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On the Embryo in Graupel Particles Observed in Greenland

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Abstract

Graupel particles were observed during the observation period of the snow crystals of low temperature types in Godthåb, Greenland. Even under low temperature conditions graupel formation was considered to be an important process of precipitation formation, so we tried to identify graupel embryo and to study the relation between embryo types and meteorological conditions. The results are summarized as follows.

Graupel particles were observed under the temperature condition of -10.6°C ~ -13.0°C at Godthåb, Greenland. All of their embryos were snow crystal type. Plane crystals were most predominant in snow crystal embryo. The relationship between embryo type and meteorological conditions was consistent with Harimaya's result (1988). That is to say, all graupel embryos are snow crystal type under this temperature condition.

1. Introduction

Graupel particles often fall from winter convective clouds in the seaside areas of Japan Sea side regions. It is well known that graupel particles grow accreting cloud droplets in snow clouds and their mass growth rate is faster than that of snow crystals in snow clouds. Therefore, graupel particles usually fall from snow clouds first and snow crystals follow after graupel particles. As graupel particles have a faster growth rate, it is important that we study the mechanism of graupel formation as the basis in the case of developing the method of snowfall forecast. Studies of graupel formation are divided into two themes regarding the generation and growth. The generation is related to graupel embryo. In the case of modifying artificially the snowfall phenomena, if we desire to make snowfall early, we must first produce the particles which become the origin of graupel particles. In such a study, it is important to identify graupel embryos which are the origin of graupel particles.

Harimaya (1976, 1977) showed by the observations and numerical computations that both snow crystals and frozen drops can become graupel embryos. The results were proved by Pflaum et. al. (1978) who succeeded in making graupel particles from frozen drops and simulated ice plates in a vertical wind tunnel in a cold room. After that, Takahashi and Fukuta (1988) reported the observational results similar to Harimaya's papers.

Recently, Harimaya (1988, 1990) found from the observations in Sapporo and Wajima, Japan that embryo types such as snow crystals and frozen drops were closely related to meteorological conditions. That is to say, embryo types change from snow crystals to frozen drops, as the temperature at the cloud base becomes warm and as the thickness of mixed cloud becomes thicker.

On the other hand, it has been reported that solid precipitation particles such as graupel particles and rimed snow crystals fall even under low temperature conditions in the Arctic region and the Antarctic region (e.g. Magono and Kikuchi, 1980). So it is being considered that liquid cloud droplets in snow cloud perform an important role on the precipitation formation under low temperature conditions. Therefore, we focused our attention on the graupel formation under low temperature conditions.

Graupel particles were observed during the observation period of the snow crystals of low temperature types in Godthåb, Greenland. As it is important to identify graupel embryo and to study the relation between embryo types and meteorological conditions, we will describe the analytical results regarding graupel embryo in this paper.

2. Observation

Observation of snow crystals were carried out at 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". Graupel particles were observed on 25, 26, 27 and 29 December 1989 during the observation period. Graupel particles were collected on a board covered with a black velvet cloth and immediate-

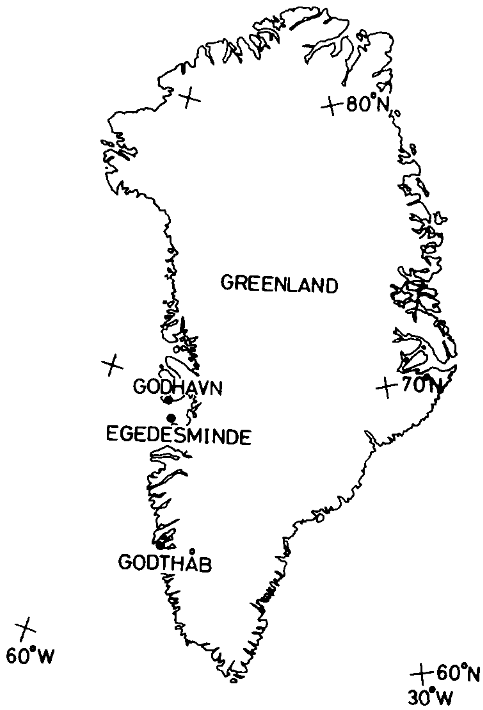

Fig. 1. Locations of observation site and upper air observation station.

ly after were photographed under a polarization microscope to record the shape. Then, graupel embryo was identified by the disassembly method under a polarization microscope (Harimaya, 1976).

