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A Climatological Study on the Mechanism of Graupel Formation

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Abstract

The distribution of the mechanism of graupel formation over the Japanese Islands was obtained by estimating the graupel formation mechanism at six places based on the classification thresholds. The results show that the graupel formation mechanism in the northern region is different from that in the southern region and the boundary line between them corresponds to 2°C line in monthly mean air temperature during the period of graupel fall. Namely, it is found that the regional characteristics of graupel formation mechanism depend on the difference in climate. But, the mechanism at Fukuoka in the southern end area of the Japanese Islands is different from the general trend. The discrepancy can be explained by introducing the effect of sublimation (evaporation) from graupel particles.

1. Introduction

The mass growth rate of graupel particles is faster than that of snow crystals in snow clouds in winter (e.g. Harimaya, 1981), thus it is considered that the formation of graupel is quite important in the mechanism of snowfall. It is well known that graupel fall is characterized by the high frequency under warmer conditions during the period of snowfall in the western seacoast of the Japanese Islands (e.g. Mizuno, 1989). Therefore, we focused our interest on the relationship between the mechanism of graupel formation and temperature.

On the other hand, recently artificial modification of snow clouds has been considered as a step towards the prevention of snow damage and reduction of snow-removing work. For this purpose, the snow formation mechanism containing the graupel formation must be studied at first. Next we must pay attention to the regional characteristics of snow formation mechanism. Because, we should utilize the method of artificial modification which is most suitable for the snow formation mechanism in different geographical areas.

Based on the observational results (Harimaya, 1976, 1977) regarding the embryo of graupel and observational result (Harimaya, 1983) regarding the internal structure of graupel, a previous paper (Harimaya, 1988) showed that the mechanism of graupel formation was as follows. At first, it showed the thresholds of certain meteorological conditions which could classify the embryo and internal structure types. Next, on the assumption that the results can be applied to other geographical locations, the embryo and internal structure types were estimated at the representative places.

Based on the result, this paper describes the regional characteristics of the mechanism of graupel formation and aims to consider the regional characteristics from a view point of climatology.

2. Regional characteristics on the mechanism of graupel formation

Figure 1 shows the results of predominant embryo type at each place estimated by Harimaya (1988), using the thresholds of certain meteorological conditions. Lines A and B show the thresholds of embryo types and this figure shows that frozen drop embryos belong to the upper region above boundary A and snow crystal embryos belong to the lower region below boundary B. And each ratio of data numbers in three regions divided by boundary A and boundary B against the total data number is indicated by the percentage values in the lower right corner of the figure. In order to estimate the ratios of snow crystal embryo number or frozen drop embryo number against the total number at each observational place, the data in the region between boundary A and boundary B must be also classified. But, it is not clear as to how to classify them at this stage. If we assume that snow crystal embryo number is equal to frozen drop embryo number in the region, we could obtain the ratios of snow crystal embryo number or frozen drop embryo number against the total number at each observational place. The values are shown in the upper left corner. S.C.E. and F.D.E. express snow crystal embryo and frozen drop embryo, respectively.

Even if we consider the uncertainness regarding the threshold of embryo, we would find that frozen drop embryos are predominant in the group of southern region such as Wajima and Yonago. On the other hand, it is seen that the case of snow crystal embryos is nearly equal to that of frozen drop embryos in the group of northern region such as Wakkanai, Sapporo and Akita. But, it is unusual that the case of snow crystal embryos is nearly equal to that of frozen drop embryos at Fukuoka in the group of southern region. The reason will be discussed in detail in section 3. It is found that the regional distribution of predominant embryo type is arranged in systematic order corresponding to the

