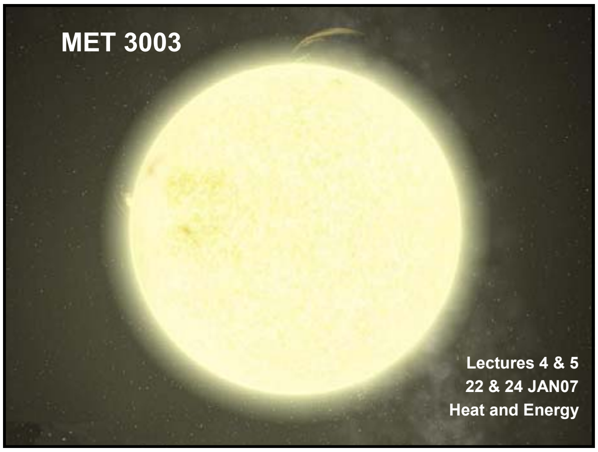
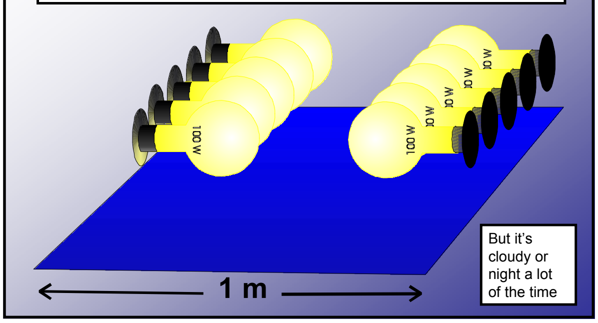


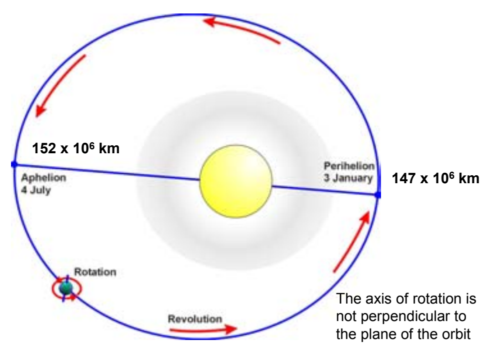
The Sun Makes it all Go

- Burns Hydrogen to Helium
- 4.5 Byr old, halfway through its life cycle
- Mean distance 150 x 10^6 km
- Radius 6.96x10^5 km
- Surface temperature 5785 K (~5800K)
- ***Solar Irradiance*** at the Earth 1366 Watts above the atmosphere
- But about a quarter of it never reaches the Earth's surface

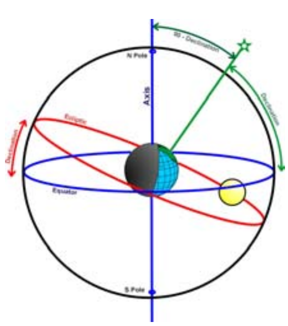
So, at noon on a cloudless day with the sun directly overhead, solar heating is 1000 Watts per square meter



