1 The Ocean System

by E. Tucker Hirsch and Amanda P. Jaksha

The ocean covers approximately three-quarters of the surface of planet Earth and makes the planet look distinctly blue from afar. Phrases such as “the blue planet” and “the water planet” make it obvious how important the ocean is to life on Earth. Without the ocean, life as we know it would not exist. This chapter explores some of the physical properties and processes that happen throughout the ocean and along its borders. Many students use terms such as *currents, tides,* and *waves* to explain processes that take place in the ocean. Although these are commonly used terms, students do not fully understand the processes that create such ocean phenomena and may use such terms interchangeably. Ways that students are often taught about the ocean can create areas of confusion. For example, memorization of the names of different ocean basins can lead to confusion and misunderstanding about the interdependence of all oceans. This chapter will explore these concepts and areas of confusion, as well as provide an overall understanding of the interconnected system and physical processes that govern the movement of water on our ocean planet.

Ocean or Oceans?

The area of water that covers the ocean basins spans more than 215 million square miles (350 million sq. km). In comparison, the United States only covers about 6 million square miles (9 million sq. km), and all of North American only comes in at about 15 million square miles (24 million sq. km)! The ocean is a large and vast system that dominates processes on Earth and governs our experiences on land.

If you were to drain all of the water out of the ocean, you would see a landscape of valleys, plains, basins, and mountain chains that looks similar to the landscapes above the ocean. When talking about **topography** below the surface of the ocean, we use words that may be less familiar, such as *trench, ridge,* and *seamount.* When you look

GRADE	STANDARD	EEI UNIT
Grade 3	3.1.d 3.1.1	The Geography of Where We Live
Grade 4	4.1.4	
Grade 5	5.3.a	Earth's Water
Grade 6	6.2.c 6.3.a 6.4.a; 6.4.d	
Grade 7		
Grade 8	8.8.a-d	

closely at the topography of the ocean it becomes clear that all of the "individual" oceans that students memorize are, in fact, part of one large interdependent global ocean. Just as we create artificial boundaries between countries on land, we create artificial boundaries between ocean basins. Water in the ocean flows between basins, through trenches and over ridges, just as air moves around and through our mountains and valleys on land. In the same way that seeds and pollen are carried by wind, so too are some ocean species moved through patterns of ocean circulation. Boundaries, such as water temperature and density, exist in the ocean and can, therefore, restrict the movement of marine organisms.

Just as the continents have distinguishable characteristics, the topography of the four main ocean basins have distinguishable characteristics as well.

The four main ocean basins are the Pacific, Atlantic, Indian, and Arctic. The Pacific covers the widest area and has the largest average depth of the four basins. The Pacific contains the Mariana Trench, the deepest known point in the ocean, which plunges to more than 10,000 meters, or 6.7 miles. The Atlantic Basin is the second largest in area. It has a large mountain chain, known as the Mid-Atlantic Ridge, running north-south through its center. The Mid-Atlantic Ridge is more than 16,000 kilometers (9,900 miles) long, which is more than five times as long as the Rocky Mountains chain! The Indian Basin, bordered mostly by Africa, Asia, and Australia, is the third largest. Finally, the Arctic Basin surrounds the North Pole. The water that flows around the edge of Antarctica is sometimes considered the Southern Ocean, encompassing the southern part of the Indian, Pacific, and Atlantic Basins.

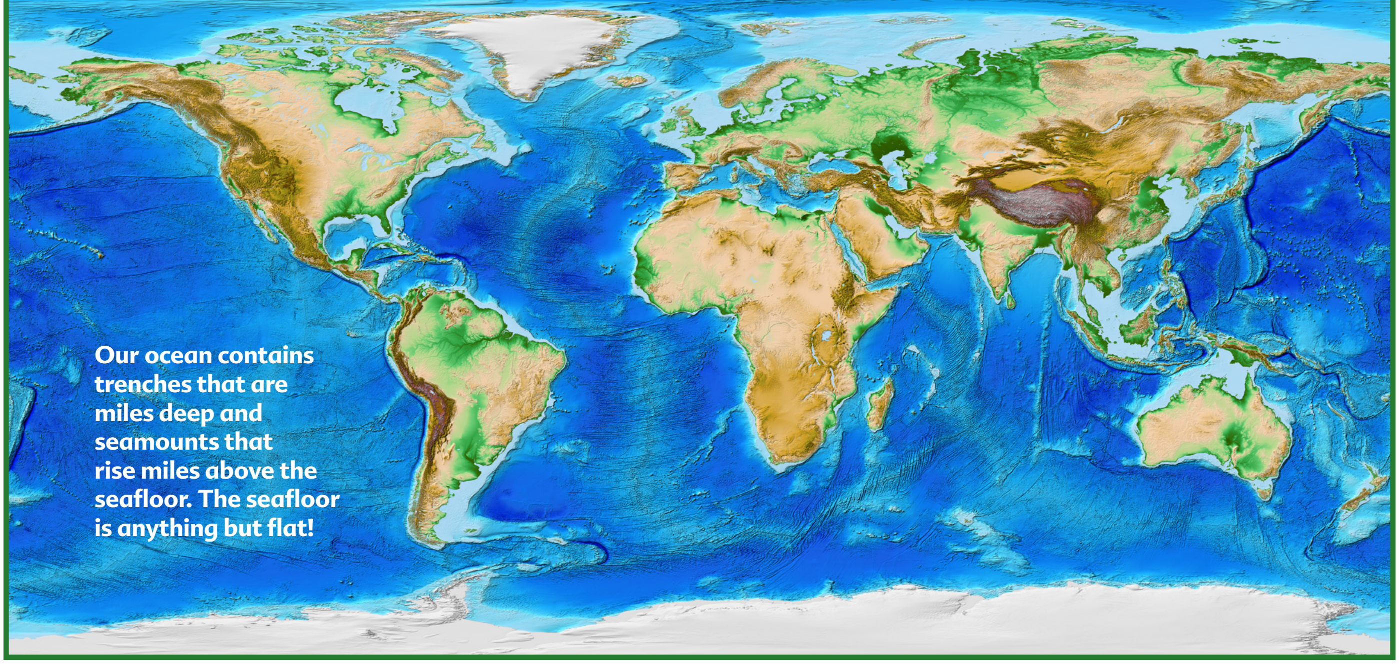
As mentioned previously, a common misconception among students is that there are separate oceans. Traditionally, students learn names for oceans—*Pacific, Atlantic, Indian,* and *Arctic*—and they learn to locate these oceans in particular places on a globe. Naming and locating oceans in such a way causes students to focus on the differences between them, as opposed to viewing Earth as having one connected ocean with different basins.

CHAPTER OVERVIEW

The ocean is a global, interconnected system that has regions, or basins. Water and ocean life move between these basins and up and down the water column. Ocean water circulates around the globe through ocean currents that are either wind-driven currents or density-driven currents. The circulation of water that is driven by differences in density is called thermohaline circulation, also known as the global conveyor belt. Additionally, waves are phenomena that do not move the ocean water; rather, they are a result of wind energy acting on the surface of the ocean.

Unlike currents and waves, tides are not caused by wind, density, or other actors on our planet. Tides are caused by the gravitational pull from the sun and moon.

This chapter explores these physical phenomena in the ocean and students' common ideas about ocean currents, tides, and waves.



One way to help students see that the oceans are interconnected is to challenge them to decide where one ocean ends and another begins. Use students' questions during this task to develop a dialogue about the arbitrary borders that have been designated in oceans. Ask students to think about why these distinctions were made in the first place, how they may help us, and how they may limit our understanding of one world ocean.

In addition, it is important to help students understand that the ocean basins are not featureless plains, but rather contain mountains, plains, canyons, trenches, hills, and more. Have students compare the features found in the ocean to features found on land. Encourage students to look for similarities and differences. Students likely realize that the ocean is "very deep," but may have trouble imagining the depth. Students' ideas of "very deep" may range from a few hundred feet to tens of thousands of miles. Students may lack experiences that help them visualize distances. Providing experiences with distance can be helpful.

One way to help students gain experiences with distance is to have them measure off different distances. Using your school's gym or outdoor areas, have students walk or run distances you have talked about in class. See if students can run or walk 30.5 meters (100 feet), 61 meters (200 feet) or more! Older students may be able to go even farther. Ask students if any of them have ever walked or run 11 kilometers (7 miles). If so, was it easy? You can also use maps of the area surrounding your school to demonstrate these distances to them. Try having students measure the school's gym and calculate how many gyms it would take to equal a specific depth in the ocean. Make sure to reinforce with students that while they are exploring horizontal distances, some distances in the ocean are measured on a vertical plane.

