Unit 2
Ocean Currents

In this unit, you will

• Investigate the forces that drive surface currents in the world’s oceans.

• Identify major ocean gyres and their physical properties — temperature, speed, and direction.

• Correlate current direction and speed with global winds.

• Examine ocean salinity and temperature patterns and their relationship to deep-water density currents.

NASA SEASAT satellite image showing average surface wind speed (colors) and direction (arrows) over the Pacific Ocean.
Warm-up 2.1  

A puzzle at 70° N

Common sense tells us that temperatures increase closer to Earth’s equator and decrease closer to the poles. If this is true, the pictures below present a strange puzzle (Figure 1). They show two coastal areas at about the same latitude but on opposite sides of the North Atlantic Ocean. Nansen Fjord, on the left, is on Greenland’s eastern coast, while Tromsø, right, lies on the northwestern coast of Norway. These places are at roughly the same latitude, but their climates could hardly be more different.

1. Why do you think the temperatures at the same latitude in Greenland and Norway are so different?
Since the first seafarers began traveling the world’s oceans thousands of years ago, navigators have known about currents — “rivers in the ocean” — that flow over long distances along predictable paths.

In 1855, Matthew Maury wrote about the Gulf Stream current, which flows off the east coast of Florida.

“There is a river in the ocean. In the severest droughts it never fails, and in the mightiest floods it never overflows; its banks and its bottom are of cold water, while its current is of warm; the Gulf of Mexico is its fountain, and its mouth is the Arctic Sea. It is the Gulf Stream. There is in the world no other such majestic flow of waters.”

—Matthew Maury, The Physical Geography of the Sea and Its Meteorology

Maury was not the first person to notice the Gulf Stream. In March 1513, the Spanish explorer Juan Ponce de León left the island of Boriquen (Puerto Rico) in search of the island of Bimini and the legendary Fountain of Youth (Figure 2). Instead, he landed on what is now Florida. After sailing northward along Florida’s east coast, he turned around and headed south. While sailing in this direction he discovered that even under full sail with a strong breeze at his back, his ship moved backward in the water! His solution was to maneuver his ship closer to shore and out of the current.

Two hundred fifty years later, Benjamin Franklin, then serving as Deputy Postmaster General, received complaints that ships delivering mail between Boston and England took as long as two months to make the return trip back to America. Merchant ships, which were heavier and took a less direct route than the mail ships, were making the trip back from England in just six weeks.

With help from his cousin Timothy Folger, a whaling captain, Franklin determined that the returning mail ships were sailing against a strong current that ran along the eastern seaboard and across the Atlantic to the British Isles. Whalers knew about the current, whose plankton-rich margins attract whales, and used or avoided the current as needed to speed their travels. Franklin and Folger offered their chart of the gulf stream (Figure 3) to the mail-ship captains, with the promise of cutting their return time in half, but they were largely ignored.

2. What are some factors that might cause ocean water to flow in currents like the Gulf Stream?
3. Explore the idea of what causes ocean currents by comparing how water behaves in a bathtub or small pond, compared to water in the ocean. In Table 1, make a list of differences between the conditions present or acting on a bathtub of water and those in an ocean, and explain how those different conditions might cause currents.

### Table 1 — Comparing bathtub water with ocean water

<table>
<thead>
<tr>
<th>Condition</th>
<th>Bathtub conditions</th>
<th>Ocean conditions</th>
<th>Why this characteristic might cause currents to form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom and surface features</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume of water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salinity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uniformity of temperature</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coriolis effect (see note at left)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Coriolis effect**

As air or water moves over Earth’s surface, the planet rotates under it. Relative to the solid Earth, the flow appears to deflect to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. In this way, the Coriolis effect influences the rotation of large-scale weather and ocean-current systems. The Coriolis effect does not influence water in sinks or toilets because the scale at which water moves in these objects is very small.

To learn more about the Coriolis effect, point your Web browser to:

http://ww2010.atmos.uiuc.edu/ (Gh)/guides/mtr/fw/crls.rxml

4. Which of the conditions above do you think are the most important in the formation of ocean currents? Explain.
Early nautical charts depicting the Gulf Stream current were useful, but were not entirely accurate. They often assumed that the Gulf Stream began in the Gulf of Mexico when, in fact, it flows westward from the equatorial Atlantic Ocean, turns northward and flows along the East Coast from Florida to the Saint Lawrence Seaway, and then across the Atlantic toward Great Britain (Figure 4).

5. Maury and Franklin both described the Gulf Stream as a warm surface current — that is, its water is warmer than the surrounding ocean. Do you think the ocean also has cold surface currents? Explain your reasoning.

Despite Maury’s assertion that “There is in the world no other such majestic flow of waters,” the Gulf Stream is not unique. Surface currents have existed in the world’s oceans throughout Earth’s history, and have influenced life on our planet in important ways.

6. Describe four ways that surface currents might affect you (or another person), either at sea or on land.
   a. 
   b. 
   c. 
   d. 

Figure 4. Satellite image of sea-surface temperatures associated with the Gulf Stream off the east coast of North America. Reds and oranges represent warm water, greens and blues cooler water. The warmest water appears dark brown or almost black in this image.
7. Recall the puzzle posed in Question 1 about the extreme climate differences between the coasts of Greenland and Norway. Map 1 shows the location of the Gulf Stream current. On the map, draw the locations of other currents that you think could solve this puzzle. Label each current as warm or cold.

Map 1 — Location of Gulf Stream current

In this unit, you will investigate the forces that drive surface currents and how these currents influence ocean processes and life on Earth.
A puzzle at 70° N
Investigation 2.2

Oceans in motion

The oceans are not stagnant, motionless bodies of water. Entire ocean basins gradually change shape, size, and location over millions of years. The oceans are continually active in many other ways as well, across a variety of time scales. Waves rush in and out on an ocean beach within seconds, and sea level rises and falls with the daily tides. Offshore, the movement of the ocean is equally pronounced, with large volumes of water flowing in tremendous currents. Currents can be thought of as vast rivers without banks that transport immense volumes of water around the globe. In this activity, you will explore the characteristics of these surface currents.

Surface currents

To understand how surface currents form, you will begin this investigation by exploring where they are found and the directions in which they flow.

Launch ArcMap, and locate and open the ddoe_unit_2.mxd file.

Refer to the tear-out Quick Reference Sheet located in the Introduction to this module for GIS definitions and instructions on how to perform tasks.

