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Observation of Size Distribution of Graupel and Snow Flake

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Abstract

Observations of size distributions for graupel particles and snow flakes were carried out. Then, characteristics of size distributions, and relations between radar reflectivity (Z) and precipitation rate (R) were obtained. The average size distributions changed characteristically as the precipitation rate increased. But the size distributions for snow flakes were different from Gunn and Marshall's results[1] in which the number N_0 decreased and the slope was gentle as the precipitation rate increased.

The results regarding the radar reflectivity showed that B values of snow flakes were larger than that of rain, that is, the radar reflectivities of snow flakes are larger than that of rain under the same precipitation rate, and B values of graupel particles were between those of snow flakes and those of rain.

1. Introduction

Size distributions of graupel particles and snow flakes at the ground surface are determined by both microphysical and dynamical processes in clouds. Graupel particles mainly grow by the cloud accretion process and snow flakes mainly grow by the coagulation process. It is considered that individual size distributions of precipitations particles reflect the growth process. Accordingly size distributions of graupel particles and snow flakes at the ground surface offer information regarding precipitation formations in clouds. But only a few reports[1),2),3)] are available regarding the size distributions of graupel particles and snow flakes.

The relation between radar reflectivity factor (Z) and precipitation rate (R) estimated from the size distributions of precipitation particles is necessary for the measurement of precipitation rate by radar. For rain, a great number of measurements of the Z-R relation have been reported[4)], in addition the Z-R relations were compiled in relation to the rainfall types and radar echo characteristics[5)]. But, only a few reports on the Z-R relations of graupel particles[6)] and snow flakes[1)] are available. In this paper, size distributions of graupel particles and snow flakes are measured and the Z-R relations of graupel particles and snow flakes are estimated.

2. Observational methods

In order to prevent snow flakes from collapsing on impact with the collecting surface, observations were carried out on the day when the wind was calm. Solid precipitation particles were collected on a sheet of velvet (40 cm×25 cm) in a shallow box. After collection, the solid precipitation particles on the sheet of velvet were photographed, and then the sheet of velvet was carried inside a warm room. The solid precipitation particles melted, but the melted droplets did not wet the velvet. Accordingly circular blue spots were printed on a filter paper when a filter paper dusted with water blue dye was laid on the velvet. A series of these procedures were carried out every 5 minutes.

If each large snow flake melts into several droplets instead of one, all spots arising from an original snow flake were totalized by comparing with the photograph of the snow flake and the diameter of a snow flake was taken as the diameter of the circular area according to total spots. The diameter (D) of melted precipitation particles was obtained from the diameter of spot on the filter paper by the use of a calibration curve. The diameters of melted precipitation particles were measured every 0.2 mm. From the measurement, a horizontal size distribution (N_H) was obtained. A precipitation rate (R: mm hour^{-1}) is given by

$$R = \frac{\pi}{6} \int_0^{D_m} N_H D^3 \, dD \,, \tag{1}$$

where D_m is the maximum diameter of melted precipitation particles. This horizontal size distribution was converted to a space size distribution (N_D) using the relations between the falling velocity and melted diameter of graupel particles[7] and between the falling velocity and melted diameter of snow flakes[8]. A radar reflectivity (Z: mm^6 m^{-3}) is given by

$$Z = \int_0^{D_m} N_D D^6 \, dD \,. \tag{2}$$

Using the above-mentioned Z and R, the Z-R relation was determined empirically as

$$Z = BR^{\beta} \,. \tag{3}$$

B and β are constants, but depend on precipitation types.

3. Observational results

3.1 Size distribution

The observation was carried out in Sapporo city and the suburbs on March 1968 and January 1969. Four groups of measurements which were observed continuously for 2 or 4 hours were analyzed.

Fig. 1 shows the size distributions of graupel particles below a precipitation rate of 1.75 mm hour^{-1} from day to day. The ordinate and abscissa indicate numbers per 1 mm diameter in 1 m^3 volume and melted diameters of graupel particles, respectively. The size distributions of 26 Jan. 1969 and 2 Mar. 1968 were broad, but those of 27 Jan. 1969 and 23 Jan. 1969 were narrow. Even the size distributions under the same precipitation rate differed markedly from day to day as shown in Fig. 1. Fig. 2 shows the size distributions of snow flakes below the precipitation rate of 0.57 mm hour^{-1} in the same manner as shown in Fig. 1. The size distributions of 27 Jan. 1969 and 26 Jan. 1969 were broad, but the size distributions of 23 Jan. 1969 and 2 Mar. 1968 were narrow. The characteristics in size distribution of graupel particles were found to be similar in that of snow flakes, likewise. It

