Solar radiation - the major source of energy for almost
all environmental flows

Radiation = electromagnetic waves

Different types of heat transfer:

Heat conduction by molecular diffusion (no large-scale transport of mass is needed; think the change of temperature within an iron bar with one end attached to a furnace)

Heat transfer accomplished by mass transport (e.g., convection, turbulent heat transfer in fluids)

Radiative heat transfer - most ubiquitous

Every object in the universe emits radiation according to its temperature

For a "blackbody" in thermodynamical equilibrium, the intensity of radiation is governed by Planck function

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5\left(\exp^{\left[\frac{hc}{\lambda k T}\right]} - 1\right)}$$

Eq. (A-1) in M&P textbook

h = Planck's constant, k = Boltzmann's constant, c = speed of light,
T = temperature (in degK)

For a given temperature (of the object under consideration),
$B_\lambda(T)$ is a function of the "wavelength" λ (of electromagnetic waves).
The radiation emitted by the object forms a "spectrum".

Example: The sun has a surface temperature of ~ 6,000 K. The following is the "spectrum" of radiation (electromagnetic waves) emitted by the sun, or by any object that has a temperature of 6,000K.

-- The "peak" of the spectrum is in the visible band

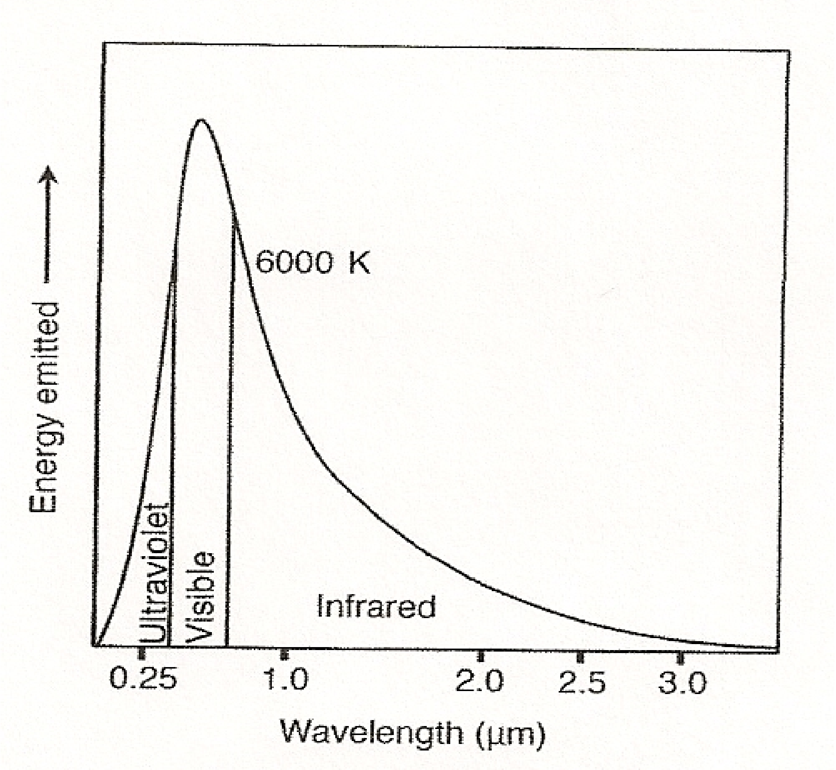


Fig. 2.2 in M&P

Speaking of electromagnetic waves ...

$\lambda \sim 0.01\ \mu\text{m}$ X-ray

$\lambda < 0.3\ \mu\text{m}$ Ultraviolet radiation (harmful to humans)

$0.3\ \mu\text{m} < \lambda < 0.7\ \mu\text{m}$ Visible light (that human eyes can "see")

$\lambda > 1.0\ \mu\text{m}$ Near-infrared, Infrared

$\lambda \sim 10000\ \mu\text{m}$ (1 cm) Microwave

[0.3 μm - 0.7 μm] : [purple, blue, green, yellow, red]

The peak of the radiation spectrum shifts to longer wavelength as temperature decreases

