ME 476
Solar Energy

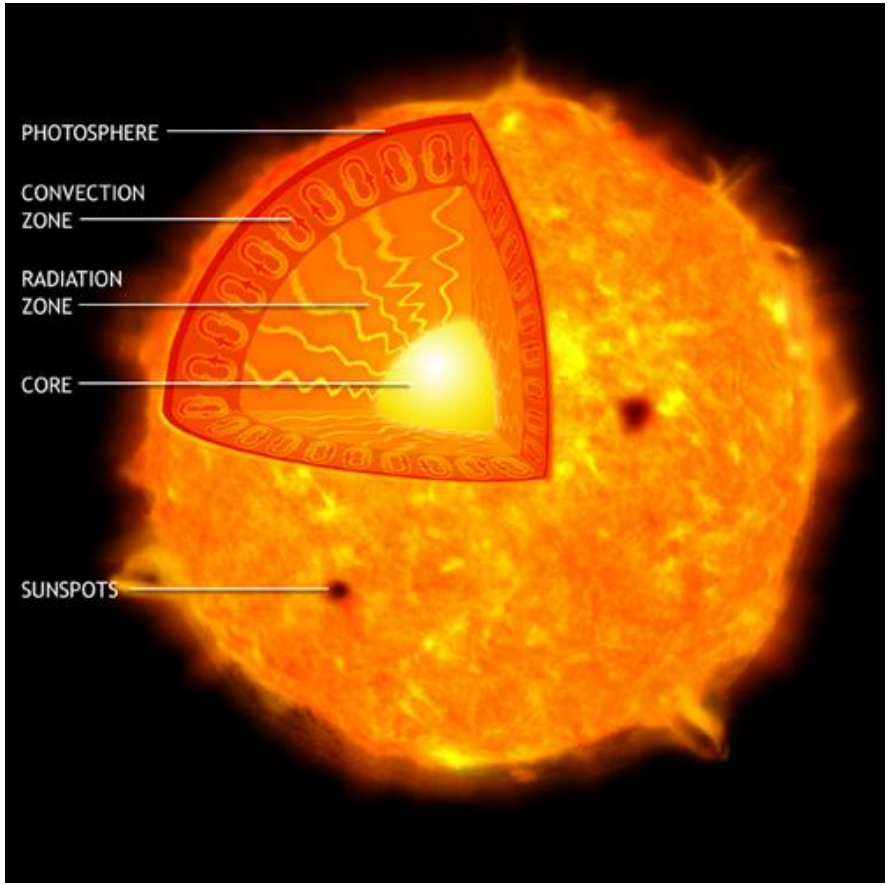
UNIT THREE
SOLAR RADIATION

Unit Outline

- What is the sun?
- Radiation from the sun
- Factors affecting solar radiation
  - **Atmospheric effects**
  - **Solar radiation intensity**
  - **Air mass**
  - **Seasonal variations**
- Calculating time
- Solar angles

What is the Sun?

- The sun is a gaseous body composed mostly of hydrogen and some helium.
- The huge gravitational force causes intense pressure and temperature at the core.
- These conditions initiate nuclear fusion reactions.
- The sun fuses hydrogen into helium at its core and the resulting energy radiates outward.
- Energy is convected to the photosphere



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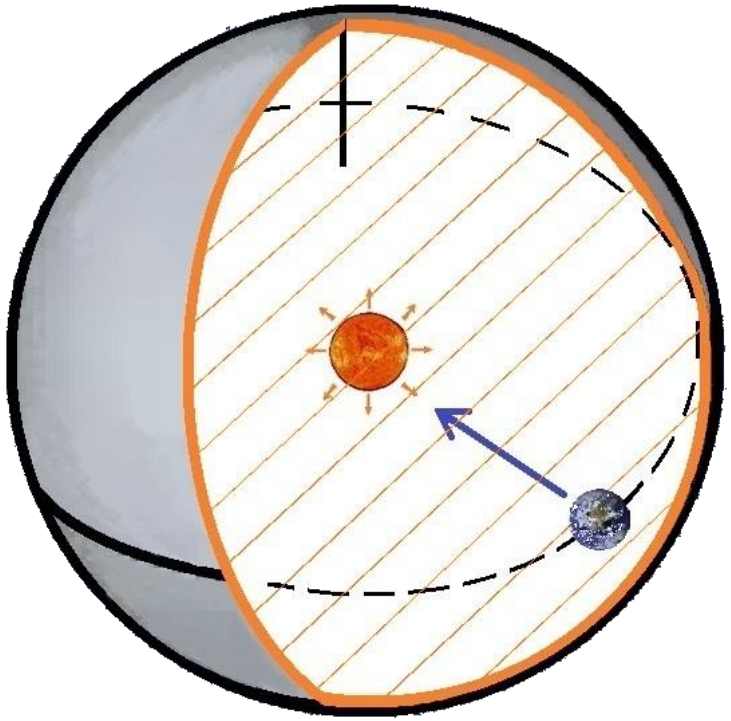
Radiation from the Sun

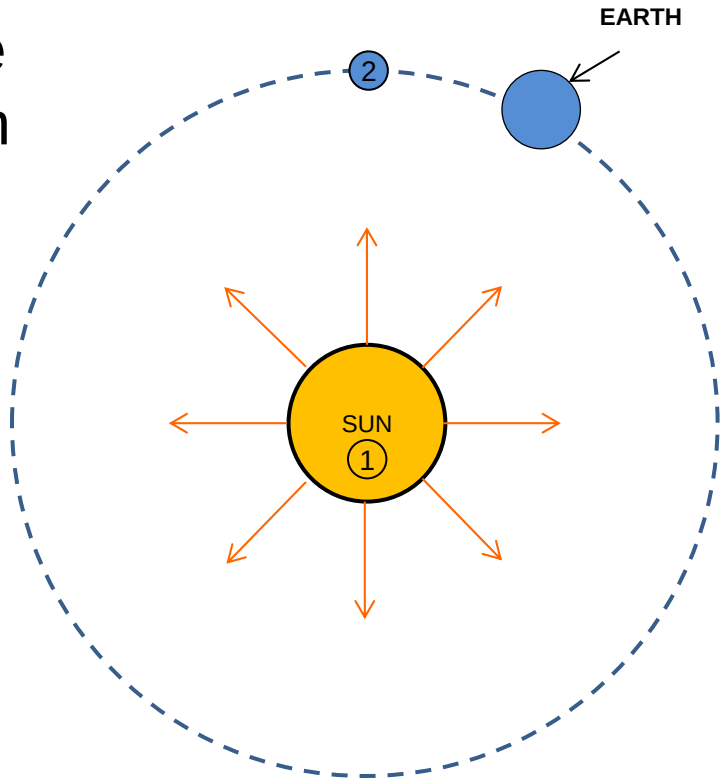
- The surface of the photosphere is at about 5777 K.
- Once the energy reaches the surface of the photosphere, it escapes to space by radiation.
- The sun is considered a blackbody.
- It radiates diffusely (uniformly) in all directions.
- All the energy leaving the sun's surface will reach a sphere containing earth.



