[Journal of the Faculty of Science, Hokkaidô University, Japan, Ser. VII, Vol. I, No. 4, 1960]

Investigation on the Growth and Distribution of Natural Snow Crystals by the Use of Observation Points Distributed Vertically, II

Choji MAGONO and colleagues*
(Received Sept. 30, 1960)

Abstract

Natural snow crystals and meteorological conditions were observed at three observation points of different altitudes, in continuation of work undertaken in the previous season. In spite of the improvement in humidity measurement it was considered that sometimes snow crystals grew at air layers not saturated with respect to ice. If the boundary of a cloud region was extended to the zone of humidity 90%, Nakaya's *Ta-S* diagram would hold very well.

1. Introduction

In the previous paper[1], results were reported of observation for natural snow crystals at Mt. Teine. The important results were that Nakaya's *Ta-S* diagram[2] was proven to represent fairly well the growth of natural snow crystals in warm temperature region and that beautiful plane dendritic snow crystals seemed to grow, even when the environment air was not saturated with respect to ice surface and clouds were not recognized near by. However, since the temperatures were fairly high during the observation period, the *Ta-S* diagram was not examined in its colder region. It was noted that it would require more careful measurement of humidity and cloud to discuss the latter observation that snow crystals grew in not saturated air.

In the second season, observations were made with particular attention to the humidity and cloud conditions.

2. Methods improved

After the previous observation of about a year ago, it was noted that following points should be improved.

2.1. *Regarding humidity*

It is well known that accurate observation of humidity below the

* The names of the colleagues are listed in Table I below.

freezing point is very difficult. However, for the observation of humidity of upper air, hair hygrometers in rawin sonde were adopted, continued from the previous season. The evaluation of accuracy of the humidity recording was made by considering whether the recorded boundary of saturation region coincided with that of the actual clouds or not. The advantage of hair hygrometer method is in that it is possible to measure the humidity of range from ice saturation to water saturation as well as the lower humidity.

To measure the humidity of air layers lower than the top of Mt. Teine, various methods were considered, namely heating dew point method, Karl & Fischer reagent method and heating aspiration psychrometer method; these were all tried, continued from the previous season. These methods seemed suitable, since they showed about the same humidities as those obtained by ordinary aspiration psychrometer in fine weather and supersaturated humidities when the observation point was covered by clouds. However, in almost all cases falling snow particles were involved in the clouds and it was impossible to decide whether the excess humidity over ice saturation resulted from the vaporization of the falling snow particles or from pure supersaturation with respect to ice. Therefore, ordinary aspiration psychrometers were used as in the 1959 observations to measure the humidity of air layers lower than the mountain summit.

In addition to the psychrometer, self-recording hygrometers of hair type were used. The advantage of the latter instrument is that it can measure humidity higher than ice saturation as well as obtain continuous records if it is adjusted accurately near ice saturation. But actually, the air humidity did not exceed ice saturation at any time during the observation period.

The humidity of air layers between altitude 2000 m and the top of Mt. Teine was assumed considering the data at the two altitudes, because the air layers would suffer the effect of the mountain.

2.2. *Regarding surface observation points*

The temperature and humidity of air at the ground surface were measured at height 1 m above snow surface at each observation point in the previous season, but it was not sure that the value of the measurements accurately represented that of free air corresponding to each altitude. In other words, there was considered a possibility that the snow surface affected the air near it.

In the second season, the measurement of temperature and humidity at ground surface was carried out at a height of 2 m above snow surface, and it was clearly ascertained that temperature and humidity of air 1 m above snow surface agreed well with those characters of air 23 m above the snow surface except under intense sun light. The exception was unimportant because the present problem was concerned with snowy period only. Accordingly it would be accepted in both seasons that the data at ground surface represented those of free air at the corresponding altitudes.

Considering the observations of the previous season, the lower two points among five observation points were abandoned, because frequently snowfalls on the two points did not belong to the same snowfall system as on the upper three observation points. From now the three upper points will be called "Summit", "800 m" and "Paradise Hut"; their altitudes are 1023, 800 and 560 m respectively. Their locations are shown in Fig. 1.

