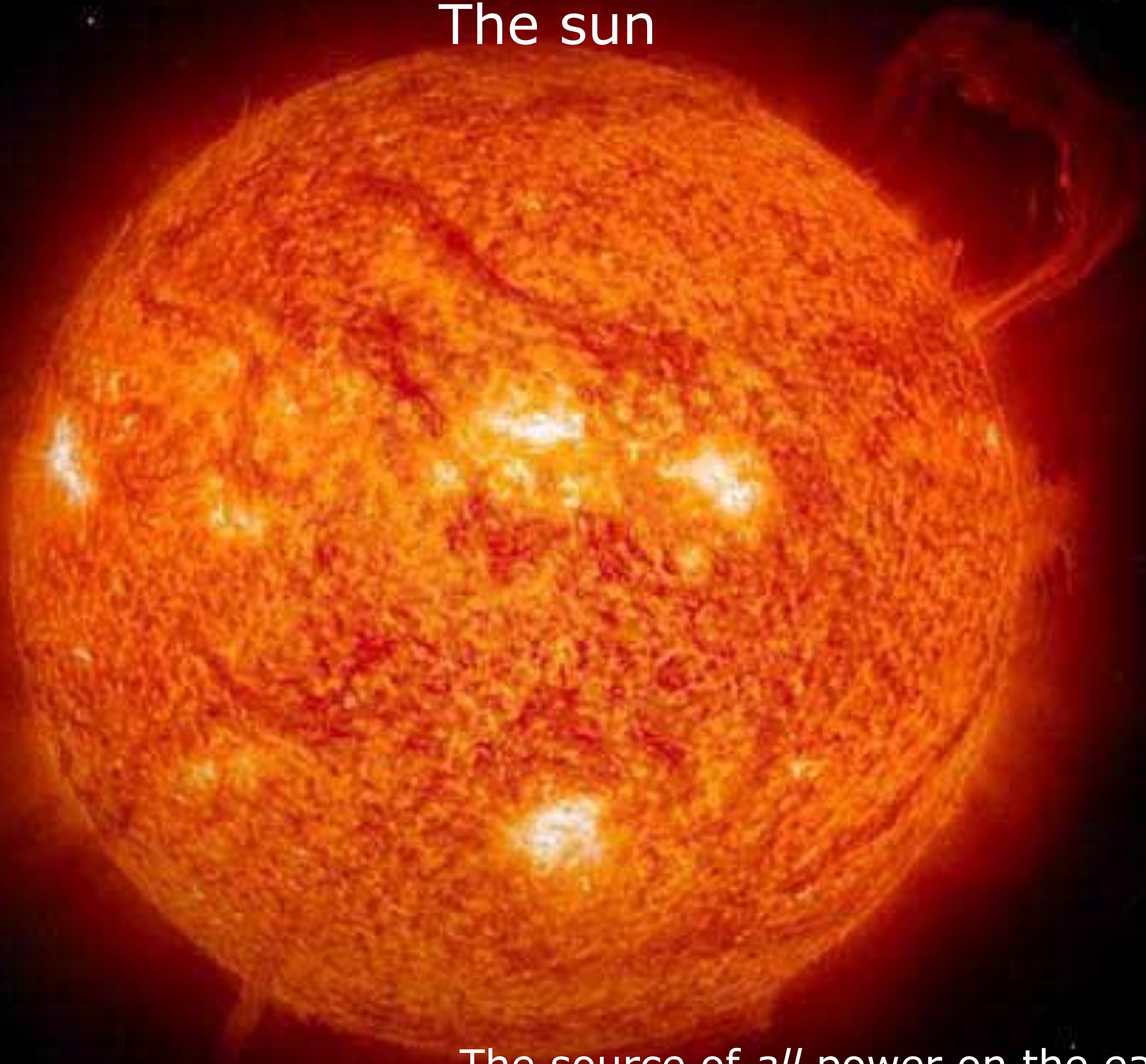
Nature of the solar resource

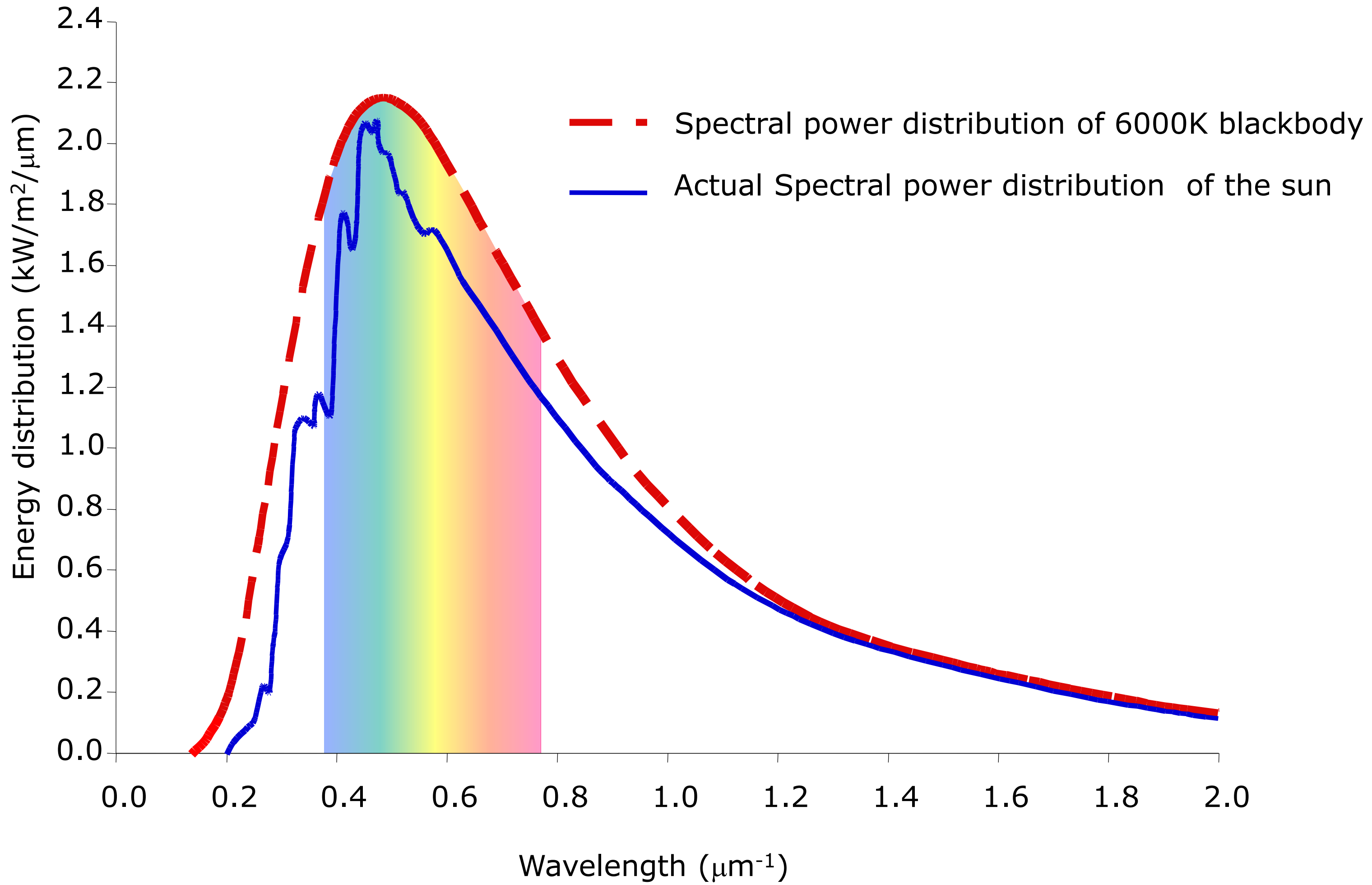
The sun



The source of *all* power on the earth
radiates at about 5,777º K
(Blackbody equivalent)

B1.1 **Nature of the solar resource**

Spectral power distribution of the sun

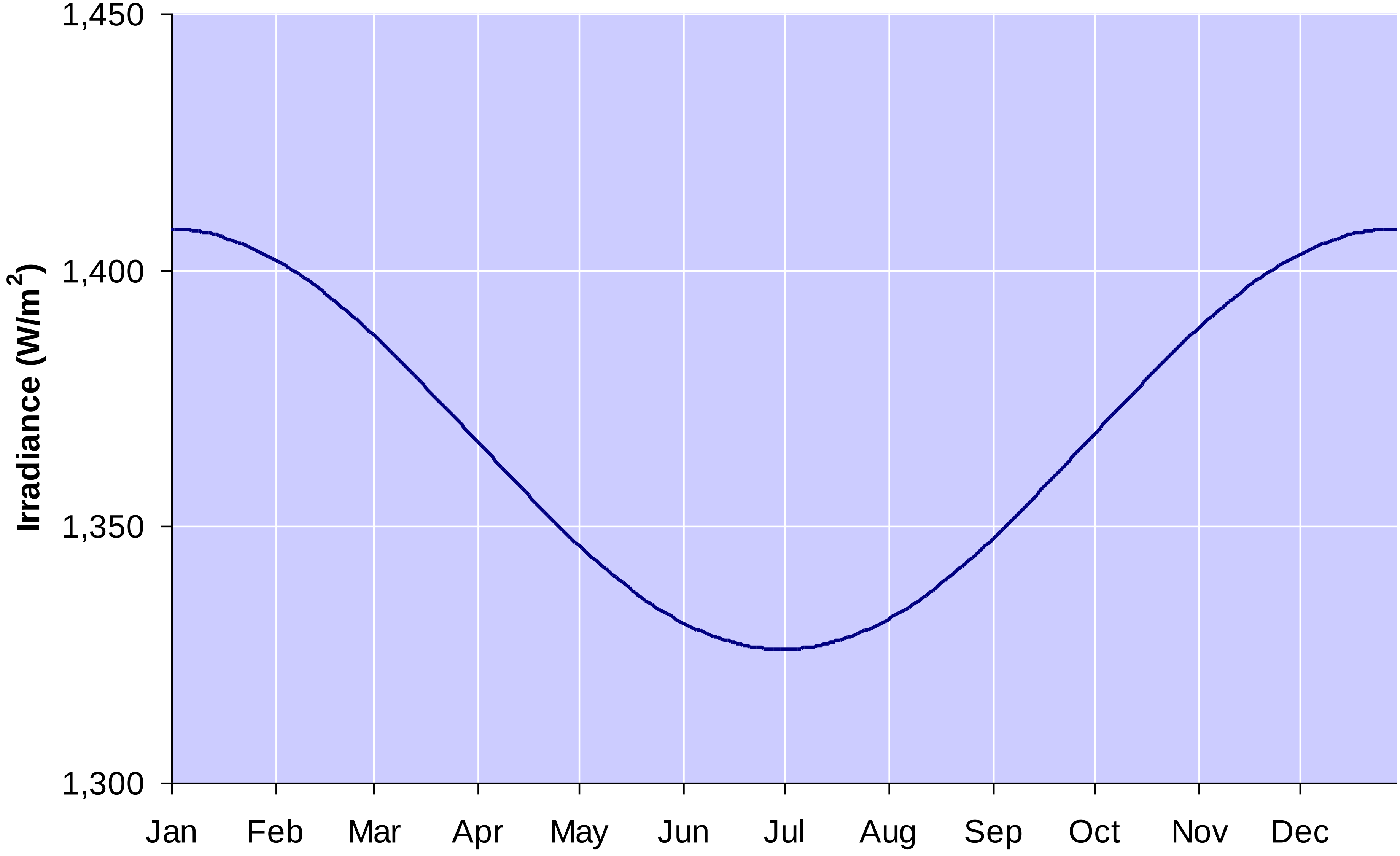


B1.1 **Nature of the solar resource**
Irradiance

- The amount of the suns energy that reaches the earth (before entering the atmosphere)
- The average value of irradiance per year is called the solar constant (G_{sc})and is equivalent to 1353, 1367 or 1373 W/m^2 depending on who you believe
  - 1353 (±1.5%) from Thekaekara (1976) – derived from measurements at very high atmosphere and used by NASA
  - 1367 (±1%) Adopted by the World Radiation Centre
  - 1373 (±1-2%) from Frohlich (1978) - derived from satellite data