Using well-known features on land may help students visualize depths as well. For example Mount Everest is only 8.9 kilometers (5.5 miles) high, in comparison to the Mariana Trench, which is 10.8 kilometers (6.7 miles) deep. As most students have not seen Mount Everest, local examples may be even more powerful. You may want to compare depths to local mountain ranges or tall buildings in cities close by that students may have visited. Some examples of ocean depths that students can explore are that the average depth of the ocean on the continental shelf is about 150 meters (500 feet), the average depth of the ocean overall is about 4,000 meters (13,000 feet), and the deepest places in the ocean are about 11,000 meters (36,000 feet) or slightly more than 11 kilometers (just shy of 7 miles)!

Ocean Color. What causes the ocean to appear blue? Is the water itself blue? Through experience, students understand that water is usually clear. They associate the color of the ocean with what they have seen, rather than sediment, plankton, or other

Teaching Tip

As you cover the concept of Earth having one large, interconnected ocean with many features, make sure you are consistent in your language. Making sure to say *Pacific Ocean Basin* or *Pacific Basin* instead of *Pacific Ocean* can exert a major influence on students' understanding of this difficult concept.

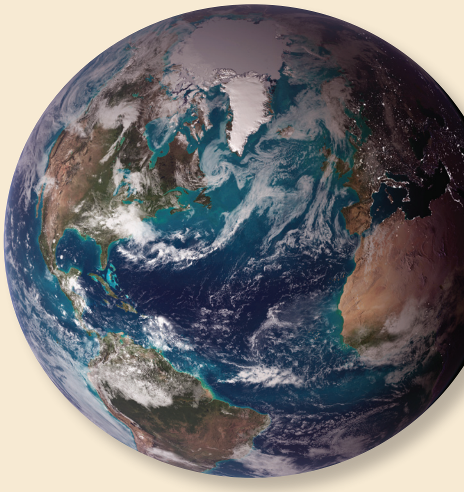
In the Classroom

How Big Is the Ocean?

A big challenge for teachers is helping students grasp just how vast the ocean really is. Students may struggle with understanding the sheer size of the ocean, just as they struggle with large numbers and distances. Activities such as the one following can help students visualize the ocean's expanse. Teachers could ask students to do research comparing the ocean or ocean basins to things with which they have experience. For instance, how many Olympic-sized swimming pools would it take to fill up the Atlantic Ocean Basin? How long would it take for a student to swim across the Indian Ocean Basin? How many times larger is the Indian Ocean Basin than their home state? While questions like these still have large numbers in their answers, students can see that the ocean is larger than anything else they are familiar with.

Materials

- Blow-up globe (beach-ball style)
- Space to toss a ball
- Chart and art supplies to record data



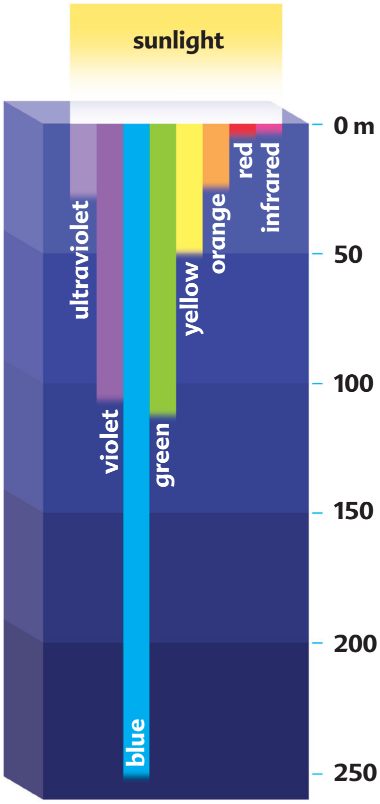
Directions

1. Students will toss a globe to one another and should be in a space that allows free movement. Either standing or sitting in a circle or sitting on top of desks works well.
2. Select an amount of time to record data (e.g., three minutes or once everyone touches the ball five times). During that time, students should individually count how many times one of their fingers (e.g., everyone's right thumb) touches an area of the ocean or an area of land. Alternatively students may count both sets of fingers for the number on land versus water, for example, seven fingers may touch the ocean while only three fingers touch land.
3. At the end of the period, students add up and record, collectively, how many "ocean hits" and "land hits" they observed.
4. Repeat the activity as time allows. For a variation, compare finger touches of land and the four different ocean basin areas.
5. This is a good visualization activity for all ages, especially younger students. For older students, this activity can also provide a good discussion about data collection, interpretation, and analysis. By repeating the activity and taking averages, teachers can point out important patterns. The data can then be used to create pie charts, bar charts, or other visual data representations. Students may also calculate ratios (7:3; ocean:land) and percentages (70 percent ocean; 30 percent land).

Discuss

1. Did the data match your expectations? How did the data support or not support your ideas about the ocean size?
2. Look at how the ocean water connects. Why is it more accurate to refer to one ocean than to many oceans?

VISIBLE LIGHT IN OCEAN



The quality and quantity of sunlight decreases with depth. Red, orange, and yellow spectrums are absorbed within meters of the surface, while blue penetrates the farthest.

contributors. For example, students may have observed patterns in water color related to depth, with lighter color typically indicating shallow water and dark blue meaning deeper water. Students can grasp that suspended algae; particles of sand, mud, or dirt; and ice can impact the ocean's color. Once they discover that some phytoplankton—tiny photosynthetic organisms—floating in the sea are green, as is common in the productive near-shore regions, while others are red (from which the Red Sea gets its name), they understand relative coloration. Additionally, explaining that sediments exist in a variety of colors will help them understand why water is sometimes very unusual colors, such as the mustard tone of the Yellow Sea.

Understanding why the ocean often appears blue requires that students understand the visible light spectrum, how different items transmit, reflect, refract, or absorb light wavelengths. For example, picture a glacial lake in Colorado or the azure waters of the Caribbean Sea. Deep, clear water, lacking in sediment and plankton, appears a brilliant blue. Of the colors of the visible light portion of the electromagnetic spectrum, those with longer wavelengths, on the red portion of the spectrum, are most easily absorbed. The blues are most easily scattered by water molecules, reflecting back into our eyes. Sediment, plankton, and other particles also result in scattering of light. For example, coastal waters, which tend to contain high concentrations of phytoplankton, appear green due to the scattering of yellow and green light from these organisms.

Ocean Currents

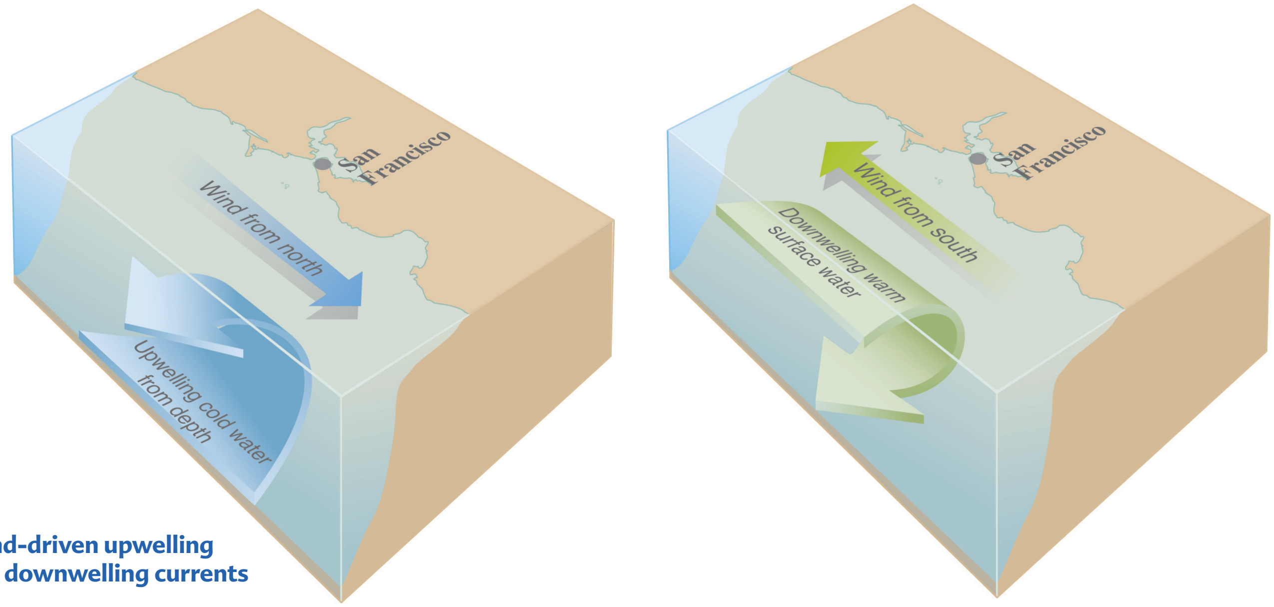
Ocean water flows between basins at the surface and at various depths under the surface of the water. Although the ocean is one body of water, water masses within different basins may behave in different ways. An analogy can be made to the air to better understand this. The air "fills up" the space above our heads and in the sky and can be thought of as one body of air. However, Los Angeles is infamous for its smog, and the Rocky Mountains are known for their clean, crisp mountain air. You can watch the movement from a breeze as it flows across a prairie, a lake, or the grass in your front yard. The open space above your head is not uniform, and L.A.'s smog and the Rocky Mountains' air could be thought of as different air masses: Each mass has its own distinct properties and can stay somewhat local but, when prompted, can move and mix with other surrounding air masses.