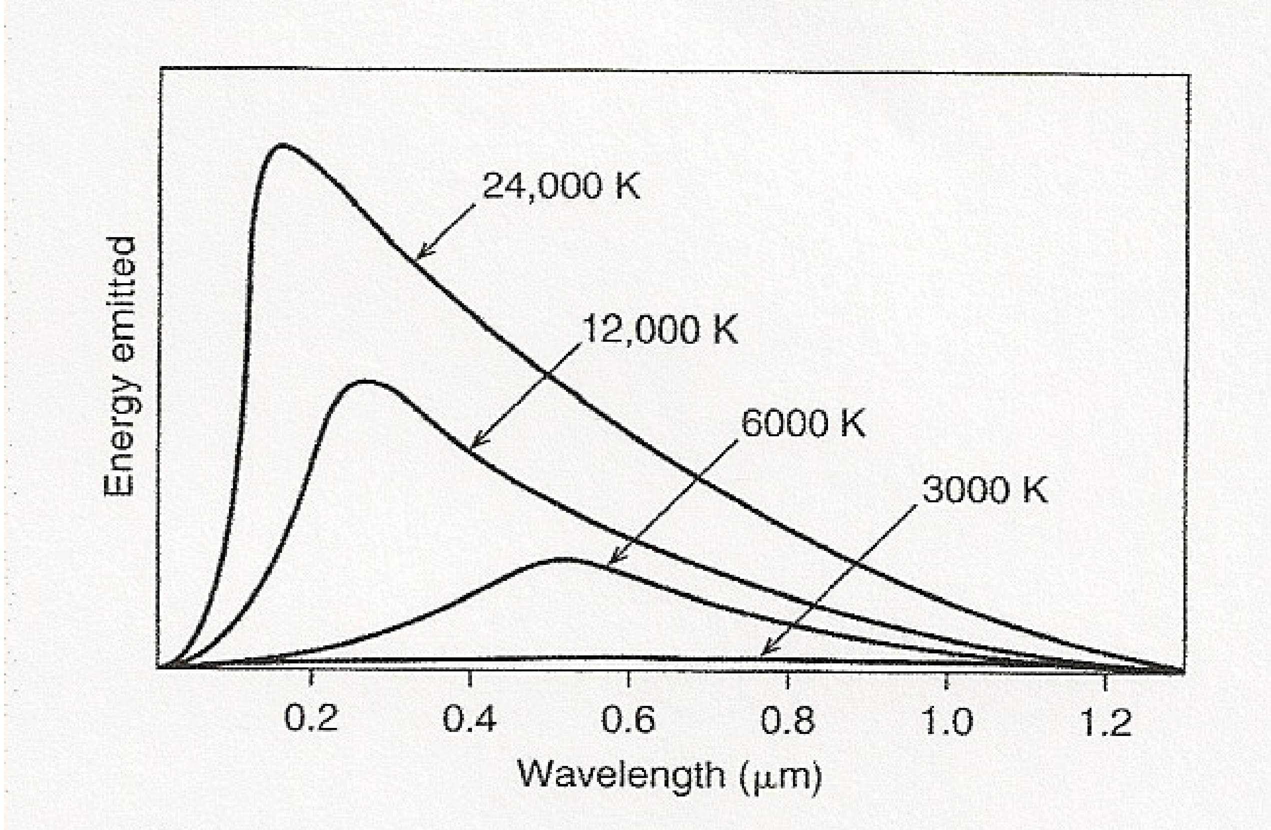


Fig. 2.3 in M&P

A star with a surface temperature of 10,000K would look more blue, while a star with surface temperature of 4,000K will look more red.

This behavior is anticipated from Planck's function

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5 (\exp^{[\frac{hc}{\lambda k T}]} - 1)} \ .$$

The peak of the spectrum occurs at the wavelength λ where

$$\frac{\partial B_\lambda(T)}{\partial \lambda} = 0 \ .$$

Straightforward math would lead to a formula of the peak wavelength as a function of temperature (sometimes called "Wien displacement law"), which would readily corroborate the behavior shown in the previous slide. We will leave this to a homework.

What about the Earth?

