TOPIC 4

The Atmosphere

Earth's atmosphere surrounds the planet like a blanket, absorbing heat from the Sun and keeping surface temperatures at an optimal level for life. All types of weather phenomena—from warm, sunny days to violent tornadoes—are caused by interactions that occur in the atmosphere. The atmosphere also affects long-term weather patterns, known as climate. In this topic, you will learn about the composition and structure of the atmosphere and examine the processes that cause weather and climate.

SUBTOPIC A ATMOSPHERE

Covers National Science Content Standards UCP.1, UCP.2, UCP.3, UCP.4, UCP.5; A.1, A.2; D.1, D.2, D.3; F.5

Unifying Concepts and Processes

UCP.1	Systems, order, and organization
UCP.2	Evidence, models, and explanation
UCP.3	Change, constancy, and measurement
UCP.4	Evolution and equilibrium
UCP.5	Form and function

Science as Inquiry

A.1	Abilities necessary to do scientific inquiry
A.2	Understandings about scientific inquiry

Earth and Space Science

D.1	Energy in the Earth system
D.2	Geochemical cycles
D.3	Origin and evolution of the Earth system

Science in Personal and Social Perspectives

F.5	Natural and human-induced hazards

VOCABULARY

ozone	dewpoint
troposphere	temperature inversion
stratosphere	humidity
mesosphere	relative humidity
thermosphere	condensation nuclei
exosphere	orographic lifting
radiation	stability
conduction	latent heat
convection	precipitation
temperature	water cycle
heat	evaporation
condensation	

Earth's atmosphere begins at the surface of the planet and extends hundreds of kilometers into space. It is composed mainly of gases with small amounts of dust and salt swept up from land and sea.

Atmospheric Gases

The two main atmospheric gases are nitrogen and oxygen. As shown in Figure 4-1 and in the *Average Chemical Composition of Earth's Crust, Hydrosphere, and Troposphere* in the *Earth Science Tables and Charts,* these two gases make up 99 percent of the troposphere. Any appreciable change in their proportions could adversely affect life on Earth. Of the remaining gases, carbon dioxide and water vapor are of particular importance. Both play crucial roles in absorbing solar radiation, which is energy from the Sun. Thus, these gases help keep Earth's surface temperature from becoming too low to support life. In addition, water vapor forms clouds, rain, and snow. Water itself is the only substance found in the atmosphere in three states of matter: gas, liquid, and solid. Every time water changes its state, heat is released or absorbed. These changes in heat energy fuel many of the processes that affect weather and climate.

Ozone

Not all solar radiation is beneficial to living things. Ultraviolet radiation, for example, can cause skin cancer and cataracts in humans. Most incoming ultraviolet radiation is absorbed by an atmospheric gas called ozone. **Ozone** (O_3) forms when an oxygen atom (O) binds to an oxygen molecule (O_2). Ozone is found in a layer of the atmosphere approximately 20 to 50 km above Earth's surface. Recent studies indicate that the ozone layer may be thinning. Scientists hypothesize that this thinning is caused by a group of chemical compounds called chlorofluorocarbons (CFCs), which are sometimes used to produce foam packaging, aerosol sprays, and coolants for refrigerators. The manufacture and use of these products causes CFCs to enter the atmosphere. When exposed to ultraviolet radiation, the CFC molecules break down and chlorine is released. The chlorine, in turn, reacts with and ultimately destroys atmospheric ozone. One chlorine atom can destroy approximately 100 000 ozone molecules. Given ozone's vital role in protecting life from harmful ultraviolet rays, more than 160 countries have signed a global agreement to reduce the production and use of CFCs.

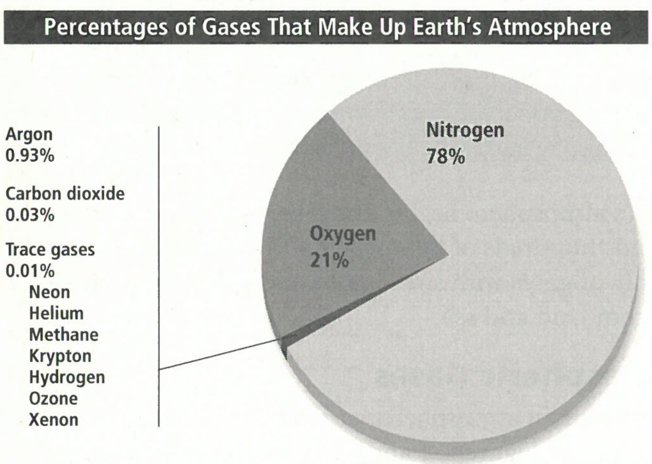


Figure 4-1 In the absence of water, Earth's atmosphere is made up of 78 percent nitrogen and 21 percent oxygen. The remaining 1 percent consists or argon, carbon dioxide, and trace gases. Water vapor displaces the other gases when it is present in the atmosphere; its proportion ranges between 0 and 4 percent.

Atmospheric Layers

The gases discussed so far are largely found in the lower region of the atmosphere. However, the atmosphere is not a uniform mass of air extending from Earth's surface into space. Rather, it can be divided into several different layers, as shown in Figure 4-2 and in *Selected Properties of Earth's Atmosphere* in the *Earth Science Tables and Charts.* Note that these layers differ in temperature and chemical composition. Furthermore, as shown in *Selected Properties of Earth's Atmosphere,* atmospheric pressure and the concentration of water vapor decrease with increasing altitude through the atmosphere.

Lower Atmosphere

The lowest atmospheric layer, the **troposphere,** stretches from Earth's surface to an average height of approximately 15 km. Most weather occurs in this layer, as does most air pollution. In addition, the troposphere contains the bulk of the atmosphere's mass and water vapor. Temperature generally decreases with altitude until the upper boundary of the troposphere, called the tropopause, is reached.