Radiation from the Sun

- The net radiation heat transfer between the sun's surface (1) and the surface of the sphere containing earth (2) is given by:

$$\dot{Q}_{1\to 2} = A_1 F_{1\to 2}\,\sigma(T_1^4 - T_2^4)$$



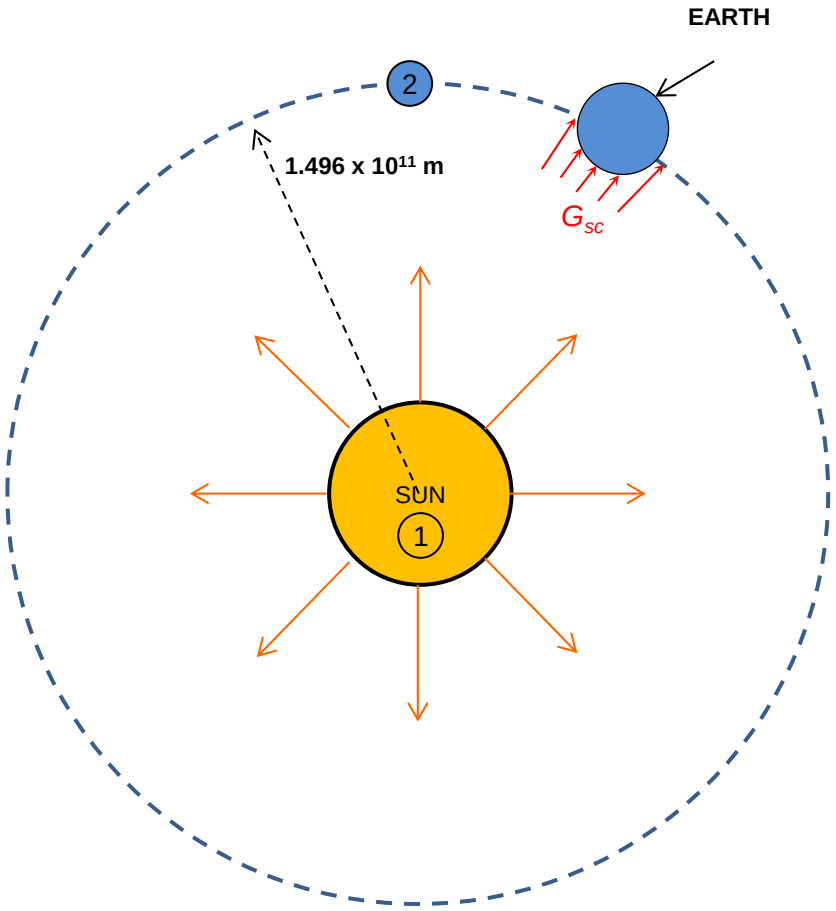
- $F_{1\to 2} = 1$
- $A_1 = 4\,\pi\,r_1^2$, where r_1 is the radius of the sun (6.955×10^8 m)
- T_2 is negligible
- The total rate of heat transfer leaving the sun's surface and reaching Surface 2 is: 3.84×10^{26} W.

Solar Constant

- The average distance between the sun and earth is 1.496 x 10^{11} m.
- This distance is called an ***astronomical unit*** (AU).
- The irradiance (G_{sc}) incident on Surface 2 (including earth) will be:

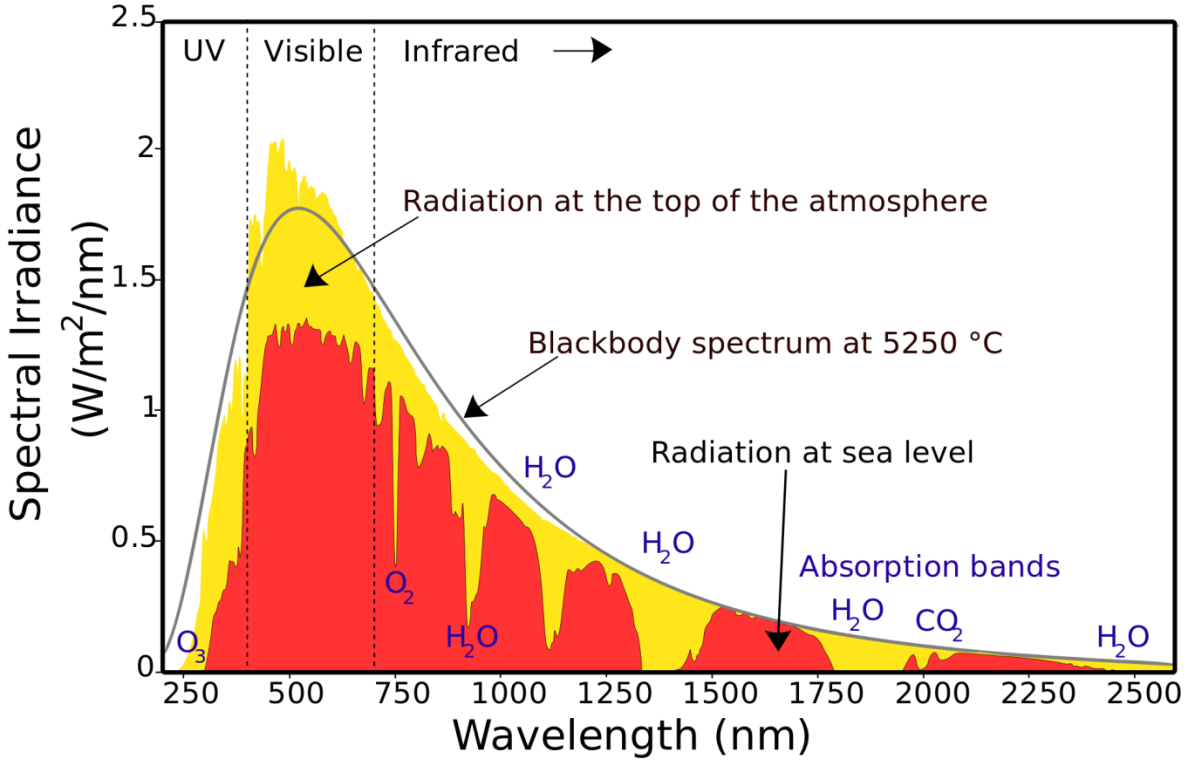
$$G_{sc} = \frac{\dot{Q}_{1\to2}}{A_2} = \frac{\dot{Q}_{1\to2}}{4\pi {r_2}^2}$$

- The value of G_{sc} is 1367 W/m^2.
- This value is called the ***Solar Constant.***



Solar Radiation Spectrum

- The solar radiation spectrum closely matches the spectrum of a blackbody (but only at the top of the atmosphere).
- Once solar radiation penetrates the atmosphere, the spectrum is affected by the presence of gases.
- For example, ozone (O_3) greatly reduces ultraviolet radiation.



