3

The Seasons

In this exercise you can learn how the times and locations of sunrise and sunset change with the seasons, and how the seasonal changes vary with latitude on the Earth. The reason why the Earth has seasons is discussed in Section 2-5 of Kaufmann and Freedman, *Universe*, Fifth Ed.

PART 1: Changes in the Position and Time of Sunrise Through One Year

A. Screen Set-up

1. Start by setting your location to New York City.

2. Click the time-stop button on the date/time box (if this toolbar is not already on the screen, activate it by clicking Time in the Window menu).

3. Face east by clicking E on the button bar near the top of the screen. If this button bar is not already visible on the screen, activate it by clicking Toolbar in the Window menu. After the screen adjusts direction, you should see a symbol showing east (E) on the horizon near the bottom of your screen.

   If the horizon is curved, then straighten it by placing the cursor hand on the screen, pressing the left mouse button, and dragging the screen straight upward or downward until the horizon is straight.

4. Notice that there is a little sun symbol in the date/time box to the left of the digital time readout. This sun symbol is the standard-time/daylight-time button and denotes daylight time if the sun is yellow or standard time if the sun is not yellow.

   The time should be set to standard time (sun symbol not colored yellow). If the sun symbol is yellow then click on the symbol once to set the time to standard time. (Alternatively, click on the sun symbol a few times and choose the setting corresponding to the earlier time in the readout.) We will maintain standard time all year so that the various trends show up more clearly (e.g., sunrise getting earlier as the months go by).

5. Set the date to March 21, 1999 (3/21/1999 AD) and the time to 6:00:00 AM.

6. If the time step in the date/time box does not show 003 minutes, click on the time-step number to highlight it, and type 3. If the time-step units are not minutes, click on the time-step units to highlight them, and click on the little up or down arrows to select minutes.

7. Use the single-step buttons in the date/time box (the outermost buttons in this box, marked by arrows with a short, vertical line through them) to place the middle of the Sun exactly on the horizon. This step should be done carefully, since the Sun is depicted on the screen as a small yellow disk that is somewhat difficult to see, particularly if a tree is in the way. If you prefer, you can remove the trees from the screen using the following steps: click Options in the Settings menu, click the down arrow to see a list of options, click Horizon, click off the Scenery, click OK to return to the screen.

   The location of the Sun on the horizon should be at or very close to the east point on the horizon, denoted by E. If this is not the case, check that the date is March 21.

B. Procedure

1. Place a strip of paper about 3 cm in height across the horizon on your screen and attach it with tape to the edge of the monitor (*do not* put tape on the screen itself). Mark the positions

SE, E, and NE on the paper. Be careful not to damage your screen as you do this. On this strip mark where the Sun rises on March 21, and write the month (March) and the time of sunrise above or below the mark.

2. Change the month to April while keeping the day and year fixed (i.e., 4/21/1999). Notice that at 6 am on April 21 the Sun has already risen and is up in the sky; therefore, run time backward for a while to place the center of the Sun exactly on the horizon again.

   On your paper strip along the horizon, mark the location of sunrise on April 21, and write "April" and the new time of sunrise above or below the mark.

3. Keeping the date set to the 21st of the month, repeat the above steps for May, June, July, August, September, October, November, December, January, and February, using a new line to mark the positions, dates, and sunrise times for the return portion of the path. You can change the year to 2000 in January, or leave it at 1999.

4. To represent the movement of the sunrise position graphically, use your measurements to plot the sunrise position as a function of time. A simple way to do this is to slide your strip of paper downward over a sheet of graph paper, plotting the sunrise positions horizontally for each month in consecutive order (i.e., March, April, May, . . .), placing the months at equal vertical intervals on your graph paper. Be careful to keep one edge of your strip aligned with a vertical reference line on the graph paper.

5. Plot a second graph of the sunrise time against time of the year. Choose the scale for sunrise time carefully to include 60 intervals per hour, for example, select 1 cm = 10 minutes of time.

Questions

1. What is the shape of the graph showing sunrise position as a function of time of the year? (E.g., linear change with time, sine wave change with time, . . .)

2. For which months of the year does the Sun rise exactly (or almost exactly) due east?

3. For which months does it rise to the north of east? During these months, does it rise earlier or later than it does on March 21?

4. For which points does it rise to the south of east? During these months, does it rise earlier or later than it does on March 21?

5. In which month does the Sun rise furthest north? In which month does it rise furthest south? Which of these months corresponds to the latest sunrise? Earliest sunrise?

