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# Preliminary Investigation on the Growth of Natural Snow Crystals by the Use of Observation Points Distributed Vertically

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**Abstract**

The Cloud Physics Group of Japan made observations of snow crystal forms by various methods at five observation points which were distributed vertically from elevations of 100 m to 1023 m at Mt. Teine, Hokkaido, through the period from 26 to 31 Jan. 1959. Aspiration psychrometers and rawin sondes were mainly used to measure the air temperature and humidity.

The results are summarized as follows,

1. Nakaya's $T_a$-s diagram represents fairly well the growth of natural snow crystals. The crystal forms observed at the earth surface are mainly effected by the temperature and humidity of the air layers of altitudes lower than 2000 m.

2. From macroscopic measurements, frequently it was observed that snow crystals of various types grew at the humidity very near to ice saturation, or some times, a little below it.

3. The beautiful plane dendritic snow crystals are not found in heavy snowfall but generally in light snowfall when cloud was not recognized near by.

4. The necessary conditions for the formation of large snowflakes are the existence of a thick moist atmospheric layer and of air temperatures higher than about −10°C.

## 1. Introduction

The relation between the snow crystal forms and the meteorological conditions was studied by Nakaya[1], in laboratory experiments, and his theory was proven by Gold and Power[2], Murai[3] and Kuettner and coworkers[4] using aerological sonde data obtained during snowfall. As for the growth of natural snow crystals, however, there are no available observational data. It is in order to observe the rate of the growth that observations are made under known meteorological conditions observed at several observation points distributed vertically.

The Cloud Physics Group of Japan made the observation of natural snow crystals by various methods at five observation points distributed vertically

* The name of the colleagues is listed in Table 1 below.

at Mt. Teine in January 1959 and measured the form and size of snow cyrstals of almost all types.

## 2. Methods employed

As one sees in Fig. 1, Mt. Teine is located about 8 miles to the west of Sapporo where rawin sonde soundings were carried out by the Sapporo Meteorological Observatory at 0900, 1500 and 2100 JST each day during the period of the observation. The predominant wind direction during the period was from the northwest, and the observation points corresponded to the windward of the wind, so the atmospheric conditions measured by the aerological sounding may somewhat differ from those above the mountain except for the case of large uniform snowfall.

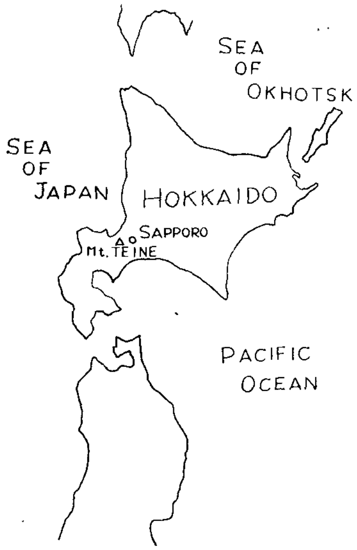



Fig. 1. Location of observations.

The horizontal distribution and vertical distribution are shown in Figs. 2 and 3. The observation points at altitudes 1023 m, 800 m, 560 m, 300 m and 100 m are called Point 1000, Point 800, Point 500 and so on respectively in this paper. The upper three points are close together, but the lower two points are somewhat far from the upper points; accordingly snow crystals observed at the lower two points were sometimes not recognized as beloging to the same falling system.

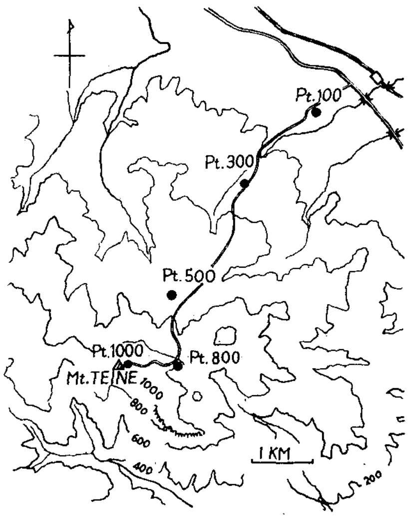



Fig. 2. Horizontal distribution of observation points.

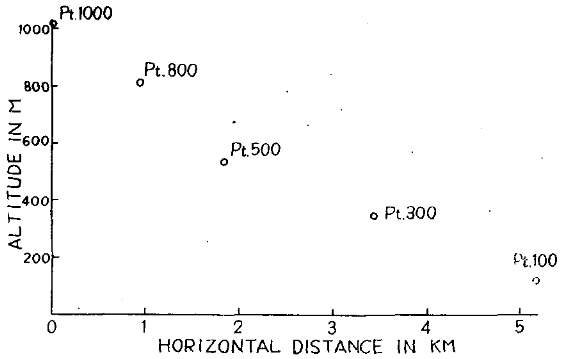



Fig. 3. Vertical distribution of observation points.

