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A Comparison of the Raindrop Size Distributions from Stratiform Clouds with Those from Convective Clouds

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Abstract

Raindrop size distributions were observed at Sasebo and Ishikari. At Sasebo, there were more large raindrops from stratiform clouds than those from convective clouds even under the same rainfall intensity and there were fewer small raindrops. But, this difference was not observed at Ishikari.

The cause is due to the formation of large snowflakes in stratiform clouds and small graupel particles in convective clouds at Sasebo. In addition, coalescent growth of snowflakes occurred efficiently due to the generation of many snow crystals in the moist and warm air mass at Sasebo, and it did not at Ishikari.

1. Introduction

The raindrop size distribution observed at the ground is considered as the result through the dynamical and microphysical processes in clouds. Its observation contributes to the understanding of mechanism on rainfall formation in the field of cloud physics. Additionally, it contributes to the formulation of radar reflectivity factor Z—rainfall intensity R relations used in the field of radar meteorology which are conversion formulae from radar reflectivity factor Z to rainfall intensity R.

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Probably, the most widely used description about raindrop size distribution is the following simple equation proposed by Marshall and Palmer (1948). The Marshall-Palmer (M-P) distribution is

$$N(D)=N_0\exp\,(-\Lambda D)\ [\mathrm{m}^{-3}\ \mathrm{mm}^{-1}], \quad (1)$$

where

$$N_0=8\times10^3\ [\mathrm{m}^{-3}\ \mathrm{mm}^{-1}], \quad (2)$$

$$\Lambda=41R^{-0.21}\ [\mathrm{mm}^{-1}]. \quad (3)$$

In this equation $N(D)\Delta D$ is the concentration of raindrops having diameters between D and $D+\Delta D$, and R is the rainfall intensity [mm h^{-1}]. Subsequently, some researchers have demonstrated that the M-P distribution is not sufficiently general to describe most observed raindrop size distribution accurately. Namely, N_0 can not be considered as a constant, but rather is a function of R. Also, the functional dependence of Λ on R varies. For example, Sekhon and Srivastava (1971) found $N_0=7\times10^3R^{0.37}$ [$\mathrm{m}^{-3}\,\mathrm{mm}^{-1}$] and $\Lambda=3.8R^{-0.14}$ [mm^{-1}]. In other cases observed raindrop size distributions have deviated considerably from an exponential type. Strantz (1971) classified them into two groups of 3 type each. In the classification, only one type conforms strictly to the M-P distribution.

Many types of raindrop size distributions may be due to the difference of dynamical and microphysical conditions in clouds. The purposes of this study are to investigate the difference between the raindrop size distributions from stratiform clouds and those from convective clouds, and to discuss its cause.

2. Observation

Observations of raindrop size distributions were carried out at Sasebo on July 1988 and at Ishikari on September to November 1988 (Fig. 1). They were measured with the optical spectrometer (Mori Technology Inc., RAL-101) shown in Fig. 2, which is the improved type of instrument developed by Gocho (1976). The smallest detectable raindrop has a diameter of 0.45 mm. The raindrops are classified according to their diameter with 0.1 mm width. Time resolution of the data is set at 10 sec. The data acquisition system is constructed by microcomputer with a RS-232C interface.

The instrument has a collecting surface of 40×51.2 mm. The adequacy was examined as follows. The raindrop size distributions were integrated over 1 minute for comparison with rapid raingage data (Rhesca Co. Ltd., RGT-3). A valid agreement between the two instruments was observed as shown in Fig. 3. The measured values were converted into the spatial size distribution $N(D)$

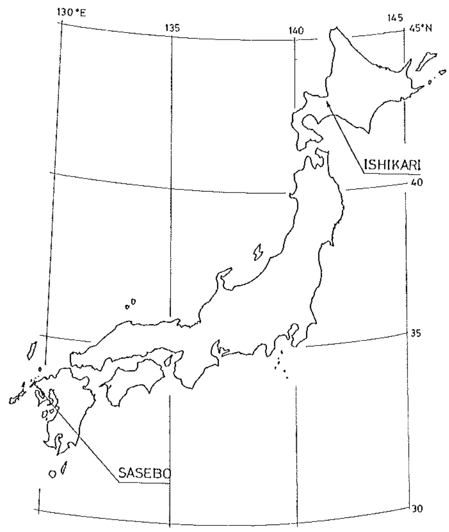

Fig. 1. Locations of observation sites.