Earth's Orbit

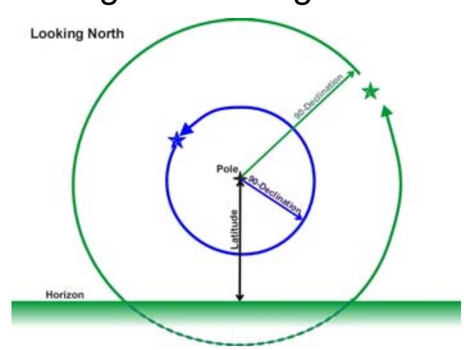


Latitude and Declination

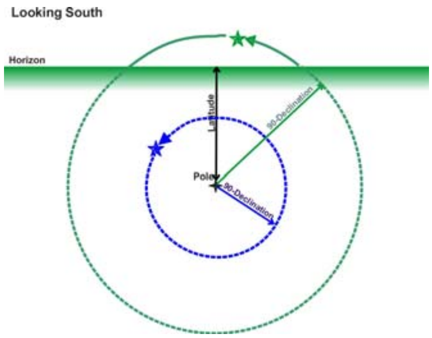


- **Equator:** a circle around the Earth in a plane perpendicular to the axis and passing through the center
- **Latitude:** Angular distance north or south of the Equator *for a place on the surface*
- **Declination** Angular distance north or south of the Equator *for an object in the sky*
- Axis always points in the same direction relative to the stars
- Because the axis is inclined 23½° to the plane of the orbit, the Sun's declination appears to change as the Earth circles it on the ***Ecliptic***
  - North of the equator in NH summer
  - South of the Equator in NH winter

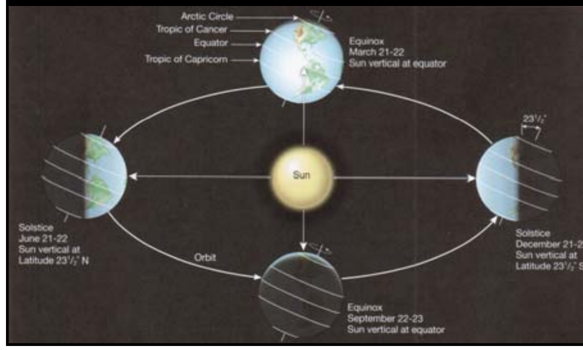
Rising and Setting of Stars



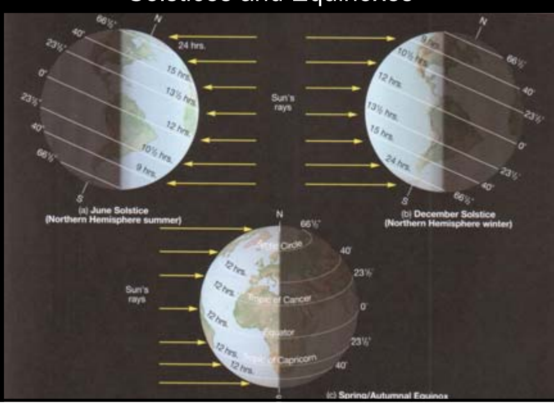
Rising and Setting of Stars



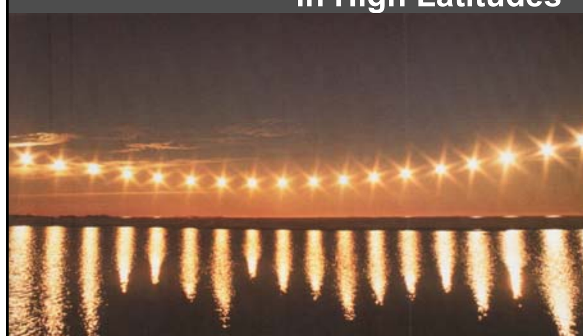
Inclination of the Axis, the Orbit and the Seasons