Table 1. The name of colleagues and the terms of their observations.

| Observation points | Altitudes | Terms of observation | Names |
|---|---|---|---|
| Point 1000 | 1023 m | chief | Choji Magono<br>Daisuke Kuroiwa |
| Point 1000 | 1023 m | humidity by special methods<br>humidity, temperature<br>semi-microscopic photographs<br>microscopic photographs<br>size distribution of cloud droplets<br>replicas of snow crystals | Kazuhiko Itagaki<br>Shoichi Koenuma<br>Katsuhiro Kikuchi<br><br><br>Tsutomu Takahashi<br>Tsutomu Nakamura |
| Point 800 | 800 m | humidity, temperature | Tsutomu Takahashi<br>Tsutomu Nakamura |
| Point 500 | 560 m | replicas of snow crystals<br>shadowing photographs<br>semi-microscopic photographs<br>microscopic photographs<br>humidity, temperature | Keiji Higuchi<br><br>Jiro Muguruma<br><br>Tadashi Kimura |
| Point 300 | 300 m | humidity, temperature<br>replicas of snow crystals | Keitaro Orikasa<br>Ken-ichi Sakurai |
| Point 100 | 100 m | humidity by special methods<br>semi-microscopic and microscopic photographs<br>replicas of snow crystals<br>shadowing photographs,<br>humidity, temperature | Teisaku Kobayashi<br><br><br>Toshiichi Okita<br>Goro Wakahama |
| Hokkaido University at Sapporo | 30 m | replicas of snow crystals<br>photograph of clouds | Masahiko Shishido |
| Sapporo Meteorological Observatory at Sapporo | 30 m | rawin sonde | Sapporo Meteorological Observatory |

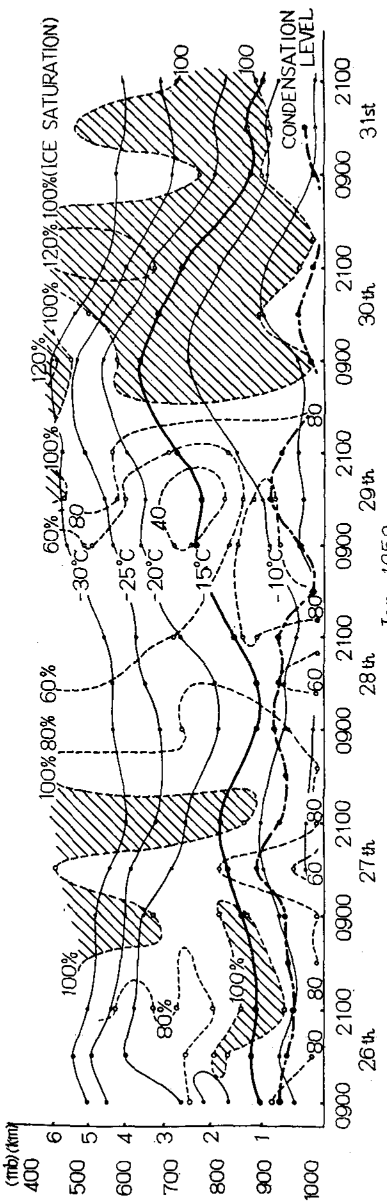



Fig. 4. Time cross section during the period of the observation.

Frequently mediate snow showers were observed at the upper points even when no snowfall was observed at lower points. This discrepancy is considered to be due to the effect of orographic snow showers.

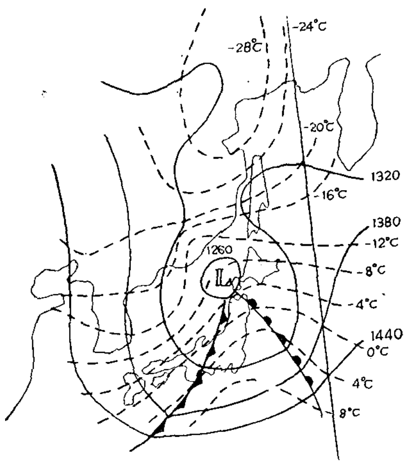
The observers and their works during the observation are listed in Table 1.

The work of the observer at Hokkaido University was to observe the cloud base and the cloud type over or above Mt. Teine from outside of the observation area. This work was very useful, because the observers located at the mountain often could not observe the clouds by which they were surrounded. Among the methods employed in observing snow crystals, the securing of replicas and microscopic photographs were most useful. As for the measurement of humidity of air, Assmann's aspiration psychrometer was most reliable.

The observations at the five points were carried out simultaneously, every 10 minutes during 3 hours after the rawin sonde sounding times (0900, 1500, 2100) from 26 to 31 Januray 1959.

## 3. General results

The time cross section obtained using aerological sounding only is shown in Fig. 4. Solid lines show isotherm and imaginary dotted lines represent relative humidity with respect to ice saturation. The thick solid line shows specially the isotherm of −15°C around which snow crystals are considered to grow rapidly to form of dendritic type. In general, moist air existed at −15°C level on the 26th and night of the 27th when light snow showers were observed at the mountain area. Early in the morning of the 30th a cyclone passed through Hokkaido as shown in Fig. 5, warm moist air flowed into the observing area and brought heavy snowfall. This snowfall was on a large scale and the observation points were located to the lee of the wind, so in this case the data obtained by rawin sonde sounding are considered to be reliable.




850 mb 0900 JST
Jan. 30, 1959

Fig. 5. Synoptic 850 mb chart for 0900, Jan. 30 1959.

Snowfall was always observed at Pt. 1000 during the period of the observation except on the 29th, but the moist air level was limited to few short periods. This strange phenomenon is considered to result from the precipitation due to the condensation by orographic ascending air, because the condensation level was always lower than the altitude of Pt. 1000 (890 mb) as shown by chain lines in the lower part of Fig. 4. In addition to that, several small crystals in the initial stage of growth were almost always observed at the upper points.

