

## Chapter 6

### Wind and Ocean Circulation

#### LEARNING OBJECTIVES

1. Understand atmospheric circulation as it relates to ocean circulation.
2. Explain the Coriolis effect and its role in atmospheric and oceanic circulation.
3. Describe surface circulation and geostrophic flow.
4. Understand the relationship between surface circulation and deep ocean circulation.

#### CHAPTER OUTLINE

##### 6-1. Atmospheric Processes

- A. Density of air is controlled by temperature, pressure, and moisture content.
  1. Warm air is less dense than cold air and moist air is less dense than dry air.
  2. **Air pressure** is the weight of the air from Earth's surface to the top of the atmosphere and equals  $1.04\text{kg/cm}^2$  (**standard air pressure, one atmosphere**) at sea level.
  3. **Low pressure zone** is where air density is lower than in surrounding areas because the air is warmer or has a higher moisture content.
  4. **High-pressure zone** is where air pressure is higher than in surrounding area because of cooling or lower moisture content.
  5. Fluids (air and water) flow from areas of high pressure to areas of low pressure.
  7. Change in pressure across a horizontal distance is a **pressure gradient**.
    - Greater the difference in pressure and the shorter the distance between them, the steeper the pressure gradient and the stronger the wind.

8. Movement of air across a pressure gradient parallel to Earth's surface is called a **wind** and winds are named for the direction *from which they come*. In contrast, ocean currents are named for the direction *towards which they travel*.

B. Rotation of the Earth strongly influences winds.

1. Global winds blow in response to variation in pressure related to uneven solar heating (**insolation**) of Earth's surface.
  - a. **Equatorial low pressure** occurs because intense heating and high moisture content makes the air less dense. Rising air produces a convergence at the surface into which air flows and rises.
  - b. **Polar high pressure** occurs as cold, dry dense air sinks to the surface and flows outward forming an area of divergence.
2. **Coriolis deflection** is the apparent deflection of objects moving across Earth's surface *to the right of direction of travel in the Northern Hemisphere and to the left of direction of travel in the Southern Hemisphere*.
  - a. The deflection is caused by the differential speed of rotation between Earth's equator and polar regions, relative to an object moving across the Earth's surface.
  - b. Coriolis deflection increases poleward and as speed increases.

C. Three major convection cells are present in each hemisphere.

1. The **Hadley cell** extends from the Equator to about 30° latitude.
  - a. At the equator warm moist air expands, becomes less dense, and rises, forming a zone of low pressure called the **doldrums**.

- b. As the air continues to rise, it cools and most of its moisture condenses and falls as tropical rainfall.
- c. At high altitude the air flows poleward, becoming cooler and denser, until it sinks to Earth's surface at about 30° latitude, forming a high-pressure zone called the **horse latitudes**.

- d. Most of this air flows southward, as the Coriolis-deflected **trade winds**, gradually warming and absorbing moisture. As the air approaches the equator it again rises and is recycled.

2. The **Ferrel Cell** extends from 30° to about 50° latitude.
  - a. Some of the air descending at 30° latitude flows poleward as the Coriolis-deflected **westerlies** to about 50° where they encounter cold, dense air moving equatorward from the poles.
  - b. The less dense warmer air is forced up over the denser cold air at the **polar front** and much of it flows equatorward at high altitude to about 30°, where it enters the horse latitudes.
3. The **Polar Cell** extends from 90° to about 50° latitude.
  - a. Some air from the polar front travels poleward becoming cold and dry.
  - b. At the pole the air descends, forming a **polar high-pressure zone**, and flows outward as the Coriolis-deflected **polar easterlies**, which eventually collide with the westerlies at the polar front.

## 6-2. Surface Ocean Currents

D. Wind-driven currents are produced by the interaction between the wind and the water.

1. As wind moves across the water, collision of air molecules with water molecules inefficiently transfers energy from the air to the water.
  - Water moves at about 3-4% of the wind speed.
2. **Zonal wind flow** is wind moving nearly parallel to latitude as a result of Coriolis deflection.
3. Westerly-driven ocean currents in the trade winds, easterly-driven ocean currents in the Westerlies and deflection of the ocean currents by the continents results in a circular current, called a **gyre**, which occupies most of the ocean basin in each hemisphere.

E. Pressure gradients develop in the ocean because the sea surface is warped into broad mounds and depressions with a relief of about one meter.

1. Mounds are caused by **convergences**, places where water flows together and sinks.
2. Depressions are caused by **divergences**, places from where water rises to the surface and flows outward.
3. Water flowing down pressure gradients on the ocean's irregular surface is deflected by Coriolis and the amount of deflection is a function of location and speed.

