PHYSICAL GEOGRAPHY LAB MANUAL



Waverly C. Ray, Taya C. Lazootin, Scott J. Crosier, Jeremy G. Patrich, and Aline Nortes Gregorio
ASCCC Open Educational Resorces Initiative (OERI)



Physical Geography Lab Manual (Ray et al)

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Detailed Licensing

Detailed Licensing

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Guiding Quotes

“Without geography, the world and how it fits together is a mystery. Geography is a skill and vision that opens the door for learners to better understand the interconnected world around them.”

Vicki Phillips (31 August 2020, *Forbes*)

“Students study geography to understand that the Earth is changing. Then they scientifically and analytically think about why it is changing. And they even dig deeper than that. Should the Earth be changing in these ways? Is there anything that I can do about it or that I should be doing about it? This not only captures the heart of spatial thinking—inquiry and problem-based learning—but also empowers students to become decision makers, to make a difference in this changing world of ours.”

Joseph Kerski (Summer 2011, *ArcUser*)

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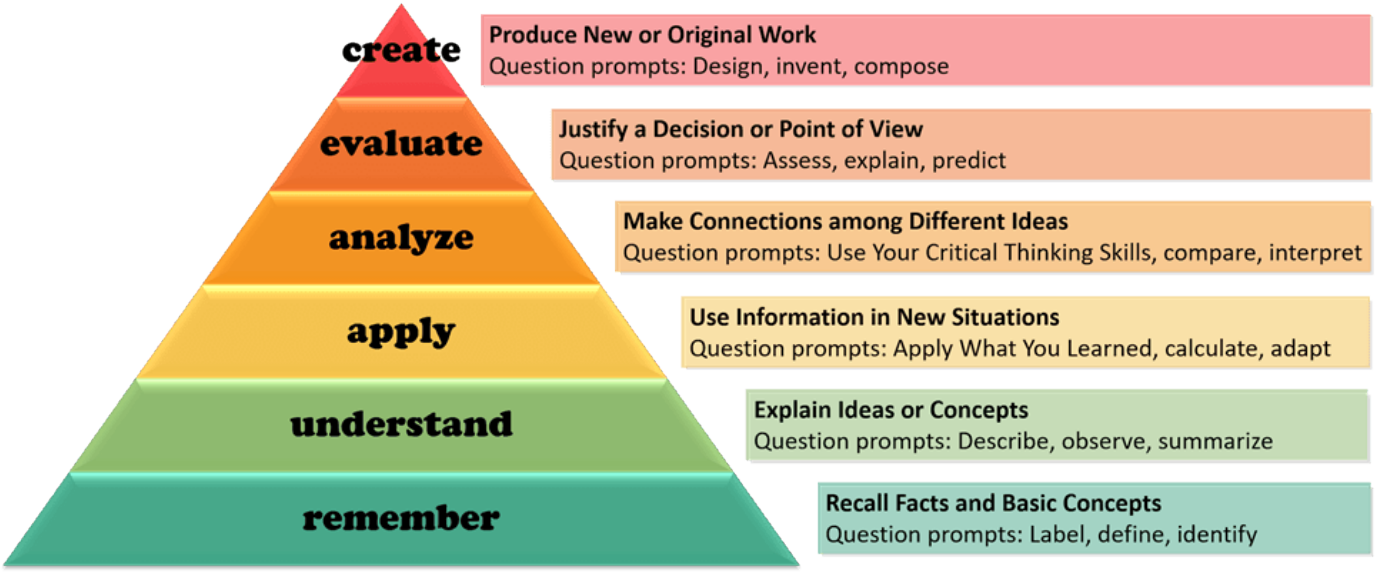
Tips for Students

Welcome to your physical geography lab manual! We hope the lab exercises bring a new appreciation for the planet we call home. Here are some tips to support your learning.

Tip 1. Know What's Being Asked of You

The questions in the lab manual can be classified using the revised version of Bloom's Taxonomy (Bloom & Krathwohl, 1956; Anderson & Sosniak, 1994). Starting from pyramid's wide base each category's width decreases to the peak of the pyramid. From the base to the peak, the categories are:

- **Remember** questions ask you to recall facts and basic concepts. You may be asked to recreate a sketch, label a diagram, define a key term, or identify a process. These are the most basic questions that are designed to ensure that you grasp the fundamental knowledge and skills in a lab.
- **Understand** questions ask you to explain ideas and concepts with prompts like describe, observe, and summarize.
- **Apply** questions ask you to calculate or adapt information. Several question prompts start with "Apply What You Learned"—this means that you will take the information presented in the lab (or a previous lab) and apply it to a new situation.
- **Analyze** questions ask you to make connections among different ideas by making comparisons and interpreting information. Several question prompts start with "Use Your Critical Thinking Skills", which means that you need to bring in other ideas because these questions can't be answered simply by reading the information in the lab.
- **Evaluate** questions ask you to assess, make predictions, or explain complex ideas. You'll need to justify a decision or point of view.
- **Create** questions ask you to produce new or original work by designing, inventing, or composing.



Bloom's Revised Taxonomy: Figure adapted from Vanderbilt University Center for Teaching is licensed under CC BY-NC 4.0

Why bother with Bloom's taxonomy? Students who understand what's being asked of them do better in their courses. Most students report that in high school, they were asked only to remember or understand information. Transitioning into college coursework goes more smoothly if you recognize what's being asked of you.

Decoding a few other question prompts will make the lab go more smoothly for you. Explain your responses:

- This means you should let your instructor know the reasoning behind your answer. If the question asks for a certain number of sentences, be sure to provide a thoughtful answer that meets that requirement.
- You don't need to write in complete sentences.

- For example, if the question is “Why is geography your favorite subject? Explain your response in one to two sentences” you don’t need to write “Geography is my favorite subject because…”. You can just jump right into your response to save space.

Lists:

- When you see this as the question prompt, you don’t need to write sentences. You can just answer the question using bullet points.

Show your work:

- This means you should include the variables that you used for a calculation.
- For example, if the question is to “Convert 100 kilometers into miles. Show your work” then you would need to write: 100 / 0.621371 = 62.1371 miles.
- You don’t need to show the long division needed to get the answer; just be sure to include the number that you entered into your calculator to find the answer.
- You definitely do need to include the units of measurement—in this case miles.
- Always include the correct unit of measurement in your responses.
- When your answer is in decimals, ask your professor if they have a preference. In the example above, they may prefer you to round the answer to 62 miles (instead of 62.1371 miles).
- You may indicate an estimation by using the ~ symbol.

Tip 2. Use Your Resources

There are four types of boxes in this lab manual to help you navigate the course:



Pin It! Boxes

Pin It! boxes refer to information that you should mentally “pin” for later. Remembering the information included in pin it boxes will help you answer questions that come later in the lab.



Think About It…Boxes

Think About It…boxes encourage you to do just that, think about the information provided in the box. The information may require you to relate physical geography to your everyday life, form an opinion on a controversial subject, or make connections across multiple topics.


Check It Out Boxes

Check It Out boxes provide supplemental resources like webpages and videos to help you understand the information or to take you deeper into the topic. We recommend these resources to increase your understanding of physical geography topics.



Guided Practice Boxes

Guided Practice boxes provide links to short videos that demonstrate tasks that physical geography students often find tricky or provide tips for navigating GIS webpages.

If there is a QR code, most camera apps on phones can be used to scan the QR code in order to open the website.

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Additional Notes

Throughout the lab manual, key terms are shown in **bold-faced** type.

For videos, you can use the settings in youtube to speed up or slow down the playback speed. You can open the transcript to read the transcript, as well.

To keep navigation consistent, some heading levels have been skipped in the document.

This lab manual makes use of potentially inaccessible interactive resources. Please work with your instructor and local campus resources to identify accommodations for certain components the following labs:

- Lab 1. Earth's Geographic Grid
- Lab 2. Map Interpretation
- Lab 8. Water Resources
- Lab 9. Climate Patterns
- Lab 10. Climate Change
- Lab 12. Introduction to Minerals and Rocks
- Lab 13. Plate Tectonics
- Lab 14. Seismology
- Lab 16. Coastal Geomorphology
- Lab 19. Pedology
- Lab 20. Biogeography

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LABS

1.1: Lab 1 - Earth's Geographic Grid

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1.1: Lab 1 - Earth's Geographic Grid

This lab contains potentially inaccessible interactive resources. Please work with your instructor and local campus resources to identify accommodations (such as alternative formatted maps) for these resources.

Learning Objectives

- Use latitude and longitude to identify locations on Earth.
- Calculate lengths of a degree of longitude at different latitudes.
- Convert between degrees, minutes, and seconds and decimal latitudes and longitudes.
- Identify the special lines of latitude.
- Calculate solar time.
- Explain the Public Land Survey system.

The Earth is spherical but not quite a perfect circle. In fact, it is a little wider in the middle due to its rotation and the resulting centrifugal forces. By understanding that the Earth is round, geographers can easily distinguish a specific location by utilizing a grid system, similar to using graph paper.

Geography is about spatial understanding, which requires an accurate grid system to determine absolute and relative location. **Absolute location** is the exact x- and y- coordinates on the Earth. **Relative location** is the location of something relative to other entities. For example, when you use Google Maps, you put in an absolute location. But as you start driving, the device tells you to turn right or left relative to objects on the ground: "Turn left on exit Valencia Blvd" is relative to the other exit points. Or if you give directions to your house, you often use relative locations to help them understand how to get to your house.[2] These lines that allow us to understand a location are called latitudes and longitudes.

Lines of **latitude**, also known as **parallels**, are measured from the center of the Earth. These lines are angles measured at the **equator** (0°) to the North Pole at 90°N, or to the South Pole at 90°S. The angles are measured as though a protractor was placed in the center of the Earth, and we are measuring an angle from the center of the Earth to the Earth's crust.

Lines of longitude, otherwise known as meridians, are measured going east or west of the **Prime Meridian**, which passes through the Royal Observatory in Greenwich, England. The reason the Prime Meridian passes through the Observatory in England is due to an international agreement of 25 countries in 1884, as technically the meridian is arbitrary and could have been anywhere in the world. Two longitudes (or meridians), connected on opposite sides of the globe, create a great circle. A single line of longitude does not make a circle on the globe—it is an arc of a great circle. The word meridian also implies that these lines are not parallel but instead intersect at both the north and south poles. The Prime Meridian is the dividing longitude of the eastern and western hemispheres. The farthest one can travel either east or west is 180°: (180°W + 180°E = 360°).

Figure 1.1 provides an illustration of how we can pinpoint a location on Earth using latitude and longitude. The location marked with a dot is 40° north of the equator and is 60° degrees east of the Prime Meridian. So this location is at 40°N, 60°E.

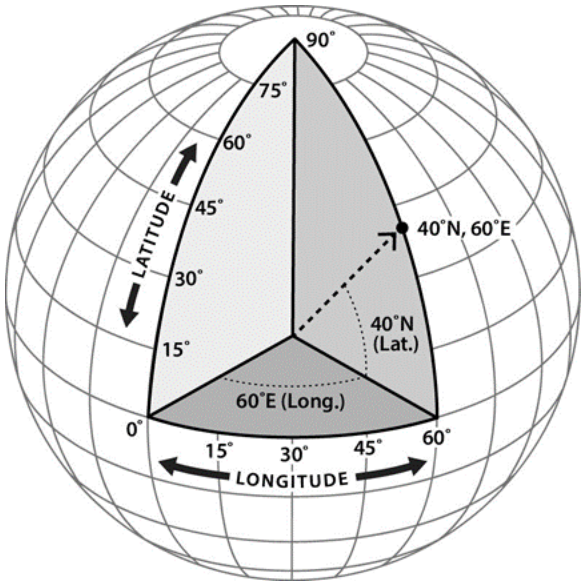


Figure 1.1: Latitude and Longitude Example. A basic diagram showing how both latitude and longitude are measured from the center of the Earth towards the surface. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

Both latitudes and longitudes can be identified as circles. This brings up the topic of great and small circles (Figure 1.2). A **great circle** is any circle that divides the Earth into a circumference of two equal halves. It's also the largest circle that can be drawn on a sphere. The line connecting any points along a great circle is also the shortest distance between those two points. Examples of great circles include the Equator; all lines of longitude; the line that divides the Earth into day and night, called the circle of illumination; and the plane of the ecliptic, which divides the Earth into equal halves. **Small circles** are circles that cut the Earth in two, but not into two equal halves.[4]

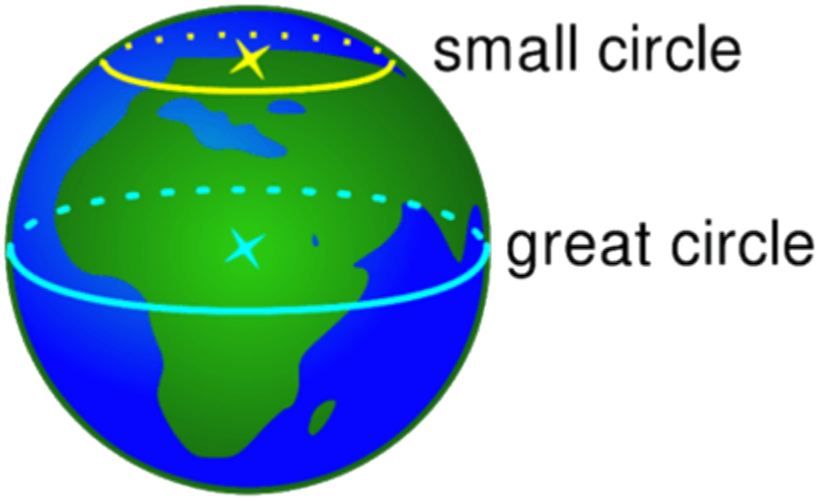


Figure 1.2: Great and Small Circles. Figure by Brian Brondel is licensed under CC BY-SA 2.5

In this lab, you will investigate a variety of ways to understand the Earth's grid system, determine the importance of distance and differences in time, and utilize the Public Land Survey.

Part A. Latitude and Longitude

The Earth's geographic grid is based on the division of a circle, which can be observed as lines of latitude or longitude (Figure 1.3).

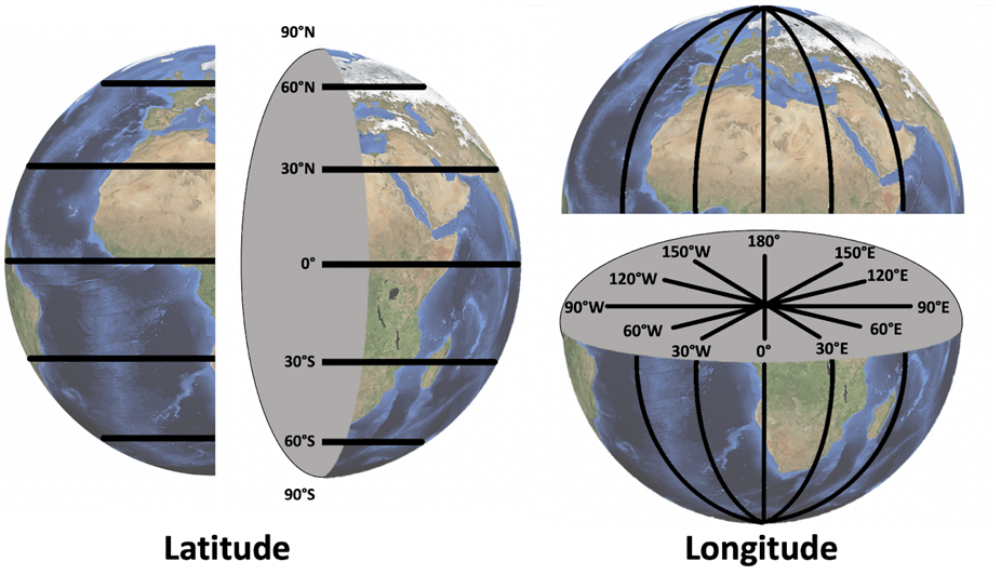


Figure 1.3: Introductory Diagram of Latitude and Longitude. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Exercise 1.1.1

1. Refer to Figure 1.3.
   a. Latitude is measured to the north or south of the:
   b. Longitude is measured to the east or west of the:
   c. Lines that are drawn from north to south (from the North Pole to the South Pole) are called:
   d. Lines that are drawn from east to west are called (from the Prime Meridian to the Antimeridian (180th Meridian):
   e. The highest degree possible for a line of latitude is:
   f. The highest degree possible for a line of longitude is:
2. In one to two sentences, describe the differences between great and small circles.
3. On Figure 1.3, label an example of a great circle and an example of a small circle.

Distance: The Length of a Degree

Because lines of latitude are parallel to one another, the measurable distance between them, from north to south, remains relatively constant. Due to Earth's curvature, one degree of latitude is approximately 68.7 miles at the equator, while at the poles one degree of latitude is approximately 69.4 miles.

As the angular distance changes between the lines of longitude, the distance along a line of latitude will either increase or decrease. To better understand this concept, use Table 1.1 shown below to answer the following questions about the length of a degree of longitude along specific latitudes. (Hint: a statute mile is the linear measurement of a mile, which is equal to 5,280 feet).

Table 1.1: The Length of a Degree of Longitude

Latitude North or South	Length of One Degree of Longitude at this Latitude in Statute Miles
0°	69.171
10°	69.128
20°	65.026
30°	59.956
40°	53.063
50°	44.552

Latitude North or South	Length of One Degree of Longitude at this Latitude in Statute Miles
60°	34.674
70°	23.729
80°	12.051
90°	0.000

Exercise 1.1.2

4. Refer to Table 1.1.
    a. How does the length of longitudes change as latitude is increased?
    b. Calculate the distance of the Earth along the equator. Show your work.
    c. Calculate the distance of the Earth along 30°N. Show your work.
    d. Calculate the distance of the Earth along 60°S. Show your work.

How would you calculate the distance in miles between two people on the same line of latitude? Here are the steps to follow:

Step 1

First, find the sum of the total longitudinal distance between the points in degrees.

Step 2

Multiply that sum by the statute miles per degree at the shared line of latitude (refer to Table 1.1).

Sometimes it is easier to complete Step 1 by visualizing the degree distance between two points on the same latitude by plotting the two points on a number line with 180 degrees West on the far-left, 0 degrees in the middle and 180 degrees East on the far-right. Figure 1.4 provides an example: if you want to calculate the distance between 90°W and 30°E, you can mark these on the number line. Once you plot the two locations, you are able to calculate the total longitudinal distance between the locations. In this example, 90 degrees West + 30 degrees East = 120 degrees total distance.

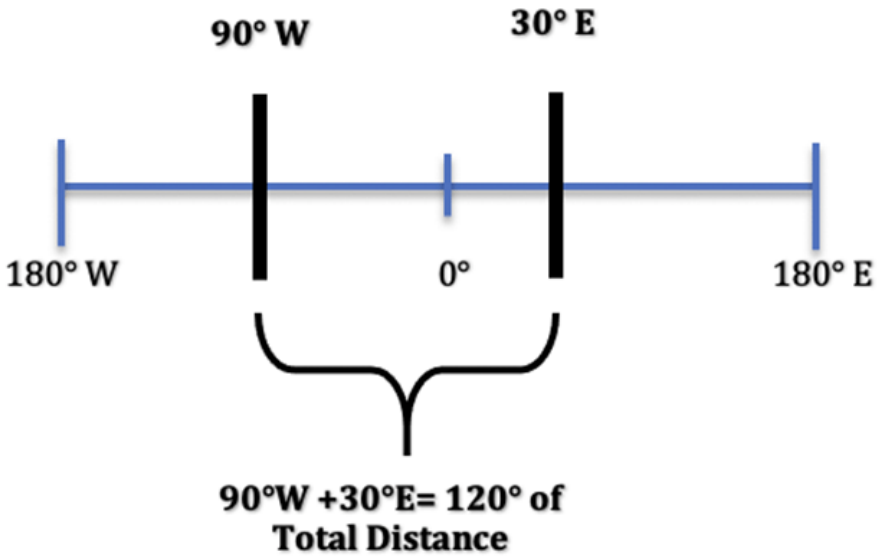


Figure 1.4: Example of How to Calculate Longitudinal Distance. Figures by Jeremy Patrich are licensed under CC BY-NC-SA 4.0

Figure 1.5 provides a graph that you can use for the following two questions (Hint: this is great practice as you will be using this number line again later in the lab).

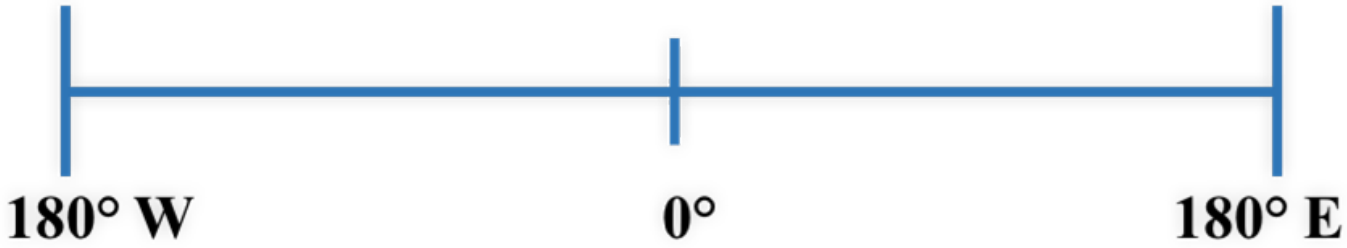


Figure 1.5: Longitude Diagram to Visualize Degree Distance between Two Locations on the Same Latitude. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Exercise 1.1.3

5. How many miles are between 60°N, 30°W and 60°N, 50°E? Show your work.
    a. First, determine the number of degrees of longitude between these two locations (use Figure 1.5):
    b. Second, refer to Table 1.1 and multiply your answer for 5a by the longitudinal distance at 60°N:
6. How many miles are between 30°S, 60°W and 30°S, 90°E? Show your work.
    a. First, determine the number of degrees of longitude between these two locations (use Figure 1.5):
    b. Second, refer to Table 1.1 and multiply your answer for 6a by the longitudinal distance at 30°S:

Degrees, Minutes, and Seconds

The primary unit in which latitude and longitude are observed is **degrees**. As learned earlier, the distance of these degrees can be quite large, which is why it is important that the subdivision of a degree be understood. There are two formats for subdividing a degree: decimal degrees and degrees-minutes-seconds (DMS).

In order to understand the DMS format, you should know that ° is the abbreviation for degrees, ’ is the abbreviation for minutes, and ” is the abbreviation for seconds. Each degree can be divided into 60 equal parts called a **minute**. Each minute can also be divided into 60 equal parts called **seconds**. This can be noted as 1° = 60’ = 3600”. To review:

- there are 60 minutes in 1 degree.
- there are 60 seconds in 1 minute.

Also note that for DMS, degrees are shown first, then minutes, then seconds.

Exercise 1.1.4

7. Write the following latitude and longitudes in DMS and use the correct abbreviations. Hint: 15 degrees, 32 minutes, and 11 seconds S would be written as 15° 32’ 11” S. Because it has the S designation, it is a latitude.
    a. 5 degrees, 20 minutes, 30 seconds N:
        i. Is this a latitude or longitude?
    b. 122 degrees, 40 seconds, and 55 minutes W:
        i. Is this a latitude or longitude?
    c. 88 degrees, 55 minutes, and 12 seconds S:
        i. Is this a latitude or longitude?

8. Apply What You Learned: Correct the errors on the following latitudes and longitudes. Hint: just like with time, minutes and seconds cannot exceed 60. For example, if there are 65' shown, you should turn 60' into 1° and keep 5' remaining. So, 20° 65' 00" N would be corrected as 21° 5' 00" N.
   a. 89° 47' 65" N
   b. 62° 59' 61" S
   c. 118° 67' 51" E

Decimal degrees are just that, the decimal version of latitude and longitude. For example, you know that there are 60 minutes in one degree. So, 30 minutes would be one-half of one degree. One-half is the same as 0.5. Therefore, you could identify a latitude as 60°30' N or as 60.5° N.

Let's say you would like to convert the following location into decimal degrees: 60° 30' 45" N. Only the conversion of the minutes and seconds needs to occur, and this can be done by taking the minutes and dividing them by 60, and taking the seconds and dividing them by 3600, then adding them together. (Hint: 1° = 60' and 60' = 3600"). Let's look at this DMS to decimal conversion step-by-step:

Step 1

Using the location 60° 30' 45" N, let's first convert minutes into a decimal by dividing it by 60. For this problem, it would be 30/60 = 0.5.

Step 2

We need to convert seconds into a decimal as well, so divide the seconds by 3600. For this problem it would be 45/3600 = 0.0125.

Step 3

Let's put it together. Since there was no conversion to the degrees, that number stands alone, followed by a decimal point. The decimal portion is the sum of the conversions from steps 1 and 2. The answer is 60.5125° N (60 + 0.5 + 0.0125 = 60.5125).



Guided Practice: DMS to Decimal Degrees

See examples of how to convert DMS to decimal degrees with this video from Scott's Geography Notebook, Degrees, Minutes, Seconds to Decimal Degrees. (Video length is 4:57).

Exercise 1.1.5

9. Convert the following latitudes and longitudes from DMS to decimal degrees.
   a. 20° 58' 33" N
   b. 04° 22' 52" S
   c. 118° 35' 51" E

Think About It...Why Is This Important?

This information is helpful in understanding locations on both digital and paper mediums. Most paper maps use DMS, while most digital interfaces like Google Maps use decimal degrees.

There are many ways to look up locations to find their latitude and longitude. In the Pin It! box below you will find an interactive website sponsored by the United States Geological Survey (USGS) that provides a global interactive map that can help identify the latitude and longitude of a certain location. Use the QR code or link below to answer the following questions. (Hint: all three locations for this activity are in California). Note that negative (-) latitudes are in the southern hemisphere and negative (-) longitudes are in the western hemisphere. For example, -118° is the same as 118° W.

To convert decimal degrees to DMS, multiple the decimal by 60 to find the minutes. Multiply the remaining decimal by 60 to get the seconds.

Pin It! Finding a Latitude and Longitude

Use this interactive Latitude and Longitude Finder to help complete the following questions. Note: your instructor may provide hard-copy atlases or another website.

Exercise 1.1.6

10. What are the latitude and longitude of Point Dume at Point Dume State Beach...
    a. ...in Decimal Degrees?
    b. ...in Degrees, Minutes, and Seconds? Show your work.
11. What are the latitude and longitude of Mt. Whitney in the Sierra Nevada?
    a. ...in Decimal Degrees?
    b. ...in Degrees, Minutes, and Seconds? Show your work.

Special Lines of Latitude

There are some special lines of latitude (Figure 1.6), which will be discussed in another lab. You should memorize these special lines of latitude. And, notice that the word “Arctic” has two letter “c”s in it. Too many students misspell “Arctic” as “Artic”—don’t let that happen to you. (Also notice, there are two letter “c”s in the word Antarctic). At the far north lies the North Pole at 90° North (90°N). Moving southward is the Arctic Circle at 66.5° North (66.5°N) and the Tropic of Cancer at 23.5° North (23.5°N). The Equator circles the center of the Earth at 0° latitude. Continuing to move southward is the Tropic of Capricorn at 23.5° South (23.5°S) and the Antarctic Circle at 66.5° South (66.5°S). The most southward latitude is the South Pole at 90° South (90°S).

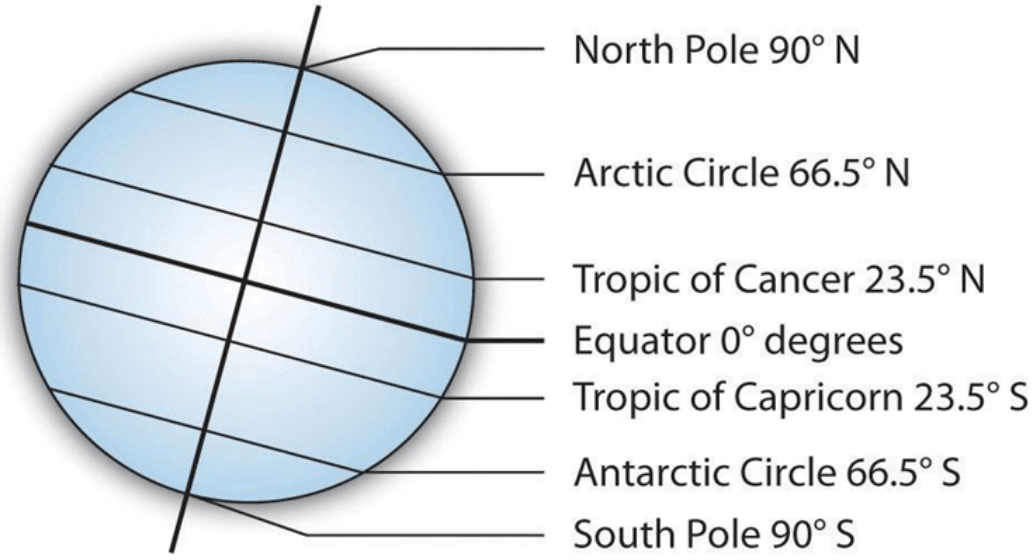


Figure 1.6: Special Lines of Latitude. Figure by University of Minnesota Libraries is licensed under CC BY-NC-SA

Exercise 1.1.7

12. Refer to Figure 1.6 to complete Table 1.2. Be sure to include if the latitude is north or south of the equator.

Table 1.2: Special Lines of Latitude

Latitude Name	Degrees of Latitude
The Equator	
The Tropic of Cancer	
The Tropic of Capricorn	
The Arctic Circle	
The Antarctic Circle	
The North Pole	
The South Pole	

13. Using Figure 1.6 and Table 1.2, sketch and label each of these latitudes on the map below (Figure 1.7). Be sure to include the latitude name and degrees on your labels.

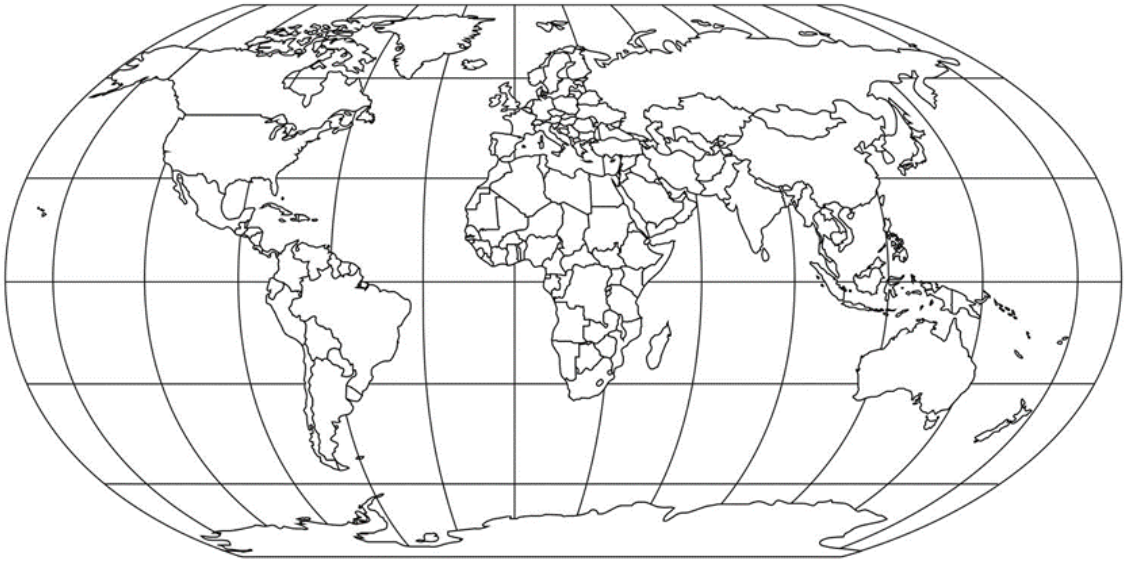


Figure 1.7: Robinson Map Projection. Figure by Bruce Jones Design and FreeUSandWorldMaps.com is licensed under CC0 1.0

The Geographic Grid

In this portion of the lab you will be applying previously learned content together on a map.

Exercise 1.1.8

14. Refer to Figure 1.8.
    a. Label the lines of latitude and longitude along the edges of the map. Note that they are in 30° increments.
    b. What are the coordinates for the location labeled A (in North America)?
    c. What are the coordinates for the location labeled B (in the Indian Ocean)?
    d. Draw a dot at 20°S, 45°W and label it with a C.
    e. Draw a dot at 60°N, 120°E and label it with a D.
    f. Draw a dot at 45°S, 15°E and label it with a E.
    g. Draw a dot at 35°N, 120°W and label it with a F.
    h. Draw a dot at 70°S, 160°E and label it with a G.
    i. Draw a dot at 10°N, 30°W and label it with a H.
    j. Use Figure 1.9 to calculate the total distance in degrees between points A and D. Then, refer to Table 1.1 to determine the total distance in miles. Be sure to show your work.

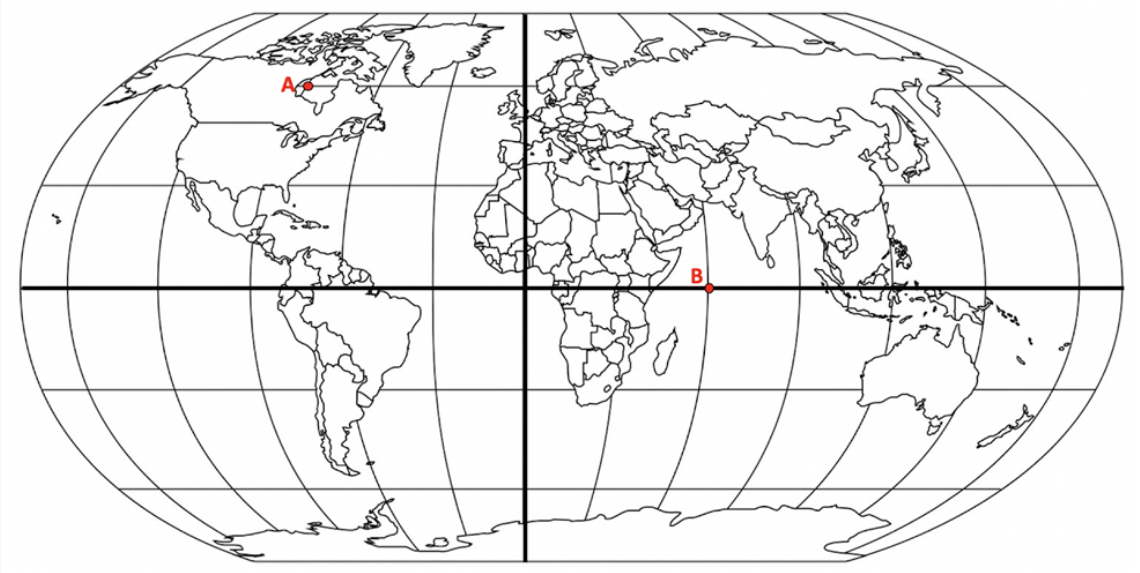


Figure 1.8: Global Robinson Projection. Figures by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

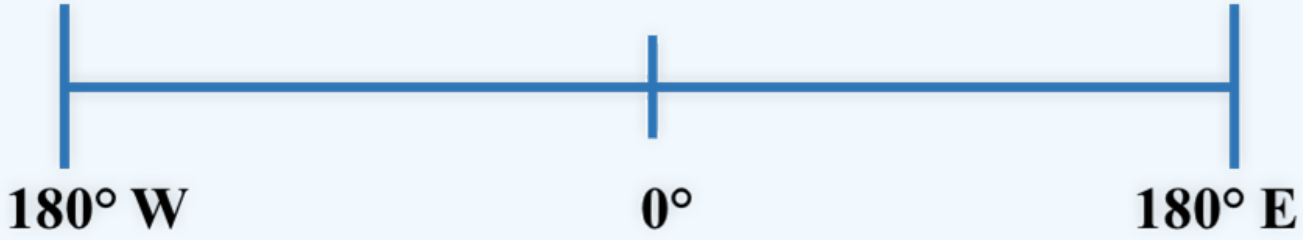


Figure 1.9: Longitude Diagram to Visualize Degree Distance between Two Locations on the Same Latitude. Figures by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Part B. Earth's Time Zones

Time on Earth can be observed in two different ways: either using the Sun or utilizing standard time. **Solar time** uses the noon sun angles to calculate the apparent solar time (like the sundial shown in Figure 1.10). **Standard time** is the time you are most accustomed to, as it is the local agreed-upon time in a region when Daylight Savings is not in use. Standard time prevents cities and towns from being divided by solar time zones. Standard time is best observed as time zones.

The Earth rotates eastward, in a prograde or counterclockwise motion when viewed from the North Star. The result of this rotation makes meridians eastward of the noon meridian later in time, while locations westward of the noon meridian are earlier in time. Here is a way to think of it: as your home rotates into the morning sunlight, you see the sun rise (in the east). You then experience the **noon meridian**, when the sun is at the highest point of the celestial sky. When your home finally rotates out of the sunlight, you see the sun set (in the west). This means that longitudes east of your location have already experienced your present solar time, which is why people in Los Angeles are able to watch the New York ball drop on New Year's Eve 3 hours before the west coast experiences midnight!



Figure 1.10: Sundial Photograph. A sundial is a device that tells the time of the day by using the apparent position of the Sun in the sky. Figure by Ines Zgonc is licensed under CC BY-SA 3.0

Check It Out! Interactive Sundial

Visit this Sundial for an interactive presentation of how sundials work!

For this section of the lab, you will investigate standard time and solar time. Each mean solar day is 24 hours, and the Earth rotates 360° in one day. This means that each hour, the Earth rotates 15° of longitude. This is the equivalent of 1° of longitude every 4 minutes). To recap:

- 360° rotation divided by 24 hours in a day equals 15° of longitude per hour.
- 15° of longitude per hour divided by 60 minutes equals 0.25 degrees of longitude per minute.
- 0.25 degrees of longitude per minute is equivalent to 1° of longitude every 4 minutes.

Pin It! Time and Earth's Rotation

Be sure to remember that a rotation of 1 degree of longitude is worth 4 minutes of solar time.

Figure 1.11 is a global time zone map, which represents standard time. A map of the world split into several vertical sections.

- On the far left, the first section is labeled 11. It includes part of Alaska. Moving left-to-right, the numbers decrease to 10, 9, 8, etc., until 0 towards the center of the map.
- The section labeled 0 includes England, parts of Europe south of England, and parts of Africa.
- Continuing to the right, the section numbering increases beginning at 1, then 2, 3, 4, etc., up to 12.
- The section labeled 12 includes the eastern part of Russia.
- The right edge of the section labeled 12 is labeled the International Date Line.
- To the right of this line is another section labeled 12 and another section labeled 11.
- The section labeled 11 on the far right of the map is a continuation of the section labeled 11 on the far left of the map.
- Each section is also labeled with times.
    - From left to right, the section labeled 11 is labeled 01:00 SUN, the section labeled 10 is labeled 02:00. This labeling continues, section 9 is labeled 03:00, section 8 is labeled 04:00, until section 0, which is labeled 12:00.
    - Then section 1 to the right of section 0 is labeled 13:00, section 2 to the right of section 0 is labeled 14, etc., until section 12 to the left of the International Date Line, which is labeled 24:00 SUN.
    - The section 12 to the right of the International Date Line is labeled 0:00 SUN. The section 11 at the far right edge of the map is labeled 01:00.

Note that eastward locations are later. For example, when it is 1 p.m. in Los Angeles it is 4 p.m. in New York because New York is three time zones from Los Angeles.

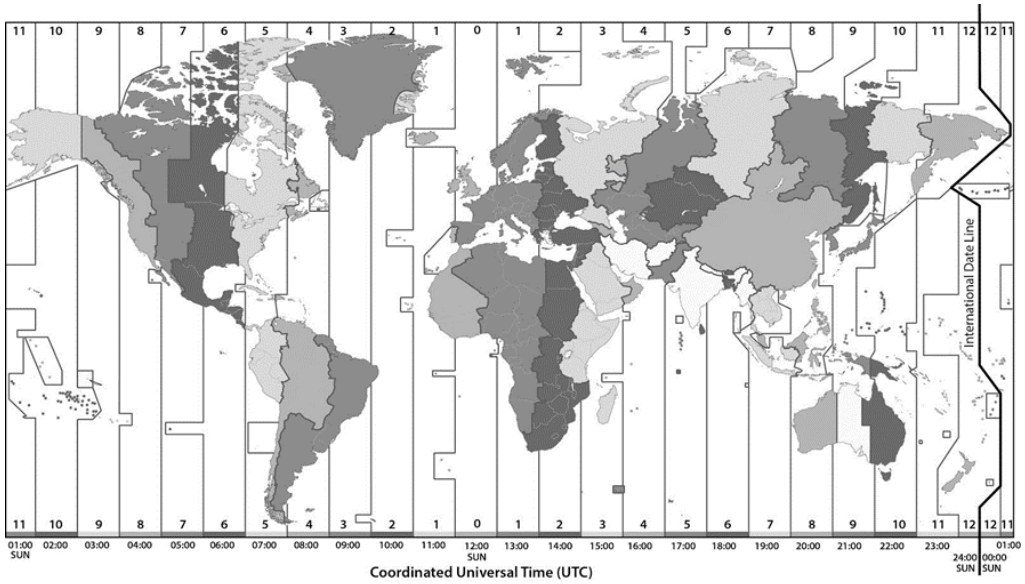


Figure 1.11: Time Zone Map. Figure by Waverly Ray is licensed under CC BY-SA 3.0

Exercise 1.1.9

15. Refer to Figure 1.11.

    a. How many time zones are shown across the map? Use Your Critical Thinking Skills: Why would there be this number of time zones?

    b. Use Your Critical Thinking Skills: The Earth rotates 15° per hour so it would make sense that each time zone spans a distance of 15°. But the time zone boundaries are not vertical lines representing exactly 15° segments of the planet. Why do you think time zone boundaries are irregular? Explain your response in one to two sentences.

Check It Out! Time Zones

Visit this interactive Time Zone Map for more information on time zones.

An important variable related to solar time is the **noon meridian**, which is the meridian (line of longitude) that is experiencing the subsolar point where the Sun is at its highest point in the sky. Figure 1.12 provides a diagram showing the location of the **subsolar point**, which is the location where the Sun's rays reach the surface of the Earth at a 90° angle. A 90° angle is also known as a perpendicular angle. So, the latitude that has the Sun's rays directly overhead is the subsolar point.

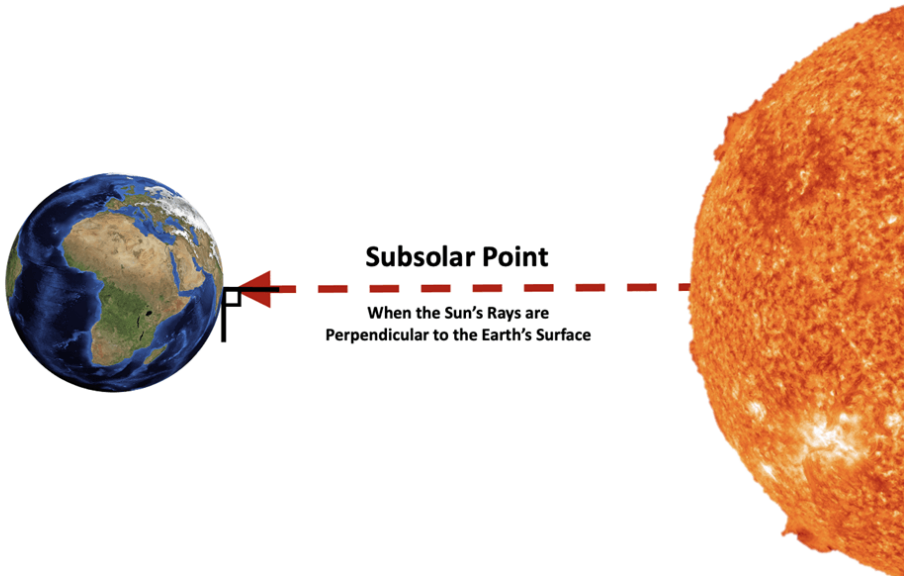


Figure 1.12: The Subsolar Point. A basic diagram showing the location of the subsolar point on Earth's surface. The angle between the Sun and the local horizontal level is exactly 90° at the subsolar point. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Let's say that you are located at the noon meridian and your friend is located 1° longitude east of your location. What is the solar time at your friend's location? Recall that 1° is worth four minutes of solar time. Also recall that locations to the east are later in time. So, your friend's location would be 12:04 p.m.

Exercise 1.1.10

16. What would be the solar time of someone 1° longitude west of the noon meridian? Show your work.
17. What would be the solar time of someone 8° longitude east of the noon meridian? Show your work.

18. Let's take greater distances into consideration. Assuming that you lived along 40°W longitude, and it was solar noon (subsolar point), what would be the solar time at each of the following different locations at the same moment in time? (Hint: first calculate the total distance in degrees, then decide if the location is either westward or eastward of your location. Lastly, convert the degrees into minutes and hours, then solve). Be sure to use Figure 1.13 to help you calculate the total distance in degrees and show your work.
    a. 60°W:
    b. 55°E:
    c. 80°W:
    d. 140°E:

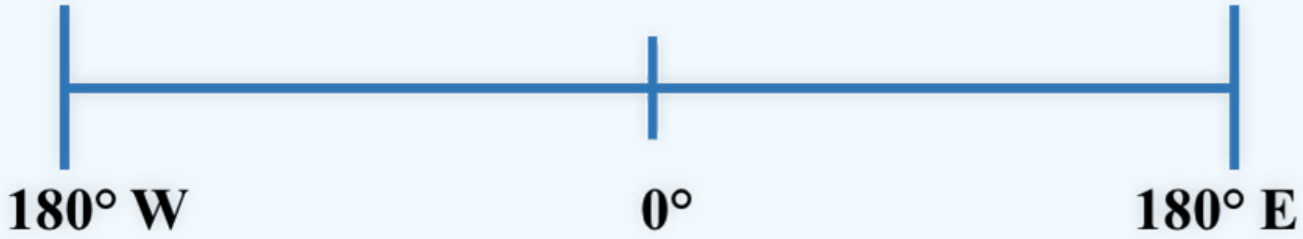


Figure 1.13: Longitude Diagram to Visualize Degree Distance between Two Locations on the Same Latitude. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

19. Assuming that you lived along 50°E longitude, and it was solar noon (subsolar point), what would be the solar time at each of the following different locations at the same moment in time? Be sure to use Figure 1.14 to help you calculate the total distance in degrees and show your work.
    a. 60°W:
    b. 55°E:
    c. 80°W:
    d. 140°E:

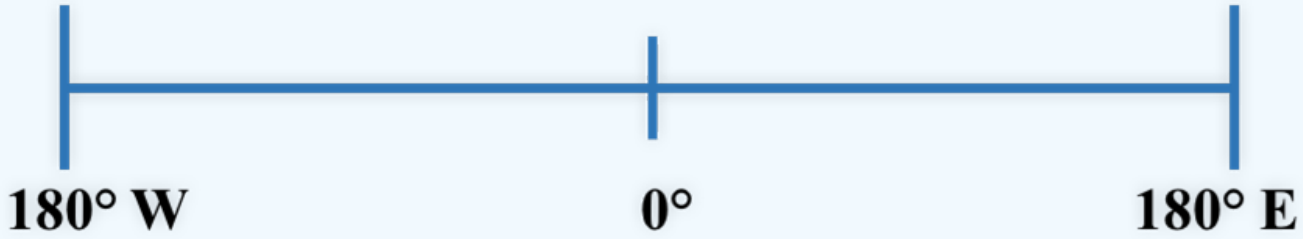


Figure 1.14: Longitude Diagram to Visualize Degree Distance between Two Locations on the Same Latitude. Figures by Jeremy Patrich are licensed under CC BY-NC-SA 4.0

20. Lastly, let's assume that you are lost at sea on an old ship. It is possible to determine your longitude if you know your solar time and the time and longitude of another location. As an example, assume the last port you were in was near Greenwich, England (the Prime Meridian), and you set your pocket watch before departure. Assuming that it is solar noon at your location on the lost ship, what is your longitude if the time at the Prime Meridian is the following? (Hint: first decide if your ship is either westward or eastward of the known location, then calculate the total difference in time between the two locations, lastly convert the time into degrees and solve). Be sure to use Figure 1.15 to help you calculate the total distance in degrees and show your work.
    a. 3:00 p.m. at Prime Meridian:
    b. 6:00 p.m. at Prime Meridian:
    c. 1:00 a.m. at Prime Meridian:
    d. 2:30 p.m. at Prime Meridian:

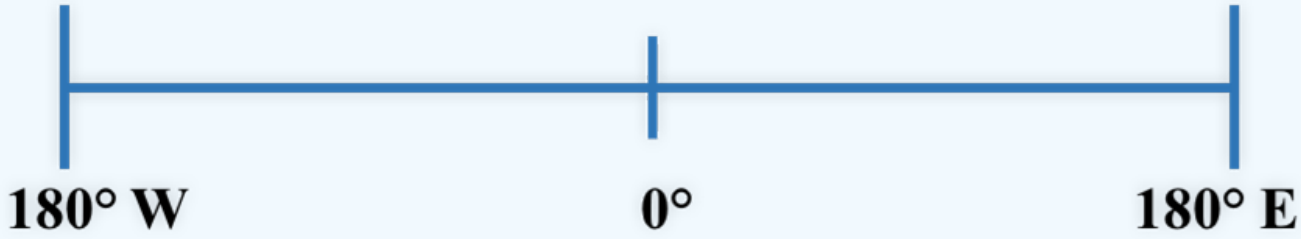


Figure 1.15: Longitude Diagram to Visualize Degree Distance between Two Locations on the Same Latitude. Figure by Ines Zgonc is licensed under CC BY-SA 3.0

21. In your own words, explain the difference between solar time and standard time in one to two sentences.

Part C. The Public Land Survey

Another way to divide up regions is by using the **Public Land Survey** (PLS). The combination of a topographical map and this system can be used to locate features within a few acres and is a primary means of subdividing tracts of land for sale. The organization of the township-section system is based on the definition of baselines and principal meridians. The position of a baseline and meridian within a region may or may not coincide with latitude and longitude. This system is still used today in some variation in most states except for the original thirteen colonies as they predate this system. Although antiquated, it is still observed in the urban designs of our landscapes, and is crucial for identifying large acreage parcels of land in undeveloped areas.

Check It Out! Baselines and Meridians

Visit this link of Baselines and Meridians to see a map of Public Land Survey across the United States.

Townships are square areas of 6 miles on a side (36 square miles), bordered on the east and west by range lines and on the north and south by township lines. Each township is subdivided into 36 sections of 1 square mile (Figure 1.16).

Sections are broken down even smaller into quadrants. These quadrants can be divided into four parts, which results in ¼ mile increments, otherwise known as 40 acres.

Hint: another way to explain this system would be similar to explaining to someone where you live. As an example, you could be specific with an address (quadrants) or you can provide the City (sections) or you can provide the region of the state (Township and Range).

Guided Practice: The Public Land Survey

Learn how to understand township and range with this video, Township & Range (PLS) Public Land Survey, from Professor Jeremy Patrich. (Video length is 10:08).

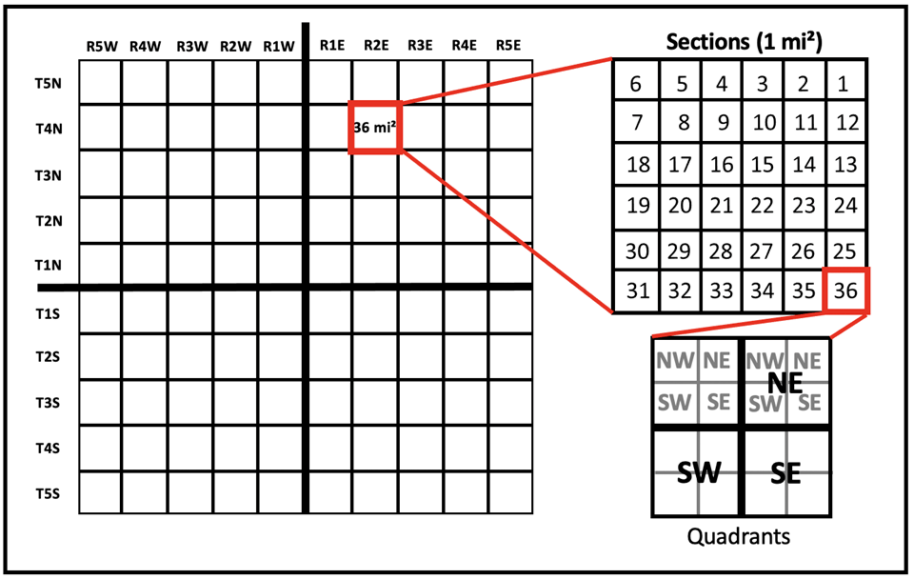


Figure 1.16: The Public Land Survey. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Observing this three-part map below, it is important to note that you can follow each letter across all three parts. This is done so cartographers do not have to keep making new maps. Using the map below (Figure 1.17), use the Public Land Survey to identify the location of each letter on Table 1.3. (Hint: Letter J has been completed for you as an example).

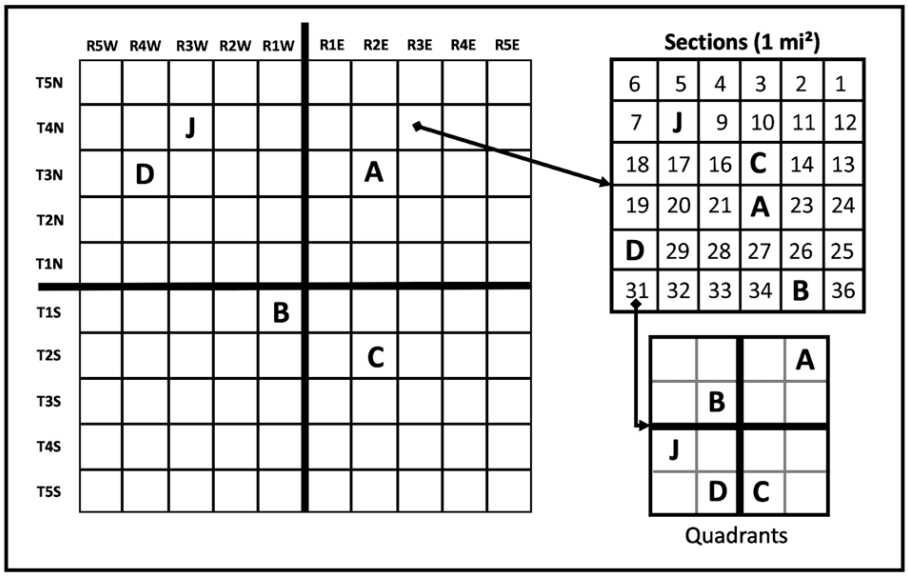


Figure 1.17: The Public Land Survey Activity. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Table 1.3: Location Identification using the Public Land Survey

Location	__ ¼,	of the __ ¼,	Section #__,	Township __,	Range __
J	NW ¼,	of the SW ¼,	Section # 8,	Township T4N,	Range R3W
A					
B					
C					
D					

Part D. Wrap-Up

Consult with your geography lab instructor to find out which of the following wrap-up questions you should complete. Attach additional pages to answer the questions as needed.

Exercise 1.1.14

22. What is the most important idea that you learned in this lab? In two to three sentences, explain the concept and why it is important to know.

23. What was the most challenging part of this lab? In two to three sentences, explain why it was challenging. If nothing challenged you in the lab, write about what you think challenged your classmates.

24. What is one question that you have about what you learned in this lab? Write your question along with one to two sentences explaining why you think your question is important to ask.

25. Review the learning objectives on page 1 of this lab. How would you rate your understanding or ability for each learning objective? Write one sentence that addresses each learning objective.

26. Sketch a concept map that includes the key ideas from this lab. Include at least five of the terms shown in bold-faced type.

27. Create an advertisement to educate your peers on the important information that you learned in this lab. Include at least three key terms in your advertisement. The advertisement should be about half a page in size (about 4 inches by 6 inches).

28. One way to think of physical geography is that it is the study of the relationships among variables that impact the Earth's surface. Select two variables discussed in this lab and describe how they are related.

29. How does what you learned in this lab relate to your everyday life? In two to three sentences, explain a concept that you learned in this lab and how it relates to your day-to-day actions.

30. How does what you learned in this lab relate to current events?
    a. Write the title, source, and date of a news item that relates to this lab.
    b. In two to three sentences, discuss how the news item relates to what you have learned in this lab.
    c. In one to two sentences, discuss whether or not the news item accurately represents the science that you learned. Tip: consider whether or not the news item includes the complexity of the topic.

22. Search O*NET OnLine to find an occupation that is relevant to the topics presented in today's lab. Your lab instructor may provide you with possible keywords to type in the Occupation Quick Search field on the O*NET website.
    a. What is the name of the occupation that you found?
    b. Write two to three sentences that summarize the most important information that you learned about this occupation.
    c. What is one question that you would want to ask a person with this occupation?

Answer available at the end of this section.

[2] Text by R. Adam Dastrup (Open Geography Education) is licensed under CC BY 4.0

[4] Text by R. Adam Dastrup (Open Geography Education) is licensed under CC BY 4.0

Answers

Exercise 1.1.14

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1.2: Lab 2 - Map Interpretation

This lab contains potentially inaccessible interactive resources. Please work with your instructor and local campus resources to identify accommodations for these resources.

Learning Objectives

- Describe how map projections transform the Earth's three-dimensional surface into a two-dimensional map.
- Explain why all maps have distortion.
- Use different map scales.
- Create a topographic profile.
- Interpret topographic maps.
- Explain basic land surveying techniques.
- Use map analysis tools in Google Earth Pro.

Introduction

Cartography is the science of map-making. Combining technical information, design, and aesthetics, cartography builds on the premise that reality can be modeled in ways that communicate spatial information effectively.

The cartographic design provides the interpreter, the map reader, a way to observe:

➢ what information must be included, and what can be left out. Including all data on a single map is impossible, so an incredible amount of power is given to the cartographer as they decide what information or elements are most important to a population.

➢ the physical geography landscape in single and multiple dimensional formats. Understanding what we stand facing in a physical environment can be interpreted in a map.

➢ a cultural understanding of a location's geography. Selected traits such as population density or political boundaries may be mapped.

➢ the organization and display of map elements to best convey the data presented to the reader. This is the main concern of design.

Understanding the elements within a map allows the reader to understand the environment without having to visit the location. Being proficient with map interpretations empowers you to be able to observe a random topographic map and identify distances, locations, and physical features. In this lab, you will explore a variety of ways to interpret the Earth's topography, by way of projections, cartography, topographic map reading, and digital mapping.

One way to view cartography is with a topographic map. **Topographic maps** provide the geographic locations and elevation of a landscape by using contour lines, shaded relief, colors, and in some cases, digital elevation models (DEM).

Part A. Map Projections

The term **map projection** refers to both the process and product of transforming spatial coordinates on a three-dimensional sphere to a two-dimensional plane. In simpler terms, how do **cartographers** take a round object such as Earth and make it into a small flat paper map? Well, if you had a clear globe the size of a beach ball and placed a light inside this globe, it would cast shadows onto a surrounding surface. If this surface were a piece of paper that you wrapped around the globe, you could carefully trace these shadows onto the paper, then flatten out this piece of paper and have your projection![1] Note that the areas tangent to the paper and globe represent a point or line of tangency, as the tracing will be of an exact replica with no distortion. Locations farther away from these points or lines of tangency will experience greater distortion.

Most projections transform part of the globe to one of three “developable” surfaces, so-called because they are flat or can be made flat: plane, cone, and cylinder (Figure 2.1). The resulting projections are called **planar**, **conic**, and **cylindrical**, respectively. We use developable surfaces because they eliminate tearing, although they will produce shearing and compression. Also, note that planar projections are sometimes called azimuthal projections.[18]

Planar projections are created using the idea of a contact point, or point of tangency, that becomes a singular focus in the projection. This is done using a central longitude and latitude, or a place or landmass.

Conic projections are created using a line of latitude as a contact line or line of tangency. This is often observed as a cone wrapped around the globe and the tangency is observed laterally as a small circle.

Lastly, cylindrical projections are created using the idea of the Equator as the contact line or line of tangency. This is observed as a paper wrapped along the Equator, and areas farther north or south of the equator become distorted.

Tearing is the term to describe when a projection places an edge on the map, or a discontinuity. Since all maps have an edge, different levels of tearing can be observed. Shearing is a term to describe the changes in the shape of a map feature, due to distortion, without changing the area. Lastly, compression is the term that is used to describe the enlarging or shrinking of landforms and features. Compression can often mislead the map interpreter, because size is frequently used as a measurement of power; this is often referred to as the “power of representation and representation of power”. This means that those who decide how to make a map have the power to represent the world in a certain way and thereby their power is represented on the map.

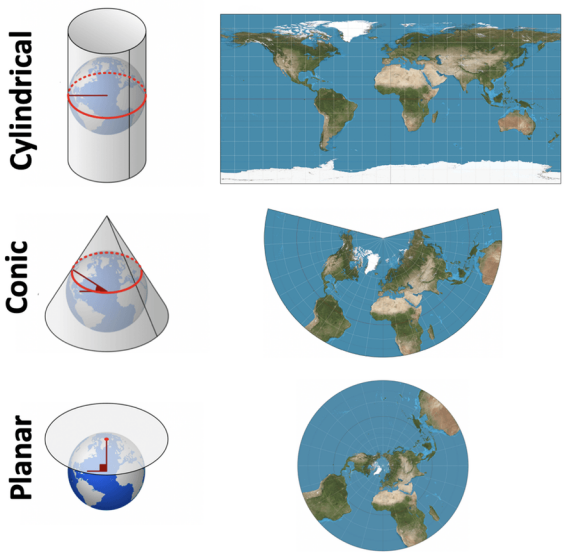


Figure 2.1: Cylindrical, Conic, and Planar Map Projections. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0 adapted from Cmglee and Strebe

Check It Out! Why All World Maps are Wrong

Ever wonder what it would look like if you took one of the beachball globes and tried to make a flat map out of it? We know it's not possible, but here is a great video showing why it's not possible! (Video length is 6:00).

Map Distortion and Social Injustice?

So what else can maps tell us about the world? Maps can illustrate how critical infrastructure is selectively parceled out from neighborhood to neighborhood. They can represent political bias by altering the shapes, sizes, and colors of regions, or by misleading an audience with altered or false information.

One of the main factors to consider is **map distortion**. All maps have distortion because it is impossible to transform the three-dimensional Earth onto a flat surface without causing errors. There are four primary types of distortion: area, shape, distance, and direction. Each of the projections found in Figure 2.1 (shown above) creates distortion on the globe. The job of the cartographer is to decide what distortion is appropriate according to the purpose of the map.

Exercise 1.2.1

1. Of the three projections shown in Figure 2.1 (shown above), which would be best for making a map along a:
    a. Great circle, say the equator? Explain your response in one sentence.
    b. Small circle, say the tropic of cancer? Explain your response in one sentence.
    c. Map of a continent, say Antarctica? Explain your response in one sentence.
2. Refer to Figure 2.2.
    a. What are your very first observations of this map?
    b. Take a closer look at the map. What do you observe?

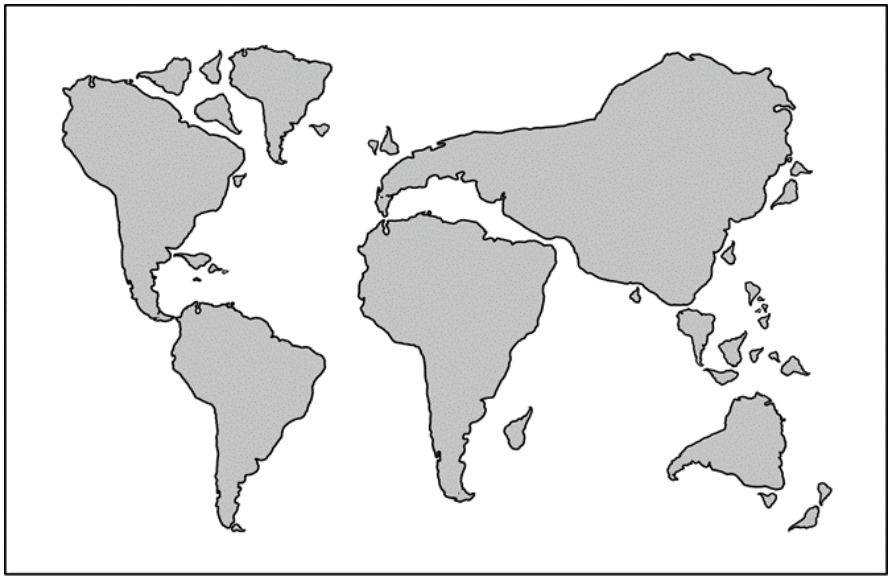


Figure 2.2: Map of South Americas. Figure by xkcd is licensed under CC BY-NC 2.5

Figure 2.2 is an example of a cartographic fallacy. This occurs when the map is not representative of reality—a map with a fallacy also has an intentional or accidental lie. Cartographers often use fallacies on maps of public transportation systems. In order to fit all of the station labels on the map, the cartographer misrepresents the distances between them.

A danger with map projections is that the map may enlarge certain countries, which can make them seem powerful and intimidating. This concept is not new—it is known as the “power of representation and representation of power”. As an example of this, observe the map below of Africa, and take note of the landmasses that have been put inside the continent of Africa (Figure 2.3).

Exercise 1.2.2

3. Refer to Figure 2.3. Interpret the map, then write down some of the things you noticed, things you found interesting, or things that might confuse you.

4. Refer back to Figure 2.1.

    a. Does the size of Africa appear distorted in any of the projections? If yes, in which projections? Tip: compare Africa and Greenland in each projection.

    b. Does the shape of Africa appear distorted in any of the projections? If yes, in which projections? Tip: use a globe, which best represents the shape of continents, to compare the map projections in Figure 2.1.



Figure 2.3: Map of Africa in Reference to 18 Countries and Land Masses. Adapted from figure by Kai Krause is licensed under CC0

Check It Out! Compare the Real Sizes of Countries

The surface of the Earth is always distorted in some way when it is projected onto a map surface. Compression is a common form of distortion where sizes are distorted. Have you ever wondered what the true size of California was in relation to the United Kingdom, or Iceland, or another place? Check out The True Size Of website to see the comparisons.

Part B. Map Elements

It is very important to be able to learn to interpret map elements. It is not always possible to see the area being studied in person. Understanding these elements allows the map reader to visualize size, topography, and other elements found within the environment. This portion of the lab will provide better examples of some elements often used, such as map scale, contour lines,

and relief features. Later in this lab, you will learn more about items found within the collar of a map (this is along the perimeter, or edges, of a map) such as the legend, orientation, geodetic data, and many more items.

Map Scale

The Earth's surface has an area of over 500 million square kilometers (approximately 193 million square miles) and any picture or map of the Earth that you can easily carry can only show general outlines of continents and countries. When we visually represent a region of the world on a map, we must reduce its size to fit within the boundaries of the map. **Map scale** measures how much the features of the world are reduced to fit on a map; or more precisely, map scale shows the proportion of a given distance on a map to the corresponding distance on the ground in the real world.[22] The map scale can be represented by a representative fraction (fractional), a verbal scale, or a graphic scale (Figure 2.4).

Fractional or Representative Fraction Scale

The most commonly used measure of map scale is the **representative fraction** (RF), where a map scale is shown as a ratio. With the numerator always set to 1, the denominator represents how much greater the distance is in the world. Figure 2.4 shows a map scale with an RF of 1:24000, which means that one unit on the map represents 24,000 units on the ground. The representative fraction is accurate regardless of which units are used; the RF can be measured as 1 centimeter to 24,000 centimeters, one inch to 24,000 inches, or any other unit. The key idea to remember is that the same unit has to be used on both sides of the representative fraction. So, if you say 1 inch for the left side, you have to follow that up with the appropriate number of inches on the right side. If you say 1 centimeter for the left side, you have to follow that up with the appropriate number of centimeters on the right side.[6]

Verbal Scale

Some maps, especially older ones, use a **verbal description** of scale. For example, it is common to see "one centimeter represents one kilometer" or something similar written on a map to give map users an idea of the scale of the map.[6]

Graphic Scale

Scale bars are graphical representations of distance on a map. One important advantage of graphic scales is that they remain true when maps are shrunk or magnified.[6]

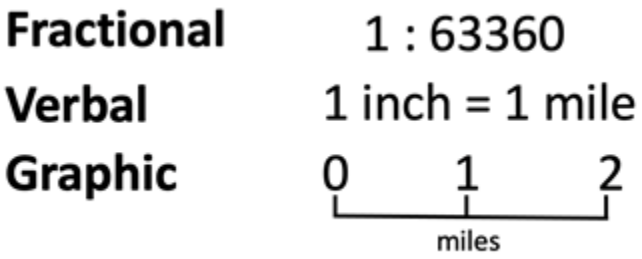


Figure 2.4: An Example of the Three Mapping Scales. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Exercise 1.2.3

5. Now that you understand the basics of map scales, write in the missing scales in Figure 2.5. Note that American units are shown for the top table and metric units are shown on the bottom table. Each row has one map scale provided. Complete the row using the equivalent information for the missing scale. For example, in the top row, write what 1:100000 would be as a verbal scale in American units. For the final row shown for both the American and metric unit tables, provide an additional example. Tip: there are 63,360 inches in one mile and 100,000 centimeters in one kilometer.

	Fractional	Verbal
American Units	1 : 100000	
		1 inch = 4 miles

	Fractional	Verbal
Metric Units	1 : 100000	
		1 cm = 40 km

Figure 2.5: Scale Conversion Activity. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Distance Conversions

The United States, Liberia, and Myanmar are the only three countries that have not adopted the metric system as its primary system of measurement. There have been reports and legislation calling for a conversion to the metric system since the 1960s. The U.S. Department of Commerce's National Institute of Standards and Technology wrote that "industrial and commercial productivity, mathematics and science education, and the competitiveness of American products and services in world markets, will be enhanced by completing the change to the metric system of units" (1997, 2). From a student's perspective, it would be better if the U.S. converted to the metric system. Because scientists globally use the metric system, most of U.S. scientists do, as well. Until the U.S. "metrifies", students in the United States will need to continue to use and understand both measurement systems.

Exercise 1.2.4

6. Refer to Appendix 2.1. Show your calculations for the following questions.
    a. 2 miles contain how many feet?
    b. 1 mile contains how many inches?
    c. 10 kilometers contain how many meters?
    d. 1 kilometer contains how many centimeters?
    e. How many miles are in a "5k" (five-kilometer) race?
    f. A marathon is 26.2 miles. How many kilometers is this?

Contour Lines

When observing a topographic map, the first thing observed is the contour lines. **Contour lines** are continuous lines on a map that join points of equal elevation, meaning that the elevation is constant along the line. Another important element to know is that contours will never cross, or overlap, as they must always remain the same value. Contour lines are especially helpful when interpreting the **topography**, or the physical shape of the landforms on the map. The spacing between the lines provide the map reader with hints about the slope of the surface.

Here's an easy way to understand how to interpret contour lines: take an object like a three-layered cake (Figure 2.6). The thickness of each layer is the same, creating its own elevation boundaries or contour lines.

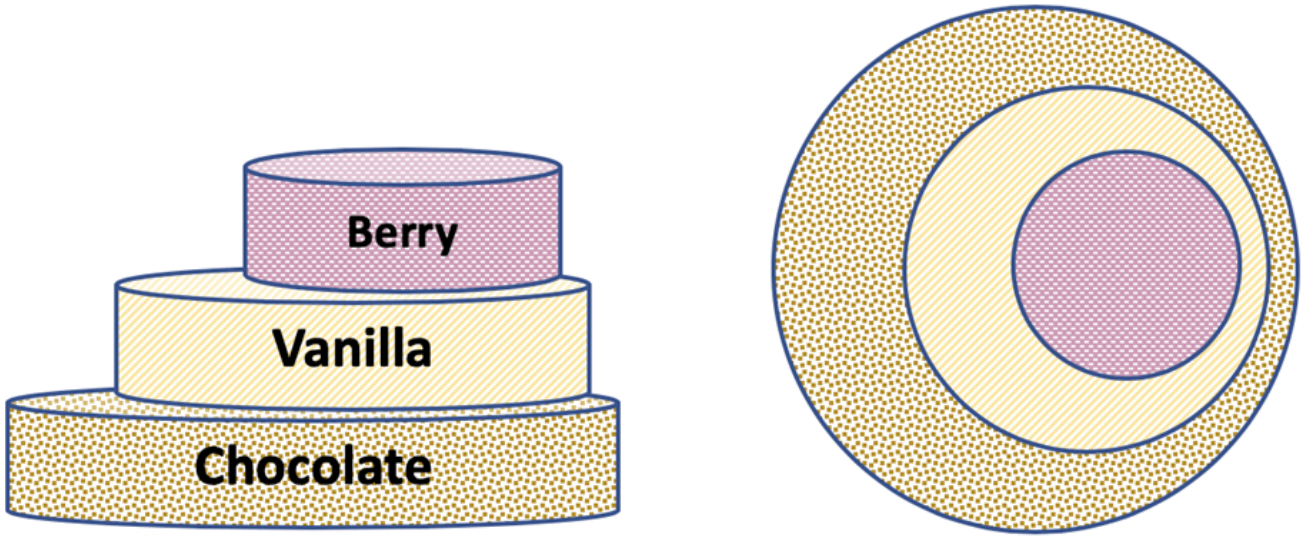


Figure 2.6: A Three-Tiered Cake as an Example of Contour Lines. The graphic to the left is a cross-section seen from the side, and the graphic on the right is a bird's eye view from above. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Exercise 1.2.5

7. Refer to Figure 2.6.
    a. Observing the cake, what do you notice about each of the three layers? Do they cross or mix, or are they parallel to one another? Is the cake symmetrical or is it asymmetrical?
    b. Assume that each layer of cake has a height of 6" (six inches) and that the bottom of the cake is at 0" (zero inches).
        i. Label each line shown on the right side of Figure 2.6 with its height.
        ii. What is the total relief of the cake? Hint: how tall is the cake?
    c. Now imagine that this cake was a hill. Which side of the hill has a steeper gradient? How do you know? (Hint: observe the contour lines or the perimeter of the circles).

Topographic maps show lines for selected elevations, otherwise the map would be too confusing to read. The elevation difference between contour lines is called the **contour interval**. If a topographic map has a 10-foot contour interval, that means that each line represents a 10-foot elevation difference between them. Whether the contour interval is a 5-foot, 10-foot, or 100-foot interval depends on the local topography.

Exercise 1.2.6

8. Refer to the contour lines that you labeled on the right side of Figure 2.6. What is the contour interval of this "map"?

Guided Practice: Drawing Isolines

Isolines are lines on a map that connect equal values. Contour lines are an example of an isoline—contour lines connect points of equal elevation. You may encounter other types of isolines in this physical geography lab course: isobars are lines that connect points of equal atmospheric pressure and isotherms are lines that connect points of equal temperature. By "connecting the dots" in the activity below, you will learn how to extrapolate the data that is displayed on the map to draw contour lines. See an example of how to draw isolines in this video, Drawing Contour & Isolines, by Professor Jeremy Patrich. (Video length is 6:01).

Connect the Dots Activity

Remember, contour lines are elevation lines that are constant. They will never cross, change, or disappear. A great way to learn the rules of contour lines is by connecting the dots.

Exercise 1.2.7

9. Below you will find an image that consists only of elevation points, and you will need to connect the dots (Figure 2.7). This can be challenging, as these elevation points are even, odd and everything in between, so you will have to interpret the data. Sometimes you will have to figure out where a specific number belongs that you can not find. As an example, contour lines for 45' and 40' have been drawn for you. Note how each of these contours never crosses, and always maintains their value (Hint: you will observe a set of 10' contours that run southwest to northeast, that is a river). Complete the following contour lines: 35', 30', 25', 20', 15', and 10'.

16'	18'	23'	28'	30'	32'	30'	25'	22'	19'	15'	12'	10'	10'	8'	10'
16'	20'	25'	30'	28'	28'	25'	20'	18'	17'	13'	12'	12'	10'	8'	8'
15'	18'	20'	25'	27'	25'	22'	18'	15'	14'	11'	10'	10'	8'	8'	8'
14'	16'	18'	22'	24'	24'	20'	17'	15'	12'	10'	8'	8'	8'	8'	10'
12'	15'	15'	18'	18'	15'	15'	14'	12'	10'	10'	10'	11'	14'	10'	12'
11'	12'	12'	12'	12'	10'	10'	10'	10'	14'	12'	15'	15'	14'	14'	14'
11'	10'	10'	10'	10'	14'	15'	15'	15'	18'	20'	18'	18'	15'	14'	12'
10'	10'	12'	13'	15'	17'	20'	18'	20'	25'	28'	24'	24'	20'	17'	14'
10'	11'	15'	15'	18'	20'	23'	25'	28'	32'	30'	28'	28'	24'	20'	16'
12'	15'	20'	19'	22'	25'	30'	33'	35'	38'	38'	35'	35'	27'	22'	18'
14'	18'	20'	20'	25'	28'	30'	38'	40'	45'	35'	32'	28'	22'	18'	15'
18'	20'	22'	22'	25'	30'	35'	40'	45'	48'	42'	35'	30'	25'	22'	18'
20'	22'	22'	25'	28'	33'	38'	45'	48'	50'	45'	35'	33'	28'	22'	16'
20'	20'	21'	22'	25'	30'	36'	42'	45'	48'	40'	32'	28'	25	20'	16'
20'	20'	22'	22'	25'	30'	35'	36'	38'	45'	38'	32'	28'	24'	19'	15'
20'	20'	20'	21'	22'	25'	30'	33'	35'	38'	35'	28'	25'	20'	15'	12'

Figure 2.7: Contour Interpretation Activity. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

10. What is the contour interval for Figure 2.7?

Relief Features

Relief features are influenced by the drainage of the area. Running water works upon the surface of the ground, eroding and transporting the softer material and leaving the terrain with characteristic valley and ridge patterns. The map below is of Three Rivers Mountain (Figure 2.8).

Exercise 1.2.8

11. Observing the patterns on the map (Figure 2.8), you see that there are three areas on the map where all the contours make a 'V' shape. When contours take this shape, the tip of the 'V' points upstream. Use a blue colored pencil to draw in each of the three rivers, and include arrows showing which way the water is flowing.
12. On the top of the mountain, draw a smaller contour line using a brown pencil, to replicate the bottom of a lake. We know the lake must be deeper than the 180' contour, so along the 180' contour line, add brown hachures, or tic marks that are perpendicular from the 180' towards the new contour drawn. These marks allow the map reader to know that the elevation is changing. Refer to Figure 2.9 for an example of a contour line with hachures.

    a. After completing the hachures, what would be the elevation of the new contour line that you drew?

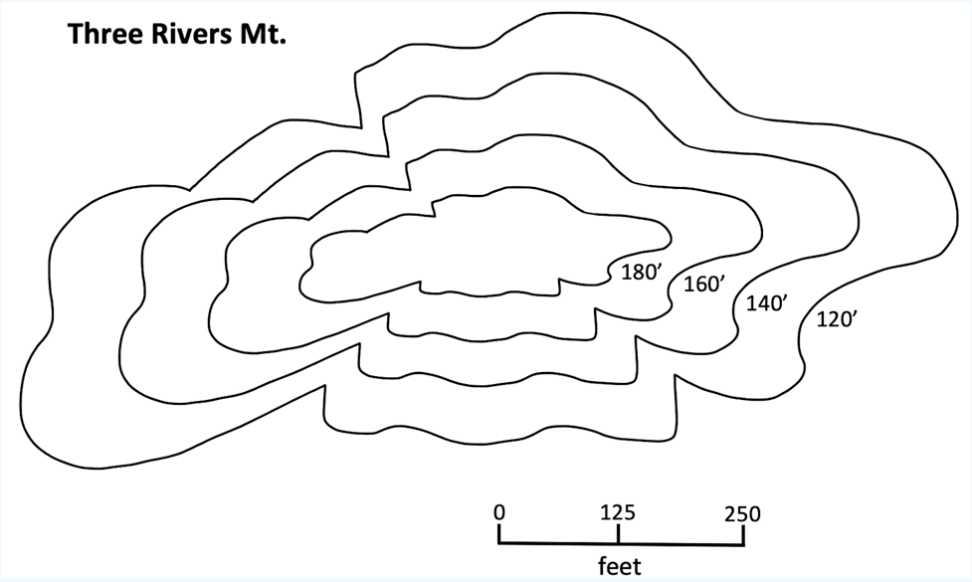


Figure 2.8: Contour Relief Feature Activity. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0



Figure 2.9: Hachure Marks on a Contour Line. Figure by USGS is in the public domain

Topographic Profiles

A common way to understand what topographic maps represent is to construct a topographic profile. A **topographic profile** is a cross-sectional view along a line drawn through a portion of a topographic map. In other words, if you could slice through a portion of a cake, pull away one half, and look at it from the side, the surface on the side would be a topographic profile. On a larger scale, imagine that you and a friend are going on a large hike, you could draw a topographic profile of the hike before completing it to better understand the terrain (gradient, length, elevation, etc.).

Exercise 1.2.9

13. A topographic profile appears If you select the cycling option on Google maps.

a.  Go to Google maps.
b. Click the Directions icon (it is blue with an arrow).
c. Click on the cycling icon (the person on a bike).
d. Type your address as the starting point.
e. Type your college as the destination.
f. Click DETAILS.
g. Sketch the topographic profile of a bike ride from your address to your college in the space below. Label the lowest and highest elevations shown.

Before completing a topographic profile, you must first identify a line of interest between two or more points. This is called a transect. An example of a transect could be the length of a hiking trail, the distance between mountain peaks or valleys, or the distance between your home and college. The objective is to better understand the region's topographic **relief**, which is the difference between the highest and lowest elevation observed along the line. After you have identified where you want to draw your profile, use the following steps to construct your profile (be sure to review Figure 2.10 that illustrates the steps).

Exercise 1.2.10

14. Refer to your topographic profile sketch from the previous question. What is the relief between your address and your college?

Step 1

Refer to Figure 2.11. The transect is the dashed line. This represents the line of interest.

Step 2

Place a blank piece of paper along the transect line (index cards work great). Make sure you align the left corner to the end of the transect you drew.

Step 3

Make a small mark where the index card intersects the contour line on the map and the index card, as seen in Figure 2.10. Then, write the corresponding elevations from the map contours onto your index card.

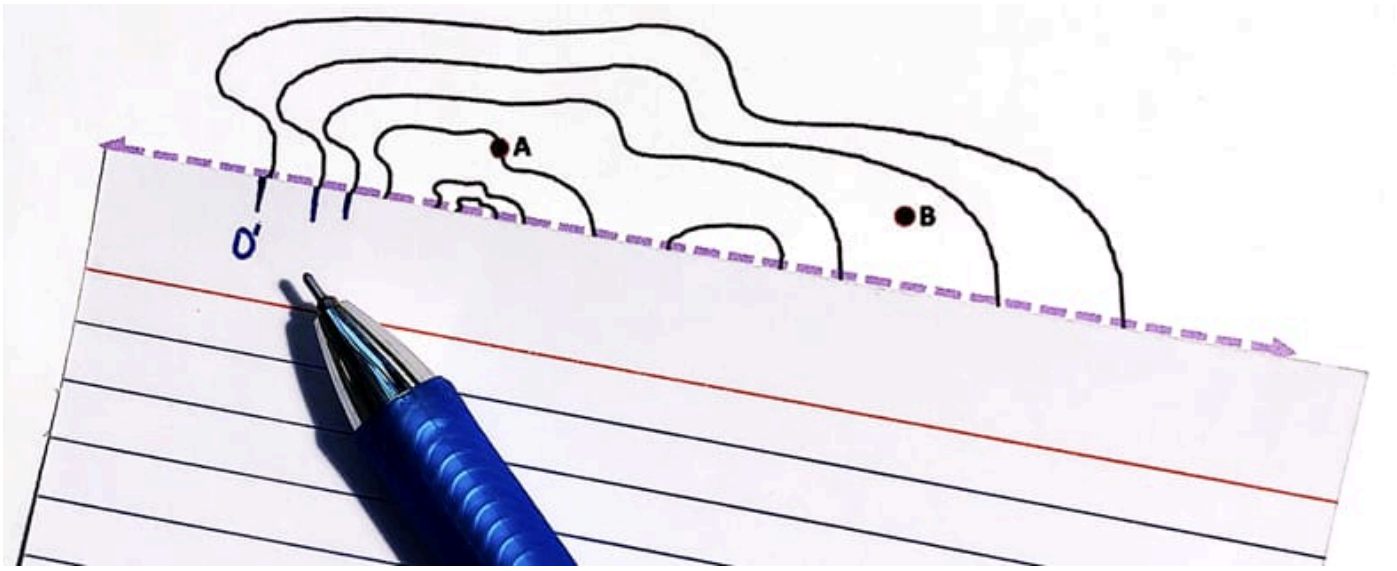


Figure 2.10: Example of Steps Needed to Create a Topographic Profile. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Exercise 1.2.11

15. Below you will find a topographic map and a dashed line of interest (Figure 2.11). Follow the steps to collect the data needed to draw a topographic profile. Once you are finished, you will align your paper on the graph below. Plot your elevation points and then connect them with a line.

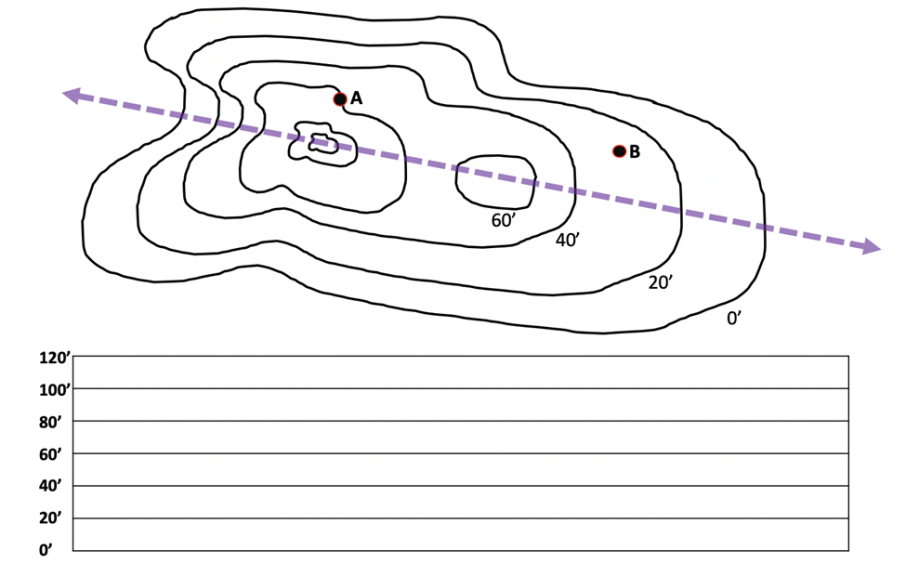


Figure 2.11: Topographic Map with Profile Line Activity. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Now that you have completed your topographic profile, below you will find a few more questions regarding your observations from the above map.

16. What is the highest elevation possible on this map?

17. What is the lowest possible elevation on this map?

18. Locate the letter A on the map. What is the elevation?

19. Locate the letter B on the map. What is the elevation?

Think About It...Gradient

Remember that gradient is the observed slope. Refer to Figure 2.11; which side has the greatest slope? The left side does, and we can see that in the topographic profile you created, but it can also be seen by looking at the contour lines. Note how close they are to each other on the left side of the map. The closer the contours are to each other, the steeper the slope!

Part C. Topographic Maps

Using the previously learned information, you will now be able to observe and interpret basic information on a topographic map. This activity will reintroduce some content from your first lab when you learned about the geographic grid system and the Public Land Survey. Topographic maps have an incredible amount of information both on the map itself and around the perimeter of the map, known as the map collar.

Guided Practice: Introduction to Topographic Maps

Watch this video, Read & Interpret Contour Lines & Topographic Maps, by Professor Jeremy Patrich for a quick introduction to the key features of topographic maps and tips on how to interpret topographic maps. (Video length is 9:41).

Check It Out! Topographic Map Symbols

The U.S. Geological Survey has a guide of topographic map symbols. This guide will help you to interpret topographic maps. (The link goes to a pdf file to download).

Step 1. Reading the Map Collar

Exercise 1.2.12

20.  Your instructor may provide hard-copy topographic maps for the following steps, or you may download one from the U.S. Geological Survey's National map webpage. Select Map Indices - All in the "Show Map Index" toggle menu on the upper right-hand side of the map. You can zoom in on an area until you see the topographic map names and boundaries, both shown in green. Click the US Topo check box underneath the Advanced Search heading on the left-hand side of the webpage. Then click on the blue Search Products button. In the US Topo row, click on results. Then click Download next to the topographic map you would like. Note: these are large map files that may take a few moments to download and view.

21. Each topographic map, or **quadrangle**, is assigned a name. The name of the map is usually found in the upper-right corner in large print. What is the name of your map?

22. Locate the scale bar on the bottom of the map. What is the fractional scale for this map?

23. What is the contour interval of this map? Tip: this is often shown below the scale bar.

24. Most quadrangles have a small reference map, usually the shape of the state in which this map is found. There you can find a little box that represents the location of this specific map within the state. What is that general location?

25. Near the bottom left corner, you will find some additional data, such as projection type and when it was made. What projection was used for this map?

26. Often maps will tell you when it was originally surveyed, plane table checked, or updated. What are some of those years?

27. The magnetic North Pole (MN) is not the same as the geographic North Pole (GN). So, a compass doesn't point exactly toward the geographic north. **Magnetic declination** is the angular difference between true north and magnetic north for a given location and time. What is the magnetic declination for this map?

28. Moving around the map, you will find the names of the maps that adjoin the edges, these are often found in a smaller italicized print along the edge or in a smaller boxed diagram in the lower-right corner. What map adjoins in each of the following corners?
    a. Western Edge:
    b. Northeastern Edge:

Step 2. Reading the Map

Exercise 1.2.13

29. The following questions reference the Public Land Survey.

    a. List all the townships represented on this map.

    b. List all the ranges represented on this map.

c. What are the section, townships, and ranges for the following locations:

i. The center of the map.

ii. The extreme northeast corner of the map.

30. The following questions reference the contour lines of the map.

a. After observing the map, briefly describe the overall topography of the map. What are some features or details you find interesting, and what helped you decide what the topography looks like? (Hint: Is the topography mountainous, or flat? Do you notice water features, etc? Don't forget to include what helped you interpret your findings).

b. What is the highest elevation found on the map? (Hint: this is usually found by following the contour lines to the top of a mountain, then the highest point is usually marked with a symbol, like a box or a triangle).

c. What is the lowest elevation found on this map?

d. What is the total relief (the difference between the highest and lowest points) of this map?

30. The following questions reference latitude and longitude.

a. Locate the latitudes for this map. Remember that latitudes are the horizontal lines on the map.
   i. Northern latitude:
   ii. Southern latitude:
   iii. Total minutes of latitude covered in this map (this is the difference between the northern and southern latitude):

b. Locate the longitudes for this map. Remember that longitudes are the vertical lines on the map.
   i. Western longitude:
   ii. Eastern longitude:
   iii. Total minutes of longitude covered in this map (this is the difference between the western and eastern longitude):

c. What is the minute series of this map? Hint: how many minutes of latitude and longitude are shown across the top and side of the map?

d. Use Your Critical Thinking Skills: What is the shape of this map? Why is it not a perfect square? Explain your response in one to two sentences.

Part D. Surveying Activity

Land surveying is the art and science of mapping and measuring the landscape. Although the details are very specific, the production of mapping space is relatively easy. Throughout this lab you have learned how to observe and interpret data on maps. In this activity, you will learn the basics of survey data collection and how to take the data and put it on a map.

The first step of surveying is knowing the language, as there are a lot of acronyms in this field (Figure 2.12):

➢ Backsight (BS): A backsight is a point of known elevation and location, or latitude and longitude. This is often observed as a benchmark, or a little brass marker found on the ground.

➢ Foresight (FS): A foresight is a location with no known elevation or location. Think of this as looking forward to the unknown.

➢ Height of the Instrument (HI): There are many different types of survey equipment, but the most common is called an Auto Level. Once the instrument is leveled onto a tripod, the height of this instrument in relation to sea level, 0 feet, must be calculated. This is done by the use of a measuring rod or ruler and a benchmark (BM). The HI is solved by adding the benchmark and the vertical distance read on the measuring rod, above the benchmark. Here is a helpful explanation: Think of your face as the instrument; now, how can you measure the height of your eyes by using the height of known objects

around you? Let's say that you observe a 3-foot desk in front of you, and you place a large ruler perpendicular to the desktop. If the 2-foot measurement is at your eye level, then you can assume your eyes are a total of 5 feet from above the ground.

➢ Elevation: This is the number you are ultimately trying to find out; what is the elevation for your foresight, or the elevation of an unknown location? This is calculated by using your height of the instrument and subtracting the new reading on a measuring rod, or ruler. Remember, you are trying to solve the elevation of the ground in relation to you.

➢ Bearing: Auto levels can only swivel left and right, with a bearing of 360°, as it doesn't move vertically, up or down.

Exercise 1.2.14

32. Write the name of each label (BS, BM, HI, FS) onto Figure 2.12. For example, next to BS write backsight.

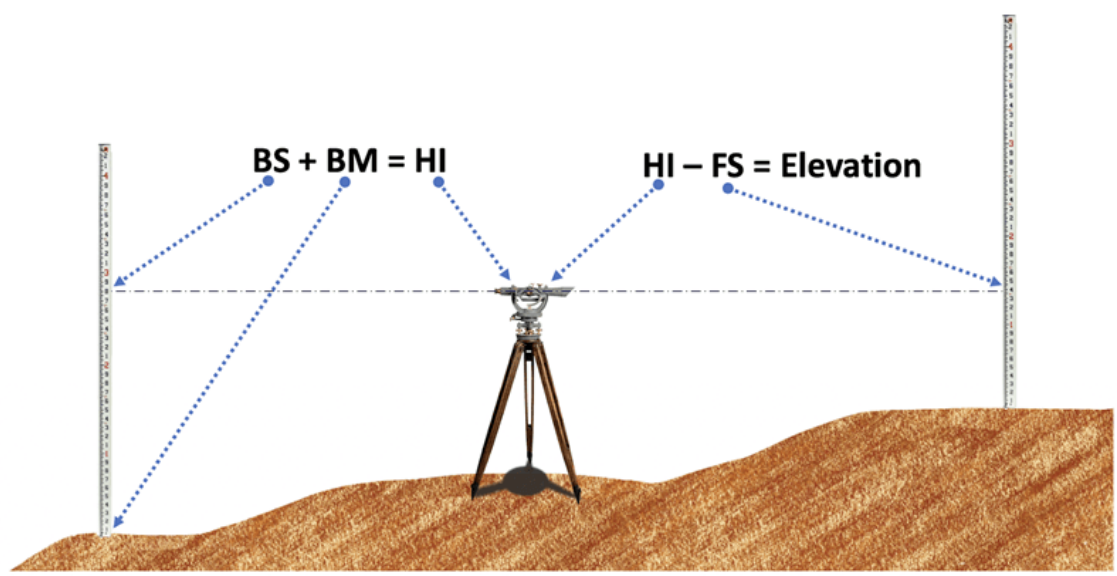


Figure 2.12: Visual Example of Terms and Formulas for Surveying. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Below you will find an image portraying what it would look like if you looked through the scope of an auto-level (Figure 2.13). Note the three horizontal lines; these are how we obtain our measurements. As you view through the scope, you are viewing the measuring rod, which is a really long ruler. The farther the rod is from the level, the larger the numerical distance between the three lines seen in the scope. In fact, if you subtract the difference between the top and bottom stadia (stadia A and B) and then multiply it by 100, you will calculate the rough distance between the level and the rod. (Hint: another way to think of this is to put your right hand in front of your face, with your three middle fingers in a horizontal position. Look around the room, the farther you are from the objects, the more of the object you can see).

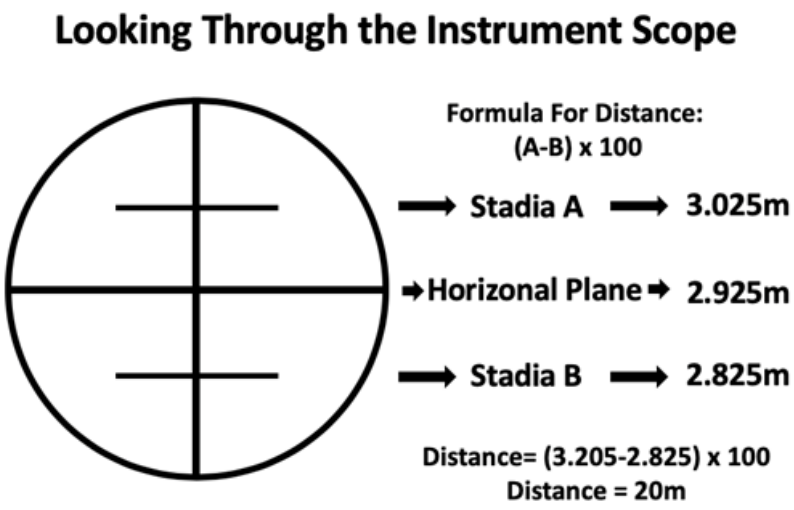


Figure 2.13: An Image Looking Through the Survey Scope and Formula for Distance. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

It has been mentioned before, but remember that the farther the survey rod is from the instrument, the farther the distance between the numbers and the stadia (this is essentially called vertical distance).

Exercise 1.2.15

33. Refer to Figure 2.14. Which image would better represent a measuring rod that is farther from the device, and why?

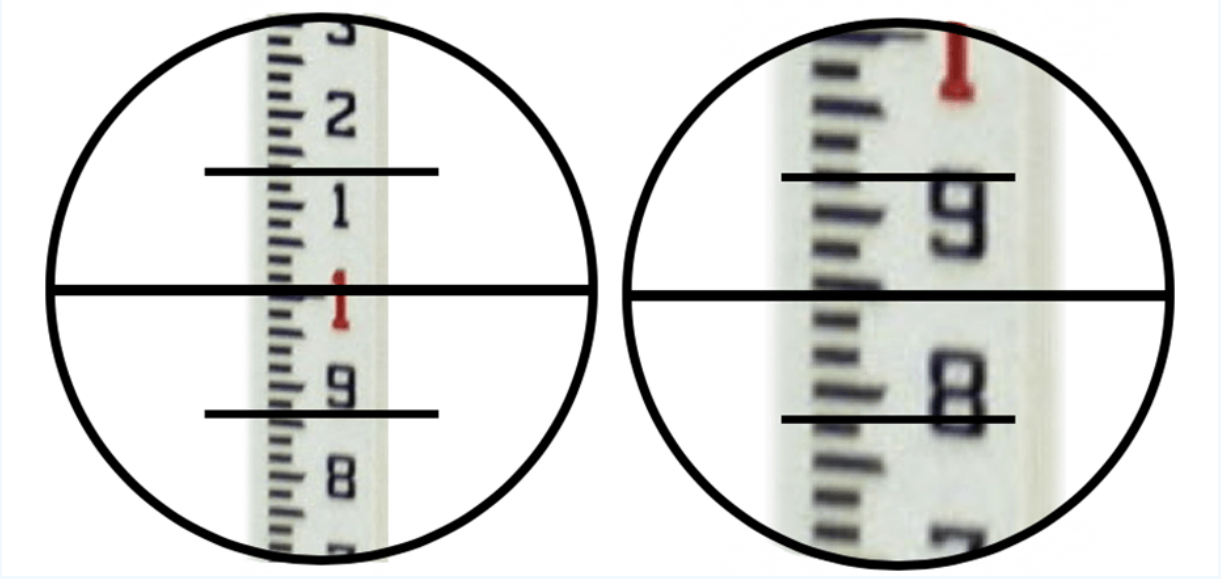


Figure 2.14: A Sample Reading From a Survey Scope. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Check It Out! Using An Auto Level in the Field

This portion of the lab might have you wondering what all this looks like in the field, so check out a video from the Illinois Surveyors Association, where they teach you about the device! (Video length is 7:54).

Exercise 1.2.16

34. It is now time to collect some data. Figure 2.15 shows incomplete survey data. The first row, the Reference, has been completed for you. As you can see in the backsight information, the height of the instrument and distances are solved; these values will remain the same for this activity, as we are not moving the instrument. Please complete the missing distances and elevation values for Stations 1 through 4.

Figure 2.15: An Incomplete Survey Form. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Station	Backsight	HI Height of Instrument	Foresight	Distance	Elevation	Bearing	Remarks
Reference	A: 5.66	HI= BM+BS		(A-B)x100		12°	BM=100m
	5.32	HI=100+5.32					
	B: 4.98	105.32		**68m**			
1			A: 3.025		(HI - FS)	**99°**	
			FS: 2.925				
			B: 2.825		**102.395**		
2			A: 3.16			**132°**	
			FS: 3.05				
			B: 2.94				
3			A: 3.982			**107°**	
			FS: 3.757				
			B:3.532				
4			A: 2.65			**107°**	
			FS: 2.2				
			B: 1.75				

35. The next step is to take these datasets and to create a topographic map. What you completed above is only four stations, and most topographic maps will have tens of thousands! That being said, use the completed data set (Figure 2.16), a printable ruler and protractor (Figure 2.17), and a blank map (Figure 2.18) to plot your data. Be sure to follow the instructions carefully; once you are done, you will have created your very own topographic map with a well-defined contour line!

Guided Practice: Making a Contour Map from Surveying

Looking for guidance on how to create a contour map from surveying data? Check out the steps to create your map in this video, Drawing Contour Lines on a Map, by Professor Jeremy Patrich. (Video length is 3:58).

Station	Back Sight	HI Height of Instrument	Foresight	Distance M	Elevation M	Bearing	Remarks
	5.66						BM=
Reference	5.32	944.00		68			938.68
	4.98						
			3.03				
1			2.93	20	942	99°	
			2.83				
			3.16				
2			3.05	22	942	107°	
			2.94				
			3.29				
3			3.17	24	942	111°	
			3.05				
			3.32				
4			3.21	22	942	117°	
			3.10				
			3.38				
5			3.25	26	942	137°	
			3.12				
			3.03				
6			3.91	24	942	142°	
			2.79				
			3.12				
7			3.00	24	942	145°	
			2.88				
			3.80				
8			3.65	30	942	147°	
			3.50				
			3.71				
9			3.53	36	942	152°	
			3.35				
			3.82				
10			3.62	40	942	154°	
			3.42				
			3.26				
11			3.06	40	942	158°	
			2.86				
			3.62				
12			3.42	40	942	159°	
			3.22				
			3.51				
13			3.29	44	942	160°	
			3.07				
			3.28				
14			3.04	48	942	161°	
			2.80				
			3.37				
15			3.15	44	942	163°	
			2.93				
			3.32				
16			3.09	46	942	165°	
			2.86				

Figure 2.16: Complete Survey Form for the Mapping Activity, Figure 2.15. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

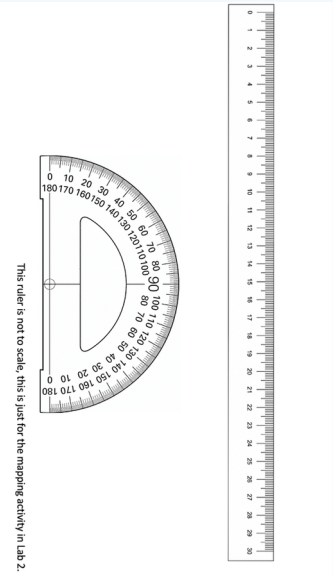


Figure 2.17: Printable Ruler and Protractor. The ruler is not to scale, this is just for the mapping activity. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

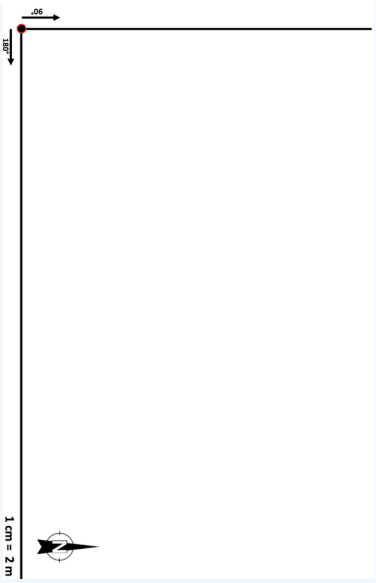


Figure 2.18: Blank Map. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Part E. Google Earth Pro Activity

For this activity, you will need to download GoogleEarth Pro program onto a desktop or laptop (tablets or phones will not be able to access all the tools needed for this activity).

Check It Out! First Time Using Google Earth Pro?

Is this your first time using Google Earth? Go to the keyboard shortcuts page to learn how to navigate in Google Earth Pro!

Step 1

Once you have opened Google Earth Pro, in the search box on the upper-left corner, type in Lake Piru. Once there, zoom in so the lake at least fits the full window of the program.

Step 2

Select the '"historical imagery" tool in the top toolbar; it looks like a clock with an arrow going counterclockwise. This will open up a slide bar showing all the historical imagery available for this region. Slide to December 2005.

Step 3

Now select the "add a path" tool; it looks like three boxes connected with a singular line. This tool will allow you to click and drop a linear path (if you make a mistake, the delete button erases the most recent plot). You can click spot by spot or click and drag along your desired path. You will now trace the perimeter of Lake Piru; be sure to title the path December 2005. Once you have traced the perimeter of the entire lake, select the "style, color" tab within the small popup window, pick your favorite color to

represent this line, and select OK to save.

Step 4

Slide the “historical imagery” tool to the most recent imagery and repeat Step 3. Be sure to label the path with the date from the imagery (refer to Figure 2.19 for an example).

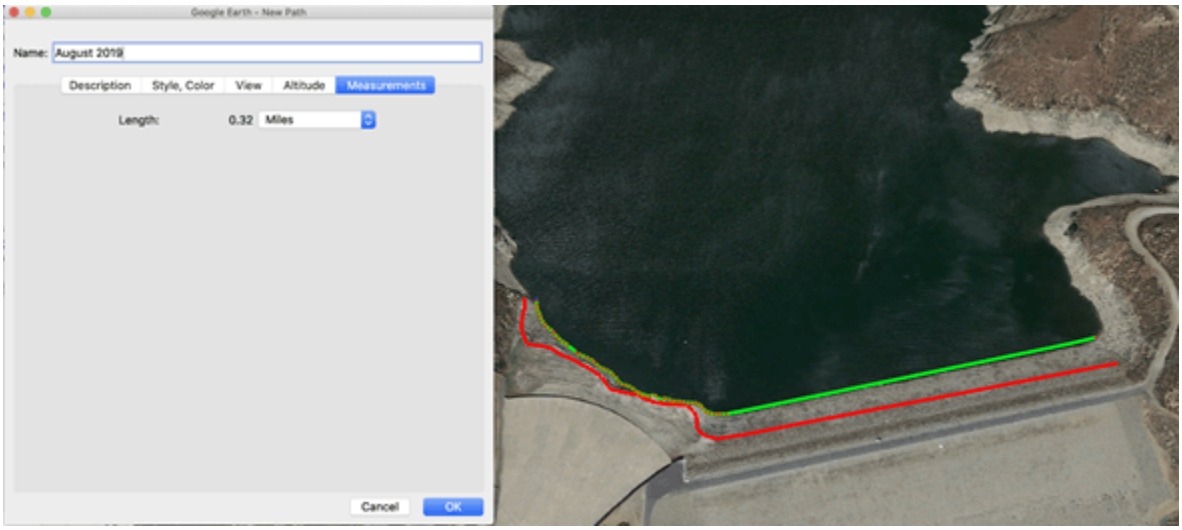


Figure 2.19: Example of a Partially Completed Google Earth Activity. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Step 5

You should see your completed paths in the Places column on the left-hand side of the program. If you right-click on your path, and select “Get info,” you will be able to access all the information from that path, including measurements. As an example, the measurement of the green line seen in Figure 2.19 (shown above) is 0.32 miles.

Step 6

Answer questions 35 through 37. Then, take a screenshot of both of your paths and submit the image with this lab.

Exercise 1.2.17

36. Using the measurement tools for both paths, what were the perimeters of Lake Piru in kilometers and miles...
    a. ... in December 2005:
    b. ... based on the most recent imagery:
37. Based on your measurements, have the lake levels increased or decreased?
38. Lake Piru is a human-made reservoir, constructed in 1955, and is only fed with rainwater and runoff from Piru Creek. Why do you think the lake levels have changed? (Hint: don’t forget to take the following into account: the season in which your data was collected, drought year, El Niño weather patterns, etc.).
39. Submit a screenshot of both of your paths. (Your instructor will provide instructions on how to submit the screenshot).

Part F. Wrap-Up

Consult with your geography lab instructor to find out which of the following wrap-up questions you should complete. Attach additional pages to answer the questions as needed.

Exercise 1.2.18

40. What is the most important idea that you learned in this lab? In two to three sentences, explain the concept and why it is important to know.

41. What was the most challenging part of this lab? In two to three sentences, explain why it was challenging. If nothing challenged you in the lab, write about what you think challenged your classmates.

42. What is one question that you have about what you learned in this lab? Write your question along with one to two sentences explaining why you think your question is important to ask.

43. Review the learning objectives on page 1 of this lab. How would you rate your understanding or ability for each learning objective? Write one sentence that addresses each learning objective.

44. Sketch a concept map that includes the key ideas from this lab. Include at least five of the terms shown in bold-faced type.

45. Create an advertisement to educate your peers on the important information that you learned in this lab. Include at least three key terms in your advertisement. The advertisement should be about half a page in size (about 4 inches by 6 inches).

46. One way to think of physical geography is that it is the study of the relationships among variables that impact the Earth's surface. Select two variables discussed in this lab and describe how they are related.

47. How does what you learned in this lab relate to your everyday life? In two to three sentences, explain a concept that you learned in this lab and how it relates to your day-to-day actions.

48. How does what you learned in this lab relate to current events?
    a. Write the title, source, and date of a news item that relates to this lab.
    b. In two to three sentences, discuss how the news item relates to what you have learned in this lab.
    c. In one to two sentences, discuss whether or not the news item accurately represents the science that you learned. Tip: consider whether or not the news item includes the complexity of the topic.

49. Search O*NET OnLine to find an occupation that is relevant to the topics presented in today's lab. Your lab instructor may provide you with possible keywords to type in the Occupation Quick Search field on the O*NET website.
    a. What is the name of the occupation that you found?
    b. Write two to three sentences that summarize the most important information that you learned about this occupation.
    c. What is one question that you would want to ask a person with this occupation?

Appendix 2.1: Distance Units of Measurement

Metric Standard Units

- 1 centimeter (cm) = 10 millimeters (mm)
- 1 meter (m) = 100 cm
- 1 kilometer (km) = 1,000 m

American Customary System Standard Units

- 1 foot (ft) = 12 inches (in)
- 1 yard (yd) = 3 ft
- 1 mile (mi) = 5,280 ft

Converting from Metric to American

- Inches to centimeters – multiply inches by 2.54
- Centimeters to inches – multiply centimeters by 0.3937
- Feet to meters – multiply feet by 0.3048
- Meters to feet – multiply meters by 3.281
- Miles to kilometers – multiply miles by 1.61
- Kilometers to miles – multiply kilometers by 0.62

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[18] Scale and Projections by Steven Manson is licensed under CC BY-NC-SA 4.0

[22] Text by Steven Manson is licensed under CC BY-NC-SA 4.0

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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]

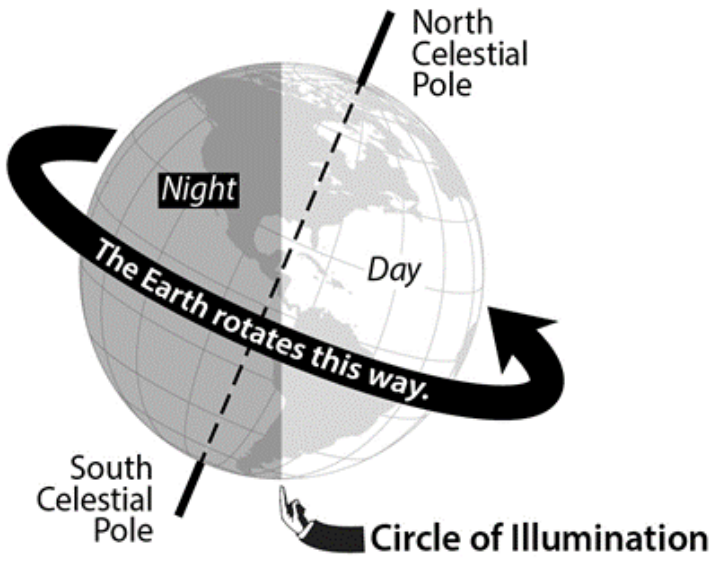


Figure 3.1: Earth's Rotation. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

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".

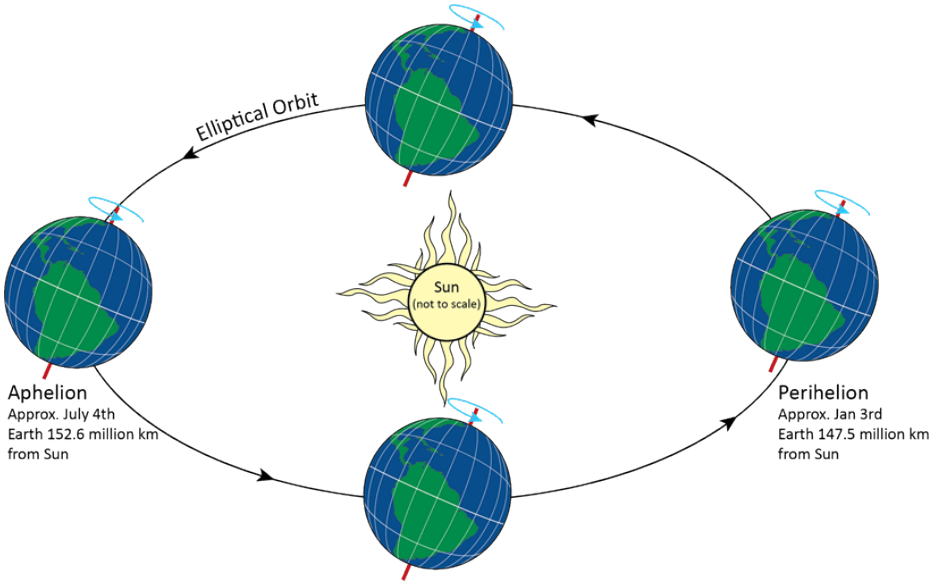


Figure 3.2: Earth's Revolution. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

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**.

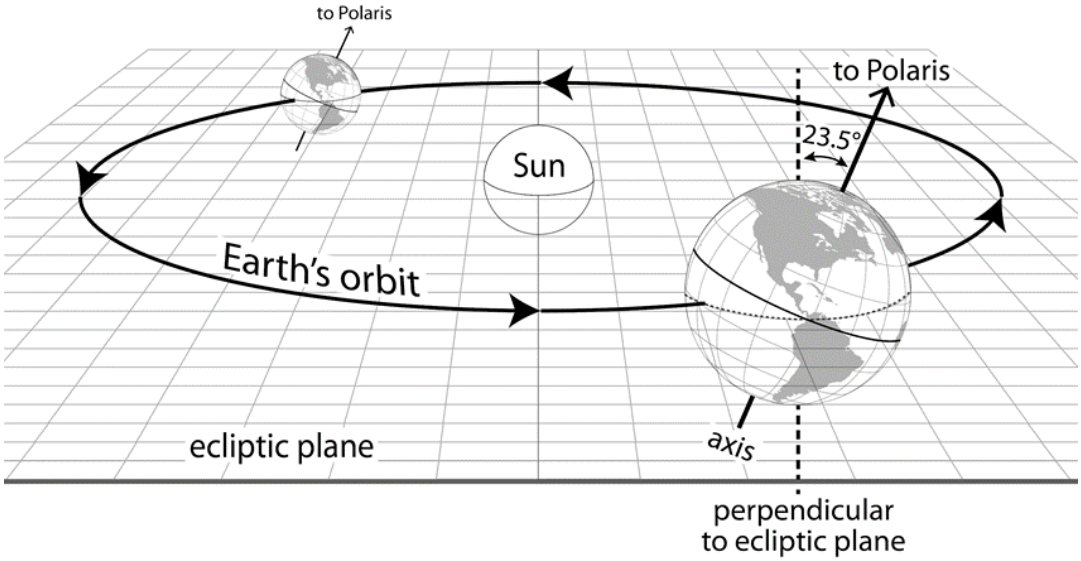


Figure 3.3: Earth's Tilt and the Plane of the Ecliptic. Note: the diagram is not drawn to scale. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

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.

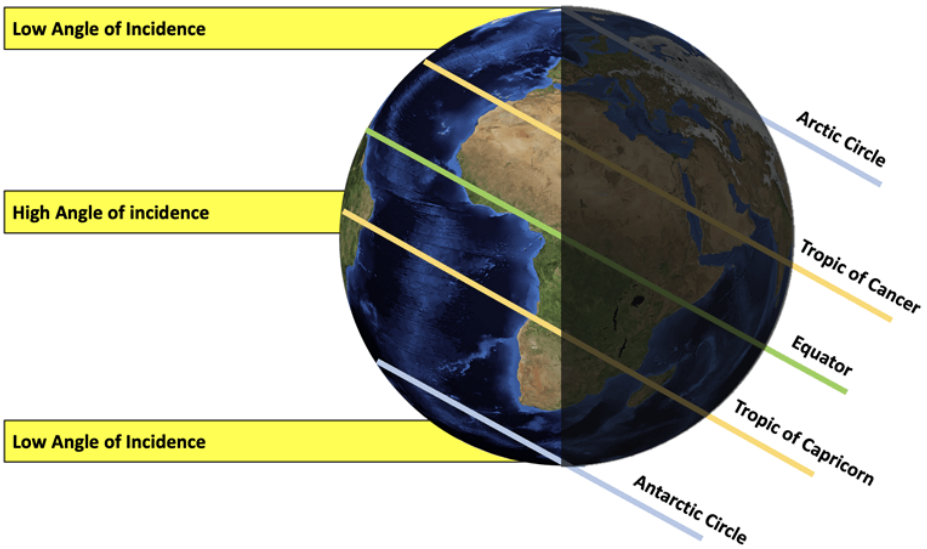


Figure 3.4: Angle of Incidence. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

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.

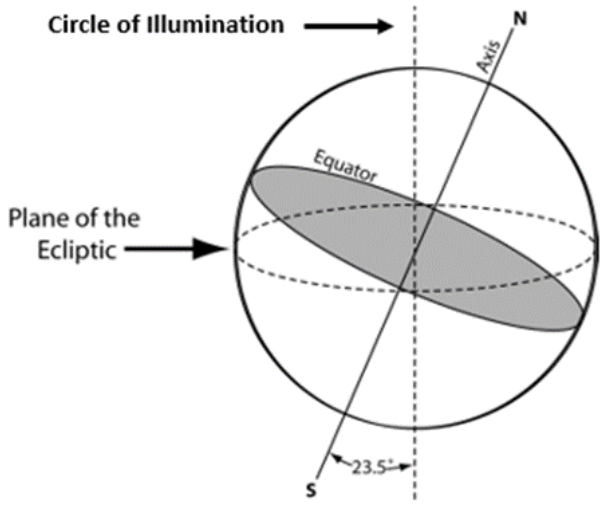


Figure 3.5: The Plane of the Ecliptic and the Circle of Illumination. Figure by Scott Crosier and Taya Lazootin is licensed under CC BY-NC-SA 4.0

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°

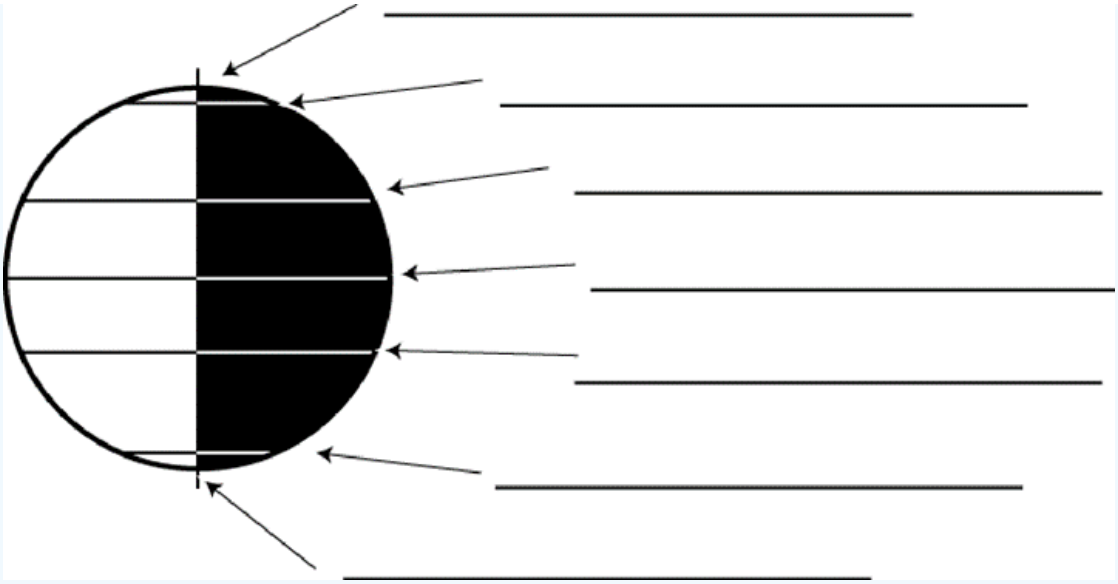


Figure 3.6: The Seven Special Parallels of the Earth. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

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)

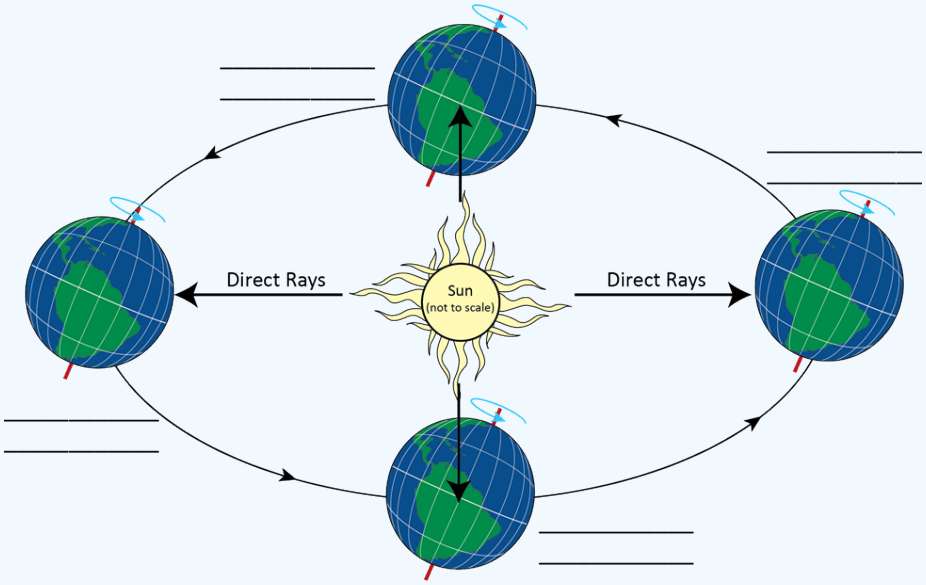


Figure 3.7: Solstices and Equinoxes Diagram for Labeling. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

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

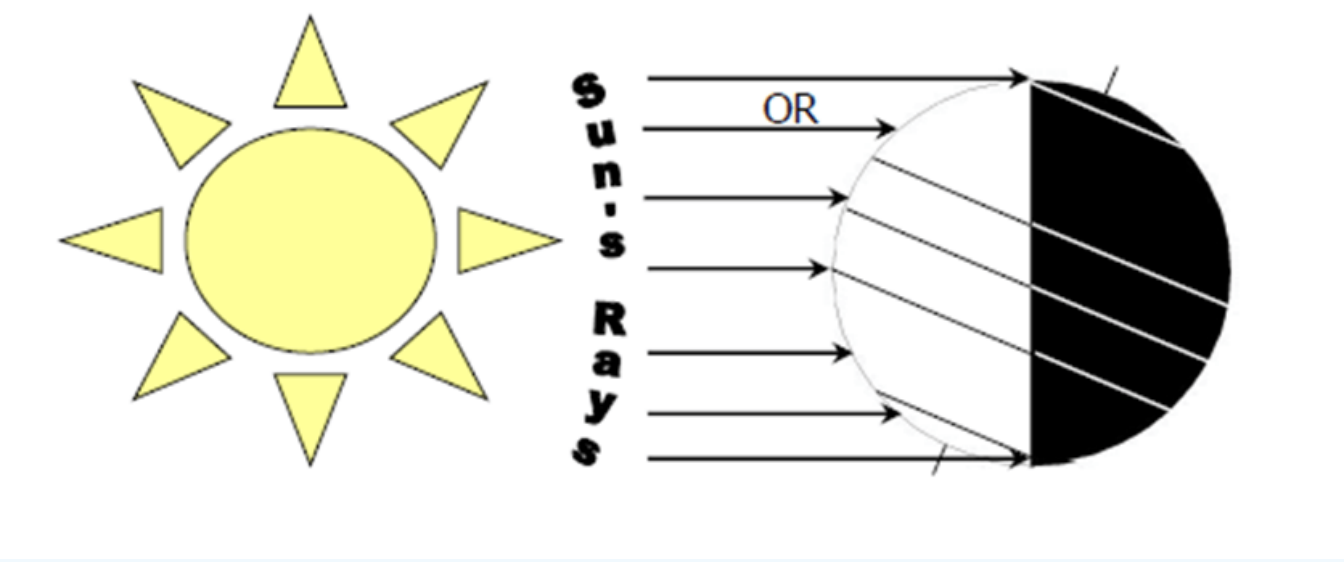


Figure 3.8: Vertical, Oblique, and Tangent Rays of the Sun. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

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?

