1.3: Lab 3 - Earth-Sun Relationships

Learning Objectives

- Describe how Earth's rotation, revolution, tilt, polarity, and shape influence the Annual March of the Seasons.
- Diagram the seven special lines of latitude and explain their relationship to solstices and equinoxes.
- Explain the relationship between the angle of incidence and radiation intensity.
- Identify vertical, oblique, and tangent rays from the Sun.
- Use an analemma to calculate solar altitude.
- Analyze daylength at different locations and times of the year.

Introduction

Earth's annual revolution around the Sun influences the angle of incoming solar rays and the length of day at different latitudes. The amount of incoming solar radiation, or **insolation**, along with daylength influence the Earth's seasons. In this lab, we will study the relationships between the Earth and the Sun and how those relationships influence the seasons we experience every year. This relationship results in what is known as the **Annual March of the Seasons**.

Part A. The Annual March of the Seasons

Earth has five key characteristics that play a role in the Annual March of the Seasons: rotation, revolution, tilt, polarity, and shape.

1. Rotation

Earth rotates on its axis every 24 hours, which we consider to be one day (Figure 3.1). Each rotation can be seen in the daily change from day to night. The circle of illumination is the line separating the part of the planet receiving sunlight and the part of the planet in darkness.

Why does Earth rotate? It will help to understand how our solar system formed. Almost five billion years ago, our solar system had its beginnings as a vast cloud of dust and gas. The cloud began to collapse, flattening into a giant disk that rotated faster and faster, just as an ice skater spins faster as she brings her arms in. The Sun formed at the center, and the swirling gas and dust in the rest of the spinning disk clumped together to produce the planets, moons, asteroids, and comets. The reason so many objects orbit the Sun in nearly the same plane (called the ecliptic) and in the same direction is that they all formed from this same disk. While the planets were forming, clumps of matter of all sizes often collided, and either stuck together or side-swiped each other, knocking off pieces and sending each other spinning.[38]

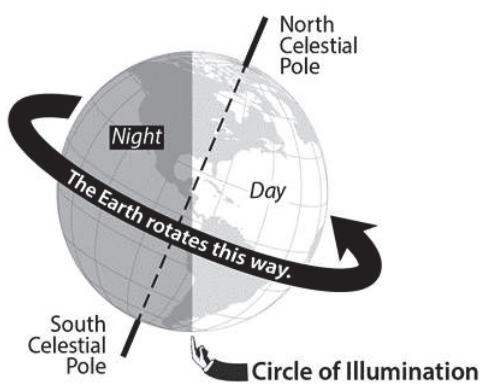

Figure 3.1: Earth's Rotation. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

2. Revolution

Earth revolves around the Sun every 365.25 days, which we consider to be one year. This orbit is not a perfect circle as we might imagine; it is actually an elliptical orbit (Figure 3.2). In one revolution, Earth travels approximately 940 million kilometers 584 million miles)! Because Earth is traveling in an **elliptical orbit**, it is closer to the Sun on or around January 3 (known as **perihelion**) than it is on or around July 4 (known as **aphelion**). At perihelion, Earth is 147.5 million kilometers (approximately 91 million miles) from the Sun and at aphelion Earth is 152.6 million kilometers (approximately 95 million miles) from the Sun. Tip:

to help you remember that aphelion occurs when Earth is furthest away from the Sun, think of the "a" in aphelion as further "away".

