

CHAPTER 9

THE CURRENTS

Objectives

1. To learn about the many different types of currents in the world's oceans.

Key Concepts

Major Concept (I) *Surface currents in the oceans are driven by winds. The major surface circulation patterns at sea are the result of the prevailing winds in the atmosphere.*

Related or supporting concepts:

- Prevailing winds in the atmosphere drive surface currents in the oceans in predictable patterns.
- Because the density of the water is about 1000 times greater than the density of the air, the motion in the water will continue even when there is no wind because of the water's inertia.
- Surface circulation is a response to the long-term average atmospheric circulation.
- Large circular surface currents called gyres dominate the wind-driven surface circulation in each hemisphere.
- The major gyres in the Northern Hemisphere rotate clockwise, while in the Southern Hemisphere they rotate counterclockwise.
- Imagine that the near surface water is actually composed of a number of thin layers lying on top of one another, each layer numbered, with layer number 1 being at the surface. The blowing wind will drive the water in layer number 1. The motion of layer number 1 will drive the water in layer number 2. In a similar manner, each deeper layer is driven by the one above it.
- Because the friction between the wind and layer number 1 is relatively small, and the friction between water layers is also small, the direction that each layer moves will be influenced by the Coriolis effect.
- The surface water will be deflected at about 45° to the right of the direction of the wind (see fig. 9.1). Each deeper layer of water will also be deflected to the right of the layer above it.
- With increasing depth there will be some loss of energy so the velocity of the motion will decrease.
- The net result is that the blowing wind will create motion in the water that decreases in velocity with depth and is deflected further to the right (in the Northern Hemisphere) or to the left (in the Southern Hemisphere). If you could see this motion it would look like a spiral extending to a depth of 100–150 m (330–500 ft) before motion stopped. This is called the Ekman spiral (see fig. 9.2).
- At the base of the Ekman spiral, the direction in which the water moves is actually opposite the direction in which the wind blows!
- The average direction in which water is being transported over the entire depth of the spiral is 90° to the right of the wind in the Northern Hemisphere and to the left of the wind in the Southern Hemisphere. This is called Ekman transport.

Major Concept (II) *The major surface currents are often given specific names to identify them. Figure 9.5 in the text locates the most important surface currents.*

Related or supporting concepts:

- In the North Pacific the surface circulation is dominated by a clockwise rotating gyre formed by:
 - a. the North Equatorial Current,
 - b. the Kuroshio Current,
 - c. the North Pacific Current, and
 - d. the California Current.This gyre is driven by the northeast trade winds and the westerlies.
- Further north, in the North Pacific, there is a smaller counterclockwise rotating gyre formed by:

- a. the North Pacific Current,
 - b. the Alaska Current, and
 - c. the Oyashio Current.
- There is very little exchange of water between the Arctic Ocean and the North Pacific through the Bering Strait.
- In the South Pacific, the surface circulation is dominated by a counterclockwise-rotating gyre formed by:
 - a. the South Equatorial Current,
 - b. the East Australia Current,
 - c. the northern edge of the West Wind Drift, and
 - d. the Peru Current.

This gyre is derived by the southeast trade winds and the westerlies.
- The North and South Pacific gyres lie on either side of 5°N due to the unequal heating of the surface between the two hemispheres.
- Between these gyres is the Equatorial Countercurrent flowing from west to east, returning some of the water driven toward the western Pacific.
- In the North Atlantic, there is a similar clockwise rotating gyre formed by:
 - a. the North Equatorial Current,
 - b. the Gulf Stream,
 - c. the North Atlantic Current, and
 - d. the Canary Current.
- In the South Atlantic, the counterclockwise rotating gyre is formed by:
 - a. the South Equatorial Current,
 - b. the Brazil Current,
 - c. the northern edge of the West Wind Drift, and
 - d. the Benguela Current.
- The Atlantic gyres are also displaced north of the equator by a small distance.
- There is a weak Equatorial Countercurrent in the Atlantic on the eastern side of the ocean basin. On the western side there is a net flow of water from the Southern Hemisphere to the Northern at the surface.
- Because the Indian Ocean is primarily a Southern Hemisphere ocean, its surface circulation is dominated by a counterclockwise rotating gyre formed by:
 - a. the South Equatorial Current,
 - b. the Agulhas Current,
 - c. the northern edge of the West Wind Drift, and
 - d. the West Australia Current.
- The waters north of the equator in the Indian Ocean move to the east in the summer and to the west in the winter with the seasonal changes in monsoon winds.
- Without any continents to block its flow, the West Wind Drift is the only continuous current flowing around the globe. It moves from west to east around Antarctica.
- Flow in the Arctic Ocean is dominated by a large clockwise gyre. This gyre is not centered on the North Pole. It is displaced toward the Canadian Basin (see fig. 9.6).
- The ice cap overlying the Arctic Ocean is driven by winds and currents at a velocity of about 0.1 knot or 2 miles/day.
- Water flows into the Arctic Ocean from the North Atlantic by the Norwegian current and, to a lesser extent, from the Bering Sea through the Bering Strait. Water flows out of the Arctic Ocean on either side of Greenland into the North Atlantic.

