

4.1 Relative Air Mass

For an assessment of extinction processes in the atmosphere it is necessary to know the total mass or 'optical path' of atmosphere which the beam traverses on its way to the surface (or the level in question).

The relative path length of direct solar beam radiance through the atmosphere is given by the ratio between the vertical optical path m and the actual optical path m_s of the solar beam. It can be described as a function of the zenith angle θ_z only:

$$\frac{m_s}{m} = \frac{1}{\cos \theta_z} = \sec \theta_z = m_r. \quad (4.1)$$

The quantity m_r is known as the *relative air mass*. In solar energy for m_r , commonly AM is used (Fig. 4.2).

Eq. (4.1) is strictly valid only for a plane parallel atmosphere. In a real, spherical atmosphere with refraction the relative air mass AM is limited to about 36.5.

More accurate values for the relative air mass at standard pressure can be obtained from (Kasten, 1966):

$$m_r = [\cos \theta_z + 0.15(93.885 - \theta_z)^{-1.253}]^{-1}. \quad (4.2)$$

Definition of relative air mass for a horizontal homogeneous atmosphere:

$$m_r = \frac{\int_0^\infty \rho ds}{\int_0^\infty \rho dz}. \quad (4.3)$$

By definition, the case of extraterrestrial radiation (i.e., no air mass at all) is described by AM 0.

Note: AM 1.5 is commonly used as a reference air mass in data sheets of photovoltaic modules.

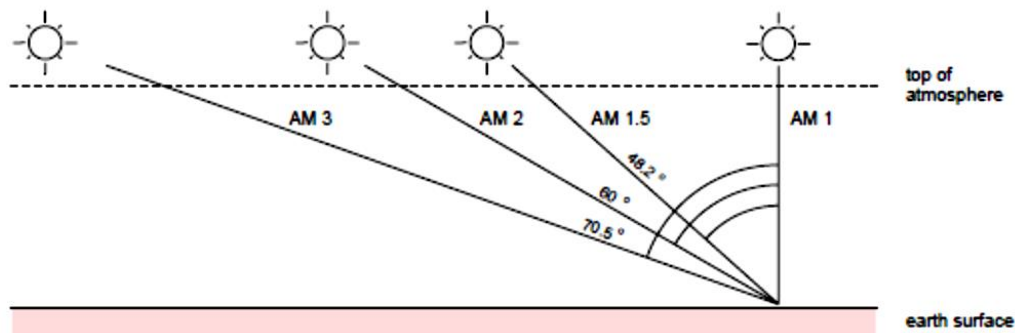


Fig. 4.2. Relative air mass and corresponding zenith angles in a plane parallel atmosphere.

4.2 Spectral Irradiance

- shift of spectrum
- spectra for clear sky
- absorption of atmospheric components

4.3 Clearness Index

The standard spectra in Chapter 4.2 apply for cloudless (i.e. clear) skies only. Thus, approximations concerning the incoming radiation are possible when geometry and atmospheric turbidity (amount of water vapour, aerosols) are known.

But: Most of the reduction in irradiance is due to clouds!

→ a quantity describing this overall reduction is the *clearness index*:

$$k_t = \frac{\int G dt}{\int G_o dt} \quad (4.4)$$

normalization of global irradiance by corresponding extraterrestrial radiation value → eliminating seasonal trend

k_t relates the global radiation to the extraterrestrial radiation and therefore gives a dimensionless number giving the percentage of the reduction of extraterrestrial

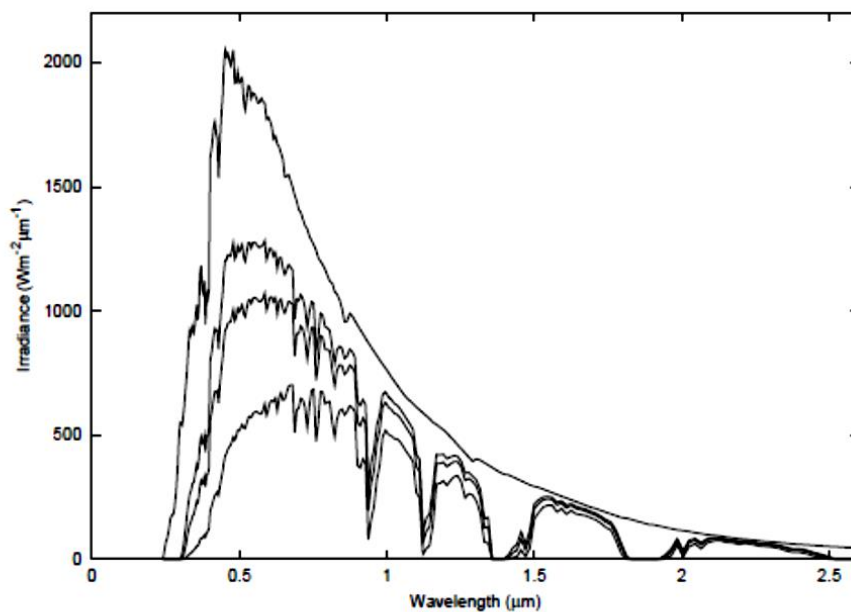


Fig. 4.3. Spectral direct normal irradiance for a clear atmosphere. different values of the atmospheric air mass (from top: AM0, AM1, AM1.5, AM3). Spectra are calculated with SB-DART using a subarctic summer atmosphere (1.42 gm^{-3} water vapour, 23 km visibility).

radiation due to absorption and scattering by air molecules, aerosols, water vapour and clouds.