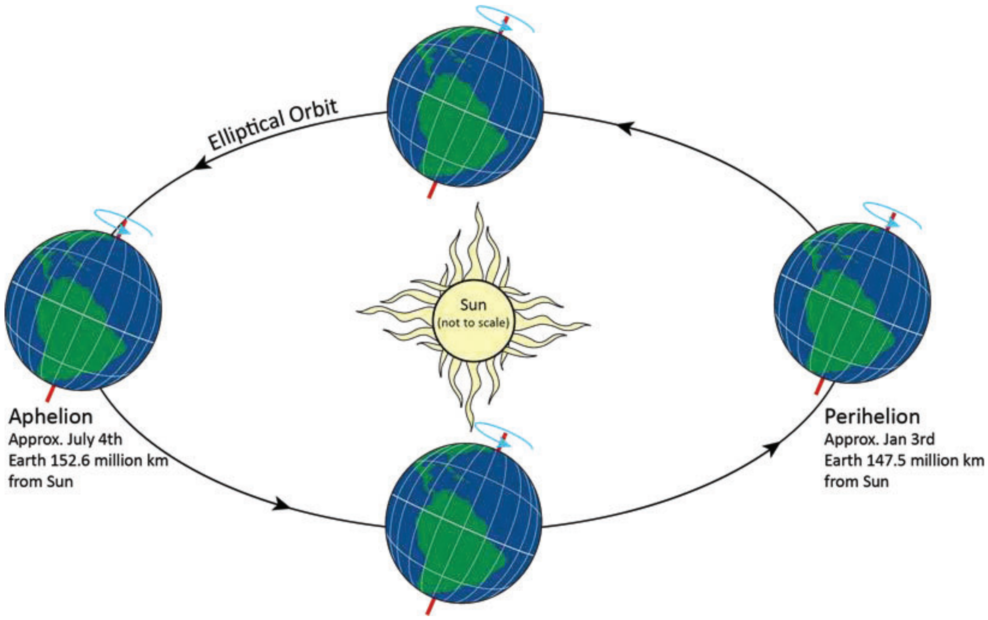

Figure 3.2: Earth's Revolution. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

3. Tilt

Currently, the axis of the Earth is tilted at 23.5°. Earth revolves around the Sun on an imaginary straight line known as the **plane of the ecliptic** (Figure 3.3).

4. Polarity

While Earth's axis is currently pointing toward Polaris, known as the North Star, the top of the Earth or the North Pole is not always orientated toward the Sun. As you can see in Figure 3.3 sometimes the North Pole is orientated toward the Sun and other times it is orientated away from the Sun. This phenomenon influences the amount of daylight received by the Earth at various latitudes, known as **daylength**.

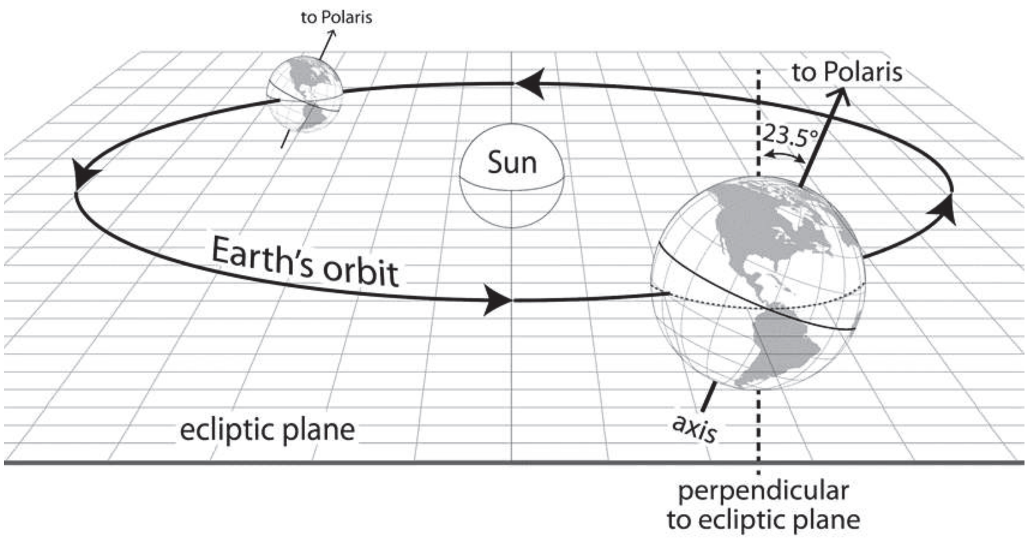

Figure 3.3: Earth's Tilt and the Plane of the Ecliptic. Note: the diagram is not drawn to scale. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

5. Shape

Earth is an oblate sphere and like all spheres, its surface is curved. This means that the Sun's rays strike the Earth at different angles for each latitude. As you can see in Figure 3.4, the Sun's rays strike the Earth at the center (equator) directly, almost at 90°, while they strike toward the poles at a lower angle, more like 10° or 20°. Because the Earth is curved, the **angle of incidence** the angle of the Sun's rays) varies by latitude. And, because the Earth is titled, the angle of incidence also varies by season.

