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The Snow Crystals of "Double Gohei Twin Types"

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Abstract

For the accomplishment of the Field Research of The Monbusho International Scientific Research Program under the title of "The Studies on the Snow Crystals of Low Temperature Types and Arctic Aerosols (The Second Expedition)", we carried out the field observations from December 23, 1987 to January 21, 1988 at Alta (69°56′ N, 23°16′E) and Kautokeino (69°01′N, 23°03′E), Finnmarksvidda, Norway. Alta is located 5 km inwards from the coast line of the Alta Fjord, Norwegian Sea, and Kautokeino is located 100 km inland from Alta. During the observation period, the snow crystals of the "Double Gohei Twin Types" were newly discovered at both observation sites on January 1 and 10, 1988. One of the formation mechanisms was considered on a basis of the laboratory experiments of supercooled hemispheric water drops frozen by the contact of a single crystalline ice of needle type.

1. Introduction

The most typical shapes of snow crystals of low temperature types, that is, peculiar shapes (Kikuchi, 1969, 1970), which are known at present are the "Gohei twin" (Kikuchi, 1969 ; Sato and Kikuchi, 1985), "Sea gull", "Spearhead" type snow crystals (Kikuchi and Kajikawa, 1979) and so on. They have been observed frequently at temperature conditions below -25°C. One of characteristic features of these snow crystals is that their prism planes $(10\bar{1}0)$ grow abnormally. And their respective formation mechanisms except for the gohei twin type crystals have not been clarified. Sato and Kikuchi (1985) have interpreted the formation mechanisms of the gohei twin type crystals assuming that the crystals briefly take a cubic structure twice on basal planes of crystals just nucleated in a supercooled cloud droplet. After that, Kikuchi and Sato (1988) pointed out that the gohei twin type crystals whose tip angle is 56° are the same as the spearhead type crystals and the spearhead type crystal is one of wings of the sea gull type crystal. Further, Sato and Kikuchi (1989) have carried out a new consideration in which the crystalline structures of the gohei twin type and spearhead type crystals have been interpreted on the basis of a cubic structure model and a rotation twin on the basal plane. This paper will describe about the "Double Gohei Twin Types" newly discovered in the northern Norway.

2. Observations

Snow crystal observations were carried out at Alta (69°56′N, 23°16′E) and Kautokeino (69°01′N, 23°03′E), Finnmarksvidda, Norway as shown in Fig. 1 from December 17, 1987 to January 31, 1988. As the observation site at Alta, the Alta River Camping grounds which is located 5 km inwards from the coast line of the Alta Fjord of the Norwegian Sea and river-bank of the Alta River was selected.

Snow crystal observations were carried out in a camping hut located in a lot on the premises of the Alta River Camping. This hut was made of woods and

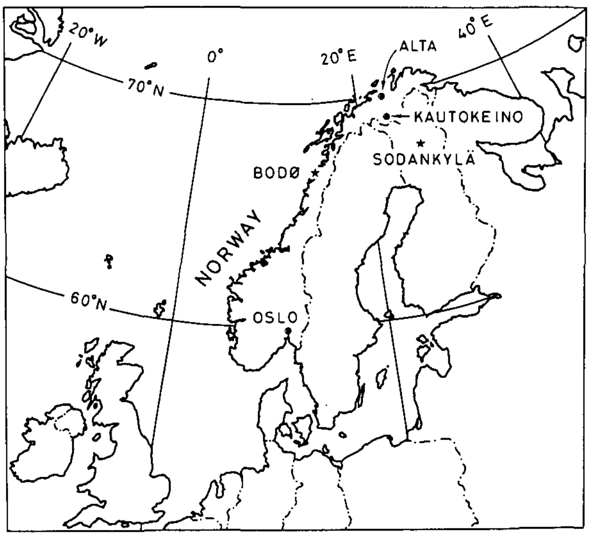


Fig. 1. Locations of observation sites and upper air sounding stations.

unheated during observation period. This allowed examination of the collected crystals without significant sublimation or melting during the short period between collection and examination. On the other hand, as the site at Kautokeino, the lot of the Prospektering Company where is located at a slope of the basin at 400 m in height and 100 km inland from the coast line was selected. A camping car was used as the observation hut in front of a private house. The camping car was unheated and hoar frost grew on the steel frames and the windows. Throughout the observations, our attention was focused on the discovery of new shapes of snow crystals and the understanding of crystalline structure of the snow crystals of low temperature types. For these reasons, microphotographs using a polarization microscope were taken by inclining and standing the gohei twin type and sea gull type crystals at different angles. Simultaneously, falling snow crystals were collected by sedimentation and replicated on 25×75 mm glass slides coated with a 1.0% Formver solution at 10 minute intervals.