Nature of the solar resource

Earth's orbit: Variation in radiation



Nature of the solar resource

Earth's orbit: Variation in radiation

$$G_{on} = G_{sc}\left(1 + 0.033\cos\frac{360n}{365}\right)$$

G_{on} = Irradiance

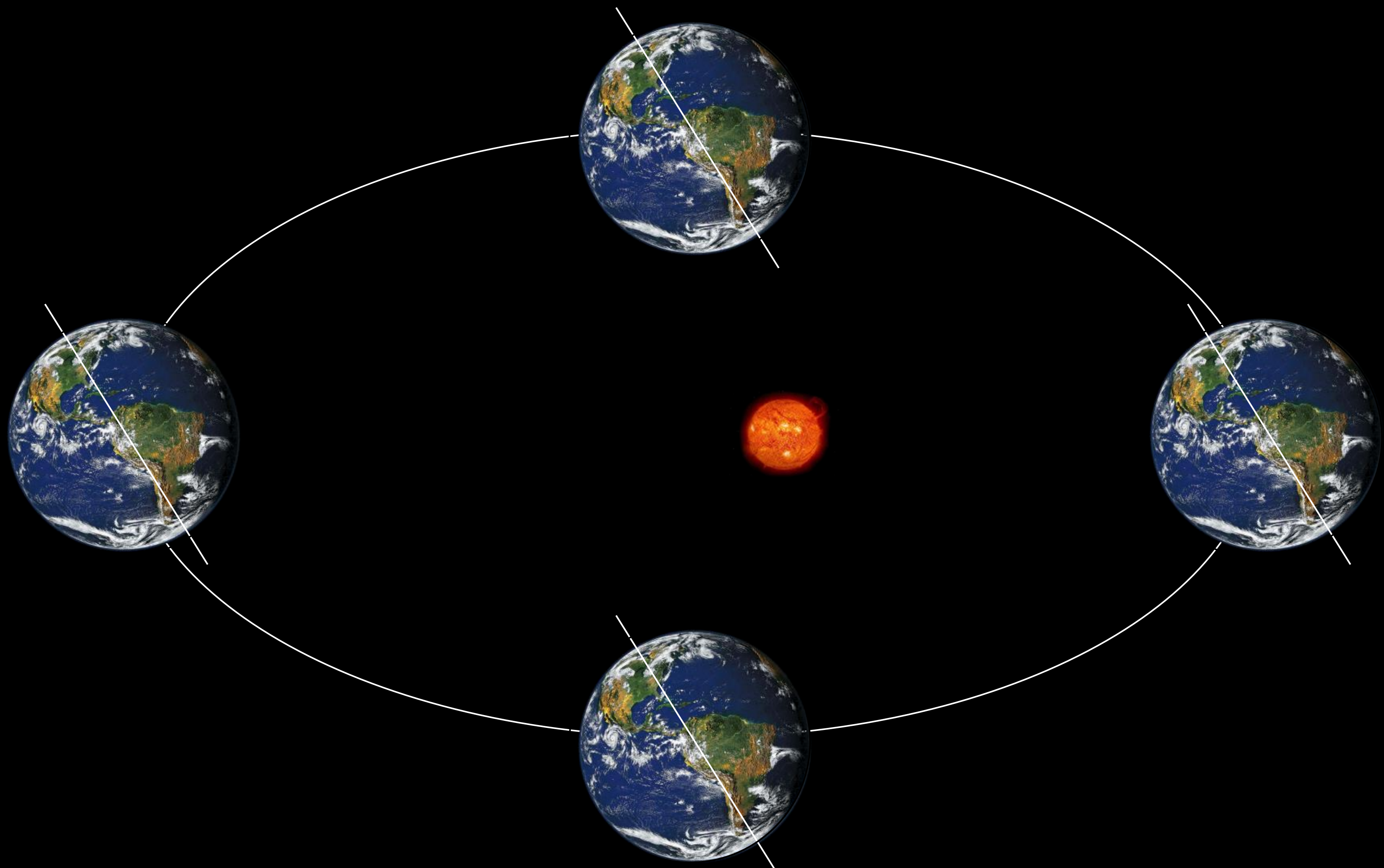
G_{sc} = Solar constant

n = day number (number of days since 1st January)

Note: cosine is for degrees

Nature of the solar resource

Earth is tilted 23.45°



Nature of the solar resource Earth is tilted 23.45°

I. On the winter solstice (December 22)

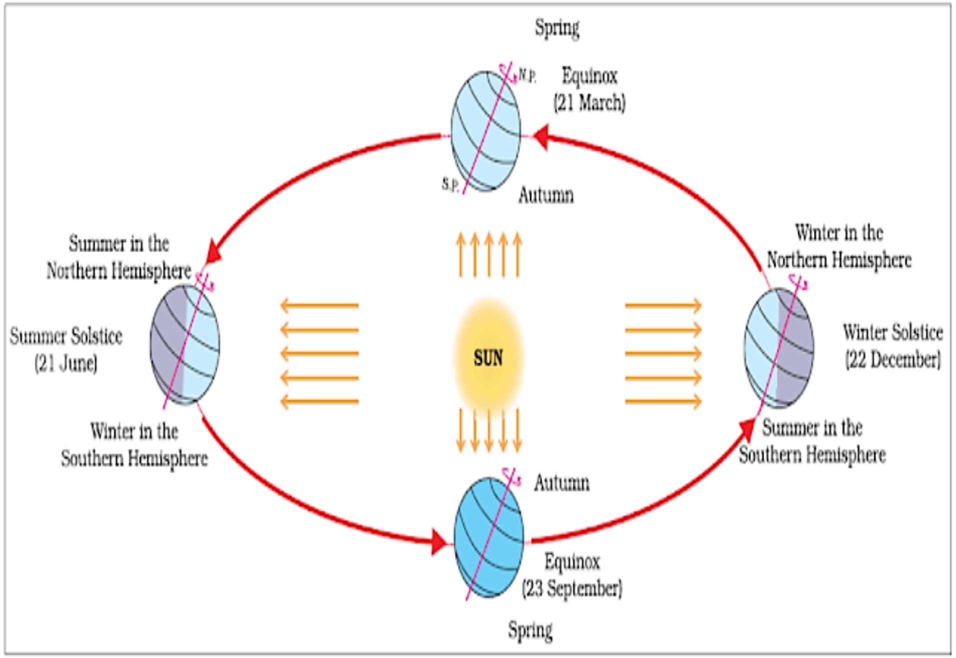
1. The north pole has its maximum angle of inclination away from the sun
2. Everywhere above 66.55° N (90-23.45) is in darkness for 24 hours, Everywhere above 66.55° S is in sunlight for 24 hours
3. the sun passes directly overhead over the tropic of Capricorn (23.45° S)

II. On the equinox (March 21 & September 23)

1. Both poles are equidistant
2. the day is exactly 12 hours long
3. the sun passes directly overhead over the equator
4. The sun tracks a straight line across the sky