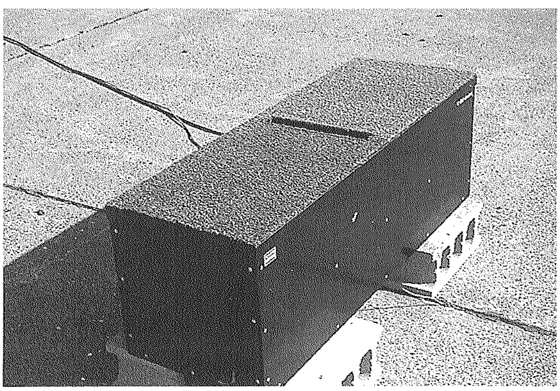

Fig. 2. Sensor unit of optical spectrometer.

[m^{-3} mm^{-1}] every 2 minutes by using the relationship between the falling velocity and the diameter obtained by Gunn and Kinzer (1949).

The situation of clouds was studied by using the data obtained by the radar of the Faculty of Science, Hokkaido University temporarily set about 13.5 km south-southwest from Sasebo. In the observation at Ishikari, the data were obtained by the radar of the Faculty of Science, Hokkaido University located

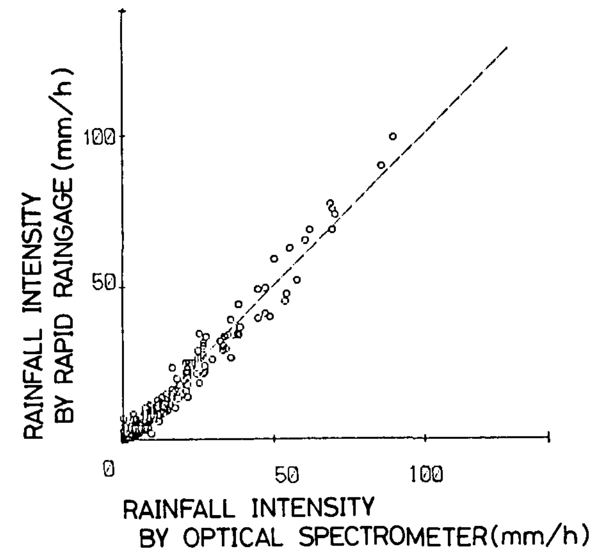

Fig. 3. Comparison between 1 minute rainfall intensity by rapid raingage and that by optical spectrometer.

about 10.4 km southeast from Ishikari.

3. Results

The present data were obtained on the raindrop size distributions from stratiform clouds and convective clouds. Some examples are shown in Fig. 4. The upper part and lower part indicate the size distributions from stratiform clouds and convective clouds at Sasebo, respectively. The thick solid curves and broken lines indicate the observed values and associated M-P distributions, respectively. The size distributions from convective clouds are seen to be similar to M-P distribution. In the size distributions from stratiform clouds, however small raindrops below 1.5 mm in diameter are fewer than those corresponding to M-P distribution and large raindrops above 1.5 mm are more than those corresponding to M-P distribution. Namely, Figure 4 shows the difference between the raindrop size distributions from stratiform clouds and those from convective clouds at Sasebo.

