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On Snow Crystals with Small Raindrops Observed in Greenland

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Abstract

Snow crystals with small raindrops were observed all day long on 1 January 1990 during the observation period of the snow crystals of low temperature types in Godthåb, Greenland. The accreted frozen raindrops were divided into single crystal and polycrystalline, and in the favorable formation of polycrystalline the size effect was detected.

The formation of snow crystals with small raindrops was considered as follows. Under the pressure pattern of east-high and west-low, Foehn wind blew across Greenland. It made wind waves on the sea surface and many NaCl particles originated from the sea. As there were usually few aerosol particles in the atmosphere over the sea, the result was that there were few aerosol particles activated as condensation nuclei and NaCl particle ratio was high. Therefore, it was possible to grow to large water drops even under meteorological conditions without an abundance of water vapor content. Then, it was important, too, that there were little water vapor content expended by ice particles.

1. Introduction

It has been reported that solid precipitation particles grown by accretion of cloud droplets such as rimed snow crystals and graupel particles fall even under low temperature conditions in the Arctic region and the Antarctic region (e.g. Magono and Kikuchi, 1980). It has been considered that solid growth is the main elemental process of precipitation formation under low temperature conditions, but it is considered from the observational results that liquid growth

is important, also.

On the other hand, it has been reported that some researchers observed snow crystals with small raindrops which accreted water drops with their diameters of above 200 μm in the Antarctic region (Kikuchi, 1972), the Arctic Canada (Kikuchi and Uyeda, 1979) and Alaska (Sakurai and Ohtake, 1981). But, it was not mentioned in the Magono and Lee classification (1966) of natural snow crystals and has not been observed in the Temperate Zones such as Japan. The formation of water drops with diameter of above 200 μm is considered to be one proof that liquid growth progresses actively even under low temperature conditions. But, there are hardly any investigations regarding the mechanism of how such water drops are formed under low temperature conditions.

Snow crystals with small raindrops were observed all day long on 1 January 1990 during the observation period of the snow crystals of low temperature types in Godthåb, Greenland. So we examined the characteristic features such as size distributions and crystal structure of the frozen drops accreted by the snow crystals. Then, the formation mechanism of snow crystals with small raindrops was considered by comparing with the meteorological conditions as to whether it fell or not and by examining the number concentrations and elemental components of aerosol particles to be condensation nuclei or ice nuclei. In this paper we will describe their results.

2. Observation

Observations of snow crystals were carried out in Godthåb (64°10′N, 51°45′W), Greenland as shown in Fig. 1 from 18 December 1989 to 3 January 1990 for the purpose of observations of "The Studies on the Snow Crystals of Low Temperature Types and Arctic Aerosols". Snow crystals with small raindrops fell on 1 January during the observation period. The snow crystals were collected on a piece of board covered with a black velvet cloth. Then, they were picked up from the board and placed on the stage of a polarization microscope. The snow crystals were photographed to measure the sizes of snow crystals and accreted frozen drops.

Other observations, likewise, were carried out at the observation site in Godthåb to obtain the number concentrations and elemental components of aerosol particles (Sakurai et al., 1992), and air temperature. Analyses were done by using the meteorological data observed at Godthåb station of Denmark Meteorological Institute and aerological data at Egedesminde as shown in Fig. 1 in addition to the observational results above-mentioned.

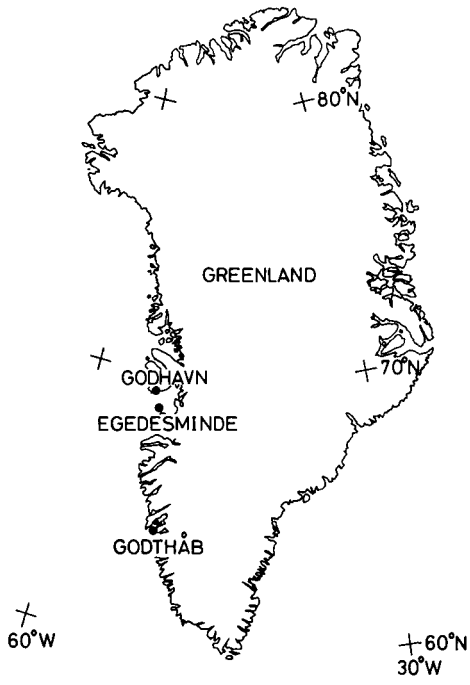

Fig. 1. Locations of observation site and upper air observation station.

