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 \( \lambda < 3 \) micrometers (\( \mu m \))
  - Long wave radiation \( \lambda > 3 \) micrometers

Absorption of Solar Radiation

**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 \( \sigma \) is the Stefan-Boltzmann constant (5.67 \times 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 \( \varepsilon \) is called the emissivity.
    - In general, the emissivity depends on wavelength just as the absorptivity does, for the same reasons: \( \varepsilon = \varepsilon_\lambda E^*_\lambda \)
Planetary Energy Balance

Energy In = Energy Out

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

\[ T \approx -18^\circ C \]

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 (H₂O) and CO₂ are pretty good at this, and abundant enough to make a big difference!
- These are the "greenhouse gases!"

“Dancing Molecules”
• Triatomic molecules have the most absorption bands
• Complete absorption from 5-8 m (H2O) and > 14 m (CO2)
• Little absorption between about 8 m and 11 m ("window")

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)

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

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

How are these numbers determined?
How well are they known?
Smaller angle of incoming solar radiation: the same amount of energy is spread over a larger area.

- High sun (summer) – more heating
- Low sun (winter) – less heating
- Earth’s tilt important!

- 75º 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)

- 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

- Shortwave solar radiation
- Longwave (infrared) radiation
- Rising warm air
- Evaporated water
- Radiation
- Turbulence

It Takes a Lot of Energy to Evaporate Water!

Energy from the Surface to the Air

- 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 (H₂O & CO₂)
- 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)