Therefore, for the condition at altitudes below 1023 m, the data obtained by the aspiration psychrometer were taken, abandoning the rawin sonde data. As for upper levels higher than 1500 m, the data obtained by rawin sonde were accepted as they were. The conditions at the intermediate level between 1500 m and 1023 m were assumed suitably using the condition of the two boundaries: 1500 m and 1023 m. The time cross section obtained thus is represented in Fig. 6 in which the layer lower than 3000 m is shown magnified. The ordinate shows the altitudes in m and the altitude of five observation points is represented by horizontal short thick lines in the ordinate. The type of representative snow crystals observed at Pt. 1000, Pt. 500 and Pt. 100 at each 3 hours interval is shown in the upper part of the figure schematically. The first type shown on each of the top lines means the

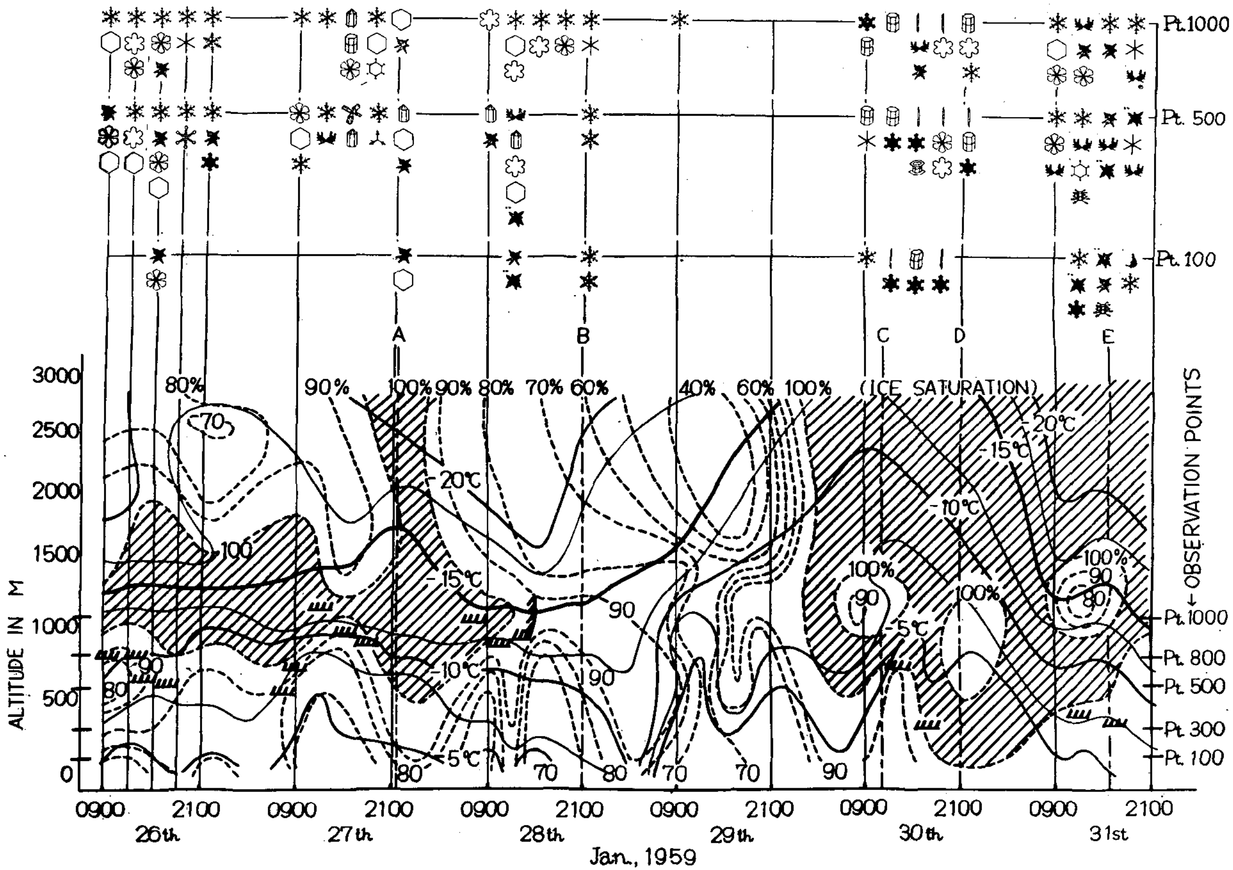



Fig. 6. Time cross section considering the observation at Mt. Teine. Principal crystal types observed at each point are shown in the upper part.

type of snow crystal which fell most frequently. The region of humidity higher than ice saturation is shown by shaded area in Fig. 6. Cloud bases are shown only when ascertained by visual observation at each observation point and by photographs from Sapporo, although the exact determination of the cloud base was difficult. From the figure it may be seen that shade hatching areas, in other words, moist atmosphere layers, existed near or above Pt. 1000 always when snowfall was observed at that point. The only one exception is on the night of the 28th. The exception is important, so it will be touched upon later.

According to Nakaya's $T_a$-s diagram, temperature of −15°C is the most suitable condition in which snow crystals grow to dendrite, while at temperature of −5°C snow crystals grow to needle form. From an inspection of Fig. 6, it may be noted that from the 26th to 28th when −15°C isotherm existed near or above the top of the mountain, snow crystals of dendrite were predominant, and on the 30th when −5°C isotherm had descended to the observation point altitudes, there were observed only thin hollow column or needle crystals. One may understand that Nakay's diagram agrees very well with the type of natural snow crystals. This fact leads to the conclusion that the type of snow crystals is determined by the temperature of the air layer below altitude 2000 m. It is well known that in the $T_a$-s diagram the region of column and plate type is distributed symmetrically around the dendritic region : −15°C. However considering the time cross section above, it will be accepted that the snow crystal type in a natural fall is mainly effected by the warmer temperature region between the two temperature regions of crystal formation, in other words, by higher temperature than −15°C. This is considered to result from the fact that at higher level vapor density is low as is air density likewise, and the absolute value of vapor is small even if the air of the upper level was saturated because the air is colder than that of the lower level. Accordingly, if any crystals are born at a comparatively higher level, they do not grow rapidly until they fall into lower layer. As for the relatively dry regions above the mountain on the 30th and 31st as seen in Fig. 6, it is not clear whether those regions have any connection with crystal forms observed or not.

