SOLAR RADIATION

Atmospheric Effects: Solar radiation is absorbed, scattered and reflected by components of and reflected by components of the atmosphere. The amount of radiation reaching The amount of radiation reaching the earth is less than what entered the top of the atmosphere We classify it in atmosphere. We classify it in two categories:

1. **Direct Radiation:** radiation from the sun that reaches the earth without scattering
2. **Diffuse Radiation:** Diffuse Radiation: radiation radiation that is scattered by the atmosphere and clouds.

Air Mass represents how much atmosphere the solar radiation has to pass through before reaching the Earth pass through before reaching the Earth s' surface surface.

• Air Mass (AM) equals 1.0 when the sun is directly overhead at sea level. $AM = 1/ \cos \theta_z$

• We are specifically concerned with terrestrial solar radiation –that is, the solar radiation reaching the surface of the earth.

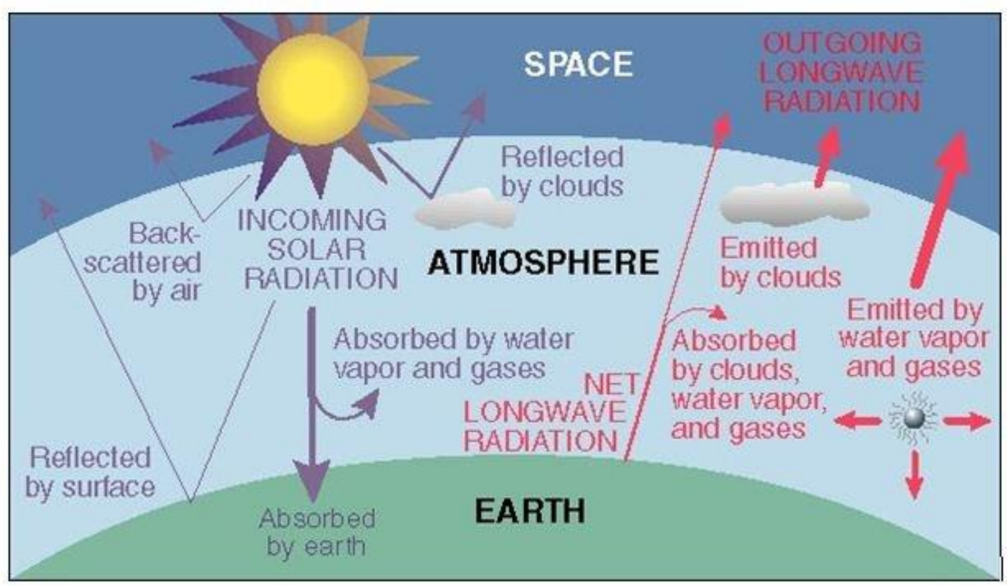
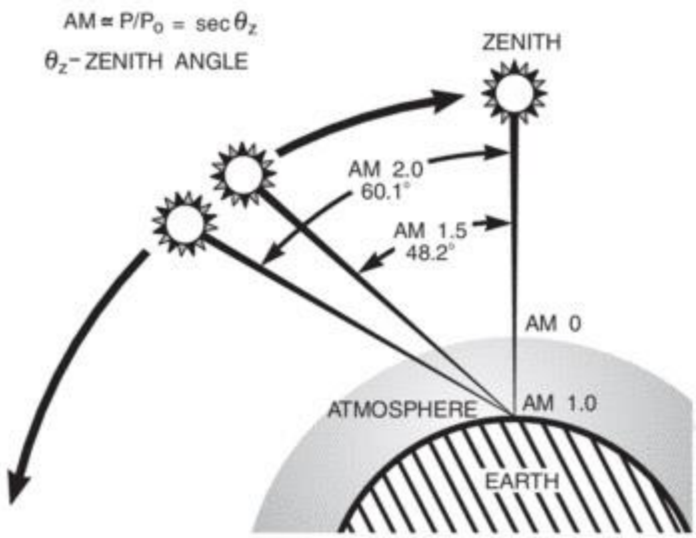


