# Principles of Energy Balance in Environmental Systems

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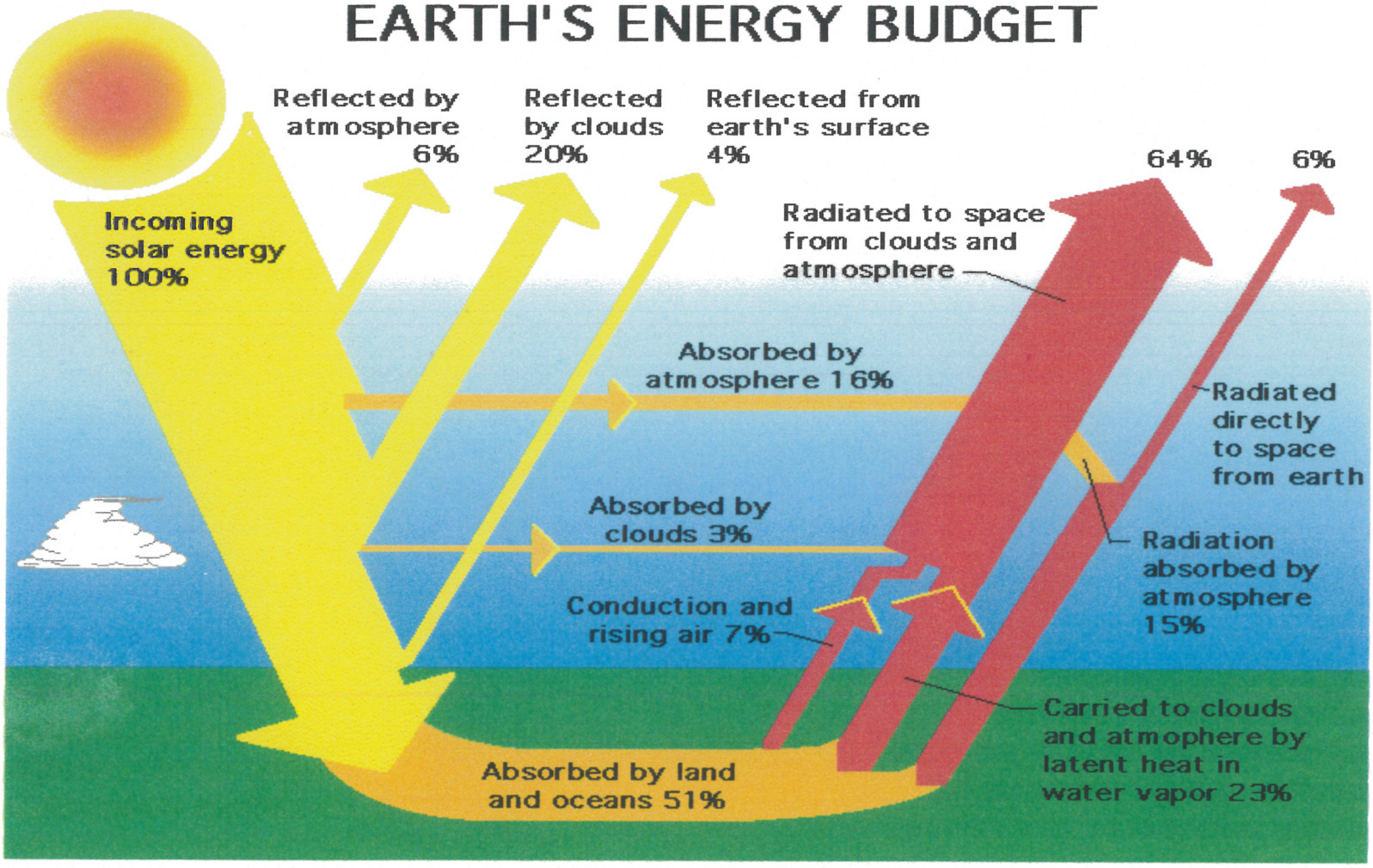
## Lecture 4