3. Results

During the snowfall on 1 January, microscope observation was carried out from 0612 LST to 1632 LST when it stopped snowing. Snow crystals with small raindrops were observed throughout the observation time. A typical example is shown in Fig. 2. It is seen that the snow crystal accretes the frozen drops with diameters of 220 μm and 190 μm which are as large as raindrops. It was detected by a polarization microscope that the frozen drops are polycrystalline.

Another example is shown in Fig. 3, likewise. The largest frozen drops are polycrystalline and are 180 μm in diameter. The frozen drop that is of secondary size is single crystal with a diameter of 120 μm and has a different axis from the substrate snow crystal. The frozen drop that is of third size is single crystal with a diameter of 70 μm which has the same axis as the substrate snow crystal. It was shown from the observation that the frozen drops accreted on snow crystals with small raindrops consisted of three types of crystals, namely single

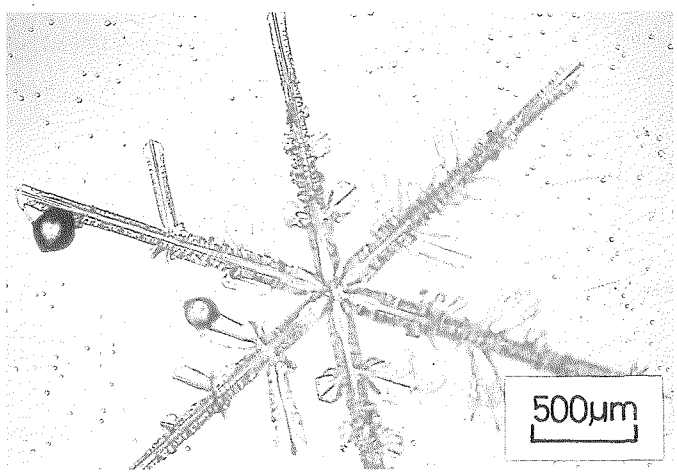

Fig. 2. A typical example of photomicrographs of stellar crystal with small raindrops.

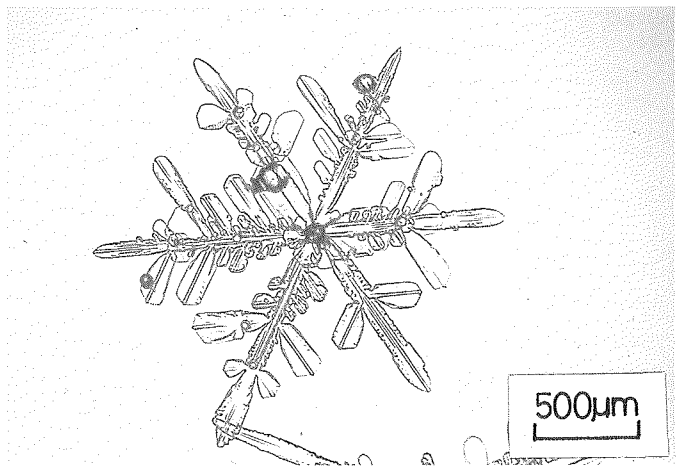

Fig. 3. As in Fig. 2.

crystals with the same axis as the substrate crystal, those with a different axis from the substrate crystal and the remainder which were polycrystalline.