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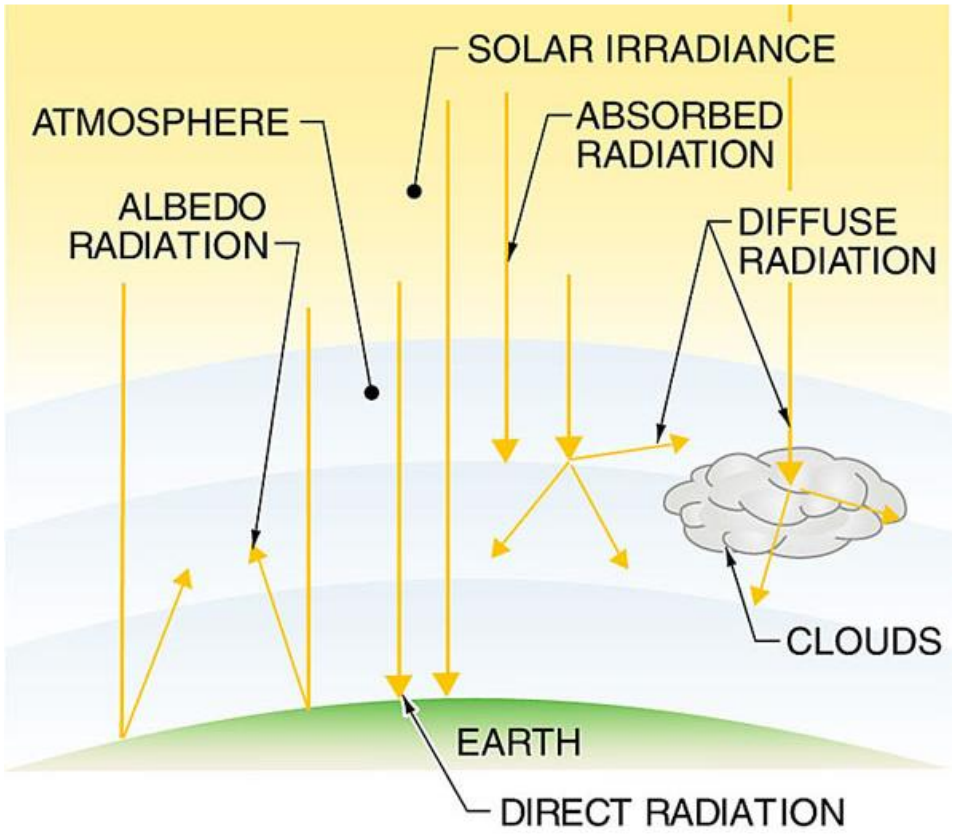
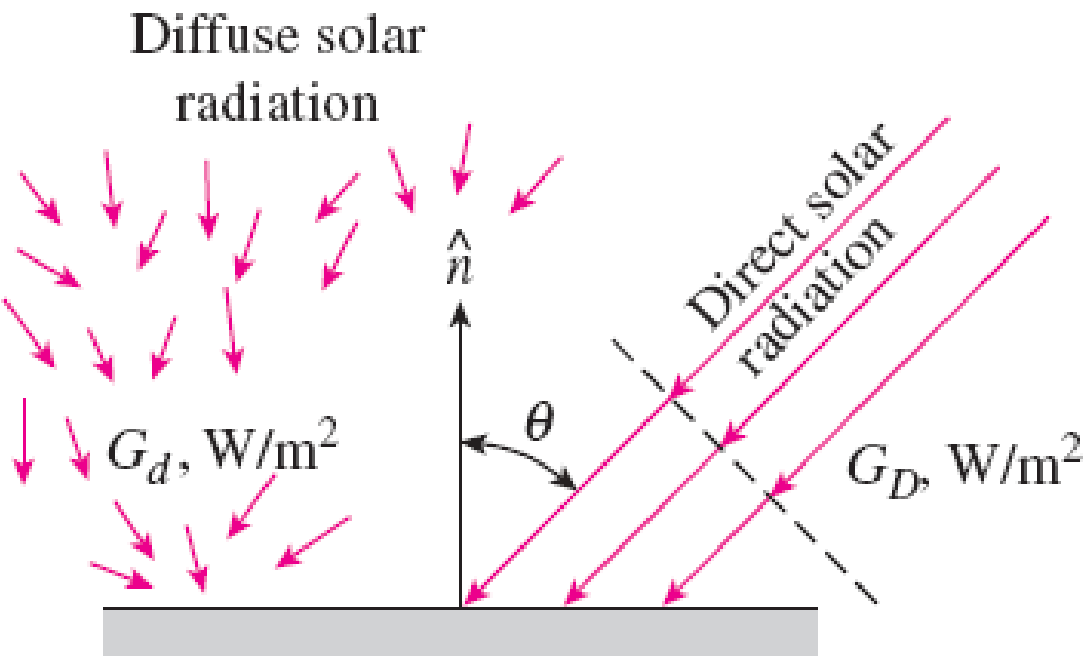
Atmospheric Effects

- The solar irradiance reaching the earth's surface is affected by:
  - **Suspended particles (e.g. dust)**
  - **Gases in the atmosphere**
  - **Clouds**
- These substances can:
  - **Absorb solar radiation**
  - **Reflect solar radiation**
  - **Scatter solar radiation**



Atmospheric Effects

- Solar radiation not affected by these substances reaches the earth's surface as ***direct radiation***.
- Remaining radiation reaching the surface is ***diffuse radiation***.
- Total of direct and diffuse radiation is called ***global radiation***.