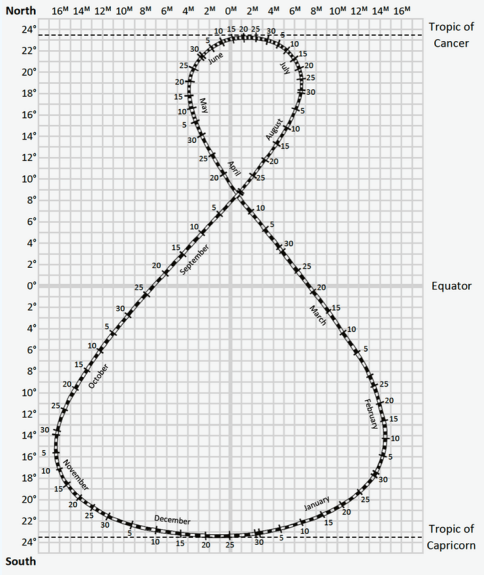


Figure 3.9: Analemma. The declination of the Sun is shown on the vertical axis for each day of the year. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

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 away. If the flashlight is shining on the ground below you, the light is less intense and you can see clearly. Figure 3.10 shows two angles of incidence represented by flashlights shining on two books.

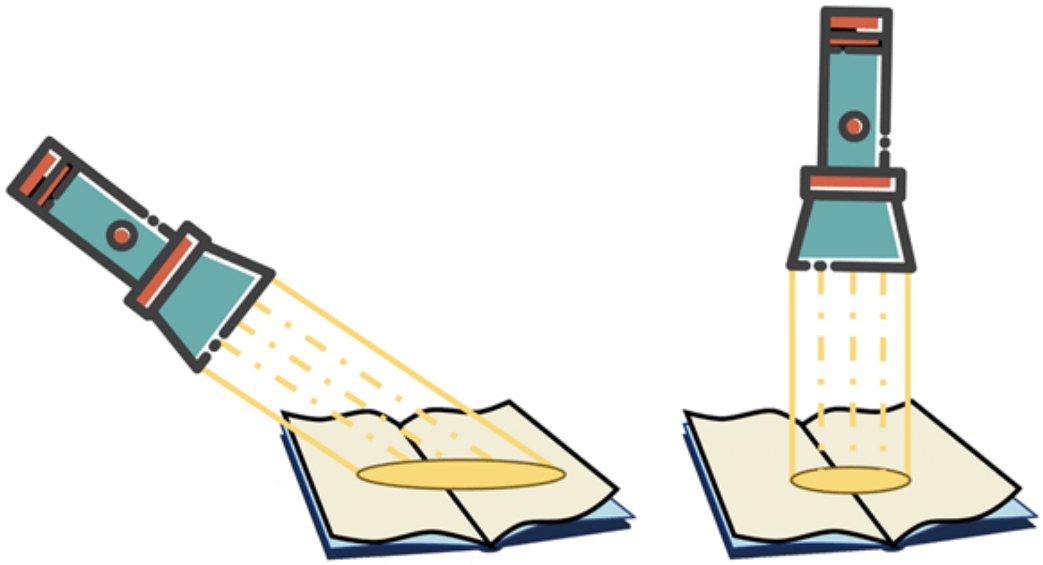


Figure 3.10: Flashlight at Two Different Angles of Incidence. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Exercise 1.3.2

15. Refer to Figure 3.10.
    a. Does the flashlight on the left or right represent a 90° angle of incidence? (Hint: a 90° angle of incidence is also known as a direct ray or a perpendicular ray.)
    b. Does the higher or lower angle of incidence result in the flashlight's energy being distributed over a wider area?

There is a direct relationship between the angle of incidence and the intensity of solar radiation that actually reaches the ground. Higher angles of incidence result in higher percentages of radiation reaching the surface of the Earth. When the angle of incidence is at a 90° angle to the Earth (called direct or perpendicular rays), approximately 75% of the radiation emitted from the Sun reaches the surface of the Earth.

Throughout the year, the angle of the Sun's rays are low (less than 25°) at the poles, compared to those closer to the equator. As a result, insolation at the poles is spread out over a much wider area as represented by the yellow color on Figure 3.4 (shown previously in this lab). The more spread out the yellow color, the more diffused the radiation will be. The opposite is true at the equator. Throughout the year, the angle of the Sun's rays at the equator is high (more than 65°) and at the equinoxes sunlight strikes the equator directly, which results in a 90° angle of incidence. Insolation at the equator is not as spread out as it is at the poles; therefore, the radiation is more intense.

Exercise 1.3.3

16. Refer to Figure 3.4 (shown previously in this lab).
    a. Which latitude has the highest angle of incidence?
    b. Which latitudes have the lowest angles of incidence?

c. Apply What You Learned: Does this diagram represent the March equinox, June solstice, September equinox, or December solstice? Explain your response in one sentence.

Table 3.1 provides angle of incidence data for the special lines of latitude at the solstices and equinoxes. The data represent the angle of incidence at solar noon.

Table 3.1: Angles of Incidence for the Special Lines of Latitude at the Solstice and Equinoxes

Latitude	March Equinox	June Solstice	September Equinox	December Solstice
90°N	0°	23.5°	0°	0°
66.5°N	23.5°	47°	23.5°	0°
23.5°N	66.5°	90°	66.5°	43°
0°	90°	66.5°	90°	66.5°
23.5°S	66.5°	43°	66.5°	90°
66.5°S	23.5°	0°	23.5°	47°
90°S	0°	0°	0°	23.5°

Exercise 1.3.4

17. Refer to Table 3.1 above. On Figure 3.11 below, draw a Sun to represent the correct angle of incidence for each time of year at the **equator**. The Sun location at the March equinox has already been drawn for you.

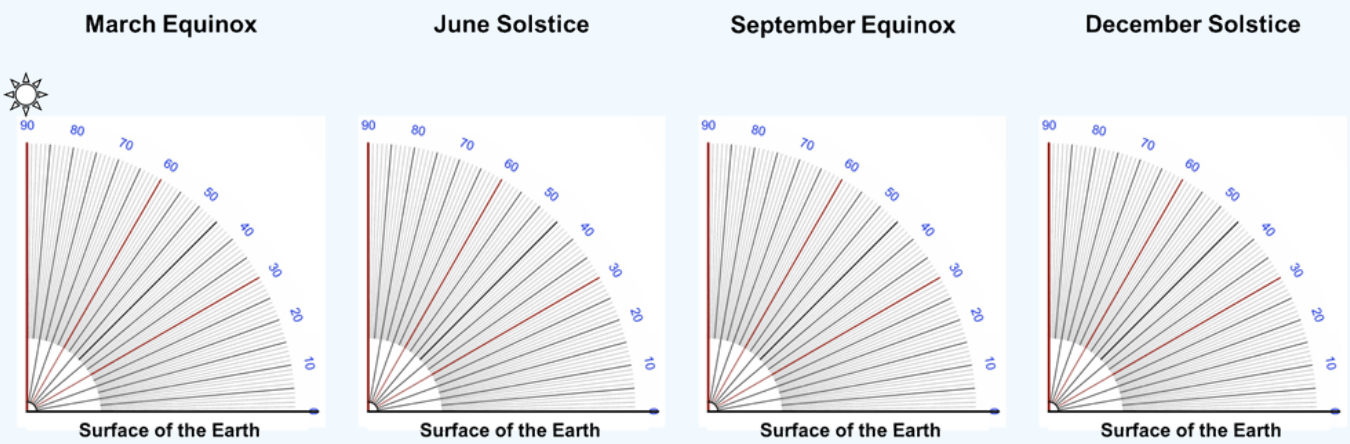


Figure 3.11: Angles of Incidence at the Equator. Figure is adapted from Scientif38 and licensed under CC BY-NC-SA 4.0

18. Refer to Table 3.1 above. On Figure 3.12 below, draw a Sun to represent the correct angle of incidence for each time of year at the **Tropic of Cancer.**

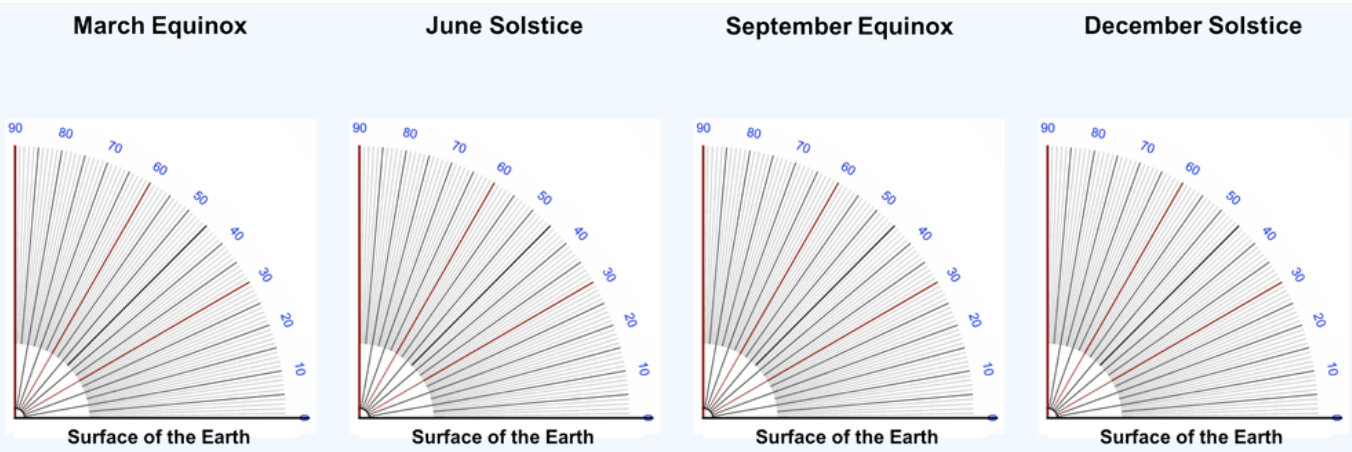


Figure 3.12: Angles of Incidence at the Tropic of Cancer. Figures are adapted from Scientif38 and licensed under CC BY-NC-SA 4.0

19. Refer to Table 3.1 above. On Figure 3.13 below, draw a Sun to represent the correct angle of incidence for each time of year at the **Arctic Circle**.

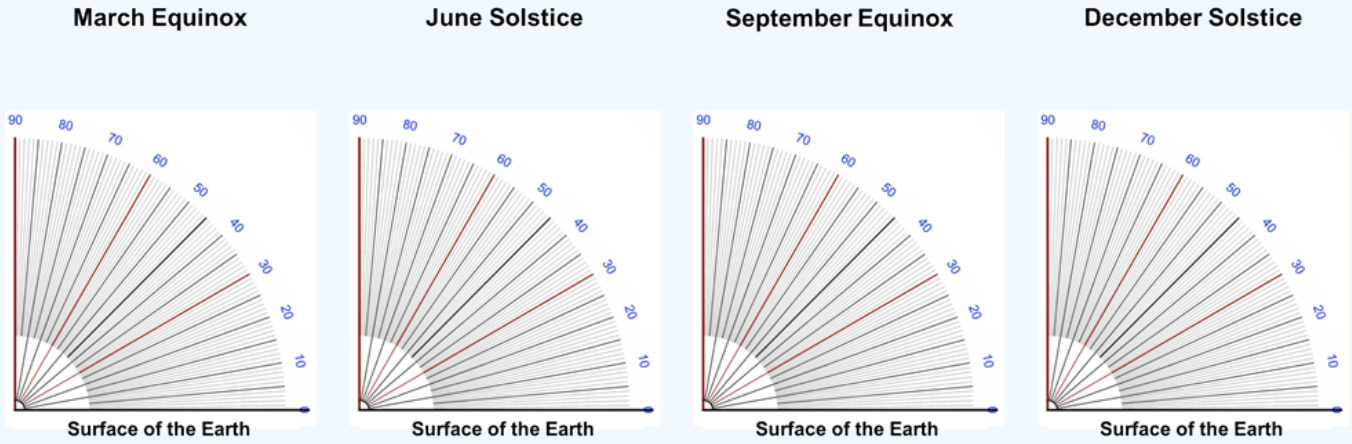


Figure 3.13: Angles of Incidence at the Arctic Circle.

20. Refer to Table 3.1 above. On Figure 3.14 below, draw a Sun to represent the correct angle of incidence for each time of year at the **North Pole.**

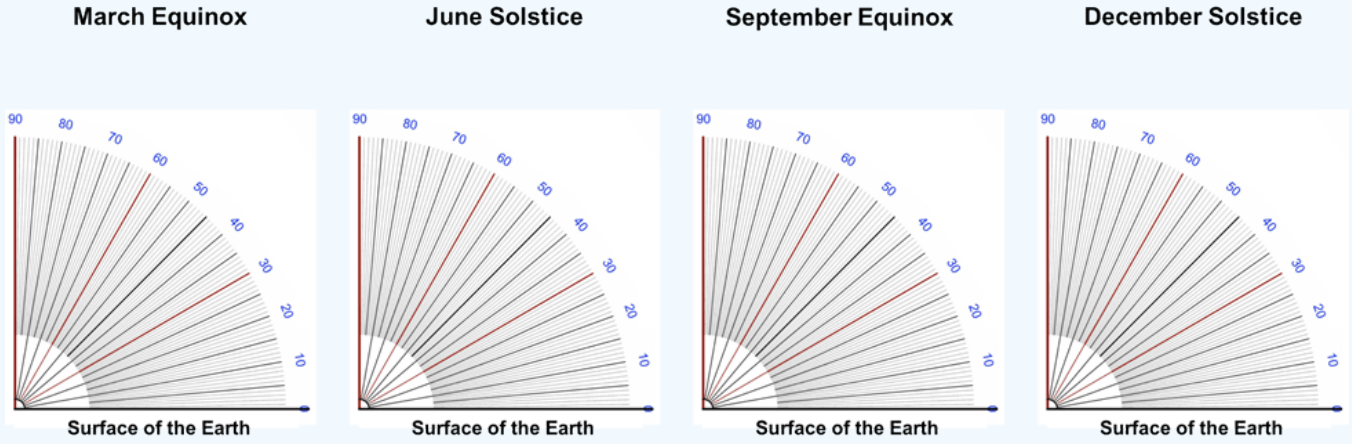


Figure 3.14: Angles of Incidence at the North Pole. Figure is adapted from Scientif38 and licensed under CC BY-NC-SA 4.0

21. Refer to your completed Figures 3.11 through 3.14.

a. Which latitude has the highest angle of incidence year-round?

b. Which latitude has the lowest angle of incidence year-round?

c. In one sentence, describe how the angles of incidence change throughout the year for the Tropic of Cancer.

d. Apply What You Learned: When would the radiation intensity be highest for the Arctic Circle?

The amount of sunlight that strikes the Earth's surface in an hour and a half is enough to handle the entire world's energy consumption for a full year. Solar technologies convert sunlight into electrical energy either through photovoltaic (PV) panels or through mirrors that concentrate solar radiation. This energy can be used to generate electricity or be stored in batteries or thermal storage.[52] Solar panel installations require an understanding of the angle of incidence. The Solar Electricity Handbook (2019, n.p.) says "to get the best out of your photovoltaic panels, you need to angle them towards the Sun. The optimum angle varies throughout the year, depending on the seasons and your location". If you lived at the Equator, you would want to lay your solar panel flat on the ground (at a 0° angle) during the equinoxes so that the maximum radiation is received.

Exercise 1.3.5

22. Apply What You Learned: Imagine that you want to install a solar panel at your latitude. At what angle(s) would you orientate the solar panel in order to maximize the amount of radiation that is received? Would you install the solar panels in a stationary position, or would you allow for the solar panels to move throughout the year? Explain your response in two to three sentences. Tip: estimate the angle of incidence at your latitude based on the data provided in Table 3.1. Hint: it may be easiest to sketch the surface of the Earth, your solar panel, and the estimated angle of incidence in order to respond to these questions.

Part C. Calculating Solar Altitude

The **solar altitude (SA)**, also called the **angle of the noon Sun**, represents the elevation of the noon Sun in the sky. Another way of understanding this is to think of the SA as the point at which the Sun is highest in the sky at noon. The **arc distance** (AD) is the number of degrees of latitude between the latitude you are determining the SA for and the declination of the Sun. The equation to determine the SA for a given location is:

SA = 90 - AD

The following steps demonstrate how to calculate solar altitude at a particular location on a particular day. For the example, we will use November 1st and the latitude of 33°N in the following example:

Step 1

Use the analemma (Figure 3.9, shown previously in the lab) to determine the declination of the Sun for the day of the year in question.

November 1st = 14°S

Step 2

Calculate the arc distance between the declination of the Sun and the latitude for which you are determining the SA. To do this, take the latitude in question and add or subtract the declination of the Sun. Remember to pay attention to the latitude's designated hemisphere (north or south). See Figure 3.15 for examples on how to calculate the arc distance for latitudes with the same hemisphere and those with opposite hemispheres. Note: values of the latitudes always remain positive in the equation, regardless of whether they are in the southern or northern hemisphere.

14° + 33° = 47 arc degrees (Refer to the bottom diagram of Figure 3.15).

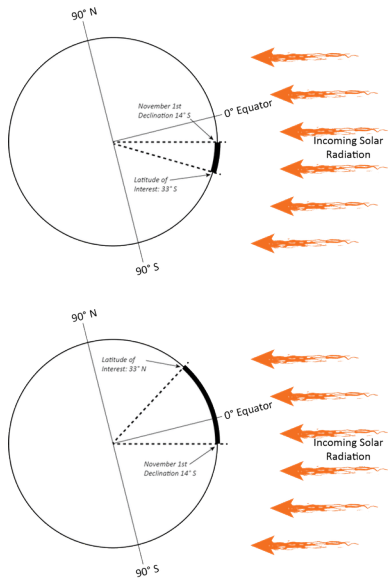


Figure 3.15: Arc Distance Calculations. Top: calculating arc distance for latitudes in the same hemisphere. Bottom: calculating arc distance for latitudes in the opposite hemispheres. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

Step 3

Calculate the SA by subtracting the arc distance from 90°. Remember, the equation from above is SA = 90°- AD.

90° - AD = SA

90° - 47° = 43°

On November 1st at 33°N, SA = 43°

Check out the diagram below (Figure 3.16). It shows where the noon Sun is in the sky on November 1st at 33°N.

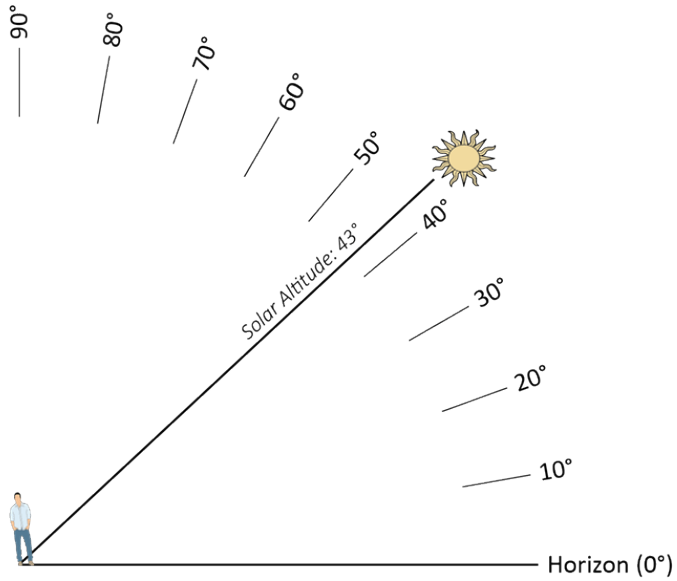


Figure 3.16: Angle of the Noon Sun on November 1st at 33°N. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0



Guided Practice: Calculating Solar Altitude

This video, Calculating Solar Altitude, goes through the above example step-by-step, and provides an explanation of what to do when the declination of the Sun and the particular latitude happen to be in the same hemisphere. (Video length is 2:54).

Exercise 1.3.6

23. Use the SA equation and the analemma to calculate the Sun's declination, arc distance (AD), and SA for the dates and latitudes shown in Table 3.2. Show your work in the space provided in the table. The first row has been done as an example.

Table 3.2: Sun Angle Calculations Exercise

Date	Latitude	Declination of the Sun	Arc Distance (AD)	Solar Altitude (SA)
April 8th	30°S	6°N	AD = 30° + 6° = 36°	SA = 90° - AD SA = 90° - 36° SA = 54°
July 17th	15°N			
October 31st	65°S			
December 7th	50°N			

24. Use the information from Table 3.2 and draw the Sun in its correct place in the sky for each of the following four dates: April 8th, July 17th, October 31st, and December 7th. Use Figure 3.16 as a model for your diagrams and write captions with the same information shown in Figure 3.16.

    a. April 8th:

    b. July 17th:

    c. October 31st:

    d. December 7th:

Part D. Daylength Analysis

Table 3.3 shows the daylength for various locations on Earth on selected days of the year. The dates February 16th, May 16th, August 16th, and November 16th were chosen at random and do not align with the solstices and equinoxes to give you an idea of daylength during other times of the year. You found the declination of the Sun for these dates earlier in this lab.

Exercise 1.3.7

25. Apply What You Learned: Add the daylength information for the North Pole and South Pole into Table 3.3.

Table 3.3: Daylength in Hours for 2020 for Selected Locations and Dates

Location (approximate latitude)	February 16th	May 16th	August 16th	November 16th
North Pole (90°N)				
White Horse, Canada (60°N)	8.78	16.81	15.36	7.09
Tokyo, Japan (35°N)	10.73	13.84	13.32	10.13
Addis Ababa, Ethiopia (10°N)	11.68	12.46	12.33	11.53
Quito, Ecuador (0°)	12.00	12.00	12.00	12.00
Palmas, Brazil (10°S)	12.32	11.54	11.67	12.47
Canberra, Australia (35°S)	13.27	10.16	10.68	13.87
South Pole (90°S)				

26. Refer to Table 3.3.

    a. Use Your Critical Thinking Skills: Why does Table 3.3 have a specific location for 60°N but no location for 60°S? Hint: look at a globe, an atlas, or Google Earth!

    b. Use Your Critical Thinking Skills: If a specific location had been provided for 60°S, would daylength at that location be similar to the daylength for 60°N? Explain why or why not in one to two sentences.

    c. Other than the poles, which of the eight locations has the greatest variation in daylength throughout the year? Explain why in one to two sentences. Tip: for each location, subtract the largest daylength number from the smallest to find the variation in daylength at that latitude.

    d. Other than the equator, which of the eight locations has the least variation in daylength throughout the year? Explain why in one to two sentences.

    e. Canberra and Tokyo are both located at a general latitude of 35°, however, their daylengths are different from each other on each of the four dates. Explain why in one to two sentences.

    f. On which date(s) does Palmas have a longer daylength than the equator? What are the seasons of these dates for Palmas?

    g. Does the equator have seasons? Why or why not?

27. Find the latitude of your home city on a map, globe, or the internet.

    a. Which of the eight locations listed are you closest in latitude to?

    b. Apply What You Learned: Based on what you have learned so far, explain how daylength would vary for your city. Explain your response in two to three sentences.

28. Use Your Critical Thinking Skills: Now that you have determined the declination of the Sun and daylength for February 16th, May 16th, August 16th, and November 16th, what connection can you make between the declination of the Sun and daylength for these dates? Explain your response in one to two sentences.

29. Using the data from your completed Table 3.3, create a line graph on Figure 3.17 that shows daylength for each season for the South Pole, White Horse, Quito, and Canberra. Create a key for your graph; be sure to use a different color for each of the four locations.

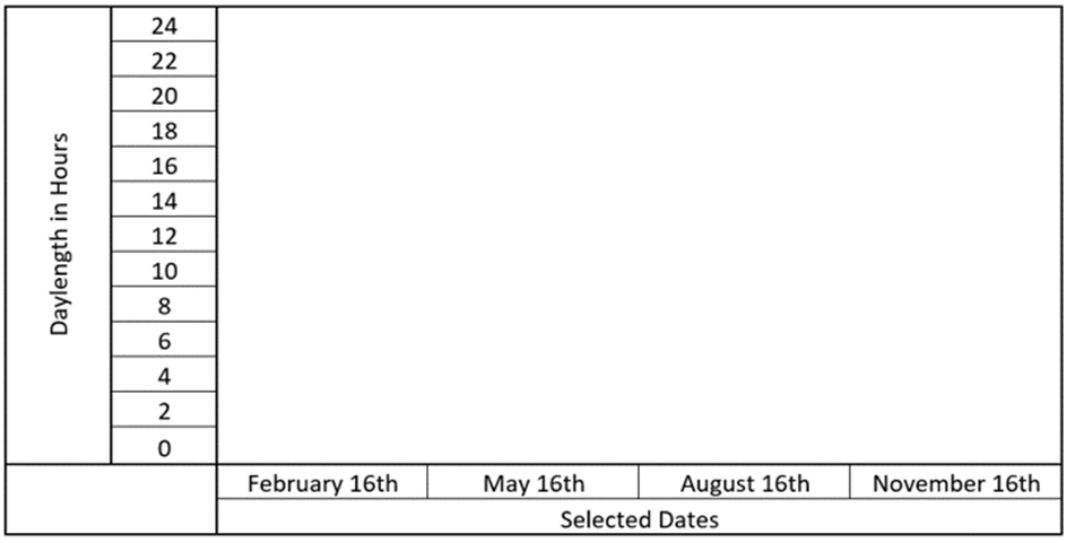


Figure 3.17: Blank Chart for Graphing Daylength for the South Pole, White Horse, Quito, and Canberra. Figure by Taya Lazootin is licensed under CC BY-NC-SA 4.0

30. Refer to your completed Figure 3.17. Tip: when appropriate, be sure to discuss the title of the Earth or the circle of illumination in your responses.

    a. Discuss how daylength changes throughout the year for each of the four locations and why those changes occur. Provide a detailed answer that is three to four sentences in length.

    b. How does the data for the South Pole vary from the other three locations you graphed?

    c. During which season does White Horse have the longest daylength?

    d. How would you explain the seasonal variation for Quito, a city located on the equator?

    e. Of the four locations you graphed, which one would you like to live in year-round? Why? Explain your response in at least one sentence.

31. Use Your Critical Thinking Skills: How could farming and other food services be impacted at latitudes with significantly less daylength throughout the year? Explain your response in at least one sentence.

31. Use Your Critical Thinking Skills: If you lived on or near the equator, do you think it would be valuable for you to use renewable energy (solar and wind) versus nonrenewable energy (gas and oil)? Why or why not? Explain your response in at least one sentence.

Part E. Wrap-Up

Consult with your geography lab instructor to find out which of the following wrap-up questions you should complete. Attach additional pages to answer the questions as needed.

Exercise 1.3.8

33. What is the most important idea that you learned in this lab? In two to three sentences, explain the concept and why it is important to know.

34. What was the most challenging part of this lab? In two to three sentences, explain why it was challenging. If nothing challenged you in the lab, write about what you think challenged your classmates.

35. What is one question that you have about what you learned in this lab? Write your question along with one to two sentences explaining why you think your question is important to ask.

36. Review the learning objectives on page 1 of this lab. How would you rate your understanding or ability for each learning objective? Write one sentence that addresses each learning objective.

37. Sketch a concept map that includes the key ideas from this lab. Include at least five of the terms shown in bold-faced type.

38. Create an advertisement to educate your peers on the important information that you learned in this lab. Include at least three key terms in your advertisement. The advertisement should be about half a page in size (about 4 inches by 6 inches).

39. One way to think of physical geography is that it is the study of the relationships among variables that impact the Earth's surface. Select two variables discussed in this lab and describe how they are related.

40. How does what you learned in this lab relate to your everyday life? In two to three sentences, explain a concept that you learned in this lab and how it relates to your day-to-day actions.

41. How does what you learned in this lab relate to current events?
    a. Write the title, source, and date of a news item that relates to this lab.
    b. In two to three sentences, discuss how the news item relates to what you have learned in this lab.
    c. In one to two sentences, discuss whether or not the news item accurately represents the science that you learned. Tip: consider whether or not the news item includes the complexity of the topic.

42. Search O*NET OnLine to find an occupation that is relevant to the topics presented in today's lab. Your lab instructor may provide you with possible keywords to type in the Occupation Quick Search field on the O*NET website.
    a. What is the name of the occupation that you found?
    b. Write two to three sentences that summarize the most important information that you learned about this occupation.
    c. What is one question that you would want to ask a person with this occupation?

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[38] Text adapted from NASA is in the public domain

[52] Text by U.S. Department of Energy is in the public domain

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1.4: Lab 4 - Earth's Energy Budget

Learning Objectives

- Define electromagnetic radiation and describe the electromagnetic spectrum.
- Analyze radiation data.
- Explain Earth's energy budget.
- Differentiate among radiation, absorption, reflection, scattering, refraction, and transmission.
- Interpret radiation data collected through remote sensing techniques.

Introduction

In the previous lab, we studied how Earth's annual revolution around the Sun influences the angle of incoming solar rays and the length of day at different latitudes. In this lab, we will look at how those angles play a role in insolation patterns at Earth's surface and the amount of energy received on Earth during a given time period and at a given latitude. **Insolation** is the amount of incoming solar radiation. **Radiation** is both the emission and transmission of energy in the form of electromagnetic rays. Insolation is the energy emitted by the Sun, and transmitted through space, that reaches Earth.

Part A. Electromagnetic Radiation

Before we investigate Earth's energy budget, let's think about radiation—energy transmitted through space. Have you ever wondered how wifi, microwaves, or radios work? Each of these devices make use of electromagnetic waves. **Electromagnetic radiation** is made up of vibrating waves of electrical and magnetic fields that can travel through empty space, air, and solid objects. This radiation differs in terms of energy, wavelength, and frequency. **Wavelength** is the distance between the individual waves measured from crest to crest (Figure 4.1). **Frequency** is the number of waves which pass a point in space each second.

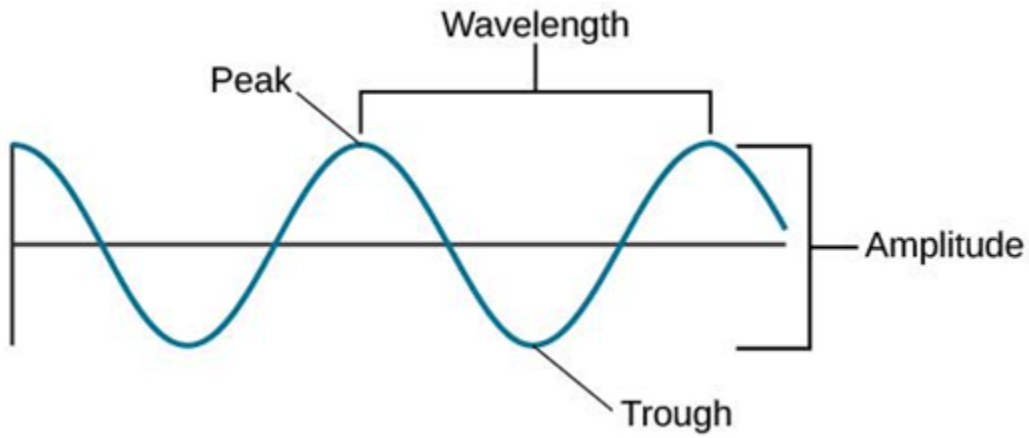


Figure 4.1: Electromagnetic Wave. Figure by OpenStax College is licensed under CC BY 4.0

Exercise 1.4.1

1. Refer to Figure 4.2 (below). Which electromagnetic wave example represents a shorter wavelength?



Figure 4.2: Two Electromagnetic Waves. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

In this part of the lab, we will focus on the forms of energy emitted by the Sun. There are several forms of electromagnetic radiation in the Universe (Figure 4.3). All objects with temperatures above absolute zero (-273.15 degrees Celsius; -459.67 degrees Fahrenheit) radiate energy proportional to its temperature. The Sun emits radiation at all wavelengths but 99% of the energy received at the Earth is in the infrared, visible light, or ultraviolet parts of the electromagnetic spectrum. Of this radiation received by our planet, 48% is infrared radiation, 44% is visible light radiation, and 7% is ultraviolet radiation. Note that infrared radiation is sometimes called **longwave radiation** or thermal radiation, and ultraviolet radiation is sometimes called **shortwave radiation** or UV radiation.

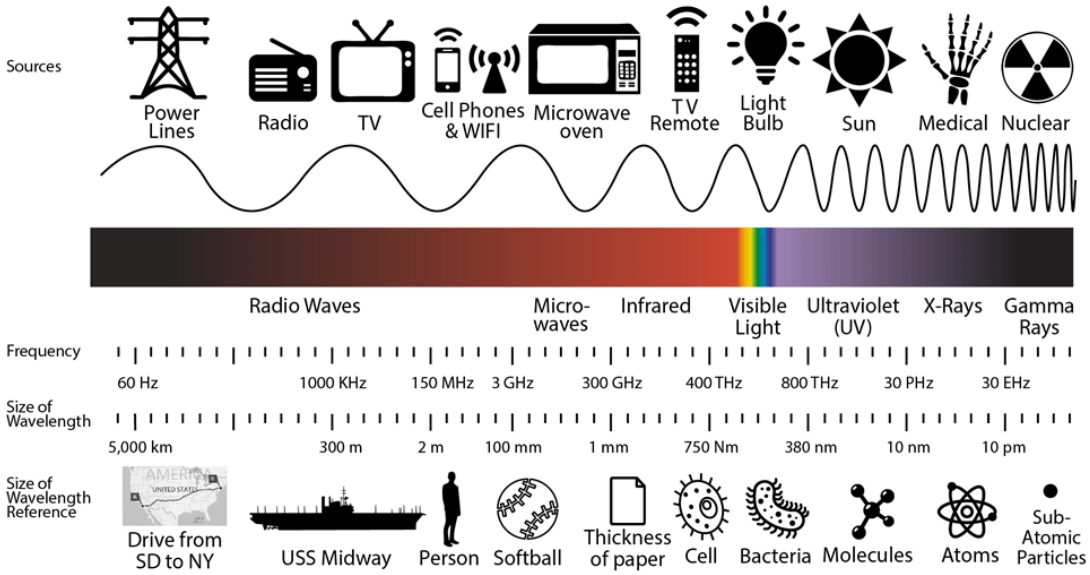


Figure 4.3: The Electromagnetic Spectrum. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

Exercise 1.4.2

1. Refer to Figure 4.3.
    a. Does infrared, visible, or ultraviolet radiation have the longest wavelength?
    b. Is wifi considered longwave or shortwave radiation?
    c. Are X-rays considered longwave or shortwave radiation?
    d. Which radiation has a longer wavelength, wifi radiation or microwave radiation?



Check It Out! Tour of the Electromagnetic Spectrum

Watch this video, Tour of the EMS 01 – Introduction, for a tour of the electromagnetic spectrum from NASA. (Video length is 5:03).

Part B. Net Radiation

Net radiation is the balance between incoming and outgoing energy at the top of the atmosphere. Some of the sunlight that reaches Earth is reflected back to space by bright surfaces like clouds or ice. The rest is absorbed by the atmosphere, oceans, and land. This absorbed light is converted to heat, which is emitted back to space by the surface of the earth and the atmosphere. Net radiation is the total amount of absorbed sunlight and heat energy that does not escape from the top of the Earth's atmosphere back into space. Specifically, net radiation is the sum total of shortwave and longwave electromagnetic energy, at wavelengths ranging from 0.3 to 100 micrometers, that remains in the Earth system. Net radiation is the energy that is available to influence the climate. On a global scale, net radiation must be zero or else the planet's overall temperature must rise or fall.[59]

Most simply, the net radiation equation is as follows:

Net Radiation = Incoming Radiation - Outgoing Radiation

Incoming radiation is insolation; outgoing radiation is both reflected shortwave radiation and longwave radiation that is emitted from the Earth's surface. It is important to point out that net radiation is calculated at the top of the atmosphere. If net radiation was calculated at the surface of the Earth, then we would include incoming longwave radiation that is absorbed and re-emitted by greenhouse gases in the atmosphere (the greenhouse effect, which is explained in greater detail in the climate change lab).

Table 4.1 provides monthly and annual average insolation data in watts per meters squared (W/m^2) for three locations. This represents incoming radiation. A watt is measurement of power, or the amount of energy that something generates or uses over time. An incandescent light bulb uses anywhere from 40 to 100 watts. A microwave uses about 1000 watts. If you could capture and re-use, for just one hour, all the solar energy arriving over a single square meter at the top of the atmosphere directly facing the Sun—an area no wider than an adult's outstretched arm span—you would have enough to run a refrigerator all day.[60]

Table 4.1: Monthly and Annual Average Insolation (W/m2) for Three Locations

Location Approximate Latitude	March	June	September	December	Annual
Deadhorse, Alaska 70°N	133	488	181	0	198
Beijing, China 40°N	323	483	351	160	330
Kamala, Uganda 0°	439	388	429	413	420

Exercise 1.4.3

3. Plot the monthly average data presented in Table 4.1 above on the blank graph provided in Figure 4.4. Use a different colored pencil for each location (blue for Deadhorse, green for Beijing, and red for Kampala) and connect the points with a line.

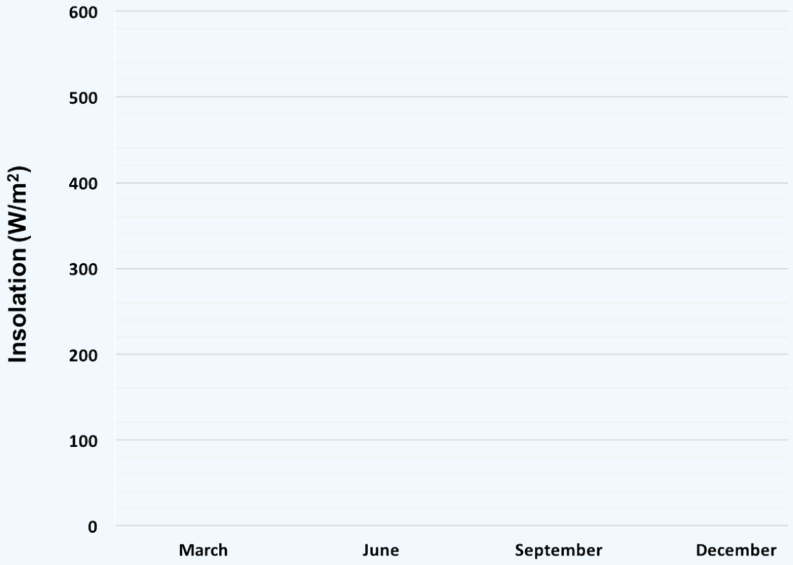


Figure 4.4: Blank Graph to Plot Insolation. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

4. Refer to your completed Figure 4.4.
    a. Describe the insolation variation for Deadhorse.
    b. Use Your Critical Thinking Skills: What explains the insolation variation for Deadhorse?
    c. Describe the insolation variation for Beijing.
    d. Use Your Critical Thinking Skills: What explains the insolation variation for Beijing?
    e. Describe the insolation variation for Kampala.
    f. Use Your Critical Thinking Skills: What explains the insolation variation for Kampala?
5. Refer to Table 4.1 and your completed Figure 4.4.
    a. Which location has the highest monthly average insolation? In which month does this occur?
        i. Apply What You Learned: Why does this location receive the highest monthly average insolation?

In the net radiation equation, outgoing radiation includes reflected shortwave radiation and **terrestrial radiation**, which is in the form of longwave radiation. Terrestrial radiation is the outgoing longwave radiation from Earth. Table 4.2 provides all of the data needed to calculate net radiation at the top of the atmosphere for Deadhorse, Alaska.

Table 4.2: Monthly Average Radiation Data for Deadhorse, Alaska (~70°N) Data in W/m2

Month	Incoming Radiation	Outgoing Shortwave Radiation	Outgoing Longwave Radiation	Net Radiation
March	133	84	147	-98
June	488	332	204	

Month	Incoming Radiation	Outgoing Shortwave Radiation	Outgoing Longwave Radiation	Net Radiation
September	181	84	147	
December	0	0	154	

In order to calculate net radiation for Deadhorse in March, subtract outgoing longwave radiation and outgoing shortwave radiation from incoming radiation:

$$133 - 84 - 147 = -98$$

Negative net radiation indicates an energy deficit. This means that more energy is lost to space than is received from insolation.

Exercise 1.4.4

6. Following the example for March provided above, complete the net radiation column in Table 4.2.
7. Apply What You Learned: Why does Deadhorse have no incoming radiation in December?
8. Use Your Critical Thinking Skills: Why does Deadhorse have an energy deficit in June even though insolation is relatively high during this month?

Table 4.3 provides all of the data needed to calculate net radiation at the top of the atmosphere for Beijing, China.

Table 4.3: Monthly Average Radiation Data for Beijing, China (~40°N) Data in W/m2

Month	Incoming Radiation	Outgoing Shortwave Radiation	Outgoing Longwave Radiation	Net Radiation
March	323	106	223	
June	483	161	246	
September	351	106	223	
December	160	55	210	

Exercise 1.4.5

9. Complete the net radiation column in Table 4.3.
10. How does the net radiation in Beijing change throughout the year?

Table 4.4 provides all of the data needed to calculate net radiation at the top of the atmosphere for Kampala, Uganda.

Table 4.4: Monthly Average Radiation Data for Kampala, Uganda (~0°) Data in W/m2

Month	Incoming Radiation	Outgoing Shortwave Radiation	Outgoing Longwave Radiation	Net Radiation
March	439	199	207	
June	388	155	228	
September	429	199	207	
December	413	170	244	

Exercise 1.4.6

11. Complete the net radiation column in Table 4.4.
12. Apply What You Learned: Why does Kampala have relatively high net radiation throughout the year?

The net heating imbalance between the equator and poles drives an atmospheric and oceanic circulation that climate scientists describe as a “heat engine”. (In our everyday experience, we associate the word engine with automobiles, but to a scientist, an engine is any device or system that converts energy into motion). The climate is an engine that uses heat energy to keep the atmosphere and ocean moving. Evaporation, convection, rainfall, winds, and ocean currents are all part of the Earth’s heat engine.[62]

Let’s explore net radiation on animated world maps provided by NASA’s Earth Observatory. The animation provides net radiation in W/m^2 from July 2006 through July 2020.

Step 1



Go to the net radiation webpage provided by NASA’s Earth Observatory.

Step 2

Read the text beneath the map so that you understand the data shown and what the colors on the maps signify.

Step 3

Click the play button on the bottom left of the map.

Exercise 1.4.7

13. Describe how net radiation fluctuates throughout the year.
14. Apply What You Learned: Why does net radiation fluctuate throughout the year?

Part C. Earth’s Energy Budget

Solar radiation reaches the surface of the Earth in the form of shortwave radiation and is considered **incoming radiation**. Radiation or energy that leaves the Earth in the form of longwave radiation is considered **outgoing radiation**, which is also known as terrestrial radiation. In the previous part of the lab, we took a simplified look at incoming and outgoing radiation. There are several important vocabulary terms related to Earth’s energy budget that will advance your understanding of net radiation:

- **Emission** is the process of energy being released or emitted by an object.
- **Absorption** refers to an object’s ability to absorb or take in electromagnetic waves.
- **Reflection** refers to electromagnetic waves “bouncing back” after hitting an object.
    - The percentage of insolation reflected back out to space is called **albedo**. Earth’s average albedo is 31, this means that 31% of insolation is reflected back out to space in a given year.
- Energy is also distributed through **scattering**, which occurs when electromagnetic waves encounter gas molecules and particulates in the atmosphere and change direction.
- **Refraction** occurs when electromagnetic radiation hits an object and then changes both wavelength and direction.

➢ Energy that passes through a substance or a medium is called **transmission**. The more transparent the medium, the more transmission occurs. This is why energy passes through and is absorbed through water more easily than through land.

Figure 4.5 shows the total amount of energy coming into and leaving Earth in a given year, also known as an **energy budget**. Similar to an economic budget, energy budgets help us better understand how much energy Earth receives from the Sun (income), how that energy is distributed around the planet (transferred among checking and savings accounts), and how much of that energy is lost in a given year (expenses). Earth is always practicing a balancing act; therefore, it makes sense that the amount of energy received from the Sun is approximately how much energy is lost.

The energy budget accounts for energy in the form of units or a percent. Let's say the Earth receives 100 units of energy from the Sun each year; Figure 4.5 shows how those 100 units are distributed throughout the planet in a given year.

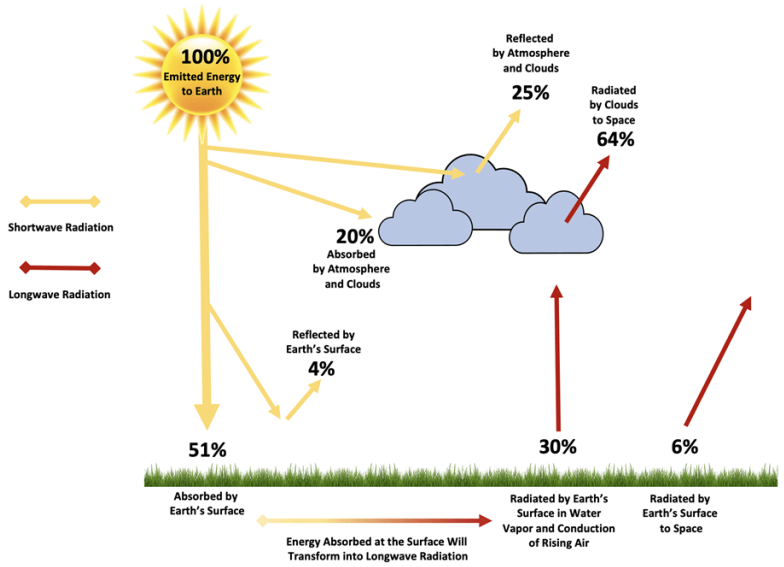


Figure 4.5: Earth's Energy Budget. Yellow numbers account for incoming shortwave radiation and red numbers account for outgoing longwave radiation. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Exercise 1.4.8

15. What percent of energy received from the Sun each year is absorbed by clouds?
    a. What percent of energy received from the Sun each year is reflected by clouds?
    b. How much energy is absorbed by the surface of the Earth? Hint: your answer will be a percentage.
    c. Of the total energy absorbed by the Earth's surface (land and ocean) as incoming shortwave radiation, how much of it is emitted back out as longwave radiation?
    d. What role do clouds play in the energy budget? Your response should be at least one sentence in length.
    e. Use Your Critical Thinking Skills: When analyzing insolation data, why is it important to pay attention to whether or not the data was collected by satellites at the top of the atmosphere or by ground stations at the surface of the Earth? Your response should be at least one sentence in length.

Part D. Remote Sensing and Earth's Energy Budget

Let's go "behind the scenes" to learn how scientists calculate Earth's energy budget. Part of the research comes from data collected by remote sensing. The term **remote sensing** is commonly used to describe the science—and art—of identifying, observing, and measuring an object without coming into direct contact with it. This process involves the detection and measurement of radiation of different wavelengths reflected or emitted from distant objects or materials, by which they may be

identified and categorized by class/type, substance, and spatial distribution. Remote sensing is used in numerous fields, including geography, land surveying and most Earth Science disciplines; it also has military, intelligence, commercial, economic, planning, and humanitarian applications.[8]

Figure 4.6 reveals the variety of remote sensing platforms used today—offering a multi-scale, multi-resolution view of our planet. Remote sensing instruments are of two primary types: active and passive. **Active sensors** provide their own source of energy to illuminate the objects they observe. An active sensor emits radiation in the direction of the target to be investigated. The sensor then detects and measures the radiation that is reflected or backscattered from the target. **Passive sensors**, on the other hand, detect natural energy (radiation) that is emitted or reflected by the object or scene being observed. Reflected sunlight is the most common source of radiation measured by passive sensors.[8]

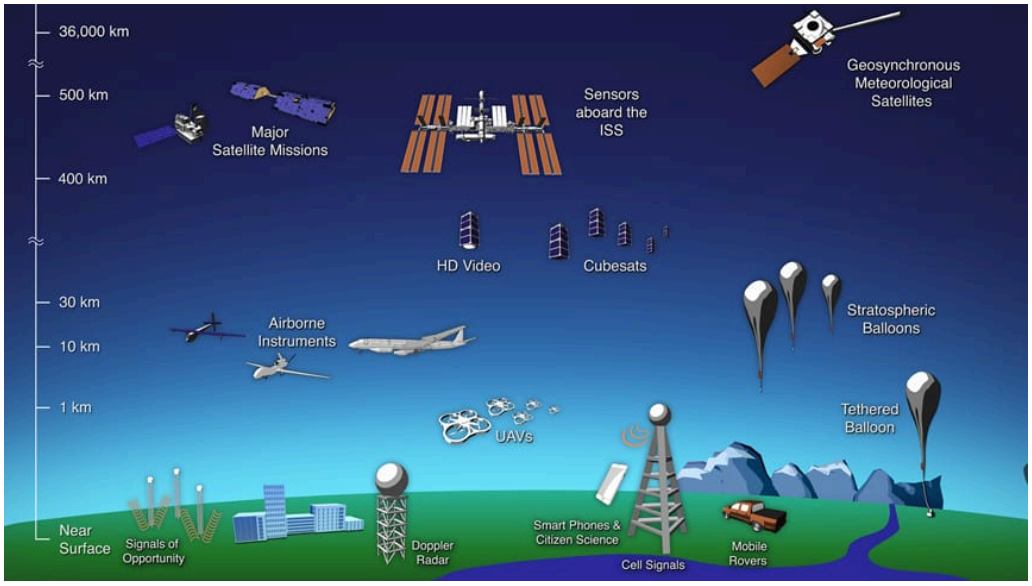


Figure 4.6: Remote Sensing Platforms. Figure and text by NASA's Goddard Space Flight Center are in the public domain

Exercise 1.4.9

16. Use Your Critical Thinking Skills: Why do you think there are so many applications, or uses, of remotely sensed data? Explain your response in at least one sentence.

17. Apply What You Learned: Let's say you are looking out onto the Earth's surface from a window seat on an airplane. Would your eyes be considered active or passive remote sensors? Explain your response in at least one sentence.

One of NASA's remote sensing instruments used to understand Earth's net radiation is CERES, which stands for Clouds and the Earth's Radiant Energy System. Here are some interesting things to know about CERES:

- First launched in 1997, there are a total of five CERES instruments currently orbiting Earth (two on the Terra satellite, two on the Aqua satellite, and one on the Suomi National Polar-orbiting Partnership satellite).
- It weighs 54 kilograms (119 pounds).
- It's accuracy is between 0.3 and 1%.

CERES program scientist explains that "CERES represents a serious attempt to create a true climate data record—that is, a time series that is precise enough and maintained for enough time that long-term trends in climate can be measured...There are some critically important science questions that cannot be answered without a very precise measurement made over multi-decadal time periods. In order to properly address these questions, we need to maintain the measurements over multiple generations of instruments—for the science".[65]

The animated net radiation false-color maps that you explored earlier in the lab were created using data from CERES. They

show the net radiation (in Watts per square meter) that was contained in the Earth system for the given time period. Regions of positive net radiation have an energy surplus, and areas of negative net radiation have an energy deficit. The maps illustrate the fundamental imbalance between net radiation surpluses at the equator, where sunlight is direct year-round, and net radiation deficits at high latitudes, where direct sunlight is seasonal. This imbalance is the fundamental force that drives atmospheric and oceanic circulation patterns.[66]

The CERES instrument also measures changes to Earth's albedo. Figure 4.7 shows how the reflectivity of Earth—the amount of sunlight reflected back into space—changed between March 1, 2000, and December 31, 2011. This global picture of reflectivity (also called albedo) appears to be a muddle, with different areas reflecting more or less sunlight over the 12-year record. Shades of blue mark areas that reflected more sunlight over time (increasing albedo), and orange areas denote less reflection (lower albedo). Taken across the planet, no significant global trend appears. Global albedo rose and fell in different years, but did not necessarily head in either direction for long. Some regional patterns emerge, however.[67]

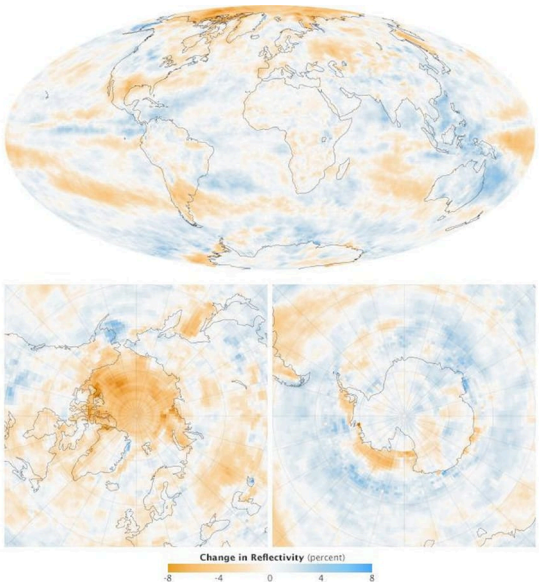


Figure 4.7: Changes to Earth's Albedo between March 1, 2000 and December 31, 2011. Figure by NASA Earth Observatory is in the public domain.

Exercise 1.4.10

18. Refer to Figure 4.7.

    a. In two to three sentences, describe how Earth's albedo changed. In your response, be sure to identify specific places on the planet that experienced increasing or decreasing reflectivity.

    b. Use Your Critical Thinking Skills: List the factors that might explain why there are regional differences in albedo.

CERES and other satellite instruments provide data on **anthropogenic** (human-caused) effects on cloud cover. One example of this comes from a study of ship tracks (Figure 4.8). As ships cruise across the ocean, they emit a large number of small airborne particles—**aerosols**—into the lower atmosphere. Under the right conditions, these exhaust particles cause long, thin cloud patterns referred to as "ship tracks". For decades, scientists have theorized that these cloud changes might alter climate by affecting the amount of sunlight reaching Earth's surface. A 2020 study measured exactly how ship emissions affect clouds at a regional scale. University of Washington scientist Michael Diamond and colleagues examined more than a decade of cloud patterns over a busy shipping lane in the southeast Atlantic that connects Europe to southern Africa and Asia.[69]

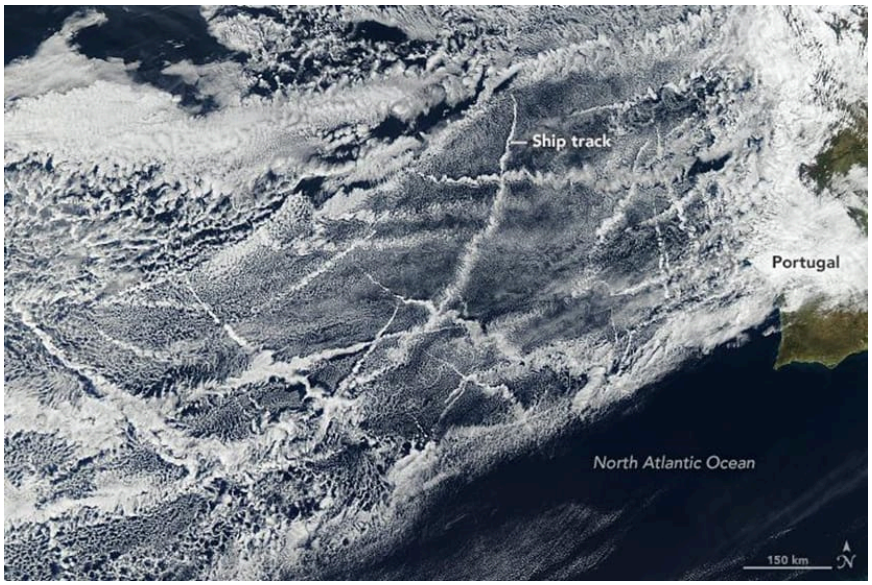


Figure 4.8: Ship Tracks In the North Atlantic Ocean on January 16, 2018. Figure by NASA Earth Observatory is in the public domain

The team measured the cloud properties inside the shipping corridor using satellite data and compared them to what they estimated the values would be without shipping activity. The scientists found that the shipping activity increased the number of cloud droplets over the shipping lane. They further showed that those clouds prevented about 2 Watts of solar energy from reaching each square meter of ocean surface along the shipping lane. The team's results agreed with previous computer modeling studies that predicted a sizeable cooling effect due to shipping. Diamond explained that the aerosols from the ships create "seeds" in the atmosphere that water vapor can latch onto and condense into small cloud droplets. These smaller droplets make clouds brighter so that they reflect more sunlight, which creates a local cooling effect at the planet's surface.[15]

That change is small on a regional scale, but it could be enough to affect global temperatures if the same phenomenon occurs worldwide, according to study co-author Hannah Director of the University of Washington. When the team scaled their findings across the planet, they found that changes in low-lying clouds from all industrial pollution sources could block about 1 Watt of energy per square meter globally. For context, greenhouse gases from industrial activities have trapped roughly 3 Watts per square meter so far.[15]

Exercise 1.4.11

19. Apply What You Learned: In your own words, explain how the aerosols in ship tracks create a local cooling effect. Be sure to indicate which of the atmospheric effects (absorption, reflection, scattering, or refraction) is responsible for the cooling.

20. Scientists create knowledge using three main types of research: lab experiments, field experiments, and computer modeling.

    - Lab experiments are conducted in a controlled setting.
    - Field experiments are conducted in a natural, real-world setting.
    - Computer models use mathematical equations based on the laws of physics to understand the natural world; data collected from lab experiments and/or field experiments are often used in computer models.

    What types of research contributed to the analysis of ship tracks? Explain your response in one to two sentences.

21. Use Your Critical Thinking Skills: Do you think it is valid to extrapolate the findings from a study done on one part of the planet (e.g., ship lanes in the southeast Atlantic) to create a global analysis based on computer modeling (e.g., ship lanes in other parts of the world)? Explain why or why not in two to three sentences. Tip: extrapolate means to "extend the application of (a method or conclusion, especially one based on statistics) to an unknown situation by assuming that existing trends will continue or similar methods will be applicable".

Part E. Wrap-Up

Consult with your geography lab instructor to find out which of the following wrap-up questions you should complete. Attach additional pages to answer the questions as needed.

Exercise 1.4.12

22. What is the most important idea that you learned in this lab? In two to three sentences, explain the concept and why it is important to know.

23. What was the most challenging part of this lab? In two to three sentences, explain why it was challenging. If nothing challenged you in the lab, write about what you think challenged your classmates.

24. What is one question that you have about what you learned in this lab? Write your question along with one to two sentences explaining why you think your question is important to ask.

25. Review the learning objectives on page 1 of this lab. How would you rate your understanding or ability for each learning objective? Write one sentence that addresses each learning objective.

26. Sketch a concept map that includes the key ideas from this lab. Include at least five of the terms shown in bold-faced type.

27. Create an advertisement to educate your peers on the important information that you learned in this lab. Include at least three key terms in your advertisement. The advertisement should be about half a page in size (about 4 inches by 6 inches).

28. One way to think of physical geography is that it is the study of the relationships among variables that impact the Earth's surface. Select two variables discussed in this lab and describe how they are related.

29. How does what you learned in this lab relate to your everyday life? In two to three sentences, explain a concept that you learned in this lab and how it relates to your day-to-day actions.

30. How does what you learned in this lab relate to current events?
    a. Write the title, source, and date of a news item that relates to this lab.
    b. In two to three sentences, discuss how the news item relates to what you have learned in this lab.
    c. In one to two sentences, discuss whether or not the news item accurately represents the science that you learned. Tip: consider whether or not the news item includes the complexity of the topic.

31. Search O*NET OnLine to find an occupation that is relevant to the topics presented in today's lab. Your lab instructor may provide you with possible keywords to type in the Occupation Quick Search field on the O*NET website.
    a. What is the name of occupation that you found?
    b. Write two to three sentences that summarize the most important information that you learned about this occupation.
    c. What is one question that you would want to ask a person with this occupation?

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[59] Text by NASA Earth Observatory is in the public domain

[60] Text by NASA Earth Observatory is in the public domain

[62] Text by NASA

[65] Quote from NASA is in the public domain

[66] Text by NASA Earth Observatory is in the public domain

[67] Text by NASA Earth Observatory is in the public domain

[69] Text by NASA Earth Observatory is in the public domain

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1.5: Lab 5 - Atmospheric Pressure and Wind

Learning Objectives

- Construct and interpret an atmospheric pressure profile.
- Identify the mechanisms that drive wind.
- Diagram a global circulation model.
- Analyze and interpret global atmospheric pressure and temperature maps.
- Explain different types of local and regional wind patterns.

Introduction

Although we cannot see it, air is all around us. Earth is covered in a layer of gasses, kept close to the surface by gravity. The gravitational pull of gasses to the surface creates **air pressure**. A variety of other atmospheric and surface conditions also influence the rising or subsiding (sinking) of air. This results in a wide range of pressure systems covering the Earth. It is these differences in air pressure from one location to another that causes the horizontal movement of air known as **wind**. This movement of air also distributes humidity and energy over the surface of the Earth and has a significant impact on the weather and climate patterns over the Earth.

In this lab you will explore a variety of ideas related to air pressure and its impacts on wind and weather patterns.

Part A. Measuring Air Pressure

Because of the gravitational pull on the gasses in the atmosphere, the greatest air pressure is at the bottom, with the "weight" of the overlying air pushing down on the surface. Further, the gas molecules are more closely packed together (have a higher **density**) at the surface than is found at higher altitudes. Figure 5.1 illustrates this idea.

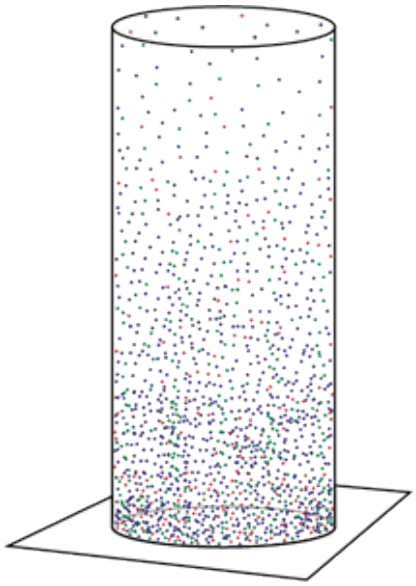


Figure 5.1: Influence of Gravity on Air Molecules. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

You may have experienced the impacts of less dense air at higher elevations. If you usually live, work, and recreate at lower elevations, you might find yourself getting short of breath while doing some of those same things at higher elevations. You may even get a headache or feel sluggish. This is because the molecules are further apart, resulting in air that is less dense, or "rarified". Although you are filling your lungs, you still are not getting as many oxygen molecules in.

Air pressure is measured using an instrument called a barometer. A **barometer** is a specialized instrument that measures the pressure of the surrounding air. You may hear different terms like air pressure, atmospheric pressure, and barometric pressure; these all mean the same thing and refer to the force of the air on the surface of the Earth. Just like length or temperature can be recorded using different units of measurement, air pressure can also be reported in a variety of units. Most commonly you will find air pressure reported in **inches of mercury** (inHg) or in **millibars** (mb). On average, the air pressure at sea level is 29.92 inHg, or 1013.25 mb. Across the Earth, you will see a variety of pressure systems with higher or lower pressure. At higher elevations, you will typically find lower surface pressure. On average, air pressure on the surface ranges between 980 mb to 1050 mb, although there are periodic outliers.

The conversions between inches of mercury (inHg) and millibars (mb) are provided below.

1.0 inch Hg = 33.87 mb

1.0 mb = 0.0295 inch of Hg

Exercise 1.5.1

Use the conversion formulas above to convert the following barometric pressure measurements.

1. Highest recorded air pressure on Earth measured in Tosontsengel, Mongolia:

   32.03 inHg = _____ mb

2. Lowest recorded air pressure on Earth measured in Typhoon Tip:

   _____ inHg = 869.9 mb

3. Current air pressure outside lab today (search the internet to find this information):

   Today's date: _____

   Time: _____

   _____ inHg and _____ mb

4. Current air pressure at your favorite/dream vacation destination (search the internet to find this information):

   Location: _____

   Today's date: _____

   Time: _____

   _____ inHg and _____ mb

Part B. Standard Atmospheric Pressure Profile

As discussed earlier, gravity has a significant influence on the vertical distribution of gasses within our atmosphere. Table 5.1 provides the average air pressure at a range of altitudes. You can see that the higher the altitude of the barometric readings, the lower the air pressure values will be. Because gravity is pulling the air down, at higher elevations you are only measuring the force from the overlying air.

Exercise 1.5.2

5. Using the data in Table 5.1, graph the atmospheric pressure profile on the graph provided below (Figure 5.2) and then connect the data points with a solid line.

Table 5.1: Standard Atmospheric Pressure by Altitude

Altitude (km)	Pressure (mb)
0	1013.25
1	898.746
2	794.952
3	701.085
4	616.402
5	540.199
6	471.810
7	410.607
8	355.998
9	307.425
10	264.363
15	120.446
20	54.7489
25	25.1102
30	11.7187
40	2.77522
50	0.759448
60	0.203143

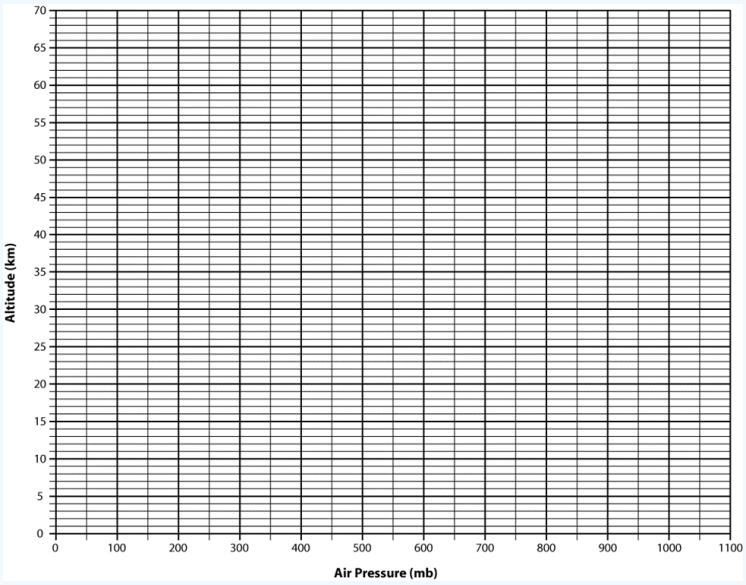


Figure 5.2: Air Pressure and Altitude Graph. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

6. Use your completed Figure 5.2 graph to answer the following questions:

    a. The highest peak in California (and the continental United States) is Mt. Whitney, outside of Lone Pine, California, with an elevation of 14,495 feet (4.4 kilometers). What is the average barometric pressure at the summit?

b. The highest peak in all of North America is Mt. Denali in Alaska. It's peak is at 20,310 feet (6 kilometers). What is the average barometric pressure there?

c. Use Your Critical Thinking Skills: Considering your answer to the questions above, why do you think hikers are short of breath when they climb to some of these very high peaks?

d. Most commercial jet planes fly at an altitude of 36,000 feet (approximately 11 kilometers). What is the average air pressure at this altitude?

7. What is the highest elevation (on the surface; not in a plane) that you have been to? Search the internet to find the location's elevation.

   a. Location:

   b. Elevation in meters:

   c. What is the average air pressure at that elevation? Tip: first, convert elevation in meters to kilometers by dividing by 1,000, and then use the Figure 5.2 graph.

Part C. Global Mechanisms of Wind

Wind is the horizontal movement of air across the surface of the earth. Although the main driver of wind is a difference in surface air pressure, there are several factors that interact to drive the winds. In this section, you will explore each of these factors.

Gravity

In the previous section, you learned that at higher elevations the air pressure is lower. If the low pressure is found at higher elevations, why does the air not rush towards those locations of lower pressure? This is because **gravity** is pulling the atmospheric gasses. So, while gravity does not have a direct impact on air movement, it does keep the air from rushing up the mountains to the low pressure found there (Figure 5.3).

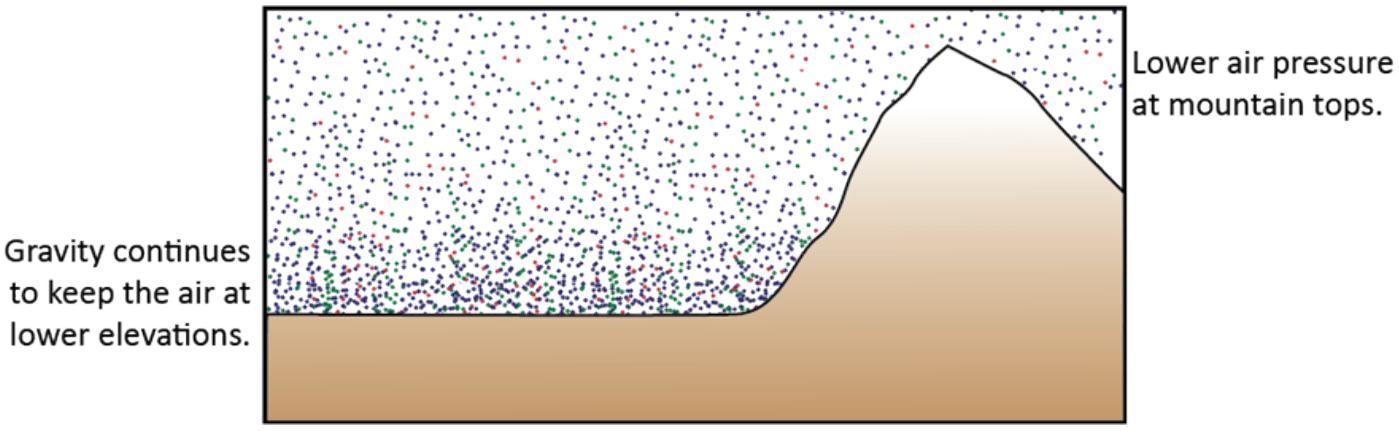


Figure 5.3: Gravity Limiting Air Movement. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

Pressure Gradient

Although in the previous section you learned that, on average, the atmospheric pressure is 1013.25 millibars (mb), the pressure actually varies, significantly at times, across the surface of the Earth. There are many reasons for this, but one of the leading causes of this difference in pressure is temperature differences. As air warms, its density decreases. This causes the warm air to rise, creating a lower pressure. Inversely, cool air becomes more dense and subsides (sinks), causing higher pressure. What happens on the surface if in one location there is a higher pressure and in an adjacent location there is a lower pressure? This is referred to as a **pressure gradient**. The air would move away from the high pressure and move towards the lower pressure, as diagrammed below in Figure 5.4.

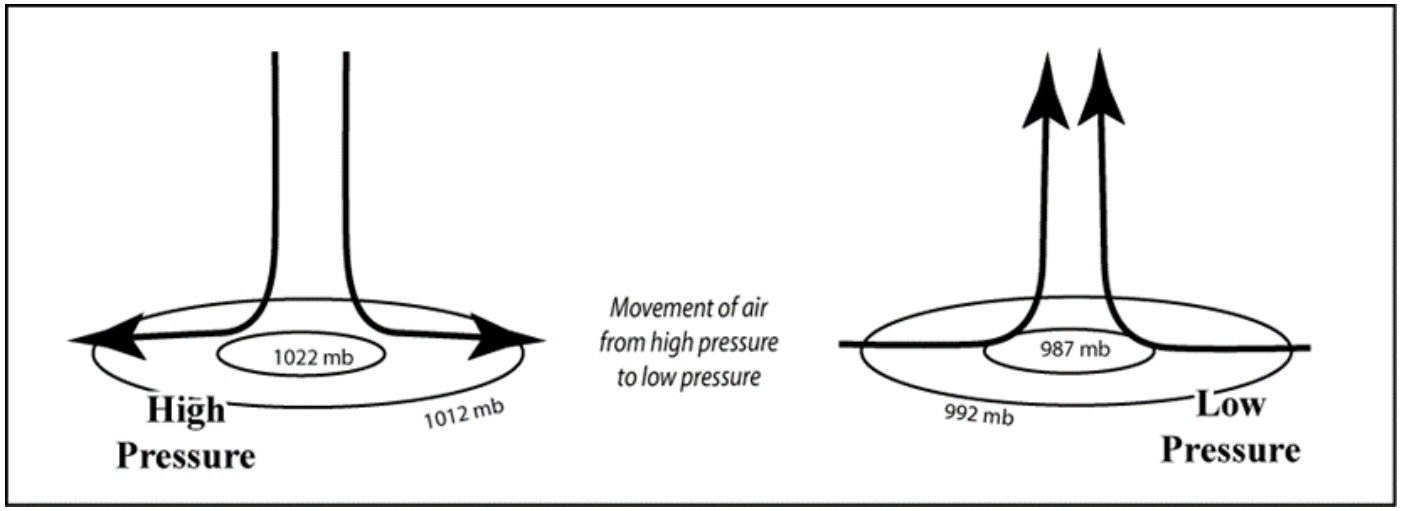


Figure 5.4: Oblique View of Pressure Gradient. Figures by Scott Crosier are licensed under CC BY-NC-SA 4.0

Coriolis Effect

As air moves between high and low pressure areas, it is affected by another important force. Due to the rotation of the Earth, as the atmosphere is moving over the moving surface, winds are deflected to the right in the northern hemisphere (clockwise) and to the left in the southern hemisphere (counterclockwise). This phenomenon is known as the **Coriolis effect**, also called the Coriolis force. The diagram below (Figure 5.5) illustrates the movement over a rotating globe.

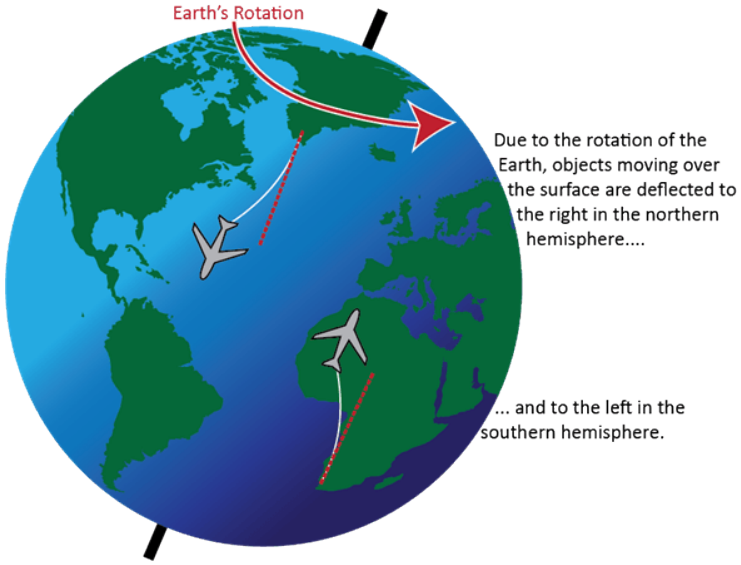


Figure 5.5: Influence of Coriolis Object Moving Over Surface of Earth. Figure by R. Adam Dastrup (Open Geography Education) is licensed under CC BY 4.0



Check It Out! The Coriolis Effect

Watch this brief video from the U.K.'s Meteorological Office to see an experiment that demonstrates how the Coriolis effect works. (Video length is 1:53).

Friction

Upper atmospheric winds, called **geostrophic winds**, are pulled evenly by the pressure gradient and Coriolis effect. So, these high altitude winds typically run parallel to the lines of equal pressure, referred to as isobars. However, within about 30 meters of the surface, **friction** acts to slow the movement of the wind, countering the force of pressure gradient and the Coriolis effect, thus causing the wind to travel diagonally over the isobars, away from a high pressure towards a low pressure system.



Pin It! Four Primary Factors of Atmospheric Circulation

These four factors influence atmospheric circulation:

- Gravity: Keeps air from rushing to higher elevations.
- Pressure Gradient: Air moves away from high pressure towards a low pressure system.
- Coriolis: Due to the rotation of the Earth, objects seem to deflect to the right in the northern hemisphere and to the left in the southern hemisphere.
- Friction: Causes a drag on the movement of air within approximately 30 meters of the Earth's surface; air moves diagonally over the isobars.

In Figure 5.6 you can see how each of these factors influence the movement of air near the surface of the Earth.

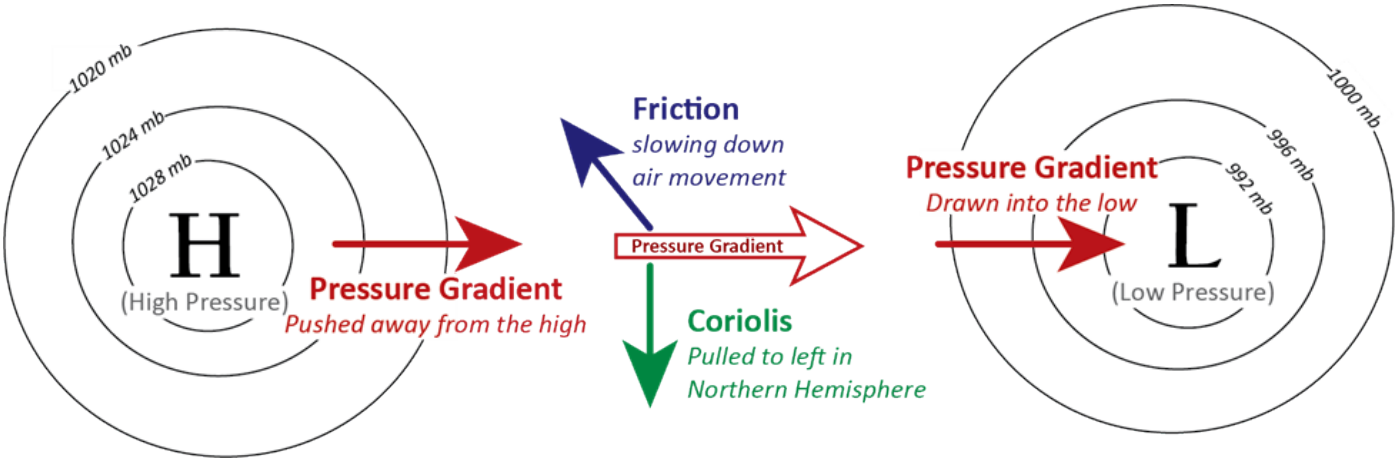


Figure 5.6: The Combined Factors that Influence Wind near the Surface of the Earth. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

As the air moves away from the high pressure system and closer to the low pressure, all three factors have an influence on the air movement. This is illustrated in Figure 5.7.

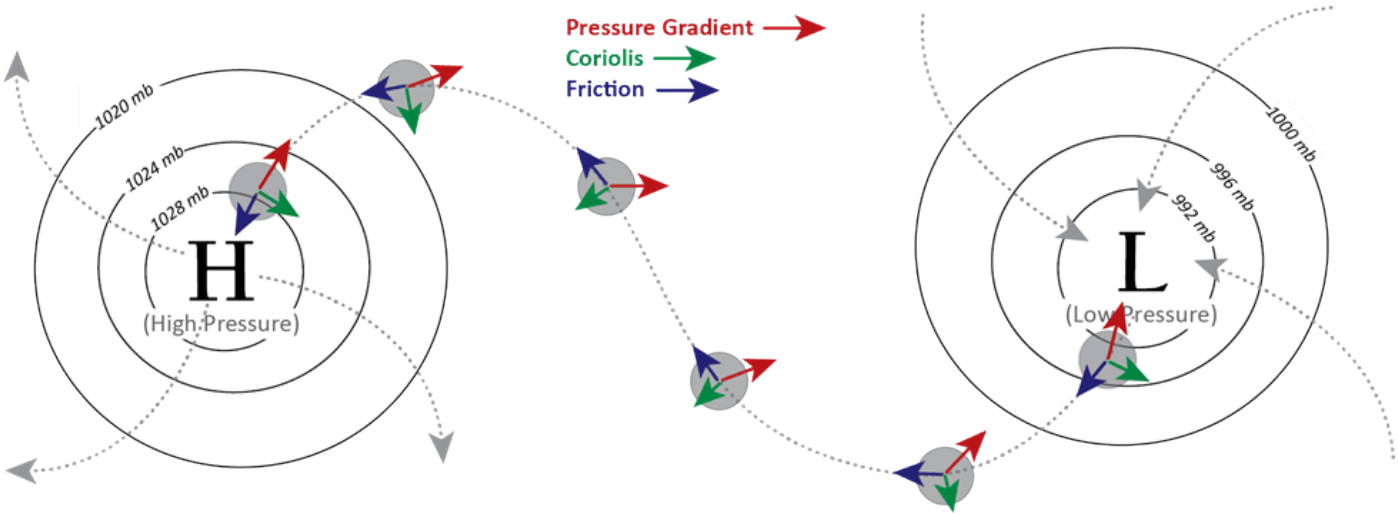


Figure 5.7: Resulting Wind Direction near the Surface of the Earth in the Northern Hemisphere. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

Exercise 1.5.3

8. In Table 5.2, indicate the movement of air in high and low pressure systems for each hemisphere. Fill in the table using one of the two choices given in italics in the far-left column.

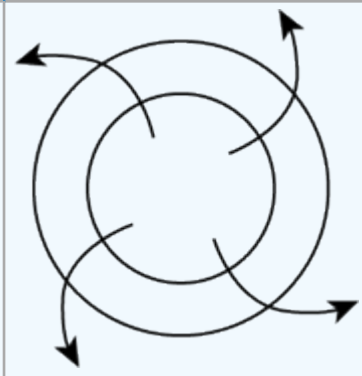
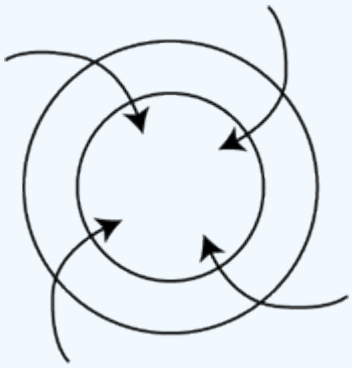
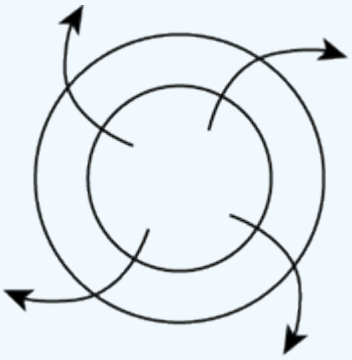
Table 5.2: Movement of Air in Pressure Systems

Location:	Northern Hemisphere High (Anticyclonic)	Northern Hemisphere Low (Cyclonic)	Southern Hemisphere High (Anticyclonic)	Southern Hemisphere Low (Cyclonic)
Surface air moves into or out of:				
Surface air will rise or subside in the center:				

Location:	Northern Hemisphere High (Anticyclonic)	Northern Hemisphere Low (Cyclonic)	Southern Hemisphere High (Anticyclonic)	Southern Hemisphere Low (Cyclonic)
Surface air motion is clockwise or counterclockwise:				

9. The circles represent isobars on the diagrams shown in Table 5.3 . The arrows represent the surface wind direction. In the center of each system, write an “H” or “L,” indicating a high or low pressure system. In the space below each diagram, indicate if it represents a system in the Northern or Southern hemisphere.

Table 5.3: Surface Pressure Systems

Questions	Diagram A	Diagram B	Diagram C	
High or Low Pressure?				
Northern or Southern Hemisphere?				

10. On Figure 5.8, label the center of the high with an “H” and the center of the low with an “L. Then draw arrows showing the direction of air movement within each of the pressure areas, and then draw a single arrow showing the direction of the surface air movement between these two pressure areas. Assume they are in the Northern Hemisphere.

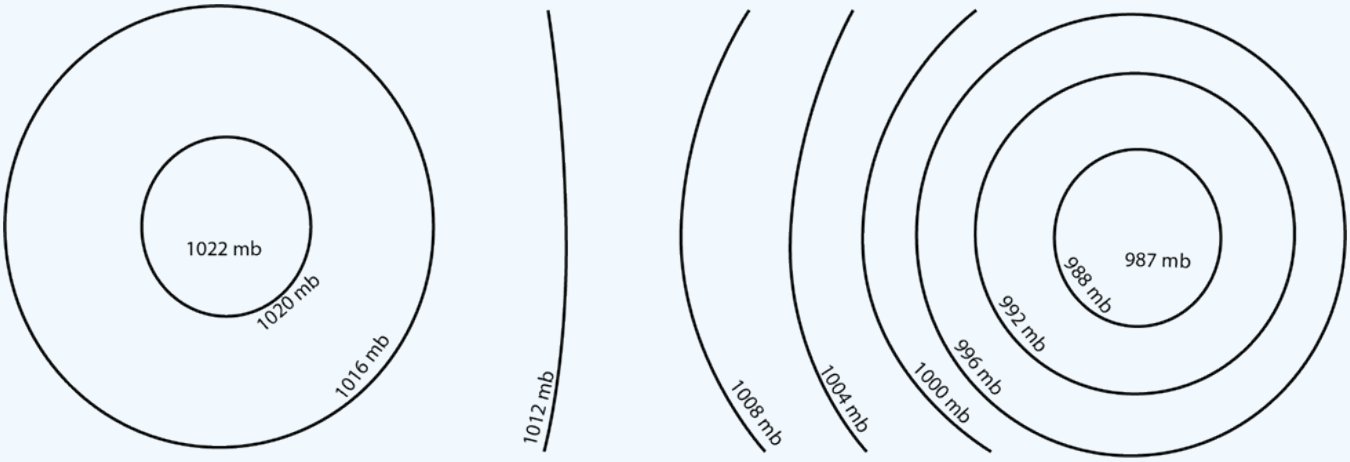


Figure 5.8: Pressure Gradient, Coriolis Effect, and Friction in the Northern Hemisphere. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

Part D. The Global Circulation Model

Before we take a look at the components of global atmospheric circulation, it will be helpful for you to know the terminology related to the latitudinal zones (Figure 5.9). When discussing the major wind patterns across the Earth, these latitudinal zones are

referenced frequently.

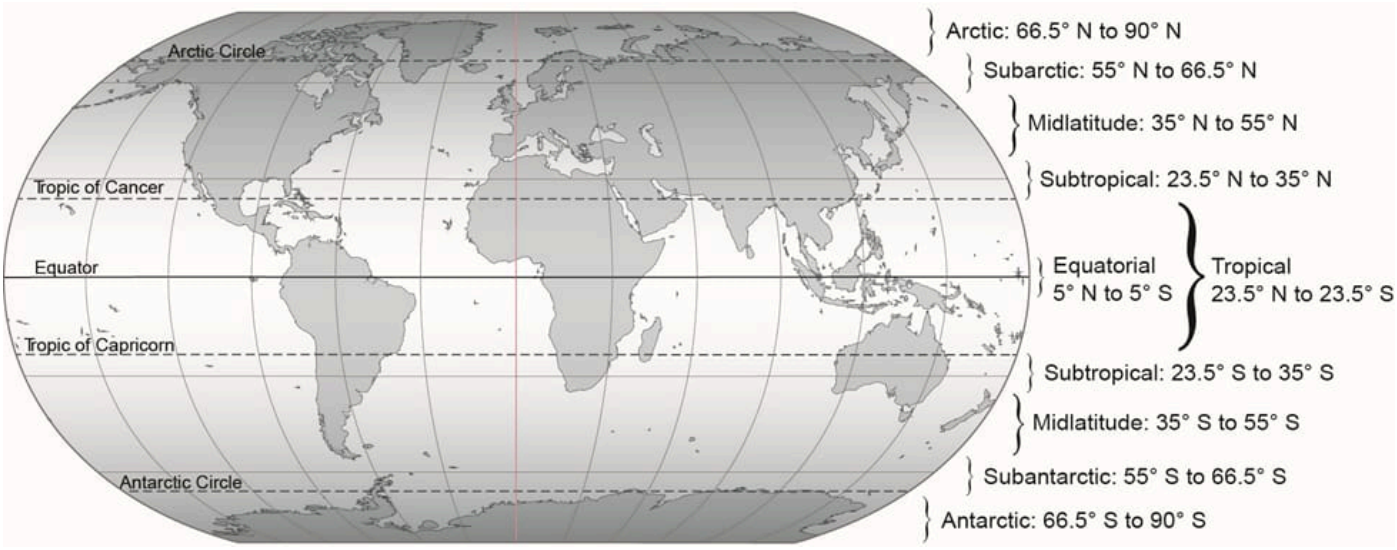


Figure 5.9: Latitudinal Zones. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

Exercise 1.5.4

11. Refer to Figure 5.9.
    a. What is the range of latitudes for the tropical latitudinal zone?
    b. In the northern hemisphere, what is the range of latitudes for the subtropical latitudinal zone?
    c. In the northern hemisphere, what is the range of latitudes for the midlatitude latitudinal zone?
    d. In the northern hemisphere, what is the range of latitudes for the subarctic latitudinal zone?
    e. In the northern hemisphere, what is the range of latitudes for the arctic latitudinal zone?

You learned that warm, rising air can cause a low pressure system and that cool, subsiding air can cause a high pressure system. These pressure systems, developed because of the temperature of the air mass, are referred to as thermal pressure systems. Across the Earth, there are two major thermal pressure systems. Because of the more direct solar energy near the equator, warm air rises, creating a thermal low pressure system. At the polar regions, cool air subsides, creating a thermal high pressure system.

The second factor affecting surface air pressure patterns is more complicated and has more to do with conditions in the upper atmosphere. Simply stated, sometimes pressure conditions cause air to be “pushed downward” on the lower atmosphere, thereby creating a dynamic high pressure area at the surface. This dynamic high pressure system is found at approximately 25 to 35 degrees north and south latitude and is what causes the deserts surrounding the Earth in the subtropics.

At higher latitudes, cold, dry air from the polar region collides with warmer, more humid air from the midlatitudes. The warmer, less dense air is forced upwards. At the same time, upper atmospheric conditions are such that air from the lower atmosphere is allowed to rise upwards. This creates a dynamic low pressure area at the surface at approximately 55 to 66.5 degrees north and south latitude.

Exercise 1.5.5

12. Based on what you know about the global circulation model, complete Table 5.4. You may need to refer to your lecture notes or your textbook, or watch the Guided Practice video.

Guided Practice: Global Circulation Model

Go step-by-step through the components of global atmospheric circulation with this video from Scott's Geography Notebook, Global Circulation Model. (Video length is 13:27).

Table 5.4: Four Hemispheric Pressure Areas

Name	Pressure (High or Low)	Thermal or Dynamic	Latitude	General Air Temp (Hot, Warm, Cool or, Cold)	Air Moisture (Humid or Dry)
Polar					
Subpolar					
Subtropical					
Equatorial					

13. Using the simplified drawing of the Earth below (Figure 5.10), use arrows along the outside edge of the globe to diagram the vertical movement of air within pressure systems (rising off or subsiding down to the surface) as well as the movement of wind between the global pressure systems.

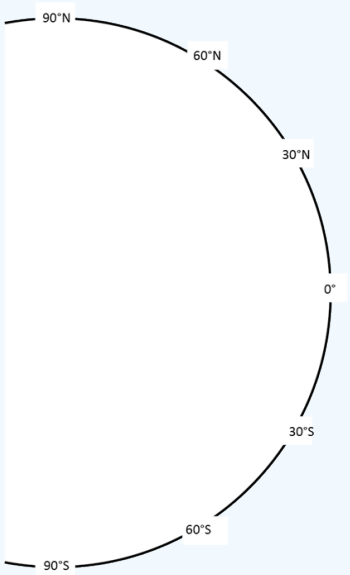


Figure 5.10: Global Pressure Systems. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

The predominant pressure systems found in the Pacific have an impact on California's weather systems. The low pressure region over the Aleutian Islands is referred to as the "Aleutian Low" while the high pressure region over Hawaii is referred to as the "Pacific High".

To answer the following questions, refer to the global barometric pressure maps for January (Appendix 5.3) and July (Appendix 5.1). Your professor may require you to use Google Earth to access these maps. The instructions on how to do this are available in Appendix 5.5.

Exercise 1.5.6

14. Which of the four hemispheric pressure areas do you see offshore in the Pacific Ocean near California on the July map?
15. On the January map, which of the four hemispheric pressure areas is located near the Aleutian Islands?

Prevailing Winds

Now that you have learned of the major pressure systems at different latitudes, you will now explore how these pressure systems contribute to larger, global patterns of wind referred to as prevailing winds. Figure 5.11 is a simplified drawing of the Earth with some predominant latitudes labeled.

Exercise 1.5.7

16. Across the corresponding latitudes on Figure 5.11 below, add several large H's for high pressure systems and several L's for low pressure systems. These will correspond with the global pressure systems you identified in Figure 5.10, above.

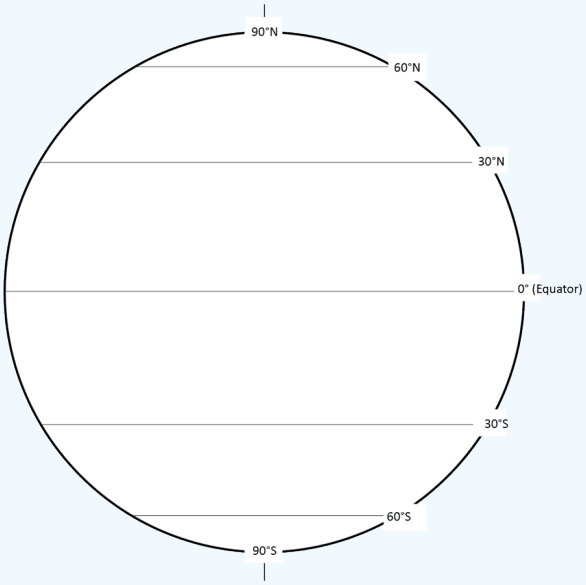


Figure 5.11: Prevailing Winds Across the Earth. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

17. Based on the three main factors of primary circulation (pressure gradient, Coriolis effect, and friction) draw arrows corresponding with the movement of air between the pressure systems on Figure 5.11.
18. Label Figure 5.11 with the following prevailing winds:
    a. Northeast Trade Winds (found in the tropical region of the northern hemisphere)
    b. Southeast Trade Winds (found in the tropical region of the southern hemisphere)
    c. Prevailing Westerlies (found in the midlatitudes of both northern and southern hemisphere)
    d. Polar Easterlies (found in the Arctic and Antarctic latitudinal zones)

The Intertropical Convergence Zone (ITCZ)

Your completed Figure 5.11 shows a low pressure at the equator. This simplifies real-world conditions in order to help you understand the prevailing winds. You can advance your understanding by recognizing the following facts:

- Your Figure 5.11 does not include continents and oceans. Continents and oceans have different heat properties that impact atmospheric pressure systems. The topography of continents also impacts atmospheric pressure.

- Because the Earth is tilted, there are seasonal differences that cause atmospheric pressure systems to shift.

Rather than thinking of the equatorial low as a straight line, we can think of it as a zone where winds converge. The **Intertropical Convergence Zone** (**ITCZ**) is the region that circles the Earth, near the equator, where the trade winds of the Northern and Southern Hemispheres come together (Figure 5.12). The intense sun and warm water of the equator heats the air in the ITCZ, raising its humidity and making it buoyant. Aided by the convergence of the trade winds, the buoyant air rises. As the air rises it expands and cools, releasing the accumulated moisture in an almost perpetual series of thunderstorms. Seasonal shifts in the location of the ITCZ drastically affect rainfall in many equatorial nations, resulting in the wet and dry seasons of the tropics rather than the cold and warm seasons of higher latitudes. Long-term changes in the ITCZ can result in severe droughts or flooding in nearby areas.[81]

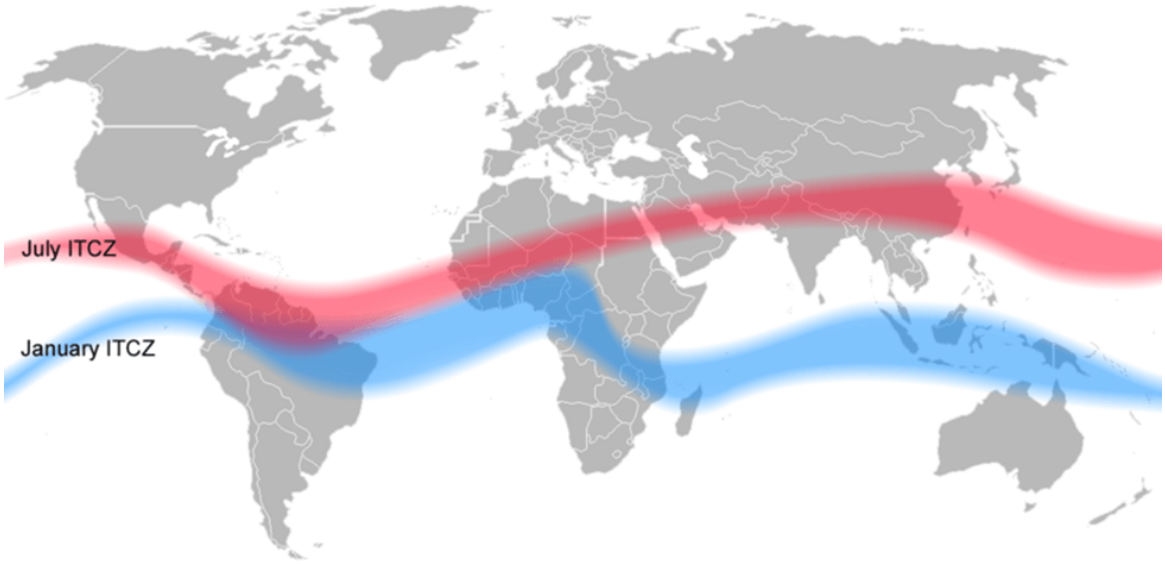


Figure 5.12: The January and July Positions of the ITCZ. Figure by Mats Halldin is in the public domain

Exercise 1.5.8

19. Refer to Figure 5.12.

    a. Apply What You Learned: Why do you think that the ITCZ shifts to the north in July and shifts to the south in January? Hint: consider the Annual March of the Seasons and where higher levels of insolation would cause air to warm and rise. Explain your response in one to two sentences.

    b. Use Your Critical Thinking Skills: How does the shifting ITCZ affect the prevailing winds? Explain your response in one to two sentences.

Part E. Global Pressure and Temperature Patterns

Exercise 1.5.9

20. Using the data provided on the July global air pressure and temperature maps (Appendix 5.1 and 5.2, respectively) record the needed data in Table 5.5. Note that you are collecting temperature and pressure along 140°W, from the north to the south. (A few of the data values have been provided). Your professor may require you to use Google Earth to access these maps. The instructions on how to do this are available in Appendix 5.5.

Table 5.5: July Temperature and Pressure Along 140°W

Coordinates	July Temp (°C)	July Pressure
80°N, 140°W	~ 0	~ 1011
60°N, 140°W	~ 6	~ 1014
40°N, 140°W	~ 16	~ 1024
20°N, 140°W		
0°N, 140°W		
20°S, 140°W		
40°S, 140°W		
60°S, 140°W		
80°S, 140°W		

21. Plot the pressure and temperature trends along 140° W longitude on the graph provided below (Figure 5.13). Use a green pencil to plot air pressure values using the left-hand vertical axis and then draw a green line connecting the points. Then use a red pencil to plot temperature values using the right-hand vertical axis on each graph and then draw a red line connecting the points.

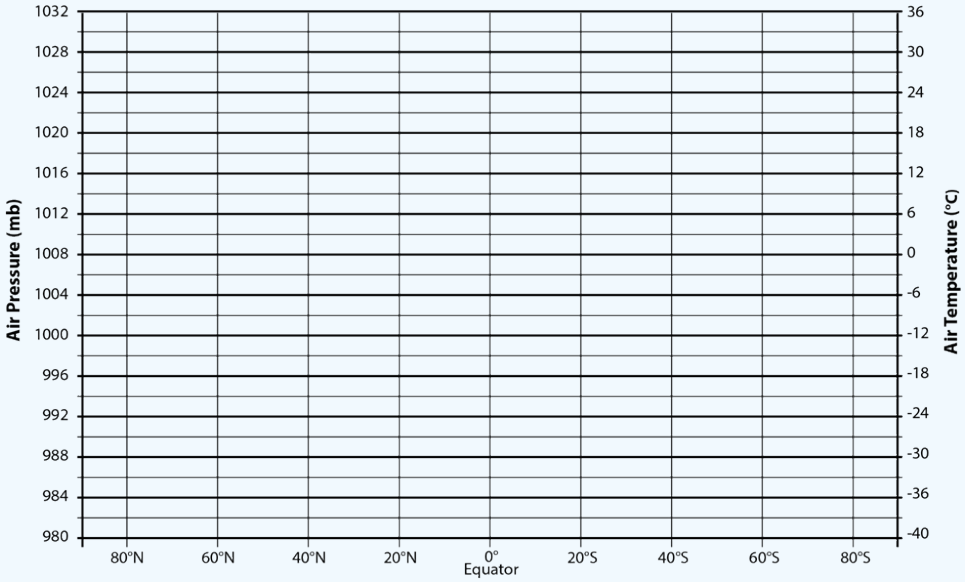


Figure 5.13: Air Pressure and Temperature Along 140°W. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

22. In two to three sentences, describe the overall pattern of temperature when looking from pole to pole.

23. What overall pattern do you observe with air pressure? Describe the pattern in one to two sentences.

24. You will find two latitudes with slightly higher pressure than the surrounding latitudes. What global pressure systems do these represent?

25. On the map, you will find significantly high pressure over Antarctica. What global pressure system does this represent?

26. Using the data provided on the January global air pressure and temperature maps (Appendix 5.3 and 5.4, respectively) record the needed data in Table 5.6. Note that you are now collecting temperature and pressure along 60°N, from the western hemisphere, across the globe to the eastern hemisphere. (A few of the data values have been provided). Your professor may require you to use Google Earth to access these maps. The instructions on how to do this are available in Appendix 5.5.

Table 5.6: January Temperature and Pressure Along 60°N

Coordinates	Jan Temp (°C)	Jan Pressure	Land or Sea?
60°N, 160°W	~ -13	~ 1001	Land
60°N, 140°W	~ -14	~ 1006	Land
60°N, 120°W	~ -22	~ 1016	Land
60°N, 100°W	~ -27	~ 1015	Land
60°N, 80°W	~ -25	~ 1006	Sea
60°N, 60°W			
60°N, 40°W			
60°N, 20°W			
60°N, 0°			
60°N, 20°E			
60°N, 40°E			
60°N, 60°E			
60°N, 80°E			
60°N, 100°E			
60°N, 120°E			
60°N, 140°E			
60°N, 160°E			
60°N, 180°E			

27. Plot the pressure and temperature trends along 60°N latitude on the graph provided in Figure 5.14. Use a green pencil to plot air pressure values using the left-hand vertical axis and then draw a green line connecting the points. Then use a red pencil to plot temperature values using the right-hand vertical axis on each graph and then draw a red line connecting the points.

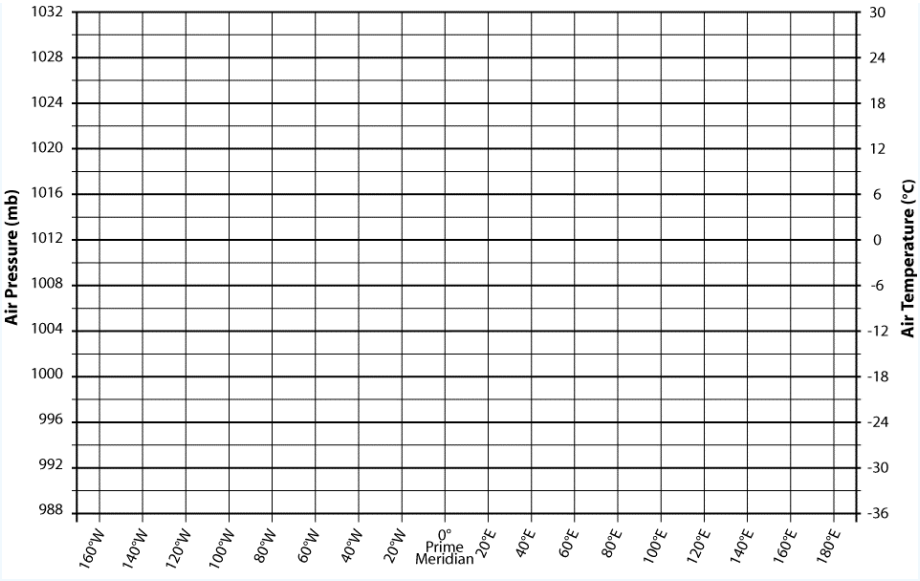


Figure 5.14: January Temperature and Pressure Along 60°N. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

28. In one to two sentences, describe the overall pattern of the temperature along 60°N latitude.

29. Use Your Critical Thinking Skills: You will note some significant patterns regarding land masses and temperature. What relationship does your data suggest between land versus water and temperature in the northern hemisphere winter? Explain why in one to two sentences.

30. What is the general relationship you observe between global air pressure and temperature values? Explain this relationship in one to two sentences.

Refer back to the pressure maps for January and July (Appendix 5.3 and 5.1, respectively). Notice that in some locations the isobars are very close to each other. In other areas, the isobars are far apart. When the isobars are close to one another, this indicates a stronger pressure gradient, resulting in stronger winds. Where the isobars are spaced further apart, there is a less severe pressure gradient, resulting in lighter winds.

31. Which general locations would have the strongest winds in January?

32. Which general locations would have the strongest winds in July?

Part F. Local and Regional Wind Patterns

Up to now, you have looked at larger, global scale pressure systems and their related wind patterns. There are, however, several local and regional wind patterns that are important to understand.

Onshore and Offshore Breezes

In the previous section, you observed the temperature differences between land and water. Although your observations were global and making observations between seasons, the same differences in land-water temperatures can be observed locally, and on a day versus night (diurnal) cycle. This difference is observed in many coastal areas.

Although exposed to the same amount of solar energy, land masses become warmer than water during the day. This causes the overlying air to become warmer. This warmer air begins to rise, creating a slight low pressure system. This draws air in, off of the ocean. These are referred to as **onshore breezes.** Inversely, at night, the temperature of the land mass cools more than the water. The overlying air also cools and subsides, creating slightly higher pressure over the land. This higher pressure over the land mass causes the wind to blow off shore, referred to as **offshore breezes**.

Exercise 1.5.10

33. In the diagrams below (Figure 5.15), draw lines indicating the movement of air in the coastal areas. Label either an H (high) or L (low) above the land and water in both diagrams. Also label each diagram as either onshore breezes or offshore breezes.

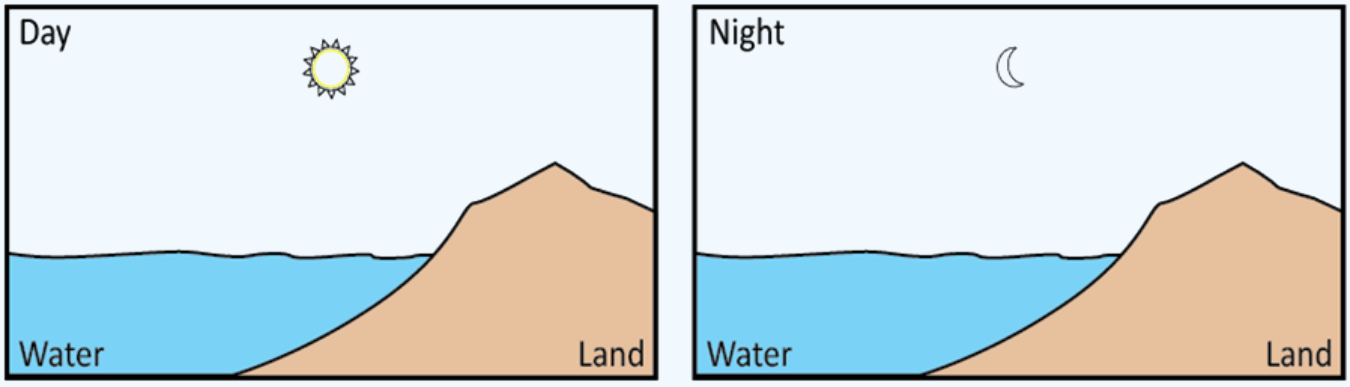


Figure 5.15: Diurnal Cycles of Onshore and Offshore Breezes. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

34. Apply What You Learned: Imagine you are standing on Stern's Wharf in Santa Barbara, CA (34.41°N, 119.68°W) on a July afternoon. Would you expect the wind to be blowing towards the land or towards the ocean? Explain your answer in one to two sentences.

35. Apply What You Learned: Now imagine that you are camping on Angel Island State Park, in San Francisco Bay (37.87° N, 122.43° W). You wake up just before sunrise. Would you expect the wind to be blowing towards the Golden Gate Bridge (towards the ocean) or towards Richmond and the rest of California? Explain your response in one to two sentences.

Mountain/Valley Breezes

Another diurnal pattern that can be observed throughout California are mountain/valley breezes. During the day, the sun on the slope of a mountain will warm the surface and the overlying air. This warmer air begins to rise, pulling with it some of the lower lying air from the valley floor. This causes a general movement of air up the slope and canyons during the daytime; these are called **valley breezes**. At night, the rarified air at higher elevations cools more quickly than the air down on the valley floor. This cooler air becomes more dense and begins to sink down the side of the slope. This creates downslope breezes called **mountain breezes**.

Exercise 1.5.11

36. In the diagrams below (Figure 5.16), draw lines indicating the movement of air in the mountain and valley areas. Label each diagram as either valley breezes or mountain breezes.

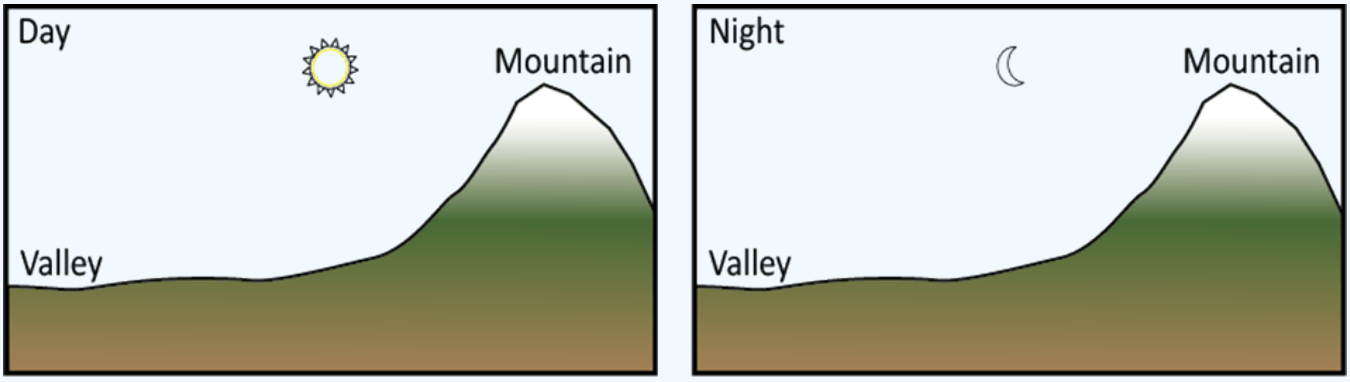


Figure 5.16: Diurnal Cycles of Mountain/Valley Breezes. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

37. Use Your Critical Thinking Skills: If there were a forest fire burning on the slope of the hill, what impacts might a mountain/valley breeze have on the fire? In two to three sentences, discuss the conditions during daytime and night time.

Santa Ana Winds

Southern California often experiences a regional wind pattern referred to as **Santa Ana winds**, also known as the Santa Anas. These winds are the result of seasonal pressure systems, elevation in the desert regions of Nevada and Eastern California, mountains surrounding Southern California, and the influence of the ocean.

Typically between March and October, there is periodically a cooler air mass that settles over central Nevada. Although still fairly dry, this cooler air is more dense, resulting in a high pressure system over Nevada. This can, at times be compounded with a low pressure system over the Pacific, generating a significant pressure gradient.

The situation however is compounded with the air moving over the Transverse Range and the Peninsular Range which surround Southern California. As the air moves from the high (elevation) desert and then down the slopes and through the canyons of the Southern California mountains, the air is heated by compression (Figure 5.17). This heating also decreases the relative humidity of the air, which makes these winds very dry. The arrows on Figure 5.16 indicate air movement over the Transverse and Peninsular Ranges. Air descends towards coastal valleys and basins (represented by the arrow labeled with “Air Warmed By Compression”) which results in warm, dry Santa Ana winds across the coastal valleys and basins.

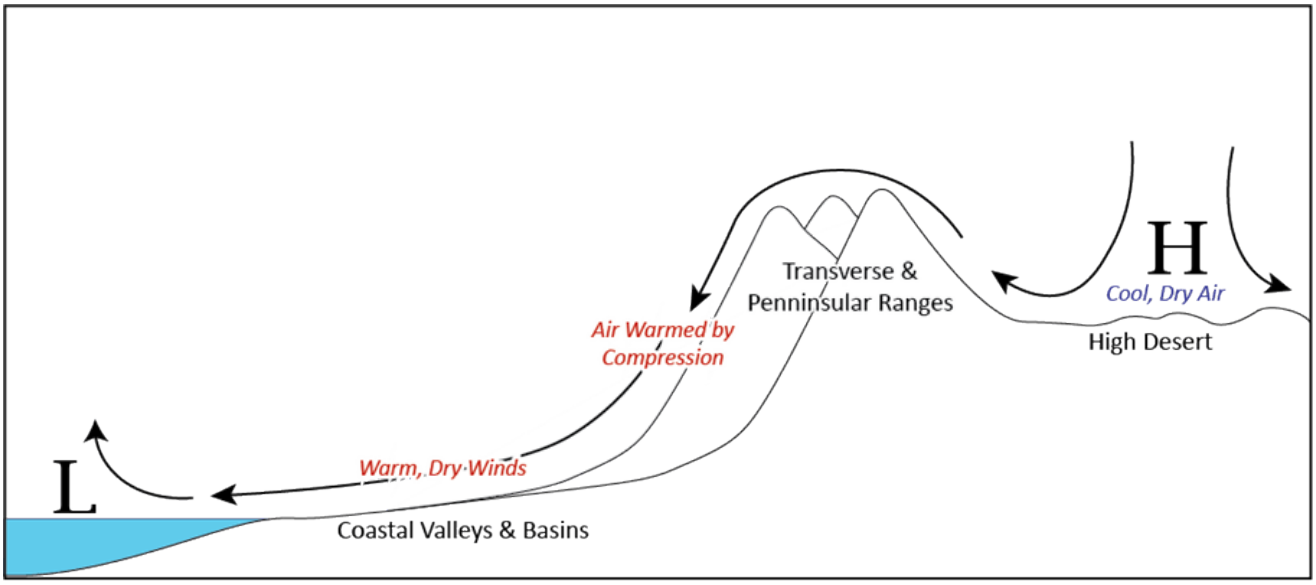


Figure 5.17: Air Heated by Compression in Santa Ana Conditions. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

The end result for Southern California is a seasonal hot and dry strong wind. Unfortunately, this also often occurs after the long dry summers and exacerbates the fire season of Southern California.

Exercise 1.5.12

38. On the map provided in Figure 5.18, draw lines indicating the flow of wind in the diagrammed Santa Ana conditions. Note: the winds will be more likely to move through passes and canyons.



Figure 5.18: Conditions Present for Santa Ana Winds. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

39. Based on the map provided in Figure 5.18, what natural areas (forests, grasslands, etc.) are most susceptible to Santa Ana winds in California? Your response should be two to three sentences in length.

Monsoonal Winds

When you hear the word monsoon, images of floods and torrential rains may come to mind. But monsoons can also include intense periods of dryness. A **monsoon** is a seasonal change in wind and rain patterns observed in certain parts of the world. The changes are driven by seasonal shifts in the temperature differences between the ocean and land. Across the Indian subcontinent and Southeast Asia, the summer and winter monsoons dominate the region's climate. Between April and September, warm land temperatures drive pressure patterns and winds that draw in moist air from the Indian Ocean, producing heavy rainfall (Figure 15.19, top). During the winter months, the winds move in the opposite direction, blowing cool air over land toward the ocean, leading to very dry conditions (Figure 15.19, bottom).[89]

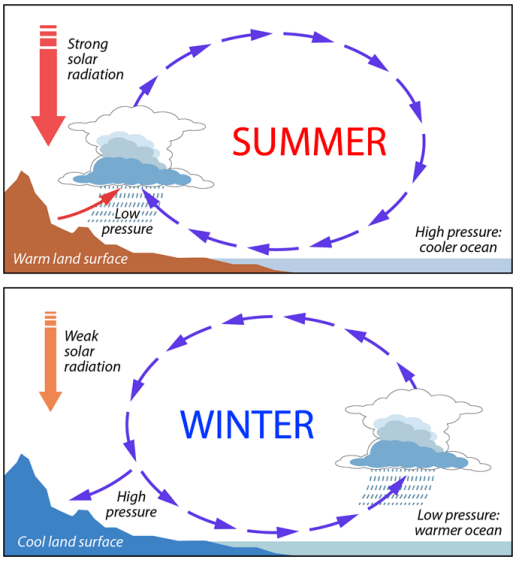


Figure 5.19: The Monsoons (Seasonal Reversal Winds). Figure by Waverly Ray is adapted from The GLOBE Program is licensed under CC BY-NC-SA 4.0

Dr. Angela Rowe writing for The GLOBE Program (2011, n.p.) explains that "the most well-known monsoon occurs in Asia, where

the high elevations of the Tibetan Plateau, extending, on average, over 5,000 meters (~16,404 feet) in height above sea level, enhance the temperature difference between land and water. The Asian monsoon influences a large percentage of Asia" (Figure 5.20).

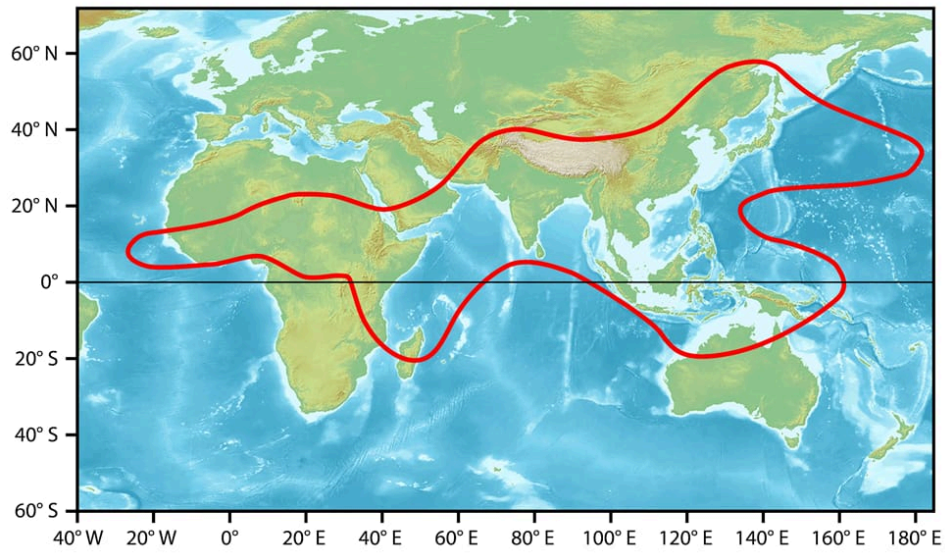


Figure 5.20: Classic Monsoon Distribution Map. Figure by Waverly Ray adapted from demis.nl is licensed under CC BY-NC-SA 4.0

Check It Out! Monsoons: Wet, Dry, Repeat...

Check out this video, Monsoons: Wet, Dry, Repeat..., from NASA's Goddard Space Flight Center for a quick introduction to the variables that influence the monsoons. (Video length is 3:31).

The monsoon is a familiar pattern in middle latitudes, occurring alongside seasonal shifts in atmospheric circulation patterns. In 2020, the low-pressure systems of Asia's summer monsoon were especially strong and stationary, allowing them to pick up even more moisture from the Indian and Pacific oceans and deliver it to land. Rainfall that accompanies Asia's summer monsoon plays an important role in the region's economy by refilling aquifers, generating hydroelectric energy, and providing water for crops. In some years, however, the amount of rainfall breaks records in certain areas. That was the case in 2020. By mid-July, severe flooding affected millions of people across South and East Asia. Figure 5.21 shows the rainfall accumulation across the region from June 1 (the start of the summer monsoon season) to July 20, 2020. The data are remotely-sensed estimates that come from the Integrated Multi-Satellite Retrievals for GPM (IMERG), a product of the Global Precipitation Measurement (GPM) mission. The darkest reds indicate places where GPM detected rainfall totals exceeding 100 centimeters (~39 inches) during this period. Due to averaging of the satellite data, local rainfall amounts may be significantly higher when measured from the ground.[92]

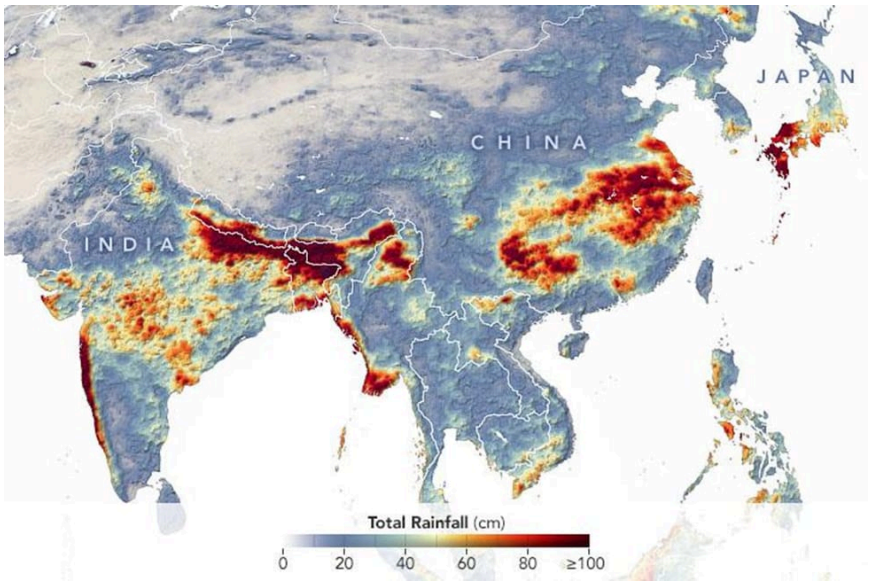


Figure 5.21: Map of Precipitation from June 1 to July 20, 2020. Figure by NASA's Earth Observatory is in the public domain.

Exercise 1.5.13

40. One hundred centimeters is approximately 39 inches. Search the internet to find the annual precipitation for your location. How does the monsoonal precipitation from June 1 to July 20, 2020 shown in the darkest red color on Figure 5.20 compare to the annual precipitation at your location?

