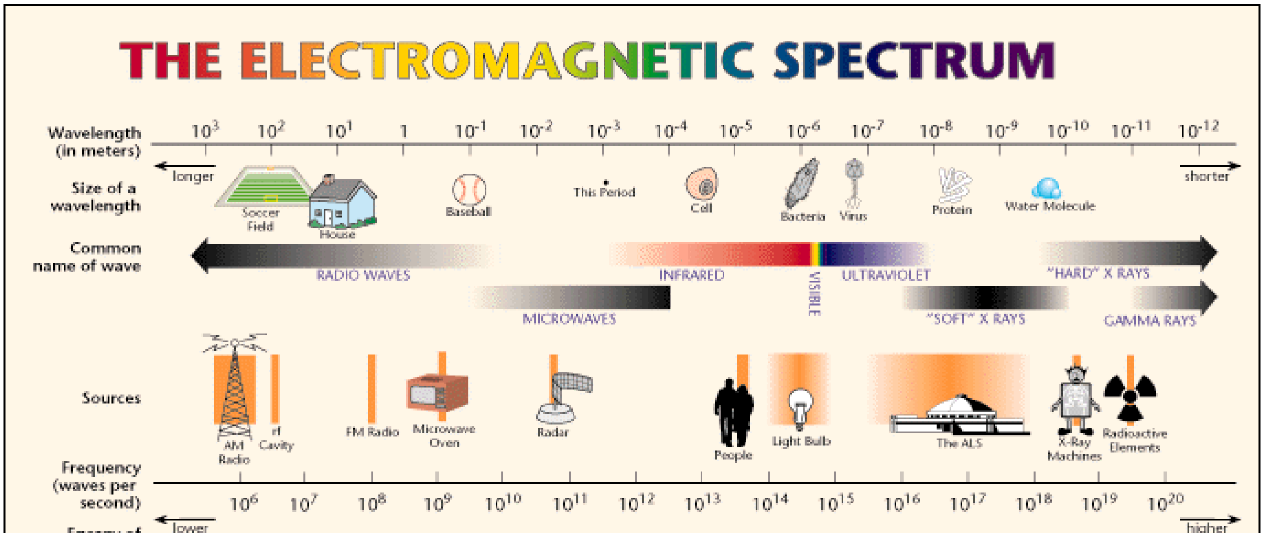
Lecture 2

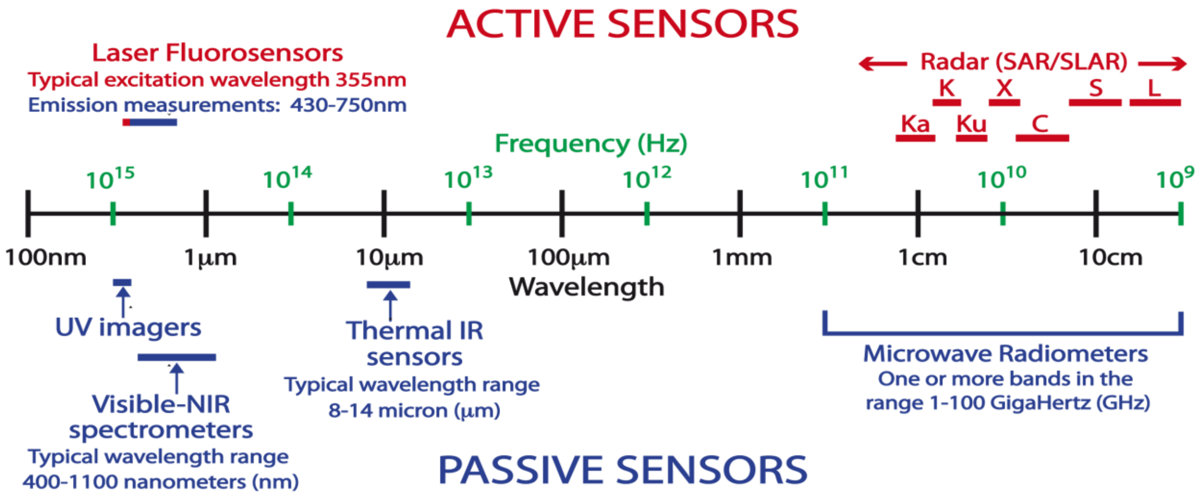
The multiple roles of radiation: Introductory survey

1. Radiation and remote sensing.
2. Radiation and Earth's climate.
3. Radiation and Earth's systems (atmosphere, biosphere, etc).

1. Radiation and remote sensing.

Electromagnetic radiation provides the foundation for various remote sensing applications.





2. Radiation and climate.

- ✓ Radiation is a key factor controlling the Earth's climate.
- ✓ Radiation equilibrium at the top of the atmosphere (TOA) represents the fundamental mode of the climate system.