Earth's global mean surface/atmospheric temperature is $T \sim 255$ K

-- The peak wavelength of the radiation emitted by the Earth is $\lambda \sim 10$ µm , in the infrared range not visible to human eyes

That Earth is at all visible from space is because it reflects sun light, which contains a substantial visible band

The atmosphere absorbs solar and terrestrial radiation in a highly wavelength-dependent manner. This has many important implications for Earth's global environment and life on earth in general.

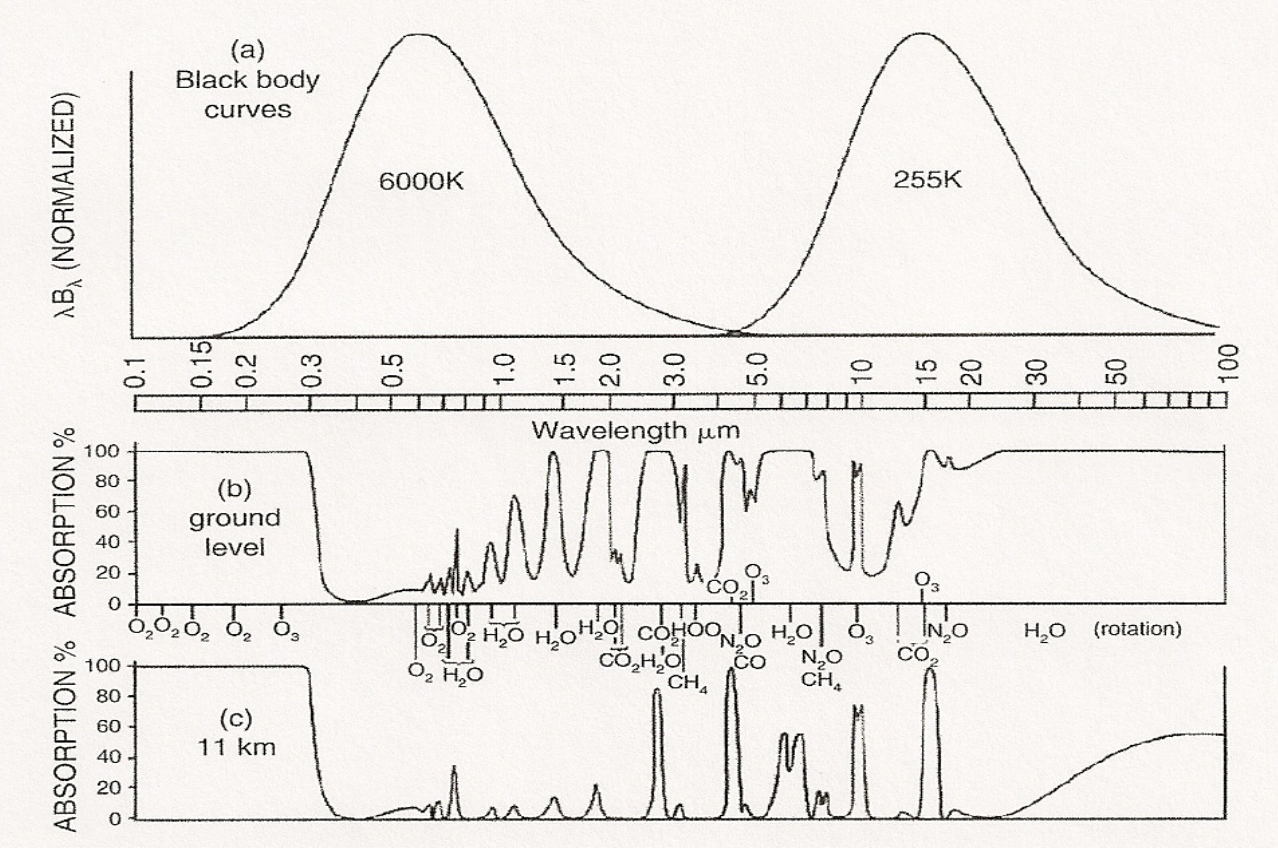


Fig. 2.6 in M&P

Beware that the radiation spectra in the top panel are "normalized". In actuality, solar radiation is much stronger than terrestrial radiation.