3. Results and discussion

Based on the careful observation, it was found that a graupel particle has a snow crystal on its top as seen in Fig. 2. This graupel particle fell under the temperature condition of −10.6°C and was 4 mm in size. Snow crystal often accretes cloud droplets on particular branches during their fall. These branches are directed downwards owing to their weight, then densely rimed branches accrete the cloud droplets increasingly. The result is that embryo exists on the top of graupel as seen in Fig. 2. On the other hand, in the case where rimed branches are not directed downwards, snow crystal embryo is confined to the interior of grown graupel particle. Therefore, in the case of identifying graupel embryo, it was regarded as the embryo of graupel particle

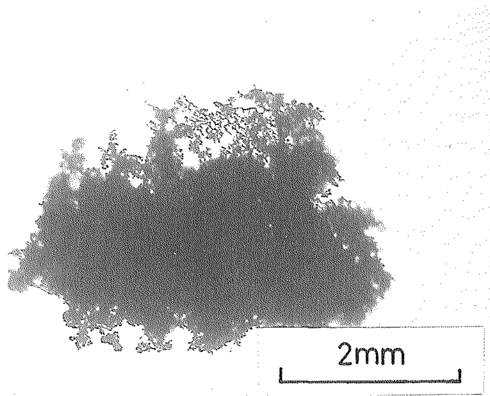

Fig. 2. A graupel particle in which original snow crystal is visible on the top.

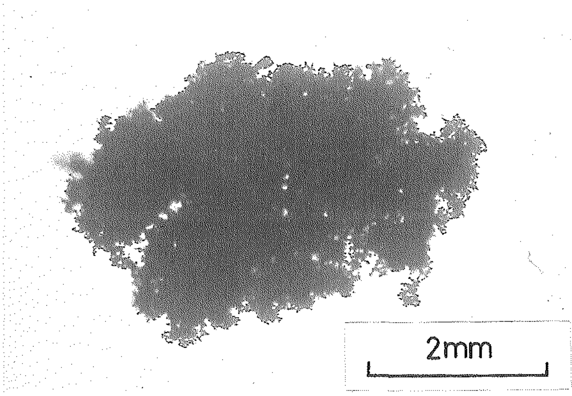

Fig. 3. A graupel particle observed on 27 December 1989.

when only one reasonably large particle was found in the graupel particle.

Figure 3 shows a photograph of a graupel particle which is representative in graupel particles collected during this observation period. This graupel particle fell under the temperature of −10.6°C and was 4.7 mm in size. The snow crystal embryo picked out from its graupel particle is shown in Fig. 4. The embryo is a broken crystal of dendritic type and about 1 mm in size. As the embryo consists of many broken crystals, it may be a broken snowflake.

Figure 5 shows the snow crystal embryo of dendritic type of 1 mm in size picked out from graupel particle observed under the temperature of −10.6°C. The dendritic type was most predominant in plane crystals during this observa-

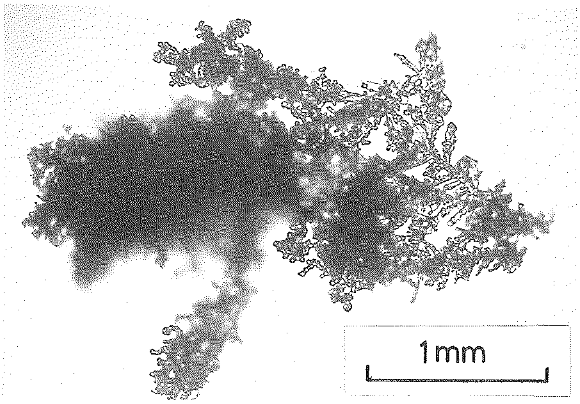

Fig. 4. Snow crystal embryo picked out from graupel particle.

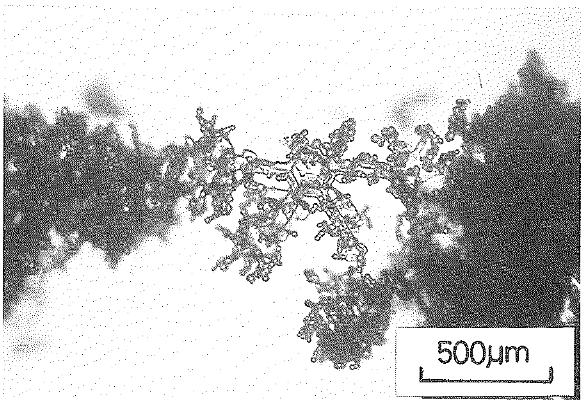

Fig. 5. As in Fig. 4.

tion period of graupel embryo.