In the Table of Contents, right-click the Surface Currents data frame and choose Activate.

Expand the Surface Currents data frame.

This data frame shows the approximate locations and extents of surface currents in each ocean. Different colors represent individual currents, and white represents areas without significant currents.

1. In addition to the Arctic Ocean, there are other large areas where surface currents are absent. In general, in what regions of the oceans are these areas located?

Turn off and collapse the Surface Currents layer.

Current directions

Next, you will search for patterns in the general movement of water within each ocean.

Turn on the Current Direction layer.

Select the Current Direction layer.

How deep are surface currents?

Surface currents typically extend to depths of less than 400 m.
In this investigation, current direction is defined as the direction the water is flowing toward. The direction of a current flowing from east to west will be described simply as west. The Current Direction layer shows the average flow direction of the ocean’s surface layer, in one of four cardinal directions (Figure 1 at left): north (N), south (S), east (E), or west (W).

2. Examine the direction of currents in each ocean, then draw circular ocean-current patterns with lines and arrows on Map 1. Indicate the direction of motion in each hemisphere and in each ocean. The North Atlantic current is already drawn as an example. Remember, there is only one Pacific Ocean; but in this map projection, half of the ocean appears on each side of the map.

Map 1 — Generalized ocean currents

The large, roughly circular paths taken by currents as they flow around the edges of each ocean are called gyres (JYE-urz).

3. Examine Map 1 and compare the circulation of gyres in the Northern and Southern Hemisphere. Complete the table below using CW (clockwise), CCW (counterclockwise), or B (both).

Table 1 — Circulation of gyres in each hemisphere

<table>
<thead>
<tr>
<th>Hemisphere</th>
<th>Circulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern</td>
<td></td>
</tr>
<tr>
<td>Southern</td>
<td></td>
</tr>
</tbody>
</table>

Turn off the Current Direction layer.

A closer look at ocean gyres

The four currents that form a gyre flow in a closed circuit around the outer edge of an ocean (Figure 2). The two currents traveling east and west across the ocean are called transverse currents, and the two flowing north and south near or along the edges of continents are called boundary currents. Next, you will examine the unique temperature and speed characteristics of currents within gyres.
Temperature patterns

In this section, you will characterize global ocean temperatures and investigate how surface currents may influence them.

- Turn on the Water Temperature layer.
- Select the Water Temperature layer.

This layer displays the average annual surface temperature of the world’s oceans. Dark red represents warmer temperatures and dark blue represents cooler temperatures.

4. Which latitude bands in each hemisphere contain the warmest surface waters? Which contain the coldest surface waters?
   a. Warmest —
   b. Coldest —

5. Given the underlying principle that heat flows from warmer to cooler areas, and knowing the direction that the gyres flow in each hemisphere, predict which boundary current — the eastern or western boundary current — will be warmer in each hemisphere. (Refer to Figure 2 and Map 1 on the previous page.)
   a. Northern Hemisphere (circle one): western / eastern
   b. Southern Hemisphere (circle one): western / eastern

To check your prediction, you will calculate the average temperature of the eastern boundary currents in the Northern and Southern Hemispheres. The western boundary currents have already been done for you and are listed in Table 2 on the following page.

- Click the Select By Attributes button.

To select the eastern boundary currents in the Northern Hemisphere, query the Water Temperature layer for (“Type” = ‘eastern boundary’) and (“Hemisphere” = ‘Northern’) as shown in steps 1-6. The query will actually read:

   (“CURRENT_TY” = ‘eastern boundary’) AND (“HEMISPHERE” = ‘Northern’)

QuickLoad Query

- Click the QuickLoad Query button and select the NHemisphere Eastern Boundary query.
- Click OK.
- Click New.
If you have difficulty entering the query statement correctly, refer to the *QuickLoad Query* described on the previous page.

The eastern boundary currents in the Northern Hemisphere should be highlighted. Next you will calculate statistics for the selected data.

- Click the Statistics button [ ] in the Select By Attributes window.
- In the Statistics window, calculate statistics for *only selected features* of the *Water Temperature* layer, using the *Temp (C)* field.

- Click **OK**.

The average water temperature of the eastern boundary currents in the Northern Hemisphere is reported in the Statistics window as the **Mean**.

6. Record the average (**Mean**) temperature of the eastern boundary currents in the Northern Hemisphere in Table 2. Round values to the nearest 0.1 °C.

**Table 2—Average temperature of boundary currents by hemisphere**

<table>
<thead>
<tr>
<th>Boundary currents</th>
<th>Average temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Northern Hemisphere</td>
</tr>
<tr>
<td>Western</td>
<td>22.2</td>
</tr>
<tr>
<td>Eastern</td>
<td></td>
</tr>
</tbody>
</table>

- Close the Statistics window.
- Click **Clear** in the Select By Attributes window to clear the previous query.
- Repeat the Select By Attributes operation to select the eastern boundary currents in the Southern Hemisphere. Query the *Water Temperature* layer for (“**Type**” = ’eastern boundary’) and (“**Hemisphere**” = ‘Southern’). The query will actually read:

(“CURRENT_TY” = ‘eastern boundary’) AND (“HEMISPHERE” = ‘Southern’)  

- If you have difficulty entering the query statement correctly, refer to the *QuickLoad Query* described at left.

The eastern boundary currents in the Southern Hemisphere should be highlighted. Next you will calculate statistics for the selected data.

- Click the Statistics button [ ] in the Select By Attributes window.
In the Statistics window, calculate statistics for **only selected features** of the **Water Temperature** layer using the **Temp (C)** field.

- Click **OK**.

The average water temperature of the eastern boundary currents in the Southern Hemisphere is reported in the Statistics window as the **Mean**.

7. Record the average (**Mean**) temperature of the eastern boundary currents in the Southern Hemisphere in Table 2. Round values to the nearest 0.1 °C.

8. How do these results compare with your predictions about the temperatures of boundary currents in question 5? Explain the patterns you see.

9. Use the temperature data in Table 2 on the previous page and the direction of the currents you recorded on Map 1 (page 52) to complete these statements about how boundary currents redistribute heat energy within oceans. Refer to Figure 2 (page 52) to review the four types of boundary currents.

   a. Western boundary currents transport *(circle one)* warm / cold water to *(circle one)* tropical / polar regions.

   b. Eastern boundary currents transport *(circle one)* warm / cold water to *(circle one)* tropical / polar regions.