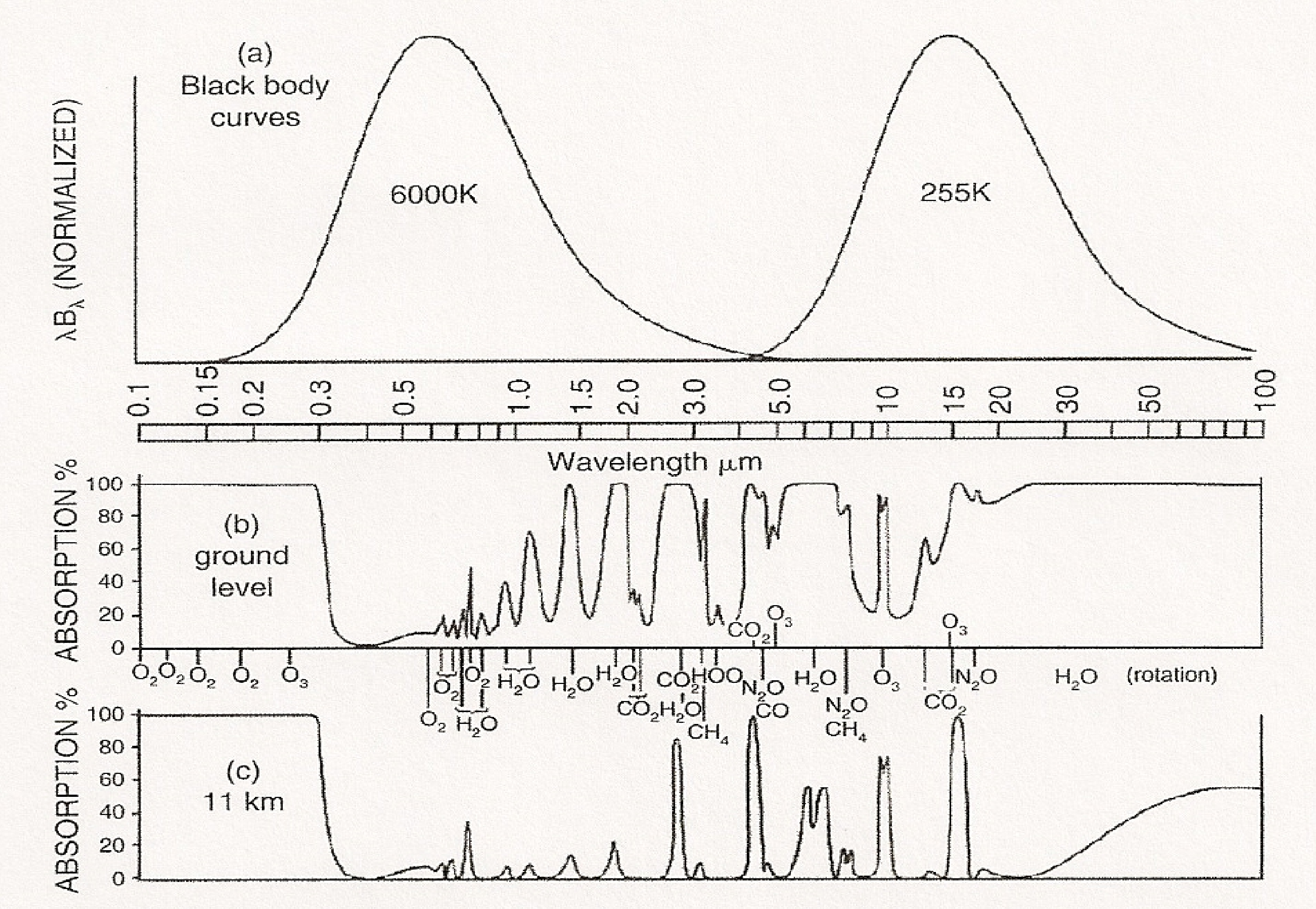


Fig. 2.6 in M&P (repeat)

Earth's surface is the biggest absorber of solar radiation. Any amount of radiation that's not absorbed by the atmosphere (including cloud, etc.) is eventually captured by the surface. This heats the surface.

To maintain long-term energy balance at the surface, there is then a net upward transfer of heat (or energy in general) from the surface to the atmosphere. This is accomplished by a combination of several processes that we will discuss later.