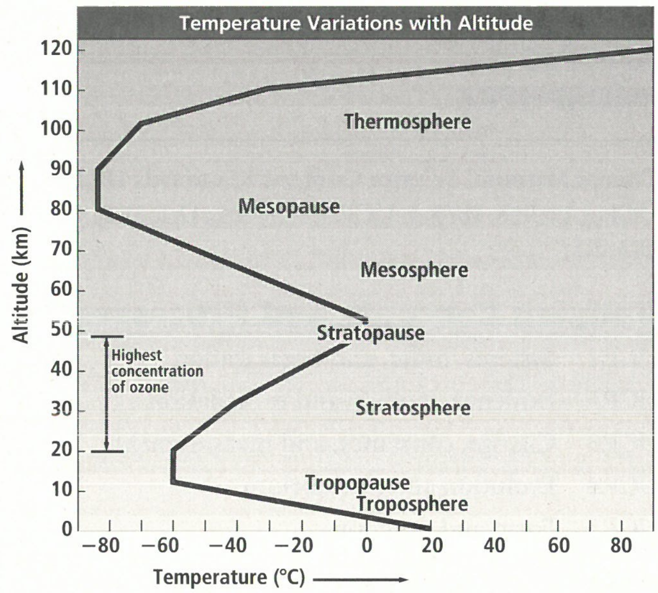


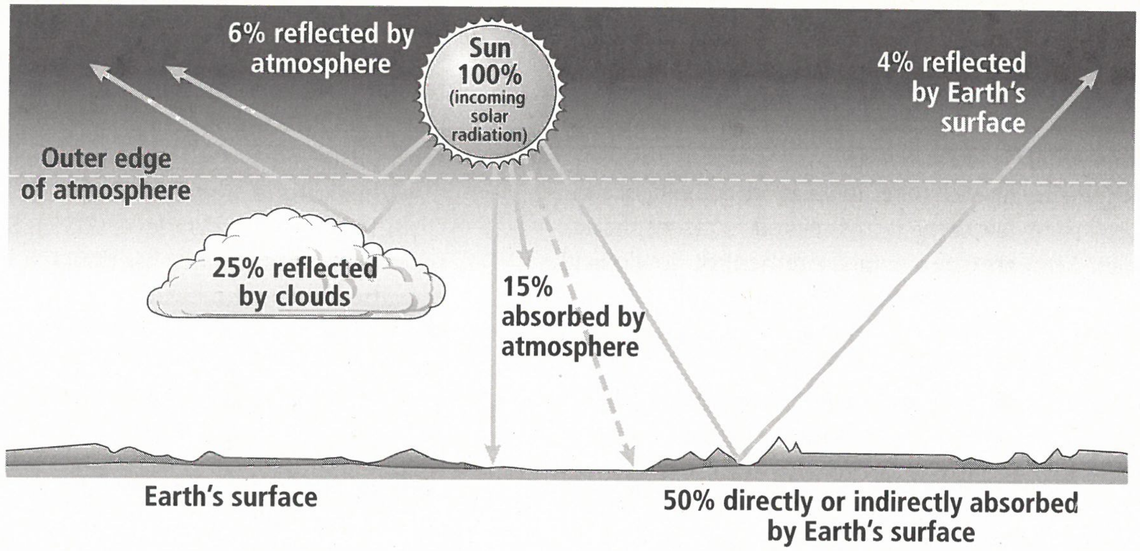
Figure 4-2 Earth's atmosphere can be divided into several layers based on differences in chemical composition and temperature.

The layer directly above the tropopause is the **stratosphere.** The stratosphere contains the sublayer of ozone discussed earlier. Since ozone absorbs ultraviolet radiation, temperature in the stratosphere increases with altitude. This increase stops at the upper limit of the stratosphere, known as the stratopause. The stratopause and the tropopause are transition areas between the layers above and below them.

Upper Atmosphere

The next atmospheric layer, located above the stratopause, is the **mesosphere,** which is characterized by a lack of ozone. Therefore, temperature in the mesosphere sharply decreases with altitude. Above the mesosphere lies the **thermosphere,** in which the air is extremely thin. Temperature again increases with altitude in the thermosphere, mainly due to the absorption of solar energy by oxygen.

Figure 4-3 Earth's surface, atmosphere, and clouds reflect 35 percent of incoming solar radiation. The atmosphere absorbs roughly 15 percent. The remaining 50 percent is absorbed directly or indirectly by Earth's surface.



The top layer of the atmosphere is the **exosphere.** Light gases such as helium and hydrogen are most common here. There is no distinct upper boundary to the exosphere. Instead, Earth's atmosphere gradually fades into outer space as fewer particles of air are found.

Insolation

The atmosphere gets all its energy from the Sun. *In*coming *sol*ar radi*ation*, or insolation, is transferred throughout the atmosphere in three distinct ways: radiation, conduction, and convection.

Radiation

The transfer of energy through space by electromagnetic waves is known as **radiation.** The Sun emits radiation, as do all substances with temperatures above absolute zero. As Figure 4-3 shows, not all solar radiation reaches Earth's surface. About 35 percent is reflected into space by clouds, the atmosphere, and the surface. The atmosphere absorbs 15 percent, and the surface absorbs the remaining 50 percent. Absorption rates vary from place to place, depending in part on the topography and latitude of an area. In addition, land absorbs and releases energy more rapidly than water because land has a lower specific heat. Color also affects rates of absorption. Dark objects generally heat up more quickly than light objects.

The solar radiation absorbed by Earth's surface is reemitted by the surface in the form of infrared radiation, as Figure 4-4 shows. This type of radiation, which cannot easily escape through the atmosphere, is largely absorbed by the atmosphere. In this way, the Sun indirectly heats the atmosphere.

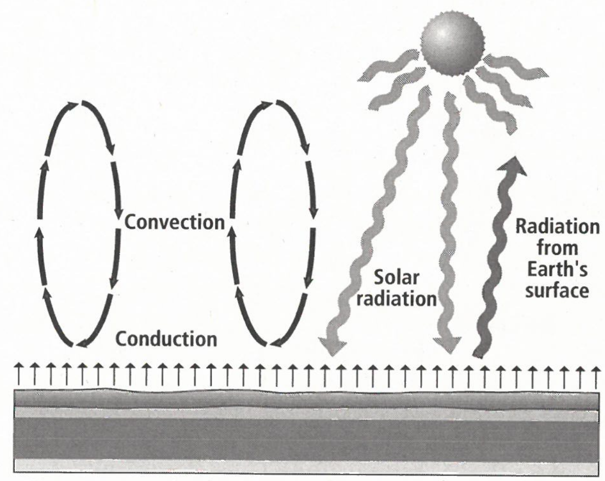


Figure 4-4 Solar energy is transferred by radiation to Earth's surface. This energy is reemitted and then transferred to the lowest layer of the atmosphere by conduction. Convection transfers the energy vertically throughout the atmosphere.