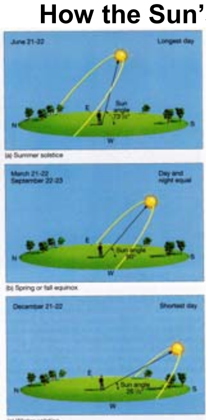
Solstices and Equinoxes



Midnight Sun Circles the Horizon in High Latitudes

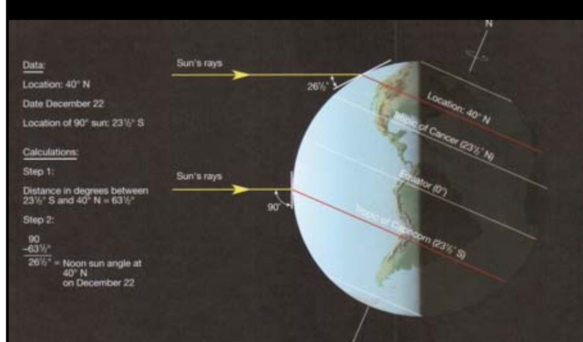


How the Sun's Apparent Motion Causes the Seasons



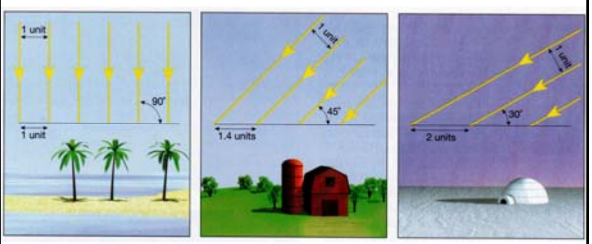
- **Sun angle**: Angle between the center of the solar disk and the horizon. (Called "altitude" in navigation)
- At the (NH) summer ***Solstice***, the Sun is 23½ ° north of the equator, but south of all of the US.
  - Over the ***Tropic of Cancer***
- At the Equinoxes it is over the equator.
- At the (NH) winter ***Solstice***, the Sun is 23½ ° south.
  - Over the ***Tropic of Capricorn***

Calculation of Sun Angle



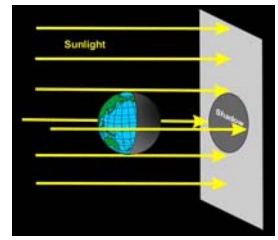
The Effect of the Angle Between the Beam and the Surface

- This is why we need to know the ***Sun Angle***
- When the sun is low in the sky, the same amount of sunlight gets spread over a larger area.
- Thus, there is less heating per unit area, and conversely.

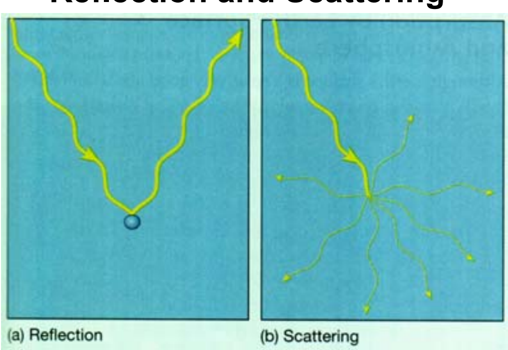


Globally Averaged Solar Constant

- The Earth is approximately a sphere, area = $4\pi r^2$
- It would cast a circular shadow, area = πr^2
- Thus it intercepts energy = $I_{sol} \times \pi r^2$ spread over area $4\pi r^2$
- So that the average value is 1/4 (I_{sol})
- Taking into account night and the effects of latitude, etc.



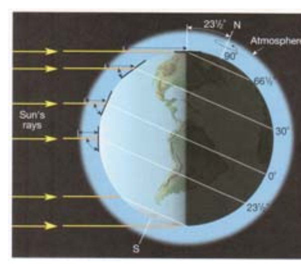
Reflection and Scattering



Air molecules scatter blue light out of the solar beam and let red light pass
That's why the daytime sky is blue and sunsets are red.

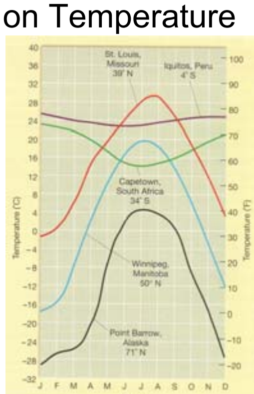
Effect of Optical Path Through the Atmosphere

- In addition to the geometric sun angle effect, passage through the atmosphere is different in high latitudes
- When the sun is low in the sky, sunlight passes through a longer ***Optical Path*** in the Atmosphere



Effect of Latitude on Temperature

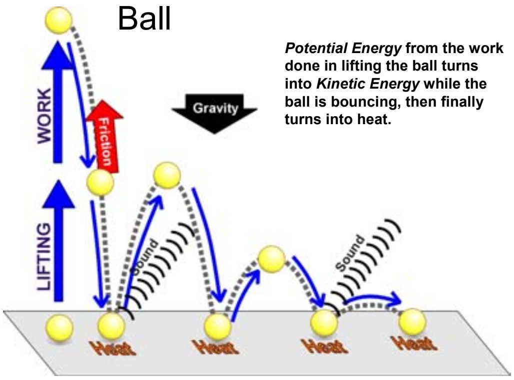
- In summer
  - More-direct sun
  - More-vertical incidence
  - Longer day
  - And oppositely in winter
- Less variation of all of these in low latitudes
- Thus, temperature is both colder and more variable in high latitudes
- As these observations show



