Energy and Environment II

Lecture #2

How much solar energy flux strikes the earth?

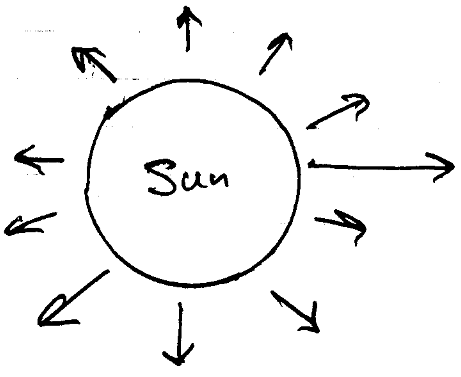
Definition:

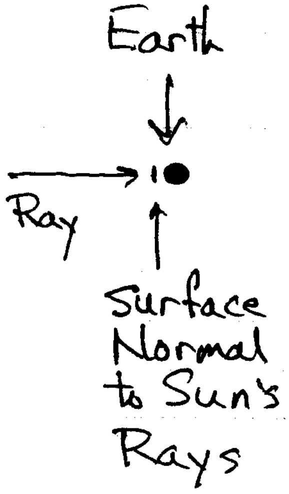
$$\underline{\text{Solar}}\ \underline{\text{Energy}}\ \underline{\text{Flux}} = \frac{\text{Energy (as Joules)}}{\text{Second-Square Meter Normal to Sun's Rays}}$$

$$= \text{J/s-m}^2$$

$$= \text{watts/m}^2$$

Picture:





There are two ways to determine the solar energy flux striking the outer edge of the earth's atmosphere:

1) Look up the data:

Go to http://rredc.nrel.gov

Click "Solar Radiation Resource Info"

Click "Archived Data"

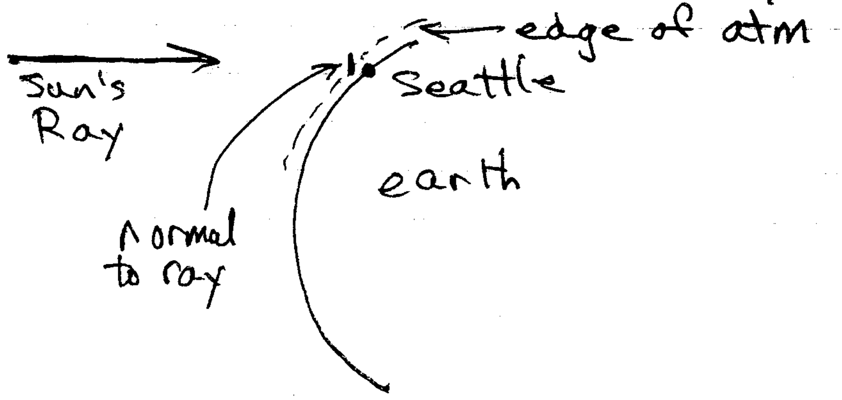
Click "Hourly Data Files"

Click a year, say 1990

Click a city, say Seattle

A BIG spread sheet comes up:

Column 1 = year
Column 2 = month
Column 3 = day
Column 4 = hour
Column 6 = solar energy flux at edge of earth's atm (above Seattle) normal to sun's rays



scanning of the spread sheet shows the following:

- Max = 1415 w/m² (in late Dec, early Jan)
- Min = 1321 w/m² (in late June, early July)
- Spring Equinox (March 21) = 1378 w/m²
- Autumn Equinox (Sept 21) = 1356 w/m²

Average = <u>1367</u> w/m²

The average is called the "solar constant"

However, it is not exactly constant: it varies by ± 3.5% over the year, due to the earth's orbit eccentricity

2) An alternative method is to calculate the solar constant from the sun-earth geometry and the temperature of the sun. A good web site for info about the sun is:

http://seds.lpl.arizona.edu/billa/trip/sol.html

(To view the earth web site, type "earth" in place of "sol".)

