# ON THE FROZEN SMALL RAINDROPS OBSERVED AT SYOWA STATION, ANTARCTICA

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***Abstract***: Frozen small raindrops of drizzle size (a few hundred microns in diameter) were observed at a surface temperature of −12°C on April 16 and July 2, 1977 at Syowa Station (69.0°S, 39.6°E), Antarctica. The morphology and size distributions of these frozen raindrops were examined. The frozen particles were classified as having rugged surfaces, spikes, bulge and shattered, these were the same morphological features examined in laboratory experiments by TAKAHASHI (J. Meteorol. Soc. Jpn, **54**, 448, 1976; *ibid.*, **57**, 458, 1979), but this time they were found in natural precipitation elements. The mean diameter of these raindrops was 180 μm in both cases. Frozen small raindrops are considered to be produced by a coalescence of supercooled droplets in layer clouds, they froze after forming.

## 1. Introduction

KIKUCHI (1972) found snow crystals with small raindrops when he stayed at Syowa Station as a member of the wintering party of the 9th Japanese Antarctic Research Expedition (JARE-9). Further, MAGONO and KIKUCHI (1978) and SAKURAI and OHTAKE (1981) found supercooled raindrops or frozen small raindrops which were captured by snow crystals at Inuvik (Arctic Canada) and Fairbanks (Alaska), respectively. Up to the present, such small raindrops have not been reported in spite of many observations of snow crystals during the winter season in Japan. Accordingly, such small raindrops are considered to be one of the characteristics of precipitation elements in polar regions.

In this paper, the morphology and size distributions of frozen small raindrops which were captured by snow crystals or fell individually on April 16 and July 2, 1977 at Syowa Station are discussed.

## 2. Method of Observation

Replicas of snow crystals were made from March to November 1977 at Syowa Station under the condition of quiet snowfall. The replica solution was polyvinyl formal containing one percent ethylendichloride. Small raindrops which were captured by snow crystals or fell individually were found in specimens of these replicas made on April 16 and July 2, 1977.

The sizes of small raindrops were measured directly to the nearest 20 $\mu$m by a scale which was inserted in an eye piece of a stereomicroscope. Particles having representative shapes were selected and photomicrographed.

## 3. Results and Discussion

### *3.1. Morphology of frozen small raindrops*

Figure 1 shows two frozen droplets having rugged surfaces. As can be seen from the hexagonal features at one side of each droplet, the stripes are parallel to the basal plane. TAKAHASHI (1979) found that the rugged surfaces of frozen droplets about 100 $\mu$m in diameter grow to hexagonal plates parallel to the basal plane in his experiments on free falling droplets in a long cold chamber. These frozen droplets may be single crystalline.