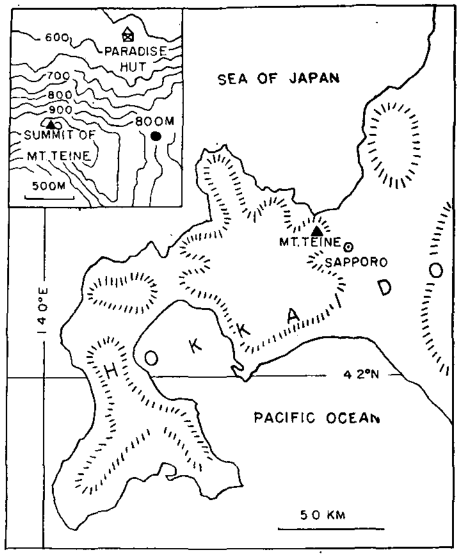


Fig. 1 Location of Sapporo and observation points.

2.3. *Regarding boundary of cloud*

The data for cloud base were insufficient in the previous season. To determine more exactly the height of cloud base and top, observations from aircraft were added to the ordinary visual observations from the ground. Heights of temperature inversion were also considered in presuming the upper boundary of clouds.

2.4. *Other improvements in observations*

Close-up photographs and shadowing photographs of snow crystals were not employed; observation points for cloud particles were increased.

Rawin sonde sounding was carried out at 0900, 1500 and 2100 for 6 days as in 1959, but observation times were changed as follows. Observation of all items at surface was made from one hour before each and every rawin sonde sounding time to one hour after the time.

The times of observation and the names of observers are listed in Table I.

Table I. *The data-gathering organization*

Observation points	*Altitudes*	*Items of observation*	*Observers*
		Chief	Choji Magono
Summit	1023 m	Temperature, humidity Microscopic photograph Humidity by Karl & Fischer reagent method Replicas of snow crystals Cloud particles on snow crystals Humidity by heating dew point method Humidity by heating aspiration psychrometer method Charge on snow crystals	Shoichi Koenuma Teisaku Kobayashi Katsuhiro Kikuchi Kazuhiko Itagaki Shin-ichiro Nakamura Keitaro Orikasa
800 m	800 m	Temperature, humidity Replicas of snow crystals Microscopic photographs	Tsutomu Nakamura Satoshi Fukuda Tsutomu Takahashi Daisuke Kuroiwa
Paradise Hut	560 m	Temperature, humidity Cloud base Replicas of snow crystals Cloud particles on snow crystals Charge on snow crystals	Ken-ichi Sakurai Toshiichi Okita Keiji Higuchi Satoru Tanigawa Shoichi Nitto Tadashi Kimura
Sapporo	30 m	Replicas of snow crystals Photographs of cloud base	Yoriko Abe
Sapporo	30 m	Rawin sonde sounding	Sapporo Meteorological Observatory
Mt. Teine region	1000 m	Photographs of cloud by aircraft	North Army Aviation Force of Japan
Mt. Teine region		Cloud top and base	Second Wing Japan Defence Force

3. Synopsis of conditions during observation period

The observations were made from 0800 25 Jan. to 2100 30 Jan. 1960. The weather was relatively cold during the period, namely air temperature was around −10°C at the summit of Mt. Teine and was lower than 0°C even at Sapporo.

In the winter season, north-west monsoon prevails in Hokkaido as indicated in the surface weather map of 25 Jan. in Fig. 2, and it brings heavy snowfall to western Hokkaido. On the second day of observation (26 Jan.) a local cyclone occurred as seen in Fig. 3 and the wind direction at Sapporo changed from north-west to south-east. The weather cleared up from noon in southwestern Hokkaido. On the third day (27 Jan.) a cold front passed over the observation region as seen in Fig. 4, and light snowfall was observed there. On the last day (30 Jan.), pressure gradient was very slow as seen in Fig. 5, but moderate snowfall due to the monsoon continued in the observation region. The relation between the property of snowfall and the pressure pattern will be described later in detail.

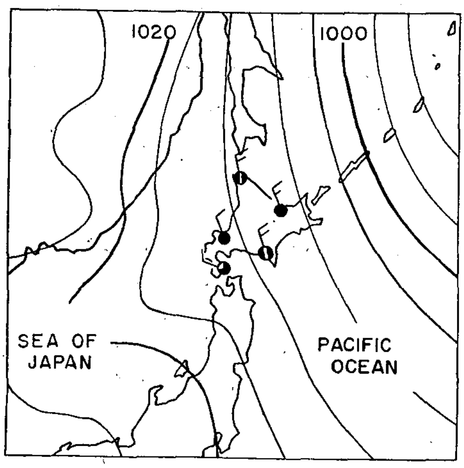


Fig. 2 2100 25 Jan. 1960 surface.

