
MATERIALS

- Clear plastic box
 - Beakers, 50 mL
 - Wood block
 - Pipette
 - Styrofoam cups
 - Plastic lids and spoons
 - Set of food coloring
 - Blue ice cubes
 - Graduated cylinder
 - Colored pencils
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BACKGROUND

Nearly all of the earth's energy comes from the sun (Figure 10-1). Some of this radiant energy is reflected by water droplets and dust particles in the atmosphere and bounced back into space or scattered throughout the atmosphere while some is absorbed by clouds or greenhouse gases. The remaining energy that is not absorbed or scattered by the atmosphere reaches the earth's surface. This energy is absorbed by the earth and re-radiated as heat. The heating of the earth's surface by the sun directly influences the heating of the air above it. Different surfaces absorb or reflect varying amounts of incoming solar energy. Land surfaces warm up and cool off faster than bodies of water. This unequal heating and cooling causes wind currents, cloud formation, and severe storms in some locations. Ice reflects more of the radiation than other land surfaces or water.



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Atmospheric Circulation and Ocean Density Currents

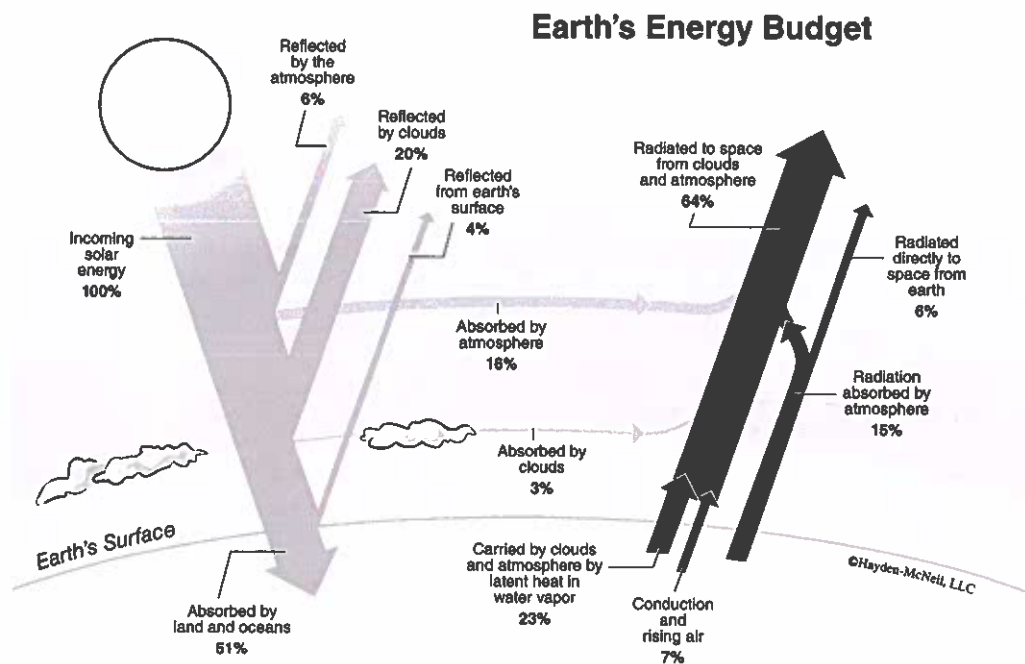


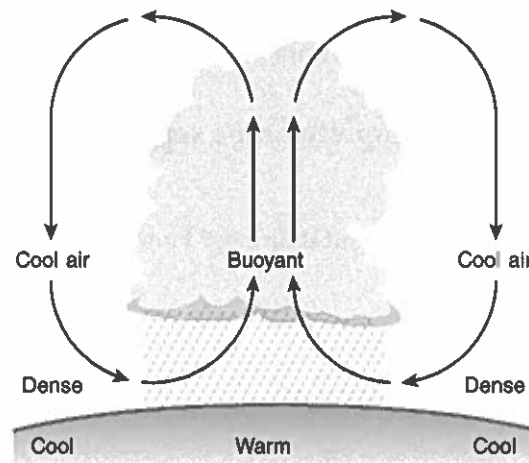
Figure 10-1. *Earth's energy budget*

Heat capacity is defined as the amount of energy (in calories) that is required to raise the temperature of one gram of a substance by 1°C . Heat capacity is a measurable physical property of all substances. Heating and cooling of substances can also cause changes in density (mass/volume). When substances are heated, their molecules move farther away from each other; therefore, they are not as compact (i.e., less dense). Substances that are less dense will rise over substances that are denser. Likewise, substances that are denser will sink beneath substances that are less dense.

