Lecture Ch. 8b

- Precipitation Processes

Curry and Webster, Ch. 8
For Tuesday: Ch. 12

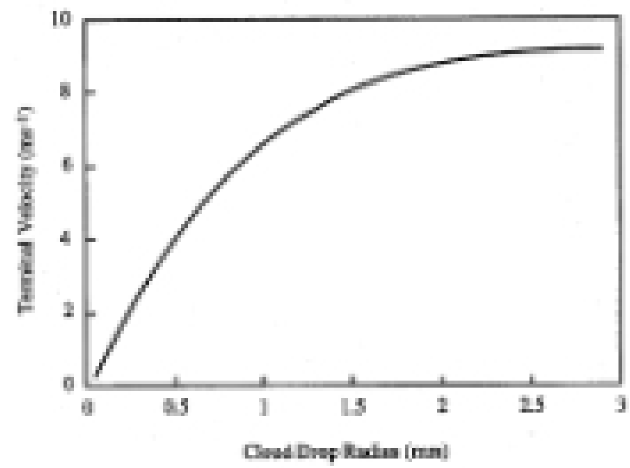


Figure 8.2 Terminal velocity of cloud drops as a function of drop radius. (Data from Gunn and Kinzer, 1949.)

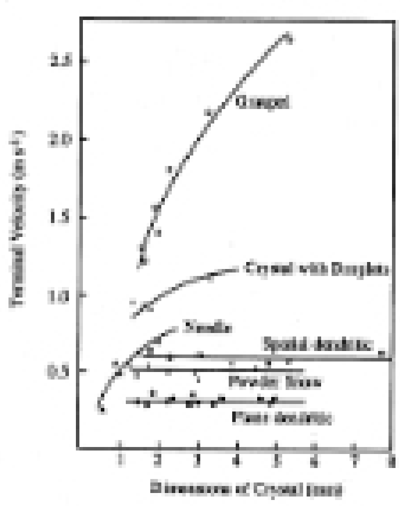


Figure 8.3 Observed terminal velocities of ice particles as a function of crystal type and size. (From Nakaya, 1942.)

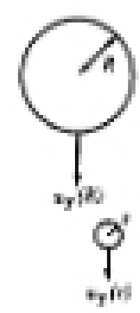


Figure 8.4 Collision geometry for a collector drop of radius R falling with speed $u_T(R)$ through a population of smaller drops of radius r, falling with a speed $u_T(r)$.

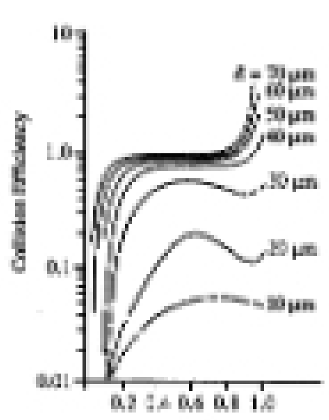


Figure 8.5 Collision efficiencies for collector drops of radius R and drops of radius r. (From Klett and Davis, 1973.)

Drop Growth and Size

- Bigger particles (~25 micron) grow faster

Since collection efficiency increases with the radius of the collecting drop, and the terminal velocity increases with radius, rate of growth by collection proceeds more and more rapidly as drop size increases. Figure 8.6 compares the condensational

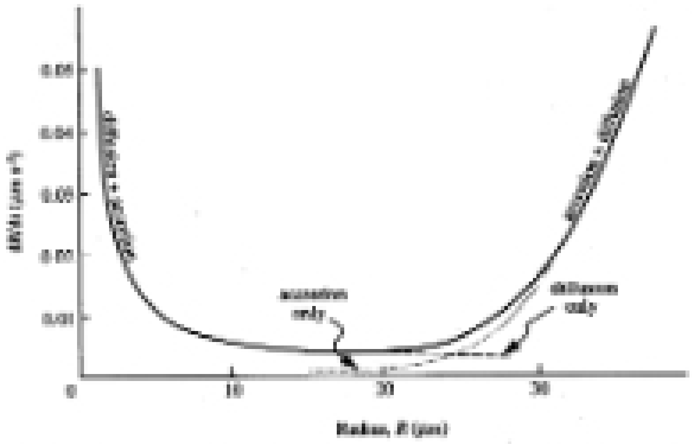


Figure 8.6 Drop growth rate by condensation and accretion. The dashed line represents growth by diffusion only, and the dotted line represents growth by accretion only, while the solid curve represents the combined growth rate. Condensational growth rate decreases with increasing radius, while accretional growth rate increases with increasing radius.

Precipitation and Drop Size

- Terminal velocity increases with drop size
- Precipitation occurs when
  - terminal velocity exceeds updraft velocity

with units mass of liquid water per mass of dry air. For a particle to reach a size large enough to precipitate out of the cloud, its terminal velocity v_T must exceed the updraft velocity within the cloud.

Precipitation and Cloud Type

- Precipitation depends on
  - Condensed water (water and temperature)
  - Updraft velocity (dynamics)
  - Temperature (cold or warm processes)
  - Drop size (aerosol effects)

Not all clouds form precipitation-size particles. Precipitation formation is favored in clouds with a large condensed water content (typically arising from adiabatic cooling) and broad drop spectra. The dynamics of cloud motions therefore play an important role in determining whether or not a cloud precipitates. Cumuliform clouds are favored for precipitation development, because of strong updraft velocities that produce a substantial amount of condensed water. Low-level stratiform clouds rarely produce more than drizzle, since they rarely have a large amount of condensed water or the cold temperatures needed to initiate ice crystal processes.

