4A The Water Cycle

How is a model of the water cycle in your classroom like the Earth's water cycle?

Earth has large quantities of water. The Sun's energy evaporates water from Earth's surface into the atmosphere. This water is then recycled as it cools and condenses into clouds and then precipitates back to the ground as rain, sleet, or snow. The processes of evaporation and condensation are very important in the *water cycle*.

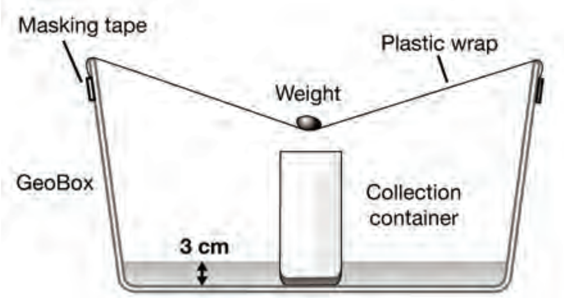
In this investigation, you will learn how to build and observe a model of the water cycle in your classroom.

Materials

- Water (preferably bottled water)
- Beaker to use for pouring water
- Table salt
- Balance
- 2 GeoBoxes
- 2 collection containers (shorter than height of GeoBox)
- 2 weights
- Plastic wrap
- Masking tape
- Metric ruler

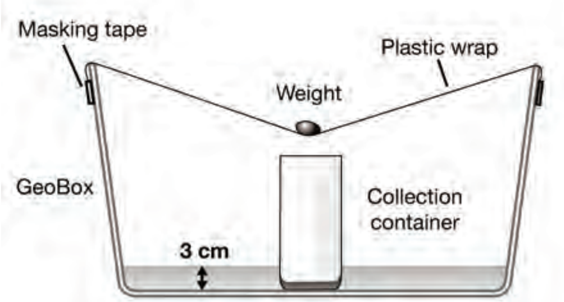
1 Setting up

1. Pour fresh water to the 3-centimeter mark in one GeoBox and pour salt water up to the 3-centimeter mark in the other GeoBox. The salt water will be approximately as salty as ocean water.
2. Put a collection container that is shorter than the height of the GeoBoxes in the middle of each of the GeoBoxes. A drinking glass works well for this purpose.



Fresh water

3. Cover the GeoBoxes with plastic wrap. Do not stretch the wrap tightly. Seal the edges using masking tape all the way around box rim.
4. Place a weight in the middle of the plastic wrap on each GeoBox so the lowest part of the plastic wrap is centered over the drinking glass.



Salt water

2 Doing the experiment

1. Place the GeoBoxes in a warm, sunny window. You have now made a *solar still*. A solar still allows you to collect pure water using the Sun's energy. You will see how this is done in the investigation.
2. Check the GeoBoxes periodically.

3. Record your observations and what you think is happening inside the GeoBoxes in Table 1.

Table 1: Observations

Day	Fresh water GeoBox		Salt Water GeoBox	
	Observation	What you think is happening	Observation	What you think is happening
1				
2				
3				
4				

3 Thinking about what you observed

a. What happened to the fresh water level in the first GeoBox?

b. What happened to the salt water level in the second GeoBox?

c. What happened to the water level inside the collection containers in each box?

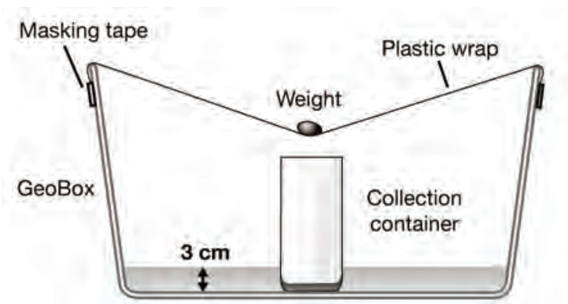
d. Where is evaporation happening inside the GeoBoxes?

e. Where is condensation happening inside the GeoBoxes?

f. How did water get into the collection containers?

g. How do you think what you observed happening in the GeoBoxes relates to the water cycle?

h. You will find a water cycle diagram in Chapter 4 of your textbook. Compare this diagram to what took place in the GeoBoxes. Label the diagram below to show where each stage of the water cycle is taking place inside the GeoBox.



i. Describe a situation where a solar still would be useful for obtaining fresh water.

j. With teacher supervision only, test the water in the collection containers. If you have permission to do so and the water has been collected in fresh plastic cups, you may taste the water. If not, allow the collected water in each collection container to evaporate. If the water is fresh, you will not see any salt crystals when all the water has evaporated.

4B Water in Earth's Atmosphere

How can we measure water content in the atmosphere?

When water evaporates from Earth's surface, the atmosphere temporarily stores that moisture, until it precipitates back down to the land and oceans. This is all part of the water cycle.

Relative humidity is a measure of how much water vapor is in the air compared to the maximum amount the air can hold at a certain temperature. Relative humidity is expressed as a percent. When the air is saturated, it has one hundred percent relative humidity. When the air holds half the humidity that it could potentially hold at a certain temperature, it has a relative humidity of fifty percent. When the relative humidity is high, it feels “sticky.”

In this investigation, you will determine some factors that influence evaporation and use a device called a sling psychrometer to indirectly measure relative humidity in the atmosphere.

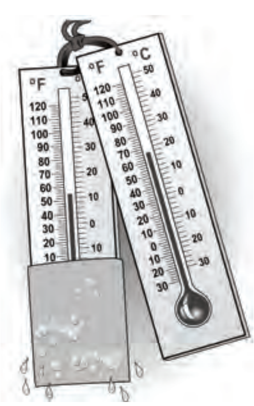
Materials

- Sling psychrometer
- Relative humidity chart
- Stopwatch
- Graph paper
- Water in a wide-mouth container
- Vaporizer
- Simple calculator

1 Doing the experiment

1. Place the felt-covered bulb in room temperature water until the felt is thoroughly wet. Place the two thermometers back-to-back. Slip a rubber band over them to hold them together.
2. Slide the string through the holes in the thermometer backing and tie off the end. Your sling pyschrometer is now assembled.
3. Take the sling psychrometer to an open, spacious area in your classroom or another indoor location. Gently swing the psychrometer in front of you in a circular pattern for three minutes.

Safety Tip: Be sure to provide enough space so that your classmates will not be struck by the swinging thermometers.



4. Record the temperature of the wet-bulb and the dry-bulb thermometers in Table 1. Your teacher will give you a version of this table to write on.
5. Record the difference between the two temperatures.
6. Repeat steps 1-3 in another location. If you are outside and precipitation is falling, choose a covered porch, walkway, or pavilion.
7. Repeat steps 1-3 in a room in which a vaporizer has been operating for at least 30 minutes.

Safety Tip: The steam from a vaporizer can cause serious burns. Do not put your hands or face near the steam vent.

8. Share the data you collected with your classmates. In the remaining rows of the table, record data collected in three additional locations by other lab groups.

Table 1: Sling psychrometer data

Location description	Dry bulb temperature (°C)	Wet bulb temperature (°C)	Temperature difference (°C)

2 Analyzing your data

a. Which was generally higher, the wet bulb temperature or the dry bulb temperature?

b. Give a reason for the temperature difference between the thermometers.

c. In which location did you find the greatest temperature difference between the two thermometers? Which location had the smallest difference?

d. What environmental factors seem to be connected to large temperature differences between the two thermometers? What factors seem to be connected to small temperature differences?

e. How might the temperature difference at each location be related to the water content of the atmosphere at each location?

3 Finding relative humidity

Relative humidity is a term that you may have heard mentioned on your local weather report. It is a measure of the actual water content of the air compared to the potential amount that could be in the air at that temperature and pressure. If the relative humidity is 100%, water added to the atmosphere condenses right back out again. Days with high relative humidity feel "sticky" because perspiration can't easily evaporate from your skin to cool you.