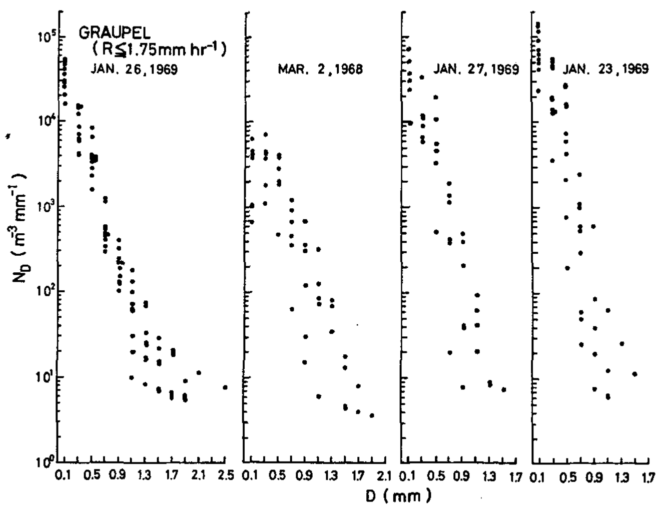

Fig. 1 Size distributions for graupel particles below the precipitation rate of 1.75 mm hour^{-1}.

follows from these characteristics that the Z-R relations are different from day to day.

In order to study the characteristics of size distributions for graupel particles, size distributions under three kinds of precipitation rates were examined as shown in Fig. 3. The ordinate and abscissa indicate numbers per

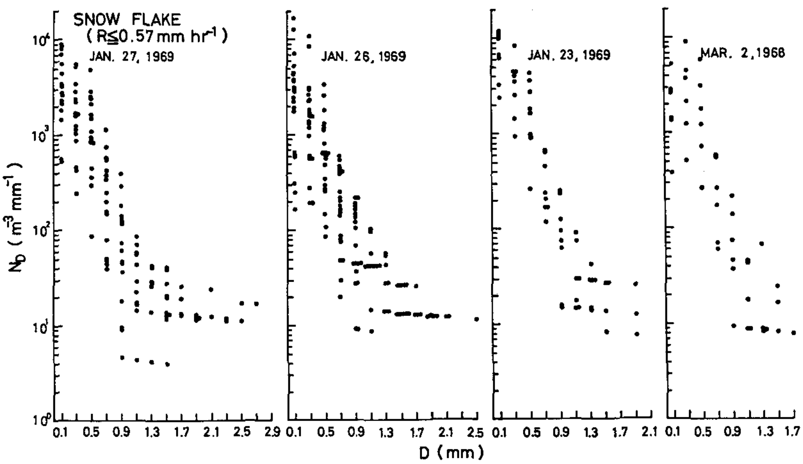

Fig. 2 Size distributions for snow flakes below the precipitation rate of 0.57 mm hour^{-1}.

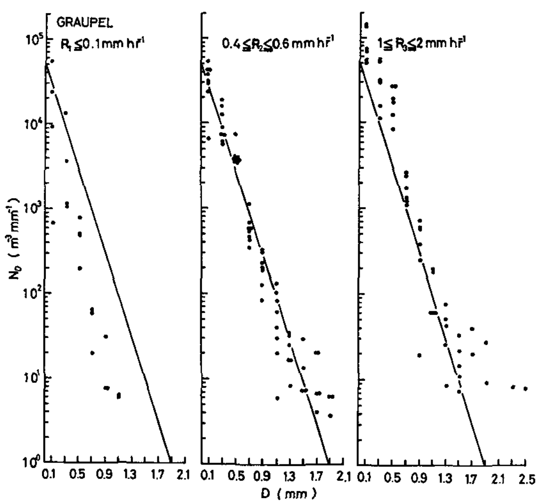

Fig. 3 Size distributions for graupel particles under each precipitation rate. Solid lines show the best fit line with respect to data of precipitation rate R_2.

1 mm diameter in 1 m^3 volume and melted diameters of graupel particles, respectively. In order to compare each size distribution, a best fit line was drawn with respect to data of precipitation rate R_2. Number (N_0) corresponding to melted diameter 0 mm did not change and slope of size distribution was gentle as precipitation rate increased from R_1 to R_2. Then, number N_0 increased slightly and the slope of size distribution was gentle slightly as the precipitation rate increased from R_2 to R_3.