Conduction

Conduction is the transfer of energy that occurs when molecules collide. In the atmosphere, energy is transferred by conduction from Earth's warmed surface to the closest layer of air above the surface, as shown in Figure 4-4. Conduction cannot occur unless molecules are in direct contact with one another. For this reason, conduction affects only the very bottom layer of the atmosphere because that is where the molecules in the air are close enough to come in contact with one another.

Convection

Convection is the transfer of energy by the flow of a heated substance. It occurs in the atmosphere when air, heated by conduction, expands, becomes less dense, and begins to rise. Since temperature generally decreases with height in the troposphere, the rising air eventually cools. It then becomes denser, sinks, and warms again, creating a cycle known as a convection current. This cycle is illustrated in Figure 4-4. Convection currents often drive the vertical movements of air that lead to changes in weather.

Temperature and Heat

Before exploring how changes in weather actually occur, you'll need to review some terms related to atmospheric properties. **Temperature** is a measurement of how quickly or slowly molecules move around. When molecules of air move quickly or when there are a large number of molecules in a given space, the temperature of the air is high. Conversely, when molecules of air move slowly or when there are a small number of molecules in a given space, the temperature of the air is low. You can measure temperature in degrees Fahrenheit (°F), degrees Celsius (°C), or kelvins (K).

Another helpful term, heat, is closely related to temperature. **Heat** is the transfer of energy that occurs because of a difference in temperature between two substances. Heat flows from warmer substances (the source) to cooler substances (the sink). If cool air passes over a sun-warmed meadow, for example, heat will flow from the land to the air, and the temperature of the air will increase. Heat can also be thought of as the average kinetic energy of molecules, or, in simpler terms, the average motion of each molecule.

Air Temperature

As a mass of air rises through the troposphere, the air mass will cool if it does not absorb heat from its surroundings. Close to Earth's surface, air temperature decreases at a rate of about 10°C for every 1000-m increase in altitude. As Figure 4-5 shows, this rate is called the dry adiabatic lapse rate. As air becomes colder, the maximum amount of water vapor it can contain decreases. Therefore, at some altitude the air becomes saturated; that is, it contains as much water vapor as it can. At this altitude, condensation occurs. **Condensation** refers to the change in state of matter from a gas to a liquid. In the atmosphere, water vapor changes from a gas to liquid water droplets that eventually form clouds and rain. Condensation cannot occur until the air reaches its dewpoint. **Dewpoint** is the temperature to which air must be cooled at constant pressure to reach saturation.

The altitude at which condensation takes place is called the lifted condensation level (LCL). Since clouds form when condensation occurs, the LCL is usually the same as the altitude of the bases of the newly formed clouds. Above the LCL, the saturated air cools at a rate of 4°C to 9°C for every 1000-m increase in altitude. This rate, shown in Figure 4-5, is known as the moist adiabatic lapse rate.

Temperature Inversion

Although temperature generally decreases with height in the troposphere, there is an exception to this relationship. A **temperature inversion** is an increase in temperature with height in the troposphere. It can sometimes happen when land cools rapidly on a cold, windless night. The air near the ground is also cool and thus denser than the air above. The dense air cannot rise above the warmer air, which acts as a lid that traps pollutants. In this way, temperature inversions can worsen air pollution in some cities.

Air Pressure and Density

Gravity causes particles of air to be pulled toward Earth's surface. The air above exerts a force on the air below, resulting in the atmospheric property known as air pressure. Air pressure is greatest near Earth's surface, where the force of the overlying particles of air is the strongest. With increasing altitude above Earth's surface, air pressure decreases.

As air above exerts pressure on air below, particles of air are compressed. The compression causes air density to increase near Earth's surface. When the temperature of air increases, particles of air move farther apart. Thus, the relationship between density and temperature is inversely proportional. Density decreases as temperature increases.

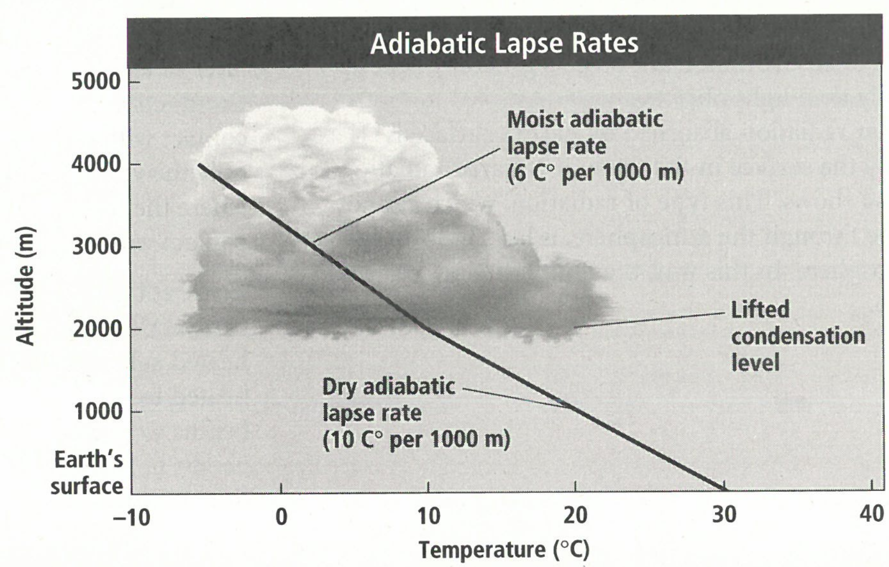


Figure 4-5 The dry adiabatic lapse rate is a decrease of approximately 10°C for every 1000-m increase in altitude. The moist adiabatic lapse rate is a decrease of 4°C to 9°C for every 1000-m increase in altitude.