- Close the Select By Attributes and Statistics windows.
- Click the **Clear Selected Features** button.
- Turn off the **Water Temperature** layer.

**Wind and current directions**

Normally, currents are labeled according to the direction they are flowing **toward**, whereas winds are labeled according to the direction they are blowing **from**. To avoid confusion, winds and currents are both labeled according to the direction they are moving **toward** in this activity. Thus, a wind or current flowing from south to north is designated **N or north**.

Major ocean currents may also be named for their geographic location. For example, the Benguela (ben-GWAY-luh) Current is named after the port city of Benguela, on the coast of western Angola, Africa.

**Speed patterns**

Just as we can predict ocean temperatures based on where a current originates, the location of a current within a gyre also provides clues about the current’s speed. Looking at the speed of the current may also help us answer the question “What drives the currents?”

- Turn on the **Current Speed** layer.
- Select the **Current Speed** layer.

This layer displays the average annual speed of water circulating in the world’s oceans. Dark red represents higher speed (faster currents), whereas pink represents lower speed (slower currents). Examine the map and look for patterns in the current speed.
10. Which of the four types of gyre currents (eastern boundary, western boundary, eastern transverse, western transverse) appear to be moving the fastest in each hemisphere?

Next, you will examine the speed of currents in gyres by summarizing the speed data based on current type.

- Click the Summarize button \( \Sigma \).
- In the Summarize window, select **Current Speed** as the feature layer.
- Select **Type** as the field to summarize in the drop-down menu.
- Double-click **Speed (m/s)** to display the statistics options and check **Average**, and click **OK**.

11. Use the summary table to complete Table 3. Round values to the nearest 0.01 m/s.

Table 3 — Average speeds of boundary current types

<table>
<thead>
<tr>
<th>Boundary current type</th>
<th>Average speed m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern boundary</td>
<td></td>
</tr>
<tr>
<td>Northern transverse</td>
<td></td>
</tr>
<tr>
<td>Southern transverse</td>
<td></td>
</tr>
<tr>
<td>Western boundary</td>
<td></td>
</tr>
</tbody>
</table>

- Close the summary table.

In the next section, you will explore why these currents flow at different speeds.
Wind and current directions

 Normally, currents are labeled according to the direction they are flowing toward, whereas winds are labeled according to the direction they are blowing from. To avoid confusion, winds and currents are both labeled according to the direction they are moving toward in this activity. Thus, a wind or current flowing from south to north is designated as \textit{N} or \textit{north}. Major ocean currents may also be named for their geographic location. For example, the Benguela Current is named after the port city of Benguela, on the coast of western Angola, Africa.

Where the wind blows

Global winds are general, consistent patterns of air movement driven by the sun's heat energy and Earth's rotation. Next, you will examine these circulation patterns and compare them to ocean surface-current patterns.

- Turn off the \textbf{Current Speed} and \textbf{Ocean Labels} layers.
- Turn on the \textbf{Wind Direction} layer.

12. Examine the predominant wind direction within each latitude band. Summarize your observations in Table 4. If there is not a clear overall movement of the wind in one direction, record the wind direction as \textit{mixed}. (Important: Read the clarification about wind and current directions in the sidebar before you fill in the table.)

Table 4 — Wind direction by latitude

<table>
<thead>
<tr>
<th>Latitude band</th>
<th>Predominant wind direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>60° – 90° N</td>
<td></td>
</tr>
<tr>
<td>30° – 60° N</td>
<td></td>
</tr>
<tr>
<td>0° – 30° N</td>
<td></td>
</tr>
<tr>
<td>0° – 30° S</td>
<td></td>
</tr>
<tr>
<td>30° – 60° S</td>
<td></td>
</tr>
<tr>
<td>60° – 90° S</td>
<td></td>
</tr>
</tbody>
</table>

13. How does the wind direction change between 30° – 60° N latitudes as the winds approach the western edge of both North America and North Africa?

14. Does the same change in wind direction occur between 30° – 60° S as the winds approach the western edge of South America, southern Africa, and southern Australia? If not, how does the pattern differ?

15. Based on the currents you drew on Map 1 (page 52), how do the ocean current directions compare to the predominant wind — the same, opposite, or at some other angle to the wind direction? Explain your answer.

16. Using your knowledge of winds and the location of large land masses, explain why you think transverse currents flow faster than boundary currents.
Surface currents and winds

Surface currents appear to be related to prevailing winds, but do the winds and currents move in exactly the same direction? Next, you will examine four currents to compare the wind and the current direction.

- Turn on the Selected Currents layer.
- Select the Selected Currents layer.

The Selected Currents layer outlines large segments of four major surface currents: the California, Benguela, North Equatorial, and South Indian currents. You will be gathering and recording data about these currents in Table 5. Data for the Benguela and North Equatorial currents have been entered in the table for you.

17. For the California and South Indian current regions, visually estimate the predominant wind direction and record your answer in the Direction - Wind column of Table 5. (Note: It may help to turn the Selected Currents layer on and off.)

- Turn off the Wind Direction layer.
- Turn on the Current Direction layer.

The Current Direction layer shows the average direction of oceanic surface currents.

18. Visually estimate the predominant current direction for these two regions and record it in the Direction - Current column of Table 5. (Note: It may help to turn the Selected Currents layer on and off.)

Table 5 — Direction of global winds and surface currents

<table>
<thead>
<tr>
<th>Surface current</th>
<th>Direction Wind</th>
<th>Bearing Wind</th>
<th>Direction Current</th>
<th>Bearing Current</th>
<th>Wind-current offset direction</th>
<th>Hemisphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benguela</td>
<td>N</td>
<td>344</td>
<td>N</td>
<td>331</td>
<td>CCW</td>
<td>S</td>
</tr>
<tr>
<td>California</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North Equatorial</td>
<td>W</td>
<td>237</td>
<td>W</td>
<td>275</td>
<td>CW</td>
<td>N</td>
</tr>
<tr>
<td>South Indian</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

19. Compare the general direction of the currents to the direction of the winds in Table 5.

- Turn off the Current Direction layer.
- Turn on the Wind Direction layer.
- Select the Selected Currents layer.
Next, you will compare your visual observation with each current’s average direction (bearing) in degrees.