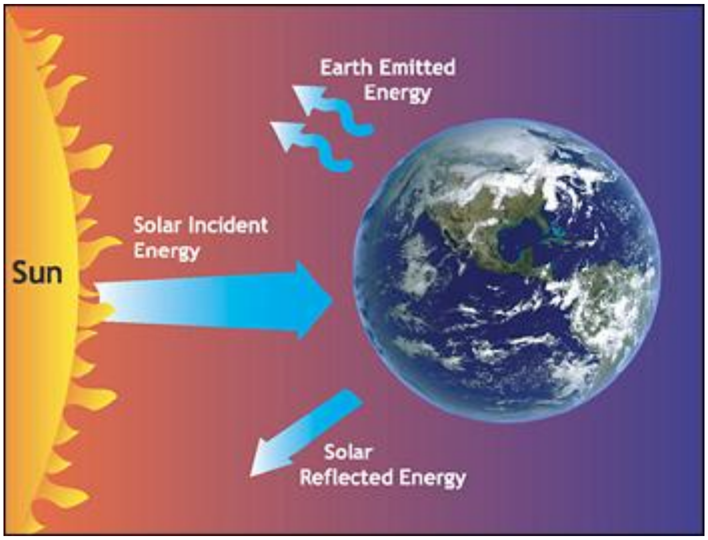
Global perspective

Planetary radiative equilibrium (over the entire planet and long time interval):

TOA incoming radiation $\equiv$ TOA outgoing IR radiation

TOA incoming radiation = incoming solar radiation – reflected solar radiation

TOA outgoing IR radiation = outgoing IR radiation (emitted by the atmosphere-surface system)



TOA incoming solar radiation:

If F_0 is the solar constant (i.e., solar flux at the top of the atmosphere, W/m^2), then incoming solar radiation (per unit area of Earth's surface) is

$$\mathbf{F_0 \pi R_e^2 / 4\pi R_e^2 = F_0 / 4}$$

where Re is the radius of the Earth.

Assuming F_0 = 1368 W/m^2, incoming solar radiation is 1368 W/m^2/4 = $\underline{342 \text{ W/ m}^2}$

Reflected solar radiation:

Taking a global mean planetary albedo $\bar{r}$ = 0.31:

Reflected solar radiation = $\bar{r}F_0 / 4$ = 107 $\underline{\text{W/ m}^2}$

Global annual mean Earth's energy balance

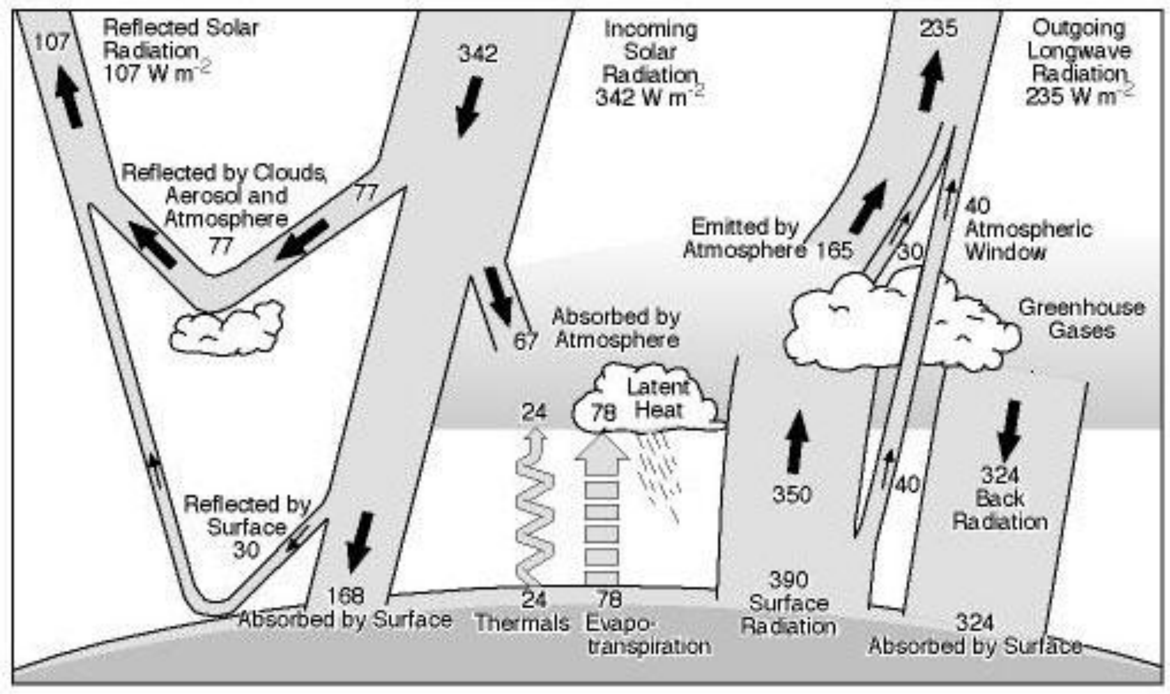


Figure 2.1 Earth's energy balance diagram from Kiehl and Trenberth (1997)

