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Investigation on the Growth and Distribution of Natural Snow Crystals, IV

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Abstract

Our forth investigation on the growth and distribution of natural snow crystals was made in the Mt. Teine region, Hokkaido. In the present work on snow clouds, drop sonde sounding and continuous one hour picture of clouds were added to the measuring method in order to obtain exact information. It was revealed that the vapor at lower levels supplied from the sea surface was important in the formation of rimed snow crystals.

1. Introduction

By the observations[1),2),3),4)] carried out through three winter seasons hitherto, it was revealed that Nakaya's T_a-s diagram[5)] is in fairly good agreement with the temperature condition (T_a) of natural snow crystals, however some problems remain unsolved regarding the humidity condition (s). The most important point of the problems in humidity seems to be in the inadequate means of measuring the humidity in cloud layer, particularly we are not sure in the measurements hitherto, whether the ascending rawin sonde actually passed through noted cloud layer as was intended.

In order to cope with this inadequacy, a drop sonde method was adopted in the observation in 1962, e.g. radio sondes were dropped from an aircraft by our team over noted clouds. Another approach to gather exact data on the noted clouds was carried out by the use of photographs over the observation area which were taken from Teine Town every hour.

The present paper will describe the results of analyzation of the data thus obtained.

2. Drop sonde

2.1 *Design of drop radio sonde*

The measuring and transmitting sets of the drop radio sonde was similar

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to the S56 Type used in routine work by meteorological observatories in Japan. However, since the drop sonde must work during its descent, unlike the S56 Type which work during its ascent, some changes in design were made: The vertical cross section of the drop sonde is shown in Fig. 1.

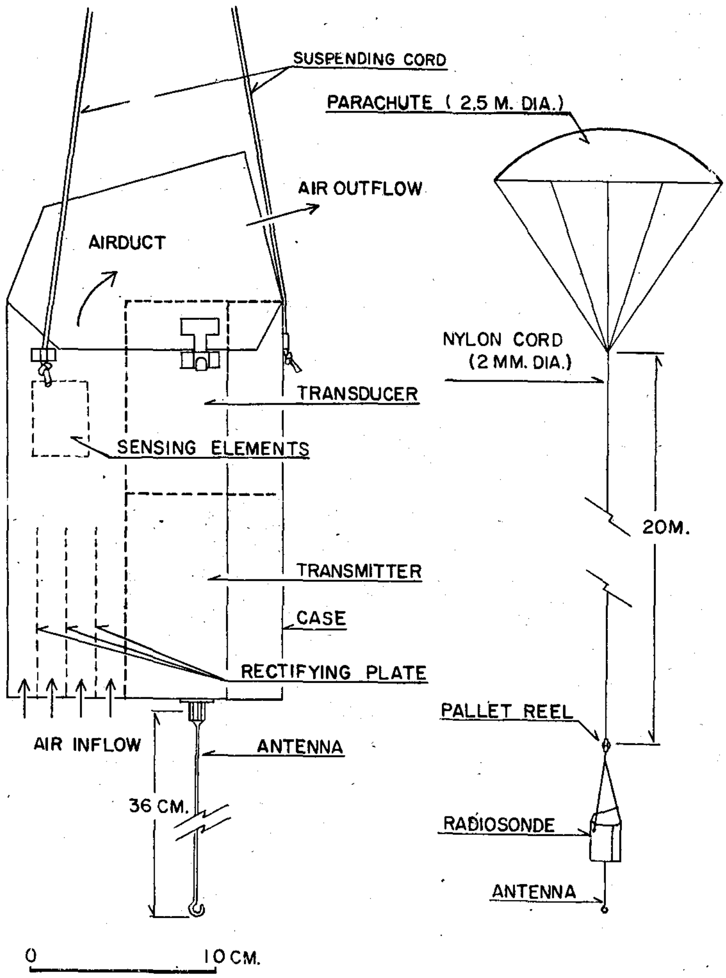


Fig. 1 Vertical cross section of drop sonde design

1. During descent the air stream enters the sonde through a hole at its base and passes sensing elements and finally through the rectifying plates, and passes out from an airduct as shown in Fig. 1.

2. A sending antenna was attached to the base pointing downwards, to send data to the receiver on the ground surface. Because of this receiving system, information from the sonde could not be received when the sonde approached the ground surface.

3. The interval of signal of atmospheric pressure was designed as small as 5 mb which is about a 50 meter drop.

4. The diameter of the parachute was 2.5 m to maintain a drop velocity of 3.5 m sec^{-1} which is about half of the ascending velocity of the S56 Type.

The sondes were dropped by hand through a special hole in the floor of the observation plane, a Cessna LM-1. The place of dropping was determined with consideration to the vertical distribution of wind measured by the Sapporo Meteorological Observatory before take off.

2.2 *Calibration of data*

Preliminary experiments were made to test the accuracy of the drop sonde sounding. The calibration was carried out by comparing the data with those

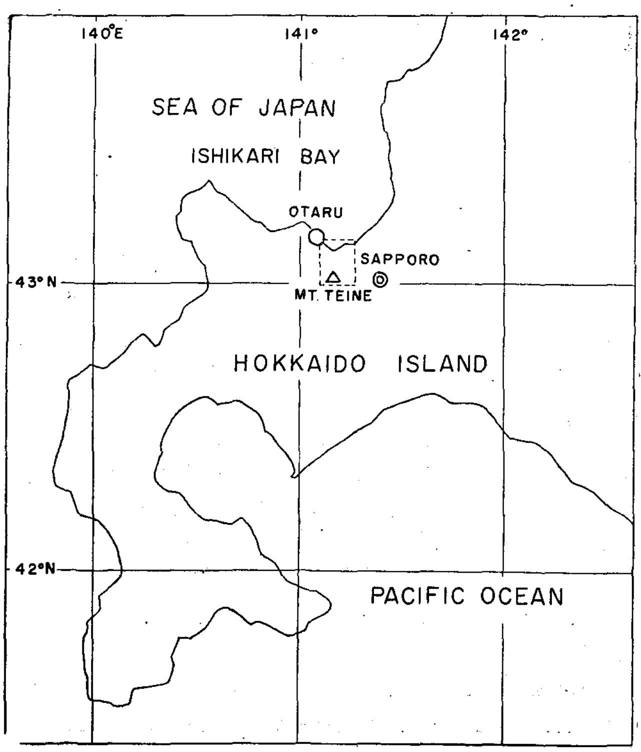


Fig. 2 Map around observation area

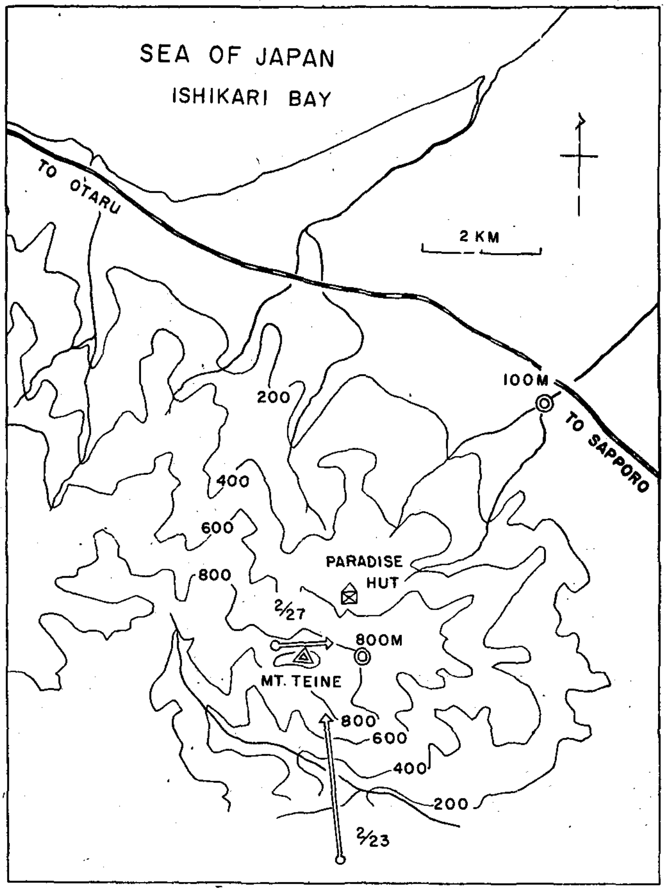


Fig. 3 Observation area and path of dropped sondes

obtained by the sounding of the S56 Type, made in the Sapporo area a little earlier. Some examples of the observation results are described below.