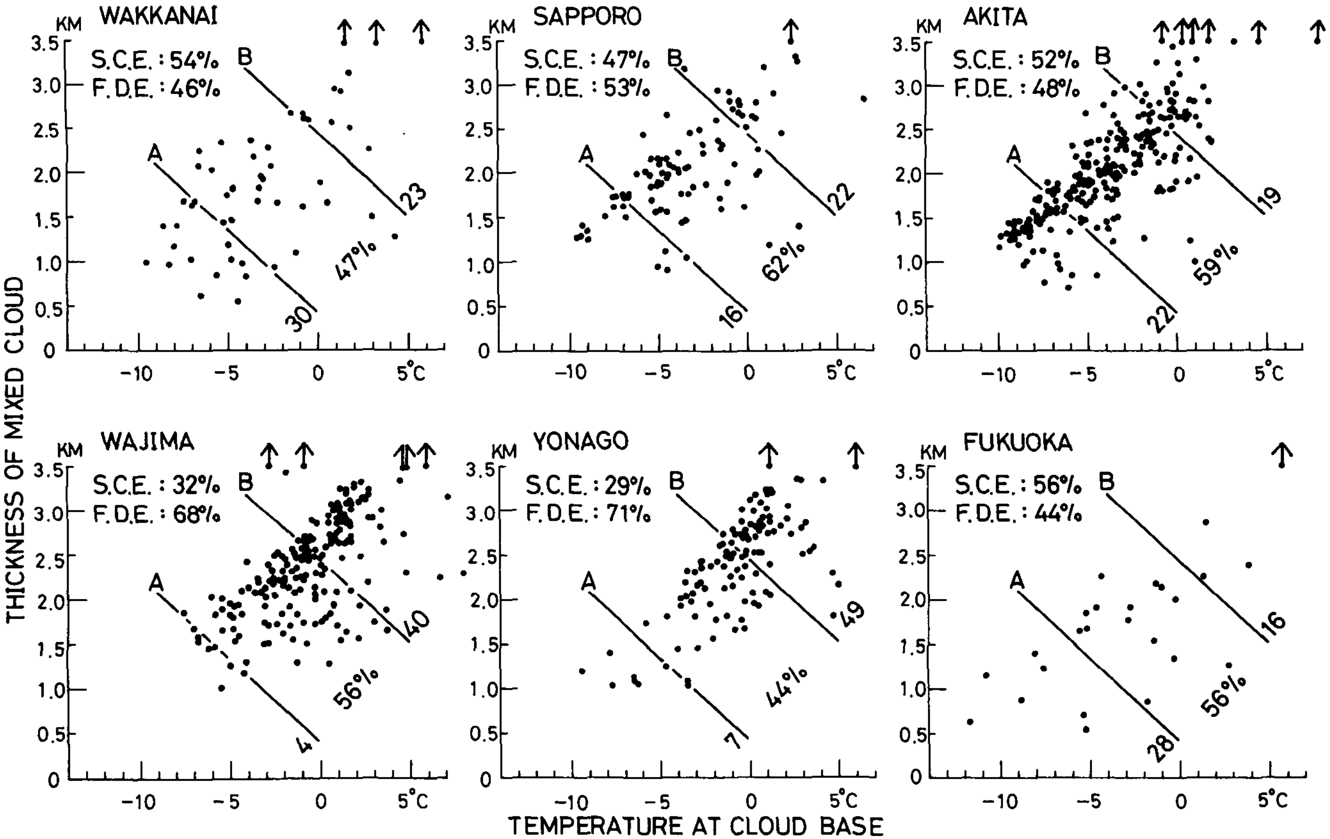

Fig. 1. Regional characteristic in embryo types. S.C.E. and F.D.E. express snow crystal embryo and frozen drop embryo, respectively.

