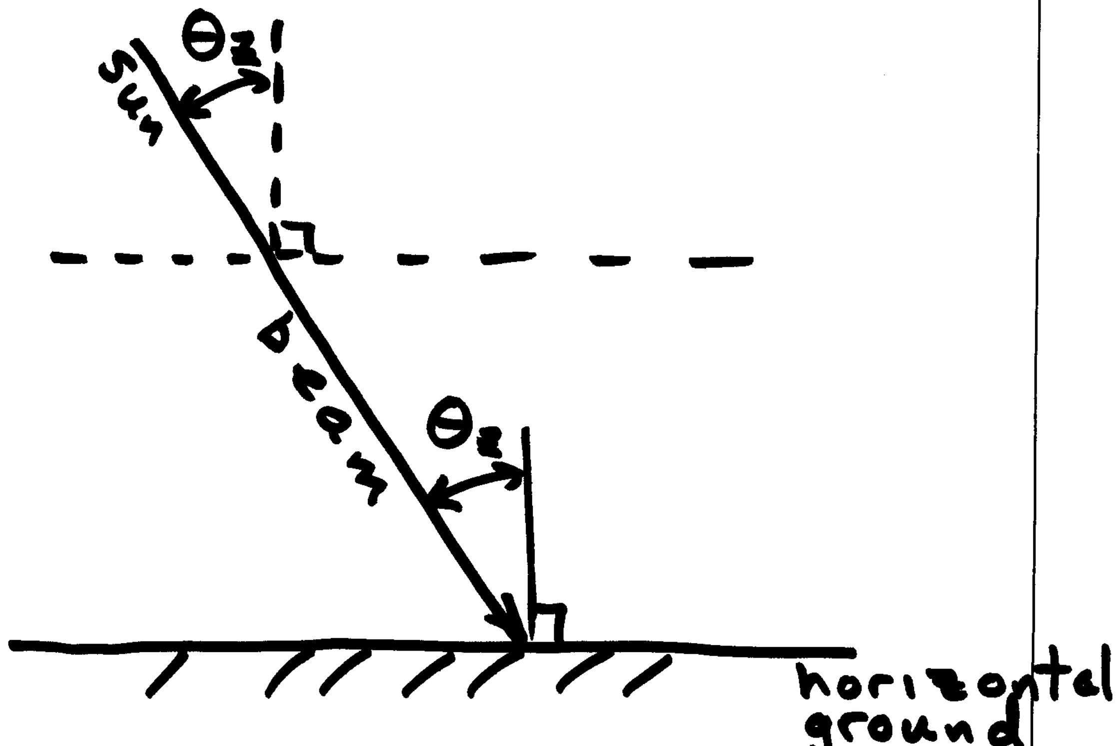
Lecture #5

More about solar energy fluxes and angles.

Our result for the solar incidence angle is:

$$\cos\theta_z = \sin\phi \sin\delta + \cos\phi \cos\delta \cos\omega$$

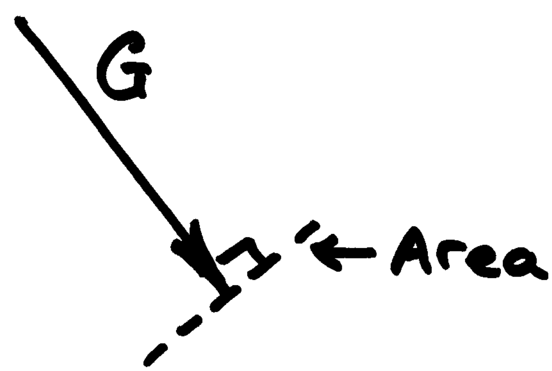
The equation holds for a surface parallel to the ground:



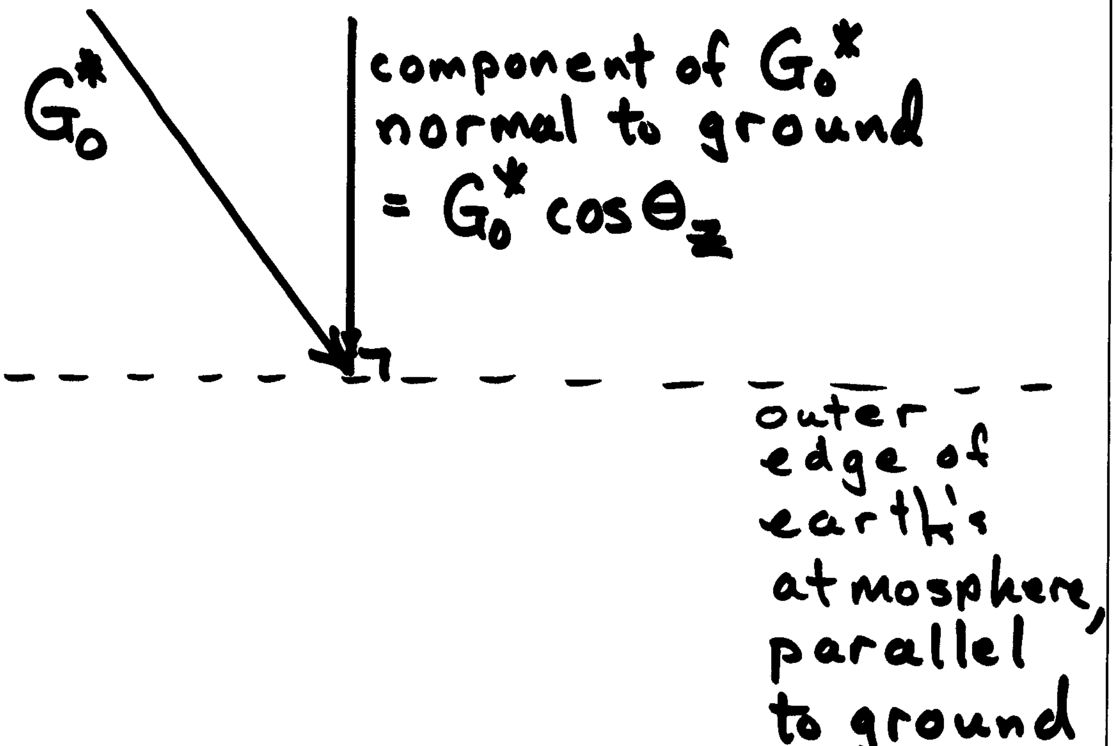
Our terminology for the different solar energy fluxes is given on the next page.

G = solar energy flux
= energy per second per unit area normal to flux
= $J/s/m^2$ = W/m^2

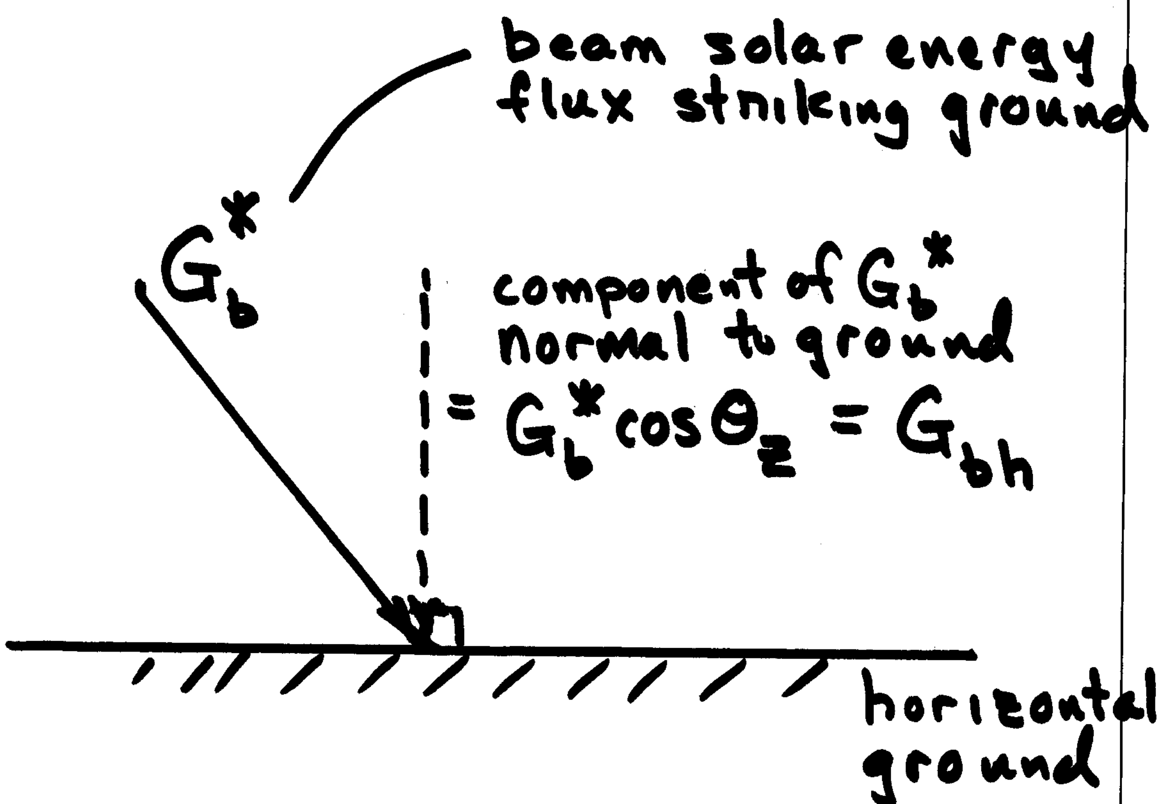
where J = joules
W = watts



The extraterrestrial solar energy flux is that flux striking the outer edge of the earth's atmosphere. It may be thought of as "the solar constant for the day". It may be thought of as the unattenuated solar beam radition. Its symbol = G_o^*.