- Click the Select By Attributes button.
- To select the California Current, query the Selected Currents layer for (“Name” = ‘California’). The query will actually read: (“CURRENT_NA” = ‘California’)
- If you have difficulty entering the query statement correctly, refer to the QuickLoad Query described at left.
- Click New.
- Close the Select By Attributes window.

The outlined region of the California Current should now be highlighted.

Next, you will perform a Select By Location operation to determine the bearing of the wind over the California Current.

- Click the Select By Location button.
- In the Select By Location window, construct the query statement:
  I want to select features from the Wind Direction layer that intersect the features of the Selected Currents layer.
- Check the Use selected features box and click Apply.
- Close the Select By Location window.
- Click the Statistics button.

In the Statistics window, calculate statistics for only selected features of the Wind Direction layer, using the Bearing (Deg) field.
- Click OK.

The average bearing of the wind above the California current is reported in the Statistics window as the Mean.

20. Round the average (Mean) wind bearing to the nearest degree and record it in the Bearing - Wind column of Table 5 on the previous page.
- Close the Statistics window.

Now you will determine the average direction (bearing) of the California Current in the outlined region.

- Click the Select By Location button.

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**QuickLoad Query**

- Click the QuickLoad Query button and select the California Current query.
- Click OK.
- Click New.

You will return here to repeat this procedure.

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**Bearing**

Bearing is the location or direction of movement of something, calculated by using a map or compass. The units of bearing are in degrees; 000° and 360° are to the north, 090° is to the east, 180° is to the south, and 270° is to the west.
In the Select By Location window, construct the query statement:

I want to select features from the **Current Direction** layer that intersect the features of the **Selected Currents** layer. (Note: The **Current Direction** layer should be the only box checked.)

Check the **Use selected features** box and click **Apply**.

Close the Select By Location window.

In the Statistics window, calculate statistics for only selected features of the **Current Direction** layer, using the **Bearing (Deg)** field.

Click **OK**.

The average bearing of the California current is reported in the Statistics window as the **Mean**.

21. Record the average (Mean) current bearing in degrees in the **Bearing - Current** column of Table 5 (page 58). Round your answer to the nearest whole number.

22. Record the wind and current bearing for the South Indian Current in Table 5. Round your answers to the nearest whole number.

23. On Graph 1 on the following page, plot each surface current from Table 5. (The Benguela Current has been done for you.)
   a. Draw a solid line to indicate the average wind bearing.
   b. Draw a dashed line to indicate the average current bearing.
   c. Draw an arrow from the wind bearing to the current bearing. This arrow represents the **wind-current offset**, the difference between the direction the current is moving and the direction the wind is moving.
   d. Label the current on the graph.

24. Examine the arrows you drew on Graph 1 from each wind to its related current and record whether the wind-current offset for each current is counterclockwise (CCW) or clockwise (CW) in the **Wind-current offset direction** column of Table 5.

25. Record the hemisphere where each current is located in Table 5. (Northern Hemisphere = N and Southern Hemisphere = S).
26. Using the data you recorded in Table 5, describe any patterns you see between the hemisphere and the wind-current offset direction.

   a. Northern Hemisphere —

   b. Southern Hemisphere —

   Graph 1 — Winds and currents of major surface currents

27. What do you think causes the small difference in direction between a wind and its associated current? Do you think the wind is driving the current or is the current driving the wind? Explain.
Current basics

Ocean waters are continuously moving, circling the ocean basins in powerful currents hundreds of kilometers wide, and in swirls and eddies as small as a centimeter across. The primary forces driving the large-scale motions are the sun's energy and Earth's rotation. Energy from the sun warms Earth's surface and atmosphere, generating winds that initiate the horizontal movement of surface water (Figure 1). Vertical movement between the surface and the ocean depths is tied to variations in temperature and salinity, which together alter the density of seawater and trigger sinking or rising of water masses. Together, the horizontal and vertical motions of water link the world's oceans in a complex system of surface and subsurface currents often referred to as the Global Conveyor Belt (Figure 2). This circulation system plays a vital role in transporting and distributing heat, nutrients, and dissolved gases that support life around the globe.

Structure of the ocean waters

The oceans contain numerous water masses, which can be differentiated by their physical and chemical characteristics such as salinity, temperature, and density. The density of seawater depends on its temperature and salinity, as well as the amount of pressure exerted on it. Water expands as it warms, increasing its volume and decreasing its density. As water cools, its volume decreases and its density increases. Salinity, the amount of dissolved solids (like salts) in the water, alters density because the dissolved solids increase the mass of the water without increasing its volume. So, as salinity increases, the density of the water increases. Finally, when the pressure exerted on water increases, its density also increases.

Density — the mass per unit volume of a substance or object.

\[
\text{density} \ (\text{kg/m}^3) = \frac{\text{mass} \ (\text{kg})}{\text{volume} \ (\text{m}^3)}
\]

Changing density

The density of water changes as its temperature or salinity (or both) change.

- If the temperature decreases and/or the salinity increases, the water becomes more dense.
- If the temperature increases and/or the salinity decreases, the water becomes less dense.
1. Rank the following types of ocean water from highest density (1) to lowest density (3).
   a. Warm, salty water _____
   b. Cold, salty water _____
   c. Warm, freshwater _____

The characteristics of a water mass typically develop at the ocean surface due to interactions with the atmosphere. Evaporation can increase salinity as freshwater is removed from the ocean and the salts are left behind. Precipitation has the opposite effect, decreasing salinity levels as freshwater is added to the ocean. Processes like photosynthesis and the exchange of energy and matter between the ocean surface and the atmosphere can affect the amounts of oxygen and other dissolved gases in the water.

In addition, water temperature (and thus density) changes rapidly as surface currents transport water masses from the equator to the poles and vice versa. Although the sun's energy is very efficient at warming the upper 100 meters of the ocean, very little solar energy penetrates to deeper waters. Therefore, water temperature decreases rapidly between 100 and 800 m depth. This region of decreasing temperature is called the thermocline, and marks the boundary between surface-water circulation and deep-water circulation (Figures 3 and 4).

2. The water temperature at the base of the thermocline is around 5 °C. Using this information, sketch and label the approximate location of the base of the thermocline in Figure 4 on the following page.
A similar zone, in which salinity changes rapidly with depth, is called the haloine (Figure 5). However, the haloine is not as well defined as the thermocline and in some places does not exist.