III. On the summer solstice (June 21)

1. The reverse of the winter solstice



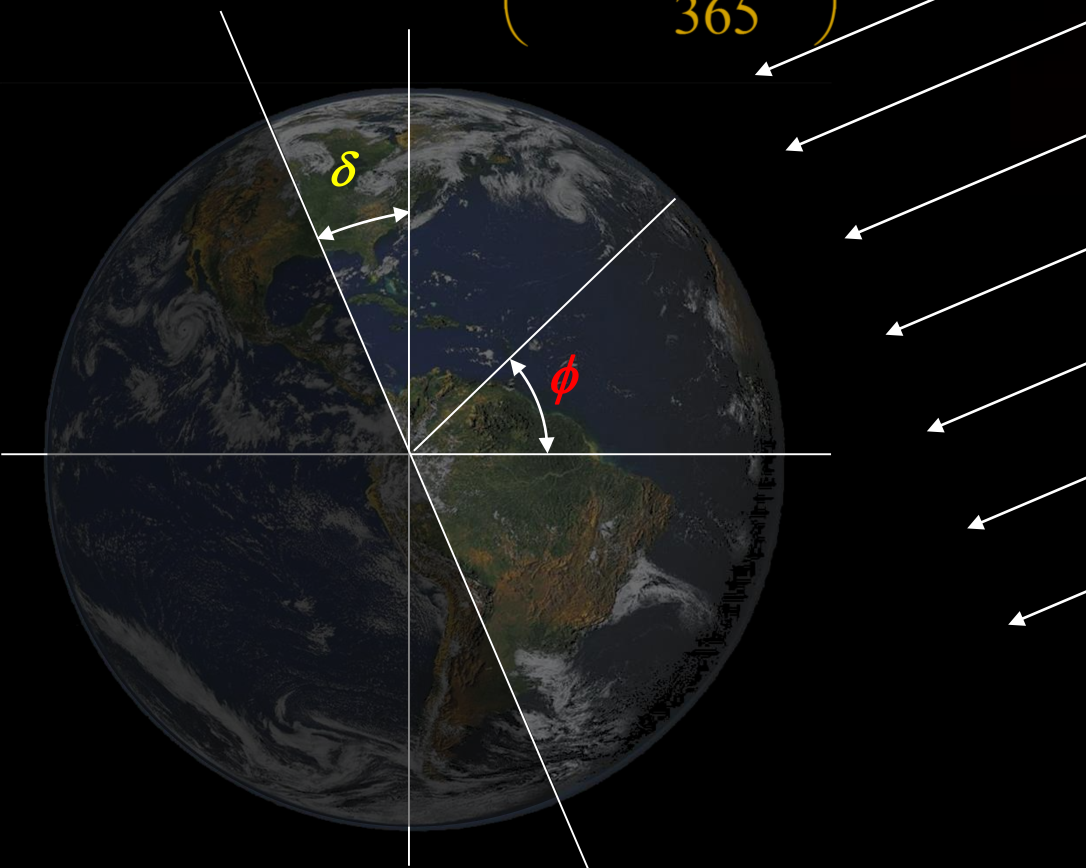
Nature of the solar resource Solar geometry

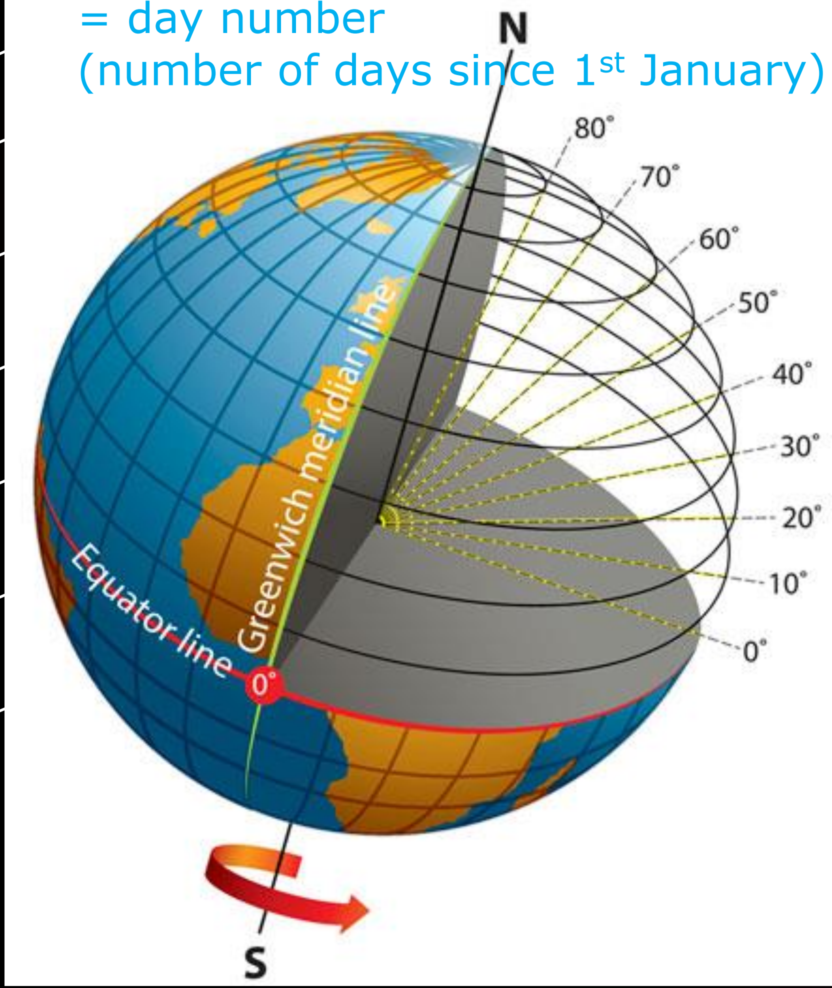
ϕ = Latitude measures the distance north or south of the equator. Latitude lines start at the equator (0 degrees latitude) and run east and west, parallel to the equator.

δ = Declination angle is between the earth’s axis of rotation and the surface of a cylinder through the earth’s orbit

$$\delta = 23.45 \sin\left(360 \frac{284+n}{365}\right)$$

n = day number (number of days since 1st January)





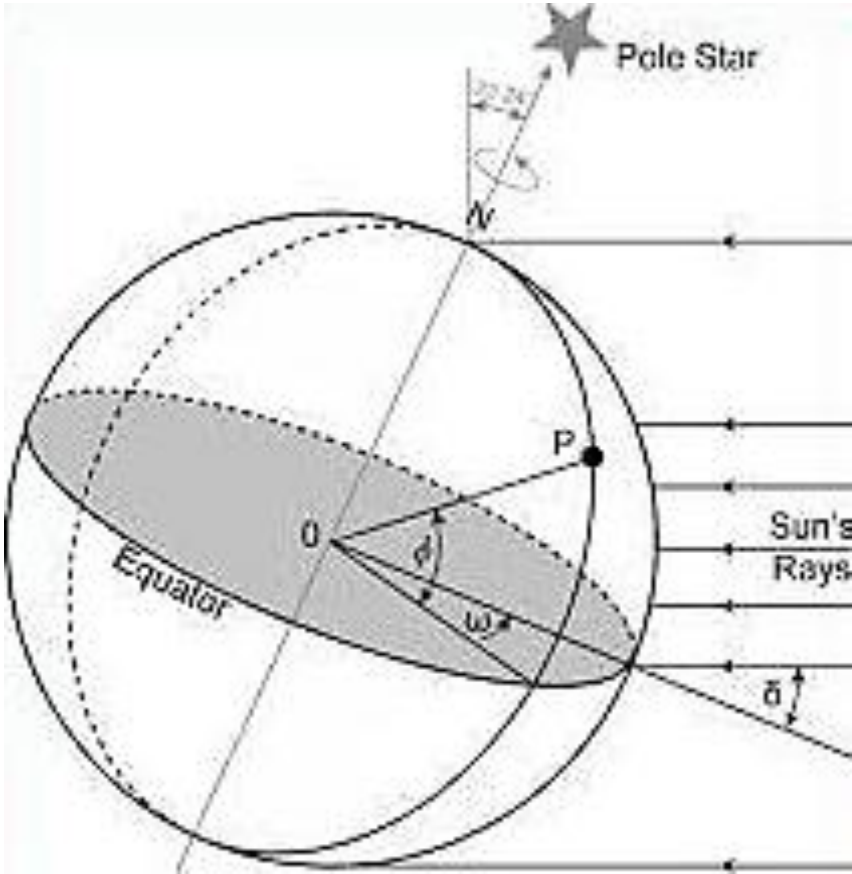
Hour angle (ω)