The size distributions for snow flakes are shown in Fig. 4 in the same manner as shown in Fig. 3. In this figure, solid lines show the best fit line with respect to the data of precipitation rate R_2 and broken line shows solid

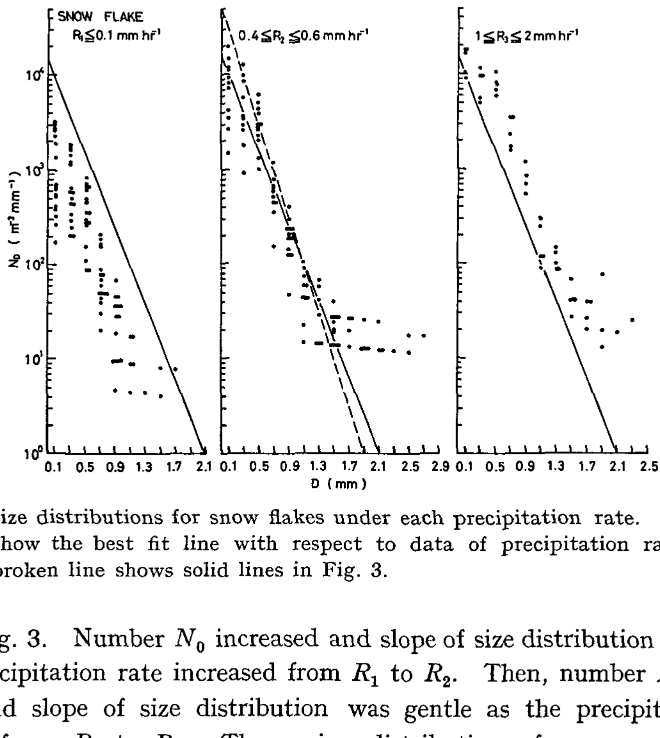

Fig. 4 Size distributions for snow flakes under each precipitation rate. Solid lines show the best fit line with respect to data of precipitation rate R_2. A broken line shows solid lines in Fig. 3.

lines in Fig. 3. Number N_0 increased and slope of size distribution was similar as the precipitation rate increased from R_1 to R_2. Then, number N_0 did not change and slope of size distribution was gentle as the precipitation rate increased from R_2 to R_3. These size distributions for snow flakes are different from Gunn and Marshall's results[1)] in which the number N_0 decreased and the slope was gentle as the precipitation rate increased, that is, the lines of size distributions crossed one another.

Comparing the size distribution for graupel particles with that for snow flakes under the same precipitation rate, number N_0 for graupel particles was more than that for snow flakes and the slope for graupel particles was steeper than that for snow flakes as shown by a solid line and broken line in Fig. 4. It follows from these difference that *Z-R* relation for graupel particles are different from that for snow flakes.

3.2 *Z-R relation*

Z-R relation were computed from measurements which were observed continuously for several hours. These values are shown in Figs. 5, 6, 7 and 8 from day to day. The ordinate and abscissa indicate radar reflectivity (Z: $mm^6\ m^{-3}$) and precipitation rate (R: $mm\ hour^{-1}$), respectively. Fig. 5 shows the measurement of the snowfall when a cyclone passed over the observation point. It is seen in Fig. 5 that the slope of *Z-R* relation line of graupel particles is the same as that of snow flakes, and the radar reflectivity of snow flakes is larger than that of graupel particles under the same precipitation rate. Fig. 6 shows the measurement of the snowfall when a cold front passed over

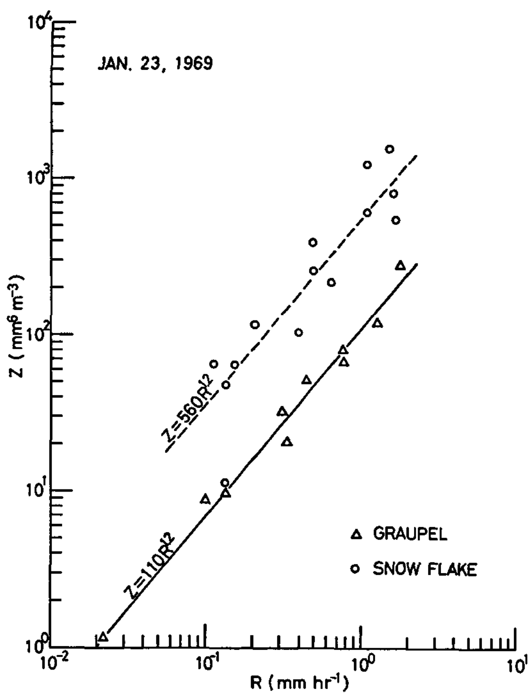

Fig. 5 Relation between radar reflectivity (Z) and precipitation rate (R) on 23 Jan. 1969. A solid line is drawn for the best fit by eye through data of graupel particles, and broken line through data of snow flakes.