Water has a very high heat capacity, which means water resists changes in temperature. If you have ever been to the lake or ocean, you may have noticed that the daytime/nighttime temperature difference is not as great as in areas distant from a surface water body. The difference in heat capacity between land and water causes unequal heating of the air immediately above the earth's surface. During the day, the surface of the water heats less rapidly than the surface of the land. The air over the water cools, sinks, and flows toward the land. The air above the land surface warms more rapidly and is less dense and is forced upward by the cooler, denser air pushing in from the water. This situation creates an **onshore breeze** as air blows onto the shore from out over the water. At night, the opposite conditions are created as the lower heat capacity land cools off faster than the water. Now the air cooled over the land grows more dense, sinks, and moves from the land to the warmer water creating an **offshore breeze**.

Convection occurs when heat is transferred through a fluid (air or water in this activity). Unequal heating produces **convection currents** (Figure 10-2). The difference in **heat capacity** between land materials and water is what causes the unequal heating of the adjacent air and the formation of **convection currents** along coastlines. This same convection process can be viewed when heating a pot of water on a stove. As the water at the bottom of the pot begins to heat up, it expands and becomes less dense than the cooler water above it. The cooler, denser water now sinks and

forces the warmer water to the surface. A **convection current** soon forms as this cycle of rising warm water and sinking cool water takes place. **Convection currents** play an integral part of many of the processes that occur on Earth. **Convection currents** affect atmospheric circulation, currents in lakes and oceans, and the movement of lithospheric plates in the earth's crust.



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Figure 10-2. A convection current

PART 1: ATMOSPHERIC CIRCULATION

The earth's atmosphere is heated in several ways. All of the energy that the earth receives from the sun travels through space as radiation. Some of this radiation is absorbed at the surface of the earth and re-radiated back into the atmosphere. This re-radiated heat is trapped in the atmosphere by greenhouse gases, such as carbon dioxide (CO_2) and methane (CH_4). This process is called the "greenhouse effect" and helps to form a kind of blanket around the earth. While many people are concerned about climate change due to rising levels of CO_2 in the atmosphere, it is important to realize that without greenhouse gases, the earth's average surface temperature would be very cold ($\sim 16^\circ\text{C}$).

Radiation is responsible for most atmospheric heating, but some heating is due to **conduction** and **convection**. Conduction occurs when heat energy is transferred by contact. As the molecules in a substance are heated, they move faster, and when the molecules collide heat is transferred from one to the other. The best conductors are solid substances with closely packed molecules. Although some heating of the lower atmosphere does take place through conduction as the air comes in contact with warm earth surfaces, generally air is not a good conductor because the molecules in air are not closely spaced.

Air that is heated by radiation or conduction becomes less dense and rises. The cooler, denser air above it begins to sink. As it does so, the cooler air pushes the warmer air upward. At the same time, the sinking cold air is now warmed by its closeness to the earth's surface and begins to rise. This continuous rising and falling of air forms **convection currents**.

Since warm air is less dense than cool air, it also exerts less pressure on the earth than an equal volume of cooler air. As a result, the atmospheric pressure beneath a warm air mass is generally lower than the pressure below a cold air mass. When a dense, cool air mass moves into a region of low pressure, it forces the warmer, less dense air upward. In general, cool air is always moving toward areas of low pressure. These pressure differences in the atmosphere are a result of unequal heating that causes convection, and ultimately create the conditions behind the formation of winds and the general movement of air worldwide.