### 4. Crystal growth and snowflake formation

At time sections A(2140, 27th), B(2100, 28th), C(1120, 30th), D(2130, 30th) and E(1610, 31st) in Fig. 6, characteristic snowfalls were noticed. For each time section, some descriptions should be offered in detail. Fortunately the

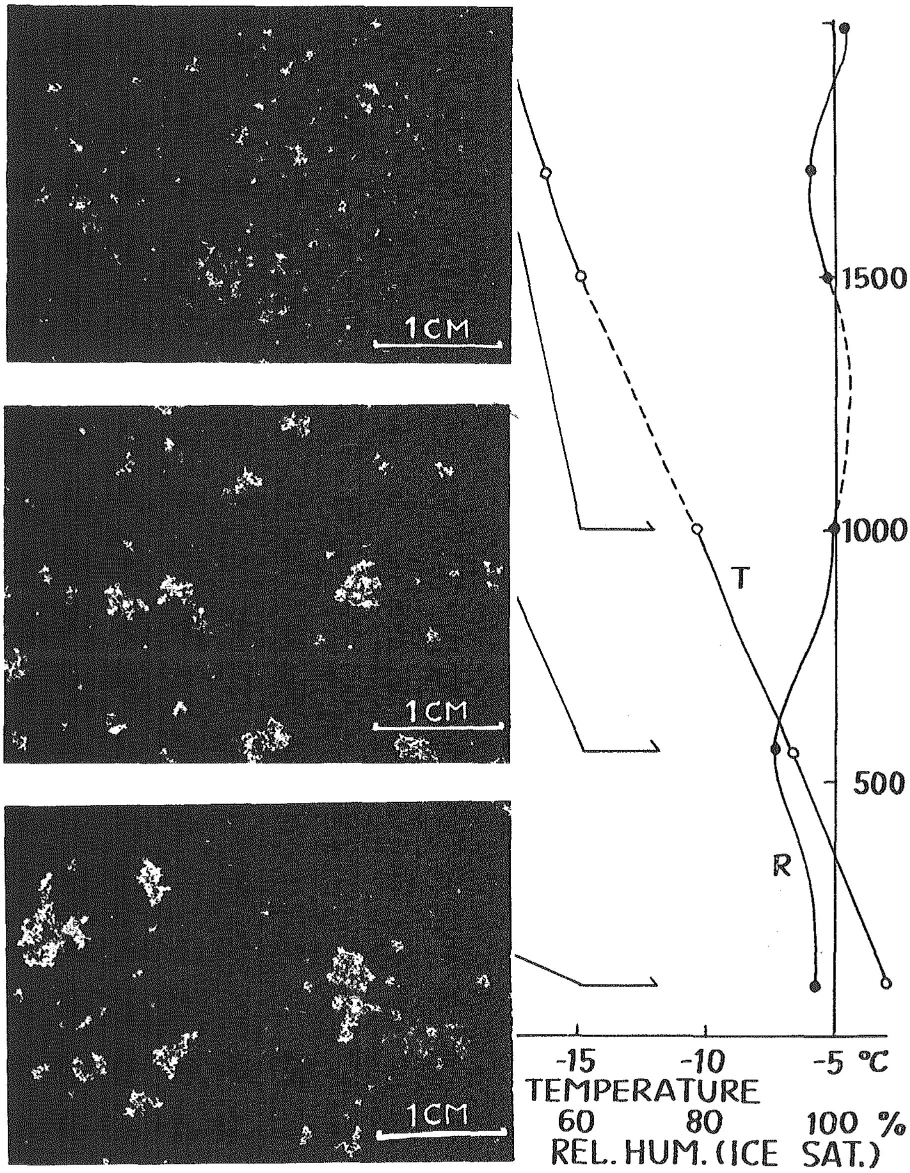



Fig. 7. Growth of snowflakes and meteorological conditions, 2130-2150, Jan. 27.