Observations of air temperature at the Alta and Kautokeino sites were made continuously using a thermister thermometer and the data were stored by a data logger. Upper air soundings were made twice (00Z, 12Z) daily at the Bodø Weather Station in Norway where was apart 400 km southwestwards from the Alta site, and at the Sodankylä Meteorological Observatory in Finland where was apart 200 km southeastwards from the Kautokeino site. Weather charts were offered from the Norway Meteorological Institute.

3. Weather Conditions

Figure 2 shows a time-height cross section of air temperature and relative humidity from the surface up to 400 mb level from 00Z December 23, 1987 to 12Z January 21, 1988 at Bodø. The local time at Norway is 1 hour before Greenwich Standard Time. In the figure, the isotherms are drawn at an interval of 5°C each. On the other hand, isopleths above 80% of relative humidity are shaded by dark screens. Short horizontal bars with spikes at both ends above the time-height cross section figure, show the observation period of snow crystals in each day. Typical shapes of snow crystals observed during the period 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). The classification is divided into 10 types and 4 characteristics, however, code number zero, hail types of particles could not be observed during the period. As may be clearly seen, the classification does not include crossed plates which are a typical shape growing in low temperature regions. Thus we have added this shape to the classification depicted by a graphic symbol (⇔). Further, we have added graphic symbols of (⊕) and (∨) for "Gohei twin" and "Sea gull" types of snow crystals, respectively which are most typical shapes in low temperature regions (Kikuchi and Magono, 1978 , Kikuchi et al., 1987)

During the observation period, the surface air temperatures recorded were approximately from +5°C to −28°C as shown in Fig. 3. As seen in Figs. 2 and

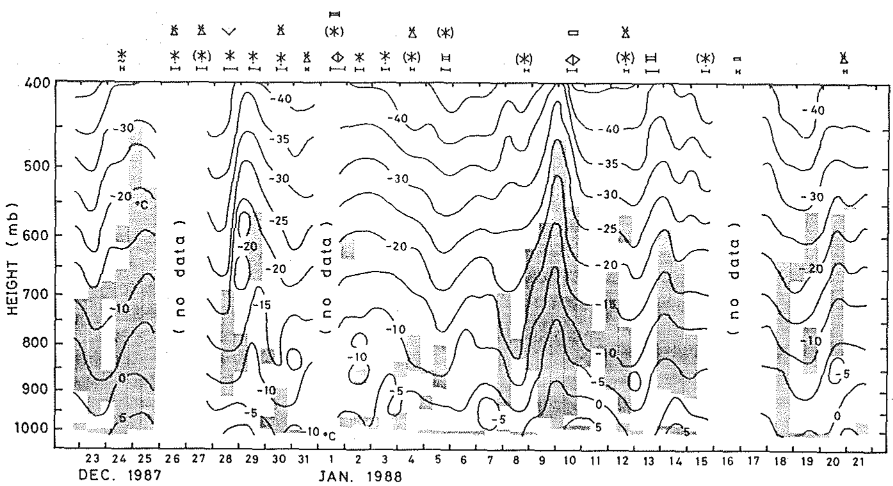


Fig. 2. Time-height cross section of air temperature and relative humidity during the observation period at Bodø, Norway.

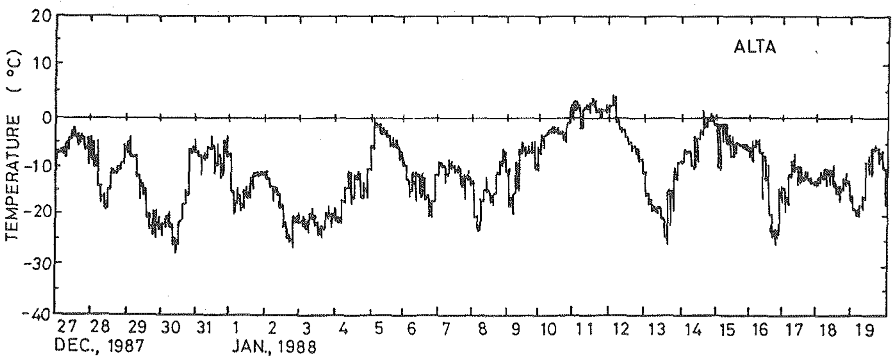


Fig. 3. Variation of the surface air temperature at Alta.