In the ocean, physical properties distinguish water masses from each other similar to air masses. Temperature and **salinity** as well as dissolved and suspended solids determine the **density** of water. Water of different densities creates layers, which are less prone to mix until disturbed. Ocean circulation systems move water through the ocean horizontally and vertically and on both local and global scales. The water in different basins may have different characteristics, including temperature, density, and salinity.

Wind-Driven Circulation. As wind moves water along the ocean's surface, it facilitates both horizontal and vertical water movement. Vertical mixing is when water moves from the depths of the ocean to the surface or vice versa. Students may not realize that water in the ocean mixes vertically. Vertical mixing brings cold, nutrient-rich water from the depths of the ocean to the surface. This process is called upwelling. Upwelling can occur along coasts of continents and is commonly seen along the coast of California. Winds blowing from north to south along the coast cause surface water to move offshore and away from land. As surface water is blown away from the land, water from below the surface moves up and into the area that was vacated, like on a conveyor belt. Coastal upwelling is very important to marine **ecosystems,** providing nutrients that help support robust food webs. Wind, therefore, not only affects the surface of the ocean but also has a significant influence on how water moves up and down in the vertical water column.

Prevailing winds can move ocean surface waters long distances and determine the paths of many of the ocean's surface currents. These currents are so consistent that early sailors, explorers, and voyagers sailed in them to cross large expanses of

WIND-DRIVEN CURRENTS

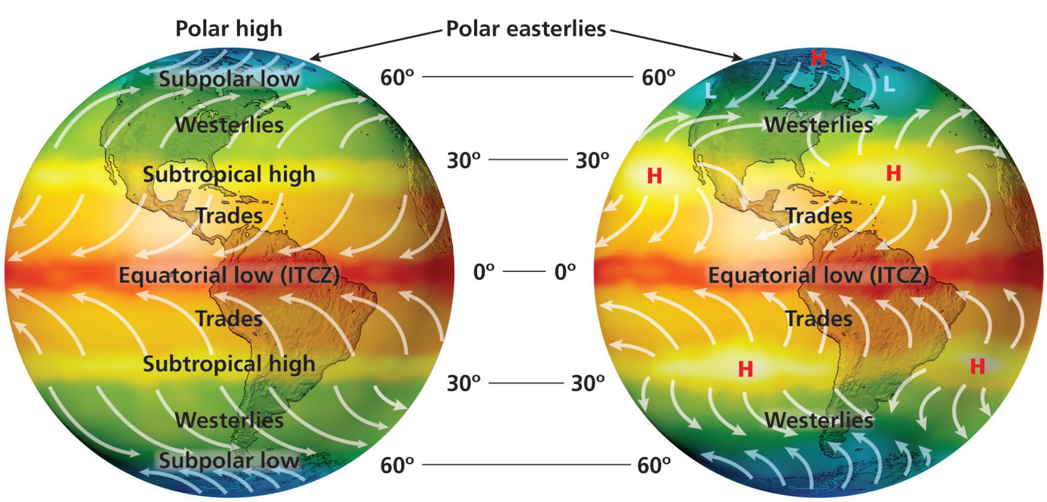


Wind-driven upwelling and downwelling currents

ocean and reliably arrive in the desired location, long before GPS and accurate navigational tools. Even today, ocean currents are integral to the shipping routes and trade industry that move goods all over the planet.

Prevailing winds and ocean surface currents aid in horizontal mixing of water masses. This mixing influences the physical characteristics of the ocean, life in the ocean, and the global climate. As water masses mix, their salinity, density, and temperature also mix and change. These changes can influence organisms that live in the ocean, from the smallest phytoplankton to the largest blue whale. The map on pages 18–19 shows some of the most significant ocean currents. These currents have well-known characteristics. For example, the dominant current near the East Coast of the United States is the Gulf Stream, which is largely driven by wind. It is a **western boundary current,** which is a type of current that is usually deep, warm, and fast flowing. On the West Coast of the United States is the California Current, which is an **eastern boundary current.** This type of current is usually shallower and moves more slowly than the western boundary currents. The California Current carries cold, nutrient-rich waters south along the western coast of the United States from British Columbia until it reaches the southern California bight, or bend, at Point Conception. There, the coastline bends eastward, which keeps the current offshore as it continues to flow south.

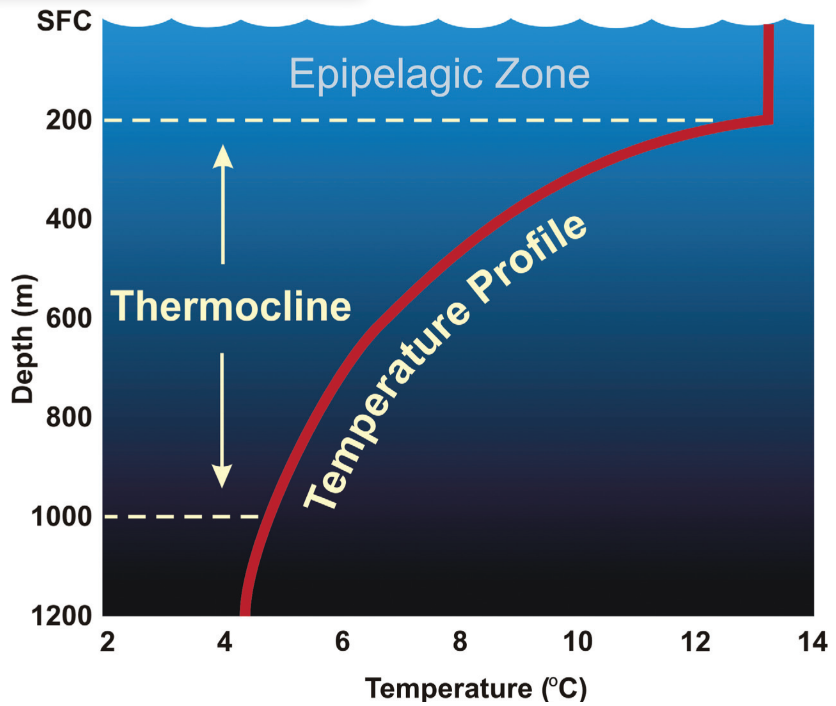
PREVAILING WINDS



Prevailing winds control how air circulates around the globe. However, the prevailing winds are affected by ongoing moving air masses that pass through the area as shown in the second figure.

A countercurrent (called the Davidson Current) flows from south to north along the coast, hugging the coastline and the Channel Islands, and bringing warmer water from the waters near Baja. Because of these very different currents, the climate of northern California can be vastly different from the climate of southern California and Baja. Many argue that the point where the two currents meet, near Point Conception, is the distinction between northern California and southern California. North of Point Conception, coastal communities such as San Francisco and Monterey experience cooler, foggy summers due to the influence of the cold California Current. South of Point Conception, the warmer, Davidson Current can keep the fog at bay, and the summers are generally warm and sunny.

THERMOCLINE DIAGRAM



As water depth increases, the temperature decreases. This diagram shows the thermocline layer that separates the warmer surface water from the colder deep water.