Since it was clear and calm on 27th Jan. as seen in Photo. 1, Pl. I, it was expected that the upper air condition would be uniform both over the observation area of Mt. Teine and Sapporo. The site of the drop sonde and its course are indicated by arrows in Fig. 3. The sonde was dropped just above the summit of Mt. Teine where observation spots were distributed, because the wind was weak at altitudes around 2000 m. Prior to the drop, the sonde was in a warmer surrounding, several degrees in C warmer than the air outside the plane, owing to insufficient ventilation around the sonde.

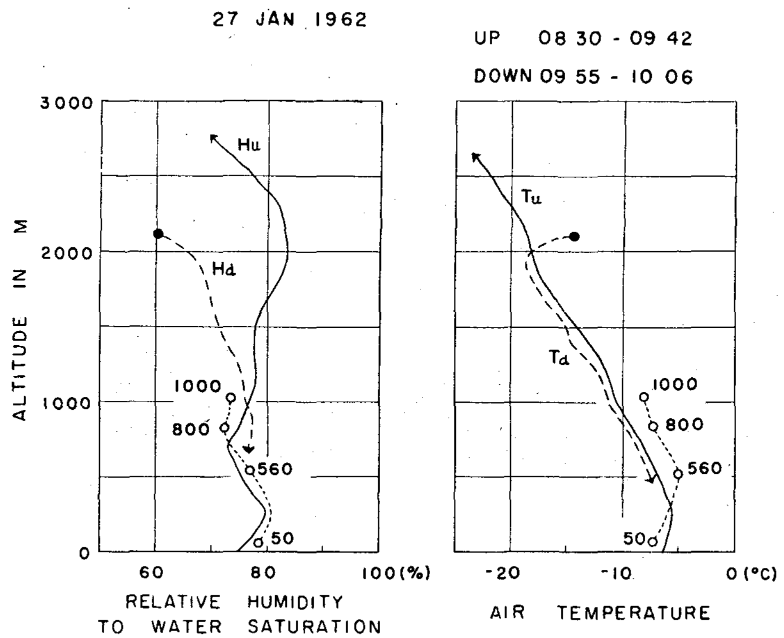


Fig. 4 Vertical profiles of air temperature and humidity obtained by means of usual ascending sonde, drop sonde and surface observation

The results obtained are shown in Fig. 4. In the figure, solid lines represent the vertical profiles of temperature T_u and humidity H_u obtained by means of the ascending sonde, and the broken lines show the vertical profiles of temperature T_d and humidity H_d obtained by means of the drop sonde respectively. Dotted lines indicate the profiles estimated from the data obtained at surface observation points at respective heights of 1000, 800, 560 and 50 m which are shown by white round marks. It may be seen in the figure that just after dropping the humidity H_d was considerably smaller than H_u, but after passing down 500 m from the drop altitude, H_d practically agreed with H_u and thereafter with the humidity of surface observation.

If the meteorological condition was in common to each other above Mt. Teine and Sapporo and if the value obtained by the use of the ascending sonde was correct, the difference just below the drop altitude must be due to the time lag of the hygrometer of the drop sonde. From this assumption, it follows that the hygrometer required an altitude drop of about 500 m before it responded to the actual humidity. This value of 500 m was reasonable considering the time lag which was determined in laboratory experiments using a cold chamber. It is therefore considered that the humidity measured by the drop sonde is reliable at any level 500 m lower than the drop altitude. As for the temperature, the time lag was small and the agreement between T_u and T_d was very good as seen in Fig. 4.

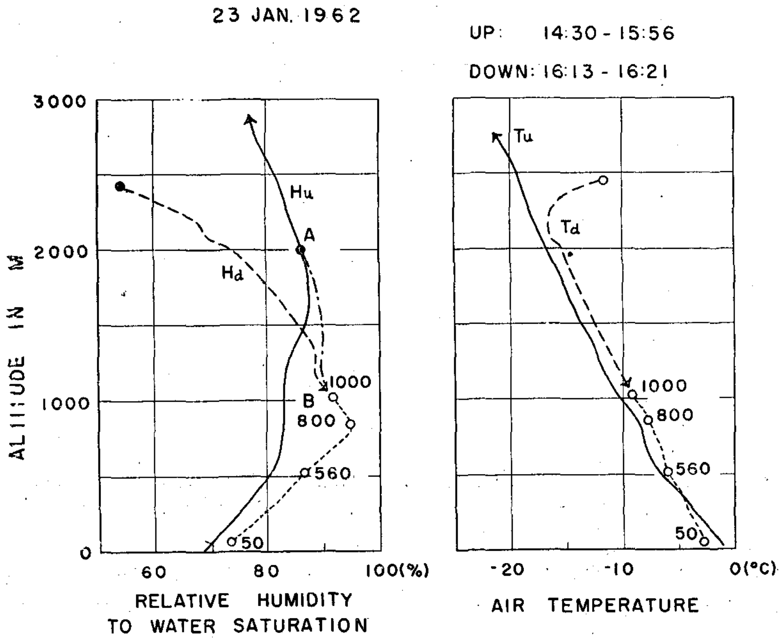


Fig. 5 Vertical profiles of air temperature and humidity obtained by means of usual ascending sonde, drop sonde and surface observation.

In the case of 23rd Jan., the Mt. Teine region was covered by Nimbostratus clouds while there were no clouds above Sapporo as seen in Photo. 2. The results obtained on this day are shown in Fig. 5. According to the vertical profile of humidity by a ascending sonde, no moist layer was detected while the drop sonde an surface observations showed a fairly moist layer of about 90% humidity near an altitude of 800 m. This value of 90% in relative humidity corresponds to near saturation humidity with respect to the ice surface. This vertical profile of humidity is reasonable because there was a Nimbostratus clouds over the mountain area but no clouds over Sapporo. It is therefore considered that both the data obtained by the ascending sonde and the drop sonde are correct.

It is reasonable to assume that meteorological conditions of the upper air layer are uniform horizontally, in a moderate scale, but for lower air layers that is not the case. In the case of the present observation, on the meteorological condition below the summit of Mt. Teine at an altitude of 1023 m, the data from the surface observation points at various altitudes were superior to the ascending sonde sounding at Sapporo. But for the meteorological condition of the air layer just above the summit, for example between 1000 and 2000 m, no exact methods are known. For the purpose of determining such an exact method, the drop sonde sounding method was introduced. This was to some extent accomplished; by the use of the drop sonde it was ascertained that the sonde showed the existence of the cloud layer above Mt. Teine even when the ascending sonde from Sapporo failed to note its presence. Unfortunately, the Cessna LM-1 could not always take off or reach an altitude higher than 2500 m in cloudy weather. Accordingly, in the present observation, the vertical profile of humidity was estimated by connecting within reason the two terminal points as shown by a chain line between A and B in Fig. 5. This method is the same as that used in the previous observations. Eitherway it was ascertained that the method used hitherto was fairly adequate, and this method was adopted also in the present observation.

3. Observation of clouds above Mt. Teine

In the study of snowfalls, one of the best ways is to observe the form of snow clouds from the outside. Actually, it was impossible to observe the form of the snow clouds at the summit of Mt. Teine, because the summit was almost always included in the clouds. In the observations in 1962, pictures of snow clouds above the mountain were taken every hour from an observation point on the north-east foot of the mountain. This point, Teine Town is about 5 km from the summit and 50 m above sea level as seen in Fig. 3. Teine Town was convenient for taking pictures of clouds to the west of Mt. Teine, in other words, of clouds to the windward of the observation area, because the point often was not under cloud cover while the mountain area was usually covered by clouds and because the point has a wide angle of view as seen in Photo. 3, Pl. I. Pictures of snow clouds over Mt. Teine at $09^{h}00^{m}$ every day are shown in Photos. 4–12, Pls. II and III.

4. Other observation methods

Other observation methods for the snow crystals and other meteorological conditions at the surface were the same as those used in the previous observation[3]. The data gathering organization is shown in Table 1 below.