At the ground we have:



The sun beam as it travels through the atmosphere is scattered (i.e, reflected), absorbed, and transmitted. The fraction transmitted is the G_b^* reaching the ground. The transmissivity of the atmosphere (for solar radiation) is

$$\tau = G_b^* / G_o^*$$

Molecules, water droplets, and dust particles in the atmosphere are responsible for the scattering and the absorption. Some of the scattered component goes to space, and some goes to the ground. The scattering leads to the blue color of the sky (since it is the color most efficiently scattered by molecules), and to the yellow color of the sun and to the red color of the setting sun (since the blue end of the visible spectrum is scattered away, and the longer wavelengths persist in the beam).

Absorption of solar radiation leads to heating of the atmosphere.

An empirical equation for atmospheric transmissivity for a "standard clear day" is:

$$\tau = 0.5\left(e^{-0.65m} + e^{-0.095m}\right)$$

where:

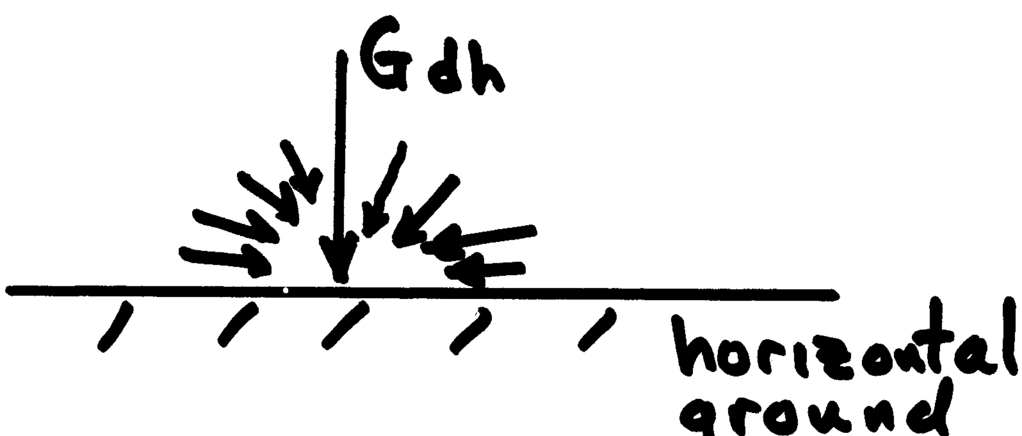
m = function of elevation above sea level and θ_z

The sea level expression for m, with $\alpha = 90 - \theta_z$, is

$$m = \left[1229 + (614\sin\alpha)^2\right]^{1/2} - 614\sin\alpha$$

At sunrise and sunset, the sun's path through the atmosphere is long, and this causes τ to decrease. At noon, the path is short, and τ is larger.

The scattered solar radiation reaching the ground is called the diffuse solar energy flux. Its symbol is G_d. For G_d falling on the horizontal ground, its symbol is G_{dh}



The diffuse radiation reaching the horizontal ground is assumed to come from all parts of sky. There is no directional preference. Thus, the resultant vector for G_{dh} is vertical down as shown.

Near sunrise and sunset this assumption breaks down - direction does matter. However, we will neglect this effect since the amount of radiation received early and late in the day is small.

The total solar energy flux received by the ground is:

$$G_{th} = G_b^* \cos\theta_z + G_{dh}$$

We also call this the global solar energy flux.

GLOBAL = G_{th}.

The solar radiation data given by the rredc.nrel.gov web site, in the hourly tables, are solar energy values for one hour per square meter. The hour is the hour preceding the time listed. That is, 13 hr means 12-13 hr.

The solar data are:

watt-hours / m^2

When we divide these data by 1 hour, we are converting them to the average solar energy flux for one hour:

average W / m^2

If we sum up all of the hourly values for the day, we obtain the solar energy per m^2 received for a day. The symbol for the solar energy/m^2/day is H. This done for all of the solar energy per m^2 received by a horizontal surface at ground level is:

$$H_{th} = \sum_{\substack{\text{sum} \\ \text{over} \\ 24 \\ \text{hours}}} G_{th}$$

Such data are found in the daily rredc.nrel.gov tables. H data for each day in a month are averaged. 30 years averaged data are also given.