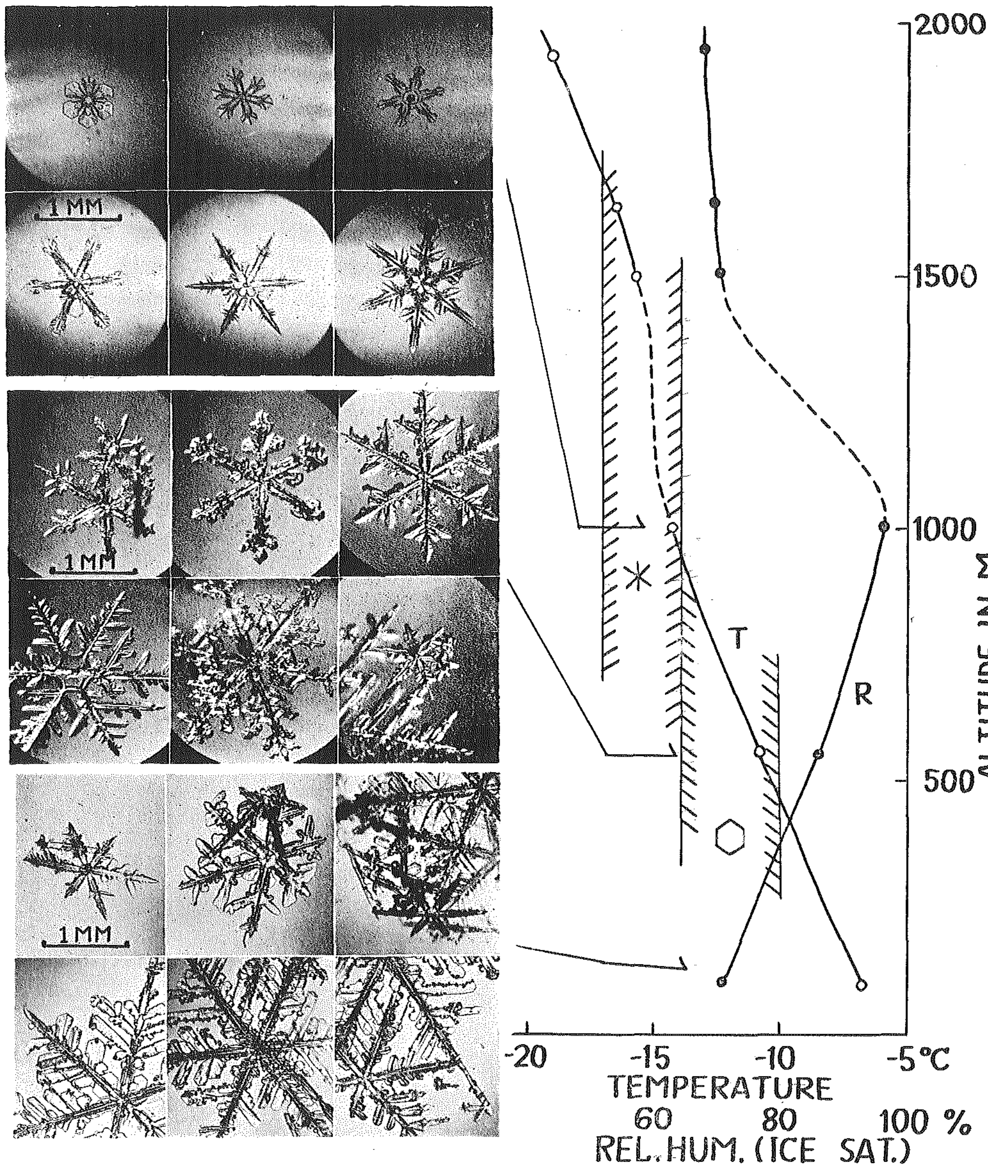



Fig. 8. Growth of plane dendritic snow crystals and meteorological conditions, 2100-2110, Jan. 28.

time sections were close to each rawin sonde sounding time respectively, therefore, the data for the vertical size distribution of air temperature and relative humidity above altitude 1500 m in the time sections are considerably reliable. Of course, as mentioned above, the data obtained by the aspiration psychrometer were adopted for the meteorological conditions below Pt. 1000 level.

The data are shown by solid lines and the condition between 1500 m and 1023 m are shown by dotted lines in following figures in which pictures of snow crystals and snowflakes are also included. The altitude at which the pictures were obtained are shown by arrows.

Time section : A. After 2100 on the 27th, large snowflakes composed of dendritic crystals were observed. It may be seen in Fig. 7 that the snowflakes began to form just at Pt. 1000 level. It seems also that the snowflake formation began when snow crystals fell into the layer warmer than −10°C as previously pointed out by the one of the present authors[5]. This fall of large snowflakes was accompanied by the occurrence of a thick moist air layer as seen in Figs. 6 and 7. This is the case also at time section D.

Time section : B. On the 28th, snow crystals of dendritic type continued to fall. Clouds had cleared up at about 1500, but the crystals continued to fall although the fall was light. All the snow crystals observed at all observation points were of very beautiful plane dendrite form. The vertical distribution of air temperature and humidity at 2100 is shown in Fig. 8. There existed

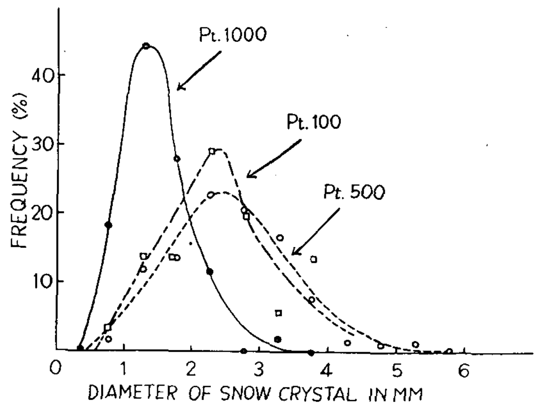



Fig. 9. Size distribution of plane dendritic snow crystals observed at three observation points, 2130-2150, Jan. 28.

a thick layer of –15°C near Pt. 1000 actually. It is notable that the air was not saturated and no clouds were recognized near by; however perfect snow crystals fell and grew as shown in the left side of the figure. The size distribution is shown in Fig. 9 in width 0.5 mm. It is noted that the mean diameter of the snow crystals observed at Pt. 500 was markedly larger than that at Pt. 1000. The mean diameter of snow crystals at Pt. 100 was about the same as that at Pt. 500, influenced by the fact that the air layer between Pt. 500 and Pt. 100 was not moist. The top of the branch of snow crystals observed at Pt. 100, to some extent, changed to sector form, perhaps owing to their falling into warmer and less humid air layer. This statement that snow crystals of dendrite grew in not saturated air with respect to ice may be thought to be strange, so about this, detailed discussion will be presented later.

Time section : C. It is characteristic to time section C(1130, 30th) that lapse rate of air temperature was very small and the atmosphere was saturated from near surface to altitude 6000 m as shown in Fig. 4. Air layer of temperatures between –5°C and –8°C was very thick. This condition is suitable for the growth of thin hollow column and needle type crystals. Conferming the results of Hallet & Mason's[6] and Kobayashi's[7] experiments, it was observed as shown in Fig. 10 that the snow crystals of hollow column grew moderately between Pt. 1000 (–9°C) and Pt. 500 (–7°C), but below Pt. 500 (–6°C) the crystal type changed to needle. In this time section it is also noticed that the layer between the lower two points also was not saturated, as seen in Fig. 10. During the daytime of the 30th, almost all snow crystals were of thin column or needle type. This fact means that almost no snow crystals formed at levels higher than the –8°C level. The relatively dry region above the mountain seen in Fig. 6 perhaps plays some role in connection with the fact above mentioned, but it is not sure.

