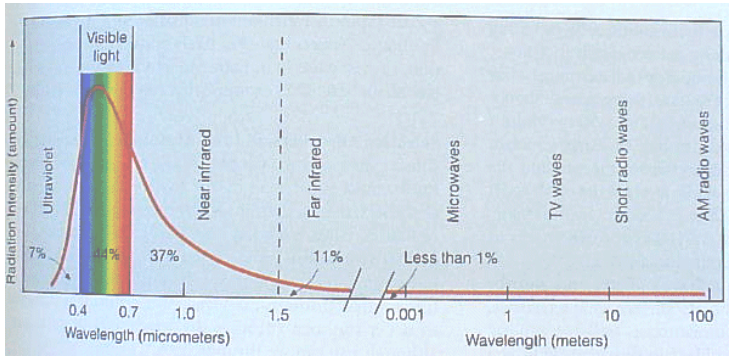
Radiation and the Planetary Energy Balance

- Electromagnetic Radiation
- Solar radiation warms the planet
- Conversion of solar energy at the surface
- Absorption and emission by the atmosphere
- The greenhouse effect
- Planetary energy balance

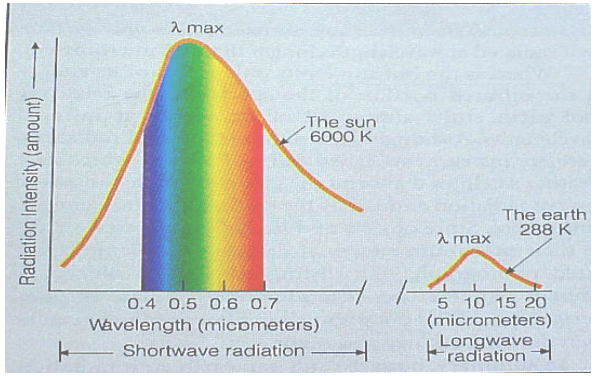
Electromagnetic Radiation

- Oscillating electric and magnetic fields propagate through space
- Virtually all energy exchange between the Earth and the rest of the Universe is by electromagnetic radiation
- Most of what we perceive as temperature is also due to our radiative environment
- May be described as waves or as particles (photons)
- **High energy photons = short waves; lower energy photons = longer waves**

Electromagnetic Spectrum of the Sun



Spectrum of the sun compared with that of the earth



Ways to label radiation

- **By its source**
  - **Solar radiation - originating from the sun**
  - **Terrestrial radiation - originating from the earth**
- **By its name**
  - **ultra violet, visible, near infrared, infrared, microwave, etc….**
- **By its wavelength**
  - **short wave radiation λ < 3 micrometers (μm)**
  - **long wave radiation λ > 3 micrometers**

Absorption of Solar Radiation

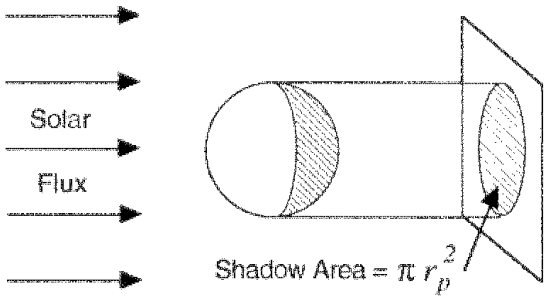


Fig. 2.2 Diagram showing the shadow area of a spherical planet.

Blackbodies and Graybodies

- A blackbody is a hypothetical object that absorbs all of the radiation that strikes it. It also emits radiation at a maximum rate for its given temperature.
  - Does not have to be black!
- A graybody absorbs radiation equally at all wavelengths, but at a certain fraction (absorptivity, emissivity) of the blackbody rate

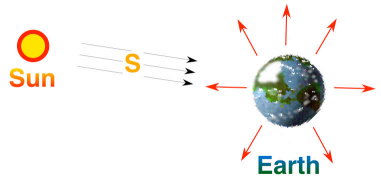
Total Blackbody Emission

- The total rate of emission of radiant energy from a "blackbody":

$$E^* = \sigma T^4$$

- This is known as the Stefan-Boltzmann Law, and the constant σ is the Stefan-Boltzmann constant (5.67×10^{-8} W m^{-2} K^{-4}).
- Stefan-Boltzmann says that total emission depends really strongly on temperature!
- This is strictly true only for a blackbody. For a **gray body**, $E = \varepsilon E^*$, where ε is called the emissivity.
- In general, the emissivity depends on wavelength just as the absorptivity does, for the same reasons: $\varepsilon_\lambda = E_\lambda / E^*_\lambda$