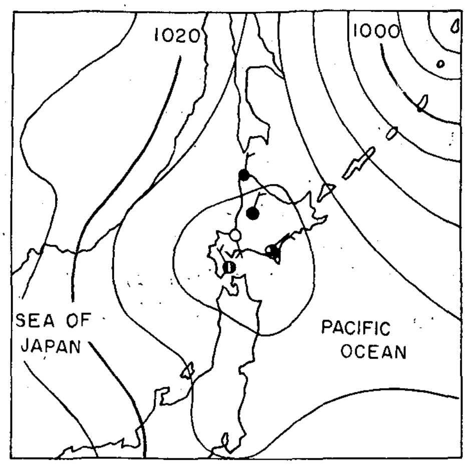


Fig. 3 2100 26 Jan. 1960 surface.

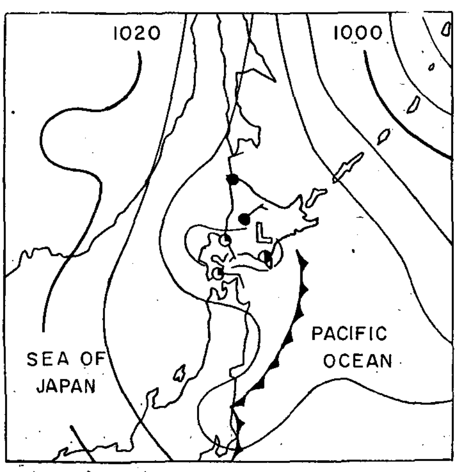


Fig. 4 2100 27 Jan. 1960 surface.

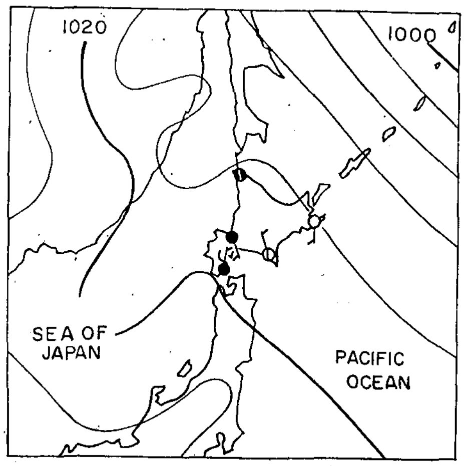


Fig. 5 2100 30 Jan. 1960 surface.

4. General results

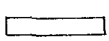
The data obtained in the observations are summarized in the time cross section in Fig. 6. The abscissa of the figure shows the date and time of observation. The times of rawin sonde sounding are shown by vertical lines. The ordinate represents altitudes. The altitudes of the observation points are specially shown by thick white arrows at the lower right corner.

Isotherms are represented by solid lines. Their values are shown in Celsius units. An area of rhombic form enclosed by thin lines, for example the area around 2100 25 Jan. at altitude 2300 m, means the existence of a temperature inversion, and the short horizontal line at a rawin sonde sounding time indicates the altitude of the upper limit of inversion. To make sure, the letter *i* is affixed to the left end of the line, for example 0900 25 Jan. at height 2700 m.

Broken lines show contour-lines of relative humidity with respect to ice. The value of the humidity is represented in %. Shaded areas mean regions of humidity higher than ice saturation. During the observation period, the humidity of air not only did not reach water saturation, but did not exceed ice saturation at either upper layer and below the top of Mt. Teine. Therefore, the term "saturation with respect to ice" will be called simply saturation hereafter.

Symbols for cloud base are shown in Table II. In the table the symbols are classified by measuring method and by amount of cloud. Only the symbol at height 3600 m at 1000 29 Jan. means the height of a cloud top.

Table II. *Symbols for cloud base*

////////	Determined by photograph taken from Sapporo	
	Determined by aircraft or by visual observation at Mt. Teine	Amount of cloud 1-4
		Amount of cloud 5-9
		Amount of cloud 10

The forms of snow crystals observed are tabulated by symbols in the upper part of Fig. 6, being grouped in three columns. The symbol of crystal form means that snow crystals of that symbol fell within one observation hour.