Time section : D. From about 1500 on the 30th, the temperature of the whole atmosphere got lower, and rimed dendritic snow crystals were observed simultaneously with those of needle type. It is shown in Fig. 11. Snow crystals of needle type grew to some extent and those of dendrite already began to form snowflakes near the level of Pt. 1000 where air temperature was about –8°C. It is probable that the snow crystals of dendrite type were formed at just above Pt. 1000 and those of needle type formed below Pt. 1000.

Time section : E. Near the end of the observation period, the process of the formation of graupel of cone-type was observed in detail as seen in the three pictures in Fig. 12. It seems that the graupel of cone-type originates from a rimed branch separated from rimed snow crystals as pointed out by

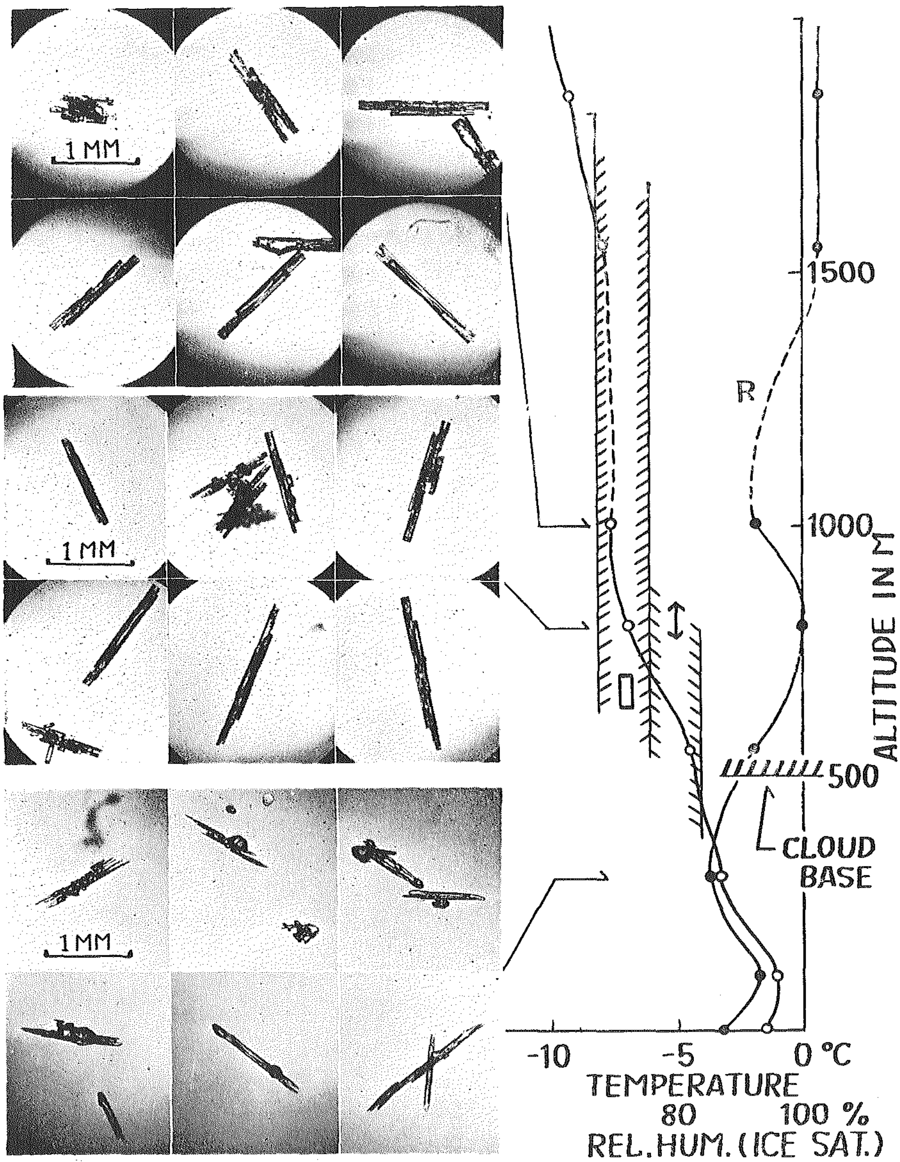



Fig. 10. Growth of snow crystals of thin hollow column type and meteorological conditions, 1120-1130, Jan. 30.

