

Lab 8: Seasons, Solstices and Equinoxes

Part I: The Reasons for the Seasons

Below are three facts about the seasons that we wish to explain. Below the facts are four **hypotheses** about what might cause the seasons to occur. Your job is to think about each one and figure out which of the four hypotheses are **most right** and which ones are wrong. Be sure to keep these three facts in mind while going through the lab.

Key facts about the seasons:

- I. In northern latitudes, it's warm in June/July and cool in Dec/Jan, on average.
- II. In southern latitudes, the seasons are reversed: it's warm in Dec/Jan and cool in June/July.
- III. It's warmer at latitudes close to the equator than at latitudes close to the poles (on average).

Hypothesis #1: The Sun-Earth distance changing due to Earth's elliptical orbit causes the seasons.

If its orbit were a circle, the Earth would always be the same distance from the Sun. But it's not. The orbit is an ellipse. As compared to the average Earth/Sun distance, the Earth is sometimes 1.7% closer and at other times 1.7% farther away from the Sun than the average.

Is this difference significant? To answer this question, it helps to be able to refer to a scale model of the Sun/Earth system. Recall the scale model of the solar system we made in Lab 1. We made the size of the Sun and Earth and the distance between them all smaller by the same factor: 10^{10} . Let's repeat these calculations for the Earth-Sun system.

Sun diameter: 1.4×10^6 km \rightarrow scale model Sun diameter = 14 cm

To get the above, remember that we **divide by the scale factor** to shrink the normal size:

$$\frac{1.4 \times 10^6 \text{ km}}{10^{10}} = 1.4 \times 10^{-4} \text{ km}$$

Then we convert to units of cm:

$$1.4 \times 10^{-4} \cancel{\text{km}} \times \frac{10^3 \text{m}}{1 \cancel{\text{km}}} = 1.4 \times 10^{-1} \cancel{\text{m}} \times \frac{10^2 \text{cm}}{1 \cancel{\text{m}}} = 1.4 \times 10^1 \text{cm} = 14 \text{cm}$$

Now try to get the values for the Earth diameter and the Earth-Sun distance, you can also look up the values from Lab 1, but make sure they are right:

Earth diameter: 1.3×10^4 km \rightarrow scale model Earth diameter = _____ cm

\rightarrow scale model Earth diameter = _____ mm

Earth-Sun distance: 1.5×10^8 km \rightarrow scale model distance = _____ m

A 1.7% change in the Earth-Sun distance is thus:

scale model Earth-Sun distance = _____ m $\times 0.017$ = _____ m = _____ cm

To make sure we all have the same model, you may remember, the Sun was represented by a small watermelon, the Earth would be about the size of a candy sprinkle and the distance between them would be the size of an apartment, small house or a big great room inside a medium/large house (15 meters).

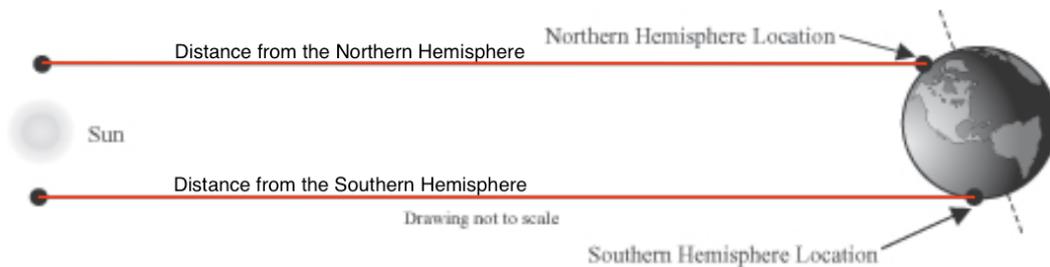
Now that we have the Earth-Sun model in our heads, imagine standing in one corner of a big room holding the tiny Earth sprinkle and you see the watermelon Sun in the other corner of the room. Also pretend that the watermelon is sitting in a bon fire, this will represent the heat we feel from the Sun.

1. If you moved closer to the fire by the amount above (1.7%), do you think you would get significantly warmer? Why or why not?

