The Sun As A Source Of Energy

1. Solar Astronomy

1.1. The Earth And It's Orbit Around The Sun

The Earth is an obligated sphere, meaning that it is a sphere that is flattened at the poles and bulges around the equator. For solar power calculations it is sufficient to treat the Earth as a simple sphere with a diameter of approximately 12 800 km. Points on the Earth's surface are defined in terms of *longitude* and *latitude*. The latitude of a point (P) is the angle between a radius drawn from the point to the centre of the Earth and a radius drawn from the centre of the Earth to the equator as illustrated in figure 1.1, values range from 0° to 90° North and 0° to 90° South (where 0° is the latitude of any point on the equator). The longitude of a point is the angle between the Greenwich (or prime) meridian and the meridian that passes through the point. A meridian is a circumference that passes through both poles. Values of longitude range from 0° to 90° East and 0° to 90° West (where 0° is the longitude of any point on the Greenwich meridian).

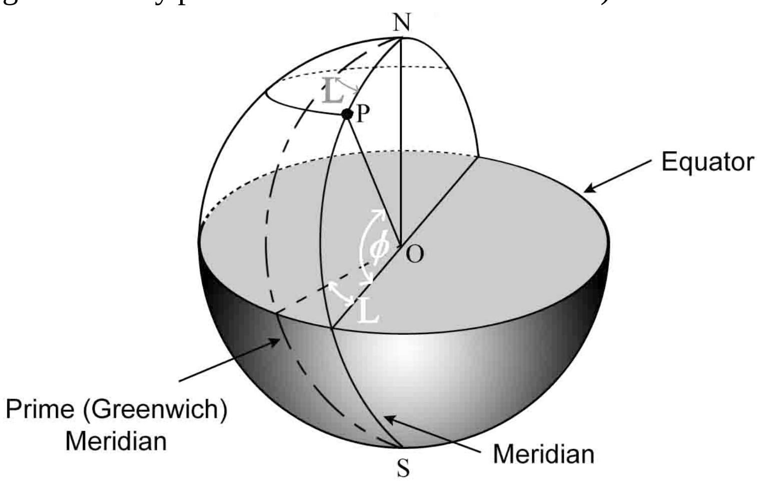

Figure 1.1: The longitude and latitude of a point P on the earth's surface. L = longitude and v = latitude.

All latitudes above 66.55° north are inside the *Arctic Circle* (figure 1.3) and all points below 66.55° south are inside the *Antarctic Circle*. All points between the latitudes of 23.45° north and 23.45° south are inside the *tropics* with the *Tropic of Cancer* being at a latitude of 23.45° north and the *Tropic of Capricorn* being at a latitude of 23.45° south. Latitudes can be written as positive values indicating north and negative values indicating south; so that the tropics span from +23.45° to –23.45°.

The Earth rotates around it's axis every 24 hours and orbits the Sun every 365.25 days (approximately). The Earth's orbit (figure 1.2) follows an elliptical path with the Sun at one of the foci so that the minimum distance between the Sun and the Earth is 146.10×10^6 km (the Earth is said to be at *perihelion* on about the 2nd January) and the minimum distance between the 152.10×10^6 km (the Earth is said to be at *aphelion* on about 3rd July). The difference between the maximum and minimum distance is only 3.3% with a mean distance of 149.5985×10^6 km is normally used.

The axis of rotation is tilted at an angle of 23.45° with respect to the plane of the orbit around the Sun. The axis is orientated so that it always points towards the Pole Star and this accounts for the seasons and changes in the length of day throughout the year. The angle between the equatorial plane and a line joining the centres of the Sun and the Earth is called the *declination angle* (δ). Because the axis of the Earth's rotation is always pointing to the Pole Star the declination angle changes as the Earth orbits the Sun (figures 1.2, 1.3 and 1.4).

