# Comments on "Evolution of Raindrop Spectra with Collision-Induced Breakup"

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29 December 1976 and 29 March 1977

List and Gillespie (1976) have studied the evolution of raindrop spectra by collision-induced breakup in an important numerical modeling effort that incorporates laboratory results. The primary result of these calculations is that an initial Marshall-Palmer drop size distribution for $R' = 100$ mm h$^{-1}$ and a liquid water content of 3.7 g m$^{-3}$ will become essentially devoid of drops $>2.5$ mm diameter within 180 s or less fall time below the melting layer. This occurs rapidly even though the initial drop distribution contained large drops. With both breaking and coalescence mechanisms operating, the large drops disappear very rapidly and the liquid water is redistributed among drops $<1.5$ mm diameter. Since observations of raindrops in natural rains with diameters $>3$ mm are not uncommon, they attribute this discrepancy to differences between warm

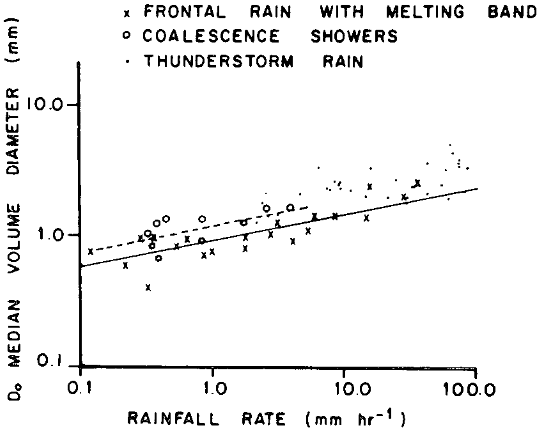

FIG. 1. Plots of median volume drop diameter versus rainfall intensity (Mason and Andrews, 1960).

and cold rain. We take issue with this attempted reconciliation of the numerical result and the observational evidence, not with the admirable modeling effort.

If the numerical model results are correct, when the depth between the surface and the base of the melting layer is typical of the tropics, it should not make any difference at all in the drop spectrum at the surface whether the ice phase was involved in the initial precipitation formation. List and Gillespie (1976) state that a 3 mm diameter drop will fall 800 m relative to the surrounding air in 1 min; using the formula they present, we calculate that fall to be closer to 550 m. Now, over most of the summer tropics the altitude of the freezing level is about 4.3–4.5 km, and the melting layer extends 300–400 m below this level. Even if the melting layer is twice this thickness, its base would still be around 3.5 km. Thus, for conditions typical of the tropics, this affords over twice the fall distance (or time) required for depletion of the large drops according to the numerical model. On the other hand, large drops certainly are reported in tropical rain. Merceret (1974a,b) reported for tropical storms that at altitudes from below cloud base ($<500$ m) to near the freezing level (4500 m), there are substantial numbers of drops $>3$ mm diameter. In fact, it is the small drops which are observed to be depleted (Merceret, 1974a). Many of the drop spectra of Blanchard (1953) and Blanchard and Spencer (1957) show significant numbers of drops $>3$ mm diameter for larger water contents ($>1$ g m$^{-3}$), particularly for tropical rains other than those from the very thin, stable orographic clouds.

A particularly interesting and pertinent result from Mason and Andrews (1960) for coalescence showers that did not extend above the freezing level is presented in Fig. 1. They conclude that the data for coalescence showers show relatively more scatter, but may be represented by the dashed line having the same slope as the Marshall-Palmer relation, though with rather

