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Characteristics of the ice pellets observed in mid-winter in the Arctic region

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Abstract: In mid-winter ice pellets were observed at Inuvik, Canada and Kiruna, Sweden in the Arctic region. The size distribution, morphology and crystalline nature were examined from the photomicrographs. Moreover, meteorological conditions in which the ice pellets could form were examined from the sounding data at Inuvik. The following results were obtained. (1) The sizes of ice pellets in the Arctic regions were considerably smaller than those in temperate regions. (2) The ice pellets simultaneously fell with the snow crystals with frozen small raindrops. (3) The morphology of ice pellets with a bulge or a spike was qualitatively similar to the results of laboratory experiments. (4) The rate of shattering was smaller than the results of laboratory experiments. (5) Single crystalline ice pellets were abundant in the size $<200\,\mu$m. (6) Ice pellets in the Arctic are formed through the freezing of supercooled drizzle drops, which are formed by condensation-coalescence process below the freezing temperature.

1. Introduction

In temperate regions the appearance of frozen raindrops, which correspond to so-called ice pellets, is not a rare phenomenon when a rain cloud or melting layer exists above a cold layer near the ground surface (*e.g.*, Kimura and Kajikawa, 1984; Stewart and King, 1987; Stewart, 1992; Stewart and Crawford, 1995). On the other hand, in polar regions several researchers have observed ice pellets which were formed by the freezing of supercooled droplets in drizzle size (*e.g.*, Magono and Kikuchi, 1980; Sakurai and Ohtake, 1981; Iwai, 1981; Kajikawa *et al.*, 2000). In those papers, it seems that incomplete points still remain concerning the morphology and crystalline nature of the ice pellets.

This paper describes some considerations regarding the size distribution, morphology and crystalline nature of ice pellets observed in mid-winter in the Arctic region (Inuvik, Canada, 68°22′N, 133°42′W and Kiruna, Sweden, 67°56′N, 21°04′E).

2. Observations

During the observation period of the "WANTS-ARCTIC" project (Kikuchi and Asuma, 1999), ice pellet events appeared in 4 and 13 cases at Inuvik and Kiruna, respectively. The ice pellets on a glass plate were photographed by a camera installed on a polarizing microscope at approximately 10 min intervals or on random occasions. Typical examples of ice pellets are shown in Fig. 1.