On the other hand, rimed stellar crystals with small raindrops were observed occasionally during the observation. One of the examples is shown in Fig. 4. It is clear in the figure that there is a difference in size of the raindrops

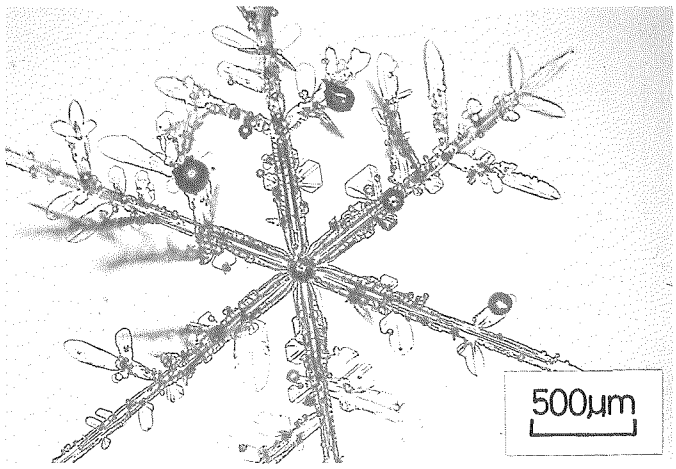

Fig. 4. A photomicrograph of rimed stellar crystal with small raindrops.

and cloud droplets accreted on the crystal.

Figure 5 shows the frequency distribution of diameters of frozen water drops and cloud droplets accreted on snow crystal in Fig. 4. It is seen in the figure that the frequency distribution continues in the range of diameter less than 50 μm, but it does not continue in the range of above 60 μm. On the other hand, previous observations showed that cloud droplets accreted on rimed crystals are usually less than 50 μm in diameter (e.g. Harimaya, 1975), so we regard the frozen drops with diameter of above 60 μm as small raindrops in this paper.

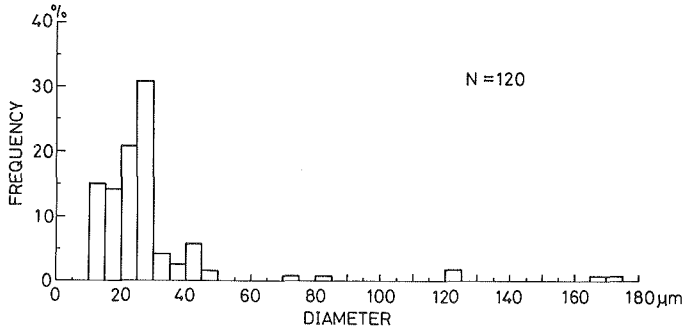

Fig. 5. Frequency distribution of diameters of frozen water drops and cloud droplets accreted on snow crystal in Fig. 4.

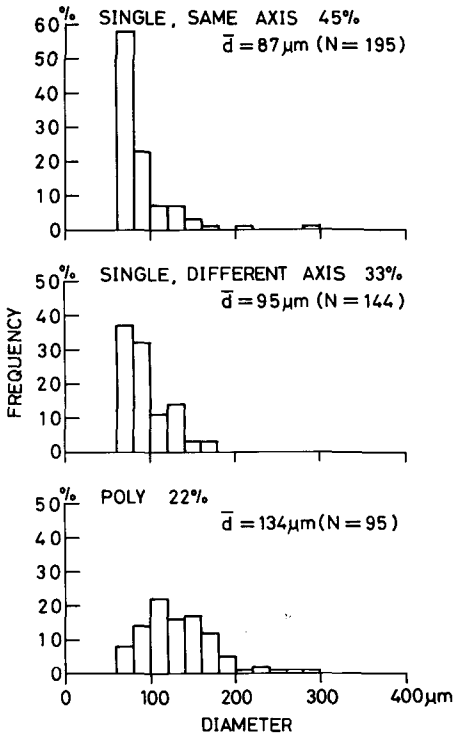

Fig. 6. Size distributions corresponding to the single crystal raindrops with the same axis as the substrate snow crystal and with a different axis to the substrate crystal, and polycrystalline raindrops.

As it was detected the frozen drops consist of single crystals and polycrystalline, their size distributions were measured in each crystal type to study their characteristic features. Figure 6 shows the size distributions corresponding to the single crystal raindrops with the same axis as the substrate snow crystal and with a different axis to the substrate crystal, and polycrystalline raindrops. As seen in Fig. 6, the number of raindrops with small size decreases and that with large size increases in the order of single crystals with the same axis as the substrate crystal and with a different axis from the substrate crystal, and polycrystalline. Their mean diameters were 87 μm, 95 μm and 134 μm, respectively. That is to say, the size effect was detected in the favorable formation of polycrystalline.

