NOTES AND CORRESPONDENCE

Raindrop Size Distribution with Collision Breakup in an Axisymmetric Warm Cloud Model

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22 February 1978

ABSTRACT

The effect of the collision breakup process, as described by McTaggart-Cowan and List (1975), on the raindrop size distribution and rainfall intensity in warm clouds was studied using an axisymmetric cloud model (Takahashi, 1977).

The cloud model demonstrates that with collision breakup the raindrop concentration decreases sharply in the large raindrop size range and exhibits a pronounced secondary maximum, at a drop size defined as the "peak drop" size, within the normal raindrop size range. The concentration at the peak raindrop size is consistent with that measured in natural warm cloud rainfall, and is much larger than the concentration obtained from computer simulations which do not include the collision breakup process.

The raindrop size distribution from warm clouds is characterized by a sharp decrease in concentration in the large raindrop size range (Blanchard, 1953). Recently, Takahashi (1977) used an airplane to study the space and time variations in raindrop size and rainwater content in warm cloud showers around the island of Hawaii. Observations indicated the occurrence during heavy rainfall of a pronounced secondary maximum in the raindrop size distribution, at a drop size defined as the "peak drop" size (see Fig. 1). Takahashi (1977) attempted to simulate the observed raindrop size distribution in an axisymmetric warm cloud model.

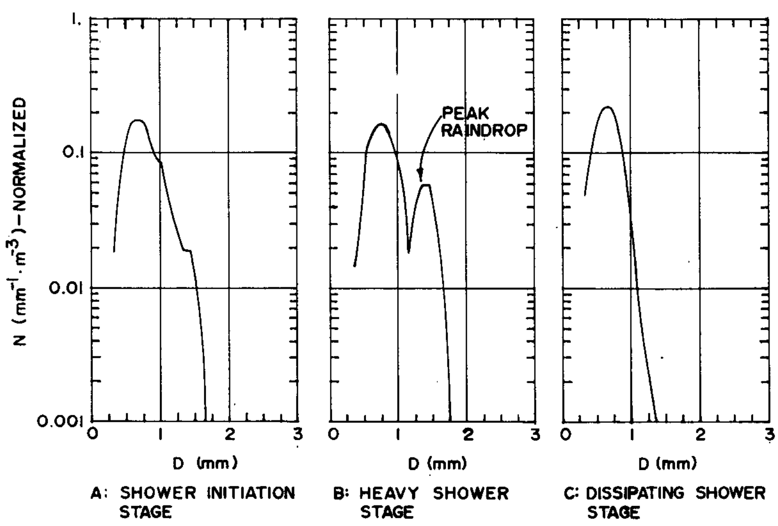

Fig. 1. Typical normalized raindrop size distributions at three stages in the shower life cycle: A, initiation (about 2.5 min prior to stage B); B, time of maximum rainfall; C, dissipation (about 10 min after stage B). Distributions were derived from aircraft observations (Takahashi, 1977) in a warm cloud with top at 2.7 km, base at 0.6 km and maximum rainwater content of 0.8 g m^{-3} (16 June 1976).