Use your data from the experiment to determine the relative humidity in each location tested.

1. Obtain a relative humidity chart from your teacher. On the left-hand column of the chart, find the dry-bulb reading for your first measurement.
2. Find the difference between the dry- and wet-bulb readings at the top of the chart.
3. Find the box where the two readings cross. The number in the box tells you the relative humidity at this location. Record the relative humidity in Table 2.
4. Repeat steps 1-3 for each location measured.

Table 2: Relative humidity for each location tested

Location	Relative humidity (%)

4 Analyzing your results

a. Make a bar graph which shows the relative humidity of the locations tested, in order from lowest to highest. On each bar, print the dry bulb temperature at each location.

Title: ______________________________

y label: ______________________________

x label: ______________________________

b. Does your graph show a relationship between dry bulb temperature (the temperature of the atmosphere) and the relative humidity? Using what you know about water content in the atmosphere, explain why or why not.

c. Challenge: It takes specialized equipment to directly measure water content in the atmosphere. This equipment tells how many grams of water are present in a cubic meter of air—a measurement called absolute humidity. If the relative humidity was 100% in two cities, but one had a dry bulb temperature of 16°C and the other was at 32°C, would their absolute humidity be the same? Why or why not?

5A The Atmosphere

Can you measure atmospheric pressure?

The *atmosphere* is often referred to as an "ocean of air." As weather systems interact in the troposphere, atmospheric pressure varies slightly above and below the average 1013.25 millibars at sea level. These slight changes in atmospheric pressure are one of the most useful measurements for weather prediction. How are these pressure changes measured? In this investigation, you will build your own atmospheric pressure gauge.

Materials

- Wide-mouth glass jar
- Permanent Marker
- Yellow (wood) glue
- Approximately 0.5 meters string
- Plastic grocery bag
- Broom straw or coffee stirrer
- Cellophane tape and duct tape
- Three index cards
- Scissors
- Shoe box
- Ruler and/or protractor
- Weather tools set

Optional materials

- Small mirror
- laser pointer

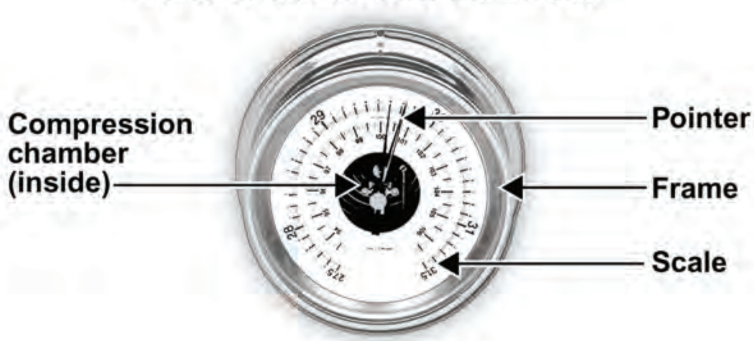
1 Parts of an aneroid barometer

How does an aneroid barometer work? An aneroid barometer consists of a sealed canister of air (the compression chamber) with a flexible top called a *tympanum*. The tympanum is pressed inward when atmospheric pressure increases. It bulges outward as the atmospheric pressure decreases. A pointer is used to measure these movements of the tympanum.

To build a reliable barometer, you will:

- Make a compression chamber to observe changes in atmospheric pressure.
- Construct a pointer that amplifies tiny changes and shows them on a scale.
- Contain the compression chamber in a sturdy frame so that you can move your barometer around and take readings that are consistent.
- Calibrate your barometer so that its readings are accurate even if it undergoes temperature changes.

Parts of an Aneroid Barometer



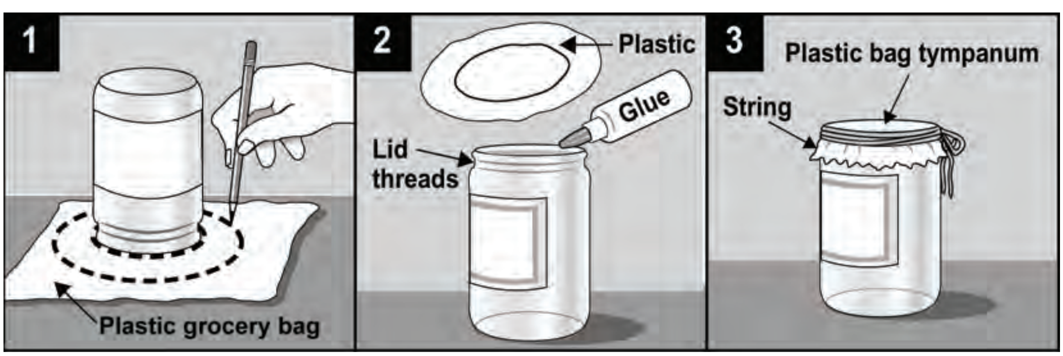
a. A compression chamber must be airtight yet flexible so that you can measure changes in volume of the gas it contains. With your group, brainstorm materials you could use for a compression chamber.

b. How will you measure your compression chamber's changes in volume?

2 Building the compression chamber

Your compression chamber must be rigid except for the tympanum. The rigid part is where you will attach a frame and where you will pick it up.

A wide-mouth glass jar will make a good compression chamber. The size of the jar affects the amount of movement of the tympanum. A large mayonnaise jar and a peanut butter jar have similar sized openings, but the larger volume of the mayonnaise jar will cause larger movements of the tympanum. You will form the tympanum by sealing a piece of plastic grocery bag over the mouth of the jar.

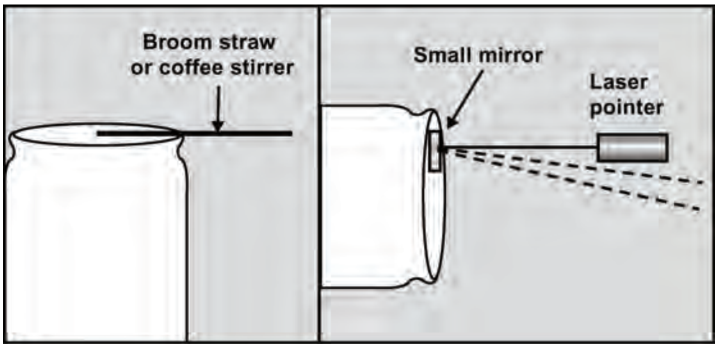


1. Cut the grocery bag in half so that you have a flat piece of plastic to spread out on your work space.
2. Place the jar upside down on an area of the plastic that is free of even the smallest holes. Use a permanent marker to trace an outline of the mouth of the jar on the plastic.
3. Remove the jar. Draw a larger circle around the first circle. Your new circle should be 6 centimeters larger in diameter than the first.
4. Cut out the larger circle with scissors.
5. Apply a generous amount of glue to the lid threads of the jar.

6. Center the plastic circle over the jar. Wind several tight turns of string around the jar's lid threads, making sure the plastic fits tightly over the jar.
7. Tie off the string. When the glue dries, cut away the excess plastic.

3 Constructing the pointer

The pointer has two purposes. It makes the small movements of the tympanum visible, and it allows those movements to be recorded as a number. Here are some suggestions:



Study the pictures above. They may spark further ideas among your group. Choose one method to try.

a. Write out a step-by-step procedure for constructing your pointer.

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b. As you construct the pointer, you may encounter unexpected issues that may require you to modify your procedure. When finished, revise the steps you listed in Part 3a to reflect your final procedure.

c. Test your mechanism by gently pushing on the tympanum with your finger. Could you see the pointer's movement? If not, devise a method to increase the distance moved by the pointer. Record any final changes made to your procedure.

