Chapter 5

Winds and Global Circulation

Chapter Objectives

Upon completion of this chapter the student will be able to:

1. Identify various means for the measurement of barometric pressure.
2. Explain how air pressure changes with altitude.
3. Describe the relationship between pressure gradients and wind.
4. Correlate global winds and pressure patterns.
5. Discuss the relationship between local winds and terrain.
6. Show the relationship between winds aloft, pressure gradients, and the lack of surface friction.
7. Describe the temperature layers of the ocean.
8. Demonstrate the relationship between ocean currents and wind patterns.
9. Define El Niño and its effects upon weather.
10. Describe various alternative power sources such as wind, waves, and ocean currents.

Chapter Lecture

I. Atmospheric Pressure Atmospheric pressure exists because air molecules have mass and are constantly being pulled toward the Earth by gravity. The acceleration of mass by gravity creates weight. Pressure is a force per unit area. This force is produced by the weight of a column of air above a unit area of surface. Standard sea–level atmospheric pressure is 1013.2 mb.

A. Measuring Atmospheric Pressure Atmospheric pressure is measured by either an aneroid or mercury barometer. It can be measured in units of pascals (Pa), bars, or millibars (mb).

B. How Air Pressure Changes with Altitude Air pressure decreases with altitude. This decrease is more rapid near the surface because the pressure is lower at higher altitudes and thus does not decrease as rapidly; a small change in elevation will often produce a significant change in air pressure. More serious effects on human physiology occur at greater elevations. Since air pressure is lower at higher altitudes, oxygen, a partial component of air, cannot as easily pass through lung tissues causing shortness of breath and fatigue.

II. Wind Wind is air motion with respect to the Earth's surface. Wind movement is dominantly horizontal. Air motions that are dominantly vertical are referred to as updrafts or downdrafts.

A. Measurement of Wind The motion of air in wind is characterized by a direction and velocity. The most common instrument to measure wind direction is a wind vane. Wind direction is always given as the direction the wind is coming from. Wind speed is measured by an anemometer. The current is measured by a meter, calibrated in units of wind speed; either meters per second, or miles per hour.

B. Winds and Pressure Gradients Wind is caused by differences in atmospheric pressure from place to place. Air tends to move from high to low pressure until the air pressures are equal. When atmospheric pressure is unequal, a pressure gradient force will push the air from the high pressure area toward the low pressure area. The greater the pressure difference between the two locations, the greater this force will be and the stronger the wind.

C. Simple Convective Wind System Pressure gradients that are created as a result of unequal heating of the atmosphere produce convection cells that move air from areas of high pressure to areas of low pressure.

D. Sea and Land Breezes These breezes are examples of how heating and cooling of the air produce convection loops to create local winds. As the land is warmed during the day, the wind brings cool air off the water. Once night falls, the wind moves cooler air, which is chilled over land by nighttime radiant cooling, toward the water. The sea breeze-land breeze convection loop provides an example of surface thermal high-and-low-pressure zones.

E. Local Winds Sea and land breezes are examples of local wind systems that are generated by local effects. Other types of local winds include mountain and valley winds, drainage winds, Santa Ana winds, and Chinooks. Valley breezes and mountain breezes are local winds that alternate in direction in a manner similar to the land and sea breezes. Drainage winds have cold, dense wind flowing under the influence of gravity from higher to lower regions. Santa Ana winds occur when the outward flow of dry air from an anticyclone are combined with the local effects of mountainous terrain. The Chinook results when strong regional winds pass over a mountain range and descend on the lee side.

F. The Coriolis Effect and Winds Through the Coriolis Effect, an object in motion on the Earth’s surface always appears to be deflected away from its course. The object moves as though a force were pulling it to the side. The apparent deflection is to the right in the northern hemisphere and to the left in the southern hemisphere. Deflection is strongest near the poles and decreases to zero at the equator. It is a result of the Earth’s rotation.