Density-Driven Circulation.

Density of ocean water can also drive ocean circulation. Temperature and salinity are two major factors that determine water's density. Cold water is more dense than warm water and salt water is more dense than freshwater. Waters of different densities only mix if physical changes occur, such as changes in temperature or salinity. For example, as surface water cools, it becomes more dense and sinks through the water column, causing it to mix with surrounding water. On the other hand, if surface water warms, it can result in evaporation, which will lead to in an increase in both salinity and density, which also causes the water mass to sink in the water column. Water masses will continue to sink or rise in the water column until they reach equilibrium (i.e., when the water below is denser, and the water above is less dense). If new water is added—from sinking, upwelling, wind, and so on—that water will spread horizontally. Differences in water density (resulting from salinity and temperature) create layers in the water column. While much of the ocean is constantly in motion, a snapshot of the water column at any given moment will show distinct layering.

The movement and mixing of water layers, driven by density, is called **thermohaline** (heat and salt) **circulation.** A thin layer of surface water tends to be relatively more stable, warmer, and less salty than the water below it. When there is a distinct difference between the temperatures of water at a particular depth, the boundary layer between them is called the thermocline. A thermocline is the point in the water column at which the water temperature changes dramatically. Often, swimmers can feel this in a lake or the ocean; their arms and head are warm enough, but their feet, down deeper, are much more chilly!

When there is a distinct difference between salinities of water at a particular depth, that difference is called the **halocline.** The halocline is the point in the water column at which the water changes salinity significantly: The upper layer is less salty and, therefore, less dense than the deeper, denser, saltier layer. Sometimes, when snorkeling or diving in the tropics, a swimmer can actually see the zone at which the water may be slightly blurry because the less salty and saltier layers are trying to mix, but because of the their different densities and salinities, the layers remain separate. This separation is sometimes referred to as stratification. A strong thermocline or halocline can prevent the layers from mixing. In the ocean, stratification from temperature or salinity can prevent the transfer of nutrients or **biomass** unless a disturbance event occurs, such as a storm or significant seasonal changes. Often the depth of the thermocline and halocline will vary with the seasons for a particular ocean region, which can impact local climate and the organisms living, feeding, or breeding in that area.

Global Currents

Wind and water density drive the global current system that circulates the water in the ocean all over the globe. These currents circulate not just the water but also anything that is in the water, such as plankton and debris (both natural and introduced), throughout the ocean. Although these currents remain constant they are not always fast. It takes approximately 2,000 years for one drop of water to travel the entire ocean. While the global currents are complex, there are specific currents that remain stable, as can be seen in the following image. This image shows the major surface and deep currents in the ocean basins. From this diagram you can see how water and everything in it can easily travel from one side of the planet to the other.

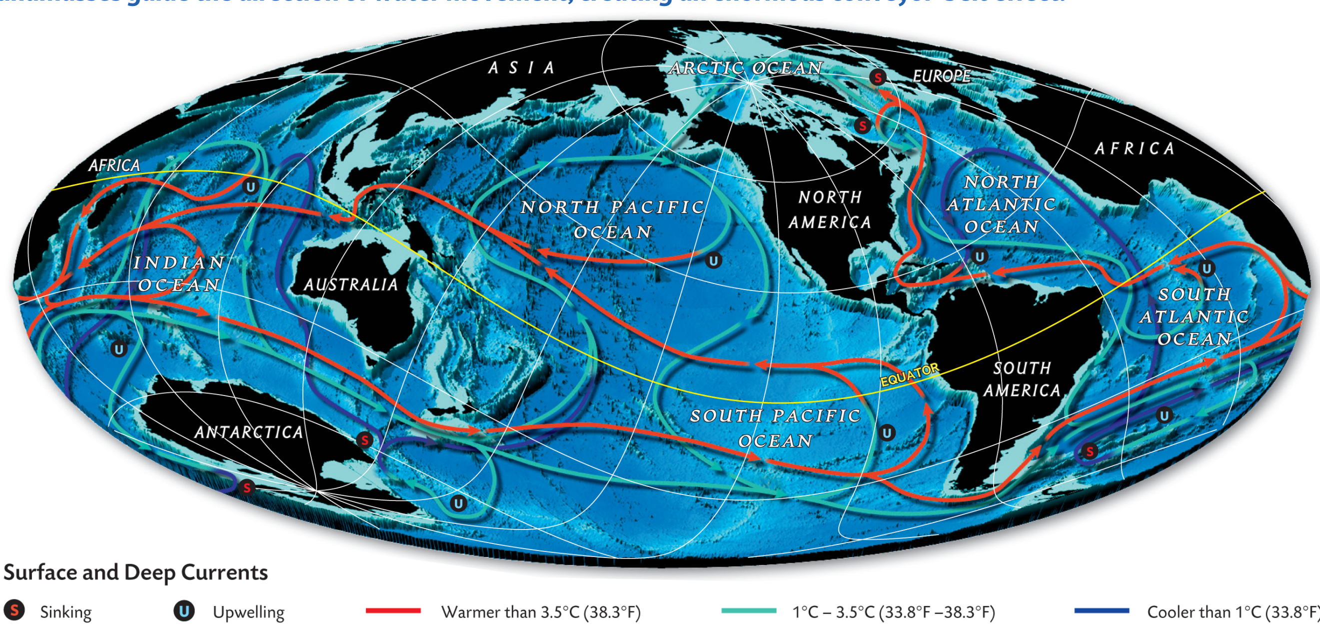
The physical and chemical characteristics of water, such as temperature and salinity, influence density and, thus, drive the global current system. Water in the North Atlantic Basin is cold, salty, and dense. This water mass sinks and travels along the bottom of the Atlantic Basin away from the ice caps, all the way to the southern end of the globe! When it reaches the Southern Ocean it mixes with more deep, cold, salty water from Antarctica. Some of this water upwells because it follows the contours of the ocean bottom and rises at the edges