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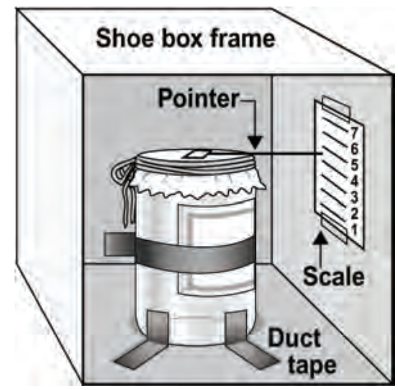
4 Attaching a frame and scale

The frame must allow the barometer to be moved without disturbing the pointer. The frame also supports the pointer scale. The frame must be sturdy so that the positions of the pointer and scale cannot change. Movement between the pointer and the scale will cause enormous errors.

A sturdy box makes a good frame. The compression chamber with attached pointer must fit easily inside the frame. The pointer should almost touch one of the walls of the box.



1. Attach the compression chamber to the frame. The position of the compression chamber inside the frame should not change even if the frame is moved from one location to another.
2. Create a scale to help you measure the movement of the pointer. Use a pen and a ruler to make a series of evenly-spaced marks on a piece of white paper. Number each mark 1, 2, 3, and so on.
3. Slide your scale between the pointer and the wall of your frame. Attach the scale with tape so that you can record movements of the pointer. For example, if the pointer currently points to the space between 4 and 5 on the scale, you would record the atmospheric pressure as 4.5 units.

5 Calibrating your barometer

Changing atmospheric pressure is not the only force that will cause the tympanum to bulge in and out. If your barometer warms up, the air inside will expand and that, too, will make the tympanum bulge out. Similarly, if the barometer cools, the tympanum will bulge inward. You need a way to correct readings for temperature. Commercial barometers do this with a second mechanism inside so that the displayed readings are already adjusted, or compensated, for temperature changes. To keep your barometer from becoming too difficult to build, you will read the temperature from a separate thermometer and use a graph to adjust your barometer readings for changes in temperature.

1. The first step in calibrating your barometer is to make a table of readings over the course of at least one week. Each day, record the temperature in the first column, the pointer reading in the second column, and the reading from the commercial barometer in the last column.
   If you find that the temperature varies widely over the course of the week, you may wish to take readings for a second week. Once you have at least three barometer readings at the same temperature you will be able to begin graphing your data.

Table 1: Atmospheric pressure data, Week 1

	Temperature	Scale mark on barometer	Commercial barometer reading
Sample	24°C	3	1031 millibars
Sample	26°C	4	1031 millibars
Day 1			
Day 2			
Day 3			
Day 4			
Day 5			
Day 6			
Day 7			
Day 8			
Day 9			
Day 10			
Day 11			
Day 12			
Day 13			
Day 14			

2. Make a graph to help you convert your barometer readings to millibars. First, rewrite your table, grouping together all readings at one temperature.

3. Label the *x*-axis of your graph with your pointer scale and the *y*-axis with the commercial barometer readings. Plot all of the readings *for one temperature* and draw a trend line through the points. Label that line with its temperature. Repeat this process for each group of temperatures. The end result will be a series of trend lines, one for each temperature.

Title: ______________________________

y label: ______________________________

x label: ______________________________

4. After you have taken several sets of readings, you will be able to determine atmospheric pressure using your barometer. Find your pointer scale reading on the *x*-axis, and then follow that line upward until you meet the trend line for the current temperature. Then read the *y*-coordinate of that point to find the barometer reading in millibars. Continue to compare your barometer with the commercial one until you can read yours with confidence.

6 Evaluating your design

a. Use your barometer, thermometer, and graph to measure barometric pressure for an additional week. Record your data, along with data from a commercial barometer, in the table below.

Table 2: Atmospheric pressure data, Week 2

Day	Your barometer reading	Commercial barometer		Day	Your barometer reading	Commercial barometer
1				5		
2				6		
3				7		
4						

b. What is the maximum difference, in millibars, between your reading and the commercial barometer reading? Calculate the percent error of this reading.

c. Name two adjustments you could make to increase the accuracy of your barometer.

d. Look back on your barometer readings for the past week. Can you see a relationship between air pressure and the weather? Do sunny days tend to have high or low pressure? How about rainy days?

5B Heating Land and Water

How does solar radiation affect the heating and cooling of continents and oceans?

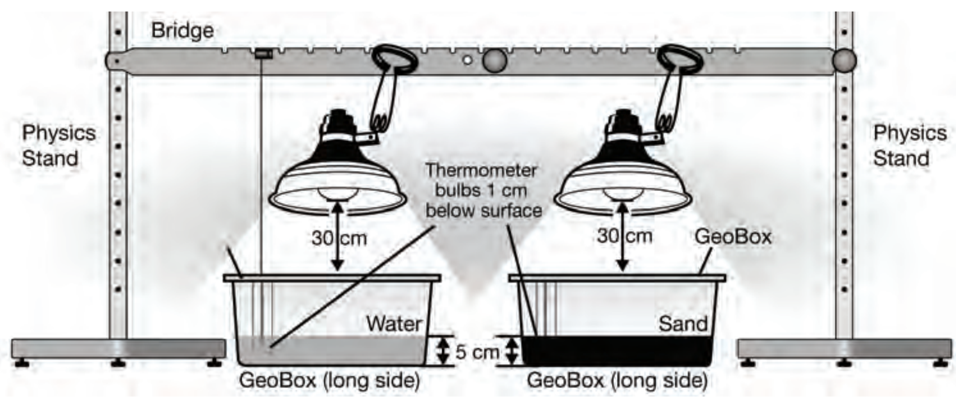
When solar radiation reaches Earth's surface, it is absorbed differently by different surfaces. An important term, which will be useful in explaining the results of this investigation, is specific heat. *Specific heat* is the amount of energy needed to raise the temperature of 1 gram of a substance by 1 degree Celsius.

Which has a higher specific heat—the oceans or the land? Having a higher specific heat means that it takes more energy to raise a substance's temperature, but once the substance is warm, it takes longer to cool off. In this investigation, you will find out whether water or land has the higher specific heat, and how that affects local temperatures.

Materials

- 2 GeoBoxes
- 2 Physics stands
- Bridge
- Stopwatch
- 2 pieces of string
- 2 thermometers
- 2 light sources with clips
- Sand (to fill one bin 5 cm deep)
- Water (to fill one bin 5 cm deep)

1 Doing the experiment



1. Set up your materials as shown above. You will need to team up with another lab group in your class to have two physics stands.
2. One tray will contain water and the other will contain sand. Both the water and sand should be added to a depth of 5 centimeters. Each tray will have its own light. Place the lights so that the bottom of the bulbs are about 30 cm directly above the top of their respective trays.
3. Place one thermometer in the sand so that the thermometer bulb is about 1 cm below the surface. Using the piece of string, suspend the other thermometer so that the bulb is about 1 cm below the surface of the water.
4. Wait three minutes. Record the initial temperature of each thermometer in the space provided.
5. Turn the lights on at exactly the same time and use the stopwatch to record temperatures from both thermometers each minute for 10 minutes. Record your data in Table 1.