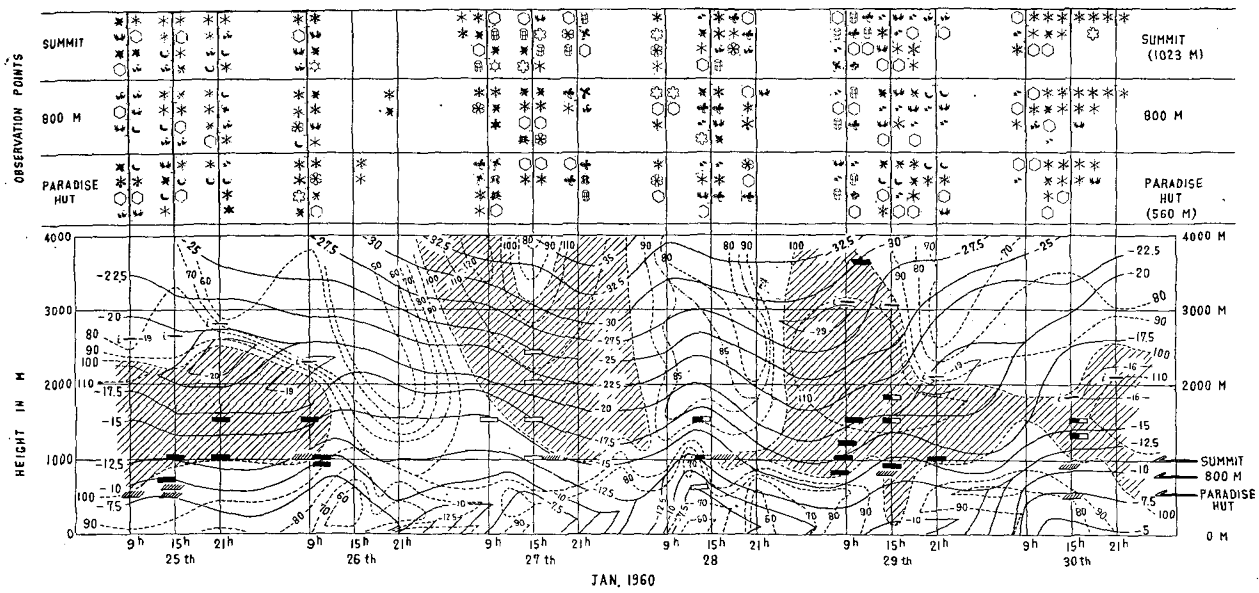
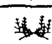
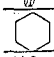
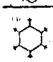
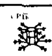
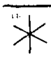
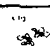


Fig. 6. Time cross-section and type of snow crystal during observation period.

The symbols are explained in Table III following Nakaya's classification[3]. In each column of Fig. 6, that is, at each observation point, the order of vertical arrangement of the symbols means that the higher a symbol is, the more frequently the crystal of that symbol fell for the corresponding one hour.

Table III. *Symbols for snow crystal type*

	Hexagonal column		Stellar crystal with plates at its ends
	Combination of bullets		Plate with dendritic extensions
	Combination of columns		Spacial hexagonal type
	Simple plate		Radiating type
	Branches in sector form		Rimed crystal of radiating type
	Plate with simple extensions		Column with plates
	Broad branches		Column with dendritic crystals
	Simple stellar form		Irregular assemblage of columns and plates
	Ordinary dendritic form		Columnar crystal with extended side planes
	Rimed crystal of dendritic form		Irregular snow particles
	Fernlike crystal of dendritic form		Graupel

4.1. *Examination of humidity near saturation*

As noted above, there are expected some difficulties in the exact measurement of relative humidity below the freezing point. So the examination of humidity was made by comparing a boundary of a saturation region in time cross section with the base or top of a cloud, on the assumption that air within clouds was saturated with respect to ice. It is also considered generally that the top of a cloud is suppressed by temperature inversion. So to examine humidity near saturation, one method is to compare the upper boundary of the saturation region with that of the temperature inversion instead of cloud. In the observation data one may see in Fig. 6 that the upper boundaries of a shaded region coincide fairly well with those of temperature inversion; for examples see 25, 26, 29 and 30 Jan. The upper boundaries of saturation region are only 100 m lower than those of temperature inversion. This disagreement may be neglected because the top of clouds would not always reach just above the end of the inversion, and there was some possibility that air within the cloud was not saturated near the boundary of the cloud. In the cases of high clouds of cumulus form, the coincidence was not good, for example on 29 Jan. However it is supposed that this discrepancy did not result from errors in humidity sounding but from irregularity in the top of cloud of cumulus form.