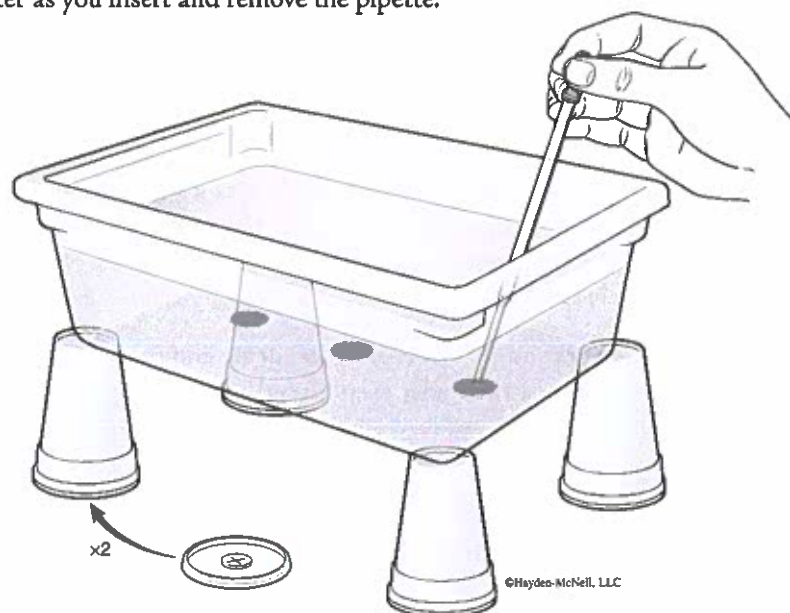
Inquiry Questions to be completed on a separate piece of paper prior to coming to class:

1. Where does the sun heat the earth most directly? How does this influence global temperature?
2. What is responsible for seasons?
3. Convection occurs in a variety of situations. Name an example of convection in your everyday life.

1 Activity: Atmospheric Circulation

Setup A

1. Fit two plastic lids on each of four styrofoam cups. Set the clear plastic box onto the four Styrofoam cups. Carefully fill the plastic box with cold tap water to within 3–4 cm from the top. Let the water become calm before proceeding.
2. Using a pipette, carefully place 3 spots of red food coloring onto the bottom of the box. Insert the pipette all the way down to the bottom of the plastic box before squeezing out the food coloring. Each spot should be about 2–4 cm in diameter. Try to minimize disturbing the water as you insert and remove the pipette.



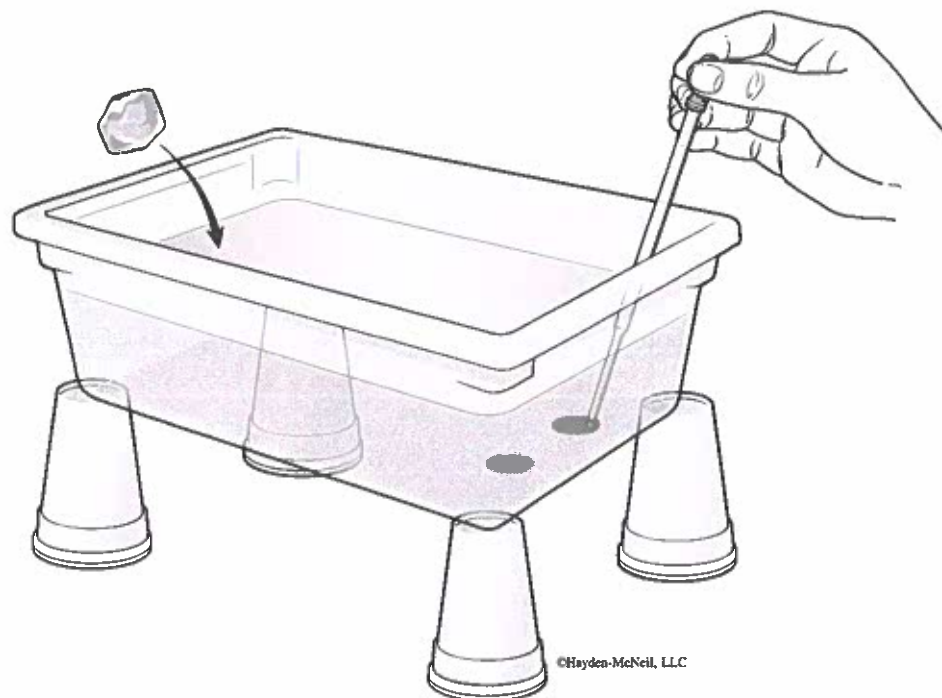
3. Fill one empty Styrofoam cup with hot water, and then carefully position it beneath the center red spot in the plastic box. The plastic lid spacers you fitted on the corner cups should provide you with enough clearance to gently slide the cup with hot water under the spot.
4. Now position yourself so that you can view the box from the side at eye level. Observe what happens to the 3 spots over the next five minutes. Be sure to look for changes in all 3 spots. Sketch a picture of your observations below. Be sure to include arrows to show the direction of flow.
5. Carefully empty the water from the plastic box into the sink and begin Setup B.