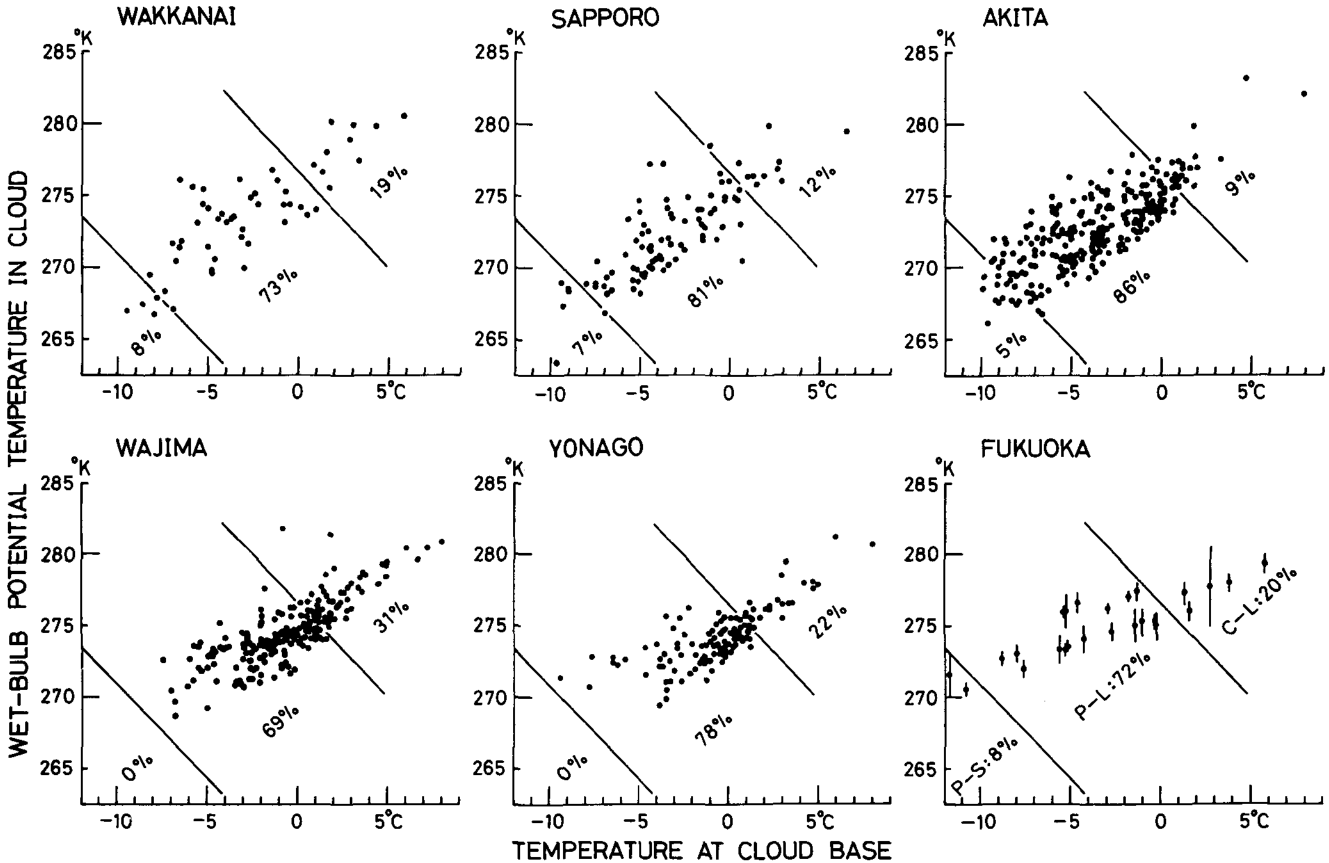

Fig. 2. Regional characteristic in internal structure types. The width of wet-bulb potential temperature in clouds is shown by small bars only in the figure of Fukuoka.

latitude rather than being arranged randomly.

Figure 2 shows the result of predominant internal structure types at each place estimated by Harimaya (1988), using the thresholds of certain meteorological conditions. In this figure, two thick solid lines show the thresholds of internal structure types and divide the parts of porous ice with small crystals (P-S), porous ice with large crystal (P-L) and compact ice with large crystals (C-L). And the ratios of each type number against the total number are shown by the numerals in the figure. It was characteristic that porous ice with small crystals (P-S) type was observed in the group of the northern region such as Wakkanai, Sapporo and Akita while this was not observed in the group of the southern region such as Wajima and Yonago. But, it was unusual that P-S type was observed at Fukuoka in the group of the southern region. The reason will be explained later. The distribution of predominant internal structure type is not arranged randomly but it is arranged systematically corresponding to the latitude. It is worthy of note that the boundary line which divides into the northern region and the southern region was observed at the same position as obtained in the case of predominant embryo type.

It was found that the regional characteristics regarding the embryo and internal structure types of graupel were shown by the division of northern and southern groups. As the Japanese Islands extend along the meridian, it can reasonably be expected that there would be some temperature difference at