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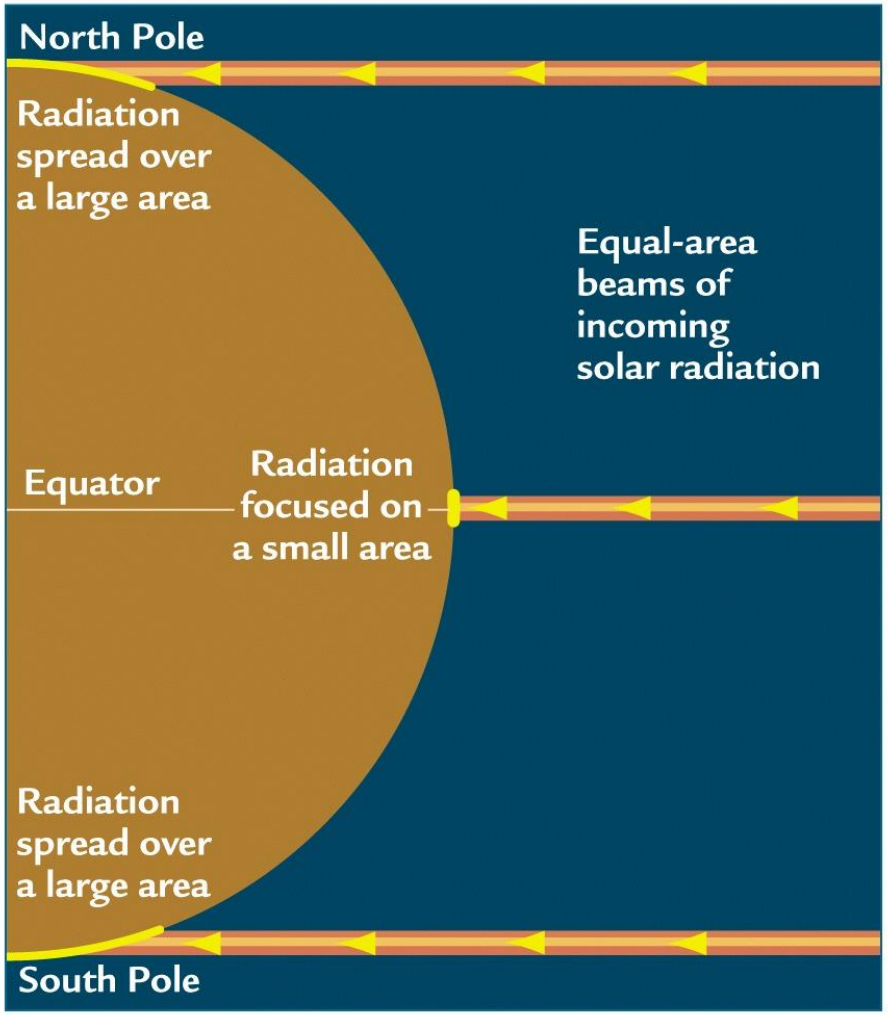
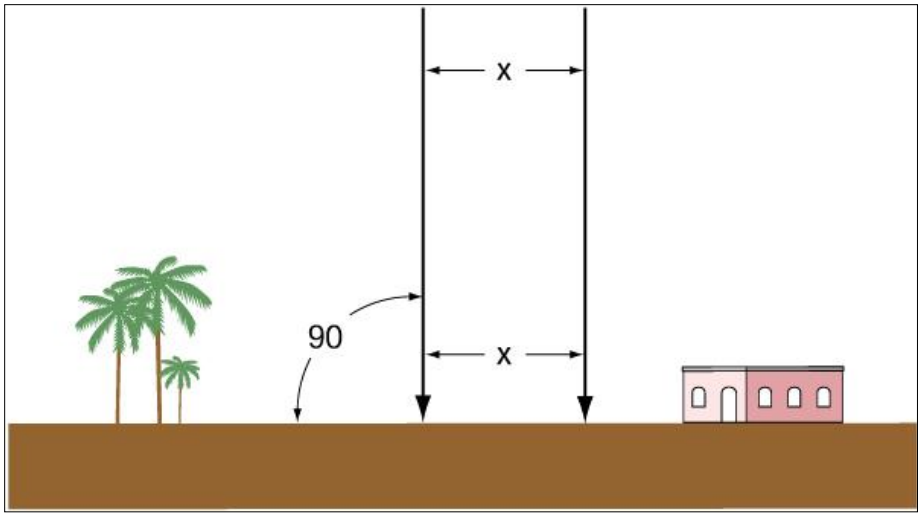
Solar Radiation Intensity

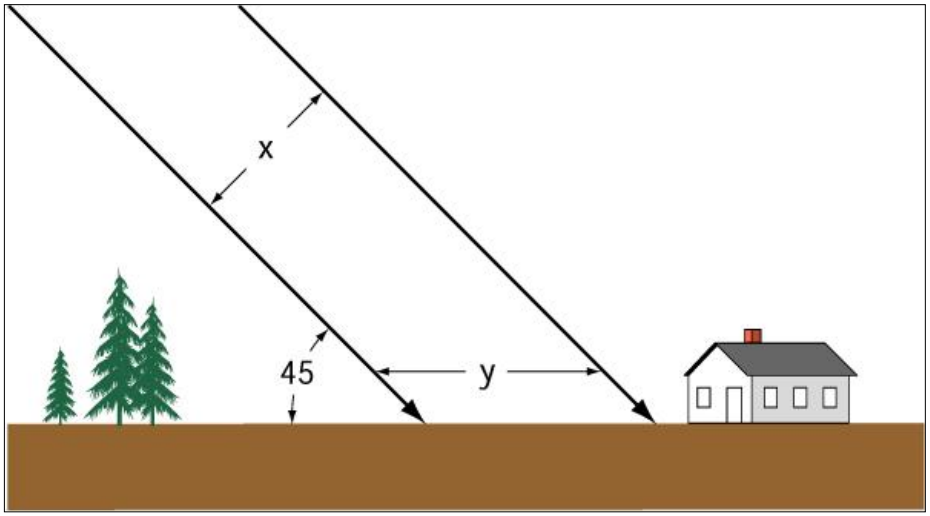
- Solar irradiance (*G*) incident on the earth's surface in the normal direction is focused on a small area.
- If the same (*G*) is incident at a different angle, it will be spread over a larger area.
- This means that the solar intensity in the normal direction is highest.
- Solar intensity at high **latitudes** is lower.