6. Turn the lights off and continue to record temperatures for an additional 10 minutes. Record your data in Table 1.

Table 1: Time and temperature

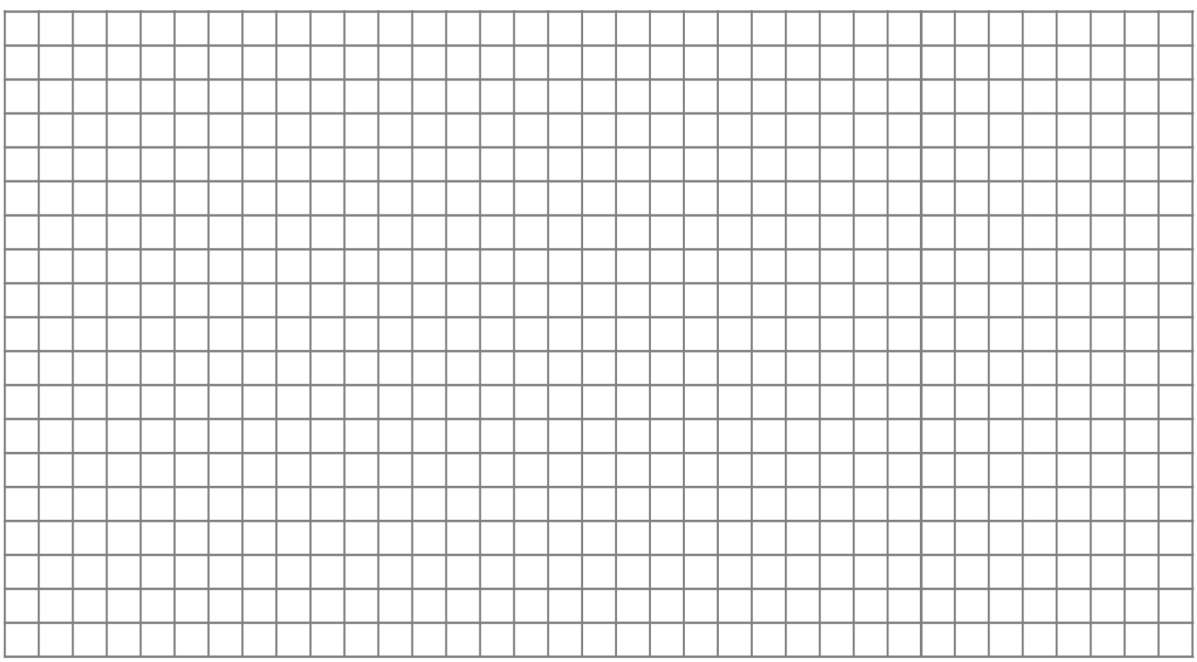
	Initial	Heating (light turned on)										Cooling (light turned off)									
Time (minutes)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Sand Temp. (°C)																					
Water Temp. (°C)																					

2 Graphing your results

Graph the data, using time as the *x*-axis variable and temperature as the *y*-axis variable. Make a key to indicate the curves for sand and water. Don't forget to label your axes, to use units, and to title your graph.

Title: ____________________

y label: ____________________



x label: ____________________

3 Thinking about what you observed

a. Which received more heat (radiation) from its lamp, the sand or the water? Or did they receive the same?

____

b. Which material heated up faster? ___

c. Which material cooled down faster? ___

d. Using the term *specific heat*, explain your results.

e. Based on your results, which places on Earth would have the smallest/greatest temperature ranges—the land or the sea?

4 Exploring on your own

a. Find out which of the world's hemispheres has a higher proportion of water to land and describe how that might influence the temperature variations in the hemispheres.

b. Use the term specific heat to explain how sea and land breezes work. Also, refer to Section 6.3 of your text to answer this question in terms of convection in the atmosphere.

c. Give an explanation for why the temperature range (8 degrees) for Boston, MA (a coastal city) is smaller compared to the temperature range (11 degrees) for Las Vegas, NV (a landlocked city).

	Temperature range for January (°C)	Total degrees in range
Coastal city Boston, MA	- 6 to 2	8
Landlocked city Las Vegas, NV	3 to 14	11

6A Observing the Weather

How can you use weather data to make predictions?

In this investigation, you will go outside to practice your observation skills. You will observe cloud types and use instruments to measure temperature, air pressure, and humidity. You will use the Beaufort wind scale to make observations about wind speed and direction.

In this investigation, you will keep a journal of weather conditions for four weeks. Then you will graph your data and look for patterns in the measurements you recorded.

Materials

- Weather tools set (includes a thermometer, a barometer, and a hygrometer)
- Cloud chart
- Beaufort wind scale
- Compass
- Graph paper
- Blue and pink highlighter pens

1 Setting up

1. Gather the instruments and charts you'll need to collect your weather data.
2. Take a look at the data chart on the next page. Decide as a group which instrument or chart is needed to take each measurement.
3. In your group, pass around each instrument. Discuss the unit you'll use to report each of your measurements. Everyone should practice reading each instrument and chart.
4. Decide on an outdoor location and a time of day to make your measurements.

2 Stop and think

a. Why is it important to take measurements in the same location every day?

b. Why is it important to take measurements at the same time every day?

c. What season are you currently experiencing? Will you have more hours of daylight at the end of this four-week period, or fewer? Do you think the temperatures you measure will be getting warmer, cooler, or staying about the same over the next four weeks?

3 Doing the experiment

1. Assign each person in your group an instrument or chart and one type of data to collect. Rotate after four or five days so that each person has a chance to collect each type of data. Note: Be sure to use the correct units for your measurements.
2. Spend five minutes at the beginning or end of class each day collecting and recording your weather data in the chart on the following page. For percent cloud cover, estimate whether 0%, 25%, 50%, 75%, or 100% of the sky is cloudy.
3. In the notes section, record any precipitation (rain, snow, etc.) that has fallen since last time you took measurements, and whether any precipitation is currently falling.

Table 1: Weather data

Date:______ Time:______	Date:______ Time:______	Date:______ Time:______	Date:______ Time:______	Date:______ Time:______
Temp:__________ Pressure:_______ Humidity:______ Wind speed and direction:_______ _______________ Cloud type and % sky covered: _______________ _______________ Notes:__________ _______________	Temp:__________ Pressure:_______ Humidity:______ Wind speed and direction:_______ _______________ Cloud type and % sky covered: _______________ _______________ Notes:__________ _______________	Temp:__________ Pressure:_______ Humidity:______ Wind speed and direction:_______ _______________ Cloud type and % sky covered: _______________ _______________ Notes:__________ _______________	Temp:__________ Pressure:_______ Humidity:______ Wind speed and direction:_______ _______________ Cloud type and % sky covered: _______________ _______________ Notes:__________ _______________	Temp:__________ Pressure:_______ Humidity:______ Wind speed and direction:_______ _______________ Cloud type and % sky covered: _______________ _______________ Notes:__________ _______________
Date:______ Time:______	Date:______ Time:______	Date:______ Time:______	Date:______ Time:______	Date:______ Time:______
Temp:__________ Pressure:_______ Humidity:______ Wind speed and direction:_______ _______________ Cloud type and % sky covered: _______________ _______________ Notes:__________ _______________	Temp:__________ Pressure:_______ Humidity:______ Wind speed and direction:_______ _______________ Cloud type and % sky covered: _______________ _______________ Notes:__________ _______________	Temp:__________ Pressure:_______ Humidity:______ Wind speed and direction:_______ _______________ Cloud type and % sky covered: _______________ _______________ Notes:__________ _______________	Temp:__________ Pressure:_______ Humidity:______ Wind speed and direction:_______ _______________ Cloud type and % sky covered: _______________ _______________ Notes:__________ _______________	Temp:__________ Pressure:_______ Humidity:______ Wind speed and direction:_______ _______________ Cloud type and % sky covered: _______________ _______________ Notes:__________ _______________
Date:______ Time:______	Date:______ Time:______	Date:______ Time:______	Date:______ Time:______	Date:______ Time:______