1. The angular displacement of the sun east or west of the local meridian due to the rotation of the earth or The angle through which the earth must turn to bring the Meridian of a point directly in line with the Sun's rays.

   It is a measure of the time of the day with respect to Solar noon.
2. 15° per hour
   1. Noon is zero,
   2. Morning negative,
   3. Afternoon positive.
3. Depends on Apparent Solar Time

$$AST = LCT + TZ + \frac{L}{15} + \frac{EQT}{60}$$

AST	=	Apparent solar time
LCT	=	Local clock time
TZ	=	Time zone
L	=	Longitude (west = +^{ve})
EQT	=	Equation of time



Equation of time (EOT or EQT)

Solar time: Solar radiation calculations such as the hour angle are based on local solar time (LST).

Since the earth's orbital velocity varies throughout the year, the local solar time as measure by sundial varies slightly from the mean time kept by the clock running at uniform rate.

A civil day is exactly equal to 24 hours, whereas a solar day is approximately equal to 24 hours.

The variation is called as equation of time (EOT) and is available as average values for different months of the year.

The EOT may be considered as constant for a given day.

An approximate equation for calculating EOT given by Spencer (1971) is:

EOT=0.2292(0.075+1.868cosN - 32.077sinN - 4.615cos2N - 40.89sin2N)

or

$$EQT = 229.2\begin{pmatrix} 0.000075 + 0.001868\cos B - 0.032077\sin B \\ -0.014615\cos 2B - 0.04089\sin 2B \end{pmatrix}$$

where N or B =(n-1)(360/365);

n is the day of the year counted from January 1st

LST=Standard time ±4(Standard Time Longitude – Longitude of Location)+Equation of time correction)

The –ve sign is applicable for Eastern Hemisphere.

NOTE: Hour angle (ω) = 15(12 - LST)

Problem 1: Determine Hour Angle (ω) for : 09:00 AM, 11:00 AM, 02:00 PM, 04:30 PM.

Solution:

Hour angle (ω) = 15 (12 – LST)

09:00AM; ω = 15 (12 – 9) = 45°

11:00AM; ω = 15 (12 – 11) = 15°

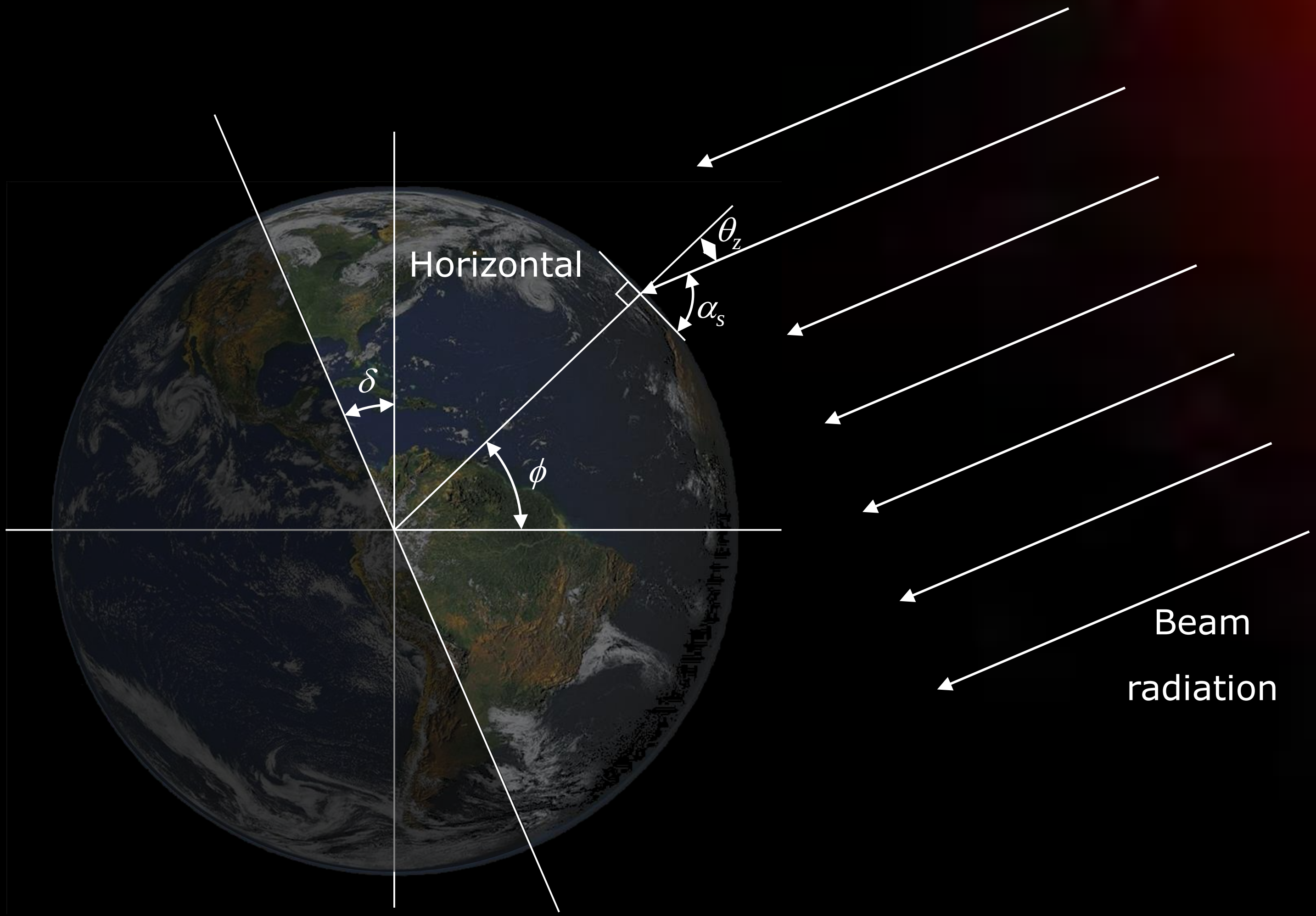
02:00PM; ω = 15 (12 – 14) = -30°

04:30AM; ω = 15 (12 – 16.5) = -67.5°

Problem 2: Determine the LST and Declination at a location latitude 23°15' N, longitude 77°30' E at 12.30pm IST on June 20. EOT correction = -(1'02"). Standard time Longitude for IST = 82.5°.