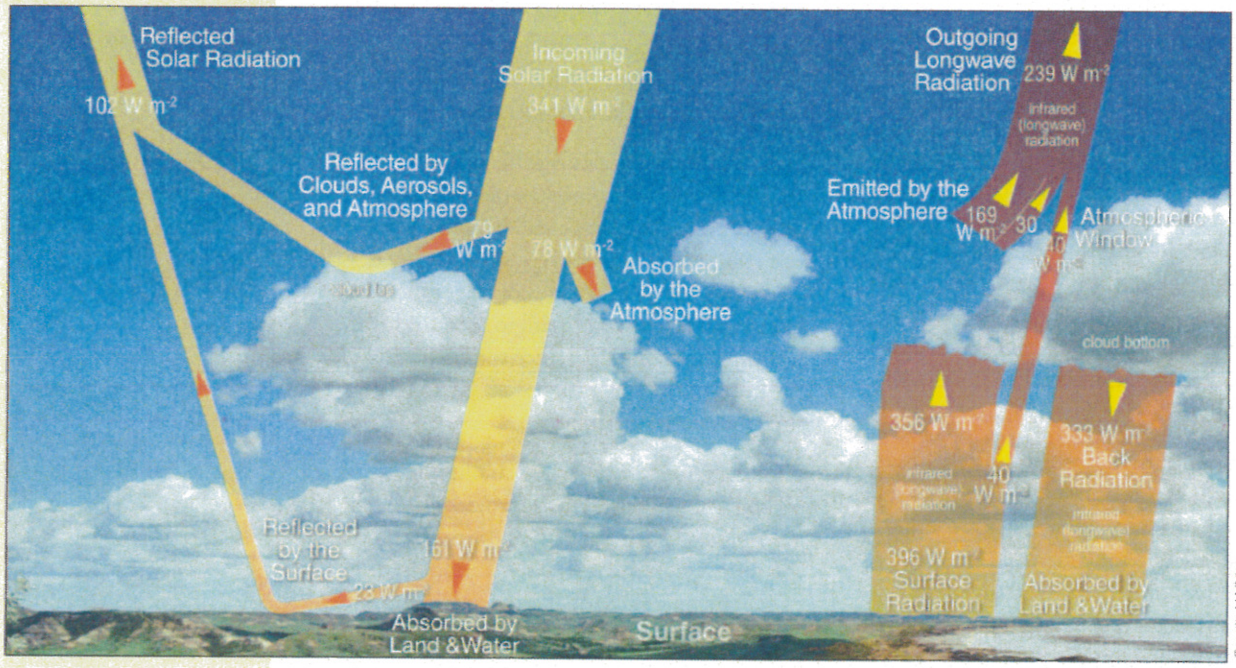
1. Understanding the radiation balance on Earth
2. Differential absorption of Shortwave radiation
3. Reflectance of longwave radiation
4. Wein's Law
5. Planck's Equation

# EARTH'S ENERGY BUDGET



# The Energy Budget

## Energy In, Energy Out




Above: About a quarter of incoming solar radiation gets reflected back to space by the atmosphere and a quarter gets absorbed. The rest reaches the surface, where it is absorbed by land and water.

Energy in, energy out: The balance between the two allows life to thrive on Earth. But that balance—between incoming radiation from the sun and outgoing radiation reflected and emitted by Earth—is extraordinarily delicate.

Ramp up the amount of energy trapped in the atmosphere only a small amount, and rising temperatures could evaporate the oceans and leave a scorching Earth that's reminiscent of Venus. Dial it back just a notch and Earth could become a freezing world like Mars.

Earth is a long way from either of these extremes, but our planet's climate is slowly changing. During the last century, global average temperatures at the surface have increased 0.7°C (1.3°F). And climate models estimate that temperatures will increase by another 1.1°C to 6.4°C (2.0°F to 11.5°F) during the twenty-first century.

