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On Raindrop-size Distribution in Warm Rain (I)

by

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Abstract

The raindrop data obtained at three stations 3.4, 2.1 and 1.3 km above sea level (a.s.l.) along the Mt. Fuji slope were evidently under a warm rain situation, and compared with those at Hawaii (FUJIWARA, 1967). The comparison resulted in good agreement in that the spectra are very narrow with extremely high concentrations and that accordingly both parameters B and β in Z-R relationship are excessively small. Although with the Hawaiian data a tendency was found that the mean values of both parameters decreased with height, since the topographical slope was gentle (about 3/100), some doubt remained as to whether this tendency is due to the height or to the horizontal distance. This doubt is almost removed by the present result for which the network extended vertically and horizontally to a comparable order of distance (about ½ of slope).

1. Introduction

On raindrops from warm rain many papers have been presented so far (WOODCOCK, 1950; BLANCHARD, 1953; TURNER, 1955; KOMABAYASHI, 1957) mainly motivated by an interest in rain mechanism. Since radar meteorologists are concerned with the raindrop-size distributions as parameters in the conversion equation from the back-scattering signal intensity, which is approximately proportional to Z ($\equiv \Sigma N_D D^6$), to the corresponding rainfall intensity R, the raindrop-size distributions were measured and analyzed in terms of the Z-R relationship (e.g. STOUT and MUELLER, 1968). BLANCHARD was the first to give the raindrop characteristics of warm rain in terms of Z and R based on his Hawaiian data. FUJIWARA (1969) obtained characteristic parameters similar to BLANCHARD's that the mean diameter is small while the concentration is large and correspondingly the radar parameters B and β are both exceptionally small compared with ordinary rain. He also analyzed the data in the light of precipitation physics and found that the parameters determined empirically by equation $Z=BR^{\beta}$ are the indices for the rain growth mechanisms associated with it. Briefly speaking, Z is a 6th power moment whereas R, approximately 3.5th power moment, and accordingly any increase in the mean diameter enhances the value in Z more than in R. This results in an increase in B for a certain β value. The low B and β values obtained from warm rain indicate that the rain intensity increases with spatial concentration rather than with the mean diameter of raindrops. This must be representative of the mechanisms of raindrop generation and growth of warm rain.

As additional evidence to our previous paper on warm rain, a rainshower analysis in terms of B and β and as well as the spectrum will be reported in the present paper.

2. Evidences as warm-type rain

Nine reports of flights on the commercial airlines JAR, which pass near Mt. Fuji, are available for the period from 1300 to 2100 JST. It is strongly suggested by the reports that the rainfall was the warm type. Summarizing the reports, the vertical distribution of clouds near Mt. Fuji is given schematically in Fig. 1. The cumulus cloud tops were described more positively than the bases, and the levels of the tops are considered to be pretty accurate because they were determined by referring to the summit of Mt. Fuji (3,776 m a.s.l.). In the afternoon, the tops of the cumulus clouds were immediately below 4,000 m level, whereas there were cirrus-type clouds at about 8 km or higher. The dashed curve in the figure represents the level of the cumulus tops.