Figure (19): Diagram of overall solar radiation

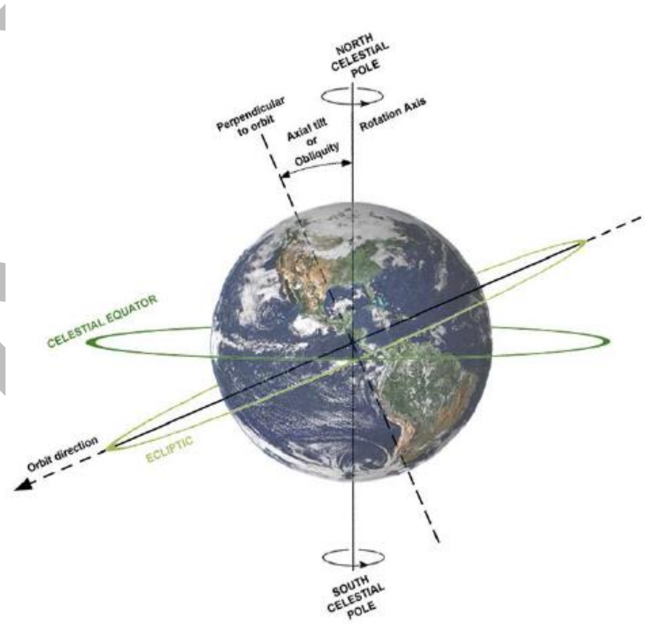
INSOLATION

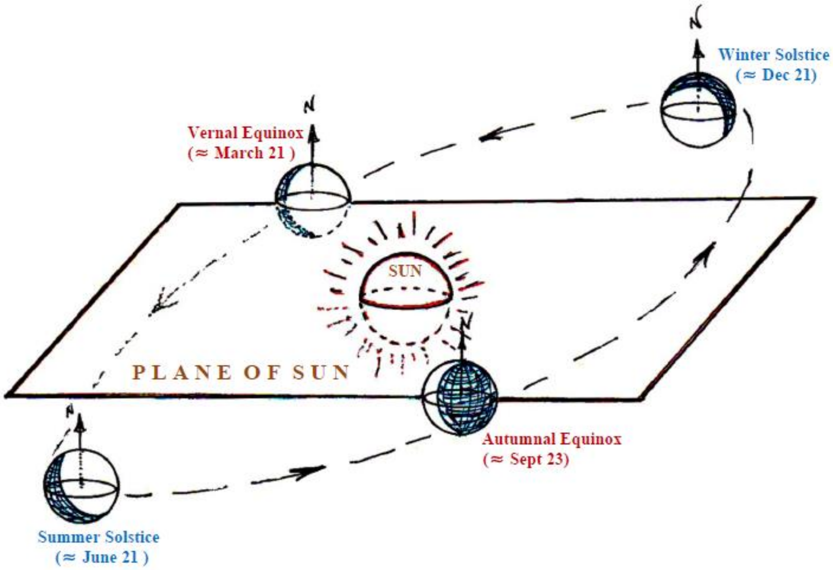
Insolation is the incident solar radiation. A measure of the solar energy incident on a given area over a specific period of time. Usually expressed in kilo watt hours per square meters per day or indicated in peak sun hours.