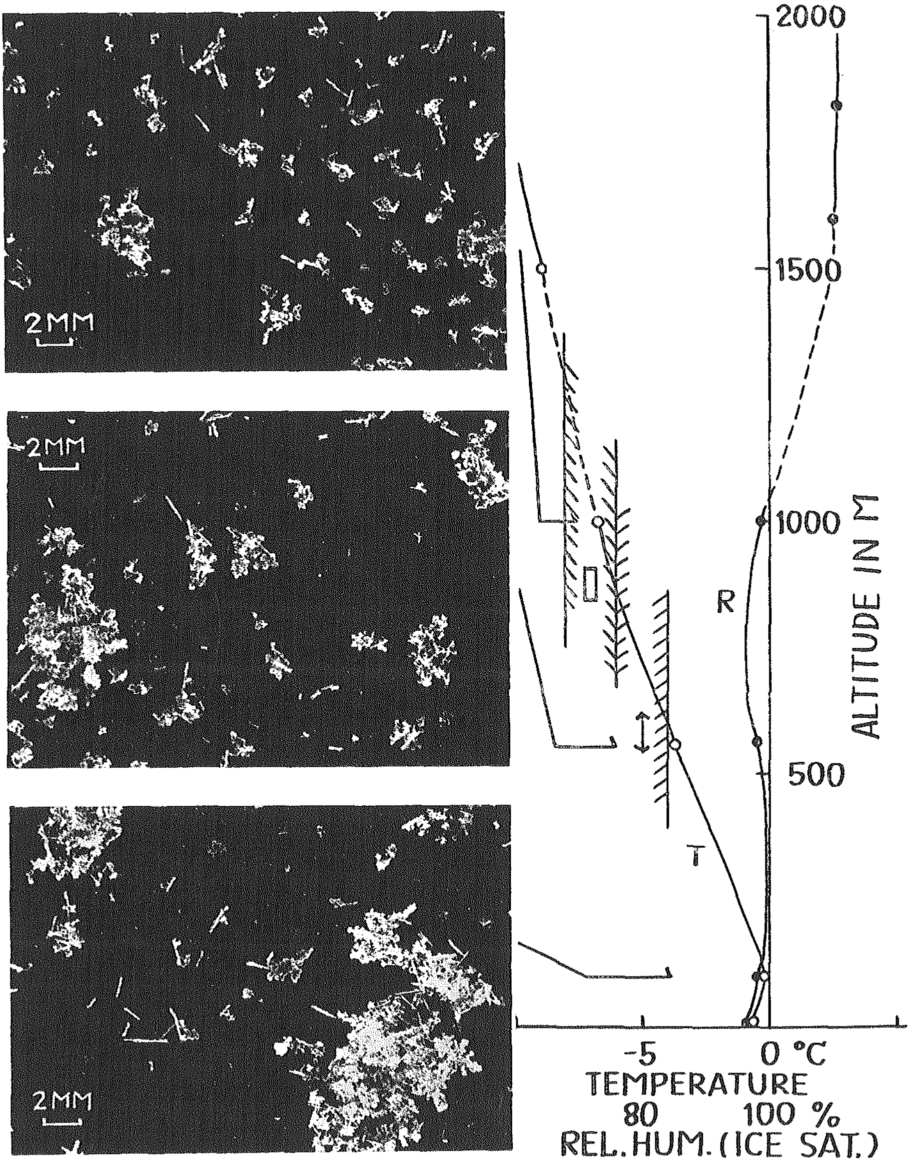



Fig. 11. Formation of snowflakes and growth of snow crystals of thin hollow column type, 2130–2140, Jan. 30.

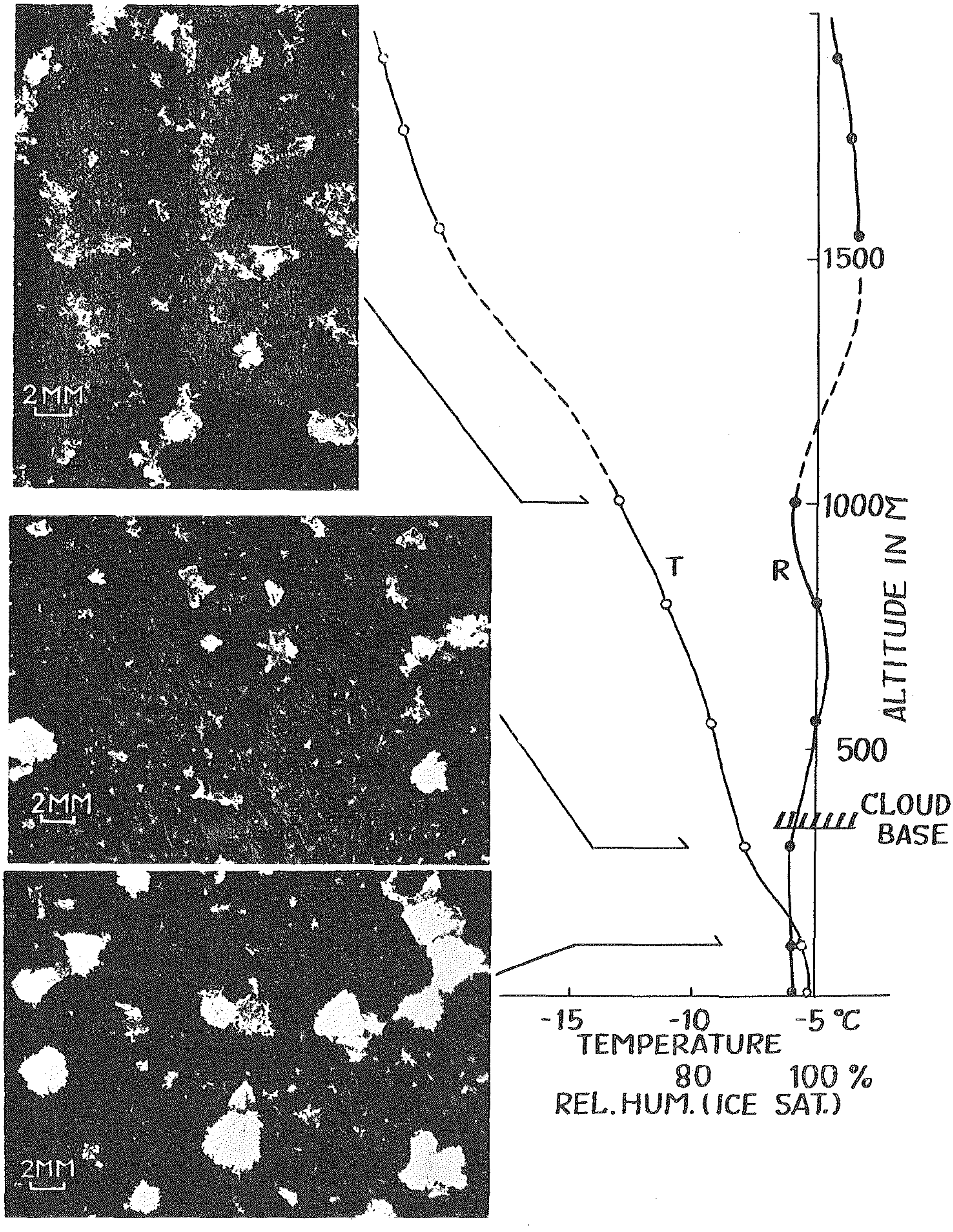



Fig. 12. Formation of graupel, 1610-1620, Jan. 31.