On the other hand, it was reported from the freezing experiment (Pitter and Pruppacher, 1973) of small water drops that frozen drops were single crystal or polycrystalline depending on the drop size, the temperature of freezing, and the heat dissipative capability of the medium surrounding the drops. As water drops freeze by contact with snow crystals in this case, it is considered that each

drop is under equal conditions regarding the heat dissipative capability of the medium surrounding the drops. Under such conditions, the size effect and temperature effect are expected in the favorable formation of polycrystalline. As the freezing temperature was not measured in this observation, the temperature effect could not be detected. But, the size effect was detected. So this observational result is considered to be consistent with the Pitter and Pruppacher's experimental result (1973).

In order to find the characteristic features of raindrop formation, the size and number concentration of raindrops were studied in the form of time change of the relationship between both values as seen in Fig. 7. Bars in the lower part indicate the diameter from first value to fifth value and solid circles with solid lines indicate mean diameter. Though the maximum diameter was about 180 μm in the morning, it became more than 200 μm in the afternoon. Regarding the mean diameter, it was about 90 μm in the morning and about 120 μm in the afternoon. So it is considered that raindrops accreted in the afternoon were larger than those in the morning.

The number of raindrops per one snow crystal was within a range of 1.5-

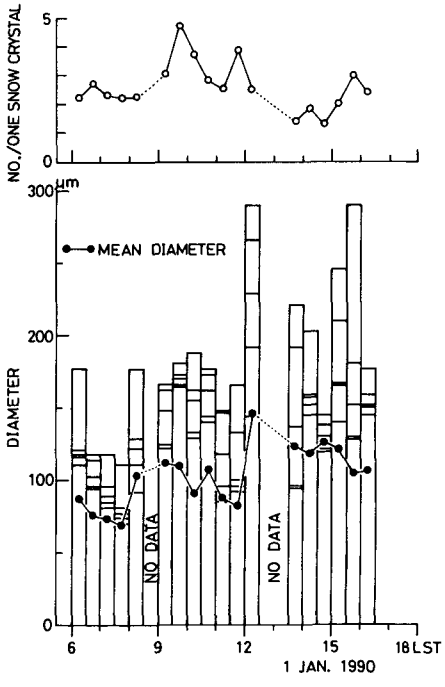

Fig. 7. Time changes of the diameter and number concentration of raindrops. Bars in the lower part indicate the diameter from first value to fifth value. The number concentration of raindrops in the upper part indicates the number per one snow crystal.

5 and 2.6 in mean value. It may be seen that the numbers in the afternoon were fewer than those in the morning. So it is considered that the numbers may have a tendency to decrease, as those sizes increase.

Next, we will study the characteristic features of meteorological conditions when snow crystals with small raindrops fell. Figure 8 shows the time changes of meteorological elements from 29 December to 1 January by using the data of surface observation at Godthåb station of Denmark Meteorological Institute. Horizontal bars in the column of precipitation show the observation period of snow crystals for each day. Typical shapes of snow crystal observed during the period were sketched by graphic symbols and additional characteristics, based on the classification of solid precipitation agreed upon by the International Commission on Snow and Ice in 1949 (Mason, 1971). As may be clearly seen, the classification does not include crossed plates which are a typical shape growing in low temperature regions. Thus we have added this shape to the classification

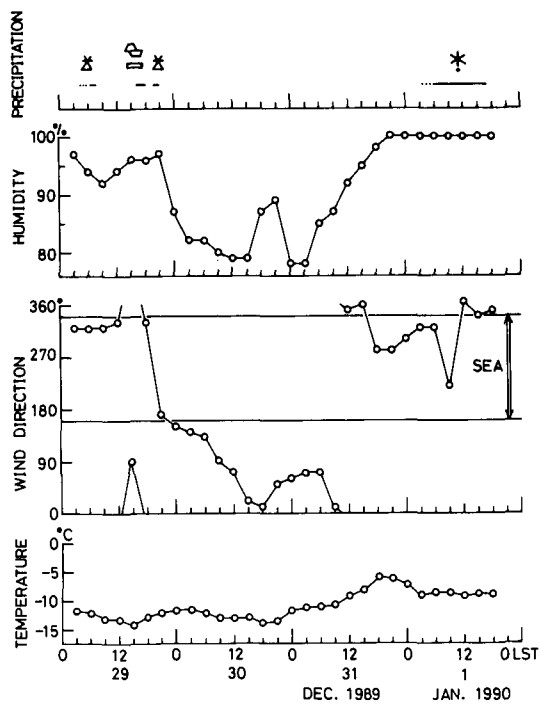

Fig. 8. Time changes of meteorological elements at Godthåb, Greenland. Typical snow crystal observed at Godthåb are shown on the top. Wind directions of 160°-340° show the wind from the sea.