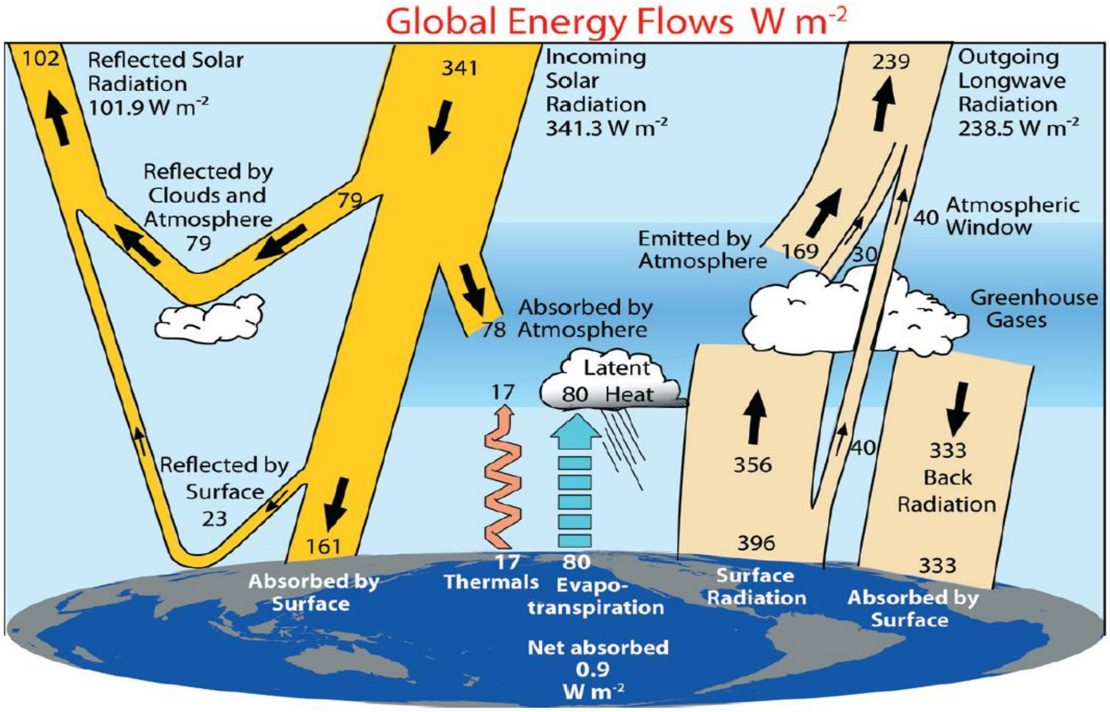


Figure 2.2 Updated Earth's energy balance diagram from Trenberth et al. (2009): global mean earth energy budget for March 2000- May 2004 period.

Zonal mean radiation budget:

When globally averaged over a year, net energy gains are balanced by energy losses, or nearly so. This is not the case when the radiation gains and losses are averaged as a function of latitude. Regions between approximately 30°N and 30°S gain radiant energy while the polar regions are losing energy through radiation processes. Transport of energy from the tropics to the poles is accomplished by the atmosphere and ocean currents and is the reason we have weather and different climatic zones.

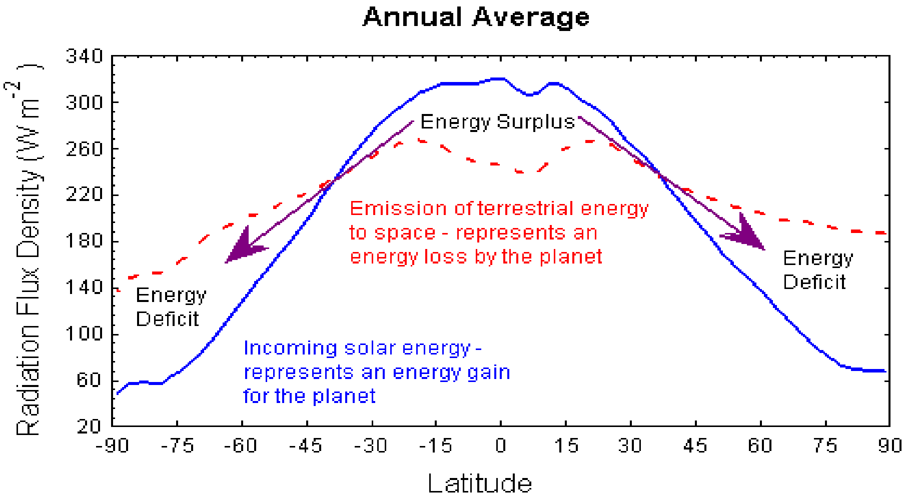


Figure 2.3 Schematic representation of zonal mean radiation budget.

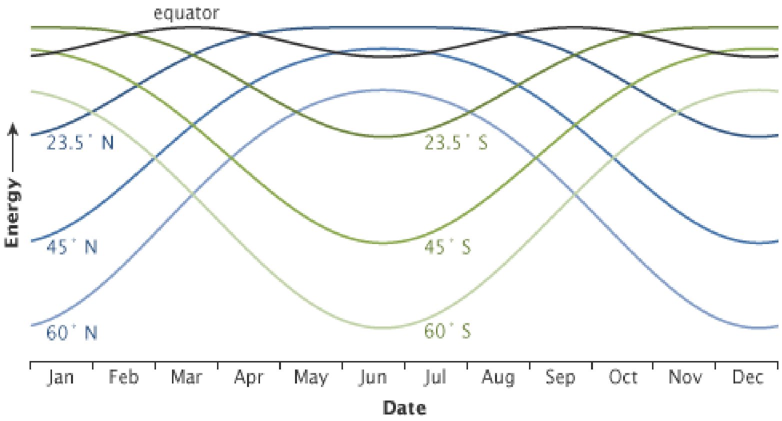


Figure 2.4 The peak energy received at different latitudes changes throughout the year. This graph shows how the solar energy received at local noon each day of the year changes with latitude. At the equator (gray line), the peak energy changes very little throughout the year. At high northern (blue lines) and southern (green) latitudes, the seasonal change is extreme (NASA illustration)

Spatial and temporal distribution of radiation

✓ The **planetary albedo** is a key climate variable as it, combined with the solar insolation determines the radiative energy input to the planet. The albedo varies quite markedly with geographic region and time of year. Oceans have a low albedo, snow a high albedo. While the Northern Hemisphere has more land than the Southern Hemisphere, the annual average albedo of the two hemispheres is nearly the same, demonstrating the important influence of clouds in determining the albedo.

