Lecture Ch. 8a

- Review of Ch.7 Concepts
  - Homework Ch. 7, Prob. 3
- Cloud Classification
- Precipitation Processes

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

Atmospheric Structure

- Structure of the atmosphere
  - Decreasing temperature with altitude
  - Decreasing pressure with altitude
  - Changes in water vapor with altitude
- Temperatures in meteorology
  - Potential temperature (meteorologists' entropy)
  - Virtual (potential) temperature
  - Equivalent (potential) temperature

- Describing the atmospheric structure
  - *Example: Skew-T log P plot*
  - *Example: Tephigram*

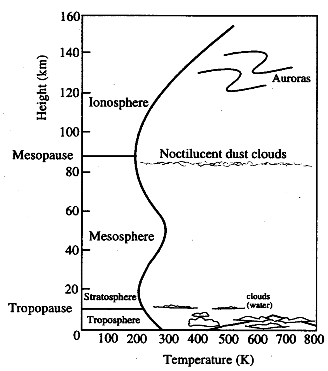


Figure 14.1 Vertical structure and features of Earth's atmosphere.

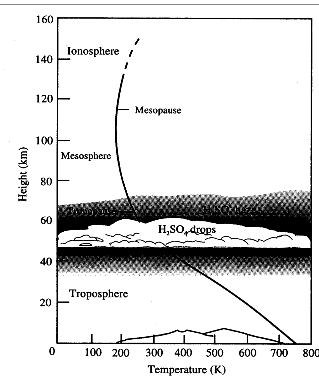


Figure 14.2 Vertical structure and features of Venus's atmosphere.

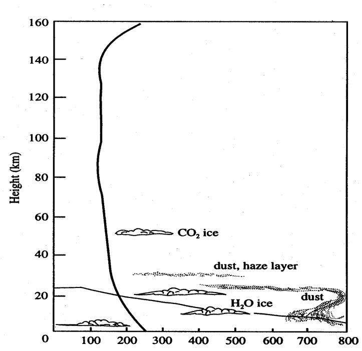


Figure 14.3 Vertical structure and features of the Martian atmosphere.

Inversions

- Inversion: A condition of strong stability characterized by a positive temperature gradient.

Subsidence Inversions

- Subsidence Inversion
  - Cause: adiabatic compression and warming of a large layer of earth as it sinks to lower altitude.
    - $dT/dP = 1/(C_p\,\rho)$, where C_p is essentially constant over T.

Radiation Inversions

- Radiation Inversion

  Cause:
    - radiation of heat by the ground at night
    - air adjacent to the the surface has a T < layer at higher elevations

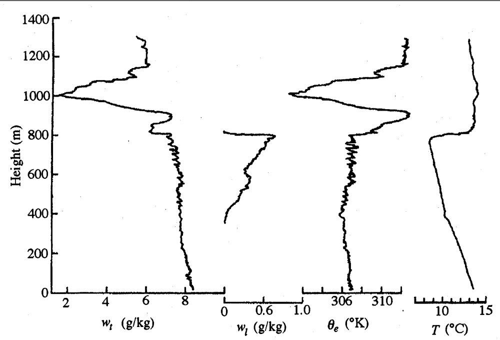


Figure 8.19 Vertical structure of a stratocumulus cloud deck observed over the North Sea (55°N). Over the depth of the boundary layer, the total water mixing ratio and the potential temperature are nearly constant, indicating a well-mixed layer. The cloud base is at about 400 m. (After Nicholls, 1984.)

Water Vapor in the Atmosphere

- the Earth's surface is the primary source of water vapor for the atmosphere
- the amount of water vapor in the atmosphere depends on
  - (1) the amount which enters the atmosphere through evaporation and sublimation,
  - (2) its transport by motions of various scales throughout the troposphere and the lower stratosphere,
  - (3) the amount which leaves the atmosphere intermittently as rain, hail and snow
- $w_{v,sat}$, the amount of water vapor in air at saturation on a mass-per-mass basis, decreases with decreasing temperature
  - the amount of water in an air parcel consequently decreases with altitude, reaching a minimum in the lower stratosphere a few kilometers above the tropopause
  - stratosphere has very low water content
- clouds and fogs form by cooling of moist air
  - cloud formation is driven by the rise of moist air due to thermally-driven updrafts, which result in simultaneous cooling and expansion; in many cases this expansion is close to adiabatic
  - fog formation and some stratus cloud formation can occur by isobaric cooling, caused by surface cooling
  - after a sufficient amount of cooling $w_v = w_{v,sat}$ and a liquid condensate is formed; this process occurs when the dew-point temperature (T_d) is reached