depicted by a graphic symbol (⊕). In the column of wind direction, the wind directions from 160° to 340° at Godthåb indicate the wind from the sea. In this figure, we can compare the meteorological conditions between the day of snowfall of snow crystals with small raindrops and other days.

The surface temperature continued under −10°C from 20 December and changed to above −9°C from the afternoon of 31 December to 1 January. The wind blew from the sea and the humidity was higher on 29 December and 1 January when it snowed. The meteorological condition on 1 January may not be judged to be singular though surface temperature and humidity were high. So the formation mechanism of snow crystals with small raindrops was not suggested from the meteorological conditions.

Next, we will pay attention to the aerosol particles which become condensation nuclei in order to consider the formation mechanism of small raindrops. Aerosol particles were collected on a filter paper by the impactor operated two times daily. The operation time of the sampler was 30 minutes and the flow rate was 3 liter per minute. The filter papers were mounted on a stage of a system of a scanning electron microscope (SEM) and an energy dispersive X-ray microanalyzer (EDX) to measure the size distributions of aerosol particles and to analyze their elemental components (Sakurai et al., 1992).

Figure 9 shows a typical photograph of the SEM image of aerosol particle collected on 1 January when snow crystals with small raindrops fell. As seen in this photograph, this aerosol particle is of a cubic structure with size of 4 μm. The EDX spectrum of the aerosol particle is shown in Fig. 10. As seen in the spectrum, the aerosol particle contains the elemental components of Na and Cl.

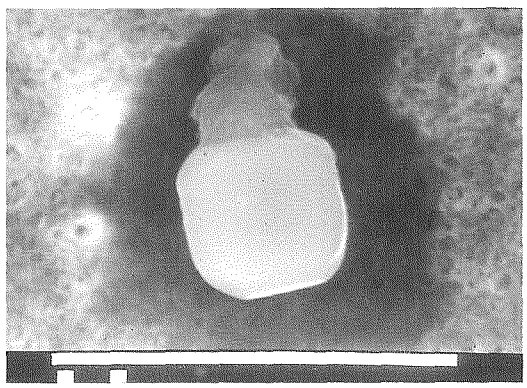

Fig. 9. Photograph of the SEM image of aerosol particle collected at 09 LST 1 January 1990. Scale is indicated in 10 μm by horizontal bar under a photograph.

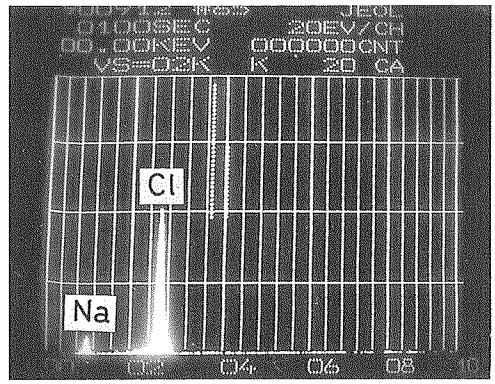

Fig. 10. EDX spectrum of aerosol particle in Fig. 9.

So the aerosol particle was identified to be NaCl particle from the results of SEM image and EDX spectrum.