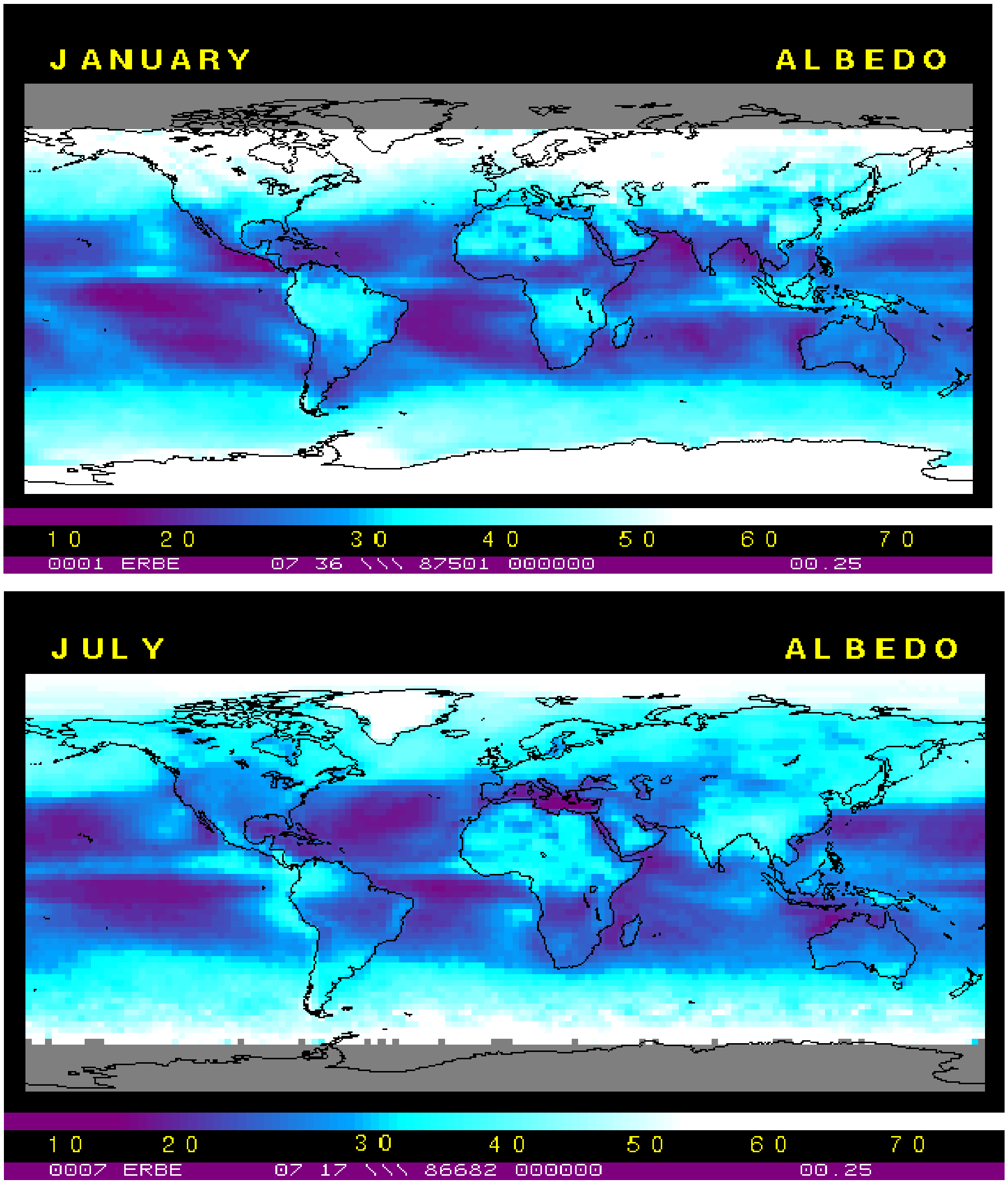


Figure 2.4 Examples of monthly mean albedo measured by the NASA Earth Radiation Budget Experiment (ERBE) satellite.

<u>Outgoing longwave (infrared) radiation</u>

Low values usually indicate cold temperatures while high values are warm areas of the globe. The minimum in OLR near the equator is due to the high cloud tops associated with the inter-tropical convergence zone. This minimum migrates about the equator as seen in the monthly mean maps, and is also seen as a maximum in albedo (see Figure 2.4). Notice how it is difficult to observe the oceanic stratus regions we observed in the albedo maps. This is because the temperature of the clouds is similar to the surrounding oceans, making it difficult to observe. Note how the major deserts have their largest OLR during their summer. Note also the large emission in the vicinity of the oceanic subtropical highs (30N and 30S).