41. Apply What You Learned: How would increasing Indian Ocean temperatures influence the monsoons affecting South Asia, Southeast Asia, and East Asia? Explain your response in one to two sentences.

42. Draw and label the January and July positions of the ITCZ on Figure 5.21. Tip: refer to Figure 5.12 (shown earlier in the lab). Use a red pencil for the July ITCZ line and label. Use a blue pencil for the January ITCZ line and label. Use a blue pencil for the January ITCZ line and label. Use a red pencil for the July ITCZ line and label.
43. Draw four arrows across the map that show the direction of the winds. Use a blue pencil for the winds in January and a red pencil for the winds in July.
44. Apply What You Learned: How does the shifting ITCZ influence the monsoons? Explain your response in one to two sentences.

Part G. Wrap-Up

Consult with your geography lab instructor to find out which of the following wrap-up questions you should complete. Attach additional pages to answer the questions as needed.

Exercise 1.5.14

45. What is the most important idea that you learned in this lab? In two to three sentences, explain the concept and why it is important to know.

45. What was the most challenging part of this lab? In two to three sentences, explain why it was challenging. If nothing challenged you in the lab, write about what you think challenged your classmates.

45. What is one question that you have about what you learned in this lab? Write your question along with one to two sentences explaining why you think your question is important to ask.

45. Review the learning objectives on page 1 of this lab. How would you rate your understanding or ability for each learning objective? Write one sentence that addresses each learning objective.

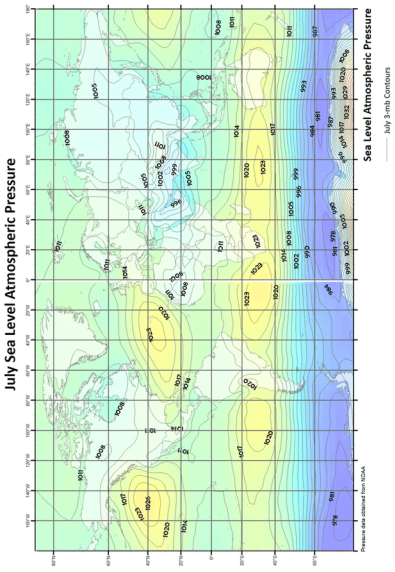
45. Sketch a concept map that includes the key ideas from this lab. Include at least five of the terms shown in bold-faced type.
46. Create an advertisement to educate your peers on the important information that you learned in this lab. Include at least three key terms in your advertisement. The advertisement should be about half a page in size (about 4 inches by 6 inches).
47. One way to think of physical geography is that it is the study of the relationships among variables that impact the Earth's surface. Select two variables discussed in this lab and describe how they are related.

45. How does what you learned in this lab relate to your everyday life? In two to three sentences, explain a concept that you learned in this lab and how it relates to your day-to-day actions.

45. How does what you learned in this lab relate to current events?
    a. Write the title, source, and date of a news item that relates to this lab.
    b. In two to three sentences, discuss how the news item relates to what you have learned in this lab.
    c. In one to two sentences, discuss whether or not the news item accurately represents the science that you learned. Tip: consider whether or not the news item includes the complexity of the topic.

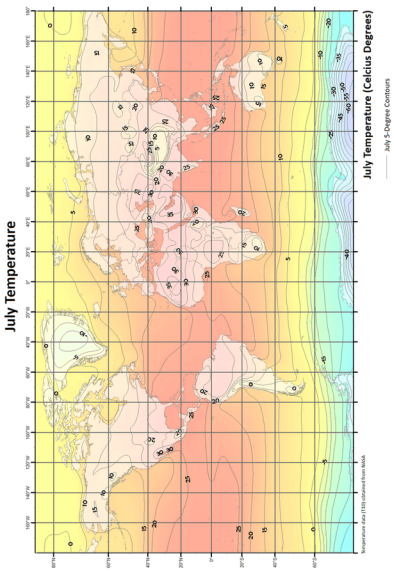
45. Search O*NET OnLine to find an occupation that is relevant to the topics presented in today's lab. Your lab instructor may provide you with possible keywords to type in the Occupation Quick Search field on the O*NET website.
    a. What is the name of occupation that you found?
    b. Write two to three sentences that summarize the most important information that you learned about this occupation.
    c. What is one question that you would want to ask a person with this occupation?

Appendix 5.1: July Atmospheric Pressure Map



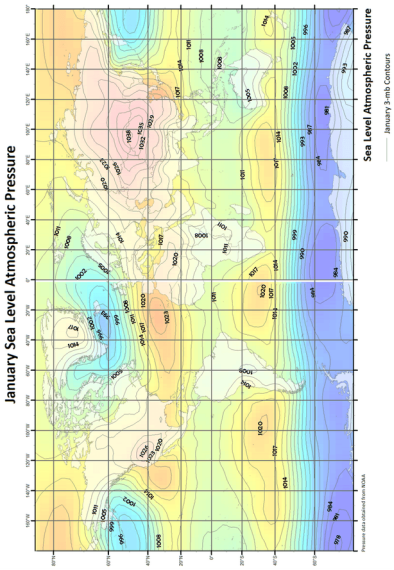
Map by Scott Crosier is licensed under CC BY-NC-SA 4.0

Appendix 5.2: July Temperature Map



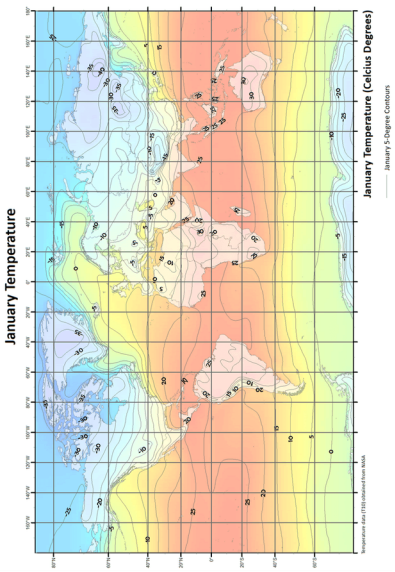
Map by Scott Crosier is licensed under CC BY-NC-SA 4.0

Appendix 5.3: January Atmospheric Pressure Map



Map by Scott Crosier is licensed under CC BY-NC-SA 4.0

Appendix 5.4: January Temperature Map



Map by Scott Crosier is licensed under CC BY-NC-SA 4.0

Appendix 5.5: Accessing Atmospheric and Temperature Maps in Google Earth

Guided Practice: Using kmz Files in Google Earth

Go through the steps to download kmz files and upload them in this video, Using a KML File in Google Earth. (Video length is 2:26).

Step 1

Go to the google drive folder called “Lab 5. kmz files (Atmospheric Pressure and Wind)”.

Step 2

Download the kmz files to your computer. Right-click on the file, then select Download. Click Save File, then Okay. Select the folder where you want to save the kmz file, then click Save. Repeat this for all four files in the google drive folder.

Step 3



Go to the Google Earth website.

Step 4

Click the Launch Earth button.

Step 5

On the left-side of your screen, click on the three horizontal lines.

Step 6

Click on Projects.

Step 7

Click New Project, then click on Open, and then select Import KML file from computer. Navigate to the location of the kmz files that you downloaded in Step 2 above. Select the first file and then click Open.

Step 8

Return to Projects and repeat Step 7 so that all four kmz files have been added as new projects in Google Earth.

Step 9

To answer the questions in the lab, it is helpful to know the following:

➢ You can move the globe view by clicking and dragging your mouse.

➢ You can "Turn on Gridlines" to view latitude and longitude on the map. Click on the Map Styles icon on the left-hand menu and scroll down to find this toggle button.

➢ You can click on a point to open a pop-up box with the data.

- For the temperature kmz files, temperature is shown in degrees Celsuis.
  - Jan Temp (c) 9 means the average January temperature is 9°C.
- For the pressure kmz files, pressure is shown in millibars.
  - Jan Pressure 1012 means the average January atmospheric pressure is 1012 mb.
- There is also a four-digit reference number shown in the pop-up boxes; you can disregard these numbers.

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[81] Text by NASA's Earth Observatory is in the public domain

[89] Text by NASA is in the public domain

[92] Text by NASA's Earth Observatory is in the public domain

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1.6: Lab 6 - Atmospheric Humidity

Learning Objectives

- Identify the processes that occur when water changes phases.
- Calculate the energy required to change the phase of water.
- Calculate relative humidity and the dew point temperature.
- Use a sling psychrometer to collect field data and interpret psychrometric tables to determine relative humidity and dew point temperature.
- Describe the atmospheric lifting mechanisms.
- Use the adiabatic rates to calculate how air temperatures and relative humidity change when an air parcel goes over an orographic barrier.

Introduction

Water is an amazing substance! It is made of the two most abundant elements in the universe, two hydrogen atoms and an oxygen atom, forming H_2O. More than seventy percent of the Earth's surface is covered with it. We are constantly surrounded with water, in its gaseous form, in the air around us.It can also be found in its liquid form in the ground under our feet as soil moisture and groundwater. Serve yourself a glass of ice water (Figure 6.1). You'll have the only substance on Earth found in all three phases (solid, liquid, and gas) simultaneously.

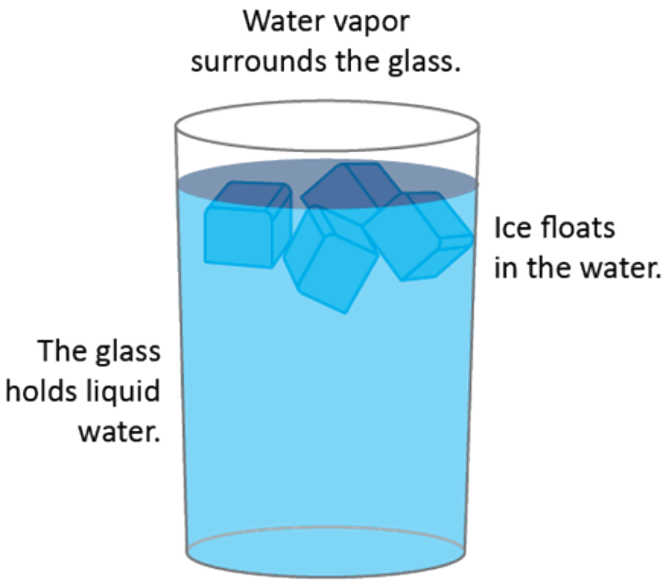


Figure 6.1: Water Can be Found in Three Phases Simultaneously. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

Water is the only substance that is less dense in its solid state than in its liquid state. Ice floats on water. Because of this, life can continue to thrive in our lakes, rivers, and streams that freeze over each winter. Water is a universal solvent. Given enough time, everything will dissolve in water. This not only allows our blood to carry nutrients throughout our body, but water also functions in nature, bringing nutrients to the leaves of plants, transporting minerals across the landscape, and acting as a major erosional process. Water is the basis of life on Earth.

Further, water conserves heat energy much more efficiently than other natural substances such as soil. It requires a much greater amount of energy to change the temperature of water. This is referred to as the specific heat capacity. With our world being 70% covered with water, our oceans have an extraordinary capacity to store and distribute energy.

Water releases a huge amount of energy when it condenses or freezes. Inversely, water absorbs that same, huge amount of energy when it evaporates and melts. This is referred to as latent heat. You will learn much more about latent heat below.

Part A. The Many Forms of Water

As mentioned previously, water is found naturally in three different phases. You will be exploring the processes of phase change and the energy that is related to those phase changes. You are probably already familiar with most of the six phase changes of water:

- Freezing occurs when liquid water transforms into ice.
- Melting occurs when ice transforms into liquid water.
- Evaporation occurs when liquid water transforms into water vapor.
- Condensation occurs when water vapor transforms into liquid water.
- Deposition occurs when water vapor transforms into ice.
- Sublimation occurs when ice transforms into water vapor.

Exercise 1.6.1

1. Label the six phase changes of water on the diagram below (Figure 6.2).

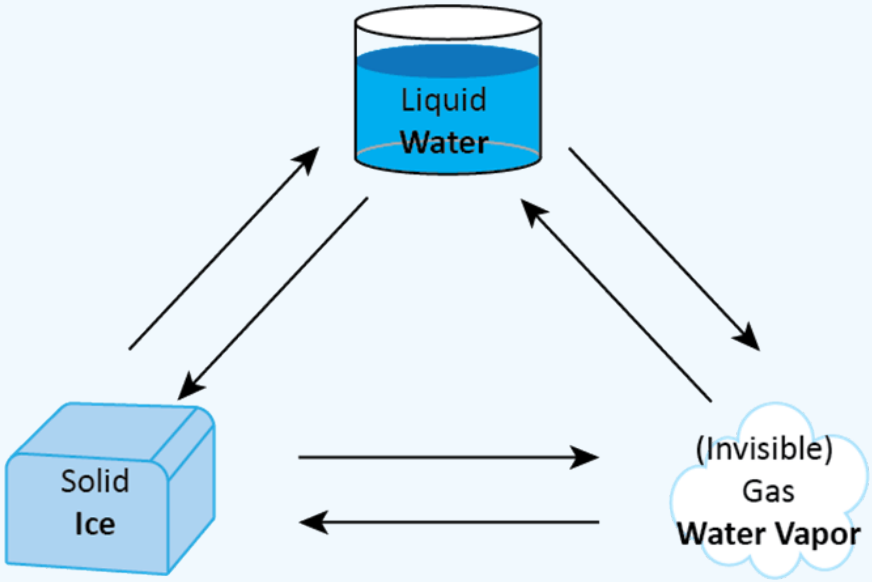


Figure 6.2: Phase Changes of Water. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

What is required to change the phase of water? For each of these steps, there is a significant transfer of energy between the water and the surrounding environment. Let's think of a few examples:

- In the morning you take a warm shower. Some of the warm water evaporated in the bathroom. When you get out of the shower, you find that the cold glass of the mirror has small water droplets all over it. The cold glass absorbed some energy causing water to condense on the surface. **Condensation** releases energy and warms the environment (in this case, the glass).
- Later that day, you injure your knee in a soccer accident. Your coach pulls out a plastic bag, fills it with ice and tells you to sit down and "ice" it. What happens? As the ice begins to melt (changing from a solid to a liquid) it absorbs heat. It makes your knee feel cold because that energy is being absorbed from your knee. So, the process of melting absorbs energy and cools the environment.
- After practice, you head to the nearest river, lake, or beach to cool off. It's several degrees cooler near the water than the soccer field. **Evaporation** absorbs energy and cools the environment.

While these are some common examples, this absorption and release of heat energy by the phase changes of water help regulate temperature and distribute energy from equatorial areas to polar regions.

This transfer of energy between water and the surrounding environment is referred to as **latent heat**. Each phase change of water will either absorb or release latent heat energy. Figure 6.3 outlines the amount of energy required to change the phase of one gram (1 gram of water is equivalent to 1 milliliter or 1 cubic centimeter) of water. Between ice and liquid water, 80 calories are absorbed during melting or released during freezing at 0°C. It takes 100 calories to raise or lower the temperature of water between 0°C and 100°C. Between liquid water and water vapor, 540 calories are absorbed during evaporation or released during condensation.

Exercise 1.6.2

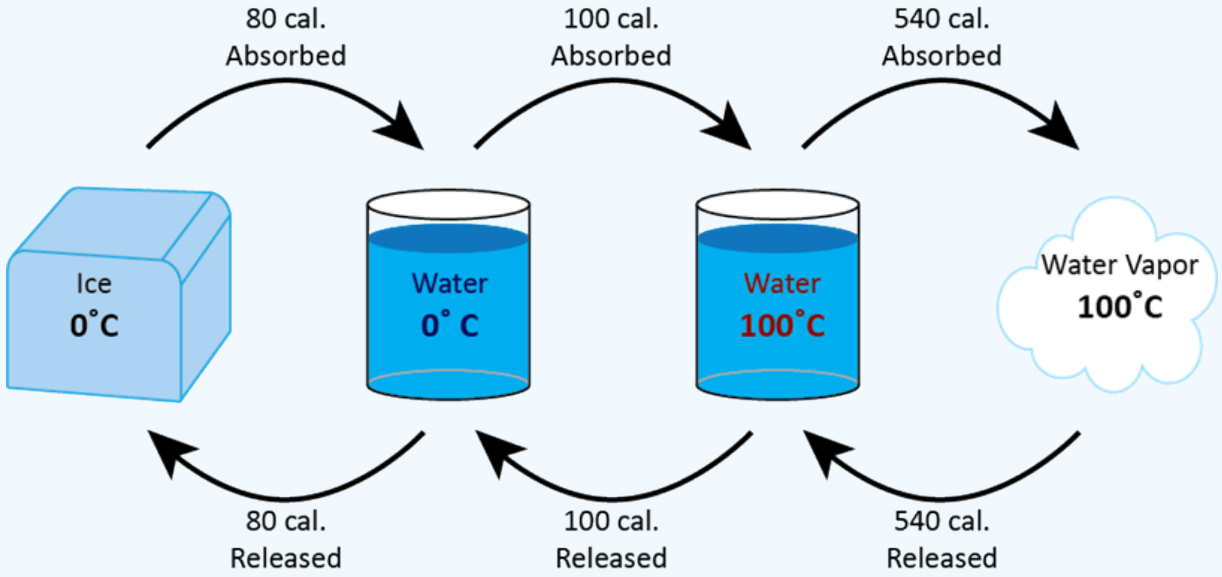


Figure 6.3: Latent Heat Related to Phase Changes of Water. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

2. Using Figure 6.3 above, complete Table 6.1 below. Provide the energy required for one milliliter of water.

Phase Change	Heat Calories Exchanged	Latent energy released or absorbed?	Warming or cooling the surrounding environment?
Solid (0°C) → Liquid (0°C)			
Liquid (0°C) → Solid (0°C)			
Liquid (0°C) → Gas (100°C)			
Gas (100°C) → Liquid (0°C)			
Solid (0°C) → Gas (100°C)			
Gas (100°C) → Solid (0°C)			

Pin It! Latent Heat

Consider the huge amount of energy absorbed and released through evaporation and condensation! This is a major means of storing and transferring energy across our Earth. At the equator, water evaporates and then condenses as it rises. Further, the condensation that takes place in some storms actually causes an additional uplift in the storm. This is particularly true in tropical storms like hurricanes, which you will learn about later in the course.

Part B. Atmospheric Humidity

When we discuss the "humidity of the air," we are typically talking about a calculated value referred to as relative humidity. There are two main variables that are considered when calculating relative humidity. These include specific humidity and the maximum water vapor of the air.

Specific humidity refers to the actual, measurable amount of water vapor in the air. It is the amount of water (in the form of a gas) that would be found if we were able to isolate each of the different types of gasses in the air. The value is usually reported in grams of water vapor per kilogram of air (g H_2O/kg air).

The **maximum water vapor of the air parcel** must also be considered. Think of an **air parcel** as a small box of the atmosphere that is distinct from the atmosphere surrounding it in terms of temperature and humidity. How much water can this air parcel hold? The ability of an air parcel to hold water vapor is a function of the temperature of the air parcel. Warmer air has a greater capacity for holding water vapor, while colder air has a lower capacity. These values are shown in the table on the left in Figure 6.4 below. The maximum water vapor is also reported in grams of water vapor per kilogram of air (g H_2O/kg air).

The more commonly used **relative humidity** is simply the ratio (expressed as a percentage) of the amount of water in an air parcel (the specific humidity), compared to the amount of water an air parcel can hold (the maximum water vapor). The equation used to calculate the relative humidity is as follows:

Relative Humidity = (Specific Humidity / Maximum Water Vapor) X 100



Guided Practice: Calculating Relative Humidity

Watch a tutorial video on how to calculate relative humidity. (Video length is 4:55).

Exercise 1.6.3

3. Based on the data table provided on the left-side of Figure 6.4, plot the maximum water vapor of an air parcel in the blank graph on the right. Connect the points with a solid line.

Temperature (°C)	Max. Water Vapor (g H_2O/kg air)
-40	0.1
-30	0.3
-20	0.75
-10	2
0	3.5
5	5
10	7
15	10
20	14
25	20
30	26.5
35	35
40	47

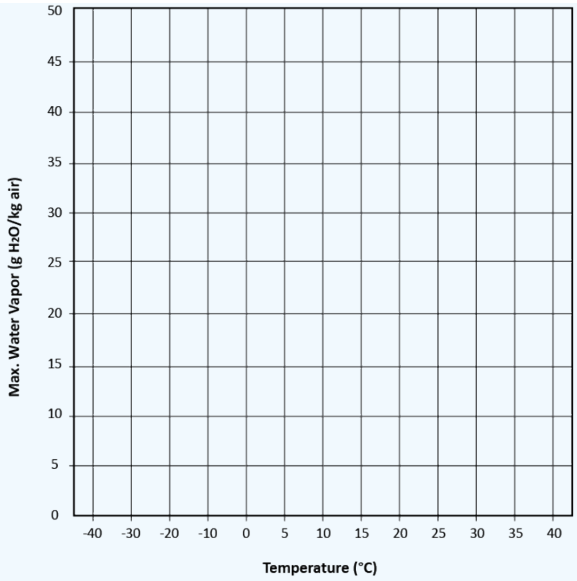


Figure 6.4: Data and Table for Maximum Water Vapor based on Temperature. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

4. Using the data provided and your completed Figure 6.4, answer the following questions:

    a. Just before sunrise, the temperature is 15°C (59°F) with a specific humidity of 8.5 kg H_2O/kg air. Calculate the relative humidity. Show your work.

    b. By 10 am, the temperature has risen to 25°C (77°F). Assume that the specific humidity remains at 8.5 kg H_2O/kg air. Calculate the relative humidity. Show your work.

    c. When the heat of the day strikes at 2 p.m., the temperature has risen to 35°C (95°F). Assume that the specific humidity remains at 8.5 kg H_2O/kg air. Calculate the relative humidity. Show your work.

    d. Santa Barbara has a temperature of 22°C (70°F) and a relative humidity of 60%. What is the specific humidity of the air?

Table 6.2 contains temperature and relative humidity data over the course of three days.

5. Using a red pencil in the blank graph provided below (Figure 6.5), plot the temperature over the three days and connect your plotted points with a solid red line. Repeat the process using a blue pencil for the relative humidity.

Table 6.2: Temperature and Relative Humidity, April 20-22

Date and Time	Temperature (°F)	Relative Humidity (%)
Apr 20, 00:00	65.7	58
Apr 20, 04:00	61.6	47
Apr 20, 08:00	60.3	48
Apr 20, 12:00	74.4	33
Apr 20, 18:00	82.2	19
Apr 20, 20:00	72.9	43
Apr 21, 00:00	60.1	58
Apr 21, 04:00	54	72
Apr 21, 08:00	59.9	62
Apr 21, 12:00	77.3	35

Date and Time	Temperature (°F)	Relative Humidity (%)
Apr 21, 18:00	86.8	23
Apr 21, 20:00	79.6	30
Apr 22, 00:00	64.3	59
Apr 22, 04:00	58.4	69
Apr 22, 08:00	63.4	55
Apr 22, 12:00	79.4	34
Apr 22, 16:00	87.5	18
Apr 22, 20:00	80	21

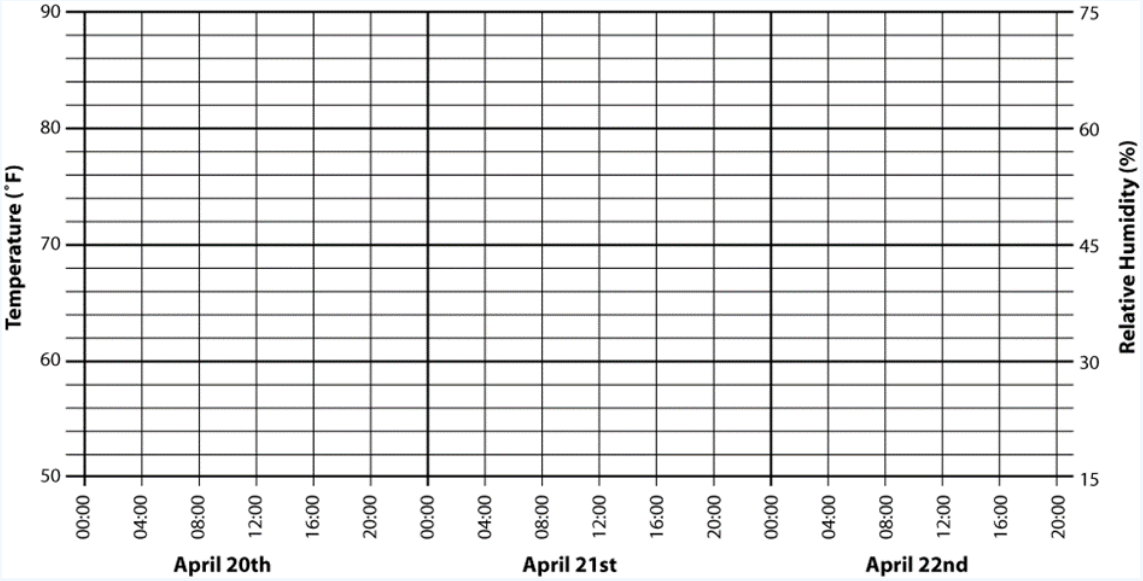


Figure 6.5: Plotted Temperature and Relative Humidity. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

6. Based on the plotted data on Figure 6.5, what time of day would you see the highest relative humidity readings: early morning or late afternoon? Why is this? Explain your response in one to two sentences.

7. What observations can you make regarding the relationship of temperature and relative humidity?

Dew Point Temperature

So far, you have learned about the relationship between temperature and relative humidity. You have noted that as temperature increases, relative humidity decreases. You have discovered that early in the morning, when the temperatures are the lowest, relative humidity is typically at its highest. What would happen if night time temperatures dropped even colder? The relative humidity would increase, but by how much?

Relative humidity can only reach a maximum of 100%. At this point, the air parcel can no longer hold the same amount of water vapor (an invisible gas) and so water droplets begin to form (suspended water droplets in the form of fog or clouds are created by condensation). The temperature at which relative humidity reaches 100% is called the **dew point temperature**.

In order to calculate the dew point temperature, you will still need to know the specific humidity of the air parcel, but your goal is to determine at what temperature the maximum water vapor will be the same as the specific humidity. You will continue to use the plotted data in Figure 6.4 above, but you may find you are using it in the opposite order from your previous use.

Exercise 1.6.4

Let's return to some of the scenarios you were working with before.

8. If the air parcel has a specific humidity at 8.5 kg H_2O/kg air, what is the dew point temperature? Show your work.
9. Santa Barbara has a temperature of 22°C (70°F) and a relative humidity of 60%. What is the dew point temperature of the air? Show your work.
10. Apply What You Learned: If you wake up to a foggy morning, what is the relative humidity? Explain your response in one to two sentences.

Psychrometric Tables and the Sling Psychrometer

One instrument used to measure humidity is called a **psychrometer**. A sling psychrometer has two thermometers mounted together in a manner that they can be swung around or twirled. The two thermometers include one that is simply mounted to the apparatus. This is referred to as the dry bulb thermometer, and is used to measure the ambient (surrounding) air temperature. The second thermometer has a wick that is moistened with water at the ambient air temperature. This is referred to as the wet bulb thermometer. Moisture evaporates from the wick as air is intentionally circulated over it by twirling the psychrometer (the so-called "sling psychrometer"). The latent heat of evaporation from the wick lowers the wet bulb temperature. If the air is dry, there will be a lot of evaporation, lowering the wet bulb temperature. If the air is very humid, there will be very little evaporation and the temperature will not drop far on the wet bulb. The difference between the dry bulb and wet bulb temperatures is called the **wet bulb depression**.

Dry Bulb Temperature \ Wet Bulb Depression	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0
-10.0	85	69	54	39	24	10										
-7.5	87	73	60	48	35	22	10									
-5.0	88	77	66	54	43	32	21	11	1							
-2.5	90	80	70	60	50	42	37	22	12	3						
0.0	91	82	73	65	56	47	39	31	23	15						
2.5	92	84	76	68	61	53	46	38	31	24						
5.0	93	86	78	71	65	58	51	45	38	32	1					
7.5	93	87	80	74	68	62	56	50	44	38	11					
10.0	94	88	82	76	71	65	60	54	49	44	19					
12.5	94	89	84	78	73	68	63	58	53	48	25	4				
15.0	95	90	85	80	75	70	66	61	57	52	31	12				
17.5	95	90	86	81	77	72	68	64	60	55	36	18	2			
20.0	95	91	87	82	78	74	70	66	62	58	40	24	8			
22.5	96	92	87	83	80	76	72	68	64	61	44	28	14	1		
25.0	96	92	88	84	81	77	73	70	66	63	47	32	19	7		
27.5	96	92	89	85	82	78	75	71	68	65	50	36	23	12	1	
30.0	96	93	89	86	82	79	76	73	70	67	52	39	27	16	6	
32.5	97	93	90	86	83	80	77	74	71	68	54	42	30	20	11	1
35.0	97	93	90	87	84	81	78	75	72	69	56	44	33	23	14	6
37.5	97	94	91	87	85	82	79	76	73	70	58	46	36	26	18	10
40.0	97	94	91	88	85	82	79	77	74	72	59	48	38	29	21	13

Table 6.3: Relative Humidity Psychrometric Table

Dry Bulb Temperature	Wet Bulb Depression															
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0
-10.0	-12	-14	-18	-21	-27	-36										
-7.5	-9	-11	-14	-17	-20	-26	-34									
-5.0	-7	-8	-10	-13	-16	-19	-24	-31								
-2.5	-4	-6	-7	-9	-11	-14	-17	-22	-28	-41						
0.0	-1	-3	-4	-6	-8	-10	-12	-15	-19	-24						
2.5	1	0	-1	-3	-4	-6	-8	-10	-13	-16						
5.0	4	3	2	0	-1	-2	-4	-6	-8	-10	-48					
7.5	6	6	4	3	2	1	-1	-2	-4	-6	-22					
10.0	9	8	7	6	5	4	2	1	0	-2	-13					
12.5	12	11	10	9	8	7	6	4	3	2	-7	-28				
15.0	14	13	12	12	11	10	9	8	7	5	-2	-14				
17.5	17	16	15	14	13	12	12	11	10	8	2	-7	-35			
20.0	19	18	18	17	16	15	14	14	13	12	6	-1	-15			
22.5	22	21	20	20	19	18	17	16	16	15	10	3	-6	-38		
25.0	24	24	23	22	21	21	20	19	18	18	13	7	0	-14		
27.5	27	26	26	25	24	23	23	22	21	20	16	11	5	-5	-32	
30.0	29	29	28	27	27	26	25	25	24	23	19	14	9	2	-11	
32.5	32	31	31	30	29	29	28	27	26	26	22	18	13	7	-2	
35.0	34	34	33	32	32	31	31	30	29	28	25	21	16	11	4	
37.5	37	36	36	35	34	34	33	32	32	31	28	24	20	15	9	0
40.0	39	39	38	38	37	36	36	35	34	34	30	27	23	18	13	6

Table 6.4: Dew Point Temperature Psychrometric Table

With the help of a psychrometer, data has been collected around California. Table 6.5 below contains the dry bulb and wet bulb temperatures for locations around California.

Exercise 1.6.5

11. Complete Table 6.5. Tip: the wet bulb depression is simply the difference between the dry bulb temperature and the wet bulb temperature.
    a. Use the psychrometric tables above to determine the relative humidity and the dew point temperature for each location. Along the left axis, find the temperature closest to the dry bulb temperature. Along the top, find the closest wet bulb depression value. If your exact depression value is not listed, you may need to estimate your value between two that are listed.

Table 6.5: Psychrometric Data Across California. Data collected on March 19, 2020 at 13:00 from The Weather Channel

Location	Dry Bulb Temp. (°C)	Wet Bulb Temp. (°C)	Wet Bulb Depression	Relative Humidity (%)	Dew Point Temperature (°C)
Eureka	12	10			
Redding	14	8			
San Francisco	13	9			
Bishop	8	2.5			
Bakersfield	14	9			
Sacramento	12	9.5			
Death Valley	17	9			
Avalon	14	10			
Los Angeles	14	9.5			
San Diego	17	12			

12. Using the internet or an atlas, find each of the locations shown in Table 6.5. Mark and label each point on the map below (Figure 6.6).



Figure 6.6: Blank Map of California. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

13. Which locations had the lowest ambient temperatures (dry bulb temperatures)? Why do you think these locations had the lowest temperatures? Explain your response in one to two sentences.

14. Which locations had the highest relative humidity? Why do you think that is the case? Explain your response in one to two sentences.

15. Which locations had the lowest relative humidity? Why do you think that is the case? Explain your response in one to two sentences.

16. Which of the locations on the map is closest to your college? What is the relative humidity at this location?

17. Use Your Critical Thinking Skills: Based on your spatial and data analysis, what conclusions can you draw regarding the relationship of location and relative humidity? Explain your response in two to three sentences.

Data Collection with a Sling Psychrometer

If you have access to a sling psychrometer, take some readings! Your professor may have some suggested or required locations. Instructions for using a sling psychrometer:

Step 1

Use clean, distilled water at the ambient air temperature to moisten the wet bulb's wick.

Step 2

Avoid handling the bulbs themselves when recording temperature because this can change the temperature. Also, for the same reason, try to avoid taking readings from the psychrometer in direct sunlight unless directed to do so at a particular site.

Step 3

Twirl the psychrometer for a minimum of 60 seconds. Read the values quickly (always read the wet bulb thermometer's value first). Twirl the thermometers again for a minimum of 20 seconds, and read the results quickly again. Repeat this procedure until you get two consecutive readings that are identical. This may take three or more repetitions at each site.

Record only the final wet bulb and dry bulb temperatures.

Step 4

Complete the following data collection forms (one for each site). Use the psychrometric tables provided above to determine the relative humidity and dew point temperature.

Variable	Your Data
Date:	
Time:	
Description of location (surrounding vegetation, proximity to buildings, water, landscaping, etc.):	
Dry Bulb Temperature:	
Wet Bulb Temperature:	
Relative Humidity:	
Dew Point Temperature:	
Notes:	

Variable	Your Data
Date:	
Time:	
Description of location (surrounding vegetation, proximity to buildings, water, landscaping, etc.):	
Dry Bulb Temperature:	
Wet Bulb Temperature:	
Relative Humidity:	
Dew Point Temperature:	
Notes:	

Variable	Your Data
Date:	
Time:	
Description of location (surrounding vegetation, proximity to buildings, water, landscaping, etc.):	
Dry Bulb Temperature:	
Wet Bulb Temperature:	
Relative Humidity:	
Dew Point Temperature:	
Notes:	

Variable	Your Data
Date:	
Time:	

Variable	Your Data
Description of location (surrounding vegetation, proximity to buildings, water, landscaping, etc.):	
Dry Bulb Temperature:	
Wet Bulb Temperature:	
Relative Humidity:	
Dew Point Temperature:	
Notes:	

18. What patterns did you observe across your different data collection sites? Explain your response in one to two sentences.
19. Were there any results that surprised you or that you were not expecting? Why do you suspect you had these findings? Explain your response to one to two sentences.
20. Were there any other noteworthy findings or observations that you found in your data collection? Explain your response to one to two sentences.

Part C. Lifting Mechanisms

You have learned that temperature has a significant impact on relative humidity. Temperature patterns vary based on time of day as well as physical location. One other significant impact on temperature is the vertical movement of air. As an air parcel rises, the less dense surrounding air gives room for the air parcel to expand. As it expands, the temperature decreases. If an air parcel rises and cools down to the dew point temperature, clouds begin to form. This may lead to precipitation.

There are four major **lifting mechanisms** in which air is forced upwards:

- **Convergent Lifting**: Air flowing from different directions “crashes” into one another, causing the air to be forced upward.
- **Convectional Lifting**: Over a warm surface, the heated air is forced upwards.
- **Orographic Lifting**: Air forced up and over a mountain.
- **Frontal Lifting**: As two different air masses intersect, the warm, humid air is forced upward.

Exercise 1.6.6

21. Label the following lifting mechanism diagrams based on their descriptions provided above.
    a. _____:

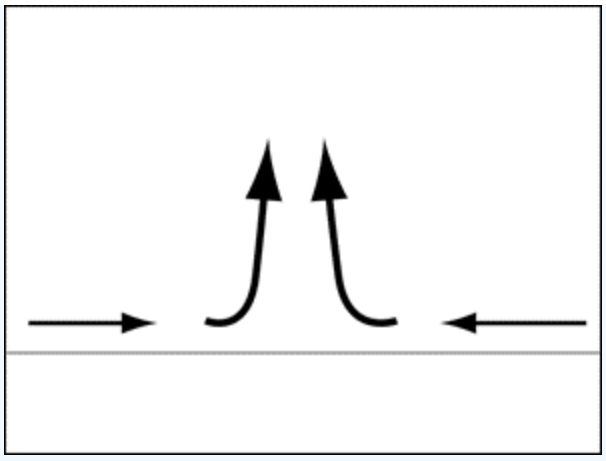


Figure 6.7: Lifting Mechanism Sample 1. Figures by Scott Crosier is licensed under CC BY-NC-SA 4.0

b. _____:

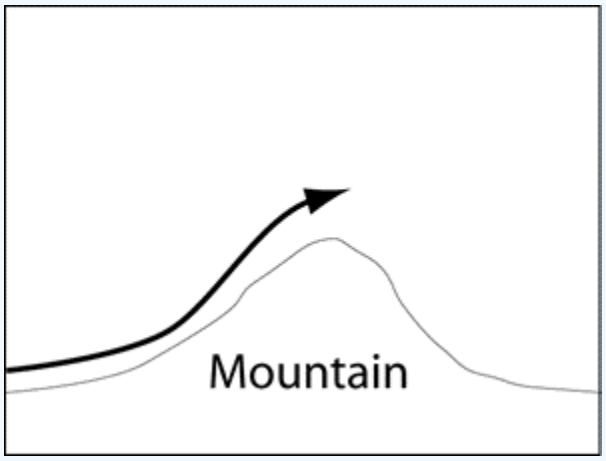


Figure 6.8: Lifting Mechanism Sample 2. Figures by Scott Crosier is licensed under CC BY-NC-SA 4.0

c. _____:

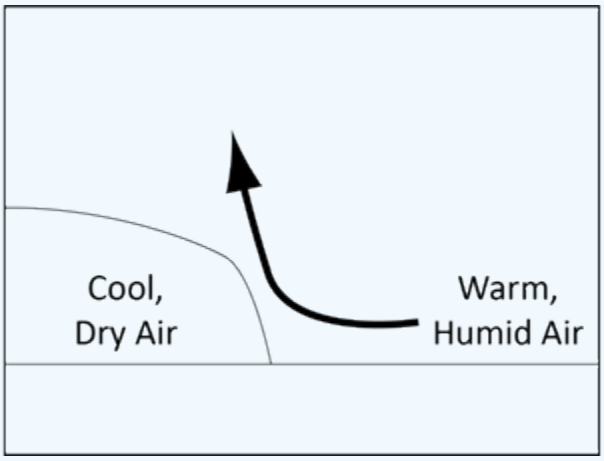


Figure 6.9: Lifting Mechanism Sample 3. Figures by Scott Crosier is licensed under CC BY-NC-SA 4.0

d. _____:

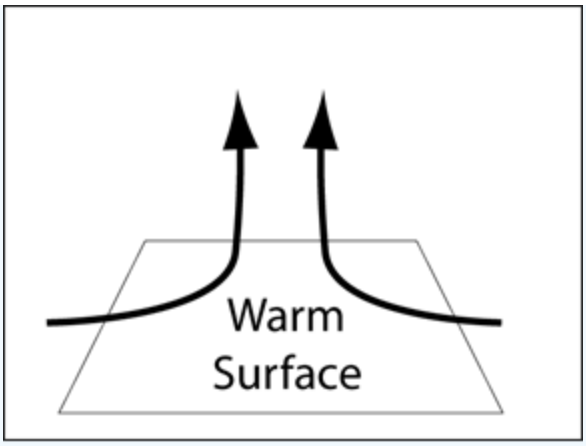


Figure 6.10: Lifting Mechanism Sample 4. Figures by Scott Crosier is licensed under CC BY-NC-SA 4.0

Pin It! Rising Air

These lifting mechanisms cause the air to rise, cool, and eventually form clouds. If conditions are right, this could lead to precipitation. In fact, whenever there is precipitation, it began with a lifting mechanism. The spatial patterns of precipitation are determined by the distribution of these lifting mechanisms!

Part D. Adiabatic Rates

As an air parcel rises, there is less pressure surrounding the outside of that air parcel and it is allowed to expand. As it expands, its temperature decreases. It is said to cool by expansion. Inversely, as an air parcel subsides or is forced downward, it is heated by compression. The warming and cooling rates for a parcel of expanding or compressing air are termed **adiabatic rates**. Figure 6.11 shows adiabatic cooling as an air parcel rises and adiabatic warming as it subsides.

Exercise 1.6.7



Figure 6.11: Temperature Changes as Air Rises or Subsides. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

22. Label the windward (the side where the wind begins to rise) and the leeward (the side where the wind subsides) sides of the mountain on Figure 6.11.

Depending on the relative humidity of an air parcel, the adiabatic rate will be different. In a dry air parcel, which means the air parcel has a relative humidity that is less than 100%, the rate of change is the dry adiabatic rate (DAR) of +/- 10°C per 1,000 meters (5.5°F per 1,000 feet). This is the rate of change that occurs solely through the process of expansion or compression.

However, once the relative humidity reaches 100%, the air is saturated, and if it continues to cool, water vapor condenses into water droplets. These suspended water droplets are clouds. The air parcel will continue to cool by expansion, but it is also being heated through latent heat. The change of temperature for an air parcel with a relative humidity of 100% is the saturated adiabatic rate (SAR) of -6°C per 1,000 meters (-3.3°F per 1,000 feet). The saturated adiabatic rate is sometimes referred to the saturated adiabatic lapse rate, the moist adiabatic rate, or the wet adiabatic rate.

Exercise 1.6.8

23. In one to two sentences, explain why the saturated adiabatic rate is lower than the dry adiabatic rate. Hint: consider whether or not latent heat is released when condensation occurs.



Guided Practice: Using the Adiabatic Rates

Watch a tutorial video on how to use the adiabatic rates to understand how an air parcel warms or cools according to how its altitude changes. (Video length is 5:35).

Exercise 1.6.9

In this section, you will explore the change of temperature and relative humidity as an air parcel is forced up and over the Sierra Nevada mountain range. Using the adiabatic rates provided, answer the following questions. You may find it helpful to work on diagramming the scenario (Figure 6.12) as you proceed.

24. Assume an unsaturated air parcel located at sea level (0 meters) in the Sacramento Valley has an initial air temperature of 17°C and a specific humidity of 4kg H_2O/kg air. The prevailing westerlies are forcing the air parcel eastward towards the western slope of the Sierras.

    a. Calculate the relative humidity and the dew point temperature of the air parcel at 0 meters. Show your work.

As the air rises and cools, the relative humidity becomes greater and greater. Eventually, the air has a relative humidity of 100%. This altitude is referred to as the **lifting condensation level (LCL)**. This altitude, at which clouds will start to form, is the base of clouds.

LCL = (Air Temperature - Dew Point Temperature)

|DAR| (in '000s of m)

b. At what elevation will clouds start to form? Calculate the LCL for this air parcel using the preceding formula. Show your work.

LCL = _____ meters

The temperature is always equal to the dew point temperature at the lifting condensation level. As the equation above suggests, the lifting condensation level (LCL) is defined by the air parcel rising and cooling at the dry adiabatic rate until it reaches its dew point temperature.

As the air rises above the lifting condensation level, the air continues to cool by expansion; however, the development of clouds (water vapor to water droplets) releases latent heat. The air parcel continues to cool, but not as quickly. The air parcel will cool at the saturated adiabatic rate.

c. Calculate the expected temperature of the air parcel at the ridge of the Sierras (4,000 meters). Don't forget to calculate the DAR of the air before it reaches the LCL and the SAR as it continues to rise to the peak. Show your work.

The following formula might be of assistance:

Change in Temp = Rate (DAR or SAR) x Change in Elevation

Temp at the LCL =_____°C

Temp at 4,000 m =_____°C

As the air descends down the leeward side of the Sierra Nevada mountain range, the air parcel is heated by compression.

d. If temperature rises, does relative humidity increase or decrease?

e. Based on your answer above, will the sinking air warm at the DAR or SAR? Why? Explain your response in one to two sentences.

f. What is the temperature of the air parcel once it reaches Reno at 1,500 meters? Show your work.

Temp at Reno=_____°C

g. Based on your calculations above, use the profile below (Figure 6.12) and fill in any missing information about the labeled locations.
h. Draw arrows indicating the movement of air over the range and label the regions where the air will warm or cool based on the DAR or the SAR. Also, label the windward and leeward sides of the mountain.

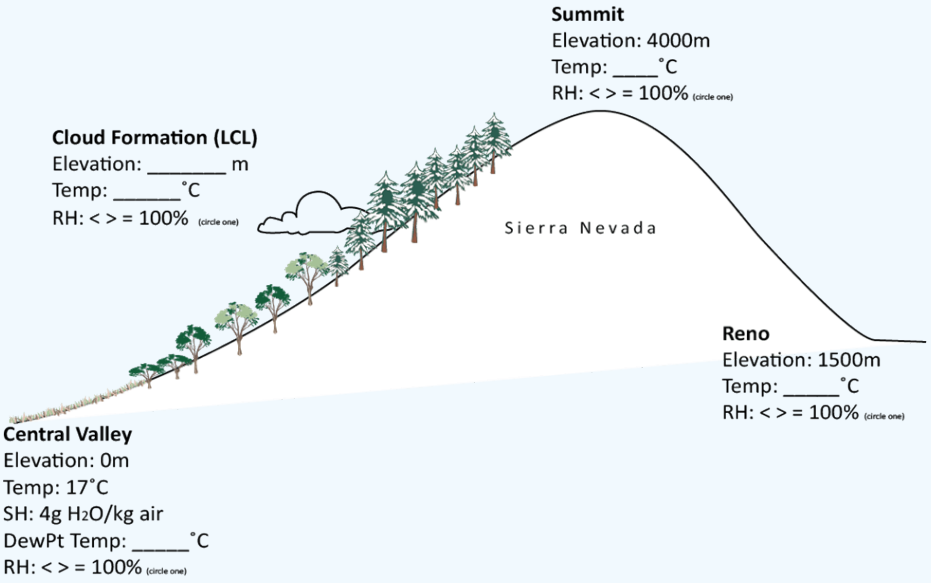


Figure 6.12: Temperature and Relative Humidity over the Sierra Nevada Mountain Range. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

Part E. Wrap-Up

Consult with your geography lab instructor to find out which of the following wrap-up questions you should complete. Attach additional pages to answer the questions as needed.

25. What is the most important idea that you learned in this lab? In two to three sentences, explain the concept and why it is important to know.

26. What was the most challenging part of this lab? In two to three sentences, explain why it was challenging. If nothing challenged you in the lab, write about what you think challenged your classmates.

27. What is one question that you have about what you learned in this lab? Write your question along with one to two sentences explaining why you think your question is important to ask.

28. Review the learning objectives on page 1 of this lab. How would you rate your understanding or ability for each learning objective? Write one sentence that addresses each learning objective.

29. Sketch a concept map that includes the key ideas from this lab. Include at least five of the terms shown in bold-faced type.

30. Create an advertisement to educate your peers on the important information that you learned in this lab. Include at least three key terms in your advertisement. The advertisement should be about half a page in size (about 4 inches by 6 inches).

31. One way to think of physical geography is that it is the study of the relationships among variables that impact the Earth's surface. Select two variables discussed in this lab and describe how they are related.

32. How does what you learned in this lab relate to your everyday life? In two to three sentences, explain a concept that you learned in this lab and how it relates to your day-to-day actions.

33. How does what you learned in this lab relate to current events?
    a. Write the title, source, and date of a news item that relates to this lab.
    b. In two to three sentences, discuss how the news item relates to what you have learned in this lab.
    c. In one to two sentences, discuss whether or not the news item accurately represents the science that you learned. Tip: consider whether or not the news item includes the complexity of the topic.

34. Search O*NET OnLine to find an occupation that is relevant to the topics presented in today's lab. Your lab instructor may provide you with possible keywords to type in the Occupation Quick Search field on the O*NET website.
    a. What is the name of occupation that you found?
    b. Write two to three sentences that summarize the most important information that you learned about this occupation.
    c. What is one question that you would want to ask a person with this occupation?

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1.7: Lab 7 - Cyclones

Learning Objectives

- Identify the major types of air masses and the air masses that influence North America.
- Differentiate between cold and warm fronts.
- Describe the progression of a midlatitude cyclone.
- Identify the conditions that lead to tropical cyclones.
- Analyze the track of a hurricane.

Introduction

In the previous lab, you learned about humidity in the air and what happens to humidity as the temperature cools. You were introduced to the four main lifting mechanisms (orographic, convergent, convective, and frontal) that cause air to be forced upwards and cool. In this lab you will expand your knowledge of these processes by exploring the development of storm systems, called cyclones. **Cyclones** are low pressure systems and in this lab you will learn about two very distinct types of cyclones: midlatitude cyclones and tropical cyclones. The lab begins with an investigation of air masses, which will help you to understand how midlatitude cyclones form.

Part A. Air Masses

Air masses have specific and distinct characteristics from the atmosphere that surrounds them. This is specifically true in relation to their humidity and their temperature. Meteorologists have developed a type of coding to identify the overall humidity and temperature. This closely relates to their source region. **Continental** (c) air masses form over land masses. **Maritime** (m) air masses form over water bodies. Air masses that form in **polar** regions are designated with a P and air masses that form in **tropical** regions are designated with a T.

Exercise 1.7.1

1. What would the general temperature and humidity conditions be for the following types of air masses?
   a. cP:
   b. mP:
   c. mT:
2. Refer to Figure 7.1, which shows the source region and direction of most of the air masses that influence the weather conditions of North America.
   a. Label each of the air masses (cP; cT; mP; or mT).

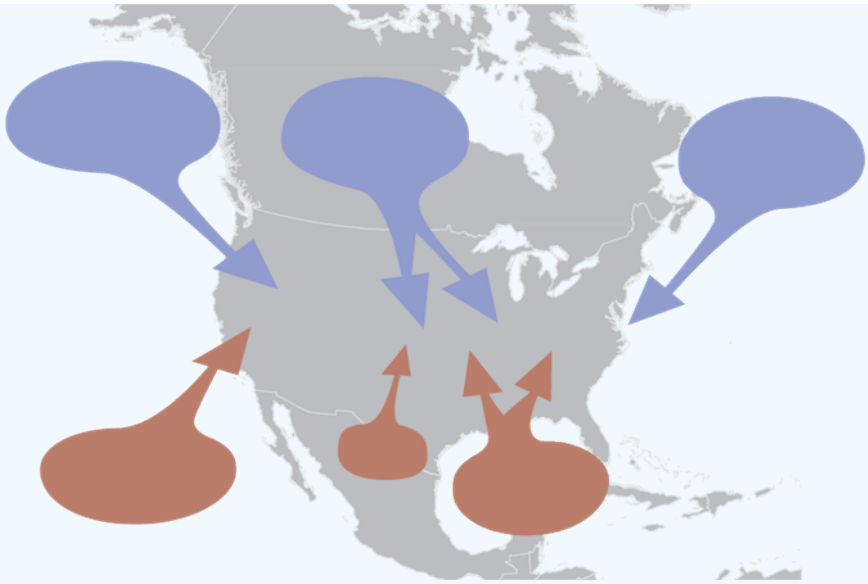


Figure 7.1: Map of North America and Significant Air Masses. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

b. What two major air masses influence the weather of California?

c. Which air masses have the greatest impact on weather along the central part of the United States?

Pin It! Air Masses

You will notice in Figure 7.1 that colder air masses (in the Northern hemisphere) are to the north while warmer air masses are towards the south. The line between these air masses is always present, although the line will move further north in the summer and further south in the winter. It is along this boundary line that you will find frontal lifting and midlatitude cyclones.

Part B. Fronts and Frontal Lifting

The place where two different air masses make contact is referred to as a front. In the previous lab, **frontal lifting** was identified as one of the lifting mechanisms. Although they are in contact, air masses often will retain their individual characteristics. There are several standardized methods for symbolizing different fronts. When the two air masses are next to each other, but are not moving, this is referred to as a **stationary front**. The symbol that would be found on a meteorology map includes the line of contact with blue triangles radiating from one side (representing the cold air mass) and red half-circles radiating from the other side (representing the warm air mass) as illustrated in Figure 7.2.

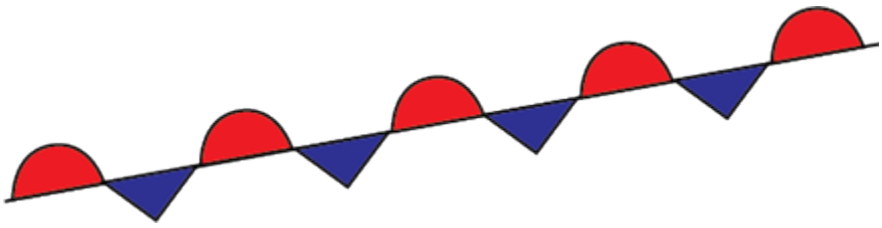


Figure 7.2: Stationary Front. Figures by Scott Crosier are licensed under CC BY-NC-SA 4.0

If either air mass begins to move, it is referred to as a **cold front** (if the cold air mass is advancing) or a warm front (if the warm

air mass is advancing). Cold fronts are drawn as a line with blue triangles indicating the direction of movement of the front, as illustrated in Figure 7.3.

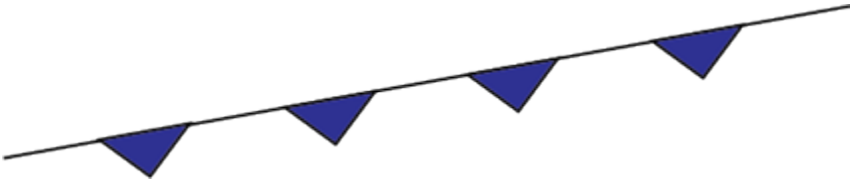


Figure 7.3: Cold Front. Figures by Scott Crosier are licensed under CC BY-NC-SA 4.0

Warm fronts are symbolized as a line with red half-circles radiating in the direction that the front is moving, as illustrated in Figure 7.4.

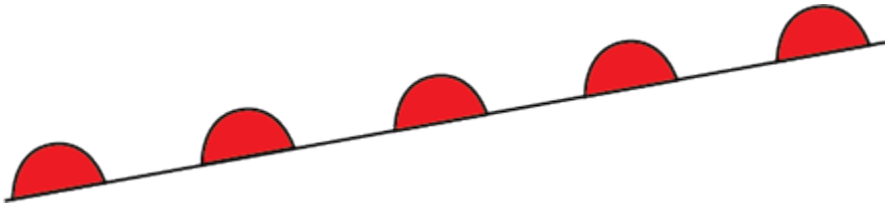


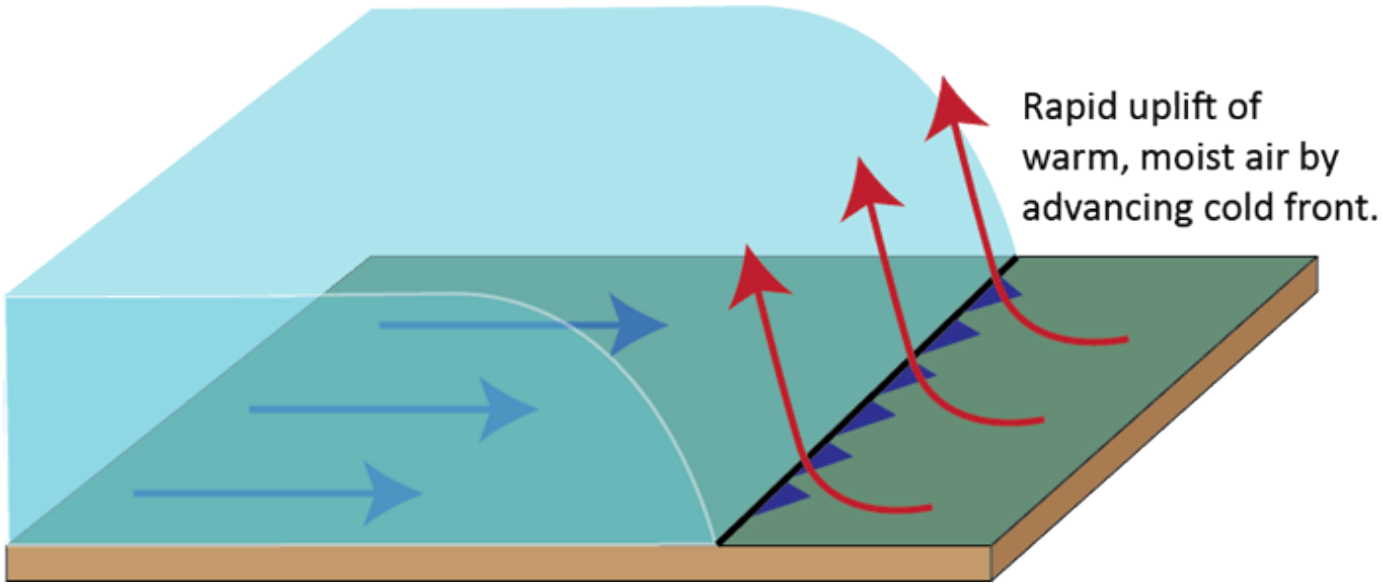
Figure 7.4: Warm Front. Figures by Scott Crosier are licensed under CC BY-NC-SA 4.0

Exercise 1.7.2

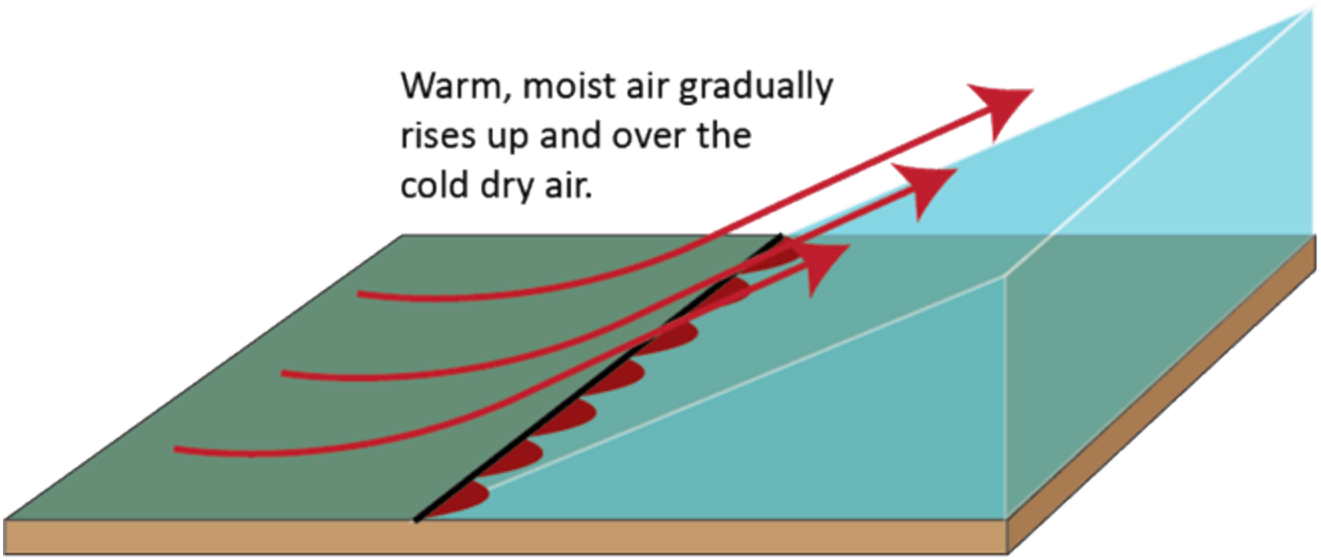
3. Based on the diagram of air masses in Figure 7.1, where would you most likely see these fronts developing in the United States?

It is important to remember that warm air is typically less dense than cold air. Thus, when they are forced towards each other, in either a warm or a cold front, the cold, usually dry, dense air will remain at the surface and the warm, humid air will rise. That rising humid air cools as it rises, condensation occurs, and clouds form, which may lead to precipitation.

The speed and severity of rising will vary based on the presence of a cold front (Figure 7.5) or a warm front (Figure 7.6).



7.5: Typical Cold Front Profile. Figures by Scott Crosier are licensed under CC BY-NC-SA 4.0



7.6: Typical Warm Front Profile. Figures by Scott Crosier are licensed under CC BY-NC-SA 4.0

Exercise 1.7.3

4. Compare Figures 7.5 and 7.6.
   a. Along a _____ front you will find the warm, humid air rapidly being forced up, leading to more severe storms.
   b. Along a _____ front, the warm, humid air more gradually slides up and over the cooler, more dense air mass, leading to mild storms.

The collision of very cold air and warm, humid air can generate very significant storm systems, specifically in cold fronts. Based on data from 1982 to 2011, the National Weather Service's Storm Prediction Center mapped tornado probabilities for the date of May 13 (Figure 7.7). Probabilities of 80% or more closely match the location of Tornado Alley, which consistently experiences a high frequency of tornadoes every year.

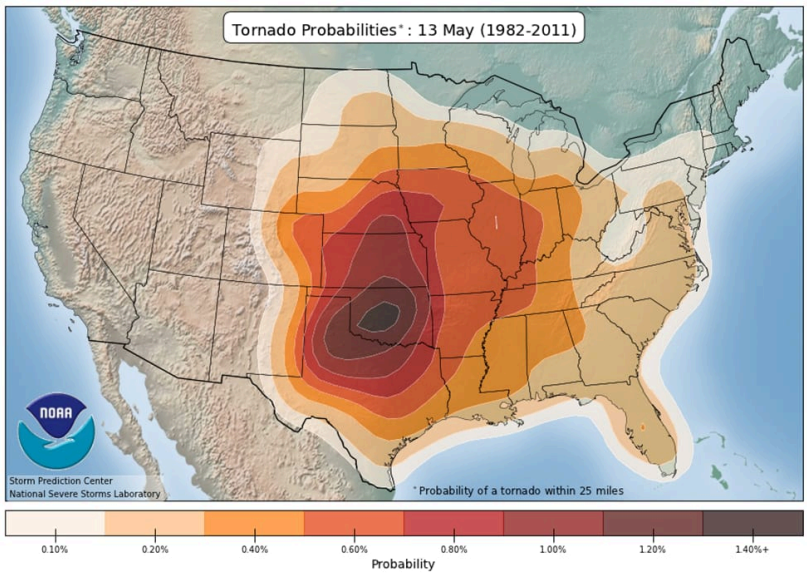


Figure 7.7: Map of Tornado Probabilities for May 13. Figure output from the Storm Prediction Center of the National Weather Service is in the public domain

Exercise 1.7.4

5. Refer to Figure 7.7.
    a. In one sentence, describe the location of Tornado Alley.
    b. Refer back to Figure 7.1 (shown earlier in the lab). What influence do you think the colliding air masses have on the high probability of tornadoes occurring in Tornado Alley? Explain your response in one to two sentences.
    c. Use Your Critical Thinking Skills: Why do you think California has so few tornadoes? Explain your response in one to two sentences.

Part C. Midlatitude Cyclonic Storm Progression

As you discovered above, two opposing air masses meet at the midlatitudes. Although this line of contact will migrate north or south based on the season, it is along this contact line where we see storms developing. The description below will discuss and diagram the storm progression of a typical **midlatitude cyclone** in the northern hemisphere.

Stage 1: Stationary Front

While cold air from the north and warm, humid air from the south are in contact, there is not always a storm raging! At times, the two fronts are simply in contact. This is referred to as a stationary front. You will note in Figure 7.8 that north of the line is dominated by continental polar air and that south of the line is dominated by maritime tropical air.

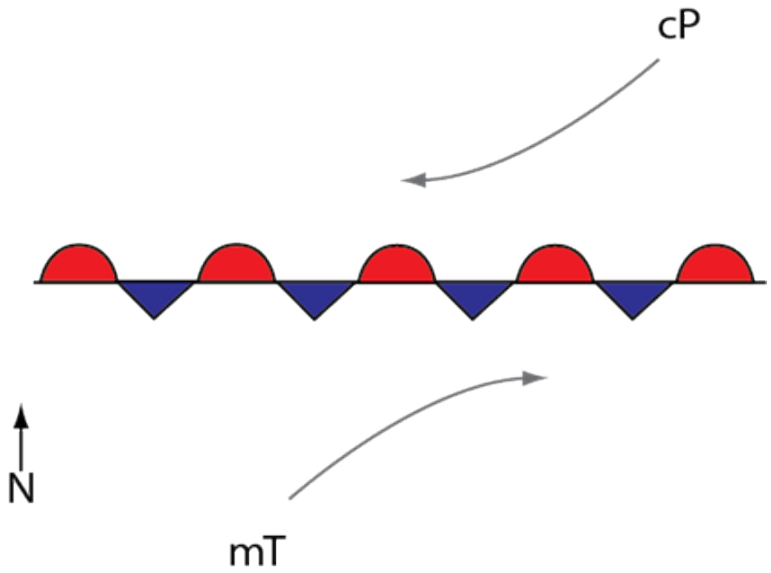


Figure 7.8: Stationary Front. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

Exercise 1.7.5

6. How would the air pressure differ between the north side of a stationary front versus the south side of the same front? Explain your response in one to two sentences.
7. Storms typically include cloud formation and precipitation. Which air mass contains the greater amount of humidity?

Stage 2: Cyclogenesis

A storm begins when there is a slight instability along the line. **Instability**, in this case, refers to a lift, or rise in the air. This creates a low pressure system.

Recall from a previous lab that the Coriolis effect is the apparent deflection of winds due to Earth's rotation. As winds move over the Earth's surface, winds are deflected to the right in the northern hemisphere (clockwise) and to the left in the southern hemisphere (counterclockwise). At the surface, this causes winds to move out of an anticyclone in a clockwise direction in the northern hemisphere.

Exercise 1.7.6

8. In the northern hemisphere, would the Coriolis effect cause surface-level winds to move into a low pressure system in a clockwise or counterclockwise direction?

The diagram below (Figure 7.9) illustrates the initial formation of a midlatitude cyclonic storm. This stage is referred to as **cyclogenesis**.

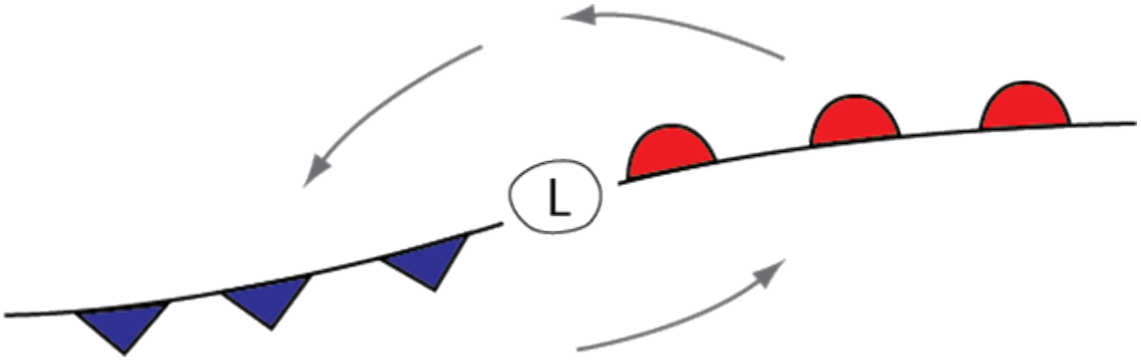


Figure 7.9: Cyclogenesis. Figure by Scott Crosier are licensed under CC BY-NC-SA 4.0

Typically across North America these initial low pressure systems move from west to east due to the prevailing westerlies. In California, many of the storm systems develop off the Pacific coast and move inland. You will note from Figure 7.9 (above) that as the rotation within the system begins, there is the development of a cold front and warm front. Although these diagrams illustrate the movement of these fronts from a top-down perspective, keep in mind the lifting and movement of air because of these two fronts, as discussed in the previous section.

Stage 3: Open Stage

While the entire rotation and low pressure system moves from west to east, the fronts are also moving, pushing, and forcing their respective air masses around. Cold fronts typically will move faster than warm fronts. You will note in Figure 7.10 that the low pressure system has developed even stronger and that the cold front has moved further south in its rotation around the low pressure center.

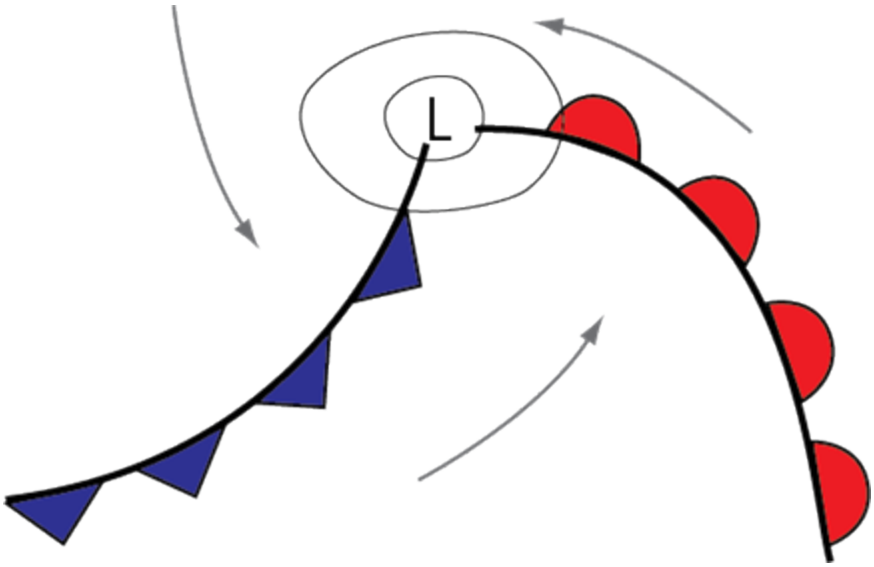


Figure 7.10: Open Stage. Figures by Scott Crosier is licensed under CC BY-NC-SA 4.0

Exercise 1.7.7

9. Cold fronts typically move faster than warm fronts. If the cold front rotates faster around the central low pressure, what would you expect to happen to the two different fronts? Explain your response in one to two sentences.

Stage 4: Occluded Front

Eventually, the cold front does catch up to the warm front. That line is referred to an **occluded front** and is symbolized with the triangles and half circles facing the same direction. This is illustrated in Figure 7.11.

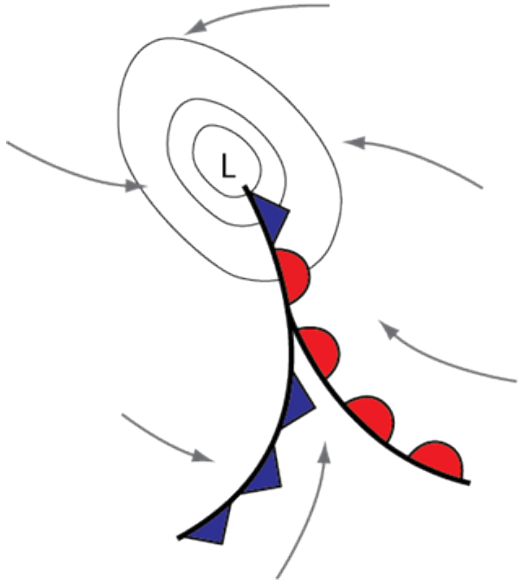


Figure 7.11: Occluded Stage. Figures by Scott Crosier is licensed under CC BY-NC-SA 4.0

Remember that the initial creation of the storm began with the development of a low pressure system. In the occluded stage, the low pressure system has been pinched off and is now surrounded by continental polar (cold and dry) air. You may recall that colder air, with its higher density, tends to have a higher surface pressure. This leads to the final, dissolving stage of the storm system.

Stage 5: Dissipating Stage

With the low pressure isolated to the north, the storm system may pull in surrounding air, but that air is cold, dry, and dense. The more dense air will cause the low pressure system to dissipate or die out, as illustrated in Figure 7.12.

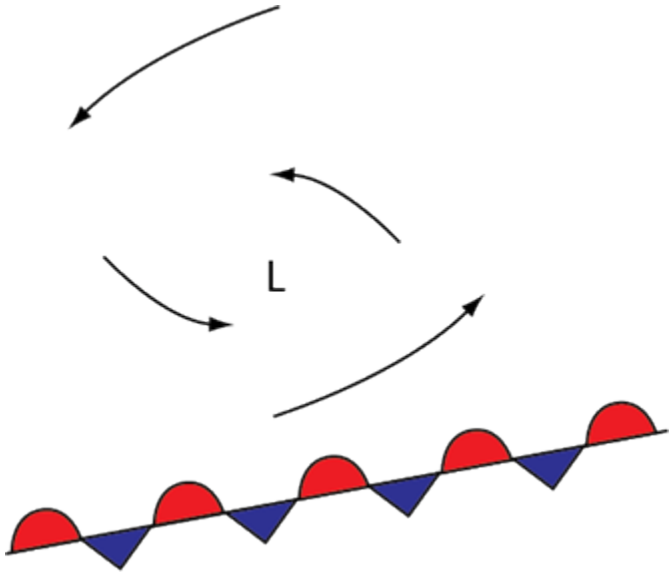


Figure 7.12: Dissipating Stage. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

Although the storm is practically over, you will note the stationary front has developed once again. This provides the setting for this whole storm development process to start once more.

Exercise 1.7.8

10. Review the five stages of midlatitude cyclones.
    a. List the initial conditions needed to cause a midlatitude cyclone to form:
    b. List the ending conditions that cause a midlatitude cyclone to dissipate:

Part D. Tropical Cyclones

You previously learned about several lifting mechanisms:

- You examined the change in temperature and humidity as an air mass is lifted over a mountain during orographic lifting.
- In Part B of this lab you learned about the process of frontal lifting.

In this section of the lab, you will learn about storm development in the warmer, tropical areas. These are extraordinary examples of convectional lifting.

While they are only found over warm waters, **tropical cyclones** are found in many different regions. In the United States, we are primarily impacted by tropical cyclones in the Atlantic Ocean and Gulf of Mexico. These are called **hurricanes**. Around the globe, you will find tropical cyclones referred to as tropical cyclones in Southeast Asia, willy willies in Australia, and typhoons in the western Pacific.

Figure 7.13 is an ocean circulation map that shows warm currents in red arrows.

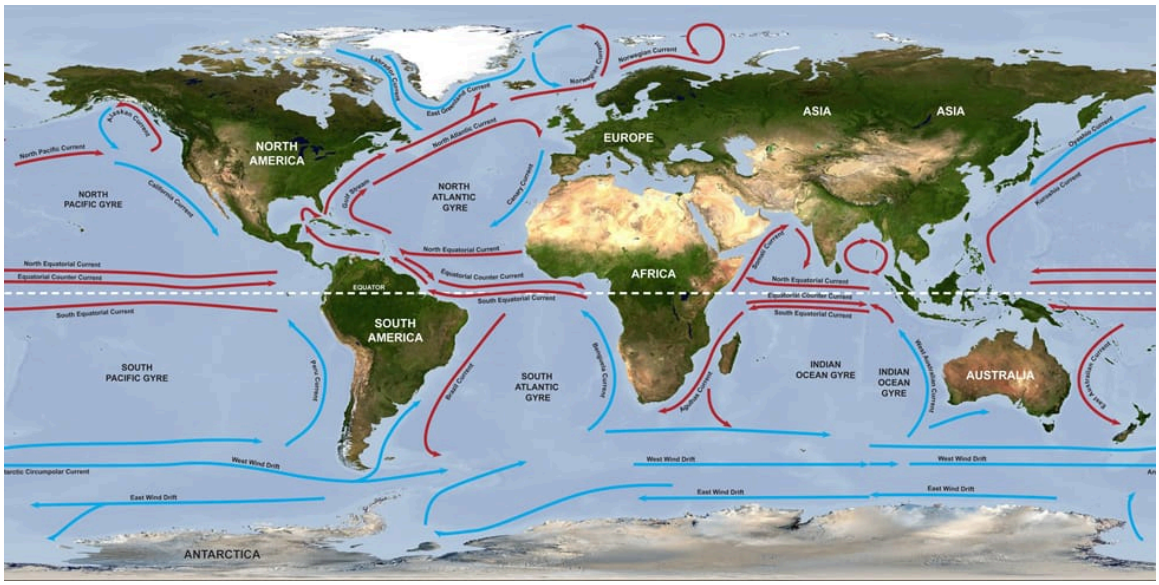


Figure 7.13: Map of Surface Ocean Currents. Used by permission. Dataset source: Laura Walker, Program Manager, O'Neill Sea Odyssey

Exercise 1.7.9

11. Based on the temperature of the ocean currents off the Pacific and Atlantic coasts (Figure 7.13), why do we find much greater tropical storm development in the Atlantic Ocean influencing the United States? Why don't we see many in California? Explain your responses in two to three sentences.

If you have spent much time in Florida or in other warm, humid tropical areas, you are aware of what real humidity is like. When a low pressure system develops over tropical waters, the warm air begins to rise and cool by expansion. Once the dew point temperature is reached, the vast amount of water vapor begins to condense. This releases a huge amount of latent heat. That latent heat causes additional lift, strengthening the low pressure system. The Coriolis effect causes rotational spin. Tropical cyclones depend on access to the tropical ocean and the vast amount of humidity in their overlying air. Once these systems move over land, they typically weaken. However, these have been some of the most destructive storms along the coastal regions of the southeast United States.

Tropical cyclones are categorized based on the wind speeds found in those storms using the **Saffir-Simpson Hurricane Severity Scale** (Table 7.1). Beginning on June 1st of each year, the annual storm season begins. Each tropical storm is given a name, beginning with the letter A; each subsequent storm is given a name beginning with subsequent letters in the alphabet. For example, in 2019, the storms over the Atlantic were named Andrea then Barry, followed by Chantal, Dorian, Erin and so forth. Each storm basin (tropical waters in the Atlantic Ocean, Pacific Ocean, etc.) has their own sequence of storm names.

Table 7.1: The Saffir-Simpson Hurricane Severity Scale

Tropical Cyclone Classification	Wind Speed in meters per second (m/s)	Wind Speed in knots (kn)	Wind Speed in miles per hour (mph)	Wind Speed in kilometers per hour (km/h)
Hurricane Category 5	≥ 70 m/s	≥ 137 kn	≥ 157 mph	≥ 252 km/h
Hurricane Category 4	58–70 m/s	113–136 kn	130–156 mph	209–251 km/h
Hurricane Category 3	50–58 m/s	96–112 kn	111–129 mph	178–208 km/h
Hurricane Category 2	43–49 m/s	83–95 kn	96–110 mph	154–177 km/h
Hurricane Category 1	33–42 m/s	64–82 kn	74–95 mph	119–153 km/h

Tropical Cyclone Classification	Wind Speed in meters per second (m/s)	Wind Speed in knots (kn)	Wind Speed in miles per hour (mph)	Wind Speed in kilometers per hour (km/h)
Tropical Storm	18–32 m/s	34–63 kn	39–73 mph	63–118 km/h
Tropical Depression	≤ 17 m/s	≤ 33 kn	≤ 38 mph	≤ 62 km/h

Hurricane Paths

If you mention hurricanes to most Americans, the one that comes to mind is Hurricane Katrina. This was a very severe storm in 2005 that especially devastated New Orleans. Because of their local geography, a significant portion of the city was inundated with water. The suffering of the people as portrayed through the media was striking and unforgettable. The storm brought to light the need for communities throughout the U.S. to be prepared for natural disasters.

Exercise 1.7.10

In Table 7.2 below, you will find a series of readings from Hurricane Katrina.

12. Complete Table 7.2 by determining the storm category (the far-right column) based on the wind speed by referencing Table 7.1 above.

Table 7.2: Hurricane Katrina Data. Data sourced from NOAA National Centers for Environmental Information

Date	Time	Approx. Degrees North	Approx. Degrees West	Pressure (mb)	Wind Speed (knots)	Category
Aug 23, 2005	1800	23	75	1008	30	
Aug 24, 2005	1800	25	77	1003	40	
Aug 25, 2005	1800	26	80	988	60	
Aug 26, 2005	1800	25	83	968	85	
Aug 27, 2005	1800	25	85	948	100	
Aug 28, 2005	1800	26	89	902	150	
Aug 29, 2005	1800	31	90	948	80	
Aug 30, 2005	1800	37	87	990	30	
Aug 31, 2005	600	40	83	996	25	

13. Refer to Table 7.2. What relationship do you notice between pressure and wind speed?

14. Based on the provided coordinates in Table 7.2, plot the daily location of Hurricane Katrina on the map provided below (Figure 7.14). Using colored pencils, code each point according to the category of storm. Create a legend in the space below that shows the color used for each storm category. With a black line, connect each of the points to mark the storm's trajectory.

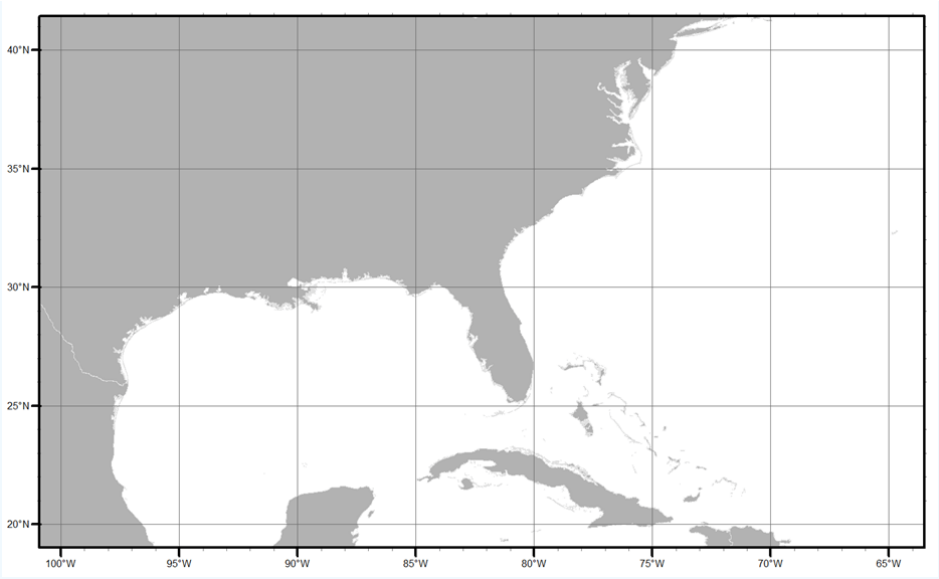


Figure 7.14: Progression of Hurricane Katrina, August 23–31, 2005. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

15. Compare the direction of travel of the storm between the 23rd to the 26th with the projection of the storm between the 27th to 30th. List the differences that you notice.

16. Did the storm travel the same speed each day? What trends in storm speed do you see? Explain your response in two to three sentences.

Another tropical storm which had a significant impact on Houston and the surrounding areas was Hurricane Harvey in 2017. As you will note in the mapping exercise below, it stayed in that region for multiple days. At times, it seemed to repeat the pattern of coming inland to rain, going back over the warm waters to recharge, and coming back in once again with more rain. Some areas received more than 40 inches of rain within those few days.

In Table 7.3 below, you will find a series of readings from Hurricane Harvey.

17. Complete the far-right column of Table 7.3 by determining the storm category based on the wind speed. You should refer to the Saffir-Simpson Hurricane Severity Scale (Table 7.1, shown above) to complete the Category column.

Table 7.3: Hurricane Harvey Data. Data sourced from NOAA National Centers for Environmental Information

Date	Time	Approx. Degrees North	Approx. Degrees West	Pressure (mb)	Wind Speed (knots)	Category
Aug 16, 2017	1200	14	47	1010	25	
Aug 17, 2017	1200	13	53	1008	30	
Aug 18, 2017	1200	13	60	1004	40	
Aug 19, 2017	1200	14	68	1006	30	
Aug 20, 2017	1200	14	75	1006	30	
Aug 21, 2017	1200	16	83	1008	25	
Aug 22, 2017	1200	19	89	1010	25	
Aug 23, 2017	1200	21	92	1006	30	
Aug 24, 2017	1200	24	93	986	60	

Date	Time	Approx. Degrees North	Approx. Degrees West	Pressure (mb)	Wind Speed (knots)	Category
Aug 25, 2017	1200	26	96	949	95	
Aug 26, 2017	1200	29	97	978	65	
Aug 27, 2017	1200	29	97	998	35	
Aug 28, 2017	1200	29	96	997	40	
Aug 29, 2017	1200	28	96	995	40	
Aug 30, 2017	1200	30	93	992	40	
Aug 31, 2017	1200	32	92	1001	20	
Sep 1, 2017	1200	36	87	1002	25	
Sep 2, 2017	1200	38	85	1013	15	

18. Based on the provided coordinates in Table 7.3, plot the daily location of Hurricane Harvey on the map provided below (Figure 7.15). Using colored pencils, code each point according to the category of storm. Use the same colors as you did for question 14 (Figure 7.14) and add a legend to the map. With a black line, connect each of the points to mark the storm's trajectory.

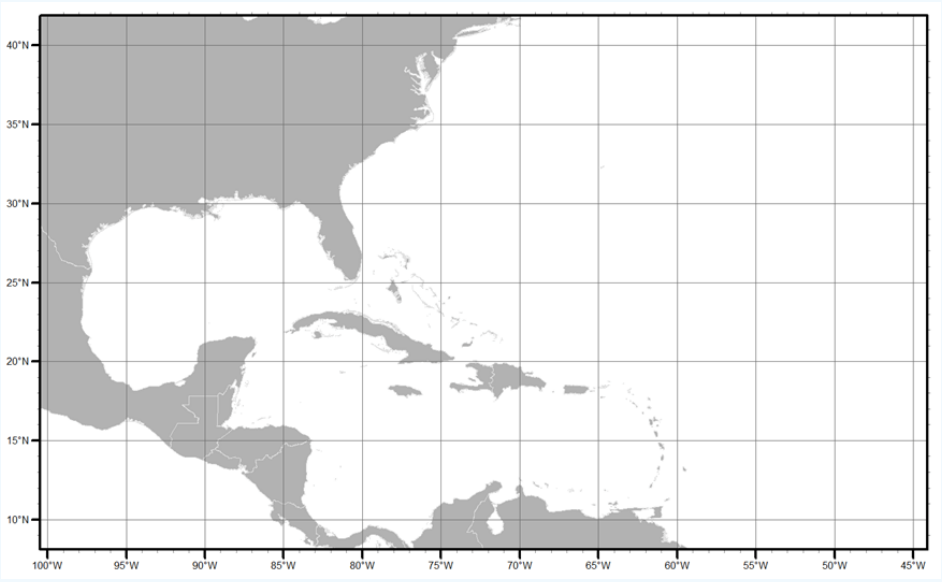


Figure 7.15: Progression of Hurricane Harvey, August 16–September 2, 2017. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

19. Comparing your two maps (Figures 7.14 and 7.15), how does the storm path of Hurricane Harvey differ from Hurricane Katrina? How does the speed compare between the two storms? List the differences that you notice.

20. Do you observe any other differences or similarities between these two storms? Explain your response in two to three sentences.



Check It Out! Explore Other Hurricanes

The National Oceanic and Atmospheric Agency (NOAA) has provided an online tool to discover and explore hurricanes.

Part E. Wrap-Up

Consult with your geography lab instructor to find out which of the following wrap-up questions you should complete. Attach additional pages to answer the questions as needed.

Exercise 1.7.11

21. What is the most important idea that you learned in this lab? In two to three sentences, explain the concept and why it is important to know.
22. What was the most challenging part of this lab? In two to three sentences, explain why it was challenging. If nothing challenged you in the lab, write about what you think challenged your classmates.
23. What is one question that you have about what you learned in this lab? Write your question along with one to two sentences explaining why you think your question is important to ask.
24. Review the learning objectives on page 1 of this lab. How would you rate your understanding or ability for each learning objective? Write one sentence that addresses each learning objective.
25. Sketch a concept map that includes the key ideas from this lab. Include at least five of the terms shown in bold-faced type.
26. Create an advertisement to educate your peers on the important information that you learned in this lab. Include at least three key terms in your advertisement. The advertisement should be about half a page in size (about 4 inches by 6 inches).
27. One way to think of physical geography is that it is the study of the relationships among variables that impact the Earth's surface. Select two variables discussed in this lab and describe how they are related.
28. How does what you learned in this lab relate to your everyday life? In two to three sentences, explain a concept that you learned in this lab and how it relates to your day-to-day actions.
29. How does what you learned in this lab relate to current events?
    a. Write the title, source, and date of a news item that relates to this lab.
    b. In two to three sentences, discuss how the news item relates to what you have learned in this lab.
    c. In one to two sentences, discuss whether or not the news item accurately represents the science that you learned. Tip: consider whether or not the news item includes the complexity of the topic.
30. Search O*NET OnLine to find an occupation that is relevant to the topics presented in today's lab. Your lab instructor may provide you with possible keywords to type in the Occupation Quick Search field on the O*NET website.
    a. What is the name of occupation that you found?

b. Write two to three sentences that summarize the most important information that you learned about this occupation.
c. What is one question that you would want to ask a person with this occupation?

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1.8: Lab 8 - Water Resources

This lab contains potentially inaccessible interactive resources. Please work with your instructor and local campus resources to identify accommodations for these resources.

Learning Objectives

- Identify key processes in the hydrologic cycle.
- Describe the distribution of water around the world and in the United States.
- Analyze water consumption patterns.
- Define watershed and describe watershed pollutants.
- Analyze water budget data.

Introduction

You have likely heard before that there is more water on Earth than there is land. In fact, more than 70% of Earth's surface is covered by water. Water is composed of two hydrogen atoms and one oxygen atom and it is known as a "universal solvent". Water is called the universal solvent because it is capable of dissolving more substances than any other liquid. It is water's chemical composition and physical attributes that make it such an excellent solvent. Water molecules have a polar arrangement of oxygen and hydrogen atoms—one side (hydrogen) has a positive electrical charge and the other side (oxygen) has a negative charge. This allows the water molecule to become attracted to many other different types of molecules. Water can become so heavily attracted to a different compound, like salt (NaCl), that it can disrupt the attractive forces that hold the sodium and chloride in the salt compound together and, thus, dissolve it. This is important to every living thing on Earth. It means that wherever water goes, either through the air, the ground, or through our bodies, it takes along valuable chemicals, minerals, and nutrients.[122]

In this lab, we will discover where water is held on Earth and how it cycles through the planet. We will learn about how we access freshwater and how our actions impact natural water systems.

Part A. The Hydrosphere

As you have learned, there are four main spheres on Earth: the biosphere, the atmosphere, the lithosphere, and the hydrosphere. All water on Earth exists within the **hydrosphere** (Figure 8.1). Water exists in three states at Earth's ambient temperature and atmospheric pressure: as a solid, as a liquid, and as a gas. In addition, water does not only exist as freshwater, but also as salt water. In fact, the percentage of freshwater is much lower than the percentage of salt water, which means the amount of freshwater available for human consumption is actually quite low.

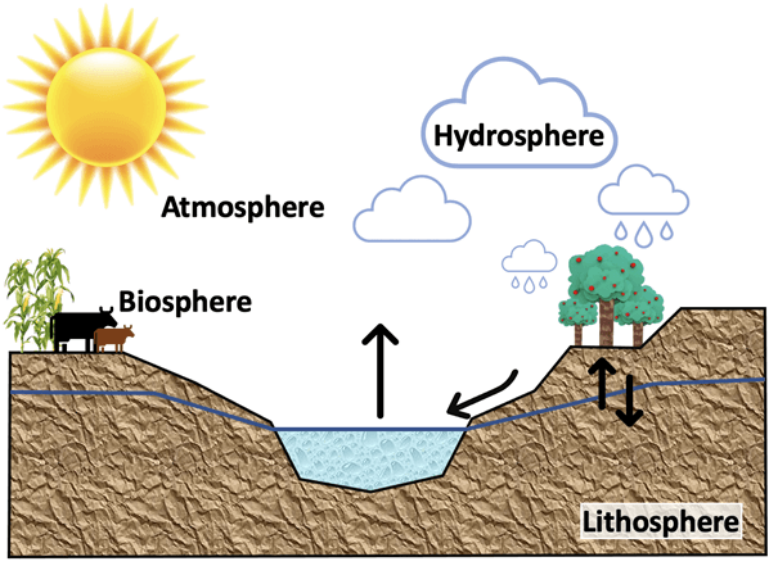


Figure 8.1: The Four Spheres of the Earth. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Water cycles through Earth in something called the **hydrologic cycle**, also known as the water cycle. Much like energy, water cannot be created nor destroyed, it simply changes form. In fact, the very first water ever to exist on Earth is still here today!

Water moves in a variety of ways within the hydrologic cycle. First, water is evaporated from the Earth in two ways: through evaporation from the surface (such as from oceans, lakes, streams, surfaces, and reservoirs) and through **transpiration,** a process in which water leaves a plant through its leaves. Recall that **evaporation** occurs when water changes from a liquid to water vapor. The combination of these two processes is called **evapotranspiration** and accounts for all water that leaves the surface of the Earth. As water evaporates into the atmosphere as a gas, it cools and condenses in a process called condensation. **Condensation** occurs when water vapor changes into a liquid. This liquid water falls back onto Earth in a process called **precipitation**. Once the water reaches the surface of the Earth, it can either runoff along the surface or infiltrate into the ground, which is called **groundwater flow**. Water that does not infiltrate into the ground is called **runoff**. Water enters into the ground through a process called **infiltration** and moves through the soil into deeper depths of the water table in a process called **percolation**. Some water is also stored underground in layers of permeable rock, called **aquifers**.

Exercise 1.8.1

1. Refer to the hydrologic cycle diagram below (Figure 8.2). What is the correct process for each of the labels on the diagram? Tip: you will use all but one of the terms shown in **bold-faced** type in the previous paragraph.
   a.
   b.
   c.
   d.
   e.
   f.
   g.
   h.
   i.

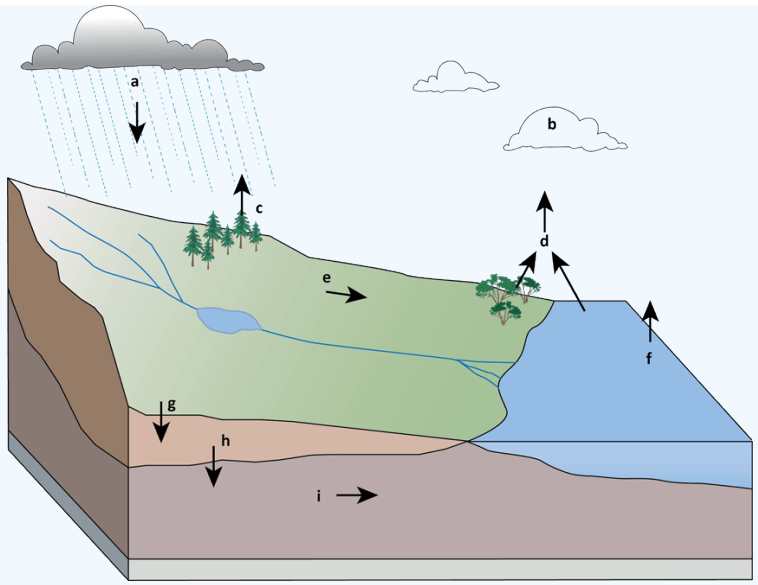
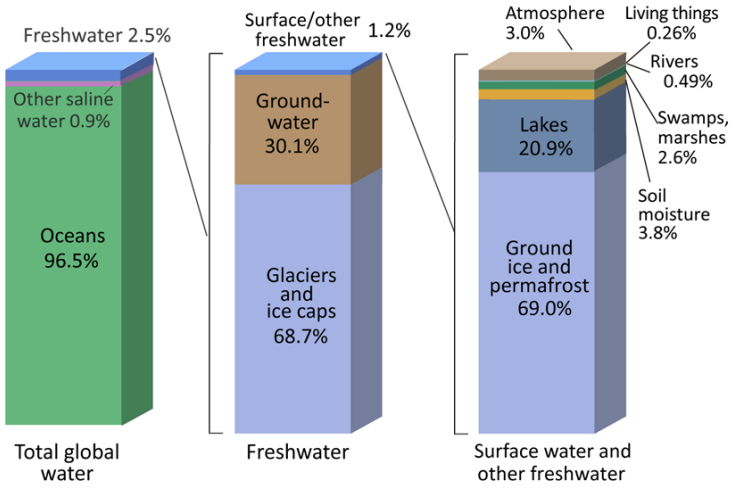


Figure 8.2: The Hydrologic Cycle. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

The Global Distribution of Water

Figure 8.3 shows the distribution of water on Earth. As you can see, only 2.5% of water on Earth is freshwater and of that amount, only 30.1% is groundwater. This means that 0.08% of all water on Earth is available to humans as freshwater for irrigation, drinking, and sanitation! Water is stored on Earth in five main reservoirs: oceans (holding 96.5% of all water on Earth), glaciers and ice caps, groundwater, surface water (water in lakes, rivers, and soil), and atmospheric water.



Credit: U.S. Geological Survey, Water Science School. https://www.usgs.gov/special-topic/water-science-school
Data source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources. (Numbers are rounded).

Figure 8.3: Global Distribution of Water. Figure by USGS Water Science School is in the public domain

Exercise 1.8.2

2. Refer to Figure 8.3.
    a. What percentage of water on the planet is freshwater?

b. What percentage of water on the planet is in glaciers and ice caps? Tip: notice that the percentage of water in glaciers and ice caps globally is 68.7% of 2.5%. So, you need to calculate how much 68.7% of 2.5 is. Show your calculation.

c. What percentage of water on the planet is available as groundwater? Show your calculation.

According to the U.S. Geological Survey (USGS), there is approximately 326 million cubic miles (1.32 billion cubic kilometers) of water on Earth. The distribution of water is shown below in Table 8.1.

Table 8.1: Sources of Fresh and Salt Water on Earth. Data from USGS: Shiklomanov, I. (1993). World freshwater resources. In P.H. Gleick (ed.), Water in Crisis: A Guide to the World's Fresh Water Resources. New York: Oxford University Press.

Water Source	Freshwater Volume (cubic kilometers)	Salt Water Volume (cubic kilometers)
Oceans, Seas, and Bays	0	1,338,000,000
Ice Sheets, Glaciers, and Permafrost	24,364,000	0
Groundwater	10,530,000	12,870,000
Surface Water	122,210	85,400
Atmosphere	12,900	0
Subtotals	**35,029,110**	**1,350,955,400**
Grand Total (rounded)		**1,386,000,000**

Exercise 1.8.3

3. Refer to Table 8.1.

   a. Which water source contains the highest amount of freshwater?

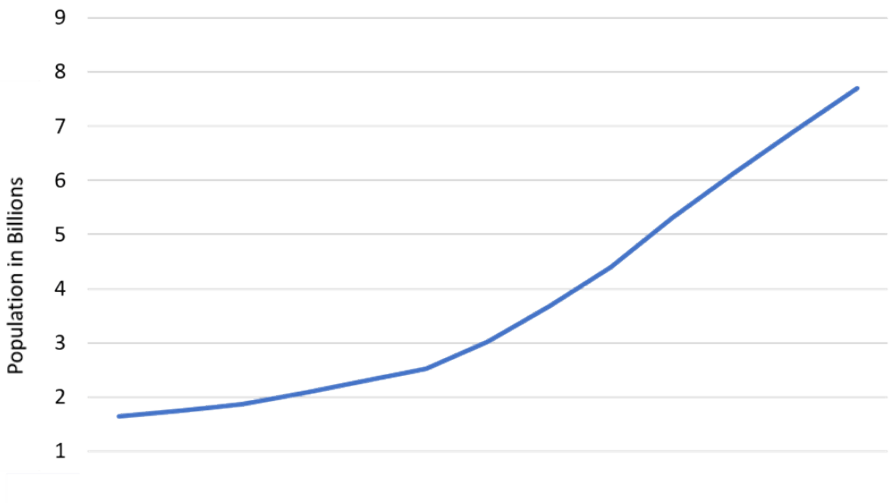
   b. Does salt water exist in all 5 water sources? Explain why or why not.

   c. If frozen water on the planet does not contain salt water, where does the water from a floating iceberg over the sea come from?

   d. What happens to the freshwater that drains into the sea from a melting ice sheet or glacier?

Human Population and Water Use

As we can see from Figure 8.3 and Table 8.1, there is minimal freshwater water available to people. The distribution of water on Earth changes over time and is dependent upon climate. For example, as Earth warms, more water is stored in the ocean as salt water and as Earth cools, more water is stored in snow, glaciers, and ice sheets as freshwater. Currently, Earth is experiencing a global warming period and the snow, glaciers, and ice sheets are melting rapidly and draining into the sea. This decreases the amount of freshwater available to people. As the amount of freshwater available to people continues to decrease, Earth's human population is increasing at an extraordinary rate (Figure 8.4). How might this impact water supplies for people?



Year	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000	2010	2020
Population in Billions	1.65	1.75	1.86	2.07	2.30	2.53	3.02	3.68	4.40	5.31	6.13	6.93	7.7

Figure 8.4: Population of People on Earth over the Last 120 Years. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

Exercise 1.8.4

4. Refer to Figure 8.4.
    a. What does Figure 8.4 tell you about Earth's human population?
    b. What other information might be helpful to add to this figure?
    c. What is the difference in population between 1920 and 2020? Tip: subtract the 2020 population from the 1920 population. Show your calculation.
        i. What percent did the population increase during this period? Tip: divide your answer from 4c by the 1920 population. Then, multiply that number by 100 to get the percentage. Show your calculation.
    d. What decade experienced the largest increase in population and by how much?

Figure 8.4 provides basic statistics for population and is useful for determining a general idea of what population looks like on the planet. However, in order to plan sustainably and ensure that all of humanity has access to resources like water on the planet, it is important that we look at various factors that influence how water is used and where.

The distribution of water varies globally and in order for us to manage water supplies and ensure all humans have access to water, it is important that we understand the global distribution of water as well as how it is used. One way to geographically display information is by using a cartogram. A cartogram is a map in which the geometry of the regions is distorted in order to show information for a particular variable, such as the distribution of population or income. In this section we will evaluate cartograms that show water usage around the world. Figure 8.5 is a cartogram of water use. The territory size shows the proportion of the worldwide water use occurring in a country. Countries that have enlarged territory sizes have higher rates of water usage. Figure 8.6 is a world population cartogram for comparison.

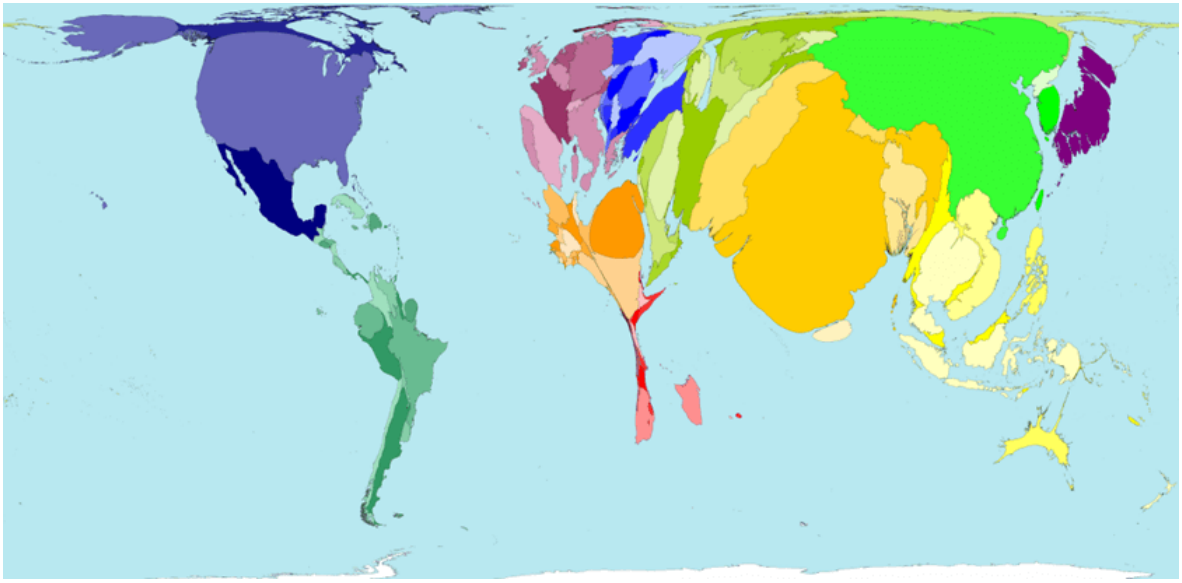


Figure 8.5: Water Use Cartogram. Figure by Worldmapper is licensed under CC BY-NC-ND 3.0

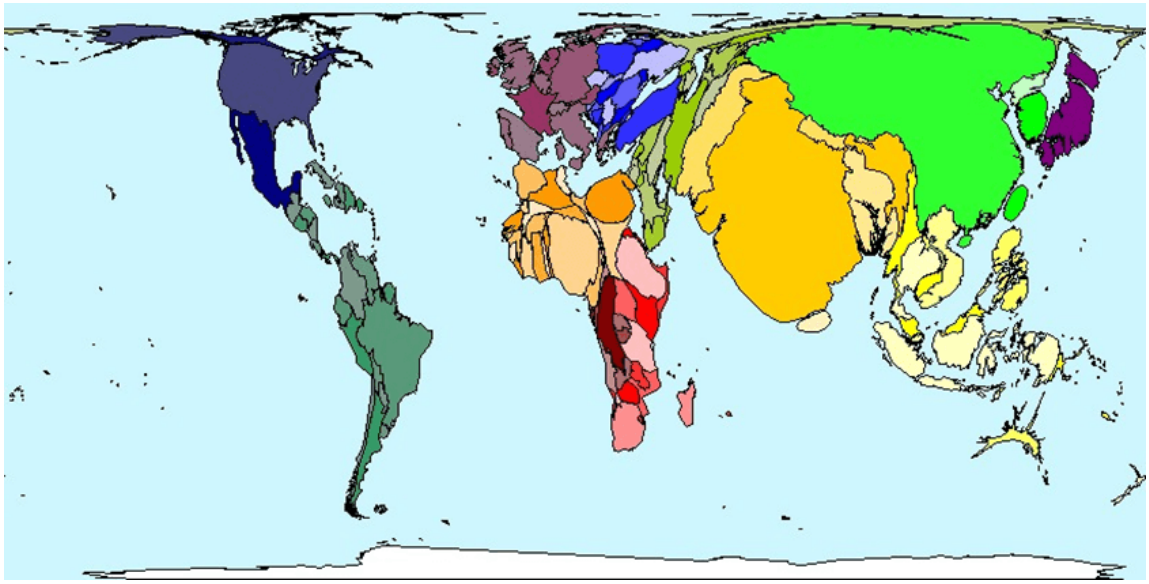


Figure 8.6: World Population Cartogram. Figure by Worldmapper is licensed under CC BY-NC-ND 3.0

The Worldmapper brief on water use explains that:

> Four thousand cubic kilometres of water are used by people each year around the world, for domestic, agricultural and other industrial purposes. This does not include non-consumptive uses such as energy generation, mining, and recreation.
>
> China, India, and the United States use the most water. These are also the territories where the most people live. But water use per person is about three times higher in the United States than it is in India and China.

While everyone needs water,the quantity used varies widely. On average, people living in Central Africa individually use only 2% of the water used by each person living in North America.[130]

Figure 8.7 maps countries based on per capita water usage, measured in cubic meters per year. The data includes water withdrawals from agricultural, industrial, and household/public services uses.

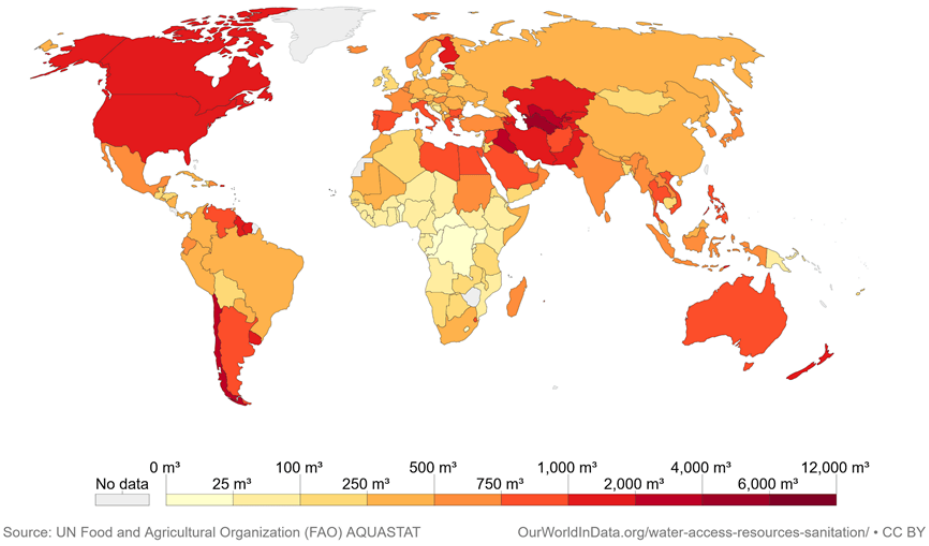


Figure 8.7: Water Withdrawals per capita (2005). Figure from AQUASTAT and Our World in Data is licensed under CC BY 4.0

Exercise 1.8.5

6. Refer to Figure 8.7.
    a. Do you notice any spatial patterns on the map? Which regions have the most water withdrawals and which regions have the least? Explain your response in three to four sentences.
    b. Use Your Critical Thinking Skills: List factors that might explain why some countries have high levels of water withdrawals.
    c. Use Your Critical Thinking Skills: List factors that might explain why some countries have low levels of water withdrawals.
    d. Use Your Critical Thinking Skills: List strategies governments and schools could use to improve water conservation practices.
7. Use Your Critical Thinking Skills: How does food play a role in water supplies? Explain your response in one to two sentences.

Check It Out! Water Withdrawals by Sector

Find out how countries compare in terms of water withdrawals in the agricultural, industrial, and household/public services sectors by going to the Our World in Data website and scrolling down through the maps.

Water Use in the United States

Now that you have a better understanding of how water is used globally, let us take a look at how water is used in the United States. Approximately 87% of the water used in the United States is freshwater, the remaining water used is salt water from the ocean or brackish water bodies such as lagoons and estuaries. According to the USGS, the United States used 322 billion gallons of water per day in 2015. The distribution of that usage is shown in Figure 8.8.

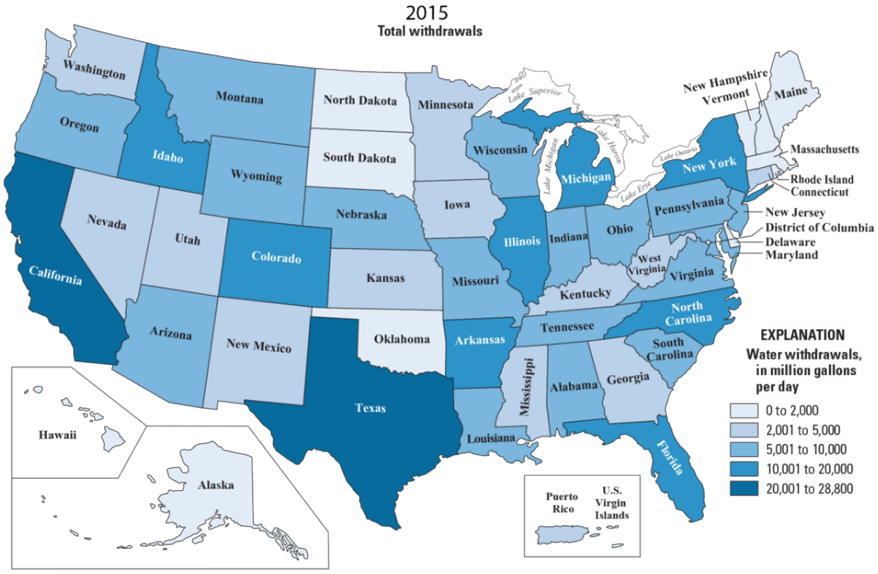


Figure 8.8: Surface and Groundwater Withdrawals in 2015. Withdrawal displayed in millions of gallons per day. Figure by USGS is in the public domain

Exercise 1.8.6

8. Refer to Figure 8.8.
    a. Which states use the most water?
    b. Which states use the least water?
    c. Use Your Critical Thinking Skills: List reasons why some states use more water than others.

Do you think population plays a role in your state's water usage? How does the United States use the water it withdrawals from natural systems? Figure 8.9 shows the distribution of how the 322 billion gallons per day of water was used in 2015. Seven categories were selected for top water usage in the United States by the USGS. We can see that 118 billion gallons per day of water is used for irrigation, and according to the USGS all of this water is pulled from freshwater sources. In other words, the second largest usage of freshwater in the United States is used to provide water for plant growth. This plant growth accounts for all agriculture uses, including chemical application, crop cooling, and harvesting. In addition, irrigation is used for plant growth in golf courses, cemeteries, nurseries, and parks.

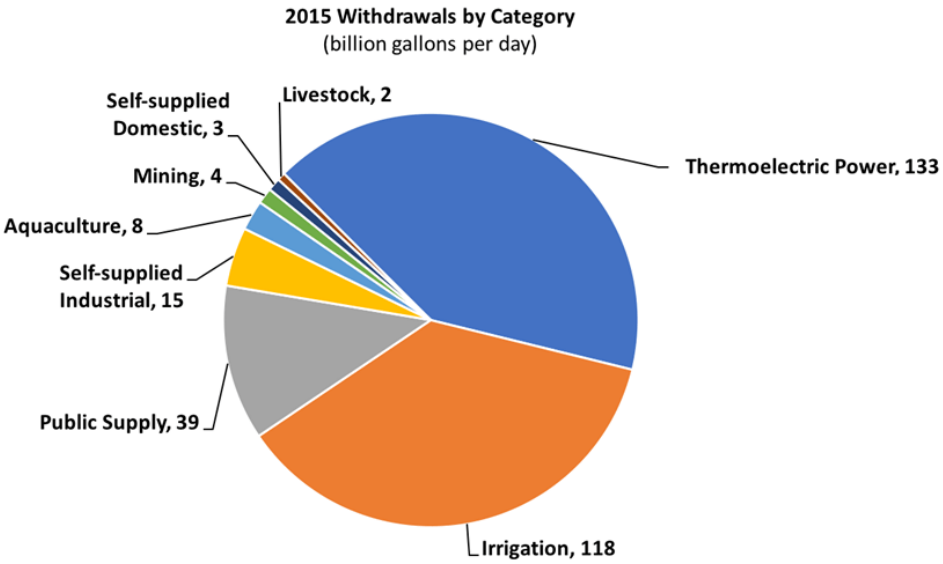


Figure 8.9: Distribution of Total Surface and Groundwater Withdrawals in the United States; Withdrawals displayed in billions of gallons per day. Figure by Taya Lazootin is licensed under CC BY-NC-SA 4.0

Exercise 1.8.7

9. Refer to Figure 8.9.
    a. In the United States, which two categories use the most water?
    b. What percentage of water is used for irrigation and livestock? Tip: Add the two values and then divide by the total amount of water withdrawals (322 million gallons) and then multiple by 100 to get the percentage. Show your calculation.
        i. What are some ways the United States could lower this percentage?
        ii. What are some actions you could take to help lower this percentage?

Part B. Watersheds and Groundwater

A **watershed** is the area of land where all of the water that falls in it and drains off of it goes to a common outlet, such as a river, a lake, or the ocean (refer to Figure 8.10). Watersheds exist everywhere and everyone lives within a watershed. Notice in Figure 8.10 how elevation plays a role in where water drains. Gravity pulls water toward the center of the Earth, so the water at higher elevations will naturally drain to lower elevations. This means that all of the water that falls at the top of a watershed will flow over or seep into the ground downstream. Some of this water flows directly to the sea or a nearby water body, and some of it seeps into the ground. This water either flows underground or is stored in an aquifer.

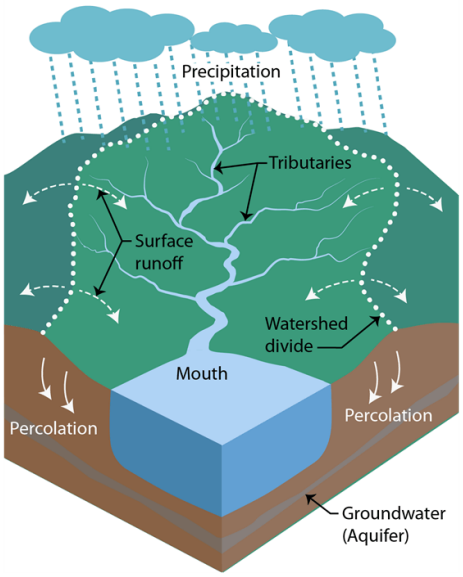


Figure 8.10: A Watershed. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

Watersheds are divided into **hydrologic areas (HA)** that are given distinct numbers (Figure 8.11). Each hydrologic area will contain unique land uses and habitats based on location, elevation, and climate. Because wildlife and people depend on water for survival, it is important that watersheds are monitored for water quality. If access to clean water is limited or unavailable, human and wildlife health can be severely compromised.



Figure 8.11: San Diego River Watershed and Hydrologic Areas. Used by permission. Source: Project Clean Water (County of San Diego, Department of Public Works, Watershed Protection Program)

All components of the hydrologic cycle have an impact on water quality in a watershed. One of the key factors to water quality is runoff, which is determined by the relationship between precipitation and infiltration. Regardless of how much precipitation a watershed receives, the amount of water that infiltrates into the soil and how quickly this happens depends on soil type. Soil type is determined by several factors. In this lab, we will focus on two key factors: porosity and permeability. The size of soil particles and the space between them determines how much water can pass through and how quickly.

Porosity is the amount of water a substance, such as soil, can hold and is dependent upon the amount of space in the soil, known as pore space. The greater the pore space, the greater the porosity. Water will move quickly and more freely in soil like gravel, which has greater porosity. Water will move less quickly or not at all in soil like clay, which has less porosity. Porosity is usually stated as a percentage of a substance's total volume.

Permeability is the ability of water to flow through soil. Permeability depends on how large the pore space in a soil is and how well the soil particles fit together. Figure 8.12 shows four sediment columns with different configurations of particle sizes that are either uniform, mixed, or sorted. Remember that aquifers are layers of permeable rock that store water underground. Watersheds that contain permeable rock layers underground will have more aquifers and therefore, are more likely to store more water underground. Some watersheds are able to store more groundwater than others. This is why it is important to understand what type of soil and rock lies below the surface in your watershed.

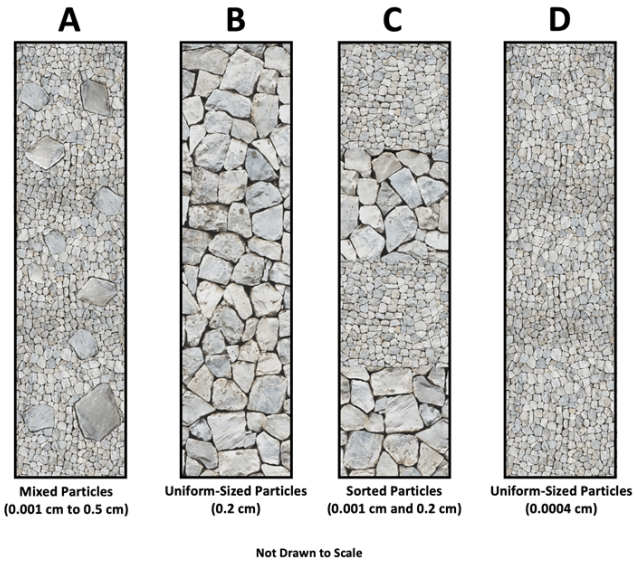


Figure 8.12: Sediment Columns. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Exercise 1.8.8

10. Refer to Figure 8.12.
    a. Which column of soil would allow for the fastest infiltration rate? Explain your response in one to two sentences.
    b. Which column of soil might experience the most flooding during a downpour? Explain your response in one to two sentences.
    c. Which column of soil might be the best to use for planting tropical plants? Explain your response in one to two sentences.
11. Apply What You Learned: In one to two sentences, explain the changes in porosity and permeability in areas where natural land use within a watershed has been removed and covered with hardscapes such as concrete or asphalt.
    a. Use Your Critical Thinking Skills: Taking these changes into consideration, how would infiltration and runoff change in this watershed when additional concrete or asphalt covers its surface?

Watershed Management and the Clean Water Act

Federal, state, and local jurisdictions manage, monitor, and regulate our water resources. A key piece of federal legislation is the Clean Water Act, which was enacted in 1972. This legislation accomplished the following:

- Established the basic structure for regulating pollutant discharges into the waters of the United States.
- Gave the Environmental Protection Agency (EPA) the authority to implement pollution control programs such as setting wastewater standards for industry.
- Maintained existing requirements to set water quality standards for all contaminants in surface waters.

- Made it unlawful for any person to discharge any pollutant from a point source into navigable waters, unless a permit was obtained under its provisions.
- Funded the construction of sewage treatment plants under the construction grants program.
- Recognized the need for planning to address the critical problems posed by nonpoint source pollution.[137]

Under the Clean Water Act and state law, California identifies more than 860 water quality monitoring variables, including chemical contaminants. Table 8.2 provides an overview of selected water quality indicators. Many of these variables have different thresholds, or limits to Determine when a water body is unhealthy, for both human health and aquatic life. When the water quality standards have been exceeded, a water body is designated as impaired.

Table 8.2: Selected Water Quality Monitoring Indicators

Indicator	Sources	Impact
Fecal Coliform and Enterococcus Bacteria	Sewage, farm animal waste, pet waste	Outbreaks of disease and illness in humans, cattle, chickens, pigs, and sheep
Plant Nutrients, including Nitrogen, Phosphorus, and Manganese	Application of fertilizers, sewage, vehicle exhaust, feedlots/farm manure	Prompts algal blooms that result in low levels of dissolved oxygen, which harms aquatic life
Metals and Metalloids including Lead, Mercury, and Selenium	Paints, automotive parts, brake pads, power plants	Can be harmful to human health, particularly during child development. Have been known to cause cancer, organ damage, nervous system damage, and death
Chloride	Sewage, application of inorganic fertilizers, animal feeds	Can increase the corrosivity of water
Sulfates	Sewage, discharges from industries such as tanneries, pulp mills, textile mills	May cause plumbing issues and can cause intestinal issues in mammals
pH	Carbon dioxide	Can change the acidity of the water, more acidic water prevents growth and development of shelled creatures and stony corals
Total Dissolved Solids	Wastewater treatment plants, agriculture, stormwater	Alter the flavor of drinking water, alter the color and clarity of freshwater sources

Exercise 1.8.9

12. In your own words, what does it mean when a water body is impaired?
13. Apply What You Learned: How would the hydrologic cycle influence the health of watersheds?
14. Apply What You Learned: How would the physical characteristics of the watershed (such as tributaries and terrain) influence the health of a watershed?
15. Use Your Critical Thinking Skills: Which of the water quality monitoring indicators shown in Table 8.2 do you have a direct impact on?

Case Study: San Diego River Watershed

The San Diego River watershed (Figure 8.11, above) is located in San Diego County, California. It is the second largest watershed in the county and receives minimal precipitation throughout the year. The San Diego River watershed is unique because it is one of the most biodiverse regions in the country. Because of its Mediterranean climate, a broad and diverse distribution of plant and animal species currently reside in this watershed. It is also home to five major reservoirs that provide potable (safe to drink) water to 760,000 residents in the area.

To learn more about the San Diego River watershed, you will explore information provided on the Project Clean Water website.

Step 1



Go to the San Diego River Watershed webpage from Project Clean Water.

Step 2

Read the Overview section of the webpage.

Exercise 1.8.10

16. How many hydrologic units exist within this watershed and what are they called?
16. Regarding development within the watershed:
    a. What percentage of the watershed is developed?
    b. What are the developed land uses and their percentages?
    c. What land uses are included in the “other” category?

Step 3



Go to the Table of Contents and click on “8. Hydrologic Area (HA) Descriptions”.

Step 4

Read the information about the Lower San Diego HA (907.1).