Next, whether the above-mentioned observational fact is concluded or not was examined by *RATIO* : k_1 and *RATIO* : k_2 through all data of present observations,

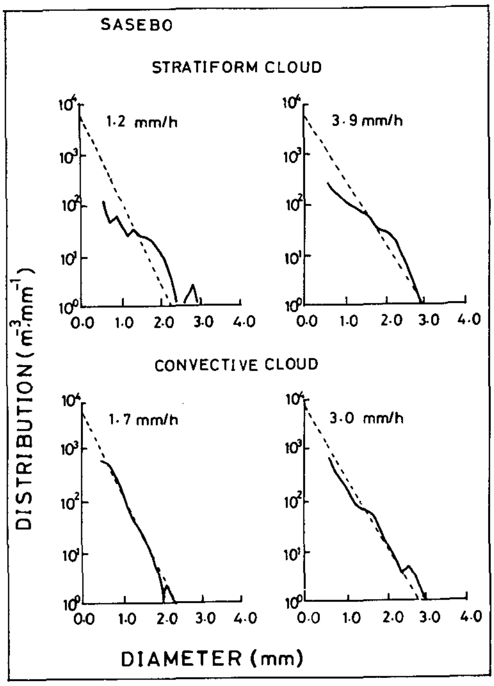

Fig. 4. Some raindrop size distributions from stratiform clouds and convective clouds at Sasebo. The thick solid curves and broken lines indicate the observed values and associated M-P distributions, respectively.

where

$$RATIO: k_1 = \frac{\log N(\varDelta D_1)}{\log N_{M-P}(\varDelta D_1)}, \quad (4)$$

$$RATIO: k_2 = \frac{\log N(\varDelta D_2)}{\log N_{M-P}(\varDelta D_2)}. \quad (5)$$

$N(\varDelta D_1)$ and $N(\varDelta D_2)$ represent the observed concentrations of raindrops having diameters between 0.45 mm and 1.45 mm, and between 1.45 mm and 2.45 mm, respectively. $N_{M-P}(\varDelta D_1$ or $\varDelta D_2)$ represents the concentration of M-P distribution corresponding to the diameters.

Figures 5 and 6 show the $RATIO: k_1$ and $RATIO: k_2$ at Sasebo. $RATIO: k_1$ (average value 0.97) of convective clouds is near 1 and $RATIO: k_1$ (average value 0.78) of stratiform clouds is seen to be smaller than that of convective clouds. Although $RATIO: k_2$ of convective clouds varies widely under weak rainfall intensity ($\sim$3 mm h^{-1}), it becomes near 1 with the increase in rainfall intensity. Compared between $RATIO: k_2$ of stratiform clouds and that of convective clouds, $RATIO: k_2$ of stratiform clouds may be seen to be

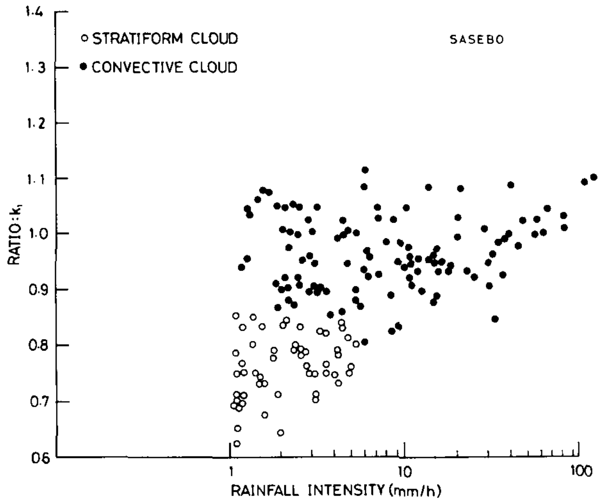

Fig. 5. Comparison between *RATIO* : k_1 of stratiform clouds and that of convective clouds at Sasebo.

