Exercise 12

Earth–Sun Relations

To life on this planet, the relations between Earth and the sun are perhaps the most important of all astronomical phenomena. The variations in solar energy striking Earth as it rotates and revolves around the sun cause the seasons and therefore are an appropriate starting point for studying weather and climate.

In this exercise you will investigate the reasons why the amount of solar radiation intercepted by Earth varies for different latitudes and changes throughout the year at a particular place. The next exercise, Exercise Thirteen, examines how the atmosphere is warmed by this radiation.

Objectives

After you have completed this exercise, you should be able to

1. Describe the effect that sun angle has on the amount of solar radiation a place receives.
2. Explain why the intensity and duration of solar radiation varies with latitude.
3. Explain why the intensity and duration of solar radiation varies at any one place throughout the year.
4. Describe the significance of these special parallels of latitude: Tropic of Cancer, Tropic of Capricorn, Arctic Circle, and equator.
5. Diagram the relation between Earth and the sun on the dates of the solstices and equinoxes.
6. Determine the latitude where the overhead sun is located on any day of the year.
7. Calculate the noon sun angle for any place on Earth on any day.
8. Calculate the latitude of a place using the noon sun angle.

Materials

metric ruler colored pencils
protractor calculator

Materials Supplied by Your Instructor

globe
large rubber band or string

Terms

weather weather element solar intensity solar duration
solar constant equator Tropic of Cancer Tropic of Capricorn Arctic Circle

Introduction

Weather is the state of the atmosphere at a particular place for a short period of time. The condition of the atmosphere at any place and time is described by measuring the four basic elements of weather: temperature, moisture, air pressure, and wind. Of all the controls that are responsible for causing global variations in the weather elements, the amount of solar radiation received at any location is the most important.

Solar Radiation and the Seasons

The amount of solar energy (radiation) striking the outer edge of the atmosphere is not uniform over the face of Earth at any one time, nor is it constant throughout the year at any particular place. The amount of solar radiation received at any particular place on Earth, on any given day, is determined by the sun’s intensity and duration. Intensity is the angle at which the rays of
sunlight strike a surface, whereas duration refers to the length of daylight.

The standard unit of solar radiation is the **langley**, equal to one **calorie** per square centimeter. The **solar constant**, or average intensity of solar radiation falling on a surface perpendicular to the solar beam at the outer edge of the atmosphere, is about 2 langleys per minute. As the radiation passes through the atmosphere, it undergoes absorption, reflection, and scattering. Therefore, at any one location, less radiation reaches Earth’s surface than was originally intercepted at the upper atmosphere.

**Solar Radiation and Latitude**

The amount of radiation striking a square meter at the outer edge of the atmosphere, and eventually Earth’s surface, varies with latitude because of a changing sun angle. To illustrate this fact, answer questions 1–11 using the appropriate figure.

1. On Figure 12.1, extend the 1 cm wide beam of sunlight from the sun vertically to point A on the surface. Extend the second 1 cm wide beam, beginning at the sun, to the surface at point B.

Notice in Figure 12.1 that the sun is directly overhead (vertical) at point A and the beam of sunlight strikes the surface at a 90° angle above the horizon.

Using Figure 12.1, answer questions 2–5.

2. Using a protractor, measure the angle between the surface and the beam of sunlight coming from the sun to point B.

   \[ \text{? } \text{°} = \text{angle of the sun above the surface (horizon) at point B.} \]

3. What are the lengths of the line segments on the surface covered by the sun beam at point A and point B?

   Point A: _____ mm  point B: _____ mm

4. Of the two beams, beam (A, B) is more spread out at the surface and covers a larger area. Circle your answer.

5. More langleys per minute would be received by a square centimeter on the surface at point (A, B). Circle your answer.

Use Figure 12.2 to answer questions 6–11 concerning the total amount of solar radiation intercepted by each 30° segment of latitude on Earth.

6. With a metric ruler, measure the total width of incoming rays from point x to point y in Figure 12.2. The total width is _____ centimeters (_____ millimeters). Fill in your answers.