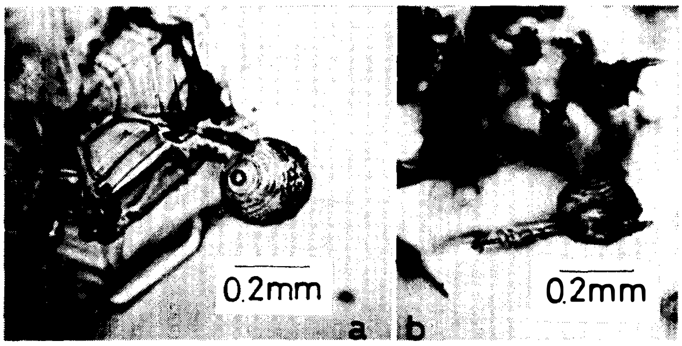


*Fig. 1. Photomicrographs of frozen droplets having rugged surfaces.*

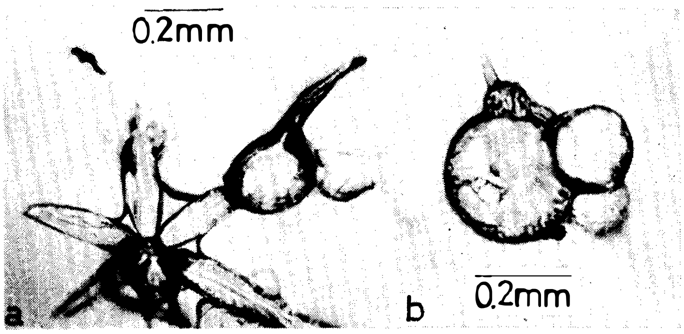


*Fig. 2. Photomicrographs of frozen droplets with spikes.*

Figure 2 shows two frozen droplets with spikes which were considered to be formed when they froze. One is long and curved (a) and the other is a small hump with a short spike (b).

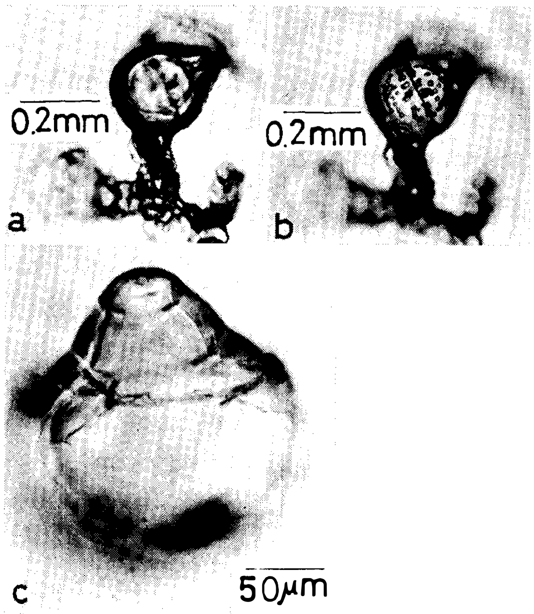


*Fig. 3.* *Photomicrographs of frozen droplets classified as bulge. a) and b) are the same except for the focusing.*

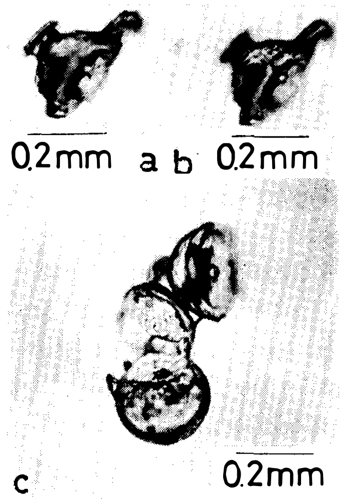


*Fig. 4.* *Photomicrographs of shattered frozen droplets. a) and b) are the same except for the focusing.*

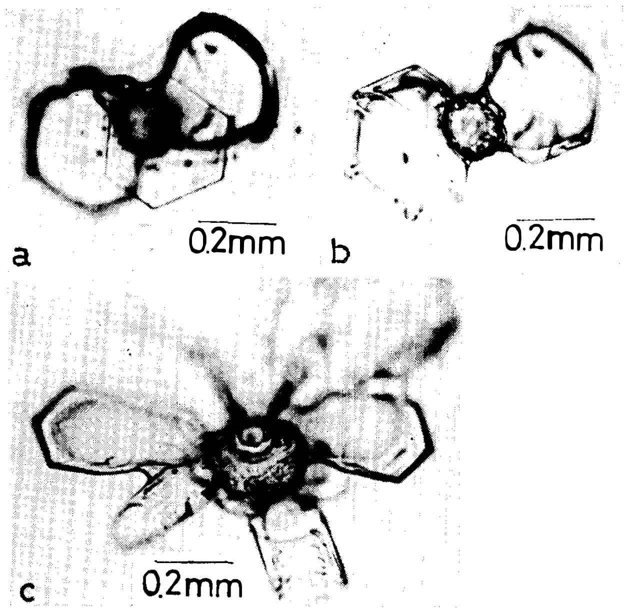


*Fig. 5.* *Photomicrographs of snow crystals grown from frozen small raindrops. a) is upper focusing, b) is lower focusing.*