In a similar vein, the lower latitudes (equatorial region) of the earth receives more solar radiation then the polar region. The sun heats the Tropics more. To maintain a long-term climatology (i.e., a climate state in statistical equilibrium), there is a net poleward transfer of energy from the tropics to higher latitudes by the atmosphere and oceans

Understanding these energy transfer processes is one of the main objectives of geophysical fluid dynamics

Clearly, the energy transfer processes mentioned in the preceding slide would involve atmospheric (and oceanic) motion (fluid flows)

The direct consequence of solar heating is the change of temperature. How does it leads atmospheric motion?
(Hint: This is a case of the conversion from heat to kinetic energy)

We will revisit these points later.

How much energy does the earth receive from the Sun?
-- The "solar constant"

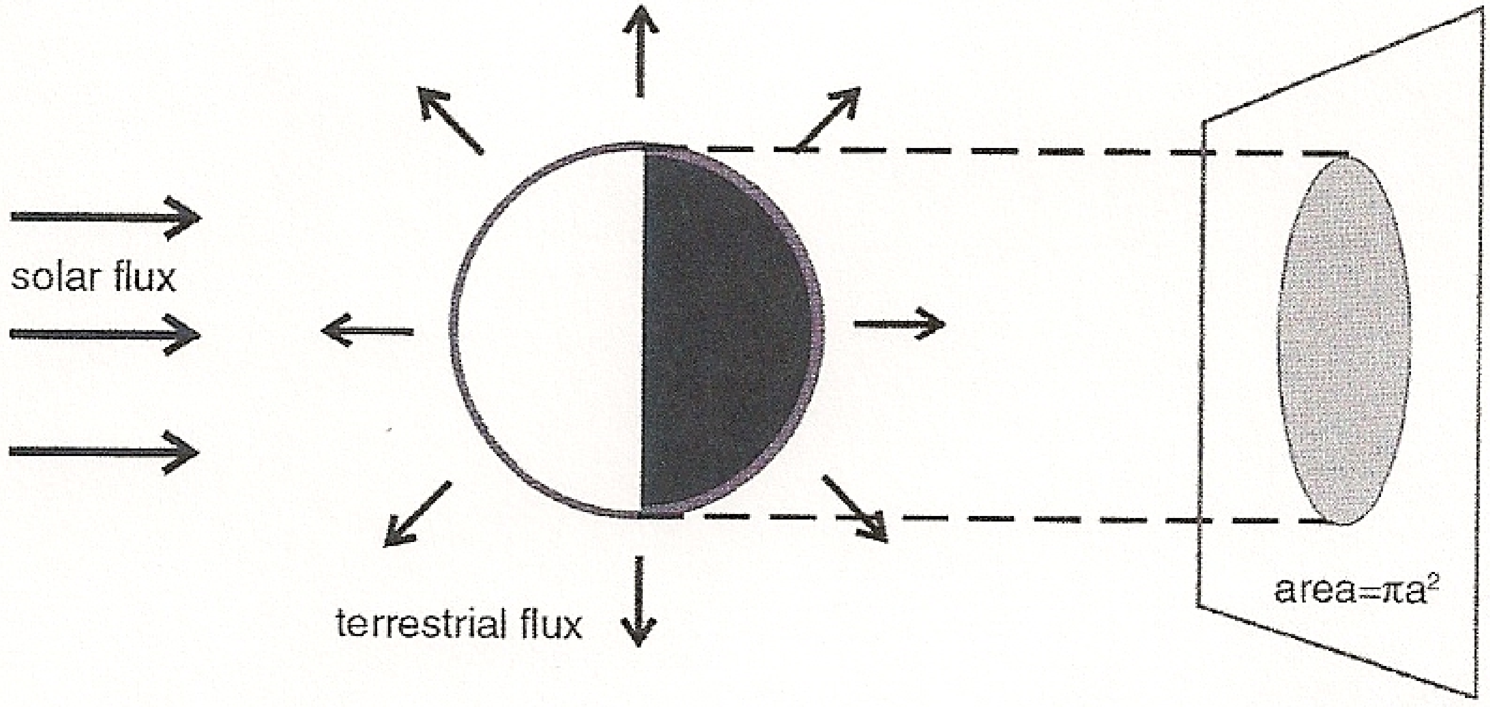


Fig. 2.4 in M&P

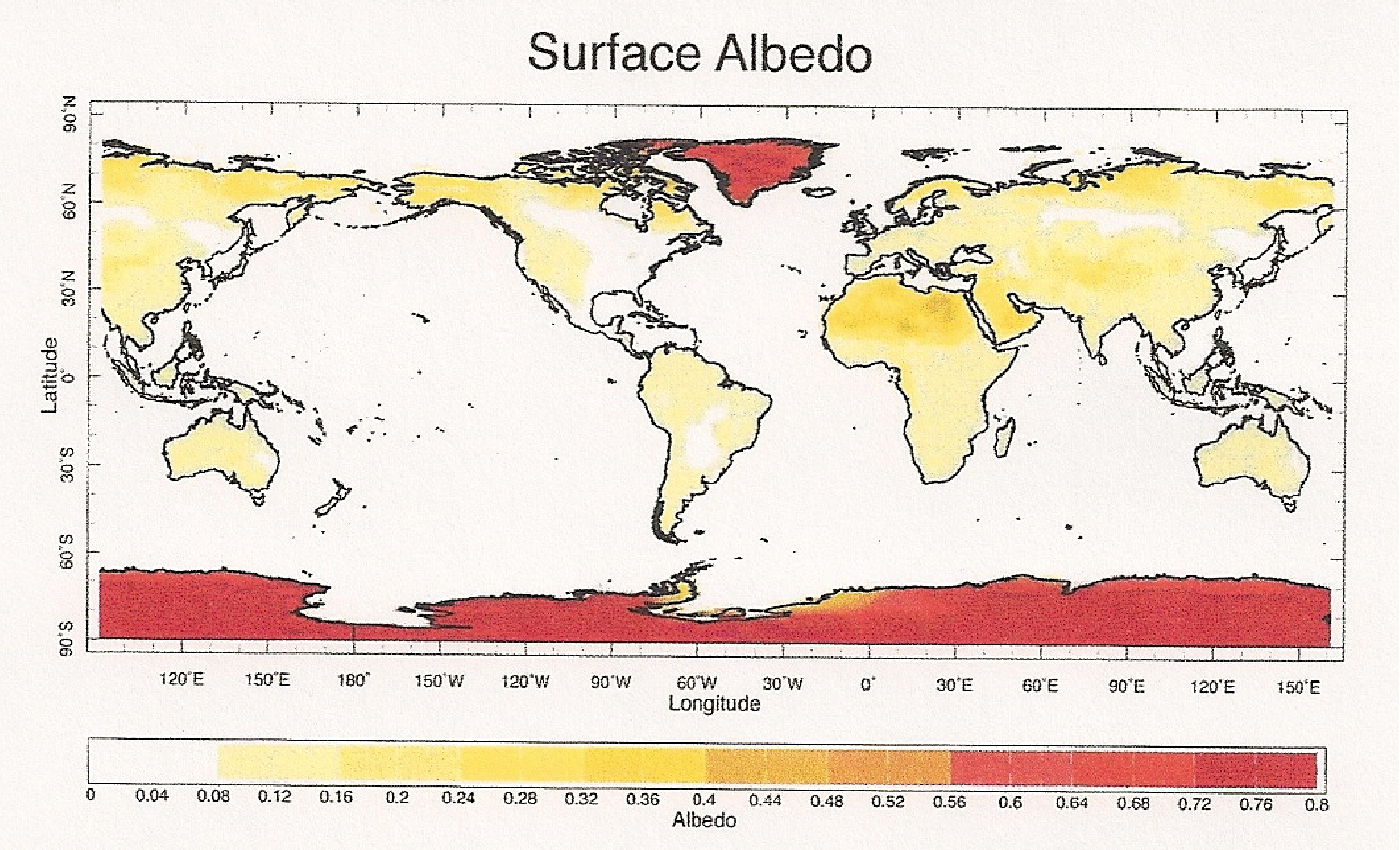
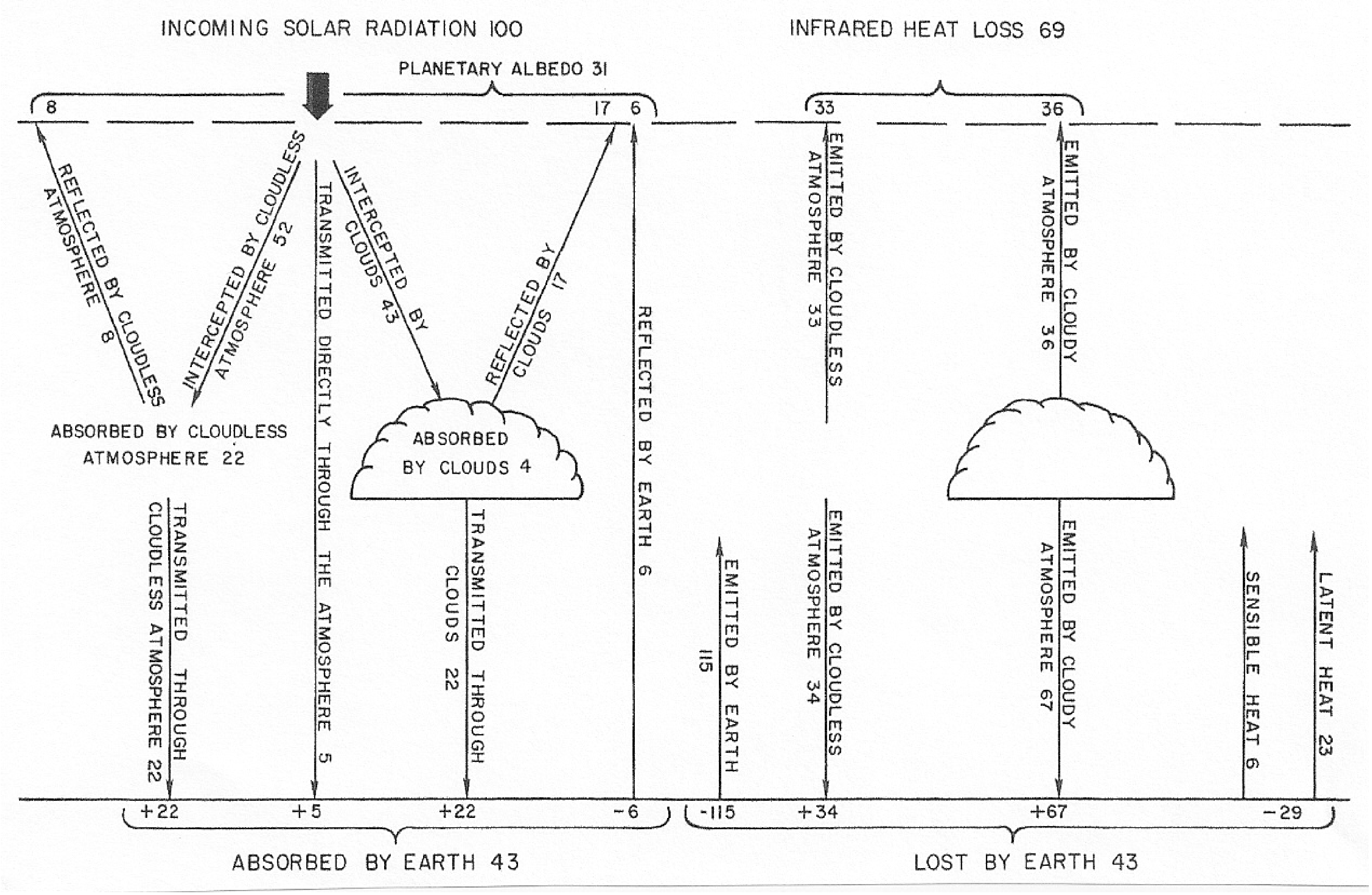


Fig. 2.5 in M&P

Cloud and molecules in the atmosphere also reflect sun light

Energy balance of global atmosphere



From Liou (1980)   (Not recent; needs some update)