3, sometimes very warm air masses invaded into the layers between the surface and 400 mb, especially, it was notable from 24 to 25 December 1987 and from 9 to 12 January 1988. Therefore, dendritic crystals including twelve-branched crystals were predominant through the observation period (Uyeda and Kikuchi, 1990a, b). Peculiar shaped snow crystals, that is, gohei twin and sea gull type crystals were observed mainly on January 1 and 10. Ice fog and diamond dust type ice crystals were observed rarely. On the other hand, graupel particles and rimed crystals were observed frequently. The same time-height cross

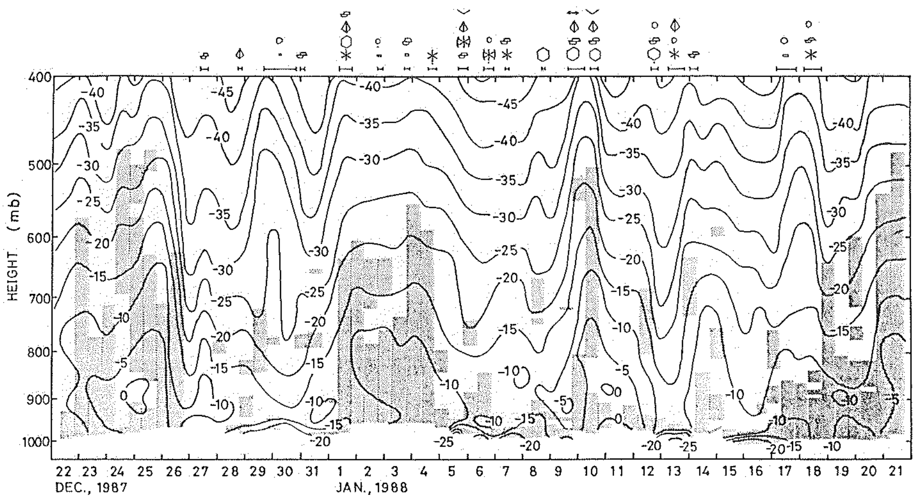


Fig 4 Time-height cross section of air temperature and relative humidity during the observation period at Sodankyla, Finland

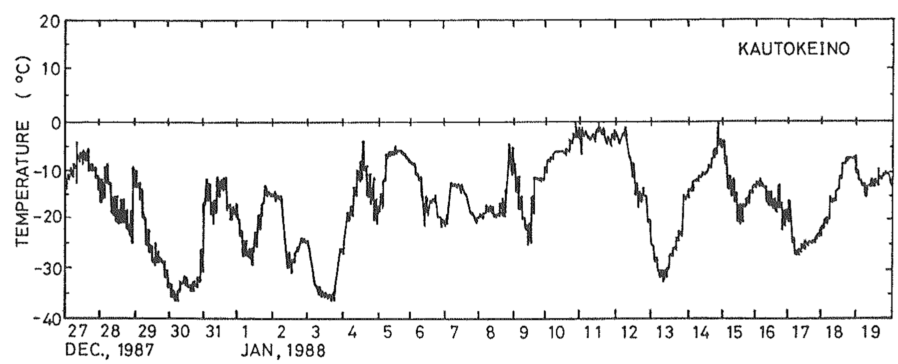


Fig. 5. Variation of the surface air temperature at Kautokeino.

section at Sodankylä is shown in Fig. 4 during the same observation period for Kautokeino site. The local time at Sodankylä is one hour ahead of the local time at Kautokeino.

During the observation period, the surface air temperatures recorded at the observation site was approximately from 0°C to −36.7°C as shown in Fig. 5. As seen in Figs. 4 and 5, sometimes very warm air masses invaded into layers between 950 mb and 700 mb, especially, it was notable from 23 to 25 December, from 1 to 5 January and from 9 to 11 January. Therefore, as similar to the Alta site, dendritic crystals including twelve-branched crystals were predominant (Uyeda and Kikuchi, 1990a, b), and on January 18, eighteen-branched crystals (Kikuchi, 1987; Kikuchi and Uyeda, 1988) were reconfirmed. Peculiar shaped snow crystals, that is, "gohei twin" and "sea gull" type crystals were observed on December 28, 1987, January 1 and 5, and from January 8 to 10, 1988. Ice fog and diamond dust type ice crystals were observed frequently on December 29 and 30, 1987, January 3, 9, 12, 15, 17 and 18, 1988. Some of them had plate or dendrite caps at the tips of their crystals (Uyeda and Kikuchi, 1990a). On the other hand, graupel particles and rimed crystals were observed frequently. As seen in the graphic symbols, throughout the observation period, some types of snow crystals were observed except for a few days.