Setup B

1. Repeat steps 1 and 2 from Setup A to set up the plastic box once again.
2. This time, fill two Styrofoam cups with hot water and position them beneath the two outside spots. Observe what happens to the 3 spots over the next ten minutes. Be sure to look for changes in the middle spot. Sketch a picture of your observations below. Be sure to include arrows to show the direction of flow.
3. Carefully empty the water from the plastic box into the sink and begin Setup C.

Setup C

1. Set up the plastic box once again as in Setups A and B and fill with cold tap water to within 3–4 cm of the top. Let the water become calm. Next, place two spots of red food coloring near one end of the plastic box. Position a cup of hot water beneath each spot.
2. Use a plastic spoon to obtain a blue ice cube from your instructor. Carefully set the cube into the water at the opposite end of the plastic box from the red spots. Use the spoon to steady the cube until it stops moving.



3. Position yourself at eye level with the side of the plastic box and observe the water as the ice cube melts. Sketch a picture of your observations below. Be sure to include arrows to show the direction of flow.

QUESTIONS

Use both your observations and the background material at the beginning of this lab (including lecture) to answer the following questions.

1. Sketch and label diagrams that depict both onshore and offshore breeze.

ONSHORE BREEZE

OFFSHORE BREEZE

2. During the lab, what effect did the cups of hot water have on the density of the water directly above them?
3. What happened as a result of the change in density?
4. Which situation would result in a decrease in atmospheric pressure at the earth's surface? Air gets hot and begins to rise or cold air is sinking to the surface (circle the correct answer).
5. Go back to the three sketches you constructed in the lab activity. Label the spots in each sketch that became areas of lower pressure.

6. Above which area would the air become hotter in the afternoon? A parking lot, a forested area around a parking lot, or a retaining pond next to a parking lot (circle the correct answer).
7. Above which area would you find the lowest air pressure? The parking lot, the forest, or the retaining pond (circle the correct answer).
8. Based on your answers to questions 6 and 7, would you expect a breeze to blow toward the parking lot or away from it?
9. From your knowledge of onshore and offshore breezes, explain why the wind would blow in from the sea toward the land during the afternoon.
10. A "monsoon effect" may occur in the summer as air over a continent becomes much warmer than the air over the ocean. Fill in the blanks in the following statements:
As air over the continent becomes hotter, it will begin to _____. (sink, rise)
This causes _____ pressure over the continent. (lower, higher)
The flow of air will be _____ the center of the continent. (away, toward)
11. Which region in our atmosphere is heated most intensely by the sun? The polar region, the mid-latitude regions (45 degrees north or south of the equator), or the equatorial regions (circle the correct answer).
12. As air near the equator rises, does this become an area of higher or lower pressure (circle the correct answer)? What moves in to replace the rising air and where does it come from?

