3. Which does NOT contribute to atmospheric convection currents?
   (a) Hadley cells
   (b) gyres
   (c) polar cells
   (d) the intertropical convergence zone
4. The maximum amount of water vapor air can hold at a given temperature is called the
   (a) saturation point.
   (b) absolute humidity.
   (c) dew point.
   (d) vapor pressure.
5. The Coriolis effect is responsible for
   (a) the convergence of two ascending Hadley cells.
   (b) the location of atmospheric currents caused by the unequal heating of Earth.
   (c) the cooling effect of air as it rises and expands.
   (d) the deflection of atmospheric currents.
6. Which does NOT play a role in causing a rain shadow?
   (a) cold polar air
   (b) a mountain range
   (c) adiabatic cooling
   (d) humid ocean air
7. Which is the correct order of the convection cells, starting from the equator?
   (a) Ferrell, Hadley, polar
   (b) polar, Hadley, Ferrell
   (c) Hadley, Ferrell, polar
   (d) Hadley, polar, Ferrell

MODULE 11

Ocean Currents

We have seen that the unequal heating of Earth together with the Coriolis effect drives air currents around the world. These two phenomena also affect ocean currents. In this module, we will explore the circulation of ocean waters, both at the surface and in the deep ocean. We will see how ocean circulation affects the transport of heat around the globe, how this heat movement affects the climates of continents, and how disruptions to these circulation patterns can dramatically alter global climates.

Learning Goals

After reading this module you should be able to

- describe the patterns of surface ocean circulation.
- explain the mixing of surface and deep ocean waters from thermohaline circulation.
- identify the causes and consequences of the El Niño–Southern Oscillation.

Surface ocean currents move warm and cold water around the globe

The flow of ocean water is an important factor for global climates because it moves warm and cold waters to different parts of the globe. For example, the Gulf Stream is a current of warm water that emerges from the Gulf of Mexico and warms much of the eastern coast of the United States. In doing so, ocean currents affect the primary productivity found in different ocean regions as well as the climate of the adjacent continents. When warm ocean currents flow from the tropics to higher latitudes, the neighboring continents receive warm air from the