F. With time, wind-driven surface water motion extends downward into the water column, but speed decreases and direction changes because of Coriolis deflection.

1. **Eckman Spiral** is the spiraling pattern described by changes in water direction and speed with depth.
2. **Eckman transport** is the net transport of water by wind-induced motion.

- Net transport of the water in an Eckman spiral has a Coriolis deflection of  $90^\circ$  to the direction of the wind.

3. Along coastal areas Eckman transport can induce downwelling or upwelling by driving water towards or away from the coast, respectively.

a. **Upwelling** is when near shore surface water is driven seaward, resulting in deeper water being pulled to the surface.

- Upwelling also occurs between gyres.

b. **Downwelling** is when near shore surface water is driven landward, and its accumulation depresses the deep water.

- Downwelling also occurs in the center of the gyres.

G. **Langmuir circulation** is a complex horizontal helical (spiral) motion that extends parallel to the wind.

1. Adjacent helices rotate in opposite directions creating alternating zones of convergence and divergence.
2. Material floating on the surface becomes concentrated in the zones of convergence and form **sea stripes** which parallel the wind direction.

H. Geostrophic flow allows currents to flow long distances with no apparent Coriolis deflection.

1. Coriolis deflects water into the center of the gyres, forming a low mound.
2. As height of the mound increases, the pressure gradient steepens pushing the water outward in an attempt to level the mound.
3. When the pressure gradient equals Coriolis deflection, the current flows parallel to the wind around the mound as a **geostrophic current** and this is called **geostrophic flow**.

4. Gyres in the northern hemisphere rotate clockwise and in the southern hemispheres counterclockwise.
5. The current flow pattern in gyres is asymmetrical with narrow, deep and swift currents along the basin's western edge and broad, shallow slower currents along the basin's eastern edge.
  - **Western boundary current intensification** is the result of the Coriolis effect increasing with distance from the equator, forcing the eastward-flowing current to turn to the south much more strongly and quickly than the westward –flowing equatorial currents that turn to the north.
6. The geostrophic mound is deflected to the western part of the ocean basin because of the eastward rotation of the Earth on its axis.
  - This creates a steeper slope on the western side of the mound because more water is being forced into the mound by the greater deflection from the faster flowing current.
7. The **Sargasso Sea** is a large lens of warm water encircled by the North Atlantic gyre and separated from cold waters below and laterally by a strong thermocline.
8. Western boundary currents, such as the Gulf Stream, form a meandering boundary separating coastal waters from warmer waters in the gyre's center.
  - a. Meanders of the current can break free and form **rings**, large swirling migrating eddies, hundreds of kilometers in diameter and kilometers thick. They can last for years until they are reabsorbed into the gyres.
  - b. **Warm-core rings** are those which enclose a mass of warmer water compared to the body of water in which they located.

c. **Cold-core rings** are those which enclose a mass of cooler water compared to the body of water in which they located.

### 6-3. Deep-Ocean Circulation

- I. **Thermohaline circulation** is a density driven flow of water generated by differences in salinity or temperature.
  1. Water at the surface is exposed to more rapid changes in salinity through evaporation or precipitation and in temperature through cooling or heating.
  2. Once water is isolated from the atmospheric influences, salinity and temperature are largely set for an extended period of time.
  3. Based upon depth, surface water masses can be broadly classified as:
    - a. **Central waters**—from 0 to 1 km,
    - b. **Intermediate waters**—from 1 to 2 km,
    - c. **Deep and bottom waters**—greater than 2 km.
  4. Most deep and bottom water originated at the surface where cooling and increased salinity raised their density until they sank.
  5. Ocean basins interconnect and exchange water with each other and with the surface. Inter-ocean basin circulation and exchange between surface and deep water appears largely driven by waters of the North Atlantic.
  
- J. The major thermohaline currents appear to flow mainly equatorward, but this is because they originate in the polar regions and their outward flow is confined between the continents.
  1. Warmer water ( $>10^{\circ}\text{C}$ ) is confined between  $45^{\circ}$  north and south latitude.
  2. Poleward of  $45^{\circ}$ , density of water increases because of declining temperature and increased salinity because of evaporation or ice formation.
  3. The water sinks to a density-appropriate level and then slowly flows outward in all directions across the basin until they are blocked by a continent.
  4. Deep water gradually mixes with other water masses and eventually rises to the surface.
  5. The Atlantic Ocean has the most complex ocean stratification.
  6. The Indian Ocean has the simplest stratification.
  8. Climate change affects thermohaline circulation.
    - a. Increased freshwater influx to the North Atlantic will reduce salinity and density of surface water, and could shut down downwelling, changing weather patterns in Europe and North America.