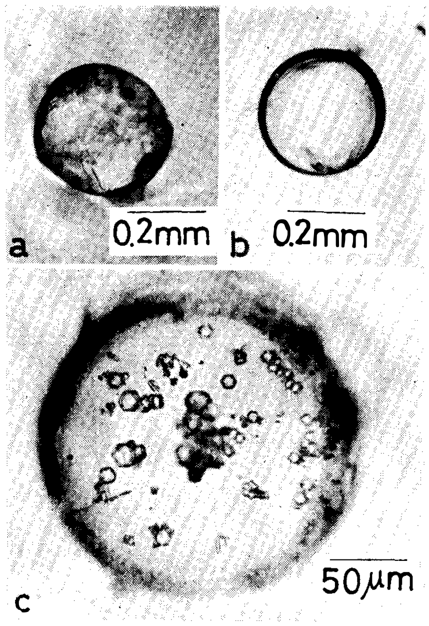


*Fig. 6.* *Photomicrographs of nearly spherical drops which fell individually on glass slides.*

Figure 3 shows examples which are classified as bulge. We can see a crack on the droplet surface perpendicular to the direction of the bulge and also can see a number of etch pits on ice crystal surface (Figs. 3a and b). As the thermal etch pits on the prismatic faces of ice crystals show rectangular shapes as pointed out by MUGURUMA and HIGUCHI (1958), it is understood easily that the direction of the *c*-axis of this frozen crystal is parallel to the direction of the bulge and the crack is parallel to the basal plane. The crystal in Fig. 3c seems to be a single bullet or pyramidal ice crystal as reported by MAGONO *et al.* (1979). However, the size of this crystal is larger than that reported by them by one order.

Figure 4 shows shattered droplets which fell individually (a, b) and aggregated with each other (c). As seen in Figs. 4a and b, it is recognized that hexagonal plates grow from both sides of a hemisphere of a frozen droplet. The shattered surface, therefore may be the basal plane, and if this inference is correct, the shattered surfaces are coincident with the cleavage planes of ice crystals.

Figure 5 shows frozen raindrops which are seen in the central part of snow crystals. According to GUNN and KINZER (1949) and KAJIKAWA (1972), the falling velocities of a small raindrop of 0.2 mm diameter and snow crystal having broad branches as shown in Fig. 5c are 70 cm/s, and less than 40 cm/s, respectively. Therefore the possibility is considered that small raindrops collide against the center of the snow crystal. However, as the chance of colliding against the center of a snow crystal is considered to be rare, the snow crystal shown in Fig. 5c is thought to grow from a frozen droplet. Figures 5a and b show three hexagonal plates which developed from the top and bottom of a frozen droplet as seen from upper (a) and lower (b) focusing. It seems that apparently these hexagonal plates were not captured by the frozen small raindrop, but grew from the frozen droplet.

Figure 6 shows three small spherical particles which fell individually on glass slides. As we cannot see the rugged surfaces of the particles shown in Figs. 6a and b, these small raindrops may be replicated as supercooled droplets. Figure 6c shows spherical droplet having well oriented hexagonal thermal etch pits.

Various shapes of frozen droplets which have been examined in laboratory experiments by TAKAHASHI (1976, 1979) were found in natural precipitation particles at Syowa Station, Antarctica.

### *3.2. Size distribution of small raindrops*

Figure 7 shows the time change of the frequency distribution of the size of small raindrops at an interval of 20 $\mu$m from 1411 to 1550 LST on April 16, 1977. Most of these particles were distributed in the size range between 160 $\mu$m and 200 $\mu$m in diameter. The particles reaching a diameter of 400 $\mu$m fell from 1524 to 1531 LST. These sizes are larger than the maximum diameter of 328 $\mu$m observed by KIKUCHI (1972) at Syowa Station. The mean diameter is 180 $\mu$m and the standard deviation is 42 $\mu$m.