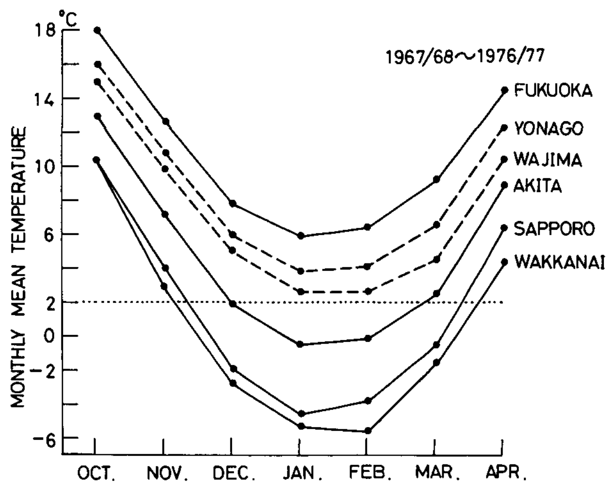

Fig. 3. Monthly mean temperatures for ten winter seasons (1967/68~1976/77) at six places.

opposite ends of the Japanese Islands. Moreover, the classification thresholds regarding embryo and internal structure types were closely related to the air temperature on the ground. Therefore, it is considered that the regional characteristics on graupel formation mechanism reflect the climatological conditions. In order to charify the relation quantitatively, the monthly mean air temperatures on the ground are shown in Fig. 3. The temperature at Wakkanai in the northern region is about 12°C colder than that at Fukuoka in the southern region and boundary between both regions with different graupel formation mechanisms corresponds to 2°C line of monthly mean temperature during the period of graupel fall.

3. Consideration

As the analytical results regarding Fukuoka were different from the general tendency of the regional characteristics of embryo and internal structure types, the reasons should be examined. Based on the data used in Figs. 1 and 2, the frequency distributions of graupel fall are shown in Fig. 4 in the manner of representing the frequency with an air temperature interval of 1°C at three places. And the thick chain line indicates the total data in which graupel and rain fell simultaneously at each observational place. As the peak value is included in the width between 3 and 4°C, it may be considered that graupel particles melt into rain drops in most cases when the air temperature on the ground is warmer than the temperature threshold (3~4°C). While the air

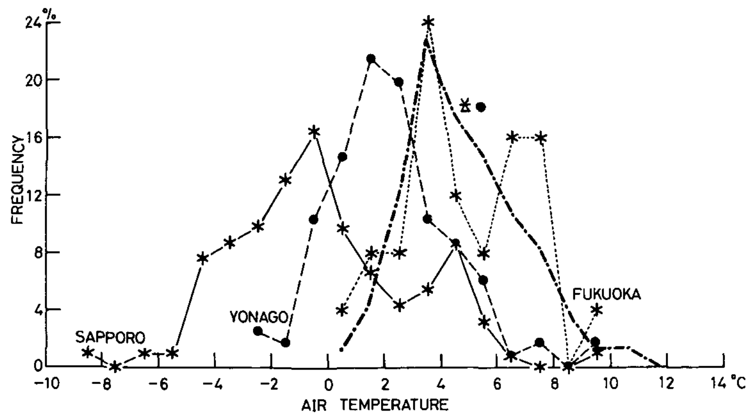

Fig. 4. Frequency distributions of graupel fall against air temperature at three places. The thick chain line indicates the total data in which graupel and rain fell simultaneously at each place.

temperature on the ground is colder than the temperature threshold when graupel falls at the places except Fukuoka, the air temperature on the ground is warmer than the temperature threshold in most cases when graupel falls at Fukuoka. Therefore, it is considered that graupel which should have originally melted into rain did not melt and fell as it is, under special meteorological conditions at Fukuoka.

Next, these special meteorological conditions must be examined. When precipitation phenomena were observed at Fukuoka during the winter periods 1967/68 to 1976/77, the air temperature and relative humidity on the ground in the case of graupel fall were compared with those in the cases of rain fall. The results are shown in Fig. 5. The ordinate and abscissa indicate the relative humidity and air temperature on the ground respectively, open circles and closed circles are graupel and rain respectively. And the mean vertical distributions of relative humidity in the cases of graupel fall and rain fall are placed in the lower right of the figure. It is seen in the figure that the temperature threshold,