PART 2: OCEAN DENSITY CURRENTS

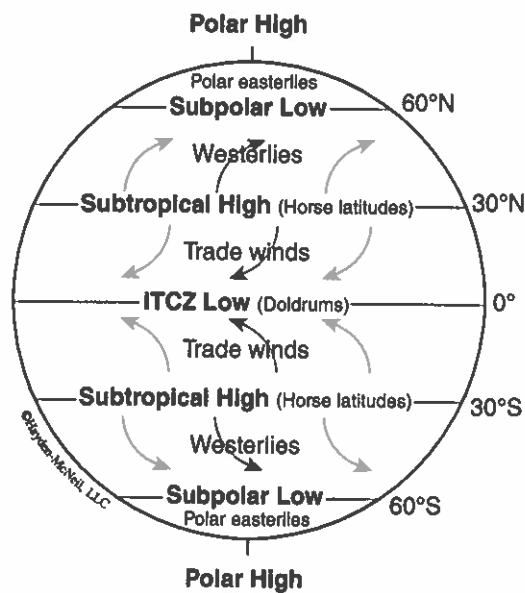


Figure 10-3. *Idealized wind belts and atmospheric circulation*

Ocean currents are responsible for heat transport from the low latitudes toward the high latitudes as well as the distribution of nutrients and salt within the ocean. The two principal types of currents are surface currents and deep currents. Surface currents are driven by winds and usually have a depth of only several hundred meters. The unequal heating of Earth's atmosphere generates winds. When combined with the Coriolis effect, a series of wind bands results (Figure 10-3). Winds blowing across the surface of the ocean generate waves and cause the surface ocean to move via energy transfer. When these two effects are combined with the Coriolis effect, large circular flow patterns, called gyres form (Figure 10-4). Surface currents may be either warm-water or cold-water currents depending on where they originate. For example, warm currents are typically moving from the low latitudes toward the poles, while cold-water currents are returning cold water from the high latitudes back toward the equator. The Gulf Stream is a well-known warm-water surface current. In contrast, deep currents move slowly at depth beneath the surface of the ocean and are driven mainly by differences in water density (mass per unit volume) that are controlled by temperature and salinity.

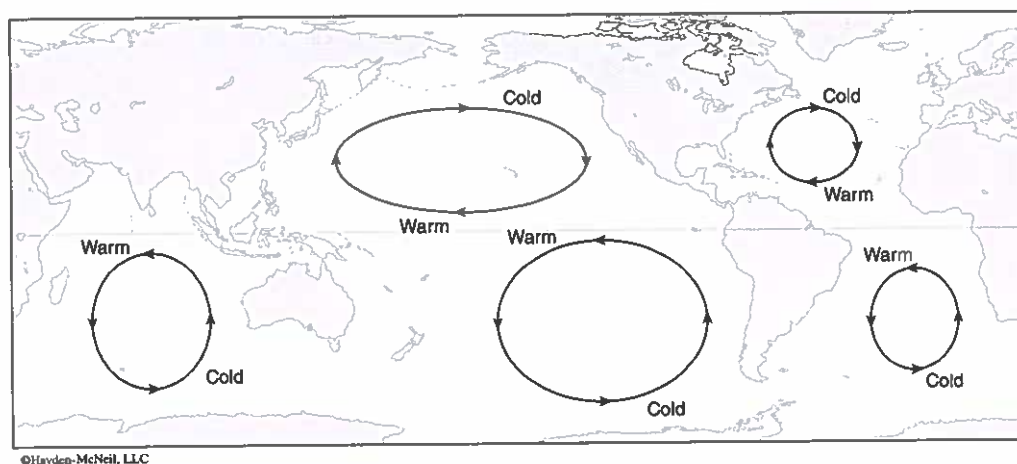


Figure 10-4. Large-scale ocean circulation and gyres

The large amounts of dissolved solids in ocean water make it more dense than pure freshwater, because the dissolved solids add mass to the water. A measure of the amount of dissolved salts in seawater is **salinity**. Salinity is expressed as a part per thousand (‰) representing the number of grams of dissolved solids in a kilogram of ocean water. As salinity increases, so does the density of the water. The salinity for most of the surface waters of the world's oceans range from 33 ‰–36 ‰. Salinity can be locally affected by the amount of freshwater and salts added to the sea by rivers and runoff, and by the rate of evaporation or freezing. For example, as seawater freezes to form sea ice, the salt cannot be incorporated into the ice and is left behind in the water. This increases salinity, and therefore increases the density of the water. When the sea ice melts, the freshwater is returned to the water and reduces the salinity and density of the water. Temperature also affects the density of ocean water, with density increasing as the water gets colder. When water is cooled, the molecules are crowded more closely together making colder water denser.