Planetary Energy Balance



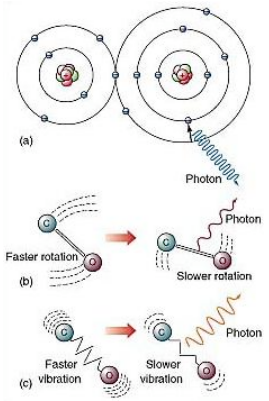
Energy In = Energy Out

$$S(1-\alpha)\pi R^2 = 4\pi R^2 \sigma T^4$$

$$T \approx -18^{\circ}\mathrm{C}$$

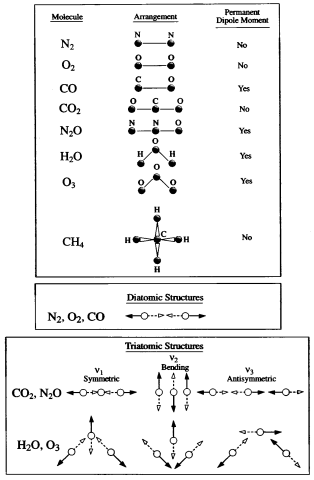
But the observed T_s is about 15° C

Atoms, Molecules, and Photons



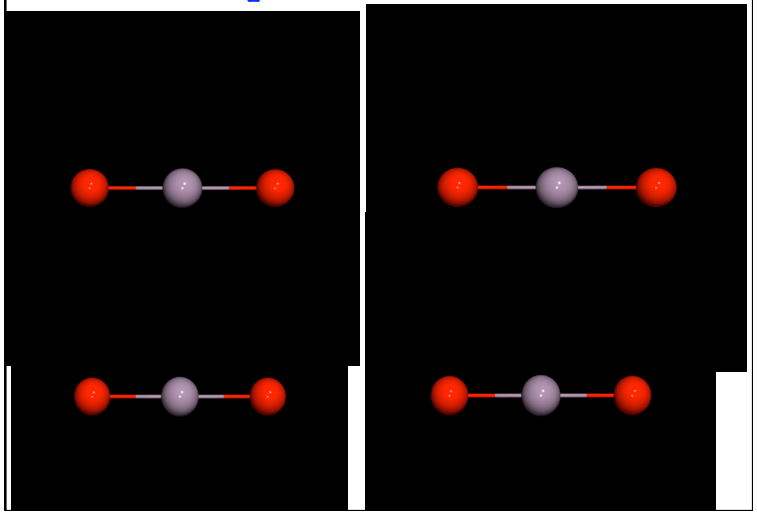
- Atmospheric gases are made of molecules
- Molecules are groups of atoms that share electrons (bonds)
- Photons can interact with molecules
- Transitions between one state and another involve specific amounts of energy

Molecular Absorbers/Emitters

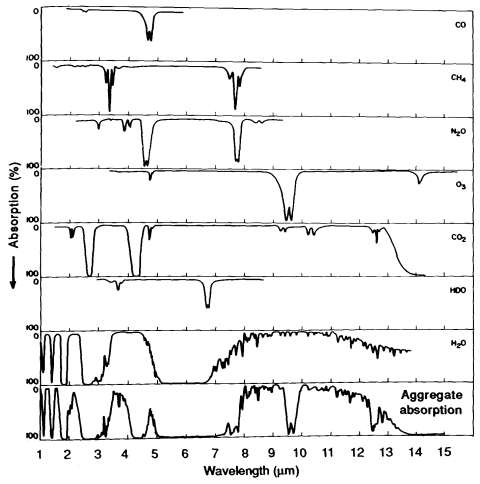


- Molecules of gas in the atmosphere interact with photons of electromagnetic radiation
- Different kinds of molecular transitions can absorb/emit very different wavelengths of radiation
- Some molecules are able to interact much more with photons than others
- Molecules with more freedom to jiggle and bend in different ways absorb more types of photons
- Water vapor (H_2O) and CO_2 are pretty good at this, and abundant enough to make a big difference!
- These are the "greenhouse gases!"