From this web site, we learn:

Diameter of sun = $d_s = 1.39 \times 10^6$ km

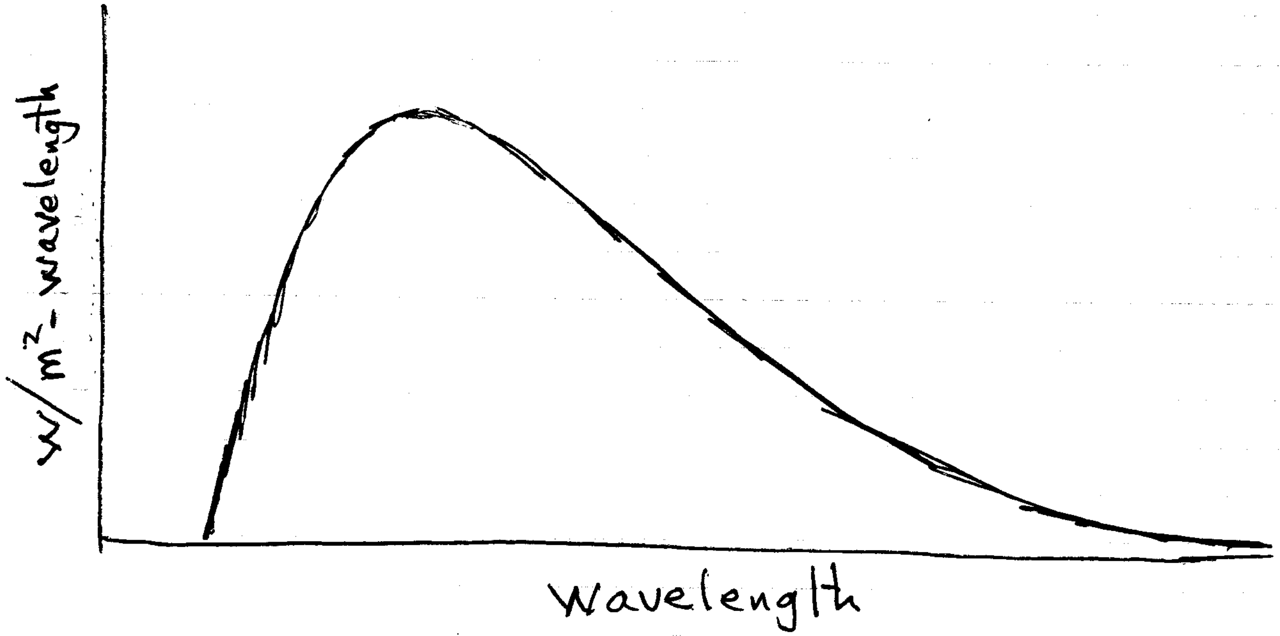
Diameter of earth = $d_e = 1.2756 \times 10^4$ km

Distance from center of sun to earth $= L = 1.496 \times 10^8$ km

The "blackbody" surface temperature of the sun is about 5780K.

The radiative emission of the sun is approximated as "blackbody" emission.

A "blackbody" is a body that absorbs and emits electromagnetic radiation, but does not reflect and transmit electromagnetic radiation. A "blackbody" has a distribution of radiation as a function of wavelength expressed by the Planck blackbody distribution law:



Blackbodies emit without preference to direction.

Integration of this curve over all wavelengths gives the energy flux of a blackbody as:

$$\sigma T^4 \quad (W/m^2)$$

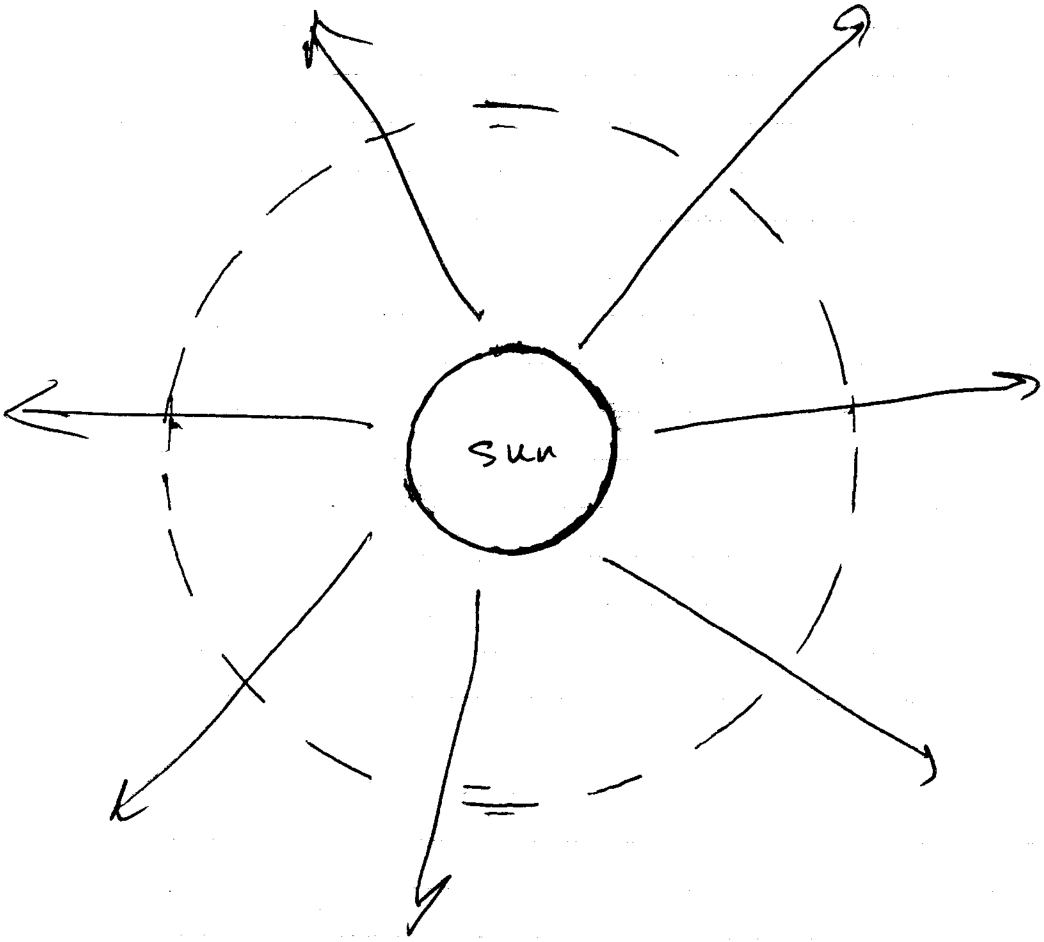
where:

σ = Stefan-Boltzmann constant
= 5.67×10^{-8} $W/m^2\text{-}K^4$

Thus, the watts of solar power emitted (on average) by the surface of the sun, into all directions, is:

$$\pi d_s^2 \, \sigma T_s^4$$

This power is constant as the power is spread over the surface of a bigger and bigger sphere as the rays move away from the sun.



when the rays reach the earth the energy flux (or power per area) is:

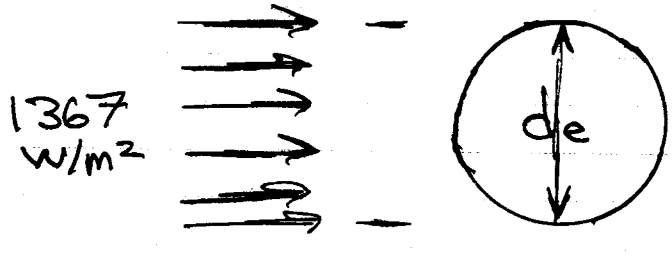
$$\frac{\cancel{\pi}\, d_s^2\, \sigma T_s^4}{4\cancel{\pi} L^2} = \sigma T_s^4 \left(\frac{d_s}{2L}\right)^2$$

$$= 5.67\times10^{-8}(5780)^4\left(\frac{1.39\times10^{6}}{2\times1.496\times10^{8}}\right)^2$$

$$\doteq 1366 \ w/m^2$$

which is very close to the preferred value of $\underline{\underline{1367}}\, w/m^2$

Next, let's distribute the solar flux around the spherical sphere area of the earth:



$$\underbrace{1367(w/m^2)\times\underbrace{\frac{\pi}{4}d_e^2\,(m^2)}_{\text{disk area of earth}}}_{\text{Solar power received by earth}} = X\ \underbrace{\pi d_e^2}_{\text{spherical surface area of earth}}(m^2)$$

$$X = \frac{1367}{4} = \underline{\underline{342}}\ w/m^2$$

Average solar flux
striking the edge of
the earth's atmosphere
(averaged over night & day,
and over all locations)

About 30% of this solar flux is reflected back into space by the earth and its atmosphere.