Summary (1)

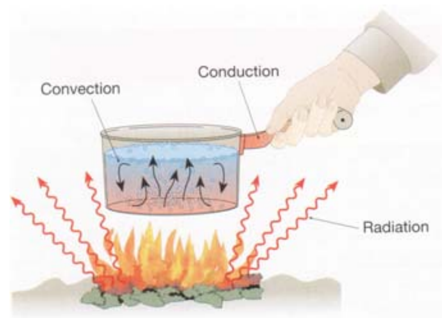
- Know the general characteristics of the Sun. Memorize surface temp & distance
- Know what ***Solar Irradiance*** is and it's value above the atmosphere
- Know the general characteristics of the Earth's orbit
- Be able to define ***Rotation*** and ***Revolution*** as applied to the Earth
- Understand the motion of the Sun throughout the year and of celestial bodies in general each day.
- Be able to define ***Declination***
- Know how the Earth's Axial Tilt (Inclination) produces the seasons
- Be able to define ***Solstice***, ***Equinox***, ***Tropics of Capricorn and Cancer***
- Be able to define and calculate noon ***Sun Angle***
- Know how sun angle effects the amount of solar heating per unit area.
- Know the definitions of ***Scattering*** and ***Reflection***
- Know how ***Optical Path*** changes with sun angle and its effect on solar heating
- Know how both temperature and temperature range vary with latitude and why
- **BE SURE THAT YOU HAVE READ CHAPTER 2.** More from there next time

Remember the Bouncing Ball



Potential Energy **from the work done in lifting the ball turns into** ***Kinetic Energy*** **while the ball is bouncing, then finally turns into heat.**

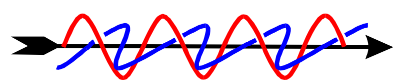
Heat Transfer Mechanisms



Heat Transfer Terminology

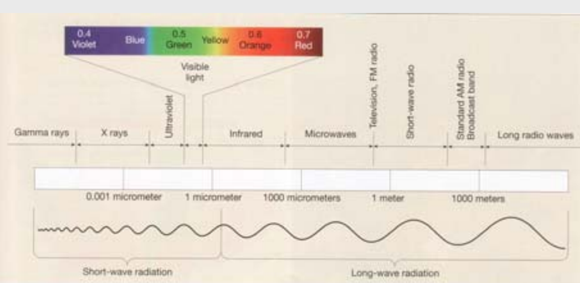
- **Conduction:** Heat diffuses through matter as fast moving molecules bump nearby molecules and set them moving
- **Convection:** Moving fluid carries the heat with it. Motions are generally vertical and primarily caused by buoyancy.
- **Advection:** Moving fluid carries the heat with it. Motions are generally horizontal and caused by horizontal pressure differences.
- **Radiation:** Oscillating coupled electric and magnetic fields propagate energy through space.