SOLAR GEOMETRY

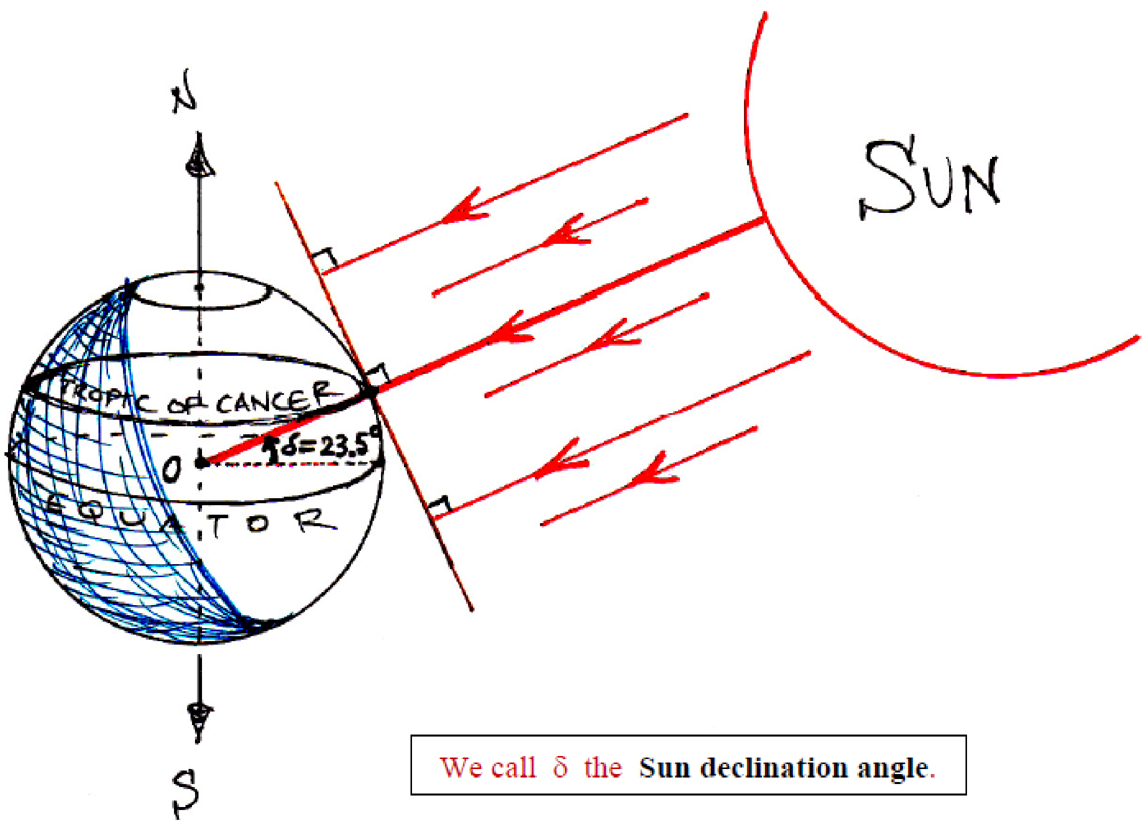
The Earth's daily rotation about the axis through its two celestial poles (North and South) is perpendicular to the equator, but it is not perpendicular to the plane of the Earth's orbit. In fact, the measure of tilt or obliquity of the Earth's axis to a line perpendicular to the plane of its orbit is currently about 23.5°. We call the plane parallel to the Earth's celestial equator and through the center of the sun the plane of the Sun. The Earth passes alternately above and below this plane making one complete elliptic cycle every year.





Summer Solstice

On the occasion of the summer solstice, the Sun shines down most directly on the Tropic of Cancer in the northern hemisphere, making an angle $\delta = +23.5°$ with the equatorial plane.

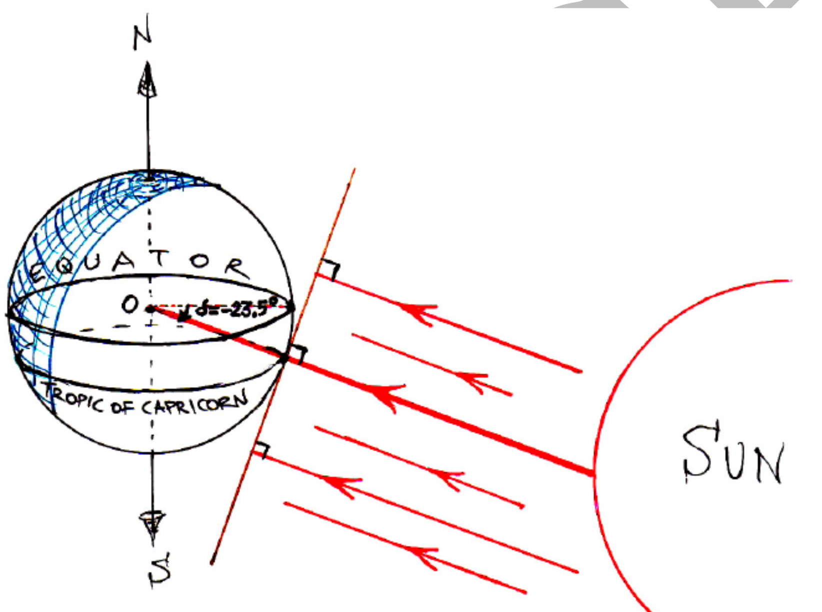


In general, the Sun declination angle, δ, is defined to be that angle made between a ray of the Sun, when extended to the center of the earth, O, and the equatorial plane. We take δ to be positively oriented whenever the Sun's rays reach O by passing through the Northern hemisphere.

On the day of the summer solstice, the sun is above the horizon for the longest period of time in the northern hemisphere. Hence, it is the longest day for daylight there. Conversely, the Sun remains below the horizon at all points within the Antarctic Circle on this day.