The remaining 70% of the solar flux is absorbed by the earth and its atmosphere.

On average, 52% of the 342 w/m^2 reaches the earth's surface

$$= 178\ w/m^2$$

This is the average solar flux averaging over night and day, averaging over all weather conditions, and averaging over all locations.

Seattle's average is 139 w/m²
(average over the year)

A very sunny place on the earth would receive about 300 w/m²

What about the instantaneous solar flux striking the ground?
What about Seattle on a sunny summer day.
Look at the rredc.nrel.gov Seattle data for:
13.0 hrs, 6/24/90
This shows:

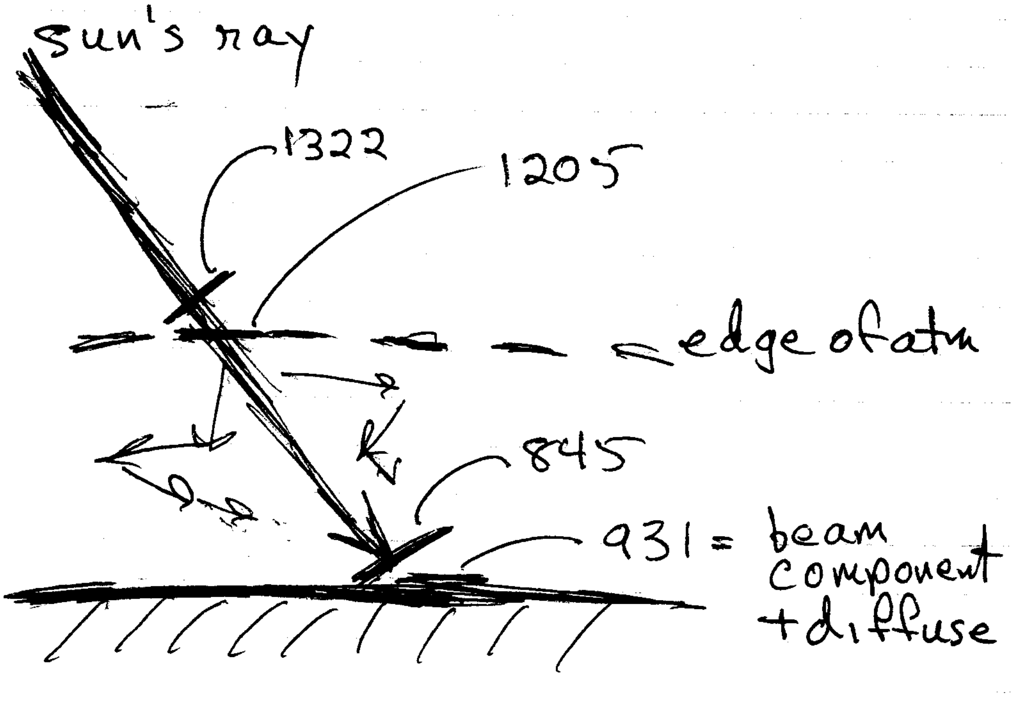
column 6: Solar flux at edge of earth's atm above Seattle, normal to sun's rays = 1322 w/m²

column 5: Solar flux at edge of earth's atm above Seattle, for surface parallel to ground = 1205 w/m²

column 7: Solar flux at ground, surface parallel to ground
= 931 w/m² (This is about as good as it gets in Seattle).

column 9: Solar flux at ground, surface perpendicular to sun's ray's
= 845 w/m^2
(we call this beam radiation)

column 11: Solar flux at ground, surface parallel to ground, diffusion radiation
= 161 w/m^2



Note:

$$931 = 845 \cos\theta_z + 161$$

Very sunny locations on the planet, that is, deserts, may reach almost 1100 w/m² on very sunny days at solar noon.