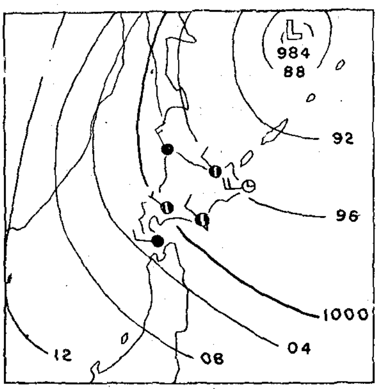
Table 1. Data-gathering organization

Observation points	Altitudes	Items of observation	Observers
		Chief	Choji Magono
Summit	1023m	{Temperature and humidity of air Replicas of snow crystals Microscopic photograph of snow crystals	{Keiji Higuchi Seiu Lee Katsuhiro Kikuchi
800 m	800m	{Temperature and humidity of air Replicas of snow crystals Microscopic photograph of snow crystals	{Minoru Satomi Kunio Enoki Tsutomu Nakamura
Paradise Hut	560m	{Temperature and humidity of air Replicas of snow crystals Microscopic photograph of snow crystals	{Shuichi Miura Takashi Nakajima Tsutomu Takahashi
Teine Town	50m	Temperature and humidity of air Photograph of clouds over Mt. Teine	Kenji Ishizaki
Over Mt. Teine	2000m -2500m	Drop sonde sounding	{Keitaro Orikasa Tadashi Kimura North Army Aviation Force of Japan
Sapporo	30m	Rawin sonde sounding	Sapporo Meteorological Observatory

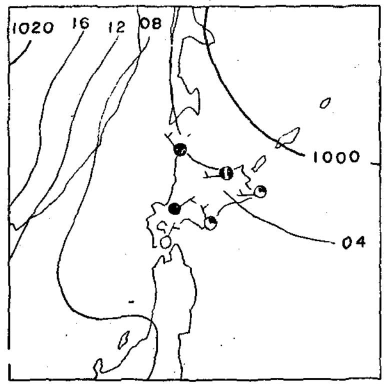
5. Results

5.1 *General view of the results*

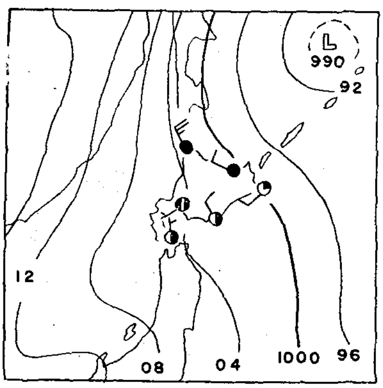
The period from 22 to 27 Jan. 1962 was selected in order to pinpoint observations on the snow crystals which grow in temperatures as low as possible. This is the coldest period in this area. It was characteristic in the present observation that no warm fronts nor cold fronts passed over the Hokkaido Island, and a north-westerly wind was prevailing as seen in the



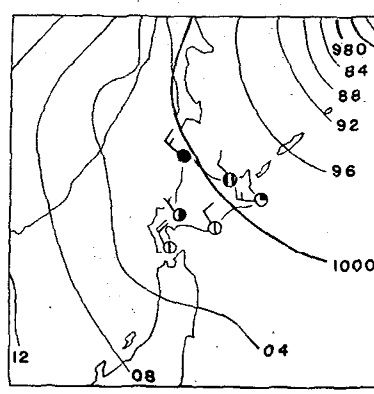
6a 0900 22 Jan. 1962



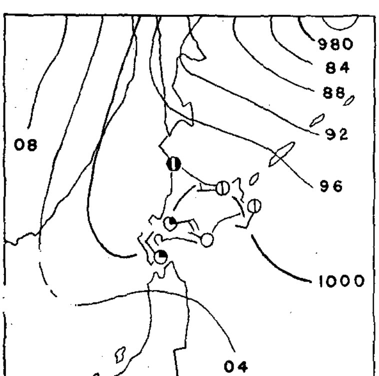
6b 0900 23 Jan. 1962



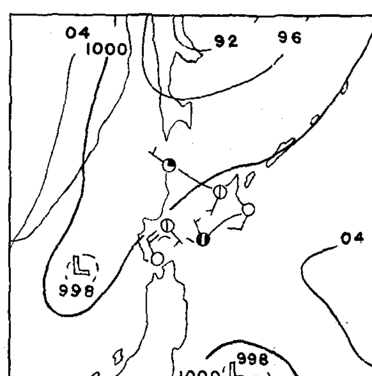
6c 0900 24 Jan. 1962



6d 0900 25 Jan. 1962

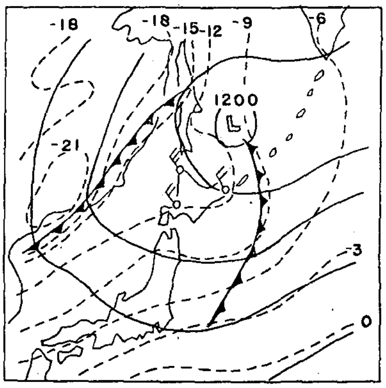


6e 0900 26 Jan. 1962

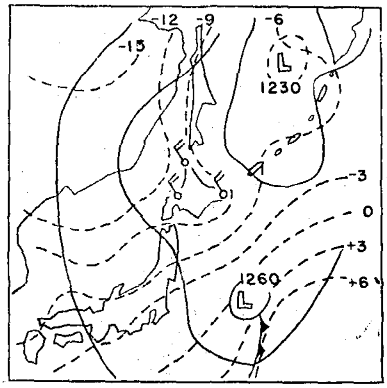


6f 0900 27 Jan. 1962

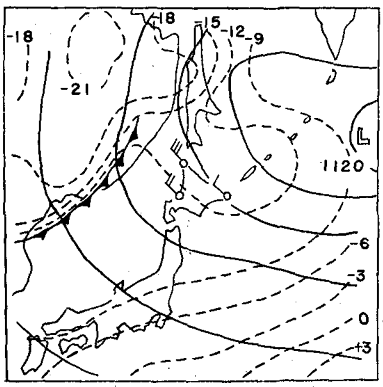
Fig. 6 Surface weather maps during observation period



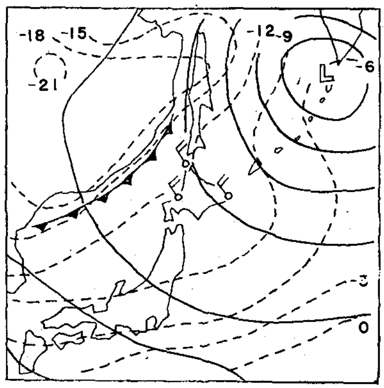
7a 0900 22 Jan. 1962



7b 0900 23 Jan. 1962



7c 0900 24 Jan. 1962



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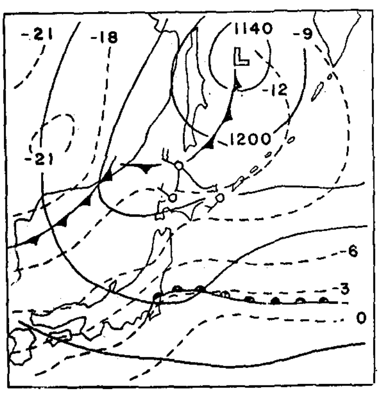

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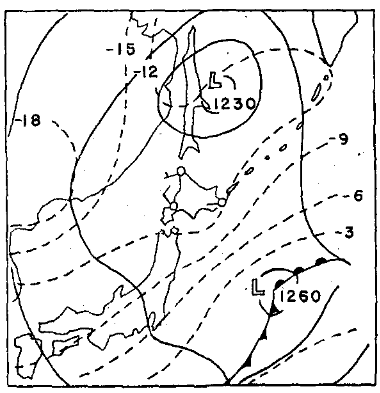


7f 0900 27 Jan. 1962

Fig. 7 850 mb weather maps during observation period surface weather maps in Fig. 6. On the other hand, a continuous snowfall was observed at Mt. Teine. This may mean that the snowfall was not frontal but was due to orographic ascending air current under a prevailing westerly monsoon. However there was an upper air cold front near the coast of Siberia to the north-east as seen in the 850 mb weather maps in Fig. 7. Regarding this upper air front, some conditions will be set forth later.

5.2 *Types of snow crystals and aerological conditions*

All results obtained during this observation period are collected in Fig. 8. Types of snow crystals are shown by symbols in the upper part of the figure. The upper part expressed as three horizontal strips, represent the type of the snow crystals observed at three sites, and the snow symbols at the top most line of each strip indicate the type of snow crystals most frequently observed. (namely the Summit, 800 m and Paradise Hut observation points) The name of snow crystals is given in Table 2 with each symbol.

Three continuous observations were carried out from $08^{h}00^{m}$ to $10^{h}00^{m}$, $14^{h}00^{m}$ to $16^{h}00^{m}$ and $20^{h}00^{m}$ to $22^{h}00^{m}$. Three radio sonde soundings were made in Sapporo at $09^{h}00^{m}$, $15^{h}00^{m}$ and $21^{h}00^{m}$ respectively.

