Radiation and the atmosphere

Of great importance is the difference between how the atmosphere transmits, absorbs, and scatters solar and terrestrial radiation streams. The most important statement that one could make is that the atmosphere is relatively transparent to solar radiation but is relatively opaque to terrestrial radiation.

In the absence of dense clouds, a large fraction of the incident solar radiation penetrates the atmosphere and reaches the surface. Most of the radiation (longwave) emitted by the earth surface is absorbed by the atmosphere but, because the atmosphere is a good absorber, it is also a good emitter (Kirchhoff’s law) and reemits a large portion of the absorbed energy back to the surface. This is the “green house effect”.

Scattering of solar radiation

The scattering of sunlight in atmosphere is responsible for the blue color of the sky in clear conditions and also for the lack of color when the air is laden with pollutants (unless pollutants are also selective absorbers in which case the sky, especially the lowest layers when viewed from the side, can appear a murky brown).

The blue or colorless appearances of the sky result from two distinct types of scattering:

1) Rayleigh scattering is by particles (molecules in this case) much smaller than the wavelength of the radiation. Rayleigh scattering is very wavelength dependent such that the scattering coefficient (a measure of the efficiency of the scattering)

$$k \propto \frac{1}{\lambda^4}$$

For example, taking the wavelength of blue light to be 0.47, and that of red light to be 0.64 μm,

$$\frac{k(\text{blue})}{k(\text{red})} \propto \left(\frac{0.64}{0.47}\right)^4 \cong 3.5$$

Thus, blue light is much more strongly scattered than red light, accounting for the blueness of the sky and for the red color of sunsets.

2) Mie scattering is by particles of the same order of size as the wavelength (such as solid particles or small liquid droplets in polluted or hazy air) is independent of the wavelength. As a result, the sky appears white or colorless when heavy with pollutants.

See also the following diagram presenting a general picture of scattering in the atmosphere.

- Show a scattering diagram

Transfer and absorption of solar radiation

Generally, a cloud-free atmosphere absorbs solar radiation (short-wave) only weakly. However, the shorter wavelengths ($\lambda <\approx 0.3\mu m$) are eliminated at high altitudes by N_2, O_2 and O_3. Strong absorption by ozone at about 50 km produces the temperature maximum at this height (the stratopause). In the near infrared, water vapor has several rather weak absorption bands. See the following two diagrams for details.

- Show a diagram for absorptivity

Clouds absorb some solar radiation but are mostly responsible for scattering and for reflection of solar energy back to space. The earth’s albedo of 0.3 is largely a consequence of the amount of cloudiness.

Atmospheric absorption of terrestrial radiation

The spectral absorptivities shown in the following diagram clearly show the large differences between absorption and transmission of solar and terrestrial radiation. Again, the atmosphere is relatively transparent to solar radiation but nearly opaque to terrestrial radiation. Recalling that the spectrum of terrestrial radiation spans a range from about 4 μm to 100 μm with a peak at about 10 μm, we see that most radiation emanating from the earth surface would be absorbed by the atmosphere, with water vapor and CO_2 being the principle absorbers.

An atmosphere “window” appears in the absorption spectrum near the peak in the spectrum of terrestrial radiation (~10 μm) allowing longwave radiation to escape to space under cloud-free conditions. This “window” in this part of the spectrum is utilized by satellite IR imagery to observe cloud cover and other features both day and night.

Clouds are very strong absorbers of longwave radiation.

The earth/atmosphere energy budget

Being a good absorber of longwave radiation, and according to Kirchhoff’s law, the atmosphere is also an excellent emitter of radiation of the same spectral composition. Clouds are also good emitters of terrestrial radiation according to their temperature, warm (usually low) clouds emit more strongly than cold (usually high) clouds, as dictated by the Stefan-Boltzmann law.

This absorption and emission of terrestrial radiation plays a large role in governing the energy balance of the earth/atmosphere system and is the reason that changes in the concentration of “greenhouse” gasses are likely to have an impact on global climate.

The following diagram summarized, in a globally averaged manner, the exchanges of energy that take place between the earth’s surface, the atmosphere, and space. All the numbers are normalized to 100 units of incoming solar radiation. Note the large magnitudes associated with longwave radiation, some of the numbers even larger than that of the ultimate energy source, the sun.

Radiative Energy Budget

Earth/atmospheric system

Net solar absorbed	70	
Net longwave emitted	-70	
	0	

Earth surface

Net solar absorbed	45	
Net longwave emitted	-16	
	29	net gain

Atmosphere

Net solar absorbed	25	
Net longwave emitted	-54	
	-29	net loss