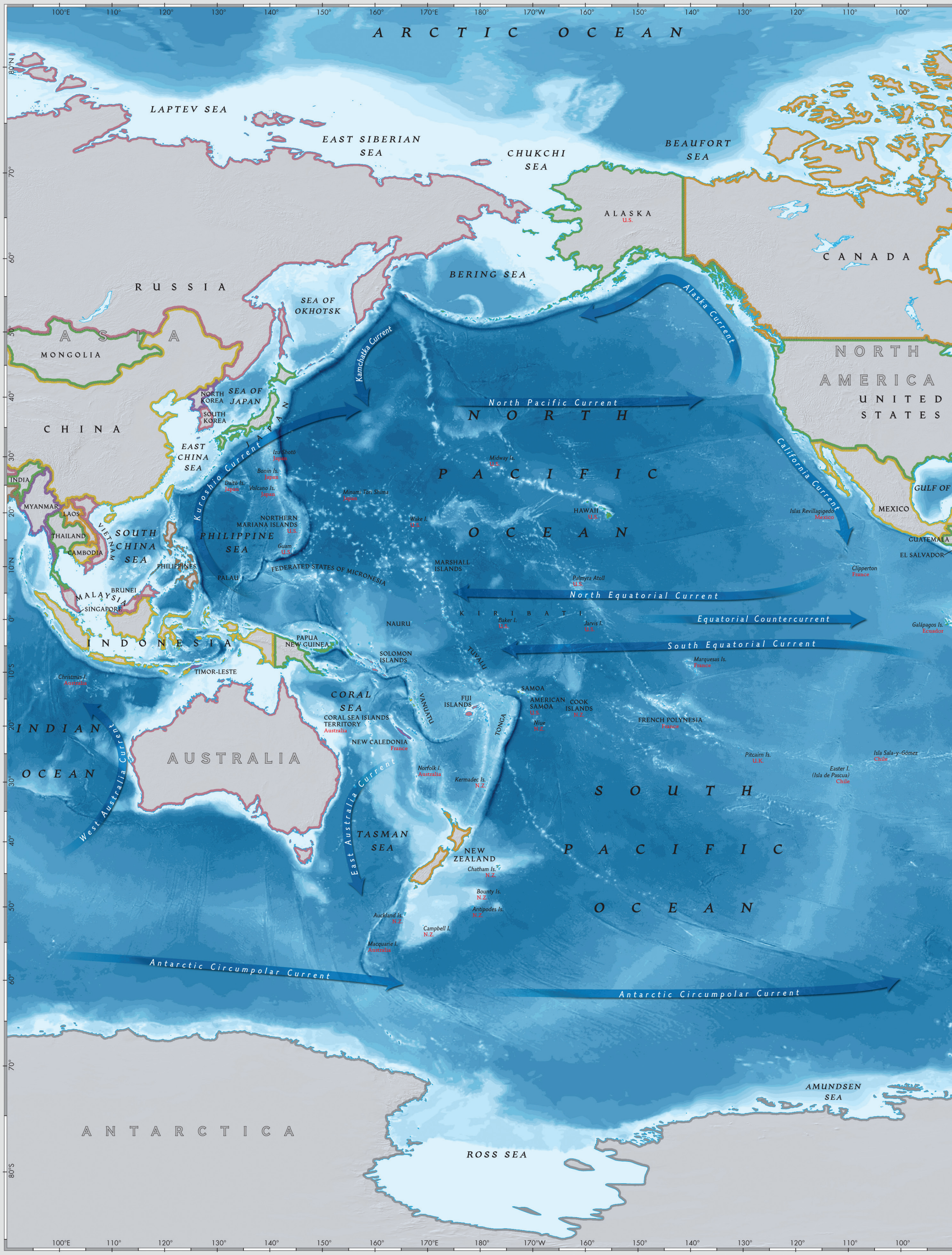
Teaching Tip

Before discussing density-driven ocean circulation, make certain your students have a solid grip on the concept of density. Density can be very difficult for students to comprehend because it relates to something happening on the molecular level—something they cannot see. Some simple activities to increase student comprehension of density include showing students images of molecules in salt water at different salinities or having students add salt to a cup of water and describe why the density is increasing (they are putting more "stuff" into the same volume of water). There are many other lessons that exist to help reinforce this student thinking, such as the Cartesian diver activity. Once the concept of density and its relation to temperature and salinity are solidified, density-driven ocean circulation becomes much more easily grasped. See activity ideas at http://www.bigelow.org/shipmates/density.html or http://www.pbs.org/wgbh/nova/teachers/activities/2402_titanic.html.

GLOBAL OCEAN CURRENTS

The ocean is in constant motion, driven by surface winds and controlled by water temperature and density. Great landmasses guide the direction of water movement, creating an enormous conveyor-belt effect.




ARCTIC OCEAN
LAPTEV SEA
EAST SIBERIAN SEA
CHUKCHI SEA
BEAUFORT SEA
ALASKA
U.S.
CANADA
BERING SEA
RUSSIA
SEA OF OKHOTSK
ASIA
MONGOLIA
NORTH KOREA
SEA OF JAPAN
SOUTH KOREA
CHINA
JAPAN
EAST CHINA SEA
INDIA
MYANMAR
LAOS
THAILAND
VIETNAM
CAMBODIA
SOUTH CHINA SEA
PHILIPPINES
PHILIPPINE SEA
BRUNEI
MALAYSIA
SINGAPORE
INDONESIA
PALAU
TIMOR-LESTE
PAPUA NEW GUINEA
Christmas I.
Australia
INDIAN OCEAN
AUSTRALIA
CORAL SEA
CORAL SEA ISLANDS TERRITORY
Australia
NEW CALEDONIA
France
SOLOMON ISLANDS
NAURU
VANUATU
FIJI ISLANDS
TONGA
TUVALU
SAMOA
AMERICAN SAMOA
U.S.
COOK ISLANDS
N.Z.
Niue
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Norfolk I.
Australia
Kermadec Is.
N.Z.
TASMAN SEA
NEW ZEALAND
Chatham Is.
N.Z.
Bounty Is.
N.Z.
Antipodes Is.
N.Z.
Auckland Is.
N.Z.
Campbell I.
N.Z.
Macquarie I.
Australia
Izu Shotō
Japan
Bonin Is.
Japan
Daitō Is.
Japan
Volcano Is.
Japan
Minami Tori Shima
Japan
NORTHERN MARIANA ISLANDS
U.S.
Guam
U.S.
FEDERATED STATES OF MICRONESIA
Wake I.
U.S.
Midway Is.
U.S.
MARSHALL ISLANDS
HAWAII
U.S.
Palmyra Atoll
U.S.
KIRIBATI
Baker I.
U.S.
Jarvis I.
U.S.
Marquesas Is.
France
FRENCH POLYNESIA
France
Pitcairn Is.
U.K.
Easter I.
(Isla de Pascua)
Chile
Isla Sala-y-Gómez
Chile
Galápagos Is.
Ecuador
Clipperton
France
Islas Revillagigedo
Mexico
NORTH PACIFIC OCEAN
SOUTH PACIFIC OCEAN
NORTH AMERICA
UNITED STATES
MEXICO
GULF OF
GUATEMALA
EL SALVADOR
Kamchatka Current
Kuroshio Current
Alaska Current
North Pacific Current
California Current
North Equatorial Current
Equatorial Countercurrent
South Equatorial Current
West Australia Current
East Australia Current
Antarctic Circumpolar Current
Antarctic Circumpolar Current
AMUNDSEN SEA
ROSS SEA
ANTARCTICA
100°E
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60°
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80°S

ARCTIC OCEAN
GREENLAND
Denmark
BAFFIN BAY
GREENLAND SEA
Svalbard
Norway
Franz Josef Land
Russia
BARENTS SEA
KARA SEA
Jan Mayen
Norway
NORWEGIAN SEA
Norwegian Current
East Greenland Current
Labrador Current
ICELAND
Faroe Is.
Denmark
HUDSON BAY
RUSSIA
FINLAND
SWEDEN
NORWAY
ESTONIA
LATVIA
LITHUANIA
BALTIC SEA
NORTH SEA
DENMARK
UNITED KINGDOM
IRELAND
NETH.
BELGIUM
GERMANY
POLAND
BELARUS
EUROPE
UKRAINE
CZECH REP.
SLOVAKIA
AUSTRIA
HUNGARY
MOLDOVA
ROMANIA
FRANCE
SWITZ.
SLOV.
CROATIA
BOS.
SERBIA
ITALY
MONT.
KOS.
BULGARIA
MACED.
ALBANIA
BLACK SEA
KAZAKHSTAN
ASIA
CASPIAN SEA
UZBEKISTAN
KYRGYZSTAN
GEORGIA
ARMENIA
AZERBAIJAN
TURKMENISTAN
TAJIKISTAN
CHINA
North Atlantic Drift
Gulf Stream
Azores
Portugal
PORTUGAL
SPAIN
MEDITERRANEAN SEA
GREECE
TURKEY
CYPRUS
SYRIA
LEBANON
ISRAEL
JORDAN
IRAQ
IRAN
AFGHANISTAN
PAKISTAN
NEPAL
KUWAIT
BAHRAIN
QATAR
U.A.E.
SAUDI ARABIA
OMAN
INDIA
NORTH ATLANTIC OCEAN
Bermuda Is.
U.K.
Madeira Is.
Portugal
Canary Is.
Spain
Canaries Current
MOROCCO
TUNISIA
ALGERIA
LIBYA
EGYPT
RED SEA
WESTERN SAHARA
Morocco
MEXICO
BAHAMAS
CUBA
DOMINICAN REP.
Puerto Rico
U.S.
HAITI
JAMAICA
ANTIGUA & BARBUDA
Guadeloupe
France
BELIZE
HONDURAS
CARIBBEAN SEA
ST. KITTS & NEVIS
DOMINICA
ST. LUCIA
NICARAGUA
ST. VINCENT & THE GRENADINES
BARBADOS
GRENADA
COSTA RICA
TRINIDAD & TOBAGO
PANAMA
North Equatorial Current
CAPE VERDE
MAURITANIA
MALI
NIGER
CHAD
SUDAN
ERITREA
YEMEN
SENEGAL
GAMBIA
GUINEA-BISSAU
GUINEA
BURKINA FASO
AFRICA
DJIBOUTI
SOMALILAND
Somalia
ARABIAN SEA
BAY OF BENGAL
SRI LANKA
SIERRA LEONE
LIBERIA
CÔTE D'IVOIRE
GHANA
TOGO
BENIN
NIGERIA
CAMEROON
CENTRAL AFRICAN REPUBLIC
ETHIOPIA
SOMALIA
North Equatorial Current
MALDIVES
Equatorial Countercurrent
VENEZUELA
GUYANA
FRENCH GUIANA
France
SURINAME
Isla del Coco
Costa Rica
Isla del Malpelo
Colombia
COLOMBIA
Equatorial Countercurrent
EQUATORIAL GUINEA
UGANDA
KENYA
ECUADOR
St. Peter and St. Paul Rocks
Brazil
SAO TOME & PRINCIPE
GABON
CONGO
DEMOCRATIC REPUBLIC OF THE CONGO
RWANDA
BURUNDI
South Equatorial Current
South Equatorial Current
BRITISH INDIAN OCEAN TERRITORY
U.K.
Arquipélago de Fernando de Noronha
Brazil
CABINDA
Angola
TANZANIA
SEYCHELLES
SOUTH AMERICA
BRAZIL
PERU
Ascension
U.K.
COMOROS
Mayotte
France
ANGOLA
MALAWI
ZAMBIA
BOLIVIA
St. Helena
U.K.
MOZAMBIQUE
ZIMBABWE
MADAGASCAR
INDIAN OCEAN
MAURITIUS
Ilhas Martin Vaz
Brazil
NAMIBIA
BOTSWANA
Réunion
France
PARAGUAY
Benguela Current
Isla San Félix
Chile
Brazil Current
SWAZILAND
SOUTH ATLANTIC OCEAN
SOUTH AFRICA
LESOTHO
Agulhas Current
Archipiélago Juan Fernández
Chile
URUGUAY
Peru (Humboldt) Current
CHILE
ARGENTINA
Tristan da Cunha Group
U.K.
Île Amsterdam
France
Île St.-Paul
France
Crozet Is.
France
Prince Edward Is.
South Africa
Falkland Is.
U.K.
Îles Kerguelen
France
Shag Rocks
U.K.
South Georgia
U.K.
Bouvet
Norway
Heard I.
Australia
SCOTIA SEA
South Sandwich Is.
U.K.
Antarctic Circumpolar Current
BELLINGSHAUSEN SEA
WEDDELL SEA
Miller Cylindrical Projection
SCALE 1:79,773,530
1 CENTIMETER = 798 KILOMETERS; 1 INCH = 1260 STATUTE MILES
0 2000 4000
KILOMETERS
0 2000 4000
STATUTE MILES
0 2000 4000
NAUTICAL MILES
Scale at the Equator
ANTARCTICA
80° 70° 60° 50° 40° 30° 20° 10°W 0° 10°E 20° 30° 40° 50° 60° 70° 80°E
80°N 70° 60° 50° 40° 30° 20° 10° 0° 10° 20° 30° 40° 50° 60° 70° 80°S