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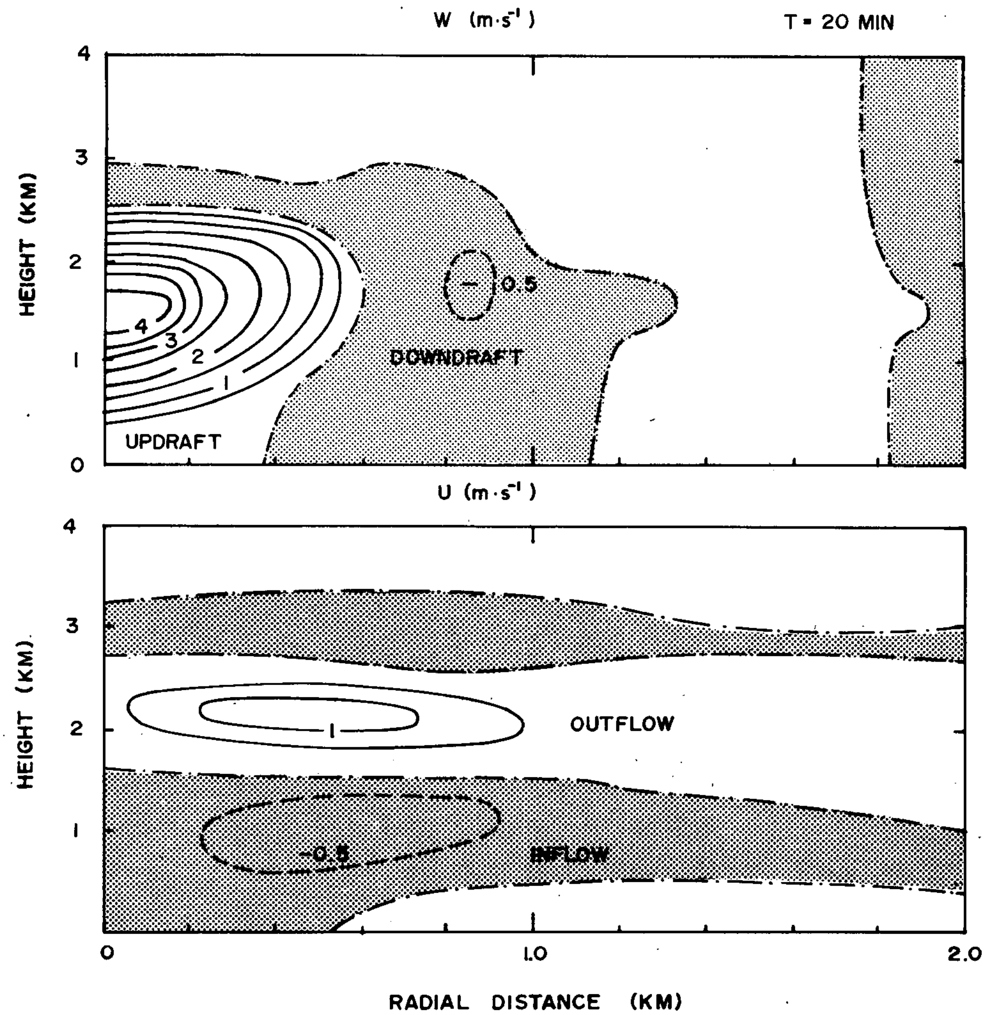

FIG. 2. Computer model results showing cross-sectional plots of vertical velocity W (upper diagram), and radial velocity U (lower diagram), 20 min after cloud development. Downdraft and inflow areas are shaded.

The model cloud was too shallow, however, and the resulting raindrops too small for the collision breakup process to function effectively. The resulting raindrop size distribution did not sufficiently simulate the secondary maximum at the peak raindrop size, although it did accurately exhibit the sharp decrease in concentration in the large raindrop size range.

The principal reason that the earlier computer result did not adequately simulate the maximum in concentration at the peak raindrop size was a lack of valid experimental data on collision breakup at small size raindrops. Takahashi's (1977) model results were based on numerical values given by List and Gillespie (1976). These values, however, were simply extrapolated to the small raindrop size range from the earlier experiments of McTaggart-Cowan and List (1975), which actually were done with raindrops of larger size.

In the present study the model cloud is permitted to develop more fully, to grow to higher altitudes and, thus, to provide an environment in which raindrops can grow to larger sizes, sizes comparable to those used in the laboratory experiments of McTaggart-Cowan and List (1975).

The basic equations and calculation schemes are the same as those used by Takahashi (1977) for an axisymmetric warm cloud model. The higher cloud was simulated by extending the previously used temperature and mixing ratio profiles by three 200 m layers (i.e., by an additional 600 m) above the level of maximum relative humidity. Calculation of the collision breakup process required small time steps, as small as 1 s, to satisfy computational stability as the cloud develops fully.