Winter Solstice

On the day of the winter solstice, the smallest portion of the northern hemisphere is exposed to the Sun and the Sun is above the horizon for the shortest period of time there. In fact, the Sun remains below the horizon everywhere within the Arctic Circle on this day. The Sun shines down most directly on the tropic of Capricorn in the southern hemisphere on the occasion of the winter solstice.



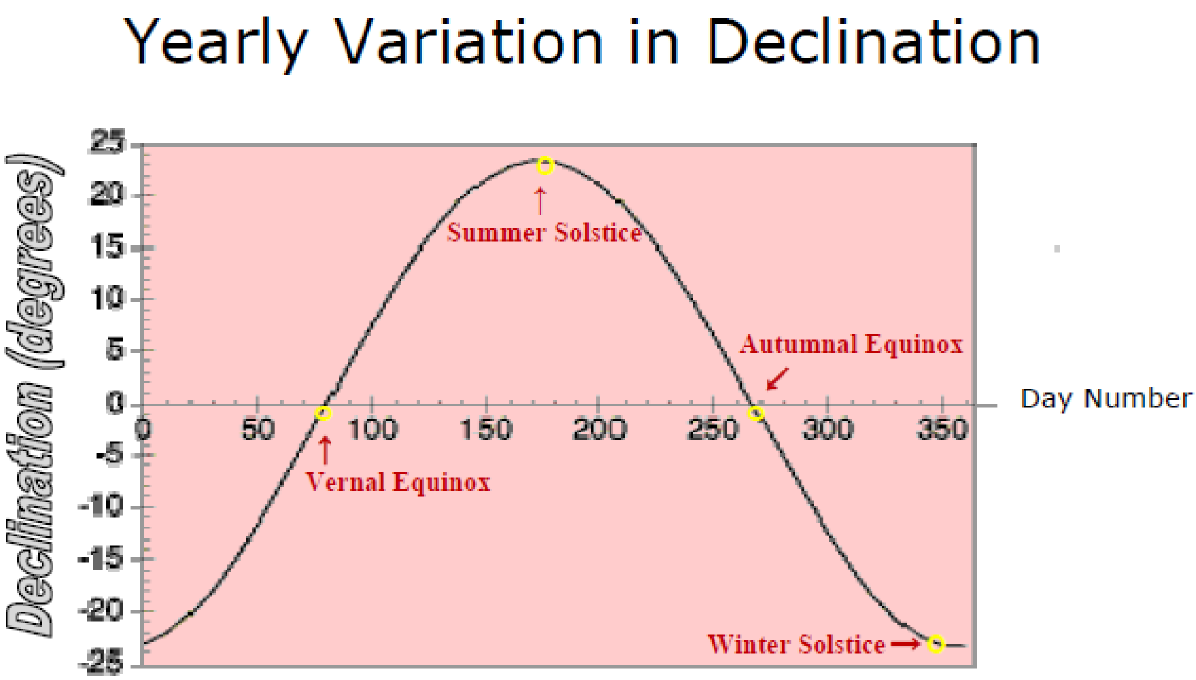
The Sun declination angle is $\delta = -23.5°$ on the winter solstice.

The Sun declination angle, δ, has the range: $-23.5° \le \delta \le +23.5°$ during its yearly cycle .

Accurate knowledge of the declination angle is important in navigation and astronomy. For most solar design purposes, however, an approximation accurate to within about 1 degree is adequate. One such approximation for the declination angle is:

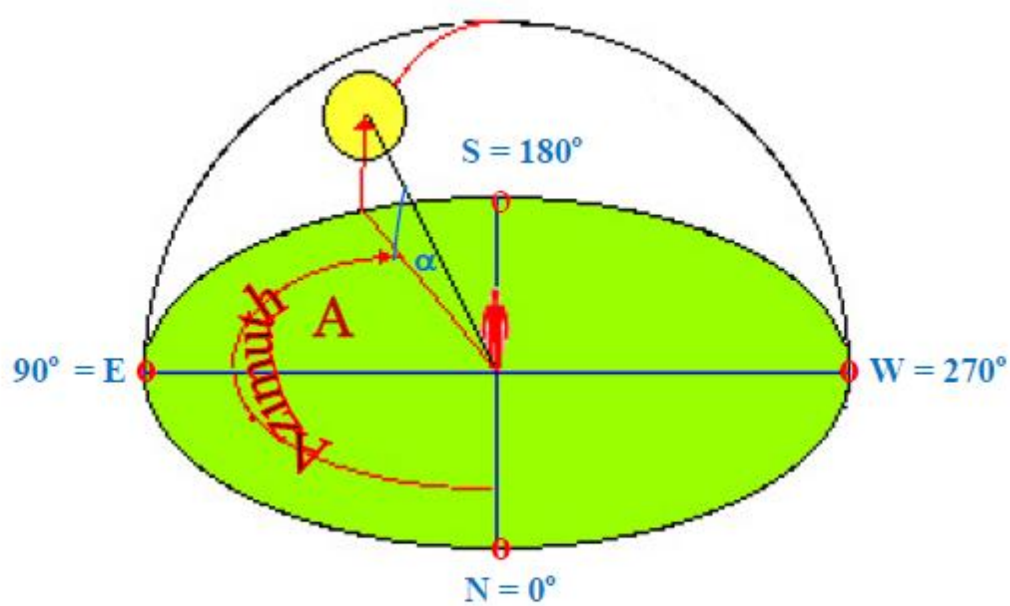
$$\sin \delta = 0.39795 \cdot \cos [0.98563 \cdot (N - 173)] \qquad (1)$$

Where the argument of the cosine here is in degrees and N denotes the number of days since January 1.

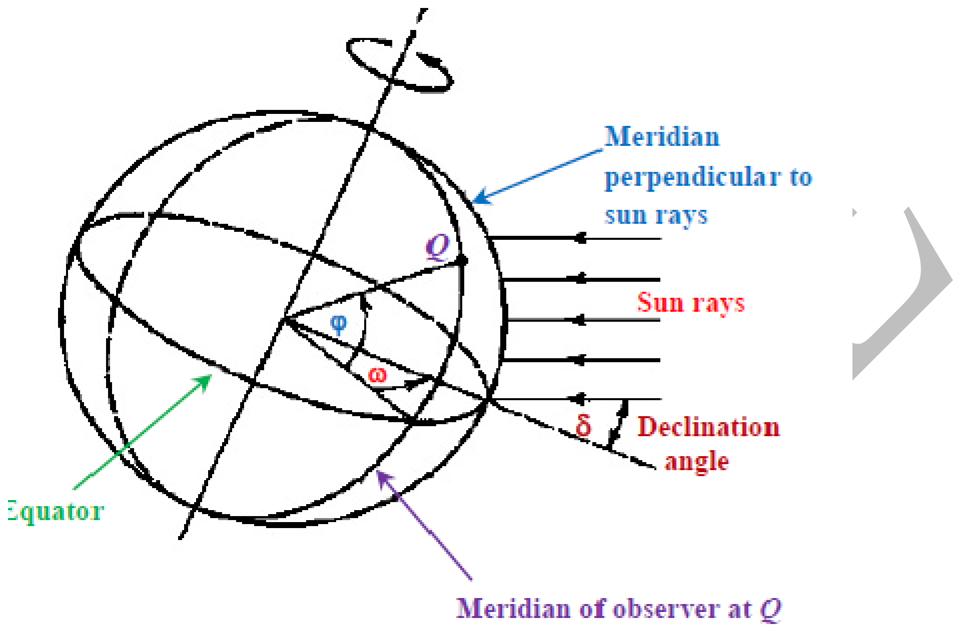


The azimuth is the local angle A between the direction of due North and that of the perpendicular projection of the Sun down onto the horizon line measured clockwise. Thus, we have the azimuth values: 0° = due North, 90° = due East, 180° = due South, and 270° = due West.

The angle of solar elevation, α, is defined as before, to be the angular measure of the Sun's rays above the horizon. Equivalently, it is the angle between the direction of the geometric center of the Sun and the horizon.



The hour angle, ω, is the angular distance between the meridian of the observer and the meridian whose plane contains the sun. Thus, the hour angle is zero at local noon (when the sun reaches its highest point in the sky). At this time the sun is said to be 'due south' (or 'due north', in the Southern Hemisphere) since the meridian plane of the observer contains the sun. The hour angle increases by 15 degrees every hour.