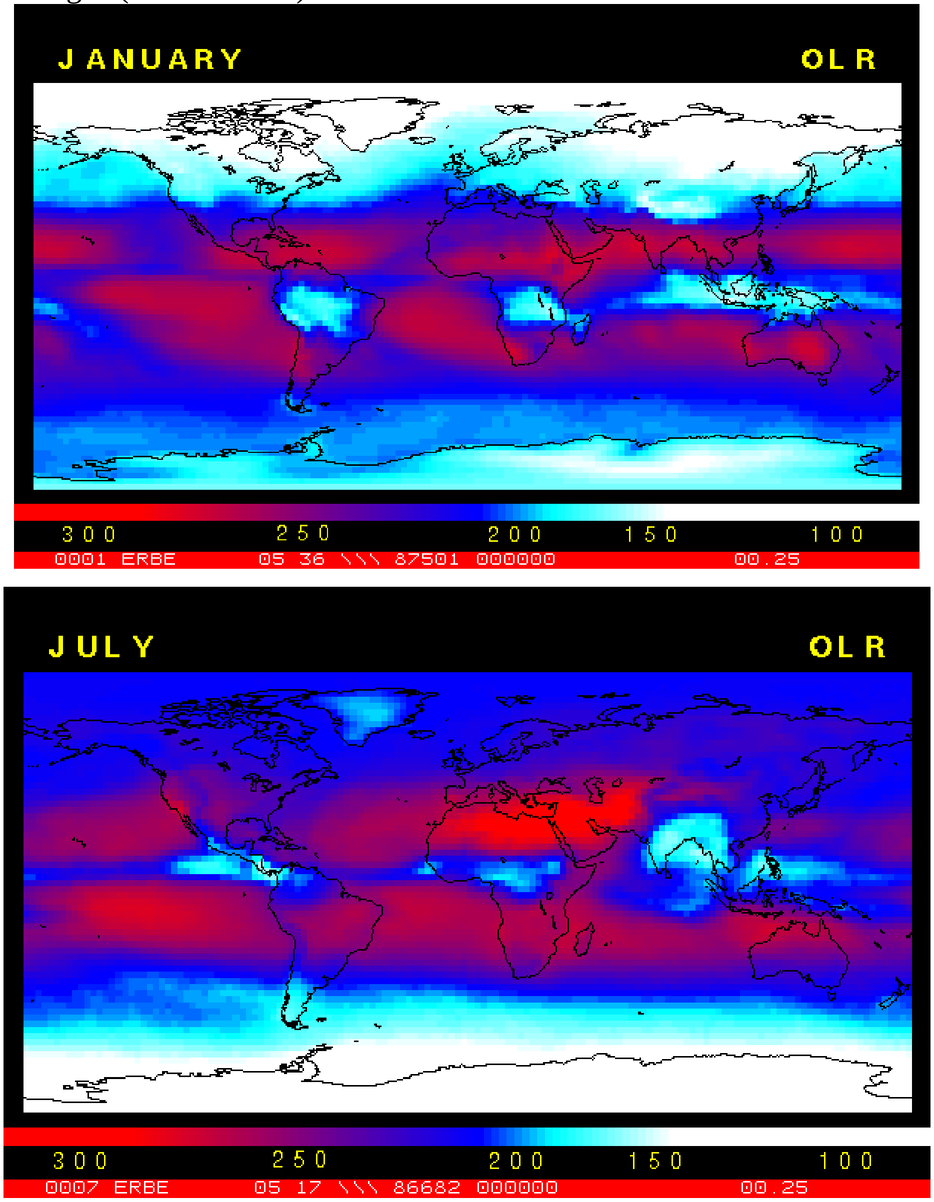


Figure 2.5 Examples of monthly mean outgoing longwave radiation (OLR) measured by the NASA Earth Radiation Budget Experiment (ERBE) satellite.

Surface energy budget:

Solar radiation (reaching the surface) and thermal radiation (emitted by the surface) are the key components of the energy budget at the surface controlling the latent and sensible heat and, hence, the surface-atmosphere interactions and the hydrological cycle.