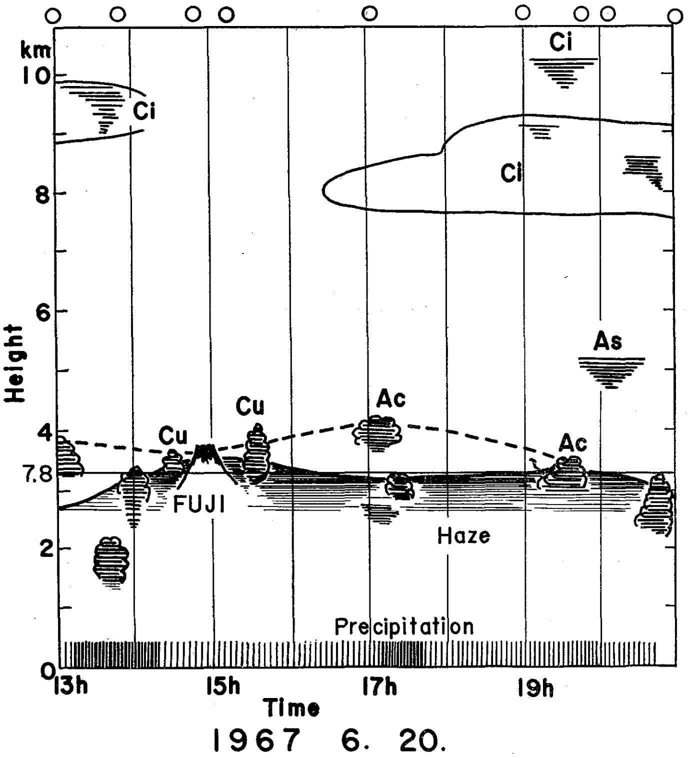

Fig. 1. A schematic illustration of the vertical distribution of cloud as deduced from the flight reports of commercial airlines.

They were also estimated by eye to be nearly 3,500 m a.s.l. from the ground station at 7.8 GO when an opening appeared in the cloud. After the rain ceased, about 2000 JST, the cloud tops descended below the station at 7.8 GO. Therefore the aviation reports give reasonable levels of the cloud tops within a few hundred meters. The air temperature at the summit of Mt. Fuji was within the range from $-1.0°C$ to

−1.5°C. The radiosounding at Tateno, about 130 km northeastward from Mt. Fuji, shows that as the balloon ascended humidity dropped sharply from 85% to about 20% at 4,000 m. This confirms that any ice crystals fallen from the cirrus cloud have evaporated before they reach the cumulus clouds. An appreciably dense haze layer whose top was also reported around 3,500 m in height and which lasted throughout the period may have been associated with this humidity discontinuity.

After Kitagawa and Maruyama (1968) a climatological evidence suggests that warm-type rainfalls are observed over the same slope of Mt. Fuji with considerable frequency from clouds with tops warmer than −8°C. This also supports the position that the present rainshower was completely of the warm type.

3. Raindrop size distributions

In Fig. 2, the ordinate and abscissa represent the drop diameter and time respec-