Once formed, water masses tend to retain their original characteristics because they mix very slowly with the surrounding water — except in places where the thermocline is very weak. Their distinctive characteristics make it possible to identify their place of origin and track their movements. In fact, it is by tracking differences in the physical properties of water masses that scientists have been able to begin mapping the Global Conveyor Belt.

**Wind-driven currents**

Winds are created by uneven heating of Earth's surface by the sun, due primarily to Earth's nearly spherical shape (Figure 6 on the next page). Surface temperature variations create temperature and pressure differences in the layer of air near the surface. To equalize these differences, air moves from regions of high pressure to regions of low pressure, creating wind.
Spreading light
When the sun is directly overhead at the equator, the same amount of sunlight that falls on one square meter at the equator would be spread over two square meters in Anchorage, Alaska.

In the Tropics, the sun’s rays are nearly perpendicular to Earth’s surface, producing maximum heating. Near the poles, Earth’s curvature causes the energy to spread over a greater area, producing less surface heating.

Figure 6. Variation in solar heating with latitude.

Low-pressure belts form where warm air rises, near the equator and around 60° latitude (Figure 7); high-pressure belts are found where cool air sinks, near the poles and around 30° latitude. Air moving from high pressure toward low pressure creates six global wind belts encircling Earth. These belts shift slightly north and south with the seasons, but they are otherwise permanent features. Strong prevailing winds and solar warming produce ocean surface currents that extend to depths ranging from 45–400 m under typical conditions. This surface layer of currents is called the Ekman layer, or the wind-blown layer.

Traditional wind names
The global wind belts in Figure 6 are named, by tradition, according to the direction they are blowing from. In these materials we name both winds and ocean currents according to the direction they are blowing toward. For example, in the Northern Hemisphere, we would describe the direction of the Westerlies as northeast (or NE).

The Coriolis effect and Ekman transport
Over short distances, winds and the ocean surface currents they generate follow straight paths, but over greater distances they curve due to Earth’s rotation. This phenomenon is called the Coriolis effect. In the Northern Hemisphere, the Coriolis effect causes winds and ocean currents to veer...
to the right; in the Southern Hemisphere, the winds and ocean currents curve to the left.

As you learned in Investigation 2.2, **Ekman transport** is an offset between a current direction and its associated wind. It is useful to think of the Ekman layer as containing many thinner layers of water flowing over one another (Figure 8). In the Northern Hemisphere Ekman transport is deflected to the right and in the Southern Hemisphere Ekman transport is deflected to the left. This phenomenon is caused by the Coriolis effect and the slowing and deflection of water due to friction between successively deeper layers of water. It is theoretically possible for water to actually flow in a direction opposite to the surface current, but this has never been observed. The overall motion of the Ekman layer, referred to as Ekman transport, is at an angle of about 90° to the wind direction.

3. If the arrows below represent the prevailing winds somewhere over the ocean in the Northern and Southern Hemispheres, draw another arrow to indicate which direction Ekman transport would cause water to flow.
   a. Northern
   b. Southern

   ![Figure 8. The Ekman spiral. The red arrow represents the net effect, called Ekman transport. Clockwise Northern Hemisphere deflection is shown here. Southern Hemisphere deflection is counterclockwise. Note: The water does not spiral downward like a whirlpool.](image)

**Wind-driven upwelling and downwelling**

In nearshore environments, it is common to have winds blowing parallel to shore over the ocean (Figure 9). Ekman transport moves surface water offshore and pulls deep, cold, nutrient-rich water to the surface. This process, known as **wind-driven upwelling**, is restricted mainly to the west coast of continents, and is responsible for the high productivity of nearshore waters.

![Figure 9. Factors that produce coastal upwelling.](image)

Upwelling occurs in the open ocean near the equator in a similar manner (Figure 10). On both sides of the equator, surface currents moving westward are deflected slightly poleward and are replaced by nutrient-rich, cold water from great depths.

![Figure 10. Factors that produce equatorial upwelling.](image)
The mechanical action of wind on the currents promotes mixing of the Ekman layer, which tends to deepen the thermocline and promote the upwelling of nutrients. The thermocline, which separates less dense, warm surface water from the more dense, cold water below, is most pronounced at low latitudes and prevents nutrient-rich deep waters from rising to the surface. In contrast, upwelling occurs more readily in high-latitude regions near the poles. These regions receive little sunlight and are not warmed by solar energy. Without a distinct thermocline, upwelling easily brings nutrients toward the surface and promotes mixing.

**Surface currents**

Gyres play a major role in redistributing the sun’s heat energy around the globe. Each gyre consists of four interconnected, yet distinct currents (Figure 11). A pair of boundary currents flows north or south, parallel to the bordering landmasses. Western boundary currents carry warm equatorial water poleward, while eastern boundary currents carry cooler temperate and polar water toward the equator. These currents interact with the air near the surface to moderate the climate of coastal regions. Within a gyre, boundary currents are connected by transverse currents. Transverse currents move east or west across the gyre’s northern and southern edges.

The speed of a current within a gyre is related to the prevailing winds and the location of landmasses. Western boundary currents are narrow but move huge masses of water quickly as the westward-blowing trade winds push water against the eastern edges of continental landmasses (Figure 12).

The Coriolis effect and resulting Ekman transport occurring at 90° from the wind direction further enhance the speed of western boundary currents, a phenomenon called **western intensification**. Although most of the water at the equator moves westward then poleward, the low-intensity winds and lack of Coriolis effect at the equator allow for some of the water at the surface to flow eastward in equatorial countercurrents.
Seawater salinity

The average salinity of seawater is 34.7 ppt or parts per thousand (also symbolized ‰). That means that a liter of ocean water (a little more than a quart) contains 34.7 grams (~2.5 tablespoons) of various salts.

To learn more about the composition of seawater, click the Media Viewer button and choose Seawater.

Density-driven currents

In addition to wind-driven horizontal surface currents, ocean circulation has a vertical component that is driven by differences in water density. When surface water cools or becomes more saline due to evaporation or other processes, its density increases and it sinks either to the bottom of the ocean or to a depth where its density equals that of the surrounding water. This density-driven circulation pattern is referred to as thermohaline circulation, and the currents it produces are called density currents. The cold water eventually returns to the surface to be reheated and returned to the poles by surface currents, or to mix with other water masses and return to the depths. Thermohaline currents move very slowly — about 1 centimeter per second — 10 to 20 times slower than surface currents.
6. Examine Figure 14. What happens to the density of water as temperature decreases? (Follow one of the vertical lines of constant salinity downward, and note what happens to the density values.)