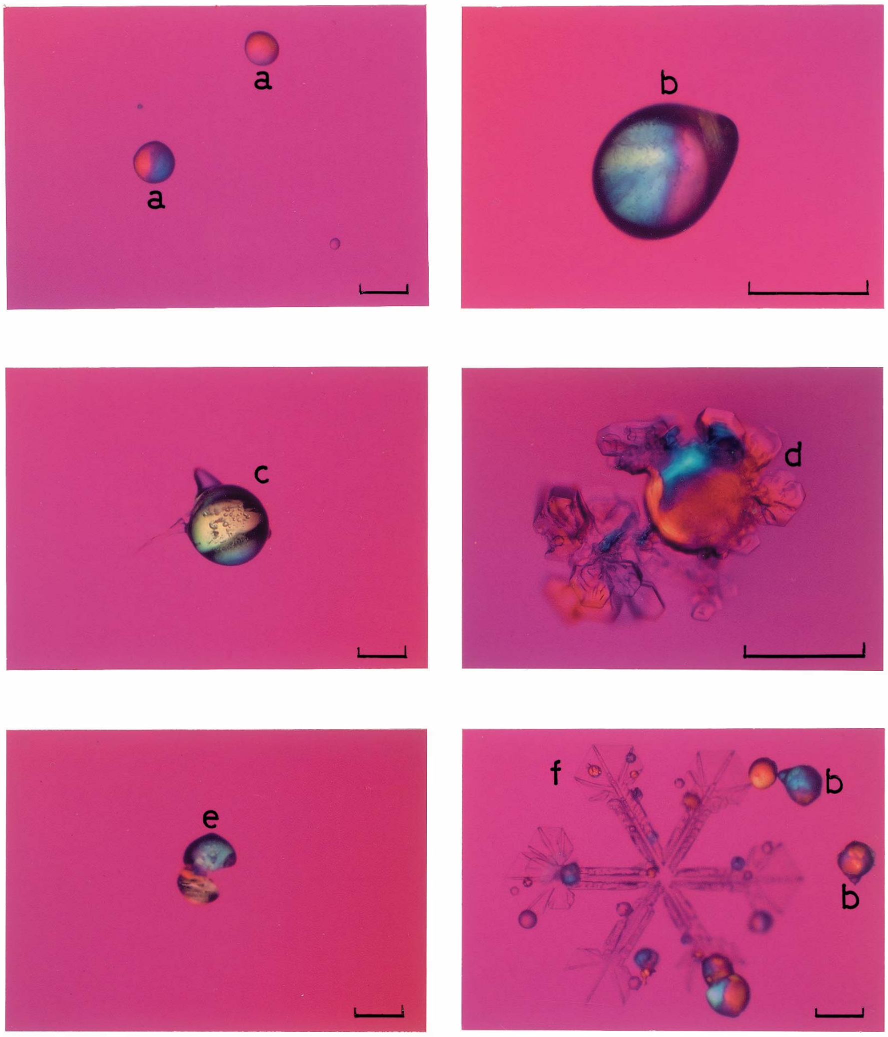

Fig. 1. Typical examples of ice pellets in transmitted light. a: An ice pellet of spherical type. b: An ice pellet with a bulge. c: An ice pellet with spikes. d: An ice pellet with plates. e: A shattered ice pellet. f: A snow crystal with frozen small raindrops. Comparison scale is 200 μm.

3. Results and discussion

At Inuvik, ice pellets were observed on December 20, 21 and 27, 1995. For three cases in which more than 10 ice pellets were obtained, the size distribution, crystalline nature (single-crystalline or poly-crystalline) and morphology are shown in Fig. 2. In the present analysis, a protrusion longer than one fourth of the diameter (D) of the spherical part was classified as a spike, following Takahashi (1975).

Figure 3 shows the time variation of surface air temperature (T) and the type of precipitation particles on December 27. In the upper part of this figure, the observed snow crystals are shown using the graphic symbols by Magono and Lee (1966) including

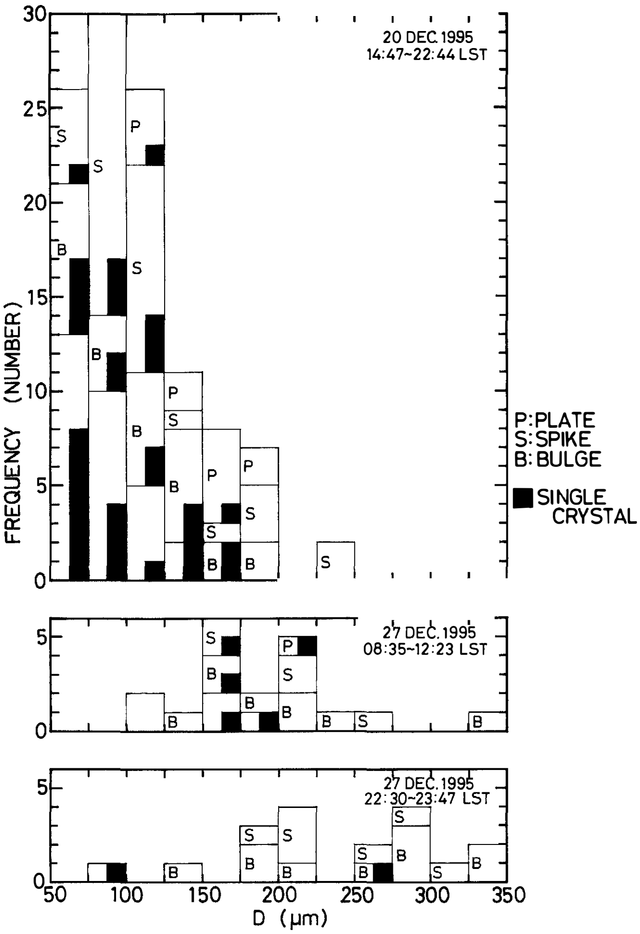

Fig. 2. Size distribution, crystalline nature and morphology of ice pellets observed at Inuvik. D: Diameter of spherical part of ice pellets. P: Ice pellet with plates. S: Ice pellet with a spike. B: Ice pellet with a bulge. Ice pellets except P, S and B are spherical particles. White and black squares are poly-crystalline and single-crystalline particles, respectively.