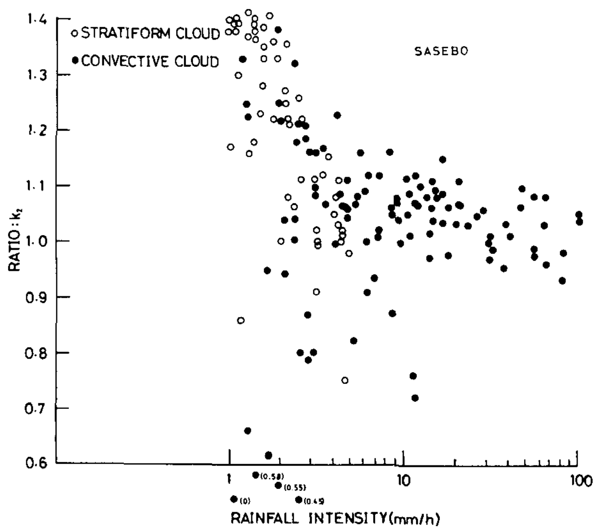

Fig. 6. As in Fig. 5 except for *RATIO* : k_2.

larger than that of convective clouds under weak rainfall intensity. Namely, under the same rainfall intensity large raindrops from stratiform clouds are more than those from convective clouds and small raindrops are fewer. A similar observational result was reported as N_0 jump by Waldvogel (1974).

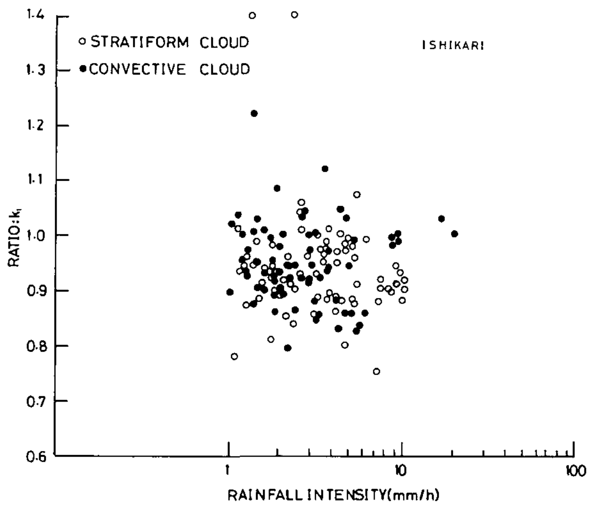

Fig. 7. As in Fig. 5 except for Ishikari.

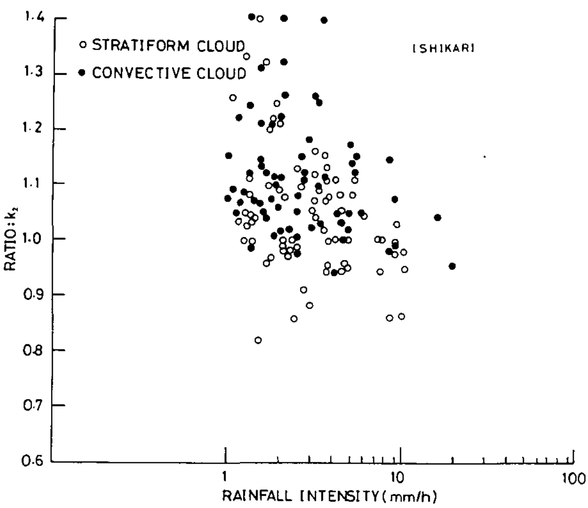

Fig. 8. As in Fig. 6 except for Ishikari.

Figures 7 and 8 compare observational results at Ishikari to those at Sasebo. In the observational result at Ishikari, it is seen that both *RATIO* : k_1 and *RATIO* : k_2 are not different between stratiform clouds and convective clouds. Namely, it was not observed at Ishikari that large raindrops from stratiform clouds are more than those from convective clouds and small raindrops are fewer under the same rainfall intensity.