It follows that at local noon, the hour angle is zero: $\omega = 0°$. Using a 24 hour time scale for the day, ($0 \le t \le 24$, then $t = 12$ *at local noon*, $t = 6.5$ *at five and one-half hours before local noon* and $t = 18.25$ *at six and one-quarter hours after local noon*) , we have that at time t_o , the measure of the hour angle is:

$$\boxed{\omega = 15 \cdot (t_o \; - 12)°} \qquad \textbf{(5)}$$

Upon solving (4) for ω_o , setting that result equal to the right side of (5), and then solving it for ($t_o - 12$), we find that

(i) *Sunrise occurs at* $\dfrac{\cos^{-1}(-\tan\varphi \cdot \tan\delta)^o}{15^o}$ hours before local noon

and

(ii) *Sunset occurs at* $\dfrac{\cos^{-1}(-\tan\varphi \cdot \tan\delta)^o}{15^o}$ hours after local noon. **(6)**

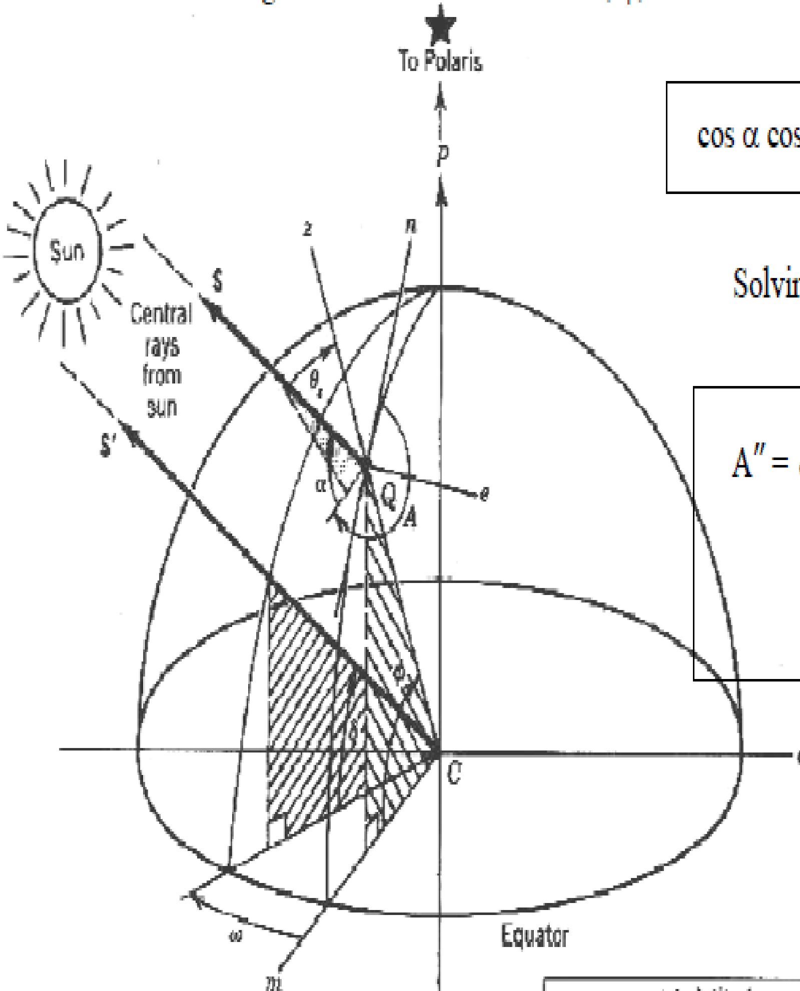
Exceptional cases: (a) *If* $(\tan\delta \tan\varphi) \ge 1$, *then no sunset that day*.
(b) *If* $(\tan\delta \tan\varphi) \le -1$, *then no sunrise that day*.

Note that cases (a) and (b) only relate to latitudes beyond $\pm 65.5°$, i.e. above the Arctic Circle or below the Antarctic Circle.

Azimuth Equation

One equation which relates the Sun's azimuth angle, A, at a given location, its angle of elevation, α, the current hour angle ω at the observer's latitude, φ, and the Sun's declination angle, δ, on this date is:

$$\cos\alpha\cos A = \sin\delta\cos\varphi - \cos\delta\cos\omega\sin\varphi \quad (8)$$



Solving for the azimuth, A, we find:

$$A'' = \cos^{-1}\left(\frac{\sin\delta\cos\varphi - \cos\delta\cos\omega\sin\varphi}{\cos\alpha}\right) \quad (9)$$

where if $\omega \leq 0$ then $A = A''$.

Otherwise, $\omega > 0$ and $A = 360° - A''$.

Earth–Sun angles	ϕ latitude angle δ declination angle ω hour angle
Observer–sun angles	α altitude angle θ_z zenith angle A azimuth angle