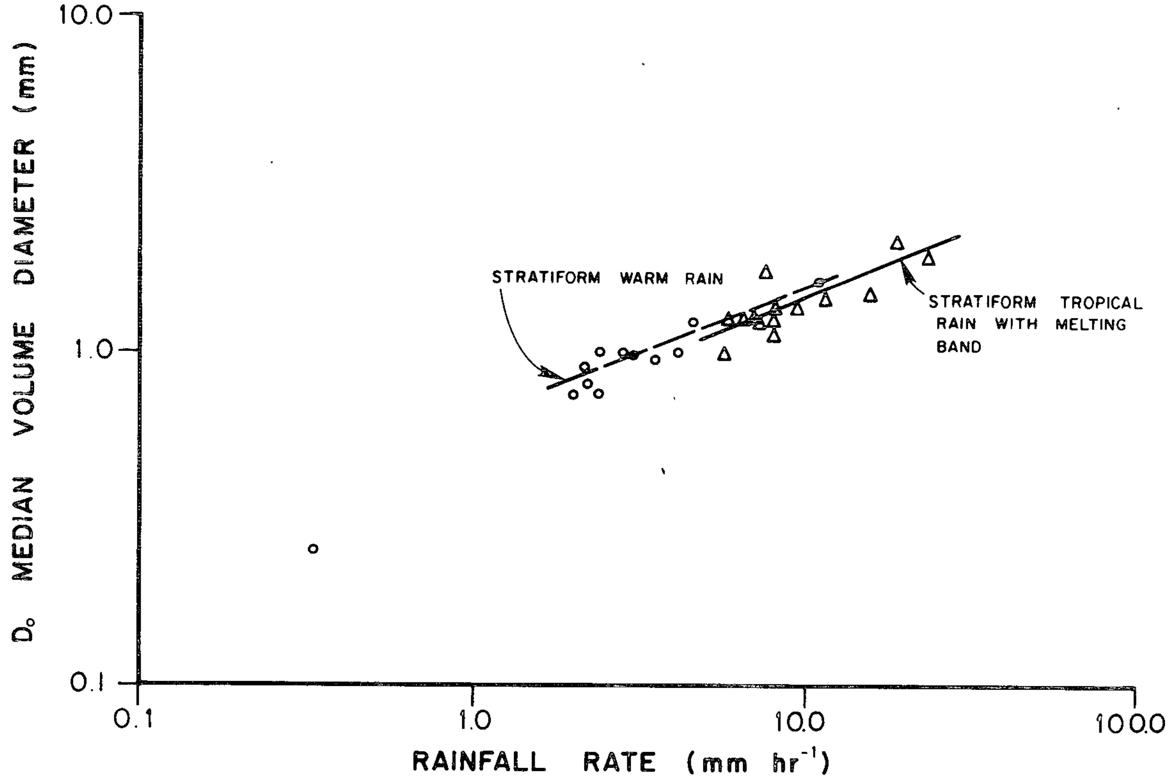

FIG. 2. Median volume drop diameter versus rainfall rate (Sivaramakrishnan, 1959).