In the Classroom Density

This activity, in which students investigate water masses, density, and mixed surface layers, will only be successful if students follow the process carefully. In this activity, students can see the effects of density on different water masses. Cold, salty, blue water will separate from warm, fresh, red water, and students will be able to see two distinct layers.

Materials

- Two small, clear beakers per group
- One large, clear container per group
- Eye droppers, pipettes, or small turkey basters (one per group)
- Blue and red food coloring
- Salt
- Spoon
- Ice
- Water
- Straws

Directions

1. Provide students with hot water and ice water in two separate cups or beakers (about ½ liter, or 2 cups, in each container). Add red food coloring to the hot water and blue food coloring and salt to the cold water, stir until the salt dissolves. The salt water should be fully saturated (i.e., add salt until no more can dissolve in the cup).
2. Have students pour the red, hot, freshwater into the large clear container.
3. Have students add the blue, cold, salty water into the large clear container. The water must be added slowly so it does not mix with the freshwater. Students can use a pipette or eye dropper, or they can carefully pour the water, letting it run down the inside of the beaker. Another option is to set up a titration-type scenario in which the blue water gets dripped or slowly streams against the side of the large, clear container. The slower the better! Teachers should practice this beforehand so they have a sense of how slowly students need to work.
4. View the stratified water masses on a white surface and background to clearly see the distinction between the two layers. The cold saltwater is more dense. The hot freshwater is less dense.
5. Using the straw, students can blow air across the surface of the water. Because of the different colors, students will be able to see the top layers moving away from the straw, see it contact the wall of the container, and reflect away from the wall and down into the bottom layer. Students can watch the layers mix.

Discuss

1. Ask students to describe in their own words what happened.
2. Ask them what would have happened if they had used the blue food coloring for the hot water and the red food coloring for the cold water. Would the experiment still work? Would the results be the same? What if the hot water was salty and the cold water was fresh—would that impact their results?
3. Ask students why it was important to pour the water so slowly.

of the continent of Antarctica. Some of it continues to move around the globe or into the Indian Ocean Basin. At the northern parts of the Indian Basin, this cool, salty, North Atlantic water mixed with the Southern Ocean upwells as it comes into contact with Africa and India. As the water masses move away from the Poles and toward the warmer waters of the Equator, they gradually warm and continue to rise to the surface due to the decreased density of warm water. On the surface, they are pushed through different ocean basins by currents from prevailing winds and tides. As the water masses on the surface return to the Poles, wind traveling over the ice sheets cools the water and aids in freshwater evaporation, driving it back down and completing the global current. This is a simplified model of the actual mixing and movement of water that occurs, but it demonstrates how water, driven by differences in density and the wind, moves through the ocean. Scientists refer to this simplified model of the global ocean currents as the global conveyor belt.

Teaching Tip

What do rubber duckies, messages in bottles, and Nike shoes have in common? They have all helped scientists learn more about ocean circulation and ocean currents after being accidently lost by cargo ships. Ask students to think about what might happen to a box of rubber duckies lost near Hawaii? What about near England? How far might these bath toys float before they make land? Encourage students to trace the paths that such items could take using maps of ocean currents. Explain to students that currents cause marine debris, such as plastic, to build up in particular locations in the ocean. Encourage students to find out more about this phenomena by researching the Great Pacific Garbage Patch online. Although there are other places in the ocean where this same phenomenom occurs, this is one of the largest and most well-known cases.

Tides

While currents are driven by physical and chemical properties of the ocean, tides are driven by forces acting on the entire planet. The moon and sun exhibit gravitational pulls on Earth. At the same time, the spinning and orbiting of Earth create **centrifugal force.** These opposing forces push and pull on Earth's surface, creating ocean tides. As the relative positions of Earth, moon, and sun change, the ocean bulges, creating the tides. The gravitational pull of the moon is the dominant force in these interactions. Because of this, the tides cycle along with the moon.

Imagine Earth as a flattened sphere, covered by a uniformly deep layer of water. Now imagine that the moon is pulling the water toward it through gravitational force. That force is felt all the way through the planet. Therefore, water in line with that pull on either side of the planet bulges. While on the far side of Earth, opposite the moon, it looks like the water is pulling away from the planet, that bulge is an artifact of the moon's pull, a result of inertia. Therefore, there are two points of high tide at any moment: both points in line with the moon's pull—one on each side of the planet.