Exercise 1.8.11

18. Describe what is shown in the photograph.
19. What water bodies in this HA are listed as impaired under the Clean Water Act?
20. What are the main pollutants in this HA?

21. Of the pollutants listed for this HA, which ones are likely caused by human and animal waste? Tip: refer to Table 8.1.

    a. Where might these pollutants come from?

    a. Use Your Critical Thinking Skills: What are some ways that San Diego could manage this particular water quality issue?

Step 5



Search the internet to learn about your watershed. You may want to use the How's My Waterway? website from the Environmental Protection Agency.

Exercise 1.8.12

22. What is the name of the watershed where you live?
23. Are there any water bodies that are listed as impaired under the Clean Water Act?
24. What pollutants are found in your watershed?
25. Use Your Critical Thinking Skills: What are some ways that you could help decrease pollutants in your watershed and in nearby watersheds? List at least three ideas.

Part C. Water Budgets

Earlier, you learned that nearly 120 billion gallons per day of water are used in the United States for agriculture and plant growth. In order to manage our water supply for food consumption, we need to understand; how much water enters a watershed; how water is processed in the watershed; how much water leaves the watershed; and how water leaves the watershed.

This information is provided in a water budget. A **water budget** calculates the total inputs and outputs of water in the watershed. Water budgets are useful because they help land managers and the agriculture industry to identify the frequency and duration of water needs for irrigation of crops and vegetation. Water budgets vary based on location, soil, climate, and land use distribution in the watershed. Each hydrologic area within a watershed requires a water budget and most water budgets are calculated monthly and analyzed over time, generally from year to year.

To calculate a water budget you need to know the factors that influence water movement in the system you are studying.

➢ **Field capacity** refers to the total amount of water a soil can hold. This is important because certain soils will not retain as much water as others. Soils with large particle sizes and coarse textures will not hold as much water as soils with smaller particle sizes and smoother textures. Remember that water also leaves the system so we must consider evaporation, including transpiration from plants!

➢ The maximum amount of water that could be lost to evapotranspiration is called **potential evaporation (PE)** and is primarily dependent upon the overall temperature of a region.

➢ The amount of water that is actually lost to evapotranspiration is called **actual evapotranspiration (AE).** Precipitation is the amount of water that enters the watershed from the sky and will determine AE. If precipitation increases in a system with

a low PE, then more water is available than can be lost through evapotranspiration. If precipitation decreases in a system, there is less water available for evapotranspiration and the system experiences a water deficit.

At the end of a month, once AE and PE are known, the amount of water remaining in the soil shows how much water the soil retains over time. During a heavy or unpredicted rain event, precipitation could be greater than potential evaporation, and water is then added to the system. This is usually beneficial because the system experiences a **water surplus (S)**. The opposite occurs during a dry season or a drought. When precipitation is less than potential evaporation, water is removed from the system and the system experiences a **water deficit (D)**. Agriculture is often negatively impacted by systems that experience prolonged water deficits.

Exercise 1.8.13

Below are water budgets for two cities in California: Eureka located in Northern California and San Diego located in Southern California. The goal of this exercise is to plot and analyze the water budget data in order to understand how water moves through the hydrologic cycle in two different watersheds.

Table 8.3 provides water budget data for sandy loam soil in Eureka, California. This soil type has a field capacity of 3.5 inches and the total annual precipitation is 34.22 inches.

Table 8.3: Water Budget Data for Eureka (2019) data shown in inches

Variable	Jan	Fed	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P	4.85	4.60	3.90	2.60	2.00	1.75	1.22	1.00	1.60	3.30	3.80	3.60
PE	0.50	0.50	1.00	1.50	1.90	2.75	3.30	3.50	3.60	1.75	1.30	0.45
AE	0.50	.50	1.00	1.50	1.90	3.00	3.12	2.90	2.80	1.75	1.30	0.45

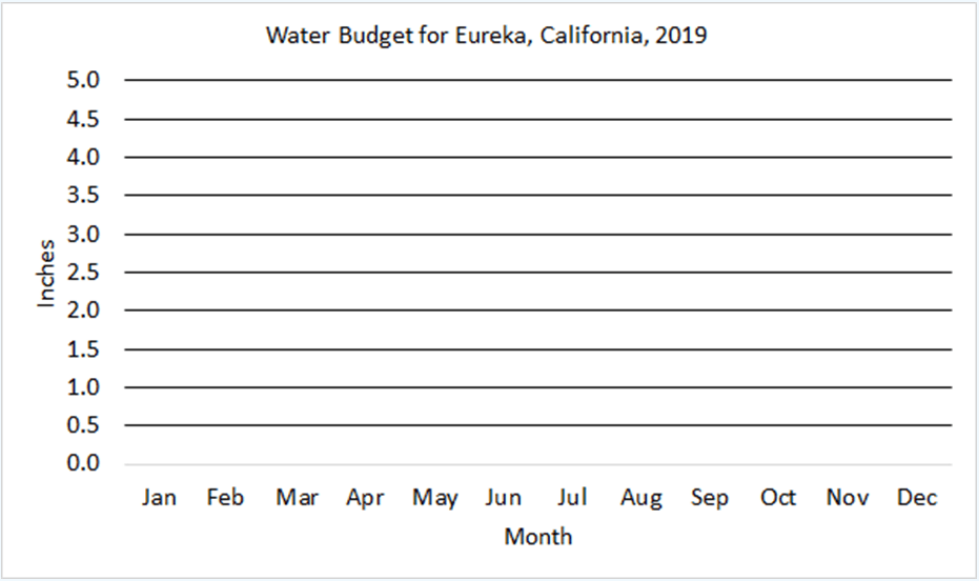


Figure 8.13: Water Budget for Sandy Loam Soil in Eureka, California (2019). Figure by Taya Lazootin is licensed under CC BY-NC-SA 4.0

27. Refer to Figure 8.13.

    a. During which months is actual evaporation (AE) less than potential evaporation (PE)?

        i. During these months is there a water surplus or a water deficit?

        ii. Shade this area red.

    b. During which months is precipitation (P) greater than actual evaporation (AE) and potential evaporation (PE)?

i. During these months is there a water surplus or a water deficit?

ii. Shade this area blue.

c. Which months of the year would industries that rely on local groundwater supplies for agricultural needs have to plan ahead?

Now let's analyze a water budget for San Diego in Southern California. Table 8.4 provides water budget data for silty clay loam soil in San Diego. This soil type has a field capacity of 2.2 inches and the total annual precipitation is 10.39 inches.

Table 8.4: Water Budget Data for San Diego (2019) data shown in inches

Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P	2.26	1.83	2.15	0.78	0.20	0.08	0.04	0.04	0.20	0.35	1.13	1.33
PE	1.37	1.60	1.79	2.26	2.81	3.39	4.06	4.21	3.71	2.81	0.91	1.37
AE	1.76	1.33	1.79	0.78	0.20	0.08	0.04	0.04	0.20	0.35	1.13	1.33

28. Create a plot on the graph below (Figure 8.14) using the P, PE, and AE data for all 12 months of data from Table 8.4. Use a blue pencil for P, a green pencil for PE, and red pencil for AE. Make sure you connect the points for each of the three variables (you should have three lines on your graph). Also, create a legend by your plot.

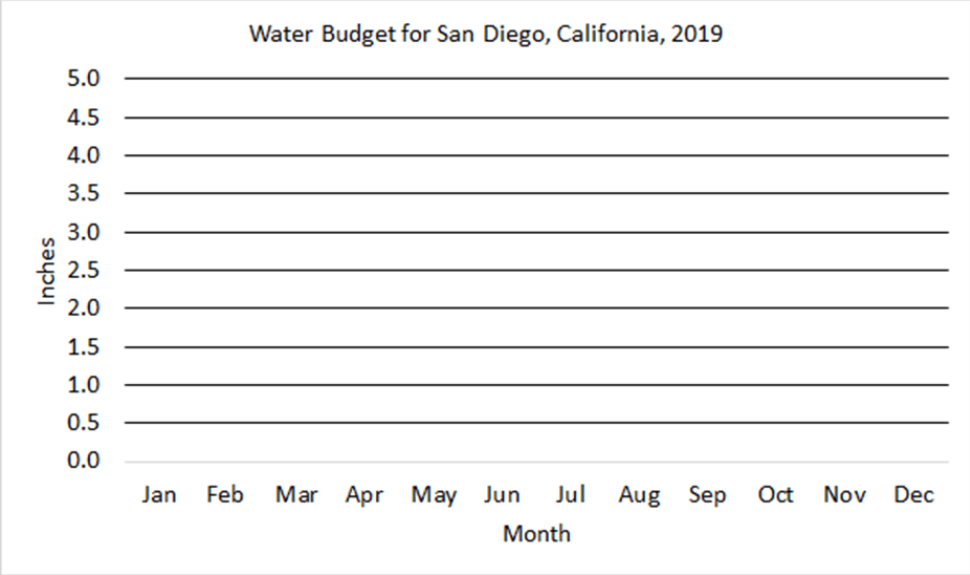


Figure 8.14: Water Budget for Silty Clay Loam Soil in San Diego, California (2019). Figure by Taya Lazootin is licensed under CC BY-NC-SA 4.0

29. Refer to Figure 8.14.

a. During which months is actual evaporation (AE) less than potential evaporation (PE)?

i. During these months is there a water surplus or a water deficit?

ii. Shade this area red.

b. During which months is precipitation (P) greater than actual evaporation (AE) and potential evaporation (PE)?

i. During these months is there a water surplus or a water deficit?

ii. Shade this area blue.

c. Which months of the year would industries that rely on local groundwater supplies for agricultural needs have to plan for ahead of time?

30. Review Figures 8.13 and 8.14. What are three key differences between the water budgets for Eureka and San Diego?

31. Apply What You Learned: Why doesn't a water budget include data about a location's groundwater supplies?

32. Use Your Critical Thinking Skills: As global temperatures continue to increase over the next several decades, what are some potential problems agricultural industries could face in regards to water supplies?

33. Use Your Critical Thinking Skills: What are some actions people could take locally and globally to prevent the negative impacts of water deficits?

One difference between Eureka and San Diego is the amount of annual precipitation for each city in 2019: 34.22 inches and 10.39 inches, respectively. If water supply to residents depends on local water supplies, then cities with large populations would need to have larger amounts of surface water and groundwater available for drinking, sanitation, and irrigation. The population of Eureka is 26,998 people and the population of San Diego is 1,426,000 people.

34. How many times larger is San Diego's population compared to Eureka's? Show your work.

35. What percentage of Eureka's precipitation did San Diego receive in 2019? Show your work.

Many cities in California don't rely on local water supplies to support their populations. In San Diego, 85% of its water supplies come from outside the local area. Figure 8.15 shows the major surface water features and water infrastructure in California, along with whether a region is a net importer or exporter of water.

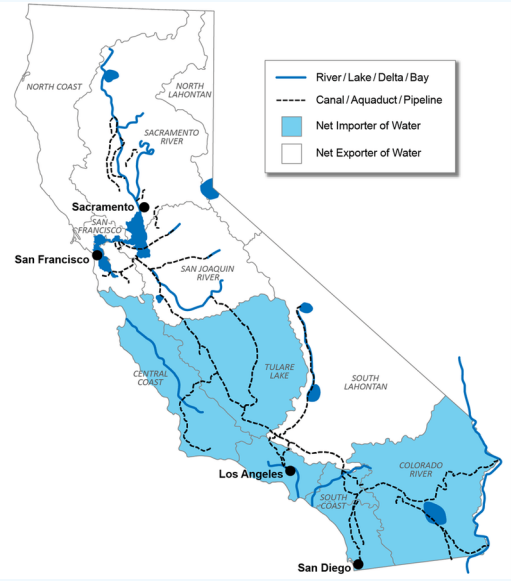


Figure 8.15: Net Importing and Net Exporting Water Regions. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

36. Refer to Figure 8.15.

a. Label the major water bodies shown on the map. From North to South:
   i. Shasta Lake
   ii. Lake Tahoe (one eastern border with Nevada)
   iii. California Delta (also known as the Sacramento-San Joaquin Delta)
   iv. San Francisco Bay (to the west of the California Delta)
   v. San Luis Reservoir (in the San Joaquin River region)
   vi. Mono Lake (in the northern part of South Lahontan region)
   vii. Owens Lake (in the southern part of South Lahontan region)
   viii. Salton Sea

b. Is Eureka in a net exporting or net importing region?

c. Is your location a net importer or net exporter of water?

d. What are two conclusions that can be drawn from the information shown on the map?

e. Use Your Critical Thinking Skills: Why is it important to analyze water resources at different scales (e.g., watershed, water region, state, country)? Explain your response in one to two sentences.

Check It Out! California's Water Policies and Infrastructure

Learn more about California's water polices and infrastructure from the Managing California's Water: From Conflict to Reconciliation report by the Public Policy Institute of California. (This links to a downloadable pdf file).

Part D. Wrap-Up

Consult with your geography lab instructor to find out which of the following wrap-up questions you should complete. Attach additional pages to answer the questions as needed.

Exercise 1.8.14

37. What is the most important idea that you learned in this lab? In two to three sentences, explain the concept and why it is important to know.

38. What was the most challenging part of this lab? In two to three sentences, explain why it was challenging. If nothing challenged you in the lab, write about what you think challenged your classmates.

39. What is one question that you have about what you learned in this lab? Write your question along with one to two sentences explaining why you think your question is important to ask.

40. Review the learning objectives on page 1 of this lab. How would you rate your understanding or ability for each learning objective? Write one sentence that addresses each learning objective.

41. Sketch a concept map that includes the key ideas from this lab. Include at least five of the terms shown in bold-faced type.

42. Create an advertisement to educate your peers on the important information that you learned in this lab. Include at least three key terms in your advertisement. The advertisement should be about half a page in size (about 4 inches by 6 inches).

43. One way to think of physical geography is that it is the study of the relationships among variables that impact the Earth's surface. Select two variables discussed in this lab and describe how they are related.

44. How does what you learned in this lab relate to your everyday life? In two to three sentences, explain a concept that you learned in this lab and how it relates to your day-to-day actions.

45. How does what you learned in this lab relate to current events?
    a. Write the title, source, and date of a news item that relates to this lab.
    b. In two to three sentences, discuss how the news item relates to what you have learned in this lab.
    c. In one to two sentences, discuss whether or not the news item accurately represents the science that you learned. Tip: consider whether or not the news item includes the complexity of the topic.

46. Search O*NET OnLine to find an occupation that is relevant to the topics presented in today's lab. Your lab instructor may provide you with possible keywords to type in the Occupation Quick Search field on the O*NET website.
    a. What is the name of occupation that you found?
    b. Write two to three sentences that summarize the most important information that you learned about this occupation.
    c. What is one question that you would want to ask a person with this occupation?

Answer available at the end of this section.

[122] Text adapted from USGS

[130] Text and data from Worldmapper is licensed under CC BY-NC-SA 4.0

[137] Text from the Environmental Protection Agency (EPA)

Answers

Exercise 1.8.14

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1.9: Lab 9 - Climate Patterns

This lab contains potentially inaccessible interactive resources. Please work with your instructor and local campus resources to identify accommodations for these resources.

Learning Objectives

- Interpret climographs.
- Explain the main controls on climate.
- Compare climates using the Köppen–Geiger classification system.
- Apply an understanding of climate types to California and your local area.
- Analyze temporal and spatial climate shifts.

Introduction

Climate patterns are long-term atmospheric conditions that influence life on Earth. Typically, scientists use thirty years of weather data, such as average monthly temperatures and precipitation, to classify a location's climate. Our climate influences our day-to-day actions and impacts our resource consumption in terms of energy usage for the heating and cooling of our homes and workplaces. Our behaviors are influenced by climate, as well:

- Do you own a raincoat and carry an umbrella most of the year?
- Do you work outdoors in the early morning to avoid the extreme heat of the afternoon sun during the summer months?
- Do you carry snow chains for your car tires in the winter months?

In this lab, you will learn the major variables that determine a location's climate, how climates are classified, and how these climate classifications change over time.

Part A. Controls on Climate

Why is New York City hot and humid in the summer? Why is Seattle known for rain? Why does San Diego experience so many days of sunshine? To answer these questions, you must understand the major variables that influence a location's **climate**—the long-term weather conditions. What you have learned so far in this physical geography laboratory course will help you to understand these variables.

Climograph Interpretation

Before we introduce these variables, let's learn how to interpret a climograph. A **climograph** is a helpful chart that graphs average monthly precipitation and temperature. A blank climograph is shown in Figure 9.1. The months are shown along the x-axis, starting with January (J) on the far-left and going through to December (D) on the far-right. Average monthly precipitation is on the left y-axis, shown in centimeters. For reference, one inch is 2.54 centimeters. So, a location that receives 10 inches of rain on average in January receives 25.4 centimeters of rain. Average monthly temperature is shown on the right y-axis, shown in degrees Celsius. For reference, 32°F (freezing/melting point of water) is 0°C, 70°F is 21.1°C, and 100°F is 37.8°C.

Pin It! Metric Conversions

The scientific community uses the metric system, so the climographs and climate classification data in this lab are shown in metric units. Try to relate the American units that you already know (such as degrees Fahrenheit and inches) to their metric equivalents. Here are some examples to help you make the connection between the American units that you know and their metric equivalents:

- 50°F is 10°C, 70°F is ~21°C, and 90°F is ~32°C.
- 1 inch is 2.54 centimeters, 5 inches is 12.7 centimeters, and 10 inches is 25.4 centimeters.

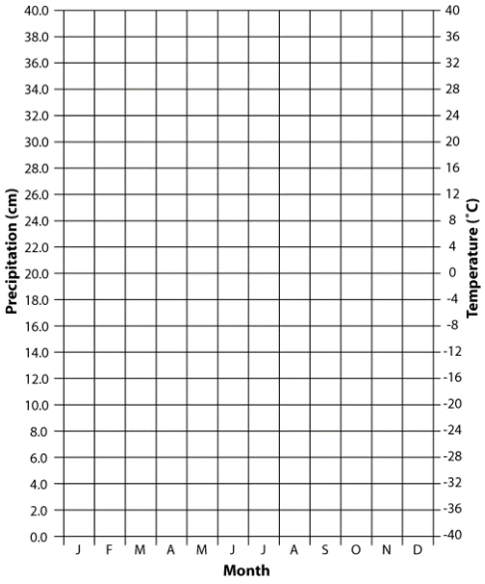


Figure 9.1: Blank Climograph. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

In order to complete the climograph, you need the average monthly precipitation and temperature for a location. Table 9.1 provides this data, which we will use to create an example climograph.

Table 9.1: Climograph Data for a Location

Month	Average Precipitation (cm)	Average Temperature (°C)
January	5.9	22.9
February	5.1	22.8
March	5.1	23.6
April	1.6	24.5
May	1.6	25.4
June	0.7	26.8
July	1.3	27.3
August	1.4	27.7
September	1.8	27.5

Month	Average Precipitation (cm)	Average Temperature (°C)
October	4.7	26.7
November	6.1	25.3
December	8.2	23.8

In this example, we'll first plot the precipitation data from Table 9.1 on the climograph using a bar graph for each month. As you will note in Figure 9.2 below, the blue bars represent average monthly precipitation. Note: the blue color is arbitrary; climographs may show precipitation in green or another color.

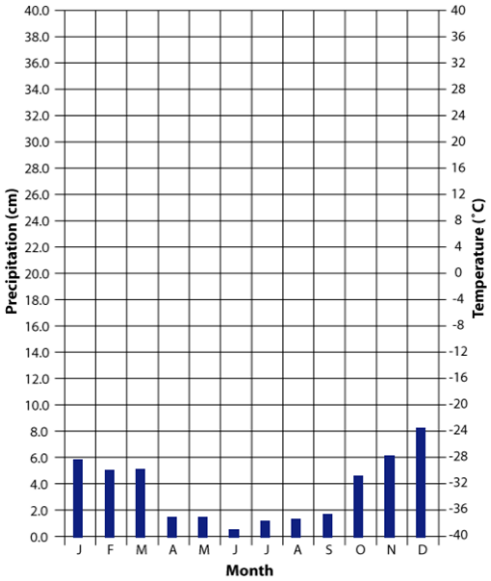


Figure 9.2: Climograph with Only Precipitation Plotted. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

The next step to create the example climograph is to plot the temperature data from Table 9.1. We have used an orange line to represent average monthly temperature as shown in Figure 9.3. Note: the orange color is arbitrary; climographs may show temperature in red or as another color.

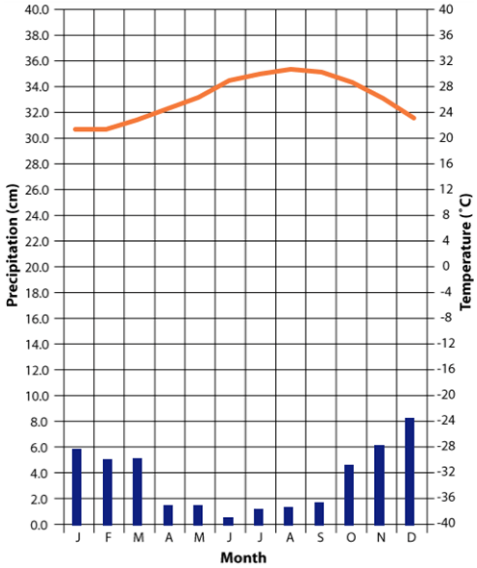


Figure 9.3: Climograph with Precipitation and Temperature Plotted. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

Exercise 1.9.1

1. Refer to Figure 9.3. How does the climograph help us understand the location's climate? Create a list of what you can determine from the climograph. Here are two questions to help you write your response: does the location's temperature fluctuate or is it within about a 15°C temperature range throughout the year? When is the rainy season? (This is when precipitation levels increase).

Five Major Controls on Climate

Now that you are familiar with climographs, let's take a look at the variables that influence a location's climate—we call these variables climatic controls (or controls on climate). These variables explain why a location might (or might not) have temperatures that fluctuate greatly throughout the year, why the location might have a rainy season, etc. While we will look at each variable individually, it's important to remember that these variables may interact to influence a particular location in a unique way.

Latitude

The first and most important variable that influences a location's climate is latitude. Low latitudes (closer to the equator) receive higher total insolation year-round than higher latitudes (closer to the poles). So, locations at tropical latitudes show little temperature changes throughout the year compared to higher latitudes. Locations at middle and high latitudes show a wider range in temperatures because of the tilt of the Earth, which influences insolation amounts and daylight hours throughout the year.

Exercise 1.9.2

2. Compare the two climographs shown below (Figure 9.4). Does climograph A (on the left) or B (on the right) represent a location at 61° North latitude? Explain your response in at least one sentence.

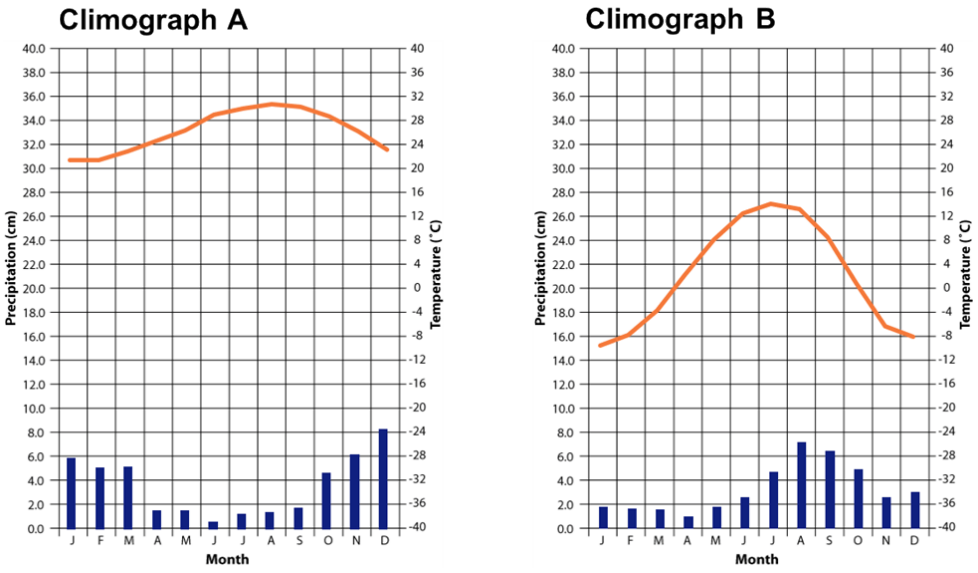


Figure 9.4: Climograph Examples A (on left) and B (on right). Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

Continentality

The second variable that influences a location's climate is **continentality**. This refers to whether a location is located along a coastline or is inland. Variations in climate are due in part to land-water contrasts. Land and water react differently to insolation. In general, land heats up and cools off faster than water does due to its specific heat. A location in the interior of a continent will be warmer in the summer and cooler in winter than a maritime (coastal) location at the same latitude. So, maritime regions have

a lower annual temperature range than continental regions.

Exercise 1.9.3

3. Compare the two climographs shown below (Figure 9.5). Both locations are near 40° North latitude. Does climograph C (on the left) or D (on the right) represent a maritime location? Explain your response in at least one sentence.

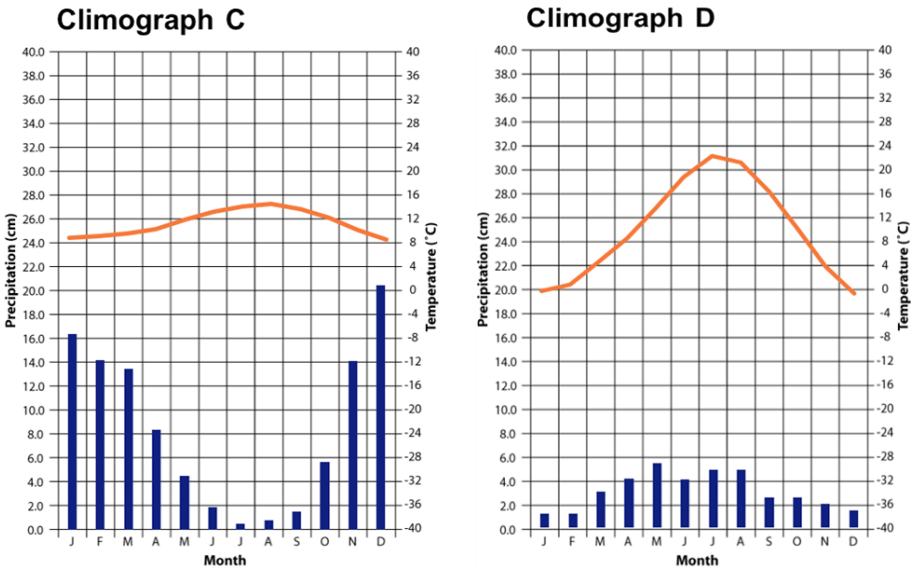


Figure 9.5: Climograph Examples C (on left) and D (on right). Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

Wind Patterns and Air Masses

Wind patterns and air masses also influence a location's climate. Here are several examples of their influence:

➢ In midlatitudes in the Northern Hemisphere, the dominant winds are the westerlies. These winds travel from west to east and bring seasonal warmth or coolness to eastern locations.

➢ Monsoons are the seasonal reversal of winds that bring very high precipitation levels around June through August in South Asia.

➢ Locations influenced by maritime tropical air masses will have higher levels of precipitation and temperature than locations influenced by polar continental air masses.

Exercise 1.9.4

4. Compare the two climographs shown below (Figure 9.6). Both locations are found at 21° North latitude. Why does the location depicted by climograph E (on the left) have higher levels of precipitation when compared to climograph F (on the right)? Explain your response in at least one sentence.

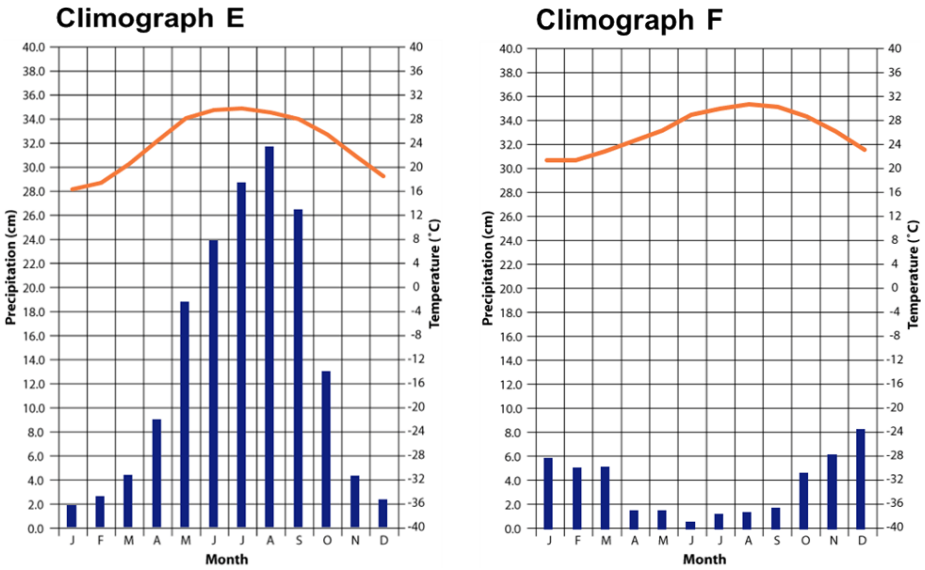


Figure 9.6: Climograph Examples E (on left) and F (on right). Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

Ocean Currents

Ocean currents also influence a location's climate. The major surface ocean currents move warm water from equatorial regions toward polar regions and they bring cool water from the polar regions to equatorial regions. As a result, ocean circulation is a significant mechanism of global heat transfer.

The surface ocean current map (Figure 9.7) shows cold currents in blue and warm currents in red. Notice that warm currents are found in equatorial locations. Recall from a previous lab that surface ocean currents are driven by global atmospheric circulation. This explains why many west coasts of continents have cold currents while east coasts have warm currents. Warm currents bring warmer temperatures and higher levels of precipitation compared to cold currents.

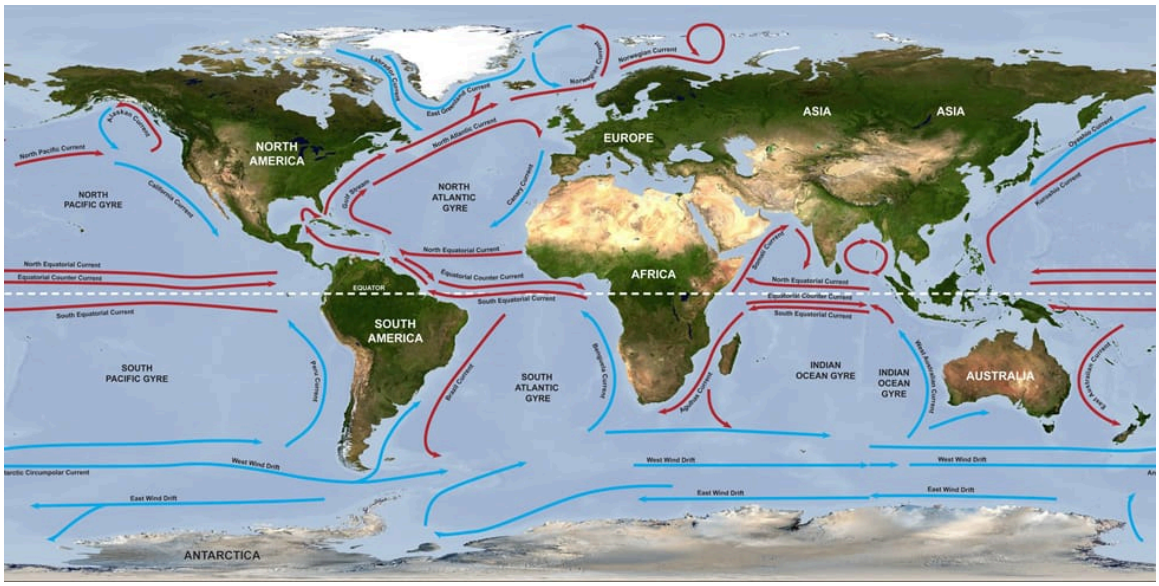


Figure 9.7: Map of Surface Ocean Currents. Used by permission. Dataset source: Laura Walker, Program Manager, O'Neill Sea Odyssey

Exercise 1.9.5

5. Both locations shown by their climographs in Figure 9.8 are near 33° latitude. Based on the temperature curves on both climographs, how do you know if these locations are in the northern or southern hemisphere? Explain your response in at least one sentence.

5. Compare the two climographs shown below (Figure 9.8). Which location is near a warm surface ocean current? Explain your response in at least one sentence.

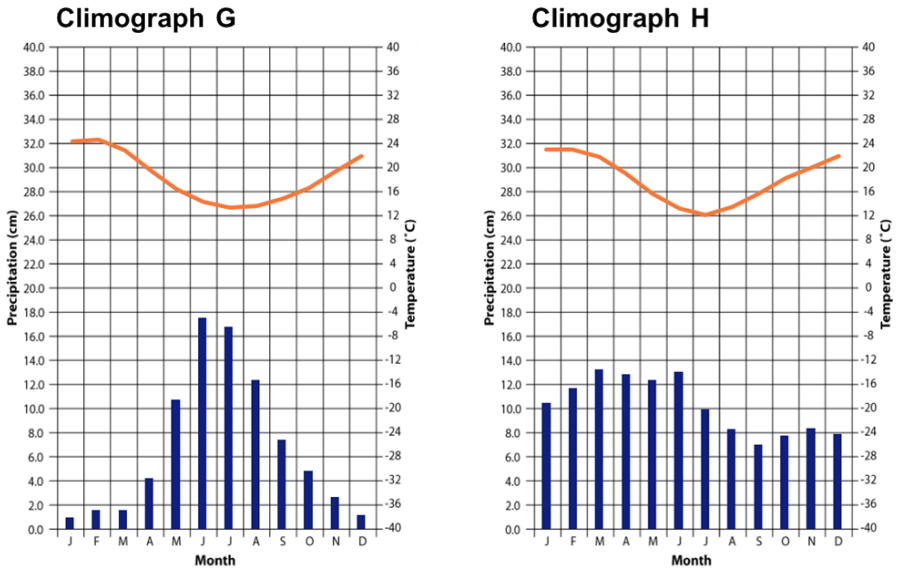


Figure 9.8: Climograph Examples G (on left) and H (on right). Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

Elevation

The final important control on climate is elevation. As you learned when you studied orographic lifting, under normal conditions temperatures decrease between 6 and 10 degrees Celsuis for every 1,000 meters that the elevation increases. Locations on the windward side of mountains receive precipitation and locations on the leeward side of mountains are in the rainshadow.

Exercise 1.9.6

7. Compare the two climographs shown below (Figure 9.9). Both locations are found at 48° North latitude. Which climograph represents a location in the rainshadow of a mountain? Explain your response in at least one sentence.

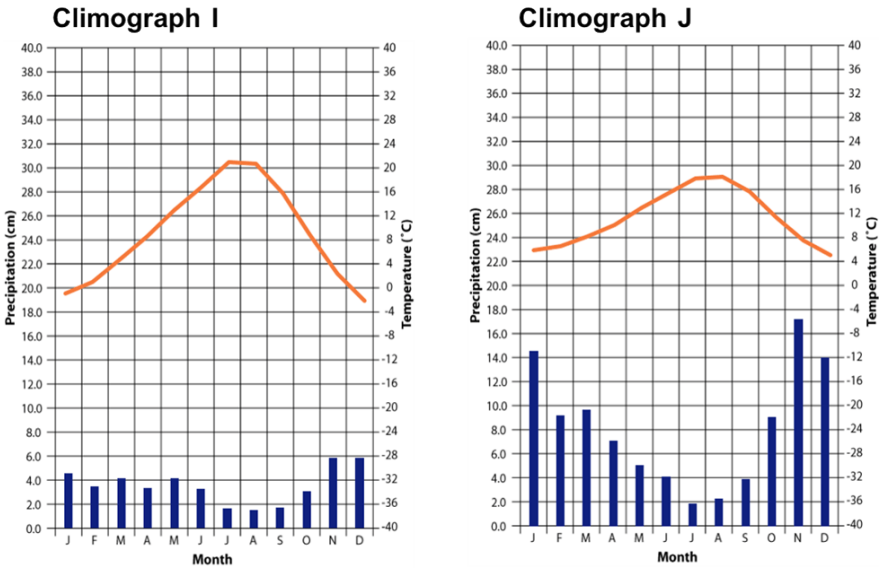


Figure 9.9: Climograph Examples I (on left) and J (on right). Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

Pin It! The Five Main Controls on Temperature

Remember the five climatic controls when analyzing a location's climate: latitude, continentality, wind patterns and air masses, ocean currents, and elevation.

Exercise 1.9.7

8. Apply What You Learned: Match climographs B through J (shown in Figures 9.4, 9.5, 9.6, 9.8, and 9.9 above) to their real-world locations shown in Table 9.2. To complete Table 9.2, use a globe, atlas, or the internet to find where each city is located, the city's elevation, and whether the city is maritime (coastal) or continental (inland of a continent). Tips:

   ➢ Remember to indicate N or S for the latitudes of each city.

   ➢ Complete the southern hemisphere locations first (their climographs should be distinct from the northern hemisphere locations in terms of temperature).

   ➢ Several questions above indicate the latitudes of the climographs so you can use this information to narrow down the cities.

Table 9.2: City-Climograph Matching

City	Latitude (to the nearest degree)	Elevation (indicate feet or meters)	Maritime or Continental	Climograph Letter (Select from B through J)	List the Major Climatic Controls at this City:
Anchorage, Alaska					
Denver, Colorado					

City	Latitude (to the nearest degree)	Elevation (indicate feet or meters)	Maritime or Continental	Climograph Letter (Select from B through J)	List the Major Climatic Controls at this City:
Eureka, California					
Hanoi, Vietnam					
Honolulu, Hawai'i					
Perth, Australia					
Seattle, Washington					
Spokane, Washington					
Sydney, Australia					

Part B. Climate Classification

Understanding the major variables that influence climate helps explain why a particular location experiences the climate that it does. In order to understand climate patterns, we need to classify climates. This helps us to know what locations experience similar climatic conditions.

The **Köppen–Geiger climate classification system** is one of the most commonly used methods to classify a location's climate. It was first developed in the late 1800s and revised through the early 1900s. This climate classification system uses average monthly temperature and precipitation data to classify climates into five main groups:

- **Tropical climates** are humid with monthly average temperatures of at least 18°C (64.4°F). Tropical climates are designated with an "A".
- **Dry climates** are found at locations with little precipitation, which causes evaporation to exceed precipitation and results in water deficiencies throughout the year. Dry climates are designated with a "B".
- **Temperate climates** have at least one month with an average temperature higher than 10°C (50°F) and a coldest month with an average temperature between 0°C (32°F) and 18°C (64.4°F). Temperate climates are designated with a "C".
- **Continental climates** have at least one month with an average temperature lower than 0°C (32°F) and at least one month with an average temperature higher than 10°C (50°F). Continental climates are designated with a "D".
- **Polar climates** have an average monthly temperature below 10°C (50°F). Polar climates are designated with an "E".

Exercise 1.9.8

9. Use Your Critical Thinking Skills: Why do you think average monthly temperatures were used to classify climates? Explain your response in one to two sentences.
10. Use Your Critical Thinking Skills: Why do you think particular temperatures were used to classify climates? In other words, why would the creators of the Köppen–Geiger climate classification system use 0°C (32°F), 10°C (50°F), or 18°C (64.4°F) to divide the climate types? Explain your response in one to two sentences.

The world map below (Figure 9.10) shows the five major climate types.

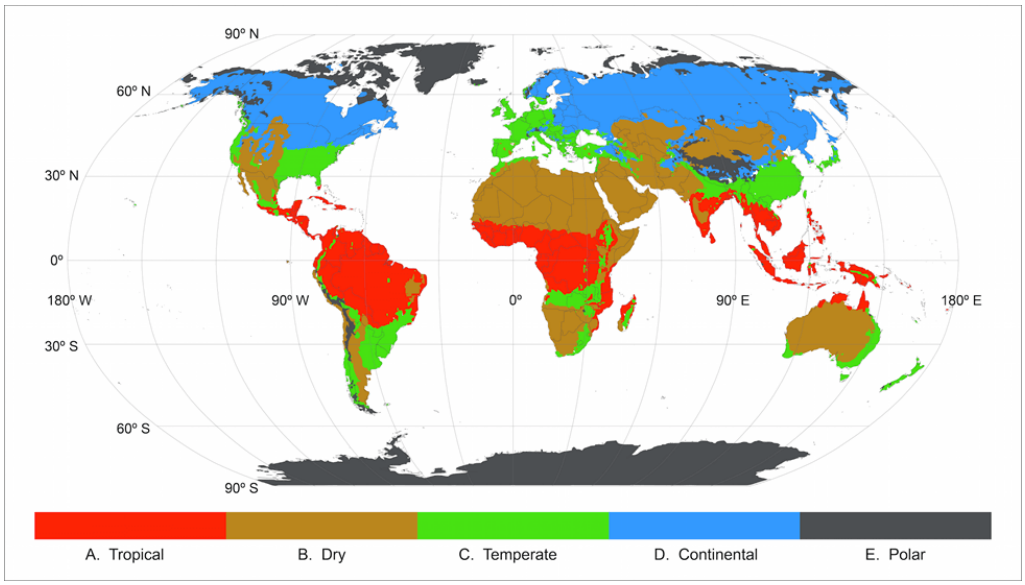


Figure 9.10: Map of Major Climate Classification Types (1901-2010). Figure by Waverly Ray based on data available from http://hanschen.org is licensed under CC BY-NC-SA 4.0

Exercise 1.9.9

11. Refer to Figure 9.10. List three observations that you can make based on the spatial patterns presented on the map. These observations could be something that is unexpected or surprising.

Within each of the five main climate types, there are further subdivisions to classify climates. Figure 9.11 is a map that shows all of these climate classifications. An enlarged version of this map is available in Appendix 9.1.

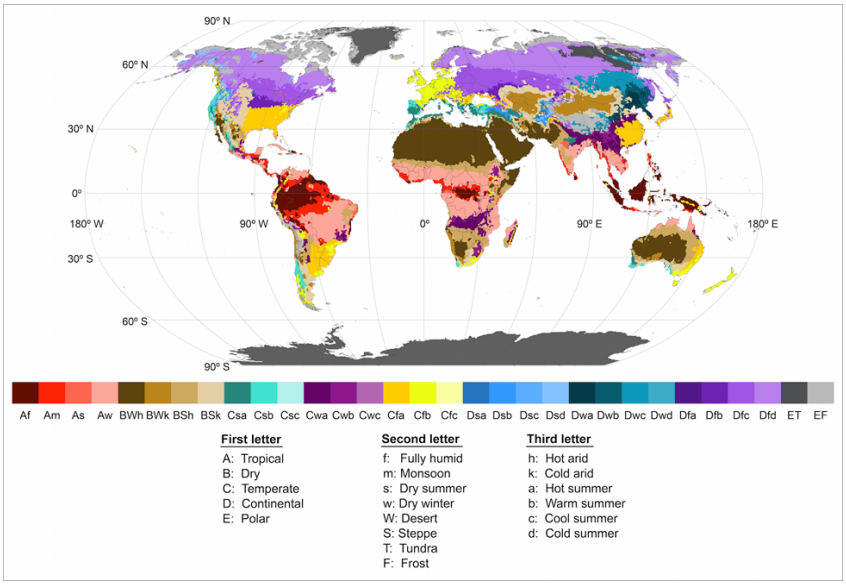


Figure 9.11: Climate Classification Map (1901-2010). Figure by Waverly Ray based on data available from http://hanschen.org is licensed under CC BY-NC-SA 4.0

Exercise 1.9.10

12. Refer to Figure 9.11 (or Appendix 9.1). List three observations that you can make based on the spatial patterns presented on the map. These observations could be something that is unexpected or surprising.

A Climates

For A climates (tropical climates), a second letter is added. It's important to note that monsoons are the seasonal reversal of winds that bring tremendous amounts of precipitation to much of South and Southeast Asia. Also note that a savanna is a grassland found in the tropics and subtropics.

- **Af** indicates year-round precipitation. This is a Tropical Rainforest climate.
- **Am** indicates monsoonal precipitation. This is a Tropical Monsoon climate.
- **Aw** indicates a savanna climate with a relatively dry winter. This is a Tropical Wet Savanna climate.
- **As** indicates a savanna climate with a relatively dry summer. This is a Tropical Dry Savanna climate.

Exercise 1.9.11

13. Refer to Figure 9.11 above. Describe the spatial distribution for the A climate types. (Where are the A climates found?)
14. Apply What You Learned: Why do you think the southeast Asian islands have a Tropical Rainforest climate but the continental parts of Southeast Asia and South Asia have both the Tropical Monsoon and the Tropical Savanna climates? Explain your response in one to two sentences.
15. *The Lion King* film is set in the Tropical Savanna of Africa. Estimate the percentage of the African continent that have this climate type. (Do you think the Tropical Savanna climate is one-quarter, one-half, or three-quarters of the continent?)

B Climates

For B climates (dry climates), second and third letters are added. If W is the second letter, then it represents a desert location. If S is the second letter, then it represents a steppe (midlatitude grassland) location. If the third letter is h, this represents a relatively hot arid location. If the third letter is k, this represents a relatively cold air location.

- **BWh** is a Hot Desert climate.
- **BWk** is a Cold Desert climate.
- **BSh** is a Hot Semi-Arid climate.
- **BSk** is a Cold Semi-Arid climate.

Exercise 1.9.12

16. Refer to Figure 9.11 above. Describe the spatial distribution for the B climate types. (Where are the B climates found?)
17. What is the latitude that intersects much of the land with the B climate types in the northern and southern hemispheres? Hint: this latitude is where subtropical high pressure systems are dominant.

C Climates

For C climates (temperate climates), second and third letters are added. If w is the second letter, then it represents a location with a relatively dry winter. If f is the second letter, there is not a dry season at this location. If s is the second letter, then it represents a location with a relatively dry summer. If a is the third letter, then it represents a location with a relatively hot summer. If b is the third letter, then it represents a location with a relatively warm summer. If c is the third letter, then it represents a location with a relatively cool summer. Here are some of the C climate types:

- **Cfa** is a Humid Subtropical climate.

- **Cfb** is a Marine West Coast climate with a relatively warm summer.
- **Cfc** is a Marine West Coast climate with a relatively cool summer.
- **Cwa** is a Humid Subtropical climate with a dry winter.
- **Csa** is a Hot-Summer Mediterranean climate.
- **Csb** is a Warm-Summer Mediterranean climate.
- **Csc** is a Cold-Summer Mediterranean climate.

Exercise 1.9.13

19. Which climate type is most common in the southeastern United States?
20. The Cfb and Cfc Marine West Coast climates are not only found on the west coasts of continents. Where is this climate type found when it is not on a west coast of a land mass?
21. The Csa, Csb, and Csc Mediterranean climates are not only found in the Mediterranean regions of Africa, Southwest Asia, and Europe. Where is this climate type found outside of the Mediterranean region?

D Climates

For D climates (continental climates), second and third letters are added. It utilizes the same second and third letter designations as the C climates, with an additional letter option for the third letter. When the third letter is d, this designates a location with a very cold winter. Here are some of the D climate types:

- **Dfa** is a Hot-Summer Continental climate.
- **Dfb** is a Warm-Summer Continental climate.
- **Dfc** is a Subarctic climate.
- **Dfd** is an Extremely Cold Subarctic climate.
- **Dwa** is a Hot-Summer Humid Continental climate.
- **Dwb** is a Warm-Summer Humid Continental climate.
- **Dwc** is a Subarctic Humid Continental climate.
- **Dwd** is an Extremely Cold Humid Subarctic climate.

Exercise 1.9.14

22. Refer to Figure 9.11 above. Describe the spatial distribution for the D climate types. (Where are the D climates found?)

E Climates

There are three types of E (polar climates):

- **ET** is a Tundra climate.
- **EF** is an Ice Cap climate.

➢ **EM** is a Polar Marine climate.

Exercise 1.9.15

23. Refer to Figure 9.11 above. Describe the spatial distribution for the E climate types. (Where are the E climates found?)

Simplified Guide to Climate Classification

In describing each of the five main climate classification categories, we have left out the details of what is meant by the descriptions such as warm summer and dry winter. In order to understand how the climates are actually classified into the different categories, use Figure 9.12, which is a simplified guide to climate classifications.

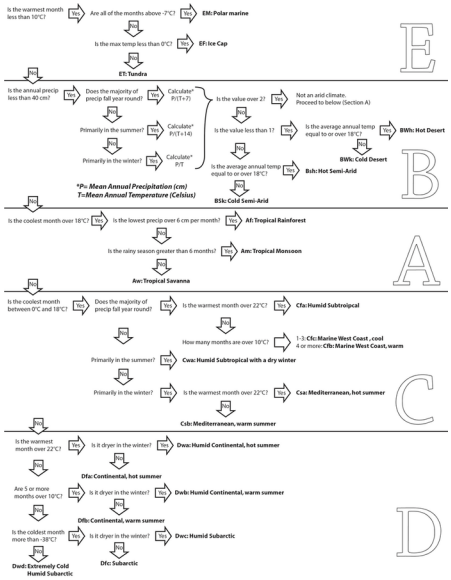


Figure 9.12: Simplified Guide to Climate Classifications. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

Next, you will use the Simplified Guide to Climate Classifications (Figure 9.12) and data from four example locations to identify each location's climate type.

Exercise 1.9.16

24. Use Figure 9.12 above and the data provided in Table 9.3 below to find the climate classification for the example 1 location. What climate classification best fits this location?

Table 9.3: Example 1 Location Climate Data

Month	Average Precipitation (cm)	Average Temperature (°C)
January	1.8	-9.6
February	1.7	-7.7
March	1.6	-3.6
April	1.0	2.6
May	1.8	8.7
June	2.6	13.2
July	4.8	14.9

Month	Average Precipitation (cm)	Average Temperature (°C)
August	7.3	13.8
September	6.5	9.1
October	5.0	1.1
November	2.6	-6.2
December	3.1	-8.0
Mean Annual	3.3	2.4
Annual Total	39.8	n/a

25. Use Figure 9.12 above and the data provided in Table 9.4 below to find the climate classification for the example 2 location. What climate classification best fits this location?

Table 9.4: Example 2 Location Climate Data

Month	Average Precipitation (cm)	Average Temperature (°C)
January	38.5	27.1
February	31.0	27.3
March	10.0	28.4
April	25.8	28.8
May	13.3	29.0
June	8.3	28.1
July	3.1	28.7
August	3.4	28.5
September	2.9	29.3
October	3.3	29.1
November	7.5	28.1
December	8.4	28.5
Mean Annual	13.8	28.4
Annual Total	165.5	n/a

26. Use Figure 9.12 above and the data provided in Table 9.5 below to find the climate classification for the example 3 location. What climate classification best fits this location?

Table 9.5: Example 3 Location Climate Data

Month	Average Precipitation (cm)	Average Temperature (°C)
January	3.7	3.1
February	3.4	5.3
March	3.7	10.3
April	2.8	16.4
May	1.5	22.1
June	0.3	27.5
July	0.3	30.4

Month	Average Precipitation (cm)	Average Temperature (°C)
August	0.2	29.2
September	0.1	25.4
October	1.4	18.5
November	2.1	11.6
December	3.6	5.6
Mean Annual	1.9	17.1
Annual Total	23.1	n/a

27. Use Figure 9.12 above and the data provided in Table 9.6 below to find the climate classification for the example 4 location. What climate classification best fits this location?

Table 9.6: Example 4 Location Climate Data

Month	Average Precipitation (cm)	Average Temperature (°C)
January	10.6	10.2
February	10.3	11.6
March	7.5	12.7
April	3.3	13.8
May	1.2	15.3
June	0.3	16.8
July	0.0	17.6
August	0.1	18.1
September	0.4	18.2
October	2.4	16.6
November	6.0	13.2
December	10.2	10.3
Mean Annual	4.4	14.5
Annual Total	52.3	n/a

California's Climate Types

Four of the five major Köppen climate types are present in California (Figure 9.13). In parts of the Great Basin desert, Mojave desert, and the Colorado portion of the Sonoran desert found in California, there is a dry (B) climate. The Mediterranean climate types (Cs) are found along coastal California and the Channel Islands. Cold continental (D) and polar (E) climates are found at higher elevations in the Sierra Nevada Mountains. The state's topography and geomorphic provinces are shown in Figure 9.14. (Topography refers to the elevation changes and features on land; geomorphic provinces are regions that have similar geographic features).

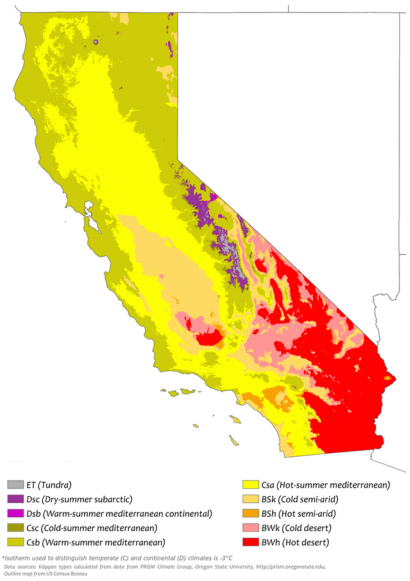


Figure 9.13: California Climate Map. Figure by Adam Peterson is licensed under CC BY-SA 4.0

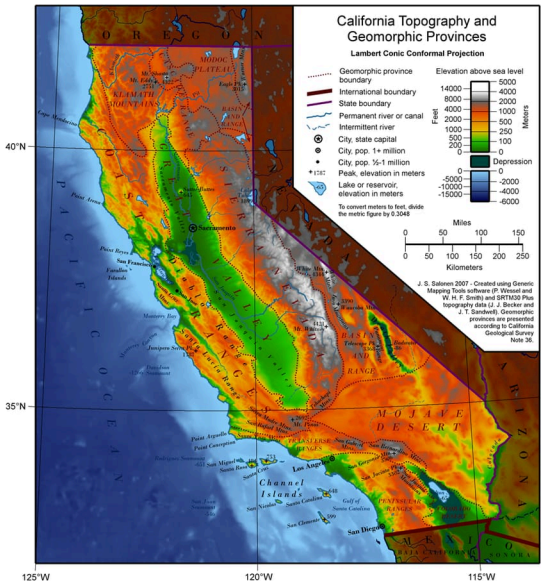


Figure 9.14: California Topography and Geomorphic Provinces Map. Figure by Ssalonen is licensed under CC BY-SA 3.0

Exercise 1.9.17

28. Compare California's climate map (Figure 9.13) to the California topography map (Figure 9.14). What are the peak elevations where an ET climate is found?

29. The San Joaquin Valley is one of the most productive agricultural areas in the world.

    a. What climate type is found there? Tip: first, locate the San Joaquin Valley on Figure 9.14 (at about 37°N) then identify the climate type shown in Figure 9.13.

    b. Use Your Critical Thinking Skills: What are the implications for the irrigation needs in the San Joaquin Valley? Explain your response in two to three sentences.

Shifting Climate Patterns

As you learned earlier in the lab, at least thirty years of precipitation and temperature data are used to classify a location's climate. As climates change across the globe, it makes sense that maps like the ones shown in Figure 9.11 and 9.13 above will need to be updated. Scientists actively research how climate classification patterns have changed over time and predict how these patterns will change in the future. The next lab in this course will go into more detail to explain why climates are changing. For now, let's explore one dynamic online map that shows historical shifting climate patterns and predictions based on data from the Institute for Veterinary Public Health, Climatic Research Unit (CRU), Global Precipitation Climatology Centre (GPCC), German Weather Service, University of East Anglia, Tyndall Centre for Climate Change Research, and the Intergovernmental Panel on Climate Change.

Step 1

Go to the Koppen-Geiger Observed and Predicted Climate Shifts website.

Step 2

Click on the legend icon. (This is on the upper-left of the window. If you hover over the icons, it is the one that says Show Map Legend).

Step 3

Scroll downwards so that you are familiar with the colors used to classify the climate types.

Step 4

Below the map, click on the blue triangle, which will start the map animation. Notice that the animation begins at 1900 and goes to 2100.

Step 5

Replay the animation in order to answer the following questions.

Exercise 1.9.18

30. What is the first year that you notice a large change in the maps?

30. In two to three sentences, describe how the climate pattern is predicted to change in North America from 2000 to 2100.

30. Globally, which climate types show the most change from 2000 to 2100?

Part C. Synthesis: Your Local Climate

What does a climograph look like for your location? What variables influence your local climate? In this part of the lab, you will find monthly average precipitation and temperature data for your location (or for a location near you), create a climograph, determine the climate type, and then identify the controls on climate at this location.

Exercise 1.9.19

33. Search the internet to find the average monthly precipitation and temperature data for your location (or for a location near you). Be sure to convert average precipitation to centimeters (cm) and average temperature into degrees Celsius (°C). Complete the table below with this data (Table 9.7). Your instructor may direct you to online resources that provide this information, or you may follow the steps below for data for selected cites from the U.S. Climate Data website.

Step 1

Go to the U.S. Climate Data website.

Step 2

In the search box, type in your location (or a location near to you). Select your location if a drop-down menu appears.

Step 3

Change the data from American to metric units. In the upper-right corner, click the gear icon to select °C. **Tip: this step is very important.**

Step 4

If the monthly average precipitation data is shown in millimeters (mm), convert to centimeters (cm) by dividing by 10. For example, if the average precipitation in January is 50.29 millimeters then divide this number by 10, which equals 5.029. Tip: round the data to the nearest hundredth decimal point, so 5.029 centimeters would be recorded as 5.03 on Table 9.7.

Add the monthly average precipitation data to Table 9.7.

Step 5

The table shows average high temperatures and average low temperatures, but you will need average temperature to complete Table 9.7. To calculate average temperature, use this formula:

$$\frac{\text{Monthly Average High Temperature + Monthly Average Low Temperature}}{2} = \text{Monthly Average T.}$$

For example, if the January average high temperature is 18.3°C and the monthly average low temperature is 9.4°C, then add 18.3°C plus 9.4°C, which equals 27.7°C. Then, divide 27.7°C by two, which equals 13.85°C (the January monthly average temperature). Tip: round the data to the nearest tenth decimal point, so 13.85°C would be recorded as 13.9°C on Table 9.7.

Exercise 1.9.20

Add the monthly average temperature data to Table 9.7

Table 9.7: Local Precipitation and Temperature Data

Month	Average Precipitation (cm)	Average Temperature (°C)
January		
February		
March		
April		
May		
June		
July		
August		
September		
October		
November		
December		
Mean Annual		
Annual Total		

34. Use Your Critical Thinking Skills: The Weather Channel website does not disclose how the average precipitation and temperature are calculated. It could be a 30-year average, a 10-year average, or something else. How would the length of time used to calculate the average affect your analysis of the data? More broadly, what are the concerns with using datasets if the source does not disclose its methods of calculations? Your response should be two to three sentences in length.

35. Following the example shown in Figure 9.3, graph your location's precipitation and temperature data on the blank climograph (Figure 9.15). Use the left y-axis to graph precipitation data as a bar graph and use the right y-axis to graph temperature data as a line graph.

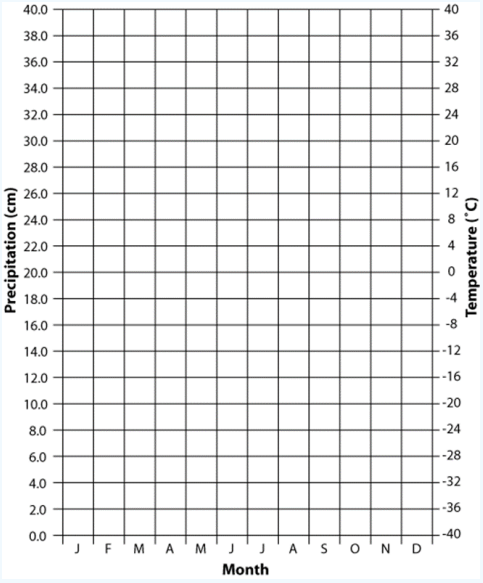


Figure 9.15: Blank Climograph. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

36. Refer to California's Climate Map (Figure 9.13). What is the climate type at your location?

37. Use your location's data from Table 9.7 and the simplified guide to climate classification (Figure 9.12) to determine your location's climate type. Based on the simplified guide, what is your location's climate type?

38. Use Your Critical Thinking Skills: Are your answers to questions 36 and 37 the same? If not, what reasons might explain why the map and the simplified guide provided different answers?

39. Refer to Figure 9.14. What geomorphic province is your location in?

40. List the major climatic controls at your location. Tip: the major climatic controls are latitude, continentality, wind patterns and air masses, ocean currents, and elevation. Be sure to discuss the specifics of each climatic control that influences the local climate at your location. For example, if a wind pattern influences the local climate, be sure to identify the name or type of wind, such as the westerlies.

41. Apply What You Learned: Considering how climate patterns are shifting globally, do you anticipate that the climate type at your location will change by 2100? Explain your response in at least two sentences.

Part D. Wrap-Up

Consult with your geography lab instructor to find out which of the following wrap-up questions you should complete. Attach additional pages to answer the questions as needed.

Exercise 1.9.21

42. What is the most important idea that you learned in this lab? In two to three sentences, explain the concept and why it is important to know.

43. What was the most challenging part of this lab? In two to three sentences, explain why it was challenging. If nothing challenged you in the lab, write about what you think challenged your classmates.

44. What is one question that you have about what you learned in this lab? Write your question along with one to two sentences explaining why you think your question is important to ask.

45. Review the learning objectives on page 1 of this lab. How would you rate your understanding or ability for each learning objective? Write one sentence that addresses each learning objective.

46. Sketch a concept map that includes the key ideas from this lab. Include at least five of the terms shown in bold-faced type.

47. Create an advertisement to educate your peers on the important information that you learned in this lab. Include at least three key terms in your advertisement. The advertisement should be about half a page in size (about 4 inches by 6 inches).

48. One way to think of physical geography is that it is the study of the relationships among variables that impact the Earth's surface. Select two variables discussed in this lab and describe how they are related.

49. How does what you learned in this lab relate to your everyday life? In two to three sentences, explain a concept that you learned in this lab and how it relates to your day-to-day actions.

50. How does what you learned in this lab relate to current events?
    a. Write the title, source, and date of a news item that relates to this lab.
    b. In two to three sentences, discuss how the news item relates to what you have learned in this lab.
    c. In one to two sentences, discuss whether or not the news item accurately represents the science that you learned. Tip: consider whether or not the news item includes the complexity of the topic.

51. Search O*NET OnLine to find an occupation that is relevant to the topics presented in today's lab. Your lab instructor may provide you with possible keywords to type in the Occupation Quick Search field on the O*NET website.

a. What is the name of occupation that you found?
b. Write two to three sentences that summarize the most important information that you learned about this occupation.
c. What is one question that you would want to ask a person with this occupation?

Answer available at the end of this section.

Appendix 9.1: Climate Classification Map (1901-2010)

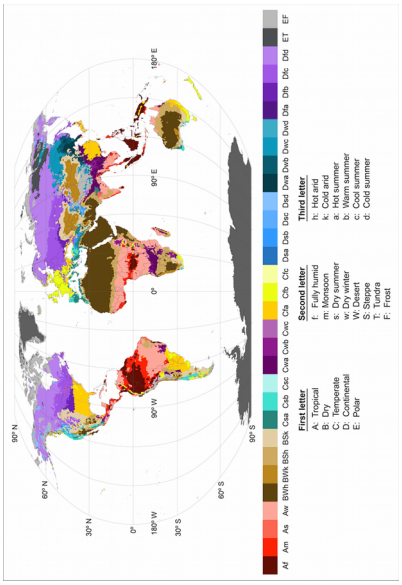


Figure by Waverly Ray based on data available from http://hanschen.org is licensed under CC BY-NC-SA 4.0

Answers

Exercise 1.9.21

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1.10: Lab 10 - Climate Change

This lab contains potentially inaccessible interactive resources. Please work with your instructor and local campus resources to identify accommodations for these resources.

Learning Objectives

- Explain the greenhouse effect.
- Differentiate among the major greenhouse gases based on their respective atmospheric concentrations and warming potential.
- Identify fluctuations of Earth's average temperature over the past 800,000 years.
- Explain the scientific consensus on anthropogenic climate change.
- Analyze carbon dioxide emissions data by country and world region in terms of time, population size, and economic development.
- Interpret global patterns of carbon dioxide emissions from a climate justice framework.

Introduction

Weather is the current atmospheric conditions in a given place and time. **Climate** is the long-term patterns of weather. Atmospheric conditions are recorded each and every day—by observation, instrument, or, in the long term, by Earth itself. Aggregate records of temperature and precipitation become climate data, revealing averages and extremes over extended periods of time. The Earth's climate system is a crucial life-sustaining system. It is complex and interdependent on the conditions of the oceans, ice sheets, atmosphere, and biosphere. In studying the Earth's climate, scientists strive to attain and analyze the longest continuous datasets possible, often spanning hundreds of thousands of years, to learn about climate controls and patterns of climate variability. Their goal is to understand one of the greatest global issues of our time: anthropogenic climate change.

This lab consists of four parts. In the first two sections, you will explore the basic processes and methods scientists use to understand the Earth's climate. This analysis will provide an understanding of the basis for the scientific consensus on anthropogenic climate change. In the last sections, a geographical analysis of four measures of global carbon footprints reveal patterns of global emissions and the disproportionate impacts of climate change.

Part A. Understanding Climate Science

The graphs below display the contemporary trends of global temperatures, based on the **instrumental record**, which is data directly recorded by instrumental measurement (Figures 10.1, 10.2, and 10.3). By comparing data sources, scientists can minimize measurement inconsistencies and create a generalized overview**.** Climate scientists often compute **temperature anomalies**—the deviation from a set average temperature—to detect temperature trends despite the variability of geographical conditions that impact temperature recordings. For example, a mountain and a valley will have quite different absolute temperature recordings. Looking at anomalies for both locations might reveal that despite different geographical conditions both places were warmer than average. Because temperature anomalies reveal trends, anomalies are often used to understand patterns of climate change.

Exercise 1.10.1

1. In one to two sentences, explain why computed temperature anomalies are often used in global climate studies instead of temperature averages.

Figure 10.1 depicts near identical long-term warming trends from four independent data sources: NOAA's National Climatic Data Center (blue line), NASA's Goddard Institute for Space Studies (black line), the Japanese Meteorological Agency (green line), and the United Kingdom's Met Office Hadley Centre/Climatic Research Unit (orange line).

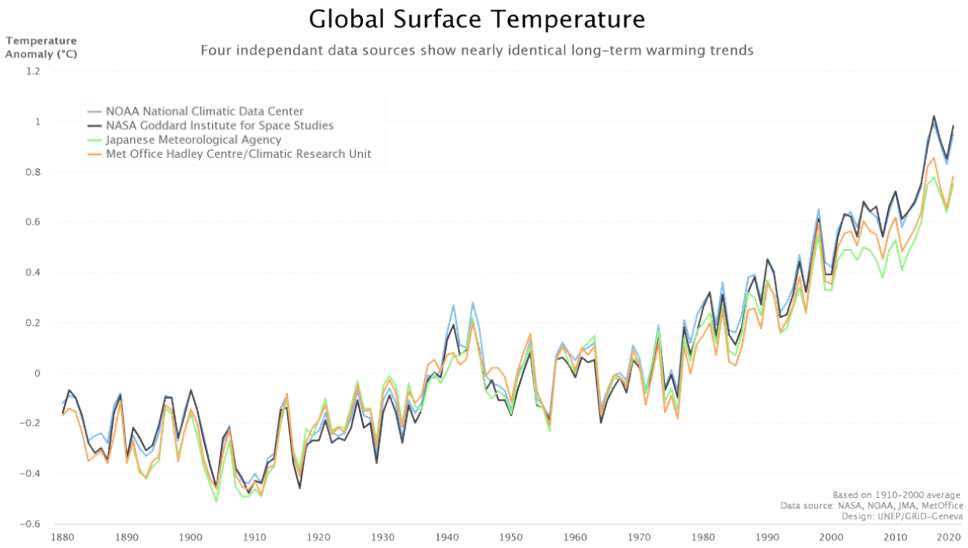


Figure 10.1: Global Surface Temperature Anomalies from Four Independent Instrumental Records Show Similar Trends, 1880-2020. Temperature anomalies are based on a 1910-2000 average. Tip: go to the UNEP/GRID website for an interactive version of this graph. Figure by UNEP/GRID is licensed under CC BY-NC-SA 2.0

Exercise 1.10.2

2. Refer to Figure 10.1.
    a. For what period of time are the displayed instrumental records available?
    b. How do the four different instrumental records compare?

Figure 10.2 shows the five-year average variation of global surface temperatures between 1880 and 2015. Before 1970, global surface temperatures were generally cooler than the 1910 to 2000 average. Since 1970, the years have been increasingly warmer than the 1910 to 2000 average. Nine of the ten warmest years during this time frame have occurred since 2000.

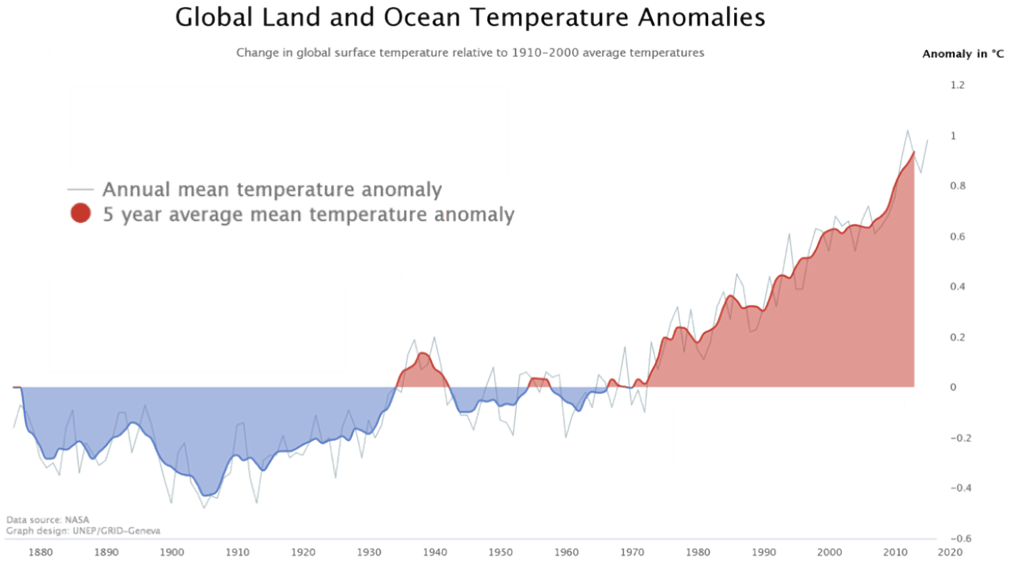


Figure 10.2: Change in Global Surface Temperatures Relative to the 1910-2000 Average. Tip: go to the UNEP/GRID website for an interactive version of this graph. Figure adapted from UNEP/GRID is licensed under CC BY-NC-SA 2.0

Exercise 1.10.3

3. Refer to Figure 10.2.
    a. What does the 0 in the y-axis symbolize?
    b. How are temperature anomalies measured?
    c. What is the overall trend of global surface temperature anomalies?
4. Refer to Figures 10.1 and 10.2. What is the overall pattern of temperature anomalies since 1880? Tip: identify the data thresholds, which are the points in time that new data patterns emerge.

Figure 10.3 maps the temperature anomaly relative to the 1951-1980 average.

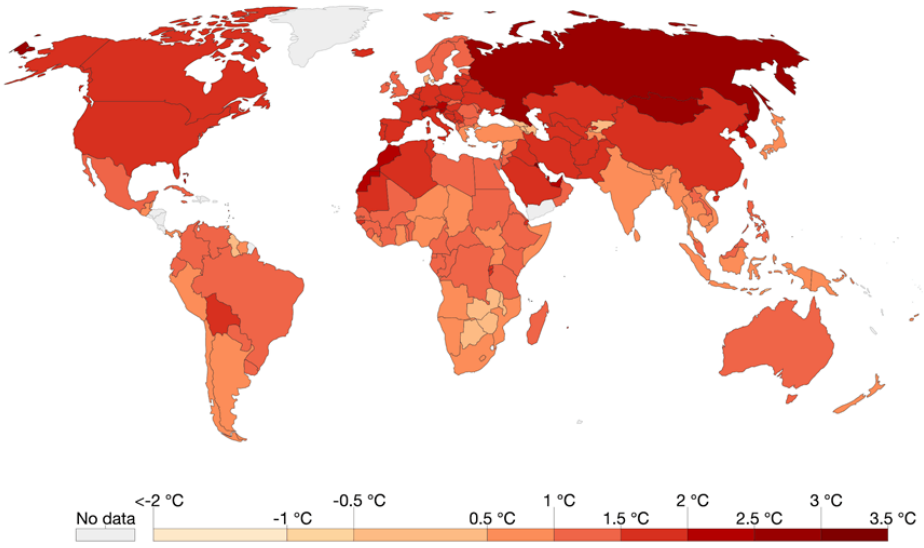


Figure 10.3: Trends in Global Surface Temperature Anomalies in 2017 Relative to the 1951-1980 Average. Tip: go to the Our World in Data website for an interactive version of this map. Figure from Our World in Data, with data published by NASA Goddard Institute for Space Studies, is licensed under CC BY 4.0

Exercise 1.10.4

5. Describe the geographical distribution of temperature anomalies (Figure 10.3). What places have experienced the greatest temperature increases? Which have not?

An AccuWeather database of more than 3,800 global cities shows that 83% of cities experienced higher than normal temperatures in 2018.

6. How much warmer was your city in 2018 compared to normal? Search a database of your city (or a nearby city).
   a. Name your city (or nearby city):
   b. Was the temperature above or below normal?
   c. In °F, how much warmer or colder was the temperature?
   d. Click on °C; how much warmer or colder was the temperature?
7. Apply What You Learned: Before searching the database, rank the following cities from 1 to 3 with 1 being the city that warmed the most and 3 with the city that warmed the least.
   a. Irkutsk, Russia (52°N):
   b. Nome, Alaska (64°N):
   c. San Luis Potosí, Mexico (22°N):
   d. Now, search the database to find out if your ranking was correct. In one to two sentences, explain why you think your ranking was accurate.

Climate Forcings

The interactions of solar energy with land, air, and water shape Earth's climate system. Earth continuously receives energy from the Sun. A portion of the emitted solar energy that reaches the Earth is reflected back into space; some is absorbed directly by the atmosphere; but some moves through the atmosphere to the Earth's surface, heating land and water. These processes contribute to Earth's energy budget calculations that you analyzed in a previous lab. The atmosphere contains **greenhouse gases;** these gases act as a blanket and trap heat in the lower atmosphere. This process is called the **greenhouse effect**—it is natural and keeps Earth warm enough to support life (Figure 10.4).

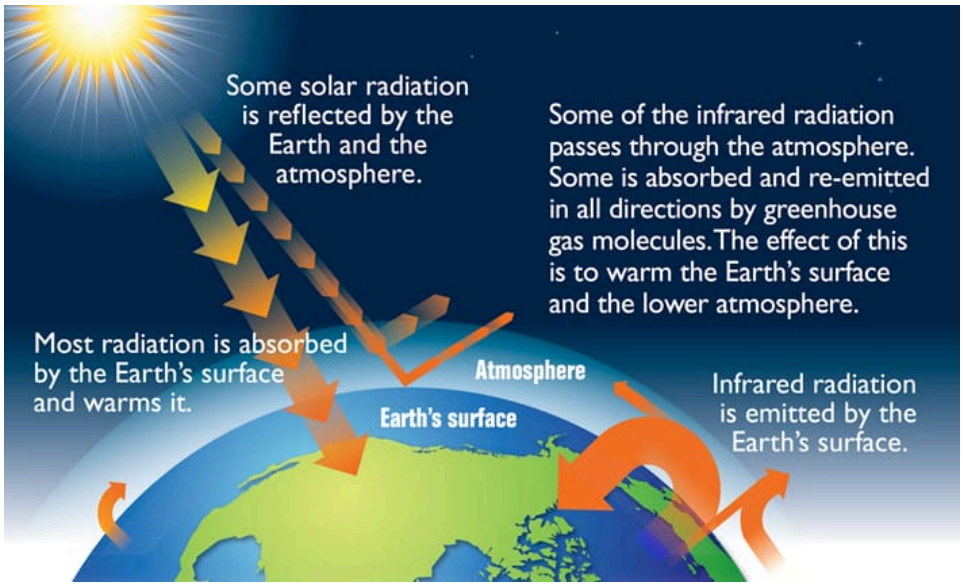


Figure 10.4: The Greenhouse Effect. Greenhouse gases absorb outgoing infrared radiation. Figure by U.S. Environmental Protection Agency is in the public domain

Exercise 1.10.5

8. Do greenhouse gases absorb infrared radiation from the Earth?
9. Do greenhouse gases re-emit infrared radiation to the Earth?
10. Use Your Critical Thinking Skills: Do you think the greenhouse metaphor or the blanket metaphor best describe how greenhouse gases trap and re-emit longwave radiation? Explain your response in one to two sentences.

As the Earth absorbs energy from the Sun, it eventually re-emits it to space. The difference between incoming and outgoing radiation is known as a planet's **radiative forcing.** A climate forcing is a factor impacting this energy budget with the potential to change the climate system. When these factors result in incoming energy being greater than outgoing energy, the planet will warm. Conversely, if outgoing energy is greater than incoming energy, the planet will cool.

Incoming Energy – Outgoing Energy = Radiative Forcing

Climate scientists have identified a number of main factors that influence Earth's radiative forcing:

- Earth's orbit: The Earth wobbles on its axis, and its tilt and orbit change over thousands of years. These cyclical changes result in significant variations in the amount of solar energy reaching the planet and pushing its climate into and out of ice ages.
- Solar output: The amount of solar energy received by the Earth varies, increasing or decreasing by about 0.1% during Sun's natural 11-year sunspot cycle.
- Volcanic activity: Volcanic eruptions release greenhouse gases such as carbon dioxide into the atmosphere that result in warming. However, large volcanic eruptions can substantially increase atmospheric concentrations of sulfate aerosols and particles that shield the Earth from solar energy by reflecting sunlight and thereby cool the Earth's climate.
- Greenhouse gases: Atmospheric gases—such as water vapor, carbon dioxide, and methane—trap heat. While these are naturally occurring gases, burning fossil fuels to fuel industrialization resulted in a large increase of emissions of greenhouse gases. Increased greenhouse gas concentrations result in greater trapping of heat in the lower atmosphere, which increases global average temperatures.

Exercise 1.10.6

11. Which of the main factors that influence Earth's radiative forcing are from solely natural causes?
12. Which of the main factors that influence Earth's radiative forcing are from both natural and anthropogenic causes?

In order to better understand singular and combined factors' impacts on climate, climatologists at NASA's Goddard Institute for Space Studies (GISS) use climate models to test their assumptions and better understand controls of climate variability. As part of a contribution to an international climate research initiative called Coupled Model Intercomparison Project Phase Five (CMIP5), GISS sought to combine results from climate models to see how well they could reproduce what's known about the climate from 1850 to 2012 and to estimate how the various climate forcings contribute to those temperatures.

Figure 10.5 shows the observed global temperatures from 1880 to 2000 in the blue line. Modeled factors include greenhouse gases, volcanic eruption, ozone, solar output, Earth's orbital changes, land use changes, and aerosols. The red line shows all of these forcings combined.

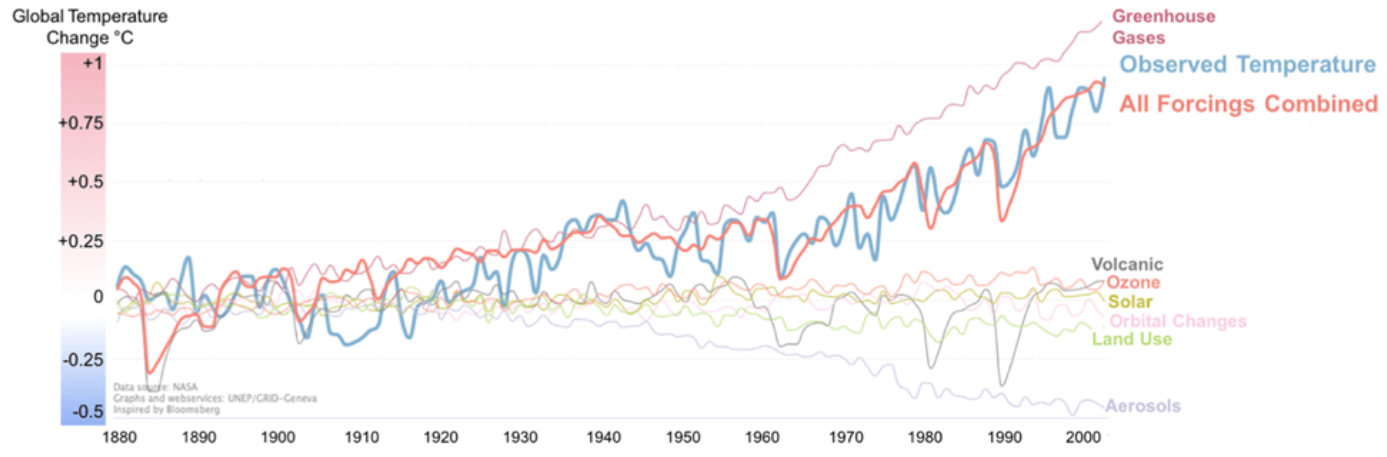


Figure 10.5: Modeled Individual Contributions to Global Temperature Changes. Tip: go to the UNEP/GRID website for an interactive version of this graph. Figure adapted from UNEP/GRID is licensed under CC BY-NC-SA 2.0

Figure 10.6 shows the same observed temperatures in blue and combined forcings in red as shown in Figure 10.5. It combines the anthropogenic contributions together in the black line and all of the natural contributions together in the green line.

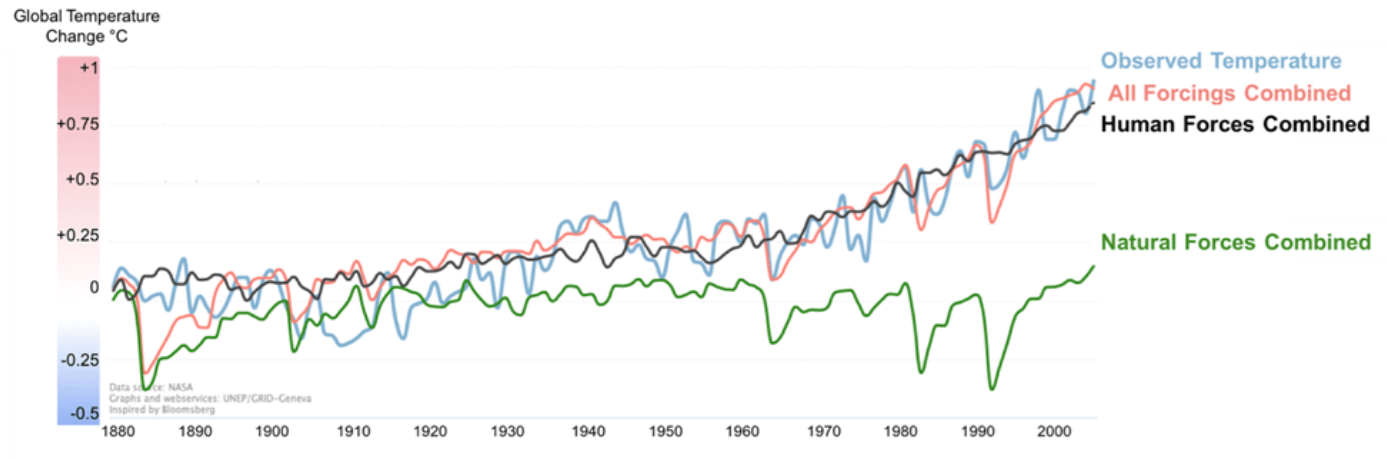


Figure 10.6: Modeled Human and Individual Contributions to Global Temperature Changes. Tip: go to the UNEP/GRID website for an interactive version of this graph. Figure adapted from UNEP/GRID is licensed under CC BY-NC-SA 2.0

Exercise 1.10.7

13. Refer to Figures 10.5 and 10.6.

    a. What is the overall observed pattern of temperature anomalies since 1880?

    b. Describe the impacts of the following climate forcings on observed temperature changes.
        i. volcanic eruptions:
        ii. aerosols:
        iii. orbital changes:
        iv. solar output:
        v. greenhouse gases:

    c. Which of these forcings appear to have the greatest impact on current temperature patterns ?

d. When looking at human factors and natural factors combined (Figure 10.6), how does the correlation to global temperature patterns change? Which factors display stronger correlation to the global temperature anomalies? Explain your response in three to four sentences.

Paleoclimatology

On a planet that is more than 4.5 billion years old, human existence is a short glimpse of time. Amidst such vast natural history, scientists attempt to understand the human context by seeking records and clues to a distant past. The field of study dedicated to understanding long-term patterns of the Earth's climate beyond human records is called **paleoclimatology.** In order to reconstruct Earth's climate history, paleoclimatologists rely on **proxy data,** or preserved physical attributes that can be measured and analyzed to understand the past. Coral reefs, lakebed and ocean sediments, pollen, tree trunks, and ice cores are some of the natural recorders of climate indicators that scientists use to understand the Earth's climate beyond the instrumental record. Reading into the past allows us to better understand the present and the future.

Analyzing Ice-Core Data

Ice cores are cylinders of ice that paleoclimatologists drill from ice sheets and glaciers (Figure 10.7). Layers of ice can act as high time-resolution capsules by freezing samples of the atmosphere in tiny air bubbles, thus allowing scientists to access and analyze atmospheric temperatures and composition well beyond the instrumental record. The deeper scientists drill, the older the ice and atmospheric samples that can be extracted.



Figure 10.7: Ice-core Sample Taken from Drill. Figure from NOAA is in the public domain

Under the European Project for Ice Coring in Antarctica (EPICA), scientists drilled and extracted an ice core that is about two miles long, the longest ice core sample as of 2020. The Dome C ice core enabled access to 800,000 years of continuous atmospheric data, revealing ancient atmospheric temperatures and greenhouse gas concentrations. Scientists can then test the data against other ice core data and other data proxies to create aggregate data sets such as the ones shown in Figure 10.8. These graphs represent proxy data from more than 63 locations interpolated by eight climate models with a 1,000-year resolution to reconstruct 800,000 years of Earth's climate.

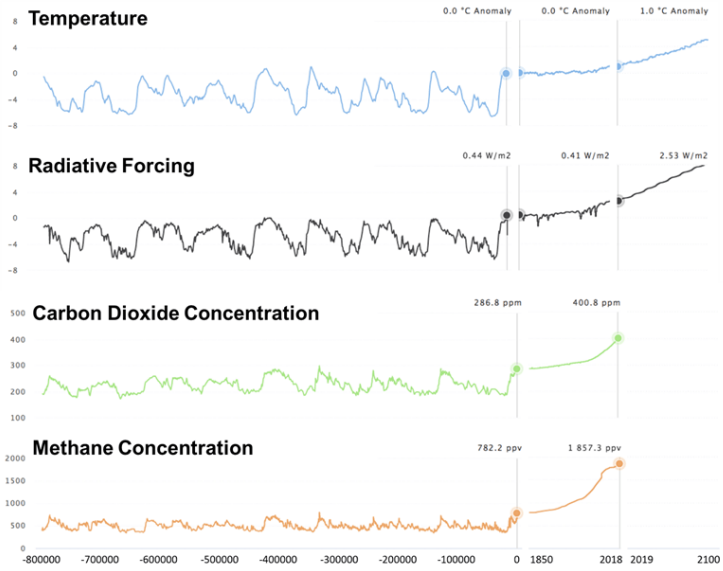


Figure 10.8: Trends in Global Atmospheric Changes from Aggregate Proxy Data. Tip: go to the UNEP/GRID website for an interactive version of this graph. Figure adapted from UNEP/GRID is licensed under CC BY-NC-SA 2.0

The trends in the mean global temperature anomaly based on the average temperature of the last 1,000 years are shown in Figure 10.9.

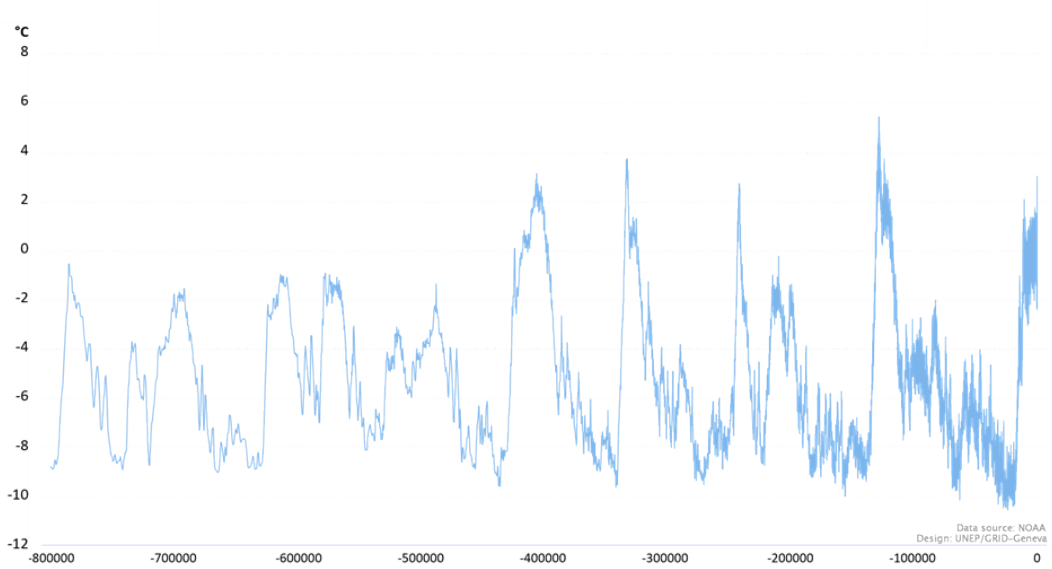


Figure 10.9: Trends in Global Temperature Change. Tip: go to the UNEP/GRID website for an interactive version of this graph. Figure adapted from UNEP/GRID is licensed under CC BY-NC-SA 2.0

Exercise 1.10.8

14. Refer to Figures 10.8 and 10.9.
    a. How many years of climate data have been reconstructed? How do scientists construct such extensive datasets?
    b. Describe the patterns of global temperature, radiative forcing, and greenhouse gases displayed in the graphs above.
    c. What are the maximum and minimum temperature anomalies recorded?

d. How many interglacial periods (times when the temperature deviation reached 0°C) can be detected in this dataset?

e. What is the correlation between temperature, radiative forcing, and greenhouse gas concentrations shown in this data record?

f. How do concentrations of carbon dioxide and methane of today compare to the patterns of this data record?

g. How do today's recorded temperatures compare to temperature patterns of the past?

h. What changes are projected for 2100? What factors do you think explain such a projection?

Part B. Anthropogenic Climate Change

"Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems."

IPCC 5th Assessment Report, 2014

The term **climate change** refers to the climatic changes that occur over long periods of time. As observed from the datasets in previous sections, Earth's temperatures varied from epoch to epoch. The paleoclimate record also shows a strong correspondence between temperature and the concentration of greenhouse gases in the atmosphere observed during the glacial cycles of the past several hundred thousand years. Furthermore, studies gauging radiative forcings (Figures 10.5 and 10.6) suggest contemporary warming to be most attributed to increased greenhouse gases.

There is a strong scientific consensus that burning fossil fuels to power global industrialization has changed global atmospheric composition, increased greenhouse gas concentrations, and exacerbated the greenhouse effect. This is what scientists call **anthropogenic climate change,** or climatic change caused by humans. This change is defined by an increase in global average temperatures, or **global warming.** Global warming triggers a series of changes in the Earth's climate system that disrupts life-supporting mechanisms, which will be discussed later in this lab.



Think About It...What is the Scientific Consensus on Climate Change?

Multiple studies in peer-reviewed scientific journals show that 97% of actively publishing climate scientists agree that warming trends of the past century are extremely likely to be anthropogenic (NASA). More than 200 scientific organizations worldwide, including the most prominent American scientific organizations, agree that the Earth is warming due to human causes (NASA).

The Intergovernmental Panel on Climate Change (IPCC) is a United Nations body of hundreds of international scientists that gathered to produce a six-year literature review of the latest climate science to guide policy makers. This panel continuously asserts that human influence on the climate is clear and it is disruptive of Earth's natural systems (IPCC).

Does the news media that you follow convey the scientific consensus on climate change? What motives do news media have to present biased information on climate change and the scientific consensus about its human causes?

Why CO_2 Matters

Carbon dioxide is an abundant greenhouse gas, a gas that absorbs and radiates heat. Different greenhouse gases have different **global warming potential (GWP),** which is the relative ability to trap heat. Carbon dioxide absorbs less heat per molecule than

other greenhouse gases such as methane or nitrous oxide (Figure 10.10). One tonne of methane has 28 times the warming impact as one tonne of carbon dioxide. Nonetheless, carbon dioxide is more abundant and it stays in the atmosphere much longer. In 2018, carbon dioxide accounted for 81% of all greenhouse gasses emitted through human activities in the United States.

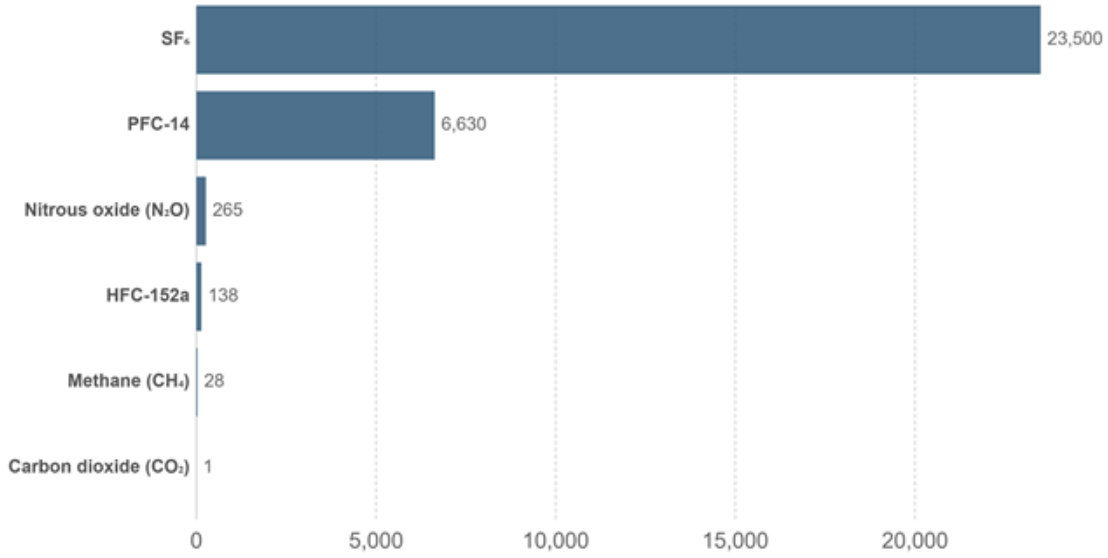


Figure 10.10: Global Warming Potential of Greenhouse Gases over 100 Years. Figure from Our World in Data, with data published in the IPCC 2014 Synthesis Report, is licensed under CC BY 4.0

NOAA's Annual Greenhouse Gas Index (AGGI) assesses the radiative forcing of long-lived greenhouse gases. The index compares the combined warming influence of these gases each year, starting in 1980 when NOAA's global air sampling expanded significantly. Figure 10.11 shows the heating imbalance in watts per square meter relative to the year 1750 caused by all major human-produced greenhouse gases: carbon dioxide, methane, nitrous oxide, chlorofluorocarbons 11 and 12, and a group of 15 other minor contributors. While the radiative forcing of the long-lived greenhouse gases increased 43% from 1990 to 2018, CO_2 has accounted for about 80% of this increase.

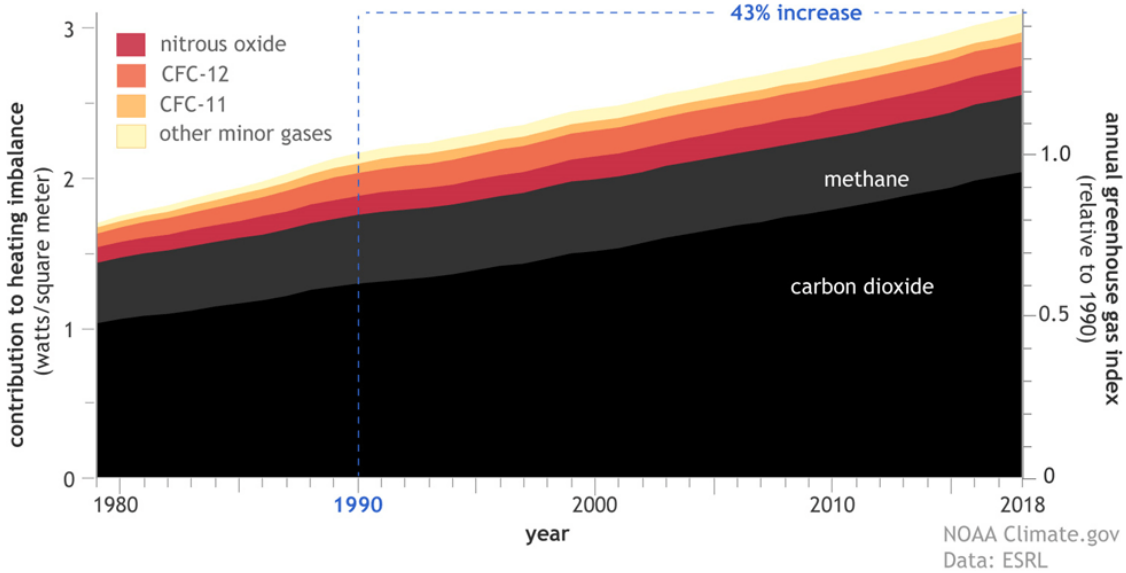


Figure 10.11: Influence of All Major Human-Produced Greenhouse Gases (1979-2018). Figure by NOAA is in the public domain

Exercise 1.10.9

15. Refer to Figures 10.10 and 10.11.

a. In your own words, explain GWP.

b. In relation to CO_2, what is the relative GWP of methane and nitrous oxide?

c. Based on NOAA's Greenhouse Gas Index, how has the radiative forcing attributable to greenhouse gases changed over time? Which gases contribute most to this heating imbalance? Explain your response in two to three sentences.

400pm Threshold

Scientists have long warned about the dangers of unprecedented CO_2 concentrations beyond 400 parts per million (ppm). The global average atmospheric carbon dioxide in 2019 was 409.8 ppm, with a range of uncertainty of plus or minus 0.1 ppm (Figure 10.12).

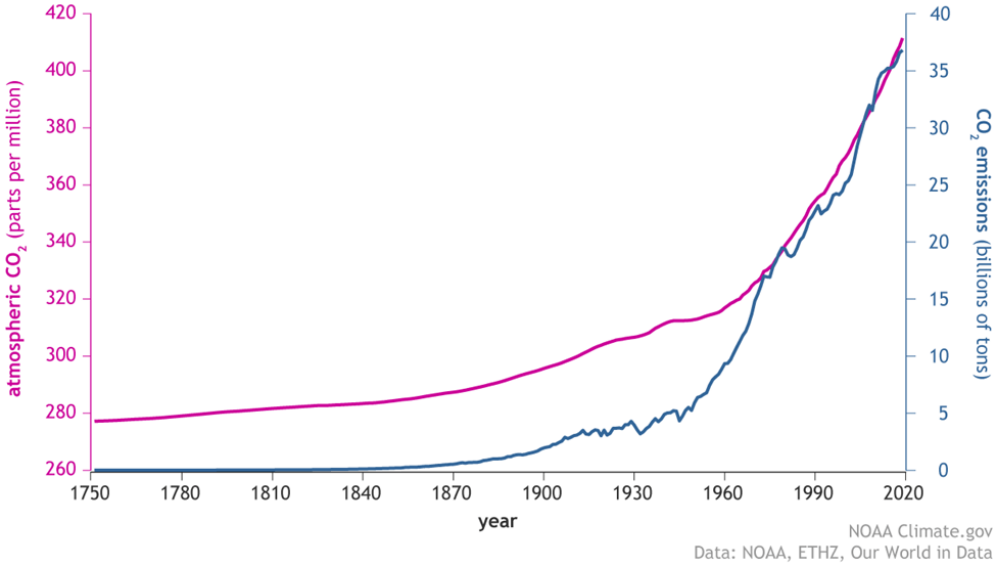


Figure 10.12: Atmospheric Carbon Dioxide (raspberry line) and Annual Emissions (blue line) from 1750-2019. Figure by NOAA is in the public domain

Exercise 1.10.10

16. Refer to Figure 10.12.

a. Figure 10.12 displays CO_2 atmospheric concentrations and CO_2 emissions. Why are such comparisons valuable? What patterns emerge from this data? Explain your response in two to three sentences.

b. What is the approximate concentration of CO_2 in the atmosphere in 2020 (in ppm)?

c. Compare and contrast early industrial atmospheric peak concentrations and emissions to contemporary data. List the similarities and/or differences.

Ice core proxy data provides evidence that carbon dioxide levels today are higher than at any point in at least the past 800,000 years (Figure 10.13).

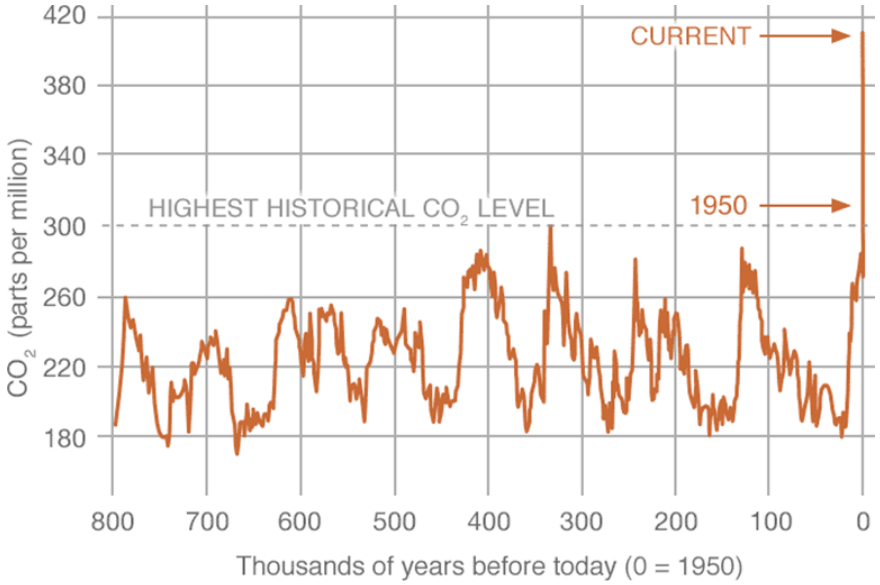


Figure 10.13: Global Atmospheric Carbon Dioxide Concentrations for the Past 800,000 Years. Figure by NOAA is in the public domain

Exercise 1.10.11

17. Refer to Figure 10.13. What is the approximate highest CO_2 concentration recorded in the paleorecord? How does this compare to the 2020 value?

Direct observations and data collection at four observatories provide evidence of monthly average carbon dioxide concentrations since the 1970s (Figure 10.14). Note that in Figure 10.14, the annual oscillations at the two northern hemisphere sites (Barrow, Alaska and Mauna Loa, Hawai'i) are due to the seasonal imbalance between the photosynthesis and respiration of plants on land. The difference between Mauna Loa and the South Pole has increased over time as the global rate of fossil fuel burning, most of which takes place in the northern hemisphere, has accelerated.

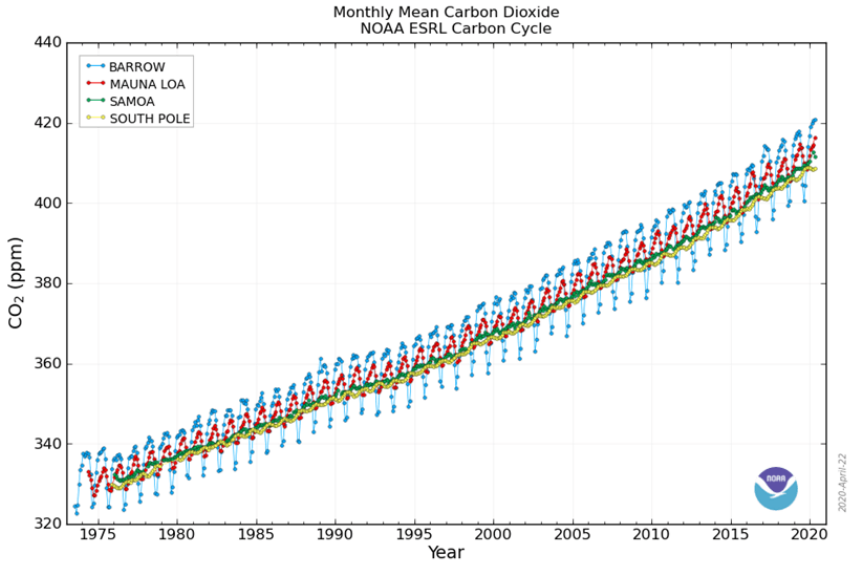


Figure 10.14: Monthly Average Carbon Dioxide from Four Baseline Observatories. Figure by NOAA is in the public domain

Think About It...Why are the Baseline Observatories Located Where They Are?

Direct instrumental observations of carbon dioxide and methane occur at stations all around the world. Only four of these locations are called the baseline observatories. Figure 10.15 shows the locations: Barrow (Alaska); Mauna Loa (Hawai'i); American Samoa; and the South Pole (Antarctica). These observatories were established in order to provide sampling of the most remote air on the planet so that the true "background atmosphere" could be monitored.[171]

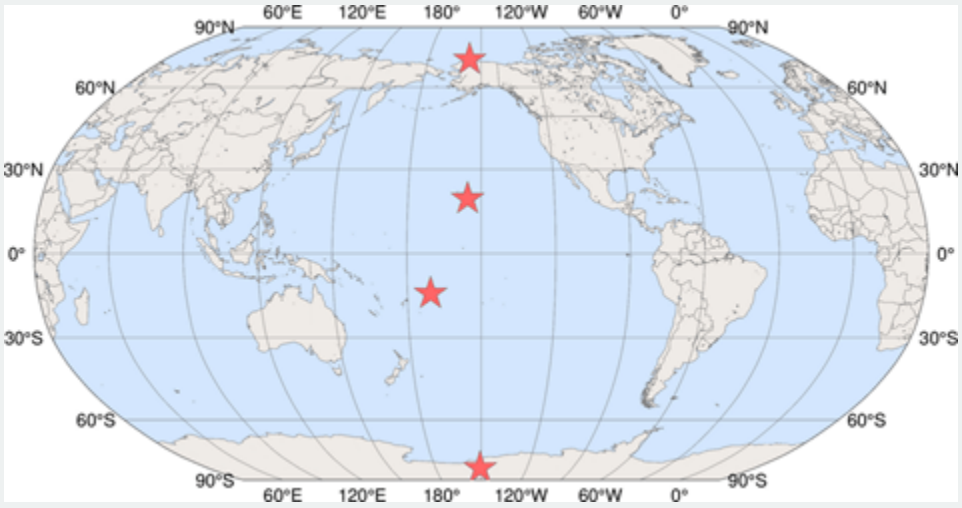


Figure 10.15: Locations of Baseline Observatories. Figure by NOAA is in the public domain

Exercise 1.10.12

18. Refer to Figure 10.14.
    a. Describe the overall trend shown.
    b. Approximately what year did all baseline observatories record 400 ppm concentrations?
    c. What CO_2 (ppm) value was the maximum-recorded concentration? When and where did this occur?
    d. Use Your Critical Thinking Skills: Why do you think this location recorded the highest concentration of carbon dioxide? Explain your response in at least one sentence.

Future Scenarios

Based on present patterns of increasing greenhouse gas emissions, scientists warn of diverse negative impacts of increased average global temperatures on natural and human systems. A warmer world threatens oceans, coastlines, biodiversity, and agriculture, and exacerbates extreme weather events and tensions over resources. Commitments to reduce greenhouse gases have evolved over a series of global agreements, all of which have shown limited results. What does the future look like? Climate policy matters.

The visualization below shows a range of potential scenarios modeled based on contemporary patterns (Figure 10.16). The graph's y-axis shows gigatonnes of carbon dioxide equivalents. Greenhouse gases are often normalized in measures of carbon dioxide equivalents, a standard unit based on the radiative forcing of a molecule of carbon dioxide over a time frame (often a 100-year

period). Each scenario shows a range of shading due to the uncertainty of emissions—whether there are low or high emissions within each pathway is unknown. Here is a summary of each of the four scenarios:

- No climate policies: Represents expected emissions in a baseline scenario if countries had not implemented climate reduction policies. This would result in a warming of 4.1 to 4.8°C by 2100.

- Current policies: Represents emissions with current climate policies in place. This would result in a warming of 2.8 to 3.2°C by 2100.

- Pledges and targets: Represents emissions if all countries delivered on the reduction pledges they have made as of December 2019. This would result in a warming of 2.5 to 2.8°C by 2100.

- 1.5°C and 2°C pathways: Represents the goals outlined in the 2016 Paris Agreement by the United Nations Framework Convention on Climate Change. These pathways were developed based on more than 6,000 research papers to show that it is possible to limit warming and its ill-effects.

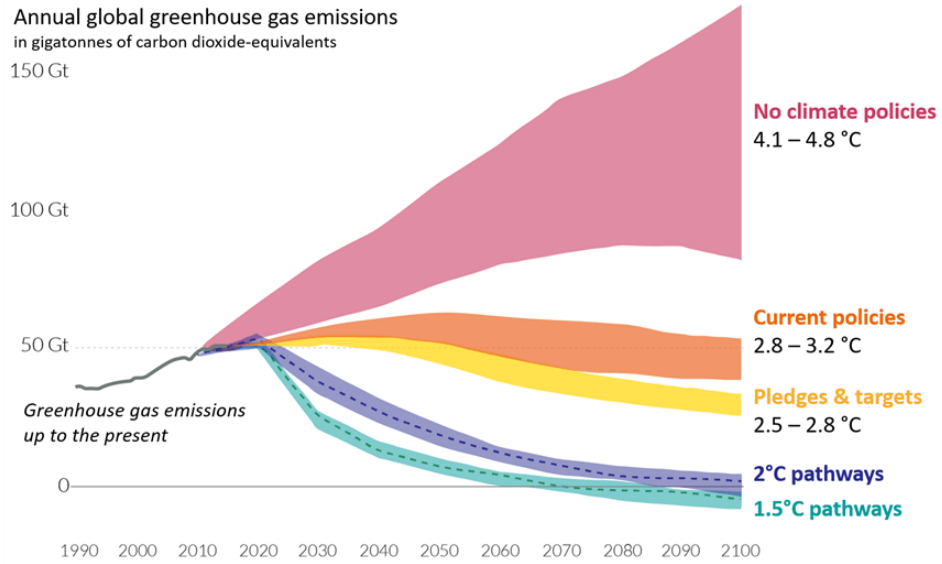


Figure 10.16: Global Greenhouse Gas Emissions and Warming Scenarios. Figure adapted from Our World in Data is licensed under CC BY 4.0

Exercise 1.10.13

19. Refer to Figure 10.16.

    a. Based on current policies, what is the projected temperature warming range for the year 2100?

    b. Use Your Critical Thinking Skills: Why do the three scenarios (no climate policies, current policies, and pledges and targets) have a wide range of emissions possible by 2100? Tip: list the variables that account for carbon dioxide emissions globally.

Part C. The Blame Game: Four Ways of Looking at Carbon Footprints

Globalized industrialization and fossil fuel based economic growth to fulfill the wants and needs of a growing population are largely responsible for increased greenhouse gas emissions, namely of CO_2. But what countries are most responsible? Certainly, some countries emit more greenhouse gases than others, thus disproportionately contributing to a problem that is shared worldwide, also in a disproportionate manner.

Let's analyze four datasets depicting global carbon footprints, mainly displayed in a series of maps:

1. Current CO_2 Emissions per Year (CO_2/year)

2. CO_2 Emissions per Capita (CO_2/person)
3. Carbon Intensity (CO_2/gross domestic product)
4. Cumulative CO_2 Emissions (from the Industrial Revolution to the present)

Depending on how emissions are measured, different countries stand out, thus exposing some nuances that relate to history, population, and economic development. As you go through each carbon footprint dataset, think about which countries and regions stand out as the largest contributors to carbon dioxide emissions (and thus anthropogenic climate change).

1. Current CO_2 Emissions per Year (CO_2/year)

Current emissions refer to the total CO_2 emissions within a one-year time frame. See below some of the ways it can be displayed (Figures 10.17 through 10.19).

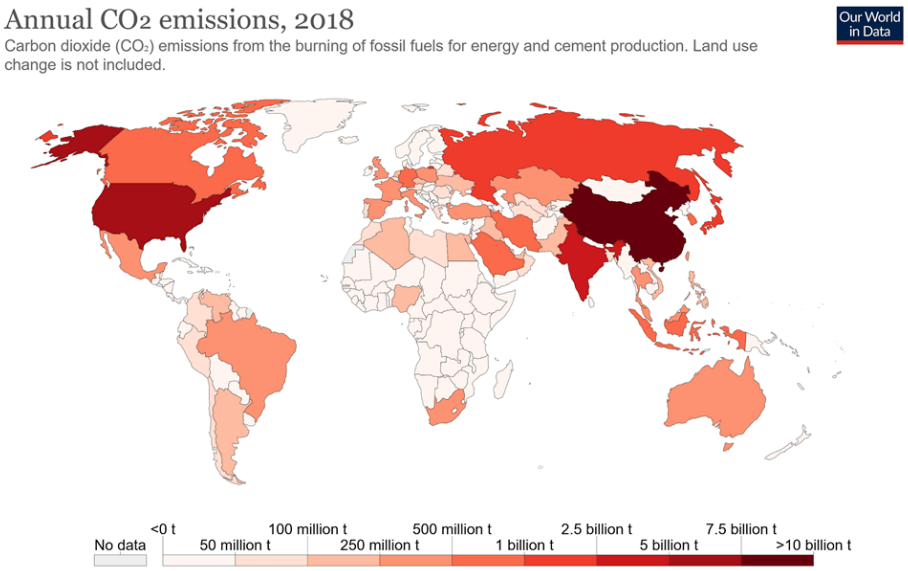


Figure 10.17: Annual Emissions by Country (2018). Tip: go to the Our World in Data website for an interactive version of this map. Figure by Our World in Data is licensed under CC BY 4.0

Exercise 1.10.14

20. Refer to Figure 10.17. Tip: use an atlas, Google maps, or go to the links provided in the captions to help you identify countries.

    a. What does Figure 10.17 convey about CO_2 emissions?

    b. Use Your Critical Thinking Skills: Are you surprised by the information presented on this map? Why or why not?

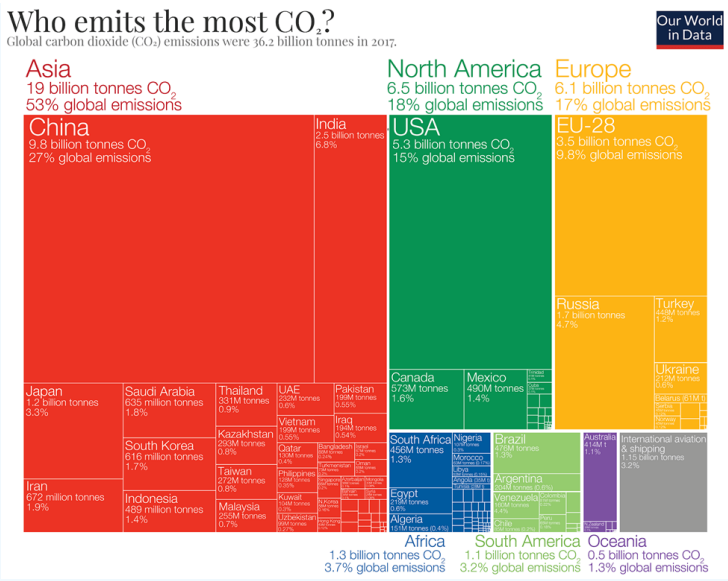


Figure 10.18: Annual CO2 Emissions by Country, Organized by Region. (2017). Figure by Our World in Data is licensed under CC BY 4.0

21. Refer to Figure 10.17.

    a. What does Figure 10.18 convey about CO_2 emissions?

    a. Complete Table 10.1 below.

Table 10.1: Emissions Analysis

Category	Country	World Region
Highest emitter of CO_2 per year (tons)		
Second highest emitter of CO2 per year (tons)		
Third highest emitter of CO2 per year (tons)		
World region that is the lowest emitter of CO2 per year (tons)	N/A	
World region that is the second lowest emitter of CO2 per year (tons)	N/A	
World region that is the third lowest emitter of CO2 per year (tons)	N/A	

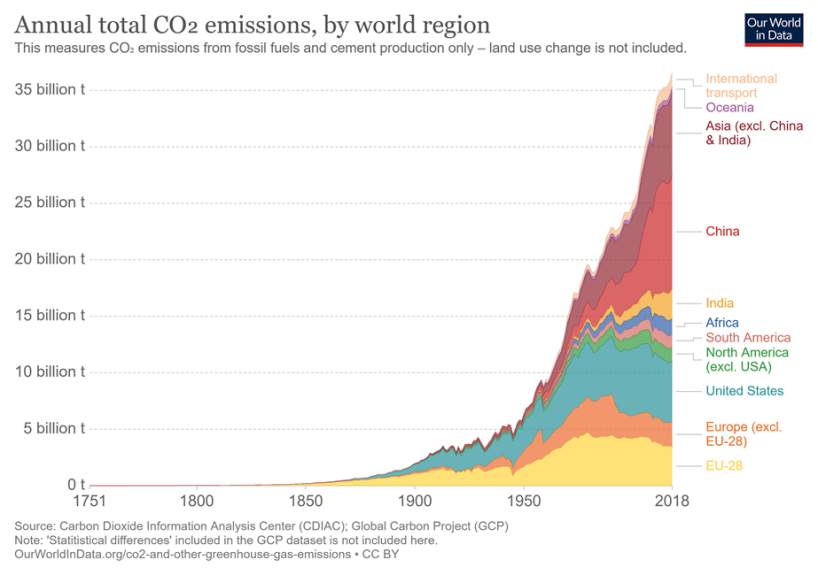


Figure 10.19: Annual CO2 Emissions from 1751-2018. Tip: go to the Our World in Data website for an interactive version of this graph. Figure by Our World in Data is licensed under CC BY 4.0

22. Refer to Figure 10.19. Tip: use an atlas, Google maps, or go to the links provided in the captions to help you identify countries.

    a. What does Figure 10.19 convey about CO_2 emissions?

    b. Over time, which countries/regions have experienced the greatest increases?

23. Refer to Figures 10.17 through 10.19. List the key differences between the three figures. Hint: compare and contrast the similarities and differences.

2. CO_2 Emissions per Capita (CO_2/person)

Another way to analyze carbon dioxide emissions is to divide the total emissions for a particular country or region by its population (Figure 10.20). This lets us know where in the world the average person emits the most CO_2.

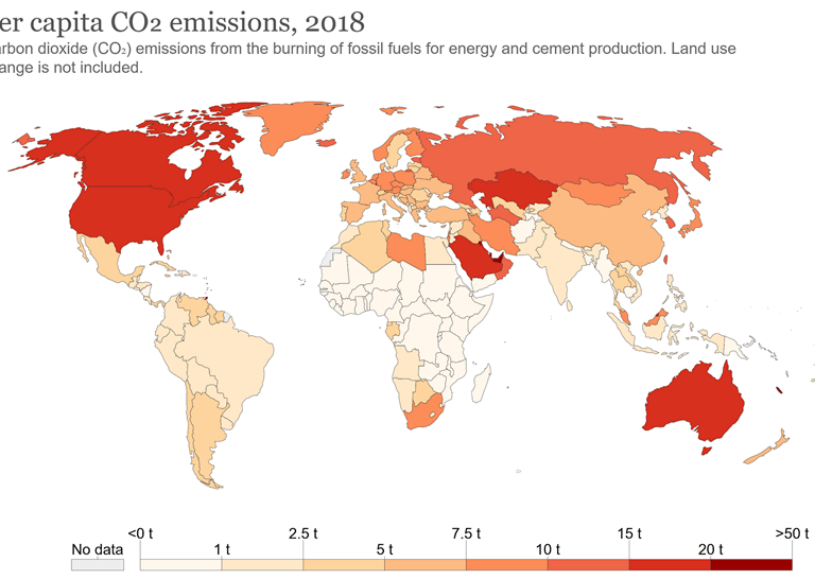


Figure 10.20: Per Capita CO2 Emissions (2018). Tip: go to the Our World in Data website for an interactive version of this map. Figure by Our World in Data is licensed under CC BY 4.0

Exercise 1.10.15

24. Compare Figure 10.17 to Figure 10.20. What are three key differences that you notice between the two maps? Tip: use an atlas, Google maps, or go to the interactive versions online to help you identify countries.

Figure 10.21 highlights the fact that countries vary in their population sizes and levels of wealth, measured by gross domestic product (GDP), focusing on CO_2 emissions per person. GDP represents all the goods and services that an economy produces in one year.

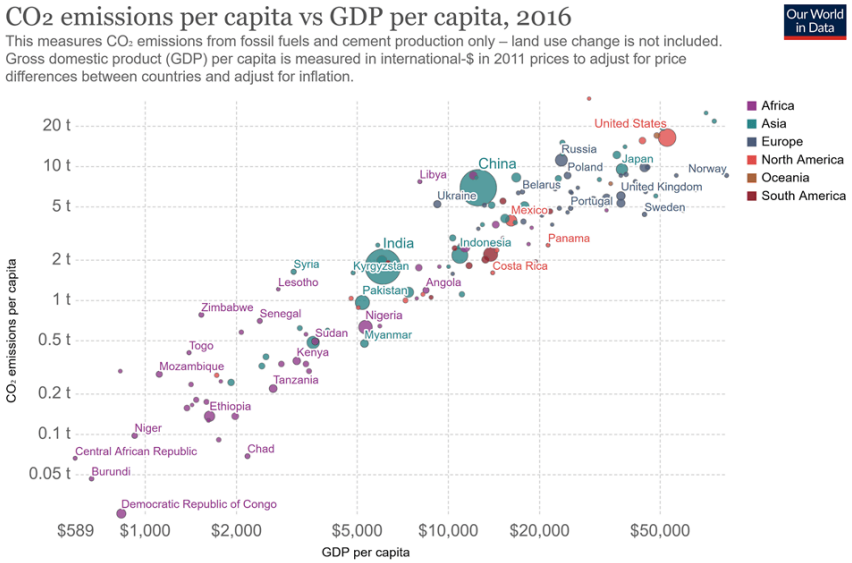


Figure 10.21: CO2 Emissions per person in Comparison to per person GDP of Countries with Populations of 1 million or More. Tip: go to the Our World in Data website for an interactive version of this graph. Figure by Our World in Data is licensed under CC BY 4.0

Exercise 1.10.16

25. Refer to Figure 10.21.

a. What does the graph convey about CO_2 emissions per capita and GDP per capita?

b. Use Your Critical Thinking Skills: What does an analysis of per capita carbon dioxide emissions and GDP reveal in terms of reducing emissions globally? Explain your response in two to three sentences.

3. Carbon Intensity (CO_2/gross domestic product)

Now you will investigate the relationship between CO_2 emissions and economic output, as measured by the gross domestic product. Countries that generate a lot of economic output by emitting CO_2 are known as **carbon dependent** economies, and they showcase high carbon intensity. Overall, as countries develop into information technology economies, the share of the GDP from carbon dependent energy and activities is likely to decrease.

Furthermore, wealthier countries are better able to invest in green technologies and enforce climate policies and commitments. Figure 10.22 presents carbon intensity as a graph while Figure 10.23 presents the same information as a map.