Major Concept (III) *The large gyres that dominate surface circulation isolate lenses of low-density water in their centers. In addition, currents on the western side of Northern Hemisphere ocean basins tend to be narrower and stronger than their counterparts on the eastern side.*

Related or supporting concepts:

- As the prevailing winds drive the large surface gyres, water is directed inward to the center of the gyres

- by Ekman transport.
- Ekman transport will create an elevated sea surface due to the piling up of the water. The difference in elevation is as great as 1 m (3 ft).
 - Gravity causes water to flow down the slopes of this elevated mound. The Coriolis effect will deflect the water and when everything is in balance, there will be a circular rotation of water around the mound. Take a look at figure 9.4 to see an illustration of this phenomenon.
 - Currents that flow as a result of a balance between gravity and the Coriolis effect are called geostrophic currents or geostrophic flow.
 - By measuring water density with depth it is possible to calculate the slope of the sea surface. This can then be used to calculate the velocity of the geostrophic flow, the volume of water transported and the depth of the flow.
 - The central water of surface gyres is isolated in the interior of the gyres.
 - An excellent example of this is the Sargasso Sea in the central North Atlantic where a lens of clear, warm water about 1000 m (3000 ft) thick is isolated by geostrophic flow. This area is often covered by large mats of brown seaweed called *Sargassum*.
 - The surface currents generated by the wind travel at speeds that are about 0.01 times the average wind speed. Typical speeds are on the order of 0.1–0.5 m/s (0.3–1.5 ft/s).
 - Current velocity will increase when large volumes of water are forced through narrow straits. An example would be the Florida Current moving out of the Gulf of Mexico and north along the coast of Florida. It moves at a speed of about 1.5 m/s (5 ft/s).
 - Major currents transport huge volumes of water. The volumes are so great that they are measured in units called Sverdrups. One Sverdrup = 1 million m³/s. The flow of the Gulf Stream is about 55 Sverdrups, over 500 times the flow of the Amazon River.
 - Currents on the western side of Northern Hemisphere ocean basins are stronger than they are on the eastern side. This is known as western intensification and it is related to:
 - a. the Coriolis effect,
 - b. friction between the currents and land, and
 - c. the piling up of water on the western side of the basin by the trade winds.
 - Western intensification is not as pronounced in the Southern Hemisphere because the eastern currents are strengthened by water from the West Wind Drift that is deflected northward by the continents.
 - Western boundary currents carry warm water to high latitudes, redistributing heat from equatorial latitudes and extending the range of marine organisms, such as corals, that must have warm water to survive.

Major Concept (IV) *Currents do not generally flow in smooth curves or straight lines. Current paths will meander and sometimes close on themselves to form eddies.*

Related or supporting concepts:

- When currents twist and close on themselves they can trap water from one side of the current on the opposite side. An excellent example of this is shown in figures 9.7 and 9.8 in the case of the Gulf Stream.
- These trapped parcels of water will rotate and retain their individual characteristics for weeks or months with little mixing. They are called eddies.
- Eddies can form at the surface or at depth.
- Eddies can vary in size from tens to hundreds of kilometers in diameter.
- Eddies will often generate current directions that are significantly different from those predicted by current charts. Current charts represent the long-term average current flow.
- The large eddies created along the Gulf Stream typically rotate at about 0.51 m/s (1.5 ft/s or 1 knot). Their diameter can be as great as 325 km (200 mi) and they may reach to the sea floor where they can cause significant turbulence on the bottom. They are sometimes called abyssal storms.
- When the western edge of the Gulf Stream develops oscillations the indentations fill with cold water from the Labrador Current side. When these indentations pinch off they create counter-clockwise cold-water eddies on the eastern side of the Gulf Stream. In a similar fashion, clockwise rotating warm-water eddies can form on the western side of the Gulf Stream.