As for the cloud base, it may be seen that cloud bases coincided fairly well with the lower boundary of a saturation region except that the cloud bases were systematically, to a small extent, outside of the saturation region. The exception perhaps resulted from the fact that the air of the cloud was not saturated near the base, because the measurement of humidity there was made exactly by aspiration psychrometers which could show the exact humidity if below ice saturation. It should be noted that sometimes cloud base determined was within boundary of saturation region as seen in Fig. 6, for example at 1500 27 Jan. and 1500 29 Jan. This strange discrepancy resulted probably from the fact that the cloud base changed rapidly owing to cumulus form, that is, from the irregularity of the cloud base. In such cases, the amount of the cloud was small.

It is noted also that cloud bases were shown even when saturation region did not exist as seen on 28 Jan. This fact indicates that actually fragmental clouds existed even when rawin sonde showed humidity considerably lower than 100 %. But the fact does not mean any essential contradiction in the rawin sonde sounding, since dilute fragmental cloud could be unsaturated or the rawin sonde could ascend through intermissions between the fragmental clouds. It is the writer's feeling that the latter reason is more reasonable because all the rawin sonde sounding which were made thrice daily showed saturated regions.

As described above, the boundary of a saturation region did not exactly coincide with that of cloud, however the top and bases of a cloud was always within the region of humidity higher than 90 %. Considering the fact, it may be accepted that humidity measurements by both rawin sonde and aspiration psychrometer were fairly reliable and that air within a cloud was not always saturated even with respect to ice. It is of course the case that the boundary of clouds was determined visually or by considering upper boundary of temperature inversion. As for not saturated clouds, more discussion will be presented later in connection with the growth of snow crystals.

4.2. *General consideration of time cross section*

The saturated region above altitude 1000 m up to noon of 26 Jan. teaches one that layer clouds were caused by local ascending of air due to monsoon, because north-west monsoon was prevailing for that period as seen in Fig. 2. The upper boundary of the cloud was limited by temperature inversions due to an aerodynamic effect. Temperature inversions due to diurnal cooling are seen in lower layers than 500 m after 26 Jan. Those lower inversions and humid regions due to the inversions were not concerned with the present work.

After noon of 26 Jan., a local gentle low pressure area occurred in Hokkaido as seen in Fig. 3. and the direction of surface wind changed from north-west to south. Accordingly air temperature of lower layers rose a little and humidity got downward. The sky was cleared up at Sapporo as seen in Fig. 3 but a slight snowfall was observed at the observation region. This will be later described in detail.

On the 27th, cloud region developed vertically. The cloud resulted from a cold front which was accompanied by a local cyclone as seen in Fig. 4.

On the 28th, every rawin sonde showed unsaturated region but light clouds of amount ranging from 1 to 9 were observed, and actually snowfall continued from noon to the next day.

The cloud region on the 29th was considered to have been caused by both a cold front and north-west monsoon. On the other hand the cloud region from the night of 29th to 30th was of layer type; it may be due to monsoon only, as supposed from Fig. 5.

It is noted in the night of 30th that the gradient of atmospheric pressure around Hokkaido was gentle and wide isotherms of –12.5 and –17.5°C were included in the cloud region. As will be stated later, beautiful snow crystals of uniform dendritic form often fell in such a gentle condition.

5. Snow crystal types and meteorological conditions

The meteological conditions of snow crystal growth have been determined by Nakaya[2] as shown schematically in Fig. 7. In the figure, the types of snow crystals are grouped to two columns according to the rate of vapor supply. Abundant vapor supply means here that relative humidity of the environment air is higher than 105% with respect to ice. Thick horizontal lines show temperature regions in which snow crystals grow to the corresponding types. A horizontal arrow means that the corresponding crystal grows when air temperature changes from a value shown by a black dot to that shown by the top of the arrow.