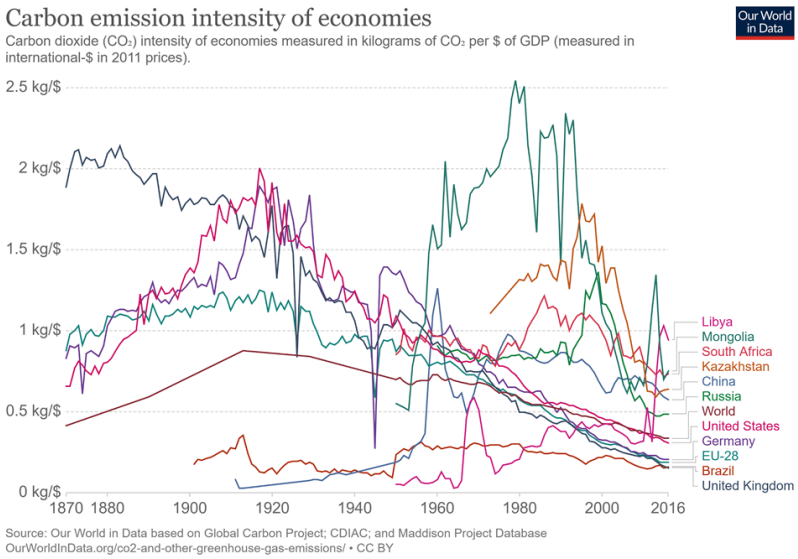


Figure 10.22: CO2 Emissions per unit of GDP. Tip: go to the Our World in Data website for an interactive version of this graph. Figure by Our World in Data is licensed under CC BY 4.0

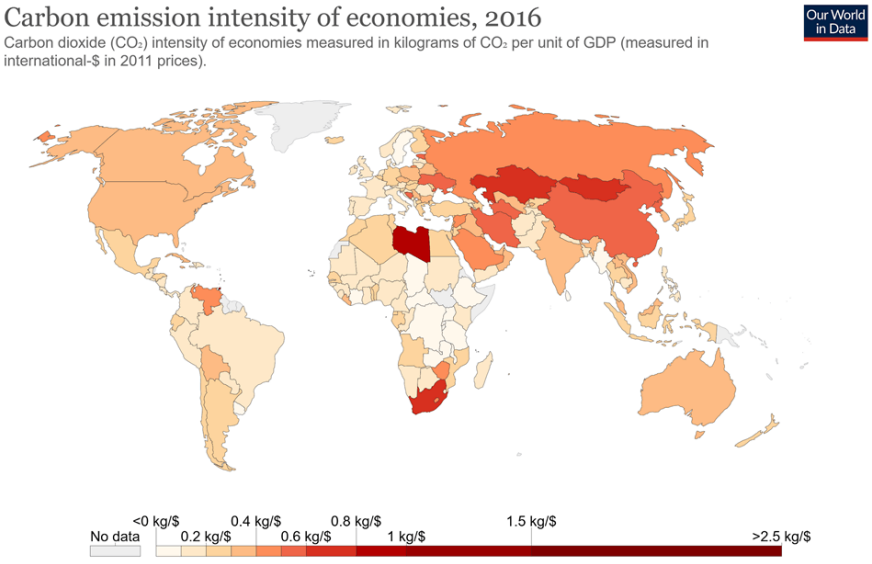


Figure 10.23: CO2 Emissions per unit of GDP. Tip: go to the Our World in Data website for an interactive version of this map. Figure by Our World in Data is licensed under CC BY 4.0

Exercise 1.10.17

26. Refer to Figures 10.22 and 10.23.
    a. As of 2016, which five countries had the highest carbon intensity?
    b. Use Your Critical Thinking Skills: List the underlying factors that explain why these five countries had the highest carbon intensity.
    c. What has happened to carbon intensity overall between 1870 and 2016?
    d. Use Your Critical Thinking Skills: List the underlying factors that explain the observed trend in carbon intensity.

4. Cumulative CO_2 Emissions (Industrial Revolution–present)

While we tend to look at emissions yearly, it is important that a long-term perspective is also applied when analyzing carbon dioxide emissions. Figure 10.24 shows the cumulative CO_2 emissions since the Industrial Revolution by country. Figure 10.25 shows the share of cumulative CO_2 emissions as a percentage of total emissions.

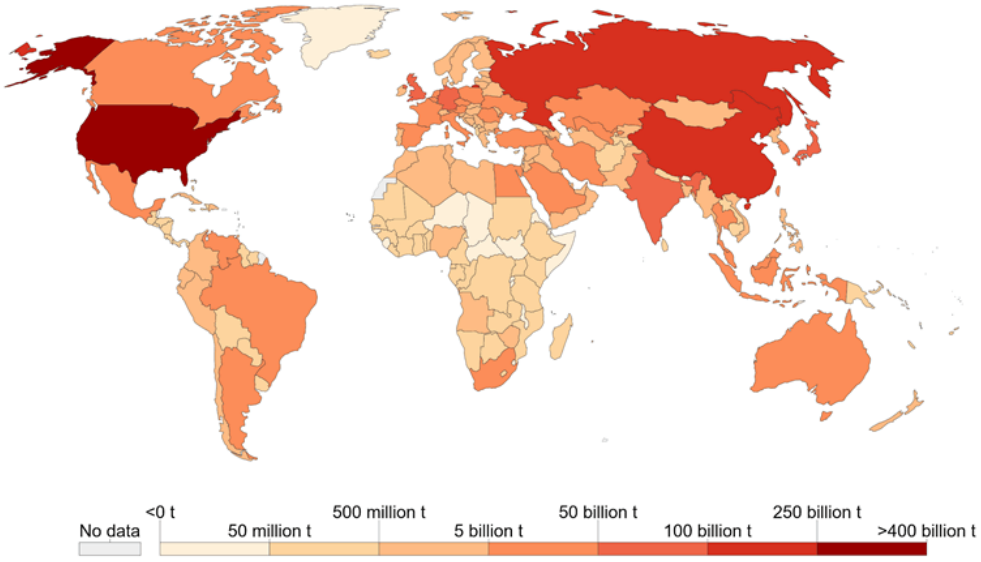


Figure 10.24: Cumulative CO2 Emissions from 1751 through 2018. Tip: go to the Our World in Data website for an interactive version of this map. Figure by Our World in Data is licensed under CC BY 4.0

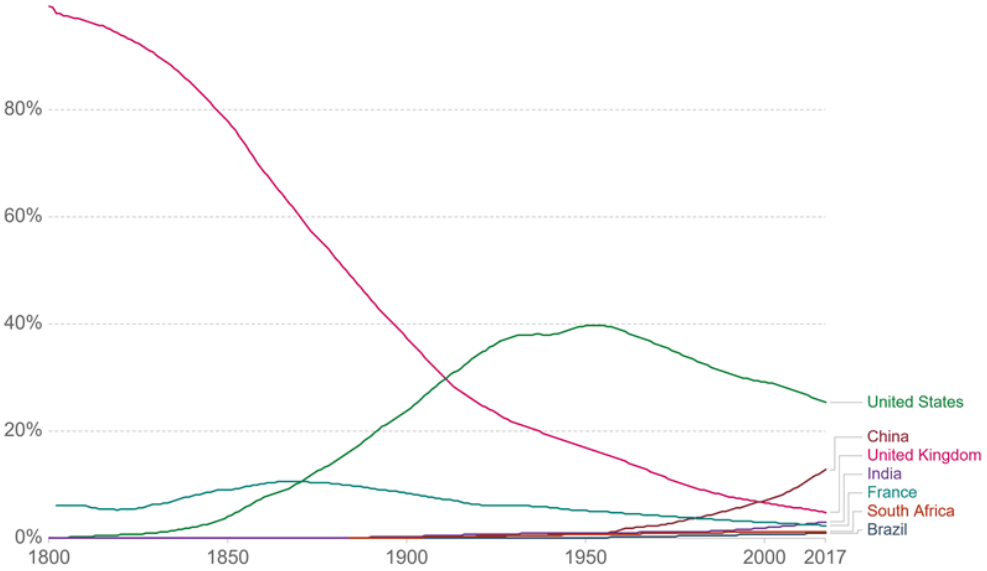


Figure 10.25: Share of Global Cumulative CO2 Emissions from 1751 through 2017. Tip: go to the Our World in Data website for an interactive version of this graph. Figure by Our World in Data is licensed under CC BY 4.0

Exercise 1.10.18

27. Refer to Figures 10.24 and 10.25.
    a. Which three countries had the highest cumulative CO_2 emissions between the Industrial Revolution and the present day?
    b. Use Your Critical Thinking Skills: How does the cumulative analysis enhance your understanding of carbon dioxide emissions?
    c. Use Your Critical Thinking Skills: List the underlying factors that explain the observed trend in the share of cumulative CO_2 emissions.
    d. Which three countries had the highest cumulative share of CO_2 emissions in 1800?
    e. Which three countries had the highest cumulative share of CO_2 emissions in 2017?
    f. Use Your Critical Thinking Skills: In one to two sentences, explain why your answers to questions a, d, and e above are not the same.
28. You analyzed carbon dioxide emissions using four different measures: current CO_2 emissions per year (CO_2/year); CO_2 emissions per capita (CO_2/person); carbon intensity (CO_2/gross domestic product); and cumulative CO_2 emissions (Industrial Revolution–present). What are three overall conclusions you can make based on your analysis?
29. Use Your Critical Thinking Skills:
    a. Which analysis would you use if you wanted to promote the narrative that the United States is to blame for carbon emissions? Explain your response in at least one sentence.
    b. Which analysis would you use if you wanted to promote the narrative that the United States is not to blame for carbon emissions? Explain your response in at least one sentence.
    c. Why is a nuanced perspective that incorporates all four methods of analysis preferred? Explain your response in at least one sentence.

Part D. Climate Justice

Given the realities of climate impacts, global movements have focused on **climate justice**, a concept that transcends discussing climate change from a purely physical or environmental issue to a political and ethical one. Because the effects of climate change are carried unevenly, discussing climate futures must consider how high-income countries will lead in resolving an issue they share greater responsibility in causing while at the same time supporting sustainable development for the world's poor. Furthermore, intersections of climate issues with racial, ethnic, gender, and national identities, for example, highlight the complexities of the issue. Climate justice contends that every person in the world has the right to enjoy the Earth's life-supporting environmental systems—a concept encompassed by the "rights to adequate standards of living" in the Universal Declaration of Human Rights.

Check It Out! Environmental Justice Atlas

Climate justice is one facet of the environmental justice movement. You can further explore case studies on environmental justice through the Environmental Justice Atlas.

Carbon Inequity

Data analysis from the previous section shows prominent global patterns of CO_2 emissions. The disproportionate manner in which countries emit carbon dioxide is called **carbon inequity**. Historically, a handful of countries have emitted the most, causing an accumulation of CO_2 in the atmosphere that scientists agree to have disrupted the Earth's climate system. The breakdown of global carbon dioxide emissions in 2016 by World Bank income group (Figure 10.26) and by world region (Figure 10.27) reveals carbon inequity. Average per capita emissions are shown on the y-axes and population size is shown on the x-axes. The area of the boxes shown represent the total annual emissions in 2016. These graphs allow for an analysis of the disproportionality of per capita emissions.

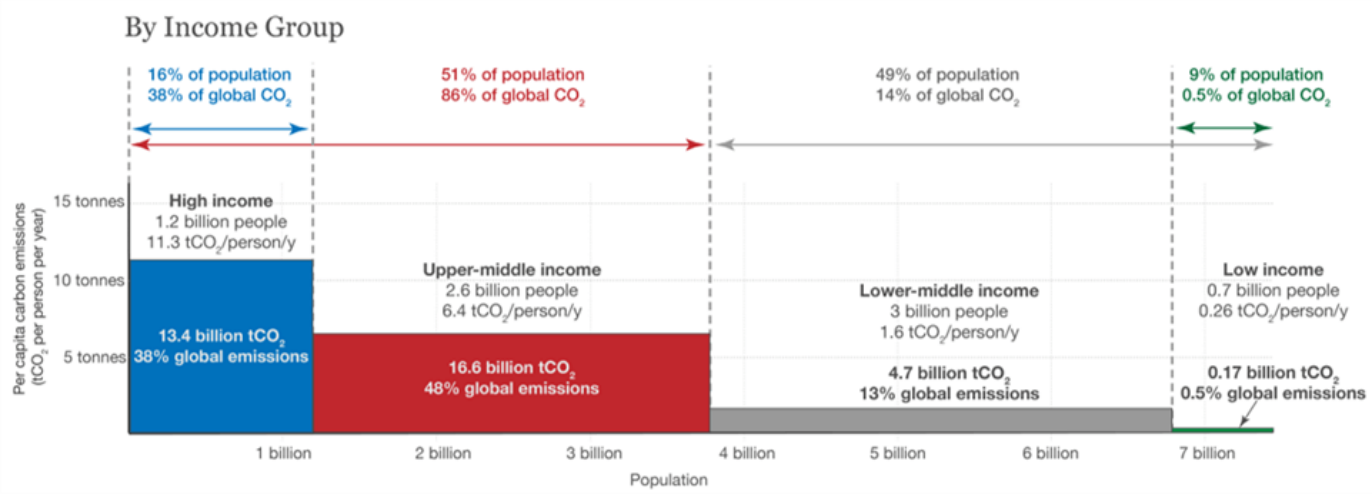


Figure 10.26: Global CO2 Emissions by Income Group. Figure by Our World in Data is licensed under CC BY 4.0

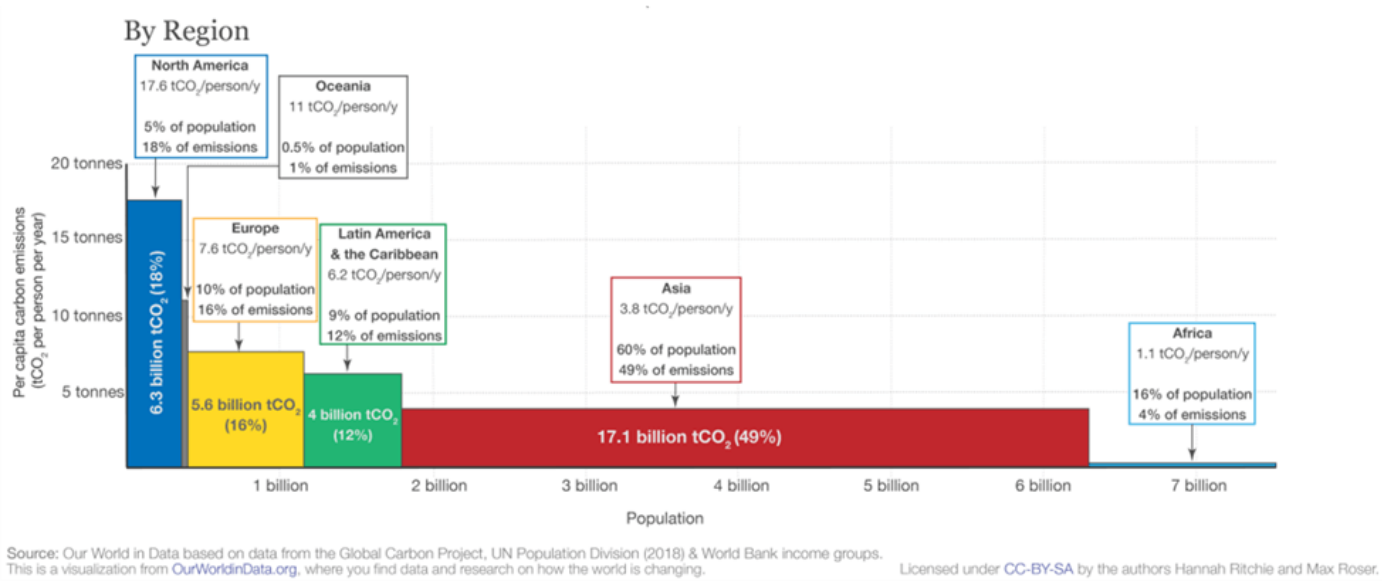


Figure 10.27: Global CO2 Emissions by Region. Figure by Our World in Data is licensed under CC BY 4.0

Figure 10.28 shows a map of the World Bank's income groups for reference.

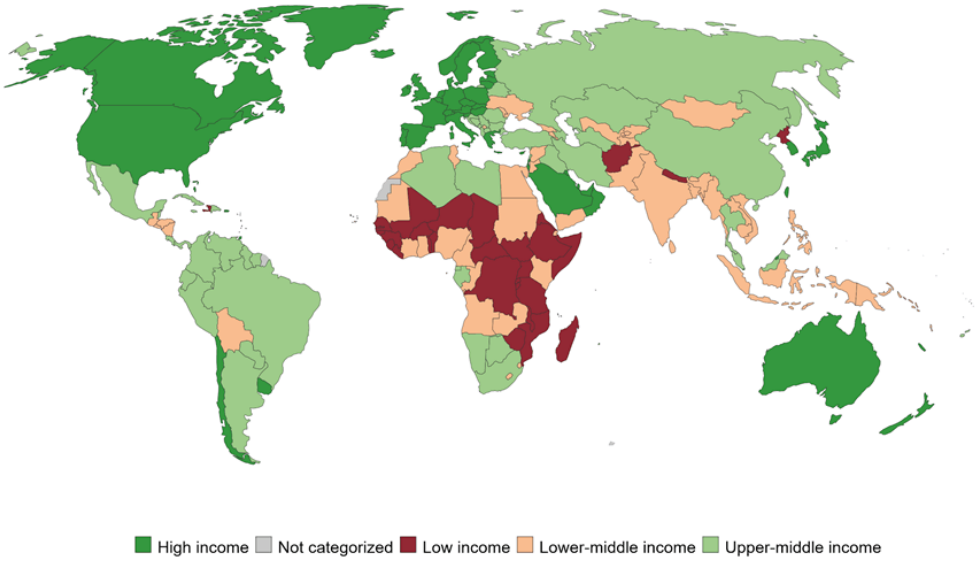


Figure 10.28: World Bank Income Groups (2016). Figure by Our World in Data is licensed under CC BY 4.0

Exercise 1.10.19

30. Refer to Figures 10.26 through 10.28.

    a. What are the five categories the World Bank uses to group countries by income?

    b. What is portrayed on the x-axes of Figures 10.26 and 10.27?

    c. What is portrayed on the y-axes of Figures 10.26 and 10.27?

    d. What income group are the United States and the United Kingdom classified as?

    e. What income group are China and Russia classified as?

f. What income group is India classified as?

g. Complete Table 10.2 below.

Table 10.2: Per Capita Emissions by World Region and Income Group

Income Group/Region	% of Global Population	% of Global CO_2
High Income Group		
Upper-middle Income Group		
Lower-middle Income Group		
Low Income Group		
North America		
Europe		
Latin America and the Caribbean		
Asia		

h. What are three conclusions that you can make about per capita emissions by world region and income group? Your response should be at least three sentences in length and cite data provided in the figures and table.

Economic Impacts of Climate Change

For decades, the IPCC has reported that the impacts of a warming planet continue to trigger climatic changes at global, regional, and local scales. Sea level rise, glacier melting, flooding, drought, loss of terrestrial and marine biodiversity, increased frequency and intensity of megafires and storms, heat waves, and increased uninhabitable land are some of the examples of the present and future impacts of climate change. While the expressions of a disrupted global climate system vary geographically, its impacts are overall detrimental to and disruptive of livelihoods all over the world—in a disproportionate manner.

There are a myriad of ways that geographers and other scientists study the distribution of climate impacts. Often, researchers utilize climate projection datasets derived from the most reputable climate models to infer climate change impacts on various facets of our society. Some studies focus on impacts on food production, mortality, poverty, coastal infrastructure, storms, heat waves, climate-induced migrations and political conflicts, and so on. The dataset below utilizes climate impact projections of a global warming of 2°C and its impact on national GDP, a universal language for policy makers (Figure 10.29). The map is based on an analysis from the “Half a degree Additional warming, Prognosis and Projected Impacts” project (HAPPI) that assessed changes in economic growth using empirical estimates of climate impacts in a global panel dataset.

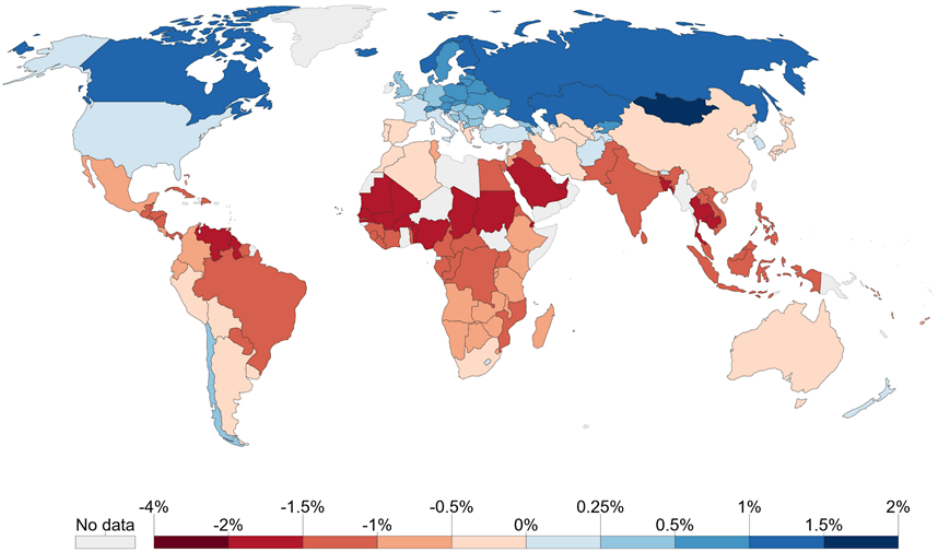


Figure 10.29: Economic Impact of 2°C Warming. Tip: go to the Our World in Data website for an interactive version of this map. Figure by Our World in Data is licensed under CC BY 4.0

Exercise 1.10.20

31. Refer to Figure 10.29.

    a. In two to three sentences, describe the geographical distribution of the economic impacts of 2°C warming.

    b. Compare Figures 10.28 and 10.29. Which income group faces the most economic losses?

    c. Compare Figures 10.24 and 10.29. Are the countries projected to face the most economic losses the same countries as those with high cumulative emissions?

Another economic measure of the climate crisis is to look at its impacts on global poverty. Despite decades of global poverty reduction, the World Bank (2020, n.p.) estimates that without climate action 100 million more people will dip below poverty by 2030 (Figure 10.30). Poverty is an important measure, as it is a control factor on various measures of human well-being and quality of life. These measures include access to vital resources, education, health, safety, and so much more. Low income countries are less able to adapt to the challenges of climate change, and thus are more vulnerable to its impacts. Figure 10.30 shows the prediction of additional people at risk of extreme poverty in 2030. The map was created based on the differences in the projected number of people living in extreme poverty between the baseline (business-as-usual) scenario and the projected scenario. The international poverty line is measured as living on less than $1.90 per day, which adjusts for inflation and cross-country price differences. The data takes into consideration how, when combined, low economic growth, low educational attainment levels, and high population growth result in challenges to climate mitigation and adaptation.

NASA explains the difference between mitigation and adaptation:

➢ Mitigation—reducing climate change—involves reducing the flow of heat-trapping greenhouse gases into the atmosphere, either by reducing sources of these gases (for example, the burning of fossil fuels for electricity, heat, or transport) or enhancing the “sinks” that accumulate and store these gases (such as the oceans, forests, and soil). The goal of mitigation is to avoid significant human interference with the climate system, and “stabilize greenhouse gas levels in a time frame sufficient to allow ecosystems to adapt naturally to climate change, ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner” (from the 2014 report on Mitigation of Climate Change from the United Nations Intergovernmental Panel on Climate Change, page 4).

➢ Adaptation—adapting to life in a changing climate—involves adjusting to actual or expected future climate. The goal is to reduce our vulnerability to the harmful effects of climate change (like sea-level encroachment, more intense extreme weather events, or food insecurity). It also encompasses making the most of any potential beneficial opportunities

associated with climate change (for example, longer growing seasons or increased yields in some regions).[187]

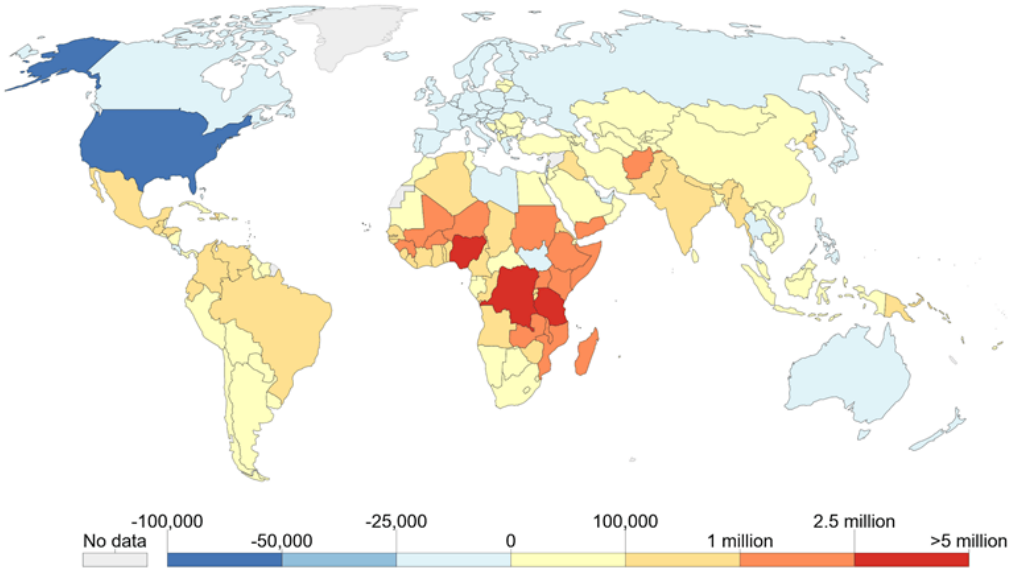


Figure 10.30: Additional People at Risk of Extreme Poverty. Tip: go to the Our World in Data website for an interactive version of this map.
Figure by Our World in Data is licensed under CC BY 4.0

Exercise 1.10.21

32. Refer to Figure 10.30.
    a. Which countries/world regions, shown in dark blue and light blue, are expected to reduce the number of people living in extreme poverty by 2030?
    b. Which countries/regions, shown in orange and red, are expected to have the highest increases of people at risk of extreme poverty by 2030?
    c. Do you think the map is a good indicator of climate vulnerability? Why or why not? Explain your response in two to three sentences.
33. Use Your Critical Thinking Skills: In thinking about carbon inequities, list what tensions may arise in global climate policy decision-making.



Check It Out! Environmental Justice and Urban Heat

Learn about urban heat and the impact of racism in this article by National Geographic called “Racist housing policies have created some oppressively hot neighborhoods”. This article shows how the impacts of climate change, combined with institutional and interpersonal forms of racism, affect populations at the neighborhood level. In this lab, you have investigated climate change primarily at global and national scales. It is important to note that geographers also study climate change at regional and local scales; this article provides an introduction to this type of research.

Part E. Wrap-Up

Consult with your geography lab instructor to find out which of the following wrap-up questions you should complete. Attach additional pages to answer the questions as needed.

Exercise 1.10.22

34. What is the most important idea that you learned in this lab? In two to three sentences, explain the concept and why it is important to know.

35. What was the most challenging part of this lab? In two to three sentences, explain why it was challenging. If nothing challenged you in the lab, write about what you think challenged your classmates.

36. What is one question that you have about what you learned in this lab? Write your question along with one to two sentences explaining why you think your question is important to ask.

37. Review the learning objectives on page 1 of this lab. How would you rate your understanding or ability for each learning objective? Write one sentence that addresses each learning objective.

38. Sketch a concept map that includes the key ideas from this lab. Include at least five of the terms shown in bold-faced type.

39. Create an advertisement to educate your peers on the important information that you learned in this lab. Include at least three key terms in your advertisement. The advertisement should be about half a page in size (about 4 inches by 6 inches).

40. One way to think of physical geography is that it is the study of the relationships among variables that impact the Earth's surface. Select two variables discussed in this lab and describe how they are related.

41. How does what you learned in this lab relate to your everyday life? In two to three sentences, explain a concept that you learned in this lab and how it relates to your day-to-day actions.

42. How does what you learned in this lab relate to current events?
    a. Write the title, source, and date of a news item that relates to this lab.
    b. In two to three sentences, discuss how the news item relates to what you have learned in this lab.
    c. In one to two sentences, discuss whether or not the news item accurately represents the science that you learned. Tip: consider whether or not the news item includes the complexity of the topic.

43. Search O*NET OnLine to find an occupation that is relevant to the topics presented in today's lab. Your lab instructor may provide you with possible keywords to type in the Occupation Quick Search field on the O*NET website.
    a. What is the name of the occupation that you found?
    b. Write two to three sentences that summarize the most important information that you learned about this occupation.
    c. What is one question that you would want to ask a person with this occupation?

Answer available at the end of this section.

[171] Text by NOAA is in the public domain

[187] Text by NASA is in the public domain

Answers

Exercise 1.10.22

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1.11: Lab 11 - The Ocean-Atmosphere System

Learning Objectives

- Differentiate between a normal year and an El Niño year in terms of oceanic and atmospheric circulation patterns.
- Explain how sea surface temperatures change during an El Niño event and how those changes impact weather around the world.
- Describe how upwelling affects nutrient concentrations.
- Identify the causes of ocean acidification.
- Explain the impact ocean acidification has on coral reef systems.

Introduction

The ocean and atmosphere are connected. They work together to move heat and freshwater across the globe. Atmospheric winds and ocean current circulations move warm water toward the poles and colder water toward the equator. The ocean can store much more heat than the land surfaces on the Earth. The majority of the thermal energy at the Earth's surface is stored in the ocean. Thus, the absorption and movement of energy on the Earth is related to the ocean-atmosphere system.[189]

The ocean couples with the atmosphere in two main ways (Figure 11.1). The first way is physically, through the exchange of heat, water, and momentum. Covering more than 70% of the Earth's surface and containing about 97% of its surface water, the ocean stores vast amounts of energy in the form of heat. The ocean receives most of its heat along the equator, where incoming solar radiation is about double that received at the poles. Hence, sea surfaces are much warmer along the equator than at the poles. The ocean has a high temperature and momentum "inertia", or resistance to change. Relative to the atmosphere, it has a very slow circulation system, so changes in its systems generally occur over much longer timescales than in the atmosphere, where storms can form and dissipate in a single day. The ocean changes over periods from months to years to decades, whereas the atmosphere changes over periods of minutes to hours to days. The interactions between ocean and atmosphere are fully nonlinear, and occur over decades, which is why their "dialogue" is so hard to interpret.[190]

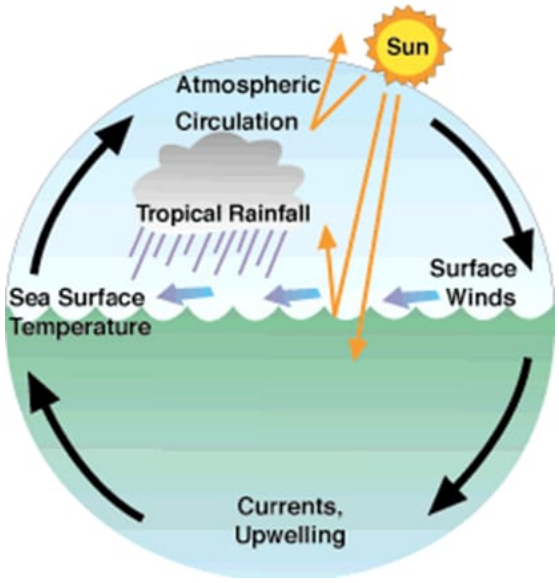


Figure 11.1: Ocean and Atmosphere Connections. Figure and text by NASA's Earth Observatory are in the public domain

The ocean and atmosphere move because they are fluid. The speed and direction of air and sea currents are determined primarily by air temperature gradients. As heat rises and eventually escapes the ocean to warm the overlying atmosphere, it creates air temperature gradients and, consequently, winds. In turn, winds push against the sea surface and drive ocean current patterns. Over time, a complex system of currents was established whereby the ocean transports a tremendous amount of heat toward the

poles. Because heat escapes more readily into a cold atmosphere than a warm one, the northward flow of ocean and air currents is enhanced by the flow of heat escaping into the atmosphere and, ultimately, into outer space.[3]

In this lab, you will investigate just two components of the ocean-atmosphere system:

- El Niño Southern Oscillation (ENSO), which shifts large-scale atmospheric circulation patterns and impacts precipitation levels as well as ocean nutrient concentrations.
- Ocean acidification, which has occurred due to the increased concentration of carbon dioxide in the atmosphere since the Industrial Revolution began.

Part A. El Niño Southern Oscillation (ENSO)

El Niño Southern Oscillation (ENSO) is a climate phenomenon on Earth that has the ability to alter atmospheric circulation. This is important because atmospheric circulation influences sea surface temperature, air temperature, and precipitation around the world. ENSO refers to changes in sea surface temperatures and atmospheric pressure that result in unusual weather patterns in the Pacific Ocean. The El Niño part of ENSO refers to the warming of surface waters and the Southern Oscillation part of ENSO refers to changes in atmospheric pressure. You have learned that air molecules move away from areas of high pressure and into areas of low pressure. This phenomenon causes regions with high pressure systems to experience dry and clear skies as opposed to regions with low pressure systems that experience humid and cloudy skies. In low pressure systems, air masses converge, rise, and condense, resulting in precipitation. Therefore, low pressure systems bring more precipitation than high pressure systems.

Exercise 1.11.1

1. Understanding the impact of high pressure versus low pressure systems is essential to explain ENSO. Figure 11.2 shows a low atmospheric pressure and a high atmospheric pressure. Label the high atmospheric pressure with an H and the low atmospheric pressure with an L.

Answer available at the end of this section.

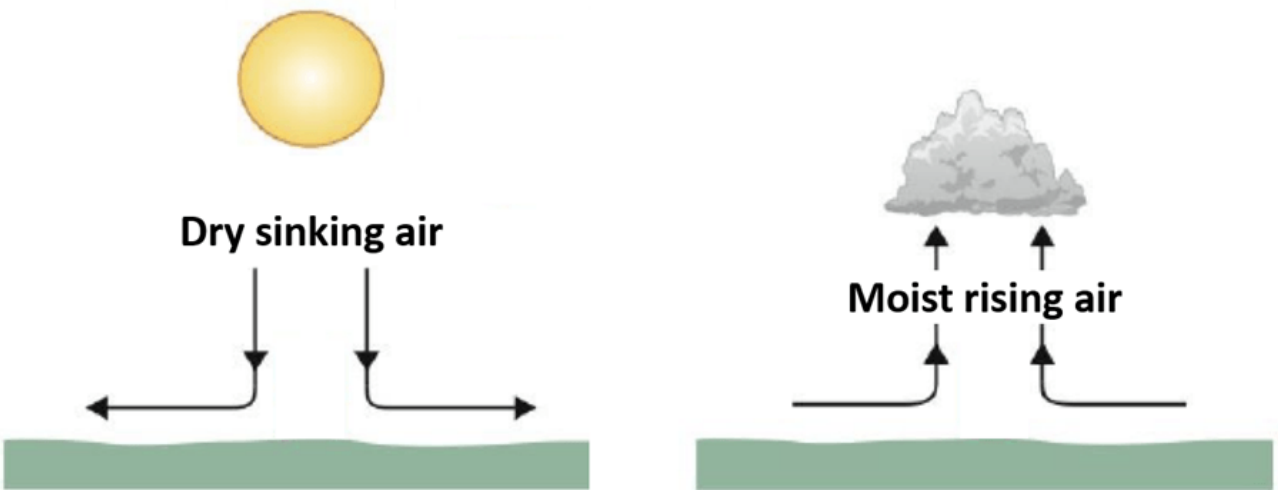


Figure 11.2: Cross-Sections of Two Types of Atmospheric Pressure. Figure adapted from the National Weather Service is in the public domain

Exercise 1.11.2

2. In one to two sentences, explain why high atmospheric pressure systems are associated with dry, sunny conditions.

El Niño events occur every 2 to 7 years off the west coast of South America. The first El Niño events were recognized by fishers off the west coast of Peru as they observed warmer waters impact their fisheries. Spanish immigrants in Peru named this phenomenon El Niño after the “Christ Child” as it normally occurs near Christmastime. Because El Niño is not predictable and not

considered a typical cycle, it is important to understand how El Niño impacts weather, ocean currents, and the health of coastal fisheries.

Check It Out! ENSO Outlook

NOAA Climate shows the current status of ENSO on their website. This website also has more information on ENSO and its impact on the United States and around the globe.

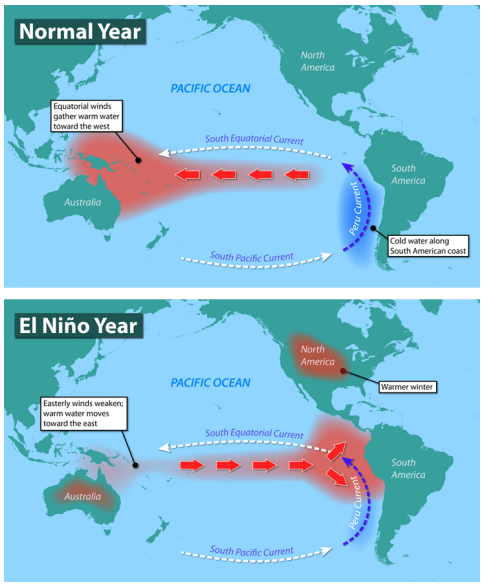


Figure 11.3: Oceanic Circulation Patterns During a Normal Year and an El Niño Year. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

In a normal year, trade winds blow from the east across the tropical Pacific Ocean just north and south of the equator (see Figure 11.3, top). These winds push warm surface water toward the western Pacific near Asia and Australia. As warm surface waters move west, deep, cold, nutrient-rich water in the eastern Pacific and along the west coast of South America rises up to the surface in a process called **upwelling** (see Figure 11.4). This nutrient-rich water is made up of nitrates and phosphates, which are vital nutrients for phytoplankton that live near the surface. Phytoplankton are **producers**; they use sunlight to process their own food through photosynthesis. **Consumers** are animals in the food chain that do not make their own food and rely on healthy populations of producers to serve as a food source. Some examples of consumers in the ocean are clams, fish, and whales.

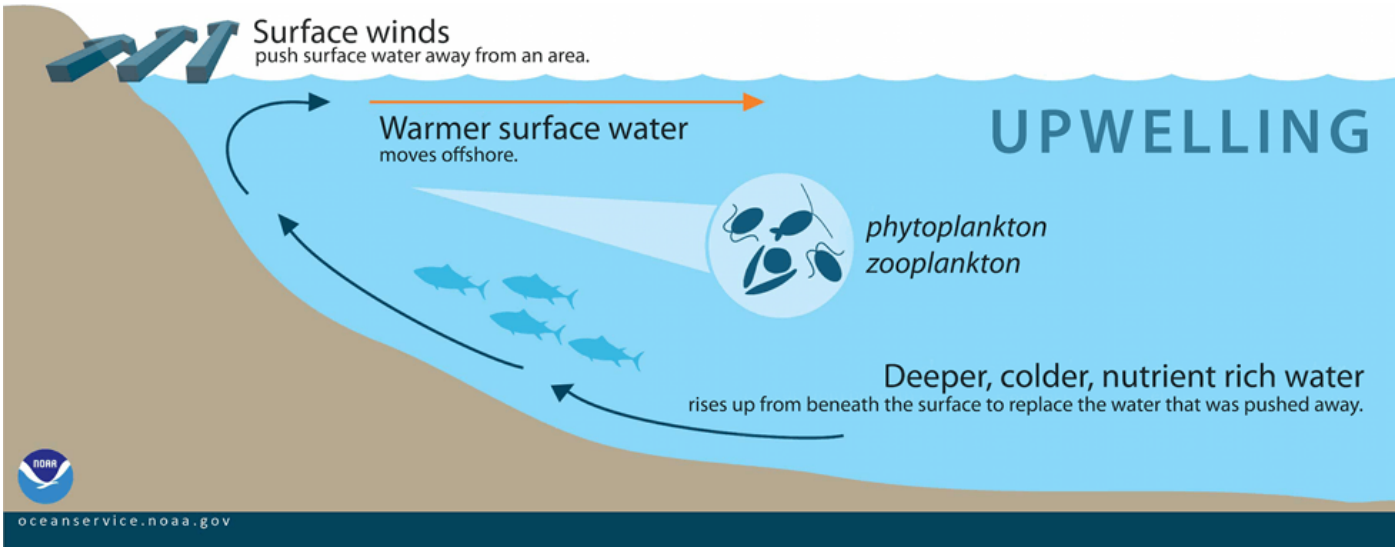


Figure 11.4: Upwelling. Figure adapted from NOAA is in the public domain

During an El Niño event, warm waters are pushed away from the western Pacific and pulled toward the eastern Pacific in what is called a **Kelvin Wave** (Figure 11.3, bottom). This Kelvin Wave travels along the equator, which is a region that receives more insolation throughout the year than other latitudes. Because the Coriolis effect is nonexistent along the equator, the Kelvin Wave travels slowly, giving it time to gain heat from the Sun as it approaches the west coast of South America. This wave of warm water then blocks the colder nutrient-rich water from rising up and the process of upwelling is reduced or sometimes prevented in this area.

Because upwelling is significantly reduced during an El Niño event, marine life that depends on phytoplankton as a food source will starve or move to cooler waters where upwelling occurs, leaving the region desolate. Fishers in South America can experience significant financial loss as seafood populations decrease dramatically due to mass migration during an El Niño event.

In addition to changes in oceanic circulation in the Pacific, atmospheric pressure also changes during an El Niño event. In a normal year, the western tropical Pacific experiences low pressure systems that bring high amounts of precipitation between August and December. During an El Niño year, low pressure systems over Asia and Australia leave as high pressure systems move in (Figure 11.5). High pressure systems result in air molecules moving away from each other, which results in dry, clear skies. Precipitation decreases and many regions experience a prolonged period of drought.

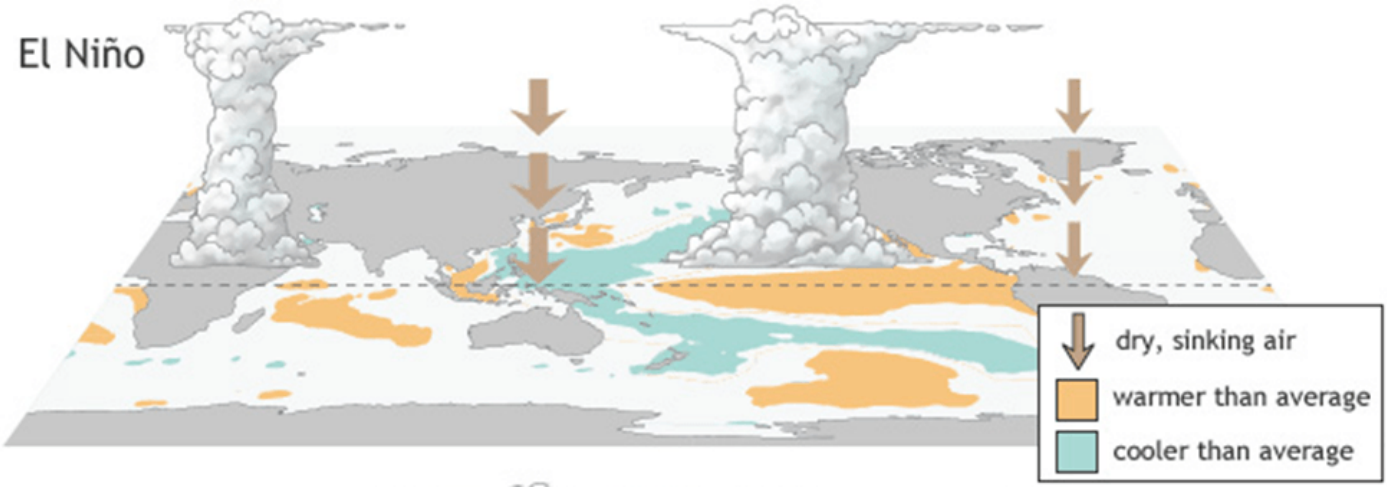


Figure 11.5: Oblique Map View of El Niño. Figure by NOAA Climate is in the public domain

Exercise 1.11.3

3. Refer to Figure 11.5.
    a. How does the change from a low pressure system to a high pressure system during an El Niño event impact the weather in Southeast Asia and Australia? Explain your response in one to two sentences.
    b. What parts of the world have thunderstorm clouds during an El Niño event? Explain why these areas have low pressure systems in one to two sentences.

Mapping El Niño Circulation Patterns

Figure 11.6 shows global wind patterns and circulation cells.

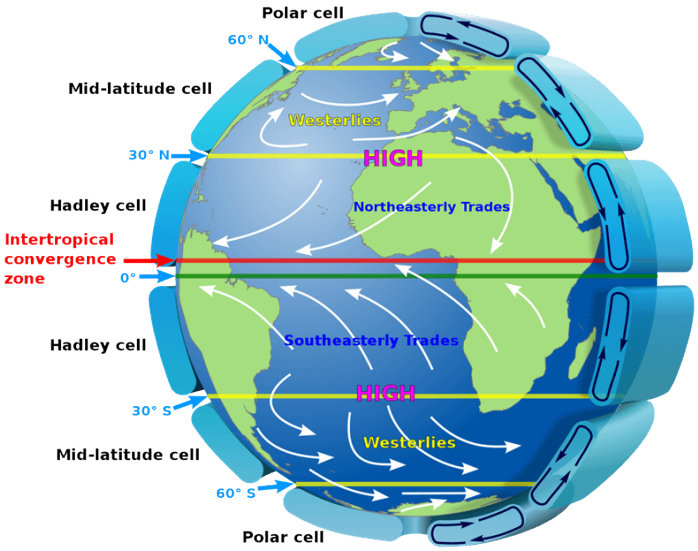


Figure 11.6: Typical Atmospheric Circulation Patterns on Earth. Figure by Kaidor is licensed under CC BY-SA 3.0

Exercise 1.11.4

4. On the following normal year map (Figure 11.7 top), sketch and label the following. Tip: refer to Figures 11.3 and 11.6.
    a. northeast trade winds,
    b. southeast trade winds,
    c. south equatorial current,
    d. south pacific current,
    e. Peru current, and
    f. Labeled textboxes on Figure 11.3.

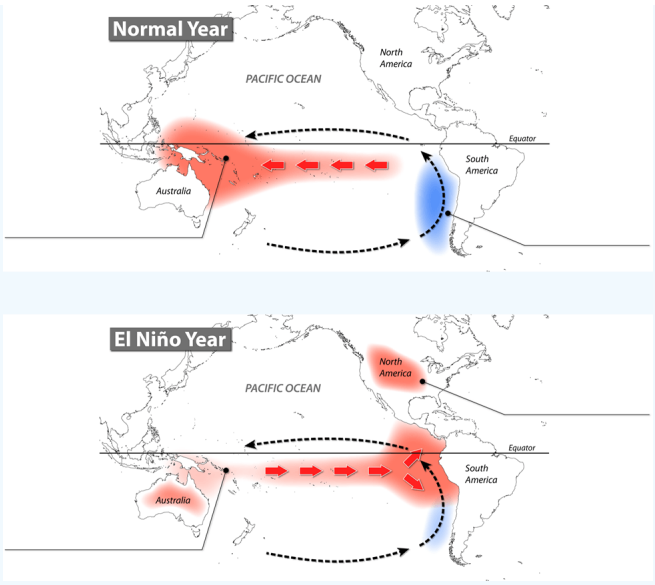


Figure 11.7: Maps for Labeling Exercise. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

5. On the El Niño year map (Figure 11.7 bottom), sketch and label the following. Tip: refer to Figures 11.3 and 11.6.
   a. northeast trade winds,
   b. southeast trade winds,
   c. south equatorial current,
   d. south pacific current,
   e. the Kelvin Wave,
   f. Peru current, and
   g. Labeled textboxes on Figure 11.3.

6. Refer to your labeled maps in Figure 11.7.

   a. During a normal year, in which direction do the trade winds travel?

   b. During an El Niño year, in which direction do trade winds travel?

      i. Toward which continent do these winds push warm surface waters?

      ii. What is the name of the warm ocean current that travels toward South America? In one to two sentences, explain how this current gains heat as it travels east.

      iii. Use Your Critical Thinking Skills: What is the impact of El Niño on California? Explain your response in one to two sentences. Hint: Refer to Figure 11.5.

Nutrient Concentrations and El Niño

Nutrient concentrations are levels of dissolved nutrients like nitrogen or phosphorus that are essential for ocean life. Nutrient concentrations vary based on longitude and ocean depth. Table 11.1 shows typical phosphate nutrient concentrations in the Pacific Ocean according to ocean depth.

Table 11.1: Typical Nutrient Concentrations (mg/L) based on Ocean Depth (meters)

Point	Longitude	Ocean Depth (meters)	Phosphate (PO_4) (milliliters per liter of ocean water)
1	124°W	50	0.5
2	123°W	150	2.0
3	124°W	250	2.5

Point	Longitude	Ocean Depth (meters)	Phosphate (PO_4) (milliliters per liter of ocean water)
4	121.5°W	400	3.5

Figure 11.8 shows the concentration of phosphate off the coast of California based on data collected by the California Cooperative Oceanic Fisheries Investigations (CalCOFI) during an El Niño event. The lines represent milliliters of phosphate per liter of ocean water (ml/L).

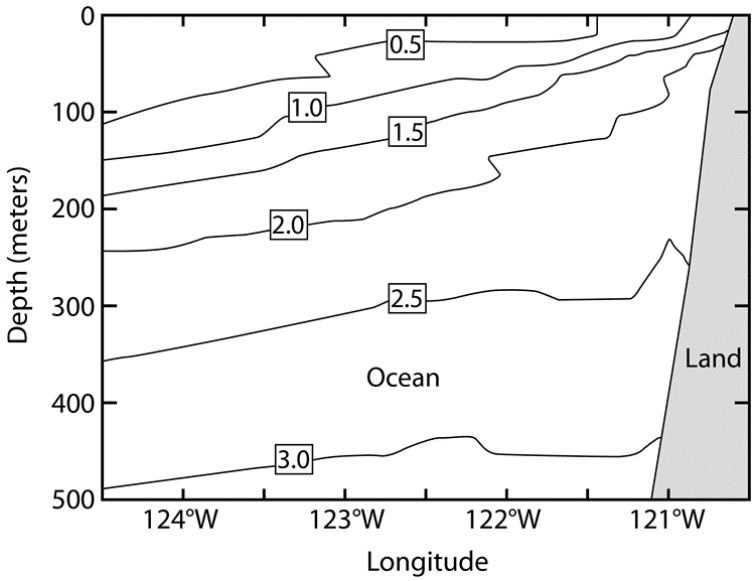


Figure 11.8: Phosphate Nutrient Concentrations during an El Niño event. Figure by Waverly Ray adapted from T. James Noyes, Jr. is licensed under CC BY-NC-SA 4.0

Exercise 1.11.5

7. Refer to Figure 11.8.
    a. Use Your Critical Thinking Skills: Why might nutrient concentrations increase closer to land?
    b. Color the water with nutrient concentrations higher than 2 mg/L green.
    c. Color the water with nutrient concentrations lower than 2 mg/L orange.
    d. How would upwelling from green sections (deeper water) improve the health of fish populations in the orange sections (surface waters)?
    e. Describe how low nutrient concentrations impact the food chain in the ocean.
8. Plot and label the data points provided in Table 11.1 onto Figure 11.8. These data points represent phosphate nutrient concentrations during a typical year.
9. Compare the typical year data points and the lines shown for the El Niño event on Figure 11.8.
    a. Overall, are the nutrient concentrations during an El Niño event higher or lower than the typical year? Tip: compare values at the same depths.
    b. In one to two sentences, explain this trend.

Carbon Dioxide and El Niño

Atmospheric carbon dioxide has increased steadily since 1960. Data shows that the long-term rise in atmospheric CO_2 (due to human activities) is more pronounced during El Niño years. In the equatorial Pacific, as the warm pool propagates eastward, clouds and rainfall move with it and leave the Western Pacific in dry conditions that often lead to drought across Indonesia, southeast Asia, and northern Australia. The problems of drought are compounded by slash-and-burn land clearing. For example, in Indonesia it is common for farmers to clear-cut forests for lumber and to burn rainforest to develop the land. Normally, these fires are extinguished by the consistent rains that fall in the tropics. But when the rain dries up during a strong El Niño, those fires burn uncontrolled. Massive El Niño-fueled fires were blamed for thousands of premature deaths from air pollution in 1997-98 and contributed to as many as 100,000 deaths in 2015-16, according to a recent study by Harvard University scientists. Wildfires also release extra carbon dioxide into the air. Vegetation that is stressed from heat and drought cannot absorb as much atmospheric carbon as it normally takes up during photosynthesis. Because of this, atmospheric CO_2 (as measured at the Mauna Loa observatory in Hawai'i) has less of a seasonal decline during the Northern Hemisphere growing season. Thus, the rise in atmospheric CO_2 is more pronounced during El Niño years (Figure 11.9).[8]

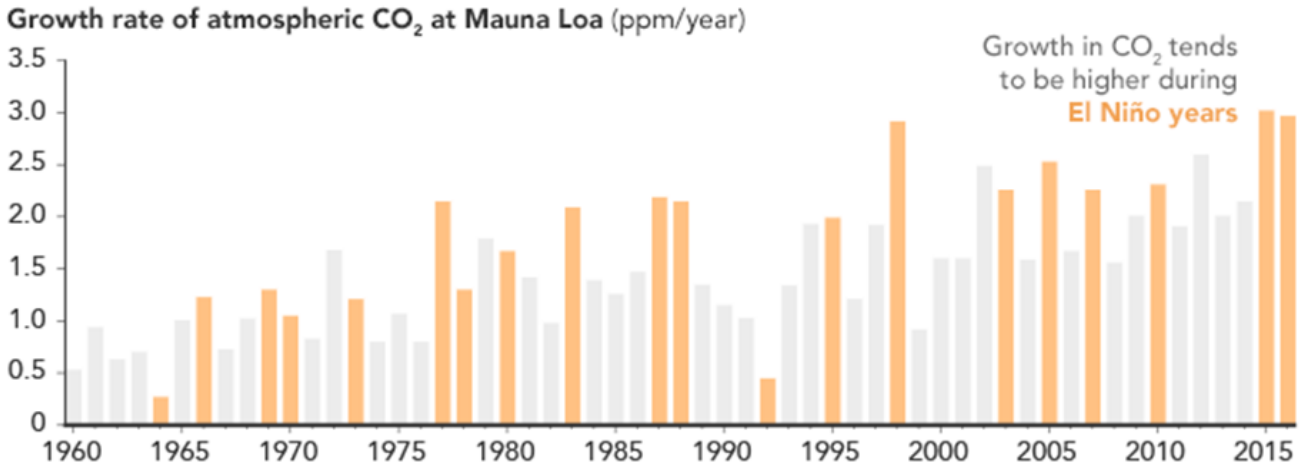


Figure 11.9: Growth Rate of Carbon Dioxide at Mauna Loa. Figure and text by NASA Earth Observatory are in the public domain

Exercise 1.11.6

10. In one to two sentences, explain the reasons why El Niño events are associated with increased levels of atmospheric carbon dioxide.

The next section of the lab goes into more details on how the overall rising levels of carbon dioxide in the atmosphere affect the oceans and ocean life.

Part B. Ocean Acidification

The ocean is a wonderful system that provides life to millions of marine plants and animals. Marine life is able to thrive in the ocean because seawater is composed of salt. Salt is the result of a base neutralizing an acid; this means that seawater is a fairly neutral zone, with a pH of 8.1. **pH** measures the amount of hydrogen ions that exist in a given substance (Figure 11.10). The more hydrogen ions present, the lower the potential for hydrogen to exist; therefore, high concentrations of hydrogen ions yield a low pH and these substances are more acidic. The fewer hydrogen ions present, the greater the potential for hydrogen to exist; therefore, low concentrations of hydrogen ions is indicative of a high pH and a substance that is more basic. Minor changes in pH concentrations can have major impacts. In fact, a simple change of one unit on the pH scale will change the concentration of hydrogen ions by a factor of 10, but a change in two units on the pH scale will change in the concentration of hydrogen ions by a factor of 100! This means a minor change in pH in seawater can negatively impact marine life. When seawater becomes more acidic, marine life with **calcium carbonate** ($CaCO_3$) shells and structures weaken and do not fully develop.

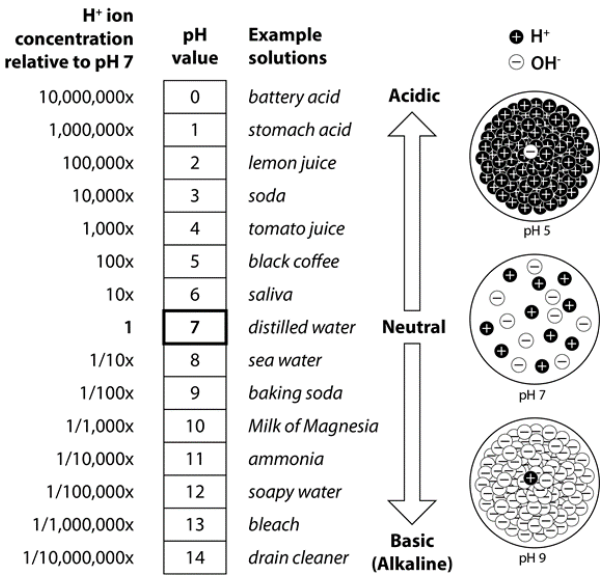


Figure 11.10: pH Scale with Examples of Solutions. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

You have learned in previous labs that carbon dioxide (CO_2) is a vital greenhouse gas on Earth. CO_2 not only exists in the air, it is also taken in by plants, animals, and the ocean. As seawater absorbs CO_2, water and carbon dioxide combine and form carbonic acid (H_2CO_3). Because H_2CO_3 is a weak acid, this reaction causes H_2CO_3 to break apart. The result produces hydrogen ions (H+) and bicarbonate ions (HCO_3^-).

To keep CO_2 concentrations balanced both in the atmosphere and on the surface, plants, animals, and the oceans store CO_2 in various forms. In fact, the oceans store approximately 35% of all CO_2 naturally emitted on Earth. However, in the last three hundred years humans have burned fossil fuels for energy, an activity that releases CO_2 into the atmosphere. As the rate of burning greenhouse gases increases, the amount of CO_2 that exits also increases. As concentrations of CO_2 increase, the oceans increase their intake of CO_2 .

Shelled organisms and corals extract calcium ions (Ca^{2+}) and carbonate ions (CO_3^{2-}) from seawater that combine into solid crystals of calcium carbonate ($CaCO_3$). As carbon dioxide concentrations increase in the ocean, pH levels drop, resulting in decreased concentrations of carbonate ions (CO_3^{2-}). As carbonate ions are reduced, seawater becomes acidic, a process called **ocean acidification** (OA) as shown in Figure 11.11. Because carbonate ions (CO_3^{2-}) are instrumental in the development of shelled creatures and coral colonies, acidic seawater prevents corals from growing and developing strong structures.

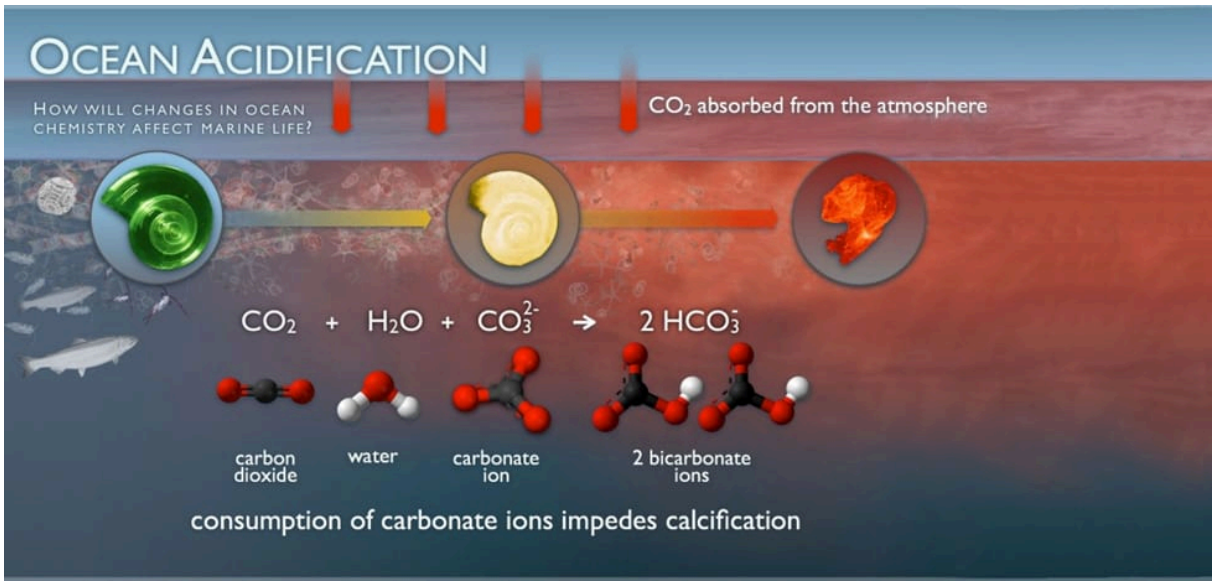


Figure 11.11: Ocean Acidification Process. Figure by NOAA is in the public domain

Exercise 1.11.7

11. Refer to Figure 11.11. How does CO_2 absorbed by the ocean prevent coral growth?

Ocean Acidification Experiment

Materials needed:

- 2 beakers with vinegar
- 2 beakers with water
- 2 limestone pebbles
- 2 scoops of $CaCO_3$ powder (calcium carbonate)
- Timer (set at 10 minutes and then 30 minutes)

Step 1

Place one scoop of calcium carbonate in the beaker with vinegar and one scoop of calcium carbonate in the beaker with water. Place one limestone pebble in the beaker with vinegar and one limestone pebble in the beaker with water. Set the timer for 10 minutes.

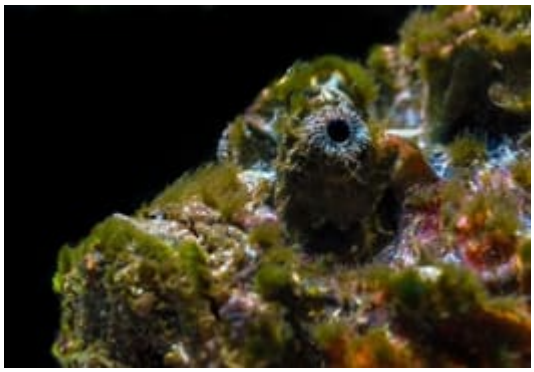
Step 2

Review Table 11.2, which represents a study done on estimated changes in marine life by 2100 due to decreases in pH in seawater. Then, answer the question below. Note: the table is divided into groups of animals, specific animals, and their responses to ocean acidification. For example, “algae” is a group, while fleshy algae are a specific animal, and +22% growth is a response to ocean acidification.

- Growth refers to changes in biomass, sizes, tissue, and rates of growth.
- Abundance refers to changes in the number of individuals as well as changes to the coverage, or spatial distribution, of individuals.

- Survival refers to changes to mortality rates.
- Calcification refers to changes to the production of calcium carbonate shells and structures by marine animals.
- Development refers to changes in embryonic or larval development.

Table 11.2: Ocean Acidification Effects among Key Taxonomic Groups. Adapted from CoastAdapt; decorative images from Unsplash from top to bottom: David Clode, Peter Boshra, NOAA, Q.U.I, Felipe Portella, and Ganapathy Kumar

Group	Example Organisms	Decorative Image	Main Response
Algae	Fleshy algae, diatoms, calcifying algae		+22% growth for fleshy algae +17% growth for diatoms -80% abundance for calcifying algae
Mollusks	Clams, scallops, mussels, oysters, pteropods, abalone, conchs, and cephalopods (squid, cuttlefish, octopuses)		-34% survival -40% calcification
Echinoderms	Sea urchins, sea cucumbers, starfish		-10% growth -11% development
Corals	Warm and cold water corals		-32% calcification -47% abundance

Group	Example Organisms	Decorative Image	Main Response
Crustaceans	Shrimps, prawns, crabs, lobsters, copepods		Relatively resistant to changes in ocean pH
Finfish	Herring, sardines, anchovies, tuna, bonitos, billfishes, flounders, halibut, cod, haddock		Loss of habitat and food supply with possible effects on behavior, fitness, and larval survival

Exercise 1.11.8

12. Refer to Table 11.2.
    a. Which animal is expected to experience the largest decline in abundance? Why might that be?
    b. List three animals that are expected to experience a 40% decline in calcification.
    c. Why might echinoderms experience the least amount of decline in growth and development compared to other groups?
    d. Finfish are indirectly affected by ocean acidification. Explain in two to three sentences how finfish are indirectly affected and why they might not experience large declines in growth and development compared to other groups.
    e. Which species group is expected to experience the least amount of change with ocean acidification?

Step 3

After the $CaCO_3$ and limestone pebble have been in the water and the vinegar for 10 minutes observe what has happened to both materials.

Exercise 1.11.9

13. Describe your observations of the $CaCO_3$ and limestone pebble.

Step 4

Reset the timer for 30 minutes.

Step 5

Read the following information provided by CoastAdapt and then answer the questions below.

Changes in marine ecosystems will have consequences for human societies, which depend on the goods and services these ecosystems provide. The implications for society could include substantial revenue declines, loss of employment and livelihoods, and other indirect economic costs. Socioeconomic impacts associated with the decline of the following ecosystem services are expected:

- Food: Ocean acidification has the potential to affect food security. Commercially and ecologically important marine species will be impacted, although they may respond in different ways. Mollusks such as oysters and mussels are among the most sensitive groups. By 2100, the global annual costs of mollusk loss from ocean acidification could be over US$100 billion for a business-as-usual (RCP8.5) CO_2 emissions pathway.

- Coastal protection: Marine ecosystems such as coral reefs protect shorelines from the destructive action of storm surges and cyclones, sheltering the only habitable land for several island nations. This protective function of reefs prevents loss of life, property damage, and erosion, and has been valued at US$9 billion per year.

- Tourism: This industry could be severely affected by the impacts of ocean acidification on marine ecosystems (e.g. coral reefs). In Australia, the Great Barrier Reef Marine Park attracts about 1.9 million visitors each year and generates more than US$3.9 billion to the Australian economy.

- Carbon storage and climate regulation: The capacity of the ocean to absorb CO_2 decreases as ocean acidification increases. More acidic oceans are less effective in moderating climate change.[203]

Exercise 1.11.10

14. What is the expected financial loss for businesses if mollusk populations continue to decline due to ocean acidification?
15. How many people visit the Great Barrier Reef every year?
16. How much revenue does this generate for Australia?
17. Why would this business potentially have a significant decline in revenue if ocean acidification increases in the future?

Step 6

After the $CaCO_3$ and limestone pebble have been in the water and the vinegar for 30 additional minutes observe what has happened to both pieces. Continue on to the next section of the lab as you are waiting.

Exercise 1.11.11

18. Describe your observations of the $CaCO_3$ and limestone pebble.

Anthropogenic Impacts on Ocean Acidification

Humans began burning fossil fuels in the mid-1700s and early 1800s for energy during a period called the Industrial Revolution. As fossil fuels burn, carbon is released into the atmosphere as carbon dioxide (CO_2), the greenhouse gas mentioned earlier.

When carbon dioxide settles on the ocean and mixes with the water, it is partially converted into four things: carbonic acid (H_2CO_3), hydrogen ions (H+), bicarbonate (HCO^{3-}), and carbonate ions (CO_3^{2-}). A CO_2-derived chemical species in the water is known as dissolved inorganic carbon (DIC).

Table 11.3 provides data related to ocean acidification. Calcite and aragonite are two calcium carbonate minerals created by ocean organisms such as corals and mollusks. PPM stands for parts per million and mol/kg stands for moles per kilogram.

Table 11.3: Changes in Oceanic Concentrations from the Preindustrial Period to 2100

Variable	Preindustrial (1750)	Recent (2013)	Projected (2100)
Atmospheric concentration of CO_2 (ppm)	280	380	560
Carbonic Acid, H_2CO_3 (mol/kg)	9	13	19
Bicarbonate ion, HCO^{3-} (mol/kg)	1,768	1,867	1,976
Carbonate ion, CO_3^{2-} (mol/kg)	225	185	141
Total dissolved inorganic carbon (mol/kg)	2,003	2,065	2,136
Average pH of surface oceans	8.18	8.07	7.92
Calcite saturation	5.3	4.4	3.3
Aragonite saturation	3.4	2.8	2.1

Exercise 1.11.12

19. In two to three sentences, describe how concentrations of atmospheric CO_2 have changed and are projected to change from the Preindustrial Revolution to 2013 and then to 2100.

To better understand how concentrations change over time, you can do a basic percentage of change calculation. This includes looking at the difference in concentrations from one year to another and then dividing that value by the value of the earlier year. For example, if you want to see how bicarbonate ion (HCO^{3-}) mol/kg have changed from 1750 to 2013 you would calculate the following:

Changes in bicarbonate ion (HCO^{3}-) mol/kg from 1750 to 2013

Value for 1750 Value for 2013 Difference Percent change

1768 1867 1867-1768 = 99 99/1768 = 0.05 or 5%

Exercise 1.11.13

20. Use the data provided in Table 11.3 to calculate the percent change for each variable in order to complete Table 11.4. For each variable, indicate whether the percent change was an increase or decrease. Using the bicarbonate ion example from above, the correct answer would be 5% decrease.

Table 11.4: Percent Change of Ocean Acidification Variables

Variable	Percent Change from 1750 to 2013	Percent Change from 2013 to 2100
Atmospheric concentration of CO_2 (ppm)		
Carbonic Acid, H_2CO_3 (mol/kg)		
Bicarbonate ion, HCO^{3-} (mol/kg)		
Carbonate ion, CO_3^{2-} (mol/kg)		
Total dissolved inorganic carbon (mol/kg)		
Average pH of surface oceans		
Calcite saturation		
Aragonite saturation		

21. Based on your calculations shown in Table 11.4, how many years did it take atmospheric CO_2 to increase by 36%?
22. Based on your calculations shown in Table 11.4, how many years will it take for atmospheric CO_2 to increase by 47%?
23. Compare the rate of change in CO_2 from 1750 to 2013 and from 2013 to 2100.
    a. Is the rate of change in CO_2 from 2013 to 2100 greater or less than the rate of change from 1750 to 2013?
    b. In one to two sentences, explain the variables that influence the rate of change.
24. Use Your Critical Thinking Skills: What actions do you think can be taken to decrease this rate of change in CO_2? List at least five actions.

Figure 11.12 graphs atmospheric carbon dioxide (CO_2 in ppm) and seawater carbon dioxide (pCO_2 in µatm) on the left y-axis, and pH change on the right y-axis, from 1958 to 2012 for the North Pacific ocean.

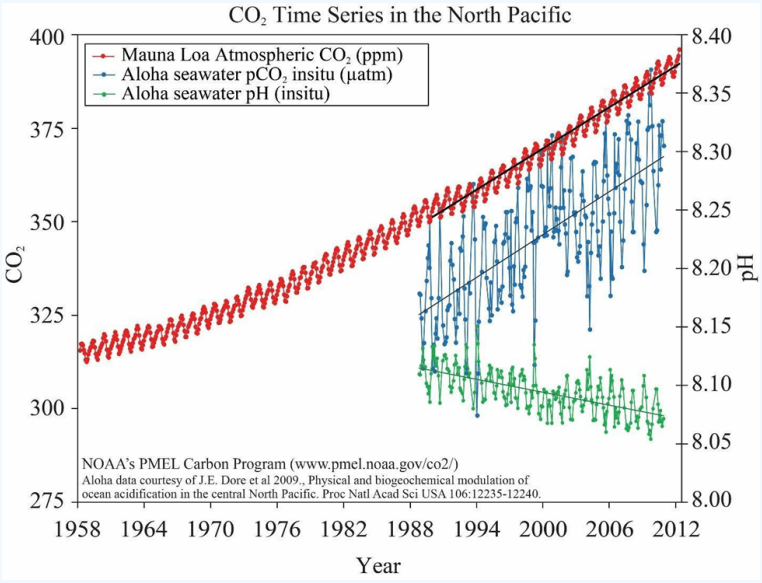


Figure 11.12: Time Series of Carbon Dioxide and Ocean pH at Mauna Loa, Hawai'i. Figure by NOAA Pacific Marine Environmental Library is in the public domain

25. Refer to Figure 11.12.
    a. What year did scientists begin collecting data for concentrations of carbon dioxide and pH level in seawater (according to the graph)?
        i. Use Your Critical Thinking Skills: Why do you think scientists began collecting data for concentrations of carbon dioxide and pH level during this year?
    b. Describe the changes in atmospheric CO_2, seawater pCO_2, and seawater pH from 1958 to 2012.
    c. What relationship do you observe between CO_2 and pH? What explains this relationship?
    d. List the impacts of lowered pH levels in the ocean.

Part C. Wrap-Up

Consult with your geography lab instructor to find out which of the following wrap-up questions you should complete. Attach additional pages to answer the questions as needed.

Exercise 1.11.14

26. What is the most important idea that you learned in this lab? In two to three sentences, explain the concept and why it is important to know.

27. What was the most challenging part of this lab? In two to three sentences, explain why it was challenging. If nothing challenged you in the lab, write about what you think challenged your classmates.

28. What is one question that you have about what you learned in this lab? Write your question along with one to two sentences explaining why you think your question is important to ask.

29. Review the learning objectives on page 1 of this lab. How would you rate your understanding or ability for each learning objective? Write one sentence that addresses each learning objective.

30. Sketch a concept map that includes the key ideas from this lab. Include at least five of the terms shown in bold-faced type.

31. Create an advertisement to educate your peers on the important information that you learned in this lab. Include at least three key terms in your advertisement. The advertisement should be about half a page in size (about 4 inches by 6 inches).

32. One way to think of physical geography is that it is the study of the relationships among variables that impact the Earth's surface. Select two variables discussed in this lab and describe how they are related.

33. How does what you learned in this lab relate to your everyday life? In two to three sentences, explain a concept that you learned in this lab and how it relates to your day-to-day actions.

34. How does what you learned in this lab relate to current events?
    a. Write the title, source, and date of a news item that relates to this lab.
    b. In two to three sentences, discuss how the news item relates to what you have learned in this lab.
    c. In one to two sentences, discuss whether or not the news item accurately represents the science that you learned. Tip: consider whether or not the news item includes the complexity of the topic.

35. Search O*NET OnLine to find an occupation that is relevant to the topics presented in today's lab. Your lab instructor may provide you with possible keywords to type in the Occupation Quick Search field on the O*NET website.
    a. What is the name of occupation that you found?
    b. Write two to three sentences that summarize the most important information that you learned about this occupation.
    c. What is one question that you would want to ask a person with this occupation?

Answer available at the end of this section.

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[189] Text by the National Ocean Service is in the public domain

[190] Text by NASA's Earth Observatory is in the public domain

[203] CoastAdapt (2017)

Answers

Exercise 1.11.1

Exercise 1.11.14

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1.12: Lab 12 - Introduction to Minerals and Rocks

This lab contains potentially inaccessible interactive resources. Please work with your instructor and local campus resources to identify accommodations for these resources.

Learning Objectives

- Describe the basic mineral properties and identify common rock-forming minerals.
- Explain the rock cycle and the processes that form igneous, sedimentary, and metamorphic rocks.
- Distinguish among igneous, sedimentary, and metamorphic rock samples.

Introduction

The minerals identified in this lab represent a small collection of the most common rock-forming minerals. To understand the relationship between minerals and rocks, think of a candy bar made up of several different materials such as chocolate, sugar, nuts, and caramel. The minerals are the ingredients (chocolate, sugar, nuts, caramel) that make up a rock (the candy bar). Minerals differ from each other in chemical composition and structure. Rocks differ from each other based on the environmental setting in which they formed. This lab will introduce you to the three families of rocks as well as the environment and material needed to create them. You will learn how these rocks interact in what is known as the rock cycle. And, you will learn the basics in mineral and rock identification by utilizing your observation and interpretation skills.

Part A. Introduction to Minerals

A **mineral** must satisfy all four of the following criteria:

- Minerals are a naturally occurring substance (not made by humans),
- Minerals are an inorganic substance (not composed of living or once living organisms),
- Minerals have a fixed chemical composition (elements), and
- Minerals have an orderly internal structure (based on how the elements bond with each other).

Check It Out! How Many Minerals Are There?

There are approximately 4,000 different minerals found on Earth, and each of those minerals have a unique set of properties. Some minerals are abundant, like quartz, while others are rare, like the California State gemstone benitoite. Check out the California Department of Conservation website to learn more about the State gemstone!

The vast majority of the minerals that make up the rocks of Earth's crust are **silicate** minerals. These include minerals such as quartz, feldspar, mica, amphibole, pyroxene, olivine, and a great variety of clay minerals. Lighter-colored silicates are called **felsic**, as they lack iron and magnesium, while darker-colored minerals are called **mafic**, as they do contain iron and magnesium. The building block of all of these minerals is the silica tetrahedron, a combination of four oxygen atoms and one silicon atom.[205]

The remaining minerals are **non-silicate** minerals, meaning that they do not have silicon as part of their chemistry. Non-silicates include sulfides, oxides, native elements, sulfates, carbonates, and halides. Often these minerals are formed in either sedimentary or metamorphic rocks.



Check It Out! Silicate vs. Non-Silicate Minerals

Watch a tutorial video on the differences between silicate and non-silicate minerals, and learn how to identify the differences between these two types of minerals. (Video length is 4:25).

Conflict Minerals

Some mineral mining operations fund violence and cause human rights abuses. You may have heard of “blood diamonds” or “dirty gold” before. Conflict minerals are mined in locations with political instability, corrupt governments, armed conflict, and/or lax regulations and then sold on the global market; profits are used to perpetuate further violence and human rights abuses. By increasing the funds of armed groups, mine profits increase fighting and spread violence. Conflict mineral violence has been documented in numerous countries including Colombia, Myanmar (Burma), Côte d'Ivoire, and other countries. A 2012 U.S. federal law requires companies to publicly disclose their use of the conflict minerals that are the source of tantalum, tin, gold, and tungsten that originate in the Democratic Republic of the Congo or a neighboring country. These four minerals are used in electronic products like cell phones and laptops. Conflict minerals compose end-user products through a complex chain of local and international traders, processors, and manufacturers.

Let’s take a closer look at the minerals that provide the metals identified in the 2012 law.

- The metal tantalum (symbol Ta) is found in the mineral tantalite. The chemical formula for tantalite is (Fe, Mn)Ta_2O_6—either one iron atom or one manganese atom bonds with two tantalum atoms, and six oxygen atoms. Tantalum is used in electronics as a capacitor.

- The metal tin (symbol Sn) is found in the mineral cassiterite. The chemical formula for cassiterite is SnO_2—one tin atom is bonded to two oxygen atoms. Tin is used as a sorter on circuit boards in electronics.

- The metal gold (symbol Au) is often found in its elemental form as gold nuggets, as veins in rocks, or in alluvial (river) deposits. Gold is used as a coating for electric wires in electronic devices.

- The metal tungsten (W) is found in the mineral wolframite. The chemical formula for wolframite is (Fe,MN)WO_4—either one iron or one manganese atom bonds with one tungsten atom and four oxygen atoms. Tungsten is used for electronic filaments and gives mobile phones their vibrating capacity.

Exercise 1.12.1

1. Select either tantalite, cassiterite, or wolframite and explain how this mineral meets the four criteria of a mineral. Also indicate if the mineral is a silicate or non-silicate mineral.

Basic Mineral Properties

Minerals can be identified by their physical characteristics. The physical properties of minerals are related to their chemical composition and bonding. Some characteristics, such as a mineral's hardness, are more useful for mineral identification. Color is readily observable and certainly obvious, but it is usually less reliable than other physical properties.[206] The five basic properties you will investigate for mineral identification are as follows: color, streak, luster, hardness, and cleavage/fracture.

Exercise 1.12.2

2. Using the photographed specimen below (Figure 12.1), answer the following questions:
    a. What is the general color of the specimen?
    b. What is the general shape (square, triangle, etc.) of the specimen?
    c. Is the specimen shiny like glass, reflective like metal, or greasy like a candle?
    d. If the specimen were dropped, do you think it would shatter or break into a geometric design?



Figure 12.1: Fluorite Crystals. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Think About It...Why Is This Important?

The previous question provided you the general steps on identifying a mineral. It is important to know that when asking critical and constructive questions it is best not to make a judgment after the first questions. Following a set of rules or guidelines ensures the best results. So, don't jump to conclusions as you follow the instructions on how to identify minerals and rocks in the upcoming exercises.

Color

For most of us, **color** is one of our key ways of identifying objects. While some minerals have particularly distinctive colors that make good diagnostic properties, many do not. For many others, color is simply unreliable. The mineral sulphur is always a distinctive and unique yellow. Hematite, on the other hand, is an example of a mineral for which color is not diagnostic. In some forms hematite is deep dull red, but in others it is black and shiny metallic. Many other minerals can have a wide range of colors (e.g., quartz, feldspar, amphibole, fluorite, and calcite). In most cases, the variations in colors are a result of varying proportions of trace elements within the mineral. In the case of quartz, for example, yellow quartz (citrine) has trace amounts of ferric iron (Fe^{3+}), rose quartz has trace amounts of manganese, purple quartz (amethyst) has trace amounts of iron, and milky quartz, which is very common, has millions of fluid inclusions (tiny cavities, each filled with water).[208]

Search the internet or use the QR codes/website links shown below to research mineral colors.

Exercise 1.12.3

3.  Identify four different variations or types of quartz, as well as their general color.
   a. Variation 1 (name and color):
   b. Variation 2 (name and color):
   c. Variation 3 (name and color):
   d. Variation 4 (name and color):
4.  Identify four different minerals that can be green.
   a. Mineral 1:
   b. Mineral 2:
   c. Mineral 3:
   d. Mineral 4:
5.  Identify four different minerals that can be blue.
   a. Mineral 1:
   b. Mineral 2:

c. Mineral 3:
d. Mineral 4:

6. Explain why although the most obvious tool for mineral identification is the color, it is not the most accurate or definitive tool. Your response should be one to two sentences in length.

Check It Out! Minerals in Fireworks!?

Minerals provide the colors for fireworks. Check out this link by the United States Geologic Survey that identifies which minerals produce some of your favorite colors in fireworks!

Streak

Streak is the color of a mineral's powder. Streak is a more reliable property than color because streak does not vary. Minerals that are the same color may have a different colored streak.[209] Many minerals, such as quartz, do not have a streak, as they are harder than the streak plate. To check the streak, you must scrape the mineral across an unglazed white porcelain plate.

Exercise 1.12.4

7. Observe the streak provided below (Figure 12.2). The photograph shows that the streak color is similar although the specimen colors are not. These two samples are the same mineral, which is why the streak plate color is the same, so why do you think the samples look different? Tip: read the Think About It box below.



Figure 12.2: Examples of a Mineral's Streak. Figure by KarlaPanchuk is licensed under CC BY-SA 4.0

Think About It...How Can These Samples Be the Same Mineral?

Hematite is a common iron oxide mineral, which means that this mineral can rust. The name hematite is derived from the Greek word *haima*, meaning blood, which makes reference to the mineral's streak! Fun fact: hematite is used as a pigment in red paint and is used in some makeups as a natural glitter!

Luster

Luster is the way light reflects off the surface of a mineral, and the degree to which it penetrates into the interior. The key distinction is between metallic and non-metallic lusters. Light does not pass through metals, and that is the main reason they look "metallic". Even a thin sheet of metal—such as aluminum foil—will prevent light from passing through it. Many non-metallic minerals may look as if light will not pass through them, but if you take a closer look at a thin edge of the mineral you can see that it does. If a non-metallic mineral has a shiny, reflective surface, then it is called glassy. If it is dull and non-reflective, it is called earthy. Other types of non-metallic lusters are waxy (like a crayon or candle) or pearly (like a shell). Luster is a good diagnostic property, since most minerals will always appear either metallic or non-metallic.[211]

Use the luster flow chart (Figure 12.3) to answer the following questions about the two specimens pictured in Figure 12.4.

Exercise 1.12.5

8. Sample A (Figure 12.4, left photograph):
   a. What is the luster?
   b. What is the color?
9. Sample B (Figure 12.4, right photograph):
   a. What is the luster?
   b. What is the color?

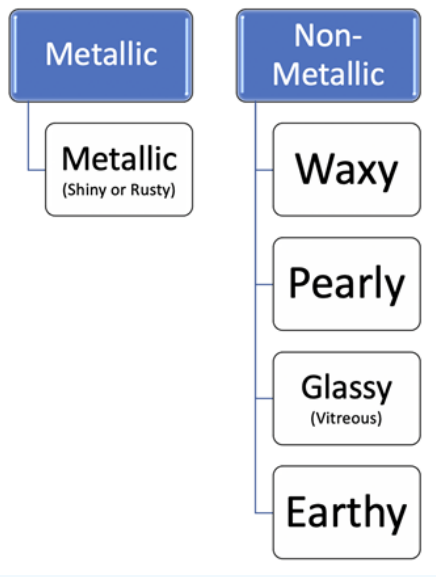


Figure 12.3: Metallic and Non-Metallic Luster Flow Chart. Figures by Jeremy Patrich are licensed under CC BY-NC-SA 4.0

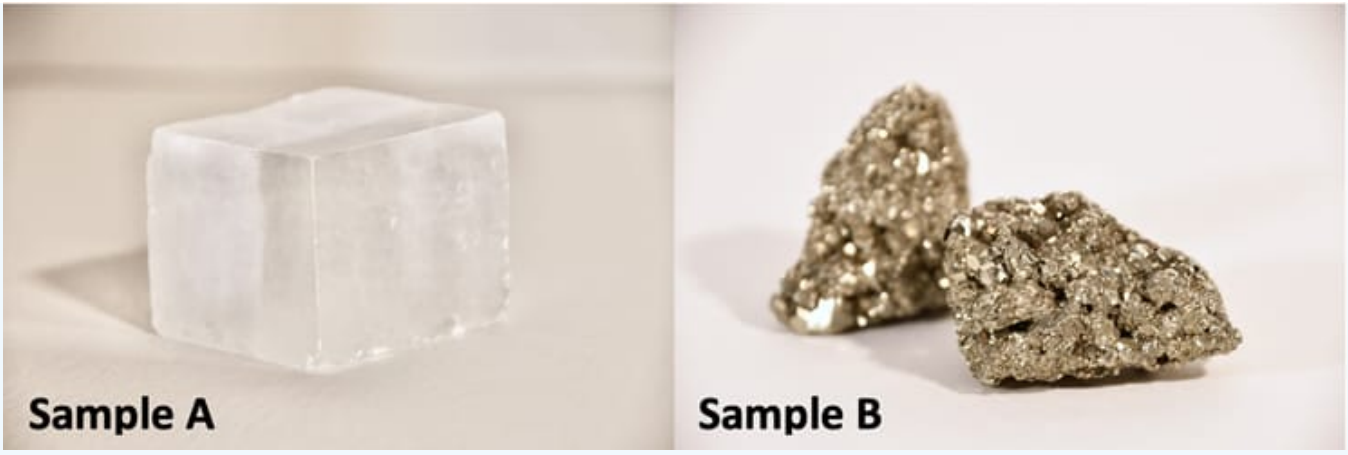


Figure 12.4: Images of Two Unknown Samples. Figure by University of Minnesota Libraries is licensed under CC BY-NC-SA

Check It Out! Mineral Luster

This lab simplifies luster to five options, but the Mineralogical Society of America acknowledges 10 different types of luster!

Hardness

Mohs' scale of mineral hardness is named after Sir Friedrich Mohs, a mineralogist who invented a scale of hardness based on the ability of one mineral to scratch another. According to the scale, talc is the softest: it can be scratched by all other materials. Gypsum is harder as it can scratch talc but not calcite, which is even harder. An easy benchmark to remember is that the human fingernail has a hardness of about 2.5, so if you can scratch it with your nail, it must be softer than a 2.5. The **hardness** of a mineral is controlled mainly by the strength of the bonding between the atoms and partly by the size of the atoms. It is a measure of the resistance of the mineral to scratching. Mohs' scale is for natural minerals. Diamond is always at the top of Mohs' scale, being the hardest mineral. There are ten minerals in Mohs' scale (from softest to hardest): talc, gypsum, calcite, fluorite, apatite, feldspar, quartz, topaz, corundum, and diamond (Figure 12.5).[213]



Figure 12.5: Image of Minerals Used in the Mohs' Hardness Scale. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Cleavage and Fracture

The way in which a mineral breaks is determined by the arrangement of its atoms and the chemical bond between those atoms. It is difficult for us to observe these bonds, but we can observe the shape and design into which minerals break. A mineral that exhibits **cleavage** will consistently break, or cleave, along a parallel flat surface. Muscovite mica is a good example as it breaks along very closely spaced flat planes that yield thin sheets. We would identify this as having one plane of cleavage (a plane represents a flat surface with a top and bottom). If a mineral had six flat sides, we would say that the specimen has three planes of cleavage. A helpful way of visualizing cleavage is with the use of an ax (Figure 12.6). An ax makes a single cut, defining a top and bottom, so, if a specimen needs two axes, it would have two directions of cleavage, and have four flat sides.

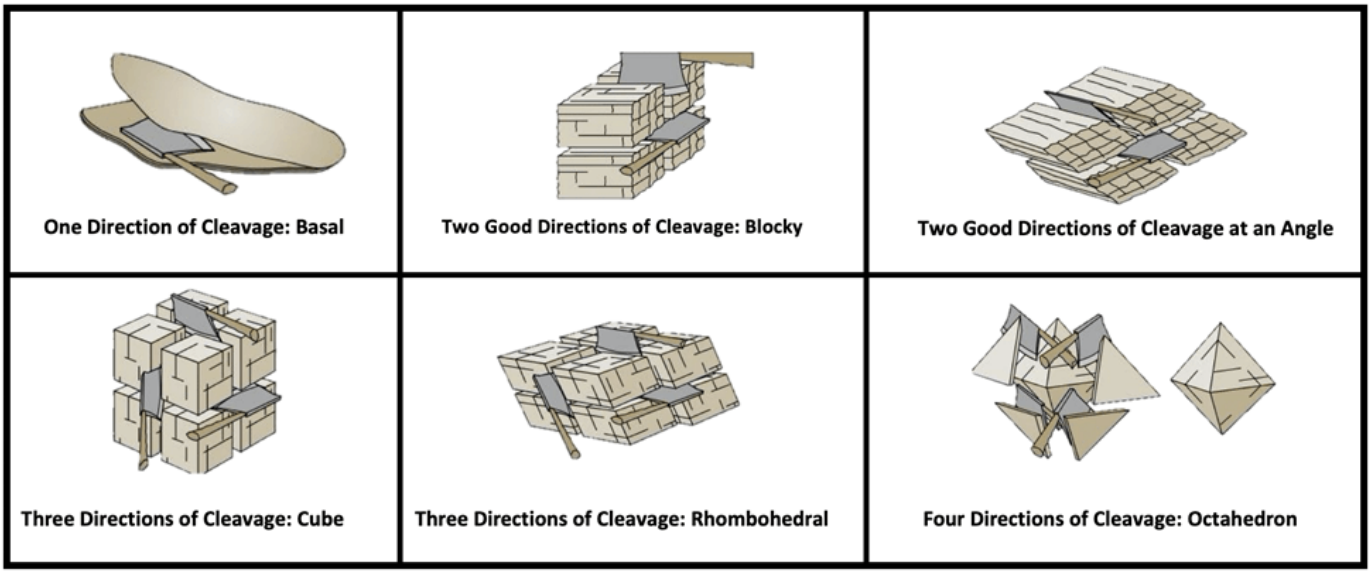


Figure 12.6: Image of Mineral Cleavage. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Some minerals will be observed in a solid crystalline form. The arrangement of the atoms within the mineral will determine the external shapes, and as the mineral begins to solidify, these microscopic crystals, or seeds, will form and begin to grow. The longer the mineral has to form, the larger the crystal. Other minerals **fracture**, which means that they break in a rough or irregular pattern. Some minerals, such as quartz, will fracture along the surface and create a conchoidal fracture. A conchoidal fracture does not have any surface planes like those seen in Figure 12.6.

Think About It...California Beach Sand?

Most of the sand that is found along California's beaches are composed of quartz and feldspar crystals. Quartz is known for its conchoidal fracture. Conchoidal fractures result in a curved breakage, that resembles the gradual curves of a mussel shell, which is the origin of the name! Next time you are at the beach, examine a quartz grain up close to see its conchoidal fracture.

Exercise 1.12.6

Now that you understand mineral cleavage and fracture, answer the following questions about the two samples shown in Figure 12.7.

10. Sample A (Figure 12.7, left shape):
    a. If you had to describe this sample as a shape, what shape would it be?
    b. How many sides does this sample have?
    c. How many planes or directions of cleavage does this sample have?
11. Sample B (Figure 12.7, right shape):
    a. If you had to describe this sample as a shape, what shape would it be?
    b. How many sides does this sample have?
    c. How many planes or directions of cleavage does this sample have?

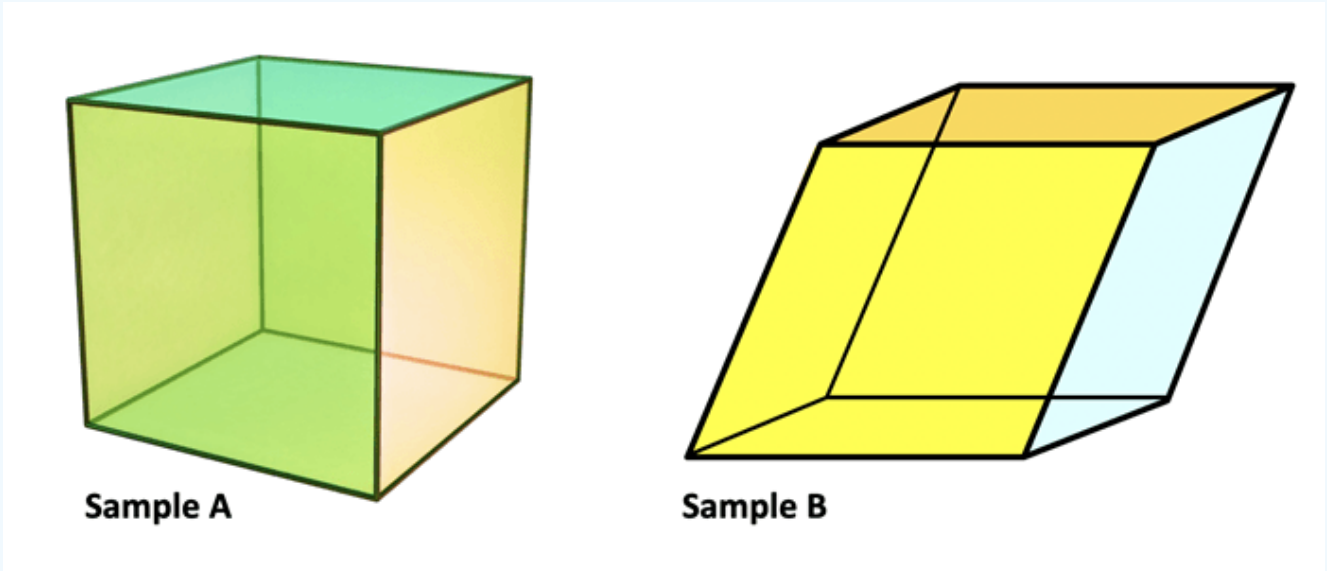


Figure 12.7: Image of Two Shapes Exhibiting Cleavage. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Part B. Mineral Identification



Guided Practice: Mineral Identification

Go to this tutorial video from Professor Jeremy Patrich on how to identify minerals based on their properties. (Video length is 7:27).

How to Use the Basic Mineral Identification Table

As you have learned up to this point, minerals have many physical properties. Table 12.1 provides different properties of minerals organized by hardness (the softest minerals are at the top and the hardest minerals are at the bottom). Remember that your fingernail has a hardness of 2.5. If a specimen has most or all of the properties along a horizontal row, then the name of that sample is shown on the far-left column.

Table 12.1: Basic Mineral Identification Table

Mineral Name	Mineral Hardness	Mineral Color	Mineral Luster	Mineral Streak	Cleavage or Fracture	Other Properties
Talc	1	White to Gray White	Waxy to Pearly	White	Cleavage: 1 Direction	Feels Slippery
Gypsum	2	Colorless to Brownish	Pearly	White	Cleavage: 1 Direction	Used in Drywall
Muscovite Mica	2-2.5	White to Greenish	Vitreous (Glassy)	White	Cleavage: 1 Direction	Is Elastic, Peels into Sheets
Galena	2.5	Light to Dark Gray	Metallic	Grayish-Black	Forms in Perfect Cubes	Is a Lead Sulfide (Very Dense)
Halite	2.5	White to Pink	Vitreous	White	Cleavage: 3 Directions (Square)	Salty in Taste
Biotite Mica	2.5-3	Dark Brown to Blackish	Vitreous to Pearly	Gray	Cleavage: 1 Direction	Is Elastic, Peels into Sheets
Calcite	3	Clear, Blue, Pink, Green, to Brown	Vitreous to Earthy	White	Cleavage: 3 Directions (Rhombohedral)	Double Refraction
Azurite	3.4-4	Blue	Vitreous to Earthy	Light Blue	Conchoidal Fracture	Mammillary
Malachite	3.6-4	Green	Vitreous to Waxy	Light Green	Fracture is Uneven: Breaks	Copper Ore
Flourite	4	White, Green, Yellow, to Red	Vitreous	White	Cleavage: 4 Octahedral (8 sides)	Glows When Exposed to UV Light
Kyanite	4-6.5	Blue to Black	Vitreous or Pearly	White	Elongated or Bladed Crystals	Fibrous and Flaky

Mineral Name	Mineral Hardness	Mineral Color	Mineral Luster	Mineral Streak	Cleavage or Fracture	Other Properties
Apatite	5	Lime Green to Brown	Vitreous to Resinous	White	Hexagonal Prisms	Glows When Exposed to UV Light
Hematite	5.5-6	Reddish to Blackish	Metallic	Reddish-Brown	Flaky	Used as Glitter (unless oxidized)
Orthoclase Feldspar	6	White to Pink	Vitreous	White	Cleavage: 2 Blocky	Looks Like a Broken Brick
Pyrite	6.5	Gold	Metallic	Greenish-Black	Forms in Perfect Cubes	Is a Lead Sulfide (Very Dense)
Olivine	6.5	Yellow Green to Green	Vitreous	White	Conchoidal Fracture	Crystals Will Have 6 Sides
Quartz	7	Clear to Brown	Vitreous	White	Conchoidal Fracture	Crystals Will Have 6 Sides
Topaz	8	Clear to Red	Vitreous	White	Conchoidal Fracture	Used as a Gemstone
Corundum	9	Red to Gray	Vitreous	None	None- Crystal is Hexagonal	Extremely Hard

Exercise 1.12.7

Mineral Identification Activity (Hands-On Version)

Using the tools provided and Table 12.1, identify the mineral samples provided by your instructor. Write your answers in question 12 below.

Mineral Identification Activity (Digital Version)

Your instructor will indicate which playlist (set 1, 2, or 3) you should use for this activity. Each playlist begins with the Guided Practice video on mineral identification followed by six mineral specimens. Click on the correct QR code or link to access the playlist. **Be sure to read the mineral properties shown in the video details and use Table 12.1 to identify each specimen.** Write your answers in question 12 below. Note: the mineral specimen videos provided in the playlists do not have audio.

Playlist 1:

Playlist 2:

Playlist 3:

Mineral Identification Activity: Your Answers

12. Identify the minerals.
    a. Sample _____ (number or letter) is the mineral: _____
    b. Sample _____ (number or letter) is the mineral: _____
    c. Sample _____ (number or letter) is the mineral: _____
    d. Sample _____ (number or letter) is the mineral: _____
    e. Sample _____ (number or letter) is the mineral: _____

f. Sample _____ (number or letter) is the mineral: _____

Part C. Rocks and Their Properties

Rocks are naturally occurring aggregates of one or more minerals. The rock components of the crust are slowly but constantly being changed from one form to another and the processes involved are summarized in the rock cycle (Figure 12.8). The **rock cycle** is driven by two forces:

- Earth's internal heat engine, which moves material around in the core and the mantle and leads to slow but significant changes within the crust, and
- The hydrological cycle, which is the movement of liquid water, ice, and water vapor at or near the surface of the Earth, and is powered by the Sun.[217]

The rock cycle is still active on Earth because our core is hot enough to keep the mantle convecting, our atmosphere is relatively thick, and we have liquid water. On some other planets or their satellites, such as the Moon, the rock cycle is virtually dead because the core is no longer hot enough to drive mantle convection and there is no atmosphere or liquid water.[8]

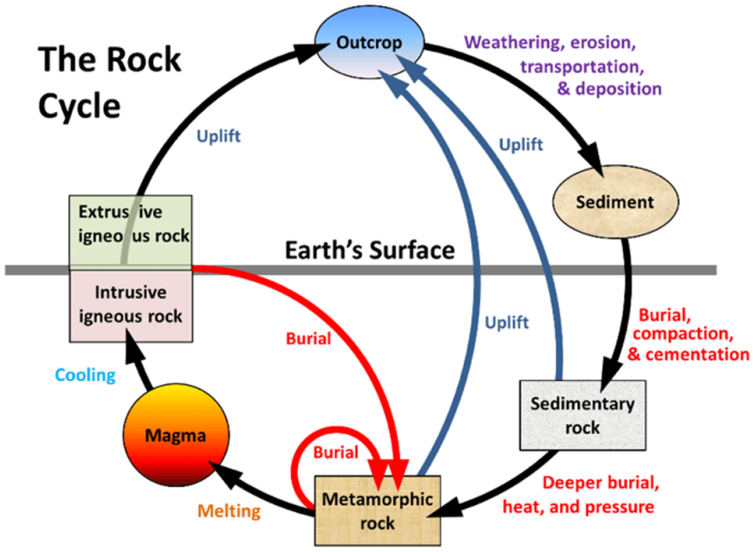


Figure 12.8: The Rock Cycle. Figure by Steven Earle is licensed by CC BY 4.0

Exercise 1.12.8

13. Refer to Figure 12.8.
    a. What types of rock form from the cooling of magma?
    b. What are the four processes that create sediments?
    c. What rock is formed when sediments are buried, compacted, and cemented?
    d. What three arrows are pointing to the metamorphic rock box? Hint: these are the three rock types that can be transformed into a metamorphic rock through burial, heat, and pressure.

Igneous Rocks

Igneous rocks form when molten material cools and hardens. They may form either below (intrusive) or above (extrusive) the Earth's surface. They make up most of the rocks observed on Earth. Most igneous rock is buried below the surface and covered

with sedimentary rock, so we do not often see just how much igneous rock there is on Earth. In some places, however, large areas of igneous rocks can be seen at Earth's surface.[219]

A key to understanding the crystalline structure of igneous rocks depends on the rate of cooling. The faster the material cools, the smaller the crystals. If the crystals or the minerals are so small that they can not be identified with the naked eye, we call those aphanitic crystals (think microscopic organisms). If the crystals are large, maybe the size of a pencil eraser, we call those porphyritic crystals.

Classifying Igneous Rocks

Igneous rocks are classified according to how and where they formed and what they are composed of. In other words, igneous rocks are classified based on the following:

- whether or not they are plutonic (they cool and crystallize inside the Earth) or volcanic (they cool and crystallize at the surface of the Earth), and
- what their mineral composition is; this is described as being felsic, intermediate, or mafic.

Intrusive igneous rocks crystallize deep beneath Earth's surface and if slow cooling occurs, then large crystals can form. Some examples of intrusive igneous rocks are granite, gabbro, diorite, pegmatite, and peridotite. Intrusive igneous rocks are also known as plutonic rocks.

Extrusive igneous rocks erupt onto Earth's surface and they cool very quickly to form small crystals. In fact, some cool so quickly that they can form into glass. Some examples of extrusive igneous rocks include basalt, andesite, obsidian, pumice, scoria, rhyolite, and tuff. Extrusive igneous rocks are also known as volcanic rocks.

Felsic is a term used to describe igneous rocks that are rich in elements that form quartz and feldspars. An example of a felsic rock is granite. **Mafic** is a term used to describe igneous rocks that are rich in magnesium and iron. An example of a mafic rock is basalt. Intermediate igneous rocks have compositions between felsic and mafic.

Table 12.2 provides basic information to identify selected igneous rocks.

Table 12.2: Basic Igneous Rock Identification Table

Rock Name	Composition	Intrusive or Extrusive	Rock Color	Rock Texture	Other Properties
Pumice	Felsic	Extrusive	Cream to Gray	Glassy (Frothy)	Will Float in Water
Obsidian	Mafic	Extrusive	Dark Brown to Black	Glassy	Known as Nature's Glass
Basalt	Mafic	Extrusive	Gray to Black	Aphanitic	Earth's Most Abundant Rock
Scoria	Mafic	Extrusive	Black to Deep Reds	Aphanitic	Similar to Basalt but Has Bubble-Like Cavities
Gabbro	Mafic	Intrusive	Dark Green to Gray	Phaneritic	Most Abundant Rock of the Deep Oceanic Crust
Granite	Felsic	Intrusive	Varies	Phaneritic	Oldest and Hardest Rocks Known
Rhyolite	Felsic	Extrusive	Pink to Peach	Aphanitic	Silica-rich, Caused by Quick Cooling
Diorite	Intermediate	Intrusive	White and Black	Phaneritic	Like a Dalmation, Large Spots of Feldspar and Hornblende Minerals
Andesite	Intermediate	Extrusive	Green to Dark Gray	Aphanitic	Usually Found on Earth's Surface above Subduction Zones

Rock Name	Composition	Intrusive or Extrusive	Rock Color	Rock Texture	Other Properties
Tuff	Intermediate to Felsic	Extrusive	Red to Black	Fragmental	From Large Volcanic Eruptions, the Settling Materials Compact into Cement



Check It Out! Igneous Rocks

This lab simplifies igneous rocks, but with some help from National Geographic, a lot more information is available.

Sedimentary Rocks

Transportation is the movement of sediments or dissolved ions from the site of erosion to a site of deposition; this can be by wind, flowing water, glacial ice, or mass movement down a slope. **Deposition** takes place where the conditions change enough so that sediments being transported can no longer be transported, like when a current slows. **Lithification** is what happens at depths of hundreds to thousands of meters when those compacted sediments become cemented together to form solid **sedimentary rock**.[220]

Clastic Sedimentary

A **clast** is a fragment of rock or mineral, ranging in size from less than a micron (too small to see) to as big as an apartment block. maller clasts tend to be composed of a single mineral crystal, and the larger ones are typically composed of pieces of rock. Most sand-sized clasts are made of quartz because quartz is more resistant to weathering than any other common mineral. Most clasts that are smaller than sand size are made of clay minerals. Most clasts larger than sand size are actual fragments of rock, and commonly these might be fine-grained rock like basalt or andesite, or if they are bigger, coarse-grained rock like granite or gneiss.[221]

Exercise 1.12.9

14. Refer to Table 12.1. What is the hardness of quartz? Do you think its hardness is one reason why quartz is more resistant to weathering than other common minerals? Explain your response in at least one sentence.

Chemical Sedimentary

Whereas clastic sedimentary rocks are dominated by components that have been transported as solid clasts (clay, silt, sand, etc.), **chemical sedimentary rocks** are dominated by components that have been transported as ions in solution.[222]

The most common chemical sedimentary rock, by far, is limestone. Others include chert, banded iron formations, and a variety of rocks that form when bodies of water evaporate.

Biological processes are important in the formation of some chemical sedimentary rocks, especially limestone and chert. For example, limestone is made up almost entirely of fragments of marine organisms that manufacture calcite for their shells and

other hard parts, and most chert includes at least some of the silica tests (shells) of tiny marine organisms such as diatoms.[18] When these marine organisms die, their shells sink to the seafloor. After a very long time, these shells are buried, compacted, and cemented into chemical sedimentary rocks.

Exercise 1.12.10

15. Is the sedimentary rock sample shown in Figure 12.9 clastic or chemical. How do you know?



Figure 12.9: A Sedimentary Rock. Figure by Geodiversite.net is licensed under CC BY-SA 3.0

Table 12.3 provides basic information to identify selected sedimentary rocks.

Table 12.3: Basic Sedimentary Rock Identification Table

Rock Name	Clastic or Chemical	Rock Color	Rock Texture
Coquina	Clastic	Tan to Cream	Medium to Coarse
Chert	Chemical	Varies	Aphanitic
Coal	Chemical	Dark Gray to Black	Banded, but Glassy
Shale	Clastic	Blue, Green, Gray	Aphanitic (Mudstone)
Conglomerate	Clastic	Varies	Course- Rounded
Breccia	Clastic	Varies	Course- Angular
Siltstone	Clastic	Gray to Brown	Coarse (Between Shale and Sandstone)
Limestone	Clastic	White, Blue to Cream	Coarse (Also Reacts to Acid)
Sandstone	Clastic	Varies	Coarse
Travertine	Chemical	White to Brown	Crystalline- Result of Mineral Springs

Check It Out! Sedimentary Rocks

This lab simplifies sedimentary rocks, but with some help from the National Science Foundation, we can observe how clastic sedimentary rocks are formed. Note: Adobe flash player is needed to view this animation.

Metamorphic Rocks

Metamorphism is the change that takes place within a body of rock as a result of being subjected to conditions that are different from those in which it formed. In most cases, but not all, this involves the rock being deeply buried beneath other rocks, where it is subjected to higher temperatures and pressures than those under which it formed. Metamorphism can also take place if cold rock near the surface is intruded by rising magma. **Metamorphic rocks** typically have different mineral assemblages and different textures from their parent rocks, but they may have the same overall composition.

Foliated

A rock that is **foliated** means that there is an observable layering or banding. Each layer can be as thin as a sheet of paper or even a meter in width. Imagine such high pressure and temperature that the minerals within a sample are realigned into a banded sequence! Imagine squishing a scoop of ice cream between two cookies.

Non-Foliated

A rock that is **non-foliated** means that the rock does not have platy or sheet-like structure. These rocks appear as a mass or large uniform piece, such as marble. Imagine such high pressure and temperature that the minerals within a sample can not be aligned or moved. Think of squeezing saltwater taffy. No matter how hard you squish it, the ingredients will never separate, it will just squish!

Exercise 1.12.11

16. Does the metamorphic sample below (Figure 12.10) exhibit foliation or is it non-foliated? How do you know?



Figure 12.10: A Metamorphic Rock. Figure by Siim Sepp is licensed by CC BY-SA 3.0

Table 12.4 provides basic information to identify selected metamorphic rocks.

Table 12.4: Basic Metamorphic Rock Identification Table

Rock Name	Foliated or Non-Foliated	Rock Color	What Was it Before?
Marble	Non-Foliated	Varies	Limestone
Schist	Foliated	Gray but Sparkles	Shale- Mudstone
Quartzite	Non-Foliated	White, Pink, to Gray	Sandstone
Anthracite	Non-Foliated	Black with Gold Luster	Coal
Gneiss	Foliated	Black Stripes with White to Red Filling	Granite
Slate	Foliated	Purple to Black	Shale- Mudstone
Phyllite	Foliated- Splits Easily into Sheets	Greenish to Black	Shale- Mudstone

Here is a fun fact: if shale (a sedimentary rock made of compacted clay minerals) undergoes continuous metamorphism, it will transition into four different rocks the longer it undergoes metamorphism. Initially, shale will metamorphose into slate. With increasing heat and pressure, it will then metamorphose into phyllite, then into schist, and lastly into gneiss!

Check It Out! Metamorphic Rocks

This lab simplifies metamorphic rocks, but with some help from the National Science Foundation, we can observe how metamorphic rocks are formed. Note: Adobe flash player is needed to view this animation.

Part D. Rock Identification

How to Use the Basic Rock Identification Tables

The first step is to use the rock dichotomous key shown below to help determine the family of an unknown rock, whether it be igneous, sedimentary, or metamorphic. You will then use the identification tables to determine the name of the specimen (Tables 12.2, 12.3, and 12.4), which are broken into rows and columns. If a specimen has most or all of the properties along a horizontal row, then the name of that sample will be found in the first column on the left.

Rock Dichotomous Key

You can use the following steps to identify a rock sample.

Step 1: Can you see separate mineral crystals in the rock that are randomly intergrown?

- If yes, go to step 2.
- If no, go to step 7.

Step 2: Is the rock made up of just one kind of mineral?

- If yes, go to step 3.
- If no, go to step 4.

Step 3: If the rock has crystals of the same mineral, it is probably a metamorphic rock.

Step 4: Are the minerals in a banded or striped pattern?

- If yes, go to step 5.
- If no, go to step 6.

Step 5. A rock that has a banded pattern is probably a metamorphic rock.

Step 6: A rock with minerals in a mixed pattern is probably an igneous rock.

Step 7: Is the rock full of small air pockets?

- If yes, go to step 8.
- If no, go to step 9.

Step 8: A rock with small air pockets is probably an igneous rock.

Step 9: Does the rock look like a piece of dark, broken glass?

- If yes, go to step 10.
- If no, go to step 11.

Step 10: A dark, glassy-looking rock is probably an igneous rock.

Step 11: Is the rock made up of flat plates or sheets?

- If yes, go to step 12.
- If no, go to step 13.

Step 12: A rock that splits easily into sheets is probably a metamorphic rock.

Step 13: Does the rock have particles in it, like sand, mud, or gravel?

- If yes, go to step 14.
- If no, go to step 15.

Step 14: A rock that is made of sediment (clay, sand, or pebbles) or fossils is a sedimentary rock.

Step 15: You have a hard rock to identify; try again, and study the rock more carefully before answering each question.

Exercise 1.12.12

Rock Identification Activity (Hands-On Version)

Using the tools provided, the dichotomous key shown above, and the abbreviated lists of common igneous, sedimentary, and metamorphic rocks (Tables 12.2, 12.3, and 12.4), identify the samples provided by your instructor. Write your answers in question 17 below.

Rock Identification Activity (Digital Version)

Your instructor will indicate which playlist (set 1, 2, or 3) you should use for this activity. Click on the correct QR code or link to access the playlist. Use the dichotomous key shown above and the abbreviated lists of common igneous, sedimentary, and metamorphic rocks (Tables 12.2, 12.3, and 12.4). Write your answers in question 17 below. Note: the videos provided in the playlist do not have audio.

Playlist 1: Playlist 2: Playlist 3:

Rock Identification Activity: Your Answers

17. Identify the rocks.
    a. Sample _____ (number or letter) is the rock: _____
    b. Sample _____ (number or letter) is the rock: _____
    c. Sample _____ (number or letter) is the rock: _____
    d. Sample _____ (number or letter) is the rock: _____
    e. Sample _____ (number or letter) is the rock: _____
    f. Sample _____ (number or letter) is the rock: _____
    g. Sample _____ (number or letter) is the rock: _____
    h. Sample _____ (number or letter) is the rock: _____
    i. Sample _____ (number or letter) is the rock: _____
    j. Sample _____ (number or letter) is the rock: _____
    k. Sample _____ (number or letter) is the rock: _____
    l. Sample _____ (number or letter) is the rock: _____

Part E. Wrap-Up

Consult with your geography lab instructor to find out which of the following wrap-up questions you should complete. Attach additional pages to answer the questions as needed.

Exercise 1.12.13

18. What is the most important idea that you learned in this lab? In two to three sentences, explain the concept and why it is important to know.

19. What was the most challenging part of this lab? In two to three sentences, explain why it was challenging. If nothing challenged you in the lab, write about what you think challenged your classmates.

20. What is one question that you have about what you learned in this lab? Write your question along with one to two sentences explaining why you think your question is important to ask.

21. Review the learning objectives on page 1 of this lab. How would you rate your understanding or ability for each learning objective? Write one sentence that addresses each learning objective.

22. Sketch a concept map that includes the key ideas from this lab. Include at least five of the terms shown in bold-faced type.

23. Create an advertisement to educate your peers on the important information that you learned in this lab. Include at least three key terms in your advertisement. The advertisement should be about half a page in size (about 4 inches by 6 inches).

24. One way to think of physical geography is that it is the study of the relationships among variables that impact the Earth's surface. Select two variables discussed in this lab and describe how they are related.

25. How does what you learned in this lab relate to your everyday life? In two to three sentences, explain a concept that you learned in this lab and how it relates to your day-to-day actions.

26. How does what you learned in this lab relate to current events?
    a. Write the title, source, and date of a news item that relates to this lab.
    b. In two to three sentences, discuss how the news item relates to what you have learned in this lab.
    c. In one to two sentences, discuss whether or not the news item accurately represents the science that you learned. Tip: consider whether or not the news item includes the complexity of the topic.

27. Search O*NET OnLine to find an occupation that is relevant to the topics presented in today's lab. Your lab instructor may provide you with possible keywords to type in the Occupation Quick Search field on the O*NET website.
    a. What is the name of occupation that you found?
    b. Write two to three sentences that summarize the most important information that you learned about this occupation.
    c. What is one question that you would want to ask a person with this occupation?

Answer available at the end of this section.

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Answers

Exercise 1.12.13

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1.13: Lab 13 - Plate Tectonics

This lab contains potentially inaccessible interactive resources. Please work with your instructor and local campus resources to identify accommodations for these resources.

Learning Objectives

- Distinguish between oceanic and continental tectonic plates.
- Diagram a cross-section of the Earth.
- Identify the three types of plate tectonic boundaries.
- Explain how oceanic hotspots create chains of volcanic islands.
- Compare hotspots to plate tectonic boundary types.
- Identify geographic examples of different plate tectonic boundaries and hotspots.
- Explain why plate tectonics theory is the unifying theory of geology.

Introduction

The Earth's crust is broken up into large slabs of slowly moving rock called tectonic plates. Plate tectonic movements cause earthquakes, volcanoes, and mountain building events. By understanding tectonic plates and the theory that explains their movement, you will be able to explain why different places experience earthquakes, why volcanoes are located where they are, and how the world's mountain chains were created. For this reason, plate tectonics theory is known as the unifying theory of geology. An understanding of plate tectonics is fundamental to understanding the dynamic planet that we call home.

In the early 1960s, the emergence of the theory of plate tectonics started a revolution in the earth sciences. Since then, scientists have verified and refined this theory, and now have a much better understanding of how our planet has been shaped by plate tectonic processes. We now know that, directly or indirectly, plate tectonics influence nearly all geologic processes, past and present. Indeed, the notion that the entire Earth's surface is continually shifting has profoundly changed the way we view our world. People benefit from, and are at the mercy of, the forces and consequences of plate tectonics. With little or no warning, an earthquake or volcanic eruption can unleash bursts of energy far more powerful than anything we can generate. While we have no control over plate tectonic processes, we now have the knowledge to learn from them. The more we know about plate tectonics, the better we can appreciate the grandeur and beauty of the land upon which we live, as well as the occasional violent displays of the Earth's awesome power.[225]

Part A. Tectonic Plates

Tectonic plates, also called **lithospheric plates**, are the rigid outer surface of our planet. These plates push against each other, pull apart from each other, or slide past each other. Over 300 to 500 million-year cycles, tectonic plate movements cause the continents to collide to form one large landmass called a "supercontinent". Pangaea, the most recent supercontinent in Earth's history, formed approximately 335 million years ago and started breaking apart approximately 175 million years ago. Figure 13.1 shows a simplified map of Earth's current major tectonic plates and their boundaries. The arrows on the map show the direction the plates are moving. Compare the plate tectonics map (Figure 13.1) to the world map (Figure 13.2). Notice that some of the tectonic plates have oceans above them while others are composed of the continents. These are the two main types of tectonic plates: **continental** and **oceanic**.

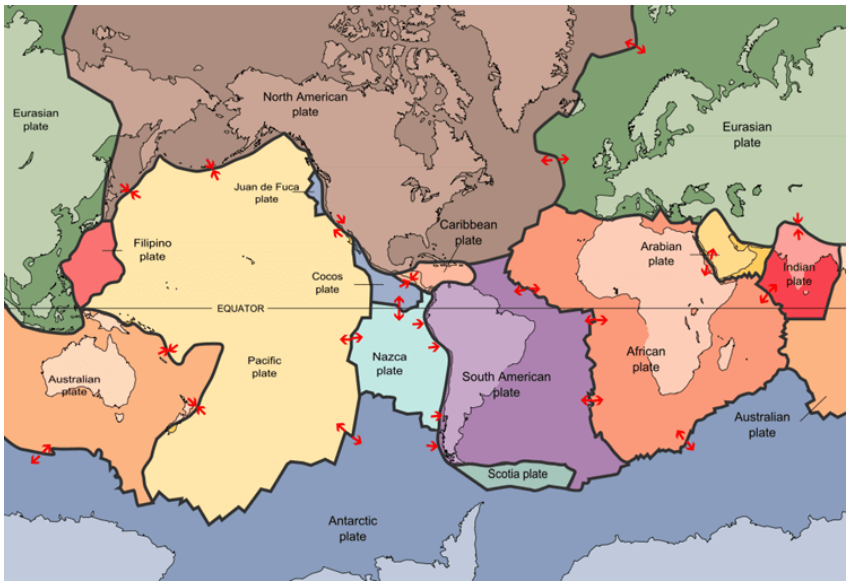


Figure 13.1: Simplified Map of Earth's Plates and Their Corresponding Tectonic Boundaries. Figure by USGS is in the public domain

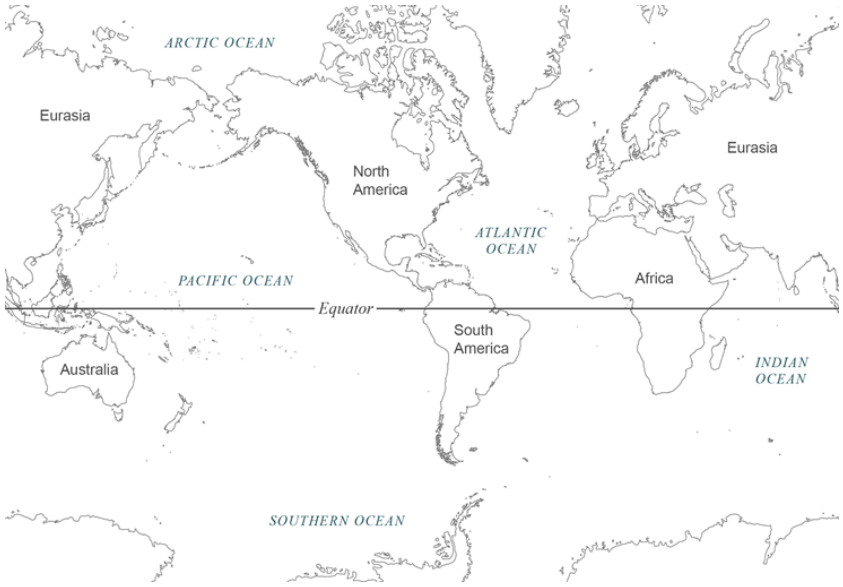


Figure 13.2: World Map. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

Exercise 1.13.1

1. Refer to Figure 13.1.
    a. What are the names of the large continental plates that surround the Pacific oceanic plate?
    b. What are the names of the smaller oceanic plates that surround the Pacific oceanic plate?
    c. Along the California coast, do the arrows show the oceanic Pacific Plate converging (arrows pointed into each other), diverging (arrows pointed away from each other), or sliding past (arrows pointed in opposite directions) in relation to the North American plate?
    d. What is the name of the oceanic plate that is found between the oceanic Pacific plate and the continental South American plate?

Part B. Earth's Interior

In order to understand the movements of tectonic plates, we need to take a look at Earth's interior. Figure 13.3 is a cross-section of the Earth.