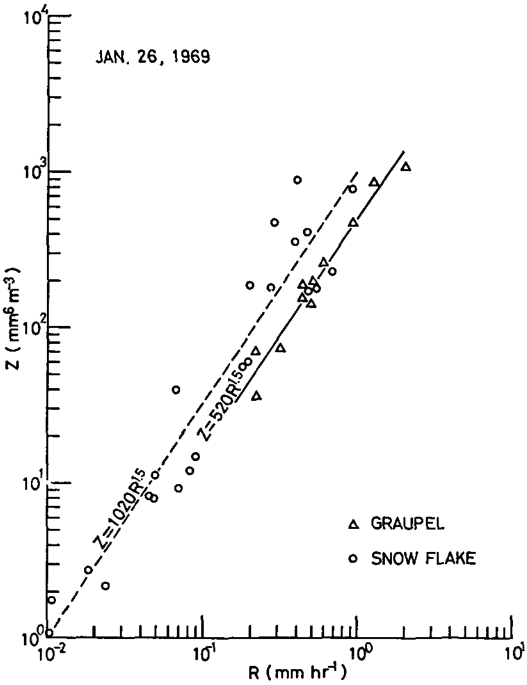

Fig. 6 Same as Fig. 5 except for 26 Jan. 1969.

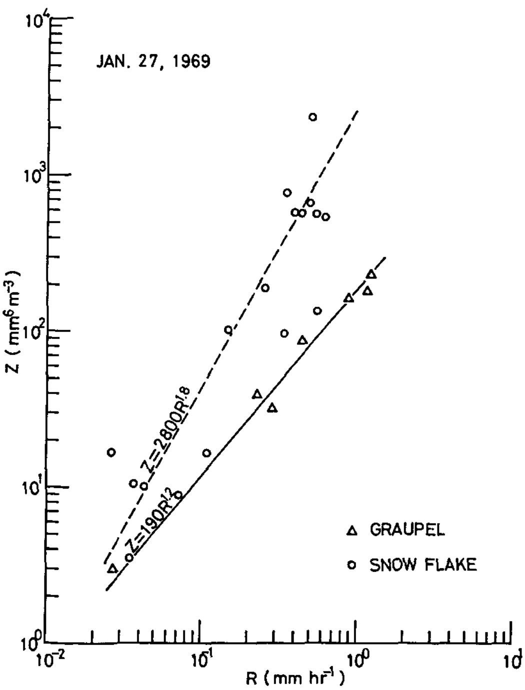

Fig. 7 Same as Fig. 5 except for 27 Jan. 1969.

the observation point. The characteristics of the slope of Z-R relation line and the radar reflectivity under the same precipitation rate were the same as in Fig. 5. Fig. 7 shows the measurement of the snowfall during a weak winter monsoon. The slope of Z-R relation line of snow flakes was steeper than that of graupel particles. Under a precipitation rate above 0.02 mm hour^{-1} the radar reflectivity of snow flakes was larger than that of graupel particles. Fig. 8 shows the measurement of the snowfall after a cyclone passed over the observation point.

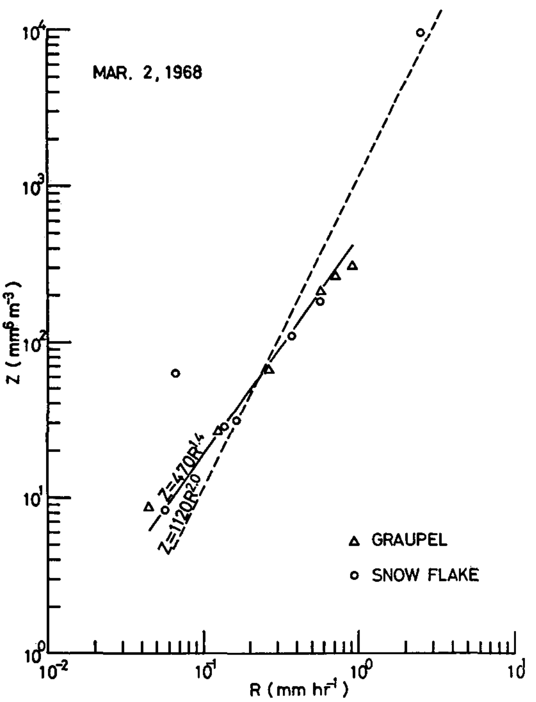

Fig. 8 Same as Fig. 5 except for 2 Mar. 1968.