G. Cyclones and Anticyclones Cyclones are high pressure systems in which air spirals inward and upward. This inward spiraling motion is convergence. Cyclones are low pressure areas in which air spirals downward and outward. This outward spiraling motion is divergence. Cyclones are often associated with cloudy or rainy weather, and anticyclones are associated with fair weather.

H. Surface Winds on an Ideal Earth An ideal Earth is defined as one with no pattern of land and oceans and no seasonal changes. The most important features for understanding the wind pattern are Hadley cells. They form in the northern and southern hemispheres and rise over the equator and are drawn poleward by the pressure gradient. They are turned by the Coriolis force and move westward as well as poleward. The rising air at the equator will form a low pressure center around the equatorial region. This low pressure center will draw in air at the surface level, and it will converge at the equatorial low pressure trough. This narrow equatorial region is known as the intertropical convergence zone (ITCZ). Very little horizontal movement of air occurs in this region, and subsequently it is also known as the doldrums. On the poleward side of the Hadley cell circulation, air descends and surface pressures are high. This produces two subtropical high-pressure belts centered at about 30° north and south latitude. Winds around the subtropical high-pressure centres are outspiraling and move toward equatorial as well as middle latitudes. The winds moving equator-ward are the strong and dependable trade winds. Between 30 and 60° latitude, the pressure and wind patterns become more complex. This latitudinal belt is a zone of conflict between air bodies with different characteristics. Masses of cool, dry air move into the region, heading eastward and equator-ward forming polar outbreaks. As a result, pressures and winds can be quite variable in the midlatitudes. At the poles, the air is intensely cold and high pressure results. Outspiraling winds around a polar anticyclone should create surface winds from a mainly easterly direction, known as polar easterlies.

III. Global Wind and Pressure Patterns The real world wind flow is different than the idealized version due to the simple fact that there are oceans and land in contact with each other and mountains and valleys that can modify the flow.

A. Subtropical High-Pressure Belts These prominent wind flow features are caused by Hadley cell circulation. They differ between the southern and northern hemispheres.

B. The ITCZ and the Monsoon Circulation In general, the ITCZ shifts with the seasons. In the western hemisphere the shift is moderate, moving a few degrees north from January to July over the oceans. The shift is more dramatic in the eastern hemisphere. The Asiatic monsoon winds alternate in direction from January to July responding to reversals of barometric pressure over the large continent. Although North America does not have a monsoon season, during the summer months, there is a prevailing tendency for warm, moist air originating in the Gulf of Mexico to move northward across the central and eastern part of the continent.

C. Wind and Pressure Features of Higher Latitudes The northern and southern hemispheres are quite different in their geography. These differing land-water patterns strongly influence the development of high-and-low-pressure centres with the seasons. In summer, the pattern reverses. The continents show generally low surface pressure, while high pressure builds over the oceans. The higher latitudes of the southern hemisphere present a polar continent surrounded by a large ocean. Since Antarctica is covered by a glacial ice sheet and is cold at all times, a permanent anticyclone (the South Polar High) is centered there. Easterly winds spiral outward from the high-pressure centre. Surrounding the high is a band of deep low pressure, with a strong inward-spiraling westerly winds.

IV. Winds Aloft These are high altitude winds that are not affected by surface friction. Air aloft will move in response to pressure gradients and will be influenced by the Coriolis effect.

A. The Geostrophic Wind At upper levels in the atmosphere, a parcel of air is subjected to a pressure gradient force and a Coriolis force. As a parcel of air moves in response to a pressure gradient, it is turned progressively side ways until the gradient force and Coriolis force balance, producing the geostrophic wind.

B. Global Circulation at Upper Levels- This circulation pattern has four major features – weak equatorial easterlies, tropical high-pressure belts, upper-air westerlies, and a polar low. The overall picture is of a band of weak easterly winds in the equatorial zone, belts of high pressure near the tropics of Cancer and Capricorn, and westerly winds, with some variation in direction, spiraling around polar lows.