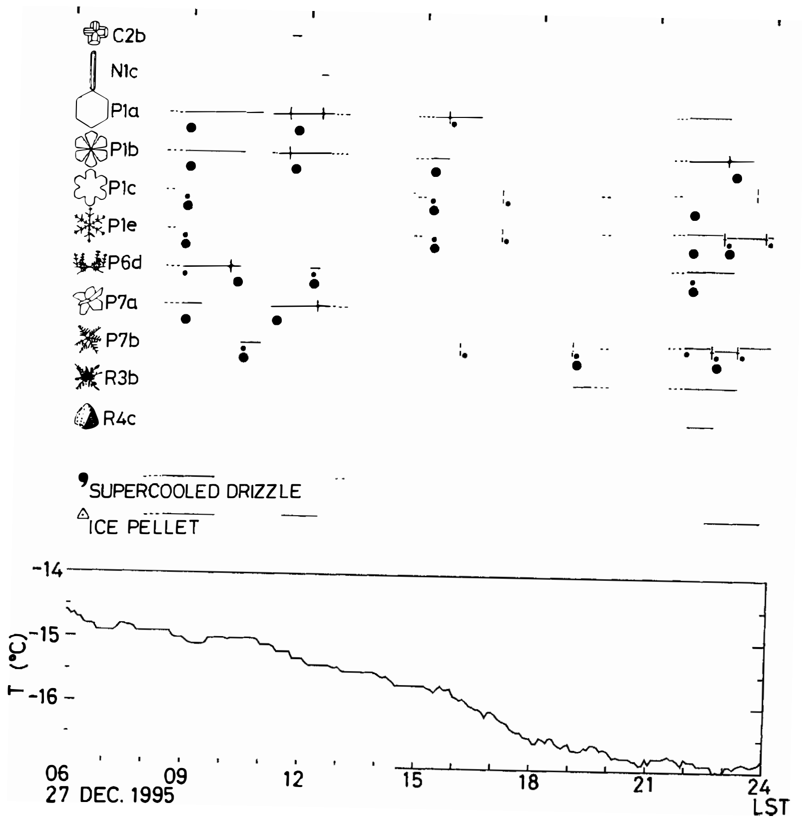

Fig. 3. Time variation of the surface air temperature and precipitation particles at Inuvik on December 27, 1995. Graphic symbols of snow crystals follow the manner of Magono and Lee (1966) , and Kikuchi and Asuma (1999).

ice pellets and supercooled drizzle drops. Solid lines in this figure indicate the appearance time of the particles. The short vertical lines attached to the solid lines denote the change of riming state of crystals. Small and large solid circles beneath the solid lines indicate rimed crystals and crystals with frozen small raindrops (diameter $\geq 100\,\mu$m), respectively. In the polar regions, such snow crystals with several small raindrops had been observed previously (*e.g.*, Kikuchi, 1972; Kikuchi and Uyeda, 1979; Iwai, 1981; Konishi and Wada, 2000). It can be seen from Fig. 3 that the ice pellets simultaneously fell with the snow crystals with small raindrops, rimed stellar crystals and rimed spatial dendrites, even when the surface air temperature was about -15 or -17°C. These situations were similar to the case of December 20 (refer to the same type figure of Kajikawa *et al.*, 2000).

Figures 4, 5 and 6 show the size distribution, crystalline nature and morphology, respectively, of ice pellets observed at Kiruna during two mid-winter seasons. The variations of typical shapes of snow crystals during the observation periods are shown in Figs. 7 and 8 with the variation of surface air temperature, by graphic symbols and additional characteristics, namely rimed crystals and snowflakes, based on the classific-