Electromagnetic Radiation

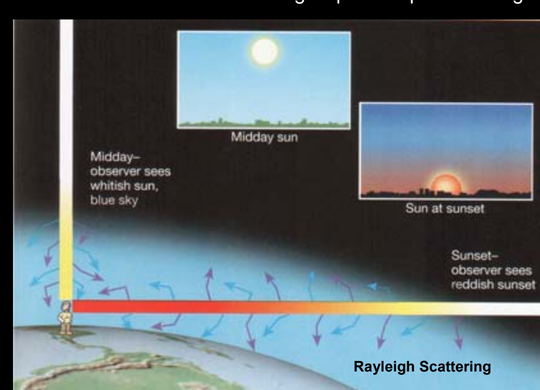


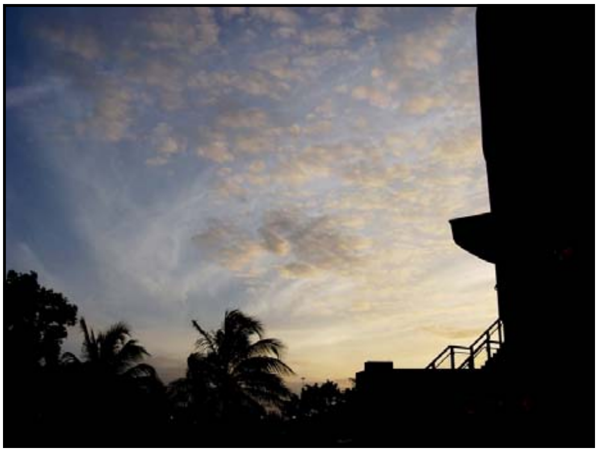
- Perpendicular, coupled, oscillating electric and magnetic fields
- Propagates through space at 300,000 km s^{-1} or 300 m (~ 1000 ft) per μs.
- Described by Maxwell's Equations
- Shorter wavelengths carry more energy

Electromagnetic Spectrum



How the Amount of Scattering Depends Upon Sun Angle

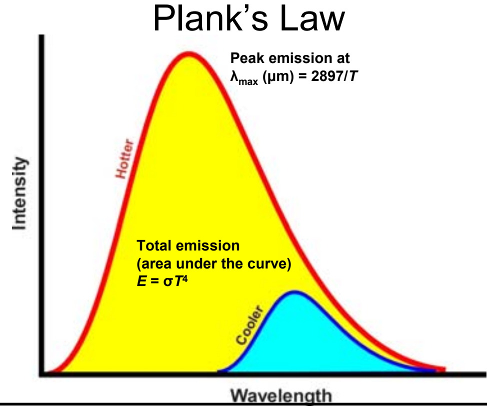




About Radiation

- The wavelength depends upon the temperature of of the emitting object. The colder the object the longer the wavelength of the peak emitted radiation.
- **Wien's Displacement Law:** λ_{max} (μm) = 2897/T
- The total amount of radiation is proportional to the fourth power of the absolute temperature, **Stefan-Bolzman Law**: $E = \sigma T^4$, where $\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}
- This amount of electromagnetic energy crossing a square meter of surface in called **Irradiance**.
- Consider the surface of the Sun at 5785K.
- Peak radiation is 2897/5785= 0.5 μm, light blue color.

Plank's Law



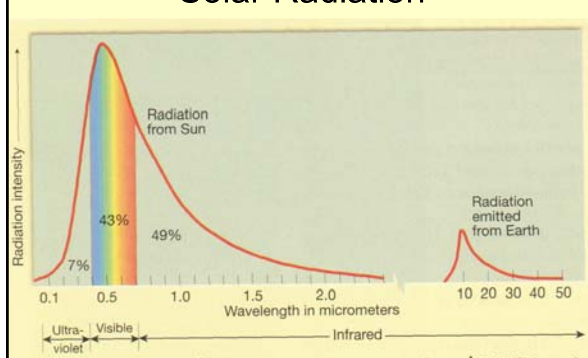
About Radiation, Continued

- The sun looks more white (yellow) because it emits at many other wavelengths.
- Solar radiation reaching the Earth, **solar irradiance** (or solar constant) , is **1385 W m^{-2}** because it spreads geometrically so that most is lost to space.
- Because of atmospheric absorption and reflection, only about **1000 W m^{-3}** reach the surface at **noon in the tropics**
- Because it is night half the time and away from the equator sunlight reaches the surface at an angle, the global average is 250 W m^{-3}.
- The average blackbody IR irradiance at 15°C, the Earth's average temperature is:
  $E = \sigma T^4 = 5.67 \times 10^{-8} \times 288^4 = 5.67 \times 2.88^4 = 390$ W m^{-2}
- Consider the earth at 15°C = 288K, peak radiation = 2897/288 = 10 μm.