Such amounts may seem small, yet even increases on this scale could have profound consequences for humans. Rising sea levels, changing ocean currents, and fiercer storms, coupled with altered cloudiness, rainfall patterns, and changing growing seasons are real possibilities confronting our home planet as the climate changes.

With such high stakes, understanding Earth's energy budget—the balance of incoming and outgoing radiation—is of critical importance. Indeed, in the last few decades, scientists have gone to great lengths to understand and quantify what happens to the solar radiation that constantly floods Earth's atmosphere and helps drive the climate system. Using satellites, aircraft, ground-based sensors, and a host of other scientific tools, researchers have determined the outlines of Earth's energy budget.

Scientists estimate that on average each square meter of the atmosphere receives 341 watts of radiation from the sun, less than half of what reaches the top of Venus' atmosphere, and about twice as much as Mars receives.

Not all of that radiation will affect Earth's climate. About 23 percent of it reflects off clouds and certain types of airborne particles—called aerosols—and back into space. Another 7 percent of the sun's radiation gets reflected by the surface. The rest gets absorbed by atmospheric gases, aerosols, or Earth's surface and can affect the climate system.

There's a catch behind these numbers. The climate system is stunningly complex, and scientists are still in the process of refining their understanding of the energy budget to better predict how even the most subtle changes in energy might affect the climate.

It's well-understood, for example, that greenhouse gases can heat the lower atmosphere and change the balance between incoming and outgoing energy. Indeed, an Intergovernmental Panel on Climate Change (IPCC) report published in 2007 listed the level of scientific understanding about greenhouse gas effects as "high."

Yet to predict how climate change will continue to unfold, scientists need more information about aerosols. These particles tend to cool Earth by reflecting light and changing the behavior of clouds. Like greenhouse gases, aerosols can have a strong impact on climate, but many questions remain about the global distribution of the particles, the degree to which darker aerosols absorb sunlight and heat the atmosphere, and how the particles affect clouds. These uncertainties caused the IPCC to call for more research into aerosols.

Solar variations are also capable of forcing the climate to warm or cool. Overall, scientists believe the sun has brightened slightly in the last 100 years, causing a very small degree of warming. Though they are confident that solar variations are too small to account for the warming seen on Earth since the beginning of the industrial era, questions remain about the sun's long-term variability.

Glory, a climate-observing satellite, will extend and improve measurements of both aerosols and solar variability. In doing so, the mission will refine scientists' understanding of Earth's energy budget and improve our ability to predict how climate change will impact different regions of Earth.

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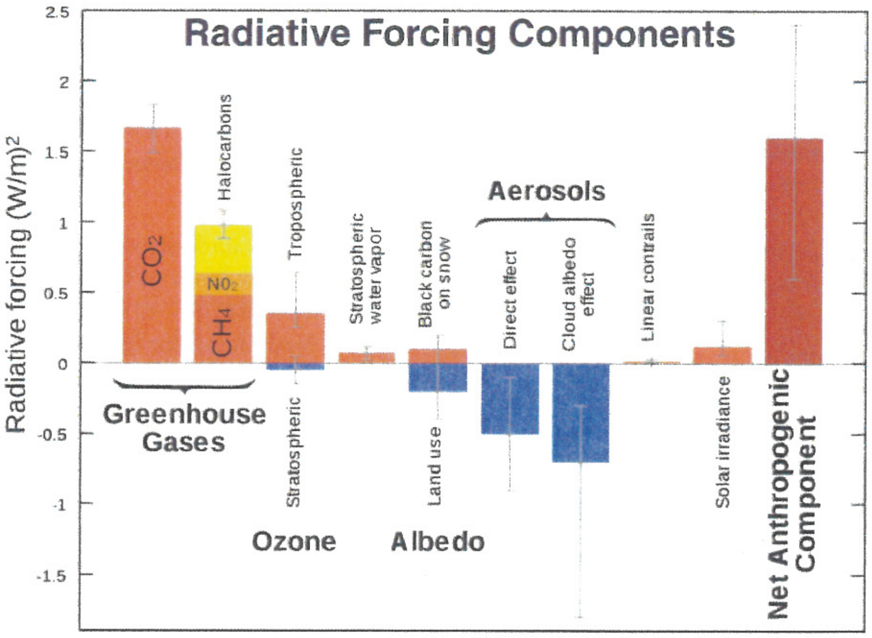