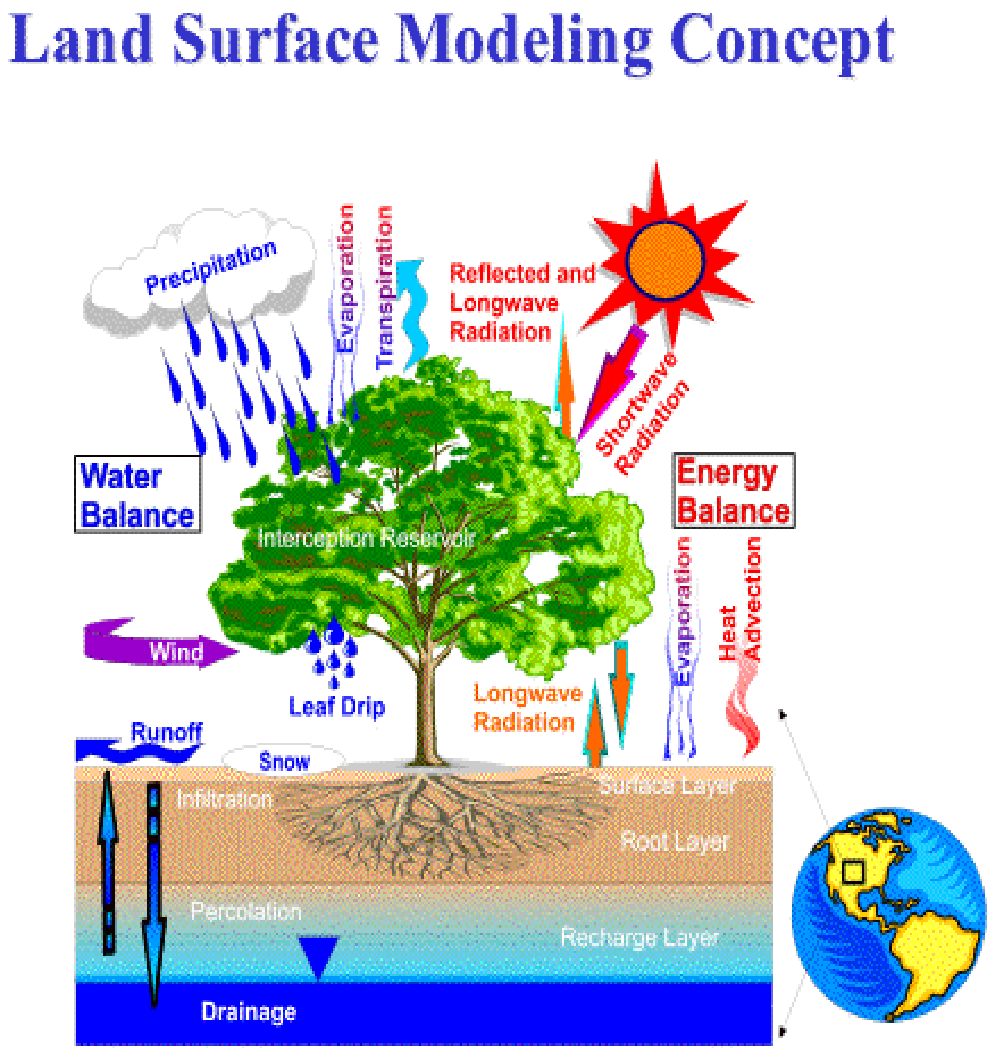


Figure 2.6 NASA Land Information System (LIS)

Energy budget of an atmospheric layer:

Atmospheric radiation provides an addition source (or a sink) of energy causing the radiative heating (or cooling) of an atmospheric layer and thus affects the dynamics and thermodynamics of the atmosphere.

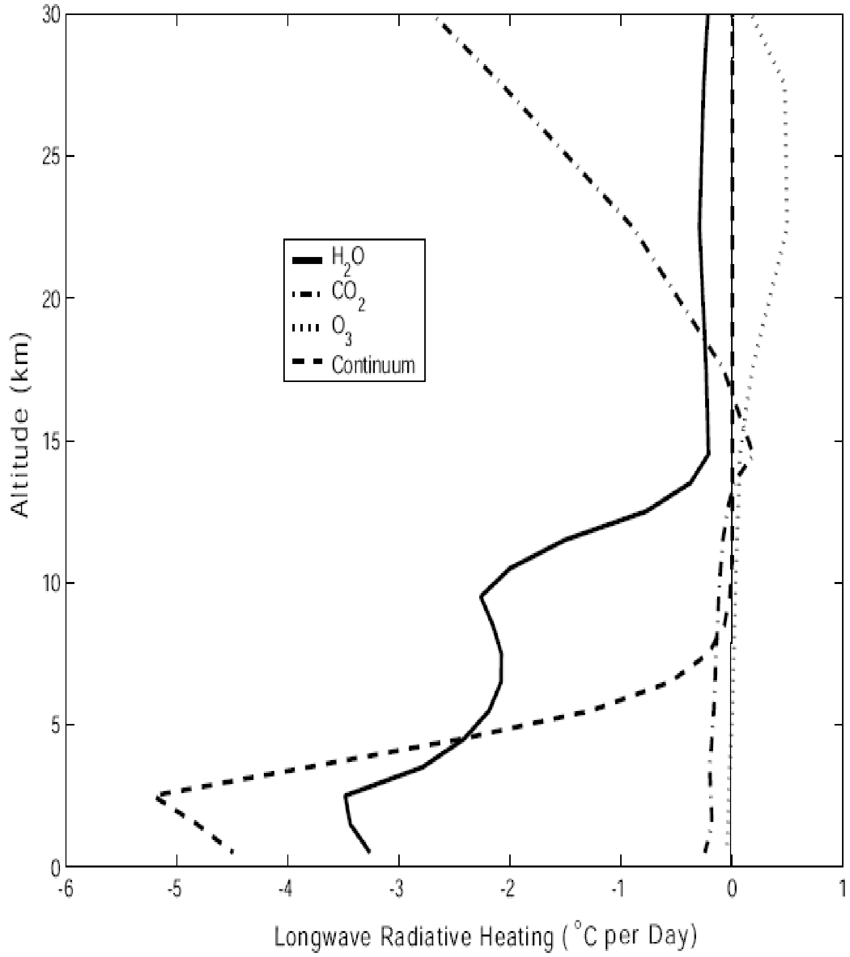


Figure 2.7 Example of IR heating rate profiles in a cloud-free tropical atmosphere, segregated according to main absorbing gases. Note that negative values represent cooling (will be discussed in detail later in class)

3. Radiation and Earth’s systems.

Atmospheric chemistry

Atmospheric radiation (actinic flux) controls the photolytic reactions that are central to the chemistry of the atmosphere.

