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.

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

Low clouds

Sharp outlines, rising, bright white

Swelling Cumulus

Active heaped-up cloud with flat bottom and growing cauliflower top.

Figure 8.21 Typical temperature profiles in a convective environment. The solid profile represents the environmental temperature; the dashed profile corresponds to the temperature within the cloud. The cloud base forms near the lifting condensation level, \( z_c \). Near the cloud base, the temperature increases more rapidly with height in the cloud than in the surroundings, resulting in a relatively large temperature difference between the environmental temperature and the cloud interior temperature. A cloud that reaches the level of free convection (LFC) will accelerate upwards until it reaches the level of neutral buoyancy (LNB), where the environmental temperature is equal to the interior cloud temperature.
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 = 10s of km
  - Heavy precip, lightning, thunder, hail
- Mesoscale convective complex
  - Aggregation of cumulonimbus (10s of km)
  - Large amount of rain
  - Can develop circulation pattern

Cumulonimbus Clouds

Cumulonimbus
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

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

If you are in Cape Town when the Southeaster blows (usually in the summer of the southern hemisphere), you will see a layer of cloud just covering the top of Table Mountain. This is the "tablecloth."
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 8.4 that fog may be considered as a stratus cloud whose base is low enough to reach the ground. [http://www.tqnyc.org/2009/00767/fog.jpg]

Global Cloud Distribution

Zonally averaged climatology of cloud type

Adiabatic cloud thickness of stratiform boundary layer clouds

PBL Clouds are thin!
Cloud Types and Drop Sizes

- Frequency distributions of the mean cloud droplet size for various cloud types

What Determines Drop Size?

Nucleation/Activation +

- Köhler curve
  - Particle dry size
  - Particle soluble components
- Condensational growth from water
  - Latent heating
  - Available water

Condensation +

- Condensational growth from additional water
  - More cooling
  - More water vapor
- Collision of droplets and their coalescence
  - Distribution of big/small drops

Taller and longer-lived clouds get bigger drops

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.

Figure 8.8: Growth rates for ice crystals and water drop. Initially, the ice growth rate exceeds the water drop growth rate. However, since the water drop grows to a sufficient size, its collection efficiency is no longer small, and its growth rate decreases rapidly. (From Rogers, 1978.)
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 conditional growth and size.

Whether or not the two particles stick is determined by the collection efficiency $E$. Collection Efficiency $E$ is the probability that a collision AND coalescence event will occur.

Stochastic collection model: based on probability

Flow field around large particle will move smaller particle, lower $E$.

Inertia of collected drop increases, higher $E$.

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

$r/R = 0.2$

$r/R = 1$

Larger than 3 mm, drops break up due to aerodynamic forces.

Small, spherical drop $w_g = \frac{4}{3}\pi r^3$

with $w_g = 1.19 \times 10^5 \text{ cm}^2 \text{ s}^{-1}$. This quadratic dependence of fall speed on size for drops with $r < 50 \mu\text{m}$ is called Stokes' law. Stokes' law does not hold for larger particles, since the shape of larger drops is deformed 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 $w_g = \frac{4}{3}\pi r^3$.

where $w_g = 8 \times 10^6 \text{ cm}^2 \text{ s}^{-1}$. 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 $w_g = \frac{4}{3}\pi r^3$.

where $w_g = 2.01 \times 10^7 \text{ cm}^2 \text{ s}^{-1}$. Figure 8.2 shows the terminal velocity of cloud drops as a function of drop radius. (Data from Gans and Kinzer, 1949.)
What is the difference between “rain” and “drizzle”?

Isn’t it just that you say “po-tay-to”
I say “po-tah-to”?
No! It’s far more scientific than that!

Precipitation and Drop Size

- Terminal velocity increases with drop size
- Precipitation occurs when
  - terminal velocity exceeds updraft velocity
    - "Drizzle" occurs in stratus where 50 μm drops fall faster than 0.1-1 m/s updrafts
    - "Rain" occurs in cumulus (inter alia) when 1 mm drops fall faster than 1-10 m/s updrafts

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

Precipitation and Cloud Type

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

Drizzle evaporates, net cooling
Drizzle forms, net warming

Decoupling of Stratocumulus-Topped Boundary Layer

Figure 8.20 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; solar heating; and entrainment of warmer, drier air. (After Turton and Nicholls, 1987.)
Observations:
Varying cloudy structure

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:

$$W_L = \int q(z) dz$$

(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 circulation, $P$, would be...