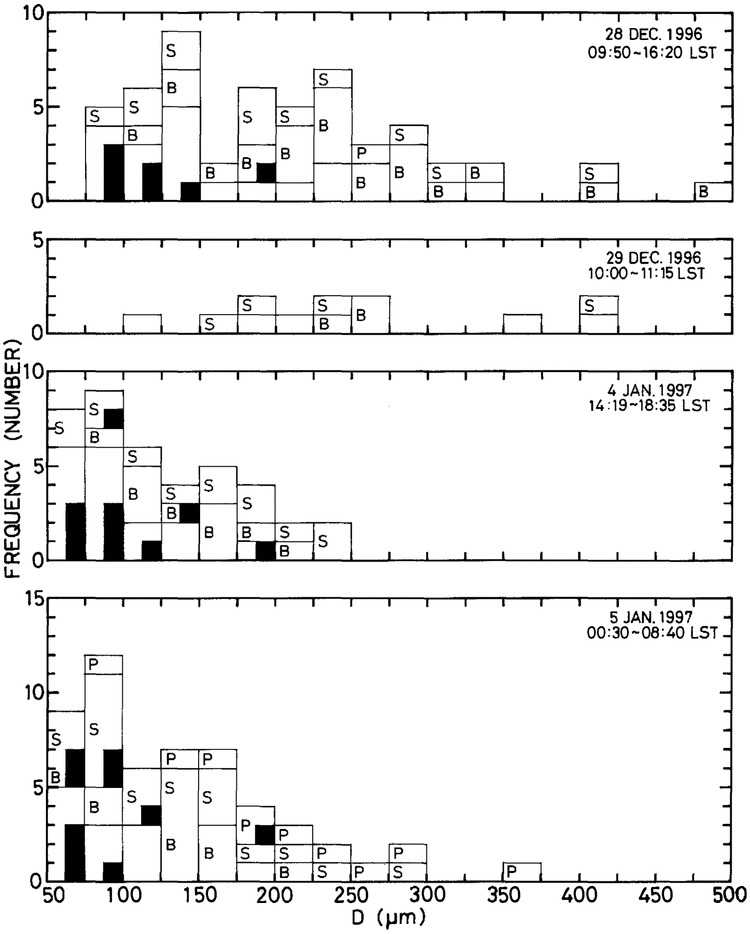

Fig. 4. Size distribution, crystalline nature and morphology of ice pellets observed at Kiruna on December 28 and 29, 1996 and January 4 and 5, 1997. The marks are identical with Fig. 2.

ation of solid precipitation by the International Commission of Snow and Ice in 1949 (*e.g.*, Mason, 1971). Graphic symbols of crossed plates type () and peculiar shapes (Gohei twin type,  and Sea gull type,  , which were not included in this classification, were added to Figs. 7 and 8 following Kikuchi and Asuma (1999).

The maximum diameter of ice pellets was 350μm on the morning of December 27, 1995 in Inuvik and 500μm on December 28, 1996 in Kiruna as shown in Figs. 2 and 4, respectively. These are much smaller than pellets observed in temperate regions. The morphology of ice pellets with a bulge or a spike is qualitatively similar to the results of laboratory experiments (*e.g.*, Takahashi, 1975, 1976). Spherical ice pellets (without a bulge, a spike or grown plates) were abundant in diameter $D < 250\mu$m. In the case without supercooled drizzle, the rate of spherical ice pellets was small ($<25\%$). In other words, ice pellets with a bulge, a spike or plates were abundant in this case. The

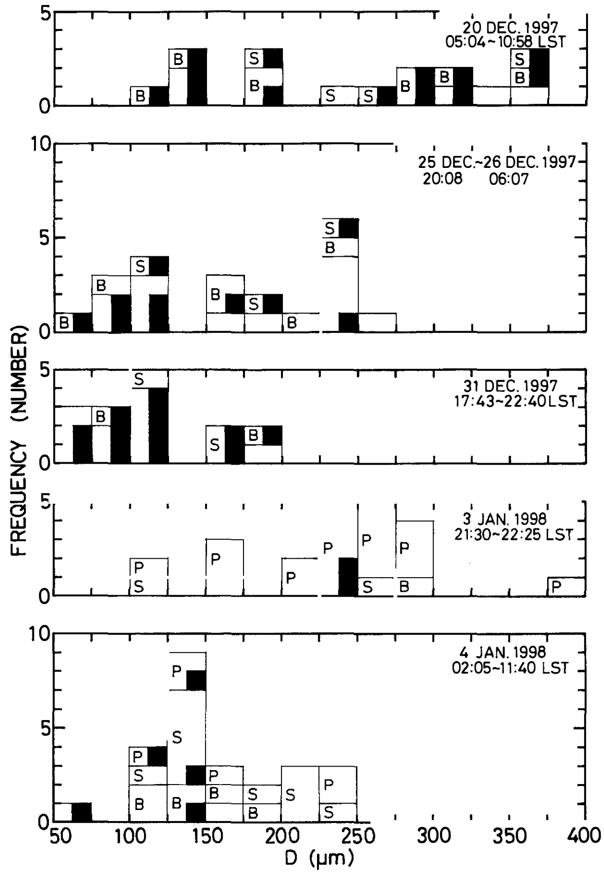

Fig. 5. Size distribution, crystalline nature and morphology of ice pellets observed at Kiruna on December 20, 25–26, and 31, 1997 and January 3 and 4, 1998. The marks are identical with Fig. 2.

frequency of shattering was 12.5% in maximum value and the ratio was smaller than the results of laboratory experiments (Takahashi, 1975, 1976). Unlike the laboratory experiments, about one-half of shattered particles were poly-crystalline. On the other hand, single crystalline ice pellets were abundant in diameter $D < 200\,\mu$m.