The Z-R relation of four groups of measurements were completed in Fig. 9. Solid lines show the Z-R relation about graupel particles and broken lines shows that of snow flakes. It is seen in Fig. 9 that the radar reflectivity of snow flakes was larger than that of graupel particles under the same precipitation rate. This is based on the observation that size distribution of snow flakes was broader than that of graupel particles under the same precipitation rate as shown in Fig. 4. It is naturally expected from the size distributions in Figs. 1 and 2 that the radar reflectivity of graupel particles on 26 Jan. and

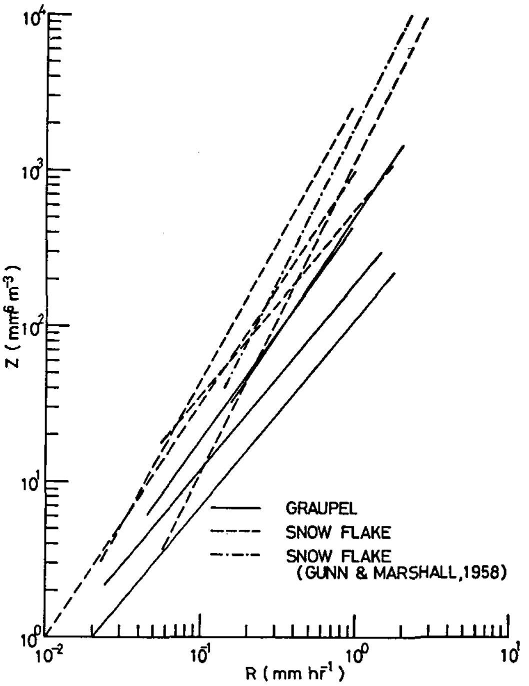

Fig. 9 Composite figure regarding relations between radar reflectivity (Z) and precipitation rate (R). Solid lines depict graupel particles and broken lines depict snow flakes. A chain line shows the relation by Gunn and Marshall[1].

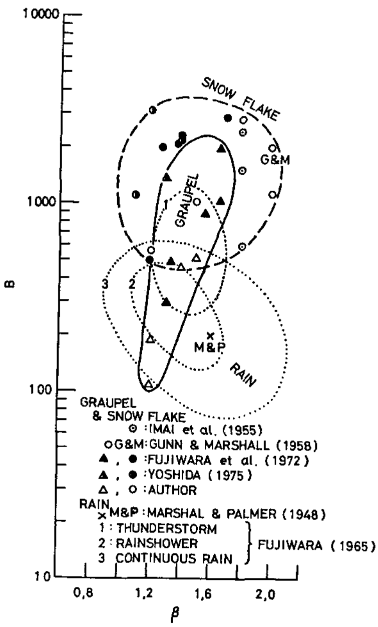

Fig. 10 B and β values in the equation $Z=BR^{\beta}$ for graupel particles, snow flakes and rain.

2 Mar. is larger than those on the other days, and that the radar reflectivity of snow flakes on 27 Jan. and 26 Jan. is larger than those on the other days, because the size distributions on these days were broader than those on the other days under the same precipitation rate.

Next, the radar reflectivity of graupel particles, snow flakes and rain were compared with one another. Fig. 10 shows the Z-R relations of each precipitation particle on B-β plane. Areas enclosed by dotted lines and X mark show Z-R relation about rain.[5),10)] The Z-R relations of graupel particles and snow flakes are indicated by solid line and broken line respectively, based on the measurement.[1),6),9),11)] It is seen that B values of snow flakes are larger than those of rain. This is the same as the thing that the radar reflectivities of snow flakes are larger than that of rain under the same precipitation rate. B values of graupel particles were between those of snow flakes and those of rain.

4. Conclusion

An observation of size distributions for graupel particles and snow flakes was carried out. The results are as follows. Even the size distributions under the same precipitation rate differed remarkably from day to day. But, after compiling all data by precipitation rates, the results showed that size distributions for graupel particles and snow flakes changed characteristically as the precipitation rate increased. The size distributions for snow flakes were different from Gunn and Marshall's results[1] which number N_0 decreased and the slope was gentle as precipitation rate increased, that is, lines of size distributions crossed one another. Under the same precipitation rate, the size distributions for graupel particles were narrower than those for snow flakes. It follows from these differences that radar reflectivity (Z) for snow flakes are larger than that for graupel particles under the same precipitation rate.

The Z-R relations of graupel particles, snow flakes and rain were compiled. The results showed that B values of snow flakes were larger than that of rain, that is, the radar reflectivities of snow flakes were larger than those of rain under the same precipitation rate, and B values of graupel particles were between those of snow flakes and those of rain.

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