Table I: Weather data

Date:______ Time:______	Date:______ Time:______	Date:______ Time:______	Date:______ Time:______	Date:______ Time:______
Temp:__________ Pressure:_______ Humidity:______ Wind speed and direction:_______ ________________ Cloud type and % sky covered: ________________ ________________ Notes:__________ ________________	Temp:__________ Pressure:_______ Humidity:______ Wind speed and direction:_______ ________________ Cloud type and % sky covered: ________________ ________________ Notes:__________ ________________	Temp:__________ Pressure:_______ Humidity:______ Wind speed and direction:_______ ________________ Cloud type and % sky covered: ________________ ________________ Notes:__________ ________________	Temp:__________ Pressure:_______ Humidity:______ Wind speed and direction:_______ ________________ Cloud type and % sky covered: ________________ ________________ Notes:__________ ________________	Temp:__________ Pressure:_______ Humidity:______ Wind speed and direction:_______ ________________ Cloud type and % sky covered: ________________ ________________ Notes:__________ ________________
Date:______ Time:______	Date:______ Time:______	Date:______ Time:______	Date:______ Time:______	Date:______ Time:______
Temp:__________ Pressure:_______ Humidity:______ Wind speed and direction:_______ ________________ Cloud type and % sky covered: ________________ ________________ Notes:__________ ________________	Temp:__________ Pressure:_______ Humidity:______ Wind speed and direction:_______ ________________ Cloud type and % sky covered: ________________ ________________ Notes:__________ ________________	Temp:__________ Pressure:_______ Humidity:______ Wind speed and direction:_______ ________________ Cloud type and % sky covered: ________________ ________________ Notes:__________ ________________	Temp:__________ Pressure:_______ Humidity:______ Wind speed and direction:_______ ________________ Cloud type and % sky covered: ________________ ________________ Notes:__________ ________________	Temp:__________ Pressure:_______ Humidity:______ Wind speed and direction:_______ ________________ Cloud type and % sky covered: ________________ ________________ Notes:__________ ________________

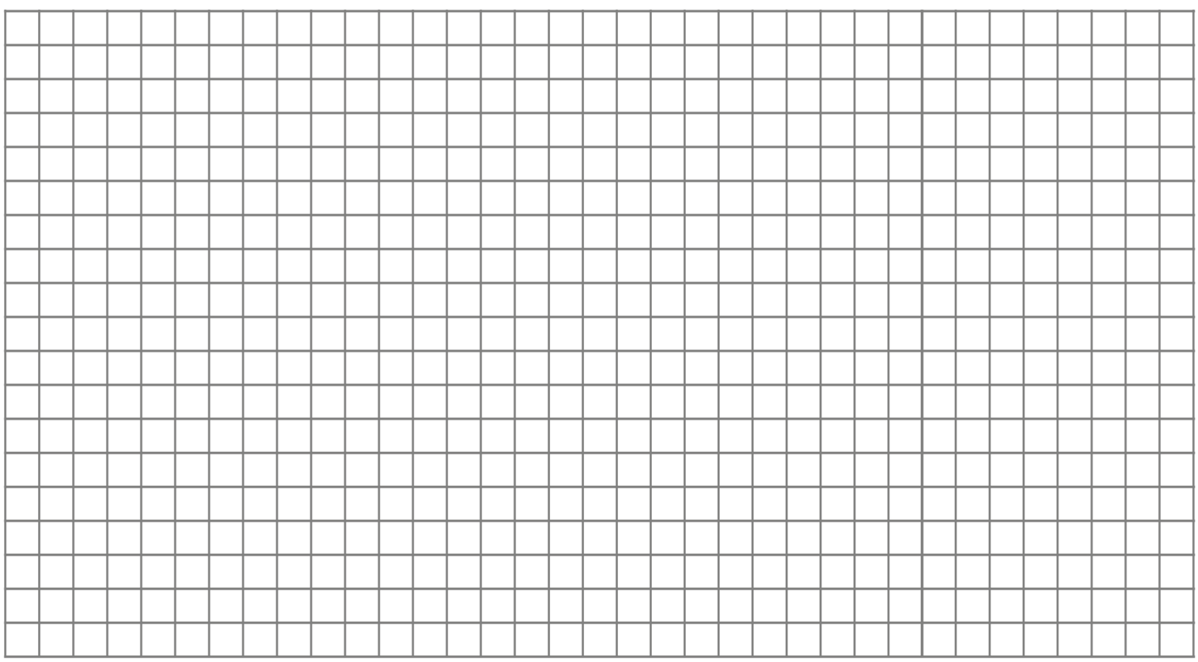
4 Graphing your data

You have collected weather data for four weeks. Making graphs of this data can help you to find patterns that influence the weather in your region. Each member of your team will be responsible for a different graph. Make separate line graphs for temperature, pressure, humidity, wind speed, and percent cloud cover.

1. For each graph, plot the data you collected on the *y*-axis against time in days on the *x*-axis. Be sure to include even the days no data was collected. Remember to draw a line or curve of best fit rather than simply connecting the dots on your graph.
2. Using a blue highlighter pen, color in each column of your graph that represents a day where precipitation fell.
3. Label each graph appropriately.

Title: ____

y label: ______________________



x label: ______________________________

Title: ______________________________

y label: ______________________________

x label: ______________________________

Title: ______________________________

y label: ______________________________

x label: ______________________________

Title: ____________________

y label: ____________________

x label: ____________________

Title: ____________________

y label: ____________________

x label: ____________________

5 Thinking about what you observed

The following questions will help you think like a meteorologist! You will be looking for patterns in your data that could help you recognize when certain weather events are likely to occur.

a. Examine the blue colored-columns on your five graphs. Is there a pattern to the data on days with precipitation? For example, is the air pressure usually higher or lower on rainy days? Does it tend to snow on the coldest days, or warmer days? Of course, your answers will depend on your season and climate. Just note any data patterns you find in your graphs.

b. Meteorologists look for patterns to help them predict what will happen in the future. Take a second look at your five graphs. Is there anything that usually happens *before* you get precipitation? For example, does the temperature usually rise, or the wind speed up? Provide specific evidence from your data as you answer these questions.

c. Look at your cloud cover data. Which type of cloud did you see most often? Mark those days with a pink highlighter. Since the column may already be colored blue, just highlight the number on the x-axis for those days. Do you see any patterns here? Does this type of cloud usually occur with rising or falling pressure, temperature, humidity, or wind speed? Or do the clouds seem to appear randomly?

d. Go back and look at the prediction you made in part 2c. Was there a relationship between hours of daylight and the temperatures you recorded? Why or why not?

6 Exploring on your own

Watch a local weather forecast. What sorts of evidence does the forecaster use to predict the weather? Which types of data—temperature, pressure, humidity, wind speed, cloud type or cloud cover—were mentioned in the predictions? Were other types of measurements used as well?

6B Storms

How does Doppler radar work?

"The National Weather Service has just issued a severe thunderstorm warning for the following locations..."

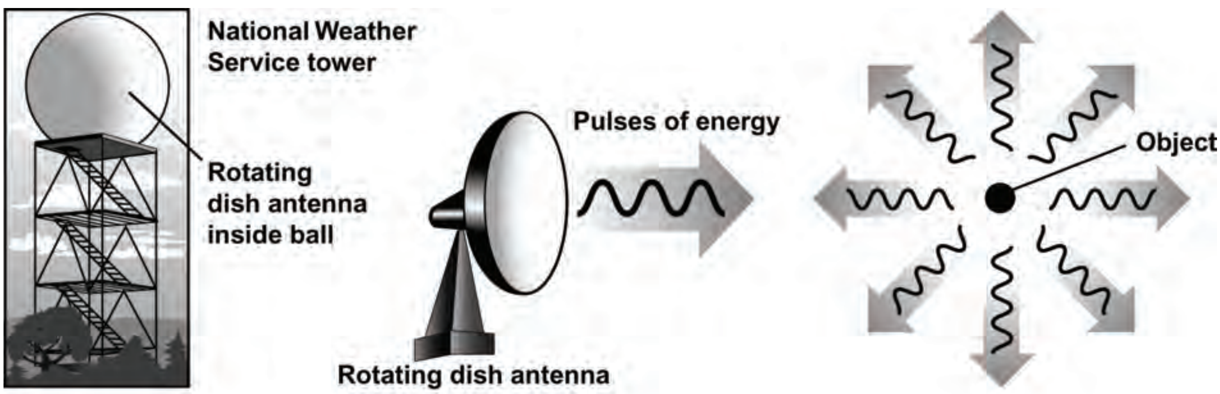
Has a broadcaster ever interrupted your favorite television program with these words? In this investigation, you will learn about one of the important tools the National Weather Service uses to track storms: *Doppler radar*.