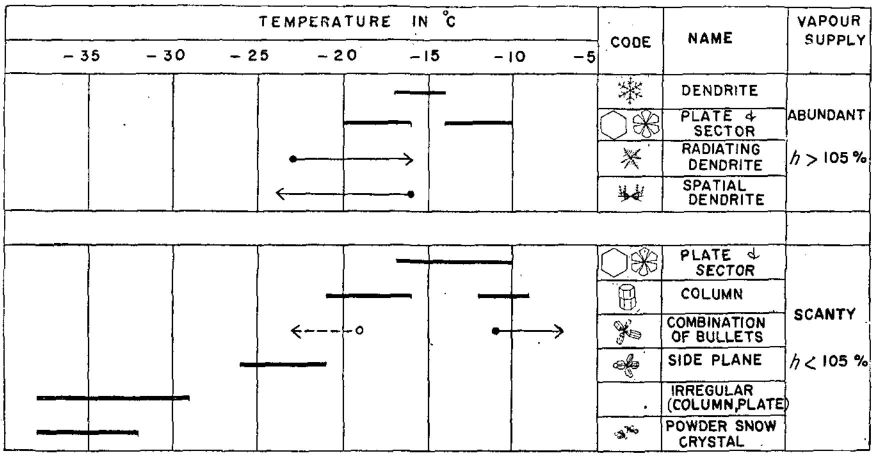


Fig. 7 Temperature region of crystal growth by Nakaya.
h: relative humidity with respect to ice.

Day to day account

25. Jan. In the period from the beginning of this observation to noon of the 26th, clouds ranged in temperature from layer of –20°C to one of –10°C as seen in Fig. 6. The types of snow crystal observed in the period are shown in the upper left part of the figure. It will be noted that dendritic and stellar crystals were most frequent. This fact is understood because the temperature zone of dendrite (–14∼–17°C) was included in the lower half of the cloud region.

Plate crystals of the second frequent type seemed to develop in the colder temperature region of plate formation (–16∼–20°C). If so, the crystals of plate type would develop to the type of plates with dendritic extensions in the lower part of the cloud region. But that was not the case as observed. Therefore it is supposed that the crystals of plate type were born near the base of the clouds of temperature –10°C. This assumption is supported also by the facts that the crystals of plate type were of initial stage, and that ends of branches of other dendritic crystals which fell at the same time were developed, to some extent, to sector form.

Irregular snow crystals also were frequently observed. The wind was fairly strong for the period compared with the later periods. Accordingly snow crystals were broken to pieces. The irregular crystals were almost all such fragments. Therefore the irregular crystals are not important in the present consideration of crystal growth.

It is also noteworthy that graupel was observed at every observation point through the present period. The cloud in the period was fairly dense although humidity of air appeared not to be very high as seen in the time cross section. This dense cloud containing numerous cloud particles would be a reason for the growth of the graupel. Regarding the observed dendritic crystals of radiating type it is understood that they would have developed in the temperature region from –23 to –16°C as supposed from Fig. 7.

Nakaya reported that snow crystals of spacial dendritic form developed when air temperature went down from –16 to –24°C as seen in Fig. 7; if in natural case, in temperature inversion corresponding to the temperature range. In accord with the possibility suggested by him, a number of snow crystals of spacial dendritic form fell actually in the daytime of 25 Jan., however it seems that the warmer temperature region of plane dendritic form was a few degree colder than expected by him; the colder temperature region (–20∼–24°C) corresponding to spacial part of the crystal was not observed in the cloud region. If examined in detail, there is left a very slight disagreement between data derived Nakaya's experiment and the actual observation of events in nature.

26 Jan. The condition of snowfall and cloud like that of 25th continued till noon of 26 Jan. as seen in Fig. 6. After-noon of that day weather cleared up in southern Hokkaido as seen in Fig. 3. But light snowfall composed of dendritic crystals was observed at the observation area, although there was no saturated region in the period as seen in the time cross section. Only a thin air layer of humidity higher than 90% existed. Such a strange phenomenon was also reported in the previous paper[1].

It is of course true that snow crystals can not develop in not saturated air, however it was not rare by ordinary measurement of humidity that the snow crystals appeared to develop and fall in air of humidity slightly below ice saturation. It is the writer's opinion that the snow crystals observed late on the 26th were born and developed in the thin air layer of humidity higher than 90 % being carried along horizontally by wind.

27 Jan. The cloud region ranged from 1000 m to higher than 4000 m.

Accordingly the temperature range of crystal growth was very wide. Corresponding to the wide temperature range, various snow crystals of warm and cold region were observed as seen in Fig. 6. Specially after the temperature of air layers went down in the night of the day, there were observed snow crystals of cold region, for example, combination of columns and plates, and powder snow. Crystals of those types are considered to develop around –35°C. Actually the cloud included such cold air layers in its upper part.

As seen by the symbols at the cloud base, the cloud was not dense; therefore snow crystals requiring abundant vapor supply, such as dendritic form were not numerous. Specially in the night, dendritic crystals were not observed but snow crystals formed under condition of scanty vapor supply such as plate, column and side plane were predominant.