4. Observational results

A peculiar shape of snow crystals of low temperature types was observed at both observation sites, Alta and Kautokeino, on January 1 and 10, 1988. Examples of this shape are shown in Figs. 6 and 7. The external shape of this crystal closely resembles that of the gohei twin type. However, the crystal grows from a center nucleus to both sides. Therefore, the crystal was named "Double Gohei Twin Type". Furthermore, the crystal of the same type as shown in Fig. 8 was found from the data of the former expedition carried out in the winter of 1985 and 1986 at Inuvik, Northwest Territories, Canada. On the other hand, although the external shape was the double gohei twin type, there was a gohei twin type judging from crystalline structure as shown in Fig. 9. Therefore, a polarization microscope must be utilized for judging whether it is either the double gohei twin types or not.

Barry (1967) and Hare (1968) emphasized that 850 mb weather charts should be used for the synoptic analysis in winter seasons in the arctic regions because of the surface fronts and troughs were masked by the cold air pools originating by the radiative cooling on the ground surface. Figure 10 shows an 850 mb

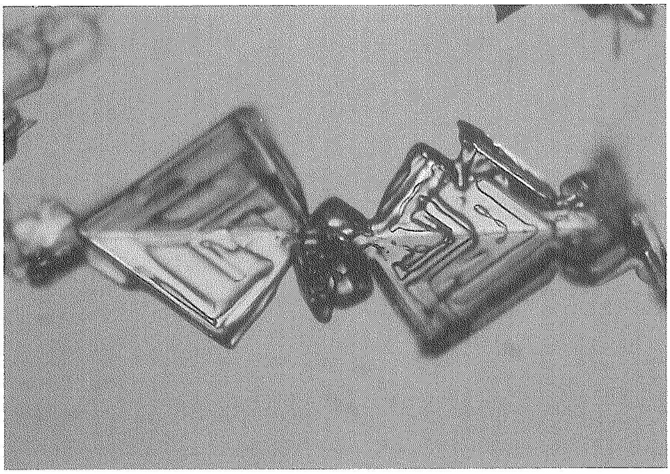


Fig. 6. A polarization microphotograph of double gohei twin type crystal observed at Alta.

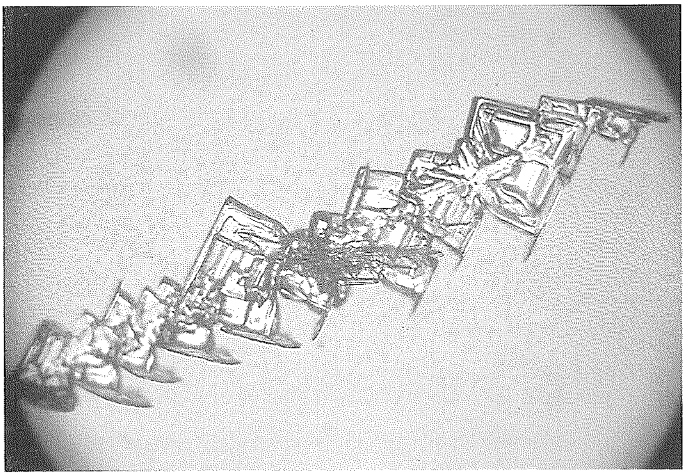


Fig. 7. Same as Fig. 6 but for at Kautokeino.

weather chart of northern Europe centered on the Scandinavia Peninsula on 00Z January 2, 1988. The local time of Norway is 1 hour ahead of GMT. This chart is the closest time when the double gohei twin types were observed at night on January 1, 1988. The observation area was covered by a low pressure. The closest upper air sounding stations in the observation area are at Bodø in

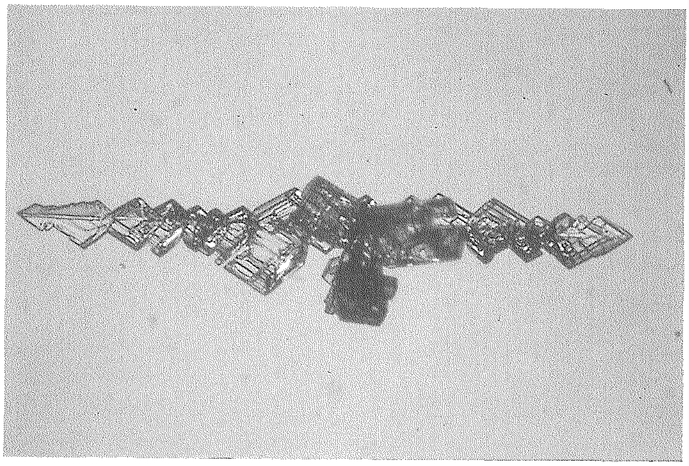


Fig. 8. Same as Fig. 6 but for at Inuvik, Arctic Canada.