Figure 6 shows the snow crystal embryo of 250 μm in size observed under the temperature of -13.0°C. This snow crystal is referred to the snow crystal of low temperature types and has the shape with abnormally grown prism faces.

It is seen in Fig. 7 that a columnar crystal became an embryo. It was picked out from graupel particle observed under the temperature of -12.5°C. This crystal is as small as 140 μm in maximum dimension. As its crystal is inclined against the glass slide under a polarization microscope, it may be seen that it is a thick plate type.

During this observation period, all embryos were identified as snow crystals.

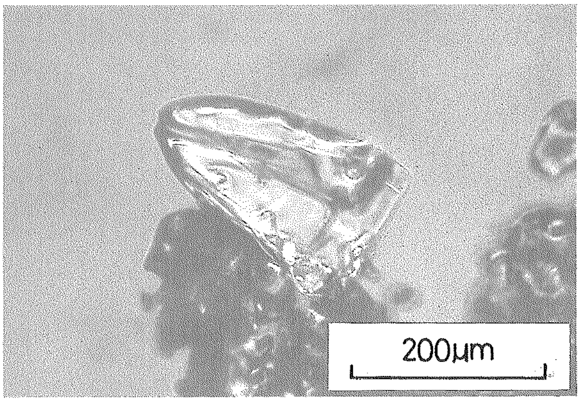

Fig. 6. As in Fig. 4.

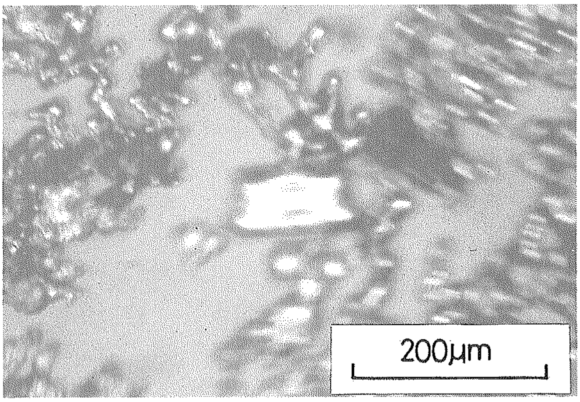

Fig. 7. As in Fig. 4.

Table 1. Frequency in each embryo type.

Embryo type	Frequency (%)
Plane crystal	25
Columnar crystal	8
Broken crystal	17
Unidentifiable particle	50

The embryo type is summarized in Table 1 by the frequency in each crystal shape. It is seen from Table 1 that plane crystals, columnar crystals, broken crystals and unidentifiable particles occupy 25, 8, 17 and 50%, respectively. It is similar to the results of Harimaya (1976, 1977 and 1988), and Takahashi and Fukuta (1988) that plane crystals are most predominant as a snow crystal embryo.

As each type of embryo is found in graupel particles which fall from snow clouds on different days, it is considered that the predominant type is dependent on the meteorological conditions at the time of the formation of graupel particles. Harimaya (1988) studied the relationship between embryo type and meteorological conditions and found that embryo types were closely related to meteorological conditions. That is to say, embryo types change from snow crystals to frozen drops, as the temperature at the cloud base becomes warmer and as the thickness of mixed cloud becomes thicker. Next, we will examine how this observational result in Greenland is related to the meteorological conditions.

In the case of adopting the temperature at the cloud base and thickness of mixed clouds as the meteorological conditions, aerological data are required in order to calculate each value. There are no aerological observatories near

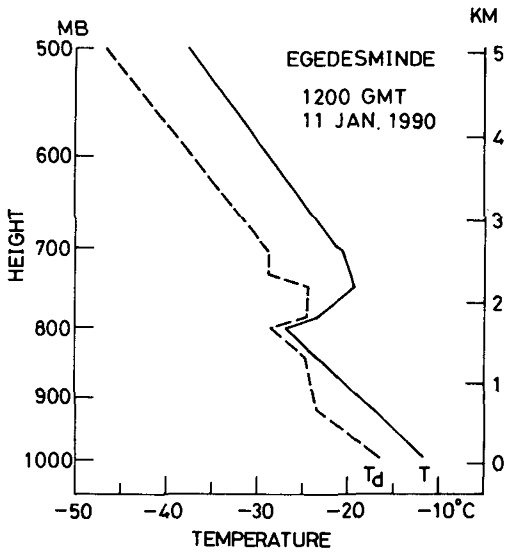

Fig. 8. Vertical distributions of air temperature and dew-point temperature at Egedesminde.