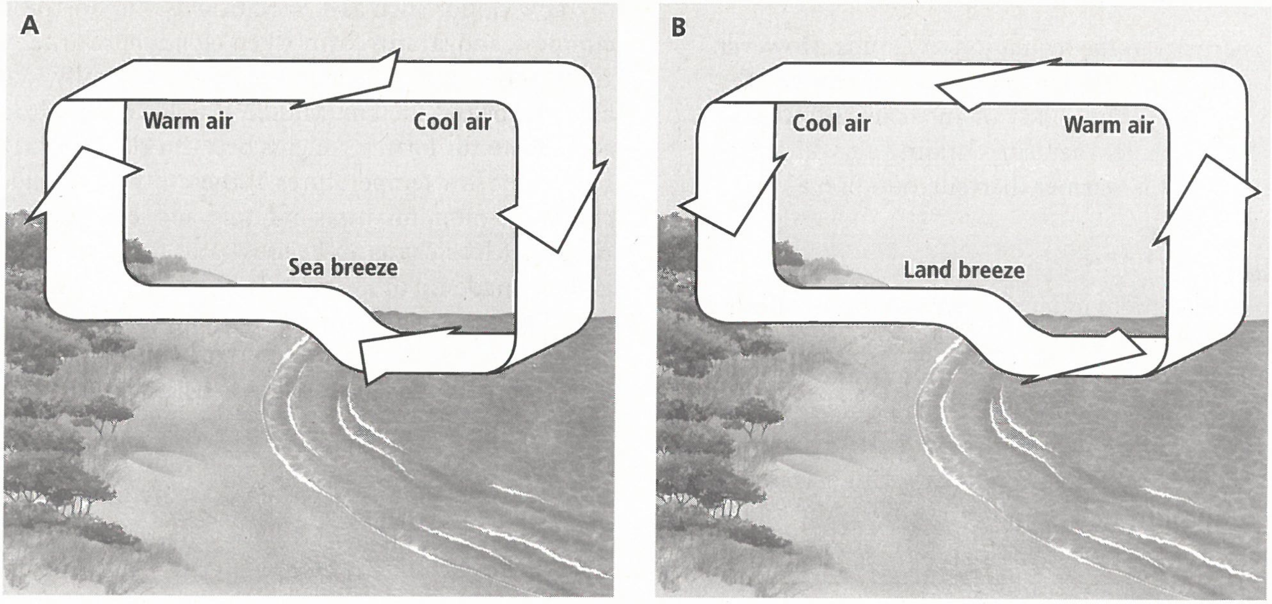


Figure 4-6 During the day, cool air over the ocean moves inland and creates a sea breeze. The cool air forces warm air over the land to rise. The rising air cools and sinks, creating a convection current (A). In the evening, the opposite occurs. Cool air over the land forces warm air over the ocean to rise, creating a land breeze (B).

Conversely, air pressure is directly proportional to air temperature. If density remains constant, then as air pressure increases, temperature increases, and vice versa.

Wind

Differences in density, temperature, and pressure combine to cause wind. Because different parts of Earth's surface are heated unequally by the Sun, some masses of air are warmer than others. Warm air is less dense than cool air. Thus, warm air rises and cool air sinks. This phenomenon is responsible for the direction of land and sea breezes, as shown in Figure 4-6. Wind is the generally horizontal movement of air from areas of higher density to areas of lower density. The unequal heating of Earth also creates pressure differences in the atmosphere. Wind, therefore, can be described as the movement of air from areas of high pressure to areas of low pressure. In general, wind speed increases with altitude because wind encounters less friction with trees and other obstacles, which slow it near Earth's surface.

Relative Humidity

The amount of water vapor in the lower atmosphere varies from 0 to 4 percent, depending on the time of year, the place, and other factors. **Humidity** refers to the actual amount of water vapor in air. In contrast, **relative humidity** is the ratio of the amount of water vapor in a given volume of air relative to how much water vapor the air is capable of holding at that air temperature. Relative humidity, which is expressed as a percentage, is related to temperature. Warm air is capable of holding more moisture than cold air. Air with 100 percent relative humidity is considered saturated. At that point, condensation can occur and clouds can form.

Cloud Formation

The formation of a cloud begins when convection currents cause warm, moist air to rise. As the air rises, it expands and eventually cools to its dewpoint. Condensation occurs when atmospheric water vapor condenses in liquid droplets around particles of dust, pollen, and sea salt called **condensation nuclei.** Millions of such droplets form a cloud.

A mountain can also cause clouds to form by forcing air up so that it cools and expands, as shown in Figure 4-7. Cloud formation of this type is called **orographic lifting.** Yet a third type of cloud formation occurs when two air masses of different temperatures collide. The warmer air is forced above the cooler, denser air. Again, the rising air will expand, cool, and eventually reach its dewpoint.

Figure 4-7 Clouds form when warm, moist air is forced to rise up a mountainside in a process known as orographic lifting.

Stability

Rising air is crucial to the formation of clouds. However, the rate at which air rises depends on the stability of the air. **Stability** refers to the ability of an air mass to resist rising. Air that is cooler than surrounding air will not rise; it is stable. Air that is warmer than surrounding air will rise; it is unstable.

Latent Heat

Unstable air rises and condenses, releasing heat into the atmosphere. The source of this heat is energy stored in water vapor. The energy was transferred to the water vapor when water changed state from a liquid to a gas and entered the atmosphere. The stored energy is called **latent heat.** When condensation occurs, this released heat warms the atmosphere and can provide the additional energy needed to form the clouds associated with thunderstorms.

Types of Clouds

Clouds come in many shapes and sizes, depending on the atmospheric conditions that exist at the time of their formation. Clouds are classified according to their shape and the altitude at which they form, as shown in Figure 4-8.

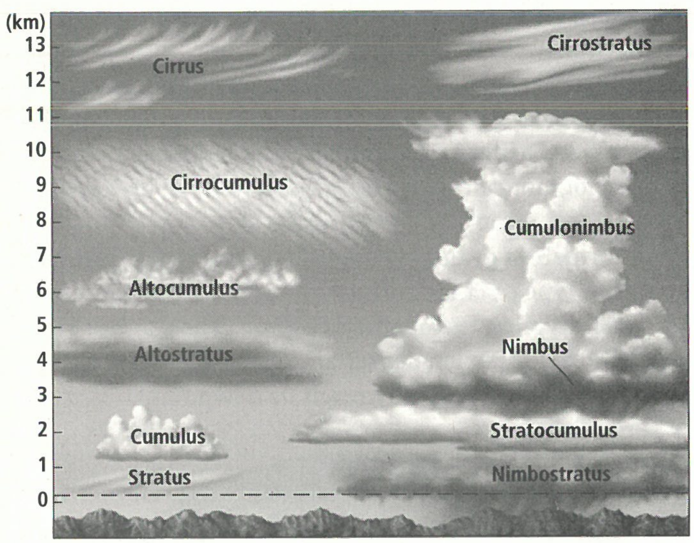


Figure 4-8 Clouds are classified according to the height at which they form and their shape.