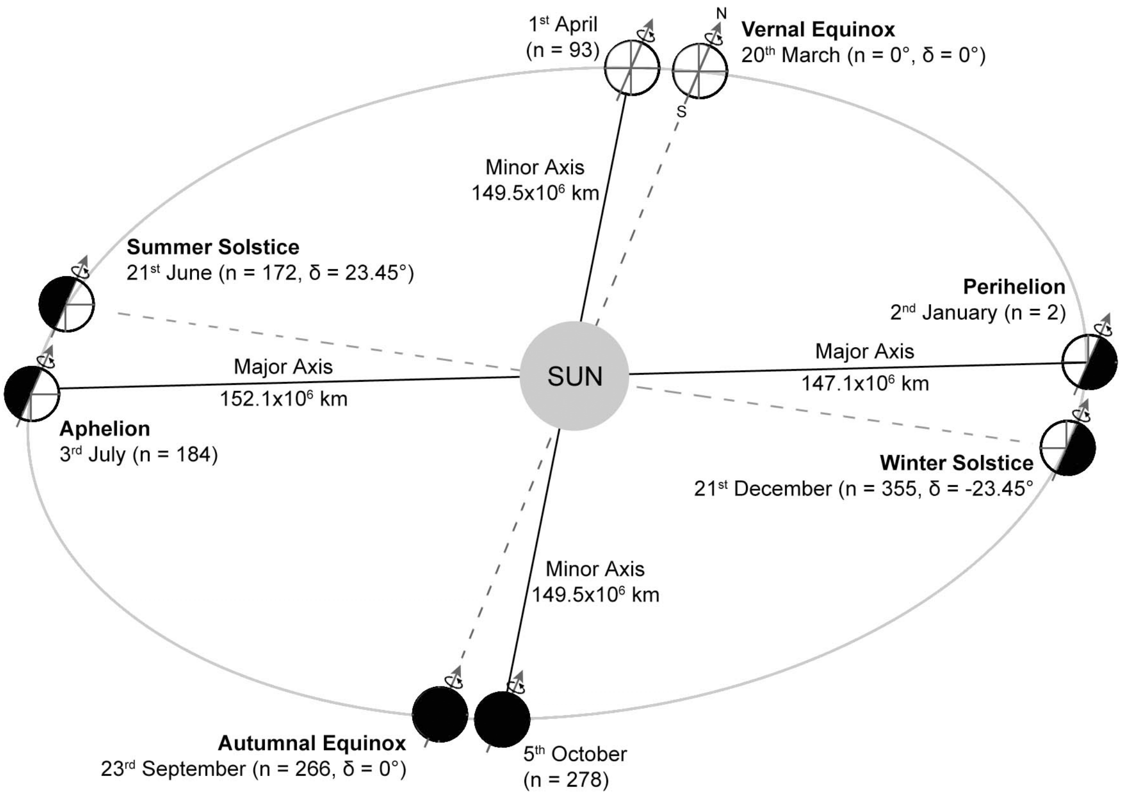

Figure 1.2: The orbit of the Earth around the Sun: n is the day number, where on the 1st January n = 1; δ is the declination angle.