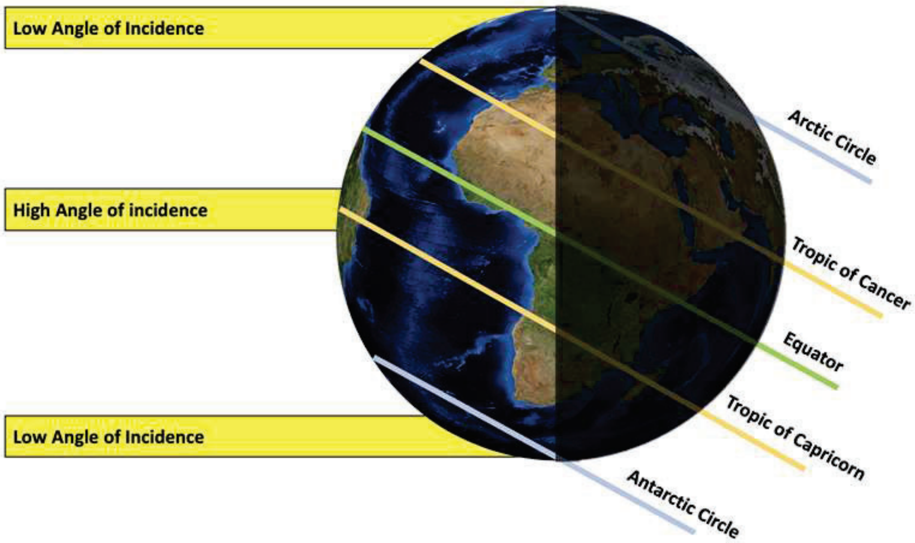

Figure 3.4: Angle of Incidence. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Pin It! Annual March of the Seasons

Ever wonder why Earth has different seasons and variations in daylength? This video, Why Do We Have Different Seasons?, by the California Academy of Sciences demonstrates how Earth's tilt and its revolution around the Sun influence the annual march of the seasons. Understanding the reasons for the seasons is important to know for your physical geography class. (Video length is 3:17).

The Sun's vertical rays strike the Earth at the equator (0°) on the March equinox (March 20) and the September equinox (September 21). The March equinox is known as spring in the northern hemisphere and fall in the southern hemisphere, while the September equinox is known as fall in the northern hemisphere and spring in the southern hemisphere. During the equinoxes, the **circle of illumination** bisects all parallels (remember that parallels are lines measured in latitude). This even division creates an equal amount of daylight of exactly 12 hours for all latitudes. The circle of illumination can be seen in Figure 3.5.

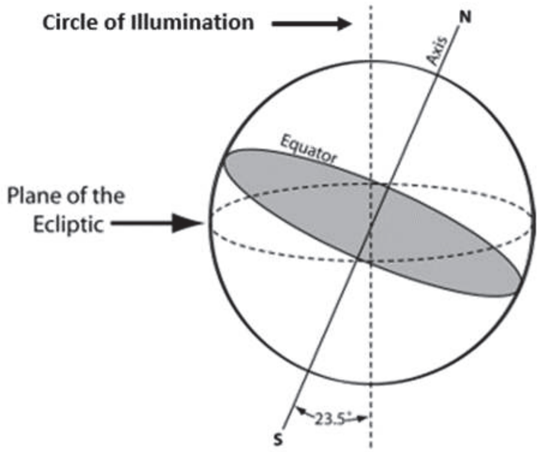

Figure 3.5: The Plane of the Ecliptic and the Circle of Illumination. Figure by Scott Crosier and Taya Lazootin is licensed under CC BY-NC-SA 4.0