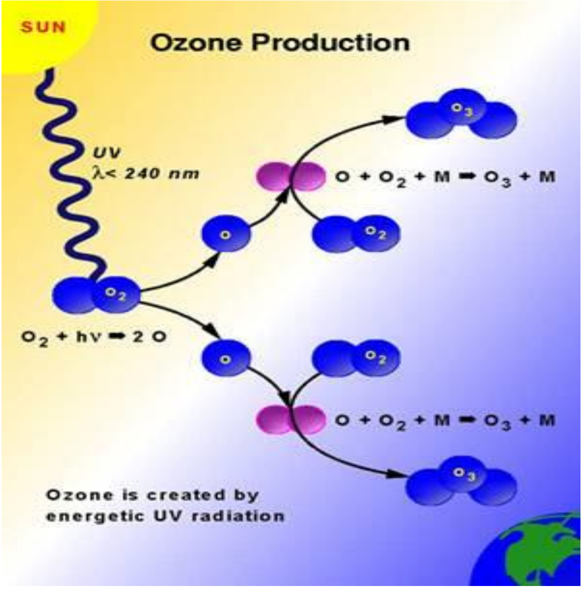


Figure 2.8 Example of zone production controlled by availability of sunlight.

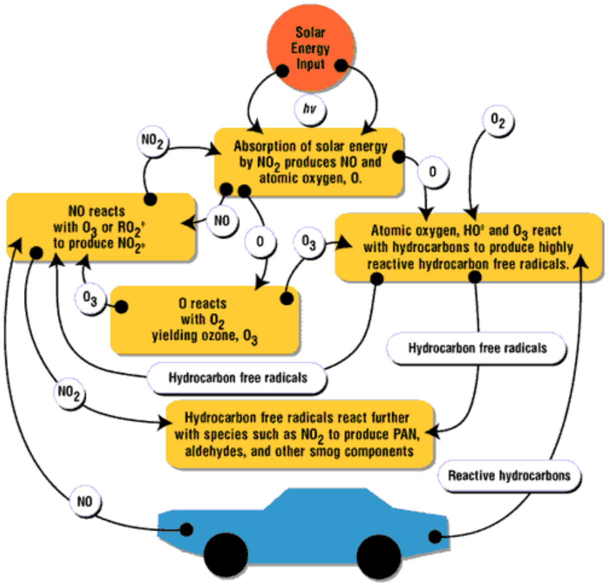


Figure 2.9 Photochemical formation of smog

Biosphere/Ecology

Solar UV radiation (especially, PAR, photosynthetically active radiation, 400-700 nm) is a key to the functioning of the terrestrial and aquatic ecosystems.

