Lecture Ch. 8a

- Cloud Classification
- Precipitation Processes

Curry and Webster, Ch. 8
Please complete online evaluations!

Cloud Classification

Clouds are also distinguished by the heights above ground level at which they form:

1) High clouds whose bases are higher than 6 km in the tropics and 3 km in the polar regions (prefix: cirro);
2) middle clouds whose bases lie between 2 and 8 km in the tropics and 2 and 4 km in the polar regions (prefix: alto);
3) low clouds whose bases lie below 2 km;
4) clouds of vertical development.

The prefix nimbo or the suffix nimbus indicates the presence of rain.

Cloud classification is based on ten main cloud...
10 main cloud types

1. Cirrus (Ci)
2. Cirrocumulus (Cc)
3. Cirrostratus (Cs)
4. Altocumulus (Ac)
5. Altostratus (As)
6. Nimbostratus (Ns)
7. Stratocumulus (Sc)
8. Stratus (St)
9. Cumulus (Cu)
10. Cumulonimbus (Cb)

All high clouds

Middle clouds
Grayish, block the sun, sometimes patchy

Sharp outlines, rising mounds, bright white

Cumulus Clouds

Swelling Cumulus
Active heaped-up cloud with flat bottom and growing cauliflower top.
[http://www.fox8wghp.com/spacious.htm]

Types of cumulus

- Fair weather cumulus
  - Horizontal/vertical scale = 1 km
  - No precipitation
- Towering cumulus
  - Horizontal/vertical scale = several km
  - Frequently precipitate
- Cumulonimbus
  - Vertical extension to tropopause with anvil tops
  - Width = 30s of km
  - Heavy precip, lightning, thunder, hail
- Mesoscale convective complex
  - Aggregation of cumulonimbus (100s of km)
  - Large amount of rain
  - Can develop circulation pattern

Cumulonimbus Clouds
Massive cloud system producing heavy showers, sometimes with hail. Most active clouds may have lightning and thunder. A few spawn tornadoes.
[http://www.fox8wghp.com/spacious.htm]

Stratus Clouds
Low lying layer of cloud (called fog if on the ground) with no structure.
[http://www.fox8wghp.com/spacious.htm]
Cirrus Clouds

Cirrus
An ice crystal cloud, wispy in appearance. May produce ice crystal snow in winter or in mountains.
[http://www.fox8wghp.com/spacious.htm]

Altostratus Clouds

Altostratus
Thickly layered water droplet cloud. Sun seen as through ground glass.
[http://www.fox8wghp.com/spacious.htm]

Nimbostratus Clouds

Nimbostratus
Thick layered cloud - usually dark gray. Produces continuous rain or snow over large area.
[http://www.fox8wghp.com/spacious.htm]

Fog

Fog is not included as a genus in this cloud classification scheme. Fog is composed of very small water drops (sometimes ice crystals) in suspension in the atmosphere and it reduces the visibility at the surface to less than 1 km. It will be shown in Section 8.1 that fog may be considered as a stratus cloud whose base is low enough to reach the ground.

Global Cloud Distribution
Zonally averaged climatology of cloud type

Cloud Types and Drop Sizes

• Frequency distributions of the mean cloud droplet size for various cloud types
Decoupling of Stratocumulus-Topped Boundary Layer

Drizzle forms, net warming

Drizzle evaporates, net cooling

Figure 8.2g Idealized boundary-layer profiles of total water content and equivalent potential temperature. In (b), the cloud and subcloud layers are decoupled from the surface mixed layer by a stable intermediate layer. Decoupling may occur for a number of reasons, including the fallout of drizzle from the upper cloud layer, and its subsequent evaporation in the subcloud layer, a decrease in surface buoyancy fluxes; sensible heating; and entrainment of warmer, drier air. (After Turton and Nicholls, 1987.)

Precipitation Processes

- Warm clouds
  - liquid water droplets only
- Cold clouds
  - ice particles
- Collision/coalescence (accretional growth)
  - Water drop + water drop
  - Ice crystal + water drop
  - Ice crystal + ice crystal

Small, spherical drop

$$v_s = \frac{1}{2} \frac{\rho g r^2}{\rho_d}$$

with \(k_s = 1.19 \times 10^6 \text{ cm}^3 \text{ s}^{-1}\). This quadratic dependence of fall speed on size for drops with \(r < 30 \mu \text{m}\) is called Stokes' law. Stokes' law does not hold for larger particles, since the shape of larger drops is different as they fall and the frictional force becomes more complex. Experiments with falling drops have provided the following approximations for larger drops to be

Larger, spherical drop

$$v_L = k_L r$$

with \(k_L = 8 \times 10^4 \text{ cm}^3 \text{ s}^{-1}\). This equation is valid for particles in the size range \(40 \mu \text{m} < r < 0.6 \text{ mm}\). For the largest category of particles, \(0.6 \text{ mm} < r < 2 \text{ mm}\), we have

Largest, spherical drop

$$v_L = k_{LL} r$$

where \(k_{LL} = 2.01 \times 10^7 \left(\frac{\rho_d}{\rho_0}\right)^{1/2} \text{ cm}^3 \text{ s}^{-1}\) and \(\rho_0\) is a reference density of 1.2 kg m\(^{-3}\).

Collection Efficiency \(E\) is the probability that a collision AND coalescence event will occur.

Larger drops are faster so they collide with the smaller drops in their way.

Whether or not the two particles stick is determined by the collection efficiency.
Drop Growth and Size

- Bigger particles (~25 micron) grow faster

Precipitation and Drop Size

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

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 spectra. The dynamics of cloud motions therefore play an important role in determining whether or not a cloud precipitates. Convection-like 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.
Diffusion of water onto ice in water-saturated environment

Collision/coalescence is faster for larger droplets

Slow growth by collision/coalescence

Aggregation is slower

Liquid Water Path

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

\[ Ψ_l = \int_0^z \rho_l w_l \, dz \]

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, \( P_{\text{ad}} \), would be

Precipitation Efficiency

with units kg m⁻³. If all of the adiabatic liquid water were to fall out of the cloud, the depth of the adiabatic precipitation, \( P_{\text{ad}} \), would be

Depth of precip

\[ P_{\text{m}} = \frac{Ψ_l}{\rho_l} \]

(6.7)

where \( Ψ_l \) is the adiabatic liquid water path. Taking the time derivative of (6.7) and incorporating (6.3) and (6.6) gives

Adiabatic precipitation rate

\[ P_{\text{ad}} = \frac{ρ}{ρ_l} \int_0^z \left( \frac{dρ}{dt} \right) \, dz = \frac{ρ}{ρ_l} \left. \left( \frac{C_p}{C_p - C_v} \right) \frac{dT}{dz} \right|_{T_0} 

\]

where \( P_{\text{ad}} \) is therefore the adiabatic precipitation rate in units of 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 condensation, precipitation efficiency typically does not exceed 0.2.