7. Use Figure 14 to determine what happens to the density of ocean water as the salinity increases. (Follow one of the horizontal lines of constant temperature from left to right, and note what happens to the density values.)

Deep currents are generated by relatively small density variations. In fact, the density of seawater must be determined to several decimal places to detect significant differences. The points labeled A and B on Figure 14 represent the salinity and temperature values for two water masses.

8. Use Figure 14 to determine the temperature, salinity, and density of water masses A and B and record them in Table 2.

Table 2 — Mixing of water masses A and B

<table>
<thead>
<tr>
<th>Point</th>
<th>Temperature °C</th>
<th>Salinity ppt</th>
<th>Density kg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
When two water masses of the same density meet, they tend to mix. The temperature and salinity of the new water mass lie somewhere between those of the two original water masses. Imagine mixing equal parts of the two water masses. The temperature and salinity of the new water mass would lie at the midpoint of a straight line connecting point A to point B.

9. Draw a straight line connecting points A and B on Figure 14. Plot the midpoint of the line and label it C.

10. Would the density of the new water mass C be higher or lower than the densities of the two original water masses, A and B?

11. Record the temperature and salinity of point C in Table 2. Use the curved equal-density lines to estimate the density of water mass C and record it in Table 2.

12. Would the new water mass remain at the surface or sink? Explain.

Stability and instability of water masses

When the density of a water column increases with depth, the water column is stable and mixing does not occur. Conversely, when the density of a water column decreases with depth, it is unstable. As the dense water sinks, it produces turbulence and mixes with the layers beneath it. Instability is caused by an increase in the density of surface water due to a decrease in temperature, an increase in salinity, or both.

High evaporation rates can increase the salinity of the surface water; and low air temperatures can cool the surface water, causing it to become unstable and sink. When sea ice forms near the poles, most of the salt remains in the liquid water, increasing its density and producing instability.

There is also a seasonal aspect to ocean stability. During spring and summer, stability increases as the ocean surface warms. In fall and winter, stability decreases as the ocean surface cools.

Areas of instability can produce complex patterns of stratification and thermohaline and surface circulation in the ocean.

As sea ice forms along the coast of Antarctica, surface water cools and becomes more salty. This process is called brine rejection. This salty water sinks and flows northward along the ocean floor, forming the
Antarctic Bottom Water mass (AABW). As winds blow the Antarctic Surface Water (AASW) eastward, the Coriolis effect deflects it toward the north. This causes upwelling of warmer, salty water, the Northern Atlantic Deep Water (NADW). This water mass mixes with the AASW to form the Antarctic Intermediate Water mass (AAIW). Because the AAIW is denser than the surface water (the Subantarctic Water mass or SAAW), it sinks below the SAAW at the Antarctic convergence.

Figure 15. Thermohaline and surface currents off the coast of Antarctica. Colors represent water temperature, and dashed lines represent the boundaries between water masses.

13. Is the water column shown in Figure 15 stable or unstable? Explain.
Deep-water currents

Deep-water currents, also called density currents or thermohaline currents, play a crucial role in maintaining the delicate balance of energy and nutrients in the marine environment. In this activity, you will examine two key factors that control water density — global temperatures and salinity patterns — to understand how they vary and how they affect where density currents form.

Water temperature

The first step in investigating the formation of density currents is to examine the average temperature of the ocean’s surface. Temperature alters the density of seawater because water contracts when it cools. Thus, cooler water takes up less space or volume than warmer water. As a result, the density of water increases as water temperature decreases.

Launch ArcMap, and locate and open the ddoc_unit_2.mxd file.

Refer to the tear-out Quick Reference Sheet located in the Introduction to this module for GIS definitions and instructions on how to perform tasks.

In the Table of Contents, right-click the Deep-water Currents data frame and choose Activate.

Expand the Deep-water Currents data frame.

The Avg Solar Radiation layer shows the average amount of solar radiation per year, in watts per square meter, that would strike the surface if there were no clouds in the atmosphere to reflect the sunlight. Dark shades represent low amounts of radiation, and lighter shades indicate higher amounts.

1. Describe how the average solar radiation varies with
   a. latitude (from pole to pole).

   b. longitude (from east to west).
2. If there were no surface or deep-water currents circulating in the ocean, what effect might solar radiation have on the average temperature of the ocean waters?

- Turn off the **Avg Solar Radiation** layer.
- Turn on the **Avg Sea-Surface Temperature** layer.

This layer shows the average sea-surface temperature. Red represents warmer temperatures and blue represents cooler temperatures.

3. How well does the pattern of sea-surface temperature compare to the solar radiation?

4. Identify areas where surface currents may carry warm water into colder regions or cold water into warmer regions. On Map 1, place a C where sea-surface temperatures are cooler than expected and a W where they are warmer than expected. (Look for four or five of each.)

**Map 1 — Temperature / solar-radiation anomalies and salinity extremes**

Sea-surface temperature is determined by many factors, such as solar radiation and the transfer of warm water from the equator to the poles and cold water from the poles to the equator. Deep-water convection also contributes to sea-surface temperature.

- Turn on the **Upwelling** layer.

The **Upwelling** layer shows where deep-ocean currents rise to the surface, often becoming less dense than the surrounding waters.
5. On Map 1, mark places where upwelling occurs with the label U.

☐ Compare the locations of the upwelling sites to their corresponding surface-temperature anomalies (if any).

6. Are upwelling sites more likely to be associated with cold or with warm surface-temperature anomalies? Explain.

Upwelling can occur as winds that blow parallel to the shoreline cause the surface waters to move away from the coastline, due to Ekman transport (Figure 1). Next you will examine whether winds play a role in developing these particular upwelling sites.

☐ Turn off the Avg Sea-Surface Temperature layer.

☐ Turn on the Wind Direction layer.

The Wind Direction layer displays the bearing of the surface winds over both land and ocean.

☐ Examine the Wind Direction layer to determine the direction of the winds over the boundary currents. (Important: Read the clarification about wind and current directions in the sidebar.)

7. On Map 1 on the previous page, mark the upwelling sites that have winds moving parallel to shore with PW (parallel winds).