7. Assume the total width of the incoming rays from point x to point y equals 100% of the solar radiation that is intercepted by Earth. Each centimeter would equal _____% and each millimeter would equal _____%. Fill in your answers.

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**FIGURE 12.1**

Vertical and oblique sun beams.
8. What percentage of the total incoming radiation is concentrated in each of the following zones?

- $0^\circ$–$30^\circ = \text{______ mm = ______ \%}$
- $30^\circ$–$60^\circ = \text{______ mm = ______ \%}$
- $60^\circ$–$90^\circ = \text{______ mm = ______ \%}$

9. Use a protractor to measure the angle between the surface and sun ray at each of the following locations. (Angle b is already done as an example.)

- Angle $a$: ______ $^\circ$
- Angle $c$: ______ $^\circ$
- Angle $b$: $60^\circ$
- Angle $d$: ______ $^\circ$

10. What is the general relation between the amount of radiation received in each $30^\circ$ segment and the angle of the sun's rays?

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11. Explain in your own words what fact about Earth creates the unequal distribution of solar energy, even though each zone represents an equal $30^\circ$ segment of latitude.

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**Yearly Variation in Solar Energy**

The amount of solar radiation received at a particular place would remain constant throughout the year if it were not for these facts:

- Earth rotates on its axis and revolves around the sun.
- The axis of Earth is inclined $23 \frac{1}{2}^\circ$ from the perpendicular to the plane of its orbit.
- Throughout the year, the axis of Earth points to the same place in the sky, which causes the overhead (vertical or $90^\circ$) noon sun to cross over the **equator** twice as it migrates from the **Tropic of Cancer** ($23 \frac{1}{2}^\circ$N latitude) to the **Tropic of Capricorn** ($23 \frac{1}{2}^\circ$S latitude) and back to the Tropic of Cancer.

As a consequence, the position of the vertical or overhead noon sun shifts between the hemispheres, causing variations in the intensity of solar radiation and changes in the length of daylight and darkness. *The seasons are the result of this changing intensity and duration of solar energy and subsequent heating of the atmosphere.*

To help understand how the intensity and duration of solar radiation varies throughout the year, answer questions 12–31 after you have thoroughly reviewed the appropriate chapter of your text and have examined the location of the Tropic of Cancer, Tropic of Capricorn, **Arctic Circle**, and **Antarctic Circle** on a globe or world map.
12. List some of the countries each of the following special parallels of latitude pass through.
   September 22: ___________________________ equinox
   Tropic of Capricorn: ___________________________
   Arctic Circle: ___________________________

13. Write the date represented by each position of Earth at the appropriate place in Figure 12.3. Then label the following on Earth at an equinox and a solstice position.
   North Pole and South Pole
   Axis of Earth
   Equator, Tropic of Cancer, Tropic of Capricorn
   Arctic Circle and Antarctic Circle
   Circle of illumination (day-night line)

Questions 14–19 refer to the June solstice position of Earth in Figure 12.3.

14. What term is used to describe the June 21–22 date in each hemisphere?
   Northern Hemisphere: ______________ solstice
   Southern Hemisphere: ______________ solstice

15. On June 21–22 the sun’s rays are perpendicular to Earth’s surface at noon at the (Tropic of Cancer, equator, Tropic of Capricorn). Circle your answer.

16. What latitude is receiving the most intense solar energy on June 21–22?
   Latitude: ___________________________

17. Toward what direction, north or south, would you look to see the sun at noon on June 21–22 if you lived at the following latitudes?
   40°N latitude: __________
   10°N latitude: __________

18. Position a rubber band or string on a globe corresponding to the circle of illumination on June 21–22. Then determine the length of daylight at the following latitudes by examining the proportionate number of degrees of longitude a place located at each latitude spends in daylight as Earth rotates. (Note: Earth rotates a total of 360° of longitude per day. Therefore, each 15° of longitude is equivalent to one hour.)
   70°N latitude: ______ hrs
   40°S latitude: ______ hrs
   40°N latitude: ______ hrs
   90°S latitude: ______ hrs
   0° latitude: ______ hrs

19. On June 21–22, latitudes north of the Arctic Circle are receiving (6, 12, 24) hours of daylight, while latitudes south of the Antarctic Circle are experiencing (6, 12, 24) hours of darkness. Circle your answers.