Credit: IPCC/Graph adapted by Leland McInnes

Left: Most aerosols have a cooling effect (in blue) on the climate because of the way the particles scatter incoming radiation and change cloud properties. As a result, aerosols tend to counteract the strong warming effect of greenhouse gases (in red) such as carbon dioxide, methane, and ozone. The sun is thought to be responsible for some warming, though the proportion is far less than that caused by human activity (the net anthropogenic component).

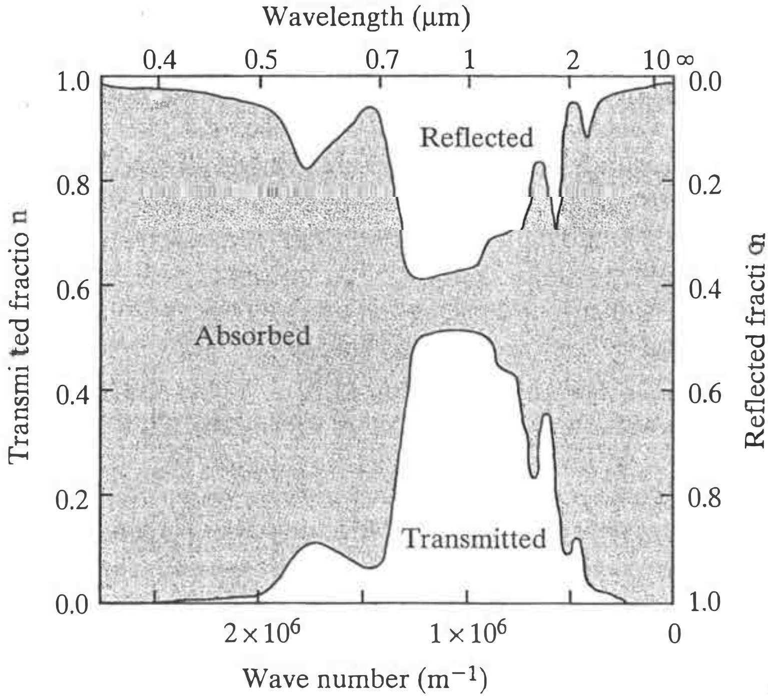



**Figure 7-4.** Representative fractions of irradiation absorbed (shaded region), reflected, and transmitted by a leaf as a function of wave number and wavelength. The sum $a_\lambda + r_\lambda + t_\lambda$ equals 1.