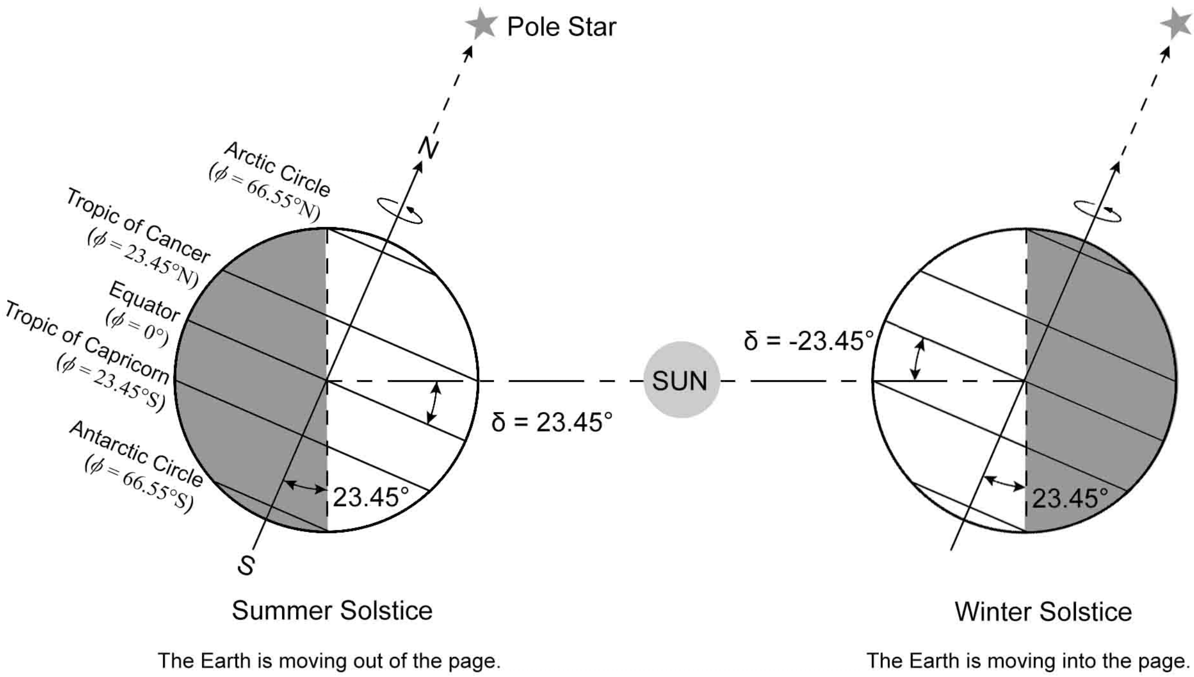

Figure 1.3: The summer and winter solstices. δ is the declination angle and v is the latitude.

On the *summer solstice* (21st June) the Earth's axis is orientated directly towards the Sun, therefore the declination angle is 23.45° (figure 1.3). All points below 66.55° south have 24 hours of darkness and all point above 66.55° north have 24 hours of daylight. The sun is directly over head at solar noon at all points on the *Tropic of Cancer*. On the *winter solstice* (21st December) the Earth's axis is orientated directly away from the Sun, therefore the declination angle is -23.45° (figure 1.3). All points below 66.55° south have 24 hours of daylight and all point above 66.55° north have 24 hours of darkness. The sun is directly over head at solar noon at all points on the Tropic of Capricorn. At both the a*utumnal* and v*ernal equinoxes* (23rd September and 21st March respectively) the Earth's axis is at 90° to the line that joins the centres of the Earth and Sun, therefore the declination angle is 0° (figure 1.4). All latitudes have 12 hours of sunlight and the Sun is directly overhead at solar noon for all points on the equator. Note that the Sun is never directly overhead outside the tropics.