- Satellites can locate eddies by accurately measuring temperature, elevation, and the reflection of light off the surface (see figs. 9.8 and 9.9).
- Small surface eddies have been located 800 km (500 mi) southeast of Cape Hatteras in the North Atlantic containing water with the properties of the eastern Atlantic near Gibraltar more than 4000 km (2500 mi) away.
- Eddies from the Mediterranean exit the Strait of Gibraltar and sink to a depth of 500–1000 m (1600–3300 ft) where they spread out across the Atlantic. These are sometimes called "Meddies."
- The motion of deep eddies can be monitored using instruments that are designed to float just above the bottom and emit radio signals that can be heard with hydrophones in the SOFAR channel.

Major Concept (V) *Zones of surface convergence and divergence mark regions of sinking and rising water, respectively. These occur on a relatively small scale as Langmuir cells and on a very large scale in the ocean basins.*

Related or supporting concepts:

- Strong wind blowing across the sea surface can create shallow circulation cells known as Langmuir cells (fig. 9.10).
- The vertical extent of Langmuir cells is about 4 to 10 m (12 to 30 ft).
- Langmuir cells are often separated on the surface by long streaks of foam or debris called windrows.
- Windrows mark the convergence zones of adjacent Langmuir cells.
- Spacing between windrows is typically 5 to 50 m (16 to 160 ft). The spacing increases with increasing wind speed.
- Low-density water rising to the surface spreads out and moves away. This is surface divergence.
- On a larger scale in the oceans, sinking surface water is replaced by lower-density water that flows into the region of sinking. This is called surface convergence.
- Low-density water rising to the surface spreads out and moves away. This is surface divergence.
- Blowing wind along continental margins and in the open ocean causes other areas of surface convergence and divergence.
- Figure 9.11 illustrates the locations of permanent zones of surface convergence and divergence.
- Surface convergence in the open ocean occurs at:
 - a. 0° in the tropical convergence,
 - b. 30°–40°N and S in the subtropical convergences,
 - c. 50°N and S in the Arctic and Antarctic convergences, and
 - d. the Antarctic divergence.
- Sinking water in zones of convergence carries oxygen from the surface to greater depth.
- Surface divergence in the open ocean occurs in three areas:
 - a. on either side of the tropical convergence, and
 - b. in the Antarctic divergence.
- In regions of surface divergence, deep water comes to the surface carrying high concentrations of nutrients and dissolved gas that promote high levels of biological productivity.
- On the western sides of continents, the trade winds drive water away from the coast, creating nearly continuous upwelling and rich fishing grounds.
- Seasonal changes in upwelling and downwelling can occur as prevailing wind directions along continental margins change with the seasons. One example occurs off the west coast of the U.S., where Ekman transport drives water away from the coast due to north winds in the summer and just the opposite occurs in the winter when the winds blow from the south (see fig. 9.12).

Major Concept (VI) *Patterns of global circulation have changed with time in response to changing configurations of continents, climate patterns, and atmospheric circulation.*

Related or supporting concepts:

- Studies of fossil organisms in marine sediments show that the temperature of the North Atlantic Ocean has varied during glacial and interglacial periods. These changes have been related to Milankovitch