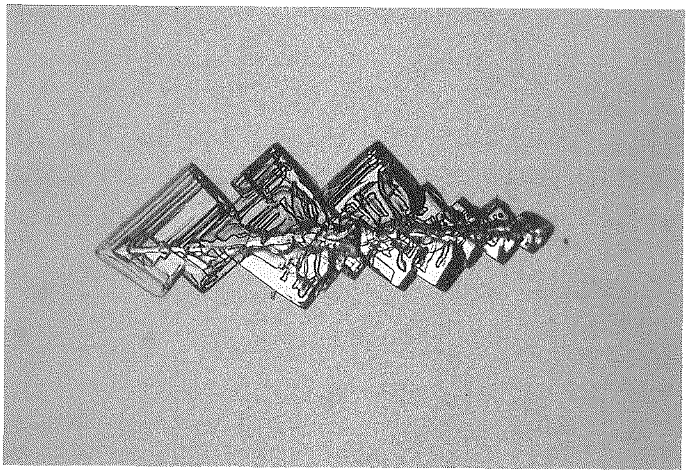


Fig. 9. A polarization microphotograph of gohei twin type crystal observed at Inuvik, Arctic Canada.

Norway and Sodankylä in Finland as shown in Fig. 10. As seen in this figure, the air temperature at the 850 mb level was −11°C under southerly winds. Generally, the southerly winds from far inland at the observation area were relatively colder than other wind directions. On the ground surface, since the Alta River Valley is running from the north to south direction, the southerly

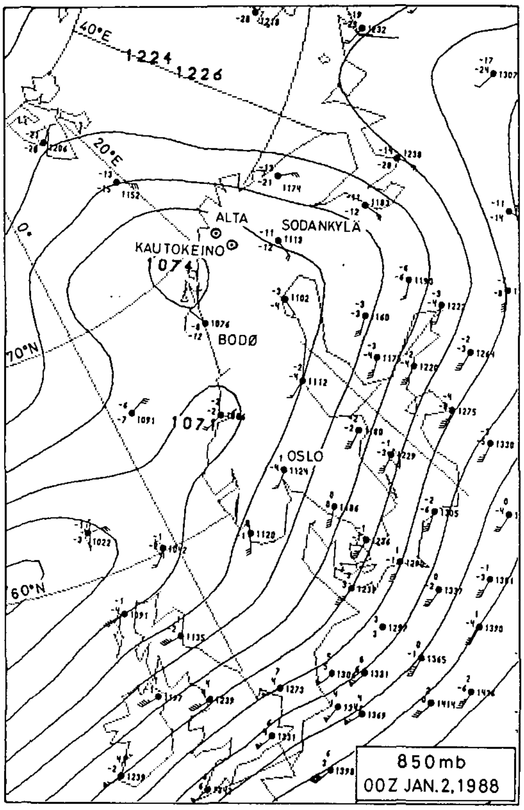
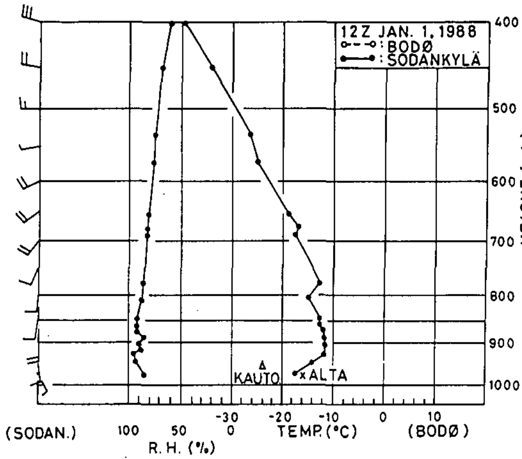


Fig. 10. 850 mb weather chart at 00Z Jan. 2, 1988.

winds at the Alta site carry colder air which is formed by a radiative cooling at inland and mountain areas.