Materials

- Radar image plates (set of six)
- A metric ruler (with millimeter marks)

1 How can we use radar to track precipitation?

You may be familiar with the radar images used by weather forecasters on the news. Did you ever wonder how these images are produced?



The National Weather Service has radar stations located across the United States. At each station there is a tower with what looks like a large soccer ball on top. Inside this protective ball is a 10-meter- diameter rotating dish antenna that sends out pulses of energy. If a pulse of energy strikes an object like a raindrop, the energy is scattered in all directions. A small part of the energy will bounce back to the antenna.

This reflected energy is then received by the radar station during its listening period. This process of sending a signal, listening for any returned signal, then sending the next signal, takes place very fast, up to around 1,300 times each second. Computers analyze the strength of the returned signal and the time it took to travel to the object and back. They use this information to create a color diagram showing the location, amount, and movement of precipitation falling over a region. In this reflectivity mode, four colors are typically used to show the rainfall rate per hour. For example, green may indicate traces of precipitation; yellow, a light rain; orange, heavy rainfall; and red, severe thunderstorms or hail. A color key is usually provided on the radar image.

a. Look at Radar Image Plate 1. Over which state is the most intense rain falling?

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b. Name two states in which mixed precipitation is falling.

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2 How can we use radar to detect a tornado?

Doppler radar, developed in 1988, has an advantage over earlier radar systems: It can detect the direction of air movement inside a storm. Doppler radar works by detecting the difference between signals bouncing off raindrops moving away from the antenna and signals bouncing off raindrops moving toward the antenna. In Doppler mode (also called velocity mode), the radar image is presented in two colors: green represents raindrops moving toward the antenna, and red represents raindrops moving away from the antenna. Doppler radar is very useful for locating rotating columns of air within a storm. One feature meteorologists pay close attention to is the appearance of a "J" hook-shape appearing near the back of the storm. This means that air is beginning to circulate in a pattern that often leads to the formation of a tornado.

Central Oklahoma tornado, May 3, 1999

a. Look at Radar Image Plate 2. Near which interstate highway intersection is a tornado possibly beginning to form?

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b. The National Weather Service issues tornado watch and tornado warning bulletins when certain atmospheric conditions are observed. Use the Internet to find out what each notice means. How does Doppler radar help meteorologists issue these bulletins?

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3 Recognizing insects, birds, or airborne debris on a radar image

Of course, the pulses of energy sent by the antenna can bounce off things other than raindrops or other forms of precipitation. Interference from objects on the ground can be easily recognized because those objects do not move. However, in the spring and fall, swarms of insects or flocks of migrating birds can show up on radar images. Meteorologists practice looking at images and recognizing the characteristic patterns these creatures create, so that they do not mistake the birds and bugs for rain.

In some cases, the interference is actually important to meteorologists. In Radar Image Plate 3, locate the white spot in the center of a very intense storm. The color white represents an area that is reflecting back a large number of energy pulses—too many pulses to be bouncing off raindrops. These energy pulses are bouncing back from debris in the air thrown there by a tornado. This white area helps meteorologists locate places where the tornado is causing damage.

a. Near which city is the airborne debris located? ______________________________

b. What safety precautions does the National Weather service recommend when conditions like these are observed?

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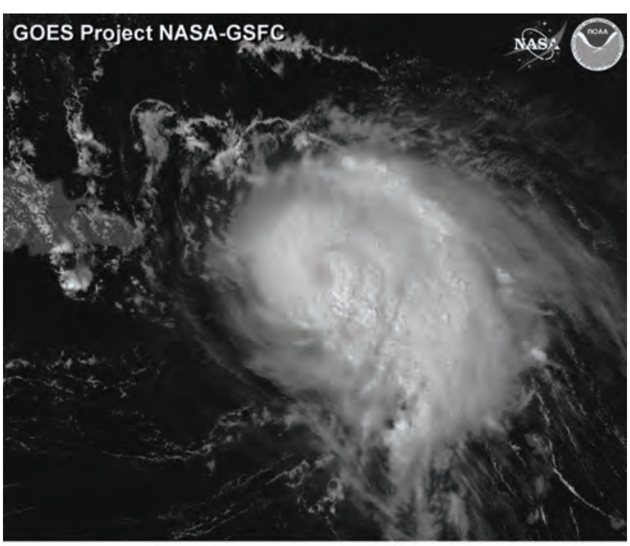
4 How can we use radar to track a hurricane?



Satellite image of Hurricane Georges as it hit Puerto Rico on September 21, 1998.

Hurricane Georges, a category 3 hurricane, struck the island of Puerto Rico on Monday, Sept. 21, 1998. The next six radar images are from the National Weather Service's San Juan headquarters. The radar station is located in the Guavate Forest just south of the city of Cayey. All of the hurricane images are in reflectivity mode, depicting the intensity of the rainfall through a series of colors. The color key to the right of each image tells you that blue indicates light rainfall; green moderate rainfall; and yellow, orange, red, purple, and white indicate increasingly severe rainfall, often accompanied by thunderstorms and hail.

a. The hurricane's eye is the low-pressure center around which the storm rotates. Inside the eye, winds are calm and skies are blue. Look at Hurricane Image 1. Where is the eye located?

Airplane entering the eye of Hurricane Georges to take storm measurements. The sky above is clear and sunlight can be seen reflecting off clouds.

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b. In the afternoon, Georges gathered strength because of the combination of the Caribbean Sea's warmer waters, the demise of some earlier wind shear, and the fact that as the storm moved over open sea between St. Croix and Puerto Rico, the wind circulating around the eye had no resistance from land objects. What evidence can you see in Hurricane Image 2 that the storm is gaining strength?

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c. The National Weather Service reported that Georges made landfall on Puerto Rico at 7 p.m. local time (23:00 GMT). Landfall is defined as the time when the center of the hurricane's eye reaches land. Use the scale printed on Hurricane Image 3 to determine the diameter of the eye when it made landfall.

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d. As the hurricane moved across Puerto Rico, intense rain and a possible tornado were spawned as the eye wall's heavy thunderstorms interacted with the mountainous terrain. Notice the strong bands of precipitation found in Hurricane Image 4. Why do you suppose it is harder to see the eye in this image?

Hurricane George's high winds tore the roof and exterior walls from this home in Puerto Rico.

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e. Just after midnight on the morning of Sept. 22, 1998 (04:01 GMT), the eye of Hurricane Georges began to move off the west coast of Puerto Rico. Using the time stamps on Hurricane Image 3 and Hurricane Image 5, calculate the time it took for Georges to make its way across Puerto Rico.

Hurricane Georges' travel time (round to the nearest hour): __________

Then, using a ruler and the scale provided on the radar images, calculate the distance from the center of the eye in the third image to the center of the eye in the fifth image.

Hurricane Georges' travel distance (round to the nearest km): __________

Divide the distance traveled by the time taken in order to calculate the speed of the hurricane as it moved across the island.

Distance ___________ ÷ time ___________ = speed ___________ km/hour

Hurricane Georges' speed (round to the nearest km/hour): __________

a. By 2:51 a.m. local time (06:51 GMT) the eye of Hurricane Georges was again over water. Use information from Hurricane Image 5 and Hurricane Image 6 to calculate the speed of the storm as it moved off of Puerto Rico. Does the storm appear to be intensifying or dissipating? Explain your answer.