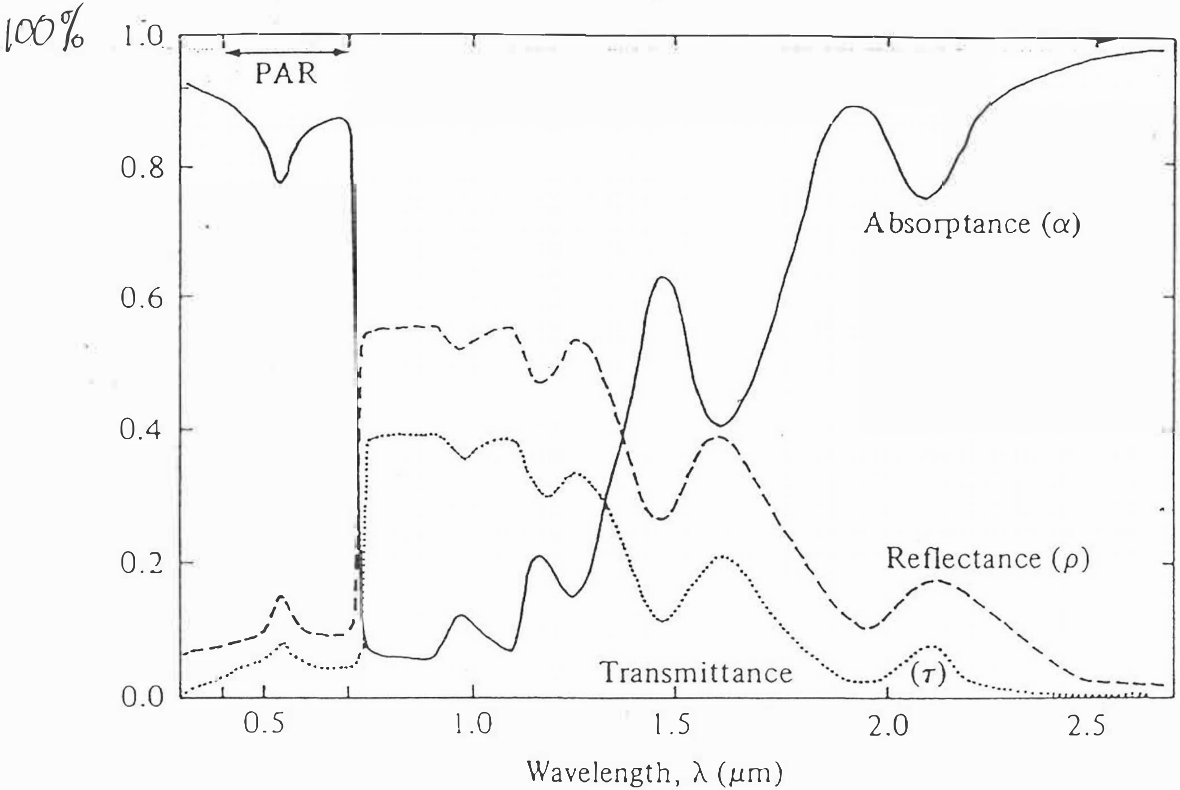



Fig. 2.12. Absorption, transmission and reflection spectra for 'typical' leaves (mean from various sources).

PAR = PHOTOSYNTHETICALLY ACTIVE RADIATION

# ----- Typical values -----

Reflectance of Shortwave radiation (albedo) (280 to 2800 nm)