Figure 11 shows the upper air sounding data at Bodø and Sodankylä stations. Open circles connected with dashed lines and solid circles connected with solid lines show the data from Bodø and Sodankylä stations, respectively. Wind directions and velocities at both stations are represented on the right hand side for Bodø and the left hand side for Sodankylä by barbs and flags. The short and long barbs, and flags are 5, 10, and 50 knots, respectively. On the 12Z Jan. 1, 1988, we obtained no data at Bodø. Surface temperatures at Alta and Kautokeino are approximately −16°C marked by a cross and −24°C marked by an open triangle, respectively. Therefore, considering the air temperature profile of upper air sounding, it is understood that there are the surface temperature inversions at both sites. The level of −25°C where there are suitable



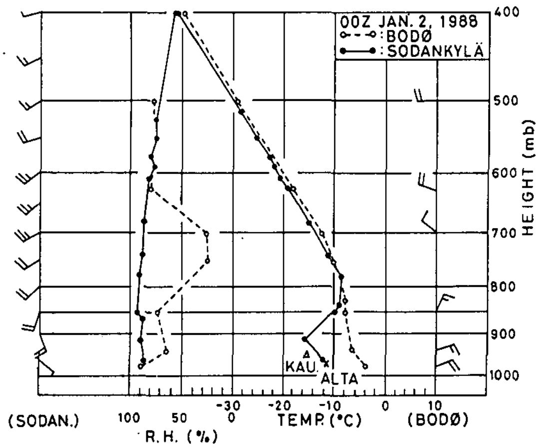


Fig. 11. Upper air sounding curves at Bodø and Sodankylä. Upper: 12Z Jan. 1, 1988. Lower: 00Z Jan. 2, 1988.

conditions for the growth of snow crystals of low temperature types (Kikuchi, 1969) was recognized at 580 mb and there was saturation with respect to ice (Sato and Kikuchi, 1987) from this level to the ground surface. However, at 00Z Jan. 2, 1988, although the level of $-25°C$ was held at the same height, the temperature conditions of lower layer below 700 mb level changed to warm conditions. The surface temperature at Sodankylä increased from $-18°C$ to $-12°C$ and at Bodø was $-4°C$. The surface temperatures at Alta and Kautokeino increased from $-16°C$ to $-11°C$ and from $-24°C$ to $-15°C$, respectively.

Figure 12 shows an 850 mb weather chart at 12Z, Jan. 10, 1988. The

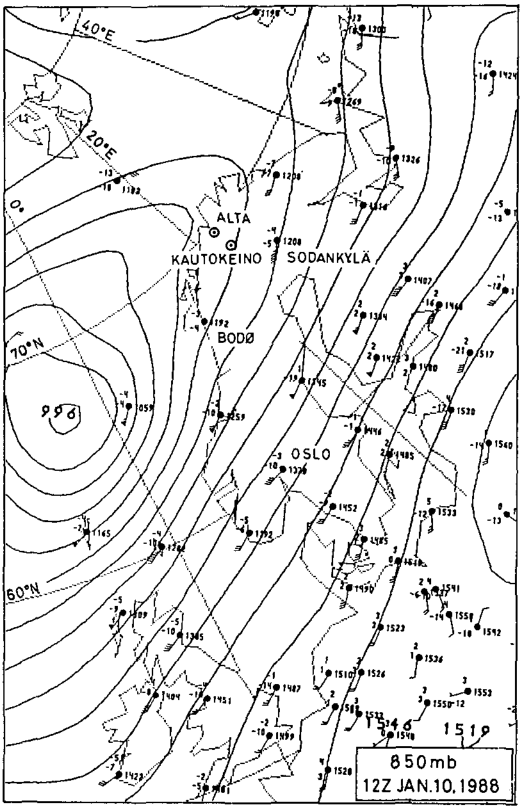


Fig. 12. Same as Fig. 10, but for 12Z Jan. 10, 1988.

observation area was under a low pressure where the center of low pressure was found to the west of Bodø in the Norwegian Sea. Therefore, the southwesterly winds prevailed at Bodø and Sodankylä. In general, the southwesterly winds bring a warm air advection that passed over the Gulf Stream towards north along the Scandinavia Peninsula. The air temperatures at Bodø and Sodankylä, as a result, were as warm as -3°C and -4°C, respectively. Figure 13 shows the upper air sounding data at both stations. As shown in the figure, the level of -25°C was very high on the 480 mb at both stations. However, at 12Z Jan. 10, the level of -25°C decreased to 570 mb in height at Bodø. This means a cold air advection from high altitudes. On the other hand, the level of 850 mb showed a water saturation at both stations, however, above this level, all levels show below ice saturations at both stations. The air temperatures corresponding to the level of the water saturation were very high as described previously.