The lower part of Fig. 8 represents the time cross section in which the coordinate shows the height above sea level in meters. The solid lines, dotted lines are isotherms and equal humidity lines respectively. The humidity is represented with respect to ice surface. The heights of cloud base and cloud top which were determined by means of picture of clouds from the Teine Town observation point and by means of airplane sounding. Regions supersaturated with respect to ice surface are particularly shown by the shaded area in the figure.

It may be seen that the supersaturated regions were much higher compared with those in the previous observation[3] and that no temperature inversions were observed below an altitude of 3000 m except near the ground surface, although inversions were almost always observed in the previous observation. This is the most remarkable character in the results of the present observation. It is reasonably supposed that the supersaturation region, in other words, the moist region reached a much higher level, because there were no inversion layers which acted to suppress the vertical development of clouds.

Since, according to the time cross section, highly supersaturated regions existed at levels higher than 2000 m, it seems that most of the snow crystals were formed at levels higher than 2000 m. However, it should be noted here that at much higher levels, in other words, at much colder temperatures,

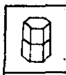
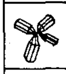
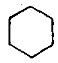
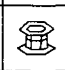
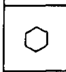
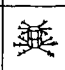
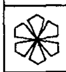
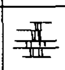
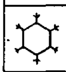
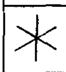
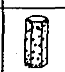
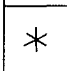
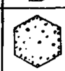
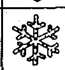
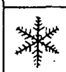
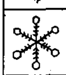
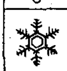
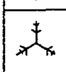
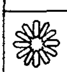
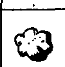
	Hollow hexagnal column		Radiating type of dendritic plane
	Combination of bullets		Radiating type of plate or sector
	Simple plate		Column with plates
	Small hexagonal plate		Column with dendritic crystals
	Branches in sector form		Complicated capped column
	Plate with simple extension		Bullet with plates
	Broad branches		Radiating type of columns and plates
	Simple stellar form		Rimed column or thick plate
	Stellar germ		Rimed plate or sector
	Ordinary dendritic form		Rimed dendritic crystal
	Fernlike crystal		Plane with rimed spacial branches
	Stellar crystal with plate at ends		Graupel-like crystal of hexagonal type
	Plate with dendritic extension		Graupel-like snow of lump type
	Three-branched crystals		Graupel-like crystal with not rimed extensions
	Broad branches		Hexagonal graupel
	Fernlike crystal		Lump graupel
	Malformed crystal		Rimed broken branch
	Stellar crystal with spacial dendritic branches		Miscellaneous

Table 2 Symbols for snow crystals

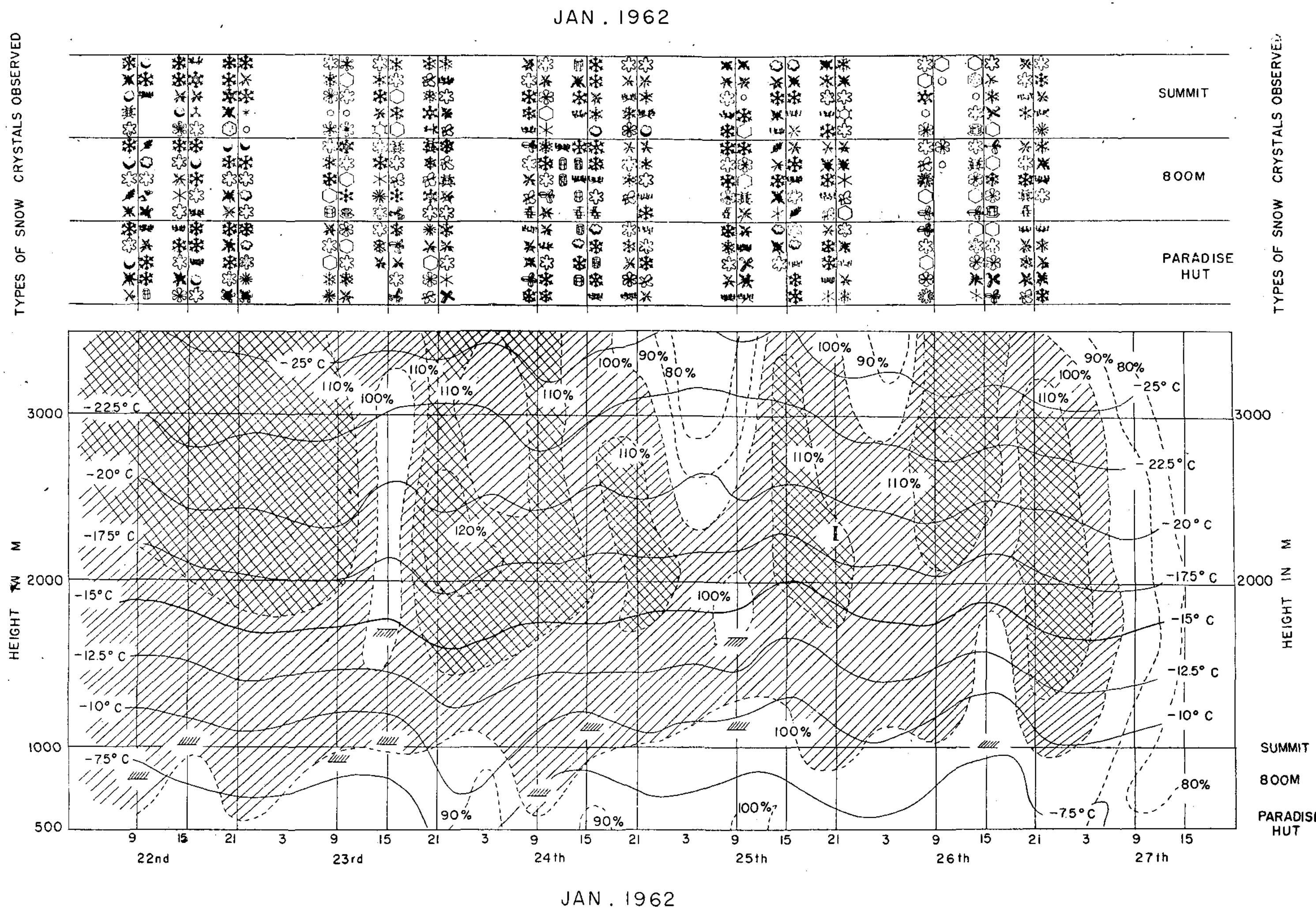


Fig. 8 Types of snow crystals observed and time cross section during the observation period. The humidity is shown in relative humidity with respect to ice surface.