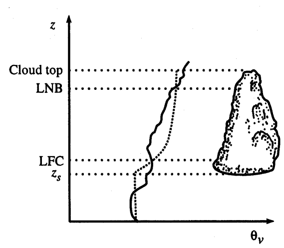
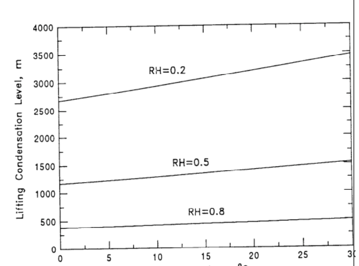


Figure 8.21 Typical temperature profiles in a convective environment. The solid profile represents the environmental temperature; the dashed profile corresponds to the temperature within the cloud. The cloud base forms near the lifting condensation level, z_s. Near the cloud base, the temperature increases 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.

10.1

Lifting Condensation Level

- Lifting condensation level varies with initial relative humidity and is a weak function of initial temperature



Seinfeld and Pandis, Fig. 15.11

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.
... the cloud classification is based on ten main cloud

10.2

Cumulus Clouds

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

10.2

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]

10.2

Stratus Clouds

Stratus
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

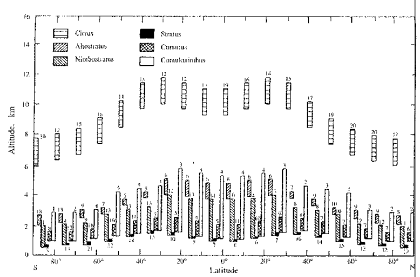
Thick layered cloud - usually dark gray. Produces continuous rain or snow over large area. [http://www.fox8wghp.com/spacious.htm]

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 8.4 that fog may be considered as a stratus cloud whose base is low enough to reach the ground.

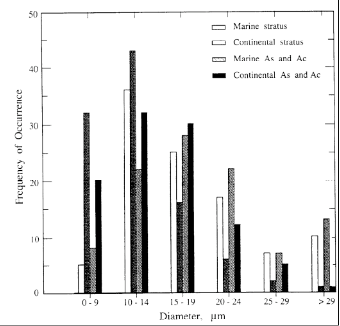
Global Cloud Distribution

- Zonally averaged climatology of cloud type



Cloud Types and Drop Sizes

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



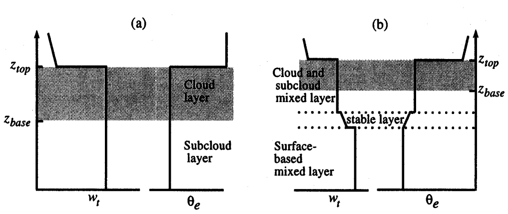


Figure 8.20 Idealized boundary-layer profiles of total water content and equivalent potential temperature. In (b), the cloud and subcloud layers are decoupled from the surface mixed layer by a stable intermediate layer. Decoupling may occur for a number of reasons, including the fallout of drizzle from 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.)

Precipitation Processes

- Warm clouds (liquid water droplets only)
- Cold clouds (ice particles)

tween a cloud particle and the earth is balanced by the frictional force of the particle as it falls through the air, the speed at which the particle is falling is called the *terminal velocity*. For a small spherical liquid drop,[1] we may approximate the terminal velocity, u_T, as

$$u_T = k_1 r^2 \tag{8.1a}$$

with $k_1 = 1.19 \times 10^6\ \mathrm{cm^{-1}\ s^{-1}}$. This quadratic dependence of fall speed on size for drops with $r < 30\ \mu\mathrm{m}$ 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

$$u_T = k_2 r \tag{8.1b}$$

with $k_2 = 8 \times 10^3\ \mathrm{s^{-1}}$. This equation is valid for particles in the size range $40\ \mu\mathrm{m} < r < 0.6\ \mathrm{mm}$. For the largest category of particles, $0.6\ \mathrm{mm} < r < 2\ \mathrm{mm}$, we have

$$u_T = k_3 r^{1/2} \tag{8.1c}$$

where $k_3 = 2.01 \times 10^3 (\rho_o/\rho_a)^{1/2}\ \mathrm{cm^{1/2}\ s^{-1}}$ and ρ_o is a reference density of $1.2\ \mathrm{kg\ m^{-3}}$.