Questions 20–24 refer to the December solstice position of Earth in Figure 12.3.

20. What name is used to describe the December 21–22 date in each hemisphere?
   Northern Hemisphere: ______________ solstice
   Southern Hemisphere: ______________ solstice


22. On December 21–22 the (Northern, Southern) Hemisphere is receiving the most intense solar energy.

23. If you lived at the equator, on December 21–22 you would look (north, south) to see the sun at noon.

24. Refer to Table 12.1, “Length of daylight.” How many hours of daylight would there be at each of the following latitudes on December 21–22?
   90°N latitude: ______ hrs
   40°S latitude: ______ hrs
   40°N latitude: ______ hrs
   90°S latitude: ______ hrs
   0° latitude: ______ hrs

Questions 25–31 refer to the March and September equinox positions of Earth in Figure 12.3.

25. For those living in the Northern Hemisphere, what terms are used to describe the following dates?
   March 21: ___________________________ equinox
   September 22: ___________________________ equinox

26. For those living in the Southern Hemisphere, what terms are used to describe the following dates?
   March 21: ___________________________ equinox
   September 22: ___________________________ equinox

27. On March 21 and September 22 the sun’s rays are perpendicular to Earth’s surface at noon at the (Tropic of Cancer, equator, Tropic of Capricorn). Circle your answer.
As you have seen, the latitude where the noon sun is directly overhead (vertical, or 90° above the horizon) is easily determined for the solstices and equinoxes.

Figure 12.4 is a graph, called an analemma, that can be used to determine the latitude where the overhead noon sun is located for any date. To determine the latitude of the overhead noon sun from the analemma, find the desired date on the graph and read the coinciding latitude along the left axis. Don’t forget to indicate North or South when writing latitude.

28. What latitude is receiving the most intense solar energy on March 21 and September 22?

Latitude: __________________________

29. If you lived at 20°S latitude, you would look (north, south) to see the sun at noon on March 21 and September 22. Circle your answer.

30. What is the relation between the North and South Poles and the circle of illumination on March 21 and September 22?

31. Write a brief statement describing the length of daylight everywhere on Earth on March 21 and September 22.

32. Using a colored pencil, draw lines on Figure 12.4 that correspond to the equator, Tropic of Cancer, and Tropic of Capricorn. Label each of these special parallels of latitude on the figure.

33. Using the analemma, Figure 12.4, determine where the sun is overhead at noon on the following dates.

   December 10: __________
   March 21: __________
   May 5: __________
   June 22: __________
   August 10: __________
   October 15: __________

34. The position of the overhead noon sun is always located on or between which two parallels of latitude?

   _______°N (named the Tropic of ________) and
   _______°S (named the Tropic of ________)
FIGURE 12.4
The analemma, a graph illustrating the latitude of the overhead (vertical) noon sun throughout the year.
35. The overhead noon sun is located at the equator on September _____ and March ____. Together, these two days are called the _______. Fill in your answers.

36. Write a brief paragraph summarizing the yearly movement of the overhead noon sun and how the intensity and duration of solar radiation varies over Earth’s surface throughout the year.

Calculated Noon Sun Angle
Knowing where the noon sun is overhead on any given date (the analemma), you can determine the angle above the horizon of the noon sun at any other latitude on that same day. The relation between latitude and noon sun angle is

For each degree of latitude the place is away from the latitude where the noon sun is overhead, the angle of the noon sun becomes one degree lower from being vertical (or 90°) above the horizon.

For example, a place which is 30° of latitude away from the latitude where the overhead noon sun is located would have a noon sun angle of 60° (90° − 30° = 60°). A place 60° of latitude away would have a 30° noon sun angle (see Figure 12.2).