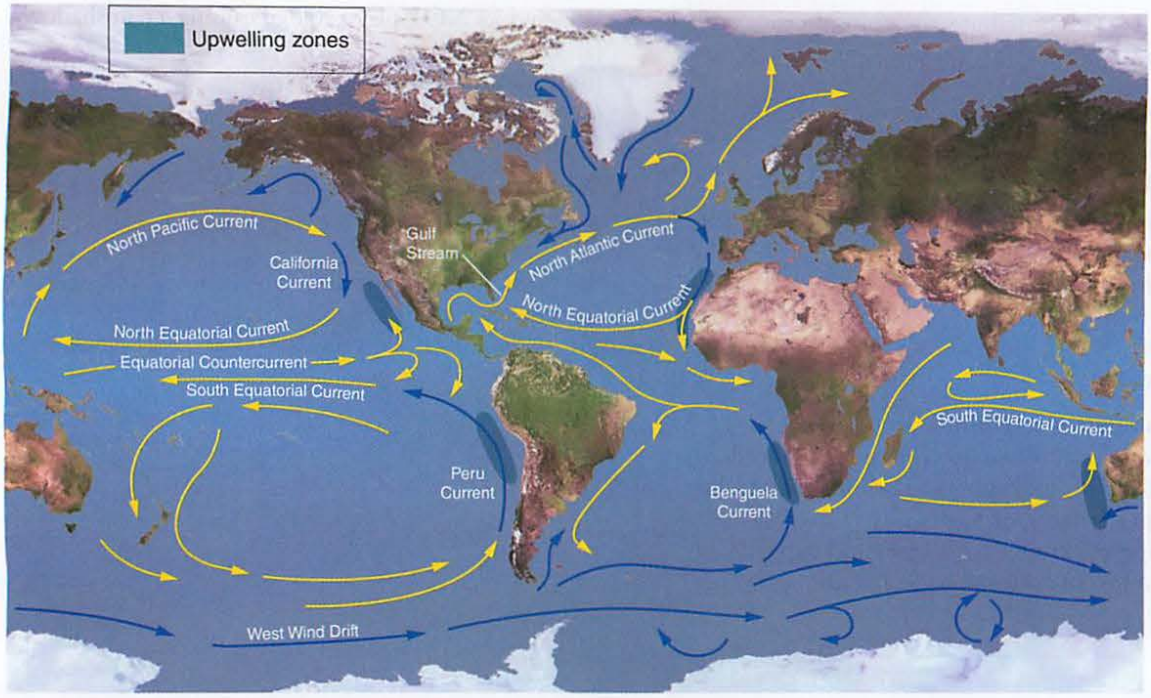


FIGURE 11.1 Oceanic circulation patterns. Oceanic circulation patterns are the result of differential heating, gravity, prevailing winds, the Coriolis effect, and the locations of continents. Each of the five major ocean basins contains a gyre driven by the trade winds in the tropics and the westerlies at mid-latitudes. The result is a clockwise circulation pattern in the Northern Hemisphere and a counterclockwise circulation pattern in the Southern Hemisphere. Along the west coasts of many continents, currents diverge and cause the upwelling of deeper and more fertile water.

ocean. In this section, we will examine the major ocean currents that occur near the oceans and then consider currents that mix the surface water with much deeper water.

Ocean currents are driven by a combination of temperature, gravity, prevailing winds, the Coriolis effect, salinity, and the locations of continents. As we have already observed, the tropics receive the most direct sunlight throughout the year, which generally makes tropical waters warm. Warm water, like warm air, expands and rises. This process raises the tropical water surface about 8 cm (3 inches) higher than mid-latitude waters. While this difference might seem trivial, the slight slope is sufficient for the force of gravity to make water flow away from the equator. As we will see, this movement away from the equator due to gravity combines with other forces to make the surface waters circulate.

Gyres

As the warm tropical waters are pushed away from the equator by gravity, prevailing wind patterns around the globe also play a role in determining the direction in which ocean surface water moves. In the Northern Hemisphere, for example, the trade winds near the equator push water from the northeast to the southwest. However, the Coriolis effect deflects this wind-driven current so that water actually moves from east to west at the equator. Similarly, when winds in northern mid-latitude regions push water from the southwest to the northeast, the Coriolis effect deflects this current so that water actually moves from west to east. **FIGURE 11.1** shows the overall effect: Ocean surface currents between the equator and the mid-latitudes rotate in a clockwise direction in the Northern Hemisphere and in a counterclockwise direction in the Southern Hemisphere. These large-scale patterns of water circulation that move clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere are called **gyres**.

Gyres redistribute heat in the ocean, just as atmospheric convection currents redistribute heat in the atmosphere. Cold water from the polar regions moves along the west coasts of continents, and the cool air immediately above these waters brings cooler temperatures to the adjacent continents. For example, the California Current, which flows south from the North Pacific along the coast of California, causes coastal areas of California to have cooler temperatures than areas at similar latitudes on the east coast of the United States. Similarly, warm water from the tropics moves along the east coasts of continents, and the warm air immediately above these waters causes warmer temperatures on land.

Gyre A large-scale pattern of water circulation that moves clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere.