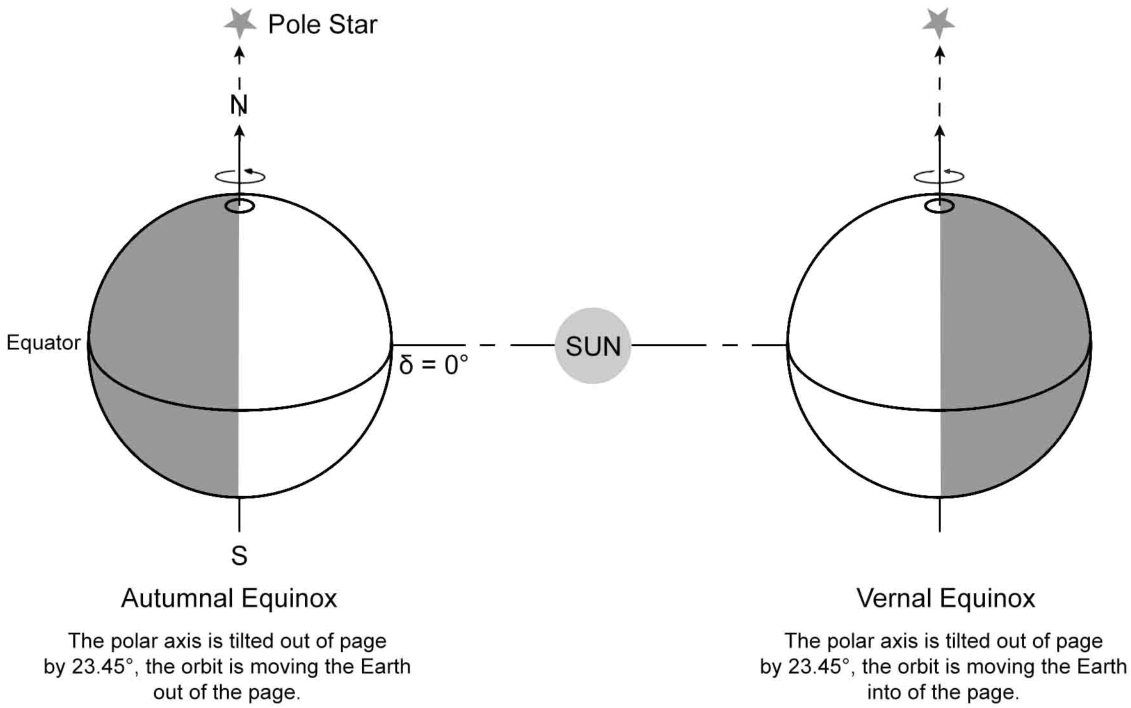

Figure 1.4: The autumnal and vernal winter solstices

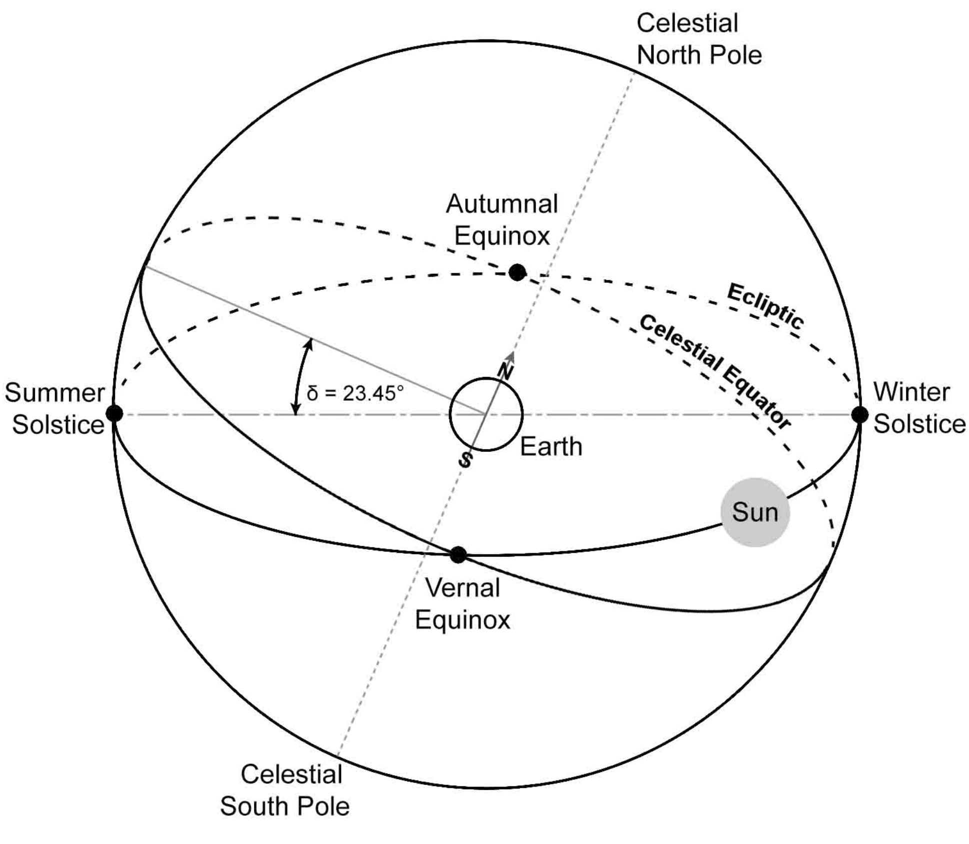

Figure 1.5: The celestial sphere. δ is the declination angle, which is at a maximum at the solstices and zero at the equinoxes.

Another way to view the motion of the Earth around the Sun is to consider the Earth as stationary and plot the apparent motion of the Sun throughout the course of one year, such a view is called the *celestial sphere* and is shown in figure 1.5. In this model the Sun moves around the ecliptic and the Earth's equator is projected onto the celestial sphere as the *celestial equator*. The variation in the declination throughout the year is clearly seen in figure 1.5; where the declination angle is the angle between the lines joining the centre of the Earth to the ecliptic and the celestial equator. δ is the declination angle.

1.2. Plotting The Sun Around Across The Sky

The position of the Sun in the sky as viewed from any point on the Earth's surface can be defined using a variety of angles. The *declination angle* (δ) and the *hour angle* (ω) most easily defined from a view looking back at the Earth (figure 1.6). The declination angle is described in section 1.1 and is the same for the whole Earth on any particular day.