2. The Earth is closest to the Sun in early January and farthest from it in early July. Can both facts I and II above be explained by the changing Earth-Sun distance? Give your reasoning.

Hypothesis #2: The change in the Sun-Earth distance due to the tilt of the Earth causes the seasons.

In the summer months, the northern hemisphere of Earth tilts 23.5 degrees toward the Sun, while in the winter months, it tilts away from the Sun. Another hypothesis we could make is that the hemisphere that is tilted toward the sun is warmer because it's closer to the Sun than the hemisphere that is tilted away from the Sun. (See diagram from Prather, Slater, Adams, and Brissenden below)



To test this hypothesis, consider the scale model you constructed. Try tilting the North Pole of your model Earth toward or away from the model Sun on the other side of the room (without changing the distance from the center of the Earth to the Sun).

1. Is there a significant difference in distance from our model Sun (15 meters away) to the northern hemisphere of the sprinkle then from our model Sun to the southern hemisphere of the sprinkle?

2. Is this a plausible explanation for the seasons? Explain.

Hypothesis #3: The change in the length of the day due to the tilt of the Earth's axis causes the seasons.

Before going into how the length of the day changes due to the tilt, let's focus on the tilt itself. The image below shows how over the course of a year (orbit) the tilt stays the same. Why is that? Recall that the Earth's spin axis points at the North Celestial Pole, a point on the Celestial Sphere that is very close to Polaris, also known as the North Star. It keeps pointing steadily at the same position as the Earth goes around the Sun. (Recall that precession occurs so slowly that even over your whole lifetime, the effect will be very small and can be ignored for most purposes.)

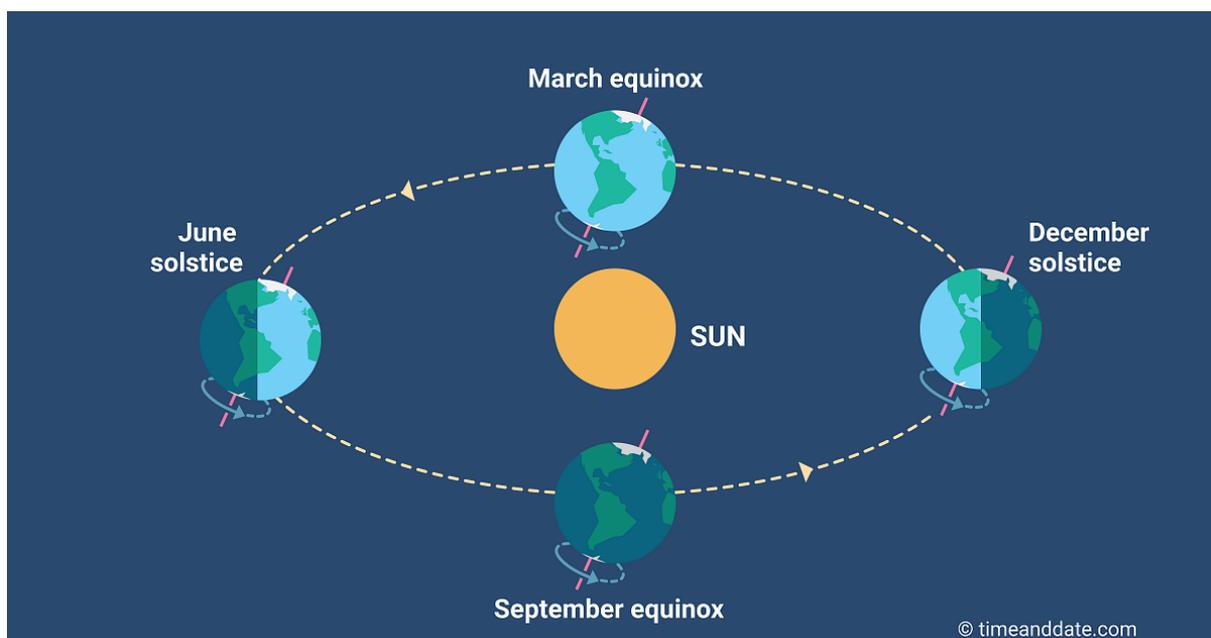


Figure 1: source: <https://www.timeanddate.com/astronomy/equinox-not-equal.html>

Notice how when it is the Summer in the Northern hemisphere and Winter in the Southern Hemisphere (June), the North Pole is tilted towards the Sun while the South Pole is tilted away. Also notice that when it is the Winter in the Northern Hemisphere and Summer in the Southern Hemisphere (December), the North Pole is tilted away from the Sun and the South Pole is tilted towards the Sun. The two Earth's in the middle of the diagram are neither tilted towards or away from the Sun. This is when it is Spring and Autumn in the Northern and Southern Hemispheres.