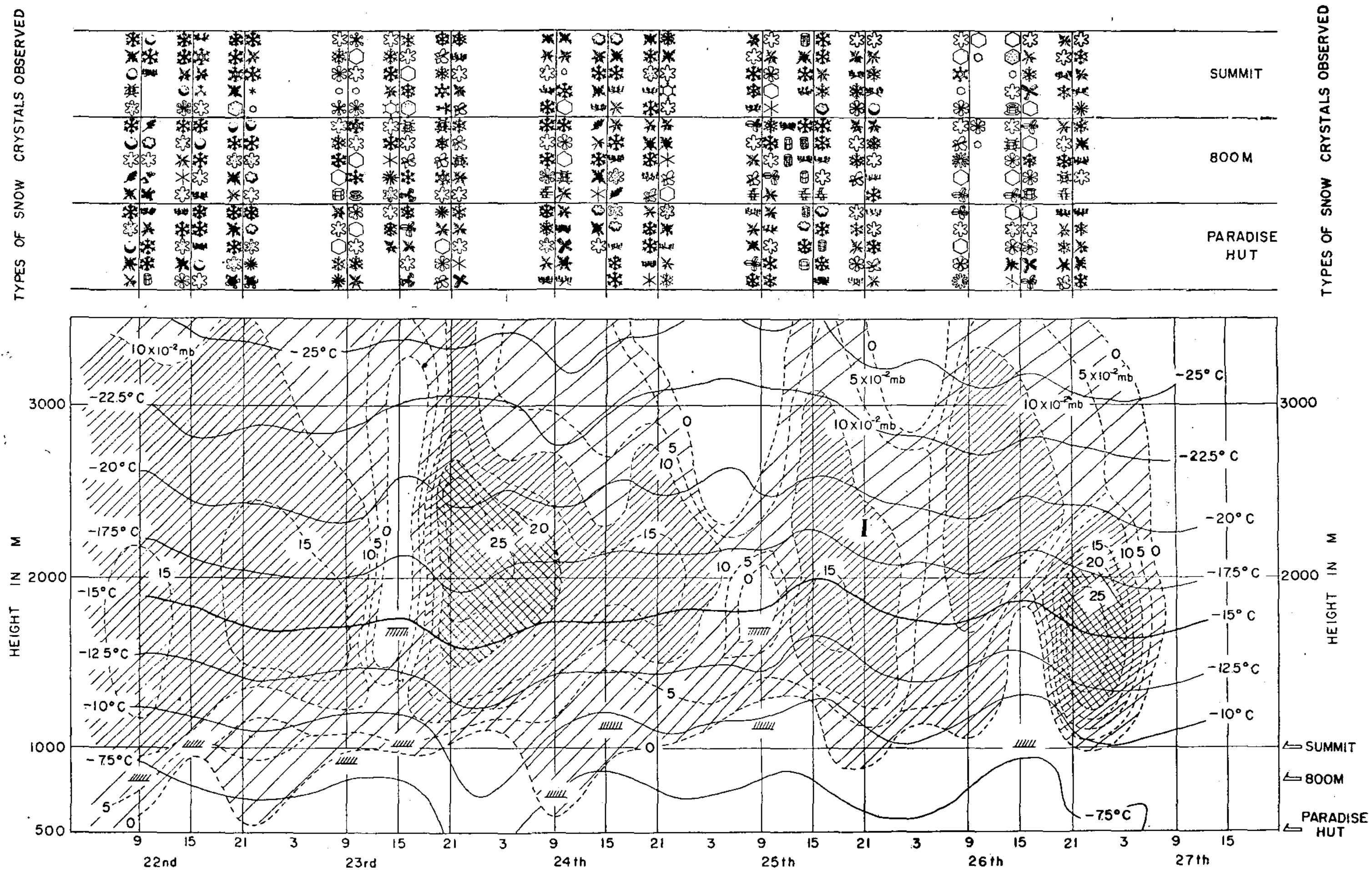


Fig. 9 Types of snow crystals observed and time cross section during the observation period. The humidity is shown in water vapor excess over ice saturation surface.

absolute magnitudes of both water saturation vapor pressure and ice saturation vapor pressure themselves are small, even if their relative humidity in percentage is apparently high. Accordingly, the difference between the saturation pressures is cannot be large. Since the rate of growth of snow crystals proportional to the gradient of vapor pressure just near the crystal's surface, it is considered that the moisture at altitudes as high as 4000 m has very little effect on the growth of snow crystals such as observed at ground surface. It is usually believed that the type of snow crystals is determined by the rate of growth of the crystals.

According to the ice crystal theory, sufficient gradient of vapor pressure is mainly given by the excess of ice saturation vapor pressure over water saturation vapor pressure within the clouds. In natural conditions it is not always that the air within cloud is saturated with respect to water, but almost always the air is saturated with respect to ice.

From this point of view, the absolute value of vapor pressure excess of air over ice saturation vapor pressure was used as an indicator of humidity as shown in Fig. 9. This method of representation of humidity in clouds will be better than the simple relative humidity in percentage in the discussion of the growth of snow crystals as will be seen later. In Fig. 9 the supersaturation region is classified into three region by means of the grade of supersaturation, that is, from 0 to 0.1, from 0.1 to 0.2 and larger than 0.2 mb which are shown by the grade of darkness. In the present paper the region of supersaturation larger than 0.2 mb will be called the "moist region", because the "moist region" seemed to be effective in the determination of the type of snow crystals.

5.3 *Day to day account*

22 *Jan.* 1962 In Fig. 9, it may be noted that the type of snow crystals was various and almost all crystals were rimed more or less, with a considerable amount of graupel. The former fact may be understood by considering that the supersaturation region, specially the moist region ranged widely from near the ground surface to altitudes over 4000 m. Regarding the latter fact, the following is considered. As seen in Fig. 6a, the surface pressure pattern was of the so-called "west high east low type" and a north-westerly monsoon was prevailing. At higher levels of 850 mb as seen in Fig. 7a, a cyclone existed not too far away to the north-east and the Island of Hokkaido was between two upper air cold fronts. The aerological condition in the morning is shown in Fig. 10a in which it is seen that the effective winds on the snow clouds between 500 and 3000 m were uniformly north-west and fairly strong. The pressure

pattern and the wind system suggest that the snowfall observed was not frontal but mainly was brought about by orographic ascending air currents at the mountain region on the west side of the Hokkaido Island. The strong westerly wind at levels lower than 1000 m is important because the wind at such low levels brings abundant moisture from the sea surface.

According to recent investigations[6], the vapor which is at lower levels plays the main role in forming rimed snow crystals. Particularly vapor supplied from the sea surface may be important. The vapor perhaps exists in the form of supercooled droplets. Probably these facts described above are the principal reasons why the snow crystals were mostly rimed on 22nd. This will be more apparent if compared with the result of the next day.

23 *Jan*. 1962 On 23rd no snow crystals were rimed as seen in Fig. 9. In the morning, snowfall occurred both over mountain and plain areas (Photo. 6, Pl. II). In the afternoon, the snowfall became light and clouds changed to a broken type (Photo. 7). As seen in Fig. 6b, the width of isobars became larger and the two upper air cold fronts disappeared as seen in Fig. 7b. These facts indicate that the weather was very calm synoptically. Actually it was fine elsewhere in the Hokkaido Island except in the mountain regions.

It is seen in Fig. 10b that a slight inversion layer existed below an altitude of 500 m and the wind was very weak there. This presumably may have resulted from the cold air mass produced by radiation cooling in the clear previous night in the island. And the cold air flowed out to sea as shown by the southerly wind at the ground surface. On the other hand, at levels higher than 1500 m, a north-west wind was prevailing. Accordingly, the upper air only reached the mountain area. The vapor was not supplied from the sea surface where vapor for producing supercooled droplets was produced. This is the main reason why only non-rimed crystals were observed on 23rd at Mt. Teine.

In the daytime, snow crystals of hexagonal plate and broad branch type were predominant. According to Nakaya's diagram[5], snow crystals of such types are formed at a temperature a little warmer than −13°C. One may see in Fig. 9 that a supersaturated region actually existed at only levels lower than about 1500 m, in other words, at only temperatures warmer than −13°C.

During the night, a moist region developed vertically, in other words, ranging widely from −10 to −30°C level. Accordingly, snow crystals of cold temperature type such as side plane and assembly of plates were frequently involved.

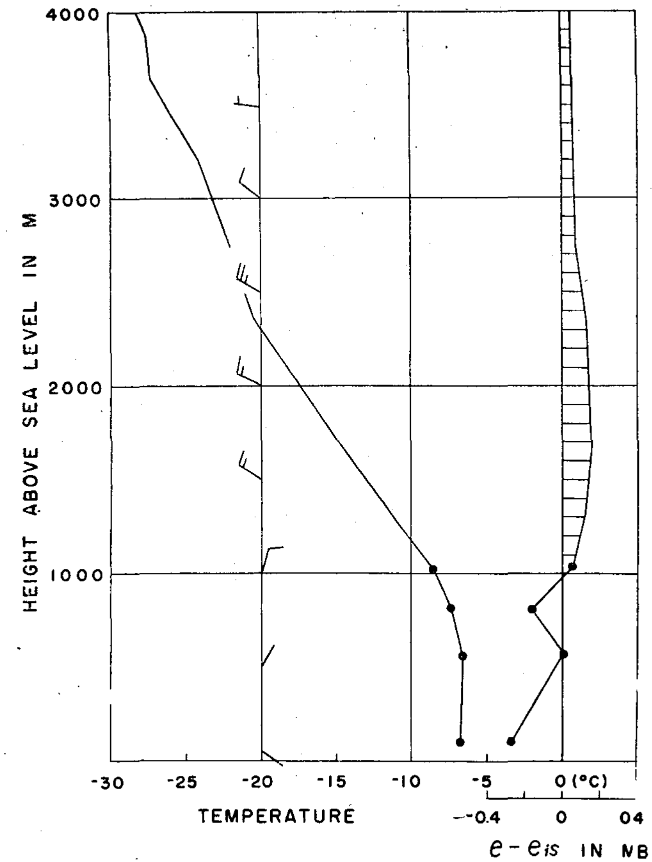


Fig. 10b 0900 23 Jan.