Upwelling

Ocean currents also help explain why some regions of the ocean support highly productive ecosystems. Along the west coasts of most continents, for

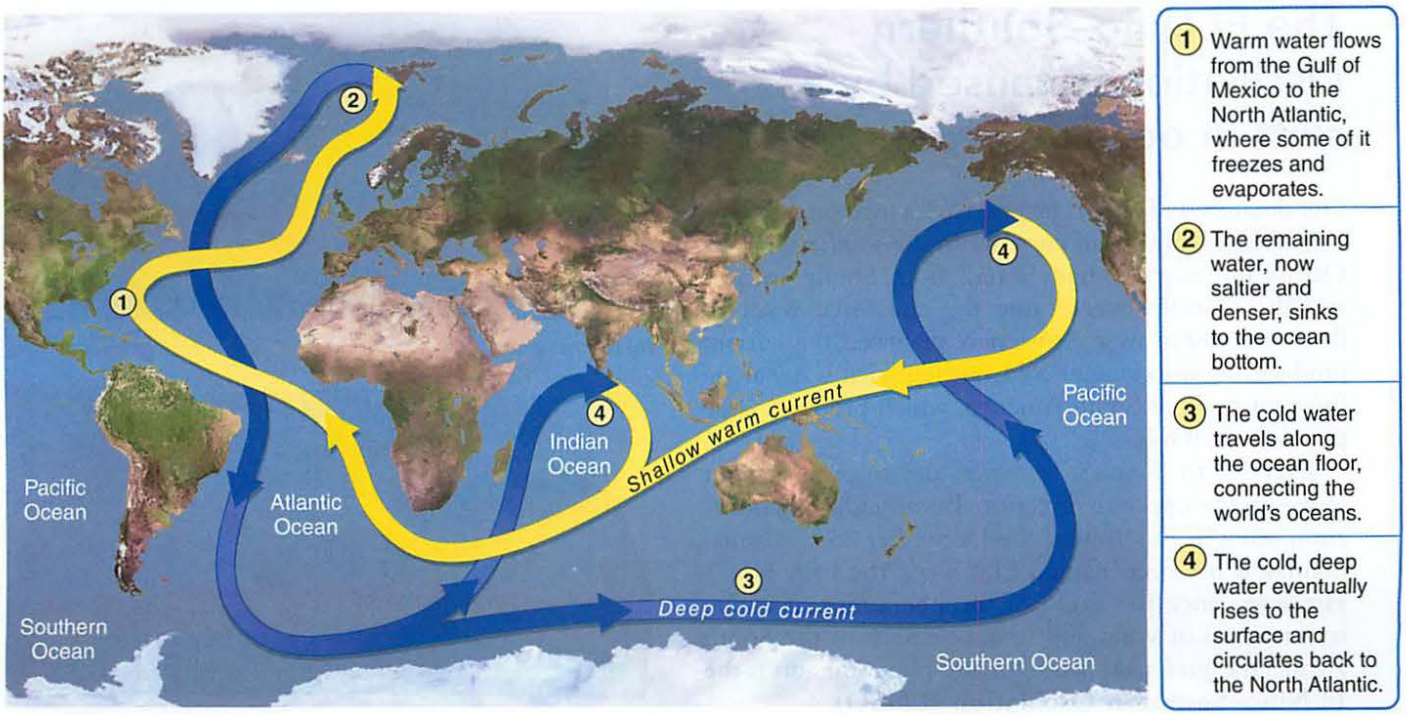


FIGURE 11.2 Thermohaline circulation. The sinking of dense, salty water in the North Atlantic drives a deep, cold current that moves slowly around the world.

example, the surface currents diverge, or separate from one another, causing deeper waters to rise and replace the water that has moved away. This upward movement of water toward the surface, shown as dark blue regions in Figure 11.1, is called **upwelling**. The deep waters bring with them nutrients from the ocean bottom that support large populations of producers. The producers, in turn, support large populations of fish that have long been important to commercial fisheries.

