# NOTES AND CORRESPONDENCE

## Collision Efficiency and Cloud Drop Spectrum Evolution

H. G. LEIGHTON

*Department of Meteorology, McGill University, Montreal, Quebec, Canada H3A 2K6*

24 May 1977 and 29 August 1977

### ABSTRACT

The variation in the evolution of a cloud droplet spectrum with collision efficiency is examined for sets of efficiencies based on different fluid mechanical models. The results indicate that the variation of collision efficiencies for droplet radii $\lesssim 30$ μm are large enough to give appreciable variation in the droplet spectrum development. This is in contrast to the relative insensitivity to variations in the collision efficiencies of larger drops.

---

In the past few years a number of studies of the collision efficiencies of cloud droplets and of small rain drops have appeared. Davis (1972) allowed for gas kinetic effects in the collision of droplets by means of slip-flow theory. The resulting efficiencies are significantly larger than the earlier values of Hocking and Jonas (1970) for drop radii of 10 and 20 μm, but tend to be slightly smaller for 30 μm droplets. Davis speculates that his efficiencies are not sufficiently different from those of Hocking and Jonas to appreciably alter the production rate of large drops by condensation and coalescence. Klett and Davis (1973) presented efficiencies for drops in the radius range 10–70 μm based on a modified form of the Oseen equation and taking into account the mutual interaction of the two drops. The Klett and Davis model produces efficiencies which are considerably larger than those from previous models, particularly for pairs of drops of comparable size. More recently, Lin and Lee (1975), using a superposition method, calculated collision efficiencies of drops in the radii range 20–200 μm and obtained results in substantial agreement with those of Klett and Davis [but see the further discussion in Klett (1976) and Lin and Lee (1976)]. Lin and Lee conclude that if only inertia, gravity and drag forces are significant, the dominant factor in forming precipitation is collisional growth of drops of approximately equal size. Cataneo and Semonin (1976) claim that this conclusion is supported by their experimental results.

The object of this note is to examine the changes in the development of a droplet distribution by condensation and coalescence, by comparing model calculations with efficiencies referred to above, to calculations based on the commonly used efficiencies of Shafrir and Neiburger (1963) [as modified by Neiburger (1967)] and Hocking and Jonas (1970). The framework for this comparison is the model of droplet growth by condensation and coalescence described in detail by Leighton and Rogers (1974). The initial droplet spectrum is a gamma distribution centered at 8 μm radius, with a dispersion of 0.2 and a concentration of 600 drops $\mathrm{cm}^{-3}$. The cloud parcel has an initial temperature of 5°C, and ascends pseudoadiabatically in an updraft of 15 m $\mathrm{s}^{-1}$ from the 700 mb level. Curve *a* in Fig. 1 is the same as Fig. 7 in Leighton and Rogers and shows the droplet spectrum after 7 min ascent based on the collision efficiencies of Hocking and Jonas (1970) and Shafrir and Neiburger (1963). Curve *b* results from using Davis's efficiencies for droplet radii $\leqslant 30$ μm; curve *c* from Klett and Davis's efficiencies for radii $\leqslant 70$ μm; and curve *d* from the Klett and Davis efficiencies for radii $\leqslant 70$ μm and Lin and Lee efficiencies for radii $>70$ μm. In all cases the coalescence efficiency is taken to be unity, an assumption which, according to the experiment of Levin *et al.* (1973), would lead to an overestimate of the spectrum development.

The collision efficiencies of Davis result in a small but significant enhancement of the spectrum development. A more dramatic enhancement results from the use of the Klett and Davis efficiencies with a small further acceleration of the spectrum evolution by including the Lin and Lee efficiencies. Further tests show that it is the significantly larger efficiencies of Klett and Davis for drop radii $\leqslant 30$ μm compared to those of Davis that are primarily responsible for the difference between curves *b* and *c*.