The aerosol particles on 31 December were examined for comparison with those on 1 January when snow crystals with small raindrops fell. Figure 11 shows a typical photograph of the SEM image of aerosol particle collected at 09 LST 31 December. As seen in this photograph, this aerosol particle has the size of 5.5 μm. The EDX spectrum of the aerosol particle is shown in Fig. 12. The aerosol particle was identified to be soil particle from Al and Si elemental components in EDX spectrum and SEM image. It is considered from the analytical results above-mentioned that NaCl particles originated from the sea

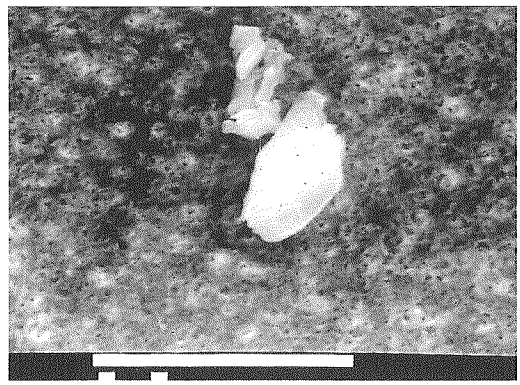

Fig. 11. As in Fig. 9 except for 09 LST 31 December 1989.

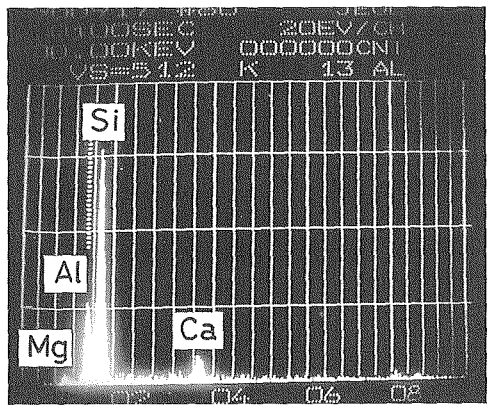

Fig. 12. As in Fig.10 except for aerosol particle in Fig. 11.

were predominant on 1 January when snow crystals with small raindrops fell though soil particles were usually predominant in Godthåb as the aerosol particles in the atmosphere.

4. Discussion

In this section we will discuss why NaCl particles increased in the atmosphere on 1 January, and how the increase of NaCl particles are related with the formation of raindrops. A developing cyclone passed to the north easterly direction near the southern end of Greenland from the morning of 30 December to the afternoon of 1 January. Then, another cyclone occurred in the west coast of Greenland. The meteorological situation is seen in Fig. 13 which is the surface weather chart at 21 LST 31 December 1989. As seen in the surface weather chart, there are a cyclone on the west coast and an anticyclone in the center of the east coast. Based on the pressure pattern, the east wind blew across Greenland. Then, as an air parcel moved over the ice sheet of about 3000 m in height, Foehn phenomenon occurred on the west coast and the wind became stronger and warmer. The wind situation is seen in Fig. 14 which shows the time change of the upper wind at Egedesminde on the west coast. It is seen that the wind speed changed rapidly and became stronger since 09 LST 31 December.

Figure 14 shows how the number concentration and elemental composition of aerosol particles changed in Godthåb before and after the Foehn phenomenon occurred on the west coast near Egedesminde. The number concentrations of

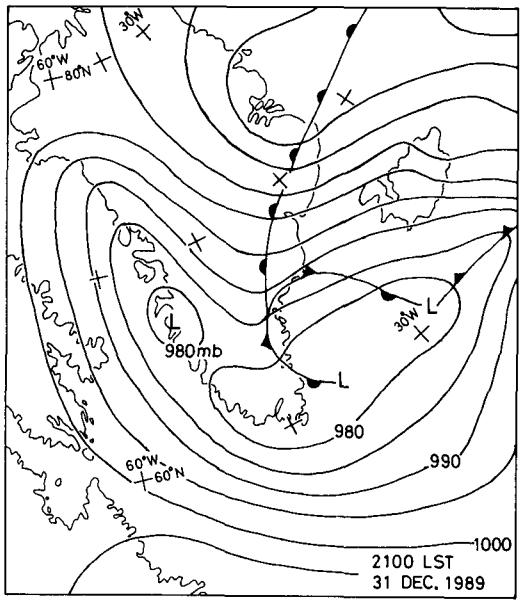

Fig. 13. Surface weather chart at 21 LST 31 December 1989.

aerosol particles are shown by numbers per 1 cm^3 which were based on aerosol particles larger than 1 μm in diameter collected on a filter paper. The upper column shows the ratio of NaCl particle numbers to the total aerosol numbers by percentage.