The computer simulation shows that at 20 min after cloud development the maximum updraft at the cloud center has increased to 4 m s^{-1} and the downdraft region extends from the cloud top to the ground along the cloud boundaries (Fig. 2). Outflow is seen near the

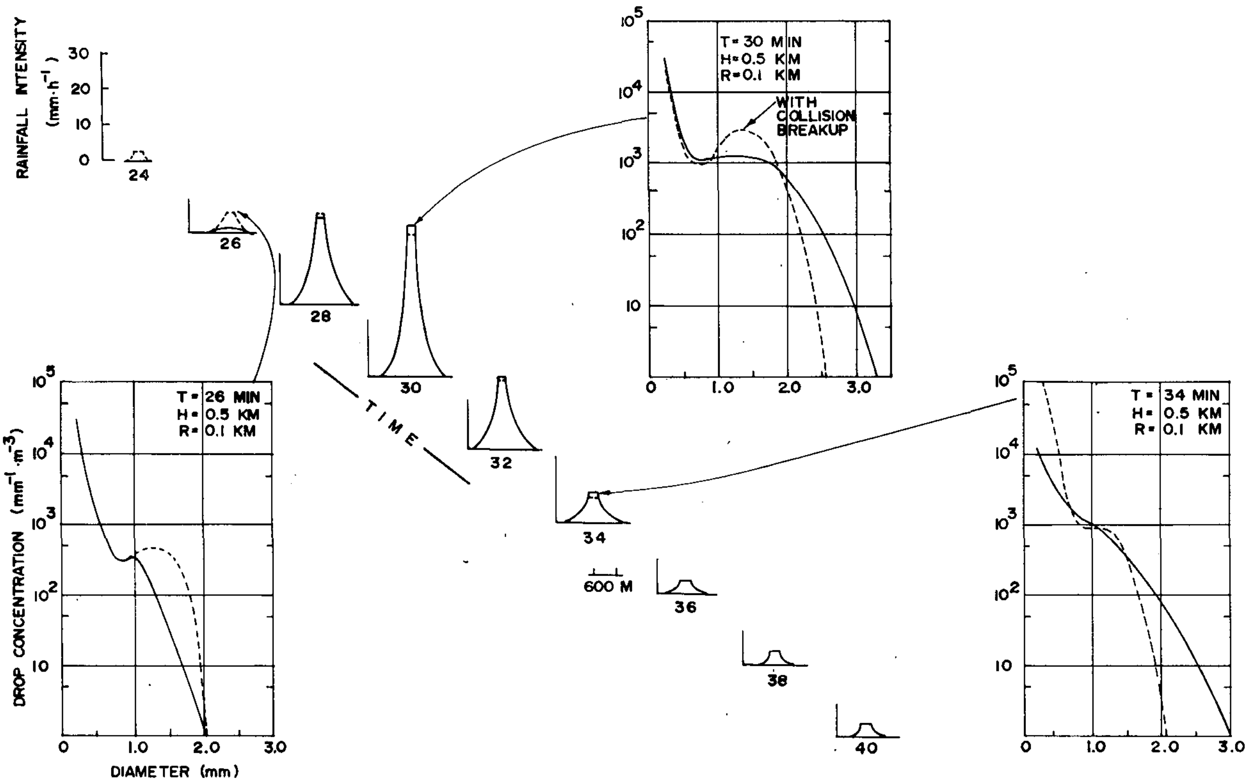

Fig. 3. Computer model results showing rainfall intensity at $H=0.5$ km and $R=0.1$ km as a function of time and raindrop size distributions at selected times, both with (dashed lines) and without (solid lines) the collision breakup process.

cloud top, at 2.5 km, as well as inflow near the cloud base in response to cloud convection.