8. Describe any patterns you observe between the upwelling sites and the coastal winds.

Wind and current directions

Normally, currents are labeled according to the direction they are flowing toward, whereas winds are labeled according to the direction they are blowing from. To avoid confusion, winds and currents are both labeled according to the direction they are moving toward in this activity. Thus, a wind or current flowing from south to north is designated N or north.

Major ocean currents may also be named for their geographic location. For example, the Benguela Current is named after the port city of Benguela, on the coast of western Angola, Africa.

Upwelling sites are very important for bringing nutrient-rich water from the deep ocean to the surface where marine life can flourish.

☐ Turn off the Upwelling layer.

☐ Turn off the Wind Direction layer.

☐ Turn on the Density-Driven Downwelling layer.

☐ Turn on the Avg Sea-Surface Temperature layer.

Deep-water currents
The **Density-Driven Downwelling** layer shows where surface water sinks as it becomes more dense than the surrounding waters. It will sink to a depth at which all the water below it is more dense and the water above is less dense. Next, you will compare the locations of density-driven downwelling sites to their corresponding surface-water temperatures.

- Click the Identify tool.
- In the Identify Results window, select the **Avg Sea-Surface Temperature** layer from the list of layers.
- Next, click within each of regions displayed by the **Density-Driven Downwelling** layer. The water temperature is listed in the **Temp (C)** field under **Value**.

9. In what range of surface-water temperatures are you most likely to find density-driven downwelling sites?

- Close the Identify Results window.

Global ocean circulation requires that if water is rising in one area, it must be sinking in another area. Next you will continue to explore the factors that influence the location of deep-water convection sites.

- Turn off the **Density-Driven Downwelling** layer.
- Turn off the **Avg Sea-Surface Temperature** layer.

### Seawater salinity

The average salinity of seawater is 34.7 ppt or **parts per thousand** (also symbolized ‰). That means that a liter of ocean water (a little more than a quart) contains 34.7 grams (~ 2.5 tablespoons) of various salts.

To learn more about the composition of seawater, click the Media Viewer button and choose **Seawater**.

### Global salinity patterns

Salinity, in addition to temperature, strongly influences water density. The salts dissolved in seawater increase the density by adding to the water’s mass without changing its volume. Next, you will explore global patterns of ocean salinity and the factors that influence this important property of seawater.

- Turn on the **Ocean Salinity** layer group.
- Select the **Avg Annual Salinity** layer.

This layer group displays the average annual salinity values for the world’s oceans as well as some labels that you will examine later. Higher salinity is shown in shades of green, whereas lower salinity is shown in shades of blue.

- Turn on the **Major Rivers** layer.
- Use the Zoom In tool to examine the average annual salinity data. Look for patterns and anomalies in the data.
- Examine the regions with the highest and lowest salinity. Be sure to look around the edges of the continents as well as in the smaller seas.
10. Describe how the average salinity varies with
   a. latitude (from pole to pole).
   b. longitude (from east to west).

11. What factors might account for the salinity levels in the areas of
    highest and lowest salinity? (Hint: Look at the different layers in
    the Table of Contents for possible factors.)

   - Click the Full Extent button to view the entire map.
   - Turn on the Net Annual Evaporation layer.

   This layer shows the overall loss or gain of freshwater from Earth’s surface
   in centimeters per year. Lower levels of evaporation are shown in green
   and higher levels of evaporation are shown in brown. Evaporation, in
   which liquid water is converted to a gas, moves freshwater from the ocean
   to the atmosphere. When ocean water evaporates, the salt dissolved
   in the water is left behind, increasing the ocean’s salinity. Precipitation
   removes freshwater from the atmosphere and delivers it back to the ocean,
   reducing the ocean’s salinity. Net evaporation is calculated by subtracting
   the total annual precipitation from the total annual evaporation.

   \[
   \text{Net Evaporation} = \text{Total Evaporation (E)} - \text{Total Precipitation (P)}
   \]

12. Predict how you think net evaporation will affect salinity: Areas
    with positive net evaporation will have (circle one) higher / lower
    salinity than areas with negative net evaporation.

13. Where do you find areas with the
   a. *highest* net evaporation? Why might they be found there?
   b. *lowest* net evaporation? Why might they be found there?
Seawater salinity

The average salinity of seawater is 34.7 ppt or parts per thousand (also symbolized ‰). That means that a liter of ocean water (a little more than a quart) contains 34.7 grams (~2.5 tablespoons) of various salts.

To learn more about the composition of seawater, click the Media Viewer button and choose Seawater.

Figure 2. Net evaporation and surface salinity by latitude.

Figure 2 shows the relationship between net evaporation and ocean salinity between 60° N and 60° S. The dip near the middle corresponds to the Intertropical Convergence Zone (ITCZ), a band of moist, unstable air that circles the globe around 7° N latitude. The high net evaporation near 30° N and 30° S is due to global bands of high pressure. The cool, sinking air in these bands produces clear skies and dry conditions. Most of the world’s deserts are found at these latitudes.

14. How well do the data in Figure 2 compare to the prediction you made in question 12?

- Turn off the Net Annual Evaporation layer.
- Turn off the Major Rivers layer.
- Turn on the Density-Driven Downwelling layer.
- Click the Identify tool.
- In the Identify Results window, select the Avg Annual Salinity layer from the list of layers.
- Next, click within each of regions displayed by the Density-Driven Downwelling layer.

15. What range of salinity correlates with the density-driven downwelling sites?

- Close the Identify Results window.
Seventy-five percent of the ocean has a salinity between 33 and 35 ppt. Thus, the salinity at density-driven downwelling sites is not particularly unusual. However, the temperature of seawater in these downwelling sites is definitely colder than the average sea-surface temperature. How does one water mass get colder and saltier than the waters around or below it? You will explore this question by following a water molecule from the saline mid-latitude waters to the polar region of the Atlantic Ocean.

**Forming deep-water masses**

Evaporation creates ocean-water masses with high salinity, but they are too warm to sink as density currents. In this section, you will investigate how cold, dense waters are generated.

The Density-Driven Downwelling layer shows several regions with significant downwelling in the North Atlantic and Southern Oceans. By measuring the surface characteristics in and around these regions, you will better understand the conditions under which density currents form.

- Click the QuickLoad button.
- Select Spatial Bookmarks, choose North Atlantic from the list, and click OK.
- Turn on the Salinity Measurements layer.
- Turn on the Surface Currents layer.