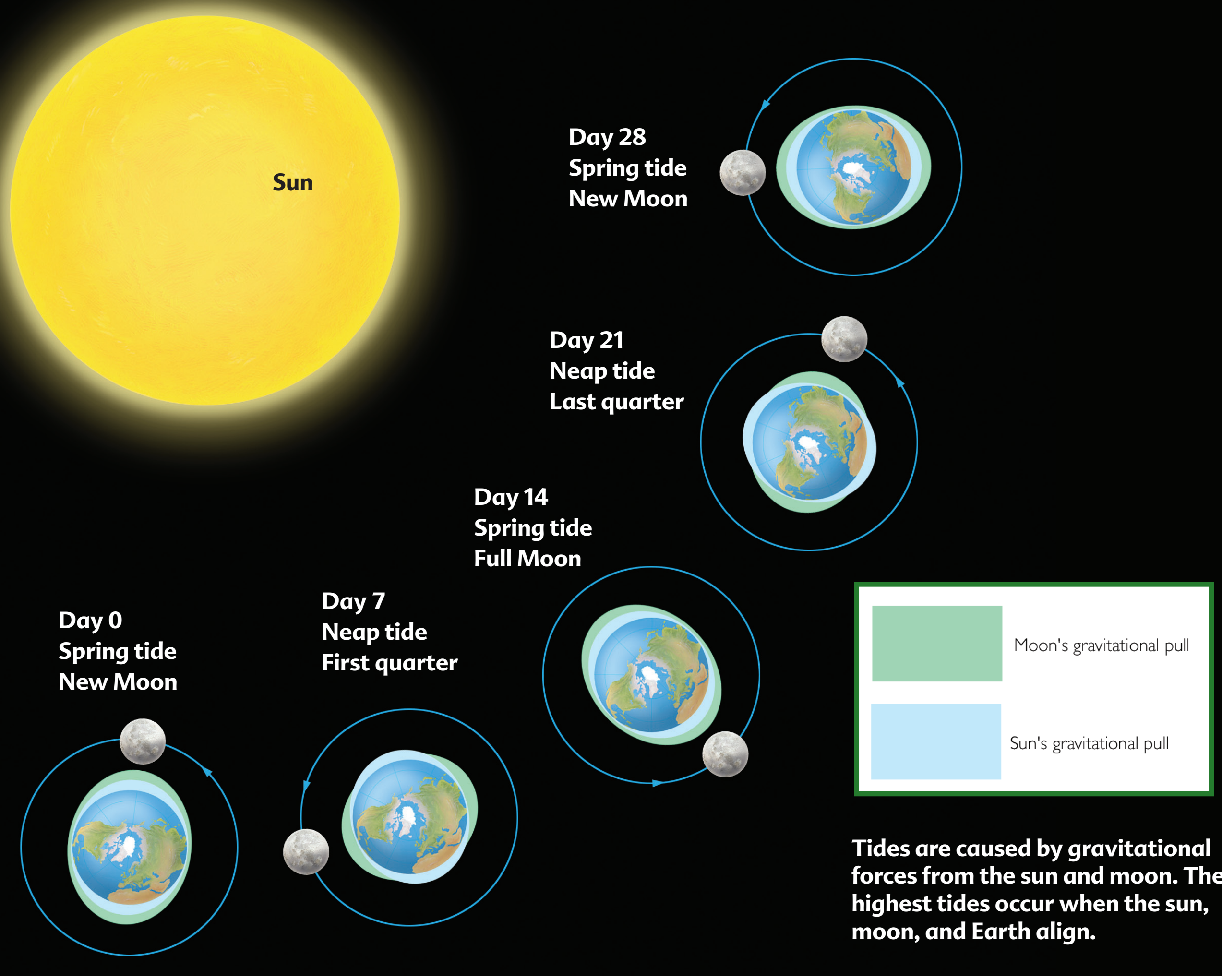
As the moon pulls on the water in line with its gravitational force, the water opposite the moon's pull must follow, leading to an area of low tide. As there are two points directly opposite the moon's pull, there are two low tides at any moment—each at approximate right angles to the high tide if looking down on the planet from space.

This is the most basic tide. On the side of Earth closest to the moon, and on the side opposite the moon, the tide is high. Other places on Earth experience low or intermediate tides at the same time depending on their relative locations.

To understand the effect of the sun in this model, imagine the sun in line with the moon. Now the gravitational forces are all aligned and have created even larger bulges in line with the sun and moon, leading to deeper troughs where the water is pulled away. Therefore, when the gravitational forces of the moon and sun are in the same plane, there are extremely-high high tides, and extremely-low low tides. (This occurs when we see a full or new moon.) This phenomenon is called a spring tide (although it has nothing to do with the spring season). When the sun and moon are in line, the ocean experiences the highest high tides and lowest low tides of the tidal cycle.

As the moon travels around Earth, the bulge of water follows the moon's pull. When the moon and sun are at a 90 degree angle, the bulges are pulled in opposite directions and not as exaggerated. This scenario occurs during the quarter-moon phase and produces what we call neap tides. During neap tides the difference between the high and the low tides can be small.

The level of the tides between different tidal scenarios, such as spring and neap tides, is not static. As the angles between Earth, moon, and sun are constantly changing, so are the tidal levels. Just



Tides are caused by gravitational forces from the sun and moon. The highest tides occur when the sun, moon, and Earth align.

as we can predict the moon cycles, we can predict the tidal cycles. Because the tidal cycles follow the moon cycles, they repeat approximately every 28 days.

These images and descriptions represent a very basic explanation of the tides and explain the driving force behind tides. However, the actual heights and timing of tides vary throughout the ocean and along our coastlines. If the perfect sphere mentioned previously increases in complexity, with underwater mountain chains, deep canyons, volcanoes, and other features, the bulge of the ocean cannot move as smoothly around the sphere. This is the effect that continents and the topography of ocean basins have on the tides. The depth, size, and underwater features of the ocean basin affect tidal cycles, as do the shape of the coastline and the surrounding land features. Some areas experience extremely drastic tides—differences of more than 38 feet (10 m) between high and low tides can occur on a daily basis. Other areas experience nearly imperceptible tidal changes every day. Many areas, including California and much of the East Coast of the United States, have semidiurnal tides: a high tide and a low tide occur twice daily. Other areas, such as the northern Gulf of Mexico, have diurnal tides in which only one high and one low tide occur daily. These cycles are predictable and are often published in Tidelogs for a year's tides for a specific area.

Tides are most evident along coastlines, where rocks, sand, and other coastal features are visible during low tides and are covered with water during high tide. The shape of harbors, bays, and other coastal features also influence the tidal range, the vertical distance between low and high tide, as measured along the coast. In some areas where the coast is extremely narrow and shallow for long distances the tidal range can be drastic. For example, the northern end of the Gulf of California can have tidal changes up to 7 vertical meters (23 vertical feet). In comparison, the maximum tidal range for San Diego is 2.4 vertical meters (8 feet). Although it is hard to see, tides affect the open ocean as well. However, the effects are not as significant.

Waves

Most waves are created by the wind moving across the surface of the water. The energy from the wind is being transferred to the water, and that energy moves through the water in waves that we can see. In the open ocean, these waves are often swells and may not break until they come into contact with land. Closer to land, the momentum of the swell as it travels toward the coastline is often disturbed by a sudden or gradual decrease in the depth of the ocean floor. This slows the bottom part of the wave, but the upper portion of the wave carries forward with its momentum, causing the wave to increase in height and eventually fall forward, or break. This action could be compared to a person tripping. Imagine tripping on a doorstep that you did not see—your feet slow down and your head lunges up and then falls forward.

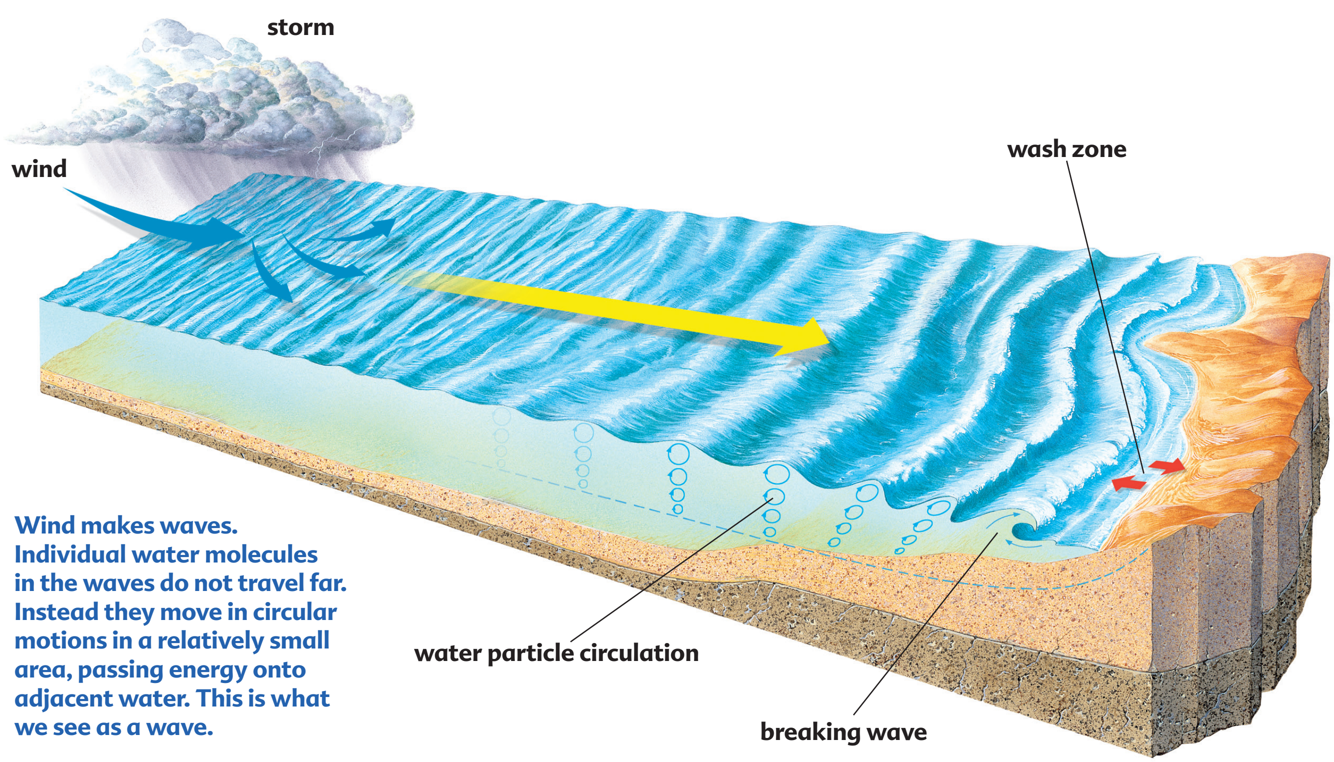
As a wave approaches the shore and breaks, water is moving vertically beneath the surface. The water in a wave moves in a circular motion, while the energy travels horizontally and eventually reaches the beach. The energy from a wave is released onto the beach, creating sea spray and movement of rocks and sand. If you watch a bird sitting on the sea surface, you can see it move up and down with the vertical motion of the water, but the bird does not experience horizontal motion.