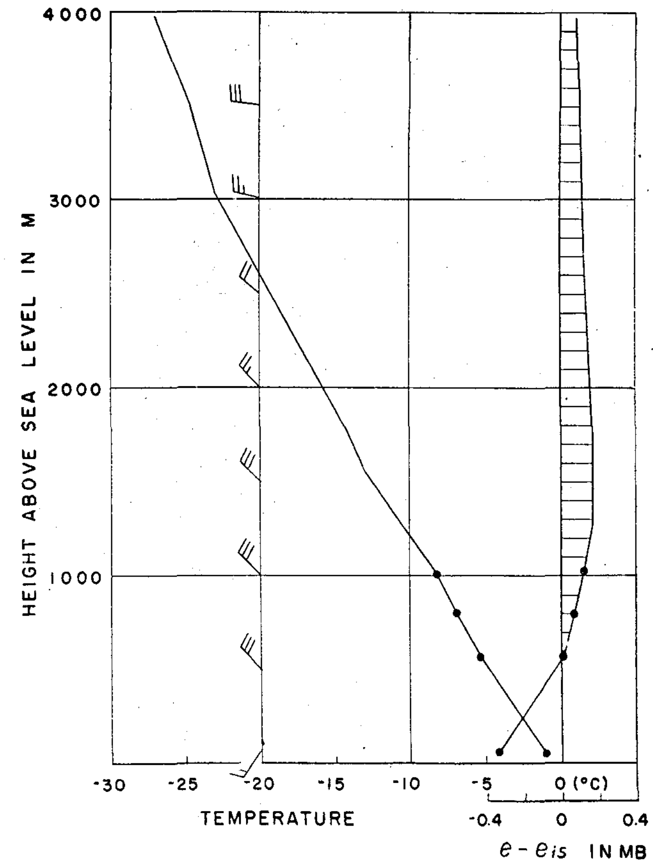


Fig. 10a 0900 22 Jan. Vertical profiles of wind, temperature and vapor excess over ice saturation

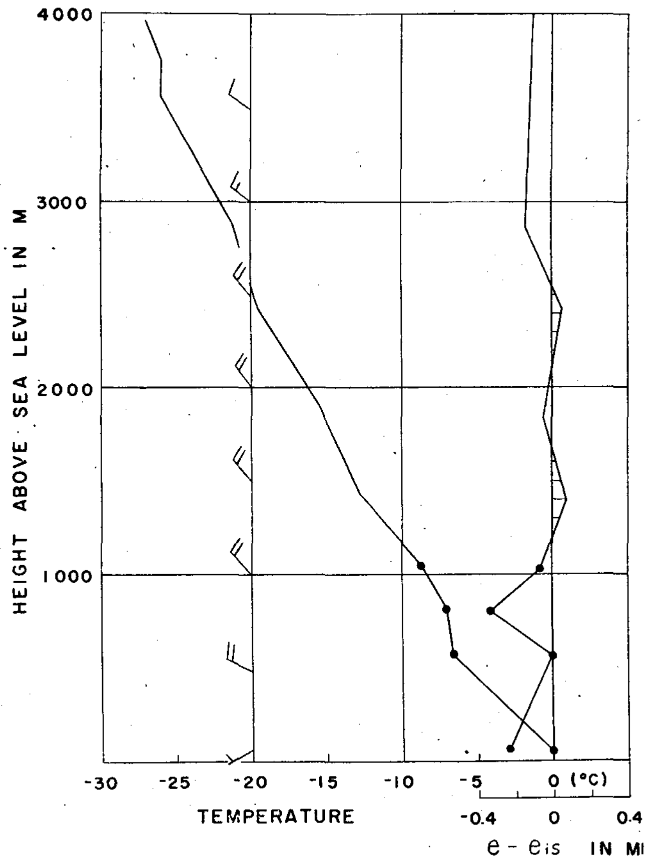


Fig. 10d 0900 25 Jan.

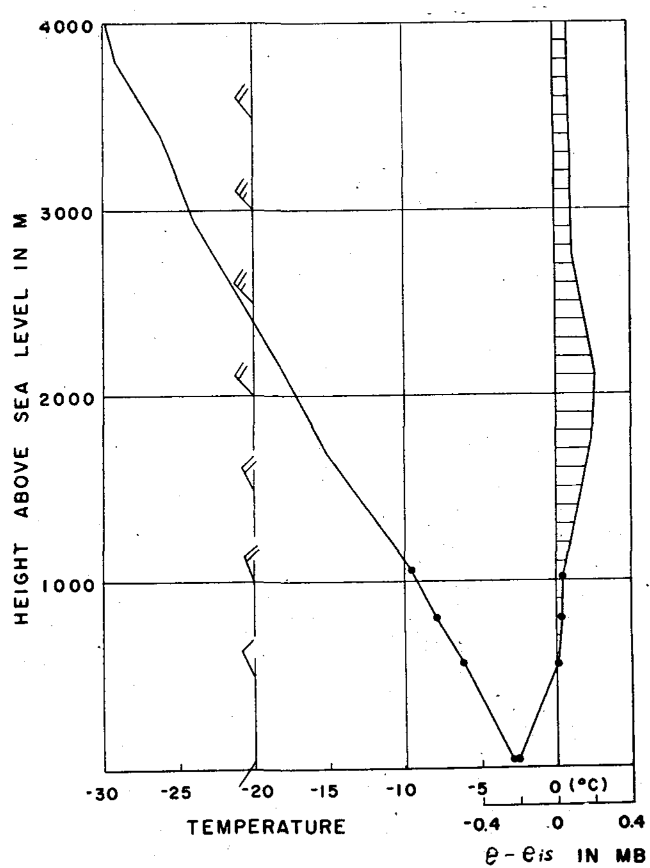


Fig. 10c 0900 24 Jan.

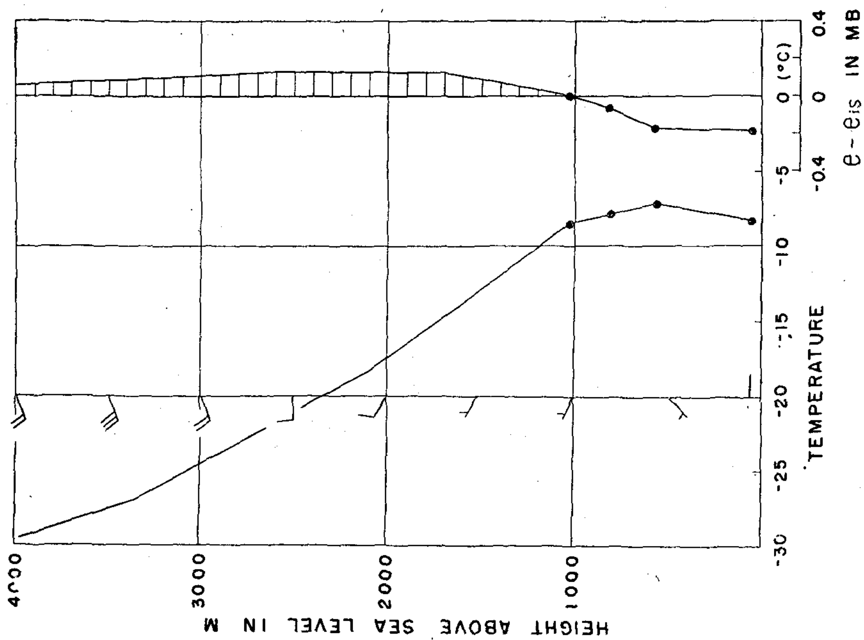


Fig. 10e 0900 26 Jan.