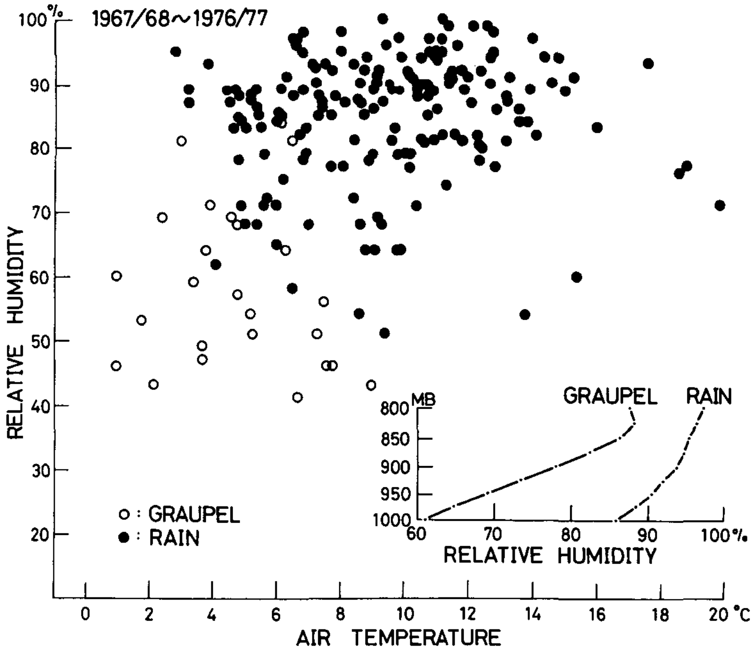

Fig. 5. Air temperature and relative humidity on the ground in each case of graupel fall and rain fall. The figure in the lower right indicates the mean vertical distributions of relative humidity in the cases of graupel fall and rain fall.

at which graupel does not melt and falls as it is, depends extremely on the relative humidity and graupel can fall under the warmer conditions as the relative humidity becomes drier. And the mean vertical distribution of relative humidity is extremely dry when graupel does not melt and falls as it is. Accordingly we can consider the process such that Matsuo and Sasyo (1981) discussed regarding snowflake. When graupel falls into a very dry layer under the cloud base as seen in Fig. 5, it happens that graupel does not melt even when it falls into the layer warmer than 0°C, because the cooling of graupel particles by sublimation (evaporation) is greater than the warming by sensible heat from the environment.

It is expected that the cloud base at Fukuoka is higher than those at other places when graupel falls, as the layer at Fukuoka is drier than those at other places. Next, it is examined by calculating the lifting condensation levels. The result is shown in Fig. 6 in the manner of representing the frequency within a height interval of 200 m. It is seen in the figure that the lifting condensation

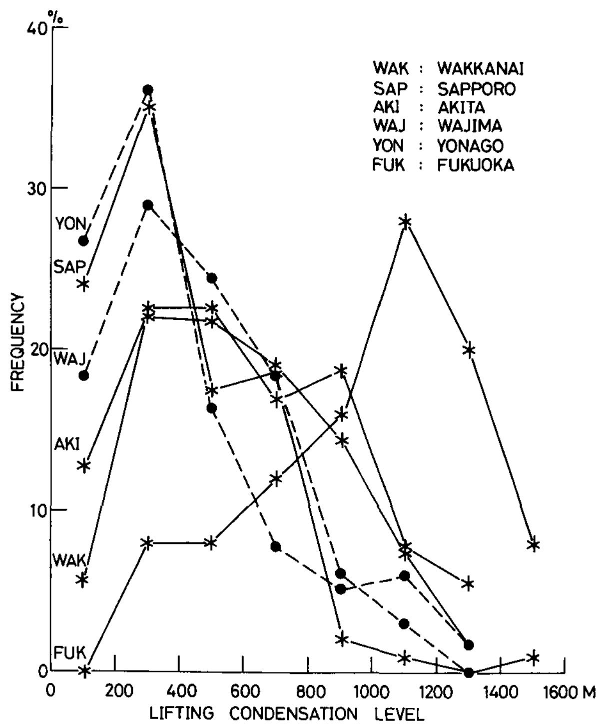

Fig. 6. Frequency distributions of lifting condensation level at each place.

level at Fukuoka has a peak at 1,000 to 1,200 m in height, against peaks at 200 to 400 m at other places. The results are explained as follows. When graupel falls at Fukuoka, it happens that the cloud base temperature is cold and the thickness of the mixed cloud is thin in spite of the warm temperature on the ground, because the cloud base is high. Therefore, the result is that the graupel formation mechanism at Fukuoka is presented by the northern group's characteristics in which the case of snow crystal embryos is nearly equal to that of frozen drop embryos and the graupel contains P-S type as the internal structure. It causes the graupel formation mechanism at Fukuoka to be different from the general tendency of regional characteristics.