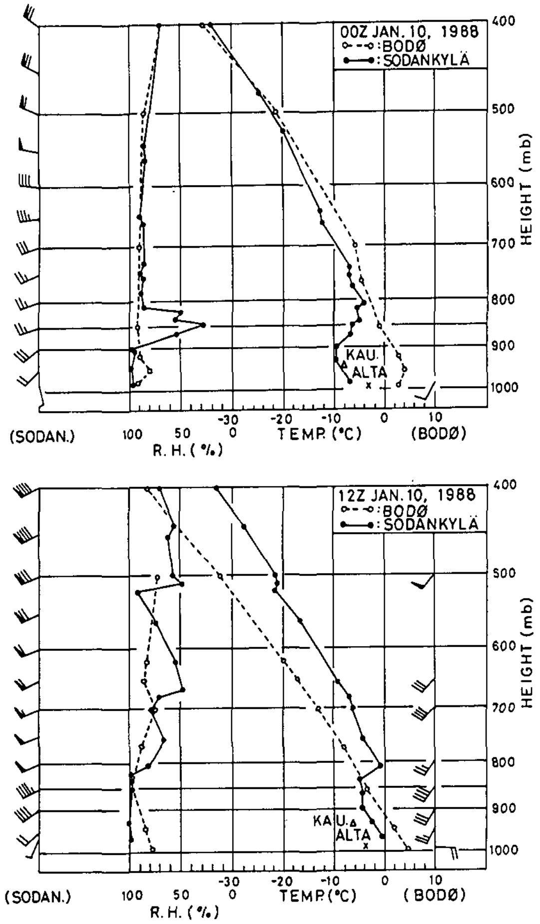


Fig. 13. Same as Fig. 11. Upper: 00Z Jan. 10, 1988. Lower: 12Z Jan. 10, 1988.

The surface air temperatures at both stations were 5°C at Bodø and −0.5°C at Sodankylä, respectively. Further, the temperatures recorded were −4°C at Alta and −7°C at Kautokeino at the observation sites, respectively. Since a typical shape of snow crystals shown in Figs. 6 and 7 was observed at 09Z Jan. 10 at Alta and at 16Z Jan. 1 at Kautokeino.

5. Consideration and conclusions

Considering the growth mechanism of snow crystals of "Double Gohei Twin

Types", we were reminded of our laboratory experiments carried out about ten years ago (Uyeda and Kikuchi, 1980). The experimental mode is transcribed schematically in Fig. 14. In their experiments, hemispheric water drops of the size from 0.6 to 1.0 mm in diameter were made. The drops were cooled down to the intended temperatures which were measured by a thermojunction on the stage of the apparatus in a cold room. The supercooled hemispheric water drops were seeded with a single crystalline ice of needle type (frost growing in a cold room) about 1 cm in length prepared in advance. The ice needle was set on a supporter fixed on a microscope tube in order to make the direction of the *c*-axis of the needle perpendicular to the plane of the stage of the microscope. By adjusting the supporter upward and downward in this way, supercooled hemispheric water drops were seeded around the top with a basal plane of the ice needle. As soon as the ice needle touched the surface of supercooled hemispheric water drop, the drop froze suddenly. The frozen hemispheric water drops were cut into thin sections by a small safely razor blade. The plane of the thin section was parallel to the plane of a glass slide. The thin sections were converted to the stage of polarization microscope and taken by color photographs. Figures 15 and 16 show features of thin sections of frozen water drops seeded with a basal plane under a polarization microscope. In Fig. 15, the crystals named as "a", "b", and "c" have the same orientation. Therefore, the crystals of "a" and "b" are in a relationship of "twin" to each other. In a similar manner, the crystals of "b" and "c", "c" and "a" show "twin" relations. Figure 16 has the same relation, however, in this case, "a" and "b" relation alone. It is well known that tiny single crystalline ice particles (ice fragments) are present in the atmosphere during snowfall (Magono et al., 1962). On the

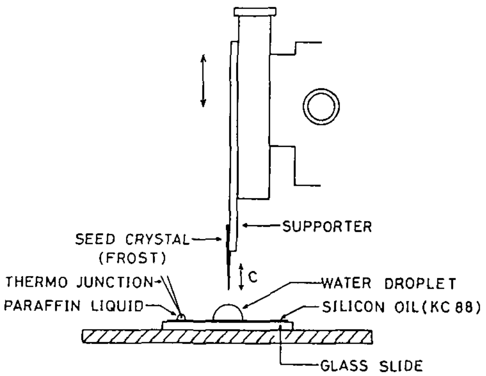


Fig. 14. Schematic figure of experimental mode (Uyeda and Kikuchi, 1980).