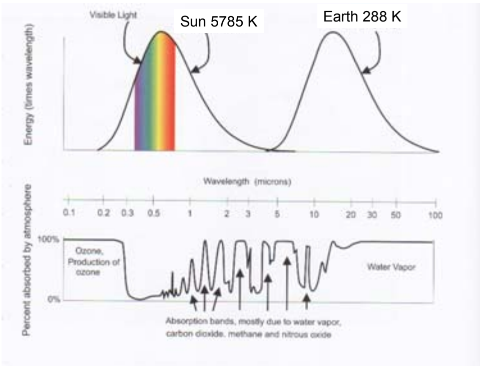
Radiation Laws

- All objects (not at 0 K) both radiate and absorb at all wavelengths.
- An ideal radiator, (as described by S-B, Wien & Plank) is called a **Blackbody**.
- The Sun is almost a black body.
- So are most everyday objects at temperatures where they radiate in the IR
- Non-ideal radiators are called Grey bodies.
- Such substances are called Selective Absorbers.
- Snow---white in the visible and essentially black in the IR--- is another example.
- The ratio of actual emitted radiation to blackbody is ***Emissivity***
- The ratio of actual absorbed radiation to blackbody is ***Absorptivity***
- By Kirchhoff's law they are equal. For Blackbodies they are both 1.
- **Radiative Equilibrium** ---Where absorbed radiation balances emitted radiation.
- For example, the Earth would have a ***Radiative Equilibrium Temperature*** of 255K (or -18°C or 0°F) if it had no atmosphere.
- But the actual surface temperature is 288K (or 15°C or 59°F) because the atmosphere absorbs IR radiation even though it is fairly transparent to solar visible radiation.

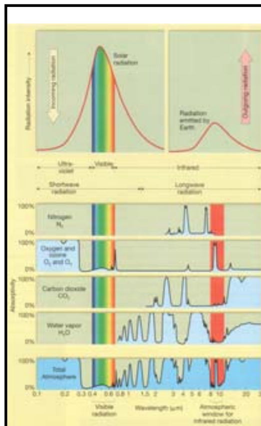
Solar Radiation



Radiation from the Sun and Earth



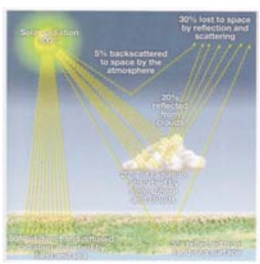
Details of Atmospheric EM Absorption



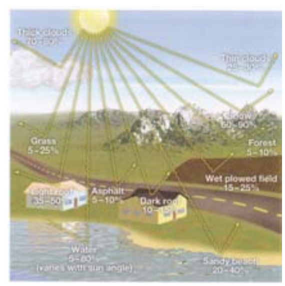
- N_2 absorbs a little in the IT
- O_2 and O_3 absorb in the IR at $\lambda < 0.3$ µm
- H_2O absorbs at various bands in the IR
- CO2 absorbs mostly at λ > 12 µm
- Atmospheric windows:
  - Visible 0.4-0.7 µm
  - Infrared 8-12 µm

Albedo

- Ratio of incident EM radiation to radiation scattered or reflected
- Of 100 units of solar irradiance
  - 5% backscattered
  - 20% reflected by clouds
  - 5% reflected from surface
- For an effective Albedo of 30%
- Absorbed radiation
  - 20% absorbed by atmosphere
  - 50% absorbed by surface