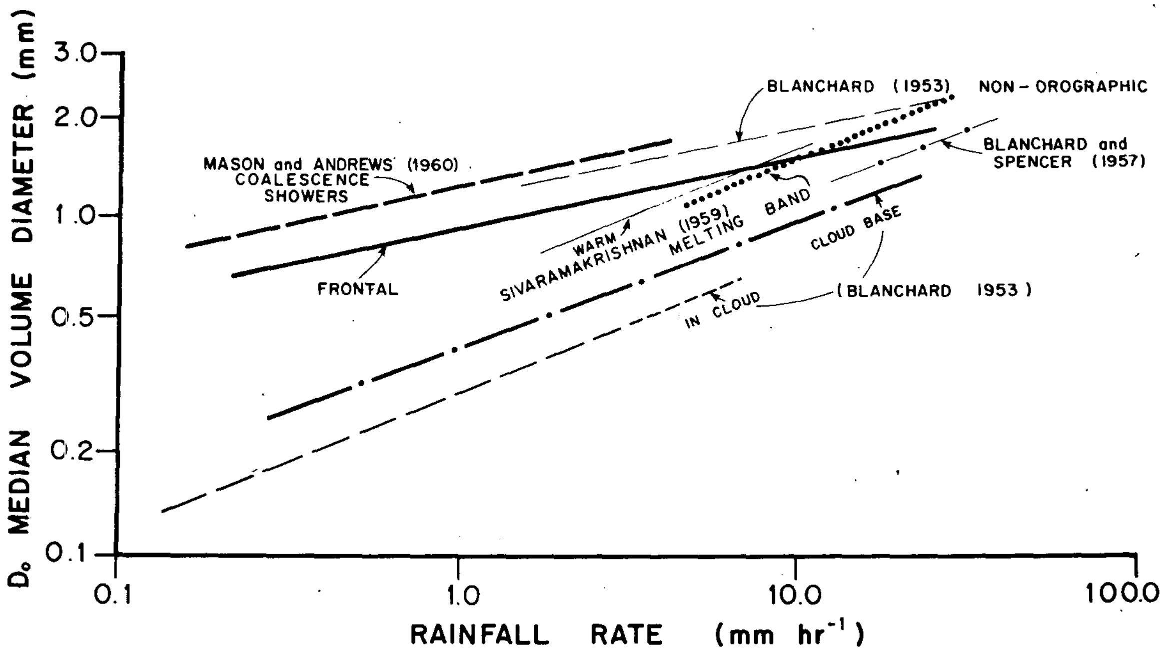

FIG. 3. Rainfall rate versus median drop diameter.

large median-volume drop diameters for the same rainfall intensity.

Another result that contradicts the reasoning of List and Gillespie (1976) is from Caton (1965). He finds in a pulsed Doppler analysis of frontal rains with echoes extending above the freezing level, that the drop distributions 750 m above the surface show both fewer small drops and fewer large drops than the Marshall-Palmer distribution. At greater heights, however, he finds that there are more small drops and even fewer large drops. If the numerical model and the reasoning for cold rain were correct, there would be fewer small drops and more large drops with increasing altitude up to the base of the melting layer. In fact, for drop spectra in the tropics which do contain large drops, tremendous drop diameters would be implied just below the base of the melting layer if the size actually observed at the surface were to survive, according to the argument of List and Gillespie. We don't believe radar or drop size data support the existence of these huge drops at the base of the melting layer.

Sivaramakrishnan (1959) presents some interesting drop spectral data from stratiform, presumably orographic, cloud at Poona for a case with melting band, and for two cases of similar, but nonfreezing, rain. So here we have data from two very similar rainfalls, one involving the ice phase and the other warm rain. His data are plotted in Fig. 2, and there is essentially no difference in the two curves. If anything, the drop diameters for the warm rain are slightly larger for a given rainfall rate. [The curve fits are those of the authors and not those of Sivaramakrishnan (1959).]

The very narrow drop spectra for Hawaiian orographic rain of Blanchard (1953) and Fujiwara (1967) do appear to lend some support to the result of List and Gillespie (1976). The results of Blanchard (1953) are plotted in Fig. 3 along with the results previously presented. Note that for a given rainfall rate, the median drop diameters are significantly lower for the orographic rain. However, the Hawaiian orographic rain is not at all typical of tropical convective cloud. It is limited in vertical cloud depth to 600–1500 m by the trade wind inversion, but nevertheless produces significant amounts of rain. The average vertical air velocities are of the order of 10 cm s$^{-1}$, as opposed to several meters per second vertical air motions in active convective clouds. Squires and Warner (1957) attribute the unusual microstructure they observed in this cloud to these low vertical air speeds. They found the cloud droplet spectra characterized by larger and fewer droplets than the cumuli seaward of the orographic cloud. They noted that the seaward cumuli as well as similar clouds off the east coast of Australia did not produce rain until they reached a depth of at least 1800 m; this is in contrast to the orographic stratiform cloud which rained significantly from as little as 600 m cloud depths. The unusual microstructure, the remarkably fine but dense rain, and the slow orographic uplift are not typical of tropical rain showers. This tropical, stable, warm orographic rain may be a remarkable natural laboratory for the study of microphysics, but it is not typical of tropical rainfall nor is it a substantive part of rainfall in the tropics.