Godthåb, thus we tried to analyze each value by the following method. We examined the upper air sounding curve at Egedesminde (aerological observatory) near Godhavn at the time when other members of this project observed small graupel particles at Godhavn. The upper air sounding curves represented the characteristic features during snowfalls in Japan which show a temperature inversion in the middle layer and wet layer below the inversion as seen in Fig. 8. Based on the previous analyzing method (e.g. Magono et al., 1964), it was estimated that the cloud top was 802 mb in height and −26.7°C in temperature. On the other hand, there were cloud droplets only in the parts warmer than −20°C in snow clouds (e.g. Harimaya, 1988). Therefore, in this study the thickness of mixed clouds was defined as the thickness between the cloud base level and −20°C level, where the cloud base level was obtained from the lifting condensation level. In such a case, the thickness of mixed clouds can be estimated from only meteorological data at the ground surface if the lapse rate

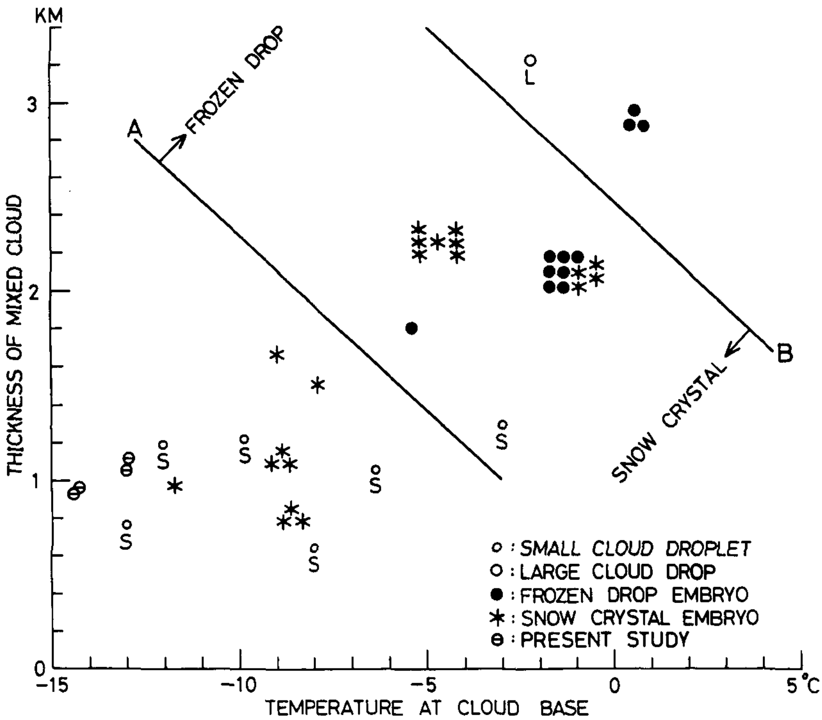

Fig. 9. Relationships between meteorological conditions and embryo types or cloud droplet types. The data of the present study are superimposed on Harimaya's diagram (1988).

of international standard atmosphere is adopted as the vertical distribution of air temperature. In the same manner as above-mentioned method, the temperature at the cloud base can be obtained as the temperature at the lifting condensation level, likewise.

The temperature at the cloud base and the thickness of mixed cloud were estimated about the representative values in the afternoon of 25, morning of 27, morning and afternoon of 29 December when graupel embryos were identified at Godthåb. It is seen in Fig. 9 that their values were superimposed on Harimaya's diagram (1988). The values of present study (⊖ symbol) correspond to the coldest temperature in the temperature at the cloud base and belong to a range of the thinnest layer in the thickness of mixed clouds. Therefore, it is found that graupel embryos indentified in Greenland correspond to the range in the diagram which is led from the observational results in Japan. Namely, this result is consistent with Harimaya's result (1988).

4. Conclusions

Graupel particles were observed at Godthåb, Greenland during the observation period of the snow crystals of low temperature types. As graupel embryos are an important theme in investigation of graupel formation, we observed graupel embryos by the disassembly method under a polarization microscope. The results are summarized as follows.

Graupel particles were observed under the temperature condition of $-10.6°C \sim -13.0°C$ at Godthåb, Greenland. All of their embryos were snow crystal type. Plane crystals were most predominant in snow crystal embryo. The relationship between embryo type and meteorological conditions was consistent with Harimaya's result (1988). That is to say, all graupel embryos are snow crystal type under this temperature condition.

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