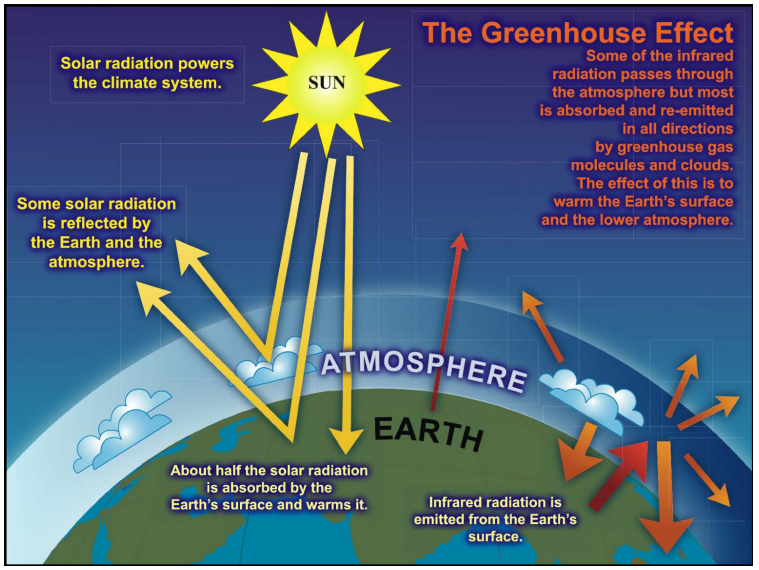
CO_2 Vibration Modes



Atmospheric Absorption

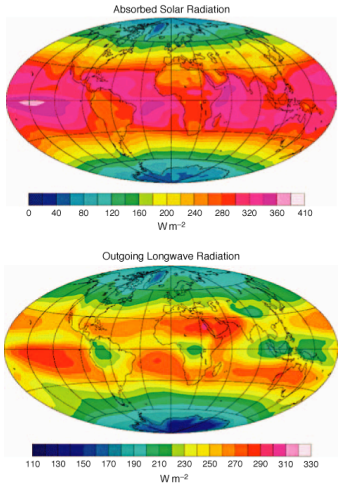


- Triatomic modelcules have the most absorption bands
- Complete absorption from 5-8 m (H_2O) and > 14 m (CO_2)
- Little absorption between about 8 m and 11 m ("window")

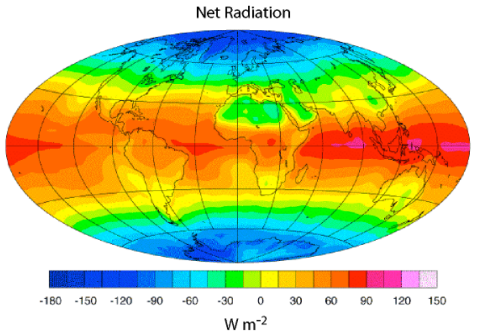


Energy In, Energy Out

- Incoming and outgoing energy must balance on average
- But there are huge differences from place to place
- Way more solar heating in tropics
- Some places (deserts) emit much more than others (high cold clouds over rainforests)



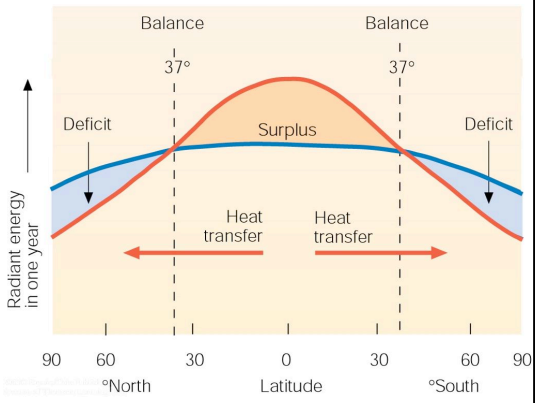
Top of Atmosphere Annual Mean



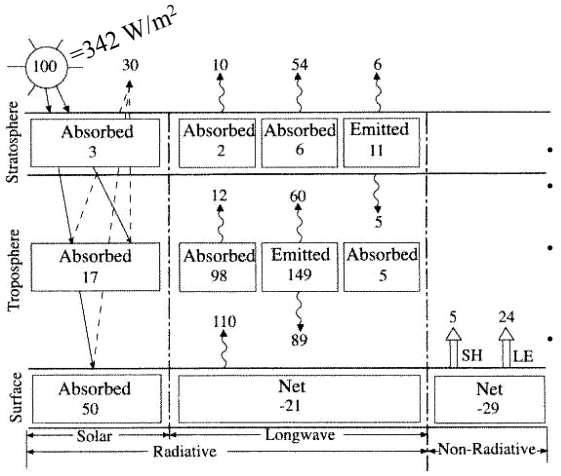
- Incoming solar minus outgoing longwave
- Must be balanced by horizontal transport of energy by atmosphere and oceans!