- cycles.
- The position and orientation of Earth with respect to the Sun change in a predictable fashion. This changes the distribution and intensity of solar radiation reaching the surface of Earth that influences climate and ocean circulation.
 - These cyclical changes are known as Milankovitch cycles, named after a Serbian mathematician who studied them. The Milankovitch cycles are driven by variations that include:
 - a. changes in the shape of Earth's orbit from elliptical to more circular with a period of about 100,000 years,
 - b. changes in the tilt of Earth's axis of rotation from 22° to 24.5° with a period of 41,000 years, and
 - c. the precession, or circular revolution, of Earth's axis of rotation with a period of about 23,000 years.
 - There seems to be a time lag between the occurrence of minimum levels of solar radiation and minimum water temperatures.
 - The recent history of climate changes and water temperature fluctuations includes:
 - a. minimum incoming solar radiation values about 23,000 years ago,
 - b. maximum land ice and minimum water temperatures about 17,000 years ago,
 - c. a return to high solar radiation values about 12,000 years ago with a rapid warming of the water, and
 - d. the appearance of a mini-ice age, called the Younger Dryas event, about 11,000 years ago in the Northern Hemisphere that lasted about 700 years.
 - Eleven thousand years ago the surface water temperatures in the North Atlantic and the air temperature of northern Europe decreased suddenly and remained low for 700 years creating a mini-ice age. These changes were unrelated to long-term solar cycles. This period of time is also known to have had large changes in carbon dioxide concentration in the atmosphere.
 - The changes in temperature and carbon dioxide concentration in the atmosphere can be explained by major changes in ocean circulation that transport heat and carbon dioxide. Specifically, it is thought that there was a sudden shutdown of the circulation of the North Atlantic that interfered with the production of North Atlantic Deep Water.
 - A change in the location of freshwater runoff could have sent large volumes of cold, low salinity, low density water into the North Atlantic. This water would not have sunk to create North Atlantic Deep Water and the colder-than-normal surface water temperatures would not have warmed northern Europe.
 - A recently developed ocean current model for the North Pacific indicates the presence of a north-south oscillation of currents in the northeast Pacific (see fig. 9.15). These changes in current direction appear to be related to changes in atmospheric pressure and shifts in climate.
 - Cold and wet conditions are associated with a southerly current flow and warm and dry conditions are associated with a northerly current flow.
 - Tree ring data indicates that there have been 34 north-south oscillations since the time of Columbus. The most common time period between oscillations, determined by tree ring data, is 17 years and periods of 23 and 26 years are not uncommon.
 - The climate pattern is currently warm and dry and has not changed since 1967—an unusually long period of time.
 - The current changes are associated with changes in atmospheric pressure, winds, precipitation, and water temperature. Together these are known as the Pacific Decadal Oscillation (PDO).
 - Circulation changes occur in the North Atlantic on a regular basis as well.
 - Pools of warm and cold surface water circle the North Atlantic. These pools seem to have life spans of 4 to 10 years.
 - These pools of water cause changes in climatic conditions. Cold pools off the European coast are associated with colder-than-normal temperatures across Europe.
 - This cyclic change in currents is known as the North Atlantic Oscillation (NAO).

Major Concept (VII) *Currents can be measured using either stationary instruments or instruments designed to float and move along with the current.*

Related or supporting concepts:

- Moving water at any depth can be monitored using specially designed buoys or floats whose density can be changed to keep the instrument at a specific depth. Data from the instrument can then be relayed to a ship.
- Buoys can also be instrumented to measure other physical properties of the water such as temperature.
- A crude method of studying the currents is to use drift bottles that carry postcards inside. The bottles are released at a specific location and the cards ask the people who find them washed up on shore to return the card with notations on where and when the bottle was recovered.
- Surface buoys can also be tracked with satellites or photography to determine speed and direction of travel.
- Surface currents can be seen more readily if a dye is released into them.
- Current meters that are fixed in position by being attached to bottom-anchored buoys record water velocity with a rotor and current direction with a vane (see fig. 9.18a). The current meter is often submerged to remove the effect of wind and waves.
- A new method of measuring currents is to emit sound of a known frequency into the water and measure the frequency of the sound of the returning echoes (fig. 9.18b). If the sound travels in the same direction as the water, its frequency will be higher. If it travels against the current, its frequency will be lower. This is the Doppler effect that is more familiar to us when an emergency vehicle with its siren on first approaches and then passes by. By measuring in two perpendicular directions it is possible to calculate the actual direction and speed of the current.

Major Concept (VIII) *There is a tremendous amount of energy available in the oceans due to the constant motion of the water.*

Related or supporting concepts:

- Only a fraction of the energy in a major ocean current could be converted to practical use because of the tremendous size of major currents.
- Methods of harnessing the energy in moving currents typically rely on using the water's motion to turn turbine-driven generators either directly or indirectly.
- Two large currents located relatively near the shore in regions with large demands for energy are the Florida current and the Gulf Stream.
- There are some problems associated with extracting energy from currents, including:
 - a. most currents move too slowly,
 - b. many currents are not located near where the energy would be needed the most, and
 - c. the cost of any such product is currently greater than the value of the energy.

Matching Key Terms with Major Concepts

At the end of the chapter in the textbook is a list of key terms. You should be able to match each of these with one of the previously listed major concepts. To test your ability, try to match the following key terms with the number (I–VIII) of the appropriate major concept identified in this section:

geostrophic flow
Antarctic convergence
Ekman spiral
divergence
tropical divergence
Antarctic divergence
Langmuir cell

convergence
gyre
Ekman transport
tropical convergence
Doppler effect
subtropical convergence

eddy
Arctic convergence
western intensification
current meter
drift bottle
windrow