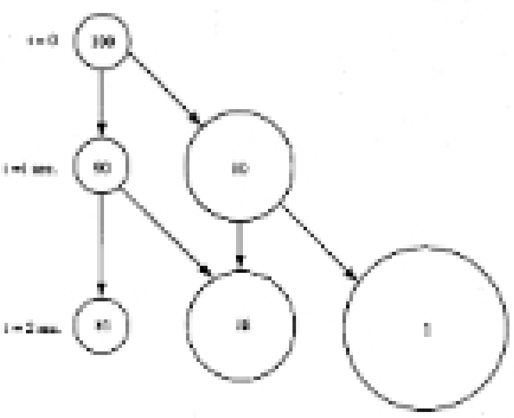


Figure 8.7 Illustration of stochastic collection model. [illegible]

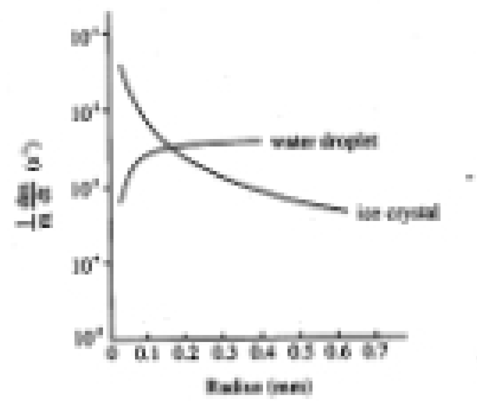


Figure 8.8 Growth rates for ice crystals and water drop. Initially, the ice growth rate exceeds the water drop growth rate. However, once the water drop grows to a sufficient size, its collection efficiency is no longer small, and its growth rate increases rapidly. (From Rogers, 1976.)

Liquid Water Path

which gives the rate of condensation at level z. The *liquid water path*, W_l, is defined as the vertical integral of the liquid water mixing ratio:

$$W_l = \int_{z_b}^{z_t} \rho_a w_l \, dz \qquad (8.6)$$

with units kg m^{-2}. If all of the adiabatic liquid water were to fall out of the cloud, the depth of the adiabatic precipitation, P, would be

Precipitation Efficiency

with units kg m^{-2}. If all of the adiabatic liquid water were to fall out of the cloud, the depth of the adiabatic precipitation, P_{ad}, would be

$$P_{ad} = \frac{\mathcal{W}_l}{\rho_l} \qquad (8.7)$$

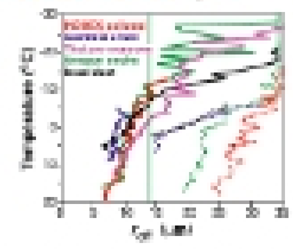
where $\mathcal{W}_l$ here is the adiabatic liquid water path. Taking the time derivative of (8.7) and incorporating (8.5) and (8.6) gives

$$\dot{P}_{ad} = \frac{\rho_a}{\rho_l}\int_{z_b}^{z_t} \frac{dw_l}{dt}\, dz = \frac{\rho_a}{\rho_l}\int_{z_b}^{z_t} \frac{c_p}{L_v}\left(\Gamma_d - \Gamma_s\right) u_z\, dz$$

where $\dot{P}_{ad}$ is therefore the *adiabatic precipitation rate* in units m s^{-1}. A *precipitation efficiency* can then be defined as the ratio of the actual precipitation rate to the adiabatic precipitation rate. Even in cumulonimbus, precipitation efficiency typically does not exceed 0.1.

Current Research: Cloud Drops

- Additional particles also reduce droplet size
  - Slowing growth to precipitation-size droplets



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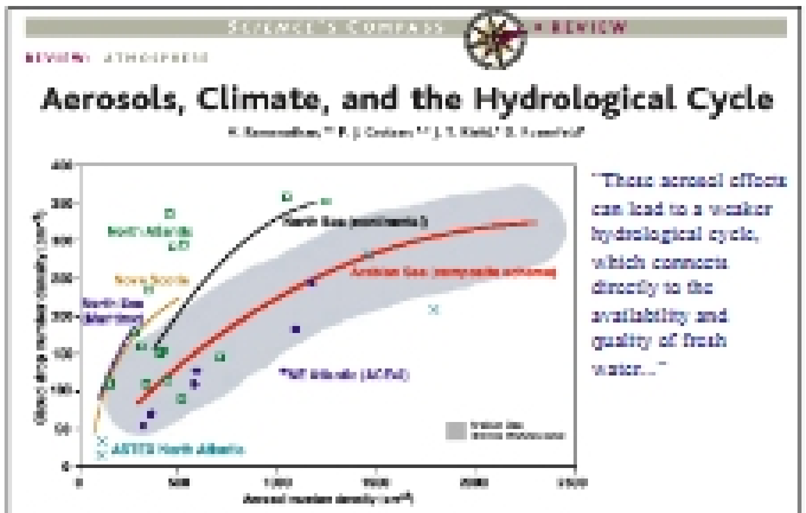
Ramanathan et al., 2001



"These aerosol effects can lead to a weaker hydrological cycle, which connects directly to the availability and quality of fresh water..."

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