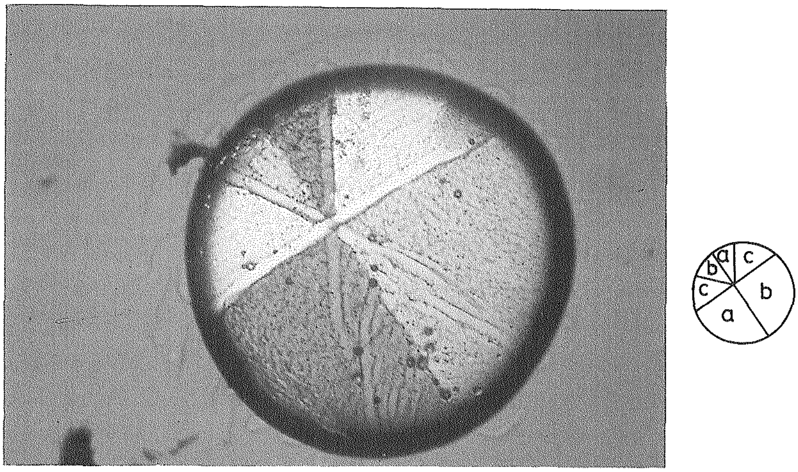


Fig. 15. A polarization microphotograph of thin section of frozen water drop (Uyeda and Kikuchi, 1980).

other hand, it is well known that a number of supercooled cloud droplets are present in the atmosphere during snowfall. Therefore, it is understood easily that if the ice fragments come in contact with the surface of supercooled cloud droplets, some of droplets are frozen in a twin types manner. If one of snow crystals were grown from the frozen droplets (Kikuchi and Ishimoto, 1974) under

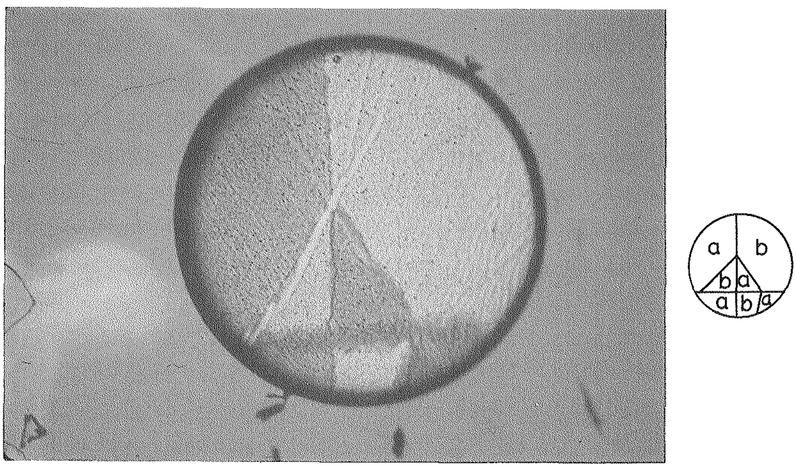


Fig. 16. Same as Fig. 15.

the temperature conditions in which the column types are suitable to grow, the crystal might grow the "Double Gohei Twin Types" rarely.

The snow crystals of double gohei twin types were observed in the polar regions of the northern Norway. Considering the growth conditions of air temperature and relative humidity of this crystal, however, it is concluded that the crystal shown in Fig. 6 did not grow in the low temperature conditions below $-25°C$ but high temperature conditions between $-3°C$ and $-10°C$, that is, "column region" in the warm air temperature conditions. On the other hand, as to the crystal observed on Jan. 1 at Kautokeino shown in Fig. 7, the growth of plates at the ends of all columns constituting the crystal was recognized. Considering the growth conditions of air temperature and relative humidity, and the size of this crystal, therefore, it is concluded that the crystal might have grown in the low temperature conditions. Thus it is concluded that the snow crystals of double gohei twin types observed in the polar regions of northern Norway grew in different air temperature conditions from each other.

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