Test Your Recall

Answer the following questions to test your understanding

FILL IN THE BLANK

1. Currents can twist and pinch off rings of water called _____.
2. North Atlantic deep water flows toward the _____.
3. The phenomena of stronger currents in the western North Pacific than in the eastern North Pacific is called _____.
4. Microphones placed in the water to detect sound are called _____.
5. The large, roughly circular cells of water that rotate around ocean basins and are driven by the prevailing winds are called _____.
6. The far southern current that circles the globe around Antarctica is called the _____.
7. The eastward flowing current along the equator, under the doldrums, is called the equatorial _____.
8. Water movement that occurs as a result of a balance between gravity and the Coriolis effect is called _____.
9. Wind driven currents will continue to move after the winds cease because of _____.
10. The Gulf Stream is fed by the _____ current.
11. Gyres in the Northern Hemisphere rotate _____.
12. Water is driven into the center of gyres by _____.
13. Bottles that carry postcards in them are sometimes called _____.
14. The changing direction of water movement with depth in response to the overlying wind is called the _____.
15. Measuring current directions and speeds by changes in the frequency of sound is based on the _____.
16. _____ are the most common instruments used to measure the speed and direction of currents.
17. Surface water sinks in areas of _____.
18. Deep water rises to the surface in areas of _____.
19. An excellent example of the transport of water into the center of a large gyre is the _____ Sea in the North Atlantic.
20. Cyclical changes in global climate are known as _____ cycles.

TRUE - FALSE

1. Zones of permanent divergence along the western sides of continents are good fishing grounds.

2. When the wind stops blowing, wind driven surface currents stop flowing.
3. Ekman transport is 90° to the direction of the wind.
4. There is no source for dense bottom water in the North Pacific similar to the North Atlantic.
5. Deep water comes to the surface in areas of divergence.
6. The Kuroshio Current flows in the South Atlantic.
7. The North and South Pacific gyres form symmetrically on either side of the equator.
8. The Ekman spiral twists to the left in the Northern Hemisphere.
9. At the bottom of the Ekman spiral, water moves in the opposite direction from the wind.
10. The Ekman spiral extends to a depth of 300 meters.
11. Geostrophic currents are created by narrow straits.
12. Typical speeds for surface currents are usually about 0.1 to 0.5 m/s (0.3–1.5 ft/s).
13. Wind-driven surface currents flow at velocities that are about as fast as the wind.
14. *Sargassum* is a type of jellyfish.
15. There was a mini-ice age about 11,000 years ago.
16. Meanders in the Gulf Stream can pinch off to form eddies.
17. Eddies always rotate clockwise in the Northern Hemisphere.
18. The West Wind Drift moves to the west around Antarctica.
19. The equatorial countercurrent moves to the east.
20. The Ekman spiral is restricted to zones of divergence.

MULTIPLE CHOICE

1. The net flow of water set in motion by the overlying wind is at an angle of _____ degrees to the direction of the wind.
 - a. 45
 - b. 90
 - c. 30
 - d. 20
 - e. 0
2. The Ekman spiral extends to a depth of roughly
 - a. 500–1000 meters.
 - b. 50–200 meters.
 - c. 1000–1500 meters.
 - d. 100–150 meters.
 - e. 75–300 meters.
3. The current that circles the globe around Antarctica is called the
 - a. West Wind Drift.
 - b. southern circumpolar current.
 - c. Antarctic Current.
 - d. Agulhas Current.
 - e. Kuroshio Current.
4. Water moving horizontally at the surface toward a region of sinking is called
 - a. upwelling.
 - b. divergence.
 - c. convergence.
 - d. thermohaline.
 - e. chaotic.
5. A minimum in solar radiation reaching Earth occurred about _____ years ago.
 - a. 5000
 - b. 13,000
 - c. 7000
 - d. 54,000
 - e. 23,000
6. The rate of rotation of large eddies is about
 - a. 5 m/s.
 - b. 0.5 m/s.