The rainfall intensity and raindrop size distribution at the cloud base (500 m), both with and without collision breakup, are shown in Fig. 3. The model results indicate that rain begins at 26 min and attains its maximum intensity (42 mm h^{-1}) at 30 min. Thereafter the rain gradually decreases in intensity with time.

The drop size distribution without collision breakup exhibits only a slight increase in concentration (the "peak" raindrop diameter is 1 mm at 26 min) as a secondary maximum. The peak raindrop size increases with time. Physically, it appears that the drops are sorted into various size categories by the updraft. Near the cloud top, where the updraft still is strong, only the larger drops are able to fall. As they fall they grow even larger by the collection process. Thus, the raindrop size distribution is broad with the number concentration decreasing gradually toward the larger raindrop size range.

On the other hand, when the collision breakup process is included, the larger raindrops break up, form raindrops in the "peak raindrop" size range, leading to a pronounced secondary maximum in concentration. At 26 min the peak raindrop diameter is 1.5 mm and the secondary maximum in concentration at this size is increasing in magnitude. The concentration becomes pronounced at 30 min, coincident with the time of maximum rainfall intensity. As the rainfall intensity decreases at 34 min, the secondary maximum disappears and the number concentration of drizzle size drops, with diameters <0.3 mm, increases to one order of magnitude higher than the concentration observed in the case without collision breakup.

The raindrop size distribution simulated with the collision breakup process included is much closer to that observed in natural rainshowers, although the secondary maximum is not observed in the initial stages of rainfall. The failure to observe peak raindrops at the beginning of the shower is thought to be due to the small sampling volume of the collector used. Since the collision breakup process is working most effectively in the late mature stage of the cloud life cycle, when a downdraft predominates in the lower parts of the cloud (Fig. 4), small broken droplets will not be carried to the higher regions of the cloud and will not grow to larger size. The rainfall intensity profile with collision breakup, therefore, is substantially the same as the profile obtained without collision breakup,