Distance ___________ ÷ time ___________ = speed ___________ km/hour

7A Global Winds and Ocean Currents

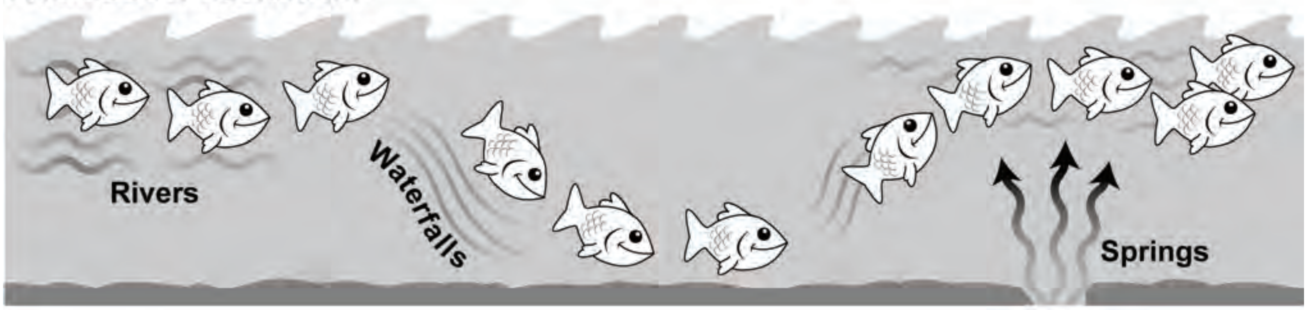
How do temperature and salinity cause ocean layering?

Did you know that there are rives in the ocean? In some places, there are two rivers running side-by-side—in opposite directions. Now imagine underwater waterfalls and underwater springs. All of these exist in the world's oceans as a result of differences in water temperature and salinity (saltiness). How do temperature and salinity differences cause these underwater rivers, waterfalls, and springs? Density changes are the key. In this investigation, you will discover how temperature and salinity create currents, underwater waterfalls, and springs in the ocean.

Materials

- A clear plastic cup
- Two foam coffee cups
- Eyedropper
- Pipette with a barrel longer than an eyedroppers
- Salt
- Measuring spoon—teaspoon size
- 10 cm square of single ply cardboard
- Pencil
- Scissors
- 20 staples
- Newspapers
- Cafeteria tray or paper plate
- Source of hot and cold water
- Food coloring: red, green, and blue

The ocean contains:



1 Density and ocean currents

As global winds push ocean currents around the planet, the ocean water undergoes several changes. As the current moves nearer to the equator, the water warms up. As it moves toward the poles, the water cools down. These changes affect the density of ocean water.

When the current moves through a warm area, there is an increase in evaporation. Since evaporation removes fresh water and leaves salt behind, the salinity of the current increases. This increases the current's density. Fresh water is added back to the ocean through melting ice, rivers, and rain. Adding fresh water to the salty ocean water decreases its density.

These changes in density cause ocean currents to float and sink at different points in their journeys. In this investigation, you will model underwater rivers, waterfalls, and springs. Then you will use your observations to help you understand the movements of the Atlantic gyre, an ocean current system. You will also discover how these density differences play an enormous role in the life of the world's most important fishing grounds.

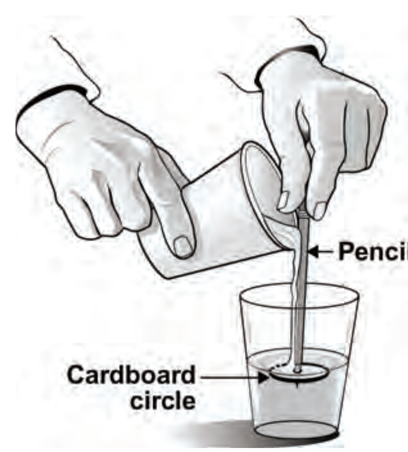
a. Which do you think is more dense, warm or cold ocean water? Why?

b. Explain why dissolved salt increases the density of ocean water.

2 Observing salinity-dependent layering

This investigation requires care and preparation to keep your cleanup quick and easy. Spread newspaper over your work area to catch drips. Keep any water-filled cups over a tray or paper plate. Wipe up any spills before they get tracked around. Discard any water in the bucket provided or in the sink.

1. Make a pouring stick by cutting a cardboard circle about 4 centimeters in diameter with your scissors. Press the point of a pencil into the center of the disk so that it is stuck firmly onto the pencil.
2. Fill a clear plastic cup half-full with cool water. Add 1 teaspoon of salt to the water. Add 2 drops of green food coloring. Stir until the salt dissolves.
3. Fill a foam cup half-full with cool water.
4. Have a team member hold the pouring stick at its top, near the eraser. Lower the pouring stick into the middle of the clear cup so that the cardboard disk is just under the surface of the green water. Have a second team member hold the lip of the foam cup up to the pouring stick.



5. Tip the foam cup so that the cool water flows slowly down the pouring stick. The first team member must move the pouring stick upward as the second team member pours so that the cardboard disk remains at the surface of the water. Continue to add water until the clear cup is almost full, and then gently remove the pouring stick. You have created two ocean layers, separated by their salinity.

a. Try slightly tipping the clear plastic cup. Are the layers stable? Do they resist mixing?

b. Tear off a small piece of foam cup. Press some staples into the foam, and place it on the surface of the clear water. Remove the foam and add more staples to it, one at a time, until the foam bit sinks. Where did the foam bit end up? Why?

c. Explain why the clear water floats over the saline water.

3 Exploring temperature-dependent layering

1. Fill a clear plastic cup half-full with cool water. Add 2 drops of blue food coloring. Stir to mix.
2. Fill a foam cup almost full from the hot-water source. Add 2 drops of red food coloring. Stir to mix.
3. Add hot red water to the clear cup using the pouring stick as you did in salinity-dependent layering. You have again created two ocean layers, this time separated by their temperatures.

a. Try tipping the cup slightly. Are the layers stable? Do they resist mixing?

b. Explain why the hot red water floats over the cool blue water.

4 Creating an underwater waterfall

1. Fill a clear plastic cup nearly full with cool water.
2. Fill a foam cup half-full with hot water. Add a pinch of salt. Add 6 drops of red food coloring. Stir until the salt dissolves.
3. Place the eyedropper into the hot red water to warm it up. After a minute, fill the dropper barrel with the water.
4. Hold the dropper so that it lies at a flat angle at the surface of the clear water with the tip just under the surface. Gently squeeze out a layer of hot red water onto the surface of the clear water.
5. After a short cooling time, the red layer will form little waterfalls that sink through the clear water. They may even form little smoke-ring-like structures as they fall. If this does not happen within a few minutes, add a little more salt to the hot red water, stir, and try again.

a. Explain why the red water floats at first.

b. Explain why the red water eventually sinks.

5 Observing underwater springs

1. Fill a clear cup three-quarters full with cool water. Add a heaping teaspoon of salt to the water. Stir until the salt dissolves.
2. Fill a foam cup half-full with cool water. Add 6 drops of blue food coloring. Stir to mix.
3. Fill the eyedropper with cool blue water.
4. Gently lower the dropper into the salt water so that the tip is near the bottom. Gently squeeze the dropper so that a small stream of blue water is released.

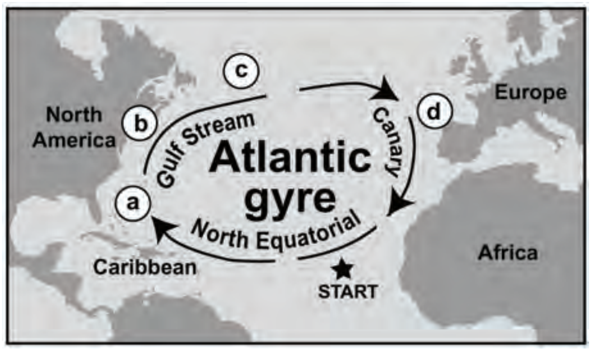
a. Where did the blue water go? Why?

b. In this model, the blue water was less salty than the surrounding water. Think of another difference you could use to create an underwater spring. Write your own procedure, test it, and explain what happened.