Convention: k_t is commonly used in a generic sense as well as for hourly values. For daily and monthly values K_t and \bar{K}_t are used, respectively.

The clearness index eliminates the influence of the zenith angle θ_z (daily and seasonal variation) and therefore characterizes the solar radiation climate at a particular location. Several additional quantities in solar meteorology are described as a function of the clearness index.

Table 4.3. Monthly and annual mean values of \bar{K}_t .

month	latitude	J	F	M	A	M	J	J	A	S	O	N	D	annual
Bergen	60.4° N	.21	.30	.36	.42	.41	.43	.38	.40	.32	.30	.23	.20	.33
Oldenburg	53.1° N	.25	.32	.37	.41	.42	.44	.41	.45	.40	.34	.28	.23	.36
Freiburg	48.0° N	.36	.39	.42	.47	.47	.49	.51	.48	.50	.43	.35	.34	.43
Carpentras	44.1° N	.44	.49	.52	.57	.57	.61	.67	.63	.57	.55	.47	.46	.55
Almeria	36.8° N	.56	.56	.52	.59	.60	.62	.66	.64	.60	.58	.56	.58	.59
Pretoria	27.0° S	.61	.55	.58	.61	.65	.69	.54	.68	.65	.59	.58	.57	.61

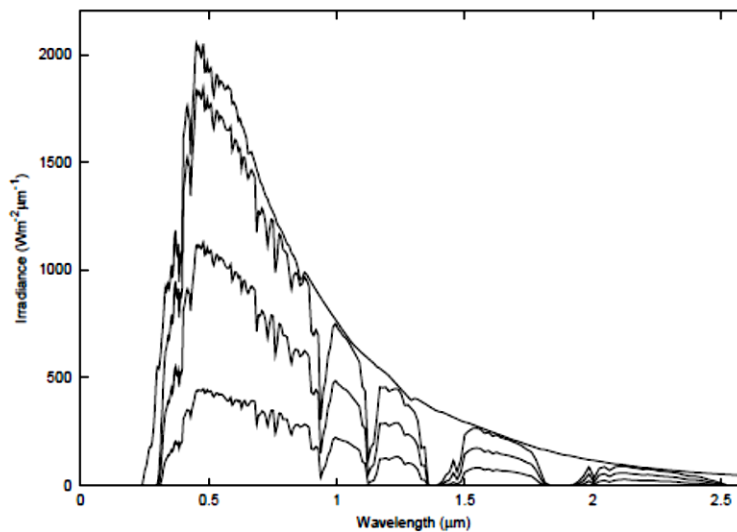


Fig. 4.4. Spectral global irradiance on a horizontal surface for a clear atmosphere. different values of the atmospheric air mass (from top: AM0, AM1, AM1.5, AM3). The corresponding total global irradiances are 1367, 1083, 669 and 276 Wm^{-2} , respectively. Spectra are calculated with SBDART using a subarctic summer atmosphere (1.42 gm^{-3} water vapour, 23 km visibility).

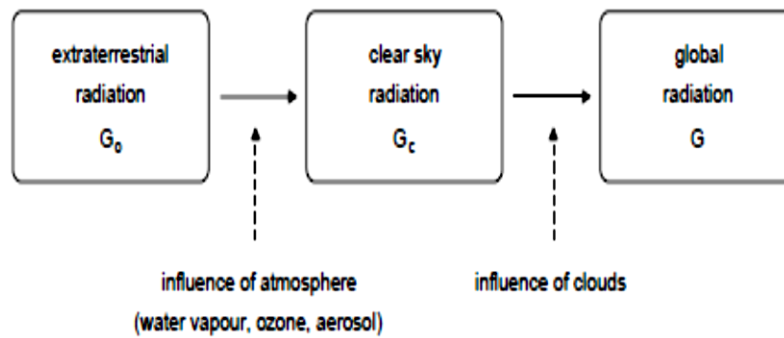


Fig. 4.5.

To eliminate also the influence of the increasing air mass with increasing zenith angle frequently the clear sky index k_t^* is used:

In this case, a standard clear sky radiation has to be considered for comparison. For AM 1.5 with given concentrations of water vapour and ozone, these values are tabulated in a spectrally resolved form.

Figure: Extraterrestrial radiation G_0 , global radiation G , clearness index k_t and clear sky index k_t^* for site xxx, date yyy.