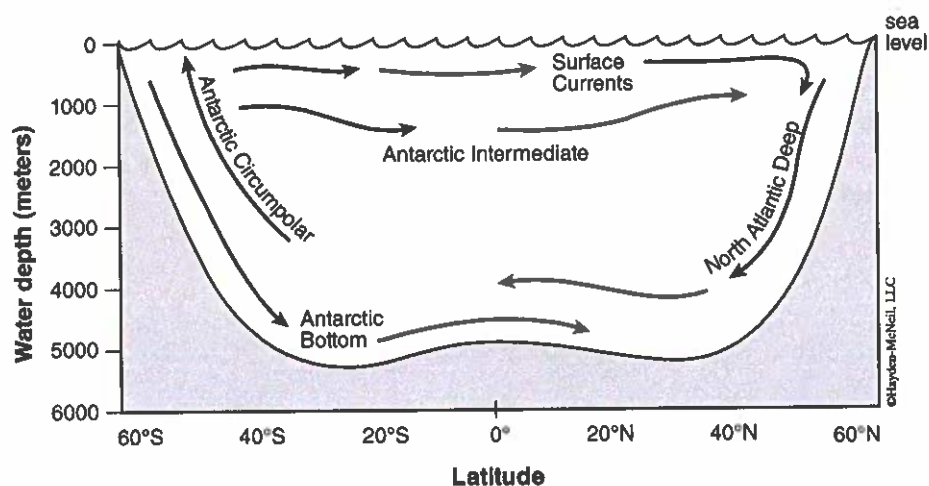


Figure 10-5. Deep ocean circulation in the Atlantic Ocean

When large masses of water that have unequal densities meet they generally do not mix. The densest water masses sink to the bottom (downwelling) beneath water masses that are less dense. Deep currents are produced as cold, dense, polar water sinks and flows beneath the warmer, less dense ocean waters that originated near the equator (Figure 10-5). North Atlantic Deep Water (NADW) forms in the north Atlantic Ocean as salty water in the Atlantic Ocean travels to the high latitudes, becomes cold, and sinks. This water then flows south in the deep Atlantic Ocean. Antarctic Bottom Water (AABW) forms along the continental margins of Antarctica as sea ice formation makes the remaining water very salty. After formation, AABW begins a journey north. AABW is denser than NADW; therefore, when these two currents meet, AABW flows beneath NADW. These deep currents move much more slowly and in a more diffuse manner than the surface currents. Upwelling is a process where cold, deep waters rise toward the surface. Upwelling is commonly caused by winds either pulling water away from a shoreline or pulling water in opposite directions in the open ocean. Both processes allow deeper water to move up and replace the surface waters. This phenomenon is characteristically observed along the western sides of continents, including the west coasts of North and South America and Africa. Upwelled water originates from deep below the surface, and is cold and nutrient-rich. The interactions between surface ocean circulation and deep ocean, thermohaline circulation result in a global pattern of ocean circulation (Figure 10-6).

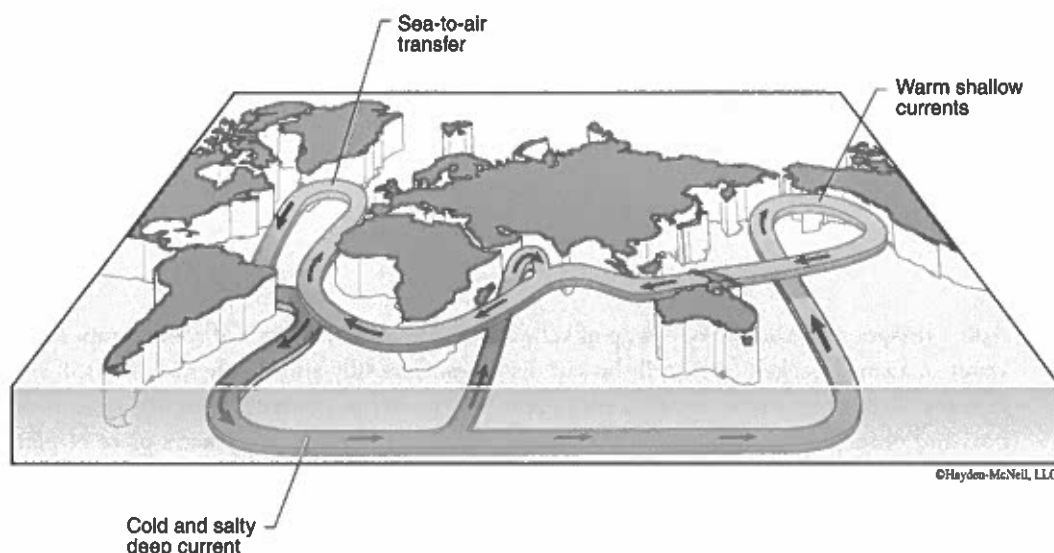
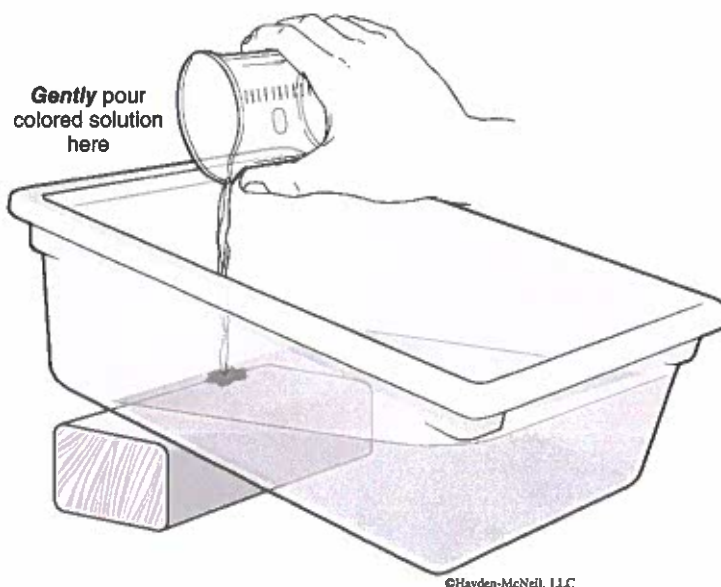