At sea the height of a wave, referred to as a swell, is determined by a number of different conditions, including the depth of the water, the speed of the wind, the length of time the wind has been blowing, and the fetch of the wind, or the distance over which it blows. These characteristics influence the wave in the open ocean and as it approaches the shore. The point at which a wave breaks can be described by a mathematical equation that takes into consideration the height of the wave, the depth of the water, and the speed the wave is traveling.

Teaching Tip

The use of a Slinky can provide students with a simple visual representation of how energy travels through waves. Add a small piece of tape to the Slinky somewhere in the middle. Tell students the tape represents a single water molecule. Have two students hold the spring. One student should play the role of the wind and move the spring up and down. As the Slinky moves, students will be able to see the wave motion of the spring and view how the water molecule (i.e., tape) moves in a small circle. This simple activity can help alleviate the common confusion that waves transport water molecules from Japan all the way to California where they break upon the shore.

HOW WAVES ARE MADE



Wind makes waves. Individual water molecules in the waves do not travel far. Instead they move in circular motions in a relatively small area, passing energy onto adjacent water. This is what we see as a wave.

Student Thinking

What Causes Tides?

Students, especially those living near a coast, experience daily changes in their ocean. They routinely hear about high tide and low tide, but students still struggle with understanding what mechanisms cause tides to occur (Ballantyne 2004). They also question why tides are sometimes more dramatic than at other times and why tides happen at different times of day.

Scenario

You are teaching a set of lessons on tides to your students. Halfway through the lessons you hear students sharing incorrect ideas during small-group work. You decide to conclude the day's lesson with a quickwrite because you want to see how many students understand that the gravitational pull of the moon (and partially the sun) causes tides. The following is a sample of responses you received from students.

Question

Explain as much as you know right now about what causes tides.

Scientific Answer

The primary mechanism that causes tides is the gravitational pull of the moon. The gravitational pull of the sun is also a factor, as is the rotation of Earth. When the two pulls are aligned, there are more dramatic differences in tides (tides are amplified). When the two pulls are offset, the difference in tides is less dramatic. Other factors, such as local coastline and physical topography of the marine and land environment, will affect tidal activity.

Student Answers

Ryan: The tides change because Earth moves on its axis. And tides that are also created by tremors, underwater volcanoes, things that set-off automatically.

Caleb: I think the gravity from the sun and the Earth moving around the sun makes the tides lower or higher, and then when we get farther from the sun they're lower, and when we are closer to the sun, the tides get higher. When we're spinning around the sun in the wintertime, the tides are normally lower because we're farther away from the sun, and in the summertime they're higher because we're closer to the sun.

Leslie: The tides are drawn by the moon.

Alice: I don't really know a lot about tides, but there can be high tides or low tides. I think the weather causes tides.

Jackson: Low tide is when the water is pulled back. That's usually caused by when there is a new moon.

Meghan: If it's winter the tide would be high, just with the weather I guess, because it's colder and then the summer it would be a lower tide because it's warmer outside.

What Would You Do?

1. What concepts do students understand at this point? What are the incorrect ideas that students are still retaining even after a couple of lessons about tides?
2. Which misconceptions would you want to address? How would you do this?

Student Thinking

Ocean Currents, Tides, and Waves

Students typically are not clear how currents, tides, or waves differ. They associate information—often incorrectly—about depth, the moon, and gravity and their effects on currents, tides, and waves. When asked what the difference among the three is, the confidence and clarity of students' responses waiver. Occasionally, tectonic activity is included in students' associations of these physical processes (i.e., confusion of the difference between a tidal wave, or tsunami, and a tide). When asked what causes currents, students often refer to the wind as a driving factor, or they may claim currents are caused by moon's gravitational pull (confusing currents and tides). Students do not generally think about tides, currents, or waves specifically as global or local processes.

	Common Student Ideas	Scientific Concepts
Currents	Currents move in one direction	A specific current has a standard direction of flow, but changing winds and interaction with other currents can affect its motion. See pages 17—19.
Tides	Tides are a local process in which water goes up and down at different times in the day. Something pushes the water ashore. Some students may see that gravity is involved but identify the wrong external factor. High tide brings larger waves.	Tides are caused primarily by the moon's gravitational pull on the waters of Earth. (Simanek 2009) See page 22.
Waves	Waves are caused by boats or ships on the water or storms and strong winds. Waves move in one direction—onshore to the beach.	Wind transfers its energy to the water as it travels across the surface of the ocean. This kinetic energy of wind motion is translated into wave motion. Strong winds that accompany a storm can create large waves. Waves move in the direction of the wind creating them. Wind blowing to the shore creates waves that travel approximately toward the shore and vice versa. See page 23.

Ask Your Students

1. Explain how a drop of water on the California coast would travel to Japan. What are other places it could travel?
2. Where does the water go during low tide? Why does it go there?
3. Where do waves start? What determines the direction a wave will travel?

Pictures of Practice

Explaining Waves

Students: Grades 5 and 7

Location: California (in coastal communities)

Goal of the Video: The goal of watching this video is to hear students describe what causes waves and compare these ideas to a scientific explanation.

Students in coastal areas may have daily or weekly experiences with currents, tides, and waves. They may drive by a coast and see waves coming to shore. They hear about times that low tide and high tide are expected to occur. They may go fishing or surfing or hang out at a beach with friends or family. When they are at the beach, they know about areas to avoid swimming near because of rip currents or undertows. Even students living in inland communities have experiences with coasts, either through trips to a beach or what they see in movies. Students may have a difficult time understanding the different mechanisms that drive rip currents and undertows (see **Student Thinking: Ocean Currents, Tides, and Waves,** on page 25, for more information). While waves are relatively easier to understand compared to currents and tides, students still struggle with identifying wind as the driving mechanism.

Classroom Context

The interview clips shown in this video were taken during the spring of the school year after both sets of students learned about the ocean. The first part of the video shows fifth-grade students describing mechanisms that cause waves. The second half of the video shows seventh-grade students answering the same question. Think about the different types of responses you hear from students in the same grade as well as differences between grade levels. How do these compare to a scientific explanation?

Video Analysis

In this video, fifth and seventh graders were asked the same question: What causes waves? A scientific explanation of waves focuses on wind moving across the surface of the water. Dominant wind patterns determine the direction of the waves. Tsunamis are a very specific kind of wave initiated by ocean floor activity, such as earthquakes on the ocean floor. But most waves are wind-driven. As you listen to the fifth-grade and seventh-grade students describe waves, think about how their answers match or do not match the scientific description of waves. For example, some students point to gravitational pull or Earth's rotation as driving waves. These students seem to be confusing mechanisms that cause tides with mechanisms that cause waves. Other students seem to have more developed ideas but could still improve their understanding to be more in line with a scientific explanation. As you listen, compare each student's answer to the scientific description and think about how to help each student improve his or her understanding.

Reflect

What patterns do you see in student ideas about waves?

What ideas seem to be common across students? Which misconceptions would you choose to address? How would you do this in your own classroom?

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Teaching Resources

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NOAA tutorial on tides: http://oceanservice.noaa.gov/education/tutorial_tides/tides01_intro.html