Problem 3: Determine the LST and Declination at a location latitude 23°15' N, longitude 67°30' E at 2.30pm IST on October 02. EOT correction = -(9'02"). Standard tim Longitude for IST = 82.5°.

Solar geometry: Sun angles



Solar geometry: Sun angles

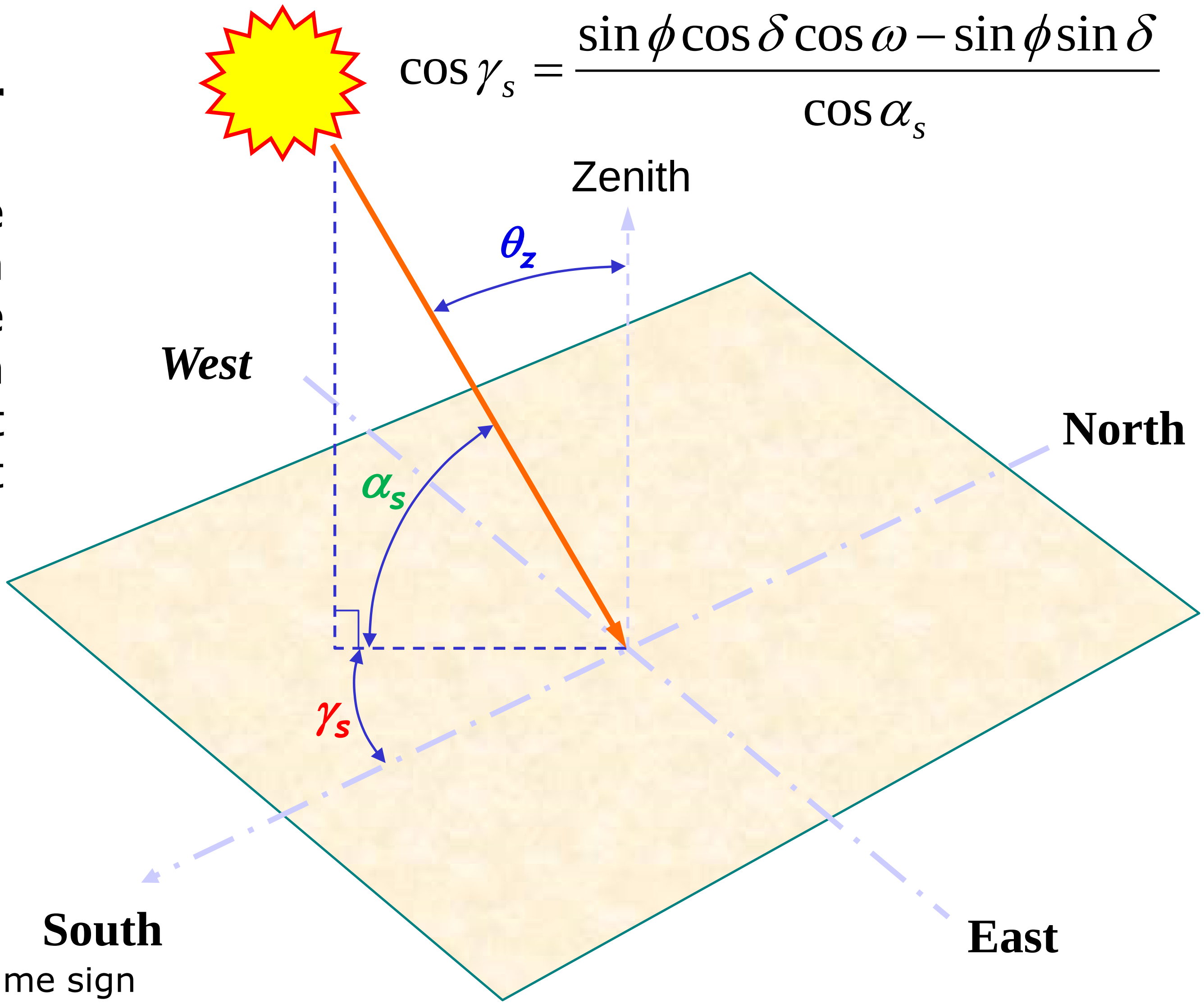
θ_z = **Zenith angle** – the angle between the vertical (zenith) and the line of the sun

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

α_s = **Solar attitude angle** – the angle between the horizontal and the line to the sun

γ_s = **Solar azimuth angle**: The angle of the projection of beam radiation on the horizontal plane (with zero due south, east negative and west positive)

$$\cos\gamma_s = \frac{\sin\phi\cos\delta\cos\omega - \sin\phi\sin\delta}{\cos\alpha_s}$$