1. How does the Earth's tilt change **with respect to the Sun** over the course of one year?

Now let's see what effect the tilt has on the length of days. Watch the youtube video linked below and answer the following questions. Remember, you can always pause and rewind the video if you missed something! (*Note: If you are in a place that can't access YouTube, you can still answer the questions below by using Figure 1 above.*)

<https://youtu.be/Em3T1qNOUsk>

Video break down:

2. Pay attention to the Earth at 1:09 OR look at the March and September Earths in Figure 1. With the Earth's spin axis vertical, does it look like the whole Earth gets the same amount of daylight no matter your latitude?

3. Now pay attention to the Earth at 1:48 OR look at the June Earth in Figure 1. With the North Pole pointed towards the Sun, does it look like both the Northern Hemisphere and the Southern Hemisphere get the same amount of day light? If not, which gets longer days?

a. Does it look like the North Pole gets both day and night? If not, what does it get?

b. What is happening in Antarctica (South Pole)? Does it get day and night? If not, what does it get?

4. Finally, pay attention to the Earth at 3:16 OR take a look at the December Earth in Figure 1. With the North Pole pointed away from the Sun, does it look like both the Northern and Southern Hemispheres get the same amount of day light? If not, which gets longer days?

a. Has anything changed about the amount of daylight at the North or South Poles? If so, describe the changes.

5. Which do you think corresponds to summer in the northern hemisphere: the Earth's axis pointing toward the Sun or away from the Sun? Explain.

6. Based on your results above, can the change in the length of the day potentially help to explain the seasons? Discuss.

Hypothesis #4: The change in the intensity of the Sun's rays due to the tilt of the Earth's axis causes the seasons.

The changing tilt of Earth relative to the Sun also affects the **intensity of the Sun's rays** on different parts of the Earth at different times of the year. First, let's compare the intensity of the Sun's rays in the summer vs. winter in northern latitudes on Earth.