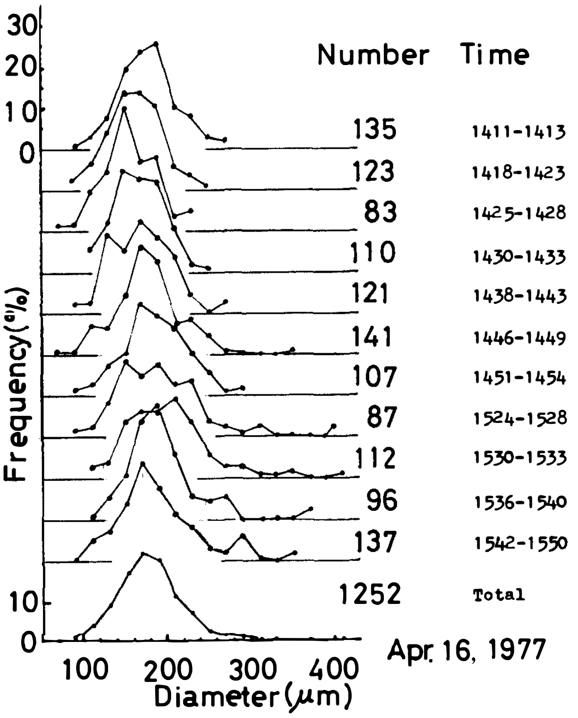


*Fig. 7. Time change of frequency distributions of sizes of small frozen raindrops observed on April 16, 1977. The frequency at each time is the same as shown in the upper left.*

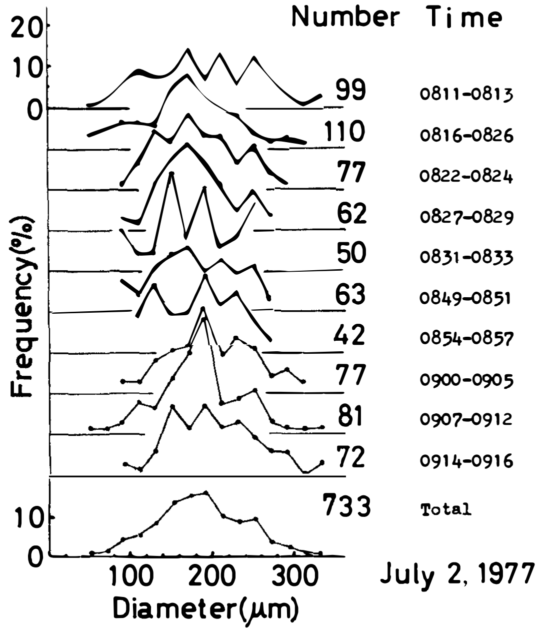


*Fig. 8. Time change of size distributions of small frozen raindrops observed on July 2, 1977.*

Figure 8 shows the time change of frequency distribution of sizes of small raindrops from 0811 to 0916 on July 2, 1977. The size distribution varies considerably with time. This may be caused by the small number of drops in each sample. The mean diameter is 184 $\mu$m and the standard deviation is 52 $\mu$m. The mean diameter of these two samples is nearly equal to that observed by KIKUCHI (1972).

### *3.3. Meteorological conditions*

Routine radio soundings of the upper atmosphere at Syowa Station were carried out at 0230 (00Z) and 1430 (12Z) LST. Unfortunately, upper air sounding was not done at 1430 LST on April 16, just when small frozen raindrops were observed. Consequently, Fig. 9 shows sounding curves at 0230 on April 16 and 17, 1977. As the temperature profiles differ little from each other, the sounding curve at 1430 on 16 is considered to be similar to that shown in Fig. 9. The surface temperature was −13°C. Although a thin inversion layer is present at the 850 mb level, no layers higher than −13°C are present. The layer between 900 mb and 840 mb is saturated