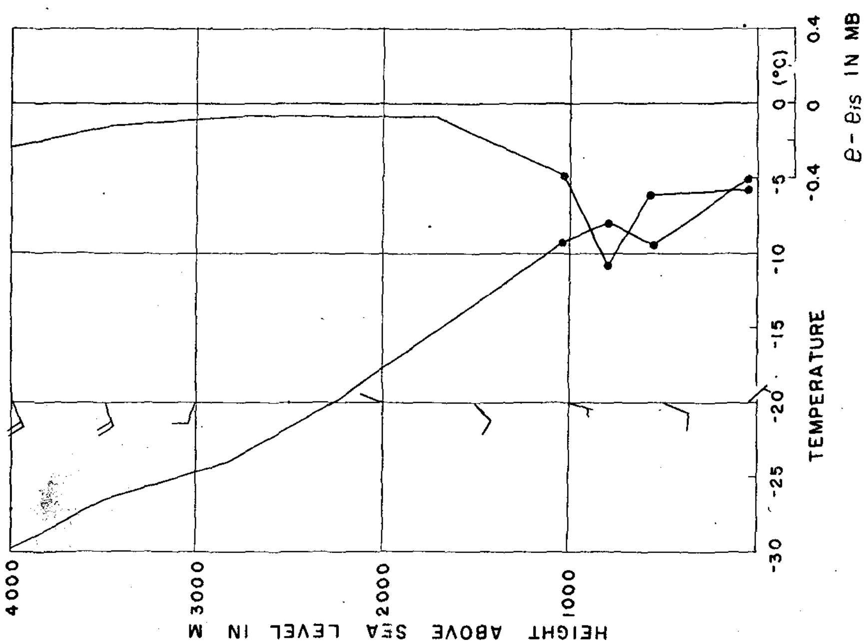


Fig. 10f 0900 27 Jan.

24 *Jan.* 1962 A fairly heavy snowfall continued through the daytime (Photos. 8 and 9, Pl. III). Cold types of snow crystals were frequently observed, for example, combination of bullets, radiating type of plates, and rimed crystals were predominant as on 22nd. It may also be seen in Fig. 9 that a supersaturated region developed vertically and the base of the region was so low as to reach the ground surface. The vertical distribution of wind, temperature and humidity was also similar to that on 22nd, as seen in Fig. 10c. In addition to these phenomena, both the surface and 850 mb pressure patterns were similar to 22nd as seen in Figs. 6c and 7c. From these facts, it was surmised that as a whole the meteorological condition was approximately the same as that on 22nd. Actually, the crystal types were almost the same as those on 22nd.

Further if the time cross section is studied in detail, it will be seen that the change in the distribution of crystal types corresponded exactly to the change in the vertical profile above Mt. Teine. For example, the existence of crystals of exceedingly cold type such as the combination of bullets at 09^h00^m indicated that the supersaturated region attains temperatures colder than –30°C for thereabouts. The disappearance of snow crystals of the cold type at 15^h00^m indicates that the top of the supersaturated region had inclinded downwards to a –23°C level. The graupel being predominant at 15^h00^m indicates that the width of isotherms became smaller at lower levels and the air was unstable. It should be noted here that graupel usually is formed in an ascending air current in an unstable air mass. At 21^h00^m, the moist region went up, and the width of isobars became a little larger. In correspondence to this movement snow crystals of cold type such as combination of plates appeared again while graupel disappeared, as seen in Fig. 9.

25 *Jan.* 1962 As seen in the pressure patterns of Figs. 6d and 7d, a synoptic condition was seen between the conditions on 22nd and 23rd. It was, therefore to be expected that the combination of crystal types would also be between those on 22nd and that on 23rd. The expectation was roughly correct except for the existence of snow crystals of column type as seen in Fig. 9. However the existence of the columnar crystals requires some explanation.

As seen in Photo. 10, Pl. IV, in the morning it was clear at the plain level but it was cloudy above the summit. In the afternoon, dense clouds covered both mountain and plain regions as seen in Photo. 11, Pl. IV. This change in weather will be easily understood if the time cross section of Fig. 9 is taken into account. But it is difficult to explain why crystals of cold temperature type such as column were observed during the daytime and disappeared at night; because the top of supersaturation region was at a level as low as 2200 m, while being at a level as warm as –18°C in the daytime. In addition to this, there was no moist region observed at 09^h00^m. If this result is true, it would be impossible for snow crystals of column type to be formed in the clouds, because crystals of such type are formed at a temperature range lower than –20°C. Presumably this contradiction resulted from the inexact measurement in the humidity of clouds. Since clouds were only above the mountain region, the ascending radio sonde probably did not pass through the clouds. In addition to that, since the air layer over 2500 m was fairly dry as seen in Fig. 10d, it would be impossible to obtain an exact correction of the humidity above the mountain region by connecting the values of humidity at 1000 m and at 2000 m, even if the data of levels lower than 1000 m were correct. The authors feel that light snow crystals of cold type such a column possibly drifted down from higher altitudes far to windward, although such high clouds (cold clouds) were not observed by the radio sonde sounding. Using such measuring methods, such small disagreements are unavoidable. A drop sonde method above the target cloud or another special ascending sonde sounding to the windward of the observation region will be required.

26 Jan. 1962 In the daytime, a light snowfall occurred. Regarding the crystal type, no dendritic crystals fell, while crystals of cold type above were observed. And no rimed crystals were observed. It was also noted that almost all crystal types observed were of the dry type. This type of snow crystals develop under an insufficient vapor supply, for example hexagonal plate, sector and broad branches.

As a whole the meteorological condition was similar to that on 23rd. That is to say, the surface pressure pattern was nearly the same as that of 23rd, as seen in Fig. 6e. And likewise the easterly wind at the surface and temperature inversion at levels below 1000 m were the same as in the case of 23rd, as seen in Fig. 10e. As described in the account on 23rd, it follows that the moist air (only at higher level) reaches over the mountain region and these snowfalls are due to orographic ascending air. In this case it is expected that snow crystals will be only of the cold type and of not of the rimed type. Actually this was the case as seen in Fig. 9. It is also noted that no dendritic crystals were observed in the daytime. This may be understood if it is considered that the moist region existed only at levels colder than

–15°C where snow crystals grow to dendritic form according to the *Ta-s* diagram.

In the night time, a small cyclone appeared in the west as may be assumed from Fig. 6f and a moist region appeared between –10 and –20°C levels as seen in Fig. 9. Because of this, snow crystals of various types corresponding to this temperature range were observed.

27 *Jan.* 1962 Snowfall did not occur.

6. Consideration

6.1 *Spacial dendritic crystals and temperature inversion*

In the previous paper, it was emphasized that spacial dendritic crystals may be recognized as an good indicator of the existence of temperature inversion at about a –20°C level. However in the present observation, as described in §5.1 no temperature inversions were observed except near the ground surface although spacial dendritic snow crystals were often observed. In regard to this disagreement, the following three points may be considered.

1. The temperature inversion layer may have been too thin to be detected by means of the ascending radio sonde.

2. Since the temperature inversion was located in a small region, the ascending sonde may have missed the inversion region.

3. Dendritic snow crystals which were formed at a –15°C level may have been raised again to higher levels colder than –20°C by the local ascending air current.

Local swellings in width of isotherms, in other words, the portion of most stable regions near –20°C in the time cross section, for example at $21^{h}00^{m}$, 23rd, $15^{h}00^{m}$ and $21^{h}00^{m}$, 24th, $09^{h}00^{m}$ and $15^{h}00^{m}$, 25th suggest that in this vicinity a limited temperature inversion existed in spite of their being too small or too localized to be measured by the radio sonde. Therefore, the first and second considerations may be reasonable. In the case of $21^{h}00^{m}$ 26th, dendritic snow crystals were frequently observed. However there was no signs to indicate the existence of inversion. In contrast, the width of isotherms was much smaller at levels lower than 2500m, in other words the condition was unstable at lower levels. This situation suggests that there were some convection currents between –15 and –20°C levels. The third consideration presumably corresponds to this case.

6.2 *Upper air front*

As described in §3, there were no fronts observed at the surface pressure maps, but upper air fronts frequently exist at the 850 mb level around Hokkaido Island. However no particular correlation has been recognized between these upper air fronts and the combination of the type of snow crystals. The upper air fronts did not move and stayed at the coast of Siberia to the west of Hokkaido, and the upper air wind was always westerly during the observation period. Under such conditions the front has no effect on the ascending air current, accordingly there was no influence on the formation of snow clouds or of precipitation. This may be the main reason why the upper air fronts had no particular relation with the shape of snow crystals at the time of the observation.

6.3 *Rimed crystals and vapor supply from the sea surface*

Lastly the above points will be reconsidered using all the results obtained in the observations from 1959 to 1962. In the previous paper, the condition in which graupel was formed was discussed in regard to the lapse rate of temperature. Here, now in a wider sense, some considerations will be made regarding the condition in which rimed crystals are formed, because most of the liquid water content of clouds are considered to be brought down to the ground surface in the form of rimed snow crystals.

As described already, the vapor supply from the sea surface was important in the formation of rimed snow crystals. Accordingly, it is suspected that the lower the cloud base, the more the snow crystals will be rimed. However, the simple height of cloud base is not suitable as criterion, because if the temperature is higher than 0°C, no rimed crystals will be formed. Therefore, the temperature at the cloud base was noted, in place of the height of the cloud base.