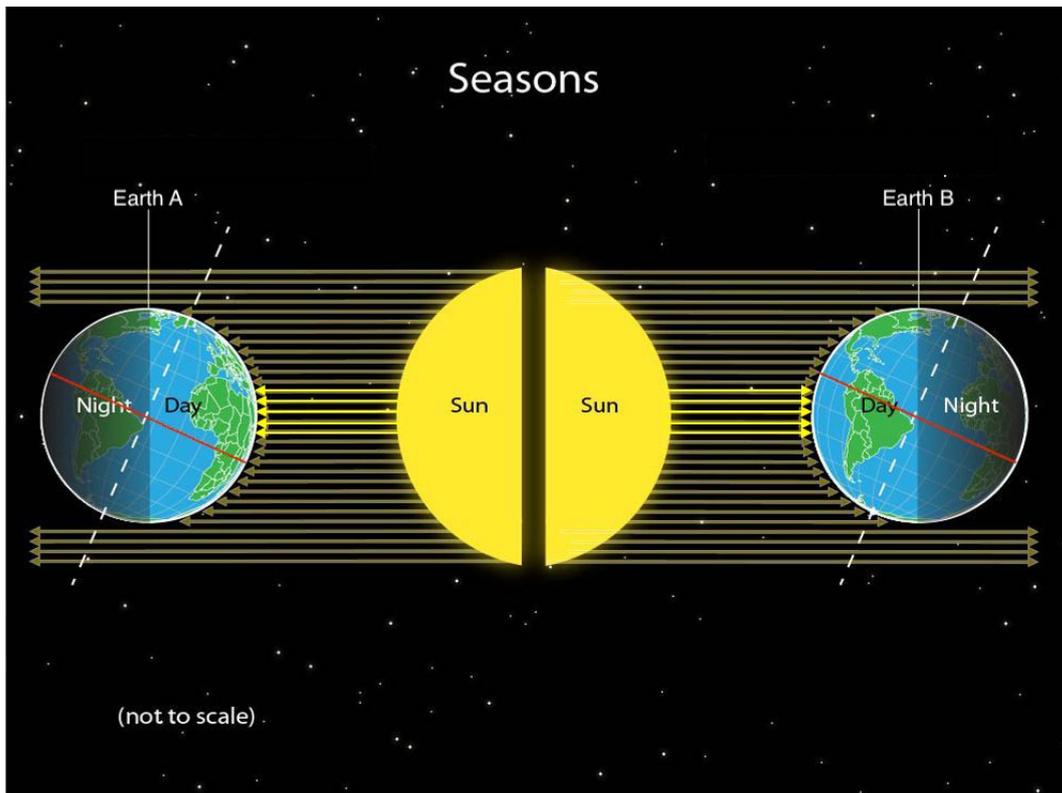


Figure 2: source: <https://media.nationalgeographic.org/assets/photos/000/312/31279.jpg>

Pay attention to Earth A on the left. Notice how the North Pole is tilted towards the Sun, also notice how the **most direct** Sun rays (shown in brighter yellow) land above the Earth's equator in the Northern Hemisphere and how the Sun's rays seem to just graze the Southern Hemisphere.

Now pay attention to Earth B on the right. The North Pole is now pointing away from the Sun. Notice now how the Sun's most direct rays fall below the Earth's equator in the Southern Hemisphere and that they only graze the Northern Hemisphere.

1. What season do you think it is in the Northern Hemisphere for:
 - a) Earth A?
 - b) Earth B?

The image below shows how these direct sun rays land on the Earth during the Summer and how the indirect rays land on the Earth during the Winter. Notice how the same amount of rays land on the Earth in both Summer and Winter, but during the Summer the rays land in a smaller area than in the Winter.

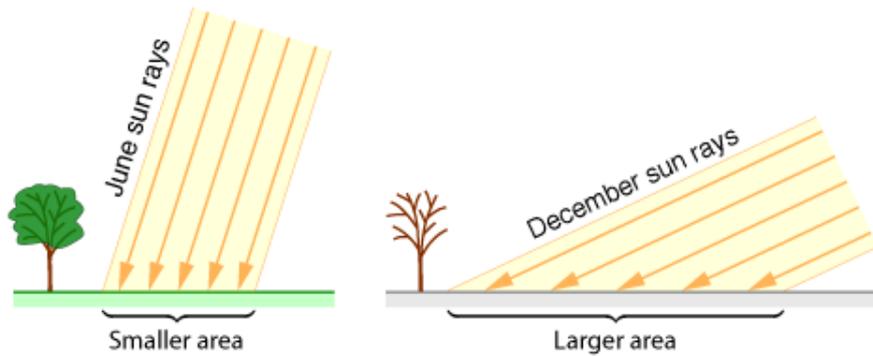


Figure 3: source: <https://physics.weber.edu/schroeder/ua/SunAndSeasons.html>

You can test this for yourself by using a flashlight (or phone flash light). Point the light directly at a table (perpendicular) to represent Summer, then point the light at an angle (45°) to represent Winter. You can also test this by using a small space heater. If you point the heater directly at yourself you may notice how much hotter it feels than if it were pointed next to you.

2. Do you think the patch of light on the table looks brighter or fainter in the winter or summer?

3. Do you think the Earth gets more energy in the summer or in the winter? Explain your reasoning.

4. Do you think that the effect of the Earth's tilt on the intensity of the Sun's rays can help to explain the seasons? Justify your answer.

Summary Questions:

1. Which of the four hypotheses listed at the beginning of the exercise were you able to rule out as plausible causes of the seasons, and why? (Include all that were ruled out.)

2. Which of the four hypotheses did you find could help to account for the seasons? More than one may be important; discuss the role played by each one.