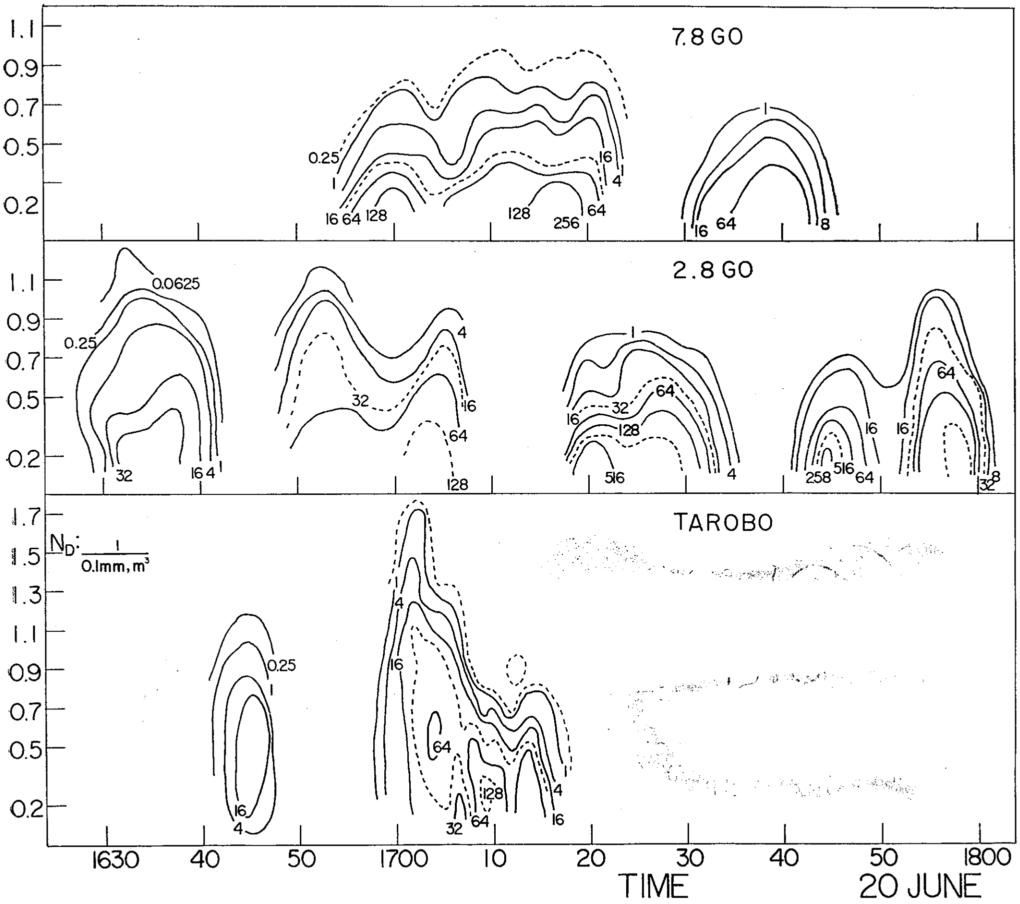

Fig. 2. Isopleths of raindrop size and concentration taken from the first rain system at three elevations. The ordinate and abscissa represent drop diameter (mm) and time (JST) respectively.

tively, and the concentrations are given by contours for every 4-time magnitude. A peak in the marginal contour shows an increase in the largest drop size. Because the maximum size of the raindrop is an indication of the effective cloud depth through which the optimum drop could have grown, variations in the height of the marginal contour imply those of the cloud top. In this respect, the general pattern shown in the figure indicates a showery characteristic.

As described in Section 2, and in a separate paper in preparation, the present rainfall was warm-type rain produced from orographic thermal clouds, which were organized into a more or less uniform cloud in the late evening as seen in Fig. 3 in comparison with Fig. 2. The maximum concentration of raindrops observed at 2.8 GO was about 50,000 drops/m^3 at 1720 JST in the mature stage of the clouds. This value is about seven times as large as the maximum concentration obtained in Hawaiian warm rain by the author.