The results indicate, for the droplet spectrum and updraft conditions considered, that the variation of collision efficiencies for drops with radii $\lesssim 30$ μm resulting from different fluid dynamical models are

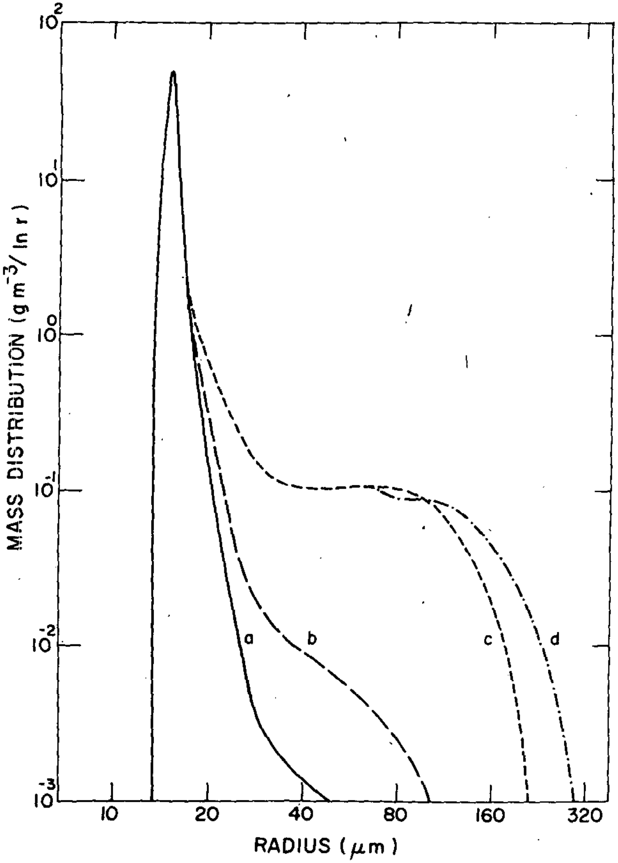

FIG. 1. Droplet spectra after 7 min of growth for different collision efficiencies as described in the text.

large enough to give appreciable variation in the droplet spectrum development. The collision efficiencies of Klett and Davis, and of Lin and Lee for large drops differ from those of Shafrir and Neiburger mainly for collisions between drops of similar size, where the latter are consistently smaller. It is evident that enhanced collision efficiencies for large drops play a rather unimportant role in spectrum development, and uncertainties of collision efficiencies in this portion of the spectrum are not as serious as the uncertainties for smaller droplets.

## REFERENCES

Cataneo, R., and R. G. Semonin, 1976: Comments on "Collision efficiency of water drops in the atmosphere." *J. Atmos. Sci.*, **33**, 1826–1827.

Davis, M. H., 1972: Collision of small cloud droplets: Gas kinetic effects. *J. Atmos. Sci.*, **29**, 911–915.

Hocking, L. M., and P. R. Jonas, 1970: The collision efficiency of small drops. *Quart. J. Roy. Meteor. Soc.*, **96**, 722–729.

Klett, J. D., 1976: Comments on "Collision efficiency of water drops in the atmosphere." *J. Atmos. Sci.*, **33**, 870–872.

——, and M. H. Davis, 1973: Theoretical collision efficiencies of cloud droplets at small Reynolds numbers. *J. Atmos. Sci.*, **30**, 107–117.

Leighton, H. G., and R. R. Rogers, 1974: Droplet growth by condensation and coalescence in a strong updraft. *J. Atmos. Sci.*, **31**, 271–279.

Levin, Z., M. Neiburger and L. Rodriguez, 1973: Experimental evaluation of collection and coalescence efficiencies of cloud drops. *J. Atmos. Sci.*, **30**, 944–946.

Lin, C. L., and S. C. Lee, 1975: Collision efficiency of water drops in the atmosphere. *J. Atmos. Sci.*, **32**, 1412–1418.

——, and ——, 1976: Reply (to Klett). *J. Atmos. Sci.*, **33**, 873–875.

Neiburger, M., 1967: Collision efficiency of nearly equal drops. *Mon. Wea. Rev.*, **95**, 917–920.

Shafrir, U., and M. Neiburger, 1963: Collision efficiencies of two spheres falling in a viscous medium. *J. Geophys. Res.*, **68**, 4141–4147.