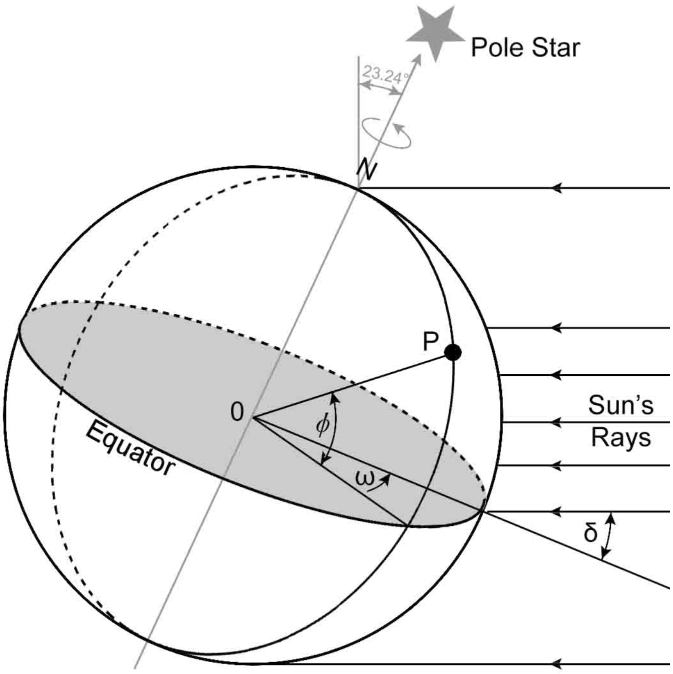

Figure 1.6: The declination angle (δ), latitude (ϕ) and hour angle (ω) for point P.

The hour angle at a point P on the Earth's surface is the angle between the meridian containing point P and the meridian that is parallel to the Sun's rays. The hour angle is negative during the morning, reduces to zero at solar noon (when point P faces the Sun) and becomes increasingly positive as the afternoon progresses. Note that hour angle at any particular time is the same for all points on any particular meridian (i.e. points with the same longitude). Since the Earth completes one revolution every 24 hours, the hour angle changes by (360/15) 15° every hour.

More angles are defined by considering the path of the Sun across the sky when viewed from point P on the surface of the Earth. Figure 1.7 shows the *solar zenith angle* (θ_Z), the *solar altitude angle* (α) and the *solar azimuth angle* (A_Z). The height of the Sun in the sky at any time can be descried as either α° from the horizon or θ_Z° from a normal running though point P from the centre of the Earth (so that $\alpha + \theta_Z = 90°$).

The compass position of the Sun is given by A_Z. Figure 1.7 shows A_Z measured from due north, so that it equals 180° at solar noon. An alternative method can be used that measures from due south so that $A_Z = 0°$ at solar noon, negative when the Sun is east from this point (i.e. in the morning) and positive when the Sun is west of this point (i.e. in the afternoon, as illustrated in figure 1.7).

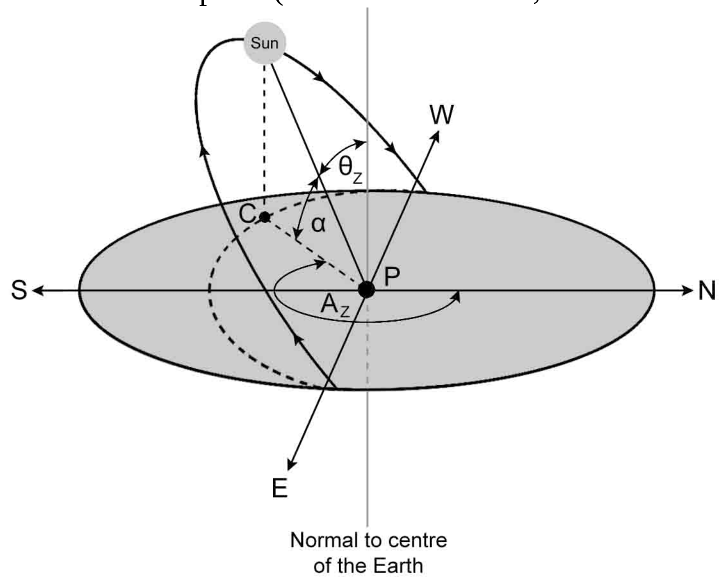

Figure 1.7: The zenith angle (θ_Z), the altitude angle (α) and the azimuth angle (A_Z) of the Sun when view from point P on the Earth's surface.