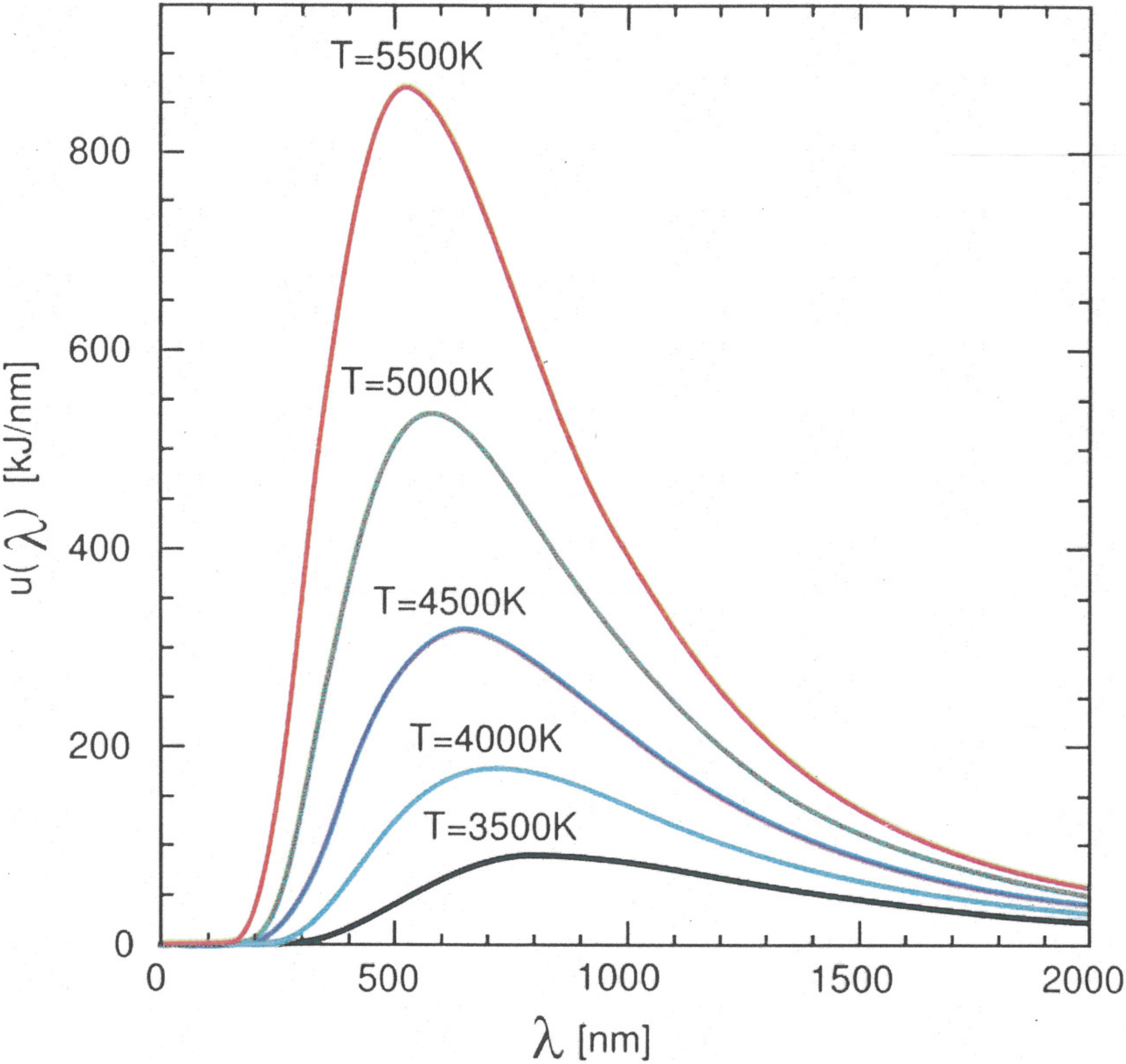
Emittance or absorbance of long wave radiation (4,000 to 100,000 nm)

| Surface | albedo | emissivity or absorptivity |
|---|---|---|
| Theoretically perfect black body | 0.00 | 1.00 |
| Fresh, clean snow | ~ 0.9 | ~ 0.8 |
| Old snow | ~ 0.8 | ~ 0.8 – 0.9 |
| White paper | ~ 0.8 | ~ 0.9 |
| Black paper | ~ 0.05 | ~ 0.9 |
| Moist soil | ~ 0.1 | ~ 0.9 |
| Dry soil | ~ 0.2 | ~ 0.9 |
| Single flat leaf | ~ 0.25 | ~ 0.96 |
| Plant community with vertical leaves | ~ 0.23 | ~ 0.98 |
| Plant community with more horizontal leaves | ~ 0.25 | ~ 0.96 |
| Aluminum foil | ~ 0.9 | ~ 0.03 |
| Human skin | ~ 0.5 | ~ 0.98 |

## Radiation is either reflected, transmitted, or absorbed by leaves

The fraction of radiation absorbed varies widely depending on the type of radiation.

| | ------ Total shortwave radiation -------- | | --Total longwave radiation-- |
|---|---|---|---|
| | Photosynthetic (400 to 700 nm) | Near infrared 700 to 2800 nm) | Longwave (far infrared) (4,000 to 100,000 um) |
| Reflection | 5 % | 45% | 4% |
| Absorption | 90 % | 10% | 96 % |
| Transmission | 5 % | 45 % | 0 % |
| Total | 100 % | 100 % | 100 % |



T=5500K
T=5000K
T=4500K
T=4000K
T=3500K
800
600
400
200
0
u(λ) [kJ/nm]
0
500
1000
1500
2000
λ [nm]