4. Interaction of Solar Radiation with the Atmosphere

In the previous chapters only the extraterrestrial radiation has been considered; i.e., the radiative transfer through the atmosphere was not influended by the atmosphere. ⟶ deterministic radiation calculation; only solar geometry

As solar radiation passes through the earth's atmosphere, some of it is absorbed or scattered by air molecules, water vapor, aerosols, and clouds. The solar radiation that passes through directly to the earth's surface is called direct solar radiation. The radiation that has been scattered out of the direct beam is called diffuse solar radiation. The direct component of sunlight and the diffuse component of skylight falling together on a horizontal surface make up global solar radiation.

Determining the irradiance at the surface requires knowledge of the influence of the atmosphere. Looking at the different components in the atmosphere which could influence the radiation transfer, mainly two groups have to be considered: The gaseous molecules of dry air which are uniformly mixed both in the horizontal and in the vertical below heights of 80 km and the highly variable amounts of water vapour (H_2O) and aerosol particles. Water vapour is present in a range between 0 and 4 per cent of the humid atmosphere with a vertical profile showing a strong decrease of concentration with height.

Finally, the liquid and solid water contained in clouds has to be considered as a main attenuator of solar radiation in the atmosphere.

Table 4.1. Composition of the dry atmosphere by volume (ppm = parts per million).

Nitrogen	78.08 %
Oxygen	20.95 %
Argon	0.93 %
Carbon Dioxide	350 ppm
Neon	18 ppm
Helium	5 ppm
Krypton	1 ppm
Hydrogen	0.5 ppm
Ozone	0.05-12 ppm (variable)

The main processes for the extinction of solar radiation passing through the atmosphere are:

– absorption by ozone

- absorption by uniformly mixed gases (O_2, CO_2)
- absorption by water vapour
- scattering by molecules of the air
- extinction by aerosol particles
- extinction by clouds (high cirrus clouds, thick clouds)

absorption:

solar radiation is converted to heat by atmospheric constituents; this energy is lost!
strongly wavelength dependent; occuring in several characteristic wavelength bands

scattering:

scattering changes direction and wavelength of the radiation; no conversion!
solar radiation is scattered partly back to space!
scattering is strongly wavelength dependent: Rayleigh-scattering ($d < \lambda$) due to molecules follows an λ^{-4}-law, Mie-scattering ($d \sim \lambda$) due to aerosols is approximately $\lambda^{-1.5}$-dependent.

Scattering is a process whereby light is actually absorbed by a particle and then emitted in another direction. Scattering particles can be air molecules, dust particles, water droplets, gases or particulates, which scatter incoming sunlight (or moonlight) in all directions. Scattering can also be viewed as a reflection off of the scatterer.

Selective scattering (or Rayleigh scattering) occurs when certain particles are more effective at scattering a particular wavelength of light. Air molecules, like oxygen and nitrogen for example, are small in size and thus more effective at scattering shorter wavelengths of light (blue and violet). The selective scattering by air molecules is responsible for producing the blue skies we often see on a clear sunny day.

Another type of scattering (called Mie Scattering) is responsible for the white appearance of clouds. Mie scattering occurs when the wavelengths of visible light are more or less equally scattered.

Rayleigh scattering models the scattering for extremely small particles such as molecules of the air. The amount of scattered light depends on the incident light angle. It is largest when the incident light is parallel or anti-parallel to the viewing direction and smallest when the incident light is perpendicular to the viewing direction.

Mie scattering is used for relatively small particles such as minuscule water droplets of fog, cloud particles, and particles responsible for the polluted sky. In this model the scattering is extremely directional in the forward direction i. e. the amount of scattered light is largest when the incident light is anti-parallel to the viewing direction (the light goes directly to the viewer). It is smallest when the incident light is parallel to the viewing direction.

The Henyey-Greenstein scattering is based on an analytical function and can be used to model a large variety of different scattering types. The function models an ellipse with a given eccentricity e. An eccentricity value of zero defines isotropic scattering while positive values lead to scattering in the direction of the light and negative values lead to scattering in the opposite direction of the light. Larger values of e (or smaller values in the negative case) increase the directional property of the scattering.

These extinction processes depend on

– amount of interacting molecules and particles (turbidity)
– path length of the radiation through the atmosphere.

⟶ concept of relative air mass

⟶ different extinction for different zenith angles even for unchanging atmosphere

Table 4.2. Contribution of atmospheric constituents to total extinction (○ = weak, • = intermediate, •• = strong).

	absorption	scattering
Ozone (O_3)	•	○
O_2, CO_2	•	○
all molecules	○	••
water vapour	••	○
aerosols	•	••
clouds	•	•

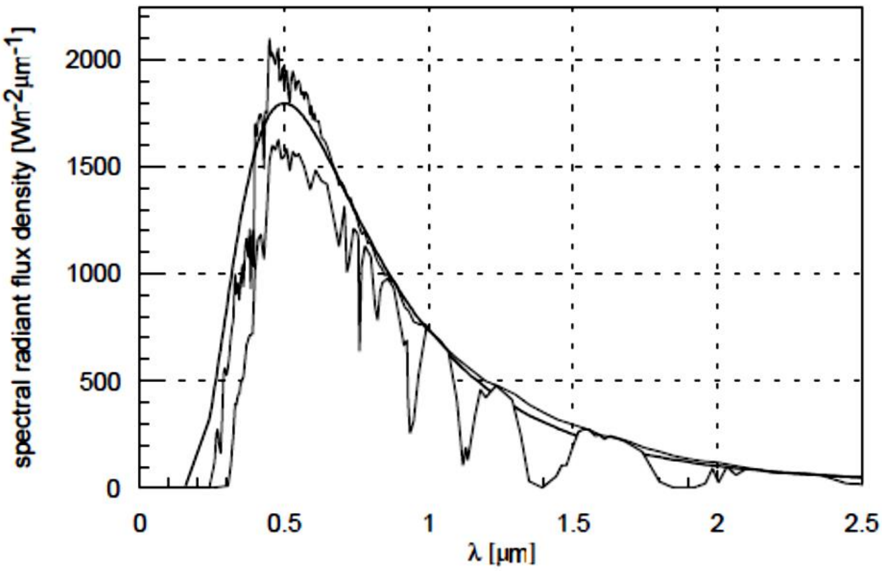

Fig. 4.1. Planck spectrum for a black body at T=5780 K (thick curve) and observed solar spectra at the top of the atmosphere (extraterrestrial, thin curve) and at the Earth surface (grey area).