Earth's Energy Balance

A global balance is maintained by transferring excess heat from the equatorial region toward the poles

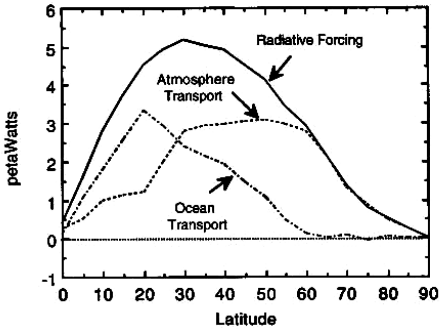


Planetary Energy Budget



- 4 Balances
- Recycling = greenhouse
- Convective fluxes at surface
- LE > H

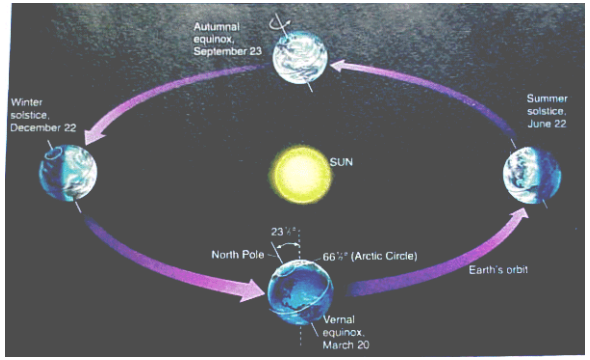
Energy Transports in the Ocean and Atmosphere



- Northward energy transports in petawatts (10^{15} W)
- "Radiative forcing" is cumulative integral of R_{TOA} starting at zero at the pole
- Slope of forcing curve is excess or deficit of R_{TOA}
- Ocean transport dominates in subtropics
- Atmospheric transport dominates in middle and high latitudes

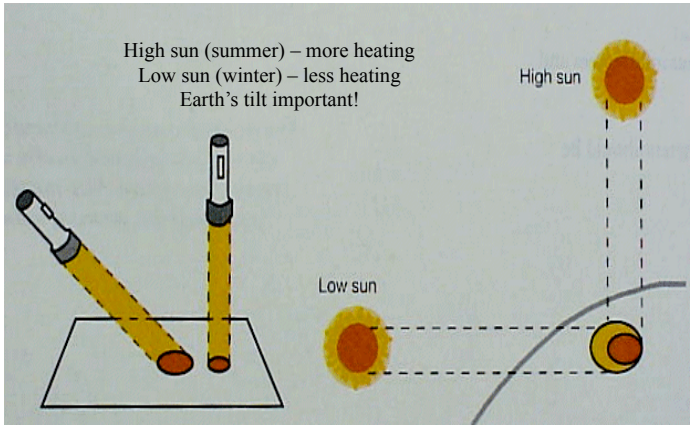
- *How are these numbers determined?*
- *How well are they known?*

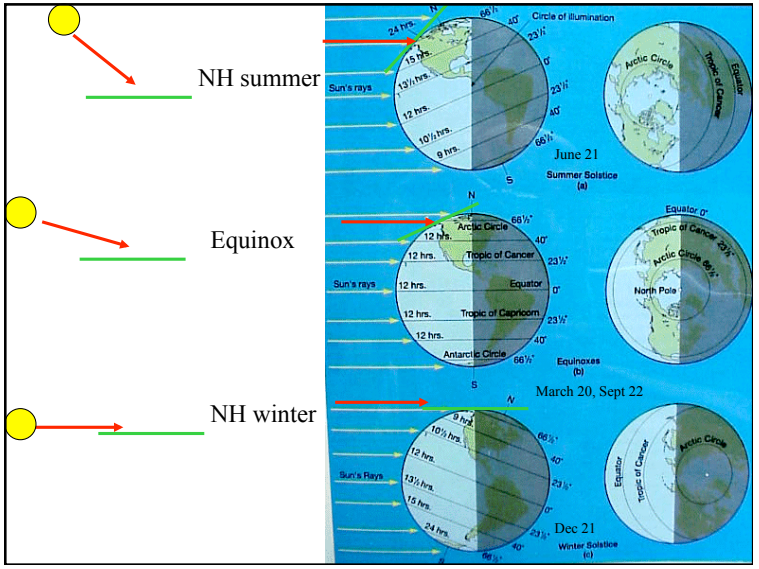
The Earth's Orbit Around the Sun



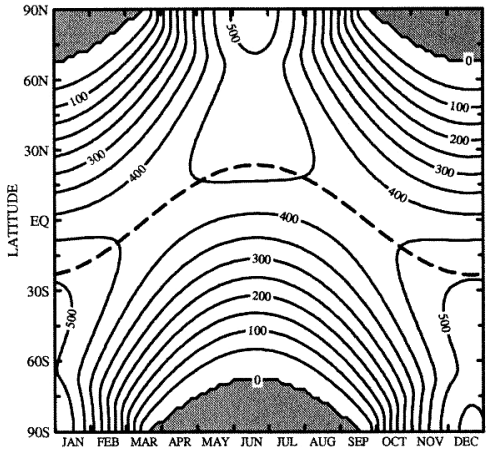
- Seasonally varying distance to sun has only a minor effect on seasonal temperature
- The earth's orbit around the sun leads to seasons because of the tilt of the Earth's axis