The formation mechanism of ice pellets in polar regions is a very interesting subject, as is that of supercooled drizzle. Here, in Inuvik, the meteorological situation was considered in detail because sufficient meteorological data were available. Figure 9 shows the vertical profiles of temperature and relative humidity with respect to water observed by the Inuvik Upper Air Station (the distance from the our observation site, about 10 km) at the nearest observation to the time when ice pellets appeared.

It can be seen from Fig. 9 that there are warm and saturated layers accompanying a temperature inversion at about the 800–900 hPa level in all cases. The depths of these layers are about 500–1500 m and the temperature range is about −7~−17°C. The wind direction around the warm layer was southerly in the three cases. Thus, it is

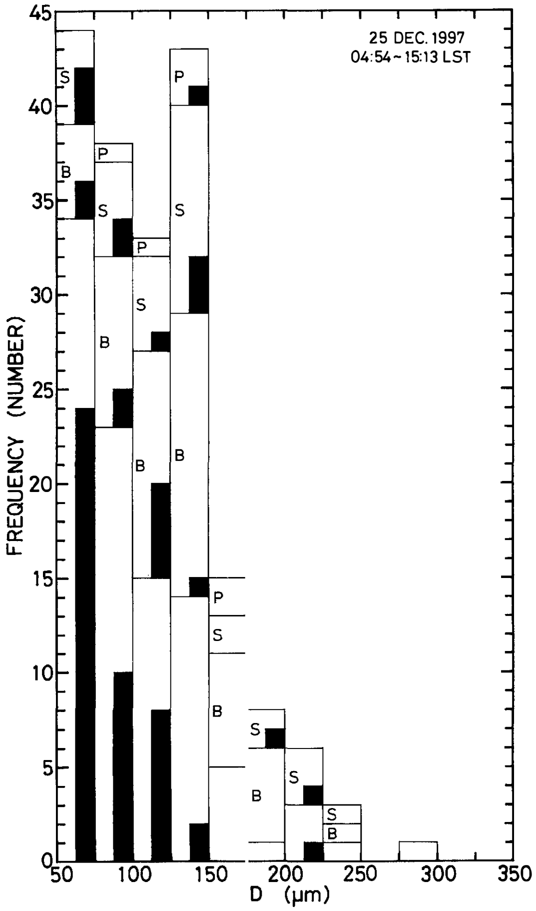

Fig. 6. Size distribution, crystalline nature and morphology of ice pellets observed at Kiruna on December 25, 1997. The marks are identical with Fig. 2.

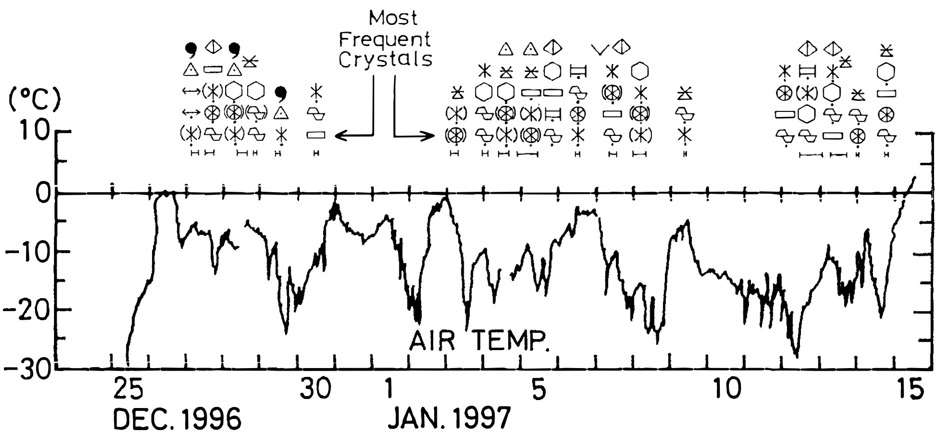

Fig. 7. Time variation of surface air temperature and predominant shapes of snow crystals at Kiruna on December 25, 1996–January 15, 1997.

