole region in the summer. *Antarctic Record*, **41**, 34-41.
- Klinov, F. Ya., 1960: Voda v Atmosfere pri Nizkikh Temperaturakh. Izdatelstvo Akademii Nauk SSSR, 170 pp.
- Magono, C. (Ed.), 1978: Snow Crystals in the Arctic Canada. Hokkaido University, 172 pp.
- Magono, C. and K. Kikuchi, 1980: Some observations of snowfall and meteorological conditions in Arctic Canada. *Mon. Wea. Rev.*, **108**, 1656-1664.
- Marshall, J. S. and W. H. Palmer, 1948: The size distribution of raindrops with size. *J. Meteor.*, **5**, 165-166.
- Mason, B. J., 1971: The Physics of Clouds. Clarendon Press, 671 pp.
- Sato, N., K. Kikuchi, S. C. Barnard and A. W. Hogan, 1981: Some characteristic properties of ice crystal precipitation in the summer season at South Pole Station, Antarctica. *J. Meteor. Soc. Japan*, **59**, 772-780.
- Shimizu, H., 1963: "Long Prism" crystals observed in precipitation in Antarctica. *J. Meteor. Soc. Japan*, **41**, 305-307.
- Takeda, T., Y. Fujiyoshi and K. Kikuchi, 1982: Observation of wintertime clouds and precipitation in the Arctic Canada (POLEX-North). Part 1. Characteristic features of clouds and precipitation. *J. Meteor. Soc. Japan*, **60**, 1203-1214.

北極圏カナダにおける冬季の雲と降水の観測 (POLEX-North)

第二部 降水粒子の特徴

菊地 勝弘・坪谷 成行*・佐藤 昇・遊馬 芳雄

北海道大学理学部地球物理学教室

武田 喬男・藤吉 康志**

名古屋大学水圏科学研究所

北極域観測計画 (POLEX-North) のサブプログラムの一つとして、「冬季の雲と降水の観測」が1979年12月1日から1980年1月5日までの間、カナダ・ノースウエスト準州イヌヴィック (68°22'N, 133°42'W) で行われた。北太平洋からの温暖な気団による降雪は、樹枝状結晶が主で、時として雲粒付や雪片を形成し、霰を降らすこともあり、波長 3.2 cm の PPI レーダエコーは対流性であった。一方、寒冷な北極気団による降雪は砲弾や

* 現在所属：新潟県上越市関根学園高等学校

** 北海道大学低温科学研究所

角柱状結晶，それに交差角板結晶の場合が多く，レーダエコーは層状性であった。観測期間中の一連の降雪の最大降水強度は $10^{-3} \sim 1 \times 10^0 \text{ mm} \cdot \text{hr}^{-1}$ で，これを使って降雪粒子の粒子数フラックスから質量を求めると， $1 \times 10^{-3} \sim 1 \times 10^{-2} \text{ mg}$ であり，これらの質量に相当する相当直径は， $0.12 \text{ mm} \sim 0.27 \text{ mm}$ であった。また，交差角板と角柱結晶に対するレーダ反射強度 (Z) と降水強度 (R) との関係は，それぞれ $Z=13R^{1.2}$ ， $Z=9R^{1.1}$ となり，先に南極点基地の夏季の氷晶粒子に対して得られた $Z=10R^{1.0}$ にほぼ等しかった。一連の降雪に対して，降雪粒子の最大直径と粒子数フラックスの間には，雲層が厚い時には粒子数フラックスが増加しても最大直径が増加する傾向が認められたが，雲層が非常に薄い時には粒子数フラックスが増加すると，逆に最大直径が減少し，また最大直径が増加すると，粒子数フラックスが減少するという傾向が認められた。これらの性質を考慮して，雲厚，雲内の最高最低温度，雲の構造と降雪粒子の結晶形との関係が Fig. 15 のように括められた。