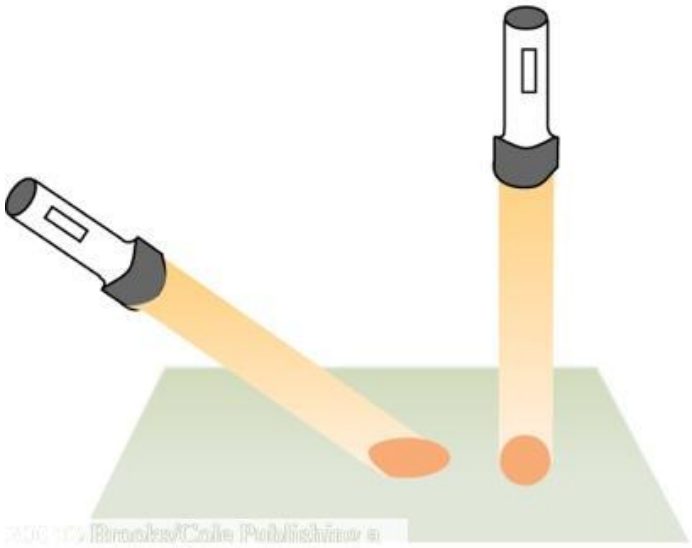
Solar Radiation Intensity

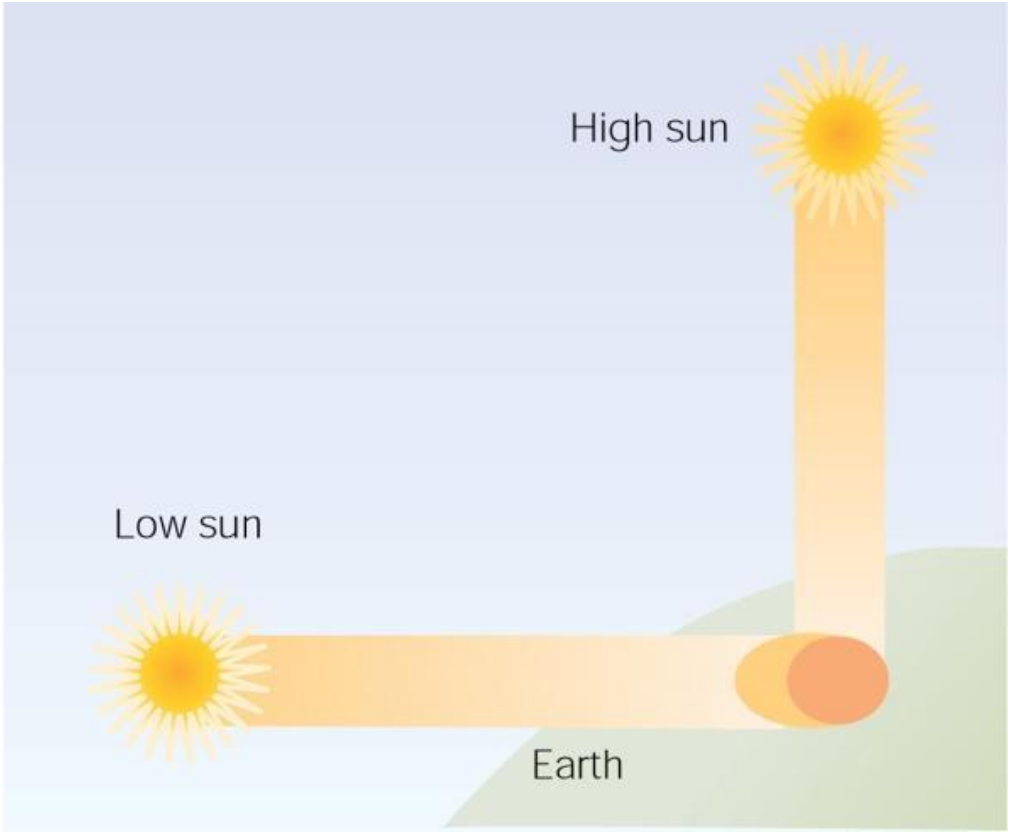
- This also means that solar intensity is higher in the middle of the day (e.g. at noon) than in the early morning or late afternoon.





Solar Radiation Intensity





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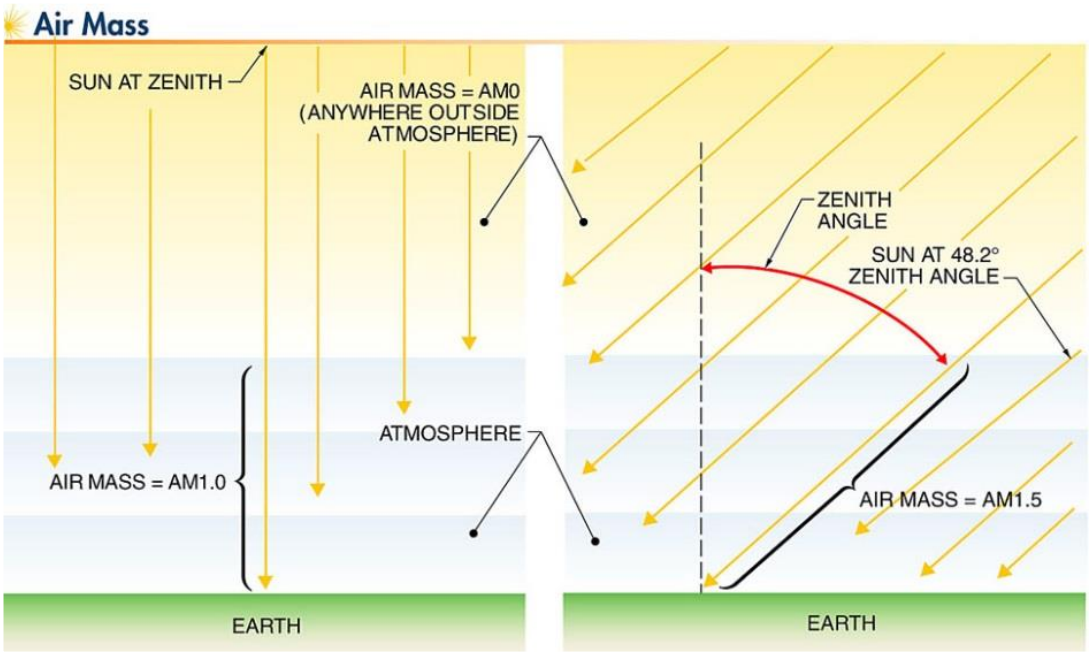
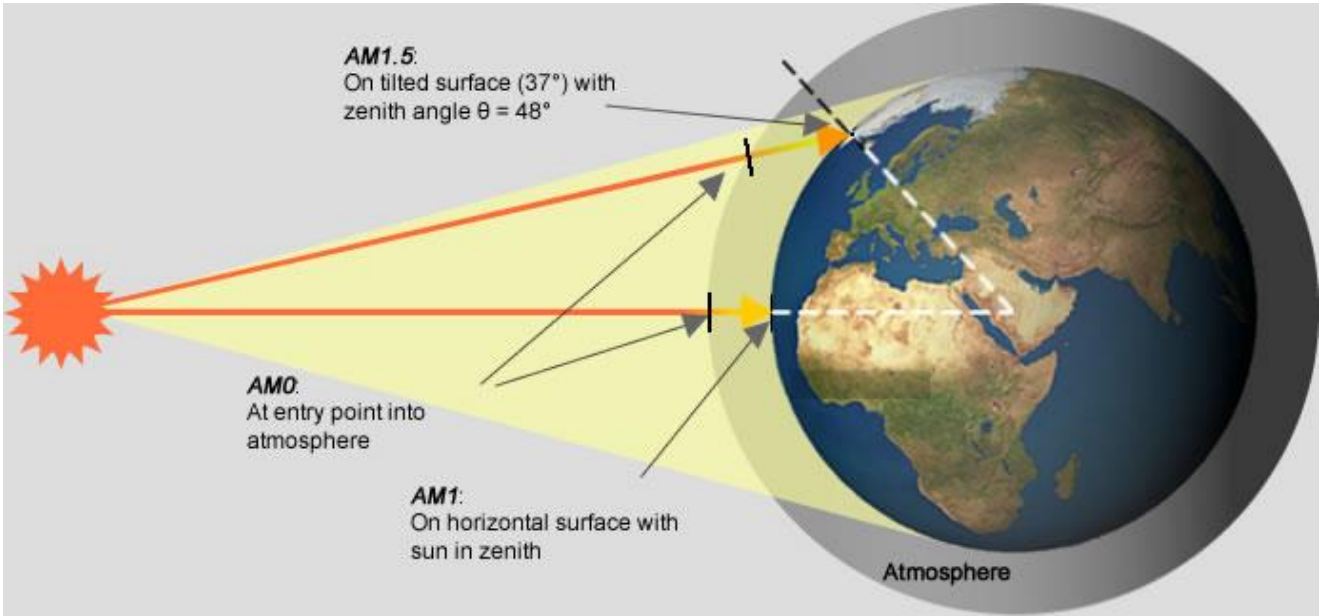
Air Mass