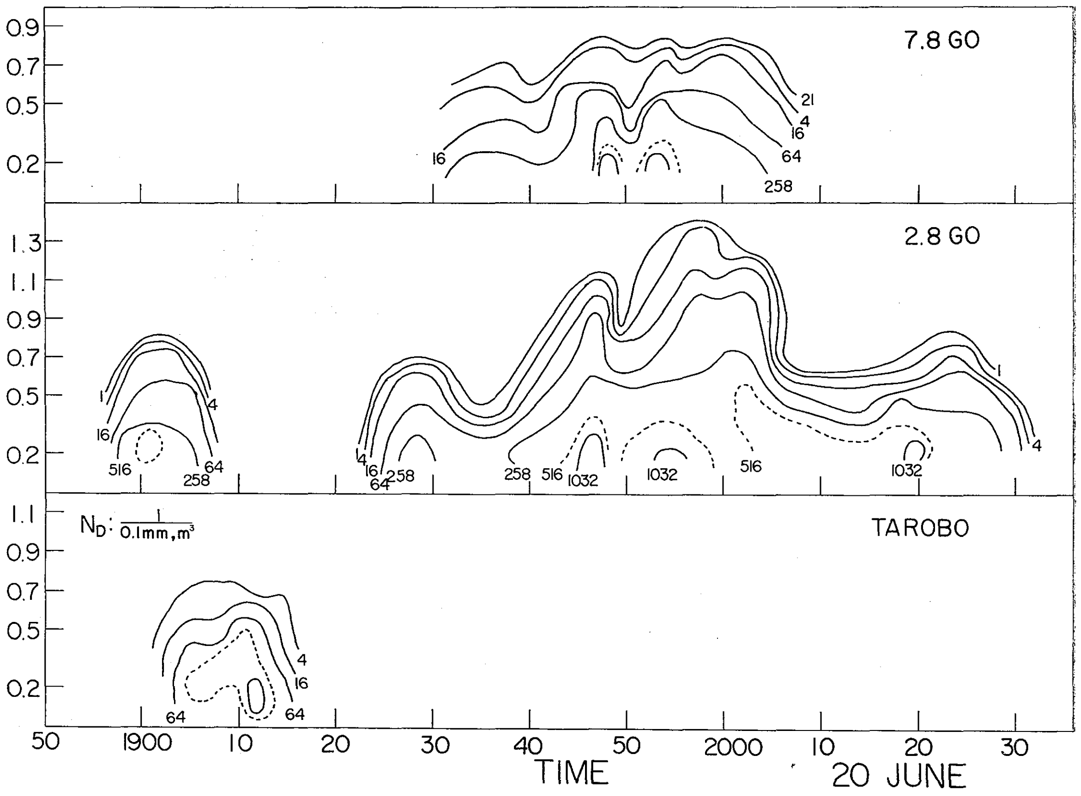

Fig. 3. Isopleths of raindrop size and concentration from the second rain system. Explanation as in Fig. 2.

Fig. 3 is a similar illustration for a later period in which the cloud was more or less stratified. The contours were drawn denser in the marginal than the inner region. This corresponds to a situation in which the raindrop spectra, if expressed in a form log [concentration] against diameter, are narrow and symmetrically monomodal shape as illustrated in Fig. 4, rather than the linear exponential type. This

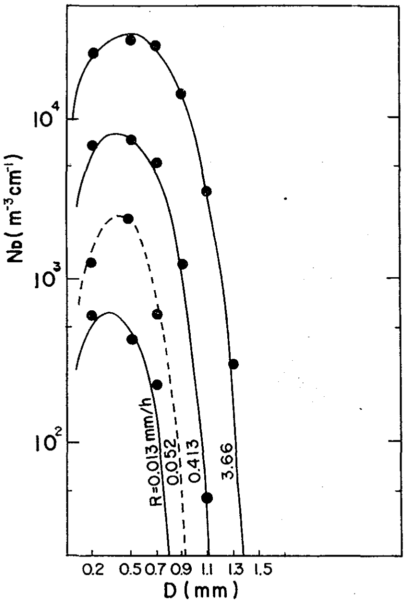

Fig. 4. A few representative N_D curves from raindrop samplings at 2.8 GO. The "representative" means that the Z-R point of the sample is nearly on the regression line.

feature was classified previously by one of the authors (FUJIWARA, 1965) into weak rains, either the shower type or the continuous type, and the low B value type.

It was also suggested by him in another paper (FUJIWARA, 1967) that such raindrop size distribution is an indication of the clouds being thin or the isolated small cumulus type in which no mixing of raindrops of different history or disintegeration of large drops occurs during their fall in an appreciable degree.

The raindrop characteristics observed in the present case are quite compatible with the conclusions given in our previous papers.

4. Z-R relationships from the warm rain

As described in Section 1, low values in B and β are expected from the nearly pure warm-rain mechanism of initiation, they are expected to increase somewhat with the convective activity. As shown in Table 1, the values B and β are generally small showing a reflection of the warm-rain mechanism and furthermore there is a tendency for both the values to decrease with height, similar to the Hawaiian data. The cause of the height dependency of B-β values was attributed in the previous paper to the difference in altitude in cloud. However, it could have been attributed to the horizontal distance rather than altitude because the top and bottom stations were apart only by 350 m vertically for a horizontal distance of 12 km. In the present case, the height difference between top and bottom is 2.1 km and the average slope is about ½. Therefore, it was confirmed that the lowest values of B and β are associated with the top of the warm cloud.