Snow crystals of combination of bullets were also found. The crystals of bullet form are considered to grow at relatively warm temperature (-7∼-11°C) as seen in Fig. 7. But such warm air layers did not exist in the observation area on the 27th. From Fig. 7 it is noted that temperature regions of crystal growth are destributed symmetrically around -15°C axis. The same phenomenon is also supposed from Houghton's[4] theory. From the facts it is assumed that another temperature region of bullet type crystals may exist between -19 and -23°C, as shown by a broken arrow in Fig. 7 although experimental data are not yet available. On the basis of that assumption, the crystals of bullet type would be understood to grow in cold air layers at 1600 to 2000 m in cloud region. Only a difficulty is in that temperature inversion (from -19 to -23°C) necessary to this mechanism was not observed.

28 Jan. Light snowfall ceased around 1000 29 Jan. and weather cleared up till near noon. Moderate snowfall continued after noon. On the other hand the time cross section did not show any saturation region except thin air layer just above the summit of Mt. Teine, but clouds of amount 5 or 9 were observed around noon. The types of snow crystals observed are shown in Fig. 6. Among the types a number of snow crystals of colder region such as side plane and combination of columns and plates were included. This fact suggests that the snow crystals grew at upper cloud layers from 1500 to 3000 m. But the air layers had only humidity of around 85 or 90 %. If it is accepted that cloud region is extended to 85 % region of the time cross section, the snow crystals observed would be all understood as to temperature region.

The observations described above may be summarized as follows. Even if air seemed to be of humidity around 90% by macroscopic humidity measurement, light scattered clouds were observed and snow crystals came down from such not saturated air layers.

29 Jan. Crystal types and cloud conditions were nearly the same as those of the 27th, for examples, the existence of temperature inversions near cloud top and for formation of spatial dendritic crystals due to the inversion.

30 Jan. From the night of 29 to 30 Jan., a thin cloud layer region existed just above the observation altitude, and the region was included into the temperature region of dendritic form (-14∼-18°C). Some temperature inversions existed just above the cloud top but their temperature was also included in dendritic region. Therefore almost all crystals were of dendritic form. Specially after 1500, both cloud region and temperature region of dendrite became wide; thus all the snow crystals were of beautiful plane dendrite. Nakaya's *Ta-S* diagram holds very well for the period.

To discuss the growth of snow crystal, it is desirable that the crystals be uniform in type. The snow crystals observed in the later half of the 30th were very suitable in this point of view.

6. Growth of natural snow crystals

Size distribution of plane dendritic snow crystals observed for the period from 1400 to 1600 of 30 Jan. are shown in Fig. 8. Black dots, white dots and cross marks show the size distribution obtained at Summit, 800 m and Paradise Hut respectively. In the figure the following points are noted as to the crystal growth.

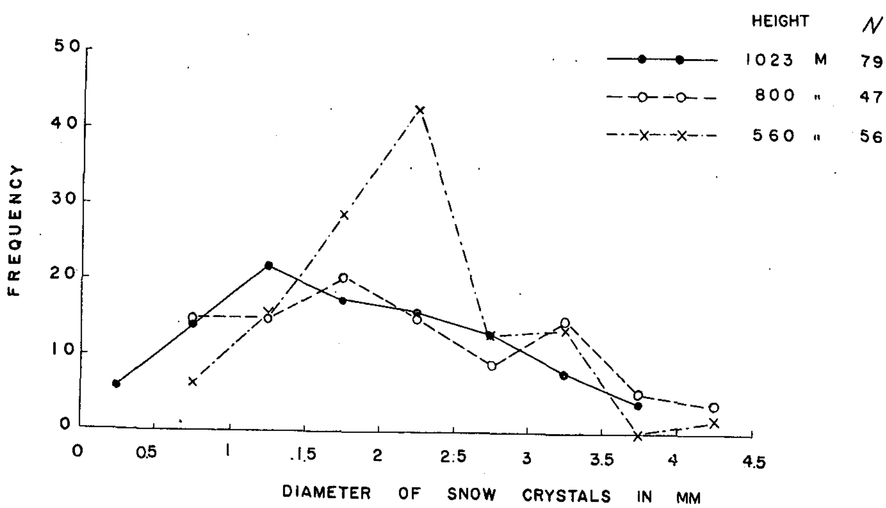


Fig. 8 Size distributions of snow crystal at three observation points from 1400 to 1600 of 30 Jan. 1960

1. A number of snow crystals of diameter <0.5 mm were observed at Summit but not observed at the lower 800 m and Paradise Hut. On the other hand, snow crystals of diameter >4 mm fell at 800 m and Paradise Hut but they did not at Summit.