The Surface Currents layer shows the direction and temperature characteristics of surface currents in the North Atlantic Ocean.

- Click the Identify tool.
- In the Identify Results window, select the Avg Annual Salinity layer from the list of layers.
- Next, click points labeled B – E and record the temperature and salinity data in Table 1. (Point A has been done for you.)

**Table 1 — Surface water characteristics in the North Atlantic**

<table>
<thead>
<tr>
<th>Point</th>
<th>Temperature °C</th>
<th>Salinity ppt</th>
<th>Density kg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>17.5</td>
<td>35.6</td>
<td>1026.0</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

16. On Figure 3 on the following page, plot and label the temperature and salinity values you recorded for points B through E. Use the curved dotted lines on the chart to determine the density of the surface water at each point, and record the water density for each point in Table 1.
17. How does the density change from point A to point E?

- Close the Identify Results window.
- Turn off the Surface Currents layer.

To cause density-driven downwelling, the surface water must be denser than the water beneath it, causing the layers to overturn. This occurs in the North Atlantic Ocean, where fresh meltwater from sea ice and the Greenland ice sheet form low-density surface water masses. As warm, high-salinity surface currents flow northward into this region, they cool rapidly and become denser. When these two water masses meet in the North Atlantic Ocean, the water column becomes unstable and the higher-density, high-salinity current sinks.

The densest waters in the ocean range from 1027 to 1029 kg/m³. These correspond to a temperature of 6 °C or less and a salinity of 34 ppt or higher. Next, you will perform a series of operations to identify where those waters lie and compare their density to the waters surrounding them.

- Click the Select By Attributes button.
- To select the densest surface waters in the Northern Hemisphere, query the Avg Annual Salinity layer for (“Hemisphere” = ‘N’) and (“Temp (C)” <= 6) and (“Salinity (ppt)” >= 34) as shown in steps 1-6 below. The query will actually read: (“HS” = ‘N’) AND (“TEMP_C” <= 6) AND (“SALINITY” >= 34)

---

*How dense is freshwater?*

Under normal sea-level temperature and pressure, pure freshwater has a density of 1000 kg/m³.
If you have difficulty entering the query statement correctly, refer to the QuickLoad Query described at left.

The densest surface waters of the Northern Hemisphere should be highlighted. Next, you will calculate statistics for the selected data.

- Click the Statistics button \( \square \) in the Select By Attributes window.
- In the Statistics window, calculate statistics for only selected features of the Avg Annual Salinity layer, using the Temp (C) and Salinity (ppt) fields. (Hold down the shift key to select more than one field.)

- Click OK.

The average salinity and temperature inside the deep-water convection areas is reported in the Statistics window as the Mean.

18. Record the Mean salinity and temperature inside the deep-water convection areas in Table 2. Round values to the nearest 0.1 units. Use these values to determine the average density from Figure 2 and record the density in Table 2 on the following page.
Table 2 — Surface-water characteristics of downwelling areas

<table>
<thead>
<tr>
<th>Area</th>
<th>Temperature °C</th>
<th>Salinity ppt</th>
<th>Density kg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep-water convection areas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjacent waters</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Close the Statistics window.
- Close the Select By Attributes window.
- Click the Clear Selected Features button.
- Turn on the **Adjacent Waters** layer.
- Click the Select By Location button.
- In the Select By Location window, construct the query statement:
  I want to **select features from** the Avg Annual Salinity layer that **intersect** the features in the Adjacent Waters layer.
- Click **Apply**.
- Close the Select By Location window.
- Click the Statistics button.

In the Statistics window, calculate statistics for **only selected features** of the Avg Annual Salinity layer, using the Temp (C) and Salinity (ppt) fields. (Hold down the shift key to select more than one field.)

- Click **OK**.

The average salinity and temperature for the adjacent waters is reported in the Statistics window as the **Mean**.

19. Record the average (Mean) salinity and temperature for the adjacent waters in Table 2. Use these values to determine the average density from Figure 2 and record the density in Table 2.

- Close the Statistics window.

20. Compare the density of water in the deep-water convection areas with that of the adjacent waters. Explain how this relates to the formation of density currents.

- Click the Full Extent button to view the entire map.
The deep-water convection area you have been studying is known as the North Atlantic Deep Water (NADW) current. Another major deep-water convection area is located in the Weddell (wuh-DELL) Sea, off the coast of Antarctica, southeast of South America. This area is the source of the Antarctic Bottom Water (AABW) density current. These deep-water density currents play a major role in the distribution of nutrients throughout the world’s oceans.

Quit ArcMap and do not save changes.
**Wrap-up 2.5**

**Stopping the flow**

The North Atlantic Deep Water (NADW) and Antarctic Bottom Water (AABW) currents are two important parts of the Global Conveyor Belt. The volume of the NADW, which forms as the warm, salty Gulf Stream current moves north, cools, and sinks, is believed to have a volume equal to that of 25 Amazon Rivers! The NADW cruises the deep ocean, eventually meeting up with the AABW, the densest water mass on Earth. Figure 1 shows a schematic of the entire path of the Global Conveyor Belt that connects surface and bottom waters in all five oceans. In Figure 1 the blue lines in Figure 1 represent deep currents and the red lines represent shallow currents.

![Figure 1. Simplified diagram of the Global Conveyor Belt.](image)

1. Besides water, what else might density currents transport to the bottom of the ocean that is crucial to deep-sea life?

2. The average temperature of the ocean is 3.5 °C, whereas the average temperature of the ocean’s surface is around 9 °C. Does this make sense? Explain.
Scientists speculate that 12,000 years ago the Global Conveyor Belt shut down, and that it could do so again in the future. They hypothesize that the density currents stopped forming in response to changes in salinity. Polar melting, changes in global winds and ocean-surface currents, and changes in precipitation patterns could all contribute to shutting down density currents. The climate and ocean currents are part of a very complex system, which makes them challenging to model precisely. Let us imagine a scenario in which a climate change results in a warmer Earth. Answer the questions below based on what you have learned in this exercise.

3. How would this climate change (a warmer Earth) influence the polar ice sheets that contain much of Earth's freshwater?

4. If the polar ice sheets were to melt, how might this influence the density of the ocean surface water?

5. How might the melting of the polar ice sheets influence the upwelling and downwelling of ocean-water masses?

6. What might be some environmental consequences if the Global Conveyor Belt were to shut down?