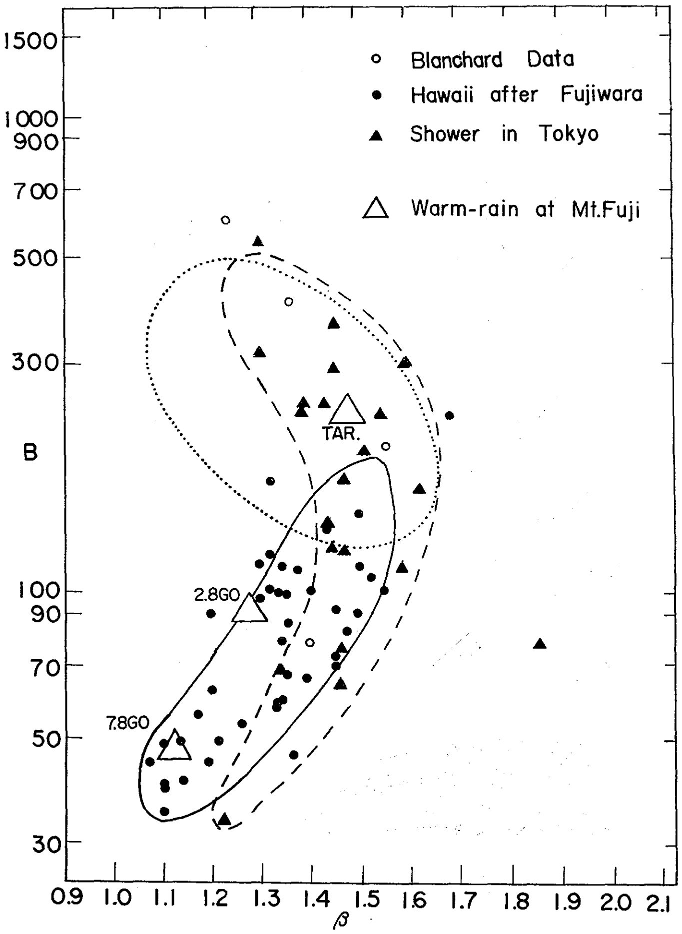

Fig. 5. B-β scatter diagram for warm rains. Three heavy triangles are those measured at Tarobo, 2.8 GO, and 7.8 GO respectively from top to bottom. The dotted circle shows the region for rain showers observed in the U.S. continent.

In Fig. 5, in which the ordinate and abscissa represent log B and β respectively, the values obtained at the three stations are shown by large triangles. For refer-

Table 1. Radar-raindrop parameters determined from raindrop data.

Station	B	β	Standard error of β	Standard error of mean log [R] from the mean log [Z] by the regression
Tarobo 1.3 km	240	1.48	0.027	0.041
2.8 GO 2.1 km	88	1.28	0.051	0.085
7.8 GO 3.4 km	48	1.11	0.033	0.073

ence, two groups of Hawaiian data are shown by small open circles after BLANCHARD and by small black circles after FUJIWARA. The three triangles fall nearly in the region of the author's Hawaii data as shown by real lines, and reveal that the raindrops with narrow spectrum width generated from the warm-rain mechanism develop their spectrum width as they fall attended by coalescence process.

5. Conclusion

The series of rain showers from which raindrop sampling was made at three elevations along the slope of Mt. Fuji, was confirmed to be purely warm-type rain. The characteristics of the raindrop size distribution were qualitatively the same as in the Hawaiian warm rain. That is, the mean diameter is small whereas the peak concentration is extremely high. The maximum total concentration of raindrops was measured as 22,000 drops/m^3 at 7.8 GO, and 50,000 drops /m^3 at 2.8 GO and the maximum diameter of drops sampled at Tarobo is 3.3 mm.

The Z-R parameters B and β measured in the present case fall into the same domain as the Hawaiian warm rain. The values B and β ranged down to 40 and 1.1 respectively.

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暖かい雨の雨滴分布について（I）

藤原美幸，柳瀬利子

富士山の東斜面の3ヶ所（高度 3.4，2.1，1.3km）で観測した雨滴資料は Warm rain であることがわかったので，前に観測したハワイ島の Warm rain の結果と比較した。まず雨滴分布の特徴としてスペクト

ルの巾は小さく濃度（空間）は非常に大きかった。従って Z-R 因子 B, β の値が共に普通の範囲よりも下方にあってしかも高度とともに減少する傾向がみられた。ハワイの場合も同様の結果が得られたが傾斜が緩やかで約 3/100 位である為，高度差よりも降水セルの発達段階の差の現われる水平距離の差によるものであるかも知れないという疑問が残っていたが富士山の場合，水平距離と高度差が同じオーダー（勾配平均1/2）である場合も同様の結果が得られたので高度と共に B, β が減少することが確められたことになる。