For Fun: Here is a short Bill Nye video explaining the seasons: <https://youtu.be/KUU7IyfR34o>

Part II: The Sun, Solstices, Equinoxes, and Seasons on Earth

Apparent motion of the Sun (*Hint: refer to Lab 7 if you are having trouble remembering*)

1. About how far in degrees does the Sun move along the ecliptic each day? (*Hint: in one year it needs to travel 360 degrees.*)

2. In which direction does the Sun travel along the ecliptic (relative to the stars) over the course of a year? Eastward or westward?

3. What is the cause of the annual motion of the Sun relative to the stars?

4. What is the direction of daily motion of the Sun? Eastward or westward?

5. What is the cause of the daily apparent motion of the Sun?

The Solstices and Equinoxes

Since the Earth is tilted relative to the plane defined by the Earth's orbit around the Sun, the apparent path of the Sun is not along the Celestial Equator, but instead follows a path in the sky known as the "ecliptic". The ecliptic is tilted by 23.5 degrees relative to the Celestial Equator.

Over the course of one year, the Sun completes one cycle around the ecliptic. On the following four dates, the Sun is at the following special locations:

Mar. 21: **the Vernal Equinox** the first day of spring (the Sun crosses the Celestial Equator, moving north)

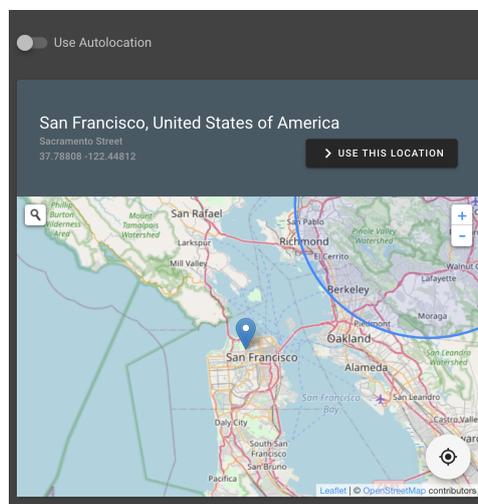
June 21: **the Summer Solstice** the first day of summer (the Sun is as far north on the Celestial Sphere as it gets)

Sept. 21: **the Autumnal Equinox** the first day of autumn (the Sun crosses the Celestial Equator, moving south)

Dec. 21: **the Winter Solstice** the first day of winter (the Sun is as far south on the Celestial Sphere as it gets)

In this exercise we will use Stellarium to explore three of the effects of the Earth's tilt by checking how the Sun's behavior compares on these various dates. These behaviors are related to the seasons. In particular, we will measure: (1) the length of the day; (2) the compass positions where the Sun rises and sets; and (3) the altitude of the Sun at noon.

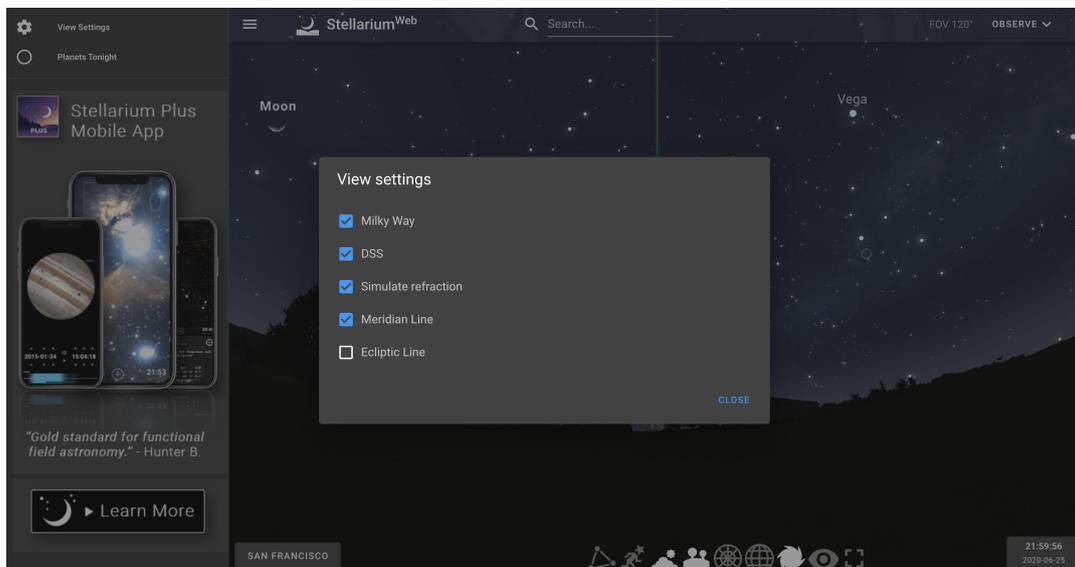
1) **Set the location.** We are all going to use San Francisco as our location so that we can all see the same constellations. At the bottom of the webpage you should see a button that tells you where you're observing from. It'll say "near (location)," click that button. Once the map pops up, drag the location pin to San Francisco and click "> use this location" above the map. Also make sure that the toggle for "Use Autolocation" is turned off.