4. Discussion

As the difference was detected in the raindrop size distributions from each type of clouds, the cause is detailed by using the observational data of clouds. Figure 9 shows some examples of stratiform clouds at Sasebo. It is seen that stratiform clouds have the layered structure of radar echo and bright band which has a strong radar reflectivity factor due to the melting effect of snow particles at 0°C level. In contrast, convective clouds have massive structure as seen in Fig. 10.

Figure 11 shows the vertical distributions of the radar reflectivity factor in stratiform clouds and convective clouds under the nearly same rainfall intensity at Sasebo. Broken curves and solid curves show the vertical distributions of stratiform clouds and convective clouds, respectively. 0°C level is shown by observed values at Fukuoka Meteorological Observatory located about 90 km

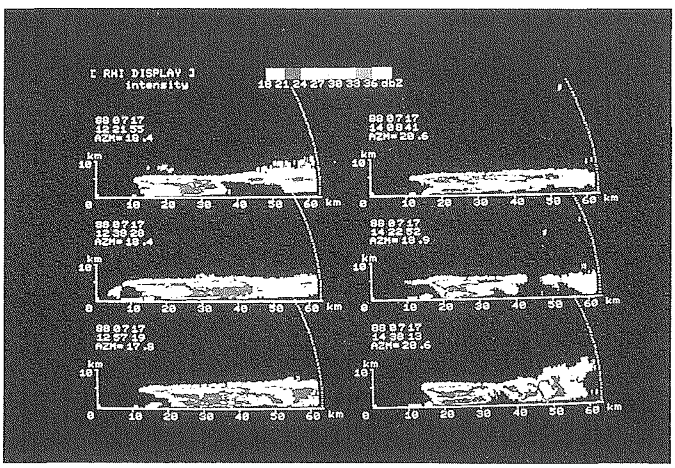

Fig. 9. Some examples of stratiform clouds at Sasebo. Radar echoes are represented by RHI (Range Height Indicator).

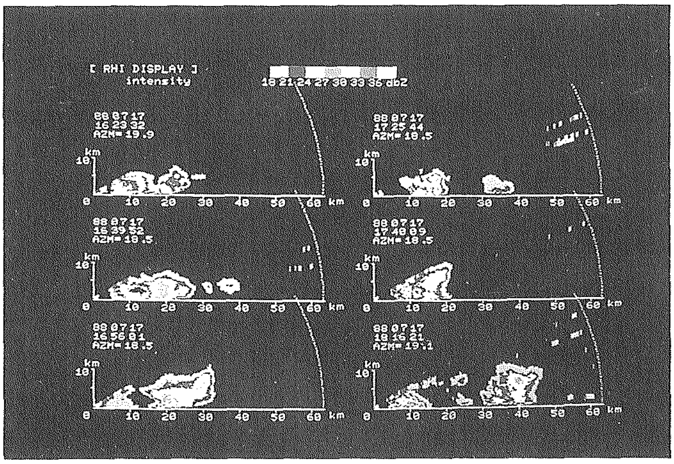

Fig. 10. As in Fig. 9 except for convective clouds.

from observation site. 0°C level is substituted by a solid bar in the case that the interval between both observational times is short. It is seen that bright band has a very strong radar reflectivity factor in case of stratiform clouds at Sasebo. The characteristics of the bright band can be explained in terms of several factors: (1) differences in the radar reflectivity factor of ice and water particles, (2) the effect of coalescent growth of the falling particles (e.g. Yokoyama et al., 1985), (3) differences in particle concentration above and below the 0°C isotherm caused by differences in the falling velocity of snow and rain particles having essentially the same mass, and (4) variations in the reflectivity factor with changes in particle size during melting. However, the increase of radar reflectivity factor was not large near the melting layer in the case of convective clouds. When precipitation particles fall through the melting layer, it is considered that second factor strongly influences the difference of radar reflectivity factor between stratiform clouds and convective clouds. The reason is that other factors have the same effect between stratiform clouds and convective clouds. Namely, large raindrops were formed even under the same rainfall intensity due to effective coalescent growth of snowflakes through the melting layer of stratiform clouds. But, it is considered that small graupel particles were formed in the case of convective clouds, because the updraft is strong and the increase of the radar reflectivity factor is weak in the melting layer. The small graupel particles do not form large raindrops. The result is that the associated raindrop size distributions are different between stratiform clouds