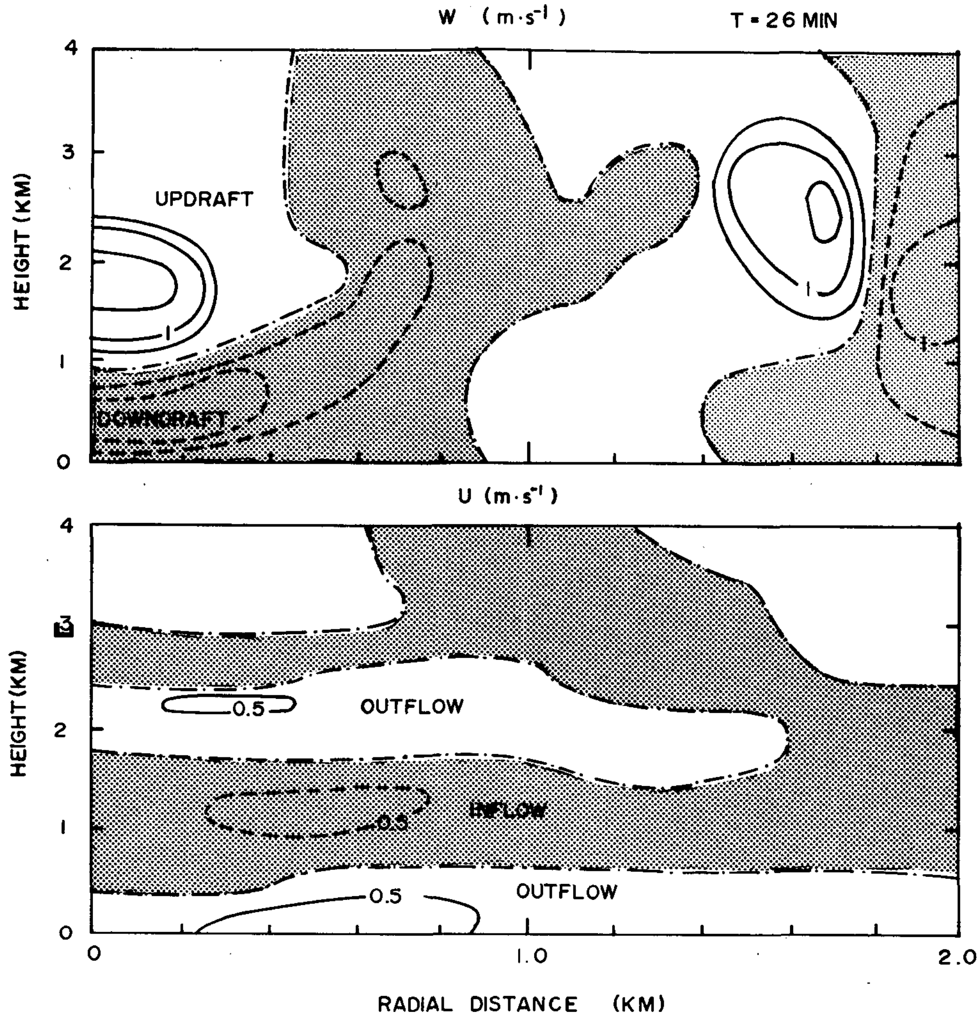

FIG. 4. Computer model results, plotted as in Fig. 2, at 26 min after cloud development. The small convective region on the right-hand side is due to wall effects in the model.

except that rain begins slightly earlier if the collision breakup process is included.

Use of the cloud model allows determination of the probable region in the cloud where the peak raindrops form. Fig. 5 indicates the raindrop size distribution at 30 min in various locations within the cloud. Peak raindrops appear to form below 1.3 km, near the cloud center; 300 m from the cloud center there appears to be no peak raindrops. The result that peak raindrops must be formed close to the cloud center conforms to the observations of Takahashi (1977) in natural rain-showers. In order to form peak raindrops (that is, achieve a secondary maximum in the drop size concentration) it appears that both large and small drops must coexist in a vertical column at the cloud center. Away from the cloud center, the smaller droplets are carried by the inflow toward the cloud center, but the larger drops essentially fall vertically.

Numerical models will probably be unable to simulate nature more precisely until experimental studies of the collision breakup process are carried out with small raindrops.

Acknowledgments. The project was supported by the National Science Foundation (ATM 76-18553). Numerical calculations were performed on the CRAY-1 computer of the National Center for Atmospheric Research, sponsored by the National Science Foundation. Dr. Richard Valent, of NCAR, was extremely helpful in assisting the author with the conversion of computer programs from the CDC 7600 computer to the CRAY-1. Dr. C. M. Fullerton kindly read and assisted with the revision of this paper.