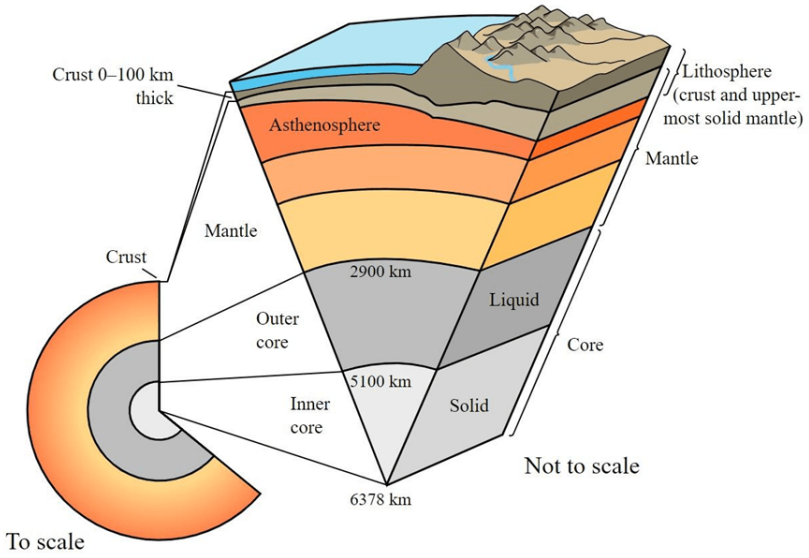


Figure 13.3: A Cross-Section of the Earth. Figure by USGS is in the public domain

At the center of the Earth is a dense metallic **core**. The **inner core** is solid, while the **outer core** is liquid. Heat from the inner core causes the outer core to convect (recall that **convection** is the transfer of heat by movement). The Earth's **mantle** surrounds the core, which also convects heat. While most of the mantle is solid rock, there is a layer of the upper mantle called the **asthenosphere**. The asthenosphere is partially molten, which means that it is partially melted. Sitting above the asthenosphere is a rigid part of the **upper mantle**.

The Earth's **crust** is above the mantle. **Oceanic crust** is thinner and denser than the **continental crust**. The **lithosphere** is the rigid part of the upper mantle and the crust. The lithosphere averages approximately 100 kilometers (~62 miles) in thickness with an approximate minimum thickness of 40 kilometers (~25 miles) and an approximate maximum thickness of 280 kilometers (~174 miles). Oceanic lithosphere is thinner and denser than continental lithosphere. (Density is mass per unit volume). The oceanic crust averages approximately 6 kilometers (~4 miles) in thickness. The density of oceanic crust averages at 3.0 grams per centimeters cubed (g/cm^3) and the continental crust has an average density of 2.7 g/cm^3. For comparison, aluminum has the same average density as the continental crust: 2.7 g/cm^3.

The lithosphere sits on top of the partially molten asthenosphere, so the lithospheric plates move because the asthenosphere moves and convects. This is the heart of plate tectonics theory; the rigid surface of the Earth (the upper-most part of the mantle and the crust, called tectonic plates or lithospheric plates) move according to movements in the asthenosphere.

Exercise 1.13.2

2. Sketch and label a cross-section of the Earth, as shown in Figure 13.3. Include the following components: solid inner core, liquid outer core, lower mantle, upper mantle, asthenosphere, upper-most solid mantle, oceanic crust, continental crust, and lithosphere. Tip: remember that the asthenosphere is a layer in the upper mantle that does not come in contact with the crust.

The Moho is the boundary between the crust and the mantle in the Earth. This is a depth where seismic waves change velocity; there is also a change in chemical composition. This is also called the Mohorovicic' discontinuity after the Croatian seismologist Andrija Mohorovicic' (1857-1936) who discovered it. The boundary is between 25 and 60 km deep beneath the continents and between 5 and 8 km deep beneath the ocean floor.[229]

Exercise 1.13.3

3. Use a highlighter to trace the Moho on the diagram you sketched for question 2 above.

To help you understand how movements in the asthenosphere cause tectonic plate movements, let's take a look at one model of convection cells in the Earth's mantle (Figure 13.4). Figure 13.4 represents the "whole mantle" convection model wherein the convection cells extend from the asthenosphere to the mantle-outer core boundary. Notice that at the center of the diagram the arrows point upward. This represents heat transferring upward from the outer core. As the heat moves toward the surface of the Earth, it diverges to form two distinct convection cells. The asthenosphere spreads in opposite directions from the center of the diagram, which causes the lithosphere above it to move apart, creating a ridge. On the outer edges of the convection cells, the lithosphere dives into the Earth, forming trenches. Note that the layers of the Earth are not drawn to scale in Figure 13.4.

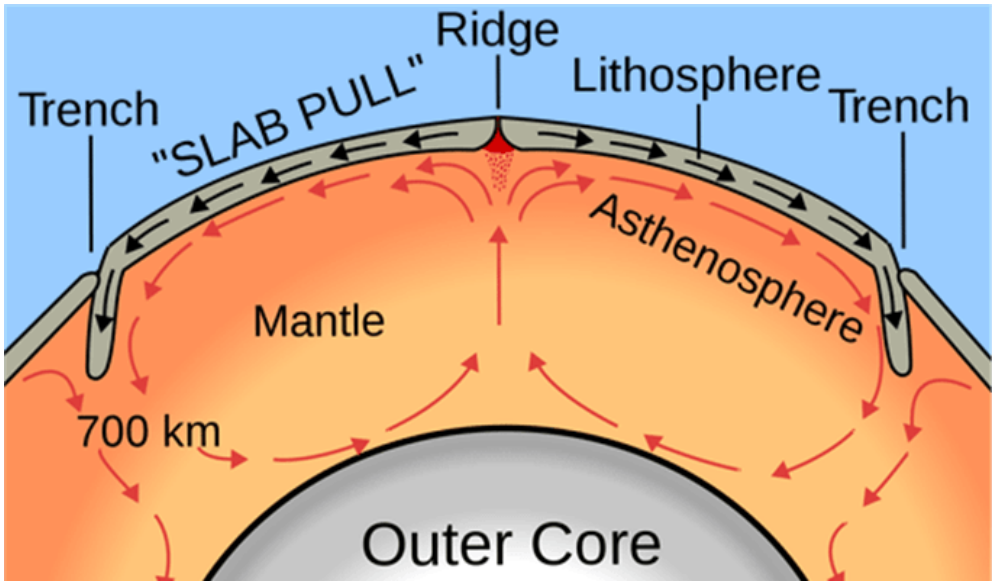


Figure 13.4: Example of Earth's Mantle Convection Cells: The Whole Mantle Model. Figure by USGS is in the public domain

Exercise 1.13.4

4. Tension is the stress that causes the lithosphere to pull apart. Where do you see the result of tension in Figure 13.4?
5. Compression is the stress that causes the lithosphere to push together. Where do you see the result of compression in Figure 13.4?

Check It Out! A Deeper Dive into Earth's Layers

Watch this video called Layers of the Earth—What are they? How were they found? from IRIS Earthquake Science to learn how scientists have come to understand Earth's interior. (Video length is 6:20).

A second model of convection, called the double-layered model (or the “layer cake” model), provides for two layers of convection (Figure 13.5). The top layer represents dynamic convection that occurs in the upper mantle to a depth of about 1,000 kilometers (~410 miles). The bottom layer represents less defined convection cells that move slowly from the lower mantle to the upper mantle. Note that the layers of the Earth are not drawn to scale in Figure 13.5.

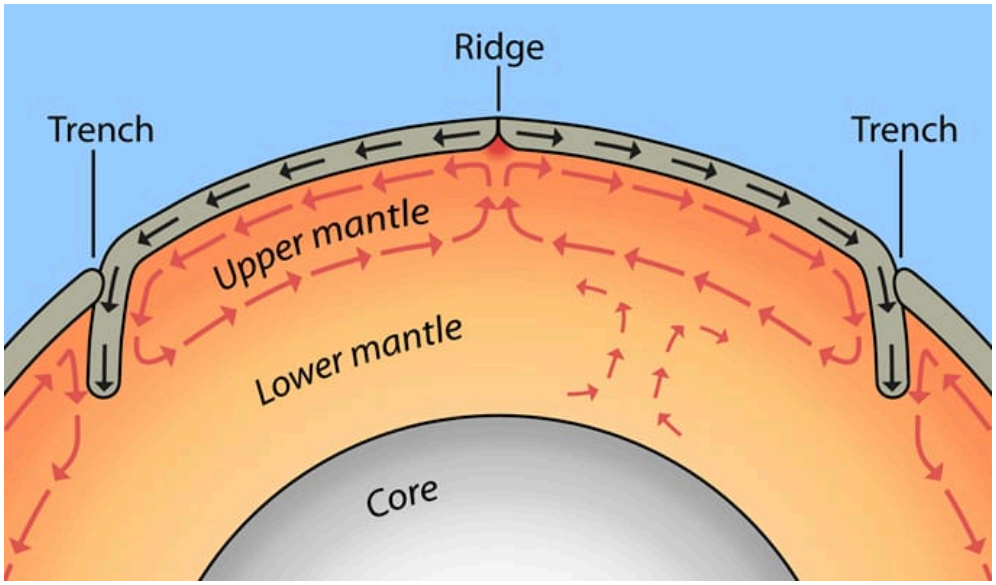


Figure 13.5: Example of Earth’s Mantle Convection Cells: The Double-Layered Model. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

Scientists are actively researching the convection cells in the mantle and asthenosphere in order to determine if one of these two models best represents the convection occurring inside the Earth. Some research points to a third model wherein all convection occurs shallowly in the asthenosphere. It’s possible that further research will provide another model of convection, or that no single model explains the convection cells. This is an exciting area of research that continues to inform our understanding of the planet we call home.

Exercise 1.13.5

6. Use Your Critical Thinking Skills: List the reasons why scientists debate the different convection models. Tip: consider the methods that scientists have to research deep into the Earth.

Part C. Tectonic Plate Boundaries

The edges where different tectonic plates meet are called plate tectonic boundaries. There are three types of boundaries as follows:

- **Convergent**, caused by **compressional stress** whereby plates are pushed towards each other.
- **Divergent**, caused by **tensional stress** whereby plates are pulled apart.
- **Transform**, caused by **shear stress** whereby plates slide past each other.

Remember that the reasons why a plate tectonic boundary is either convergent, divergent, or transform is due to the asthenosphere and the convection cells in the Earth’s mantle. When two convections cells converge, a convergent boundary is found. When two convection cells diverge, a divergent boundary is found.

In order to better understand the three main plate tectonic boundary types, you will access an online map and answer the following questions.[232]

Step 1

Go to the Cracked Plates Earth Science GeoInquiry by Esri.

Step 2

Look at the legend on the left.

Exercise 1.13.6

7. What does a red line represent?
8. What does a blue line represent?
9. What does a dark gray line represent?
10. Use three colors to draw and label the plate tectonic boundaries on the map provided in Appendix 13.1. Refer to Figure 13.1 to label each tectonic plate name. Be sure to include a legend.

Step 3

Zoom in on California.

Exercise 1.13.7

11. What type of tectonic plate boundary extends from the Gulf of California to Northern California?

Step 4

Use the measure tool to find the distance of the transform plate boundary from the U.S.-Mexico border to where it meets the Pacific Ocean west of Six Rivers National Forest in Northern California. Follow steps A through E to use the measure tool.

A. Above the map, click on Measure.
B. Click on the ruler icon to measure distance.
C. Click on the location where the transform plate boundary begins at the U.S.-Mexico border.
D. Click along the transform plate boundary, following the line of the boundary.
E. Double-click once you reach where the transform plate boundary meets the Pacific Ocean.

Exercise 1.13.8

12. What is the approximate length of the transform plate boundary in California? Tip: be sure to indicate miles or kilometers in your answer. Note: this boundary represents the San Andreas Fault Complex.
13. What type of tectonic plate boundary is found in Northern California (from Six Rivers National Forest to north of Eureka)?
14. What type of tectonic plate boundary is found in the Gulf of California?

15. Apply What You Learned: Do you think that Baja was once attached to mainland Mexico? Why or why not?

Step 5

Zoom out so that the world is in view.

Step 6

Click on Content on the left-side of the window.

Step 7

Click on "Global Quakes of Large Magnitude 5.8 or Greater" checkbox.

Exercise 1.13.9

16. Describe the patterns of earthquakes. Where are the earthquakes located? (Your response should be at least two sentences in length).

Step 8

Uncheck "Global Quakes of Large Magnitude 5.8 or Greater".

Step 9

Click on the "Absolute Plate Motions" checkbox. This is showing the distance in millimeters that a plate moves in one year.

Exercise 1.13.10

17. Which tectonic plate has the highest rates of plate movement?
18. What is the range in millimeters shown for this tectonic plate?

Step 10

Uncheck "Absolute Plate Motions".

Step 11

Zoom in on South America and click on the "South American Quakes" checkbox.

Step 12

When you hover over the South American Quakes heading on the left (next to the checkbox), you see additional options. Click on the table icon to show the data table.

Step 13

Review the data in the table. Features means the number of earthquakes shown on the map.

Exercise 1.13.11

19. How many earthquakes (features) are shown?

Step 14

Click on Year and sort both ascending and descending so that you can see the range of years that the data includes.

Exercise 1.13.12

20. What years of data are included in the table?

Step 15

Click on Magnitude and sort by both ascending and descending so that you can see the range of magnitudes.

Exercise 1.13.13

21. What is the range of earthquake magnitudes included in the table?

Step 16

Click on Depth and sort both by ascending and descending so that you can see the range of depths (data is shown in kilometers).

Exercise 1.13.14

22. What is the range of earthquake depths included in the table?

Step 17

Analyze the location of the South American earthquakes.

Exercise 1.13.15

23. What type of plate tectonic boundary is found where most of the earthquakes occurred?
24. Do all of the earthquakes occur right on the boundary?

Step 18

When you hover over the South American Quakes heading on the left (next to the checkbox), you see additional options. Click on the Change Style icon (it is the three shapes - triangle, square, and circle).

Step 19

Next to 1, change "Show location only" to "Depth".

Step 20

Click the blue "DONE" button.

Step 21

Analyze the location of the deepest earthquakes.

Exercise 1.13.16

25. Explain the location of the deepest earthquakes based on the plate tectonic boundary type. Include a labeled cross-section sketch of the boundary type.

Step 22

Uncheck the South American Quakes box and zoom out so that the world is in view.

Exercise 1.13.17

26. Zoom in on each mountain range and identify the plate tectonic boundary type to complete Table 13.1. Include whether the boundaries are between oceanic and/or continental plates. The first mountain range, the Andes Mountains, is completed as an example.

Table 13.1: Active Mountain Ranges and Tectonic Plate Boundaries

Active Mountain Range	Continent	Tectonic Plate Boundary Type
Andes Mountains	South America	Oceanic-continental convergent
Himalayan Mountains		
Tian Shan Mountains		
Alaska Range		

Along with earthquake activity and the locations of mountain ranges, we can explain the locations of volcanoes around the world based on plate tectonics theory. Let's look at another online map to look for spatial patterns of volcanic activity along plate boundaries.[233]

Step 1

Go to the Plate Type Effect on Volcanoes Earth Science GeoInquiry by Esri.

Step 2

On the panel to the left of the map, there is an option to "Show Contents of Map" (hover your mouse over the icons to find it). Click the icon to show the contents of the map.

Step 3

Check the box next to Plate Boundaries.

Step 4

Underneath where it says Plate Boundaries, click on the icon on the far-left to view the legend (when you hover your mouse over the icon, it says Show Legend).

Step 5

Check the box next to Global Volcanoes.

Step 6

Underneath where it says Global Volcanoes, click on the icon on the far-left to view the legend (when you hover your mouse over the icon, it says Show Legend).

Exercise 1.13.18

27. Do the majority of volcanoes occur along plate tectonic boundaries?
28. Which plate tectonic boundary type has the most volcanoes? Tip: use the Plate Boundaries legend and zoom in and out of the map to answer this question.

Step 7

Zoom in on California.

Exercise 1.13.19

29. Describe the locations of the two plate tectonic boundaries found in California.

Step 8

Zoom out so that you see the Pacific west coast of the United States from Washington state to California.

Exercise 1.13.20

30. What plate tectonic boundary type caused the Pacific Northwest volcanoes? Tip: include whether the tectonic plates are oceanic or continental.

Step 9

Scroll to the north and west on the maps so that Alaska and the Aleutian Islands are in view.

Exercise 1.13.21

31. What plate tectonic boundary type created the Aleutian Islands?

Step 10

Zoom out so that the Hawaiian Islands are in view.

Exercise 1.13.22

32. Are the Hawaiian Islands found on a plate tectonic boundary?

Part D. Hotspots

While the majority of earthquake and volcanic activity is found along tectonic plate boundaries, some occurs along hotspots. **Hotspots** are commonly intraplate features (not found along the boundaries of tectonic plates) where volcanic activity occurs. A hotspot is an area in the lithospheric plate where molten magma breaks through and creates a volcanic center: islands in the ocean and mountains on land. As the plate moves across the hotspot, the volcano center becomes extinct because it is no longer over an active magma source. Instead, the magma emerges through another area in the plate to create a new active volcano. Over time, the combination of moving plate and stationary hotspot creates a chain of islands or mountains (Figure 13.6). The classic definition of hotspots states they do not move, although recent evidence suggests that there may be exceptions.[234] Figure 13.6 shows how a chain of volcanoes is created as a tectonic plate moves over a hotspot. The diagram on the left shows the first volcano forming above the hotspot. The middle diagram shows new volcanoes forming as the tectonic plate moves across the stationary hotspot. The diagram on the right shows the chain of volcanoes as a new volcano forms above the hotspot.

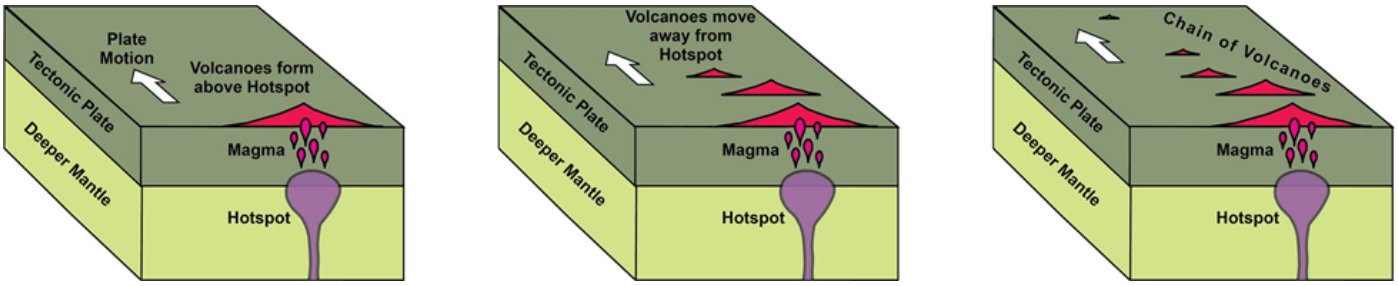


Figure 13.6: Hotspot Volcano Formation over Time. Figure by National Park Service is in the public domain

Scientists are divided over how magma is generated in hotspots. Some suggest that hotspots originate from super-heated material from as deep as the core that reaches the Earth's crust as a mantle plume. Others argue the molten material that feeds hotspots is sourced from the mantle. Of course, it is difficult to collect data from these deep-Earth features due to the extremely high pressure and temperature.[10]

How hotspots are initiated is another highly debated subject. The prevailing mechanism has hotspots starting in divergent boundaries during supercontinent rifting. Scientists have identified a number of current and past hotspots believed to have begun this way. Subducting slabs have also been named as causing mantle plumes and hotspot volcanism. Some geologists have suggested another geological process not involving plate tectonics may be involved, such as large space objects crashing into the Earth. Regardless of how they are formed, dozens are on the Earth. Some well-known examples include the Tahiti Islands, Afar Triangle, Easter Island, Iceland, Galapagos Islands, and Samoan Islands. The United States is home to two of the largest and best-studied hotspots: Hawai'i and Yellowstone.[11] The locations of selected prominent hotspots are shown in Figure 13.7.

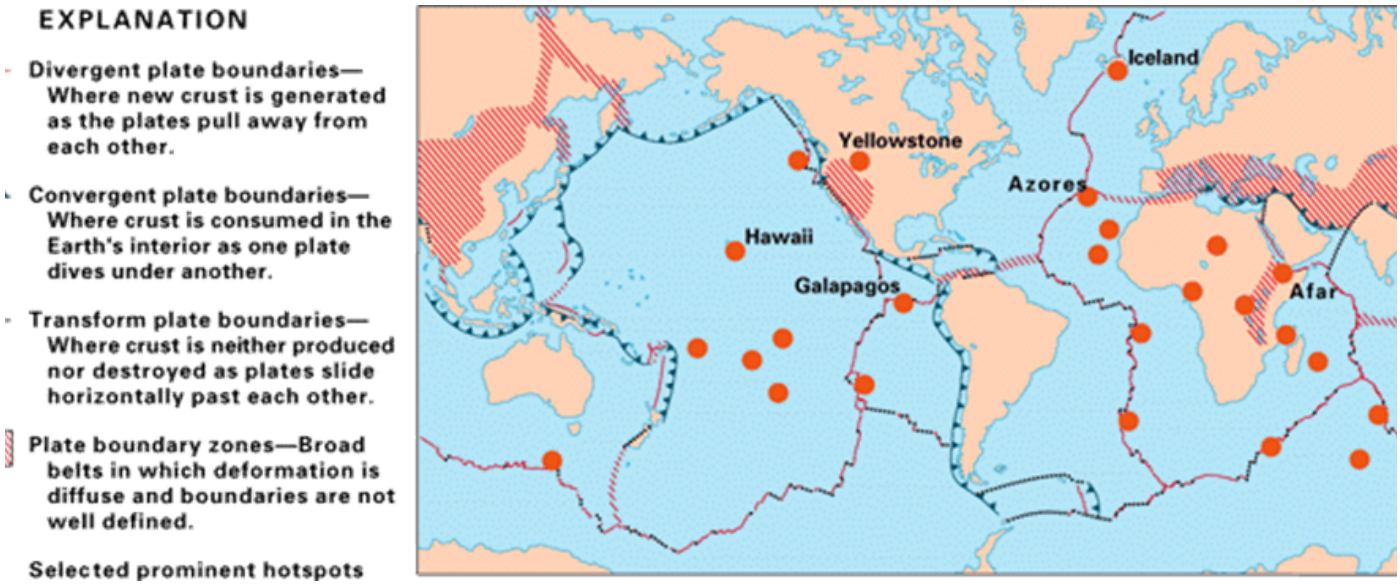


Figure 13.7: Plate Tectonics Map with Selected Prominent Hotspots. Figure by USGS is in the public domain

Exercise 1.13.23

33. Refer to Figure 13.7.

    a. How many hotspots are located within the Pacific oceanic tectonic plate?

    b. What is the name of the hotspot found on the continental North American plate?

Figure 13.8 shows the ages of the seafloor of the Pacific plate. By following the Hawaiian Islands to the Midway Atoll and Emperor Seamount, you are able to see how the Pacific plate has moved over the hotspot. The Hawaiian Islands are shown in red and atolls and seamounts extend linearly away from the hotspot. Atolls are islands formed from coral that once surrounded an island that is now weathered below sea level. Seamounts are islands below sea level—submarine mountains.

On Figure 13.8, the shape of the seamounts are outlined based on their shape at a water depth of two kilometers. Gray lines on the map are fracture zones, which are essentially cracks within the Pacific plate caused by tectonic activity. The black lines on the map that are labeled with Ma identify the age of the volcanoes of the Emperor Seamount in millions of years.

The map also shows the average plate movement of 85 millimeters per year (mm/yr) and 114 millimeters per year at different locations.

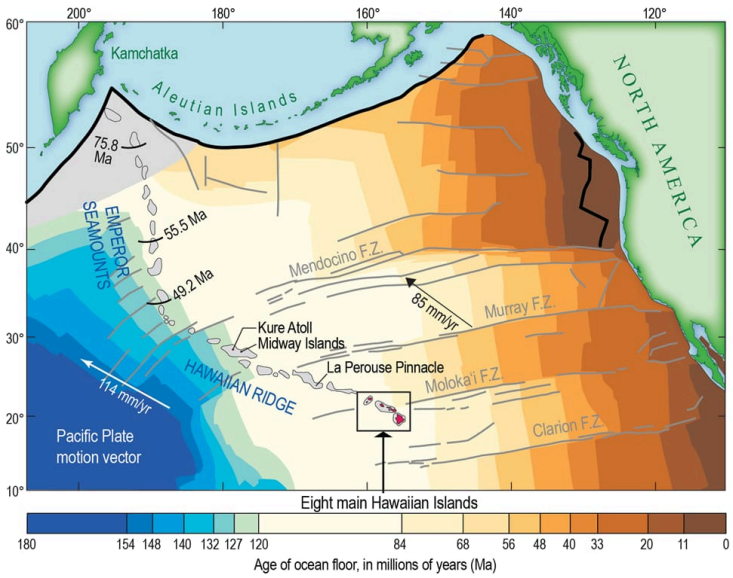


Figure 13.8: Pacific Plate Map with Seafloor Ages. Figure by USGS is in the public domain

Exercise 1.13.24

34. Refer to Figure 13.8.

    a. What is the age range of the seafloor where the Emperor Seamounts are located?

    a. How many millions of years ago did the volcanoes that created the Emperor Seamounts erupt?

    a. Using your answers to questions a and b above and your understanding of hotspots, in one to two sentences explain how the Emperor Seamounts formed.

    a. The Midway Islands are approximately 2,400 kilometers from the Hawaiian Islands. If the Pacific Plate moves at an average rate of 85 millimeters per year, how long will it take for the Hawaiian Islands to move to where the Midway Islands are currently located? Tip: First, convert kilometers to millimeters by multiplying by 1,000,000. Second, divide this number by 85. Show your calculations.

Check It Out! The Yellowstone Hotspot

Watch this video called Geology of Yellowstone and Heat Flow in the Earth created by Dr. Jay Chapman from the Geology and Geophysics Department at the University of Wyoming. The video helps to explain what caused the Yellowstone Hotspot and gives insights into how scientists study it.

Part E. Plate Tectonics Synthesis

Review the above information on the Earth's interior, plate tectonic boundaries, and hotspots, and then answer the following questions.

Exercise 1.13.25

35. Why is it necessary to understand the layers of the Earth's interior in order to understand plate tectonic boundaries types and hotspots? Explain your response in at least three sentences.

36. Students often confuse the three plate tectonic boundary types (convergent, divergent, and transform) and hotspots. What are the similarities and differences between these geologic features? Tip: consider which boundary types are associated with mountains, volcanoes, and earthquakes. Explain your response in at least three sentences.

37. Refer to Figures 13.1 and 13.5 and/or your labeled Appendix 13.1 map. Complete Table 13.2 with examples of each of the tectonic plate features. For the column on the right, name a specific geographic location. For example, the Nazca Plate-South American Plate boundary or the Galapagos Hotspot.

Table 13.2: Tectonic Plate Features and Geographic Examples

Tectonic Plate Feature	Geographic Example
Oceanic-Oceanic Convergent Plate Boundary	
Oceanic-Continental Convergent Plate Boundary	
Continental-Continental Convergent Plate Boundary	
Oceanic Divergent Plate Boundary	
Continental Divergent Plate Boundary	
Oceanic Hotspot	
Continental Hotspot	

38. Why do you think plate tectonics theory is called the unifying theory of geology? Explain your response in one to two sentences.

Part F. Wrap-Up

Consult with your geography lab instructor to find out which of the following wrap-up questions you should complete. Attach additional pages to answer the questions as needed.

Exercise 1.13.26

39. What is the most important idea that you learned in this lab? In two to three sentences, explain the concept and why it is important to know.

40. What was the most challenging part of this lab? In two to three sentences, explain why it was challenging. If nothing challenged you in the lab, write about what you think challenged your classmates.

41. What is one question that you have about what you learned in this lab? Write your question along with one to two sentences explaining why you think your question is important to ask.

42. Review the learning objectives on page 1 of this lab. How would you rate your understanding or ability for each learning objective? Write one sentence that addresses each learning objective.

43. Sketch a concept map that includes the key ideas from this lab. Include at least five of the terms shown in bold-faced type.

44. Create an advertisement to educate your peers on the important information that you learned in this lab. Include at least three key terms in your advertisement. The advertisement should be about half a page in size (about 4 inches by 6 inches).

45. One way to think of physical geography is that it is the study of the relationships among variables that impact the Earth's surface. Select two variables discussed in this lab and describe how they are related.

46. How does what you learned in this lab relate to your everyday life? In two to three sentences, explain a concept that you learned in this lab and how it relates to your day-to-day actions.

47. How does what you learned in this lab relate to current events?
    a. Write the title, source, and date of a news item that relates to this lab.
    b. In two to three sentences, discuss how the news item relates to what you have learned in this lab.
    c. In one to two sentences, discuss whether or not the news item accurately represents the science that you learned. Tip: consider whether or not the news item includes the complexity of the topic.

48. Search O*NET OnLine to find an occupation that is relevant to the topics presented in today's lab. Your lab instructor may provide you with possible keywords to type in the Occupation Quick Search field on the O*NET website.
    a. What is the name of the occupation that you found?
    b. Write two to three sentences that summarize the most important information that you learned about this occupation.
    c. What is one question that you would want to ask a person with this occupation?

Answer available at the end of this section.

Appendix 13.1: World Map



Figure downloaded from Esri GIS Education

[225] Text by USGS is in the public domain

[229] Text by USGS is in the public domain

[232] Adapted from Esri GeoInquiries

[233] Adapted from Esri GeoInquiries

[234] Text by C. Johnson, M.D. Affolter, P. Inkenbrandt & C. Mosher is licensed under CC BY-NC-SA 4.0

Answers

Exercise 1.13.26

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1.14: Lab 14 - Seismology

This lab contains potentially inaccessible interactive resources. Please work with your instructor and local campus resources to identify accommodations for these resources.

Learning Objectives

- Identify the three types of stresses that cause normal, reverse, and strike-slip faults.
- Analyze the spatial distribution of faults in southern California.
- Describe the differences between p-waves and s-waves.
- Explain how an earthquake's epicenter is located.
- Differentiate between earthquake magnitude and earthquake intensity.
- Analyze liquefaction hazard probability estimates and earthquake probability data.
- Explain how earthquake vulnerability varies for different communities.

Introduction

Seismology is the study of earthquakes and the energy produced by earthquakes. Each earthquake represents movement along a fault. This movement could be caused by pressure put on the rock from tectonic activity, volcanic activity, or human activity such as fracking. A **fault** is a fracture in a rock; this is where energy is released by an earthquake. You could think of the fault as having potential energy due to the pressure that is placed on it. Once the pressure builds up and it can no longer withstand it, kinetic energy is released when the rocks move along the fault.

Figure 14.1 illustrates the fault line between two rock blocks. The earthquake occurs and energy is released at the **hypocenter**, also called the earthquake's **focus**. The **epicenter** is the location on the surface of the Earth directly above the hypocenter. Tip: the prefix hypo- means under (e.g., a hypodermic needle is one that injects underneath the skin); the prefix epi- means above or on (e.g., epidermal means the outer layer of the skin).

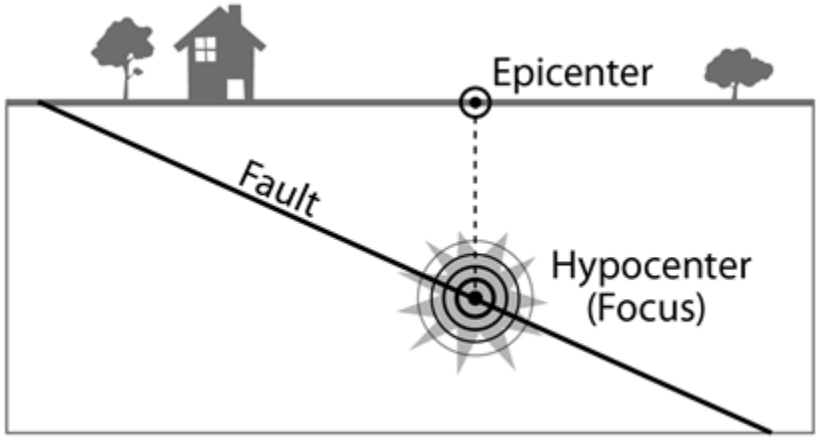


Figure 14.1: Simplified Fault Diagram. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

Think About It...Earthquake Frequency

Millions of earthquakes occur across the world each year. The U.S. Geologic Survey estimates that in any given year only 16 major earthquakes will occur globally (major earthquakes are defined as a 7.0 on the moment magnitude scale). Why do you think there are millions of earthquakes but so few are powerful ones that measure at least a 7.0?

Part A. Fault Types

There are three main types of stress: **compression** (pushing together), **tension** (pulling apart), and **shear** (sliding past). Each of these types of stress results in a different fault type (Figure 14.2) with particular features as follows:

- A **fault scarp** occurs when rocks are offset in compressional and tensional faults. The offset could be small (a few centimeters) or larger (dozens of meters). Larger fault scarps create cliffs.
- A **hanging wall** is a block of rock that is on top of the fault.
- A **footwall** is a block of rock that is underneath the fault.

Notice that for **reverse faults**, compression causes the hanging wall rocks to rise up relative to the footwall rocks. For **normal faults**, tensional stress causes the hanging wall rocks to drop down relative to the footwall rocks. And, for **strike-slip faults**, shear stress does not create a fault scarp because the two rock blocks slide laterally across the fault.

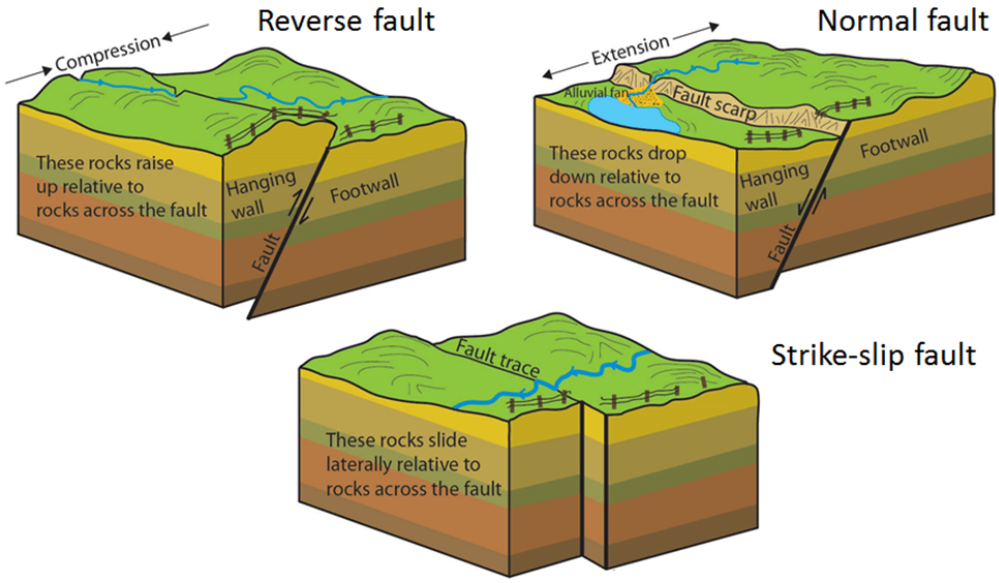


Figure 14.2: Three Basic Fault Types. Figure by Steven Earle is licensed under CC BY 4.0



Check It Out! The Three Basic Fault Types

View the three basic fault types in motion in this IRIS Earthquake Science video. (Video length is 51 seconds).

It is easy to confuse the scale and vocabulary of tectonic plate boundary types and fault types. This is because the three types of stress (compression, tension, and shear) apply to both plate tectonics and earthquakes. But, it's important to remember that plate tectonic boundaries represent very large blocks of rock whereas faults are relatively small-scale. Also consider that along any plate tectonic boundary, the movement caused by the main stress will likely place different stresses around the boundary.

For example, along a mid-oceanic ridge, tensional stress is pulling apart the oceanic tectonic plate. This causes shear stress to occur along the oceanic rocks being torn apart. As you learned in the previous lab, the San Andreas Fault Complex represents the transform plate tectonic boundary between the Pacific plate and the North American plate, so the main stress is shear. But, there are areas with compressional stress and tensional stress that are created when these two massive blocks of rock slide past each other. Therefore, California has all three fault types.



Pin It! Fault Vocabulary

Remember to use the correct vocabulary when talking about faults:

- Normal faults are caused by tensional stress.
- Reverse faults are caused by compressional stress.
- Strike-slip faults are caused by shear stress.

For example, you would never call a fault convergent—there are convergent tectonic plate boundaries caused by compressional stress, but we don't use the term convergent for faults. Compressional stress creates reverse faults.

Exercise 1.14.1

1. Complete Table 14.1 below.

Table 14.1: Fault Types. Figures by Ralph L. Dawes and Cheryl D. Dawes are licensed under CC BY 3.0

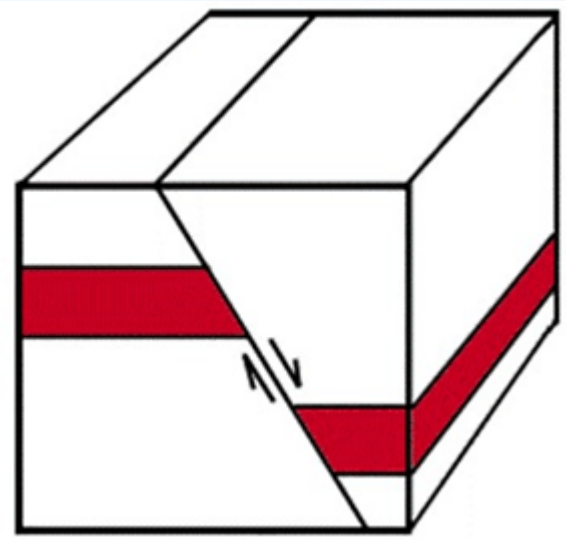
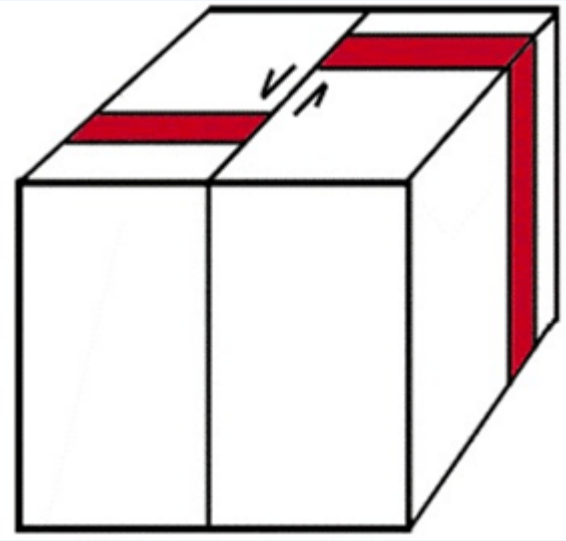
Diagram	Stress Type that Created the Fault	Fault Type Name
 Figure 14.3: Fault Example 1		
 Figure 14.4: Fault Example 2		

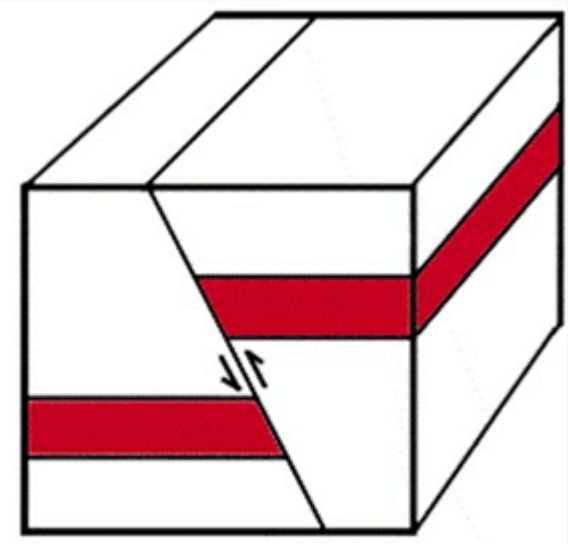
Diagram	Stress Type that Created the Fault	Fault Type Name
 Figure 14.5: Fault Example 3		

Figure 14.6 shows where the three fault types are located in Southern California. The dashed lines represent normal faults caused by tensional stress. The dotted lines represent reverse faults caused by compressional stress. The black lines represent strike-slip faults caused by shear stress. The **San Andreas Fault Complex** includes the numerous faults that mark the transform boundary between the Pacific and North American tectonic plates. Notice that the San Andreas Fault Complex is not a straight line, which makes sense because two tectonic plates are sliding past each other so a smooth surface wouldn't be expected. There is a lot of accumulating pressure and different rock types so the transform boundary is jagged.

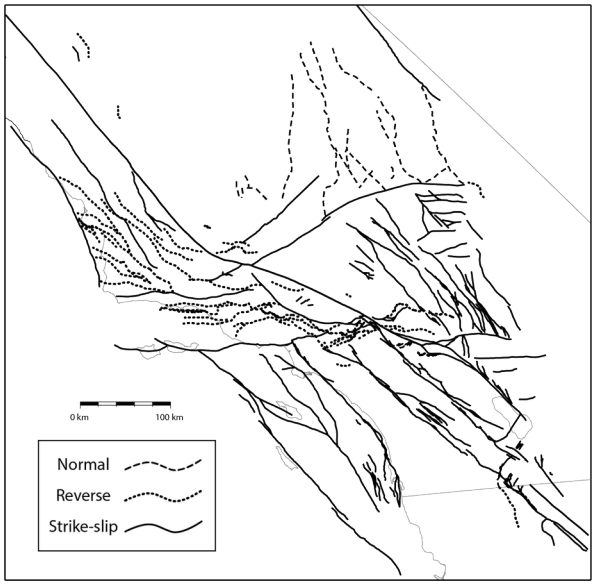


Figure 14.6: Map of Fault Types in Southern California. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

Exercise 1.14.2

2. With a highlighter or colored pencil, trace the main fault of the San Andreas Fault Complex. Hint: find the Salton Sea in the southeast area of the map. Tip: if needed, use an atlas or the internet to find where the Salton Sea is located. The faults extending on the northeast side of the Salton Sea are part of the San Andreas Fault Complex. Highlight those faults as they extend all the way to the northwest part of the map.

3. Use an atlas or the internet to find the locations of Bakersfield, Los Angeles, San Diego, and El Centro. Label these cities on Figure 14.6.
4. In one sentence, describe the location of the San Andreas Fault Complex. Hint: use the scale bar to estimate how far inland the fault is located.

5. Why are there three types of faults found in Southern California when the San Andreas Fault Complex represents a transform plate boundary? Your response should be two to three sentences in length and include an explanation of the location of the compressional faults seen along the coast and inland (around Los Angeles County). Tip: refer to this diagram from the Southern California Earthquake Center at USC.

Answer available at the end of this section.

Part B. Seismic Energy

Earthquake energy, known as **seismic energy**, travels through the Earth in the form of seismic waves. Seismic waves are an expression of the energy released after an earthquake in the form of **body waves** and **surface waves** (Figure 14.7). When seismic energy is released, the first waves to propagate out are body waves that pass through the body of the planet. Body waves include **primary waves** (**P waves**) and **secondary waves** (**S waves**). Primary waves are the fastest seismic waves, averaging 6 kilometers per second in the outer crust. This is equivalent to a speed of about 13,422 miles per hour. They move through rocks via compression, very much like sound waves move through the air. Particles of rock move forward and back during the passage of the P waves (Figure 14.8). Primary waves can travel through both fluids and solids. Secondary waves travel slower—averaging 3.5 kilometers per second in the outer crust—and follow primary waves, propagating as shear waves. Particles of rock move from side to side during the passage of S waves (Figure 14.9). Because of this, secondary waves cannot travel through fluids, plasma, or gases. Surface waves only travel at the Earth's surface; they cause the most destruction to human-built structures.

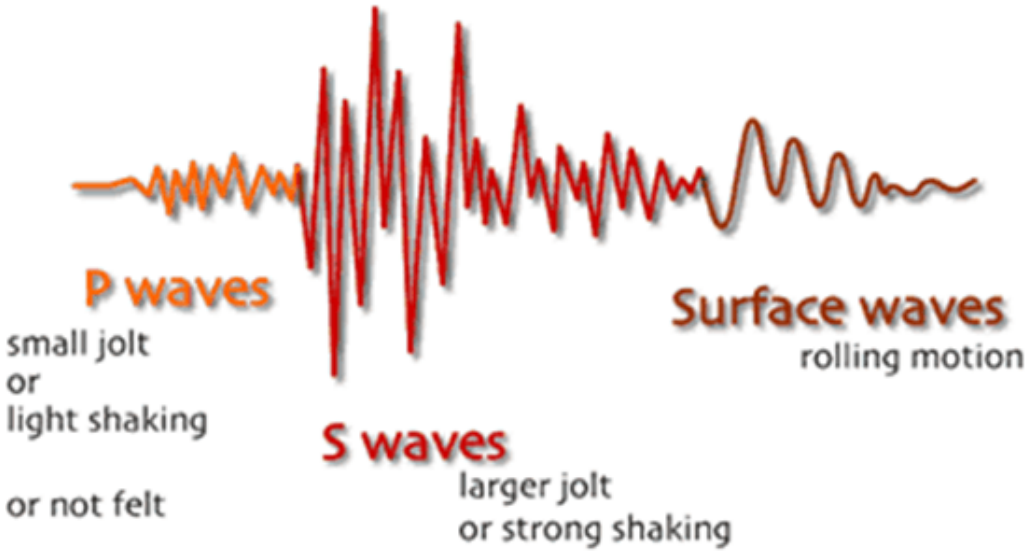


Figure 14.7: Three Types of Seismic Waves. Figures adapted by Waverly Ray from the USGS are licensed under CC BY-NC-SA 4.0

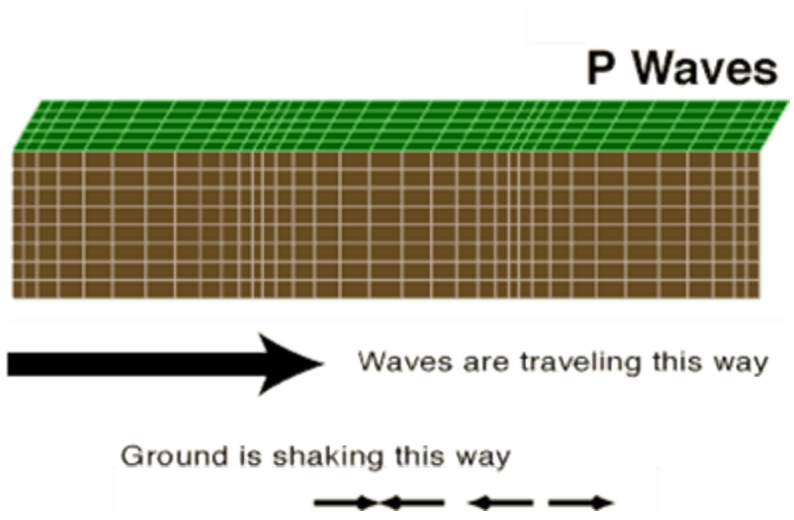


Figure 14.8: P Waves. Figure by Brian Brondel is licensed under CC BY-SA 2.5

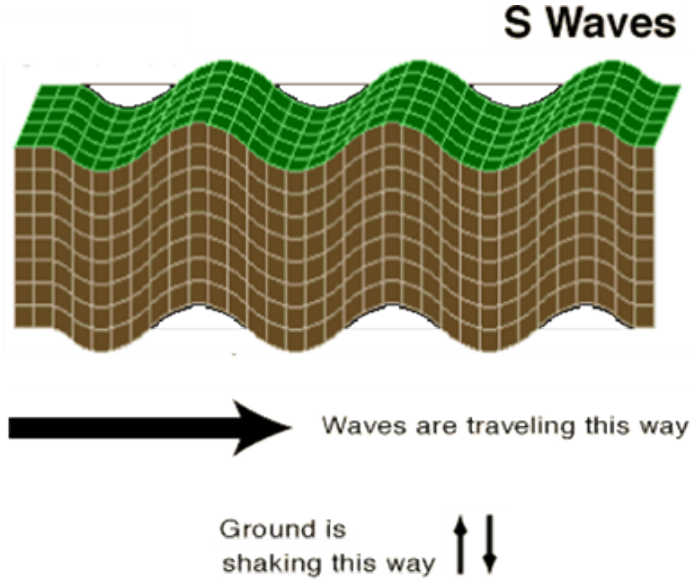


Figure 14.9: S Waves. Figure by Brian Brondel is licensed under CC BY-SA 2.5

The equipment used to detect and record earthquakes are called **seismographs** (also known as **seismometers**). There are thousands of seismographs across the world. Figure 14.10 shows a basic horizontal-motion seismograph. A pen is suspended by a weight that touches a rotating drum. As the ground shakes, the drum moves and the pen records the movements on a record called a **seismogram**.

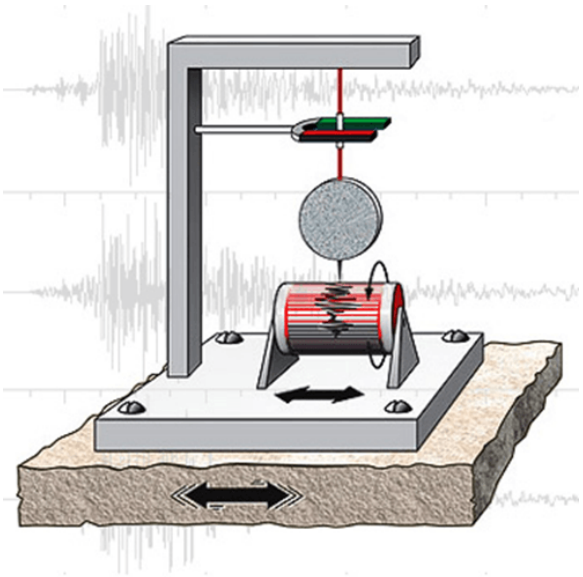


Figure 14.10: A Seismograph. Figure by Dollynarak is licensed under Free Art License 1.3

Figure 14.11 is the seismogram from a magnitude 4 earthquake with time in seconds along the x-axis and wave amplitude in millimeters per second along the y-axis. Notice how on the left, the line is flat until the P wave arrives at 0.7 seconds on the seismogram. The S wave arrives 8 seconds after the P wave. The difference in time between the P and S wave arrivals is used to determine how far the seismograph is relative to the earthquake's location (this is known as the **S-P time**). The amplitude of the largest seismic wave is used to estimate the earthquake's magnitude.

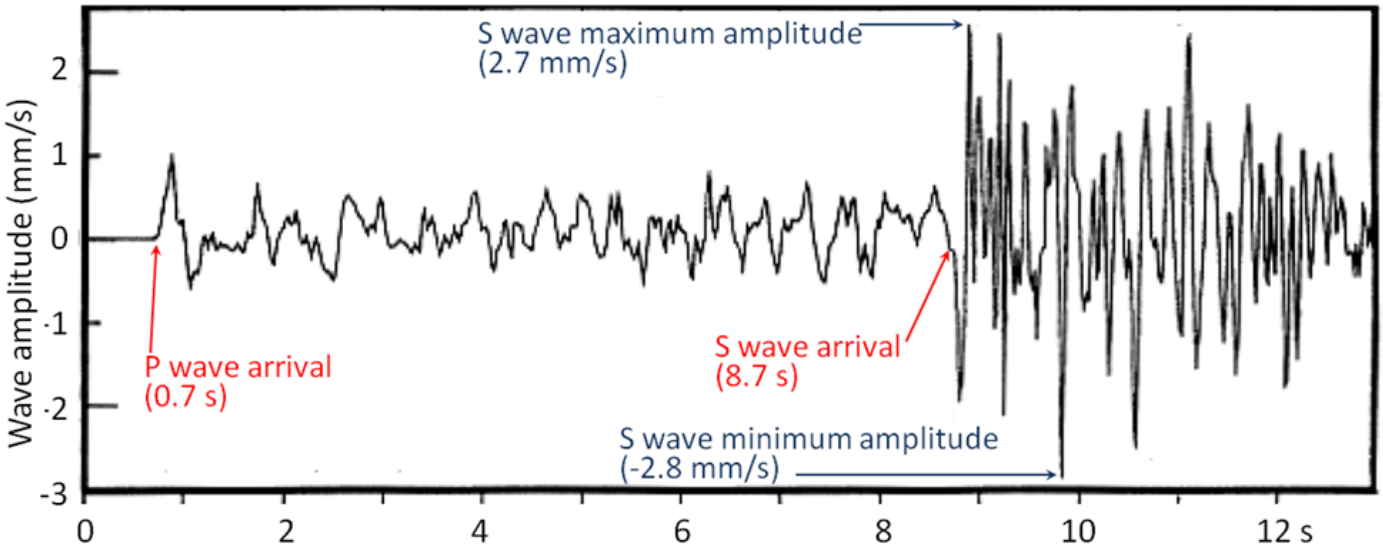


Figure 14.11: An Example Seismogram. Figure by Steven Earle is licensed under CC BY 4.0



Check It Out! A Seismograph Recording P and S Waves

View a seismograph recording P and S waves in this IRIS Earthquake Science video. (Video length is 11 seconds).

P and S waves travel at different speeds through the different layers of the Earth. On average, P waves travel between 6.0 and 13.0 kilometers per second (as mentioned above, in the outer crust P waves travel at about 6 kilometers per second—the interior layers of the Earth are more dense so the P waves do not travel as fast). On average, S waves travel between 3.5 and 7.5 kilometers per second.

If we assume a P wave speed of 7.5 kilometers per second and an S wave speed of 4.3 kilometers per second, we can use observations from thousands of earthquakes to understand how far a seismograph is from the epicenter of an earthquake. Think of it this way: the moment the fault ruptures, seismic energy starts moving away from the hypocenter. P waves travel fastest and reach a seismograph first and are recorded on the seismogram. Some time later, the slower S waves arrive and are recorded on the seismogram. By knowing the average speeds of the P and S waves, we can work out the distance the seismograph is to the epicenter by calculating the S-P time. When the P wave speed is 7.5 kilometers per second and the S wave speed is 4.3 kilometers per second, every second of S-P time equates to a distance of 10 kilometers. Therefore, if S-P time recorded on a seismogram is 60 seconds then the seismograph is located 600 kilometers from the earthquake's epicenter (60 times 10 kilometers equals 600 kilometers).

Exercise 1.14.3

6. What are the main differences between P waves and S waves?
7. What is the difference between a seismograph and a seismogram?
8. Refer to Figure 14.11. What is the S-P time?
9. How far is the seismograph that recorded the seismogram shown in Figure 14.11 from the earthquake's epicenter? Show your calculations.
10. Suppose you felt an earthquake's P waves arrive to your location, causing shaking. Thirty seconds after the P waves first arrive, you feel the S waves arrive, which causes severe shaking. Assuming a S-P time of 30 seconds, a P wave speed of 7.5 kilometers per second, and an S wave speed of 4.3 kilometers per second, how far are you from the earthquake's epicenter? Provide an answer in both kilometers and miles. Hint: to convert kilometers to miles, multiply kilometers by 0.621. Be sure to show your work.

The S-P time lets us know the distance of a seismograph from an earthquake but doesn't tell you where the epicenter is in relation to the seismograph. Is it to the north, south, east, or west? For example, if the seismograph is 500 kilometers from the epicenter, you don't know in which direction the epicenter is located. It could be 500 kilometers to the east; it could be 500 kilometers to the west; etc. A triangulation method is used to locate the earthquake's epicenter. With data from at least three seismographs, you can pinpoint the earthquake's epicenter (Figure 14.12). For each of the seismographs (shown by green dots in Figure 14.12), a black circle is drawn representing the distance the seismograph is to the epicenter. Where the three circles intersect is the earthquake's epicenter.

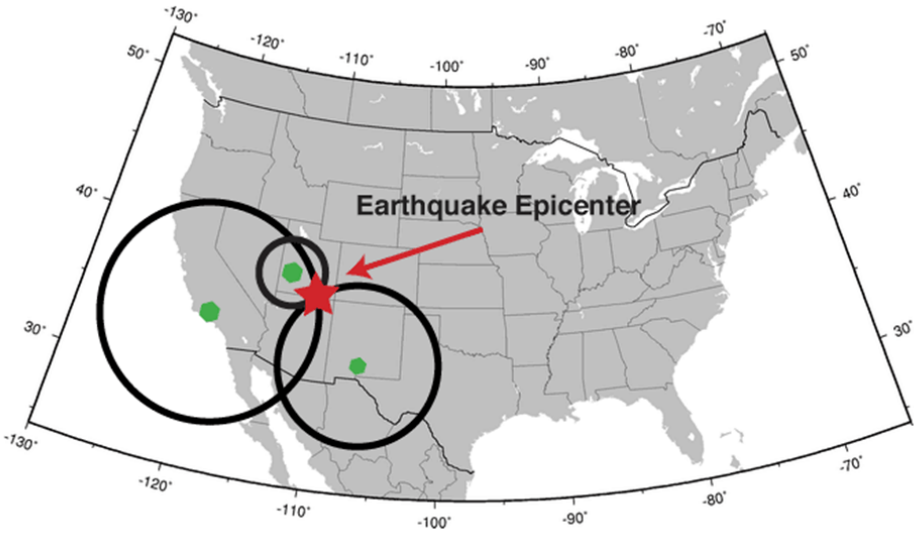


Figure 14.12: Epicenter Triangulation with Distances from Three Seismographs. Figure by USGS is in the public domain

Before we look at a specific example, let's make sure we understand the x-axis and the y-axis for the seismograms provided on the "Wilber 3" data service from the Incorporated Research Institutions for Seismology (IRIS) website. Figure 14.13 is a seismogram recorded on July 22, 2020, in Corvallis, Oregon. It recorded a 7.8 magnitude earthquake that occurred near the Alaskan Peninsula (to be exact, the latitude of the epicenter was 55.0298° North, the longitude was 158.5217° West). The P wave arrival is shown by the vertical red line on the left and the S wave arrival is shown by the vertical blue line on the right. At the far left of the x-axis is the date, 2020-07-22 (representing July 22, 2020). The x-axis shows the time in UTC. UTC is Coordinated Universal Time, which allows scientists to know the precise time of an event no matter what the local time is. The first time notch on the left represents 06:18:00 UTC (06 is the hours, 18 is the minutes, and 00 is the seconds). So the first time notch is 6:18 a.m. UTC. The next time notch is 2 minutes later. The y-axis shows the raw number recorded from the seismograph itself, which represents the movement caused by the seismic waves.

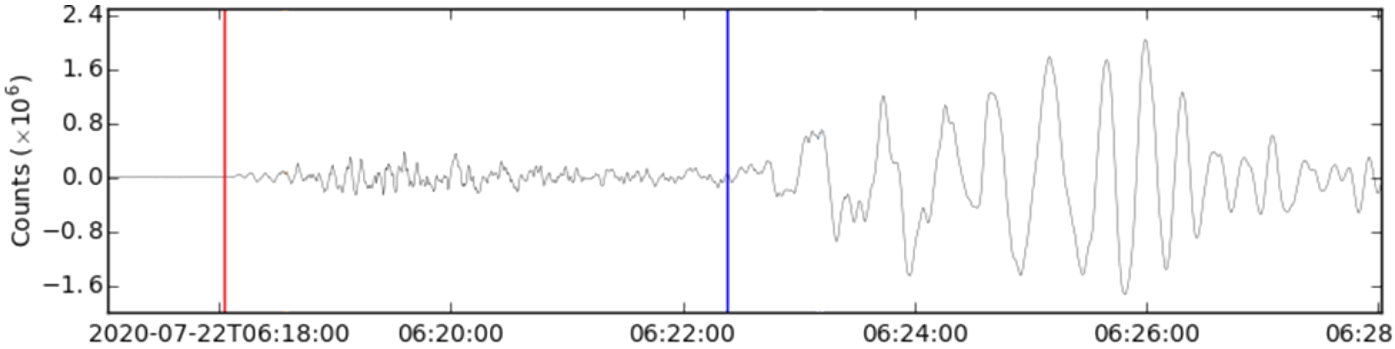


Figure 14.13: An Example Seismogram from the "Wilber 3" Data Service. Figures adapted from the Wilber 3 Data Service of the Incorporated Research Institutions for Seismology (IRIS) are used with permission

To triangulate an earthquake's epicenter, first you will need to answer questions 11 through 13. Note that the latitudes and longitudes provided do not indicate north, south, east, or west. Positive latitudes are in the northern hemisphere (N) and negative longitudes are in the Western hemisphere (W).

Exercise 1.14.4

11. The first seismogram (Figure 14.14) is located at Station 1. Station 1 is in the Disney Wilderness Preserve in Florida. It's latitude is 28.11° (this is the same as 28.11° N) and it's longitude is -81.43° (this is the same as 81.43° W). The P wave arrival is marked by the red vertical line on the left and arrived at 15:33:15 UTC. The S wave arrival is marked by the blue vertical line on the right and it arrived at 15:36:38 UTC. Find the S-P time and the kilometers distance Station 1 is from the epicenter.

a. S-P time:
b. Distance in kilometers:

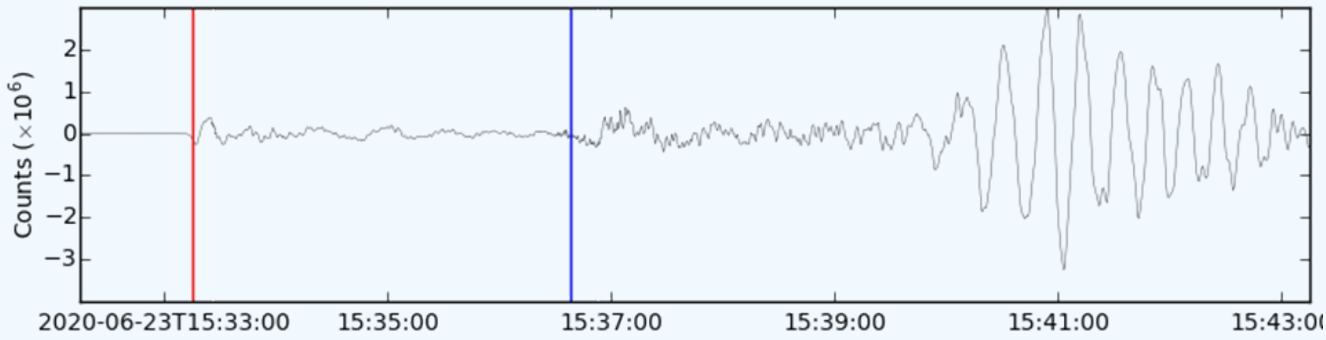


Figure 14.14: Station 1 Seismogram. Figure by Bruce Jones Design and FreeUSandWorldMaps.com is licensed under CC0 1.0

12. The second seismogram (Figure 14.15) is located at Station 2. Station 2 is at Las Juntas de Abangares in Costa Rica. Its latitude is 10.29° and its longitude is -84.95°. The P wave arrival, marked by the red vertical line on the left, arrived at 15:31:55 UTC. The S wave arrival, marked by the blue vertical line on the right and it arrived at 15:34:11 UTC. Find the S-P time and the distance in kilometers from the epicenter to Station 2.
    a. S-P time:
    b. Distance in kilometers:

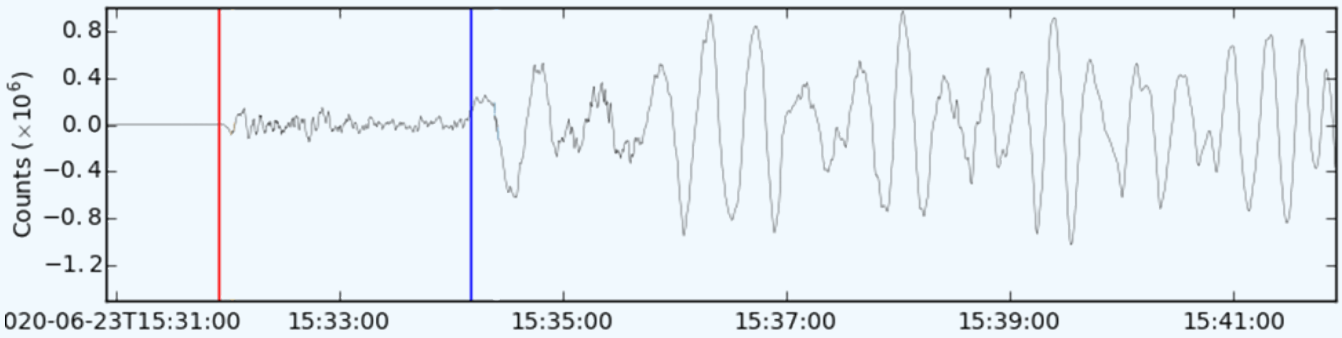


Figure 14.15: Station 2 Seismogram. Figures by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

13. The third seismogram (Figure 14.16) is located at Station 3. Station 3 is at Sierra la Laguna Baja, California Sur, in Mexico. Its latitude is 23.69° and its longitude is -109.94°. The P wave arrival,marked by the red vertical line on the left and arrived at 15:32:37 UTC. The S wave arrival, marked by the blue vertical line on the right and it arrived at 15:35:27 UTC. Find the S-P time and the distance in kilometers from the epicenter to Station 3.
    a. S-P time:
    b. Distance in kilometers:

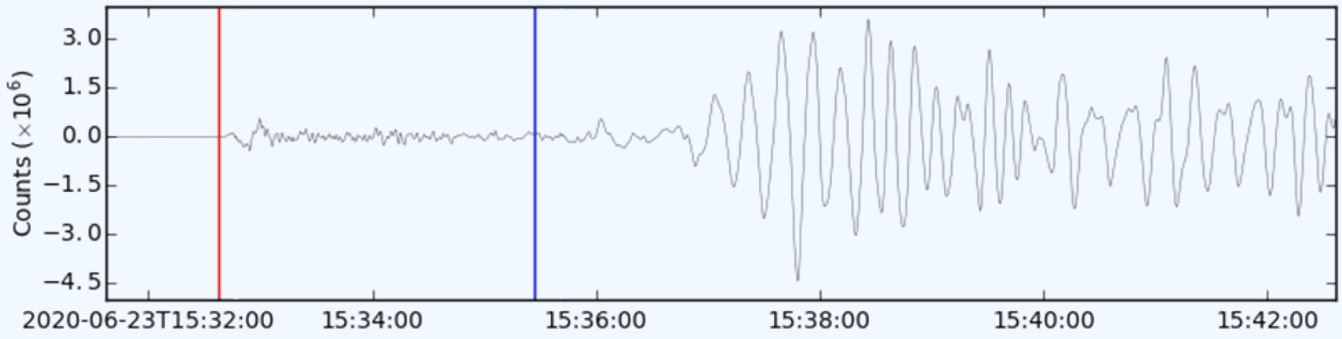


Figure 14.16: Station 3 Seismogram. Figures adapted from the Wilber 3 Data Service of the Incorporated Research Institutions for Seismology (IRIS) are used with permission

Next, you'll use the Earthquake Triangulation tool from the Incorporated Research Institutions for Seismology (IRIS) website.

Step 1

Go to the Earthquake Triangulation website.

Step 2.

Click on “+Station”.

Step 3

At the bottom of the website, enter the Station 1 data; you will need the latitude and longitude (provided in the question 11 text) and distance from the epicenter in kilometers that you found for question 11b. Note: the website automatically creates data in the latitude, longitude, and distance kilometers fields, but you need to add your own data to those fields instead.

Step 4

On the upper-right of the window, click on “+Station”.

Step 5

At the bottom of the website, enter the Station 2 data; you will need the latitude and longitude (provided in the question 12 text) and distance from the epicenter in kilometers that you found for question 12b.

Step 6

On the upper-right of the window, click on “+Station”.

Step 7

At the bottom of the website, enter the Station 3 data; you will need the latitude and longitude (provided in the question 13 text) and distance from the epicenter in kilometers that you found for question 13b.

Step 8

Use the + sign to zoom in on the location where the radius circles around each station come close to intersecting

Exercise 1.14.5

14. What are the names of the towns closest to the earthquake’s epicenter?
15. Use Your Critical Thinking Skills: Why do you think that the three lines don’t perfectly intersect? (This would be needed to accurately triangulate the earthquake’s epicenter).

The earthquake that you analyzed for questions 11 through 15 occurred on June 23, 2020, in Oaxaca, Mexico. The hypocenter was at a depth of 26.3 kilometers (16 miles). Figure 14.17 shows the tectonic setting for this earthquake. The IRIS Teachable Moment page (2020, p. 4) explains that:

> As part of the circum-Pacific “Ring of Fire”, Mexico is one of the most seismologically and volcanically active regions on Earth. Most of Mexico is on the North American Plate. Offshore of southern Mexico, the oceanic Cocos Plate subducts

beneath the North American Plate at the Middle America Trench. In the area of this earthquake, the Cocos Plate subducts toward the northeast at a rate of approximately 6.5 centimeters per year.

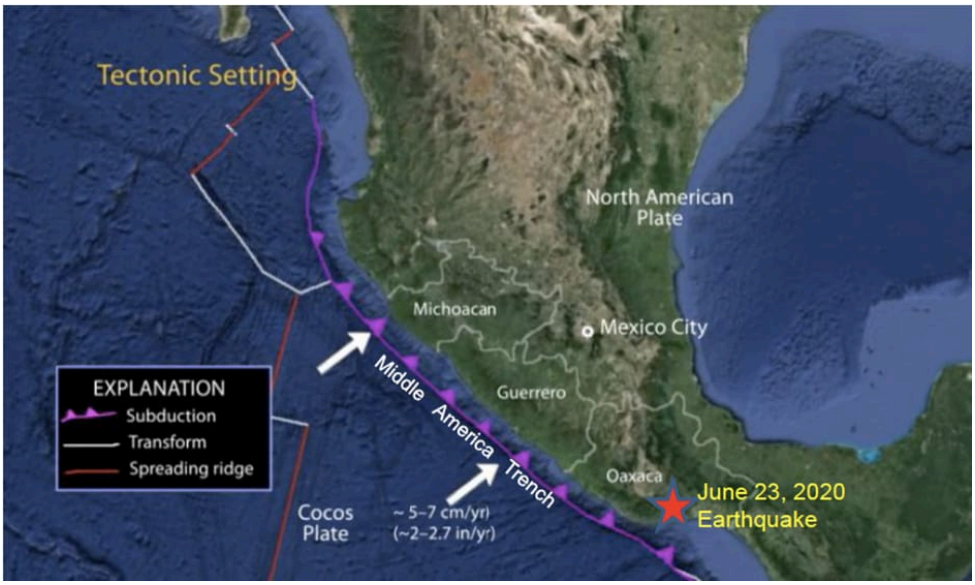


Figure 14.17: Tectonic Setting Map for the June 23, 2020 Earthquake in Oaxaca, Mexico. Figure by Incorporated Research Institutions for Seismology (IRIS) is used with permission

The June 23, 2020, earthquake was a 7.4 magnitude earthquake and more than two million people felt moderate to strong shaking. But how strong is a 7.4 magnitude earthquake? And what does moderate to strong shaking mean? The next section of the lab explains the difference between an earthquake's magnitude and an earthquake's intensity so you will be able to answer these questions!

Part C. Earthquake Magnitude and Intensity

Most of us have heard of the **Richter scale** for determining the magnitude of an earthquake. This scale uses two pieces of data from seismograms: the time difference between the first arrival of the P wave and the first arrival of the S wave (recall that this is the S-P time), and the S wave maximum amplitude. Figure 14.18 shows a sample seismogram on the top and the three scales below it. A line drawn from the S-P time plotted on the left scale to the S wave maximum amplitude on the right scale marks a magnitude of 5.0 on the middle Richter scale. The Richter scale is logarithmic so each time the magnitude increases by 1.0 there is a ten-fold increase in the measured amplitude. In terms of the energy released by an earthquake, each number increase on the Richter scale represents approximately 32 times more energy released. The Richter scale is also called M_L, where M stands for magnitude and $_L$ stands for local. Typically, seismologists no longer use the Richter scale except for local earthquakes (within about 150 kilometers) that are smaller than 4.0 on the scale. The Richter scale was developed in the 1930s and there are now more sophisticated ways to determine an earthquake's magnitude.

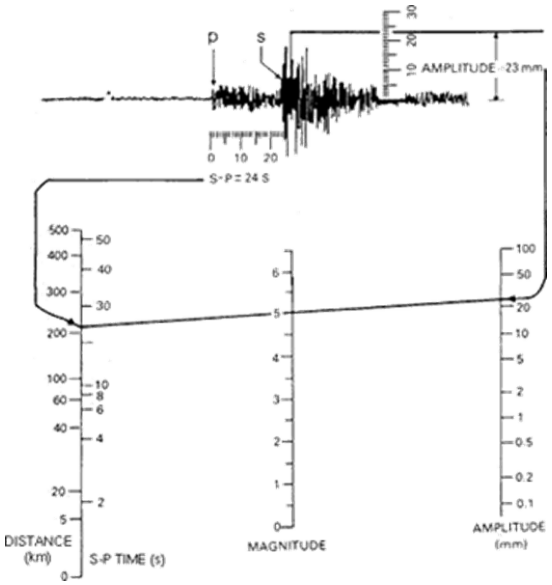


Figure 14.18: The Richter Scale. Figure by USGS is in the public domain

For earthquakes larger than 4.0, the **Moment Magnitude scale** (M_W) is used. Like the Richter scale, it is logarithmic. And, the Moment Magnitude scale was designed so it is roughly equal to the Richter scale (for example, a 6.5 earthquake on the Moment Magnitude scale is roughly equal in magnitude to a 6.5 earthquake on the Richter scale). The Moment Magnitude scale is calculated based on the distance the fault moved (it's slip), the strength of the rocks along the fault (the rock's rigidity), and the area of the fault that slipped.

To give you an idea of how much more energy is released by earthquakes of different magnitudes you will use an online calculator from the United States Geological Survey.

Step 1

Go to the "How Much Bigger...?" Calculator website.

Step 2

In the box beneath "How much bigger is a magnitude..." type 6.0.

Step 3

In the box beneath "than a magnitude..." type 5.0.

Step 4

Click on the Calculate button.

Step 5

Scroll down to read the information provided and fill in the blanks for the following question.

Exercise 1.14.6

16. A magnitude 6.0 earthquake is _____ times bigger than a magnitude 5.0 earthquake, but it is _____ times stronger (energy release).

Step 6

Scroll up and click the Reset button. Follow steps 1 through 5 using the magnitudes indicated to answer the following questions.

Exercise 1.14.7

17. A magnitude 7.0 earthquake is _____ times bigger than a magnitude 5.0 earthquake, but it is _____ times stronger (energy release).
18. A magnitude 8.0 earthquake is _____ times bigger than a magnitude 5.0 earthquake, but it is _____ times stronger (energy release).
19. A magnitude 9.0 earthquake is _____ times bigger than a magnitude 5.0 earthquake, but it is _____ times stronger (energy release).

Keep this website open as you will need to use it later in this lab.

Table 14.2 provides the number of earthquakes that occurred at different magnitude ranges above 5.0 M_w from 2000 to 2019. By comparison:

- approximately 1,000,000 earthquakes with a magnitude of 2.0-2.9 occur each year,
- approximately 100,000 earthquakes with magnitudes of 3.0-3.9 occur each year, and
- approximately 10,000 earthquakes with magnitudes of 4.0-4.9 occur each year.

The number of earthquakes with magnitudes of 7.0 and greater has remained relatively consistent since recordkeeping began. Although the average number of large earthquakes per year is fairly constant, they can occur in clusters. However, that does not imply that earthquakes that are distant in location, but close in time, are related. There has definitely been an increase in the number of earthquakes that have been detected and located due to a more than 10-fold increase in the number of seismic stations worldwide over the past century.

Table 14.2: Worldwide Earthquakes, 2000-2019. Data from USGS

Year	5-5.9 M_w Count	6-6.9 M_w Count	7-7.9 M_w Count	8.0+ M_w Count
2000	1,344	146	14	1
2001	1,224	121	15	1
2002	1,201	127	13	0
2003	1,203	140	14	1
2004	1,515	141	14	2
2005	1,693	140	10	1
2006	1,712	142	9	2
2007	2,074	178	14	4
2008	1,768	168	12	0
2009	1,896	144	16	1

Year	5-5.9 M_w Count	6-6.9 M_w Count	7-7.9 M_w Count	8.0+ M_w Count
2010	2,209	150	23	1
2011	2,276	185	19	1
2012	1,401	108	12	2
2013	1,453	123	17	2
2014	1,574	143	11	1
2015	1,419	127	18	1
2016	1,550	130	16	0
2017	1,455	104	6	1
2018	1,674	117	16	1
2019	1,492	135	9	1

Exercise 1.14.8

20. Refer to Table 14.2.

    a. In what year did the highest number of 8.0+ magnitude earthquakes occur?

        i. Is this the same year that the highest number of 5-5.9, 6-6.9, and 7-7.9 earthquakes occurred?

    b. On average, how many 8.0+ magnitude earthquakes occurred between 2000 and 2019? Tip: Add the number of earthquakes in the 8.0+ M_w column and divide that number by twenty. Show your work.

    c. On average, how many 7-7.9 magnitude earthquakes occurred between 2000 and 2019? Tip: Add the number of earthquakes in the 7-7.9 M_w column and divide that number by twenty. Show your work.

    d. Use Your Critical Thinking Skills: Suppose a friend asks you, “Why are we having so many more earthquakes this year?” Explain your response in one to two sentences.

While magnitude scales measure the strength of the earthquake—the amount of energy it releases—**intensity** scales measure the impact of the earthquake in a specific area. Seismologists in the United States typically use the **Modified Mercalli Intensity scale** to measure an earthquake’s intensity. On this scale, the impact of the earthquake is represented by Roman numerals as shown in Table 14.3. An earthquake’s intensity is based on two main factors:

- The local geology: Bedrock shakes the least while soft mud shakes the most.
- The hypocenter depth: Deeper hypocenters cause less shaking than hypocenters closer to the surface.

The strength of shaking experienced and the length of shaking also influence an earthquake’s intensity.

Table 14.3: Modified Mercalli Intensity Scale. Adapted from USGS

Intensity	Shaking	Description/Damage
I	Not felt	Not felt except by very few under especially favorable conditions.
II	Weak	Felt only by a few people at rest, especially on upper floors of buildings.
II	Weak	Felt quite noticeably by people indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.

Intensity	Shaking	Description/Damage
IV	Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Very Strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; damage considerable in poorly built or badly designed structures; some chimneys broken.
VIII	Severe	Damage slight in specially-designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Violent	Damage considerable in specially-designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations. Liquefaction.
X	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

Exercise 1.14.9

21. Why would seismologists prefer to use the Moment Magnitude scale instead of the Richter scale? Hint: compare the variables used for the two scales.

22. What is the difference between earthquake magnitude and intensity?

23. About 26,000 people felt very strong shaking during the June 23, 2020, earthquake in Oaxaca. What type of damage occurs with this level of earthquake intensity? Hint: refer to Table 14.3.

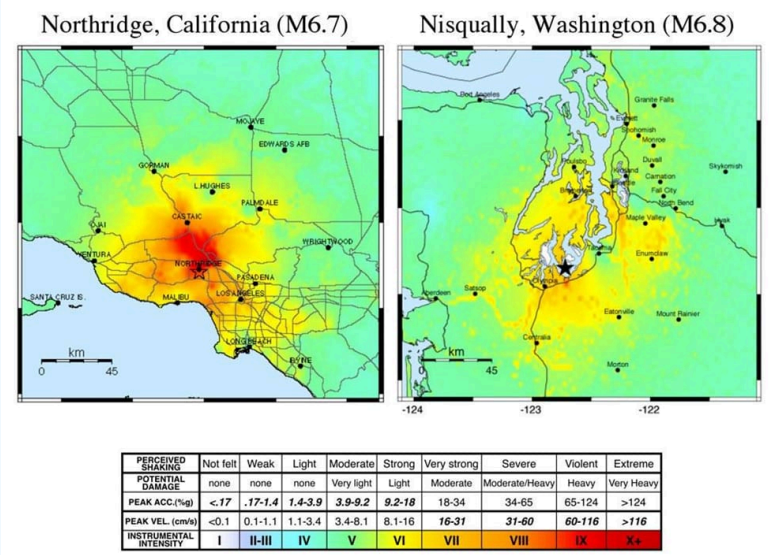
24. What is the highest earthquake intensity that you have experienced? Indicate the Roman numeral of the Modified Mercalli Intensity scale and in two to three sentences describe what you experienced. If you have not experienced an earthquake, ask a classmate or friend about their experience and respond with that information.

Figure 14.19 shows the Modified Mercalli Intensity scale mapped for two different earthquakes. The map on the left shows the intensity of the 1994 Northridge 6.7 M_w earthquake (hypocenter at a 18.20 kilometer depth) and the map on the right shows the intensity of the 2001 Nisqually 6.8 M_w earthquake (hypocenter at a 57 kilometer depth).

25. Use the earthquake magnitude comparison calculator (which you used in questions 16 through 19 above) to determine how much more energy is released in a 6.8 magnitude earthquake compared to a 6.7 magnitude earthquake.

26. Which earthquake had the greatest intensity? Explain your response in at least one sentence.

27. Why does the lower magnitude earthquake have a higher intensity? Explain your response in two to three sentences.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<.17*	*.17-1.4*	*1.4-3.9*	*3.9-9.2*	*9.2-18*	18-34	34-65	65-124	>124
PEAK VEL. (cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	*16-31*	*31-60*	*60-116*	*>116*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 14.19: The Modified Mercalli Intensity Scale Mapped near the Epicenters of Two Different Earthquakes. Figure by USGS is in the public domain

Liquefaction

Liquefaction occurs when sediments at or near the surface behave like a liquid due to the shaking caused by an earthquake. These loosely compacted and water-saturated sand and silt sediments move and flow during strong shaking. Liquefaction occurs in a variety of natural locations such as marshlands, alluvial (river-deposited sediments) floodplains, beaches, and areas with high water tables. Places with artificial fill are also susceptible to liquefaction. Artificial fill are sediments used for construction purposes to provide support for human-built structures and to build up areas that were once submerged.

Check It Out! Liquefaction

IRIS Earthquake Science has a neat video showing seismic waves and liquefaction called "Amplification and Liquefaction Animation". (Video length is 1:24). You can see the damage caused by liquefaction from a September 28, 2018 earthquake in Indonesia on a BBC News video called "Indonesia quake turns ground into liquid" (caution: the video shows upsetting scenes of destruction).

Figure 14.20 is a map of the liquefaction hazard probability estimates for northwestern Alameda County in the Bay Area. The map includes the communities of Alameda, Berkeley, Emergyville, Oakland, and Piedmont. Based on seismic models, the map predicts the percentage of area that would liquefy if a 7.1 magnitude earthquake occurred on the Hayward fault.

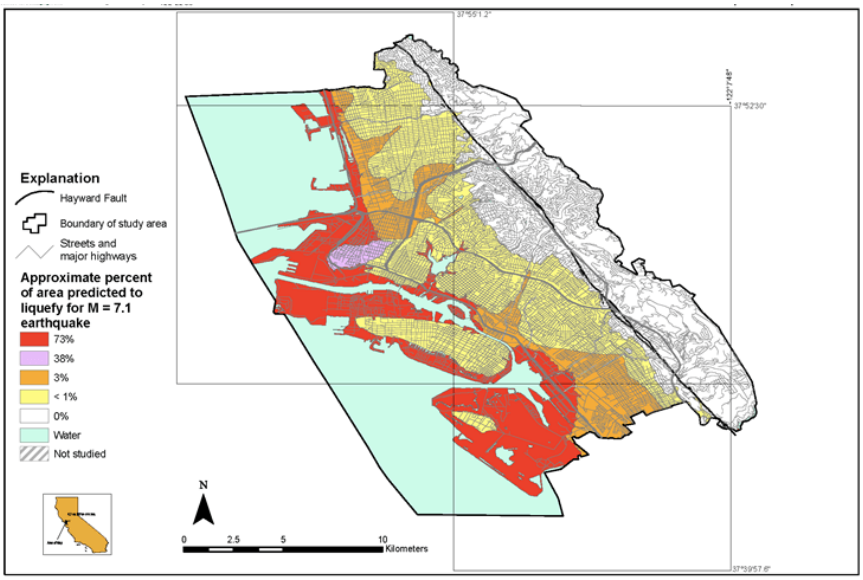


Figure 14.20: Liquefaction Hazard Map for Northwestern Alameda County. Figure by USGS is in the public domain

Figure 14.21 is a map excerpt that shows the types of sediments found in northwestern Alameda County. It provides information for part of the area mapped in Figure 14.20. Each sediment type is labeled on the sediment map as follows:

- Qhf, Qpf, Qf, and Qof are alluvial fan sediments,
- afem is artificial fill, and
- Qds are beach and dune sands.

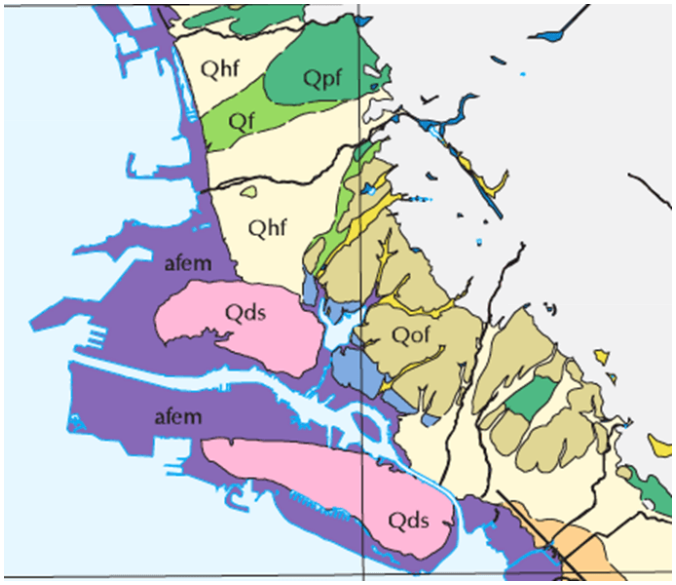


Figure 14.21: Map of Sediments found in Northwestern Alameda County. Figure adapted from the USGS is in the public domain

Exercise 1.14.10

28. Compare Figures 14.20 and 14.21. Which type of sediment has the largest area that is predicted to liquefy if a 7.1 magnitude earthquake on the Hayward fault occurs?

29. Search google maps for Alameda, California, (or search for the coordinates of 37.7906, -122.2801). Click on satellite view and zoom in on the area of the online map that matches the maps of Figure 14.20 and Figure 14.21. List five types of infrastructure and buildings that are found in areas that will likely liquefy during a 7.1 magnitude earthquake on the Hayward fault. Tip: use google's streetview to better understand what infrastructure and buildings are present.

30. If a 6.1 magnitude earthquake occurred in northwestern Alameda County, do you think the same areas would liquefy as shown in Figure 14.20? Why or why not? Explain your response in two to three sentences.

Let's find out if your college is located in an area that has the potential to liquefy. We'll use the Regulatory Maps Geo Application created by the California Department of Conservation. This geographic information system (GIS) identifies areas that are prone to three earthquake hazards: liquefaction; earthquake-induced landslides; and amplified ground shaking. Factors that cause an area to be mapped as prone to liquefaction include having groundwater within 40 feet of the Earth's surface, the presence of sands and silts deposited in the last 15,000 years, and a prediction that strong levels of shaking caused by earthquakes will occur during the next 50 years.

In California, there are environmental and earthquake hazard disclosure requirements for sellers of residential real estate. Additionally, for new construction or significant remodels, site-specific geologic studies are required so builders can avoid known hazards or incorporate mitigation features. Mitigation means to lessen the impact of something. So, mitigation features for a building might be to install reinforced concrete that could withstand higher levels of seismic energy without failing.

It is important to note that the map may not show all faults that have the potential for surface fault rupture, either within the Earthquake Fault Zones or outside their boundaries. Additionally, the map may not show all areas that have the potential for liquefaction, landsliding, strong earthquake ground shaking or other earthquake and geologic hazards. Also, a single earthquake capable of causing liquefaction or triggering landslide failure will not uniformly affect the entire area zoned.[256] Therefore, the information presented in the GIS is limited.

Check It Out! Seismic Hazards Program Information

Read more about the laws that require the Regulatory Maps Geo Application and how the GIS was created at the California Department of Conservation Seismic Hazards Program website.

Step 1

Go to the Earthquake Zones of Required Investigation website

Step 2

Read the information about the Regulatory Maps Geo Application.

Step 3

Click the checkbox to agree to the terms and conditions.

Step 4

Click OK to access the map.

Step 5

In the upper-right portion of the map, click on the legend icon. (This icon has three shapes next to three horizontal lines).

Exercise 1.14.11

31. What color represents a fault zone?
32. What color represents a liquefaction zone?
33. What color represents a landslide zone?

Step 6

Click the “x” on the upper-right to close the map legend.

Step 7

In the search box that says Esri World Geocoder, type in the address of your college.

Step 8

Click the magnifying glass.

Step 9

Click on the map where your college is located.

Step 10

Click on the arrow to open the pop-up window.

Exercise 1.14.12

34. Is your college located in a liquefaction zone?
35. Has your college area been evaluated for a liquefaction hazard?
36. Use Your Critical Thinking Skills: Some colleges are located in areas that have not been evaluated for these earthquake hazards. Does this mean that the colleges are not at risk of earthquake hazards? Why or why not? Your response should be one to two sentences in length.

Step 11

Click the “x” on the upper-left corner to close the pop-up window.

Step 12

Zoom out of the map until you find a large area that is mapped in a liquefaction zone.

Exercise 1.14.13

37. Where is the largest liquefaction zone closest to your college?

Part D. Earthquake Probability and Risk

Before we take a look at earthquake risks, we need to make sure everyone understands probability and the difference between a hazard and a risk.

➢ If you flip a coin (let's say a quarter), there is a 1 in 2 chance of "heads".

- 1 divided by 2 = 50%
- So a coin flip has a 50% probability.

➢ If you roll a six-sided die (one dice), there is a 1 in 6 chance of you rolling a 1.

- 1 divided by 6 = ~17%
- So rolling a 1 on one die has about a 17% probability.

A **hazard** has the potential to cause harm while **risk** is the probability of a hazard event causing harm. So, earthquakes are an example of a hazard and the risk of an earthquake is the probability that a particular earthquake will cause loss of life, injuries, or property damage.

In 2015, the United States Geological Survey in cooperation with the Southern California Earthquake Center, the California Geological Survey, and the California Earthquake Authority released a report on the **third Uniform California Earthquake Rupture Forecast** (a computer model known as **UCERF3**). The goal for this model is to determine where and when faults might slip. Keep in mind that the UCERF3 model provides a forecast, not a prediction. Seismologists are unable to predict earthquakes—they are unable to determine the time, date, location, and magnitude of future earthquakes. Seismologists can only calculate the probability that an earthquake will occur in an area within a certain number of years. The USGS explains the four major components of the UCERF3 model as follows:

➢ geodesy (precise data on the slow relative movement of the Earth's tectonic plates),

➢ geology (mapped locations of faults and documented offsets on them),

➢ seismology (occurrence patterns of past earthquakes), and

➢ paleoseismology (data from trenches across faults documenting the dates and offsets of past earthquakes on them).[257]

UCERF3 mathematically models each of these components but it's important to remember that the datasets are not 100% complete. For example, not all faults in the state are mapped or have documented offsets (slips) from previous earthquakes.

Figure 14.22 provides a map that was created by the UCERF3 model. The map shows the likelihood that a 6.7 magnitude earthquake will occur in the next thirty years (starting from 2014). The 6.7 magnitude was selected because this is the same magnitude as the 1994 Northridge earthquake and a thirty-year timeframe is used because that is the typical time for a residential mortgage.

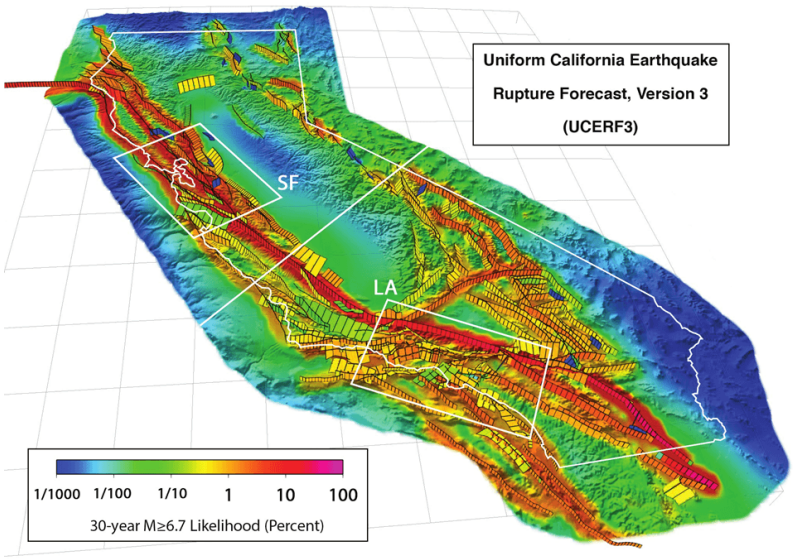


Figure 14.22: Map of Likelihood of Experiencing a 6.7 or Larger Earthquake in the Next 30 Years. Faults are shown as rectangles outlined in black. For the purposes of the source report, the white line in the middle of the map represents the boundary between Northern and Southern California. The San Francisco and Los Angeles Regions are shown as rectangles outlined in white. Figure by WGCEP 2014 team (USGS, CGS, and SCEC) is in the public domain

Exercise 1.14.14

38. Refer to Figure 14.22. Where is the highest probability (likelihood) that a 6.7 or larger earthquake will occur in the next thirty years? Hint: find the location with the pink/purple shading.

Table 14.4 provides the probabilities of earthquakes of particular magnitudes occurring in the next thirty years (starting from 2014). Refer to the caption of Figure 14.22 to see the boundaries of the locations listed in Tables 14.4a through 14.4b.

Table 14.4a: Earthquake Probabilities in the Northern California Region. Data from USGS

Magnitude	30-Year Likelihood of One or More Events
≥ 6.0	100%
≥ 6.7	95%
≥ 7.0	76%
≥ 7.5	28%
≥ 8.0	5%

Table 14.4b: Earthquake Probabilities in the Southern California Region. Data from USGS

Magnitude	30-Year Likelihood of One or More Events
≥ 6.0	100%
≥ 6.7	93%
≥ 7.0	75%
≥ 7.5	36%
≥ 8.0	7%

Table 14.4c: Earthquake Probabilities in the San Francisco California Region. Data from USGS

Magnitude	30-Year Likelihood of One or More Events
≥ 6.0	96%
≥ 6.7	60%
≥ 7.0	46%
≥ 7.5	31%
≥ 8.0	7%

Table 14.4d: Earthquake Probabilities in the Los Angeles Region. Data from USGS

Magnitude	30-Year Likelihood of One or More Events
≥ 6.0	96%
≥ 6.7	60%
≥ 7.0	46%
≥ 7.5	31%
≥ 8.0	7%

Exercise 1.14.15

Refer to Tables 14.4a through 14.4d to answer the following six questions.

39. Which regions have the highest likelihood of a 6.0 magnitude or greater earthquake?
40. Which region has the highest likelihood of a 6.7 magnitude or greater earthquake?
41. Which region has the highest likelihood of a 7.0 magnitude or greater earthquake?
42. Which region has the highest likelihood of a 7.5 magnitude or greater earthquake?
43. Which region has the highest likelihood of a 8.0 magnitude or greater earthquake?
44. What are three conclusions that you could make based on the data from Table 14.4?

As mentioned above, slip rate data is utilized in UCERF3. Figure 14.23 shows the average slip rates in millimeters per year on major faults. In addition to forecasting probabilities in Northern California, Southern California, the San Francisco Region, and the Los Angeles Region, UCERF3 also assigned individual 30-year probabilities for a 6.7 magnitude or larger earthquake occurring on major faults as follows:

- Southern San Andreas: 59%
- Hayward-Rodgers Creek: 31%
- San Jacinto: 31%
- Northern San Andreas: 21%
- Elsinore: 11%
- Calaveras: 7%
- Garlock: 6%

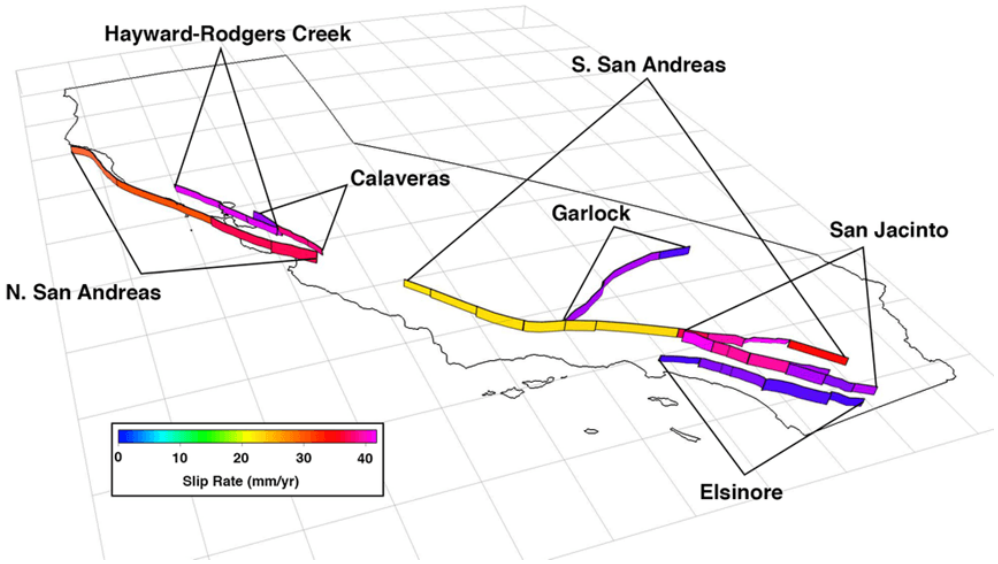


Figure 14.23: Map of Average Slip Rates on Major Faults. Figure by WGCEP 2014 team (USGS, CGS, and SCEC) is in the public domain

The California Earthquake Authority (CEA) website provides information on earthquake risks by county. In the wake of the loss of life, injuries, and catastrophic damage caused by the 1994 Northridge earthquake, the California legislature established the California Earthquake Authority. The CEA is a publicly managed and privately financed organization that provides residential earthquake insurance.

Exercise 1.14.16

47. Go to the California Earthquake Risk Map & Faults by County website. and select your county from the drop-down menu next to the text that says “What are the earthquake risks near”. What are three facts that you learned about your county and its major faults from this website? Be sure to indicate what types of faults are found in your county (e.g., normal, reverse, and/or strike-slip).

48. **Risk perception** is the subjective way that people interpret the severity of a potential harm or loss. Risk perception is a complex process based on numerous factors including, but not limited to, perceived self-efficacy (whether or not an individual feels they are able to control or influence a situation), previous experience, knowledge of the underlying causes of the risk, and peer group perspectives. Based on the probability statistics presented in Table 14.4, how do you perceive the risk of a future earthquake in your area? Write three to four sentences that incorporate the information that you have learned in this lab.

49.  How prepared are you and your loved ones for an earthquake? Read the CEA's Seven Steps to Earthquake Safety webpage, or search the internet for an earthquake preparedness guide. In two to three sentences, discuss how prepared you feel for an earthquake.

50. Which of the earthquake preparedness tips could you do right now without having to spend money? List at least three steps that you could take to become more prepared for an earthquake without spending money.

Earlier in the lab, you learned that the local geology, hypocenter depth, strength of shaking, and length of shaking influence an earthquake's intensity. The damage from an earthquake is influenced by other variables such as building age and type. Although local building codes to mitigate (lessen the impact of) the damage caused by earthquakes have been enacted since 1925, it wasn't until the early 1970s that the State of California passed widespread legislation requiring compliance with building and infrastructure standards and in 1977 the federal government adopted the Earthquake Hazards Reduction Act. Therefore, older buildings may not have been constructed with seismic safety in mind. In terms of building type, the building design and the materials used for construction play a major role in the type of damage that will be incurred from ground shaking due to an earthquake. Table 14.5 provides a brief overview of building types and seismic risks.

Table 14.5: Buildings and Seismic Risks

Building Type	Seismic Risk
Concrete	Without steel-reinforced columns, concrete buildings crack and collapse. Also, cheaper concrete (that uses more water) is weaker than concrete made with more cement
Brick	When unreinforced, likely to crack and collapse
Houses with concrete foundations	Without bracing and anchoring, houses may slide off their foundations
Living spaces above garages (or apartment buildings with parking spaces on the first floor)	Without retrofitting, garage and parking space doors and walls are not braced for ground shaking
Post and pier house (these are built without foundations an have crawl spaces underneath)	Without bracing and new footings, houses are at risk of shifting and collapsing
Buildings on slopes	Without retrofitting, these buildings may not withstand shaking

So far, you've learned about multiple factors that influence the damage done by an earthquake. These variables can be further understood by thinking in terms of a community's vulnerability to earthquake hazards. Vulnerability refers to the geographic, demographic, and economic conditions that increases a community's susceptibility to the impact of a hazard event. We can also think about how vulnerability influences a community's ability to prepare for a hazard event.

In 1998, researchers Robert Bolin and Lois Stanford published *The Northridge Earthquake: Vulnerability and Disaster*.[261] Several quotes from their book shed light on the relationship between vulnerability and the threat of hazards and their impacts:

> ➢ While earthquakes and other natural hazards may cause grave losses for a diversity of people, some of those people are much more likely to avoid or be able to cope with loss and damage. For those who cannot, the accumulated deficits of poverty, discrimination, and other structural constraints can only serve to amplify the effects of the hazard on their lives, deepening the daily struggles they face (Cannon 1994; Maskrey 1993). (p. 5)

➢ The most vulnerable are typically those with the fewest choices, those whose lives are constrained, for example, by discrimination, political powerlessness, physical disability, lack of education and employment, illness, the absence of legal rights, and other historically grounded practices of domination and marginalization (Blaikie et al. 1994). (p. 9-10)

➢ The estimated risks posed by such hazards are by no means equally distributed across the state or in Southern California specifically. They vary according to spatial factors, geological conditions, and land use patterns that locate some people and settlements nearer hazardous areas than others. The asymmetries of risk are reinforced by social inequalities that pertain in employment, income, wealth, legal protections, and the availability of secure housing. As we have suggested, it is precisely access to these social resources that can influence people's vulnerability to disaster (Blaikie et al. 1994; Dreze and Sen 1990). Employment, income, legal status, and ethnicity all bear directly on where people live, the kinds of structures they live in, and whether they have the resources to cope with untoward events in their lives. (p. 15)

➢ California's earthquake risk was produced by Anglo-European settlement and subsequent large-scale urbanization. Rapid population growth in its two primary urban centers, San Francisco and Los Angeles, has situated more than half the state's thirty million residents in areas of high seismic activity (Bolt 1993). (p. 64-65)

Exercise 1.14.17

51. List the vulnerability-related demographic and economic factors that are mentioned in the quotes from Bolin and Stanford (1998).

52. Table 14.6 below provides selected data for four census tracts located within 25 miles of the San Andreas Fault Complex. What are three conclusions that you can make regarding this data set? For example, one conclusion is that Census Tract 2 has the highest percentage of children under 10 years of age.

Table 14.6: Community Data. Data from California Office of Environmental Health Hazard Assessment

Variable	Census Tract 1	Census Tract 2	Census Tract 3	Census Tract 4
Population	3,035	5,339	6,989	4,143
% of population children under 10 years old	22%	25%	18%	9%
% of population over 65 years old	6%	7%	8%	10%
% of adults that have less than a high school education	48%	36%	31%	9%
% of population living below twice the federal poverty level	80%	86%	54%	19%
% of population making less than 80% of their counties' median family income and paying greater than 50% of their income towards housing costs	34%	43%	9%	18%
% of households with limited English proficiency	32%	13%	16%	4%

53. Based on the data provided in Table 14.6, do you think each census tract would feel the same impacts from a severe earthquake? Explain your response in three to four sentences.

54. Let's suppose that you are working on state plans to improve the earthquake preparedness of vulnerable communities in California. What is one recommendation that you would make for each census tract shown in Table 14.6?
    a. Census Tract 1:
    b. Census Tract 2:
    c. Census Tract 3:
    d. Census Tract 4:

Part E. Wrap-Up

Consult with your geography lab instructor to find out which of the following wrap-up questions you should complete. Attach additional pages to answer the questions as needed.

Exercise 1.14.18

55. What is the most important idea that you learned in this lab? In two to three sentences, explain the concept and why it is important to know.

56. What was the most challenging part of this lab? In two to three sentences, explain why it was challenging. If nothing challenged you in the lab, write about what you think challenged your classmates.

57. What is one question that you have about what you learned in this lab? Write your question along with one to two sentences explaining why you think your question is important to ask.

58. Review the learning objectives on page 1 of this lab. How would you rate your understanding or ability for each learning objective? Write one sentence that addresses each learning objective.

59. Sketch a concept map that includes the key ideas from this lab. Include at least five of the terms shown in bold-faced type.

60. Create an advertisement to educate your peers on the important information that you learned in this lab. Include at least three key terms in your advertisement. The advertisement should be about half a page in size (about 4 inches by 6 inches).

61. One way to think of physical geography is that it is the study of the relationships among variables that impact the Earth's surface. Select two variables discussed in this lab and describe how they are related.

62. How does what you learned in this lab relate to your everyday life? In two to three sentences, explain a concept that you learned in this lab and how it relates to your day-to-day actions.

63. How does what you learned in this lab relate to current events?
    a. Write the title, source, and date of a news item that relates to this lab.
    b. In two to three sentences, discuss how the news item relates to what you have learned in this lab.
    c. In one to two sentences, discuss whether or not the news item accurately represents the science that you learned. Tip: consider whether or not the news item includes the complexity of the topic.

64. Search O*NET OnLine to find an occupation that is relevant to the topics presented in today's lab. Your lab instructor may provide you with possible keywords to type in the Occupation Quick Search field on the O*NET website.
    a. What is the name of occupation that you found?
    b. Write two to three sentences that summarize the most important information that you learned about this occupation.
    c. What is one question that you would want to ask a person with this occupation?

Answer available at the end of this section.

[256] Text by the California Department of Conservation is in the public domain

[257] Text by USGS is in the public domain

[261] Bolin, R., & Stanford, L. (1998). *The Northridge Earthquake: Vulnerability and Disaster*. London: Routledge.

Answers

Exercise 1.14.2

Exercise 1.14.18

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1.15: Lab 15 - Fluvial Geomorphology

Learning Objectives

- Explain the relationship between streamflow and carrying capacity.
- Interpret a hydrograph and compare rural and urban hydrographs.
- Analyze a stream profile to determine how flow rates influence erosion and deposition.
- Calculate stream discharge.
- Identify the processes that create meandering streams, oxbow lakes, and waterfalls.
- Compare and contrast three deltas.
- Analyze fluvial processes on topographic maps before and after dam removals.

Introduction

Fluvial processes refer to processes related to rivers and streams and the landforms created by them. Due to the circulating effects of the hydrologic cycle, nearly every landscape is influenced by impacts of water flowing over the surface. Even in our desert regions, where precipitation is rare, we still see dried riverbeds (arroyos) and catchment basins (playas). Rivers have the ability to erode a landscape, transport material to other areas, and form other landscape features by depositing the materials in other locations.

In this lab you will learn about the factors and processes that influence the erosion, transportation, and deposition of material by water. You will also investigate the formation of landscape features that are created by rivers.

Part A. Streamflow and Carrying Capacity

Stream capacity refers to the total sediment that a stream carries. **Stream competence** is the ability of a stream to transport a particular size particle. Both of these variables change with the stream's velocity. Streams and rivers transport materials in a number of different ways. These include dissolved load, suspended load, and bed load:

➢ **Dissolved load** is composed of ions in solution. These ions are usually carried in the water all the way to the ocean.

➢ **Suspended load** is composed of sediments carried as solids in water. The size of particles that can be carried is determined by the stream's velocity. Faster streams can carry larger particles. Streams that carry larger particles have greater competence. Streams with a steep gradient (slope) have a faster velocity and greater competence, as well.

➢ **Bed load** are sediments that are too large to be carried as suspended load; these sediments are bumped and pushed along the stream bed. Bed load sediments do not move continuously: smaller particles are temporarily lifted and then dropped again. This jumping process is referred to as **saltation**. The intermittent movement of pushing, shoving, and dragging is called **traction**. Streams with high velocities and steep gradients do a great deal of down-cutting into the stream bed, which is primarily accomplished by movement of particles that make up the bed load.[263]

Exercise 1.15.1

1. In the space below, sketch and label a cross-section of a river with dissolved, suspended, and bed load. Include both the saltation and traction processes.

One of the strongest factors affecting a stream's ability to erode and transport material is the flow speed of the water. A Swedish geographer, Filip Hjulström, ran a series of experiments on the ability of water to transport specific particle sizes. Based on his research, he developed the **Hjulström curve** (Figure 15.1). The diagram shows the size of the particles that flowing water can erode and transport, compared to the speed of the water. **Clay**-sized grains are less than 0.002 millimeters (mm) in size, **silt**-sized grains are between 0.002mm to 0.05mm, and **sand**-sized grains are from 0.05mm to 2mm in size. Note that on Figure

15.1 the x-axis shows the grain sizes in millimeters and the y-axis shows the flow speed of the river in centimeters per second (cm/s).

There are several factors that influence the flow speed of the water. These include the amount of water, the slope of the stream bed, and the shape of the channel. You will explore some of these factors throughout this lab.

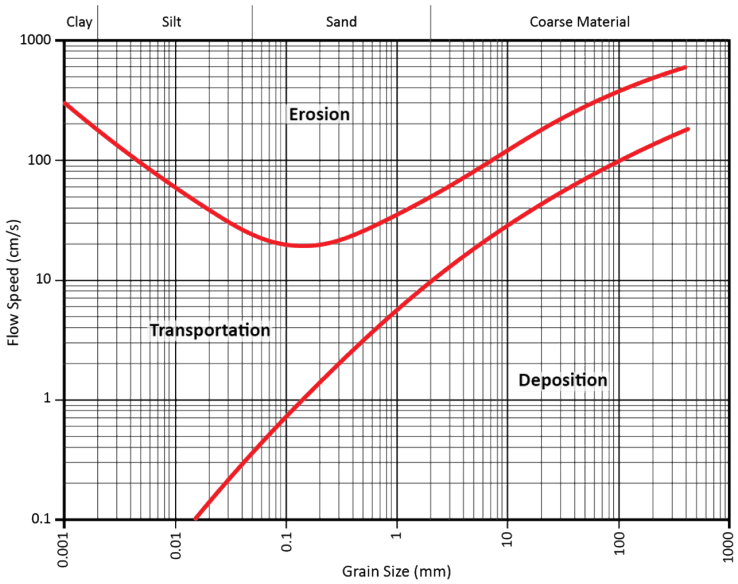


Figure 15.1: Hjulström Curve. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

Exercise 1.15.2

2. Refer to Figure 15.1.
    a. What is the minimum speed of water that will erode clay particles?
    b. What is the minimum speed of water that will erode sand particles?
    c. Why do you think the speeds to erode clay and sand particles are different? Explain your response in one sentence.
    d. You are exploring a creek bed and come upon a rock which has been transported downstream. The rock is the size of a bowling ball (8½ inches; 215 millimeters). How fast must the water have been moving to transport that rock?
    e. You are studying a river that is flowing at 1 meter/second (there are 100 centimeters in 1 meter). What size materials would you expect to see...
        i. ...eroding?
        ii. ...being transported?
        iii. ...being deposited on the riverbed?

Hydrographs and Storm Events

One of the factors that influences the speed of water in a channel is the amount of water. During a storm event, the amount of water being forced through a channel can be significant. One way of understanding the behavior of water in a channel during a storm event is by creating a **hydrograph**. Figure 15.2 illustrates two hypothetical hydrographs, one line representing a hydrograph for a rain event in an urbanized area and another line representing a hydrograph for the same rain event, but in a rural area.

The hydrograph illustrates the rate of flow as a result of the rain event in two different hypothetical situations: as it would be in an

urban area and how it would look in a rural area. Regardless of the setting, you will notice on the hydrographs that although the rain event illustrated lasted from 14:00 (2 p.m.) until 21:00 (9 p.m.) the peak flow at the hypothetical stream gauges did not take place until some time later. To explain this, consider what is happening. Rain falls on the ground, some water begins to pool, and eventually the water runs into rills and gullies, to eventually join the stream.

Stream flow, or **discharge**, is the volume of water that moves over a particular point of a stream at a particular point in time. The duration of time between the peak rainfall and the peak discharge is referred to as the **lag time**. You will notice that the lag time for urbanized areas and rural areas is different. In some very large drainage systems (such as the Mississippi River), this lag time can be even greater. In strong storm events, the discharge can also stay elevated for a greater duration. Spring melt-off of snow can also contribute to an increase in discharge.

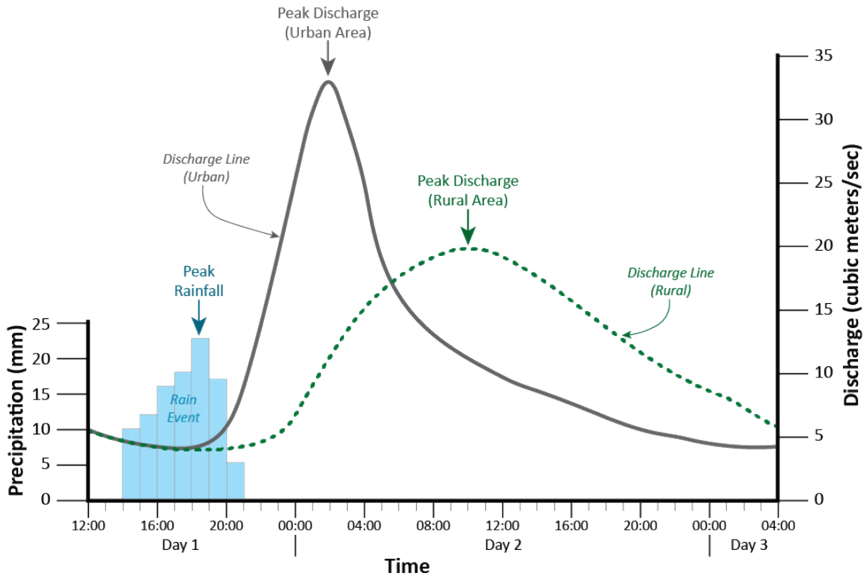


Figure 15.2: Two Hypothetical Hydrographs for Rural and Urban Environments. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

Exercise 1.15.3

3. Refer to Figure 15.2.
    a. What is the approximate lag time for the urbanized area?
    b. What is the approximate lag time for the rural area?
    c. Use Your Critical Thinking Skills: Why is there a difference between the lag time for an urbanized area and a rural area? Explain your response in one to two sentences.
    d. Use Your Critical Thinking Skills: What if the storm event dropped snow rather than rain? What would the hydrograph look like? Explain your response in one to two sentences.
    e. Use Your Critical Thinking Skills: What if the storm event was a warmer, more tropical storm dropping a larger quantity of warm rain on a pre-existing snow pack? What would the hydrograph potentially look like? Explain your response in one to two sentences.

Answer available at the end of this section.

Check It Out! More About America's Rivers

Interested in further exploring the flows of America's rivers? The US Geological Survey has made some of that information available online. Check out Water Watch to see current streamflow data, locations experiencing drought, and locations experiencing floods.

Part B. Stream Profiles

In addition to looking at the water flowing through rivers, we also study rivers by looking at the slope and the shape of rivers. These plots are referred to as **stream profiles**. A longitudinal profile illustrates the elevation compared to the mouth of a river (Figure 15.3). Vertical profiles illustrate a cross-cut view of a river at a specific location. It shows the water level, the topography under the river, and the surrounding floodplain (Figure 15.4). **Floodplains** are relatively flat, low-lying areas located near the mouth of a river that are prone to flooding during periods of high discharge.

Longitudinal Profiles

Figure 15.3 shows a hypothetical longitudinal river profile. It is, in essence, a graph showing the elevation of the river as it moves from the mountains or hills where it begins (its head) and how that elevation changes as it approaches the lake or ocean it enters (its mouth).

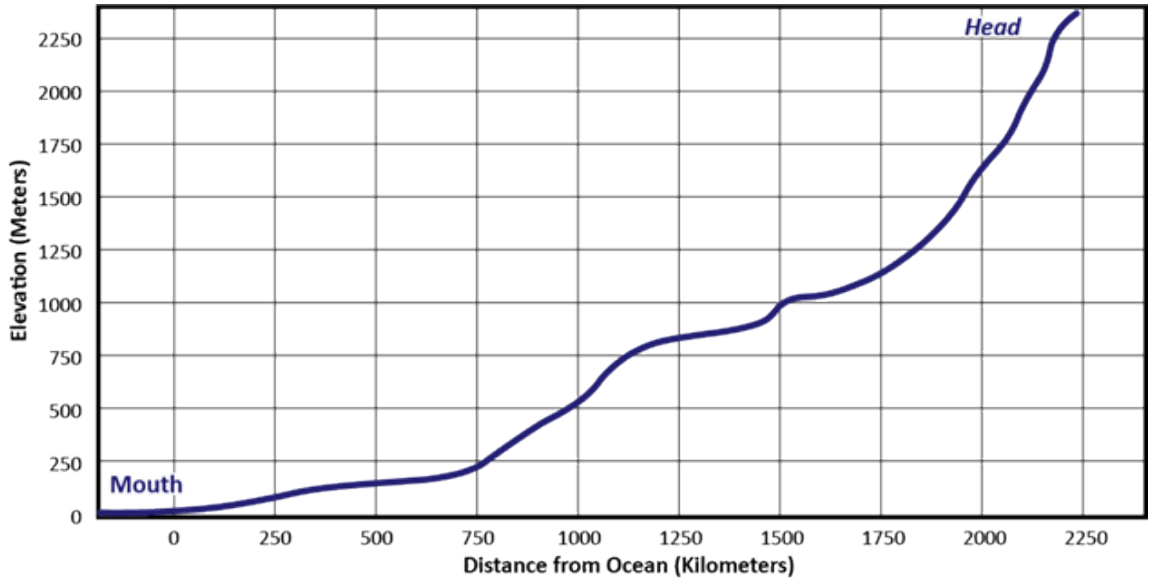


Figure 15.3: Hypothetical Longitudinal River Profile. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

Exercise 1.15.4

4. On Figure 15.3, above, label where you observe a steeper slope and a gentler slope.

With different slopes, you will see different speeds of water flow. As you learned in the previous section of this lab, different speeds of water are directly related to erosion. Thus, river erosion is not the same through the entire course of a river.

5. In what part of the river would you expect to see the greatest amount of erosion taking place? Explain your response in one sentence. Be sure to consider the river's gradient and velocity.

6. Where would you expect to see deposition of sediment? Explain your response in one sentence. Be sure to consider the river's gradient and velocity.

7. What happens to transported materials in a river, once the river reaches the mouth (flowing into a lake or ocean) and the movement stops? What type of feature is created? Explain your response in two to three sentences. Hint: consider what feature is found at the mouth of most major rivers throughout the world.

Vertical Profiles

Another way of looking at a river is in a **vertical profile**. Although it does not illustrate the movement of water through the entire course of the river, it does provide a clear snapshot at one specific location of the river. As illustrated in Figure 15.4, a vertical profile shows the cross-cut view of the river. It illustrates the riverbed shape, the area where water flows (the active channel) and often will illustrate the floodplain found on both sides of the river. These vertical profiles are developed through basic survey work, measuring the depth at regular intervals, perpendicular to the stream flow.

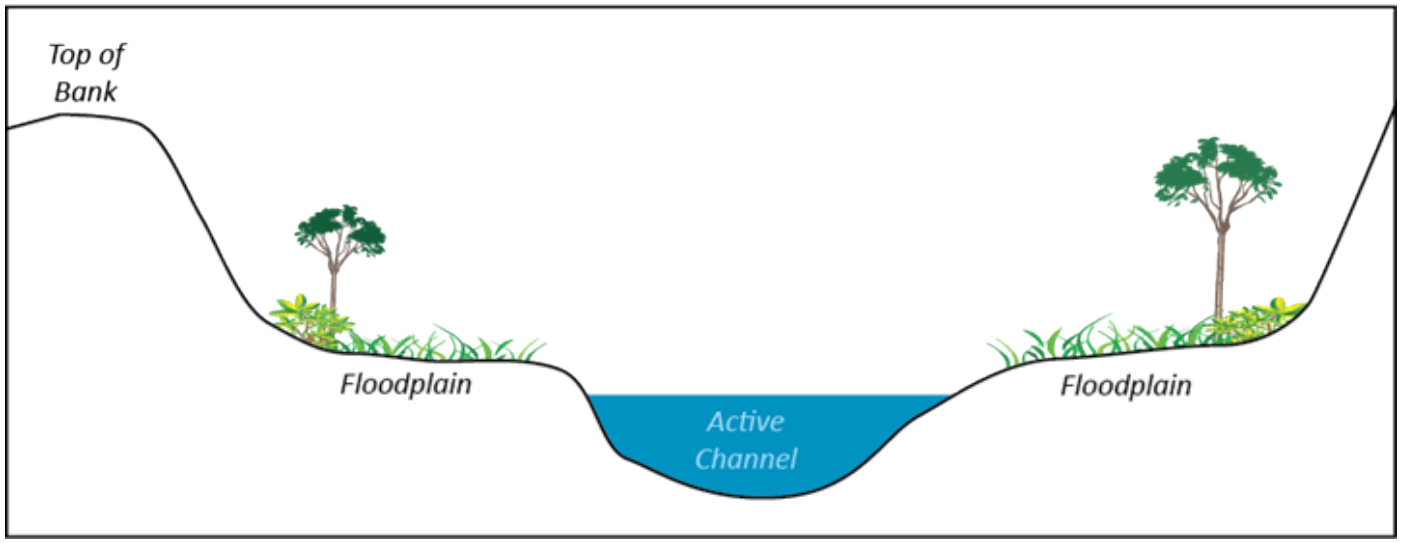


Figure 15.4: Hypothetical Vertical River Profile. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

Calculating Stream Discharge

Hydrologists—scientists who study the effects of water on and near the surface of the Earth—survey and create stream profiles to better understand the erosional impacts of a river as well as measuring the amount of water flowing through a specific area of a river. This is referred to as the stream discharge. In Figure 15.4, above, let us assume that the active channel has an area of 4.25 square meters (m^2) and that the average flow rate of the river is 1.4 meters per second (m/sec). Figure 15.5 diagrams one of these two variables: the area of an active channel.

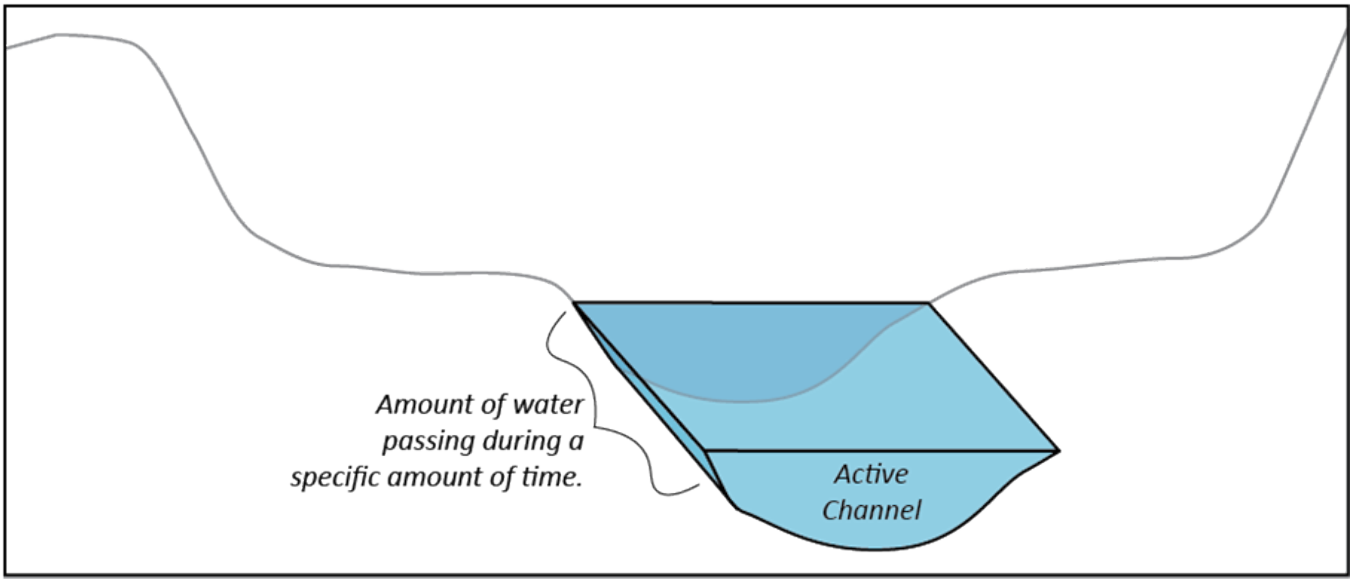


Figure 15.5: Volume of Water Passing through the River. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

To calculate the stream discharge, multiply the active channel by the flow rate. For reference, one cubic meter (m^3) has a volume of 1,000 liters, which is equivalent to about 264 gallons.