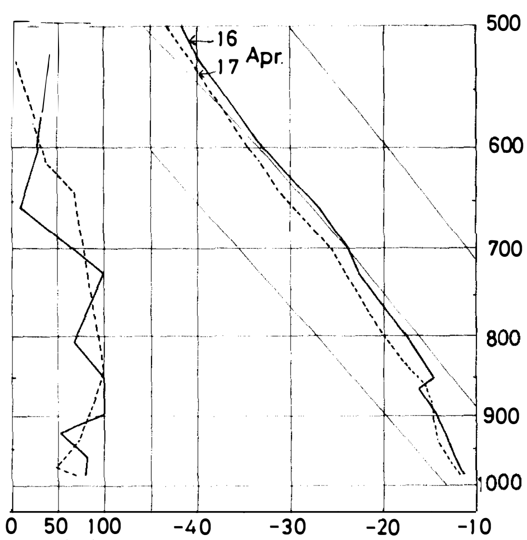


*Fig. 9. Sounding curves at 0230 LST on April 16, 17, 1977 at Syowa Station. Oblique thin solid lines are the moist adiabat. R. H. is denoted with respect to water.*

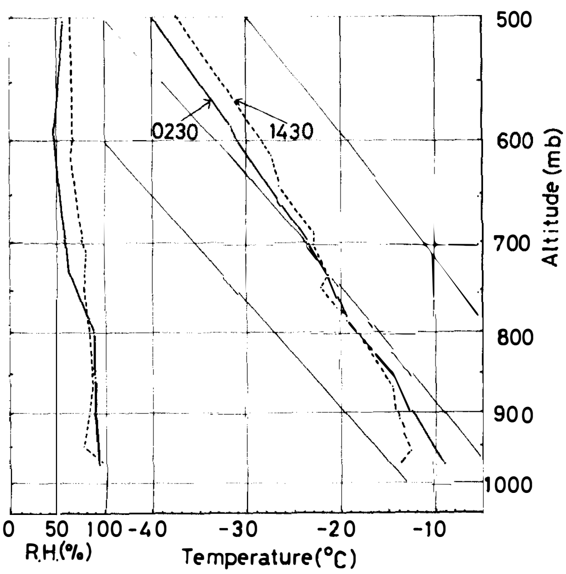


*Fig. 10. Sounding curves at 0230, 1430 LST on July 2, 1977 at Syowa Station. Oblique thin solid lines are the moist adiabat.*

with respect to water at 0230 on April 16 and their thickness is about 420 m.

The sounding curves on July 2 are shown in Fig. 10. The surface temperature was −12°C. The temperature decreased with height except at the 750 mb level where there was a thin inversion layer.

Both days were after the day on which cyclonic snow storms came and precipitation was released from layer clouds which were considered to be present along the frontal surface. Indeed, stratus and nimbostratus clouds were reported on both days.

### 3.4. *Growth of small raindrops*

Frozen small raindrops were observed at Syowa Station, Antarctica under the conditions of surface temperature below −12°C.

MAGONO and KIKUCHI (1978) observed supercooled raindrops at Inuvik, Arctic Canada under the condition of surface temperature −13°C. They thought that these drops originate from the melting of the graupel through a marked inversion layer, although a layer warmer than 0°C was not actually reported from upper soundings. However, in the present cases, frozen small raindrops are considered to grow to certain size in the supercooled states at the temperature below −12°C, since they cannot grow to an average diameter of 180 $\mu$m by condensation of water vapor and they cannot originate from the melting of snow crystals, because there was no thick inversion layer. Accordingly, these drops of drizzle size were formed by the same mechanism as in the warm rain process, though it may sound paradoxical, because they were formed in a polar region.