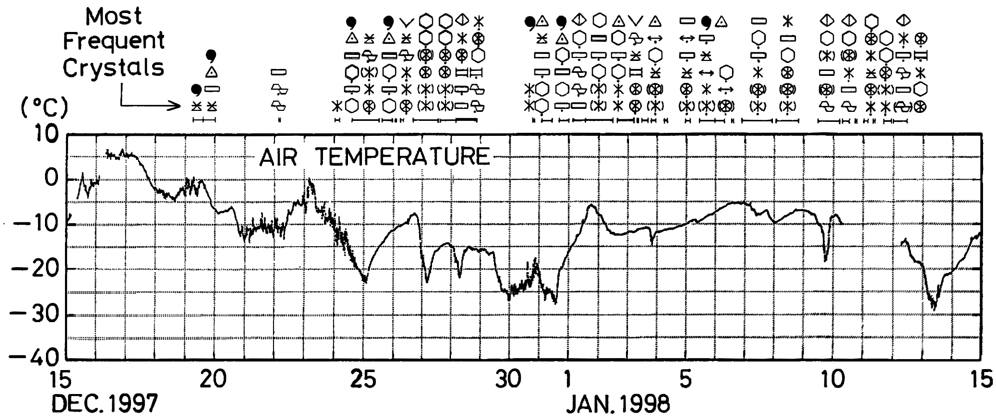

Fig. 8 Time variation of surface air temperature and predominant shapes of snow crystals at Kiruna on December 15, 1997–January 15, 1998.

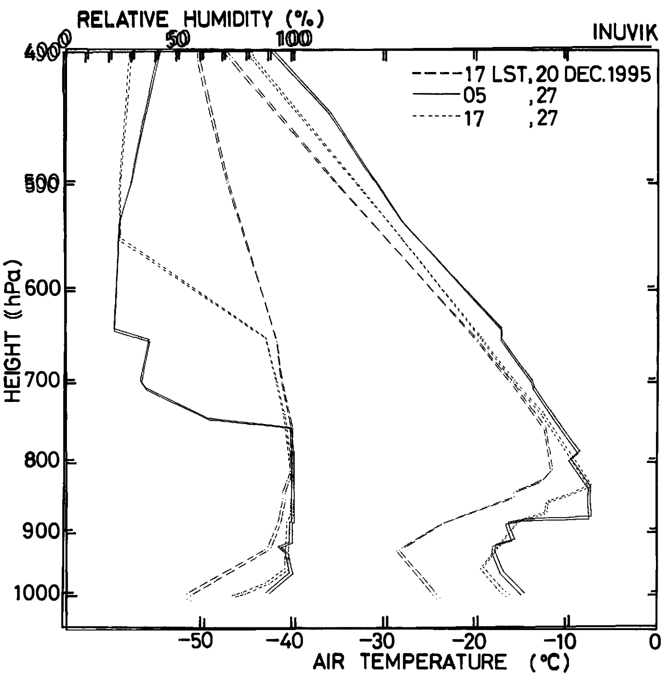

Fig. 9. Vertical profile of air temperature and relative humidity with respect to water at Inuvik.

suggested that warm air is advected from the Pacific Ocean.

Since a layer of air temperature higher than 0°C was not detected in this analysis, the melting of snow particles is impossible. It is considered, therefore, that the ice pellets were formed through the freezing of supercooled drizzle drops, which were formed by the condensation-coalescence process in the cloud layer produced by the advection of a marine air mass containing giant cloud condensation nuclei, as indicated by several researchers (*e.g.*, Sakurai and Ohtake, 1981; Iwai, 1981; Kajikawa *et al.*, 2000; Konishi and Wada, 2000).

4. Concluding remarks

Ice pellets were observed at Inuvik, Canada and Kiruna, Sweden in the Arctic region. The size distribution, morphology and crystalline nature were examined from the photomicrographs. Meteorological conditions in which the ice pellets could form in mid-winter were examined from the sounding data in Inuvik. In conclusion, the following six points are indicated.

(1) The sizes of ice pellets in Arctic regions are considerably smaller than those in temperate regions.

(2) The ice pellets simultaneously fell with the snow crystals with frozen small raindrops.

(3) The morphology of ice pellets with a bulge or a spike was qualitatively similar to the results of laboratory experiments (*e.g.*, Takahashi, 1975, 1976).

(4) The ratio of shattering was smaller than in laboratory experiments and about one-half of shattered particles were poly-crystalline.

(5) Single crystalline ice pellets are abundant in the size $<200\,\mu$m.

(6) Ice pellets in Arctic are formed through the freezing of supercooled drizzle drops, which are formed by condensation-coalescence process below the freezing temperature.

Acknowledgments

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