- c. 10 m/s.
 - d. 1 m/s.
 - e. 15 m/s.
7. Large eddies, such as those that spin off the Gulf Stream, may
- a. extend all the way to the sea floor.
 - b. have a diameter as great as 300 km.
 - c. rotate at speeds of 10 m/s.
 - d. all of the above.
 - e. a and b above.
8. Satellites can locate major eddies by monitoring
- a. sea surface temperature.
 - b. light reflection off the surface.
 - c. sea surface elevation.
 - d. all of the above.
 - e. a and c above.
9. Milankovitch cycles are driven by
- a. changes in the shape of Earth's orbit.
 - b. changes in the tilt of Earth's axis of rotation.
 - c. the precession of Earth's axis of rotation.
 - d. all of the above.
 - e. a and b above.
10. The extraction of energy from ocean currents has some drawbacks, including
- a. the relatively slow speed of most currents.
 - b. the inconvenient location of many currents.
 - c. the fact that most currents are very narrow.
 - d. the fact that most currents are deep.
 - e. a and b above.
11. The oceans are heated
- a. from below.
 - b. from above.
 - c. from ridgecrest volcanism.
 - d. evenly at all latitudes.
 - e. none of the above.
12. Maximum land ice and minimum water temperatures occurred about _____ years ago.
- a. 23,000
 - b. 11,000
 - c. 17,000
 - d. 6000
 - e. 4500
13. Surface water is driven at an angle of _____ degrees to the direction of the wind.
- a. 30
 - b. 45
 - c. 15
 - d. 90
 - e. 60
14. Geostrophic flow occurs when these balance each other:
- a. centrifugal force and gravity
 - b. centripetal force and centrifugal force
 - c. Coriolis effect and centrifugal force
 - d. gravity and centripetal force
 - e. gravity and Coriolis effect
15. Wind-driven, open-ocean surface currents travel at velocities of about _____ knots.
- a. 10–15
 - b. 1–5
 - c. 0.25–1.0

- d. 0.1–0.5
 - e. 3–4
16. Western intensification is related to
 - a. increase in the Coriolis effect with latitude.
 - b. friction between continents and ocean currents.
 - c. the changing strength and direction of the trade winds and westerlies with latitude.
 - d. all of the above.
 - e. none of the above.
 17. Current meters measure
 - a. current speed.
 - b. current temperature.
 - c. current direction.
 - d. all of the above.
 - e. a and c above.
 18. Geostrophic flow can create mounds of seawater that rise as much as _____ above the equilibrium sea level.
 - a. 1 foot
 - b. 1 meter
 - c. 1 fathom
 - d. 2 meters
 - e. 2 feet
 19. The Sargasso Sea is
 - a. created by an isolated lens of water generated by geostrophic flow.
 - b. located in the central North Atlantic Ocean.
 - c. bordered on the west by the Gulf Stream.
 - d. covered with floating seaweed.
 - e. all of the above.
 20. The Gulf Stream transports more than _____ times as much water as the Amazon River in a given amount of time.
 - a. 500
 - b. 1000
 - c. 250
 - d. 100
 - e. 2000

Visual Aids: Test Your Understanding of the Figures

1. There are many major currents in the ocean basins. Take some time to study figure 9.5 to familiarize yourself with their locations and names.
2. Look at figure 9.4. Considering the height of a typical lens of water created by geostrophic flow and the depth to which a lens can extend, how would you change this figure to make it more realistic?
3. Look at figure 9.14 and see if you can tell what the major difference is between deep water flow in the North Pacific compared to the North Atlantic.

Study Problem

1. If a typical surface current has a speed of 0.1 to 0.5 m/s, how far would it move during a 50 minute oceanography lecture?

Answer Key for Key Terms and Test Your Recall

KEY TERMS

geostrophic flow (III)
 Antarctic convergence (V)
 Ekman spiral (I)
 divergence (V)

convergence (V)
 gyre (I)
 Ekman transport (I)
 tropical convergence (V)

eddy (IV)
 Arctic convergence (V)
 western intensification (III)
 current meter (VII)

tropical divergence (V)
Antarctic divergence (V)
Langmuir cell (V)

Doppler effect (VII)
subtropical convergence (V)

drift bottle (VII)
windrow (V)

FILL IN THE BLANK

1. eddies
4. hydrophones
7. countercurrent
10. Florida
13. drift bottles
16. current meter
19. Sargasso

2. equator
5. gyres
8. geostrophic flow
11. clockwise
14. Ekman spiral
17. convergence
20. Milankovitch

3. western intensification
6. West Wind Drift
9. momentum
12. Ekman transport
15. Doppler effect
18. divergence

TRUE - FALSE

1.T 2.F 3.T 4.T 5.T 6.F 7.F 8.F 9.T 10.F 11.F 12.T 13.F 14.F 15.T 16.T 17.F 18.F 19.T 20.F

MULTIPLE CHOICE

1.b 2.d 3.a 4.c 5.e 6.b 7.e 8.d 9.d 10.e 11.b 12.c 13.b 14.e 15.c 16.d 17.e 18.b 19.e 20.a

STUDY PROBLEM

1. 300 to 1500 meters.