37. Complete Table 12.2 by calculating the noon sun angle for each of the indicated latitudes on the dates given. Some of the calculations have already been done.

38. From Table 12.2, the highest average noon sun angle occurs at (40°N, 0°, 20°S). Circle your answer.

### Table 12.2 Noon sun angle calculations

<table>
<thead>
<tr>
<th>Latitude of overhead noon sun</th>
<th>Mar 21</th>
<th>Apr 11</th>
<th>Jun 21</th>
<th>Dec 22</th>
</tr>
</thead>
<tbody>
<tr>
<td>90°N</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40°N</td>
<td>50°</td>
<td></td>
<td></td>
<td>26½°</td>
</tr>
<tr>
<td>0°</td>
<td></td>
<td></td>
<td>66½°</td>
<td></td>
</tr>
<tr>
<td>20°S</td>
<td>62°</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

39. Calculate the noon sun angle for your latitude on today’s date.

Date: ____________________

Latitude of overhead noon sun: __________

Your latitude: ____________________

Your noon sun angle: __________

40. Calculate the maximum and minimum noon sun angles for your latitude.

<table>
<thead>
<tr>
<th>Maximum Noon Sun Angle</th>
<th>Minimum Noon Sun Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date: ____</td>
<td>Date: ____</td>
</tr>
<tr>
<td>Angle: ____°</td>
<td>Angle: ____°</td>
</tr>
</tbody>
</table>

41. Calculate the average noon sun angle (maximum plus minimum, divided by 2) and the range of the noon sun angle (maximum minus minimum) for your location.

Average noon sun angle = _______ °

Range of the noon sun angle = _______ °

42. Describe some situations in which knowing the noon sun angle might be useful.

Using Noon Sun Angle
One very practical use of noon sun angle is in navigation. You, like a navigator, can determine your latitude if the date and angle of the noon sun at your location are known. As you answer questions 43 and 44, keep in mind the relation between latitude and noon sun angle.

43. What is your latitude if, on March 21, you observe the noon sun to the north at 18° above the horizon?

Latitude: __________

44. What is your latitude if, on October 16, you observe the noon sun to the south at 39° above the horizon?

Latitude: __________

Solar Radiation at the Outer Edge of the Atmosphere
Table 12.3 shows the average daily radiation received at the outer edge of the atmosphere at select latitudes for different months.
Table 12.3  Solar radiation at the outer edge of the atmosphere (langleyes/day) at various latitudes during select months

<table>
<thead>
<tr>
<th>Latitude</th>
<th>March</th>
<th>June</th>
<th>September</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td>90°N</td>
<td>50</td>
<td>1050</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>40°N</td>
<td>700</td>
<td>950</td>
<td>720</td>
<td>325</td>
</tr>
<tr>
<td>0°</td>
<td>890</td>
<td>780</td>
<td>880</td>
<td>840</td>
</tr>
</tbody>
</table>

To help visualize the pattern, plot the data from Table 12.3 on the graph in Figure 12.5. Using a different color for each latitude, draw lines through the monthly values to obtain yearly curves. Then answer questions 45–48.

45. Why do two periods of maximum solar radiation occur at the equator?

46. In June, why does the outer edge of the atmosphere at the equator receive less solar radiation than both the North Pole and 40°N latitude?

47. Why does the outer edge of the atmosphere at the North Pole receive no solar radiation in December?

48. What would be the approximate monthly values for solar radiation at the outer edge of the atmosphere at 40°S latitude? Explain how you arrived at the values.

March: _____________
June: _____________
September: ___________
December: ___________
Explanation: ___________

Earth–Sun Relations on the Internet

In today’s modern world of nearly instantaneous communication, the Internet offers an unprecedented opportunity for Earth scientists to access and share information. The following questions are intended to assist you in becoming familiar with this vast repository of knowledge.

49. Using the sun angle calculator at this location, [http://www.susdesign.com/sunangle/](http://www.susdesign.com/sunangle/), calculate the noon sun angle (altitude angle) at your location for today’s date. What are the times of today’s sunrise and sunset at your location?

Noon sun angle: ___________