Low clouds such as stratocumulus, nimbostratus, cumulus, and stratus form when clouds encounter warmer air, stop rising, and flatten out. They are usually found at altitudes below 2000 m. Middle clouds such as altocumulus and altostratus form at heights between 2000 m and 6000 m. Due to the low temperatures at these altitudes, middle clouds are often mixtures of liquid and ice crystals. High clouds such as cirrus and cirrostratus form above 6000 m and are made up of ice crystals. Cumulonimbus clouds forms when unstable cumulus clouds, fueled by the release of latent heat, grow into dark, towering clouds that extend through the atmosphere to heights of 18 000 m. Cumulonimbus clouds have anvil-shaped tops flattened by strong winds. They are the atmospheric giants that produce thunderstorms, torrential rains, and sometimes hail.

Precipitation

Rain falls when water droplets collide and join together to form larger droplets. This process is called coalescence. When the droplets reach approximately 0.2 mm in size (depending on wind or air movements), they are too heavy to remain suspended in the cloud and fall as precipitation. **Precipitation** describes all forms of water (rain, drizzle, snow, hail, and sleet) that fall from clouds.

The Water Cycle

As you have learned, water vapor condenses into liquid water droplets, which fall as precipitation. The constant movement of water between the atmosphere and Earth's surface is called the hydrologic cycle, or more commonly, the **water cycle.** The processes that make up the water cycle have been operating continuously since the outgassing of water early in Earth's history.

As shown in Figure 4-9, the water cycle gets its energy from the Sun. Solar radiation causes water to change state from a liquid to a gas, a process known as **evaporation.** Water evaporates from lakes, oceans, and rivers and enters the atmosphere. There, water cools and condensation occurs. As the water vapor condenses, it forms clouds. Water droplets in the clouds combine into larger droplets that fall as precipitation. Evaporation, condensation, and precipitation are the three methods by which water is continually recycled between the atmosphere and Earth's surface.

The Water Cycle

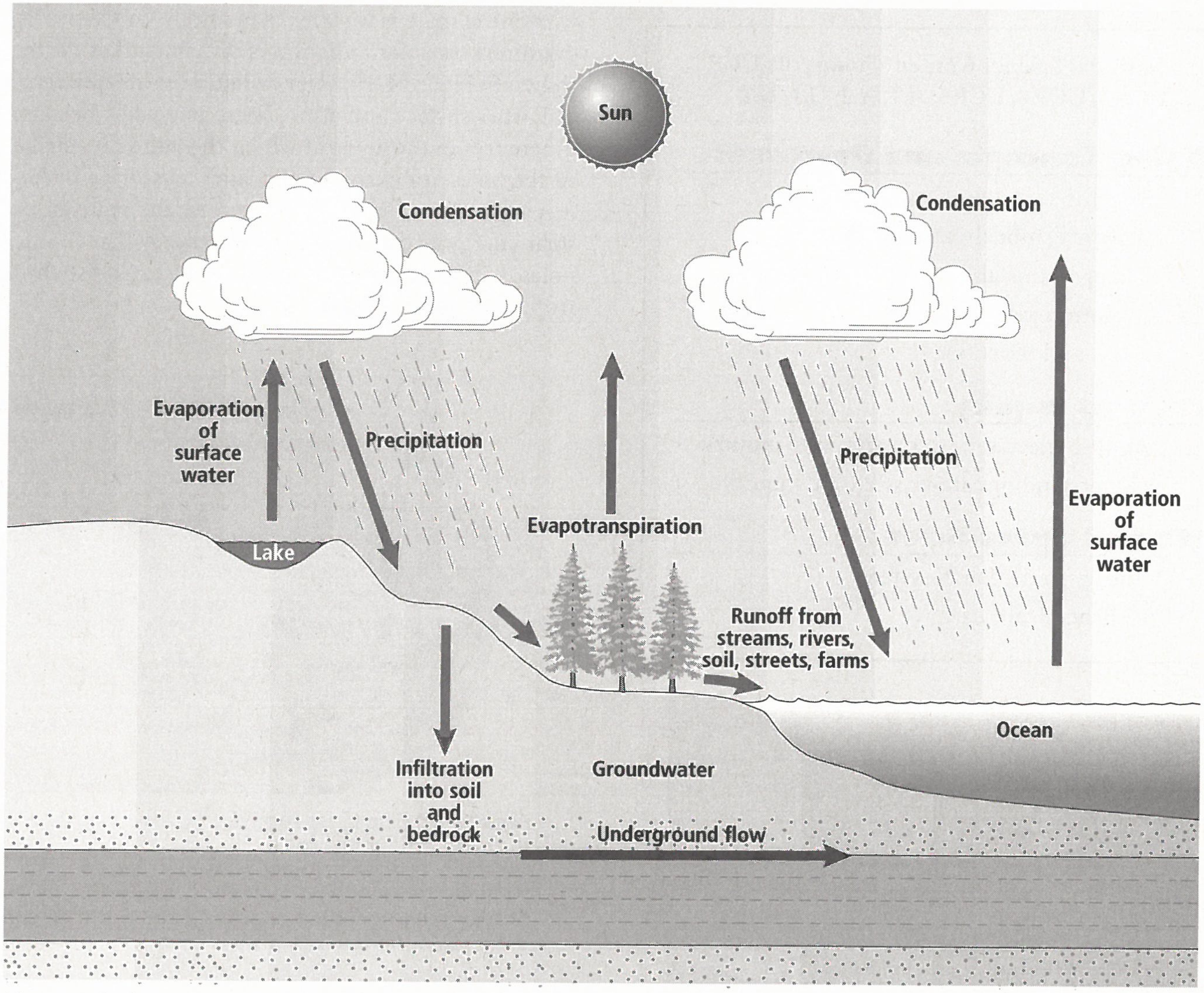


Figure 4-9 The constant movement of water between Earth's surface and the atmosphere is called the hydrologic cycle, or water cycle. The movement of water takes place through the processes of evaporation, condensation, and precipitation.