It has been considered that giant sea salt particles play an important role in the release of precipitation in warm clouds. Figures 11a and 11b are optical and scanning electron micrographs of aerosol particles collected at 0746 and 1524 LST on July 2, 1977, respectively. Most of the cubic shaped giant particles were of sea salt origin. Iwai *et al.* (1981) discussed these giant particles in this issue. The con-

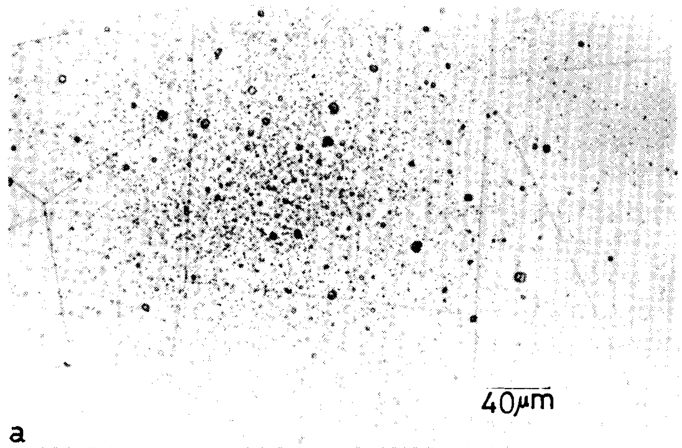


*Fig. 11a. An optical photomicrograph of aerosol particles collected at 0746 LST on July 2, 1977. Giant sea salt particles > $10^{-10}$ g (> 5 μm in diameter) were counted; it was found that there were a few particles per liter.*

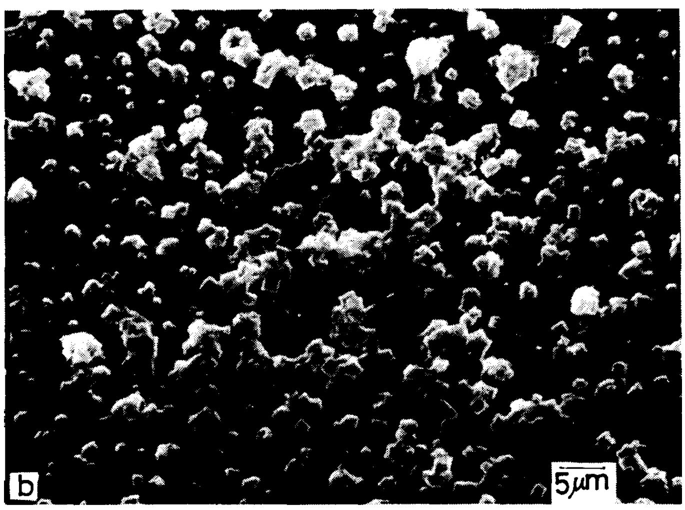


*Fig. 11b. A scanning electron micrograph of aerosol particles collected at 1524 LST, July 2, 1977. Cubic shaped particles are considered to be of sea salt origin.*

centration of giant sea salt particles whose masses were larger than $10^{-10}$ g was a few particles per liter. However, the process of warm rain in the tropics cannot necessarily be used to explain the phenomena described above. This is because most of the warm rain in the tropics falls from cumulus clouds, while in the present cases, small frozen raindrops are considered to grow in layer clouds described in the end of the foregoing paragraph.

MASON (1971) indicated that only drops of drizzle size are likely to be produced on a nucleus having a mass of $10^{-12}$ g by coalescence in layer clouds having about 0.4 g/m$^3$ of liquid water content.

We cannot discuss the growth of frozen small raindrops in the present cases in detail, because of the lack of knowledge of liquid water content and the updraft velocity in layer clouds. The author thinks that the possibility of the formation of drops of drizzle size in layer clouds exists since giant sea salt particles whose masses are larger than $10^{-10}$ g are observed.

## 4. Concluding Remarks

Small frozen raindrops of drizzle size were found in the replicas of snow crystals made on April 16 and July 2, 1977 at Syowa Station, Antarctica. These frozen raindrops were considered to be formed by coalescence of supercooled droplets which were nucleated on giant sea salt particles, and thereafter they froze. The morphology of some frozen small raindrops was found to be the same as that observed in the free fall experiments of droplets in a cold chamber by TAKAHASHI (1976, 1979), that is frozen drops with a bulging surface, with spikes, shattered and having a rugged surfaces.

The mean diameter was about 180 $\mu$m in both cases.

## Acknowledgment

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