The Sun's vertical rays strike the Earth at the Tropic of Cancer (23.5°N), located in the northern hemisphere, on the June solstice (June 22). The Sun's vertical rays strike the Earth at the Tropic of Capricorn (23.5°S), located in the southern hemisphere, on the December solstice (December 21). The June solstice is known as summer in the northern hemisphere and winter in the southern hemisphere, while the December solstice is known as winter in the northern hemisphere and summer in the southern hemisphere. In addition, both hemispheres experience longer daylength in the summer and shorter daylength in the winter. During the December Solstice the Arctic Circle receives 24 hours of darkness, while the Antarctic Circle receives 24 hours of daylight.

Pin It! The Milankovitch Cycles

To get a better understanding of how changes in Earth's orbit can impact climate and weather, watch this cool video on the natural cycles of Earth-Sun relations. These cycles will be important to remember later in the lab class when climate patterns and climate change are discussed. (Video length is 6:34).

Use what you have learned from the reading, your prior knowledge, and the **Pin It! Annual March of the Seasons** to answer the questions below.

? Exercise 1.3.1

1. In which hemisphere do you currently live?
2. On August 16th:
   a. What season are you experiencing?
   b. What is the daylength like during this season?
   c. What three key observations can you make about your daily routine?
   d. What activities might you do during this season that you might not do in other seasons? Why?
3. On January 16th:
   a. What season are you experiencing?
   b. What is the daylength like during this season?
   c. What three key observations can you make about your daily routine?
   d. What activities might you do during this season that you might not do in other seasons? Why?

4. Identify the seven special parallels of Earth and their latitude. Write each special parallel along with its degree latitude on the correct line on the diagram of the Earth (Figure 3.6). Use the following parallels and degrees:
   a. North Pole, 90°N
   b. South Pole, 90°S
   c. Tropic of Cancer, 23.5°N
   d. Tropic of Capricorn, 23.5°S
   e. Arctic Circle, 66.5°N
   f. Antarctic Circle, 66.5°S
   g. Equator, 0°

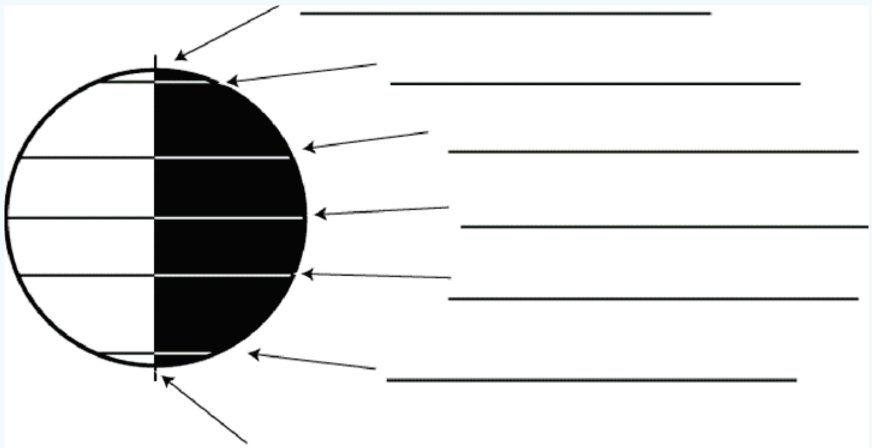

Figure 3.6: The Seven Special Parallels of the Earth. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

5. Figure 3.7 shows Earth’s complete revolution around the Sun.
   a. Label the approximate point in the elliptical revolution when the perihelion and aphelion occur.
   b. Using the terms listed below (i and ii), label the correct equinoxes and solstices that occur during this annual revolution on the top line and the season for the northern hemisphere on the bottom line.
      i. March equinox, June solstice, September equinox, December solstice
      ii. Season in northern hemisphere: winter, spring (vernal), summer, fall (autumnal)