2. Most frequent diameters of snow crystals at 800 m and Paradise Hut

(2∼2.5 mm) were larger than that at Summit (1∼1.5 mm).

3. Median diameters of size distribution at 800 m (2.3 mm) and at Paradise Hut (2.3 mm) were larger than at Summit (1.8 mm).

From these points it is obvious that the size of snow crystals observed at 800 m and Paradise Hut were larger than at Summit, in other words the snow crystals must have grown in the air layer between Summit and the lower two observation points. However it is not easy to compare the size of crystals at 800 m with that at Paradise Hut.

Turning to the time cross section around 1500 30 Jan., one sees that the air layers between Summit and 800 m were higher than the cloud base and nearly saturated and roughly included in the temperature region of dendrite.* However, the temperature of the lower air layers between 800 m and Paradise Hut was obviously out of both dendritic temperature region and saturated region. Therefore as for the air layer down to 800 m, there is sufficient possibility of crystal growth to dendritic form, but no possibility in lower air layer between 800 m and Paradise Hut. The results shown in Fig. 8 appears to agree fairly well with the meteorological conditions described above.

Even down to 800 m, snow crystals seemed to grow in air of humidity a little below ice saturation. The humidity concerned with this discussion was measured by aspiration psychrometers, therefore it is fairly accurate.

7. Conclusions

The measurement of humidity and the determination of cloud base and top were more reliable than those of one year ago. In spite of the improvement in humidity measurement, it appeared that snow crystals grew in a not saturated air layer and fell from there. This is observationally true, provided ordinary macroscopic method of humidity measurement such as by hair hygrometers and aspiration psychrometers were adopted. If the boundary of cloud region is extended to the range of humidity 85 %, all apparent discrepancies will be removed, and Nakaya's *Ta-S* diagram will hold in its cold region as well as in its warm region. The writer believes this extension in the boundary of clouds is reasonable because there must be some humidity zone at the cloud boundary where the number of coming cloud particles is balanced with that of dissipating cloud particles. Snow crystals would be able

* Warmer limit of temperature region of dendrite stated by Aufm Kampe, Weickmann and Kelly[5] and Kobayashi[6] is −12.5°C which is warmer than that by Nakaya.

to grow in such a not saturated zone being supplied vapor from the sublimating cloud particles.

It is believed on the basis of experiments by some researchers[5)6)7)] that snow crystals do not grow to dendritic form unless environment air is saturated with respect to water surface, but Nakaya's experiment[2)] shows that snow crystals grow also in air of humidity between ice saturation and water saturation. At the same time, the observation of natural snow crystals suggested that they grow in not saturated air even with respect to ice. Those discrepancies as noticed may be caused by the difference in the method and scale of humidity measurement. Improvement in the method of humidity measurement below freezing point will be continued in the coming season.

Acknowledgement

The writer wishes to express his best thanks to his colleagues of the Cloud Physics Group, and to the Sapporo Meteorological Observatory, the North Army Aviation Force of Japan and the Second Wing Japan Defence Force who cooperated in the meteorological sounding and the cloud observations. Because of their cooperation, data for humidity in clouds became much more trustworthy. The writer and colleagues are deeply indebted also to the Hokkaido Broadcasting Company whose sending station is at the top of Mt. Teine.

References

1) MAGONO, C and colleagues: Preliminary investigation on the growth of natural snow crystals by the use of observation points distributed vertically. Jour. Fac. Sci. Hokkaido Univ., Ser. VII, **1**, (1959), 195–211.
2) NAKAYA, U.: Snow Crystals, natural and artificial. Harvard Univ. Press (1954), 244.
3) NAKAYA, U.: Ibid, 81.
4) HOUGHTON, H.G.: A preliminary quantitative analysis of precipitation mechanism. Jour. Meteor., **7**, (1950), 363–369.
5) MASON B. J.: The growth of ice crystals from the vapour and the melt. Phil. Mag., **7**, (1958), 235-253.
6) KOBAYASHI, T.: On the habit of snow crystals artificially produced at low pressures. Jour. Met. Soc. Jap., Ser. II, **36**, (1958), 193–208.
7) KOBAYASHI, T.: Experimental researches on the snow crystal habit and growth using a convection-mixing chamber. Jour. Met. Soc. Jap., Ser. II, **38**, (1960), 231-238.