Area of Active Channel x Velocity = Stream Discharge

4.5 m^2 x 1.4 m/sec = 6.3 m^3/sec

Exercise 1.15.5

8. Now you try! Assume you and some classmates have surveyed a stream and found the active channel to be 7.6 meters squared. The average flow rate is 0.75 meters per second.
    a. How many cubic meters of water are passing that location per second? Show your calculation.
    b. How much water is passing that location per minute? Show your calculation.

The USGS operates over 8,200 continuous-record streamgages that provide streamflow information for a wide variety of uses including flood prediction, water management and allocation, engineering design, research, operation of locks and dams, and recreational safety and enjoyment.[269] Between April 29 and May 1, 2017, a vigorous weather system delivered intense rain, heavy snow, and tornadoes across the central and southern United States. In many areas, rainfall totals surpassed 9 inches (23 centimeters). This deluge led to dangerous flash floods and rivers cresting at record and near-record heights.[270] The discharge data collected at three streamgages along the Mississippi River during this May 2017 flood event are shown in Figure 15.6. The streamgage data for the point most upstream on the river is shown in red (St. Louis, Missouri, located at approximately 39°N latitude). The streamgage data for Memphis, Tennessee, located at approximately 35°N latitude, is shown in green. The streamgage data for the point most downstream on the river is shown in blue (New Orleans, Louisiana, located at approximately 30°N latitude).

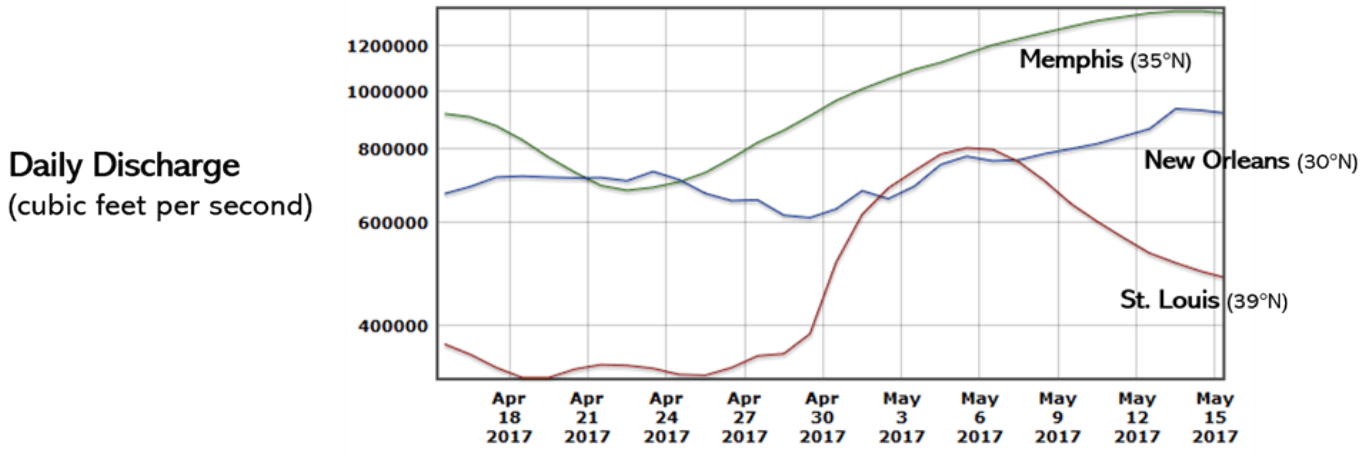


Figure 15.6: Hydrograph for Three Locations along the Mississippi River during a May 2017 Flood Event. Figure adapted from the USGS National Water Information System

Exercise 1.15.6

9. Refer to Figure 15.6.

   a. Apply What You Learned: Review the daily discharge data prior to the storm event (April 28 and earlier). Why might the daily discharge for the Mississippi River at St. Louis be much lower than the daily discharge for the Mississippi River at Memphis or New Orleans? Explain your response in one to two sentences.

   b. On the graph, lightly shade the dates when the storm precipitation was the heaviest (April 29 and May 1).

   c. Describe the daily discharge curves (the lines on the graph) for each location from April 29 through May 15, 2017.
      i. St. Louis:
      ii. Memphis:
      iii. New Orleans:

   d. Apply What You Learned: What is the lag time for each location?
      i. St. Louis:
      ii. Memphis:
      iii. New Orleans:

   e. Compare the daily discharge of the Mississippi River at St. Louis from April 24 to May 6, 2017. How much did the daily discharge increase during these dates?

   f. Use Your Critical Thinking Skills: Why do you think the daily discharge for St. Louis increased and decreased more rapidly than the daily discharge for Memphis or New Orleans? Explain your response in one to two sentences.



Check It Out! National Water Information System Mapper

Is there a streamgage near you? Check out the National Water Information System Mapper to find the locations of streamgages and access discharge data.

Floodplains

You will also notice in Figure 15.4 (shown earlier in the lab) that on both sides of the river is a region referred to as a floodplain. As the name implies, these floodplains are the areas where water flows when the water level rises higher than normal. In some stream channels, these floodplains and banks are easy to identify. In other areas, such as the Sacramento Valley, these floodplains are very wide. These floodplains are often rich agricultural soils, replenished each flood season with new, nutrient-rich sediments. The wealth and prosperity of Ancient Egypt was due to the nutrient-rich sediments flooding down the Nile River each year. Often when significant storm events take place, individuals who have used the floodplain for a variety of reasons are taken by surprise, at times with devastating outcomes.



Check It Out! More About Floodplains

Do you live on or near a floodplain? Find out! The Federal Emergency Management Agency (FEMA) has mapped out all of the floodplains. Go to the FEMA Flood Map Service and search for your address.

Exercise 1.15.7

10. Use Your Critical Thinking Skills: Now you're the city planner! The Federal Emergency Management Agency (FEMA) has designated a region near your community as a 100-year floodplain. This designation suggests that the region, statistically, has a 1% of a flood of a given magnitude in any given year. (Hint: A 100-year floodplain can be interpreted as a 1 in 100 chance).

    a. As a city planner, what do you believe is an appropriate use of that land? What is not? Explain your response in three to four sentences.

    b. A land owner proposed building a house in the floodplain. Do you approve the building permits? What extra requirements might you require for the building? Explain your response in two to three sentences.

c. What criteria do you use in these decisions? List at least three criteria.

Part C. Rivers Shaping the Landscape

There are a variety of features that are created as a result of river action. Some are formed through erosional processes. Others are created as a result of deposition. Some are formed by a combination of the two processes.

Meandering Streams

One such feature that results from both erosion and deposition is a **meandering stream**. Once a river descends down to a lower valley floor, the flow rates of the water tend to vary within the active channel. On straight stretches of river, the flow rate is typically slower along the bed due to friction on the surface. However, whenever a slight bend or turn takes place, the flow rates on either side of a river are different as illustrated in Figure 15.7. Earlier in this lab you learned the impacts of water speed on the erosional and depositional capacity of a river. Figure 15.7 shows that water speed in the river varies depending on the shape of the river channel.

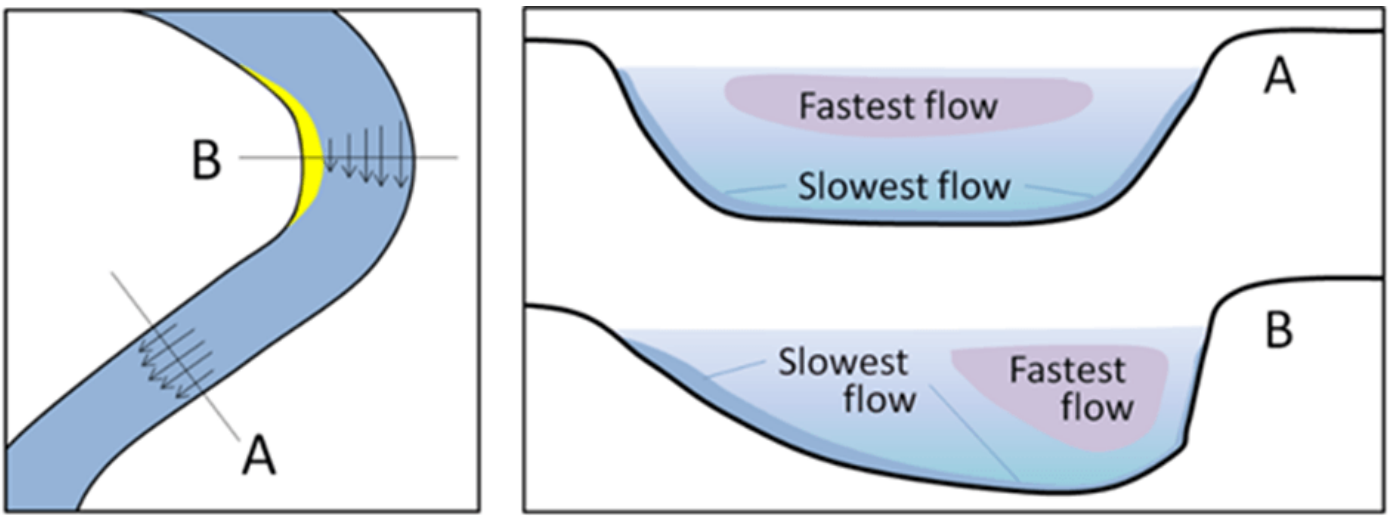


Figure 15.7: The Velocity of a Stream depends on whether the Channel is Straight or Curved. Figure by Steven Earle is licensed by CC BY 4.0

Exercise 1.15.8

11. Refer to the river channel labeled B in Figure 15.7.
    a. On which side of the river would you anticipate more erosion? On the outside of the turn (right side in diagram example B) or the inside (on the left side in diagram example B)?
    b. On which side of the river shown on example B would you anticipate more deposition?
    c. Apply What You Learned: If this were to occur over a great deal of time, what change would you anticipate for the path of the river? Explain your response in one to two sentences.

This idea of uneven erosion and deposition of either side of a river channel is exactly what creates a meandering stream. Figure 15.8 illustrates the speed of water in a channel as it responds to turns in the course of the river. The red arrows illustrate the faster moving water.

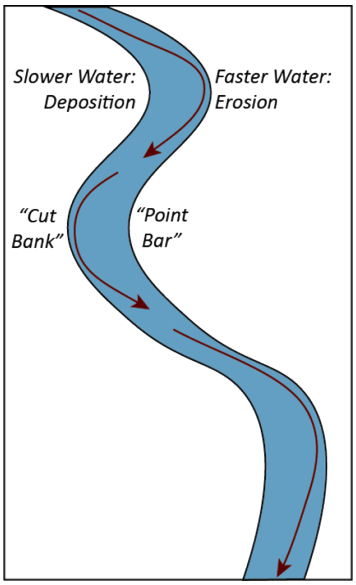


Figure 15.8: Pathway of Fastest Water Flow in a Meandering Stream. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

As a river turns, the outside of the turn is referred to as the **cut bank**. It is the region with the greatest amount of erosion. On the inside of the turn, water flows more slowly,resulting in deposited material. This is called the **point bar**.

Exercise 1.15.9

12. On the river channel labeled B in Figure 15.7, label the cut bank and the point bar. Also, label the cut bank and point bar on the bird's-eye view of the river shown on the left-side of Figure 15.7.

Oxbow Lakes

At times, the river cuts through and part of a turning loop is cut off from the course of the river. Although the old channel is still there, the water flow does not use that channel. The slower movement on both ends of the cut off section promotes sediment deposits and eventually the old channel is completely cut off of the river and forms a curved lake. This is referred to as an **oxbow lake**. Figure 15.9 shows how the progression of a meandering river creates an oxbow lake over time. In this diagram, the far-left diagram (labeled A) represents the oldest time period and the far-right diagram (labeled D) represents the most recent time period.

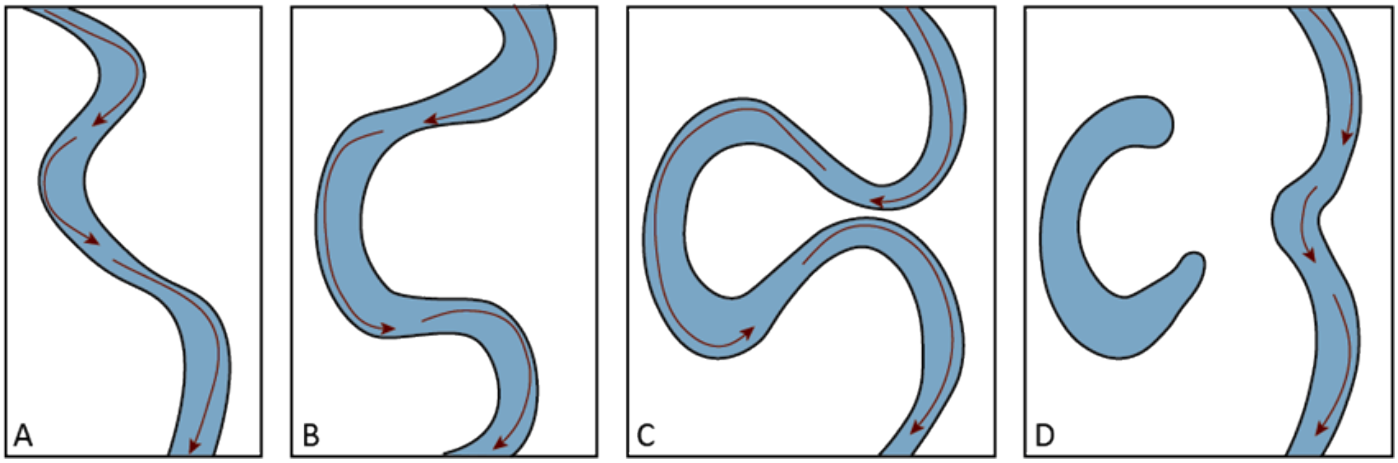


Figure 15.9: Progression of a Meandering Stream. Figures by Scott Crosier are licensed under CC BY-NC-SA 4.0

Exercise 1.15.10

Virtual Field Trip to a Meandering River

13. Using Google Maps or Google Earth, navigate to the following coordinate along the Sacramento River in Butte County, California: 39.67, -121.97. Turn on the satellite view. Zoom out to an extent where you can see several of the bends in the river.
14. In the box provided below (Figure 15.10), sketch the pathway of the Sacramento River where the river is flowing in from the upper right (Northeast) corner, making a significant turn on the left (West) side, and eventually flowing out the bottom (South) of the box.

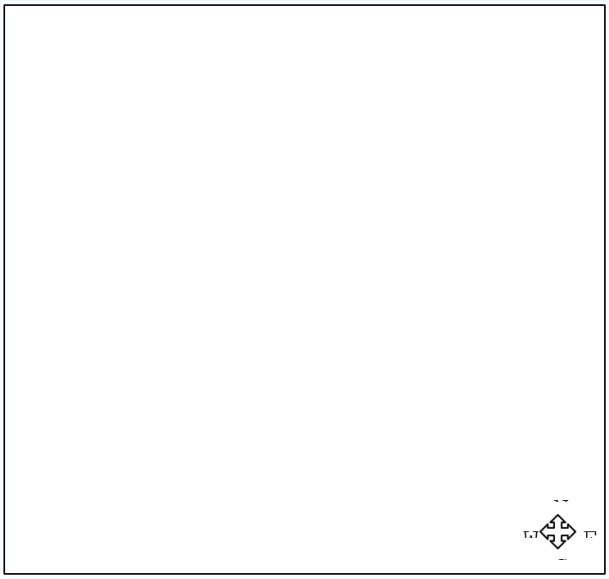


Figure 15.10: Blank Map.

15. In your sketch above (Figure 15.10), label the cut banks and point bars.
16. Do you see any signs that suggest there is or was an oxbow lake present? Sketch where you suspect and label it on Figure 15.10.
17. Based on what you have learned regarding the migration patterns of rivers, where might you anticipate a future oxbow lake? Outline with a dotted line and label the area on Figure 15.10.

Waterfalls

In previous labs, you have explored different aspects of rock structures. When a river is flowing over different types of rock, the ability of the river to erode the rock will vary. Some rock is very hard and resistant to erosion while other layers may be softer and more prone to erode. Many **waterfalls** occur at the boundary of these layers. Water flowing over the harder rock may have very little erosional impact. But, once it begins flowing over the softer rock, the water is able to erode and transport that material away. This develops a step in the river channel leading to faster movement of water, which leads to increased erosion and transportation as illustrated in Figure 15.11.

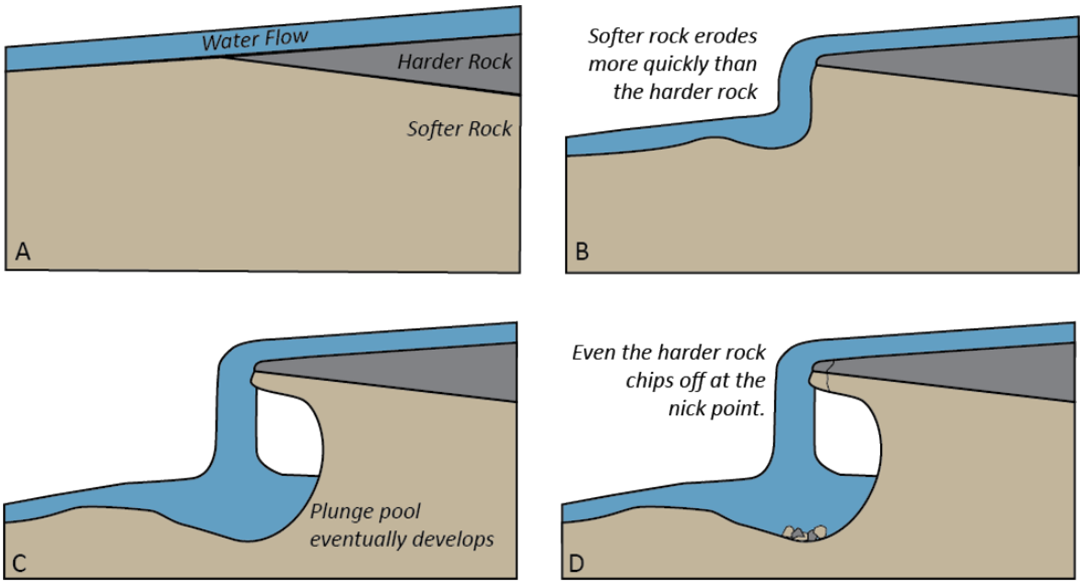


Figure 15.11: Development of a Waterfall. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

Exercise 1.15.11

18. Refer to Figure 15.11. Based on what you know about the erosional processes in waterfalls, would you anticipate that the waterfall moves upstream or downstream? Explain your response in one to two sentences.

Deltas

Through this lab you have learned the influence of water movement, specifically in regards to erosion, transportation, and deposition. Faster moving water erodes and transports while slower water causes deposition. But what happens when a river completely stops moving? This occurs when a river reaches a sea or ocean. The material that the river was carrying is deposited, often forming a triangular-shaped extension on the landmass referred to as a **delta**.

Exercise 1.15.12

Virtual Field Trip to Three Deltas

19. Perhaps the most iconic of all deltas is where the Nile River flows into the Mediterranean Sea. Using Google Maps or Google Earth, navigate to the following coordinate: 30.81, 31.09. Turn on the satellite view. Zoom out until you can see Cairo to the South and the Mediterranean Sea to the North.

    a. Based on the color of the region, what do you suspect in the main land use of the region?

    b. What is the overall shape of the area?

    c. Zoom further out. What is the land cover for most of the surrounding regions?

20. One of our country's most iconic waterways is the Mississippi River. The Mississippi flows into the Gulf of Mexico very close to New Orleans. Using Google Maps or Google Earth, navigate to the following coordinate: 29.53, -90.78. To get a full view of the Mississippi River delta, zoom out until you see Biloxi on the east side of the display, Baton Rouge on the north and Lafayette on the west.

    a. What is the overall land use for this region?

    b. What patterns do you see which are similar to or different from what you saw in Egypt at the River Nile?

c. Use Your Critical Thinking Skills: The Gulf of Mexico is prone to hurricanes and significant storm surges. These are extremely high waves that result from the strong winds in a hurricane. What influence would the Mississippi River delta have on the storm surges? Why might they be important to Gulf Coast cities such as New Orleans? Your response should be two to three sentences in length.

21. Let's come back to California! The Central Valley has two major rivers (the Sacramento River from the North and the San Joaquin River from the South) that converge further inland. This is due to the coastal range and several bays between the rivers and the Pacific Ocean. This type of delta is unique and is referred to as a "reverse delta" because the sediments are deposited further inland, rather than into the eventual water body such as an ocean. Using Google Maps or Google Earth, navigate to the following coordinate: 38.05, -121.58.

    a. As you zoom out, what land use seems to dominate this region?

    b. What patterns do you find in common with the other deltas that you have virtually visited?

    c. To see the full extent of the delta, zoom out until you see Antioch on the west side of the display and Stockton on the east. In one sentence, describe the patterns of many of the waterways in this region.

22. While you are here, navigate just slightly to the south, to the following coordinate: 37.83, -121.56. This is the beginning of the California Aqueduct! Natural water flow in the southern portion of the central valley is towards the delta. However, at this point, water pulled from the delta region begins its journey south to Southern California. There is a waterway flowing into Clifton Court Forebay from the southeast corner. This is pulling water in from the San Joaquin river much further south near Mendota. On the southwest corner of the Forebay, you will notice the large outlet. This is where the California Aqueduct begins.

    i. Using the navigation tools in Google Maps or Google Earth, follow the Aqueduct as far as you can. How far were you able to follow the aqueduct flow?

    ii. What primary type of landscape does the California Aqueduct flow through?

23. Compare and contrast the Nile, Mississippi, and California deltas. What are the similarities and differences among the deltas? Explain your response in two to three sentences.

Part D. Case Study: Elwha River, Washington

For millennia, the Elwha River ran wild, connecting mountains and seas in a thriving ecosystem. The river proved to be an ideal habitat for anadromous (sea-run) fish, with eleven varieties of salmon and trout spawning in its waters. These fish thrived in the cold, clear waters of the Elwha River and historically served as an important food source for the Lower Elwha Klallam Tribe living along its banks.[276]

American expansion spurred a continual demand for lumber. The growth of the logging industry in the region brought rapid change to the Olympic Peninsula and specifically to the Elwha River with the construction of two dams. The Elwha and Glines Canyon dams were built in the early 1900s, generating hydropower to supply electricity for the emerging town of Port Angeles and fueling regional growth on the Peninsula. However, construction of the dams blocked the migration of salmon upstream, disrupted the flow of sediment downstream, and flooded the historic homelands and cultural sites of the Lower Elwha Klallam Tribe.[12] Figure 15.12 provides a locator map of the Elwha River in the state of Washington circa 2010.

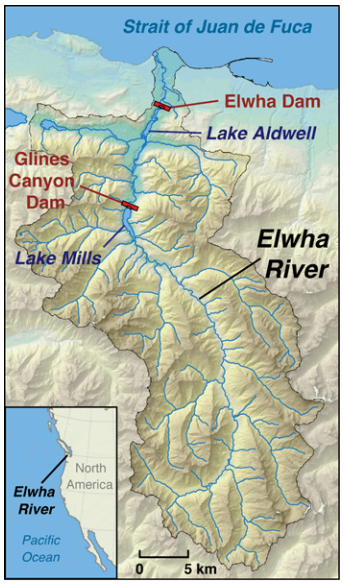


Figure 15.12: Elwha River Locator Map. Figure by USGS is in the public domain

For over a century, the web of ecological and cultural connections in the Elwha Valley were broken—then the river's story changed course. In 1992, Congress passed the Elwha River Ecosystem and Fisheries Restoration Act, authorizing dam removal to restore the altered ecosystem and the native anadromous fisheries therein. After two decades of planning, the largest dam removal in U.S. history began on September 17, 2011. Six months later the Elwha Dam was gone, followed by the Glines Canyon Dam in 2014. Today, the Elwha River once again flows freely from its headwaters in the Olympic Mountains to the Strait of Juan de Fuca.[12]

It was the world's largest dam-removal project. Over the next five years, water carrying newly freed rocks, sand, silt and old tree trunks reshaped more than 13 miles of river and built a larger delta into the Pacific Ocean. Of the 33 million tons of sediment trapped behind the dams, about 8 million tons resettled along the river or at the mouth, and another 14 million dispersed into the ocean. It would take more than 70 dump trucks running 24 hours a day for five years to move that much dirt and debris downstream. Piled up, the sediment would form a cone about one-third of a mile in diameter and taller than a 50-story building (Figure 15.13).[278]

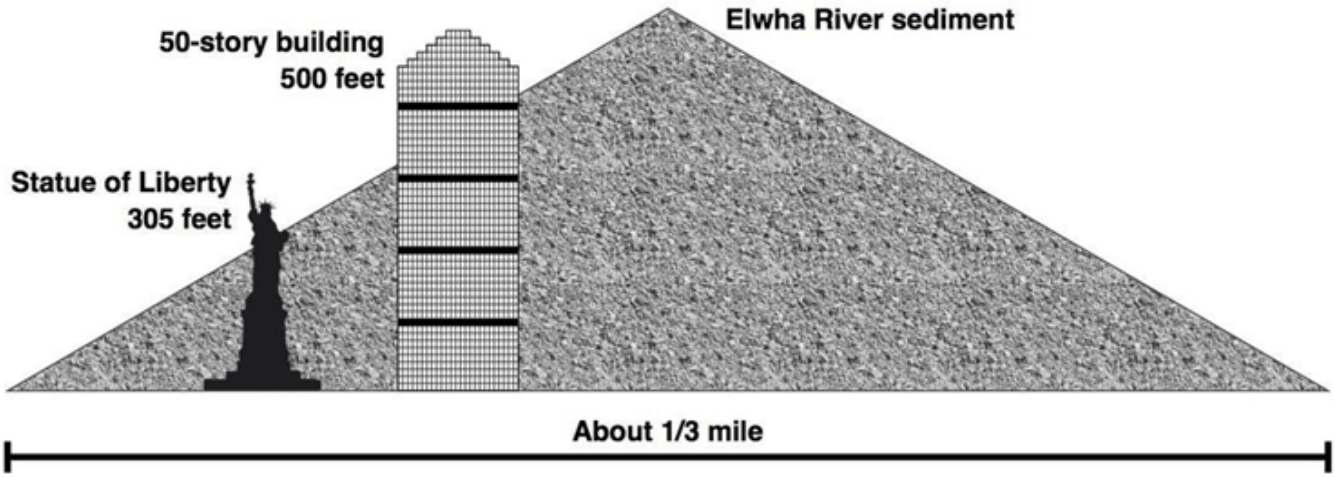


Figure 15.13: Size Comparison of Elwha River Sediment. Figure by USGS is in the public domain

Figure 15.14 shows the Elwha River delta after dam removal. Notice the brown sediment flowing into the darker colored water of the Strait of Juan de Fuca.



Figure 15.14: Elwha River Delta after Dam Removal. Figure by Jeff Duda, USGS is in the public domain

Let's use topographic maps to explore the fluvial geomorphology of the Elwha River before and after dam removal.

If you need a quick review of topographic maps, check out the Topographic Map Symbols document from the USGS.

Step 1

Go to the file in the google drive folder to access the topographic map from 1950 (before the dams were removed).

Step 2

Use the plus (+) sign and minus (-) sign to zoom in and out of the map, as needed. When zoomed in, you can click and drag your mouse pointer to view different portions of the map.

Step 3

Locate the Elwha River, the Upper Elwha Dam, and the Olympic Power Plant, which is at the site of the Elwha Dam. Note that the Upper Elwha Dam is also known as the Glines Canyon Dam.

Exercise 1.15.12

23. Does the Elwha River flow to the north or to the south? How can you tell?
24. Where do you find evidence that the Elwha River has changed its course over time?
25. Calculate the gradient of the Elwha River between the Upper Elwha Dam and the Olympic Power Plant.
    a. Use the graphic scale at the bottom of the topographic map to find the distance between the Upper Elwha Dam and the Olympic Power Plant. What is the estimated distance in miles?
    b. Find the contour line at the Upper Elwha Dam. What is the dam's elevation?
    c. Find the contour line at the Olympic Power Plant. What is the power plant's elevation?
    d. What is the difference in elevation (in feet) between these two locations? Show your work.
    e. Divide the difference in elevation by the distance between the two locations. Show your work. Your answer should be in feet per mile.

Step 4



Go to the file in the google drive folder to access the topographic map from 2020 (after the dams were removed). Note: this is a very large file and may take a few moments to load.

Step 5

Use the plus (+) sign and minus (-) sign to zoom in and out of the map, as needed. When zoomed in, you can click and drag your mouse pointer to view different portions of the map.

Exercise 1.15.13

26. Where does the Elwha River have the steepest channel? At this location, what is the difference in elevation from the riverbank to the top of the cliff at the side of the river?

Step 6

Keep both maps open in different tabs in order to compare the Elwha River between 1950 and 2020. Refer to the selected topographic map symbols shown in Appendix 15.1.

Exercise 1.15.14

27. What are three major differences along the Elwha River that you notice between the 1950 and 2020 topographic maps?

Step 7

Search the internet to find out about any dams, dam construction/maintenance projects, and dam removal projects in the county where you live.

Exercise 1.15.15

28. Would you tend to support the construction of new dams in your county? Explain your response in two to three sentences.

Part E. Wrap-Up

Consult with your geography lab instructor to find out which of the following wrap-up questions you should complete. Attach additional pages to answer the questions as needed.

Exercise 1.15.16

29. What is the most important idea that you learned in this lab? In two to three sentences, explain the concept and why it is important to know.

30. What was the most challenging part of this lab? In two to three sentences, explain why it was challenging. If nothing challenged you in the lab, write about what you think challenged your classmates.

31. What is one question that you have about what you learned in this lab? Write your question along with one to two sentences explaining why you think your question is important to ask.

32. Review the learning objectives on page 1 of this lab. How would you rate your understanding or ability for each learning objective? Write one sentence that addresses each learning objective.

33. Sketch a concept map that includes the key ideas from this lab. Include at least five of the terms shown in bold-faced type.

34. Create an advertisement to educate your peers on the important information that you learned in this lab. Include at least three key terms in your advertisement. The advertisement should be about half a page in size (about 4 inches by 6 inches).

35. One way to think of physical geography is that it is the study of the relationships among variables that impact the Earth's surface. Select two variables discussed in this lab and describe how they are related.

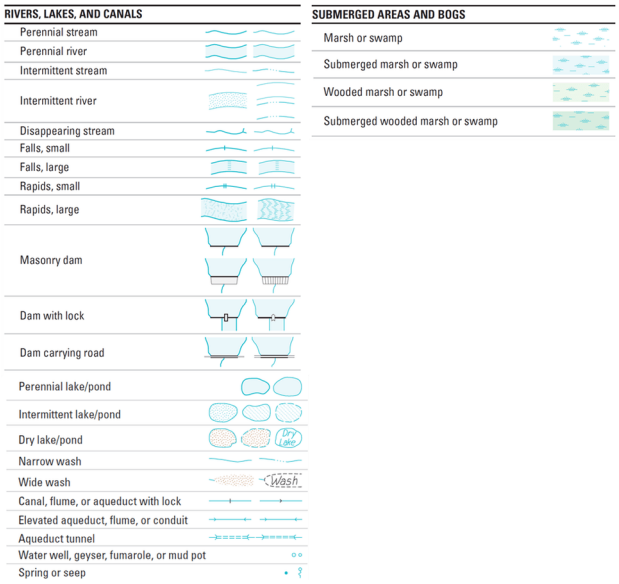
36. How does what you learned in this lab relate to your everyday life? In two to three sentences, explain a concept that you learned in this lab and how it relates to your day-to-day actions.

37. How does what you learned in this lab relate to current events?
    a. Write the title, source, and date of a news item that relates to this lab.
    b. In two to three sentences, discuss how the news item relates to what you have learned in this lab.
    c. In one to two sentences, discuss whether or not the news item accurately represents the science that you learned. Tip: consider whether or not the news item includes the complexity of the topic.

38. Search O*NET OnLine to find an occupation that is relevant to the topics presented in today's lab. Your lab instructor may provide you with possible keywords to type in the Occupation Quick Search field on the O*NET website.
    a. What is the name of the occupation that you found?
    b. Write two to three sentences that summarize the most important information that you learned about this occupation.
    c. What is one question that you would want to ask a person with this occupation?

Answer available at the end of this section.

Appendix 15.1: Selected Topographic Map Symbols



Excerpts from USGS

[263] Water Erosion and Deposition by CK-12 is licensed under CC BY-NC 4.0

[269] Text by USGS is in the public domain

[270] Text by NASA's Earth Observatory

[276] Text by National Park Service is in the public domain

[278] Text by USGS is in the public domain

Answers

Exercise 1.15.3

Exercise 1.15.16

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1.16: Lab 16 - Coastal Geomorphology

This lab contains potentially inaccessible interactive resources. Please work with your instructor and local campus resources to identify accommodations for these resources.

Learning Objectives

- Explain how longshore currents and beach drift transport coastal sediment.
- Describe the stages of barrier island development.
- Identify features on emergent and submergent coastlines.
- Interpret sea level rise data.
- Explain the location and formation of coral reefs.
- Assess threats to coral reefs.

Introduction

Coasts are the dynamic junction of water, air, and land. Winds and waves, tides and currents, migrating sand dunes and mud flats, and a variety of plant and animal life all combine to form our ever-changing coasts. Their dynamic nature results in their great diversity. Most of us envision a coast as a broad stretch of sand with frothy surf breaking along the shore; in fact, many types of coasts are found within the United States, ranging from sandy beaches to rocky shores, from coral reefs to coastal wetlands.[282]

We think of land as stable and treat it as a permanent asset. For most land, this premise is reasonable because land generally changes very slowly. Although tectonic and geologic processes, such as continental drift and erosion, are always at work, they usually result in very gradual changes that are barely noticeable during a human lifetime. Coasts, however, are not static; they are dynamic. They quickly change shape and location in response to natural forces and human activities. These forces and activities continually push and pull at coasts—sometimes in the same direction, but often in opposite directions. As a result, the shape of the coastline changes. Sand and other materials are moved onto and off of beaches by currents and waves. Seasonal movement of coastal materials creates broad summer beaches followed by narrow winter beaches in an annual cycle. During major storms, huge waves and storm surges can move large amounts of coastal sediments and can flood vast areas in a matter of hours.[1]

In this lab, you will investigate the dynamic processes that shape coasts: the erosional and depositional forces, sea level fluctuations, and coral reef development (and threats).

Part A. Sediment Transport and Barrier Islands

Ocean waves are the primary cause of erosion along a coast, which eventually influences the shape of the coastline. When a wave moves toward the shore, the wave slows down in shallow areas but maintains its speed in deeper areas. This causes the wave to bend as you can see in Figure 16.1. This phenomenon is called **wave refraction** and is important in coastline formation. Because of wave refraction, coastlines are not straight; instead, they bend much like the shape of the waves themselves.

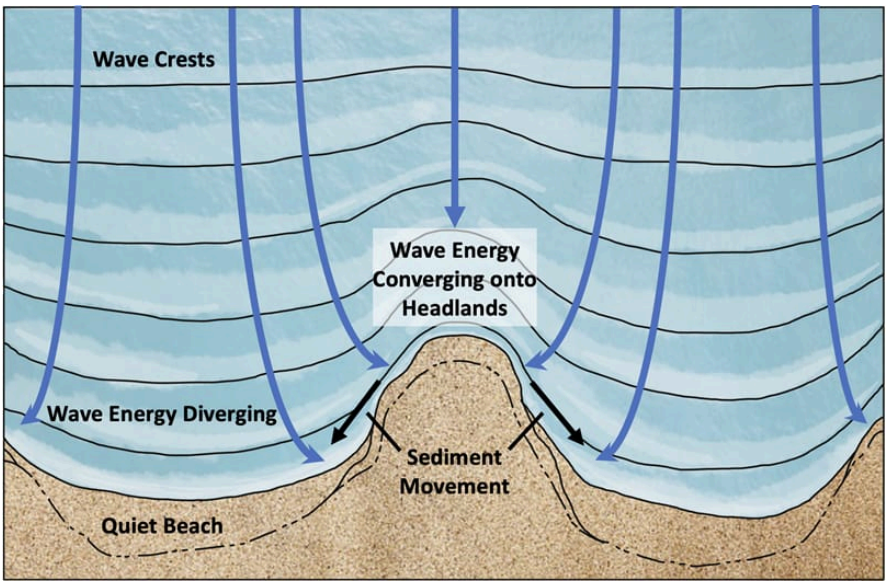


Figure 16.1: Wave Refraction. Figures by Jeremy Patrich are licensed under CC BY-NC-SA 4.0

As waves crash onto the shore, they cause weathering by breaking down rock into smaller and finer pieces called sand and sediment. Over time, coastal sediment transport occurs in which sand and sediment are transported along a shoreline in a process called **erosion**.

Sediment moves along a shoreline by two primary processes: the longshore current and beach drift. **Longshore currents** are ocean currents that move parallel to the shore yet approach the shoreline at a slight angle (Figure 16.2). Longshore currents drag water down the length of the beach in the same direction the wind is blowing. **Beach drift** also carries sand and sediment along the shoreline. As waves wash on and off the beach, they transport sediment and sand with them in a zigzag-like movement.

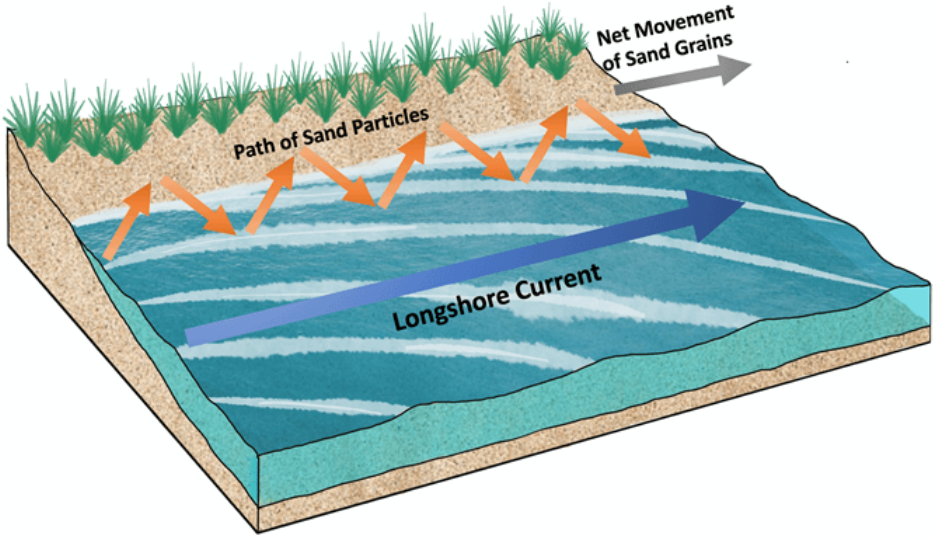


Figure 16.2: Longshore Current and Beach Drift.

Exercise 1.16.1

1. Label Figure 16.3 (shown below) with the following terms: longshore current, beach drift, net movement of sand grains, upstream, and incoming wave direction.

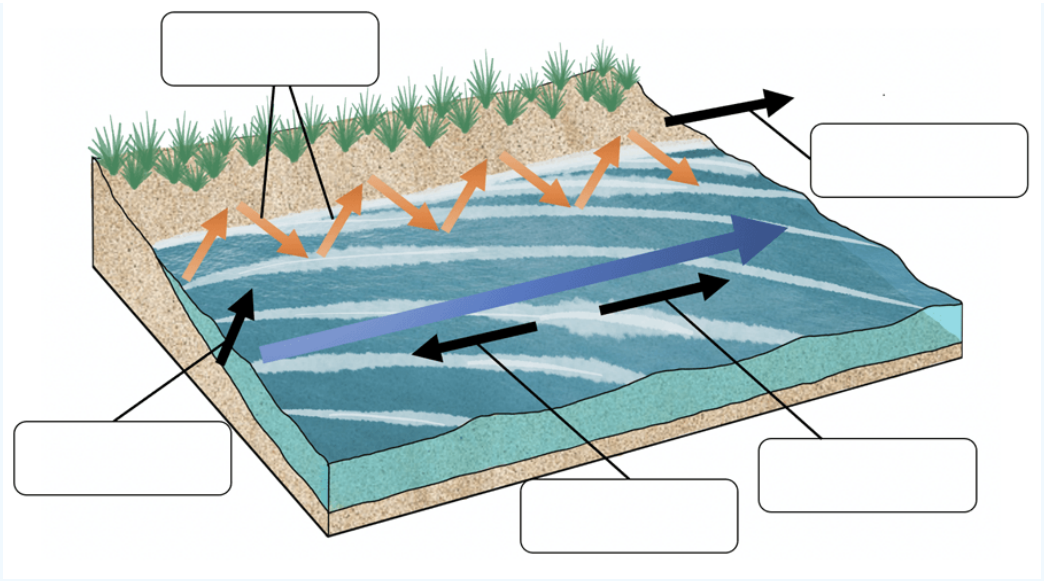


Figure 16.3: Model of How Sediment Moves along a Coastline. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

2. Describe the path of sand and sediment particles along a coastline.
3. Explain how longshore current and beach drift are similar.
4. Use Your Critical Thinking Skills: Think about the formation of beaches as we see them. Explain how a beach might form along a coastline.

Coastal sediment transport can form landscapes away from the shore as well. **Barrier islands** are long, narrow, offshore deposits of sand or sediments that run parallel to the shore. Barrier islands are separated from the mainland by a bay or lagoon.

Barrier islands can be fairly short or in some cases incredibly long. For example, Padre Island, Texas, shown in Figure 16.4, is less than 3.2 kilometers (2 miles) wide but is 182 kilometers (113 miles) long! Fun fact: the United States has more than 400 barrier islands, more than any other country.



Figure 16.4: Map of Padre Island. Figure by National Park Service is in the public domain

Barrier islands have several important functions, including protecting shorelines from severe storm damage and allowing native plant and animal habitats to thrive in a somewhat protected area of the coastline. Barrier islands are quite common in the United

States, particularly along the Gulf Coast and East Coast, where approximately 300 barrier islands have been mapped. Barrier islands form over thousands of years as a result of weathering and erosion from interglacial periods. As ice melts on land, it flows downstream toward the sea, forming creeks and rivers. River flow carries sediment and rock with it as it drains into the sea. This sediment and sand form pieces of land near and along the shore of large land masses (Figure 16.5). Eventually, the pieces of land separate from the large land mass completely, forming a barrier island.

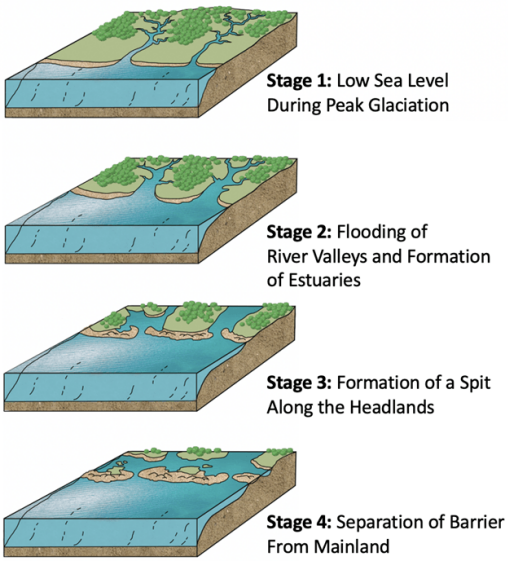


Figure 16.5: Barrier Island Development. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Barrier islands have been instrumental in protecting coastline from storm damage; but unfortunately, development and construction over the last 100 years has caused serious deterioration of barrier islands in the United States. In addition, sea level rise poses a threat to barrier islands with communities and vulnerable habitats.

Exercise 1.16.2

5. Refer to Figure 16.5.
    a. During Stage 1, why would sea level be lowest compared to the other stages?
    b. During Stage 2, what might explain the flooding from river valleys upstream?
    c. During Stage 3, what would cause the land to be broken into spits? (Tip: refer to Figure 16.6, which shows a sand spit).
    d. During Stage 4, how might the newly formed barrier islands serve as a resource to communities of people living along the coast?

Case Study: Louisiana Barrier Islands

Sea level rise and the increased erosion that results is a serious concern for barrier islands. NASA provides a quote from geoscience researcher Matthew Stutz that explains how every barrier island is unique:

> "However, rising sea level is not just like pouring more water into a bathtub," Stutz emphasized. Islands react differently based on the geology in a region and how the waves and tides in an area are affected. People tend to assume sea level rise means fewer islands no matter what, but the rate of rise is critical."[287]

Decreases in upstream sediment supplies from human activities such as dam construction also play a role in disappearing barrier islands, especially along the Mississippi Delta. The USGS explains that:

Louisiana's barrier islands are eroding so quickly that according to some estimates they will disappear by the end of this century. Although there is little human habitation on these islands, their erosion may have a severe impact on the environment landward of the barriers. As the islands disintegrate, the vast system of sheltered wetlands along Louisiana's delta plain are exposed to increasingly open Gulf conditions. Through the processes of increasing wave attack, salinity intrusion, storm surge, tidal range, and sediment transport, removal of the barrier islands may significantly accelerate deterioration of wetlands that have already experienced the greatest areal losses in the U.S. Because these wetlands are nurseries for many species of fish and shellfish, the loss of the barrier islands and the accelerated loss of the protected wetlands may have a profound impact in the billion dollar per year fishing industry supported by Louisiana's fragile coastal environment.[288]

Exercise 1.16.3

6. List the causes of barrier island destruction:
7. List the effects of barrier island destruction:

Let's explore Louisiana's barrier islands by comparing satellite imagery across multiple years.

Step 1



Go to Esri's World Imagery Wayback website. Or, if you have Google Earth Pro you could look at the historical imagery in that program.

Step 2

In the search box, type Louisiana and click the magnifying glass.

Step 3

Zoom in on one of the barrier islands off the coast of Louisiana (pick any named island).

Exercise 1.16.4

8. What is the name of the barrier island that you zoomed in on?

Step 4

Zoom in as far as you are able to.

Step 5

Click the "Only versions with local changes" box.

Exercise 1.16.5

9. What is the date of the oldest imagery available?
10. What is the date of the most recent imagery available?

Step 6

Click on each date available to see how the barrier island landscape changed over time.

Exercise 1.16.6

11. In two to three sentences, describe the changes that you observe.
12. Use Your Critical Thinking Skills: If the historical imagery at the barrier island that you selected went back 10, 50, or 100 years, what changes do you think you would have observed? Respond in one to two sentences.

Part B. Emergent and Submergent Coastlines

Emergent coasts occur where sea levels fall due to tectonic uplift or ice ages. Emergent coasts are also called erosional coasts. Some features associated with emergent coasts include high cliffs, headlands, exposed bedrock, steep slopes, rocky shores, arches, stacks, tombolos, wave platforms, and wave notches (Figure 16.6, top). In emergent coasts, wave energy, wind, and gravity erode the coastline. The erosional features are elevated relative to the wave zone. Sea cliffs are persistent features as waves cut away at their base and higher rocks calve off by mass wasting. Refracted waves that attack bedrock at the base of headlands may erode or carve out a sea arch, which can extend below sea level. When a sea arch collapses, it leaves a rock column called a stack.[289]

When rock behind the stack erodes, sand can erode from the headland. Eroded sand that collects from the headland to the stack forms a tombolo: a sand strip that connects the stack to the shoreline. Where sand supply is low, wave energy may erode a wave-cut platform across the surf zone, exposed as bare rock with tidal pools at low tide. This bench-like terrace extends to the cliff's base. When wave energy cuts into the base of a sea cliff, it creates a wave notch.[8]

Submergent coasts are also known as depositional coasts. Submergent coasts occur where sea levels rise due to tectonic subsidence—when the Earth's crust sinks—or when sea levels rise due to glacier melt. Features associated with submergent coasts include river mouths, fjords, barrier islands, lagoons, estuaries, bays, tidal flats, and tidal currents (Figure 16.6, bottom). In submergent coastlines, river mouths are flooded by the rising water.[9] As sediments travel along the longshore current and are deposited, long ridges called spits extend parallel to the coastline.

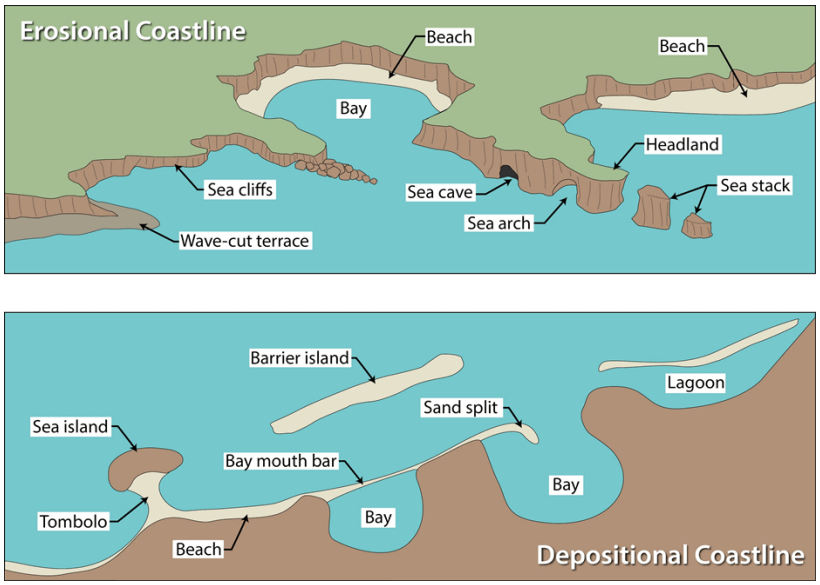


Figure 16.6: Coastal Features. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

Exercise 1.16.7

13. Refer to Figure 16.6.

    a. In one to two sentences, explain how a sea stack forms.

    b. Apply What You Learned: On the depositional coastline diagram at the bottom of Figure 16.6, draw and label an arrow that represents the longshore current.

    c. In one to two sentences, explain how a bay mouth bar forms.

14. For each of the four photographs shown in Figure 16.7, indicate whether the coastline is erosional or depositional and identify the features(s) shown on the photographs.

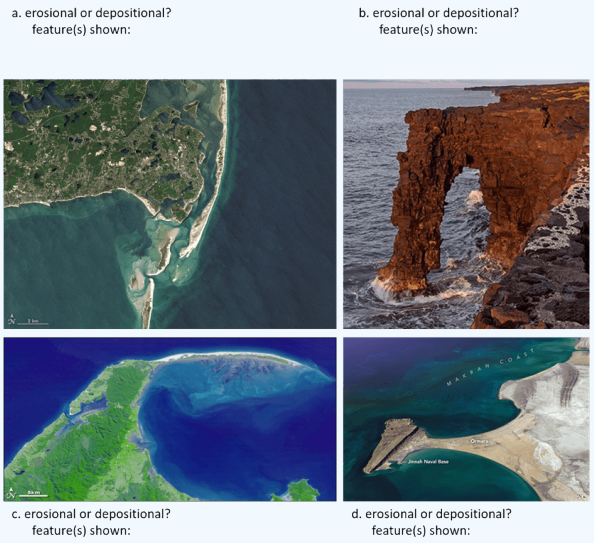


Figure 16.7: Coastal Features Identification Activity. Figure with public domain photographs by NASA Earth Observatory and the National Park Service are in the public domain

Sea Level Rise

Both erosional and depositional coastlines will be impacted by sea level rise. There are several important ideas to understand about sea level rise, which were published by NOAA in 2019[292]:

➢ Global sea level has been rising over the past century, and the rate has increased in recent decades. In 2014, global sea level was 2.6 inches above the 1993 average—the highest annual average in the satellite record (1993 to present). Sea level continues to rise at a rate of about one-eighth of an inch per year.

➢ The two major causes of global sea level rise are thermal expansion caused by warming of the ocean (since water expands as it warms) and increased melting of land-based ice, such as glaciers and ice sheets. The oceans are absorbing more than 90 percent of the increased atmospheric heat associated with emissions from human activity.

➢ With continued ocean and atmospheric warming, sea levels will likely rise for many centuries at rates higher than that of the current century. In the United States, almost 40 percent of the population lives in relatively high population density coastal areas, where sea level plays a role in flooding, shoreline erosion, and hazards from storms.

➢ Globally, 8 of the world's 10 largest cities are near a coast, according to the U.N. Atlas of the Oceans.

➢ Sea level is primarily measured using tide stations and satellite laser altimeters. Tide stations around the globe tell us what is happening at a local level—the height of the water as measured along the coast relative to a specific point on land. Satellite measurements provide us with the average height of the entire ocean. Taken together, these tools tell us how our ocean sea levels are changing over time.

To understand the projected impacts of sea level rise to the United States, NOAA developed a Sea Level Rise Map Viewer. This website provides **mean higher high water** (MHHW) data, which represents the average of the higher high water height of each tidal day. This average is based on the current National Tidal Datum Epoch of 19 years from 1983 to 2001. Figure 16.8 provides an example diagram of all of the data collected at a monitoring station at Apra Harbor, Guam. The data is shown in feet and is referenced on the mean sea level (MSL) based on the same time period (1983 to 2001). Notice that the MHHW is the highest value shown on Figure 16.8.

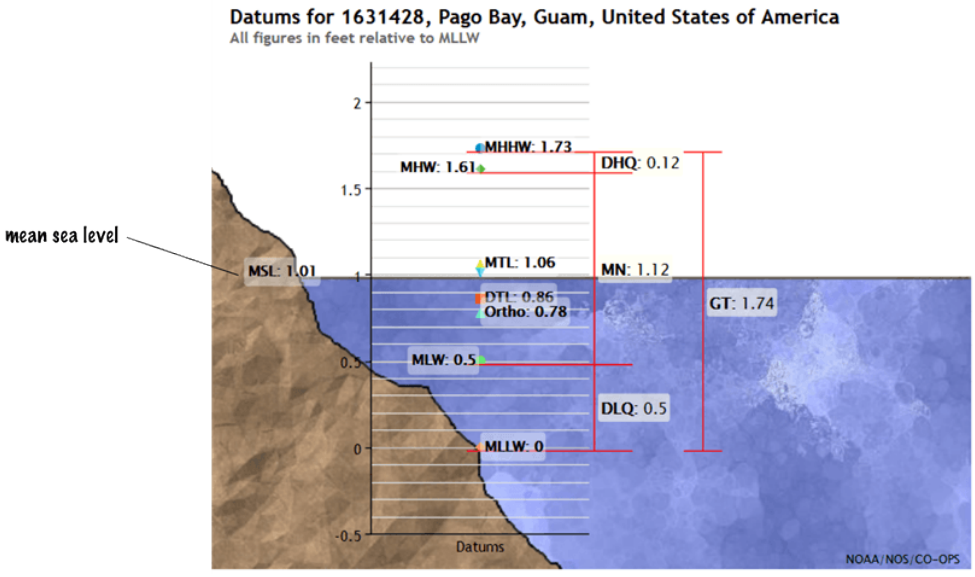


Figure 16.8: Tidal Data for Apra Harbor, Guam. Figure downloaded on September 20, 2020, by NOAA Datums is in the public domain

Table 16.1 provides the abbreviations (Abbrev.), names, and descriptions of each of the tidal datums shown on Figure 16.8. Arithmetic mean is the average that is calculated by adding all of the values together and then dividing that number by the total number of values. Some locations have diurnal tides—one high tide and one low tide per day. At most locations, there are semidiurnal tides—the tide cycles through a high and low twice each day, with one of the two high tides being higher than the other and one of the two low tides being lower than the other.[294]

Exercise 1.16.8

15. Label the abbreviations shown on Figure 16.8 with the names of the tidal datums. The MSL abbreviation has been labeled as an example.

Table 16.1: Tidal Datum Abbreviation and Descriptions

Abbrev.	Tidal Datum	Description
MSL	Mean Sea Level	The arithmetic mean of hourly heights observed over the National Tidal Datum Epoch.
MHW	Mean High Water	The average of all the high water heights observed over the National Tidal Datum Epoch.
MHHW	Mean Higher High Water	The average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch.
DHQ	Mean Diurnal High Water Inequality	One-half the average difference between the two high waters of each tidal day observed over the National Tidal Datum Epoch. It is obtained by subtracting the mean of all the high waters from the mean of the higher high waters.
MTL	Mean Tide Level	The arithmetic mean of mean high water and mean low water.
MN	Mean Range of Tide	The difference in height between mean high water and mean low water.
DTL	Diurnal Tide Level	The arithmetic mean of mean higher high water and mean lower low water.
Ortho	Orthometric Height	Distance from a reference elevation, using a system called NAVD 88.
GT	Great Diurnal Range	The difference in height between mean higher high water and mean lower low water.
MLW	Mean Low Water	The average of all the low water heights observed over the National Tidal Datum Epoch.
DLQ	Mean Diurnal Low Water Inequality	One-half the average difference between the two low waters of each tidal day observed over the National Tidal Datum Epoch. It is obtained by subtracting the mean of the lower low waters from the mean of all the low waters.
MLLW	Mean Lower Low Water	The average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch.

16. Use Your Critical Thinking Skills: Why do you think that a website designed to inform stakeholders about the potential of coastal flooding would use MHHW data rather than some of the other data shown in Figure 16.8?

Before you navigate the Sea Level Rise Map Viewer website, you will complete a tutorial that takes you through the website navigation. Complete Steps 1 through 5 below to answer questions 17 through 21 using the tutorial. Then, complete Steps 6 through 8 using the Sea Level Rise Map Viewer to answer questions 22 and 23.

Step 1



Go to the Sea Level Rise Viewer: Local Scenarios Quick Start Tutorial. (Note: the tutorial does not have audio).

Step 2

Click the blue next button on the bottom-right of the screen.

Step 3

Read each slide and continue to click the blue next button on the bottom-right of the screen to advance the slides.

Step 4

Follow any prompts provided. For example, you will need to search for Ship Bottom, New Jersey. You will be prompted to click on certain components in gray comment boxes. In the first example scenario, you will help to develop an adaptation plan for a highly populated area where stakeholders have a low tolerance for risk and the "high" sea level rise scenario should be used.

Exercise 1.16.9

17. In what year can Ship Bottom be expected to experience 3 feet of inundation?
18. What color are low-lying areas?
19. When low-lying areas are flooded, what color do they change to?

Step 5

Begin the second scenario, in which you will help develop a forty-year adaptation plan.

Exercise 1.16.10

20. In 2060, what is the water level where widespread inundation is visible with roads and property flooded?
21. Which of the following scenarios would you recommend for the forty-year adaptation plan for Ship Bottom: intermediate low, intermediate, intermediate high, high, or extreme?

Step 6

Now that you are acquainted with the website, go to the Sea Level Rise Viewer website and click Get Started.

Step 7

In the left-hand side of the screen, click on Local Scenarios.

Step 8

Exercise 1.16.11

22. With the Intermediate High Scenario selected, complete Table 16.2 with two examples from each of the regions shown in the left-hand column. (You can select any two locations that you would like).

    - Zoom in to each location marked with the green pin that shows buildings.
    - For each location, be sure to use the Water Level slider bar to see the progression of flooding through 2100.
    - Remember to use the Intermediate High Scenario.
    - Keep the option to "View By Scenario".

Table 16.2: Mean Higher High Water (MHHW) in feet

Region	Location Name	2020	2040	2060	2080	2100
Hawai'i						
Hawai'i						
West Coast						
West Coast						
Gulf of Mexico						
Gulf of Mexico						
East Coast						
East Coast						
Puerto Rico						
Puerto Rico						

23. Refer to your data in Table 16.2.

    a. Which location has the highest MHHW in 2020?

    b. Which location has the highest MHHW in 2040?

    c. Which location has the highest MHHW in 2060?

    d. Which location has the highest MHHW in 2080?

e. Which location has the highest MHHW in 2100?

f. Use Your Critical Thinking Skills: Which locations are examples of submergent coastlines? Explain your response in one to two sentences.

g. Which location seems to have the most flooding of buildings and infrastructure by 2060? Tip: estimate this by using the Water Level slider bar.

h. What are three conclusions that you can make based on the Sea Level Rise Viewer?

Part C. Coral Reef Coasts

Coral reef coasts are some of the most diverse and dynamic coastal systems on Earth! They are home to approximately 4,000 species of fish and 800 species of corals! Coral reefs provide essential habitat for tropical marine species to feed, breed, spawn, and nurse. Human societies greatly depend on marine ecosystems, including coral reefs. Approximately 500 million people worldwide depend on coral reefs for food, income, and shelter. Because coral reef structures are able to absorb much of the energy produced by ocean waves, a healthy coral reef has the ability to protect shorelines from coastal erosion, habitat loss, and property damage.

Coral reefs form in shallow warm waters of the ocean off the coasts of large land masses or around volcanic islands (Figure 16.9). The structure of the reef itself forms in shallow waters generally less than 27 meters (90 feet) deep, although reef-building corals have been found as deep as 70 meters (230 feet). Reef building corals are made of tiny animals, called **coral polyps**. Coral polyps attach themselves to the rock layer by secreting layers of calcium carbonate onto the rock. These polyps form colonies that can become quite large and weigh up to several tons. Coral colonies are unique in that they form a symbiotic and dependent relationship with microscopic algae called **zooxanthellae**. Because algae are plants and plants are producers, zooxanthellae must make their own "food" like other plants to obtain energy and survive through the process of photosynthesis. Shallow waters allow sunlight to reach the reef, which is required for photosynthesis to occur. Coral reefs are incredibly sensitive and tend to thrive in areas of ocean where surface temperatures (SST) range from 73° and 84° Fahrenheit (23° to 29° Celsius). Temperatures outside of that range cause serious harm to the health of the reef.

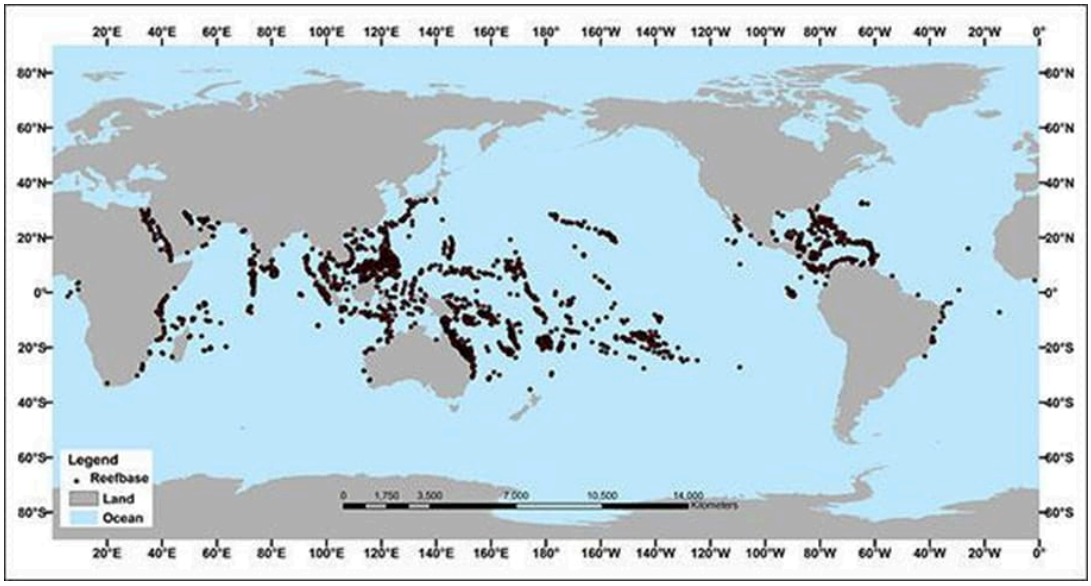


Fig 16.9: Spatial Distribution of Coral Reefs. Figure from NOAA's National Ocean Service is in the public domain

Exercise 1.16.12

24. Refer to Figure 16.9.

a. Explain the spatial distribution of coral reefs.

b. Where are coral reefs most concentrated? Why are they located there?

c. Which of the seven special lines of latitude (poles, circles, tropics, and equator) do coral reefs tend to grow near?

d. In what regions of the world do coral reefs tend to be absent? Why do you think this is?

e. What is your home state? Do coral reefs exist near your home state? Why or why not?

Coral reef coasts that form around volcanic islands can become some of the most beautiful and diverse places in the world (Figure 16.10). These reef structures begin around active volcanoes and continue to evolve over millions of years as a volcano becomes extinct. There are three key formations in the evolution of volcanic island coral reefs: fringing reefs, barrier reefs, and atoll reefs. Coral polyps secrete layers of calcium carbonate onto flanked pieces of land attached to the volcano; this is known as a **fringing reef**. Zooxanthellae quickly move in and begin a symbiotic relationship with coral polyps and soon a colony evolves. Over thousands of years, the volcano becomes extinct and weathering leads to erosion of the volcano, which causes the volcano to appear to "sink" into the ocean. Erosion causes sediment and rock to build up around the volcano, creating small bays and lagoons. This newer formation is now called a **barrier reef**. Over several million years, as weathering and erosion continue, the volcano appears to "sink" altogether and soon a large lagoon forms surrounded by coral colonies. This last formation is known as an **atoll** and can take up to 30 million years to form. Atolls are home to pristine habitats and can make a snorkeler feel as though they are swimming in an aquarium!

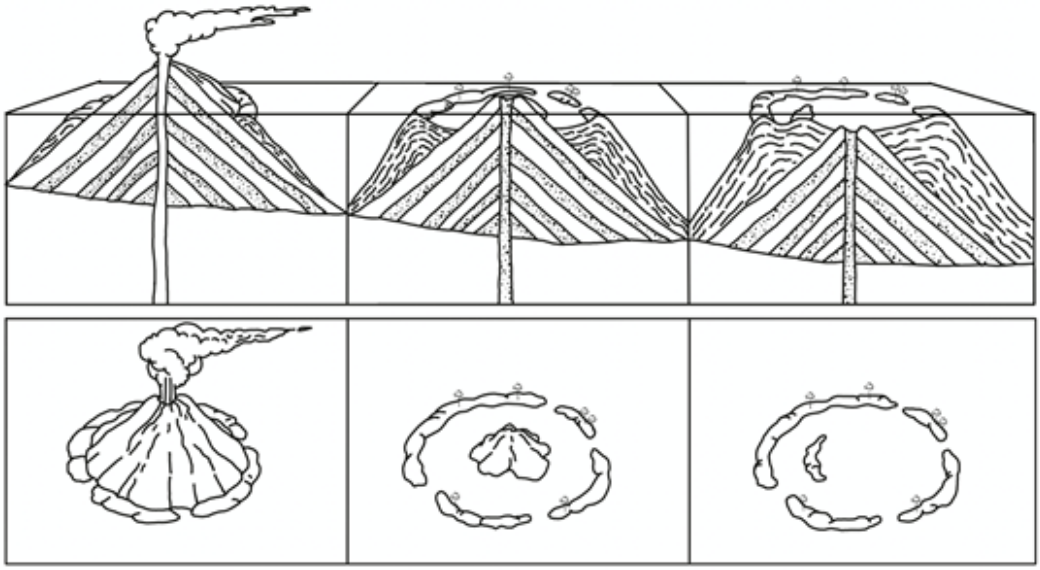


Figure 16.10: Evolution of a Volcanic Island Coral Reef. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Exercise 1.16.13

25. Based on the descriptions provided in the above paragraph, label atoll, fringing reef, and barrier reef on Figure 16.10.

Threats to Coral Reefs

Today, there are two great threats to coral reefs around the world: rising sea levels and increasing sea surface temperatures (SST). Both of these have caused **coral bleaching**, a symptom of an unhealthy or dying reef. As sea levels rise, corals submerse in deeper waters, preventing sunlight from reaching the reef. As SST increases, the water in and around the reef becomes too warm. A lack of sunlight and heat stress create poor conditions for zooxanthellae, and they expel themselves from the reef altogether. Once the zooxanthellae leave a reef, the corals lose a source of food and their source of color. While reefs can survive bleaching events, continued increase in SST and warming waters over the last 50 years have prevented reefs from recovering from bleaching events, resulting in mass die offs around the world. Bleaching events begin when SST reaches 1 to 2°C (1.8°F) above average temperatures for a particular reef. More importantly, photosynthesis pathways in zooxanthellae become impaired when SST are greater than 30°C (86°F). Figure 16.11 is a map showing average sea surface temperatures from 1981 to 2020.

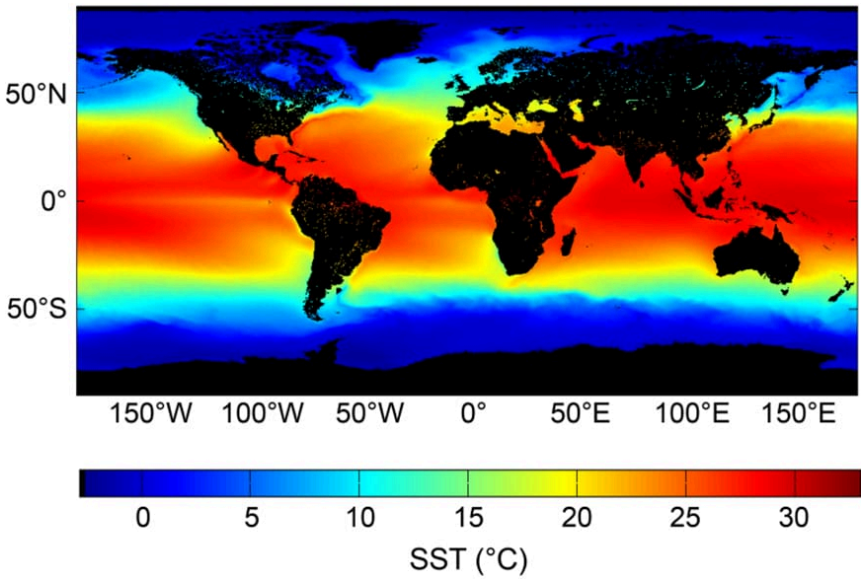


Figure 16.11: Sea Surface Temperatures Map. Figure by NOAA's National Centers for Environmental Information is in the public domain

Exercise 1.16.14

26. Refer to Figure 16.11.

    a. Explain the global distribution of sea surface temperatures (SST).

    b. What is the SST at 20°S, 150°W?

    c. Between which latitudes do most of the warmer temperatures occur?

    d. Which coast of the United States experiences warmer SST year-round? Explain why in one to two sentences.

    e. Apply What You Learned: Do you think coral reefs would be more concentrated on the west coast of the United States or the east coast of the United States? Explain your response in one to two sentences.

Figure 16.12 shows the changes in SST between 1901 and 2015.

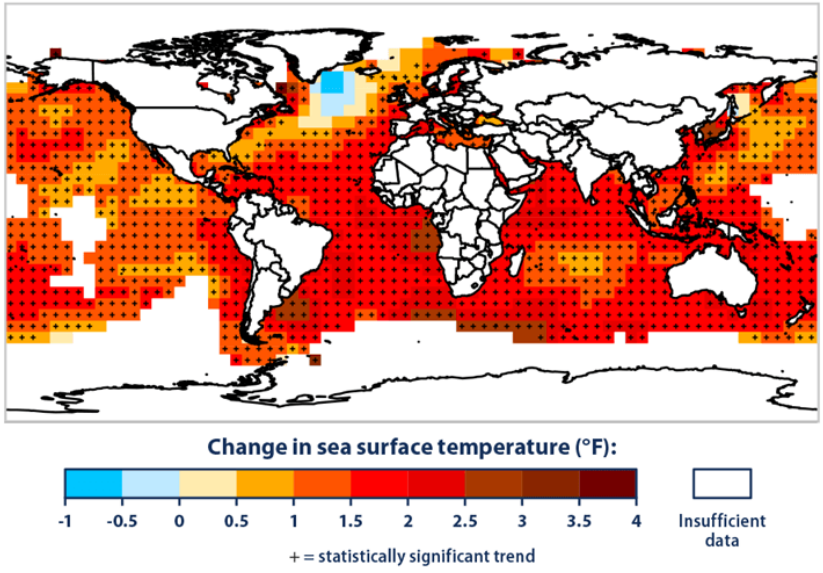


Figure 16.12: Map of Change in Sea Surface Temperature. Figure by the Environmental Protection Agency is in the public domain

Exercise 1.16.15

27. Refer to Figure 16.12.

    a. In one to two sentences, describe the overall trend in sea surface temperature change from 1901 to 2015.

    b. Which areas of the oceans experienced the greatest increase in SST? Tip: refer to a world map to identify the locations.

    c. Use Your Critical Thinking Skills: Why would there be insufficient data available for certain ocean locations? Explain your response in one to two sentences.

    d. Use Your Critical Thinking Skills: Why might the ocean area southeast of Greenland in the North Atlantic Ocean be the only location to have cooled between 1901 and 2015? Explain your response in one to two sentences.

A third threat to coral reefs is low-oxygen (**hypoxia**) stress. When there are low or depleted dissolved oxygen levels in the oceans, life is unable to be sustained and dead zones are created. There may be die-offs of corals, aquatic plants, fish, and shellfish in dead zones. NOAA's Ocean Service explains that "the amount of oxygen in any water body varies naturally, both seasonally and over time. This occurs due to a balance between oxygen input from the atmosphere and certain biological and chemical processes, some of which produce oxygen while others consume it".[299] NOAA's National Centers for Coastal Ocean Science (NCCOS) further explains that:

Hypoxia (low oxygen) poses a serious and escalating threat to marine ecosystems globally. While the impacts of hypoxia have been well characterized in temperate marine systems, they remain poorly understood for tropical coral reef ecosystems. Preliminary studies indicate that hypoxia has negative consequences for coral health and reef diversity. With many of the world's coral reefs in decline, it is important to understand the additional threat represented by hypoxia. Human-assisted coral restoration efforts are increasing to reverse the trends of coral reef loss. It is important to understand how hypoxia can impact the survival of corals to develop the best strategies for choosing restoration sites and coral species to maximize the likelihood of success.[300]

Figure 16.13 shows documented dead zones in red dots, density of coral reefs in blue to purple shading, and hypoxia-related coral reef deaths (mortality) in yellow dots. Coral reef density is the coral reef area per local bioregion (x 1,000 km^2).

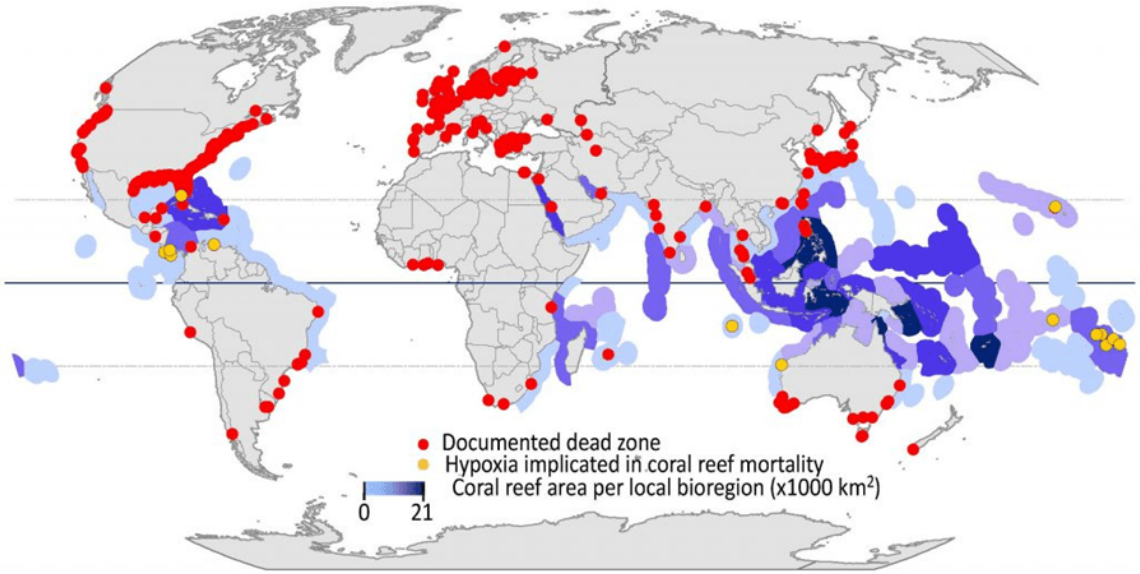


Figure 16.13: Change in Sea Surface Temperature Map. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0 adapted from Cmglee and Strebe

Exercise 1.16.16

28. Refer to Figure 16.13.
    a. Analyze the map data to complete Table 16.3 below.

Table 16.3: Analysis of Hypoxia-Implicated Coral Reef Mortality

Region	Gulf of Mexico and Caribbean	Indian Ocean	North Pacific Ocean	South Pacific Ocean
Total Number of Gold Dots in this Region				
Number of Gold Dots in Most Dense Coral Reef Areas (dark blue and dark purple shading)				
Number of Gold Dots in Least Dense Coral Reef Areas (light blue and light purple shading)				

    b. Which region has the highest concentration of hypoxia-related coral reef deaths?

    c. Is there a spatial correlation between hypoxia-related coral reef deaths and whether or not the coral is located in one of the most dense or least dense coral reef areas? Use the data in Table 16.2 in your response.

    d. Use Your Critical Thinking Skills: What might explain the spatial distribution of hypoxia-related coral reef deaths? Explain your response in one to two sentences.

Case Study: The Great Barrier Reef

The Great Barrier Reef (Figure 16.14) is the largest coral reef system in the world. It is located in Australia in the Coral Sea, off the east coast of Queensland (one of six states of Australia). The Great Barrier Reef stretches approximately 2,300 kilometers (1,400 miles) over an area of approximately 344,400 square kilometers (133,000 square miles) and is home to nearly 3,000 individual reefs and 900 islands. By comparison, the coastline of California is approximately 1,350 kilometers (840 miles) long and the area of the Great Barrier Reef is approximately the same size as the countries of Japan and Germany.



Figure 16.14: Great Barrier Reef Locator Map. Figure by NeoGeneric is licensed under CC BY-SA 4.0

Figure 16.15 shows SST data collected by satellites for the Great Barrier Reef between January 7 and March 25, 2017. Temperatures were collected weekly and the data was plotted on a graph that indicates when coral reach their bleaching limit (29.7°C). Recall that coral bleaching is a stress response that results when corals expel zooxanthellae living in their tissues, which causes the coral to turn white.

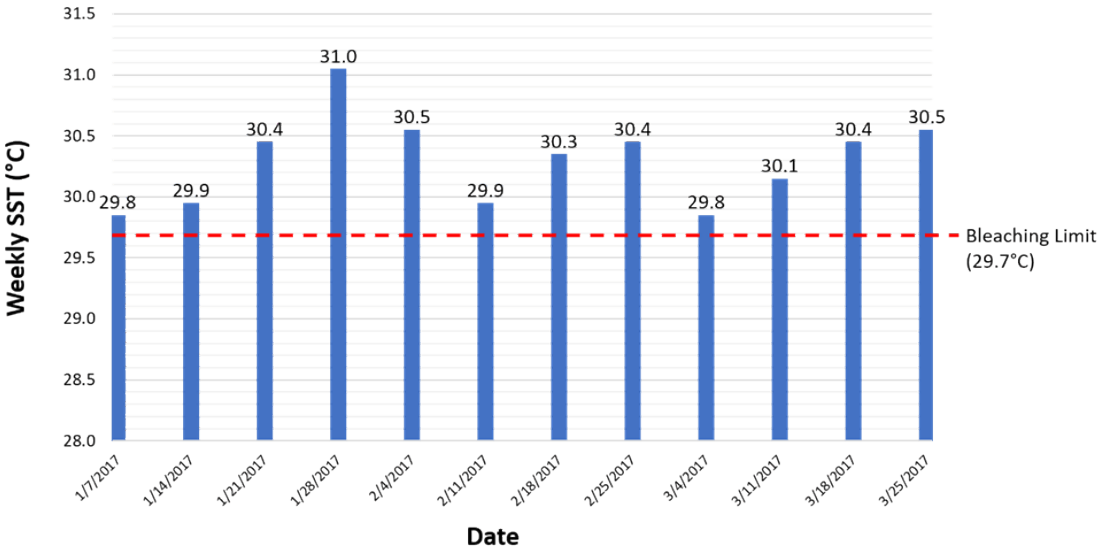


Figure 16.15: Great Barrier Reef Weekly Sea Surface Temperature. Figure by Waverly Ray with data from NOAA is licensed under CC BY-NC-SA 4.0

Exercise 1.16.17

29. Refer to Figure 16.15.

    a. On the Great Barrier Reef, what temperature do sea surfaces need to reach to cause coral bleaching? Answer in both °C and °F. (See formula below).

    Use this formula to convert °C to °F:

    (Temperature in Degrees Celsius x 1.8) + 32 = Temperature in Degrees Fahrenheit

b. Coral bleaching events begin when SST reaches 1 to 2°C (1.8°F) above average temperatures for a particular reef. What is the average SST range for the Great Barrier Reef? Answer in both °C and °F.

c. Use Your Critical Thinking Skills: Do you think the difference in temperature between average SST and the bleaching limit is small or large? Explain your response in one to two sentences.

d. How many weeks did the temperatures exceed the 'bleaching limit'?

e. How many degrees above the bleaching limit did the sea surface temperature rise during the week of January 28, 2017?

f. Were there any weeks between January 7 and March 25 when SST did not reach the bleaching limit?

g. Do you believe the corals on the Great Barrier Reef to be at high risk, moderate risk, or low risk of bleaching due to heat stress? Use the temperature data to explain your answer in one to two sentences.

Check It Out! What You Can Do to Help Protect Coral Reefs

Visit the EPA's website to learn what you can do every day to help protect coral reefs.

Australia has a population of 25 million people and nearly 65,000 are employed by industries that rely on the Great Barrier Reef. Table 16.4 shows the number of people employed and the value added by the economic activities associated with the Great Barrier Reef (GBR). This research conducted between 2015 and 2016 by the multinational accounting firm Deloitte shows the total economic value of the Great Barrier Reef to Australia to be $4.5 billion US dollars.

Table 16.4: Economic Contribution of the Great Barrier Reef (2015-2016). Data shown in US dollars based on report from Deloitte

Industry	Number Employed in GBR Regions	Number Employed in Australia	Value Added in GBR Regions	Valued Added in Australia
Tourism	19,855	58,980	1.7 billion	4 billion
Fishing	680	814	98 million	162 million
Recreation	2,889	3,218	199 million	170 million
Scientific Research	895	970	109 million	128 million
Total	**24,139**	**64,044**	**2 billion**	**4.5 billion**

Exercise 1.16.18

30. Refer to Table 16.4.

a. Which industry operating in Great Barrier Reef (GBR) Regions brought the most economic value to Australia between 2015 and 2016?

b. Tourism in GBR Regions accounts for what percent of the total value added to the entire Australian economy? Show your calculation.

c. How many people did the Great Barrier Reef employ in all of Australia between 2015 and 2016? Show your calculation.

d. What could explain the higher numbers of employment in Australia versus the Great Barrier Reef Regions for tourism?

e. How might coral bleaching and the dying of coral reefs impact communities near GBR Regions?

f. How might coral bleaching and the dying of coral reefs eventually affect the general population of Australia?

Part D. Wrap-Up

Consult with your geography lab instructor to find out which of the following wrap-up questions you should complete. Attach additional pages to answer the questions as needed.

Exercise 1.16.19

31. What is the most important idea that you learned in this lab? In two to three sentences, explain the concept and why it is important to know.

31. What was the most challenging part of this lab? In two to three sentences, explain why it was challenging. If nothing challenged you in the lab, write about what you think challenged your classmates.

31. What is one question that you have about what you learned in this lab? Write your question along with one to two sentences explaining why you think your question is important to ask.

31. Review the learning objectives on page 1 of this lab. How would you rate your understanding or ability for each learning objective? Write one sentence that addresses each learning objective.

31. Sketch a concept map that includes the key ideas from this lab. Include at least five of the terms shown in bold-faced type.

31. Create an advertisement to educate your peers on the important information that you learned in this lab. Include at least three key terms in your advertisement. The advertisement should be about half a page in size (about 4 inches by 6 inches).

31. One way to think of physical geography is that it is the study of the relationships among variables that impact the Earth's surface. Select two variables discussed in this lab and describe how they are related.

31. How does what you learned in this lab relate to your everyday life? In two to three sentences, explain a concept that you learned in this lab and how it relates to your day-to-day actions.

31. How does what you learned in this lab relate to current events?
    a. Write the title, source, and date of a news item that relates to this lab.
    b. In two to three sentences, discuss how the news item relates to what you have learned in this lab.
    c. In one to two sentences, discuss whether or not the news item accurately represents the science that you learned. Tip: consider whether or not the news item includes the complexity of the topic.

31. Search O*NET OnLine to find an occupation that is relevant to the topics presented in today's lab. Your lab instructor may provide you with possible keywords to type in the Occupation Quick Search field on the O*NET website.
    a. What is the name of occupation that you found?
    b. Write two to three sentences that summarize the most important information that you learned about this occupation.
    c. What is one question that you would want to ask a person with this occupation?

Answer available at the end of this section.

[282] Text by USGS is in the public domain

[287] Text by NASA is in the public domain

[288] Text by the USGS is in the public domain

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[292] Text by NOAA is in the public domain

[294] Text by NOAA is in the public domain

[299] Text by NOAA's National Ocean Service is in the public domain

[300] Text and figure by NOAA's NCCOS are in the public domain

Answers

Exercise 1.16.19

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1.17: Lab 17 - Aeolian Geomorphology and Desert Landscapes

Learning Objectives

- Explain how arid regions are classified.
- Analyze the spatial pattern of human-induced desertification risk.
- Analyze the relationship between grain transport and size distribution.
- Identify erosional and depositional aeolian landscape features.

Introduction

Named from Aeolus, the Greek god of wind, **aeolian processes** refer to wind's ability to shape the surface of the planet. Aeolian processes are most effective where surface material is fine, dry, and loose. Vegetation imposes a frictional force on the wind to reduce its effectiveness. Thus, aeolian processes are most effective in an environment devoid of vegetation. These conditions are met in deserts, found on every continent of the world. In most cases, wind erosion predominates over deposition, leaving a surface of stones. Most people think of dunes when they think of deserts, but only one-quarter of Earth's deserts are either partially or completely covered by sand.

Though less extensive in area, coastlines of large bodies of water are another aeolian environment. Here, waves and currents supply weathered material that is susceptible to wind action. Aeolian processes have been enhanced by human activity over the past few centuries. Overuse of soil and grazing land resources in semi-arid and arid and seasonally-dry regions has led to extensive wind erosion and desertification.

In this lab, you will explore local regions that have been shaped through aeolian processes; understand the importance of erosion, transportation, and deposition; and learn how to identify and understand the development of aeolian features.

Part A. Arid Region Classification

With nearly one third of Earth's land surface considered a **desert** or **arid land**, meaning it receives minimal rainfall, these regions support sparse yet impressive vegetation and a limited yet unique population of animals. Desert settings in films such as *The Good, the Bad and the Ugly* and *Star Wars* convey a sense of adventure and exploration. Deserts may be hot, or they may be cold. They may be regions of sand or vast areas of rocks and gravel peppered with occasional plants. But deserts are always dry.

There are almost as many definitions and classification systems of deserts as there are actual deserts in the world. Most classifications rely on some combination of the number of days of rainfall, the total amount of annual rainfall, temperature, humidity, or other factors. In 1953, Peveril Meigs divided desert regions on Earth into three categories according to the amount of precipitation they received. In this now widely accepted system, these areas are differentiated in one of three ways:

- **Extremely arid lands** have at least 12 consecutive months without rainfall.
- **Arid lands** have less than 250 millimeters (approximately 9.8 inches) of annual rainfall.
- **Semiarid lands** have annual precipitation rates between 250 and 500 millimeters (approximately 9.8 to 19.7 inches).[304]

Exercise 1.17.1

1. Refer to Figure 17.1, which shows the global annual precipitation in millimeters per year.
    a. Locate the Sahara Desert on the map. Approximately how many millimeters of rain does the majority of this desert receive?

b. Locate the Patagonian Desert on the map. Approximately how many millimeters of rain does the majority of this desert receive?

c. List three spatial patterns of global precipitation that you observe on this map:

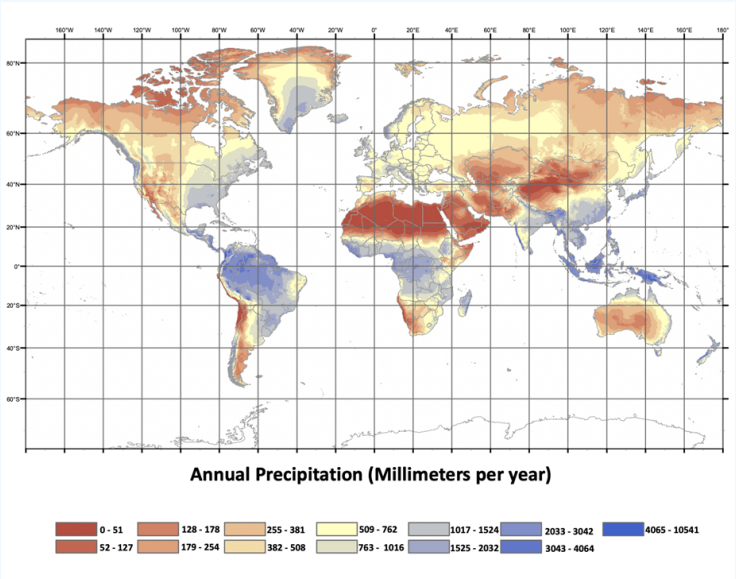


Figure 17.1: Global Precipitation Values. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

Desertification is the shift from perennial grasslands to shrublands that occurs globally to impact nearly 40% of the Earth's land surface and a fifth of the world's human population. Desertification results from interactions between human activities (such as livestock overgrazing) and prolonged drought. Desertification is a global problem that reduces plant productivity, biodiversity, air and soil quality, and water availability.[306] A classic example of desertification is the 1930s Dust Bowl period in the United States, which devastated Midwestern states. It was a time when severe droughts combined with poor land-management practices to cause tremendous suffering and economic loss.[307] Figure 17.2 is a series of three photographs from near Tucson, Arizona, that show the progression from arid grassland to desert over a 100-year period. The change is the result of grazing management and reduced rainfall in the U.S. southwest.[4]

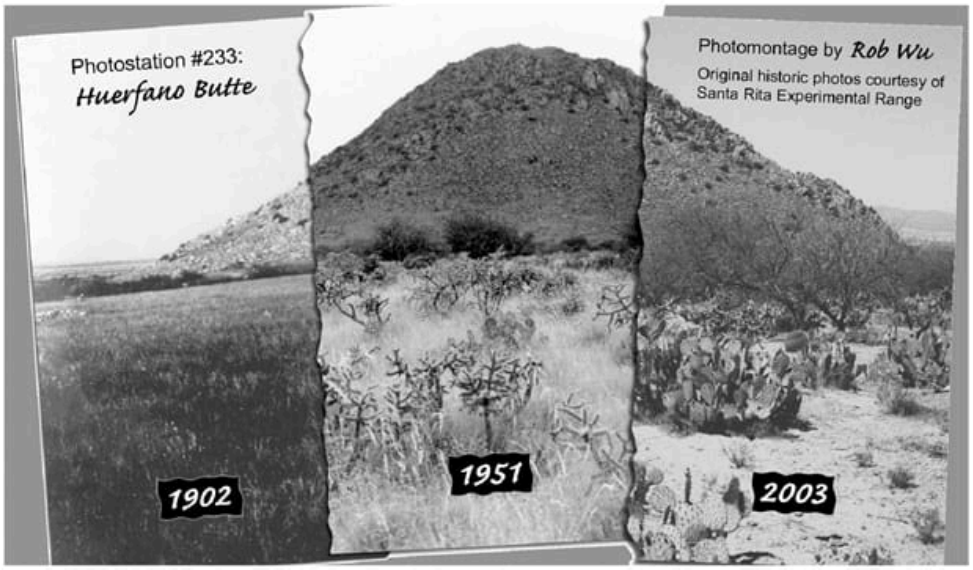


Figure 17.2: Desertification Photo Series. Figure and text by the U.S. Climate Change Science Program, Synthesis and Assessment Products, of the USDA is in the public domain

There are about 7.1 million square kilometers (km^2) of land under low risk of human-induced desertification, 8.6 million km^2 at moderate risk, 15.6 million km^2 at high risk, and 11.9 million km^2 under very high risk. Each of these classes represents a **desertification tension zone**. The major critical tension zone that requires immediate attention is the very high-risk class. There are 11.9 million km^2 of land with about 1.4 billion inhabitants. For reference, the very high-risk area is larger than the areas of the United States and Mexico combined. Major national conflicts are related to the reduced ability of the land to support the people in agriculture-based economies. Tension zones result from:

- Excessive and continuous soil erosion resulting from overuse and improper use of lands, especially marginal and sloping lands;
- Nutrient depletion and/or soil acidification due to inadequate replenishment of nutrients or soil pollution from excessive use of organic and inorganic agri-chemicals;
- Reduced water-holding capacity of soils due to reduced volume of soil and reduced organic matter content, both a consequence of erosion and reduced infiltration due to crusting and compaction;
- Salinization and water-logging from over-irrigation without adequate drainage; and
- Unavailability of water stemming from decreased supply of aquifers and drainage bodies.[309]

Figure 17.3 shows the areas at low (shaded green), moderate (yellow), high (orange), and very high (red) risk of desertification.

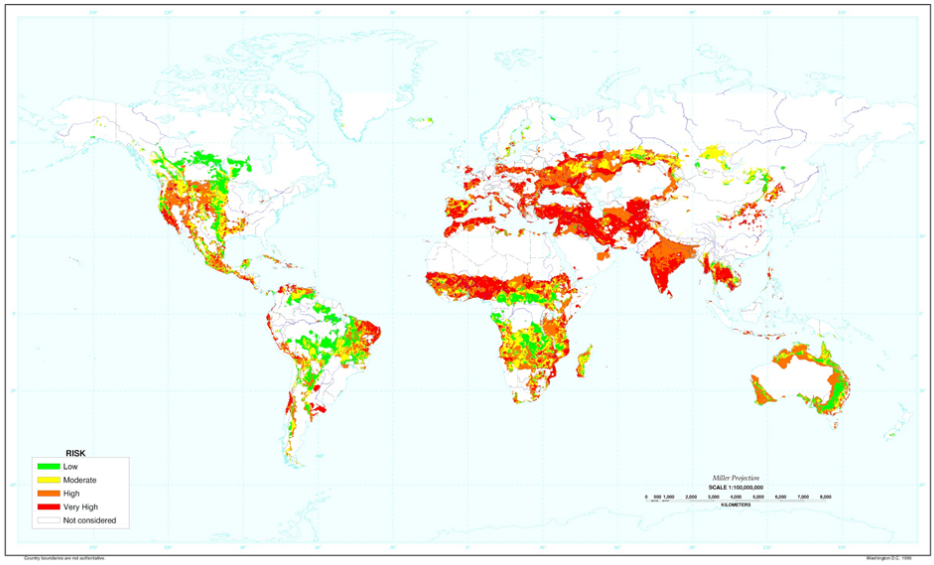


Figure 17.3: Risk of Human-Induced Desertification Map. Figure by USDA Natural Resources Conservation Service is in the public domain

Exercise 1.17.2

2. Refer to Figure 17.3.
   a. List three spatial patterns of the risk of human-induced desertification that you observe on this map:
   b. Compare Figures 17.1 and 17.3. What is the relationship between global precipitation and the risk of human-induced desertification? Explain your response in at least one sentence.

Part B. Grain Transport and Size Distribution

Sand generally begins to move when the wind achieves a velocity of about 4.5 meters per second (m/sec), which is equivalent to about 10 miles per hour. At first, sand exhibits a rolling motion called **traction** or **surface creep**. Approximately 25% of total

sand transport during sand storms occurs by traction. As wind speed increases, grains are lifted into the air by wind gusts.

Once airborne, sand grains travel downwind and then drop back to the surface several centimeters from their point of origin. Finer dust particles are lifted from the surface and suspended in the air at much greater heights than heavier sand grains. With strong winds and turbulence, sand grains can be lifted as high as 2 meters (~6.5 feet) and travel a distance of 10 meters (~32 feet) or more. About 25% of the total sand transport during these events are caused by this **suspension** process.

When a settling sand grain impacts the surface, it sends another grain of sand into the air to travel in the downwind direction in a process called **saltation**. Watching this process in action makes sand appear to be bouncing along the surface (Figure 17.4). Saltation accounts for about 50% of sand transport over dunes. Once saltation begins, transport can continue under somewhat lower wind speeds.

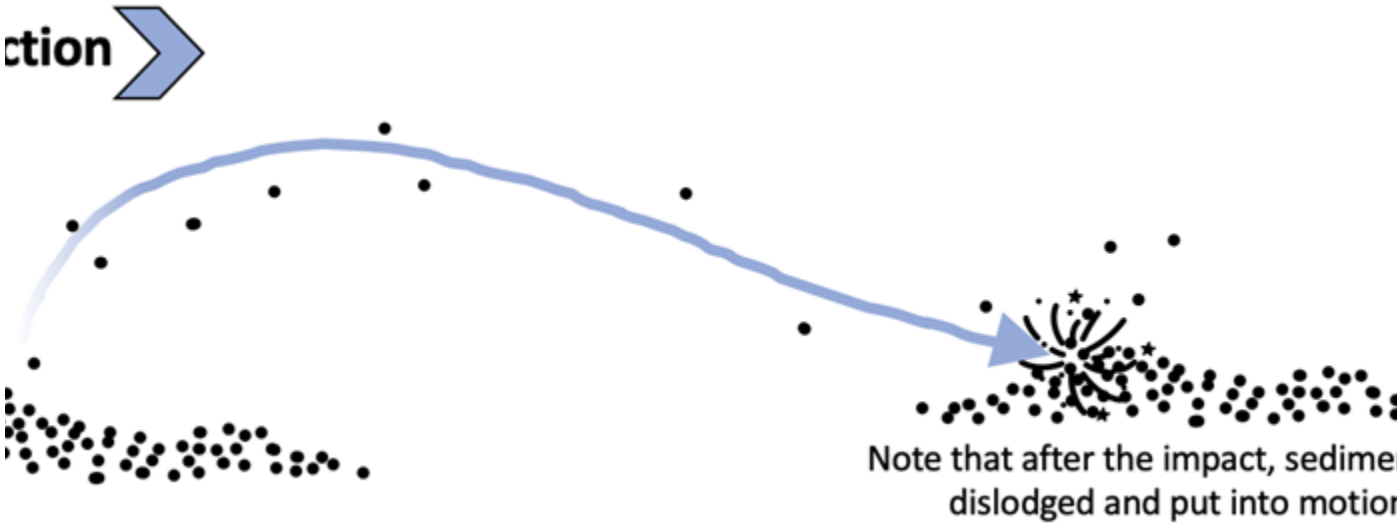


Figure 17.4: Sediment Saltation. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Exercise 1.17.3

3. Briefly summarize the three ways that material is moved by wind and include the percentage of each mode of transportation.

4. Apply What You Learned: Air reacts in a very similar way to the way a fluid reacts. With that being said, compare how material moves along a river to how material moves in wind, and identify a few similarities.

Now that you understand the three prominent ways material can move, it is important to analyze the variability of grain sizes. It's important to know that the word sand refers to the size of the material, not what it is made of. This is why some beach sand can be made of quartz and feldspars, while other sand can be made of seashells and volcanic rocks.

Below you will find a table from the International Organization of Standardization, which

establishes the basic principles for the identification and classification of soils based on those material and mass characteristics most commonly used for soils for engineering purposes (Table 17.1). Also note, as earlier identified, that material can move either by traction, suspension, and saltation. Traditionally, material that is coarse or very coarse (up to 2mm) will move via traction. Material that is between 0.1mm to 0.5mm will move via saltation and material that is 0.1mm or smaller will be suspended. For reference, 1 millimeter is about 0.04 inches.

Table 17.1: Grain Size Classification

Classification Type	Classification Subtype	Classification Name	Label	Size range (mm)
Very coarse soil	n/a	Large boulder	LBo	>630

Classification Type	Classification Subtype	Classification Name	Label	Size range (mm)
Very coarse soil	n/a	Boulder	Bo	200–630
Very course soil	n/a	Cobble	Co	63–200
Coarse soil	Gravel	Coarse gravel	CGr	20–63
Coarse soil	Gravel	Medium gravel	MGr	6.3–20
Coarse soil	Gravel	Fine gravel	FGr	2.0–6.3
Coarse soil	Sand	Coarse sand	CSa	0.63–2.0
Coarse soil	Sand	Medium sand	MSa	0.2–0.63
Coarse soil	Sand	Fine sand	FSa	0.063–0.2
Fine soil	Silt	Coarse silt	CSi	0.02–0.063
Fine soil	Silt	Medium silt	MSi	0.0063–0.02
Fine soil	Silt	Fine silt	FSi	0.002–0.0063
Fine soil	Clay	Clay	Cl	≤0.002

Exercise 1.17.4

5. Use Your Critical Thinking Skills: After reviewing the table, why do you think it is important that the grain size of material is recorded?

6. Use Your Critical Thinking Skills: Assuming you are in a location doing research and that the air is very still. How could you use the average grain size to explain the general wind flow for this environment?

7. Interpret the sample photographs shown in Figure 17.5. For each photograph, take note of the scale bar present. Identify the best name for each sample based on the average grain size shown in Table 17.1.

    a. What is the average grain size measured and classification name of Sample A?

    b. What is the average grain size measured and classification name of Sample B?

    c. What is the average grain size measured and classification name of Sample C?

    d. What is the average grain size measured and classification name of Sample D?

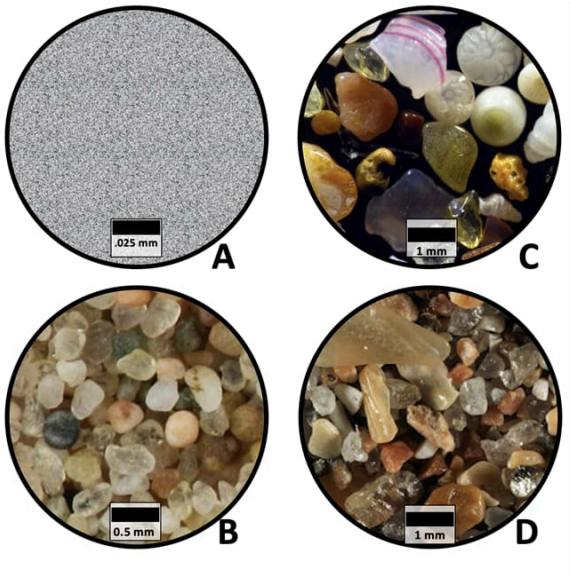


Figure 17.5: Four Microscopic Samples of Grain Sizes. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Part C. Erosional Aeolian Landforms

Landscapes formed from the work of wind result from either the removal of fine particles or the sculpting effects of material in movement. **Deflation** lifts and removes loose particles from the surface. Deserts, where soils of mixed particle size have been eroded of fine-grained sediments, leave a cobblestone-like surface behind called **desert lag** or **desert pavement**. The interlocking pavement of stones protects the underlying surface from the wind. If disturbed, the surface becomes subject to erosion.

It can be surprising to learn that water is an important agent of erosion in arid lands. Not all erosional landforms are made of cobbles and stone, or are flat and desolate. **Playas** are large, flat, dried-up lands located in the desert basins. These features are the result of evaporation rates that exceed precipitation, often leaving behind mud cracks and salt flats atop their playa surfaces. Often in arid regions, there can be steep-sided gullies, called **arroyos**, that are carved by fast-moving waters during torrential desert storms. Big or small, erosional landscapes are dynamic in arid regions, with the help of both wind and water.

Check It Out! The Lowest Elevation in North America

Ever been under the ocean? How about -282 feet below the ocean? Well, check out Badwater Basin in Death Valley! This basin is an endorheic basin also known as a playa. When you scan the QR code, Google Earth will position you so that you can zoom in and see the sea level marker, but don't forget to turn around to explore the landscape!

Lag Deposits and Desert Pavements

Due to erosion, transportation, and deposition, desert surfaces can be completely covered in sand, or have closely packed, interlocking pebbles or even a tight array of larger cobbles. Lag deposits are the result of the removal of fine-grained material,

leaving behind large and irregularly-shaped material. Desert pavements are a continuation of a lag deposit, in that the larger fragments left behind become interlocked and compacted. Due to forces such as wind, water, and thermal expansion, these larger fragments will settle into a tightly packed surface—much like a paved surface, thus earning the name desert pavement. Ventifacts are rocks that have been shaped by the erosive action of wind, similar to sandblasting.

Ventifacts are important for scientists as we are able to identify consistent direction(s) of wind flow. Below is a ventifact image of a large extrusive igneous boulder that has been left behind on a lag deposit (Figure 17.6). This is a piece of basalt; note the air bubbles that are within the rock. Observe the specimen and answer the following question. This boulder is approximately 30 pounds and more than 16 inches in length. You may observe a very distinct linear pattern on the surface of this rock, somewhere between a polishing and a pitting (abrasion).

Exercise 1.17.5

8. Apply What You Learned: What do you think caused these markings on the surface of the rock shown in Figure 17.6, and can you deduct a general pattern or direction of these markings?



Figure 17.6: Image of a Ventifact in Death Valley. Figure by Daniel Mayer is licensed under GNU FDL

Buttes, Mesas, and Plateaus

Often features observed in our environment are so large that it might be hard to even see them, and the best way to do so is to observe them from an aerial view. Some of the largest erosional features observed are buttes, mesas, and plateaus. Although the features might look similar, what differentiates one from another is their size.

Buttes: due to extensive erosion and weathering (by wind and water), buttes are formed when a more resilient caprock, or top layer of material that is more resistant to weathering, remains and the material around is worn away, leaving a column-shaped feature. Buttes can be hundreds of feet tall, and similar to a barstool, have a smaller flat top. The key observation for identification is that these features are taller than they are wide.

Mesas: similar to the formation of a butte, mesas have steep sides and a larger flat top; in fact, the feature might resemble that of a table. A mesa's top is generally large enough that standing water may be found. The key observation for identification is that these features are wider than they are tall.

Plateaus: similar still to buttes and mesas in development, what differentiates plateaus is that the flat top can extend for thousands of square miles. As an example, the Colorado Plateau, which the Grand Canyon is actively carving through, covers portions of Colorado, New Mexico, Utah, and Arizona. The key observation for identification is that these features are huge, flat, elevated highland.

Exercise 1.17.6

9. Refer to Figure 17.7, which shows an unlabeled arid landscape.
   a. Label a butte, a mesa, and a plateau.
   b. Label an additional two features that are shown in the diagram. Tip: review the erosional landforms discussed previously in the lab in order to identify two additional features.

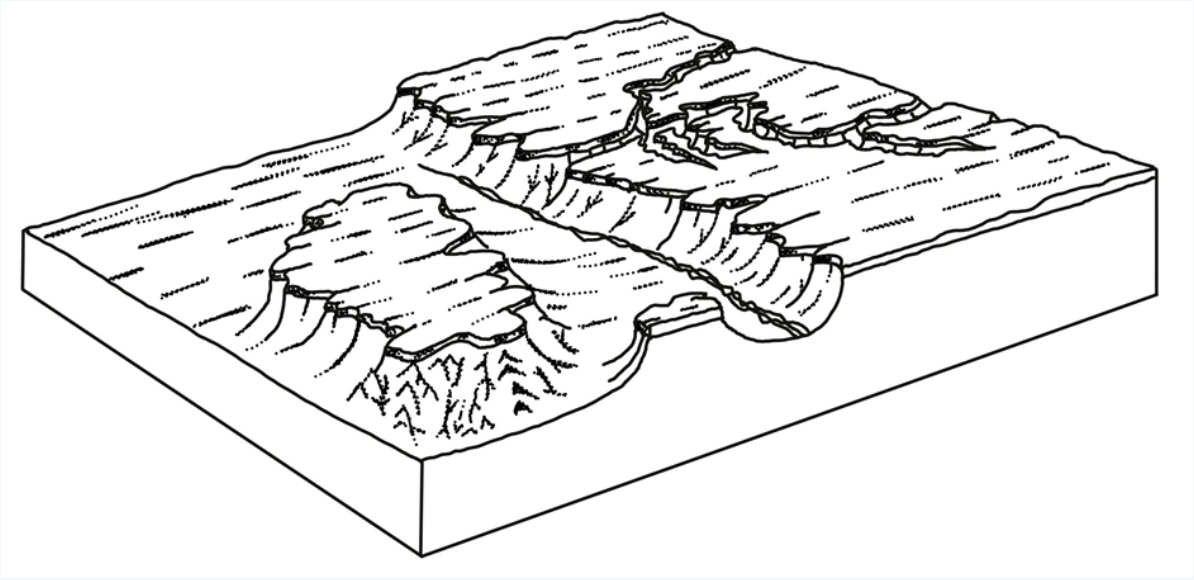


Figure 17.7: Unlabeled Arid Feature Diagram. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

10. Now that you have learned how to observe and interpret the differences between buttes, mesas and plateaus, identify them on a topographic map from New Mexico (Figure 17.8).

    a. Circle and label a butte, a mesa, and a plateau.

    b. In one sentence, explain how you identified a butte:

    c. In one sentence, explain how you identified a mesa:

    d. In one sentence, explain how you identified a plateau:

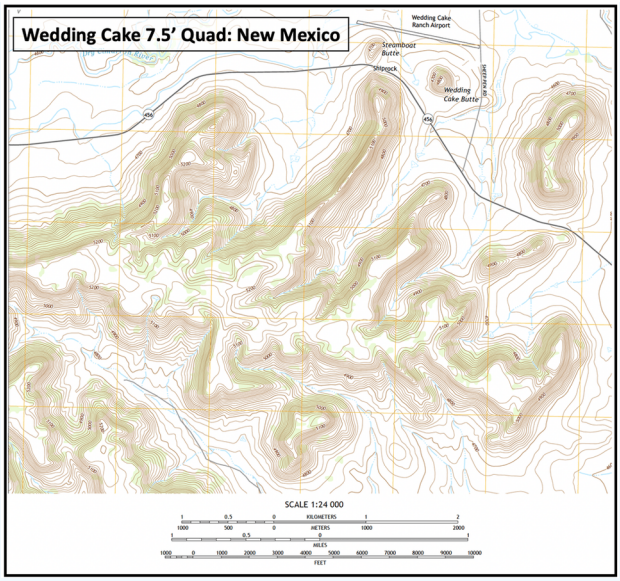


Figure 17.8: Wedding Cake, New Mexico, Topographic Map. Figure by Jeremy Patrich adapted from USGS is licensed under CC BY-NC-SA 4.0

Part D. Depositional Aeolian Landforms

There are many different types of depositional landforms; the most prominent in arid regions is the dune. Depositional landforms are the visible evidence of erosion and transportation, as these landforms are made of those materials.

Sand Dune Development

Sand dunes are formed by wind moving sand particles (Figure 17.9). Let's begin with the foundation of dune formation. Figure 17.9 shows that with the assistance of wind (transportation) the sand grains are in motion, working uphill along the stoss side of the dune until the grains reach the top. Then the heavier or coarser-grained material rolls along the leeward side and the finer grains may become suspended.

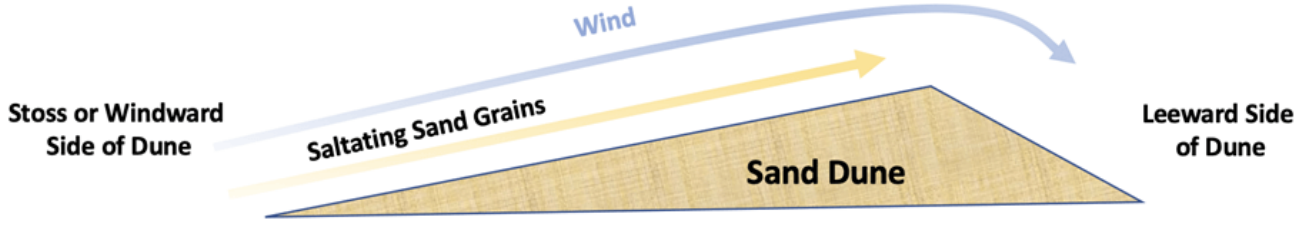


Figure 17.9: Sand Movement along a Dune. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Exercise 1.17.7

11. Refer to Figure 17.9.

    a. Apply What You Learned: Assuming that no additional material is added, but the wind direction and velocity are consistent, what do you think would happen to the shape, size, and location of the dune? Your response should be one to two sentences in length.

    a. Apply What You Learned: Assuming that additional material is added, and the wind direction and velocity are consistent, what do you think would happen to the shape, size, and location of the dune? Your response should be one to two sentences in length.

Sand Dune Properties

The shape and design of the dune vary with the amount or volume of sand available, as well as the direction(s) that the wind blows. If the wind blows steadily from one direction, then linear, transverse, or barchan dunes will form. If the direction that the wind blows shifts or comes from different directions, then star or network dunes will form. Figure 17.10 identifies a few different types of dunes possible based on the volume of sand supply and wind variability. The three types of wind variability are:

- Unimodal: the predominant winds travel in one direction;
- Bimodal: the predominant winds travel in two directions (for example, onshore during the day and offshore at night); and
- Complex: the predominant winds travel in a variety of directions.

Exercise 1.17.8

12. Use Your Critical Thinking Skills to answer the following questions.
    a. What is an example of where you might have experienced unimodal wind variability?
    a. What is an example of where you might have experienced bimodal wind variability?
    a. What is an example of where you might have experienced complex wind variability?

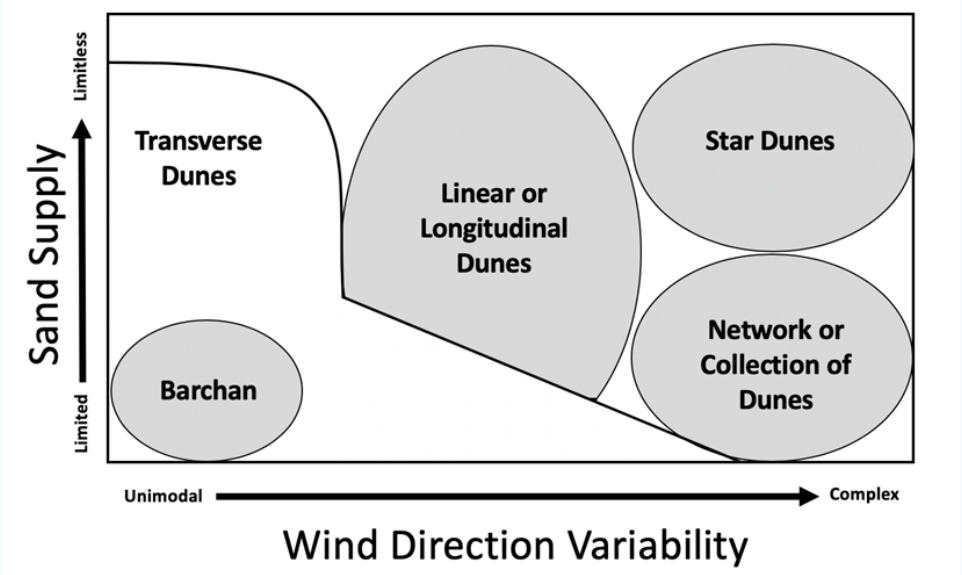


Figure 17.10: Sand Dunes by Wind Variability and Sand Supply. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

13. Refer to Figure 17.10. Sand supply can either be limited or limitless. Briefly identify where sand comes from, and explain why the supply of sediment could be either limited or limitless.

Now that you have a way to identify the dunes based on sand supply and wind variability, let's now learn how to identify these dunes in the field. Although there are many more types and variations of dunes than what are listed in the figure above, for this course we will focus on the most common six dunes: barchan, parabolic, star, transverse, linear, and barchanoid ridges. Below you will find the basic definitions of each of these six dunes. After reading about each one, identify and circle: if the wind direction is unimodal or complex, and if the sand supply is limited or limitless. (Hint: be sure to refer to Figure 17.10!).

Exercise 1.17.9

14. **Barchan Dune**: crescent-shaped dunes with the points (horns) of the crescents pointing in the downwind direction, and a curved slip face on the downwind side of the dune. They form in areas where there is a hard ground surface, a moderate supply of sand, and a constant wind direction.
    a. Unimodal or Complex?
    b. Limited or Limitless sand supply?
15. **Parabolic Dunes** (also called blowouts): "U" shaped dunes with an open end facing upwind. They are usually stabilized by vegetation, and occur where there is abundant vegetation, a constant wind direction, and abundant sand supply. They are common in coastal areas.
    a. Unimodal or Complex?
    b. Limited or Limitless sand supply?
16. **Star Dunes**: dunes with several arms and variable slip face directions that form in areas where there is an abundant sand supply and variable wind directions.
    a. Unimodal or Complex?
    b. Limited or Limitless sand supply?
17. **Transverse Dunes**: large fields of dunes that resemble sand ripples on a large scale. They consist of ridges of sand with a steep face on the downwind side and form in areas where there is an abundant supply of sand and a constant wind direction.
    a. Unimodal or Complex?
    b. Limited or Limitless sand supply?
18. **Linear Dunes** (also called seifs): long straight dunes that form in areas with a limited sand supply and converging wind directions.
    a. Unimodal or Complex?
    b. Limited or Limitless sand supply?
19. **Barchanoid Ridge**: consists of several joined barchan dunes and looks like a row of connected crescents. Each of the barchan dunes produces a wave in the barchanoid ridge. This occurs when the sand supply is greater than in the conditions that create a barchan dune.
    a. Unimodal or Complex?
    b. Limited or Limitless sand supply?

Sand Dune Identification

Exercise 1.17.10

20. Below you will find six images of dunes (Figure 17.11). For each of the dunes shown in Figure 17.11, identify and label:
    a. the dune type,
    b. the windward side of each dune,
    c. the slip face side of each dune, and
    d. draw arrows indicating the direction or directions in which the wind is blowing.

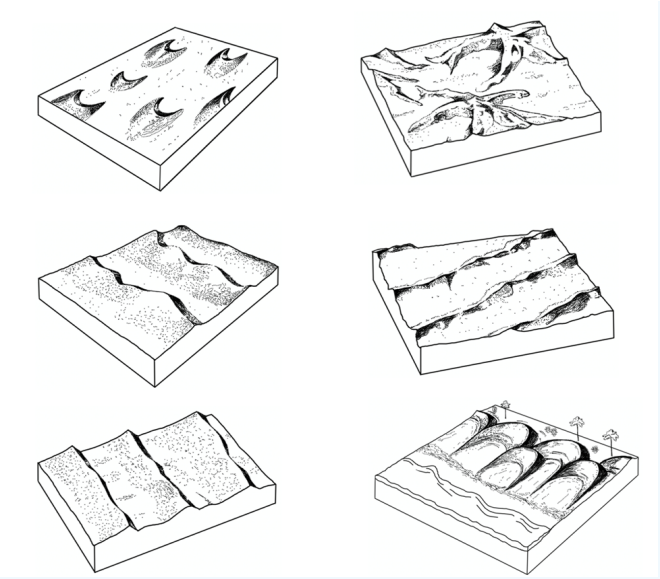


Figure 17.11: Image of the Six Most Common Dunes to Identify Wind Direction, Variability, and Dune Shape. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Alluvial Fans and Bajadas

Water is an important agent for erosion, transportation, and deposition in any region, but many are surprised to see how running water greatly impacts the topography in arid regions. Running water can move tremendous amounts of water and sediments during a flash flood or in torrent rains, which in turn will carve and shape the landscape. Furthermore, that material must go somewhere, and overtime these deposits will build up into large features called alluvial fans. **Alluvial fans** are fan-shaped deposits along the foothills of mountains, caused by flash flood material, called alluvium, being deposited at the mouth of these canyons. If the material from an alluvial fan spreads out enough to coalesce with (touch) another fan, then they are identified as **bajadas**. Lastly, when an alluvial fan is built by the debris flow, it is referred to as a debris cone or colluvial fan.

Exercise 1.17.11

22. Figure 17.12 is a satellite image, with a topographic overlay, of an alluvial fan in Death Valley, California.
    a. Using a colored pencil or pen, outline and label the farthest extent (perimeter) of the alluvial fan. With a different color, highlight the source of the material. Hint: you are looking for the river channel that deposited the material.
    b. Using the scale bar, what is the width of the alluvial fan from the source of the material to the edge?
    c. Using the scale bar, what is the length of the alluvial fan from the southeast to the northeast?

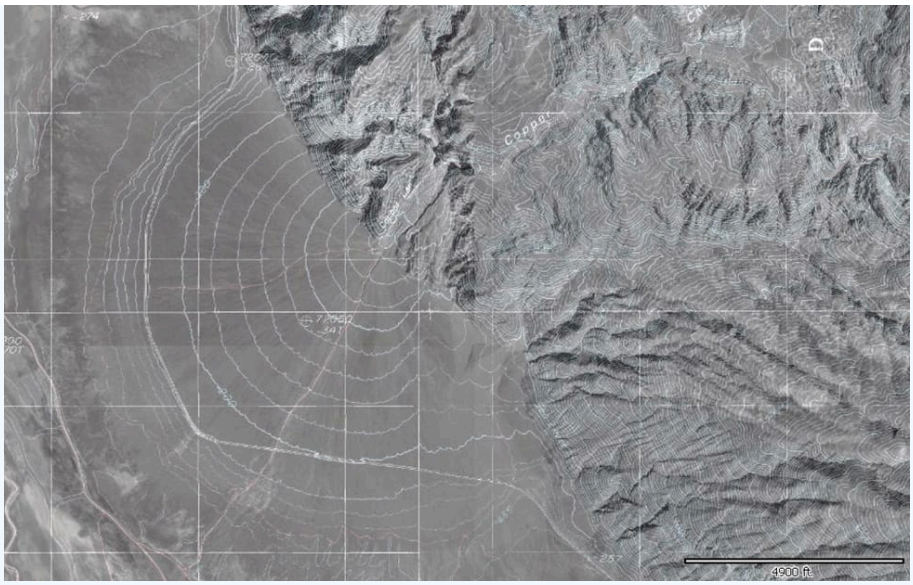


Figure 17.12: Image of an Alluvial Fan in Death Valley. Figure by Ethan O'Connor is in public domain

Check It Out! Alluvial Fans

Have you ever seen an alluvial fan? When you scan the QR Code, Google Earth will position you so that you can zoom in and see some alluvial fans in Death Valley!

Bajadas are aprons of rocky debris that form when alluvial fans overlap on their edges to form a ramp that spreads out toward the valley floor. A bajada or piedmont slope has sediment that is partially buried along its range front.

Exercise 1.17.12

22. Refer to Figure 17.13, which is a satellite image of the southeastern portion of Death Valley.
    a. Using two different colored pencils or pens, outline and label any alluvial fans and/or bajadas.
    b. In two to three sentences, describe the differences between the alluvial fans and bajadas in Figure 17.13, and how you were able to identify them.



Figure 17.13: Image of Bajadas in Death Valley National Park, California. Figure by Google and USDA Farm Service Agency is used under Google Earth's attribution guidelines

Loess Deposits

Loess are clay- and silt-sized sediments deposited by wind. These deposits are common in arid environments and also downwind of glaciers. During Ice Ages, loess was deposited in areas adjacent to continental glaciers that essentially ground rock into a powder. Approximately 10% of Earth's surface is covered by loess deposits (Figure 17.14), which range in thickness from a centimeter to more than 90 meters (approximately 295 feet).