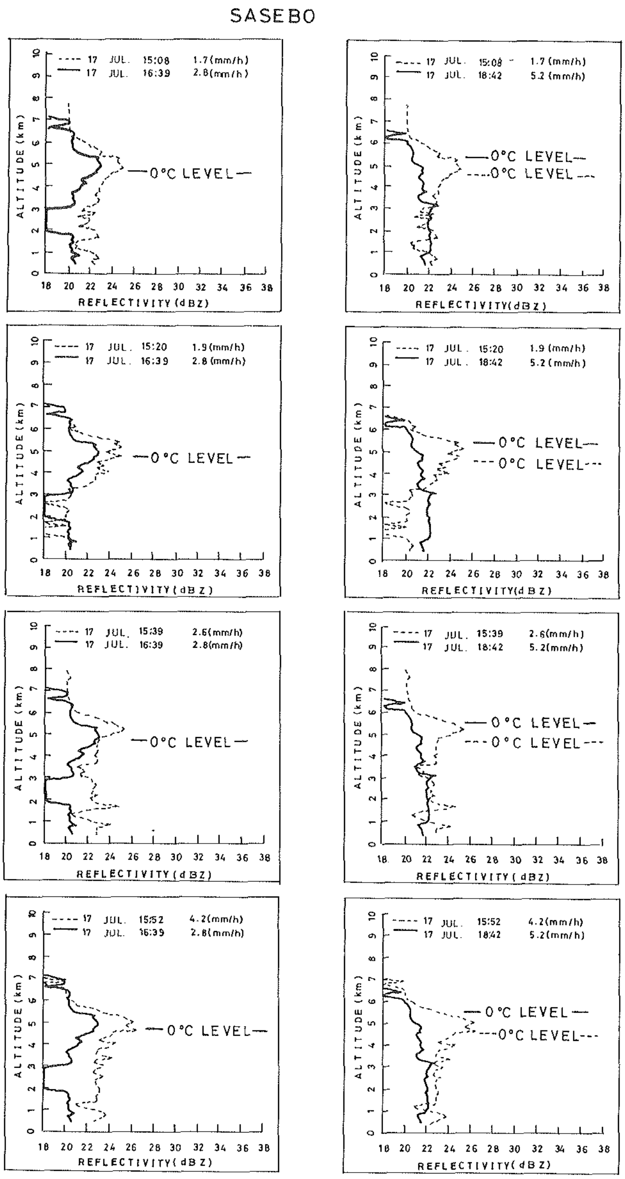

Fig. 11. Vertical distributions of the radar reflectivity factor in stratiform clouds and convective clouds under the nearly same rainfall intensity at Sasebo. Broken curves and solid curves show stratiform clouds and convective clouds, respectively.

