EARTH’S ORBIT

- Earth’s orbit is elliptical
  - Eccentricity = 0.0167
  - Period = 365.25463 days
  - Average Earth-Sun distance is 93,000,000 miles
  - Earth is closest to sun near January 3rd (perihelion, about 91,000,000 miles)
  - Earth is farthest from sun near July 4th (aphelion, about 94,000,000 miles)
  - Earth’s axis of rotation is tilted 23.5° with respect to the plane of orbit

ANGLES OF IMPORTANCE

- Latitude (φ) – the angle between a position on the Earth’s surface, the center of the Earth, and the plane of the equator
  - Latitude varies from +90° at the North Pole to −90° at the South Pole
- Declination (δ) – the angle between the sun, the center of the Earth, and the plane of the equator (the latitude over which the sun is directly overhead)
  - Declination varies from +23.5° at the Summer Solstice to −23.5° at the Winter Solstice
  - Declination can be estimated by
    \[ \delta = \pm 23.5^\circ \sin \left( \left| N \right| \right) \]  \hspace{1cm} (1)
    
    where \( N \) is the number of days to the nearest Equinox (either forward or backwards).
  - The + sign is used for dates between the March and September equinoxes, while the − sign is used for dates between the September and March equinoxes.
- Sun angle (ψ) – the angle between the Sun, a position on the surface of the Earth, and a plane tangent to the Earth at that position
○ Sun angle is negative between sunset and sunrise
○ Sun angle is maximum at local noon
○ The sun angle at any time of day is found by

\[
\sin \psi = \sin \phi \sin \delta - \cos \phi \cos \delta \cos (15^\circ t_{\text{UTC}} - \lambda)
\]

where \(\lambda\) is West longitude and \(t_{\text{UTC}}\) is the decimal hours in Universal Time.

○ The noon sun angle (\(\psi_{\text{noon}}\)) is found by

\[
\psi_{\text{noon}} = 90^\circ + \delta - \phi
\]

○ The sun angle should always fall in the range of \(-90^\circ \leq \psi \leq 90^\circ\). If either (2) or (3) yield a number that is outside of this range then the number should either subtracted (if positive) or added (if negative) to 180°.

○ Solar zenith angle (\(\Phi\)) – the angle between the Sun, a position on the surface of the Earth, and the local vertical at that position

\[
\Phi = 90^\circ - \psi
\]

SEASONS

● Because the Earth’s axis is tilted, the declination angle changes throughout the year

● The change in the declination is responsible for the differing amount of heat received at the surface of the Earth, and results in the seasons.

○ The ratio of energy flux from a tilted beam to that of a direct beam is

\[
E_{\text{tilted}} / E_{\text{direct}} = \sin \psi
\]

○ A direct beam will have more energy flux than a tilted beam

○ Sun angle is lowest in winter, so less energy is absorbed per unit area

At low sun angles, the Sun’s rays must also penetrate more of the atmosphere, resulting in more absorption, so less energy reaches the surface.

● The change in declination also results in longer days and shorter nights in the summer hemisphere.

○ Ground receives energy over a longer time period in summer than in winter.

● Solstices and Equinoxes

○ Equinoxes occur when declination is zero
Occur near March 20 (Vernal) and September 22 (Autumnal)

- Solstices occur when declination is a maximum or minimum
  - Summer solstice occurs when declination is +23.5°
    - Sun directly over 23.5°N latitude (Tropic of Cancer)
    - Occurs near June 21
  - Winter solstice occurs when declination is −23.5°
    - Sun directly over 23.5°S latitude (Tropic of Capricorn)
    - Occurs near December 21

- Astronomical seasons are defined in terms of solstices and equinoxes
  - Spring – begins at vernal equinox
  - Summer – begins at summer solstice
  - Autumn – begins at autumnal equinox
  - Winter – begins at winter solstice
- Meteorological seasons are defined in terms of the hottest and coldest months
  - Spring – March, April, and May
  - Summer – June, July, and August
  - Autumn – September, October, and November
  - Winter – December, January, and February

EXERCISES

1. What is the noon sun angle in Olathe, KS (38.9° N, 94.8° W) on November 4th?

2. What is the sun angle in Olathe, KS at 2:38 p.m. Central Standard Time (CST) on November 4th?