θ_z = Zenith Angle

ϕ = Latitude

δ = Declination

ω = Hour angle

γ_s = Solar azimuth angle

α_s = Solar attitude angle

Note: γ **&** ω should be the same sign

Solar geometry: Sun angles

Sunset angle and day length

$$\cos\omega_s = -\tan\delta\tan\phi$$

$$\text{Day length} = \frac{2}{15}\cos^{-1}\left(-\tan\delta\tan\phi\right)$$

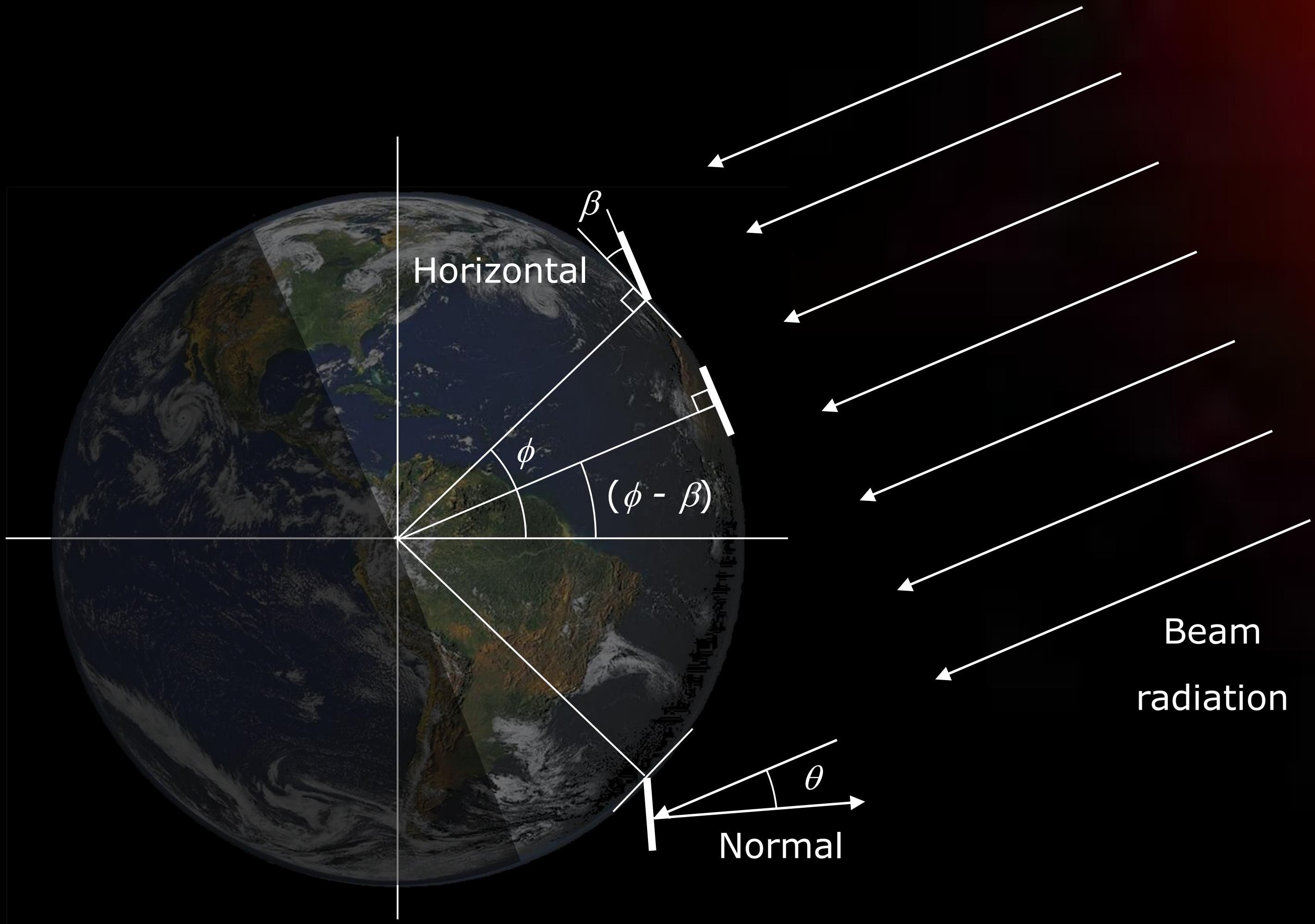
ω_s = Sunset angle

δ = Declination

ϕ = Latitude

Note: Day length is in hours

Solar geometry: Collector angles



Solar geometry: Collector angles

Earth angles

$$\cos\theta = \sin\delta\left(\sin\phi\cos\beta - \cos\phi\sin\beta\cos\gamma\right)$$
$$+\cos\delta\cos\omega\left(\cos\phi\cos\beta - \sin\phi\sin\beta\cos\gamma\right)$$
$$+\cos\delta\sin\beta\sin\gamma\sin\omega$$

Sun angles

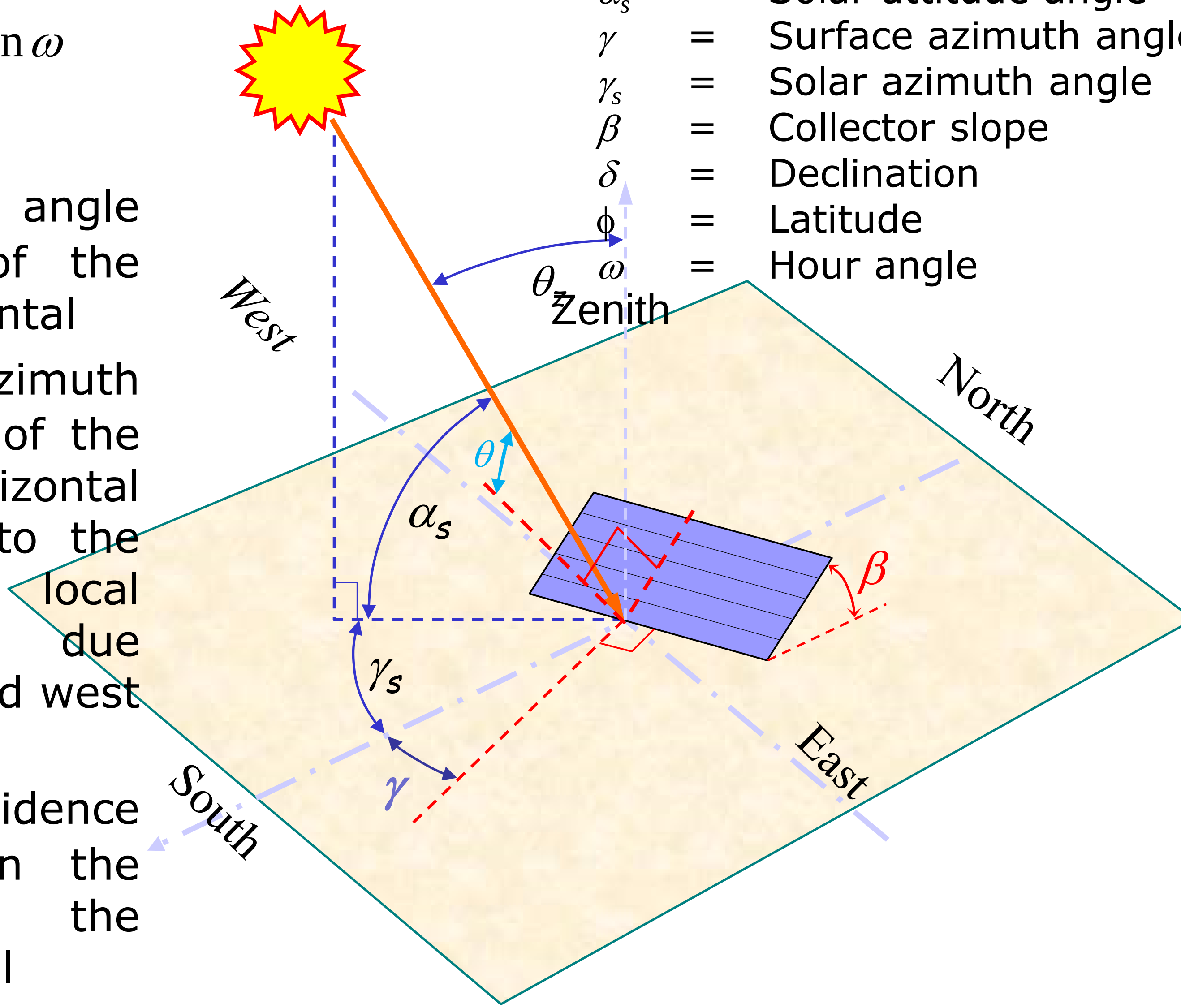
$$\cos\theta = \cos\alpha_s\sin\gamma\sin\beta\sin\gamma_s$$
$$+\cos\alpha_s\cos\gamma\sin\beta\cos\gamma_s$$
$$+\sin\alpha_s\cos\beta$$