6. During which months is the Sun moving northward (sunrise further north than it was the previous month)? During which months is it moving southward? What happens to the time of sunrise as the Sun moves northward? Southward?

7. Use your graph to estimate when the sunrise position is changing most rapidly.

8. Are the answers to the above questions exactly as you would have expected? If not, describe what was new or surprising for you.

9. You can now use your graph to tell where on the New York horizon the Sun will rise on any day of the year, and estimate the sunrise time. Remember that the graph is plotted for the 21st of each month. Estimate the time of sunrise for November 5, which is 1/2 month after October 21.

PART 2: The Length of the Day (Sunrise to Sunset)

A. Screen Set-up

Reset the screen as follows:

viewing direction, west (W);
horizon straight (drag the screen upward or downward if necessary);
date, March 21, 1999;
time, 5:45:00 PM;
time step, 3 minutes.

B. Procedure

1. Run time forward a step at a time to place the setting Sun exactly on the horizon. Write down the date and time of sunset.

2. Repeat for June 21, 1999, September 1, 1999, and December 1, 1999. Then use the times of sunrise and sunset on these dates to calculate the length of the day in New York City for all four dates.

Questions

1. What is the length of the day in New York City on March 21 (near the start of Spring) and September 21 (near the start of Fall)?

2. What is the length of the day in New York City on June 21 (near the start of Summer)? What is the length of the night on June 21?

3. Repeat the previous question for December 21 (near the start of Winter). What approximate relationship do you notice between the lengths of day and night for June 21 and December 21? (E.g., How does the length of the day on June 21 compare to the length of the night on December 21?)

4. What happens to the length of the day as the rising or setting point of the Sun moves northward along the horizon? Southward?

5. We have kept the time set to standard time through this exercise, but in fact most areas use daylight savings time (or daylight time) between April and September. If daylight time were in effect, would it have any effect on the length of the day or night? (Remember that we set our clocks one hour ahead when daylight time begins, so *both* sunrise and sunset take place one hour later than they would if we had left the clocks at standard time.)

PART 3: Lattitude Dependence of Sunrise Time and Location

A. Screen Set-up

1. For this part of the exercise, you need to be able to see the Sun even when it is below the horizon. To do this, click Options in the Settings menu, then click Horizon type, See through, OK. (The magic of computers again!)

2. Set your location to Quito, Ecuador, almost exactly on the equator (Settings/Viewing Location/South America/Others/Quito, Ecuador/Set Location).

3. Set the date to December 21, 1999 and the time to 6:12:00 AM.

4. Click E to face east (you will see that we have chosen sunrise for this location and date), and drag the screen upward to straighten the horizon.

5. Click Equatorial Grid in the Guides menu (or press CTRL+2) to switch on the equatorial coordinate system.

The lines that rise vertically from the horizon are **declination** lines (celestial latitude) and the lines that run from left to right are **right ascension** lines (celestial longitude). (The declination lines curve outward at the top of the screen because of distortions introduced by mapping a spherical sky onto a flat screen. In the real sky, the declination lines are parallel circles that decrease in size toward the north and south poles, just as the lines of latitude on a globe of the Earth are parallel circles of decreasing size.)

The declination line running straight up from E on the horizon is the **celestial equator** (0° declination), and any two adjacent declination lines are 10° apart. Thus the first line to the left of the celestial equator is 10° N declination, the next one to the left is 20° N declination, and so on.

In an equivalent way, the lines of right ascension (RA) are 1 hour apart, each 1-hour interval in RA being the angle through which the Earth rotates in 1 hour or, from an Earth-bound viewer, the angle through which a star moves in our sky in 1 hour.

B. Procedure

When we move northward or southward, we are moving over the curved surface of the Earth. This causes our horizon to tilt relative to the fixed sky. However, as we tilt, our “straight up” direction tilts along with us. Consequently our horizon always appears horizontal as seen by us, and we see the sky (apparently) tilting relative to our horizon. This tilt of the sky relative to our horizon causes the location and time of sunrise to change as we change our latitude on the Earth. This part of the exercise allows you to see how this happens.

Note that there is a pair of right ascension and declination lines which cross almost exactly at the E on the horizon. In the following steps, this crossing point will remain almost exactly fixed as long as the time remains fixed, even though the sky rotates as you change your latitude. This gives you a fixed reference point.

1. If you count the declination lines between the Sun and the celestial equator (marked by E on the horizon), then you can see that the declination of the Sun on December 21 is 23 1/2° (2 1/3 declination lines) south of the celestial equator.