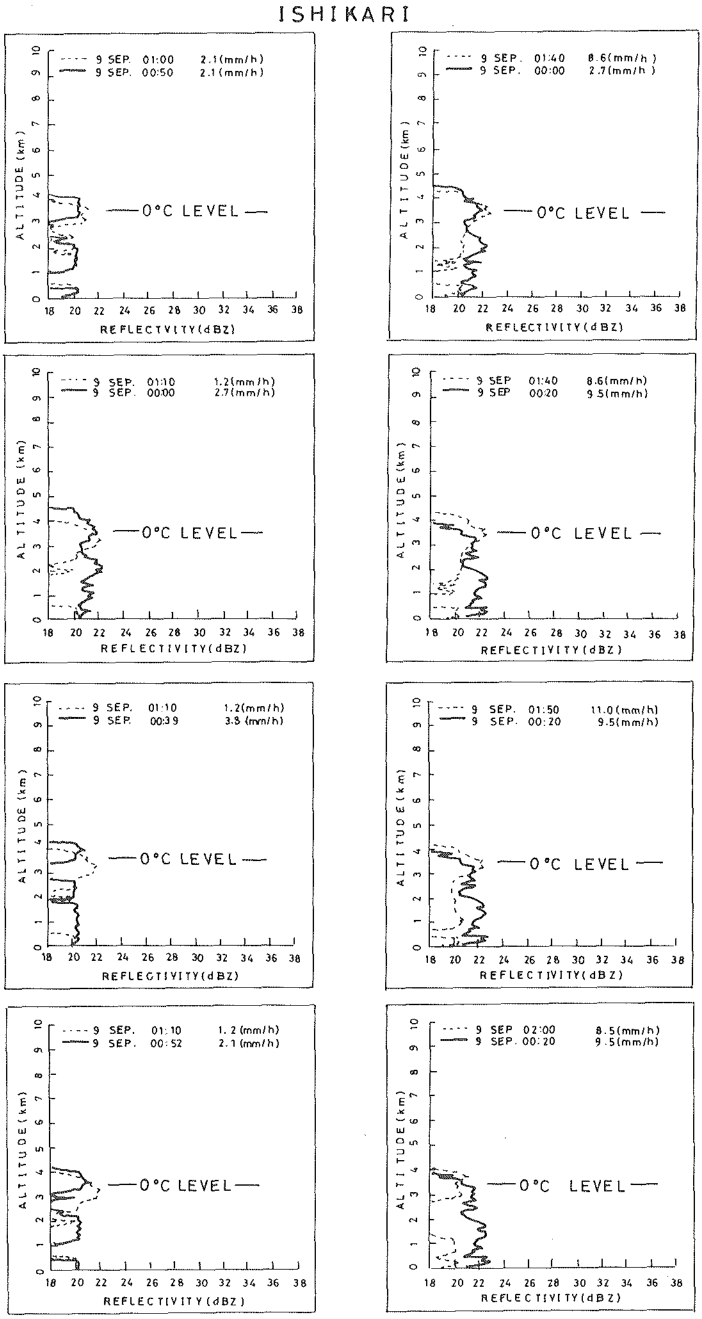

Fig. 12. As in Fig. 11 except for Ishikari.

and convective clouds.

Next the vertical distributions of the radar reflectivity factor were compared between stratiform clouds and convective clouds at Ishikari. The data at Ishikari are shown in Fig. 12 by the similar representation as Fig. 11. The difference of the radar reflectivity factor between stratiform clouds and convective clouds is not as clear as that at Sasebo. Therefore it is considered that there are only small difference at raindrop size distributions from stratiform clouds and convective clouds under the same rainfall intensity.

It is significant that the difference was not recognized at Ishakari. The reason may be considered as follows. The observation period at Sasebo was the Baiu season, so a moist and warm air mass blew from the southeast and a lot of snow crystals were formed in the layer above the melting level. But, water vapor was not supplied abundantly at Ishikari, so the generation of snow crystals is supposed to be insignificant. Therefore, snow crystals could grow to large snowflakes at Sasebo, but they could not grow to large snowflakes at Ishikari. The result was the difference in the raindrop size distributions at Sasebo and Ishilari.

5. Conclusions

The raindrop size distributions were observed at Sasebo and Ishikari. The results are summarized as follows. At Sasebo, there were more large raindrops from stratiform clouds than those from convective clouds even under the same rainfall intensity and there were fewer small raindrops. But, the difference was not observed at Ishikari.

The reason is due to the formation of large snowflakes in stratifom clouds and small graupel particles in convective clouds at Sasebo. In addition, coalescent growth of snowflakes occurred efficiently due to the generation of many snow crystals in the moist and warm air mass at Sasebo, and it did not at Ishikari.

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