- The amount of solar radiation interacting with the atmosphere depends on how much atmosphere it passes through.
- When the sun is directly overhead (at ***zenith***), the amount of atmosphere that the sun's rays pass through is at a minimum.
- As the sun approaches the horizon, the sun's rays must pass through a greater amount of atmosphere.
- This phenomenon is characterized by the ***air mass.***



Air Mass

- The larger the air mass, the more solar radiation will be absorbed (or reflected) by the atmosphere
- This reduces the quantity of solar irradiance reaching the earth's surface.
- The larger air mass also changes its wavelength composition
- This is the reason for the change in the sun's color in early morning and late afternoon.



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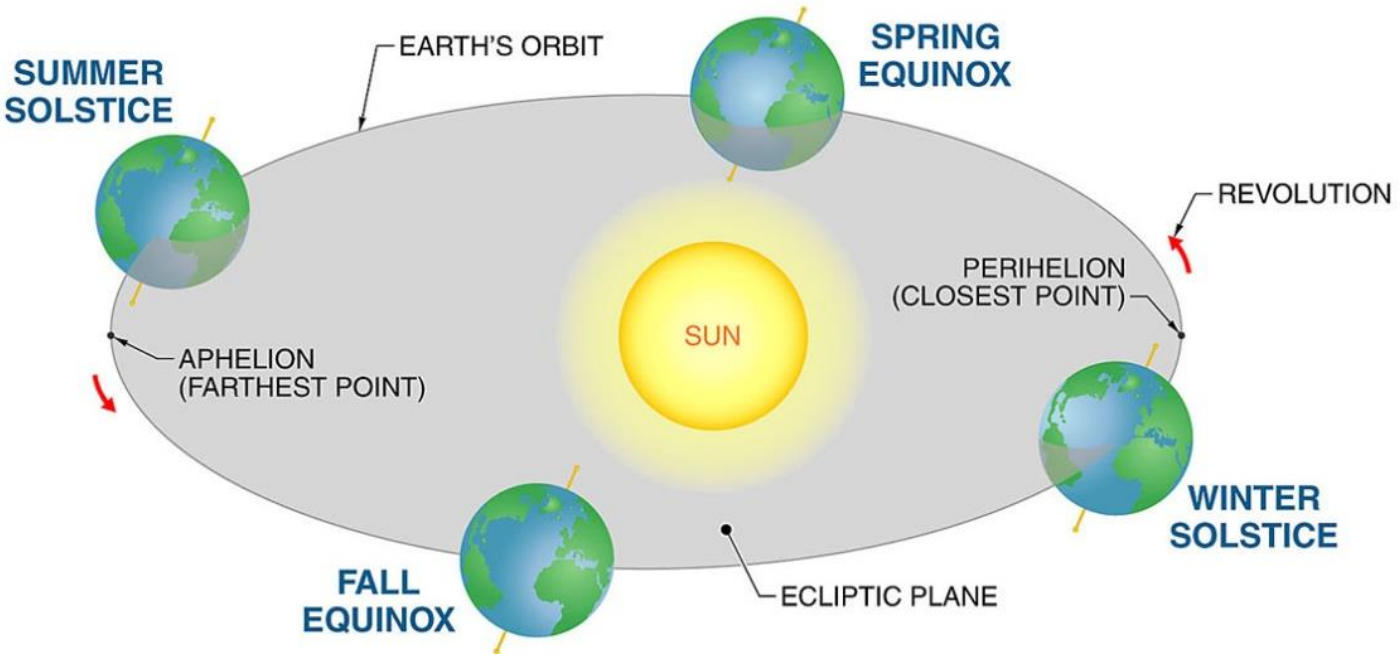
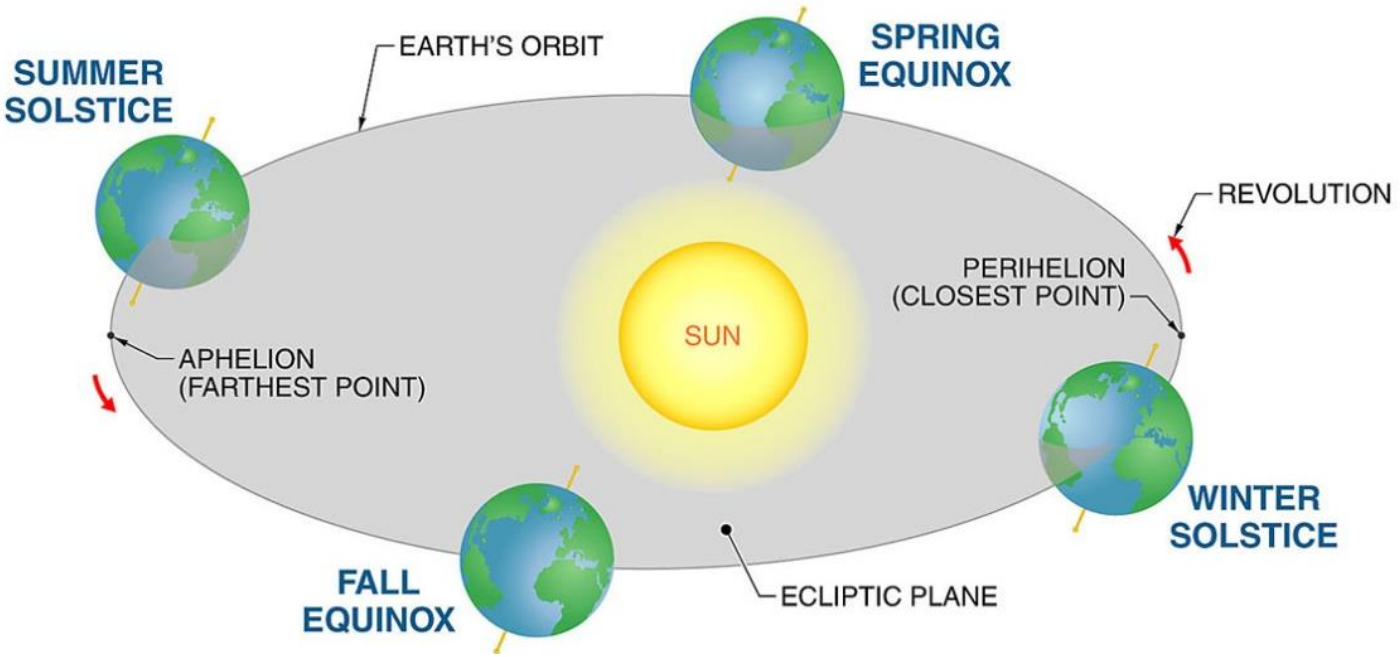
Seasonal Variation of Solar Radiation

- The earth rotates around the sun in an elliptical orbit.
- The plane formed by the earth's rotation around the sun is called the ***ecliptic plane***.
- The earth's axis is tilted by 23.5° to the ecliptic plane.
- Because of this tilt, the lengths of day and night vary throughout the year.