6 Applying your knowledge

You can use these experiments to understand the Atlantic gyre, a system of currents that occupies the North Atlantic Ocean basin. After each description, fill in the experiment that applies (salinity-dependent layering, temperature-depending layering, underwater waterfall, or underwater springs), and then determine whether the current will float or sink.

We will start with the Atlantic gyre off the coast of Africa. We will assume that the temperature of the water is cool and its salinity is low. The low salinity is dominant and the current is floating on the surface.



a. From there, the North Equatorial Current flows westward toward the Caribbean Sea. Then it turns north and becomes the beginning of the Gulf Steam. During this trip along the equator, the intense sun warms the current and evaporates a lot of water. This makes the water both warm and highly saline. The high temperature is dominant.

Experiment: ______________________ Float or sink: ______________________

b. After turning northward, the Gulf Stream flows along the United States' Atlantic Coast. The water is highly saline, but it remains warm. The high temperature remains dominant.

Experiment: ______________________ Float or sink: ______________________

c. As the Gulf Stream leaves the US coast, evaporation is not as great in the cold northern regions, but the cooling effect is very significant. The low temperature is dominant.

Experiment: ______________________ Float or sink: ______________________

d. Now part of the Gulf Stream becomes the North Atlantic Drift. Fresh water from ice melt may mix with these cold waters off the coast of Europe. Lower salinity is dominant.

Experiment: ______________________ Float or sink: ______________________

7 Extension: Thermohaline currents and the ocean food chain

Back in the 1960s, it was popularly believed that the key to feeding the world was the bountiful harvest that could be taken from the seas. Today, we are faced with the collapse of fisheries on both sides of the Atlantic. Why has the ocean proven to be such a modest food source?

The food paradox of the oceans is based on the nutrient cycle. For new creatures to grow, the nutrients from the old creatures must be recycled. Unfortunately, when ocean creatures die, they take their nutrients to the deep bottom. The photosynthetic plankton (phytoplankton) that do the recycling must live in the sunlit top-600 feet of ocean, so recyclers and the needed nutrients are hopelessly separated by thousands of feet of ocean unless something can transport the nutrients to the surface.

a. Two of the biggest fisheries in the world are off the Canary Islands and Peru. Can you explain why?

b. If global climate change eliminates all ice from the poles, how might this affect ocean currents and world fisheries?

7B Wave Speed

What is the relationship between water depth and wave speed?

In the ocean, most *waves* are driven by the wind. As long as the wave is in deep water, the water depth does not influence the wave very much. When a wave approaches the shore, however, the speed of the wave changes.

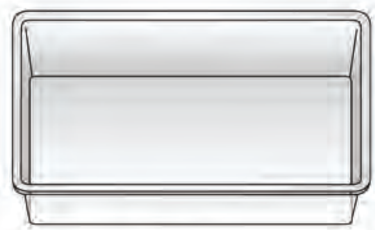
In this investigation, you will collect data to observe how water depth affects wave speed.

Materials

- GeoBox
- 1,000-mL beaker
- Masking tape
- Stopwatch
- Ruler or measuring tape
- Graph paper
- Wooden block

1 Setting up

Gather your materials including the GeoBox. Fill the 1,000-mL beaker with water.



GeoBox

2 Stop and think

Predict the relationship between wave speed and water depth. Does the wave speed increase or decrease as the water depth increases? Why?

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3 Doing the experiment

1. Place water in the GeoBox to a depth of one centimeter.
2. Place the wooden block under one end of the tray. One student will be the "timer," and the other student will watch the waves.
3. First practice the following, then measure when you are ready. Pull the wooden block out. This will create a wave as the tray falls to the table. The water will "slosh" lengthwise in the tray.
4. As soon as you begin to move the block, start the stopwatch. The person watching the wave will watch it make four round trips. That means back and forth four times. As soon as it finished making the four round trips, stop the stopwatch. Record your data (time) in the table. Repeat the same depth for two more trials.
5. Once you have made three time measurements for the one-centimeter depth, add water up to the two-centimeter mark.
6. Follow the same procedure and continue increasing water depth until you get as high as you can go (probably around six centimeters).

7. Find the average time for each depth. Then calculate wave speed using the formula below.

$$\textbf{wave speed} = \frac{\textbf{total distance traveled}}{\textbf{average time}}$$

Hint: Be careful when you measure for the total distance traveled —think about how many times the wave goes back and forth.

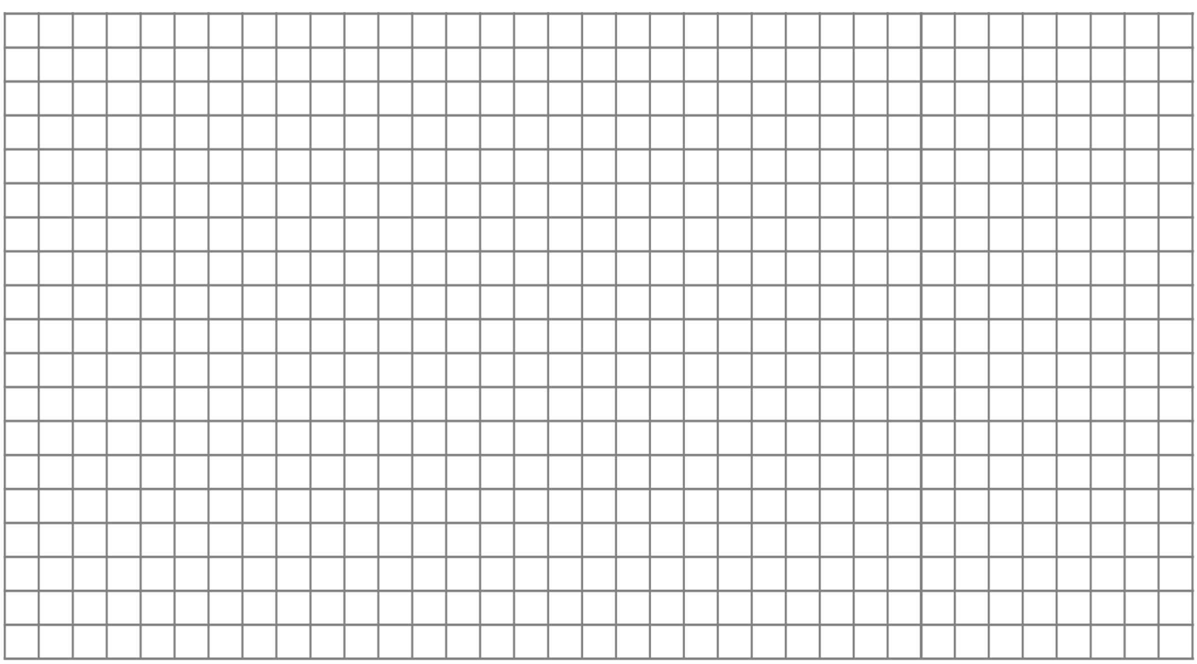
Table 1: Wave speed at different depths

Depth (cm)	Trial 1 (seconds)	Trial 2 (seconds)	Trial 3 (seconds)	Average (seconds)	Wave speed (cm/sec)
1					
2					
3					
4					
5					
6					

8. Make a graph with depth on the *x*-axis and wave speed on the *y*-axis.

Title: ______________________________

y label: ______________________________



x label: ______________________________

4 Thinking about what you observed

a. Describe the pattern of the graph.

b. Why should there be any change in wave speed?

5 Exploring on your own

a. What happens when waves reach the shoreline?

b. What is the difference between swells and whitecaps?

c. Would waves approach the shore in the same manner if the shoreline was gradual or very steep? Explain.