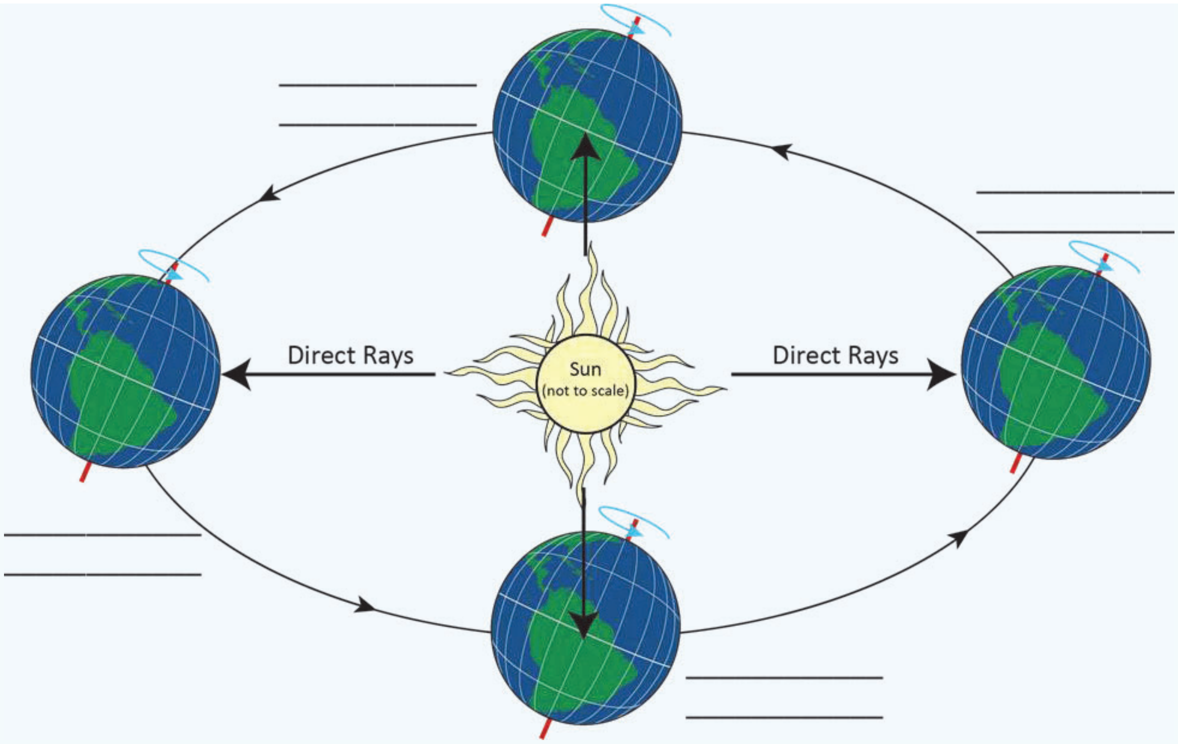

Figure 3.7: Solstices and Equinoxes Diagram for Labeling. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

6. During which northern hemisphere season does the Sun's rays strike the Earth at 23.5°N latitude?
7. During which solstice does the south pole experience winter and receive no daylight?
8. During which season in the northern hemisphere does Earth experience aphelion?
9. During which season in the northern hemisphere does Earth experience perihelion?
10. Use Your Critical Thinking Skills: According to your answers for 8 and 9, does distance between the Earth and the Sun determine the seasons of the year? Why or why not? Explain your response in at least one sentence.

As you have learned, Earth's surface is curved. Therefore, the Sun's rays strike Earth at different angles depending on latitude. Rays that strike Earth directly at a 90° angle are known as vertical rays (VR), rays that strike Earth at an angle less than 90° are known as oblique rays (OR), and rays that strike Earth at exactly 0° are known as tangent rays (TR). Note that there is only one location that experiences vertical rays on a given day, while there are multiple latitudes that experience oblique and tangent rays on a given day.