Tropical storms and disturbances are important in any consideration of rainfall in the tropics. Fig. 4 presents the median drop diameter versus rainfall intensity for drop spectra observed in Tropical Storm Felice (Merceret, 1974a). Note that at a level just

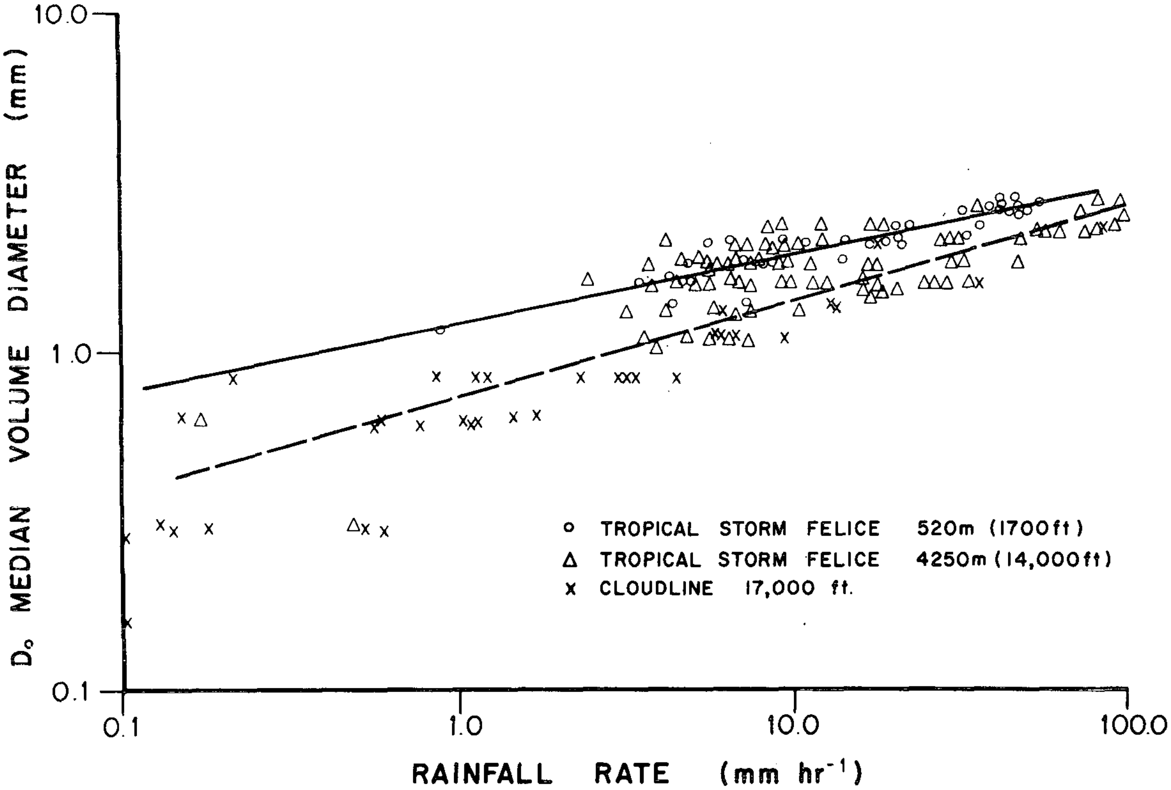

Fig. 4. Median volume drop diameter versus rainfall intensity for Tropical Storm Felice (15 September 1973) and cloud line cumulus.

below cloud base, there are numerous spectra where significant numbers of drops >2.5 mm are observed. All of these spectra contain 330 or more drop impressions to satisfy the criterion for statistical significance. Steady-state wide-range rainfall certainly is involved in a tropical storm. There is a suggestion here that the spectra divide into two families, and not just simply according to altitude. We would suggest that these two groupings of spectra might be a reflection of whether active convective updrafts were involved in the precipitation formation or whether the precipitation grew largely under the influence of gentle or no updraft, as in the case of anvil rain or warm stratiform rain. But in either case, here is tropical rain with ample fall depth below the melting layer characterized by numerous drops >2.5 mm diameter.

We do conclude, based on the physical reasoning of more than sufficient fall time below the melting layer and the observational data presented, that the discrepancy between the modeling result and observations of large drops cannot readily be explained by difference between cold and warm rain. Further, the conclusion of Section 8.3 is simply false. It is true that for the somewhat anomalous Hawaiian orographic rain, the large drops may not have grown in the first place, but rain typical of the tropics is definitely characterized by drops >2 mm diameter. We conclude from application of the result of the paper in question and from the ample fall time below the melting layer in the summer tropics that whether or not the ice phase was involved in the precipitation process should not make any difference in the large drop part of the drop spectra at the surface.

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