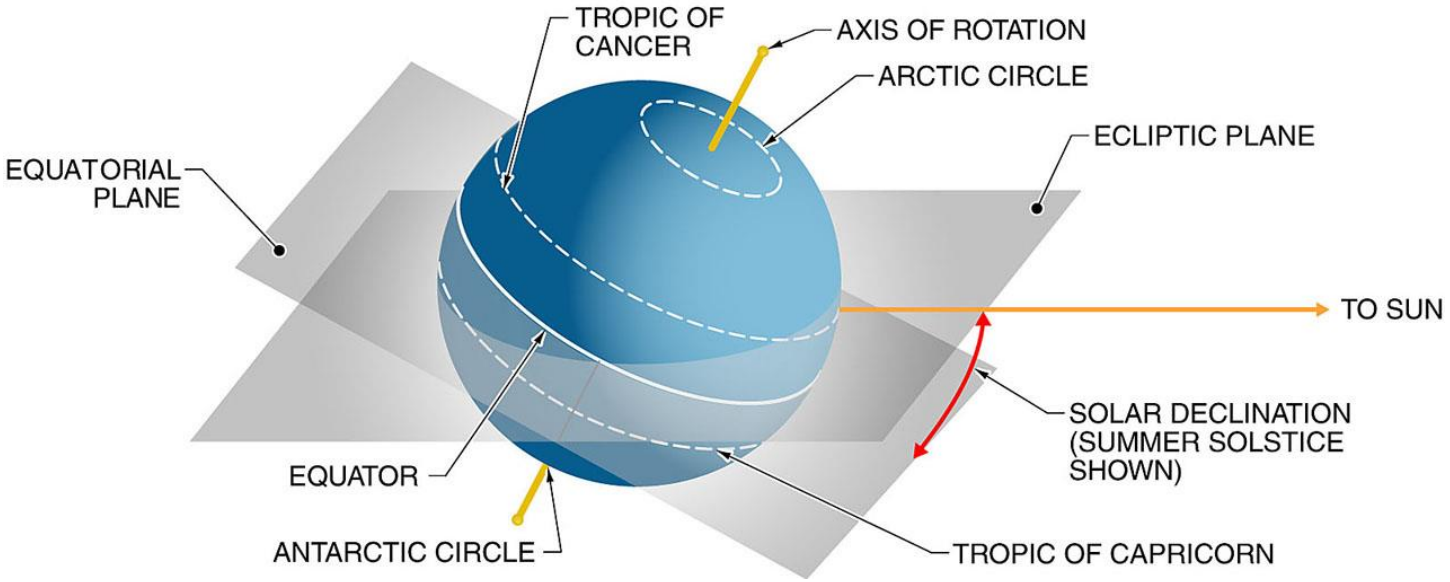
Seasonal Variation of Solar Radiation

- The point at which the day is shortest in the northern hemisphere is called ***winter solstice***.
- The point at which the day is longest in the northern hemisphere is called ***summer solstice***.
- The two points at which day and night have equal lengths are called the ***spring equinox*** and ***fall equinox***.



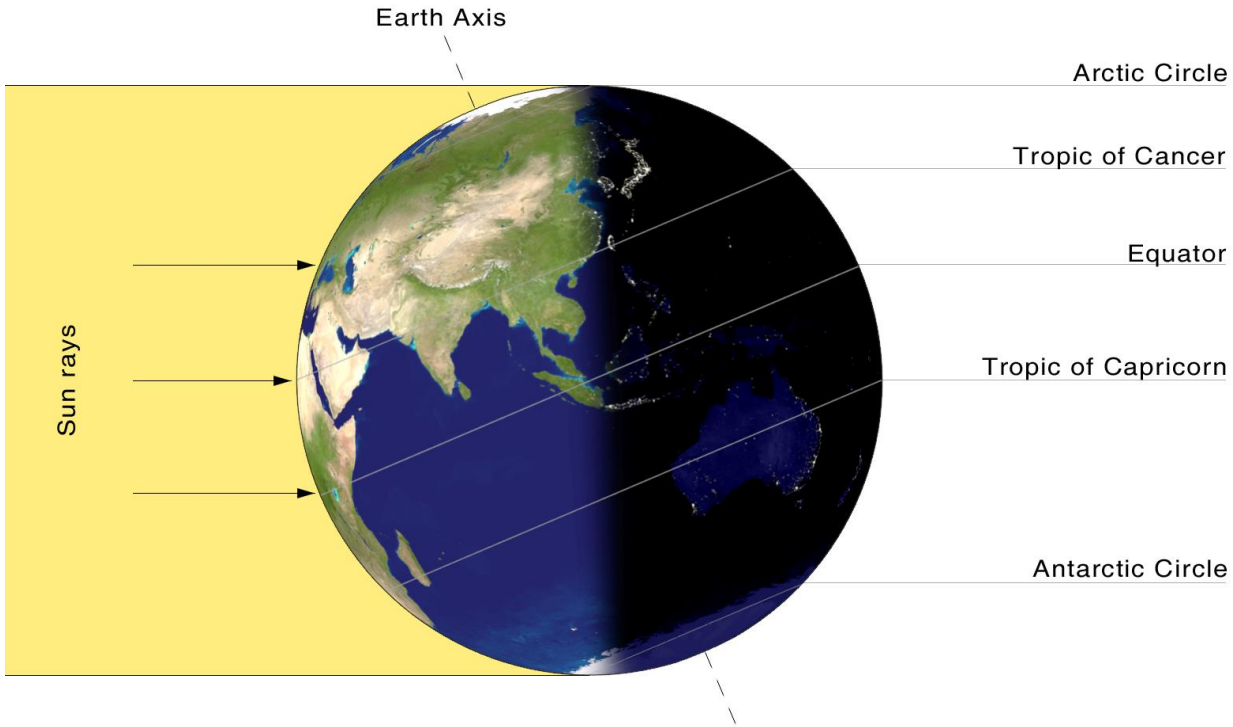
Sun's Declination

- The ***equatorial plane*** is the surface cutting through the earth's equator.
- ***Solar declination*** is the angle between the equatorial plane and the rays of the sun.
- The angle of solar declination changes continuously as Earth orbits the sun, ranging from –23.5° to +23.5° (positive when the northern hemisphere is tilted toward the sun).