11. On Figure 3.8, label each of the remaining seven rays correctly with terms listed below, you can see one has been done for you.
    a. vertical ray label as VR
    b. oblique rays label as OR
    c. tangent rays label as TR

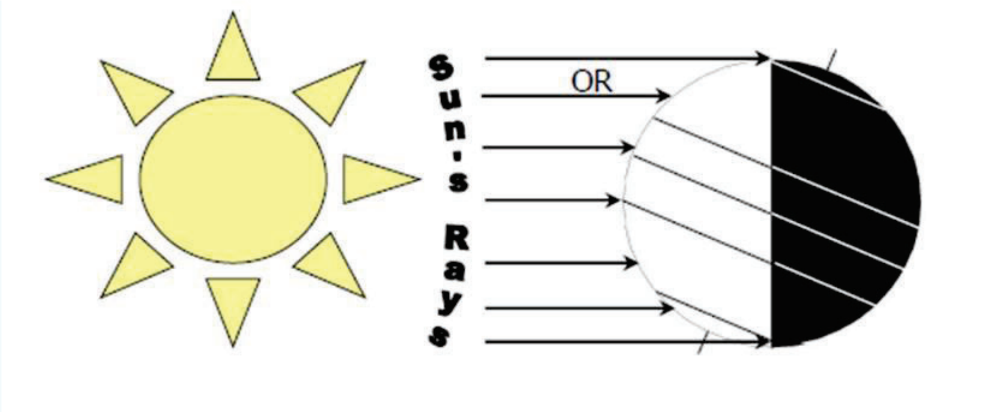

Figure 3.8: Vertical, Oblique, and Tangent Rays of the Sun. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

12. Refer to Figure 3.8. Study the position of the Earth in relation to the Sun in order to answer the following questions:
    a. What solstice is represented in this diagram? How can you tell?
    b. Which hemisphere is experiencing winter?
    c. Is daylength longer or shorter in the Southern Hemisphere?
    d. What latitude is the vertical ray striking?
    e. What parallel is the vertical ray striking?
    f. What type of ray is striking the equator?
    g. What type of ray is striking the Antarctic Circle?

As you have just learned, vertical rays are those that strike Earth at 90°. These are the most direct rays. Therefore, the latitudes on Earth that receive vertical rays will receive the most intense insolation compared to other latitudes. The latitude of the Sun's vertical rays is called the **declination of the Sun.**

The declination of the Sun changes throughout the year. Let us determine the declination of the Sun for random days of the year so you can see how it changes. To do this, we can use a tool called the analemma (see Figure 3.9). An analemma looks like a figure-eight; it is basically a calendar displaying the Sun's declination on each day of the year. On the vertical axis of the analemma, you can see the Sun's declination with values ranging from 24°N to 24°S. Along the figure eight pattern itself, you can see each day of the year. The days of the year are shown with alternating black and white bars along the figure-eight pattern (each bar represents a day). For example, on November 16th, the Sun's declination is approximately 19°S.

13. Why is the analemma's vertical axis limited to the range of 24°N to 24°S?

Guided Practice: Using the Analemma

Go step-by-step on how to use the analemma with this video from Scott's Geography Notebook, Using an Analemma. (Video length is 6:16).

14. Use the analemma (Figure 3.9) to determine the Sun's declination on the following days of the year. Tip: use a ruler or piece of paper to align the date to the vertical axis.
    a. January 1:
    b. February 16:
    c. May 16:
    d. July 4:

e. August 16:
f. November 16:
g. Write your birthdate and the Sun's declination on that date:
h. Which solstice or equinox occurs closest to your birthdate?