4. Conclusion

The mechanism of graupel formation was estimated at six places in the western seacoast of the Japanese Islands and the regional characteristics were studied by using the classification thresholds regarding embryo and internal structure. The results are summarized in Fig. 7. The predominant embryo and internal structure types are shown at each observational place on the map with the mean values of mixed cloud thickness, cloud base temperature and air temperature on the ground when graupel falls. It is seen in the figure that in the northern part from the boundary line between Akita and Wajima, the case of snow crystal embryos is nearly equal to that of frozen drop embryos and graupel particles which are formed by porous ice with small crystals (P-S) type fall. On the other hand, frozen drop type is predominant and graupel particles which are formed by P-S type do not fall in the southern part. That is to say, it is considered that liquid phase growth plays an important role in the initial stage of precipitation formation in the southern region. As seen in the results mentioned above, the graupel formation machanism in northern region is different from that in southern region and the boundary line between them corresponds to 2°C line in monthly mean air temperature during the period of graupel fall. Namely, the regional characteristics depend on the difference in climate. Besides, the graupel clouds in northern region have a colder cloud base temperature than those in the southern region and the thickness of mixed clouds is thinner.

On the other hand, it was found that the graupel formation mechanism at Fukuoka is the same as that in the northern region regardless of the fact that Fukuoka is in the southern end area of the Japanese Islands. This is explained as follows. When graupel falls at Fukuoka, it is expected that graupel particles

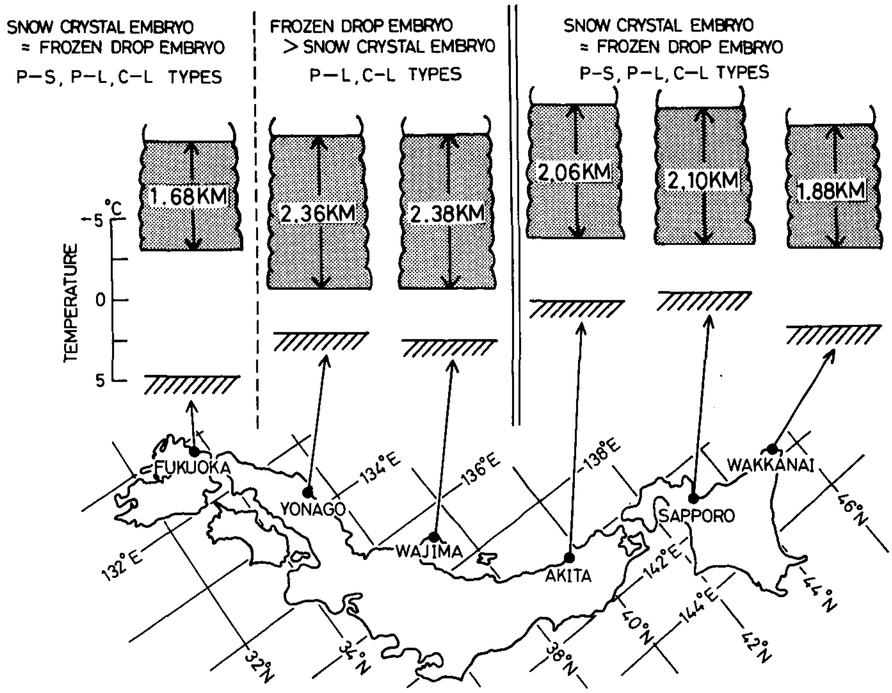

Fig. 7. Relationships between graupel formation mechanisms and meteorological conditions. The values of cloud base temperature and air temperature on the ground can be obtained by using the temperature scale on the left hand side.

would melt into rain drops, because the air temperature on the ground is warm. But, graupel can actually reach the ground without melting, because graupel particles are cooled by latent heat owing to sublimation (evaporation) under the very dry conditions below the cloud base. In this case clouds have cold cloud base temperatures and thin thickness of mixed clouds since the cloud base is high as seen in Fig. 7. Namely, they are similar to the character of clouds in the northern region. Therefore it is considered that graupel formation mechanism at Fukuoka is the same as that in the northern region.

The regional characteristics based on the difference of climate were detected in the mechanism of graupel formation. This type of study offers valuable information regarding artificial cloud modification theories and techniques in the case of their application in different geographical areas.

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