Wallace and Hobbs. *Atmospheric Science.* Academic Press, 1977.

- Atmospheric pressure and density decrease approximately exponentially with height up to ~ 100 km

$$p(z) \approx p(0)e^{-z/H}, \rho(z) \approx \rho(0)e^{-z/H}, H \approx 7 \text{ km}$$

H is "scale height"

$\frac{1}{2}$ mass below 500 mb ($5\frac{1}{2}$ km)
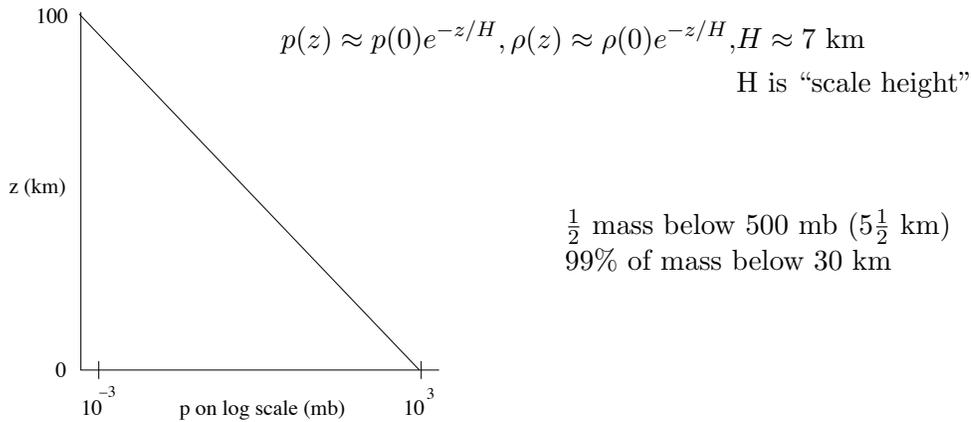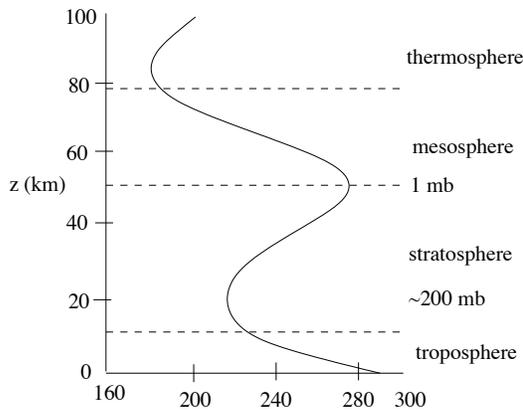99% of mass below 30 km

Figure 1.

Figure 2.

- Troposphere (all the weather, clouds, precipitation), scavenging, aerosols

- Strong change in atmospheric composition across tropopause (very low water vapor, high ozone, etc.), reduced vertical mixing in stratosphere and between stratosphere and troposphere and no rainout of material (trap nuclear fallout and volcanic aerosols out for years), region of ozone heating.

- Mesosphere - region of mixing

- Planetary motions - broadest, scale of continents and oceans
- Synoptic scale - waves and eddies - $\mathcal{O}(10^3 - 10^4)$ km
- Mesoscale - smaller, 10's to a few 100's of km (e.g. squall lines)
- Mostly horizontal winds (through with convection)

- Geostrophic relation - winds blow parallel to isobars

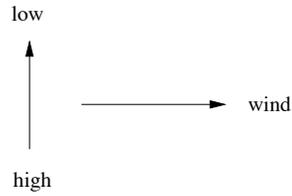- Prevailing winds at mid to high latitudes from west

Figure 3.