It is seen in this figure as follows. In Godthåb, the aerosol particle numbers were as many as over 2 particles/cm^3 when the wind blew from inland as seen on 30 December, but it decreased in about 1.2 particles/cm^3 when the wind blew from the sea as seen on 29 December and 1 January. That is to say, there were few aerosol particles in the atmosphere over the sea. The ratio of NaCl particle numbers to the total aerosol particle numbers was as low as 10% when it was calm over the sea, but the ratio increased by 25-40% when it was stormy over the sea by Foehn phenomenon. Combining the results above-mentioned, the formation of small raindrops is as follows. Strong Foehn wind created wind waves on the windward sea surface far from Godthåb, thus the result was that many aerosol particles originated from the sea. As there were usually few aerosol particles in the atmosphere over the sea, there were few aerosol particles activated as condensation nuclei. Besides, the NaCl particle ratio was high, so it was possible to grow to large water drops, namely small raindrops

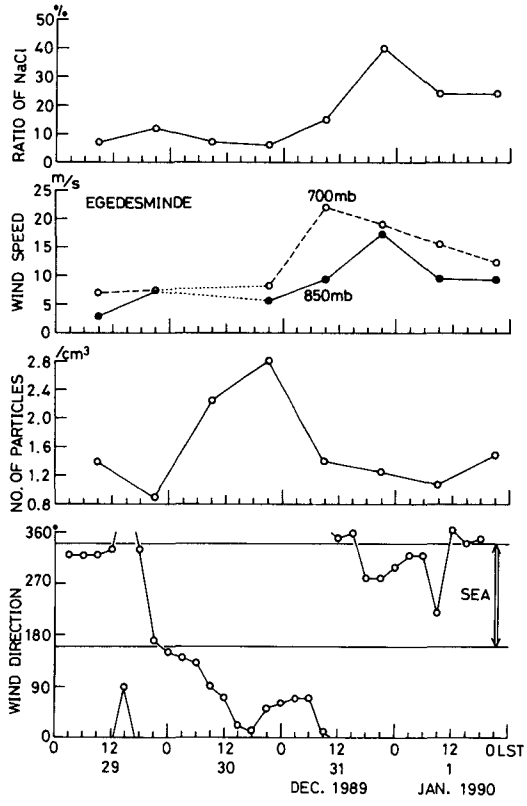

Fig. 14. Time changes of wind direction, aerosol particle number concentrations and ratio of NaCl particle numbers to total number concentrations at Godthåb. Upper wind at Egedesminde is indicated, likewise.

even under meteorological conditions without an abundance of water vapor content. The situation of 1 January was under such meteorological conditions.

If there are many ice nuclei and they make many ice particles in the clouds, they will expend an abundance of water vapor content in the clouds. Therefore, water droplets will be impossible to grow large. But, there were few aerosol particles on 1 January, so it is considered that there were few ice nuclei, likewise. Therefore, the result was that liquid growth proceeded and small raindrops were formed on 1 January.

5. Conclusions

During the observation period of the snow crystals of low temperature types in Godthåb, Greenland, snow crystals with small raindrops were observed all day long on 1 January 1990. The accreted frozen raindrops were divided into single crystal and polycrystalline. Based on the measurement of their size distributions, the size effect was detected in the favorable formation of polycrystalline.

The wind blew from the sea and it was warm on the day when snow crystals with small raindrops fell. The meteorological conditions on that day were not judged to be singular though surface temperature and humidity were higher than other snowfall days. On the other hand, from the results of aerosol particle observations, the formation of snow crystals with small raindrops was considered as follows. Under the pressure pattern of east-high and west-low, Foehn wind blew across Greenland. It made wind waves on the sea surface and many NaCl particles originated from the sea. As there were usually few aerosol particles in the atmosphere over the sea, the result was that there were few aerosol particles activated as condensation nuclei and NaCl particle ratio was high. Therefore, it was possible to grow to large water drops even under meteorological conditions without an abundance of water vapor content. Then, it was important, too, that there were little water vapor content expended by ice particles.

Acknowledgments

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