Figure 10-6. *Combined surface and deep ocean circulation*

The El Niño Southern Oscillation (ENSO) occurs in the tropical Pacific and impacts weather globally. In a normal year, the easterly tradewinds pull water away from the western coast of the Americas, causing sea surface temperatures to be cooler in the eastern tropical Pacific Ocean compared to the western tropical Pacific Ocean. El Niño events occur when the tradewinds die down and upwelling along the west coast of the Americas is reduced. During El Niño events, increased rainfall across the southern tier of the U.S. and in Peru is common and can cause destructive flooding. Also, drought occurs in the West Pacific, sometimes associated with devastating brush fires in Australia. As El Niño conditions subside, sometimes La Niña conditions develop. La Niña is described as an "overshoot" of normal conditions. The tradewinds are unusually strong, upwelling is more intense along the west coast of the Americas, and tropical Pacific sea surface temperatures are colder. La Niña also impacts global weather patterns.

2 Activity: Ocean Density Currents

1. Obtain a clear plastic box and place a wood block at one end to incline the plastic box.
2. Add 800 mL of room temperature water to the box. Let the water become calm before proceeding.



3. Add 1 teaspoon of salt and one drop of yellow food coloring to 25 mL of room temperature water in a small beaker. Stir until the salt dissolves. Carefully and slowly pour the solution into the plastic box at the elevated end. Position yourself at eye level along the side of the box, and observe what happens in the plastic box. It may help if you place a piece of plain white paper behind the box. Describe what happens in the space provided.
4. Add a drop of blue food coloring to 25 mL of ice water in a beaker and stir. Carefully and slowly pour the blue ice water into the raised end of the plastic box. Describe what happens in the space provided.

5. Add one drop of red food coloring to 25 mL of hot water and stir. Carefully and slowly pour the hot water into the raised end of the plastic box. Describe what happens in the space provided.

6. Based on your observations, which solution has a higher density (circle the answers that best fit your observations):

Salt water or the water that is not salty?

Warm water or cold water?

7. Add a teaspoon of salt and a drop of green food coloring to 25 mL of ice water. Stir until the salt dissolves (5–10 min.), and then carefully and slowly pour the solution into the plastic box as you did with the other solutions. Describe what happens in the space provided.

8. Use colored pencils to sketch your observations in the space provided. **Be sure to label the relative positions of each of the solutions in the box, noting color and condition (e.g. green—cold, salty water).**

QUESTIONS

1. How would an increase in evaporation affect the density of the ocean water?
2. Why does the density of liquid water increase as it cools?
3. When seawater freezes, most of the salt is not incorporated in the ice. How does this affect the density of the water that is left unfrozen?
4. The salinity of the Mediterranean Sea is about 40 ‰, whereas the salinity of the Atlantic is 35 ‰. Why do you think the Mediterranean is so salty?

5. Would it be easier for you to float in the Mediterranean or the nearby Atlantic? What about in the Pacific? Why?
6. The movement of cold water from the ocean depths to the surface is called **upwelling**. This movement contradicts what you have learned about density in this lab activity. What causes upwelling?
7. Regions of upwelling are often good commercial fishing areas. How does upwelling contribute to an abundance of fish?
8. Do some additional research and determine how ENSO impacts your regional weather patterns.