The results are summarized in Fig. 11. The vertical axis shows the thickness of clouds which were calculated from the difference between the cloud base and top. The thickness was adopted only when the cloud base and top were measured. The types of snowfall were classified into three categories as follows:

1. Graupel type: Snowfall in which at least graupel was included.
2. Rimed crystal type: Snowfall in which at least rimed snow crystals were included.
3. Non-rimed crystal type: Snowfall in which no graupel nor rimed crystals was included but only non-rimed crystal were observed.

It may be seen that the region of rimed crystals, enclosed by solid lines, is distributed in a region considerably warmer than the region of non-rimed

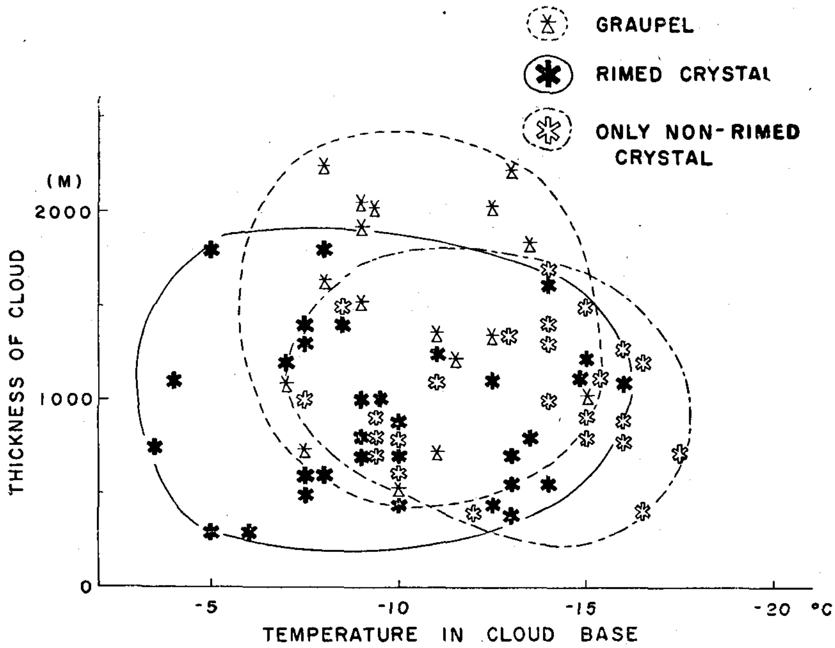


Fig. 11 Thickness of snow clouds v. s. temperature of cloud base during snowfall observed

crystals enclosed by a chain curve. This suggests that vapor at lower levels are important in the formation of rimed crystals. It is known, of course ,that rimed crystals are also produced when the temperature of the cloud base is colder than –15°C. Further, it may be seen that the region of graupel type is distributed at a higher region compared with those of rimed crystals or non-rimed crystals. This means that a large cloud thickness is required to cause a graupel-fall. Considering that graupel is formed under strong ascending air current, this is a reasonable result.

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Broadcasting Company whose sending station is at the summit of Mt. Teine. The HBC cooperated extensively by making available its facilities to the observation team.

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Pl. I Cloud conditions over mountain area and Sapporo.

Photo. 1. 0950 27 Jan. There were no clouds both over mountain area and Sapporo.

Photo. 2. 1630 23 Jan. Mountain area was covered by Ns clouds but there were no clouds over Sapporo.

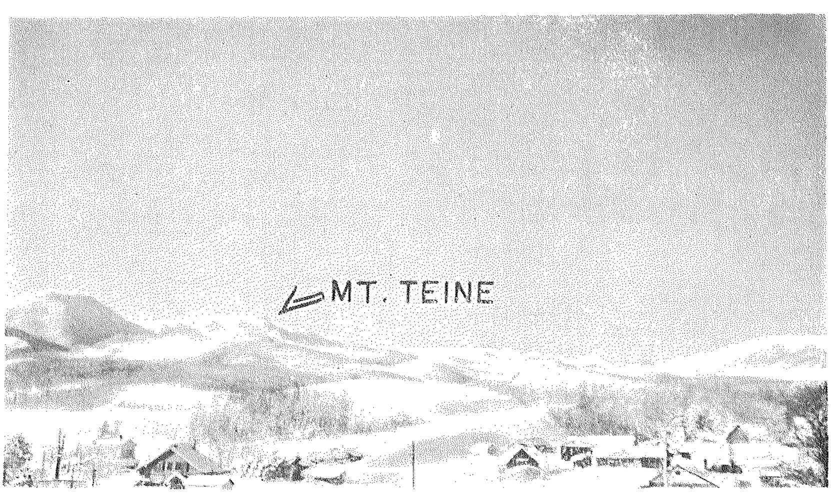

Photo. 3. View of Mt. Teine from the foot to the north east.

Pl. II Clouds over Mt. Teine.

Photo. 4. 0900 22 Jan. Heavy snowfall over mountain area only.

Photo. 5. 1500 22 Jan. Heavy snowfall over mountain area only.

Photo. 6. 0900 23 Jan. Snowfall over mountain and plain area.

Pl. III Clouds over Mt. Teine.

Photo. 7. 1500 23 Jan. Snowfall at mountain area from thin clouds.

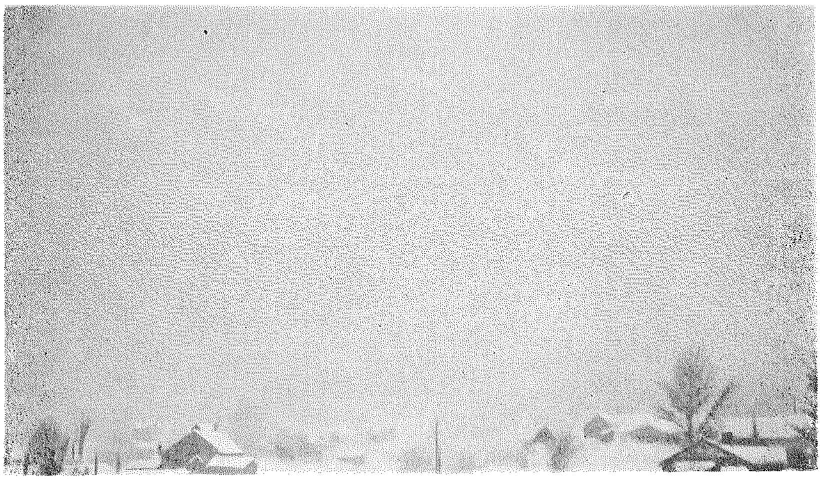

Photo. 8. 0900 24 Jan. Heavy snowfall over mountain and plain area.

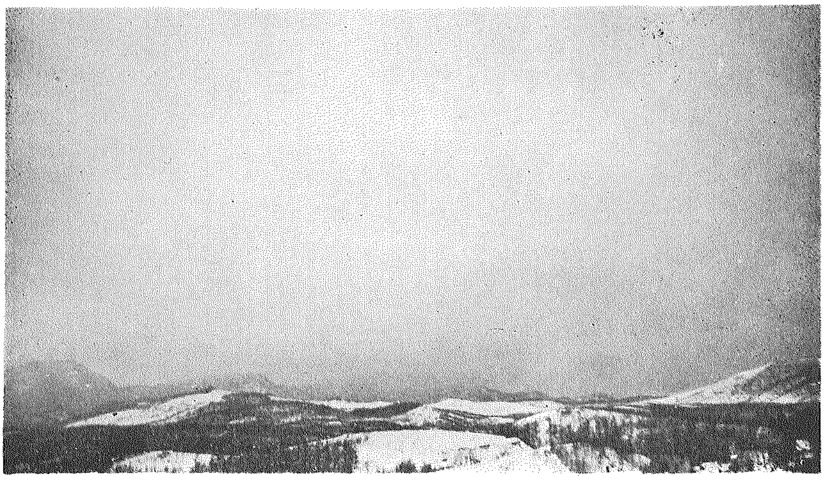

Photo. 9. 1500 24 Jan. Snowfall over mountain area

Pl. IV Clouds over Mt. Teine.

Photo. 10. 0900 25 Jan. Cb clouds over summit of Mt. Teine.

Photo. 11. 1500 25 Jan. Snowfall over mountain and plain area.

Photo. 12. 0900 26 Jan. Light snowfall over mountain and plain area.