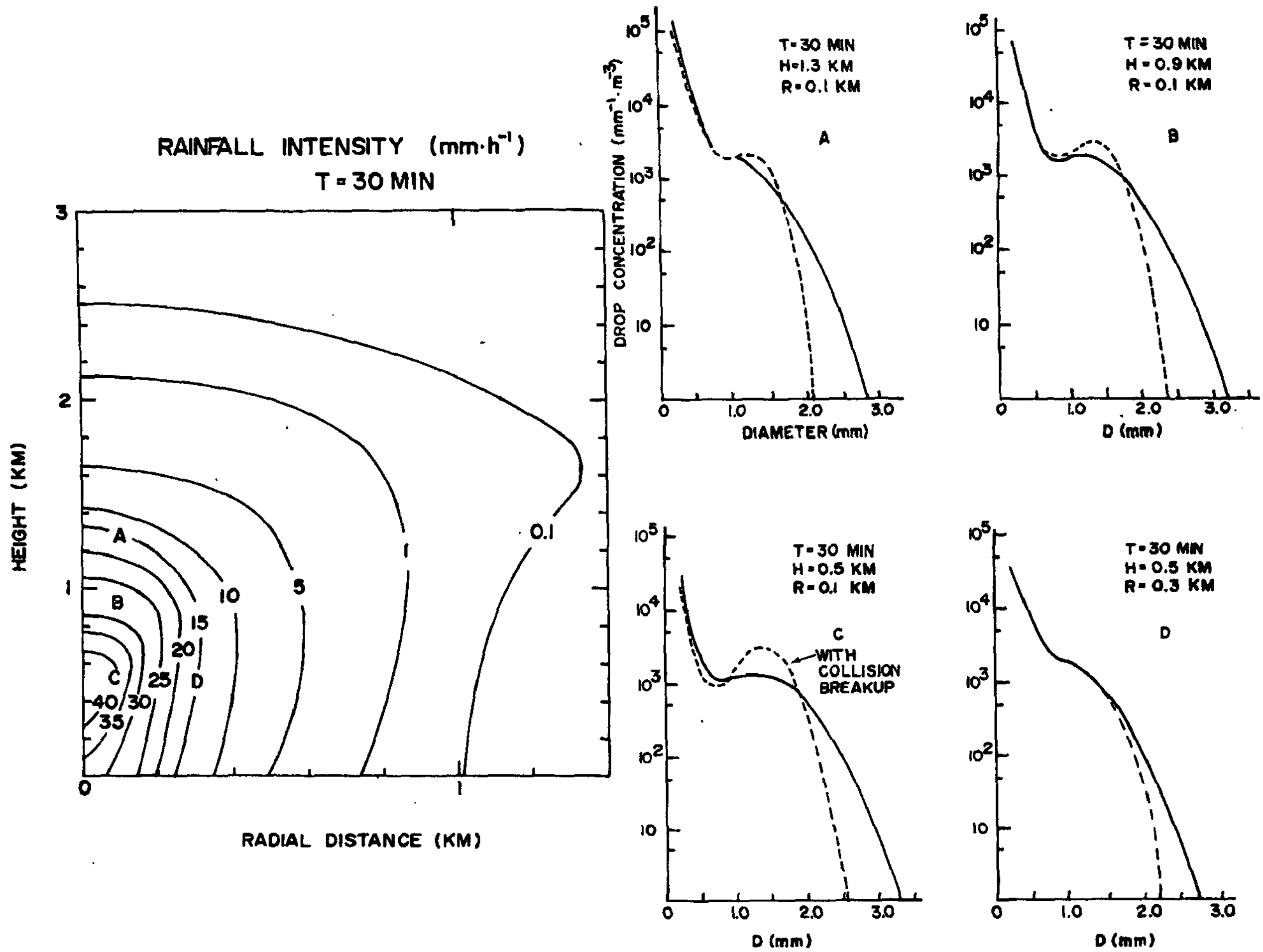

FIG. 5. The rainfall intensity profile and raindrop size distributions 30 min after cloud development at various locations (A–D) in the model cloud. The dashed line shows the distribution obtained with collision breakup included; the solid line is the distribution without the collision breakup process.

REFERENCES

Blanchard, D. C., 1953: Raindrop size-distribution in Hawaiian rains. *J. Meteor.*, **10**, 457–473.

List, R., and J. R. Gillespie, 1976: Evolution of raindrop spectra with collision-induced breakup. *J. Atmos. Sci.*, 33, 2007–2013.

McTaggart-Cowan, J. D., and R. List, 1975: Collision and breakup of water drops at terminal velocity. *J. Atmos. Sci.*, **32**, 1401–1411.

Takahashi, T., 1977: A study of Hawaiian warm rain showers based on aircraft observation. *J. Atmos. Sci.*, **34**, 1773–1790

Comments on "Numerical Simulation of the Life History of a Hailstorm"

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15 February 1978

Orville and Kopp (1977) are right in my view to stress the importance of the cloud dynamics and its interaction with the water substance. I agree, too, that highly simplified dynamical models can be valuable in shedding light on the sensitivity of various processes to changes in the model constraints. However, the authors' comparison of their model results with the observational description of a particular hailstorm

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