   Notice that, because the declination lines are perpendicular to the horizon, the declination lines also mark the horizon off in 10° intervals. Therefore, for a person in Quito, or anywhere else on the Earth’s equator, the Sun rises at a point 23 1/2° south of the East point on the horizon on December 21.

2. Note carefully where the Sun is located on the horizon at sunrise for Quito (e.g., is it located behind a particular tree, just to the right of a particular tree, etc.?). Drawing a quick diagram or using a strip of paper again might help you remember this location.

3. Now we are going to move northward on the Earth’s surface from the equator, keeping our longitude constant. Look in the icon/location box (if this box is not visible on the screen you can activate it by clicking Show Floating Palettes in the Window menu), and find where it states that your current latitude is 0° (for Quito, Ecuador, this is printed as 0 S, because Quito is a fraction of a degree south of the equator). Click once on the 0 to highlight it.

Now type 5 to set your latitude to 5° N. Notice that the declination lines now tilt downward on the right, placing the Sun below the horizon. Thus at the same instant of time when the Sun is rising for someone on the equator, it is still below the horizon for someone at 5° N latitude. Consequently, in December the Sun will rise later for a person at 5° N latitude than for a person (at the same longitude) at the equator.

4. Now type 10 to change your latitude to 10° N. (If you have not touched the mouse button then the latitude number should still be highlighted; if it is not, then click on the latitude number to highlight it again before typing 10.) Watch what happens to the tilt of the declination lines and to the distance of the Sun below the horizon.

Repeat this step for 15, 20, 30, 40, and 50 degrees north latitude, each time watching what happens to the tilt of the declination lines and to the distance of the Sun below the horizon.

Notice that, as you increase your latitude, the Sun moves downward in an arc of a circle. This is because the Sun is a constant 23 1/2° from the fixed reference point (the crossing point at the E, described above). However, the declination lines are straight; therefore, at latitude 50° N, the declination lines near the Sun (20° S and 30° S declination) intersect the horizon considerably to the right (or south around the horizon) from the point where the Sun was on the horizon at Quito.

5. Now click the time-start button, let the Sun approach the horizon, and click the time-stop button when the Sun is exactly on the horizon (just rising). Use the single-step buttons to adjust the time, if needed. Notice that the path of the Sun on the screen is parallel to the declination lines, and therefore the Sun rises considerably to the right (south) of where it rose in Quito.

Thus you can see that in winter in the northern hemisphere observers further north see the Sun rise later and at a point further south around the horizon. You can also see that this is a geometric effect caused by the increasing tilt of the celestial sphere relative to our horizon (or really the increasing tilt of our horizon relative to the celestial sphere!) as we move further north.

6. This northern movement across the Earth can be taken to extremes! Try moving to 67°N latitude. You need to move the sky so that you are viewing to the South. Let time run until the Sun reaches the South. You will see that the Sun barely reaches the Horizon on this date at this latitude, which is just above the Arctic Circle. North of this latitude is the arctic, where the Sun stays below the horizon for at least 1 day per year. The further north you go, the longer the period of 24-hour darkness.

7. The extreme position is, of course, the **North Pole of Earth**, at 90°N latitude. Move to this latitude and adjust the date to March 21, 1999 (3/21/1999 AD). You will see that the Sun is just above the horizon. If you run time forward, you will find that the Sun remains just above the horizon and tracks around it as time progresses. To experience what this must be like in real life, try magnifying the view of the Sun by clicking on the Magnification Tool, in the icon/location box (or press F8), until the field of view is 14°, say. The Sun just sails majestically along the horizon! Of course, there would be no trees at the North Pole, just icefloes!

   In the winter at the North Pole, between about September 21 and March 21, the Sun will always be below the horizon.

Answers

Position and Time of Sunrise

1. Sine wave.

2. March and September.

3. April through to August. Earlier.

4. October through to February. Later.

5. June. December. December. June.

6. January to May. July to November. Sunrise gets earlier. Sunrise gets later.

7. March and September.

8. About 6:35 AM.

Length of the Day

1. About 12 hours.

2. Length of day, 15 hours; length of night, 9 hours.

3. Length of day, 9 hours; length of night, 15 hours. The length of the day on June 21 is almost exactly equal to the length of the night on December 21 and the length of the night on June 21 is almost exactly equal to the length of the day on December 21.

4. Rising point moving northward: days get longer; rising point moving southward: days get shorter.

5. The length of the day is not affected by daylight savings time; since both sunrise and sunset take place one hour later than they would if we had left the clocks at standard time, the time interval between them has not changed.