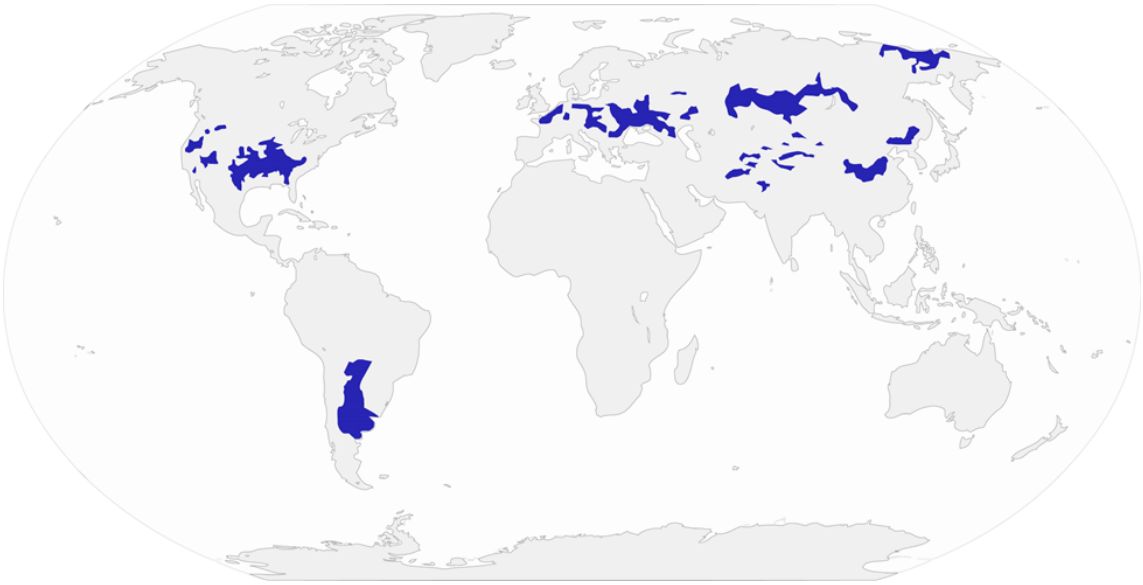


Figure 17.14: Map of Global Loess Deposits. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0

Exercise 1.17.13

23. Use Your Critical Thinking Skills: Why do loess deposits often make productive agricultural soils? Explain your response in one to two sentences.

Part E. Wrap-Up

Consult with your geography lab instructor to find out which of the following wrap-up questions you should complete. Attach additional pages to answer the questions as needed.

Exercise 1.17.14

24. What is the most important idea that you learned in this lab? In two to three sentences, explain the concept and why it is important to know.

25. What was the most challenging part of this lab? In two to three sentences, explain why it was challenging. If nothing challenged you in the lab, write about what you think challenged your classmates.

26. What is one question that you have about what you learned in this lab? Write your question along with one to two sentences explaining why you think your question is important to ask.

27. Review the learning objectives on page 1 of this lab. How would you rate your understanding or ability for each learning objective? Write one sentence that addresses each learning objective.

28. Sketch a concept map that includes the key ideas from this lab. Include at least five of the terms shown in bold-faced type.

29. Create an advertisement to educate your peers on the important information that you learned in this lab. Include at least three key terms in your advertisement. The advertisement should be about half a page in size (about 4 inches by 6 inches).

30. One way to think of physical geography is that it is the study of the relationships among variables that impact the Earth's surface. Select two variables discussed in this lab and describe how they are related.

31. How does what you learned in this lab relate to your everyday life? In two to three sentences, explain a concept that you learned in this lab and how it relates to your day-to-day actions.

32. How does what you learned in this lab relate to current events?
    a. Write the title, source, and date of a news item that relates to this lab.
    b. In two to three sentences, discuss how the news item relates to what you have learned in this lab.
    c. In one to two sentences, discuss whether or not the news item accurately represents the science that you learned. Tip: consider whether or not the news item includes the complexity of the topic.

33. Search O*NET OnLine to find an occupation that is relevant to the topics presented in today's lab. Your lab instructor may provide you with possible keywords to type in the Occupation Quick Search field on the O*NET website.
    a. What is the name of the occupation that you found?
    b. Write two to three sentences that summarize the most important information that you learned about this occupation.
    c. What is one question that you would want to ask a person with this occupation?

Answer available at the end of this section.

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[304] Text by USGS is in the public domain

[306] Text by USDA Agricultural Research Service is in the public domain

[307] Text by the Bureau of Global Public Affairs, U.S. Department of State is in the public domain

[309] Text by USDA Natural Resources Conservation Service is in the public domain

Answers

Exercise 1.17.14

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1.18: Lab 18 - Glacial Geomorphology

Learning Objectives

- Describe the processes that cause glaciers to advance or retreat.
- Analyze glacier mass balance data.
- Identify erosional and depositional glacial landscape features.
- Explain how glacial melting affects sea level rise.

Introduction

A **glacier** is a long-lasting body of ice (decades or more) that is large enough to move under its weight. About 10% of Earth's land surface is currently covered with glacial ice, and although the vast majority of that is in Antarctica and Greenland, there are still a few glaciers in California, nestled within the Sierra Nevada. At various times during the past million years, glacial ice has been much more extensive, covering at least 30% of the land surface at times.[322]

Glaciers represent the largest repository of freshwater on Earth, and they are highly sensitive to changes in climate. In the current warming climate, glaciers are melting rapidly worldwide, and although some of the larger glacial masses will last for centuries more, many smaller glaciers will be gone within decades, and in some cases, within years.[1]

California has a very rich geologic history when it comes to glaciers, which for many may be a surprise. Glaciation and its effects are present in the Cascades region, in the Sierra Nevada, and in the San Gabriel and San Bernardino Mountains. Glaciers in California are not only a thing of the past; as of 2020, there are more than 1,700 ice/snow bodies found in California. Thirteen of them are within a few-hours drive of Los Angeles. Only 70 of these features are larger than 0.1 square kilometer. There are 20 named glaciers in California (7 on Mount Shasta and 13 within the Sierra Nevada).

In this lab, you will explore local regions that have been shaped through glacial processes as well as understand how glaciers are formed, retreat, and shape the landscape. You will also learn how to identify and understand the development of glacial features.

Part A. Glacial Processes

Snow and ice exist in a crystalline form. As snow falls, the flakes are light and fluffy in texture, often referred to as powder. After the flakes reach the ground, if conditions remain cold enough, they will continue to be layered and buried under additional fresh snow. The crystals gradually change to solid ice over a period of time; this depends on factors such as temperature and speed of burial. Ice is composed of water in the crystalline solid form and under short-term stress, ice behaves like a solid. An ice cube in an environment below freezing, such as your freezer at home, will have a fixed shape. If you smash it with a hammer, it will shatter into smaller pieces. Interestingly though, as a glacier flows, it is not shattering or breaking but instead bending. This is because solid ice responds to long-term stress by bending and deformation. It is important to point out that glaciers are not just frozen water. Glacial ice forms when compression causes buried snow to recrystallize and compact over time. The formation of glacial ice can take more than one hundred years.

There are two main types of glaciers. **Continental glaciers**, also known as **ice sheets**, cover vast areas of land in extreme polar regions, including Antarctica and Greenland. **Alpine glaciers**, also known as **valley glaciers**, originate in mountains, mostly in temperate and Polar regions. Figure 18.1 shows the present-day **cryosphere**, where water is found in solid form.

Figure 18.1 utilizes the Fuller map projection, sometimes called the dymaxion projection, created by Buckminster Fuller. The surface of the Earth is projected onto a polyhedron with twenty triangular sides. Writing in *GIS Lounge*, Maxwell (2013, n.p.) explains that:

> ➢ When flattened, the Dymaxion map shows the Earth's continents as almost one contiguous land mass or island in the middle of one ocean.

➢ The Dymaxion map from Buckminster Fuller stands out because it is the only flat map of the Earth's surface in its entirety that does not contain any obvious visual distortions of the shapes and sizes of land masses relative to their global scales. It also does this without splitting any of the continents.

➢ Fuller himself was critical of the way maps exhibited the northern hemisphere as superior and the southern hemisphere as inferior. He argued that his Dymaxion map had no right way up since there is no up or down in the universe.

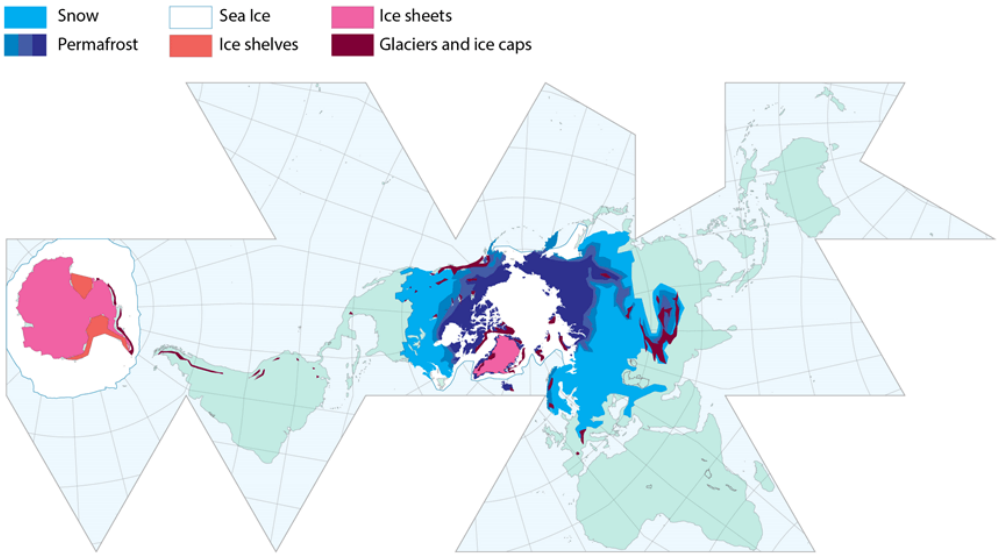


Figure 18.1: The Cryosphere. Figure is adapted from Hugo Ahlenius, UNEP/GRID-Arendal, is licensed under CC BY-SA 3.0

Exercise 1.18.1

1. Refer to Figure 18.1. Where are alpine glaciers found?

Earth's two great continental glaciers, on Antarctica and Greenland (shown in pink in Figure 18.1), comprise about 99% of all of the world's glacial ice, and approximately 68% of all of Earth's freshwater. The Antarctic Ice Sheet is vastly bigger than the Greenland Ice Sheet; it contains about 17 times as much ice. Speaking of large features, one of the fastest moving glaciers, the Jakobshavn Glacier in Greenland, moves at a rate of 12.5 to 16.4 kilometers (~7.8 to 10.2 miles) per year.

Exercise 1.18.2

2. How fast is the Jakobshavn Glacier moving per day, assuming that on average it is moving 14 kilometers per year? Your final answer should be converted into meters per day. Show your work. Tip: there are 1,000 meters in one kilometer. Multiply 14 kilometers by 1,000 to find the number of meters the glacier moves per year. Then, divide this number by 365 to find meters per day.

The Jakobshavn glacier was also a point of interest in the 2012 documentary entitled *Chasing Ice*, by cinematographer Jeff Orlowski and environmental photographer James Balog. James and his team at the Extreme Ice Survey studied the visual change of ice through the use of time-lapse photography and were able to capture the largest calving event ever observed by humans. **Calving** is the sudden breaking of ice off of a glacier.

Exercise 1.18.3

3. Watch the abbreviated *Chasing Ice* video (video length is 4:41).

   a. James and his team stated that it took about 75 minutes from start to finish for this calving event. They also referred to the size of the calving event. What size comparison was provided in the video?

   b. Now that you have been able to both observe and interpret the video, what aspect of the film did you most engage with? What will you remember and why? Was the film successful in providing visual evidence that supports the facts of climate change? Your response should be two to three sentences in length.

All glaciers have areas of accumulation and ablation (Figure 18.2). A **zone of accumulation** is an area in which snowfall accumulates and exceeds the amount of ice or snow that is lost. A **zone of ablation** refers to the low-altitude area of a glacier that experiences a net loss in ice mass due to melting, sublimation, evaporation, and calving. The area between the zone of ablation and accumulation is the **equilibrium line**, also known as the **firn line**. The greater the accumulation, the greater the glacial advancement. **Glacier mass balance** is the difference between the snow accumulated in the winter and the snow and ice melted over the summer. If the mass of snow accumulated on a glacier exceeds the mass of snow and ice lost during summer months, the mass balance is positive. Likewise, if summer melting exceeds what was gained in the previous winter, the mass balance of the glacier is negative.[324]

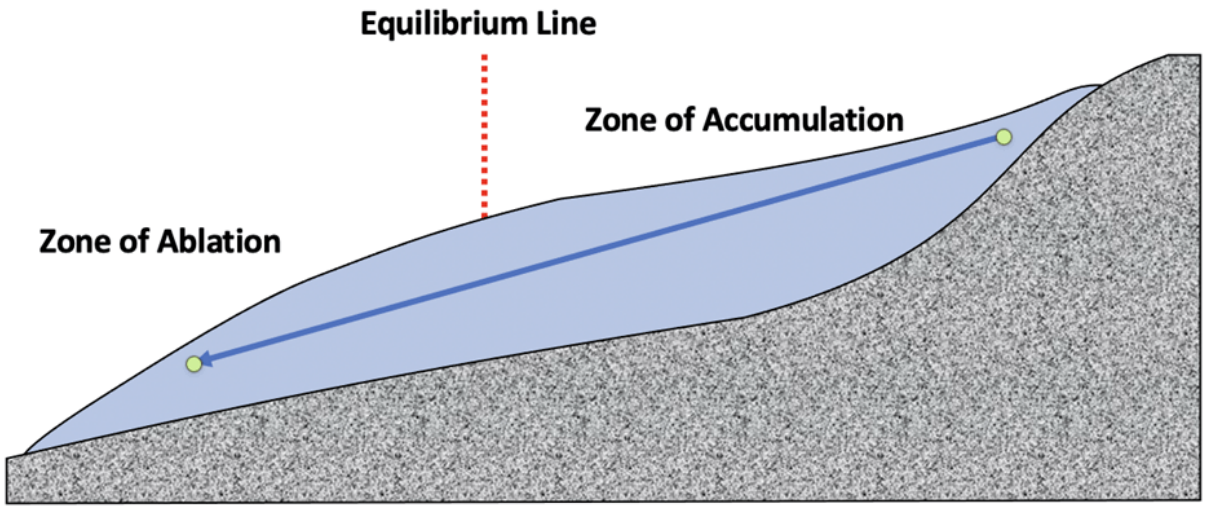


Figure 18.2: Cross-Sectional View of the Zones of Ablation and Accumulation of a Glacier. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Figure 18.3 shows mass balance data from 1976 through 2018 for three alpine glaciers: the South Cascade glacier located in the Cascade Range in Washington, United States; the Sarennes glacier located in the French Alps; and the Echaurren Norte glacier located in the Andes Mountains in Chile. The y-axis represents the difference between accumulation and ablation in millimeters. Negative numbers represent a net loss. For reference:

- There are approximately 25 millimeters in one inch.
- There are 1,000 millimeters in one meter.
- There are approximately 3 feet in one meter.

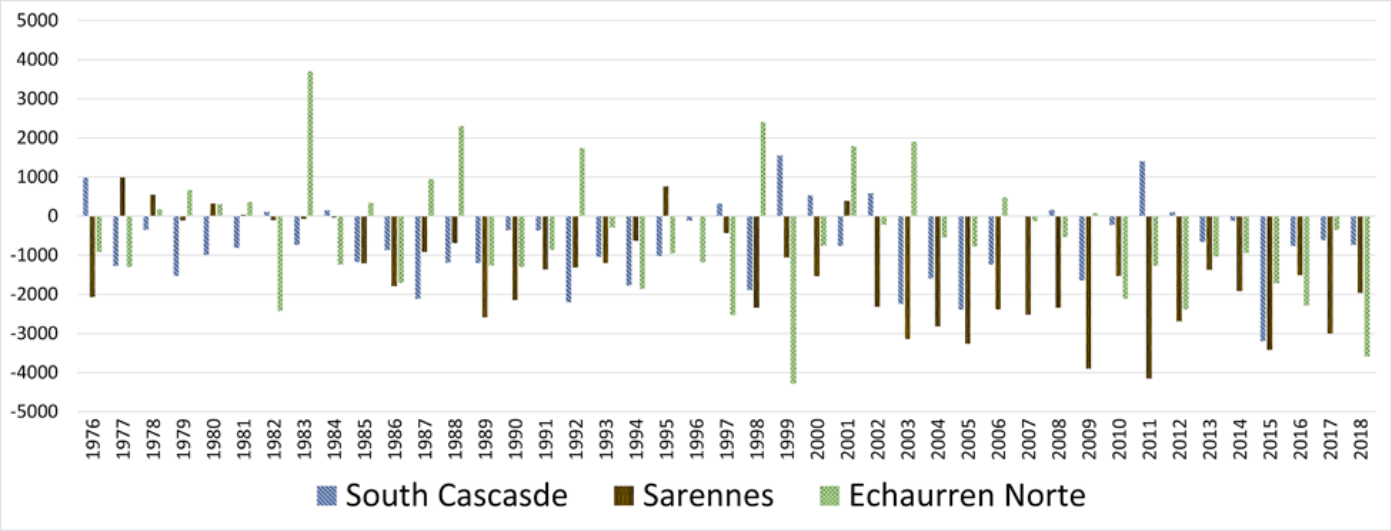


Figure 18.3: Glacier Mass Balance Data. Figure by Waverly Ray is licensed under CC BY-NC-SA 4.0 with data from the World Glacier Monitoring Service, Zurich, Switzerland. DOI:10.5904/wgms-fog-2020-08. Online access: http://dx.doi.org/10.5904/wgms-fog-2020-08

Exercise 1.18.4

4. Refer to Figure 18.3.
   a. What is the overall trend in the mass balance data for the three glaciers?
   b. Use Your Critical Thinking Skills: When looking at mass balance data, why would it be important to analyze data over a long time span?

Figure 18.4 shows the cumulative mass balance loss for alpine glaciers worldwide. Lindsey (2020)[5] explains that:

- Worldwide, most glaciers are shrinking or disappearing altogether.
- Between 1980 and 2018, glaciers tracked by the World Glacier Monitoring Service have lost ice equivalent to 21.7 meters of liquid water—the equivalent of cutting a 24-meter (79-foot) thick slice off the top of each glacier.
- Melting glaciers and ice sheets are the biggest cause of sea-level rise in recent decades.
- Glacier loss is a serious threat to ecological and human water supplies in many parts of the world.
- The pace of glacier loss has accelerated,
  - From -228 millimeters (-9 inches) per year in the 1980s,
  - to -443 millimeters (-17 inches) per year in the 1990s,
  - to -676 millimeters (-2.2 feet) per year in the 2000s,
  - to -921 millimeters (-3 feet) per year for 2010-2018.

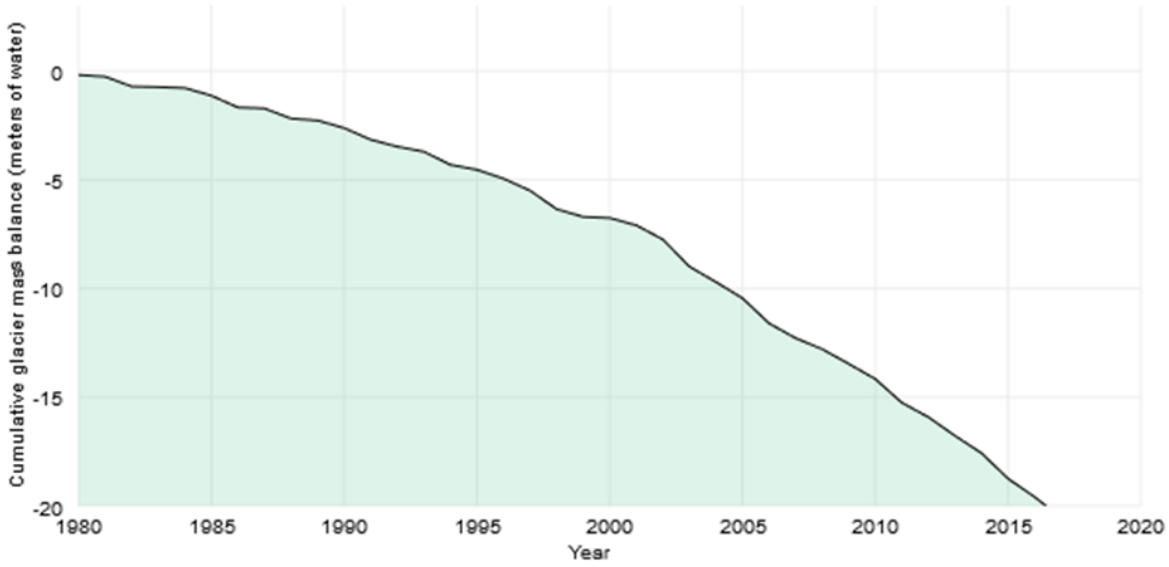


Figure 18.4: Global Loss of Alpine Glaciers (1980-2016). Figure and text by NOAA are in the public domain

Exercise 1.18.5

5. Use Your Critical Thinking Skills: When looking at mass balance data, why would it be important to analyze data from many different alpine glaciers in different parts of the world?

Part B. Glacial Erosional Landforms

Glaciers are a very effective agent of erosion, specifically when the ice is not frozen to the surface and can slide over the bedrock. What is interesting is that the ice itself is not very effective at erosion on its own, because it is relatively soft. But since ice can pluck and abrade, rock fragments are embedded in the ice and forced down onto the underlying surface. This action will often result in an observable feature known as glacial striations (refer to the definition below).

Check It Out! Devils Postpile

Devils Postpile National Monument near Mammoth in California is not just one of the few places to observe columnar basalt—extrusive igneous rock that crystallized in massive honeycomb columns—but it's also a place to observe the meeting of volcanics and glaciers. Scan the QR code or go to this Google Earth link to be transported atop the post pile, overlooking the valley. Observe the rocks you are standing on; do you see any distinct scratches or linear striations?

Exercise 1.18.6

6. Review the definitions of erosional features found in regions that underwent alpine glaciation. In Figure 18.5 (below), label an example of each of these features by drawing a line from the feature to the margin of the diagram and then writing the name of the feature.
   a. **Glacial Striations:** As glacial ice moves under its weight, coarser material can become attached at the base of the glacier that will result in scratches or gouges being cut into the bedrock by a process known as **abrasion**. In some cases, finer sediment may also be found in the base of the glacier that will further polish or scour the bedrock into a polished surface. This finer grain material is referred to as **glacial polish**.
   b. **U-Shaped Valleys or Troughs:** In a fluvial (river) environment, as water flows through the channel, the energy generally focuses along the bottom; this ultimately carves a "V" shape. In a glacial environment, as water freezes, it expands. As glaciers flow through the main channel, they will carve a distinct "U" shape trough or valley. This shape is observed not just within the main trough but also in all the contributing channels.
   c. **Cirques:** Glacial cirques are found around the world, in regions that have experienced alpine glaciation. Cirque is Latin for "circus", which relates to the shape observed: a large round amphitheater. Cirques are generally the first place to freeze and the last to melt. As the water freezes, it expands, carving a large bowl shape. If the accumulation exceeds ablation, the ice will continue downslope, resulting in additional glaciated topography.
   d. **Hanging Valleys:** Along the upper edge of the main glacial trough, tributary valleys can exist. These contributing channels have been eroded by a deep "U" shaped valley with nearly vertical sides, leaving behind an exposed shallow valley that appears to be hanging above the main valley. Often, waterfalls form at or near these hanging valleys.
   e. **Arêtes:** Narrow, bladelike ridges of rock which separate two valleys, often with cirques in between, are called arêtes. In addition to the development of a cirque and glacial erosion, freeze-thaw weathering further steepens the slopes along these sides, resulting in a sharp ridge. When three or more arêtes meet, a horn or pyramidal peak will be created.
   f. **Cols:** Along large ridges, such as arêtes, low points may be observed, and these saddle-notched shapes are called cols.
   g. **Horns or Pyramidal Peaks:** Due to the erosional development of cirques and arêtes, a sharply pointed mountain peak will result; these are known as a horn or pyramidal peak. These are best observed by identifying a collection of cirques that diverge (move away) from a central point. Tip: think of the Matterhorn in the Alps, which is copied in the Matterhorn bobsled ride at Disneyland.
   h. **Truncated Spur:** When a ridge or smaller valley that descends towards the main valley floor abruptly ends due to erosions, a truncated spur is often observed. These are observed along the edge of the hanging valley.

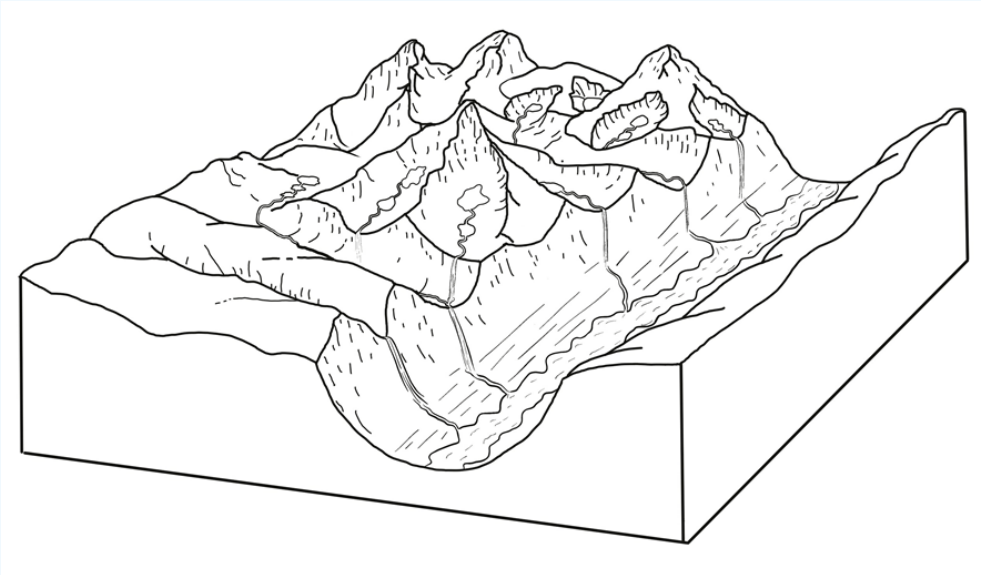


Figure 18.5: Diagram of Erosional Features from Alpine Glaciation for Labeling. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

7. For each of the four photographs shown in Figure 18.6, identify the most prominent glacial erosional landform.

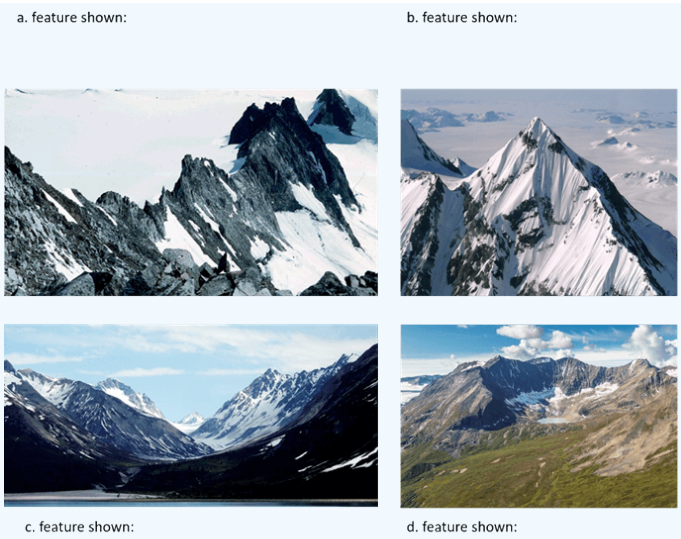


Figure 18.6: Photographs for Identification Exercise. Figure with public domain photographs by the National Park Service

Part C. Glacial Depositional Landforms

As a glacier retreats and exposes the landscape of crushed rocks and sands, sediments deposited can be observed as depositional landforms. Very large boulders can be observed that have massive linear striations atop. These rocks are called **erratics**, as they were dragged by glaciers for many, many miles and erratically placed atop the landscape. Big or small, glaciers move it all.

The sediments and material resulting from glaciation can be categorized into one of two families. The very fine material resulting from grinding and polishing is identified as **glacial flour**, while the materials larger than a grain of sand are called **glacial till**. Suspended glacial flour is what gives some alpine lakes, such as Lake Louise in Alberta, Canada, a turquoise blue color (Figure 18.7).



Figure 18.7: Lake Louise, Canada. Figure by Wenhao Ji is licensed under the Unsplash license

Check It Out! Olmsted Point

Olmsted Point in Yosemite National Park in California has some great views of the northern face of Half Dome, but it also has some unique glacial deposits. Scan the QR code or go to this Google Earth link to be transported atop the point, and in the foreground, you will observe massive round boulders that were erratically deposited on top of this rock feature by glaciers!

Exercise 1.18.7

8. Review the following definitions of depositional features found in regions that underwent continental glaciation. In Figure 18.8 (below), label an example of each of these features by drawing a line from the feature to the margin of the diagram and then writing the name of the feature.
    a. **Moraines:** There are several variations or types of moraines, but the development and lithology are the same in both alpine and continental glaciated landscapes. A moraine is a glacially-formed accumulation of unconsolidated glacial till, or debris. As a glacier advances, it bulldozes material. The location of the moraine deposit is used to distinguish what type of moraine it is. The five main types of moraines are discussed next. A **terminal moraine** is found where the glacier terminated. There are also **end moraines**, just meaning that any time a glacier stops advancing, the material was deposited, or ended up in that spot (so a terminal moraine may also be an end moraine). **Lateral moraines** are parallel ridges of material along the sides of a glacier. **Medial moraines** are the result of two lateral moraines merging due to two glaciers converging. **Recessional moraines** are created during temporary halts in a glacier retreat. The glacier advances slightly before resuming its retreat; recession “speed bumps” will occur.
    b. **Drumlins:** These are asymmetrical hills made of drifted, glacial till.
    c. **Eskers:** When sediments are carried by glacial meltwaters in subglacial tunnels, the material is deposited in a sinuous (curving) ridge, called an esker. The result is often referred to as an inverted stream, meaning that the channel of the river is not being cut into the surface, but is stacked above the surface.
    d. **Kames:** These are irregularly-shaped mounds, or hills, of glacial till with sand and gravel. As the glacier melts, rivers of flowing water will bring additional material atop or through the glacier, making deposits similar to deltas. As the ice melts further, this material will be dropped on the surface of the Earth in a mound shape.

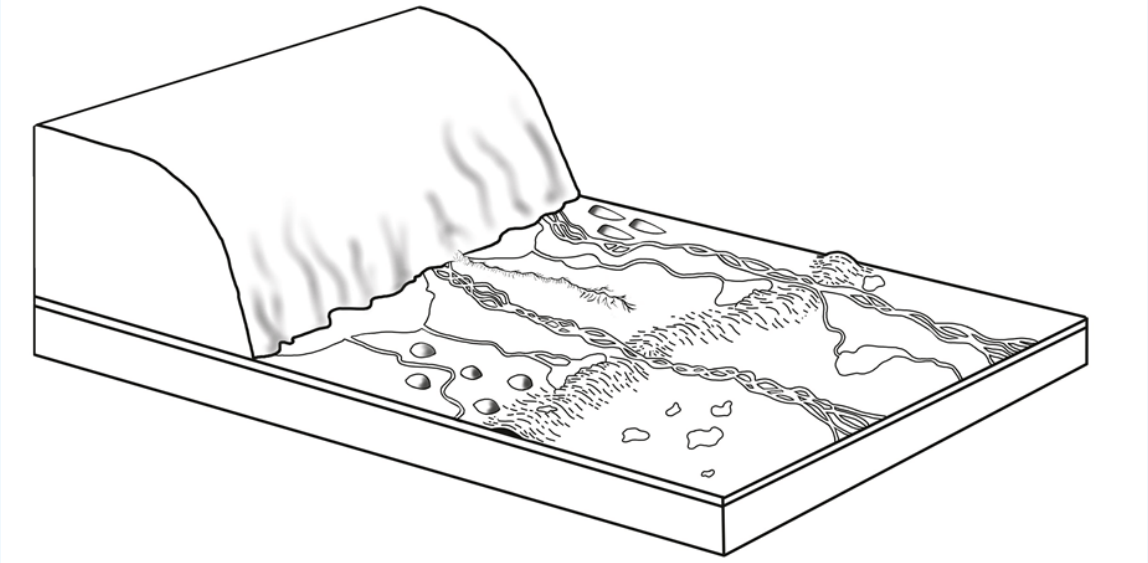


Figure 18.8: Diagram of Depositional Features from Continental Glaciation for Labeling. Figure by Jeremy Patrich is adapted from Luis María Benítez is licensed under CC BY-NC-SA 4.0

9. Label an end moraine, a lateral moraine, and a recessional moraine from alpine glaciation on Figure 18.9.



Figure 18.9: Photograph for Identification Exercise. Figure by the National Park Service is in the public domain

Part D. Glacial Lakes

Lakes are common features in glacial environments. A lake that is confined to a glacial cirque is known as a tarn. Tarns are common in areas of alpine glaciation because the ice that forms a cirque typically carves out a depression in bedrock which then fills with water. In some cases, a series of such basins will form, and the resulting lakes are called rock basin lakes or paternoster lakes.[333]



Check It Out! Lake Sabrina

Lake Sabrina is tarn nestled in the Sierra just west of Bishop, California. Scan the QR code or go to this Google Earth link to be transported to this beautifully carved cirque, and observe the tarn within it. Although the dam was built to generate hydroelectricity nearly a century ago, this still is an amazing example of glaciation in California.

Exercise 1.18.8

10. Review the following definitions of the different types of glacial lakes. On Figures 18.6 and 18.8 (both shown earlier in the lab), label an example of each of these glacial lakes by drawing a line from the lake to the margin of the diagram and then writing the name of the type of glacial lake.
    a. **Tarns:** A proglacial lake, known as a tarn, develops in cirques. Cirques form in hollow mountainsides, providing a space for the ice to freeze that is the last to melt. As a result of the melt, a lake will form in the hollow. Tarns are found in alpine glaciated regions.
    b. **Paternoster Lakes:** A series of lakes connected by a single stream are called paternoster lakes. Paternoster is Latin for “Our Father”, as the lakes resemble rosary beads. Paternoster lakes are found in alpine glaciated regions.
    c. **Kettles:** These are depressions or potholes found in an outwash plain, beyond the terminal moraine. They are formed as a result of dead ice; as the glacier retreats, large pieces of ice break off creating a dimple or indentation. As the ice melts, a lake will develop. Kettles are found in continental glaciated regions, or in the flat-lying valley floors where an alpine glacier once extended.
    d. **Moraine-dammed Lake:** Often, end moraines will be large enough to prevent the meltwater from draining from the valley. When this occurs, the moraine acts as a dam and causes the meltwater to gather as a lake. Moraine-dammed lakes are found in both alpine and continental glaciated regions.

Part E. Case Study: Taku and Norris Glaciers

Taku Glacier is a tidewater glacier located in Taku Inlet in the U.S. state of Alaska, just southeast of the city of Juneau. A **tidewater glacier** is a valley glacier that extends to the ocean. Recognized as the deepest and thickest alpine temperate glacier in the world, the Taku Glacier was 1,477 meters (4,845 feet) thick and 58 kilometers (36 miles) long in 2020.

The map on the following page is of the Juneau Icefield in Alaska. An **icefield** is a large area that has many interconnected glaciers. You will observe both the Taku and Norris Glaciers, topographic contours, and the positions of the edge of each glacier at different times since 1750. Dates have been provided by using a few different methods, such as aerial photography, survey data, absolute dating of sediment-covered vegetation, and carbon dating of deposited material in moraines. Remember that glaciers naturally gain and lose ice and snow each year. If the amount of ice and snow accumulation exceeds the amount that is lost per year, the glacier will advance (and the glacial mass balance will be positive). If the amount of ice and snow gained is less than the amount that is lost that year, the glacier will retreat (and the glacial mass balance will be negative).

Check It Out! Taku and Norris Glaciers

The Taku Glacier is found in the Juneau Icefield of Alaska, and is a great example of active glaciation! Scan the QR code or go to this Google Earth link to be transported to Alaska. If you zoom in, you're able to see the cracks, or crevices, in the glaciers, as well as the development of medial moraines!

Exercise 1.18.9

11. Refer to Figure 18.10 (below), which is a map of the Taku and Norris Glaciers.

    a. Locate the blank legend on the map and distinguish among the features shown. Shade the glacial ice as light blue, represent land with a light brown color, and leave the Taku River as white.

    b. Identify the contour lines on the map, these are numbers followed by the abbreviation for feet: '. What is the approximate total relief of the map? Hint: the total relief is the difference between the highest and the lowest elevation found within the map.

    c. What is the width of the Taku Glacier between the 1,000' contour lines? Tip: use the scale bar.

    d. What is the width of the Norris Glacier between the 1,000' contour lines? Tip: use the scale bar.

    e. What is the width of the Hole-in-the-Wall Glacier between the 1,000' contour lines? Tip: use the scale bar.

    f. Observe the lines labeled with years on the map. Describe what happened to the Taku Glacier between 1890 and 1993.

    g. Observe the lines labeled with years on the map. Describe what happened to the Norris Glacier between 1911 and 1988.

    h. Observe the lines labeled with years on the map. Describe what happened to the Hole-in-the-Wall Glacier between 1948 and 1988.

    i. The terminal mark from all three glaciers in 1750 is represented by the dashed line. What would have happened to the Taku River in 1750? How might that have changed the topography? Your response should be two to three sentences in length.

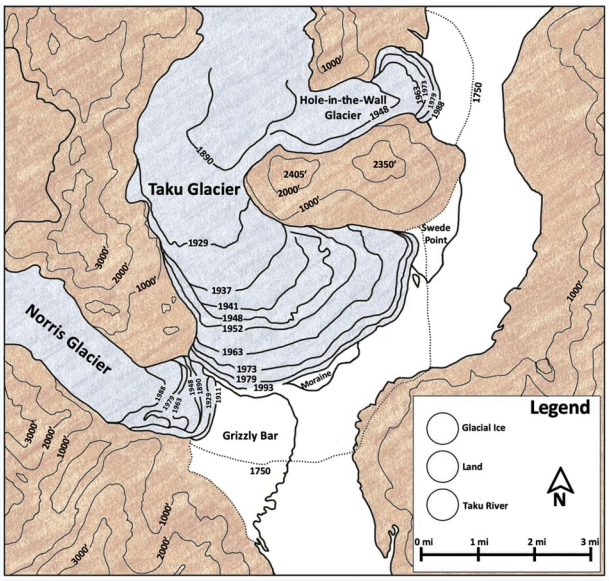


Figure 18.10: Topographic Map and Historical Glacial Extent of the Norris, Taku, and Hole-in-the-Wall Glaciers. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

The Taku Glacier's advancement was the result of a positive mass balance, meaning that the glacier was accumulating more ice than it was losing each year. That was true until 2019. Dramatic climatic change between the 1990s and today has caused the Taku Glacier to deflate, or to become thinner. Deflation can be observed in ice cores or cross-sectional profiles.

Part F. Glaciers and Sea Level Rise

As you learned in this lab, glaciers are reservoirs of stored freshwater. We have observed changes in our climate or long-term weather, and in conjunction with these changes, we have documented a dramatic loss of ice around the world. Earth scientists estimate that if all the ice in the world were to melt, the global sea level would rise approximately 70 meters, which is nearly 230 feet! Below is a chart showing the sea height variance since 1993 with an average of 3.3 millimeters (~0.13 inches) of change per year (Figure 18.11).

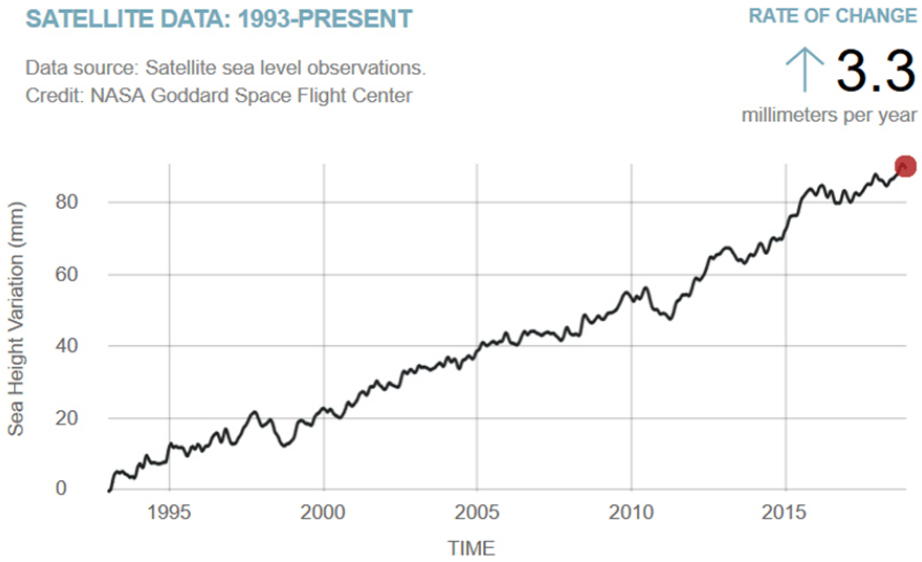


Figure 18.11: Sea-Level Observations Between 1993 and 2018. Figure by NASA is in the public domain

Exercise 1.18.10

12. Assuming that the average rate of sea-level increase is 3.3 millimeters per year, how many millimeters will the sea height increase in 30 years? Show your calculation.

    a. How many inches will the sea height increase in 30 years? Hint: multiply your answer for the previous question by 0.393701. Show your calculation.

The National Oceanic and Atmospheric Administration (NOAA) is an American scientific agency within the United States Department of Commerce that focuses on the conditions of the oceans, major waterways, and the atmosphere. NOAA's Sea Level Rise Viewer allows the public to view one of their many datasets. This online application allows us to observe and interpret the changes in our coastal cities and landscapes by increasing the global sea level. For this activity, you will use the provided website to observe and interpret sea-level change throughout the United States.

Step 1



Go to the Sea Level Rise Viewer and click on the Get Started button.

Step 2

In the search bar at the top, type in Huntington Beach.

Step 3

Move to the north and northwest on the map to view a blue water droplet pinpoint and click on it. This should be the Sunset Aquatic Park.

Step 4

On the left-hand side, you will see an adjustable bar labeled MHHW (Mean Higher High Water). Move the MHHW between the Current and 10ft water levels.

Exercise 1.18.11

13. What do you observe? What happened to the park? (Leave the marker at the 10ft mark).

Step 5

Close the window for the park and observe the map.

Exercise 1.18.12

14. What happened to Seal Beach and the surrounding areas? (Be sure to move the MHHW values between the 10ft level and the Current level).

Step 6

Let's move to a different place. Type Corpus Christi into the search bar at the top, scroll north, and click on the water droplet pushpin. This will open up Driscoll Rooke Covenant Park.

Step 7

Move the MHHW between the Current and 10ft water levels.

Exercise 1.18.13

15. What do you observe? What happens to the park? (Leave the marker at the 10ft mark).

Step 8

Close the window for the park and observe the map.

Exercise 1.18.14

16. What happens to Corpus Christi and the surrounding areas? (Be sure to move the MHHW values between the 10ft level and the Current level).

Step 9

Search for a new area of your choice or click and drag your way along the coastline of the United States, and look for one of the water droplet pushpins.

Exercise 1.18.15

17. What location did you choose?
18. Move the MHHW between the Current and 10ft water levels. What do you observe? What happens to the area? (Leave the marker at the 10ft level).

Step 10

Close the window for the area and observe the map.

Exercise 1.18.16

19. What happens to the location you selected and the surrounding areas? (Be sure to move the MHHW values between the 10ft level and the Current level).
20. Are there noticeable changes in sea level for the 30-year sea level increase that you found in question 12a?

Step 11

Now that you have spent some time looking at NOAA's Sea Level Rise Viewer, answer the following summary questions.

Exercise 1.18.17

21. Based on your observations, what regions of the U.S. are most affected by changes in sea-level? Tip: zoom out to see the entire United States and adjust the water level bar.

21. If you could ask the NOAA scientists that put this data together a question, what would it be?

Part G. Wrap-Up

Consult with your geography lab instructor to find out which of the following wrap-up questions you should complete. Attach additional pages to answer the questions as needed.

Exercise 1.18.18

23. What is the most important idea that you learned in this lab? In two to three sentences, explain the concept and why it is important to know.

24. What was the most challenging part of this lab? In two to three sentences, explain why it was challenging. If nothing challenged you in the lab, write about what you think challenged your classmates.

25. What is one question that you have about what you learned in this lab? Write your question along with one to two sentences explaining why you think your question is important to ask.

26. Review the learning objectives on page 1 of this lab. How would you rate your understanding or ability for each learning objective? Write one sentence that addresses each learning objective.

27. Sketch a concept map that includes the key ideas from this lab. Include at least five of the terms shown in bold-faced type.

28. Create an advertisement to educate your peers on the important information that you learned in this lab. Include at least three key terms in your advertisement. The advertisement should be about half a page in size (about 4 inches by 6 inches).

29. One way to think of physical geography is that it is the study of the relationships among variables that impact the Earth's surface. Select two variables discussed in this lab and describe how they are related.

30. How does what you learned in this lab relate to your everyday life? In two to three sentences, explain a concept that you learned in this lab and how it relates to your day-to-day actions.

31. How does what you learned in this lab relate to current events?
    a. Write the title, source, and date of a news item that relates to this lab.
    b. In two to three sentences, discuss how the news item relates to what you have learned in this lab.
    c. In one to two sentences, discuss whether or not the news item accurately represents the science that you learned. Tip: consider whether or not the news item includes the complexity of the topic.

32. Search O*NET OnLine to find an occupation that is relevant to the topics presented in today's lab. Your lab instructor may provide you with possible keywords to type in the Occupation Quick Search field on the O*NET website.
    a. What is the name of the occupation that you found?
    b. Write two to three sentences that summarize the most important information that you learned about this occupation.
    c. What is one question that you would want to ask a person with this occupation?

Answer available at the end of this section.

[322] Text by Steven Earle is licensed by CC BY 4.0

[324] Text by USGS is in the public domain

[333] Text by Steven Earle is licensed under CC BY 4.0

Answers

Exercise 1.18.18

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1.19: Lab 19 - Pedology

This lab contains potentially inaccessible interactive resources. Please work with your instructor and local campus resources to identify accommodations for these resources.

Learning Objectives

- Describe the physical and chemical properties of soils.
- Compare the twelve soil orders found in the United States.
- Use geographic information systems (GIS) to analyze soils.
- Identify methods of soil conservation.
- Analyze soil contamination using an environmental justice GIS.

Introduction

Soils are a vital natural resource that serve many functions. Soils provide a foundation for buildings and a medium for plants to grow in. Soils are fascinating ecosystems. In one teaspoon of healthy agricultural soil, there are more microorganisms than people on Earth. Soils are important components of the biogeochemical cycles. For example, as part of the carbon cycle, soils hold three times more carbon than plants and other living organisms (Figure 19.1). Soil conservation and restoration projects demonstrate how soils remove carbon dioxide from the atmosphere, which is one way to combat climate change. On Figure 19.1, numbers show the stores and flows of the fast carbon cycle in gigatons of carbon per year. White numbers indicate stored carbon, yellow are natural fluxes, and red are anthropogenic contributions.

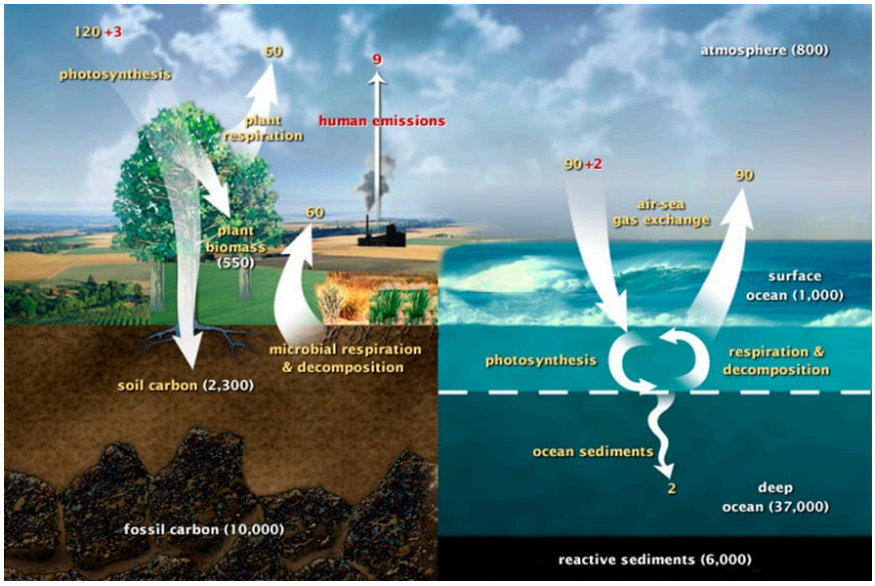


Figure 19.1: The Carbon Cycle. Figure by NASA Earth Observatory is in the public domain

Pedology is the study of soils. In this lab, you will learn the basic characteristics of soils and the main soil classification system used in the United States. You will analyze your local soils and determine how soil conservation efforts increase the resiliency of our ecosystems.

Think About It...Don't Call It Dirt

When we think of natural resources, most of us think of air and water. Soil is often neglected even though it is interconnected with the health of our water and the atmosphere. Why do you think so many of us take soil for granted?

Part A. Soil Properties

Soils are composed of mineral matter from weathered parent material, organic material, water, and air. Soil properties are the physical and chemical characteristics of soils. These properties develop over time and are influenced by variables such as climatic conditions, topography, and the biological activity of the soil location. These variables influence the rate of **weathering**, which is the breakdown of parent material by physical processes, chemical processes, and biological activity.

Physical Properties of Soil

Soil Horizons

The first physical soil property you will investigate is **soil horizons**. As shown in Figure 19.2, soil layers—called soil horizons—form over time. Younger soils have fewer horizons. Soils in tropical environments will have more developed soil horizons because of the increased rates of weathering. The physical properties of the parent material—the rocks that weather to form the mineral matter of the soils—also play a role in the formation of soil horizons.

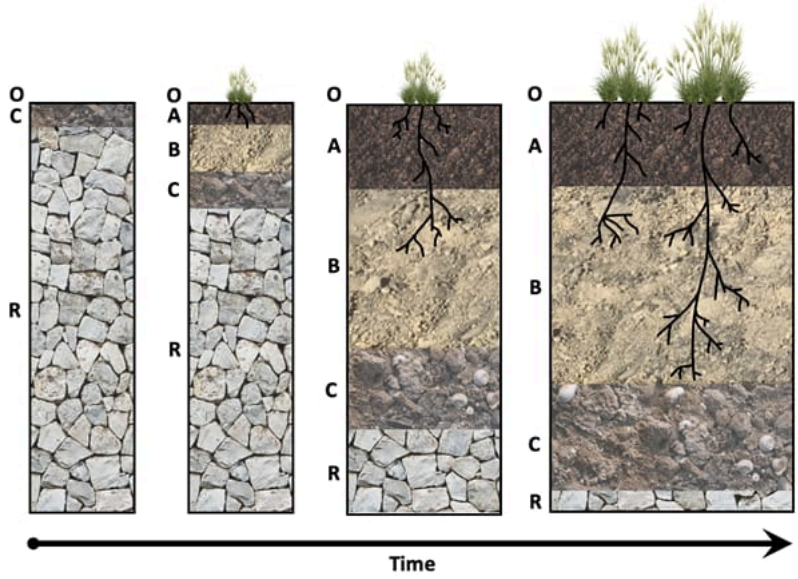


Figure 19.2: Soil Formation. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0

Exercise 1.19.1

1. Refer to Figure 19.2. List the major changes that you notice from the soil column on the far-left to the soil column on the far-right.

The process of soil formation generally involves the downward movement of clay, water, and dissolved ions. The common result of that is the development of chemically and texturally different layers known as soil horizons (Figure 19.3). The commonly developed soil horizons are as follows:

- O: the layer of organic matter
- A: the layer of partially-decayed organic matter mixed with mineral material
- E: the eluviated (leached) layer from which some of the clay and iron have been removed to create a pale layer that may be sandier than the other layers
- B: the layer of accumulation of clay, iron, and other elements from the overlying soil
- C: the layer of incomplete weathering[338]
- R: the parent material or bedrock

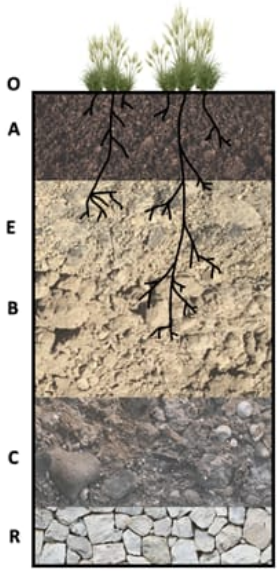


Figure 19.3: Soil Horizons. Figure by Jeremy Patrich is licensed under CC BY-NC-SA 4.0. Note that not all soils have all of the soil horizons present.

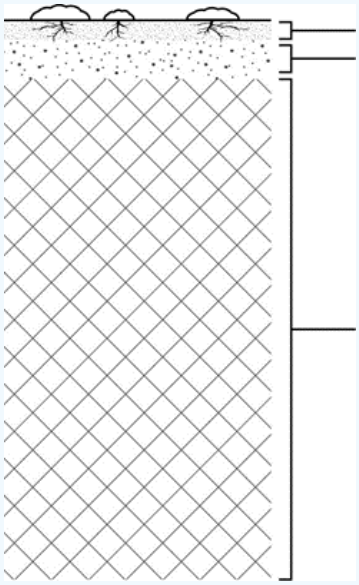
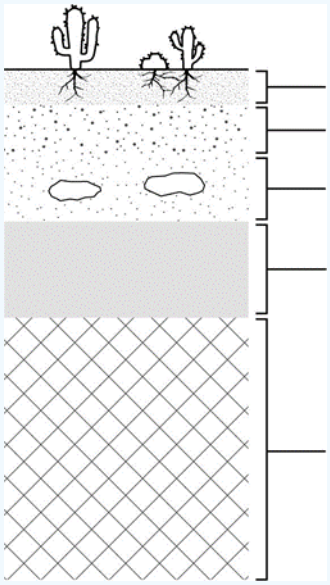
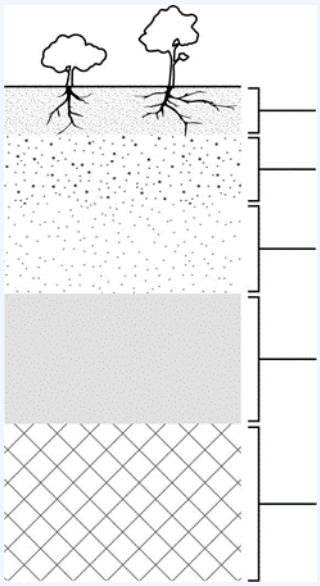
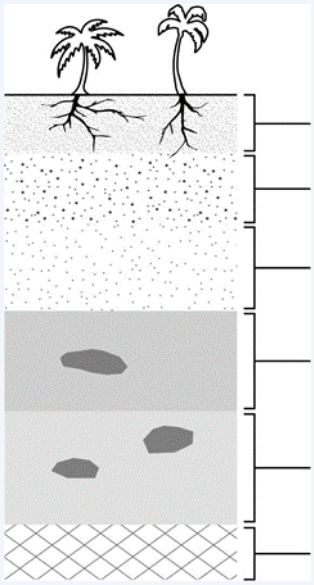
Exercise 1.19.2

2. Based on the descriptions provided in Table 19.1 below, label the soil horizons shown on each of the four soil profile diagrams.

Have you ever wondered where the aluminum comes from in a cold beverage can? **Bauxite** is an ore of aluminum commonly found in tropical and subtropical forests. The high levels of precipitation help to concentrate aluminum oxides in the B and C soil horizons after they have been leached from upper horizons.

Exercise 1.19.3

Table 19.1: Soil Horizon Labeling Exercise. Figures by Waverly Ray are licensed under CC BY-NC-SA 4.0

Profiles and Descriptions	Profiles and Descriptions
Soil Profile 1. Few horizons have formed because the parent material was recently exposed to weathering. There is some biological weathering activity initiated by moss growth. 	Soil Profile 2. This is an arid environment with low rates of weathering. Caliche (calcium carbonate) deposits are found in the B horizon. 
Soil Profile 3. This is a well-developed soil in a temperate environment. 	Soil Profile 4. This is a soil in a tropical environment with aluminum oxide deposits (bauxite) in the B and C horizons. 

3. Apply What You Learned: List the impacts that the extraction of bauxite from tropical regions has on the local environment and population.



Think About It...Interconnectedness and Social Responsibility

With an understanding of how aluminum is produced, how are you interconnected to people working and living at bauxite mines? Would a wider understanding of aluminum production and its impacts encourage people in your community to recycle aluminum beverage cans?

Soil Color

Soil color is another physical property of soil. The mineralogy of the parent material and the rates of weathering are the two main factors that determine a soil's color (Table 19.2).

Table 19.2: Minerals and Common Soil Colors. Adapted from USDA Natural Resources Conservation Service

Material	Formula	Common Soil Color
goethite	$FeO(OH)$	yellow, strong brown
hematite	Fe_2O_3	red
lepidocrocite	$FeO(OH)$	reddish-yellow, red
ferrihydrite	$Fe(OH)_3$	dark red
glauconite	$K(Si_xAl_{4-x})(Al,Fe,Mg)O_{10}(OH)_2$	dark gray
iron sulfide	FeS	black
pyrite	FeS_2	black (metallic)
jarosite	$KFe_3(OH)_6\ (SO_4)_2$	pale yellow
todorokite	MnO_4	black
calcite	$CaCO_3$	white
dolomite	$CaMg(CO_3)_2$	white
gypsum	$CaSO_{4\times}2H_2O$	very pale brown
quartz	SiO_2	light gray
humus	Humus is not a mineral but it influences soil color, especially in the upper horizons. Humus is organic material that forms in a soil when living organisms decay.	black

Exercise 1.19.4

4. Refer to Table 19.2.
    a. What colors are commonly seen when iron (Fe) is present in the parent material of a soil?
    b. What color is commonly seen when calcium (Ca) is present in the parent material of a soil?

Soil Texture

Soil texture refers to the sizes of the mineral materials in a soil. All soils can be classified by the amount of **sand** (<2 to 0.05 millimeters), **silt** (0.05 to 0.002 millimeters), and **clay** (<0.002 millimeters) found in them. Figure 19.4 shows the relative sizes of these three particles.

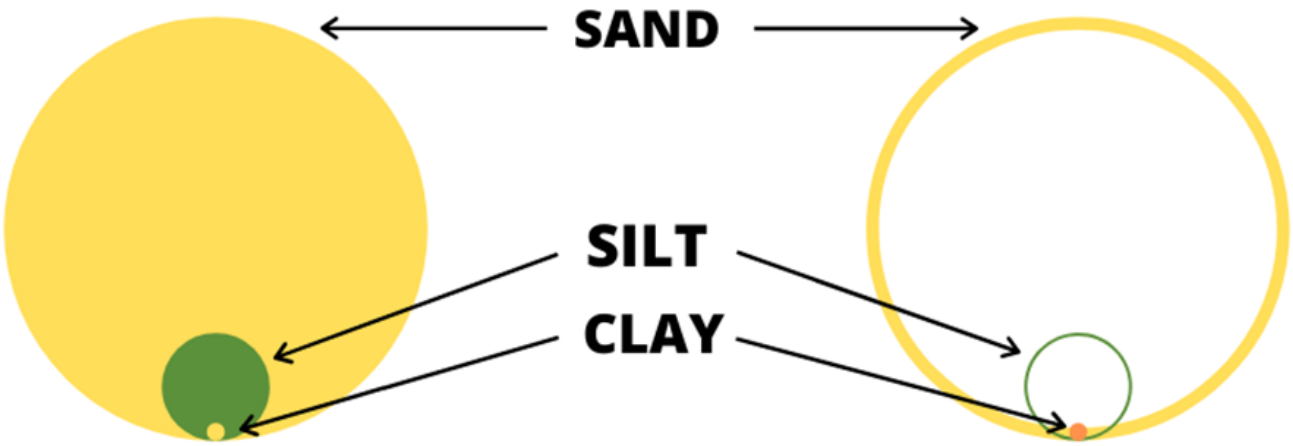


Figure 19.4: Relative Sizes of Sand, Silt, and Clay. Figure by College of the Canyons ZTC Team is licensed under CC BY 4.0

The soil texture triangle (Figure 19.5) provides the names to classify soils with varying percentages of sand (bottom side of triangle), silt (right side of triangle), and clay (left side of triangle.

Guided Practice: Using the Soil Texture Triangle

Watch a tutorial video on how to use the soil texture triangle. (Video length is 2:21).

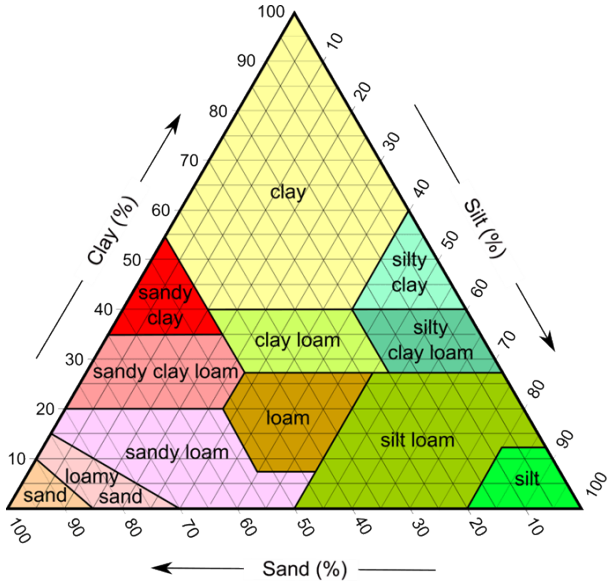


Figure 19.5: Soil Texture Triangle. Figure by Mikenorton is licensed under CC-BY-SA-4.0

Exercise 1.19.5

5. Refer to Figure 19.5.
    a. What is the soil name for a soil that has 10% silt, 80% sand, and 10% clay?
    b. What is the soil name for a soil that has 30% silt, 35% sand, and 35% clay?
    c. What is the soil name for a soil that has 75% silt, 10% sand, and 15% clay?

Each of the three soil textures have different characteristics. Table 19.3 summarizes their different properties.

Table 19.3: Soil Texture and Related Properties

Property	Sand	Silt	Clay
Soil Fertility: Ability to sustain plant growth	Low	Moderate-High	Moderate-High
Porosity: Air spaces (gaps between particles)	High	Moderate-High	Low
Permeability: Ability for water to flow through the soil	High	Moderate-High	Low
Water Holding Capacity: Ability to hold water against the force of gravity	Low	Moderate-High	High

Exercise 1.19.6

6. **Loam** is the ideal soil texture for most vegetable crops. From Figure 19.5, determine the relative amounts of silt, sand, and clay for loam soils and use Table 19.3 to describe the characteristics that you would expect to find in loam soils.

Soil Structure

Another physical property of soils is soil structure. **Soil structure** is the way in which the components of a soil aggregate together. There are several common structures called **"peds"** (Figure 19.6). The soil peds influence how water permeates through the soil.

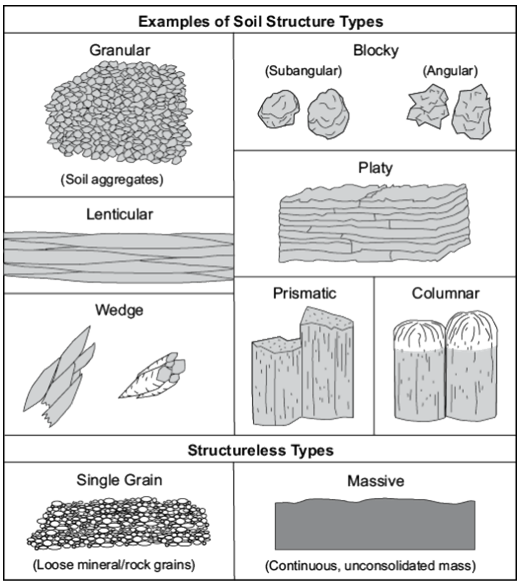


Figure 19.6: Soil Structures. Figure by USDA Natural Resources Conservation Service is in the public domain

Exercise 1.19.7

7. Refer to Figure 19.6.
    a. Apply What You Learned: Which soil structures would have the highest levels of permeability? Explain your response in one to two sentences.
    b. Apply What You Learned: Which soil structures would have the lowest levels of permeability? Explain your response in one to two sentences.

Chemical Properties Of Soils

Cation Exchange Capacity (CEC)

Cation exchange capacity (CEC) refers to the capacity of soils to hold on to cations. **Cations** are positively charged ions such as aluminum (Al^{3+}), calcium (Ca^{2+}), hydrogen (H^{+}), magnesium (Mg^{2+}), and sodium (Na^{+}). Negatively charged particles such as clays and organic matter attract positively charged cations through electrostatic forces. A soil's CEC represents the total amount of exchangeable cations that it can absorb.

When there are high levels of CEC, more nutrients are available to plants. If the cations do not find a negatively charged particle (called an anion), they can be washed away or leached. The more organic matter in a soil and the higher the clay content of that soil, the higher the CEC and thus the higher number of nutrients available for plants to utilize.

Exercise 1.19.8

8. Use Your Critical Thinking Skills: Review the four physical properties of soil (horizons, color, texture, and structure). Which characteristics of those physical properties would you expect to increase the CEC of a soil? Explain your response in one to two sentences.

Soil Ph

pH is a measure of hydrogen ions in a substance. pH is a logarithmic scale; acids range from 0 to 6.9, 7 is neutral, and 8 to 14 are alkaline. So, a pH of 3 is ten times more acidic than a pH of 4. For most crops, a pH of 6.0 to 6.8 is ideal. At this pH,

many nutrients are dissolved when water permeates the soil. This allows plants to uptake the nutrients through their roots in part because this range of pH is favorable to the microbes that help plants to uptake nutrients.

Exercise 1.19.9

9. Use Your Critical Thinking Skills: Based on what you know about cation exchange capacity, why are soils with higher levels of clay and organic matter less likely to have fluctuations in pH levels when compared to sandy soils? Explain your response in one to two sentences.

Let's Review: The Physical and Chemical Properties of Soils

Exercise 1.19.10

10. Complete Table 19.4. In your own words, briefly summarize the four physical properties and two chemical properties of soils.

Table 19.4: Summary of Soil Properties

Physical or Chemical Property?	Property Name	Property Description

11. List the variables that greatly influence the physical and chemical properties of a soil:

Local Soil Properties

For this section of the lab, you will use the California Soil Resource Lab Soil Properties GIS from the University of California, Davis.



Guided Practice: Local Soil Properties

Watch a tutorial video on how to navigate the soil properties GIS website. (Video length is 4:03).

Step 1



Go to the California Soil Resource Lab at UC Davis Soil Properties web app.

Step 2

On the left-hand sidebar, click on the Location tab.

Step 3

Click on the Use My Current Location button, or use the text box to type in your “city, state”, “zip code”, or a nearby “landmark” and click on the Go button. Note: your professor may instruct you to use a particular location for this activity.

Step 4

Click on the Properties tab.

Step 5

Select a Property by clicking on Physical. This should open a menu of physical property options.

Step 6

Click on Sand. Then, click on the question mark icon and read the information about this variable.

Step 7

Move the transparency slide bar on the upper-left of the map to the right to find a specific location to investigate. Using the light gray lines representing roads and river features may help you to pinpoint one location. Note: you are unable to zoom in when using this dataset.

Exercise 1.19.11

12. Describe the location that you selected to investigate. For example, the intersection of Interstate 5 and the Sacramento River.
13. Slide the transparency bar to the left so that you can see the percentage of sand found at your location. What is the range for the percentage of sand found there?

Step 8

Repeat the same steps to find the percentages of silt and clay found at your location.

Exercise 1.19.12

14. What is the range for the percentage of silt found at our location?
15. What is the range for the percentage of clay found at your location?

16. Use the soil texture triangle (Figure 19.6) to determine the name for the soil type found at the location. Note: there may be more than one type, depending on the ranges of sand, silt, and clay found at your location.

Step 9

Click on Avail. Water Holding Capacity. Then, click on the question mark icon and read the information about this variable.

Exercise 1.19.13

17. What is the available water holding capacity (AWC) at your location?
18. Apply What You Learned: How does the soil texture at your location help to explain the water holding capacity at your location?

Step 10

On the left-hand sidebar, click on Soil Color. Then, click on the question mark icon and read the information about this variable.

Step 11

Click on Soil Color (10 cm), then Soil Color (25 cm), Soil Color (75 cm), and Soil Color (125 cm).

Exercise 1.19.14

19. Describe how the soil colors change from a 10-centimeter (10 cm) depth to a depth of 125 centimeters (125 cm).
20. Apply What You Learned: What would explain the differences in soil color at different depths?

Step 12

On the left-hand sidebar, click Chemical.

Step 13

Click on Cation Exchange Capacity. Then, click on the question mark icon and read the information about this variable. Note that the unit of measurement is centimoles per kilogram (cmol(+)/kg), which basically measures the number of cations per kilogram of soil.

Exercise 1.19.15

21. What is the range for the cation exchange capacity at your location?
22. Based on your answer to the previous question, would you expect the soil at this location to have high levels of fertility (the ability to support plant growth)? Explain your response.

Step 14

Click on pH. Then, click on the question mark icon and read the information about this variable.

Exercise 1.19.14

23. What is the range and reaction class name for the pH found at your location?

24. Describe the spatial pattern of pH across the map. Are there any places where there are very strongly acidic or extremely acidic soils found? Are there any places where there are very strongly alkaline or strongly alkaline soils found?

25. Use Your Critical Thinking Skills: What do you think explains the spatial variability of pH on your map? Explain your response.

Part B. Soil Orders

In the United States, soils are classified into twelve categories called **soil orders**. This taxonomy is based on the dominant physical and chemical characteristics that make each soil order unique. Like many taxonomies (classification systems) within each category, there are subdivisions. You may be familiar with the taxonomy of living organisms from a biology course: domain, kingdom, phylum, class, order, family, genus, and species. With the soil taxonomy, order is the largest grouping, which can be further divided into suborder, great group, subgroup, family, and soil series. So, soil order is the largest grouping and soil series is the smallest grouping.

Before we review the key characteristics of each soil order, let's analyze the Global Soil Regions map (Figure 19.7).

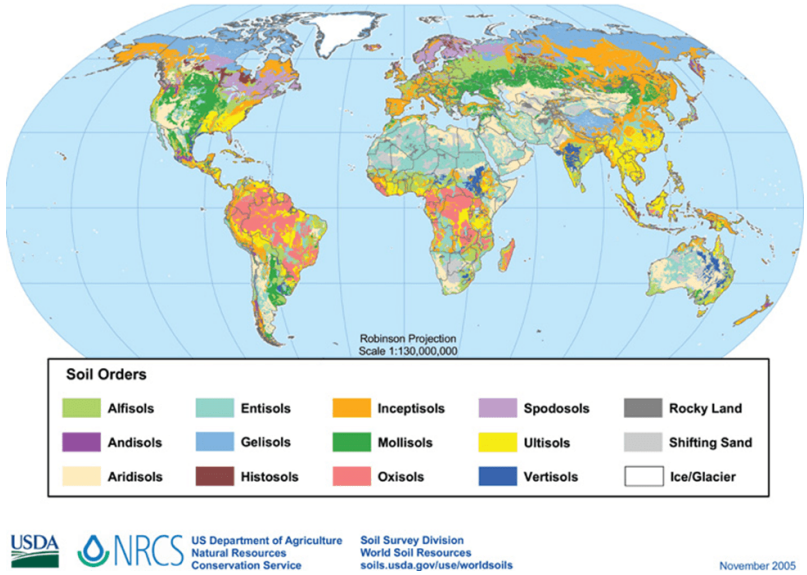


Figure 19.7: Global Soil Regions Map. Figure by USDA Natural Resources Conservation Service is in the public domain

Exercise 1.19.15

26. Refer to Figure 19.7.

    a. Which two soil orders are most common along the equator?

    b. Which two soil orders are most commonly found in the world's desert regions?

    c. Which soil order is most common in the highest latitudes of the northern hemisphere?

Soil Order Descriptions



Check It Out! Soil Order Photographs

Check out photographs of the soil orders at the University of Idaho website.

Entisols and Inceptisols

The two soil orders with the least soil weathering and development are entisols and inceptisols. **Entisols** are soils that are recent and they have the least number of horizons than any other soil order. For example, very thin O or A horizons may be present in an entisol. Entisols are found in many different environments such as dunes, steep slopes, or a location in which parent materials have been only recently exposed to weathering. **Inceptisols** are a little more developed than entisols. Inceptisols have a few more horizons present, or thicker O and A horizons, compared to an entisol. Inceptisols lack characteristics (such as clay accumulation) that are found in the other soil orders.

It is estimated that entisols cover 18% of the world's ice-free land surface while inceptisols cover about 15%. Additionally, inceptisols support the largest percentage of the world's population when compared to other soil orders. Twenty percent of the world's population lives on inceptisols.

Exercise 1.19.16

27. Return to question 2 at the beginning of this lab (Table 19.1). Which one of the four soil profiles that you labeled best represents an inceptisol?

28. Use Your Critical Thinking Skills: Given that one in five people live on an inceptisol, what impact do you think that would have on the functions of soil? Hint: explain your response based on agricultural and construction uses of soil. Your response should be one to two sentences in length.

Oxisols and Ultisols

While entisols and inceptisols are the result of weak weathering, oxisols and ultisols have very high weathering rates. Oxisols and ultisols are found in humid environments and have advanced rates of physical, chemical, and biological weathering. **Oxisols** are found in tropical and subtropical regions. Oxisols have low cation exchange capacity and commonly have quartz, aluminium oxides, or iron oxides present. Oxisols are common on stable land surfaces in the tropical regions of the world. **Ultisols** have clay-enriched subsoils along with quartz, aluminum oxides, or iron oxides present.

Oxisols cover 7.5% of the global ice-free land surface while ultisols cover 8.1%.

Exercise 1.19.17

29. Return to question 2 at the beginning of this lab (Table 19.1). Which one of the four soil profiles that you labeled best represents an oxisol?

30. Refer to the global soil regions map (Figure 19.7). Which soil order is most common in the southeastern United States?

Andisols, Aridisols, and Gelisols

Andisols, aridisols, and gelisols are soil orders that are connected to specific geologic environments. **Andisols** are found in volcanic landscapes, **aridisols** are found in desert landscapes, and **gelisols** are associated with permafrost. Andisols make highly productive soils because of their nutrient availability and water-holding capacity. Aridisols have limited soil development but can accumulate caliche and other materials that are usually leached out of soils in environments that have higher rates of precipitation.

Andisols cover about 1% of the world's ice-free land area, aridisols cover about 12%, and gelisols cover about 8.3%.

Exercise 1.19.18

31. Return to question 2 at the beginning of this lab (Table 19.1). Which one of the four soil profiles that you labeled best represents an aridisol?

32. Refer to the global soil regions map (Figure 19.7). Both aridisols and entisols are found across the Sahara Desert. In one to two sentences, explain why these two soil orders are commonly found there.

Alfisols and Spodosols

Alfisols and spodosols are common in forest environments. **Alfisols** are found in humid and temperate climates and **spodosols** are found in cooler climates with coniferous forests. Alfisols are rich in nutrients and make productive agricultural soils. In contrast, spodosols are more acidic and have low rates of fertility.

Alfisols cover about 10% of the global ice-free land surface while spodosols cover 4%.

Exercise 1.19.19

33. Return to question 2 at the beginning of this lab (Table 19.1). Which one of the four soil profiles that you labeled best represents an alfisol?

34. Refer to the global soil regions map (Figure 19.7). Which regions of the United States have alfisols?

35. Refer to the global soil regions map (Figure 19.7). Which regions of the world have spodosols?

Histosols, Mollisols, and Vertisols

Histosols are found in wetlands and **mollisols** are common in grasslands. **Vertisols** are not associated with a specific landscape—they are distinct from other soil orders because vertisols have large amounts of clays. Key ideas about these three soil orders are as follows:

- Given their wetland environment, histosols have high levels of organic content when compared to other soil orders. Little drainage in wetland areas allows for organic materials to accumulate over time.

- Mollisols also have higher levels of organic materials due to the activity of plant roots in grassland ecosystems. Mollisols are productive agricultural soils.

- Vertisols shrink and swell due to their clay content. When wet, clay absorbs moisture and swells. When dry, clay shrinks and cracks. Histosols cover about 1.2% of the world's ice-free land area, mollisols cover about 7%, and vertisols cover about 2.4%.

Exercise 1.19.20

36. **Peat** is partially decayed organic matter. Which soil order would likely be a source of peat?
37. Refer to the global soil regions map (Figure 19.7). Where in the United States are mollisols common?
38. Apply What You Learned: In one to two sentences, explain why building in vertisols can be challenging.

Part C. Soil Order Exploration

For this section of the lab, you will use the California Soil Resource Lab SoilWeb GIS from the University of California, Davis. Note: this is a different GIS than you used to investigate soil properties earlier in the lab.

Guided Practice: Soil Order Exploration

Watch a tutorial video on how to navigate the SoilWeb GIS website. (Video length is 2:02).

Step 1

Go to the California Soil Resource Lab at UC Davis SoilWeb app.

Step 2

Read the information in the pop-up box and click OK.

Step 3

Zoom out so that you can see all of the United States, including Alaska and Hawai'i.

Step 4

Think about the twelve soil orders that you learned about in the previous section. Select one of the soil orders and zoom in on a location where you think you would find this soil order.

Exercise 1.19.21

39. Which soil order did you select?
40. Which location did you select?

Step 5

Zoom into the location until you see the yellow lines, which represent boundaries between soil series. Recall that soil series are the smallest taxonomic grouping for soils (soil orders are the largest taxonomic grouping).

Step 6

Double-click on one of the areas on the map.

Step 7

A box to the left of the screen opens and may list several soil series. Select one of the soil series shown. Click on the name (it is shown in blue underlined text).

Exercise 1.19.22

41. Which soil series did you select? (What is it called?)

Step 8

Click Description and read the information shown about the soil series.

Exercise 1.19.23

42. What are three ideas listed in the description that connect to the information that you learned earlier in the lab? Your response should be at least three sentences in length.

Step 9

Click Close.

Step 10

Look at the information listed under the Soil Taxonomy heading in the box on the left.

Exercise 1.19.24

43. Which soil order does this soil series belong to?
44. Is this the same soil order that you expected to find in this location? If yes, explain why you expected to find this soil order here. If not, explain why you think another soil order is present at this location. Note: it's okay if you did not select a location that matched your soil order. You made an hypothesis and it was either proven or disproven—either outcome is okay! Your response should be one to two sentences in length.

Step 11

In the box on the left of your screen, click on Series Extent Explorer shown at the top.

Exercise 1.19.25

45. How many acres does this soil order cover? For reference, one acre is about 90% of the size of a football field.

Part D. Soil Conservation and Contamination

Soil conservation refers to the practices of maintaining healthy soils. In many regions, it takes hundreds of years to form just one inch of topsoil (this is the top five to ten inches of a typical soil). The U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) works to use current scientific techniques to analyze and manage soils. "Originally known as the Soil Erosion Service in 1933 then the Soil Conservation Service starting in April of 1935, the agency was created in response to the high rates of soil erosion seen across the Great Plains during the Dust Bowl of the 1930s (NRCS n.d., n.p.)". In addition to co-creating soil GIS like the ones that you utilized earlier in this lab, the NRCS provides recommendations that prevent soil erosion, ensure healthy soil microbes, and prevent mineral depletion in soils. The NRCS also recommends improved farming practices that will prevent water contamination (Figure 19.8).

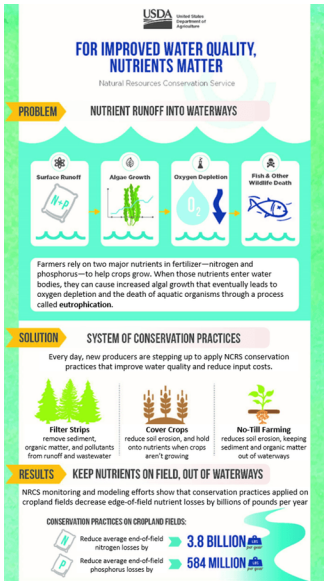


Figure 19.8: Nutrients and Water Quality. Figure adapted from USDA Natural Resources Conservation Service is in the public domain

Exercise 1.19.26

46. In one to two sentences, explain how soils are connected to other components of the biosphere.

Soil contamination refers to the occurrence of substances in soils that pose human health risks and exceed naturally-occurring levels. Soil contamination can result from a variety of intended, accidental, or naturally occurring activities and events such as manufacturing, mineral extraction, abandonment of mines, national defense activities, waste disposal, accidental spills, illegal dumping, leaking underground storage tanks, hurricanes, floods, pesticide use, and fertilizer application. Nationally, there are thousands of contaminated sites of varying size and significance in settings ranging from abandoned buildings in inner cities to large areas contaminated with toxic materials from past industrial or mining activities. Contaminated lands include the following:

- Sites contaminated by improper handling or disposal of toxic and hazardous materials and wastes.
- Sites where toxic materials may have been deposited as a result of natural disasters or acts of terror.
- Sites where improper handling or accidents resulted in release of toxic or hazardous materials that are not wastes.[347]

Contaminated lands can pose a variety of health and environmental hazards. Some contaminated sites pose little risk to human health and the environment, because the level of contamination is low and the chance of exposure to toxic or hazardous

contaminants is also low. Other contaminated sites are of greater concern because of the chemicals that may be present and their propensity to persist in or move through the environment, exposing humans or the environment to hazards. These sites must be carefully managed through containment or cleanup to prevent hazardous materials from causing harm to humans, wildlife, or ecological systems, both on- and offsite:

- Contaminated soils can leach toxic chemicals into nearby ground or surface waters, where these materials can be taken up by plants and animals, contaminate a human drinking water supply, or volatilize and contaminate the indoor air in overlying buildings.

- In dry areas, contamination in soil can be further distributed through wind-borne dust. Once soil contamination migrates to waterways, it may also accumulate in sediments, which can be very difficult to remediate, and may also affect local ecosystems and human health.

- Humans can be harmed by contact with toxic and hazardous materials on a contaminated site via exposure to contaminated land, air, surface water, and groundwater.

- When contaminated lands are not properly managed, humans and wildlife can be exposed to contaminants through inhalation, ingestion, or dermal contact. The risks of human exposure are site-specific and difficult to generalize at the national level. Potential effects may be acute or chronic.[348]

Exercise 1.19.27

47. List the causes of soil contamination.

48. List the effects of soil contamination.

Environmental justice is the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. This goal will be achieved when everyone enjoys the following:

- the same degree of protection from environmental and health hazards, and

- equal access to the decision-making process to have a healthy environment in which to live, learn, and work.[349]

CalEnviroScreen is a mapping tool that helps identify California communities that are most affected by many sources of pollution, and where people are often especially vulnerable to pollution's effects. CalEnviroScreen includes a list of indicators (variables) in four categories:

- Exposure indicators are based on measurements of different types of pollution that people may come into contact with. These include:
  - Air quality: ozone and PM2.5
  - Diesel particulate matter
  - Drinking water contaminants
  - Pesticide use
  - Toxic releases from facilities
  - Traffic density

- Environmental effects indicators are based on the locations of toxic chemicals in or near communities. These include:
  - Cleanup sites
  - Groundwater threats
  - Hazardous waste generators and facilities
  - Impaired water bodies
  - Solid waste

- Sensitive population indicators measure the number of people in a community who may be more severely affected by

pollution because of their age or health. These include:

- Asthma
- Cardiovascular disease
- Low birth weight infants

➢ Socioeconomic factor indicators are conditions that may increase people's stress or make healthy living difficult and cause them to be more sensitive to pollution's effects. These include:

- Educational attainment
- Housing burden
- Linguistic isolation
- Poverty
- Unemployment[350]

The indicators are aggregated so that each location has a percentile score. The higher the score, the higher the environmental burden.

Exercise 1.19.28

49.  Which of the indicators listed above relate to soil contamination? Go to the Indicators Overview webpage to read the definitions of the indicators. Explain why you selected these indicators.

Let's explore CalEnviroScreen 3.0 in order to analyze soil contamination in California through an environmental justice framework. Note that the data is provided by census tract, which is a spatial scale that averages about 4,000 people.

Step 1

 Go to the CalEnviroScreen 3.0 website and click OK.

Step 2

Zoom in on your location and click on the map. This opens a pop-up window with the indicators used in the CalEnviroScreen model.

Exercise 1.19.29

50. What is the number for this census tract?
51. What is the population of this census tract?
52. What is the CalEnviroScreen 3.0 percentile for this census tract?
53. What is the pollution burden percentile for this census tract?
54. What is the population characteristics percentile for this census tract?
55. Use Your Critical Thinking Skills: Are you surprised by these percentiles? Why or why not?
56. Scroll down in the pop-up window to see the individual percentiles for each indicator. Do you think soil contamination is a problem in this census tract? Why or why not? Be sure to cite the data provided in the pop-up window in your response.

Step 3

Close the pop-up window and zoom out so that you can see the entire state of California.

Exercise 1.19.30

57. Which regions of the state have the highest CalEnviroScreen 3.0 percentiles?
57. Use Your Critical Thinking Skills: What factors likely contribute to the high scores in these regions? Explain your response in two to three sentences.

Check It Out! More About Environmental Justice

Learn more about the environmental justice movement at the U.S. Environmental Protection Agency webpage. The webpage has an interactive timeline that traces the environmental justice movement from grassroots organizing by communities of color to actions in recent years.

Part E. Wrap-Up

Consult with your geography lab instructor to find out which of the following wrap-up questions you should complete. Attach additional pages to answer the questions as needed.

Exercise 1.19.31

59. What is the most important idea that you learned in this lab? In two to three sentences, explain the concept and why it is important to know.

60. What was the most challenging part of this lab? In two to three sentences, explain why it was challenging. If nothing challenged you in the lab, write about what you think challenged your classmates.

61. What is one question that you have about what you learned in this lab? Write your question along with one to two sentences explaining why you think your question is important to ask.

62. Review the learning objectives on page 1 of this lab. How would you rate your understanding or ability for each learning objective? Write one sentence that addresses each learning objective.

63. Sketch a concept map that includes the key ideas from this lab. Include at least five of the terms shown in bold-faced type.

64. Create an advertisement to educate your peers on the important information that you learned in this lab. Include at least three key terms in your advertisement. The advertisement should be about half a page in size (about 4 inches by 6 inches).

65. One way to think of physical geography is that it is the study of the relationships among variables that impact the Earth's surface. Select two variables discussed in this lab and describe how they are related.

66. How does what you learned in this lab relate to your everyday life? In two to three sentences, explain a concept that you learned in this lab and how it relates to your day-to-day actions.

67. How does what you learned in this lab relate to current events?
    a. Write the title, source, and date of a news item that relates to this lab.
    b. In two to three sentences, discuss how the news item relates to what you have learned in this lab.
    c. In one to two sentences, discuss whether or not the news item accurately represents the science that you learned. Tip: consider whether or not the news item includes the complexity of the topic.

68. Search O*NET OnLine to find an occupation that is relevant to the topics presented in today's lab. Your lab instructor may provide you with possible keywords to type in the Occupation Quick Search field on the O*NET website.
    a. What is the name of occupation that you found?
    b. Write two to three sentences that summarize the most important information that you learned about this occupation.
    c. What is one question that you would want to ask a person with this occupation?

Answer available at the end of this section.

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[348] Text by US EPA is in the public domain

[349] Text by the US EPA is in the public domain

[350] Text by California EPA is in the public domain

Answers

Exercise 1.19.31

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1.20: Lab 20 - Biogeography

This lab contains potentially inaccessible interactive resources. Please work with your instructor and local campus resources to identify accommodations for these resources.

Learning Objectives

- Explain how ecosystems are defined and mapped.
- Identify and describe global ecoregions.
- Understand the factors that impact fire behavior and fire mitigation methods.
- Explain why there is a designated biodiversity hotspot in California.
- Conduct a field study in a local ecosystem.

Introduction

Throughout this course, you have reviewed many different aspects of the physical environment. You have studied many different aspects of the atmosphere and climate. You have investigated the distribution of water and its impact on the shape of our planet. You have studied many different processes that create, modify, and destroy the surface of the Earth.

While each of the topics that you have previously covered is fascinating in their own right, (especially, perhaps to your professor) each of these aspects of the physical environment contributes to the likelihood of survival and success of the plants and animals dependent on the conditions in different areas. The plants and animals that depend upon them are influenced strongly by the non-living conditions where they survive and strive. These conditions include the winds, temperature, precipitation, humidity, soils, slope, and slope orientation (aspect). These varying conditions impact the distribution of natural vegetation and the ability of animals to glean from that vegetation.

Biogeography is the study of the distribution of plants and animals. Closely related to biogeography is the study of **ecology**. An ecologist studies the relationship between plants and animals and their relationship with the non-living things around them, such as water, soil, air, and sunlight. Interrelated plants and animals and their non-living, physical environment are referred to as an **ecosystem**.

Part A: The Geography of Ecosystems—Making Sense of Where Things Live

One common way of categorizing and mapping ecosystems is to organize them based on biomes (Figure 20.1). **Biomes** are regions defined by the predominant plant characteristics found in that area. For over a century, biologists, ecological scientists, and geographers have worked to classify and organize distinct biomes. Even today there are several different methods of categorizing these biomes. Several current geographers have adopted the following generalized terrestrial (excluding aquatic) biomes. These include:

➢ Ice Sheet and Polar Desert	➢ Xeric Shrubland
➢ Tundra	➢ Dry Steppe
➢ Taiga	➢ Semiarid Desert
➢ Temperate Broadleaf Forest	➢ Grass Savanna
➢ Temperate Steppe	➢ Tree Savanna
➢ Subtropical Rainforest	➢ Subtropical and Tropical Forest
➢ Mediterranean Vegetation	➢ Tropical Rainforest
➢ Monsoon Forest	➢ Alpine Tundra
➢ Arid Desert	➢ Montane Forest

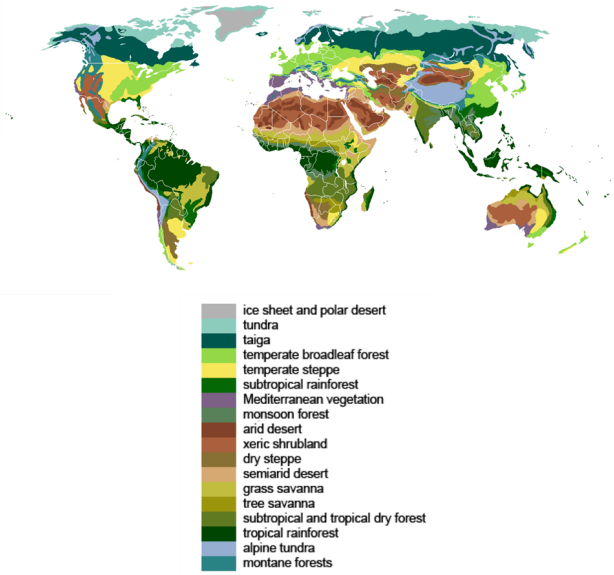


Figure 20.1: Terrestrial Biomes of the World. Figure by Ville Koistinen is licensed under CC BY-SA 3.0

One drawback of the generalization involved with defining biomes is that it tends to overlook many other aspects of an ecosystem that impact the distribution of plants and animals. Biomes primarily focus on the predominant plant species found in a region. This places the emphasis on correlations between regions but does not consider the causation for potentially similar plant communities. Some of these other ecological factors worth considering include soil type, atmospheric conditions, topography, and proximity to a water source. Also, the biomes are very general. In our global efforts for ecological preservation, there is a need for finer granularity. Greater details on specific ecosystem characteristics can help us better understand the minor differences that are important to preserve. In recent times, there have been several other approaches to categorizing and mapping ecosystems that have attempted to account for some of these other ecological factors. The Environmental Protection Agency (EPA) has developed a tiered approach of organizing ecosystems in a framework defined as **ecoregions**. In their system, there are four tiered levels of ecological regions. Level one provides a very broad overview of the ecosystems found in the region. Each of the subsequent ecoregional levels provides more and more detail. As of 2020, the EPA, working in partnership with Canada and Mexico, have only developed their ecoregion classification for North America. Other organizations have developed similar ecoregion boundaries and classifications beyond North America.



Check It Out! Environmental Protection Agency Ecoregions

The Environmental Protection Agency (EPA) has developed the ecoregions schema for organizing ecosystems. They provide a detailed description and a series of maps. One defining characteristic that they use is a nested approach, where you can see the nation divided into a few general ecological areas, with other tiers more and more detailed. So, check it out!

The United States Geological Survey (USGS,) in partnership with several other commercial and non-profit organizations, developed the **Ecological Land Unit** classification schema. This global project has defined multiple ecological characteristics based on a 250-meter grid. These ecological characteristics include:

- Bioclimate: A description of the temperature and precipitation
- Land Cover: The type of vegetation and how the land is being used
- Land Form: The physiographic features (the physical landscape)
- Lithography: the soil type or characteristic

For several continents, more specific details have been provided for each of these ecological characteristics. In the following section, you will explore the global ecological land units.

Exercise 1.20.1

1. What are the three different ways of classifying the biosphere? Hint: each method was discussed in the paragraphs above.
2. What are the similarities among the three schemas?
3. What are the main differences among the three schemas?

Exploring Ecological Land Units

The USGS and Esri (formally the Earth Systems Research Institute) have developed an online tool to explore the global Ecological Land Units. Using their online map viewer and Google Maps, you will explore several locations around the world in order to complete Tables 20.1 and 20.2 (provided below the following instructions).

Step 1



Go to the USGS Global Ecosystems Viewer. This website works best with the Chrome or Edge web browsers.

Step 2

Zoom out to a full extent of the world.

Exercise 1.20.2

4. What are your overall observations of the map? Do you notice any patterns? Explain your response in one to two sentences.

Step 3

Using the “Find address or place” search tool, search for the locations in Tables 20.1 and 20.2 based on the coordinates.

Exercise 1.20.3

5. Follow the steps below and complete Tables 20.1 and 20.2 for each location.

Step 4

Zoom in or out to discover the location description.

Step 5

Click on the map on or near the coordinate location. A small dialog box will provide Ecological Land Unit data. (For some locations, additional information may be provided. Complete Tables 20.1 and 20.2 with the basic information provided).

Step 6



Using Google Maps (Satellite or Street View) or Google Earth, navigate to the same location. Use the satellite imagery to determine the general appearance of the setting.

Table 20.1: Selected California Locations

Coordinates		36.42, -116.88	41.78, -124.11	37.72, -122.11
Location	Your Home or Your Campus			
Bioclimate				
Land Cover				
Land Form				
Lithology				
Topographic Position				
Appearance (from imagery)				

Table 20.2: World Locations

Coordinates	-3.00, -61.00	-0.35, 29.90	27.57 N, 85.42 E
Location			
Bioclimate			
Land Cover			
Land Form			
Lithology			
Appearance (from imagery)			

Exercise 1.20.4

6. List three ideas that you learned previously in the semester that help you to understand the information that you added to Tables 20.1 and 20.2.

7. List three observations that you can make based on Table 20.1. Tip: did you notice anything interesting about the ecological land units found in California?

8. List three observations that you can make based on Table 20.2. Tip: did you notice anything interesting about the ecological land units found in the world locations?

Part B: Limiting Factors

Some plant and animal species can live virtually anywhere. For example, the mallard duck will avoid the bitter tundra in the winter, avoid the scorching heat of central Mexico in the summer, and will survive and thrive throughout most of North America for most of the year. Other species, such as the Coastal Redwood, have very specific needs in terms of soil type, slope, temperature, and moisture. Any factor, or characteristic, that limits the distribution of a plant or animal is referred to as a **limiting factor**.

Several common factors can limit the distribution of plants and animals. These include temperature highs, lows, or annual ranges in temperature. It can include the amount and type of precipitation. Slope and aspect are two additional limiting factors. In the following exercise, you will decipher the impacts of limiting factors on the distribution of several tree species found across North America.

Below, you will find several maps of North America. These include an array of environmental variables that may have an impact on the distribution of tree species. The variables include January Temperature (Figure 20.2), July Temperature (Figure 20.3), Annual Precipitation (Figure 20.4), Climate (Figure 20.5), and a Shaded Relief map (Figure 20.6), which provides a general perspective of slope and elevation.

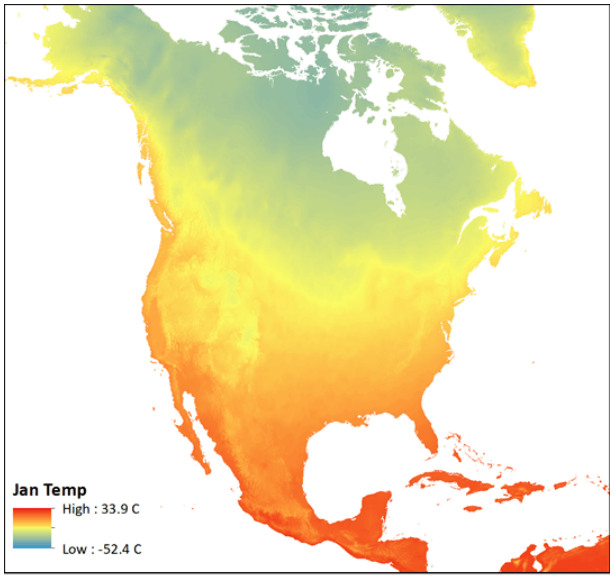


Figure 20.2: North America January Temperature Map. Figure by Scott Crosier is licensed under CC BY-NC-SA 4.0

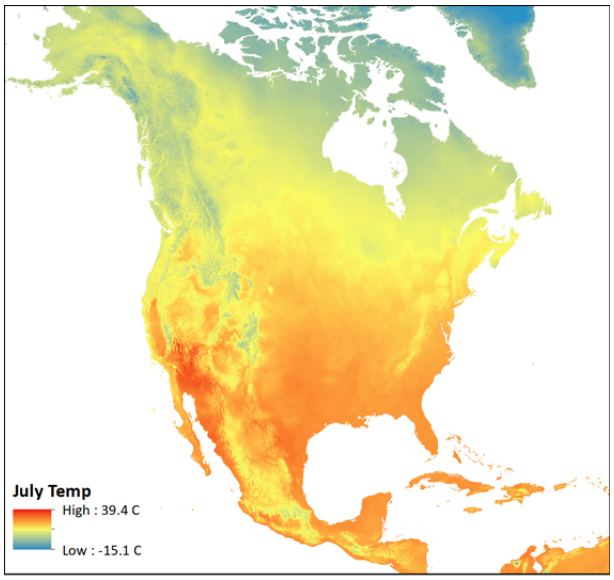


Figure 20.3: North America July Temperature Map. Figures by Scott Crosier are licensed under CC BY-NC-SA 4.0

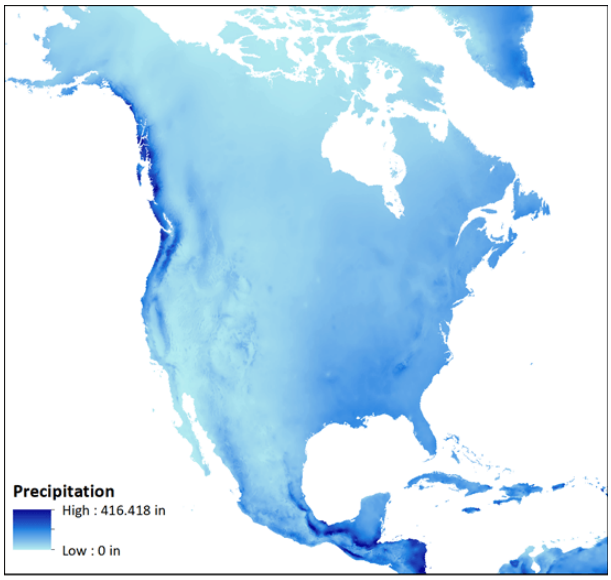


Figure 20.4: North America Annual Precipitation Map. Figures by Scott Crosier are licensed under CC BY-NC-SA 4.0

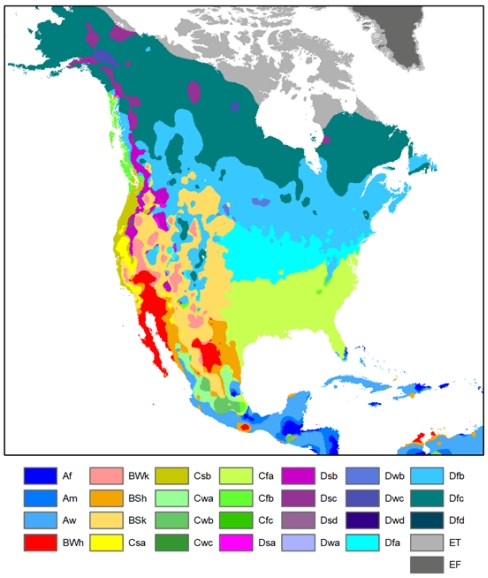


Figure 20.5: North America Climate Map. Figures by Scott Crosier are licensed under CC BY-NC-SA 4.0; GIS data for Figure 20.5 obtained from https://people.eng.unimelb.edu.au/mpeel/koppen.html

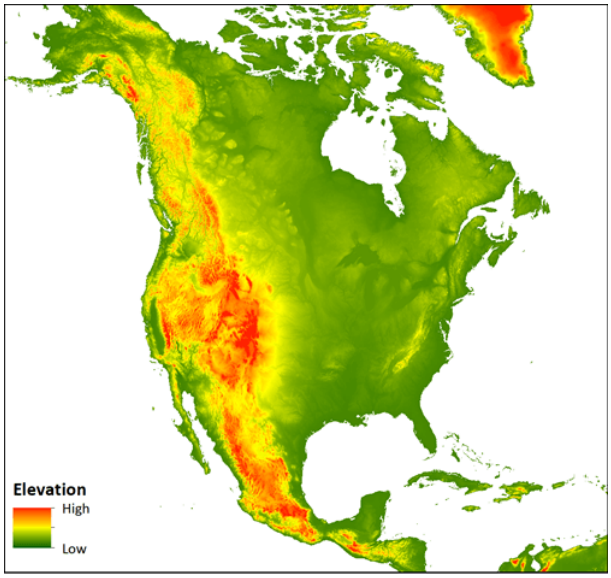


Figure 20.6: North America Elevation Map. Figures by Scott Crosier are licensed under CC BY-NC-SA 4.0; GIS data for Figure 20.5 obtained from https://people.eng.unimelb.edu.au/mpeel/koppen.html

Now, consider the following species distribution (range) maps for several tree species that are found in North America (Figures 20.7 through 20.11).

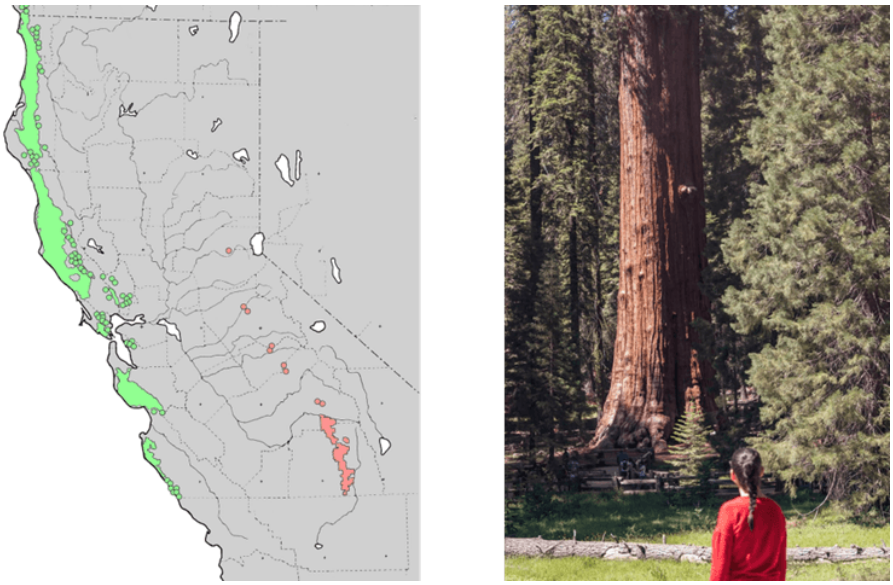


Figure 20.7: On left, distribution map of Sequoia sempervirens (Coastal Redwood; shown in green). Photograph on right. Figure by U.S. Forest Service is in the public domain; Photo by Gabriel Tovar on Unsplash

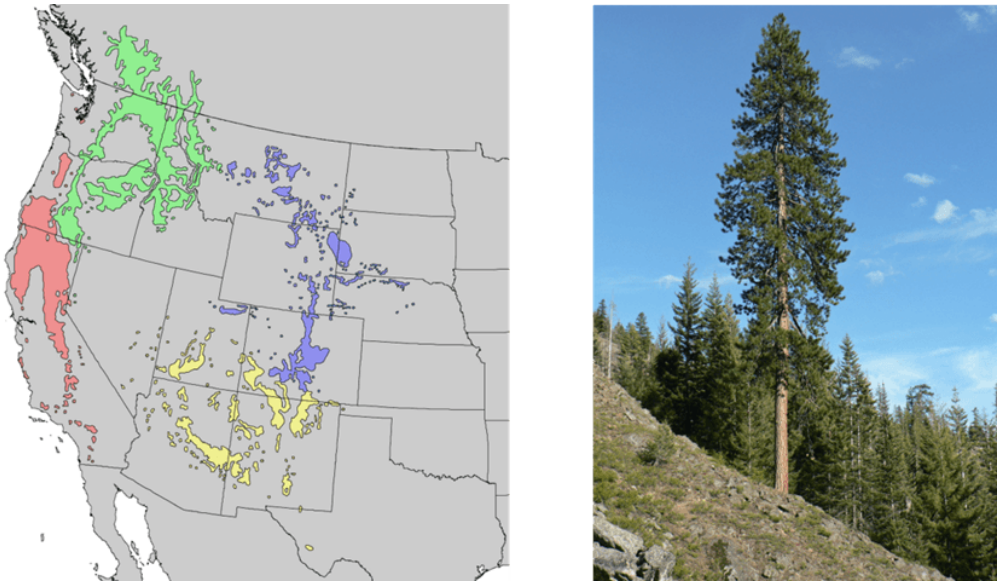


Figure 20.8: On left, distribution map of Pinus ponderosa (Ponderosa Pine; several subspecies presented) Photograph on right. Figure by USDA is in the public domain; Photo by Walter Siegmund is licensed under CC BY-SA 3.0

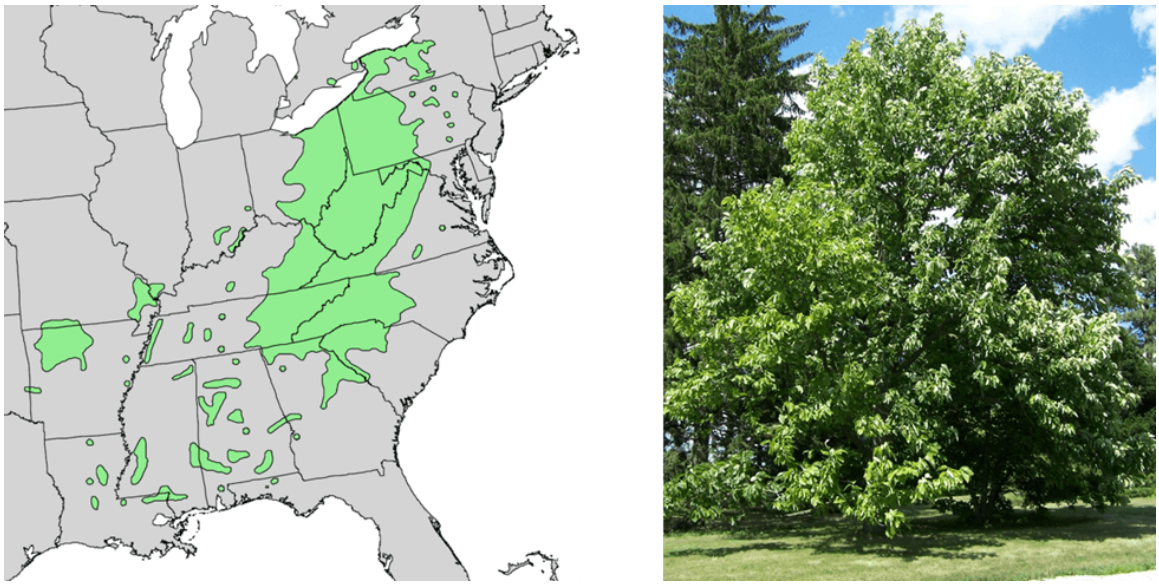


Figure 20.9: On left, distribution map of Magnolia acuminata (Cucumber Tree or Blue Magnolia) Range Map. Photograph on right. Figure by USGS is in the public domain; Photo by Bruce Marlin is licensed under CC BY 3.0



Figure 20.10: Ulmus americana (American Elm) Range Map. Photograph on right. Figure by USGS is in the public domain; Photo by Msact is licensed under CC BY-SA 4.0





On left, distribution map of Pinus pseudostrobus (Chamite or Pacingo) Range Map. Photograph on right. Figure by USGS is in the public domain; Photo by Stan Shebs is licensed under CC BY-SA 3.0

Compare each distribution map (Figures 20.7 through 20.11) with the environmental variables mapped above (Figures 20.2 through 20.6). Look for corresponding trends. To help with your analysis, you may access this google slides document that shows the tree distribution maps with the environmental variable maps.

Exercise 1.20.5

9. On Table 20.3, indicate with a checkmark if you think that the corresponding variable influences the distribution of the tree species.

10. Once you have considered all 5 variables, in the final column of Table 20.3, indicate whether you consider the variables to have a strong or weak impact on the range of the species overall.

Table 20.3: Limiting Factor Analysis

Tree Species	Jan. Temp	July Temp	Annual Precip.	Climate	Elevation	Impact on Range (strong or weak)
Sequoia sempervirens						
Pinus ponderosa						
Magnolia acuminata						
Ulmus americana						
Pinus pseudostrobus						

11. Which environmental variable impacts the largest number of tree species? Use Your Critical Thinking Skills: In one to two sentences, explain why this environmental variable has the greatest impact.
12. Use Your Critical Thinking Skills: Some species have a very limited range. Why do you think that is? Explain your response in one to two sentences.
13. Use Your Critical Thinking Skills: If a tree species has a limited range, how might that impact the ability of the tree to withstand changes to the environment, such as climate change? Explain your response in one to two sentences.

Answer available at the end of this section.

Part C: Fire Ecology

Fire is the release of heat and light as a result of the combustion of fuel. Fire requires three elements: fuel, oxygen, and a heat source. These are commonly organized as the fire triangle (Figure 20.12).

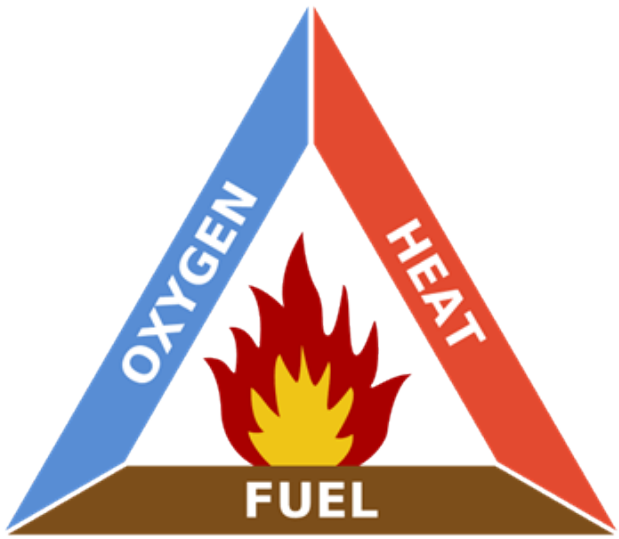


Figure 20.12: The Fire Triangle. Figure by Gustavb is licensed under CC BY-SA 3.0

When studying (and suppressing) fire, the fire triangle assists in understanding the process of fire. Because each component is essential for the process of combustion to take place, any disruption in any of the three components will slow or stop the process. This is true for the fire in your fireplace, the campfire you enjoy when in the woods, or a structural or forest fire.

In larger forest fires, there are other factors that impact fire behavior. **Fire behavior** is the way in which the fire will interact with the landscape. It includes the temperature of the fire, rate of spread, the development of convectional uplifts, and ember production. Fire behavior is influenced by the available fuel, local weather conditions, and the topography of the landscape.

Fuel

In natural settings, there are a wide variety of fuels that can be found. These range from forests and trees, to grasses and desert shrubs. Beyond just the type of fuel, it is important to consider the condition of the fuel. If you were to compare a very humid, moist, forested area with a similarly forested region in a dryer area, the fire would behave quite differently. So, the ease with which the fuel will burn can vary based on the type of vegetation as well as on the annual cycle.

Weather

The vitality of vegetation is closely tied with the soil moisture available, the humidity, and other conditions. Beyond this, the weather itself can have an impact on fire behavior. Many natural fires are caused by lightning strikes. If these strikes

are accompanied by precipitation, they tend to have lower impacts. However, when dry lightning (an electrical storm without precipitation) strikes, the results can be devastating. Humidity will impact the speed at which the fuel is consumed. Wind can also drive flames and increase the oxygen available to the flames.

Topography

Topography or the shape and surface of the landscape also impacts the likelihood of fire. In previous labs, you have explored mountain and valley breezes. These are caused by the surface temperature of a slope heating up, causing the air to rise up the slope. The same process is even stronger when a hillside is covered in flames. Topography not only impacts weather and the fuels that can grow on different surfaces but also has a direct impact on the migration of fire.

Exercise 1.20.6

14. In the Table 20.4, specify a low, medium, or high risk for each element of fire behavior for each setting. To familiarize yourself with each of the settings, go to the following websites or search the Google maps with their coordinates and select the satellite view option.

- Humboldt Redwoods State Park
- Running Springs, San Bernardino Mountains
- Joshua Tree National Park

Table 20.4: Fire Risk Analysis

Setting (Coordinates)	Fuel low, medium, or high?	Weather low, medium, or high?	Topography low, medium, or high?
Redwood coast on a foggy day (41.21, -124.0)			
San Bernardino Mountains during Santa Ana wind conditions (34.20, -117.13)			
Joshua Tree National Park on an autumn afternoon (34.01, -116.10)			

15. Use Your Critical Thinking Skills: Assume that you are a Forest Manager in the Sierra Nevada mountain range. Your concern is the health and safety of the forest as well as providing a place for people to recreate. Relate your answers to the questions below to the three elements of fire behavior. Your response to each question should be two to three sentences in length.

    a. What could you do to mitigate the impacts of these elements of fire behavior?

    b. Would it be best to suppress all fires or allow some to burn? How might this decision impact fire behavior?

    c. If you were issuing campfire permits to people visiting your forest, what considerations would you use to decide if it were safe to issue a permit?

    d. A developer wants to convert some private land near your forest to residential vacation homes. Knowing that your forest periodically burns, what concerns would you have? What practices would you want the property owners to implement? Why?

    e. What impacts would a changing climate (namely, higher temperatures) have on your forest and periodic forest fires?

Part D: California's Biodiversity

California's varied topography and climate have given rise to a remarkable diversity of habitats and a correspondingly varied array of both plant and animal species. California has more native species than any other state in the nation and also has the greatest number of **endemic species**; these are species that occur nowhere else in the world (CDFG 2003). California has a designated hotspot because of the remarkable biodiversity and significant threat of losing habitats and wildlife species unique to California (Myers et al. 2000).[361] Called the California Floristic Province (Figure 20.13), this biodiversity hotspot is one of only 36 in the world. **Biodiversity** refers to biological variety and variability of living organisms, which can be measured by the number of species in an area, by the number of individuals of each species in an area, or in terms of genetic diversity.



Figure 20.13: California Floristic Province Locator Map. Figure by NoahElhardt is licensed under CC BY-SA 3.0

California's biodiversity stems from exceptional variation in landscape features, latitudinal range, geological substrates and soils, and climatic conditions, resulting in a wide range of ecosystems to support plant and animal species. Alpine meadows; desert scrub; oak woodlands; diverse grasslands; vernal pool complexes; moist redwood forests; spring-fed lakes; freshwater streams, rivers, and marshes; coastal wetlands, beaches, dunes and bluffs; and giant marine kelp beds provide a wide variety of habitats that support a correspondingly diverse array of both plant and animal species.[363]

The frequency, intensity, and seasonal timing of fire in the landscape have been major factors determining the composition of flora throughout the state. Fire-dependent vegetation types cover over half the surface area of California (Sugihara et al. 2006). Alteration of the natural fire regime is an important ecosystem stress, particularly in forest- and shrub-dominated habitats (Ainsworth and Doss 1995). Widespread forest management practices, including fire suppression without active forest management, as well as increases in human-caused wildfires, have altered fire regimes. The effects of wildfires differ among ecological communities. In sage scrub, chaparral, and grassland systems, lightning-induced fires are relatively frequent and plants have evolved to germinate post-fire. Human-caused fires, however, have resulted in unnaturally high fire frequencies, especially along roads and near the urban-wildland interface, interrupting the natural successional dynamics of these habitats. These more frequent fires can decrease the quality of aquatic habitats by reducing shading and woody debris, as well as directly damaging terrestrial habitats. Areas where fire was relatively rare, such as the high desert, have experienced an increase in fire frequency because of changes in vegetation. Increased fuel loads associated with invasive species have resulted in an increased number of fires (Brooks 1999). An **invasive species** is an organism that is brought to a new location by human activities. It causes ecological or economic harm by outcompeting native species, reducing biodiversity, or altering habitats. The increased fire frequencies then favor the Mediterranean grasses that were introduced to California with the arrival of European settlers and livestock. Once established, the non-native grasses grow in a dense-thatch pattern that chokes out native vegetation, lowers habitat quality for wildlife, and provides additional fuel for the cycle of frequent burning (Keeley 2009).[364]

Exercise 1.20.7

16. List the ways humans have impacted California's biodiversity.

Conserving the state's outstanding biodiversity creates many values. Wildlife provides significant economic and quality-of-life benefits to the state through recreation, tourism, sport and commercial harvest, and ecological services, such as pollination. Many of the places where wildlife thrives are often the same as those valued for recreation and other human activities. By learning the causes of impacts to the state's wildlife and the steps that can be taken to reduce those impacts, California's residents have the opportunity to become more active stewards of this precious natural treasure, ensuring that the Golden State remains an important place for viable wildlife populations for generations to come.[14]

Let's learn more about the California Floristic Province by reviewing the information provided by the Critical Ecosystem

Partnership Fund.

Step 1



Go to the California Floristic Province webpage.

Exercise 1.20.8

17. Do you live within the California Floristic Province? Zoom in and out of the map, if needed.

Step 2

Read the “About this Hotspot” section.

Exercise 1.20.9

18. What percentage of the original vegetation in the California Floristic Province remains in more or less pristine condition?
19. Apply What You Learned: How would recent wildfires impact the condition of the original vegetation in the California Floristic Province? List the possible impacts.

Step 3

Click the + sign next to Species and read about plants, birds, mammals, reptiles, amphibians, freshwater fishes, and invertebrates.

Exercise 1.20.10

20. What are five important ideas that you learned about species?

Step 4

Click on the “Threats” heading to read how human activities threaten the California Floristic Province.

Exercise 1.20.11

21. List the major threats to the California Floristic Province.
22. Apply What You Learned: How do you benefit from California’s biodiversity?
23. Use Your Critical Thinking Skills: How do your day-to-day activities influence the California Floristic Province?

Part E: Field Studies of an Ecosystem

Exercise 1.20.12

24. For this portion of the lab, you will be making one or more observations of an ecosystem. This could be a location in your backyard or neighborhood, on your campus, or even further afield. Plan on observing your location for at least 30 minutes each visit.

Step 1

Choose a location to observe. Your professor may have a specific location where you should go. You may also want to discuss a location with your professor. Choose a safe location.

Step 2

Prepare yourself for your field experience. You should have the appropriate clothing for varying weather conditions, water, sunscreen, and snacks. You should also have a field journal, paper, several pencils and/or pens, and any other devices that you may use to collect data in the field. Lastly, you may want to have a hand lens (to see small things), a set of binoculars or a spotting scope (to see things farther away), and field guides.

Step 3

Head to your location! Find a comfortable spot to sit and observe.

Step 4

Record your findings on the worksheet available on the following pages. If your professor asks for multiple observations, duplicate the worksheet. You may need to use your phone to find some of the data for the worksheet.

Step 5

Prepare a report of your findings. Your professor will provide details on what you should include.

Field Worksheet
Where and When
Date:
Arrival Time:
Departure Time:
Location (address, name, or coordinates):
Elevation:
Setting (Description of area):
Atmosphere
Temperature:
Wind Direction and Speed:
Cloud Cover:
Humidity:
Air Pressure:
Hydrosphere
Current or recent precipitation:

Nearby surface water (ocean, lake, river, stream):
Lithosphere
Soil Color:
Soil Texture:
Soil Moisture:
Topography:
Biosphere
Choose a specific perimeter that you can see and assess. For your list, consult with your professor on the use of descriptions, scientific names and/or common names.
Flora (Plants) On this page, or on a separate sheet of paper, list each plant species present. Include the following: A. The name and/or description B. Total number of individuals C. Size (or range in size) of the individuals
Fauna (animals) On this page, or a separate sheet of paper, list each animal species present. Be sure to consider mammals, reptiles, insects, and so forth. Include the following: A. The name and/or description B. Total number of individuals you saw C. Their actions or behaviors D. Their interactions with one another, the plants, or with the environment

Part F. Wrap-Up

Consult with your geography lab instructor to find out which of the following wrap-up questions you should complete. Attach additional pages to answer the questions as needed.

Exercise 1.20.13

25. What is the most important idea that you learned in this lab? In two to three sentences, explain the concept and why it is important to know.

25. What was the most challenging part of this lab? In two to three sentences, explain why it was challenging. If nothing challenged you in the lab, write about what you think challenged your classmates.

25. What is one question that you have about what you learned in this lab? Write your question along with one to two sentences explaining why you think your question is important to ask.

25. Review the learning objectives on page 1 of this lab. How would you rate your understanding or ability for each learning objective? Write one sentence that addresses each learning objective.

25. Sketch a concept map that includes the key ideas from this lab. Include at least five of the terms shown in bold-faced type.

25. Create an advertisement to educate your peers on the important information that you learned in this lab. Include at least three key terms in your advertisement. The advertisement should be about half a page in size (about 4 inches by 6 inches).

25. One way to think of physical geography is that it is the study of the relationships among variables that impact the Earth's surface. Select two variables discussed in this lab and describe how they are related.

25. How does what you learned in this lab relate to your everyday life? In two to three sentences, explain a concept that you learned in this lab and how it relates to your day-to-day actions.

25. How does what you learned in this lab relate to current events?
    a. Write the title, source, and date of a news item that relates to this lab.
    b. In two to three sentences, discuss how the news item relates to what you have learned in this lab.
    c. In one to two sentences, discuss whether or not the news item accurately represents the science that you learned. Tip: consider whether or not the news item includes the complexity of the topic.

25. Search O*NET OnLine to find an occupation that is relevant to the topics presented in today's lab. Your lab instructor may provide you with possible keywords to type in the Occupation Quick Search field on the O*NET website.
    a. What is the name of occupation that you found?
    b. Write two to three sentences that summarize the most important information that you learned about this occupation.
    c. What is one question that you would want to ask a person with this occupation?

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[361] Text by California Department of Fish and Wildlife is in the public domain

[363] Text by California Department of Fish and Wildlife is in the public domain

[364] Text adapted from the California Department of Fish and Wildlife is in the public domain

Answers

Exercise 1.20.5

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INDEX

No index terms found.

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GLOSSARY

S

Sample Word 1 | Sample Definition 1

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