SUBTOPIC B METEOROLOGY

Covers National Science Content Standards UCP.1, UCP.2, UCP.3, UCP.4, UCP.5; A.1, A.2; D.1, D.2

Unifying Concepts and Processes

UCP.1	Systems, order, and organization
UCP.2	Evidence, models, and explanation
UCP.3	Change, constancy, and measurement
UCP.4	Evolution and equilibrium
UCP.5	Form and function

Science as Inquiry

A.1	Abilities necessary to do scientific inquiry
A.2	Understandings about scientific inquiry

Earth and Space Science

D.1	Energy in the Earth system
D.2	Geochemical cycles

VOCABULARY

meteorology	**front**
weather	**thermometer**
climate	**barometer**
Coriolis effect	**anemometer**
trade winds	**hygrometer**
prevailing westerlies	**ceilometer**
polar easterlies	**radiosonde**
jet stream	**Doppler effect**
air mass	**station model**
air mass modification	**digital forecast**

Clouds, precipitation, rainbows, and wind are all types of atmospheric phenomena. The study of atmospheric phenomena is called **meteorology.** This scientific field examines the current state of the atmosphere, which is known as **weather.** More specifically, weather is the condition of the atmosphere at a particular moment in time at a given location. Meteorology, however, is also concerned with **climate,** which describes the long-term variations in weather that take place in an area over the course of 30 years or more. A scientist who studies meteorology is called a meteorologist.

Heat Imbalance

To understand why weather changes from day to day, or why one climate is warmer than another, meteorologists examine how solar radiation is distributed on Earth. As shown in Figure 4-10, solar radiation heats different parts of Earth's surface and atmosphere unequally because of differences in the angle at which the Sun's rays strike Earth. At the poles, for example, the Sun's rays strike Earth at a low angle. Although the poles receive the same amount of solar energy as do the tropics, the energy that reaches the poles is spread over a larger area. This explains why the tropics are warmer than the poles.

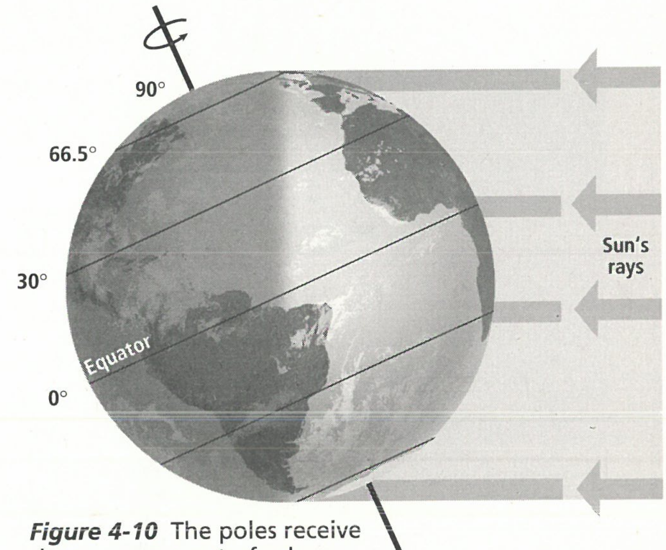


Figure 4-10 The poles receive the same amount of solar radiation as do the tropics. However, because the Sun's rays strike the poles at a low angle, the intensity of solar radiation is lower at the poles. For this reason, polar regions are nearly always cold.

Redistributing Heat

Although the tropics receive the highest intensity of solar energy year-round, they maintain fairly constant average temperatures. Heat energy absorbed by the tropics is redistributed around the world by the continual movement of air and water, which works to balance the unequal heating of Earth. The weather and climate experienced by any one place are a direct result of this redistribution of heat.

Coriolis Effect

Remember that air generally moves from areas of high density to areas of low density and that cool air is denser than warm air. Thus, cool, dense air at the poles should sink and move toward the warmer, less-dense air at the tropics, as shown in Figure 4-11. In the tropics, the cool air would force the warm air up. The rising air would cool, flow back toward the poles, and sink, and the process would start anew. In effect, two large convection cells would form in each hemisphere. In reality, two influences modify this pattern of air movement. First, the presence of landmasses interferes with the movement of air. Second, Earth rotates on its axis. This rotation creates the Coriolis effect.

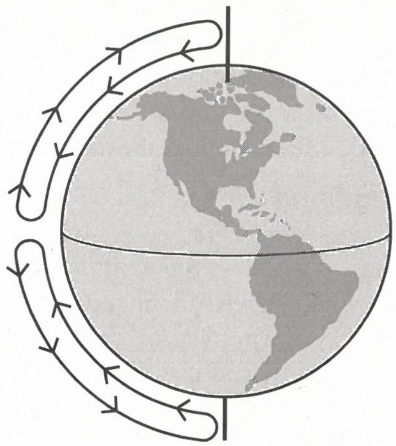


Figure 4-11 If Earth did not rotate on its axis, winds would move from the poles towards the tropics.

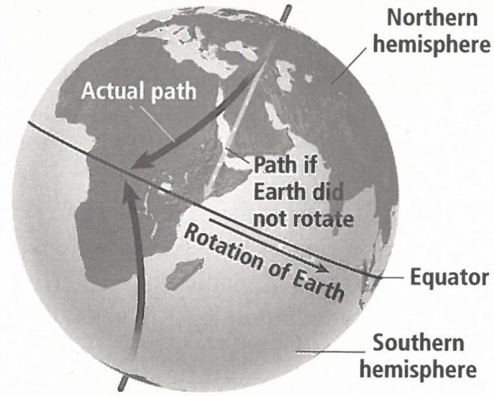


Figure 4-12 The Coriolis effect deflects air to the right in the northern hemisphere and to the left in the southern hemisphere.

The **Coriolis effect** is the deflection of fluids moving over a rotating body, such as Earth. The Coriolis effect causes free-moving particles, such as water and air, to be deflected to the right in the northern hemisphere and to the left in the southern hemisphere (Figure 4-12). The unequal heating of Earth fuels the movement of air, and the Coriolis effect helps guide that air. Together, these effects produce global wind systems that move cool air to warmer areas and warm air to cooler areas.