Deep ocean currents circulate ocean water over long time periods

Another oceanic circulation pattern, **thermohaline circulation**, drives the mixing of surface water and deep water. This process is crucial for moving heat and nutrients around the globe. Thermohaline circulation appears to be driven by surface waters that contain unusually large amounts of salt. As Figure 11.1 shows, warm currents flow from the Gulf of Mexico to the very cold North Atlantic. Some of this water freezes or evaporates, and the salt that remains behind increases the salt concentration of the water. This cold, salty water is relatively dense, so it sinks to the bottom of the ocean, mixing with deeper ocean waters. Two processes—the sinking of cold, salty water at high latitudes and the rising of warm water near the equator—create the movement necessary to drive a deep, cold current that slowly moves past Antarctica and northward to the northern Pacific Ocean, where it returns to the surface and then makes its way back to the Gulf of Mexico. This global round trip, shown in **FIGURE 11.2**, can take hundreds of years to complete. As you can see in the figure, thermohaline circulation helps to mix the water of all the oceans.

Ocean currents associated with thermohaline circulation affect the temperature of nearby landmasses much as the major gyres affect surface waters. For example, the ocean current known as the Gulf Stream originates in the tropics near the Gulf of Mexico and flows toward western Europe. This movement of warm tropical waters brings warmer temperatures to latitudes that would otherwise be much colder. For instance, England's average winter temperature is 20°C (36°F) warmer than that of Newfoundland, Canada, which is located at a similar latitude but receives cold ocean currents from the North Atlantic.

Scientists are concerned that global warming could affect thermohaline circulation. If increased air temperatures accelerate the melting of glaciers in the Northern Hemisphere, the waters of the North Atlantic could become less salty and thus less likely to sink. Such a change could potentially shut down thermohaline circulation and stop the transport of warm water to western Europe, making it a much colder place.

Upwelling The upward movement of ocean water toward the surface as a result of diverging currents.

Thermohaline circulation An oceanic circulation pattern that drives the mixing of surface water and deep water.

The El Niño–Southern Oscillation is caused by a shift in ocean currents

Our discussion of ocean currents has focused on the commonly occurring ocean currents. In the southern Pacific Ocean, for example, trade winds from South America and the Coriolis effect cause the equatorial water to flow from east to west. As we have discussed, this current produces an upwelling of cold, nutrient-rich water along the west coast of South America, which produces large populations of fish.

Every 3 to 7 years, however, the tropical current moves in the opposite direction. Because this phenomenon often begins around the December 25 Christmas holiday, it has been named El Niño ("the baby boy"). However, since the cause of the phenomenon is due to a reversal of wind and water currents in the South Pacific, the preferred name for the phenomenon is the **El Niño–Southern Oscillation (ENSO)**.

AP® Exam Tip

You should know when El Niño occurs, as well as the implications of this phenomenon. ●

FIGURE 11.3 shows this process in action. First, the trade winds that normally blow from South America and push the surface waters to the west weaken or reverse direction. This change in the wind allows warm equatorial water from the western Pacific to move eastward toward the west coast of South America. The movement of warm water and air toward South America suppresses upwelling off the coast of Peru. The effect can last from a few weeks to a few years.

Because ocean currents are so important to global climates, the ENSO has several consequences. As we have noted, it reduces the upwelling off the South American coast, which decreases productivity and dramatically reduces fish populations. It also has widespread effects around the world, including cooler and wetter conditions in the southeastern United States and unusually dry weather in southern Africa and Southeast Asia. Such changes can have major impacts of crop production, with some ENSO events leading to poor crop yields and thousands of human deaths in developing countries. The ENSO event that occurred during 2015-2016 was the most severe ENSO in 30 years. Scientists estimate that nearly 100 million people experienced food shortages as a result.

El Niño–Southern Oscillation (ENSO) A reversal of wind and water currents in the South Pacific.