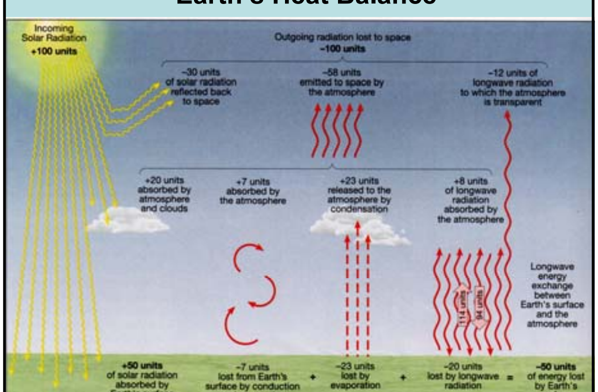


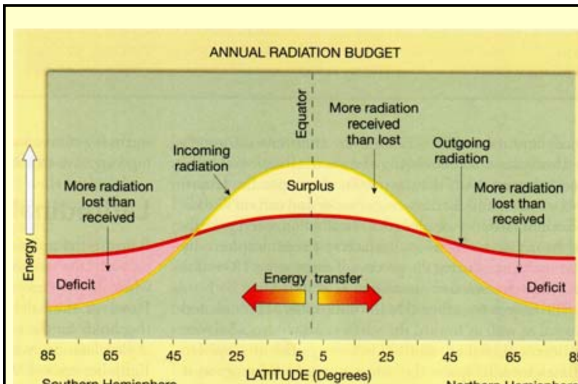
Examples of Surface Albedo



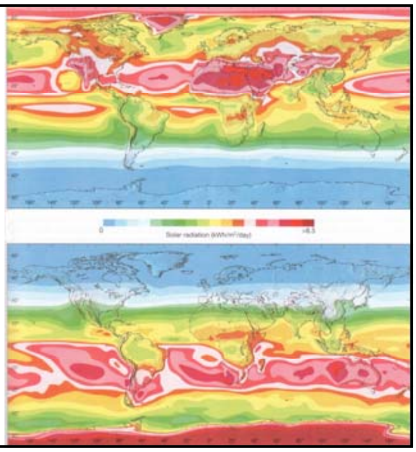
- Albedo is wavelength dependant
- Many durfaces have low (~10%) albedo for visible light
  - Except snow, ice & clouds
  - And light-colored sand
- Nearly everything radiates as a black body in the IR, as we have seen above

Earth's Heat Balance

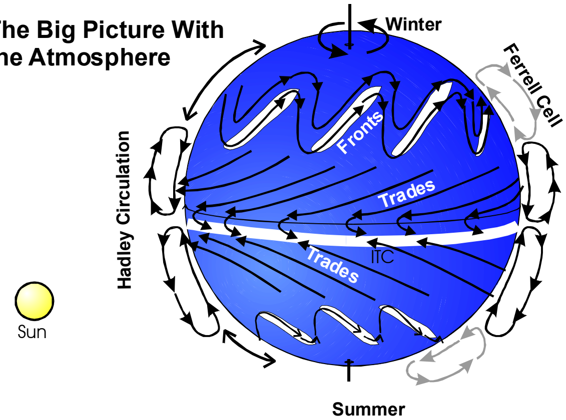




Geographic Distribution of Solar Radiation



The Big Picture With the Atmosphere



Summary (2)

- Be able to define ***Potential***, ***Kinetic*** and ***Heat Energy***
- Understand heat transport by ***Conduction***, ***Convection, Advection*** and ***Radiation***
- Know the general characteristics of EM radiation including mechanism and speed of propagation in a vacuum
- Be able to identify ***Ultraviolet***, ***Visible***, and ***Infrared*** EM radiation by wavelength
- Understand how Rayleigh scattering causes blue skies and red sunsets
- Know generally what Plank's Law is and how it relates to ***Wien's Law*** and the ***Stefan-Boltzman Law***
- Be able to calculate wavelength of peak emission and total emitted radiation using Wien's Law the Stefan-Boltzman Law.
- Be able to define ***Blackbody, Grey body, Albedo, Radiative Equilibrium Temperature, Emissivity, Absorptivity***
- Understand how the characteristics of emitted radiation vary with temperature and wavelength.
- Understand absorption of EM radiation by the atmosphere and know the wavelengths of the two atmospheric windows.
- Know a few albedo values generally, i.e., snow, clouds, soil, vegetation, the sea. Also know that most ordinary objects are nearly black bodies in the IR
- Be able to draw and explain the Earth's heat Balance
- Understand how the annual heat balance varies with latitude and how it relates to the Big Picture
- **FOR NEXT TIME: READ CHAPTER 3**