Coalescence vs. Weber number (Wang 10.8)

\[ We = \frac{CKE}{\frac{\pi d_L^3 d_S^3}{d_L^3 + d_S^3} (v_L - v_S)^2} \]  
\[ = \frac{\pi \sigma}{12 (d_L^3 + d_S^3)^{2/3}} \]  
\[ = \frac{\rho_w d_L^3 d_S^3}{12 \sigma (d_L^3 + d_S^3)^{5/3}} (v_L - v_S)^2 \]  

Schlottke et al., JAS, 2010
CKE and Weber number

![Graph showing CKE (J) vs. Radius small drop (mm) for different sizes of large drop (r_L).](image1)

![Graph showing Weber number vs. Radius small drop (mm) for different sizes of large drop (r_L).](image2)
Weber number, CKE and Ecoalescence
Influence of $w$ on drop size (11.2)

IC grow faster by diffusion than cloud droplets b/c they grow in a highly supersaturated environment. Release of latent heat is larger $w$.

- $w$ & $WBF$ will speed up growth of IC & cloud droplets shrink with chance of collision & rimed particles $W$ higher.$\phi$

- Melting $-F$ faster fall speed

![Graph Showing Drop Size as a Function of Height and Updraft]

Solving (11.4) for a given set of updraft $W$ and liquid water content $w$, we can obtain $a_1$ as a function of $z$. Fig. 11.2 shows an example (Bowen, 1950). We can see that the magnitude of the updraft would influence the drop size: drops will be larger when the updraft is larger. A cloud would need to have substantial updraft to cause the growth of large raindrops! This conclusion is generally supported by observations and is also applicable to graupel and hail, which also grow mainly by collision and coalescence. Conversely, it implies that the observation of large hydrometeors in a cloud must indicate that there are large updrafts in the cloud.

While Bowen's idea is conceptually plausible, the actual growth of large particles in clouds, especially those in thunderstorms, is not as straightforward as described above. The distribution of particles in a thunderstorm is highly heterogeneous in type, size, and concentration, and the growth history of any category of hydrometeors is complicated. The production of raindrops is not simply due to collision and coalescence of cloud drops, but can come from the melting of large snowflakes, graupel, and hail. Nevertheless, the idea that large particles can only be grown in a cloud with large updraft stands.

Fig. 11.2 The change in drop diameter with height for a range of vertical air velocities: (1) 200 cm s$^{-1}$; (2) 100 cm s$^{-1}$; (3) 50 cm s$^{-1}$; (4) 20 cm s$^{-1}$; and (5) 10 cm s$^{-1}$.

$w_0 = 2$ m/s, $w_1 = 1$ m/s, $w_2 = 0.5$ m/s, $w_3 = 0.2$ m/s, $w_4 = 0.1$ m/s.
Stochastic collection equation (11.8)

\[ \Gamma_c = 10 \mu m \quad \text{var} \sigma = 1 \]

\[ \Gamma_i = 12 \mu m \quad \text{var} \sigma = 1 \]

\[ \Gamma_i = 18 \mu m \]

+ activation of new cloud droplets will replenish small drops

Fig. 11.8 Time evolution of drop size spectra with various initial properties: (a) initial mean radius \( r_0 = 10 \mu m \) and relative dispersion \( \sigma = 1 \); (b) \( r_0 = 14 \mu m \), \( \sigma = 0.25 \); (c) \( r_0 = 12 \mu m \), \( \sigma = 1 \); (d) \( r_0 = 14 \mu m \), \( \sigma = 1 \); (e) \( r_0 = 18 \mu m \), \( \sigma = 0.25 \); and (f) \( r_0 = 18 \mu m \). Adapted from Berry and Rheinhardt (1974).
Impact of giant CCN (11.10)

Ultra giant CCN > 10 µm

CASE II,
9775^0.96

Number of Drops [l^{-1} (0.1 mm)^{-1}]

Radius [mm]

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Droplet populations
Drop break-up (Figures 11.11 and 11.12)

1. LWC = 8.539 gm⁻³, R = 207.5 mm/hr.
2. LWC = 5.572 gm⁻³, R = 134.5 mm/hr.
3. LWC = 3.471 gm⁻³, R = 81.5 mm/hr.
4. LWC = 1.766 gm⁻³, R = 41.0 mm/hr.

Fig. 11.11 Four equilibrium distributions, for rainfall rate $R = 41.0, 81.5, 134.5, \text{and} 207.5 \text{ mm h}^{-1}$, and their MP counterparts for the same liquid water contents. Adapted from Valdez and Young (1985).

Fig. 11.12 Drop spectrum at $t = 12 \text{ min}$ through evolution from an initial MP distribution due to coalescence and disk breakup (dotted curve), coalescence, disk and sheet breakup (dashed curve) and coalescence and all three types of breakup (solid curve). Adapted from Brown (1988).
Muddiest points

- Add-on
- Ice-ice collisions
- Continuous growth model
- Stochastic growth model
- Giant CCN
- Break-up
- Summary
Take home messages

- Drop break-up creates small rain drops, but it is unclear if they are visible as distinct size modes or not.
- Break-up occurs if Ecoal is small.
- Warm-rain processes seldomly lead to large amounts of precipitation, rather they form drizzle in stratiform clouds.

In convective clouds:
- Higher w
- More turbulence
- Higher chance for growth of collisions

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