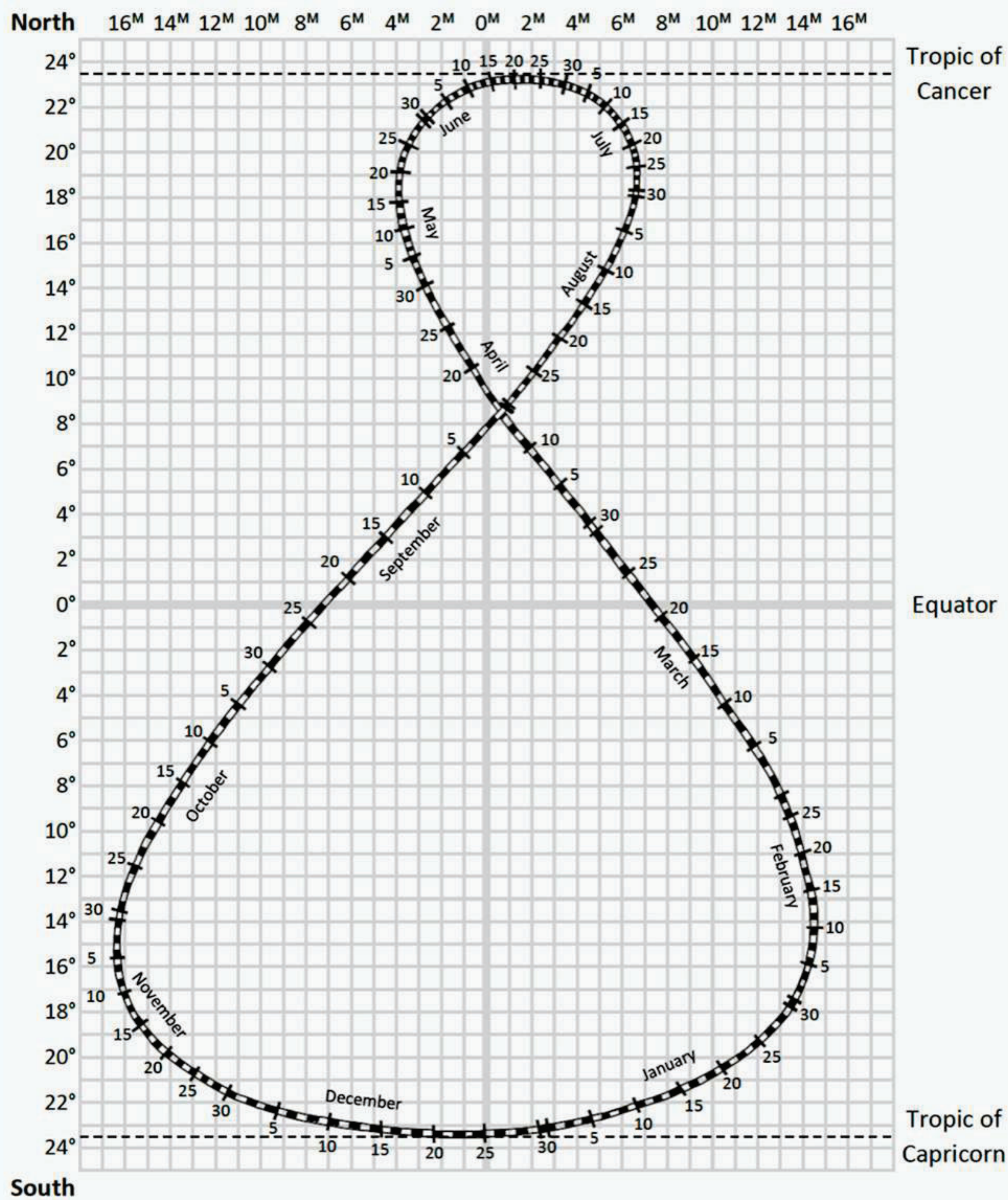

Figure 3.9: Analemma. The declination of the Sun is shown on the vertical axis for each day of the year. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Part B. Angle of Incidence

Angle of incidence is the angle at which Sun's rays strike Earth's surface. One way to understand angle of incidence is to think of someone shining a flashlight in your direction. If the flashlight is shining directly in your eyes, the light is intense and you look