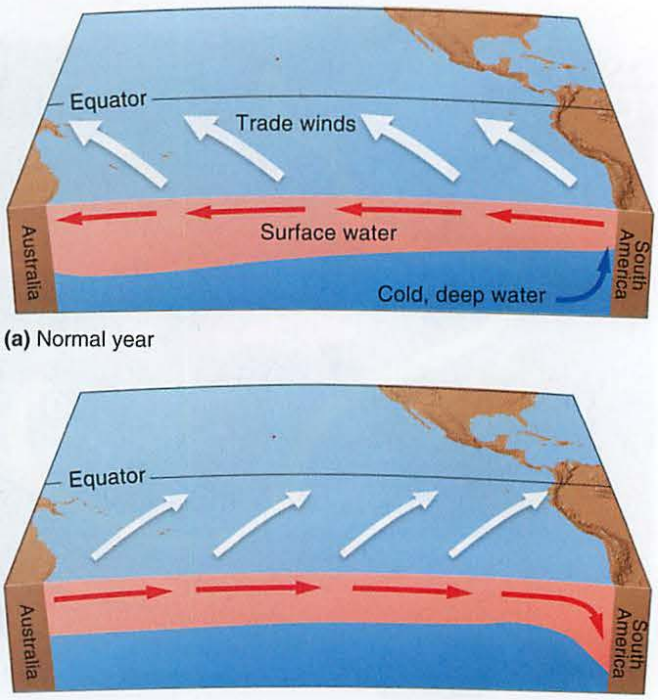


FIGURE 11.3 The El Niño–Southern Oscillation. (a) In a normal year, trade winds push warm surface waters away from the coast of South America and promote the upwelling of water from the ocean bottom. (b) In an El Niño year, trade winds weaken or reverse direction, so warm waters build up along the west coast of Peru.

MODULE 11

AP® Review

Preparing for the AP® Exam

In this module, we have learned that the circulation of surface ocean currents and deep ocean currents is driven by the unequal heating of Earth, air currents, Coriolis forces, and differences in salt concentrations. These currents help to transport heat to different regions of the world and therefore help determine the climates around the globe. The disruption of these currents—due to the ENSO, and potentially because of glacier melting—can have major impacts on these climates. In the next module, we will examine how differences in climate help to determine the plants and animals that live in different parts of the world.

AP® Practice Questions

Choose the best answer for the following.

1. Which does NOT drive ocean currents?
   (a) salinity
   (b) prevailing winds
   (c) temperature
   (d) precipitation
2. High productivity and nutrient availability in the ocean occurs in areas with
   (a) gyres.
   (b) upwelling.
   (c) warm waters.
   (d) prevailing westerlies.
3. Climate change could potentially disrupt which phenomenon?
   (a) El Niño–Southern Oscillation (ENSO)
   (b) thermohaline circulation
   (c) upwelling off the coasts of Australia and New Zealand
   (d) the polar current along Antarctica
4. Which is NOT true of an El Niño–Southern Oscillation (ENSO) event?
   (a) It causes increased upwelling on the west coast of South America.
   (b) It causes wetter conditions in the southern United States.
   (c) It includes a reversal in tropical ocean currents.
   (d) It often begins near Christmas.
5. Gyres do all of the following EXCEPT
   (a) redistribute heat in the ocean.
   (b) result from the Coriolis effect.
   (c) redistribute nutrients from the deep ocean.
   (d) affect the temperatures of coastal areas.

MODULE 12

Terrestrial Biomes

Climate affects the distribution of species around the globe. For example, only species that are well adapted to hot and dry conditions can survive in deserts. A very different set of organisms survives in cold, snowy places. In this module, we will examine how differences in climate help determine the species of plants and animals that live in each region and how scientists categorize these regions.

Learning Goals

After reading this module you should be able to

- explain how we define terrestrial biomes.
- interpret climate diagrams.
- identify the nine terrestrial biomes.

Terrestrial biomes are defined by the dominant plant growth forms

Scientists have long recognized that organisms possess distinct growth forms, many of which represent adaptations to local temperature and precipitation patterns. For example, if we were to examine the plants from all the deserts of the world, we would find many cactus-like species. Plants that look like cacti in North American deserts are indeed members of the cactus family, but those in the Kalahari Desert are members of the euphorb family. These two distantly related families of plants look similar because they have evolved similar adaptations to hot, dry environments—including the ability to store large amounts of water in their tissues and a waxy coating to reduce water loss (**FIGURE 12.1**).