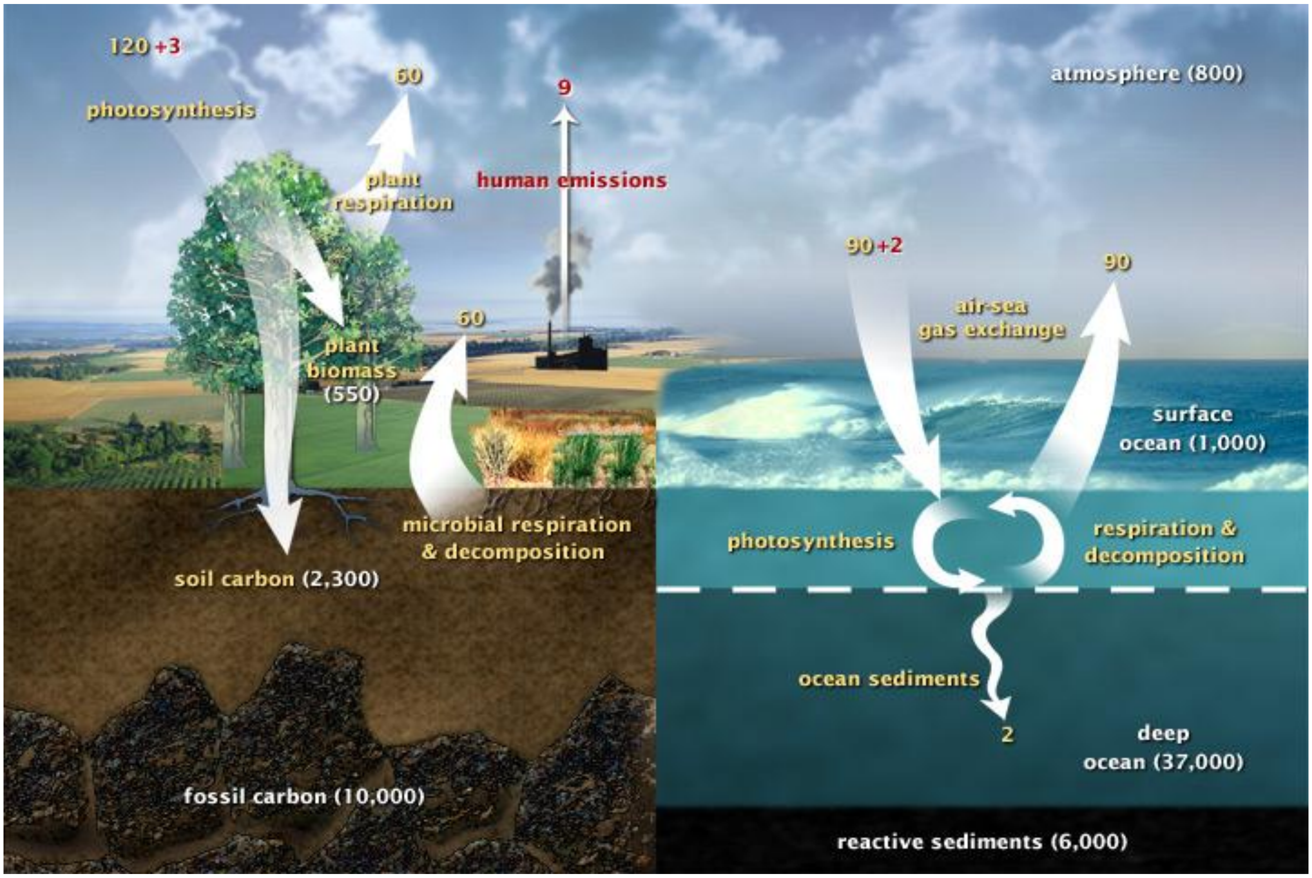
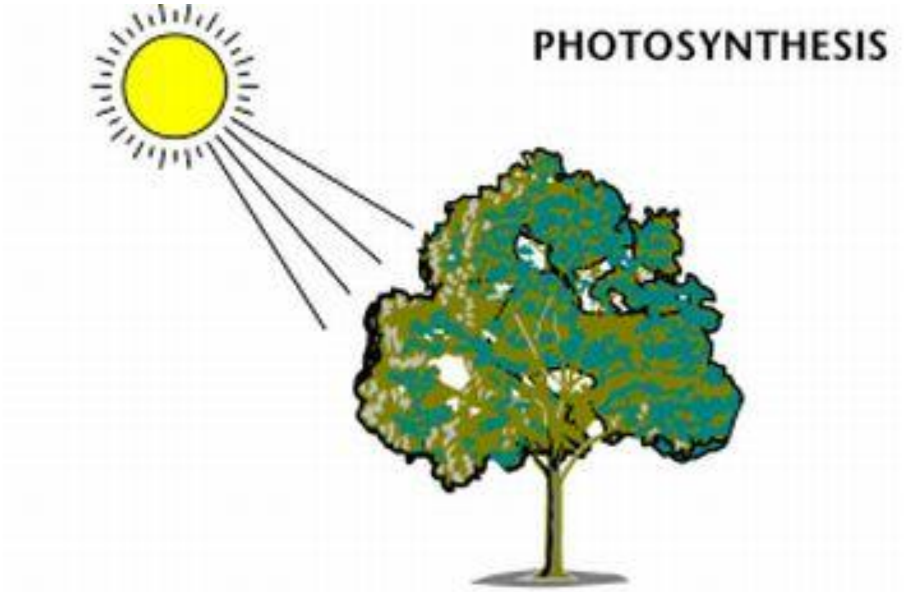


Figure 2.9 Photosynthesis and carbon cycle. Schematic of the fast carbon cycle showing the movement of carbon between land, atmosphere, and oceans. Yellow numbers are natural fluxes, and red are human contributions in gigatons of carbon per year. White numbers indicate stored carbon. (From U.S. DOE).

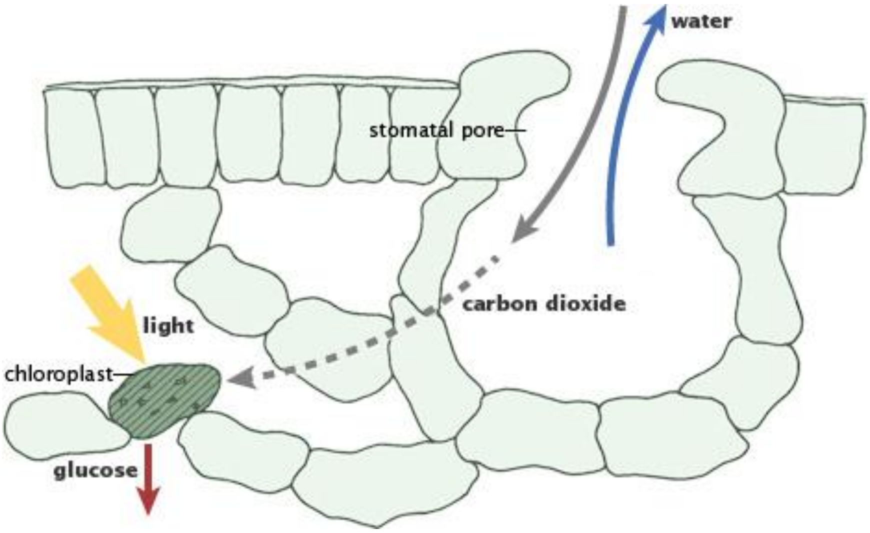
What is photosynthesis?



In the process of photosynthesis, plants convert radiant energy from the sun into chemical energy in the form of glucose - or sugar.

water + carbon dioxide + sunlight → glucose + oxygen

$6\,H_2O + 6\,CO_2 + \text{radiant energy} \rightarrow C_6H_{12}O_6 + 6\,O_2$



Plant respiration - during photosynthesis, plants absorb carbon dioxide and sunlight to create fuel—glucose and other sugars—for building plant structures.