2) **Turn on/off icon features.** At the bottom, you'll also see a bunch of symbols which will turn on and off certain features of the night sky. Turn on the “Constellations” and **turn off the “Atmosphere” symbol** as shown below. If this isn't done, you won't be able to see the stars!



3) **Turn on the Meridian.** Click the three horizontal line icon in the top left of the screen and look for “View Settings”. Open the settings and check the box that says “Meridian Line”. Once done, you can close out of the settings menu. If you look around the sky, you should notice that the Meridian is a line in the sky (much like the Prime Meridian on Earth) that goes from due North on the horizon through your Zenith (90° altitude) to due South again on the horizon. It essentially divides the sky into an Eastern and Western halves.



6. Make sure to turn South for this exercise. Fill in the tables below. For each position, use Stellarium to observe and record the following things about the path of the Sun during the course of the day. Use the Altitude coordinate grid scale to determine the altitude at noon. Use the time menu (bottom right) to change the time of day, the “hour” of sunrise and sunset and thus the total number of daylight hours. Sunrise is when the Sun is on the Eastern horizon, noon is when the Sun is on the meridian and sunset is when the Sun is on the Western horizon.

(i) Autumnal Equinox DATE: _____

SUNRISE: Compass direction	NOON: Altitude	SUNSET: Compass direction	Number of Daylight hours

(ii) Winter Solstice DATE: _____

SUNRISE: Compass direction	NOON: Altitude	SUNSET: Compass direction	Number of Daylight hours

(iii) Vernal Equinox DATE: _____

SUNRISE: Compass direction	NOON: Altitude	SUNSET: Compass direction	Number of Daylight hours

(iv) Summer Solstice DATE: _____

SUNRISE: Compass direction	NOON: Altitude	SUNSET: Compass direction	Number of Daylight hours

7. When the Sun rises in the southeast, where does it set?

8. Are the days longest when the Sun rises in the southeast, northeast, or due east?

9. At what time(s) of the year is the length of the day equal to the length of the night?

10. How many more hours of daylight are there on the summer solstice than on the winter solstice?

11. Would you expect the temperature to be warmer or cooler than the yearly average when the hours of daylight are longest?

12. At what time of year is the Sun most nearly overhead at noon, as viewed from San Francisco? Is the sun ever at the zenith, as viewed from San Francisco?

13. How much higher in the sky is the Sun at noon on the Summer Solstice than on the Winter Solstice?

14. When does the Sun feel hottest (on a clear day): when it is near the horizon, or when it is high in the sky (nearly overhead)?

15. Locate four places on the star wheel: Two where the Ecliptic and Equator cross, a third where the ecliptic is the highest it gets above the equator, and a fourth where the ecliptic is the lowest it gets below the equator (You may have to look at both sides of the star wheel). What are the RA and DEC of each of these four locations?

Location 1:

Location 2:

Location 3:

Location 4:

16. These four locations represent locations of the Sun (since we are looking at the ecliptic). What constellation is the Sun in at each of these locations?

Location 1:

Location 2:

Location 3:

Location 4:

17. To which days of the year do each of these locations correspond?

Location 1:

Location 2:

Location 3:

Location 4:

18. What do you notice about the declination of the ecliptic at the solstices? Do you recognize this number, if so from where?