- Pressure, coriolis, friction

  - Atmospheric winds reflect balance of pressure gradients (due to differential warming/cooling), the Coriolis force (effective force due to Earth's rotation), and surface friction. Coriolis force turns winds in Northern Hemisphere to the right (opposite in Southern Hemisphere)
  - 500 mb height fields - ridges on west coast; troughs on east coast low in poles, high in tropics
  - Surface highs and lows set up following circulation-
    · high - clockwise in N hemisphere
    · lows - Icelandic/Aleutian lows - storm tracks
  - Monsoons - seasonal variation associated with land warming low pressure in summer
  - Tropical winds
  - Easterly flow/trades; easterly waves and tropical cyclones
  - ITCZ; intertropical convergence zone upward motion

- Some simple dynamics

  - Hydrostatics

$$-dp = g\rho dz$$
$$\frac{dp}{dz} = -g\rho$$

  - Radiative transfer
    · Sun E (irradiance) $\sim 6.34 \times 10^7$ W/m^2 at sun's surface, and 1.38×10^3 W/m^2 at Earth's radius
    · Blackbody radiation - maximum absorbance and emission; isotropic
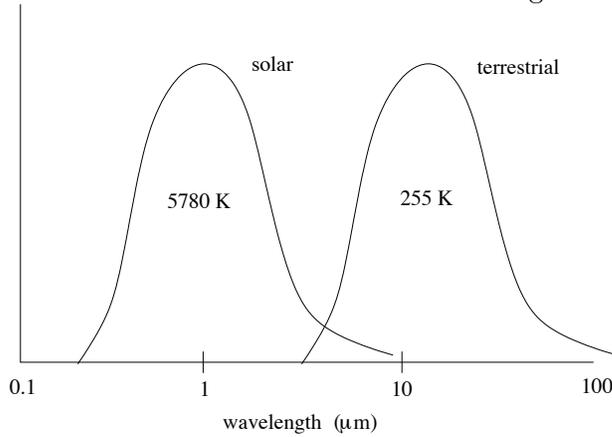   · Planck's Law
$$E_\lambda^* \approx c_1 \lambda^{-5} e^{-c_2/\lambda T}$$

    (where T is absolute)
    This gives irradiance as a function of wavelength, with

$$c_1 = 3.74 \times 10^{-16} \text{ W m}^2, c_2 = 1.44 \times 10^{-2} \text{ m K}$$

Figure 4.

$E^* = \sigma T^4$ - Stefan - Boltzmann Law (constant) $\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}

Energy balance figure - solar; longwave, latent, sensible, scattering

Physics of Climate. J. P. Peixoto and A. H. Oort. American Institute of Physics, 1992, 520 pp.

- Mean state of the atmosphere

  - Small vertical/horizontal ratio
  - Flow primarily horizontal and geostrophic (pressure balanced by Coriolis), flow parallel to isobars
  - Friction lends to ageostrophic flow (out of high pressure zone → low pressure zone)

  Vertical velocity: upward velocities near ITCZ downwelling in subtropics

- Stronger winter hemisphere Hadley (tropical) and Ferrel (mid-latitude) circulation cells.

  - Hadley cell is north-south circulation consisting of upwelling at ITCZ and downwelling in subtropics; return flow at surface turned by circulation setting up easterly trades.
  - Ferrel cells - compensating for large plantary waves - Ferrel cells artifact of averaging as rotation increases, go from single cell to multiple cells (e.g. Jupiter)

  Much of the transport is eddy driven

  Salinity difference between ocean basins; Atlantic is saltier than Pacific; must be maintained by net transport of water vapor out of Atlantic catchment basin (ocean and surrounding land mass draining into Atlantic).

  A. Gill. 1982 *Atmosphere-Ocean Dyanmics.*

  Radius of Earth $R \sim 6371$ km

  $S = 1368$ W m^{-2}, $0.2 - 4\,\mu$m solar radiation band

  $\pi R^2 S$ - total energy received from the sun

  Surface area is $4\pi R^2 \Rightarrow$ average energy is $\frac{1}{4}S = 344$ W m^{-2}

  Albedo $\alpha \sim 0.3$ is reflected back to space (clouds, surface brightness), $\frac{1}{4}(1-\alpha)S = 240$ W m^{-2}

3

ocean albedo lower $(0.15 - 0.3)$, snow much higher

$E = \sigma T^4, \sigma = 5.7 \times 10^{-8}$ W m^{-2} K^{-4}