Global Wind Systems

As shown in Figure 4-13 and in the *Earth Science Tables and Charts,* there are three major wind systems in each hemisphere: the trade winds, the prevailing westerlies, and the polar easterlies. Note that wind directions in the northern and southern hemisphere are reversed.

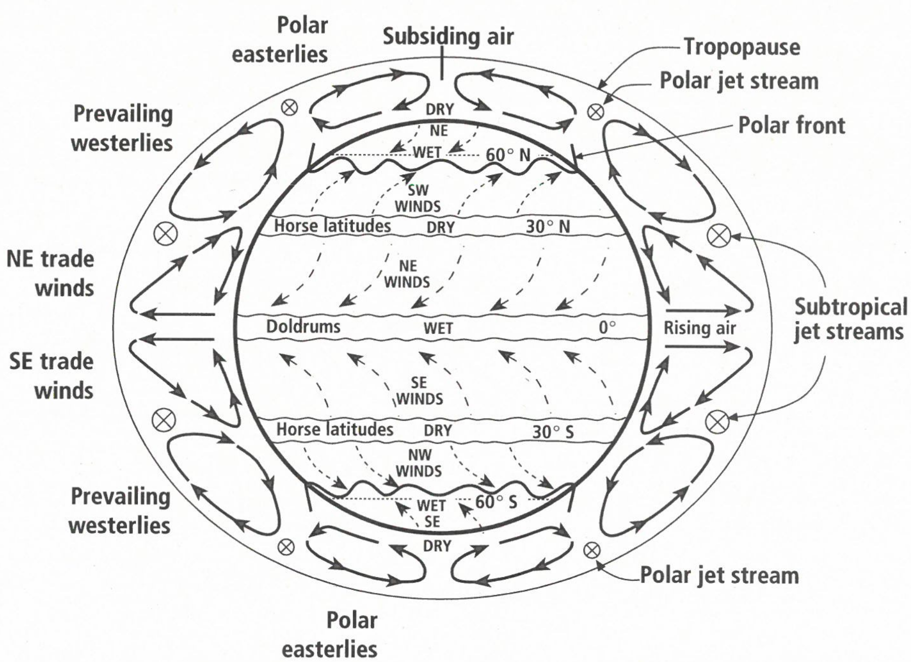


Figure 4-13 The Coriolis effect and the unequal heating of Earth's surface create three distinct global wind patterns: the trade winds, the prevailing westerlies, and the polar easterlies. Arrows show the movement of air in each convection cell.

The Trade Winds

The **trade winds** are located at 30° north and south latitude. At this latitude, air sinks and moves westward toward the equator. Warmed by the equatorial sun, the air rises again and travels back toward its origin, where it cools, sinks, and moves again toward the equator in an endless convection current. The sinking air around 30° north and south latitude forms a belt of high pressure known as the horse latitudes. The area is so named because winds there are generally light. According to legend, when the ships of Spanish sailors became stranded in the calm waters, the sailors ran out of food and water for their horses and were forced to throw them overboard.

In contrast to the sinking air at the horse latitudes, the rising air near the equator forms an area of low pressure known as the doldrums. Rising air is associated with clouds and precipitation; thus, tropical rain forests are found in moist areas along this belt.

Prevailing Westerlies

The **prevailing westerlies** are located between 30° and 60° north and south latitude. Like all winds, they are named for the direction from which they blow. The prevailing westerlies generally blow from the west and move eastward toward the poles. In North America, the prevailing westerlies actually blow from the southwest to the northeast due to the Coriolis effect. These winds greatly affect the movement of weather systems across the United States and Canada.

Polar Easterlies

Polar easterlies are found between 60° latitude and the poles. Characterized by cold air, they flow from the northeast to the southwest in the northern hemisphere. In the southern hemisphere, their direction is reversed: they flow from the southeast to the northwest.

Jet Streams

Differences in temperature, pressure, and density are found along the boundaries between wind zones. These differences produce fast, high-altitude winds called **jet streams.** A jet stream is a body of fast-moving winds in the upper atmosphere that generally move from west to east in the upper-mid latitudes. The strong polar jet streams separate the polar easterlies from the prevailing westerlies. The weaker subtropical jet streams separate the trade winds from the prevailing westerlies. Jet streams blow as fast as 185 km/h and are normally found at altitudes of 10 to 12 km.

In the northern hemisphere, the latitude of the polar jet stream varies from 40° to 60° north, and the latitude of the subtropical jet stream ranges from 20° to 30° north. Both jet streams are somewhat erratic. They can split into branches, slow down, and even temporarily disappear. Regardless of the form they take, jet streams affect the intensity of weather systems by moving air masses from one place to another.

Air Masses

An **air mass** is a large body of air that takes on the characteristics of the area over which it formed, which is called the source region. If the source region is wet and cold, then the air mass will also be wet and cold. If the source region is dry and warm, then the air mass will be dry and warm.

Classifying Air Masses

Air masses are classified according to their source regions. Figure 4-14 shows the main types of air masses that affect the United States. Warm and dry continental tropical (cT) air masses form over the desert Southwest and Mexico. Warm and humid maritime tropical (mT) air masses form over subtropical or tropical waters, such as the Caribbean Sea and the Gulf of Mexico. The source region for cold and dry continental polar (cP) air masses is the interior of Canada and Alaska during winter. Continental arctic (cA) air masses originate over ice-covered regions in Siberia and the Arctic Basin, and are colder than cP air. Lastly, cold and humid maritime polar (mP) air masses form over frigid waters, such as the North Atlantic and North Pacific.

Air Mass Modification

Air masses rarely stay in one place permanently. Jet streams and other wind currents often move air masses from one region to another. A moving air mass may travel over an area with different temperature and moisture characteristics than those of its source region. When that happens, the air mass takes on the characteristics of the new area. The process by which an air mass exchanges heat and moisture with the surface over which it travels is known as **air mass modification.**

Fronts

When two air masses with different characteristics collide, a front forms. A **front** is the narrow region that separates two air masses of different densities. The density differences are caused by differences in temperature, pressure, and humidity. A front can also be thought of as an area where two opposing air masses meet. There are four types of fronts: cold, warm, stationary, and occluded. These fronts form in middle latitudes, where differences in temperature, humidity, and pressure are common. Fronts can be thousands of kilometers long and trigger sudden changes in weather.