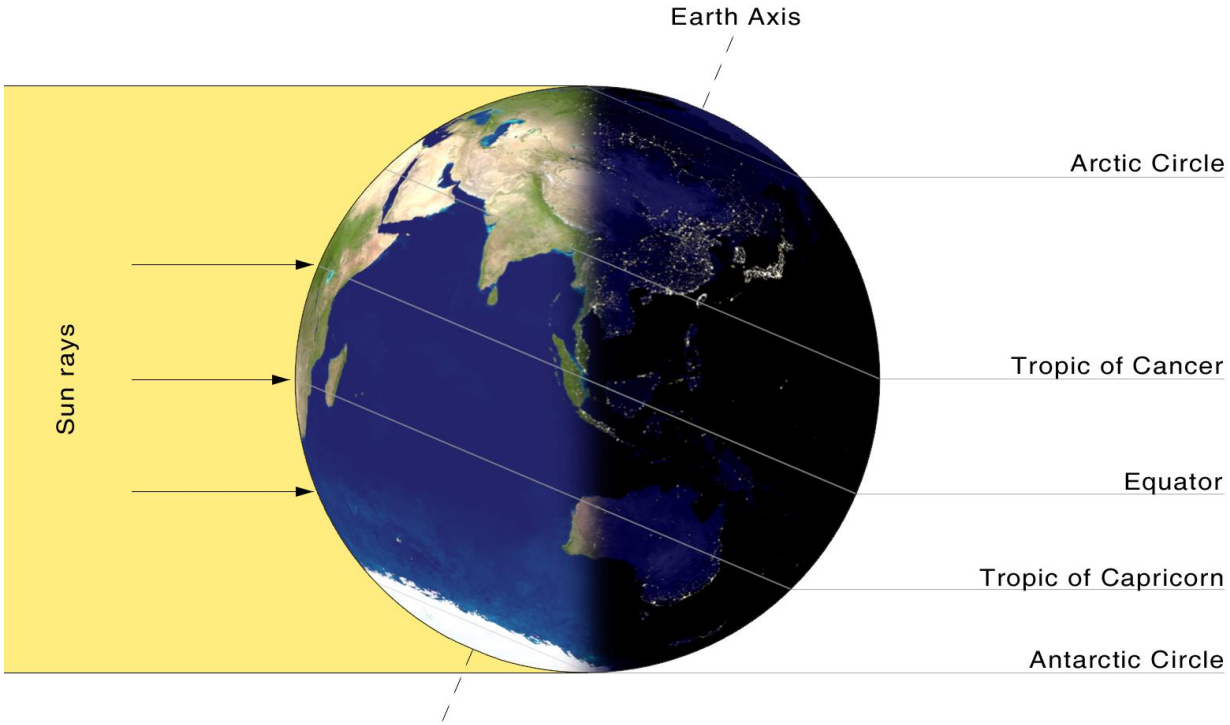
Summer Solstice

- At summer solstice, the sun's rays are perpendicular to the tropic of cancer.
- Daytime is longest in the northern hemisphere.
- Daytime is shortest in the southern hemisphere.



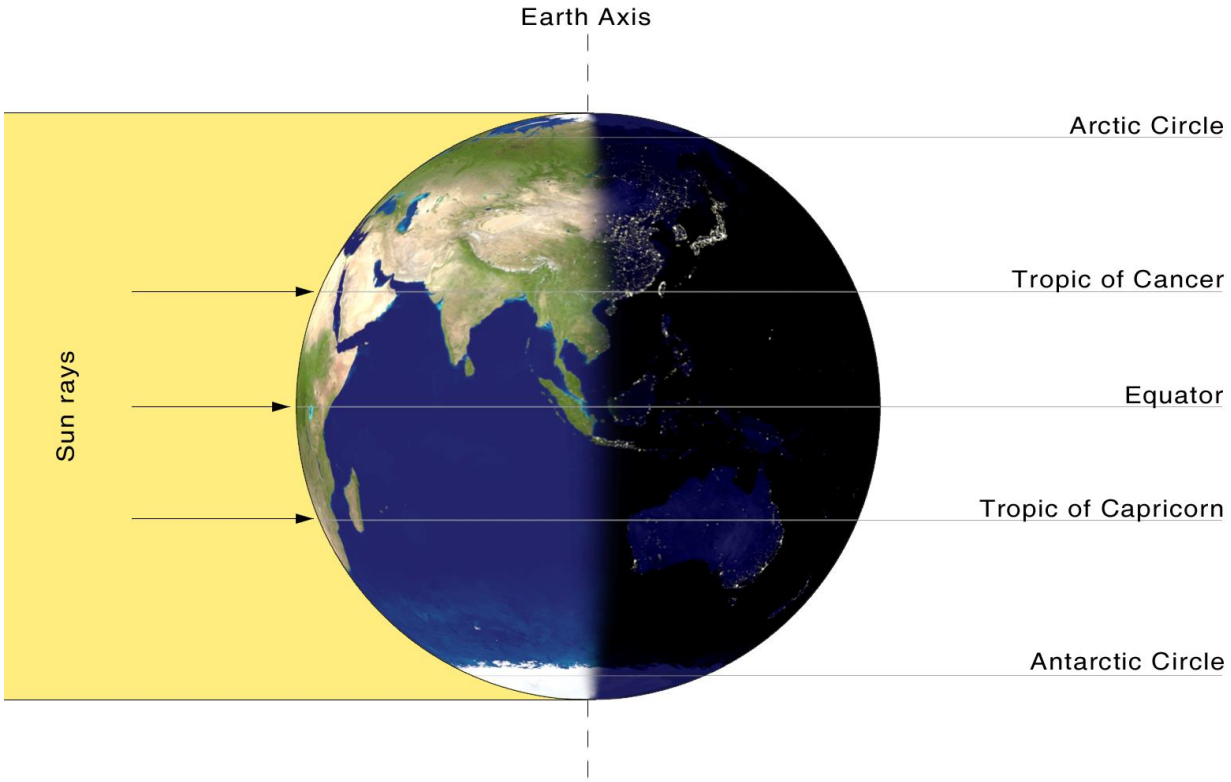
Winter Solstice

- At winter solstice, the sun's rays are perpendicular to the tropic of capricorn.
- Daytime is shortest in the northern hemisphere.
- Daytime is longest in the southern hemisphere.



Spring and Fall Equinoxes

- At spring and fall equinoxes, the sun's rays are perpendicular to the equator.
- Day and night have equal lengths.



Factors Affecting Solar Radiation

- The following is a summary of factors affecting solar radiation
  - **Atmospheric conditions**
  - **Latitude**
  - **Air mass**
  - **Seasonal variations (sun's declination)**
- Determining the location of the sun at any given time of the day is important to quantify the above factors.
- The location of the sun is determined by:
  - **Location on earth (latitude and longitude)**
  - **Day of the year**
  - **Time of the day**