C. Rossby Waves, Jet Streams, and the Polar Front The smooth westward flow of the upper-air westerlies frequently forms undulations called Rossby waves. These waves arise in a zone of contact between cold polar air and warm tropical air, called the polar front. The number of Rossby waves ranges from three to seven. Jet streams are important features of upper air circulation. They are narrow zones at a high altitude in which wind streams reach great speeds. They occur where atmospheric pressure gradients are strong. There are three kinds of jet streams; polar jet, subtropical jet, and tropical easterly jet streams.

V. Oceanic Circulation Just as there is a circulation pattern to the atmosphere, so there is a circulation pattern to the oceans. It is driven partly by differences in density and pressure as well as differences in salinity. Wind force on surface water is also a primary factor in creating oceanic circulation.

A. Temperature Layers of the Oceans The oceans also have a layered structure of thermal regions, with temperatures generally highest at the sea surface and decreasing with depth. At low latitudes a warm surface layer develops. The wave action mixes the heated surface water with the water below to form a warm layer that may be as thick as 500m. Below the warm layer is a zone called the thermocline. Below the thermocline is a layer of very cold water extending to the deep ocean floor. In the arctic and antarctic regions, the warm layer and thermocline are absent.

B. Surface Currents An ocean current is any persistent, dominantly horizontal flow of ocean water. Current systems act to exchange heat between low and high latitudes and are essential in sustaining the global energy balance. The patterns of surface ocean currents are strongly related to prevailing surface winds. Energy is transferred from wind to water by the friction of the air blowing over the water surface. The Coriolis effect changes the direction of water drift about 45° from the direction of the driving wind. Because the ocean currents move warm waters poleward and cold waters toward the equator, they are important regulators of temperature. Gyres are circulation patterns that are centered at latitudes of twenty to thirty degrees. El Niño is an ocean surface current phenomenon in which the Pacific surface currents shift into an unusual pattern. Global patterns of precipitation also change during El Niño, bringing floods to some regions and droughts to others. La Niña occurs when normal Peruvian coastal upwellings are enhanced, trade winds strengthen, and cool water is carried far west in an equatorial plume. The Pacific decadal oscillation also influences climate. It is marked by changes in sea surface temperature across the Pacific Ocean that persist on a scale of 20-30 years.

C. Deep Currents and Thermohaline Circulation Deep ocean currents, generated by the sinking of cold, salty water in the northern Atlantic, circulate sea water in slowly moving coupled loops involving the Atlantic, Pacific, Indian, and Southern oceans. Thermohaline circulation plays an important role in the carbon cycle by moving CO_2-rich surface waters into the ocean depths.

Reading/Videos

Eagleman, Joe R. *Meteorology-The Atmosphere in Action*. New York: D. Van Nostrand, 1980.

McDonald, James E. “The Coriolis Effect.” *Scientific American* 186 (May 1952): 72-76.

Starr, Victor P. “The General Circulation of the Atmosphere.” *Scientific American* 195 (December 1956): 40-45.

Thurman, Harold V. *Introductory Oceanography*. 5th ed. Columbus, OH: Macmillan Publishing Co., 1988.

Wiebe, Peter H. “Rings of the Gulf Stream.” Scientific American 246 (March 1982): 60-70.

<u>The Energy Alternative Series: A Global Perspective</u>. (1992) 52 minutes each. FL.

<u>Oceans, Coasts and Tides</u>. (1995) 19 min. EVN.

<u>Understanding Drought and Desertification</u>. (1995) 29 min. EVN.

Internet Resources

El Niño/La Niña and the Pacific Decadal Oscilation:
(http://topex-www.jpl.nasa.gov/science/el-nino.html)

U.S. Department of Energy wind energy program: (http://www.eren.doe.gov/wind/)

Wind Energy Resource Atlas of the United States: (http://rredc.nrel.gov/wind/pubs/atlas/)

Misconceptions about the Coriolis Effect:
(http://www.ems.psu.edu/~fraser/Bad/BadCoriolis.html)

Simulation of the Los Angeles sea/land breeze:
(http://www.atmos.ucla.edu/~fovell/ASother/mm5/LA_seabreeze.html)

The thermohaline circulation including animated illustration of currents:
(http://www.cru.uea.ac.uk/cru/info/thc/)