Barkow[8].

## 5. Considerations

The present investigation was undertaken with the purpose of observing the precise metoerological conditions under which natural snow crystals grew; observation was made as completely as along the pass through which the snow crystals fell. But the authors had following three difficulties in the observation.

a. The rawin sonde sounding was carried out 8 miles distant from the observation area of the snow crystals and in most cases the area was to the windward. If the upper air condition is not horizontally uniform over a wide region, the conditions above the observation area are not well represented by rawin sonde data. But the distance between the observation area and the rawin sonde location was smaller than in other investigations carried out in the past.

b. In rawin sonde, hair hygrometer was used to measure relative humidity, therefore, the humidity obtained by it was not considered to be exact in absolute value, specially below freezing point, although it showed fairly well the relative change in humidity. In such a serious matter as measurement of cloud thickness the humidity shown by the hygrometer could not be accepted. Accordingly, the height of the top of the clouds was not determined. The base of clouds was determined by visual observation at the observation area and by general photographs of clouds taken from outside.

As for the air temperature, the data obtained below the mountain top by the sonde agreed well with those measured by aspiration psychrometer at the observation points, therefore, the data of upper air temperature obtained by the sonde are considered to be correct.

c. The relative humidity near the mountain was considered to be effected by ascending of air, therefore, the measurement of the relative humidity below the mountain top was made by the aspiration psychrometer. However, the exact measurement of humidity below freezing point was fairly difficult, owing to icing on the dry bulb of the psychrometer. In addition to that, as well known, the psychrometer can not show the humidity larger than the ice saturation point when its wet bulb is frozen.

Some special method for measuring the humidity below freezing point; the Karl & Fischer reagent method, the heating dew point method, and the method of heating the aspiration psychrometer were tried in these observations but they were insufficent in their accuracy to determine surely whether air was saturated or not, because the absolute humidity itself was very small and its measurement required very high accuracy at temperature near −10°C.

It should be noted that in some cases the air within clouds is not saturated, especially in most cases near the cloud base.

5.1. It appeared that beautiful snow crystals of plane dendrite grew in non-saturated air with respect to ice as has been indicated in Figs. 6 and 8. From 1500 on the 28th to 2100 on the 29th, it was cloudless visually above the observation area, and stars were well recognized in all the sky. Only far to the west some clouds of Cb, Sc and Fc type were recognized. The upper air was also fairly dry through the 28th and the 29th.

It may seem that snow crystals flowed and came from the clouds to the west, because the wind was north-westerly and the wind speed was about 10 m/sec at the level, but that possibility is small. The point is that snow crystals observed at Pt. 1000 were very young and they grew considerably below Pt. 1000.

The air layers lower than that at altitude 1300 m was fairly moist but not saturated with respect to ice after 1500 on the 28th. Through the period light showers of snow crystals of plane dendrite continued at the mountain top. As 90% isohypse became lower after 2100 on the 28th, the snowfall area developed to the lower observation points. The air near Pt. 1000 was not saturated but the air temperature was appropriate for the growth of dendritic crystal form, becuase −15°C isotherm existed just above Pt. 1000.

Attention should be paid to the accuracy of humidity measurement. The error margin of aspiration psychrometer's thermometer was ±0.1°C, corresponding to ±2% at relative humidity at −10°C. Accordingly, it is not sure whether the air was exactly saturated with respect to ice or not, but it is sure that the air was not saturated with respect to water.

About 30 crystals fell on glass plate of size 6×9 cm in one minute in the period. The mass of the crystals was about 0.03 mg, so falling rate crorresponded to $2.8\times10^{-3}$ g.m$^{-2}$. At the same time the relative humidity increased at the rate of 20% per five hours at air temperature of −12°C from the evening to night of the 28th. The thickness of air layer which was appropriate to the snow crystal growth was about 300 m. Calculation shows that the excess of vapor produced by the increase of 20% in relative humidity, is $3.3\times10^{-3}$ per unit air column of section 1 m$^2$. This value agrees well with the falling rate of snow crystals; $2.8\times10^{-3}$ g. m$^{-2}$. Therefore, it is considered that the necessary vapor to form the snow crystals in the night of the 28th was supplied by the increase in relative humidity which perhaps resulted from the decending of air at night.

5.2. The effect of air temperature is predominant in the formation of snowflakes as pointed out by Hosler et al[9] and Hallgren & Hosler[10]. The result of the observation on the snowflakes at Mt. Teine shows that air temperature near -10°C is a critical temperature for the formation of the snowflake.

It was observed that the formation of snowflakes arose when there existed a thick cloud layer except during the daytime of the 30th. The rawin sonde sounding showed a very thick cloud layer during that period, but the type of snow crystals was almost the single crystal of hollow prism or of needle types. This fact suggests that there were not clouds above the mountain, perhaps near altitude 2000 m. It is probable that the rawin sonde failed to show the existence of the cloudless layer between the much higher clouds and the lower clouds near the surface.

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