θ = Angle of incidence
α_s = Solar attitude angle
γ = Surface azimuth angle
γ_s = Solar azimuth angle
β = Collector slope
δ = Declination
ϕ = Latitude
ω = Hour angle

β = Slope – the angle between the plane of the collector and the horizontal

γ = Surface azimuth angle – the deviation of the projection on a horizontal plane of the normal to the plane of the collector from the local meridian (with zero due south, east negative and west positive)

θ = Angle of incidence – the angle between the beam radiation on the collector and the normal



Solar geometry: Collector angles

Northern Hemisphere

$$\cos\omega_{ss} = -\tan\delta\tan\left(\phi - \beta\right)$$

ω_{ss} = Sunset angle

δ = Declination

ϕ = Latitude

β = Collector slope

Southern Hemisphere

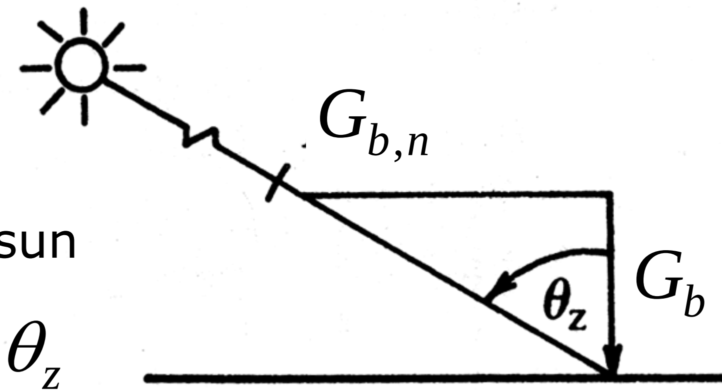
$$\cos\omega_{ss} = -\tan\delta\tan\left(\phi + \beta\right)$$

System design

Irradiance: Variables:

1. Latitude at the point of observation
2. Orientation of the surface in relation to the sun
3. Day of the year
4. Hour of the day
5. Atmospheric conditions

Irradiance on a horizontal surface

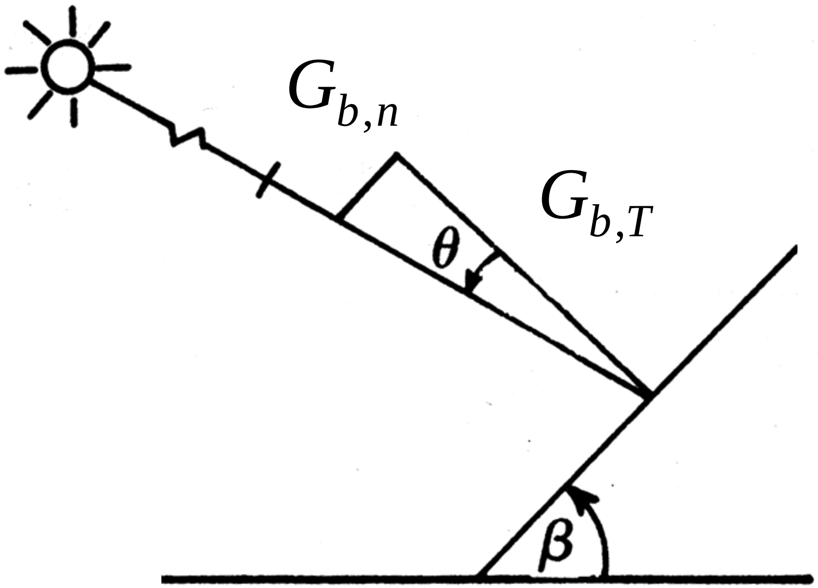


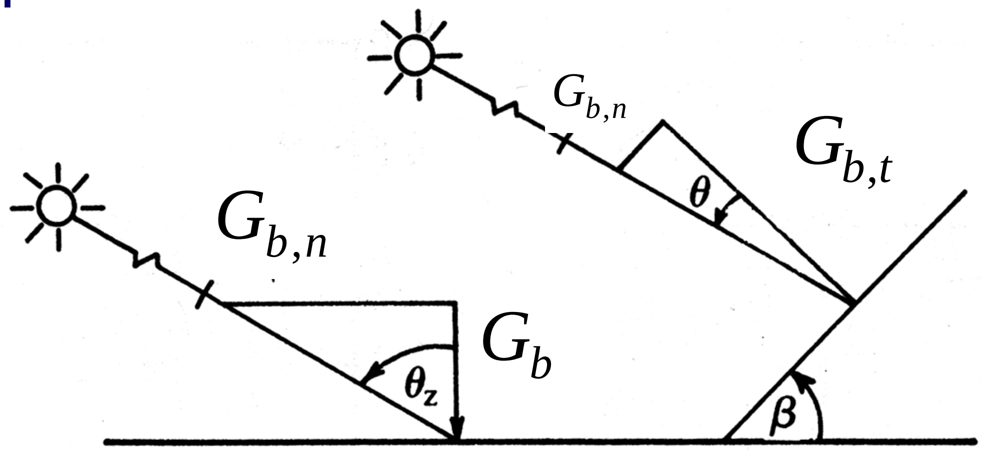
$$G_b = G_{b,n}\cos\theta_z$$

G_b = Beam Irradiance normal to the earth's surface (W/m^2)
$G_{b,n}$ = Beam Irradiance (W/m^2)
θ_z = Zenith angle

System design

Tilt: Beam radiation





$$G_{b,t} = G_{b,n} \cos\theta$$

$$R_{b,t} = \frac{G_{b,t}}{G_b} = \frac{G_{b,n}\cos\theta}{G_{b,n}\cos\theta_z} = \frac{\cos\theta}{\cos\theta_z}$$

$G_{b,t}$ = Beam Irradiance normal to a tilted surface (W/m²)

$G_{b,n}$ = Beam Irradiance (W/m²)

θ = Angle of incidence