Smaller angle of incoming solar radiation: the same amount of energy is spread over a larger area





Daily Total Sunshine



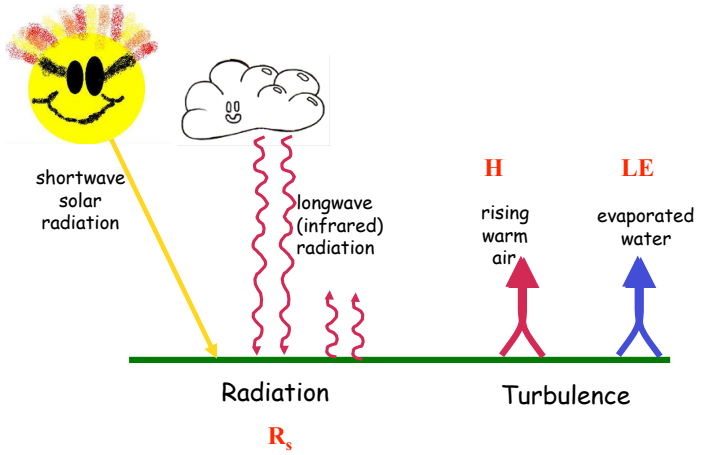
- 75° N in June gets more sun than the Equator
- N-S gradient very strong in winter, very weak in summer
- Very little tropical seasonality

Surface Albedos (percent)

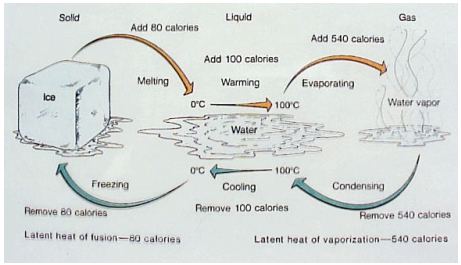
Surface type	Range	Typical value
Water		
Deep water: low wind, low altitude	5–10	7
Deep water: high wind, high altitude	10–20	12
Bare surfaces		
Moist dark soil, high humus	5–15	10
Moist gray soil	10–20	15
Dry soil, desert	20–35	30
Wet sand	20–30	25
Dry light sand	30–40	35
Asphalt pavement	5–10	7
Concrete pavement	15–35	20
Vegetation		
Short green vegetation	10–20	17
Dry vegetation	20–30	25
Coniferous forest	10–15	12
Deciduous forest	15–25	17
Snow and ice		
Forest with surface snowcover	20–35	25
Sea ice, no snowcover	25–40	30
Old, melting snow	35–65	50
Dry, cold snow	60–75	70
Fresh, dry snow	70–90	80

- Snow and ice brightest
- Deserts, dry soil, and dry grass are very bright
- Forests are dark
- Coniferous (cone -bearing) needleleaf trees are darkest

Energy Balance of Earth's Surface

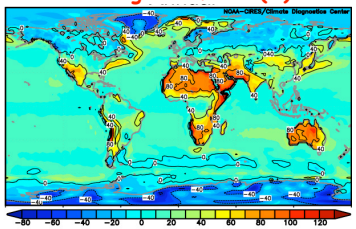


It Takes a Lot of Energy to Evaporate Water!

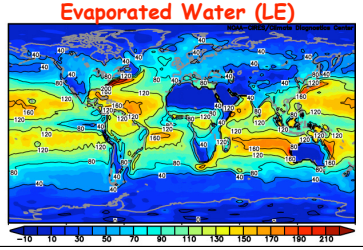


Energy from the Surface to the Air

Rising Warm Air (H)



Evaporated Water (LE)



- Energy absorbed at the surface warms the air
- Some of this energy is transferred in rising warm "thermals"
- But more of it is "hidden" in water vapor

Things to Remember

- All energy exchange with Earth is radiation
- Outgoing radiation has longer waves (cooler)
- Longwave radiation is absorbed and re-emitted by molecules in the air (H_2O & CO_2)
- Recycling of energy between air and surface is the "greenhouse effect"
- Changes of angle of incoming sunlight and length of day & night are responsible for seasons and for north-south differences in climate
- Regional energy surpluses and deficits drive the atmosphere and ocean circulations (wind & currents)