Cold Front

A cold air mass and a warm air mass collide along a cold front. At a cold front, a cold air mass overtakes the boundary of a warmer air mass. As shown in Figure 4-15A on page 76, the cold, dense air forces up the warm air at a steep angle. The rising air cools and condenses to form clouds, rain, and, if conditions are right, thunderstorms. On a weather map, a cold front is represented by a solid line with triangles. The triangles point to the direction in which the front is moving, as Figure 4-15A shows. If the map is in color, the line and triangles will be blue.

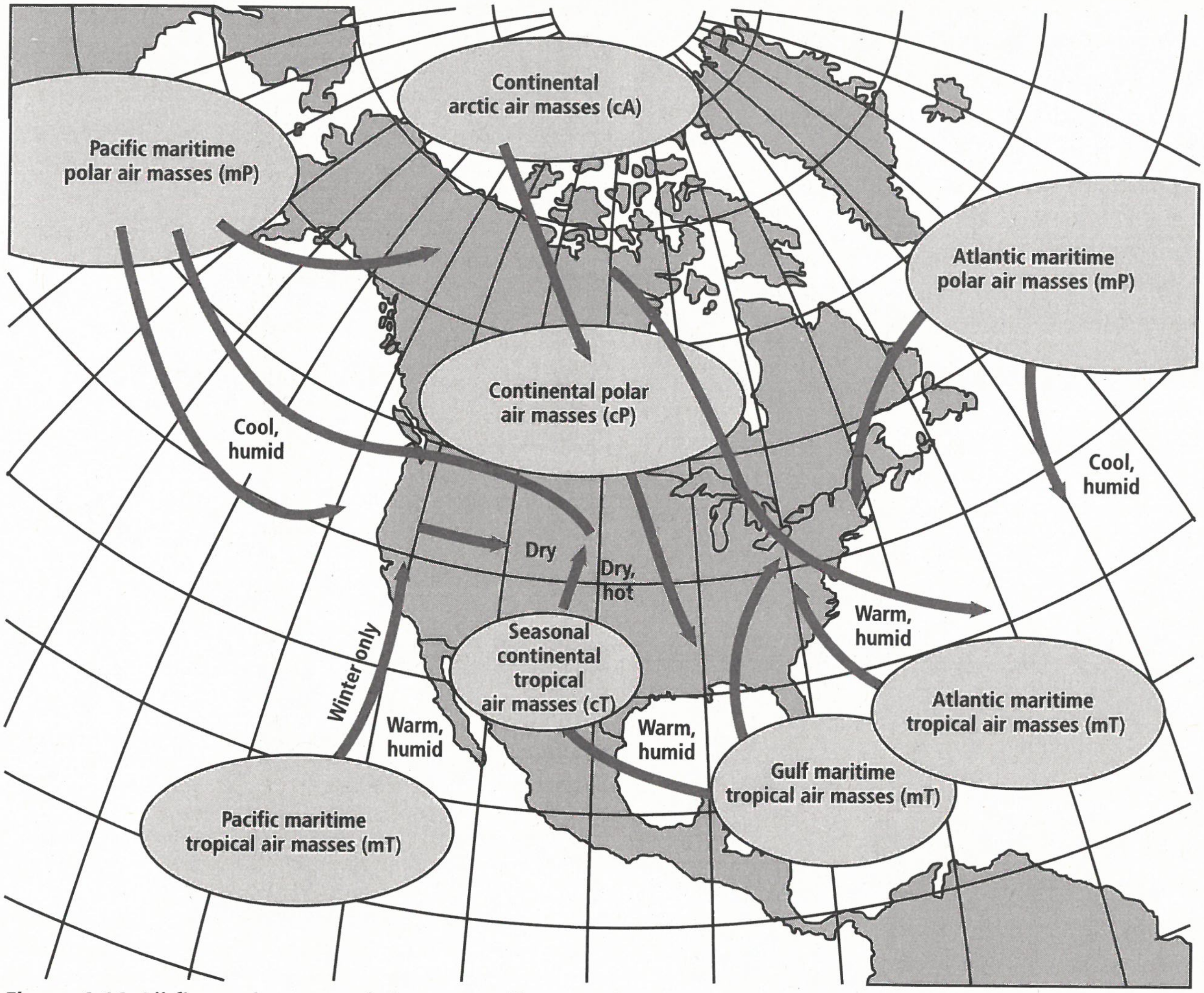


Figure 4-14 All five major types of air masses affect weather across North America because the continent is close to the source region of each air mass.

Warm Front

A warm front forms when a warm air mass overtakes a cold air mass, as shown in Figure 4-15B. Warm fronts are associated with clouds and precipitation over a wide area. A solid line and semicircles represent a warm front on a weather map. The semicircles point to the direction in which the front is moving. If the map is in color, the line and semicircles will be red.

Stationary Front

A stationary or stalled front forms when two air masses meet and stall, as shown in Figure 4-15C. Often, there are no sharp differences in temperature and pressure between the two air masses, so neither one can displace the other. Hence, there is no frontal air movement. Light wind and precipitation are sometimes associated with stationary fronts. A stationary front is represented on a weather map by a line with triangles pointing toward the warmer air and semicircles pointing toward the colder air. If the map is in color, the triangles will be blue, the semicircles will be red, and the line will be composed of alternating red and blue segments.

Occluded Front

An occluded front occurs when a cold air mass overtakes a warm front. Remember that a warm front involves a cold air mass. Thus, two cold air masses are involved in an occluded front. As shown in Figure 4-15D, the warm air is forced up between these two cold air masses. Strong winds and heavy precipitation often occur along occluded fronts, which are represented on weather maps by a line with alternating triangles and semicircles pointing in the direction of frontal movement. If the map is in color, the line, triangles, and semicircles will be purple.

Pressure Systems

When air rises, air pressure decreases. Conversely, when air sinks, air pressure increases. As air rises or sinks due to wind systems, colliding air masses, and other factors, areas of high and low pressure form in the atmosphere. Such areas are called pressure systems. Air moves around the centers of these pressure systems in a circular motion.

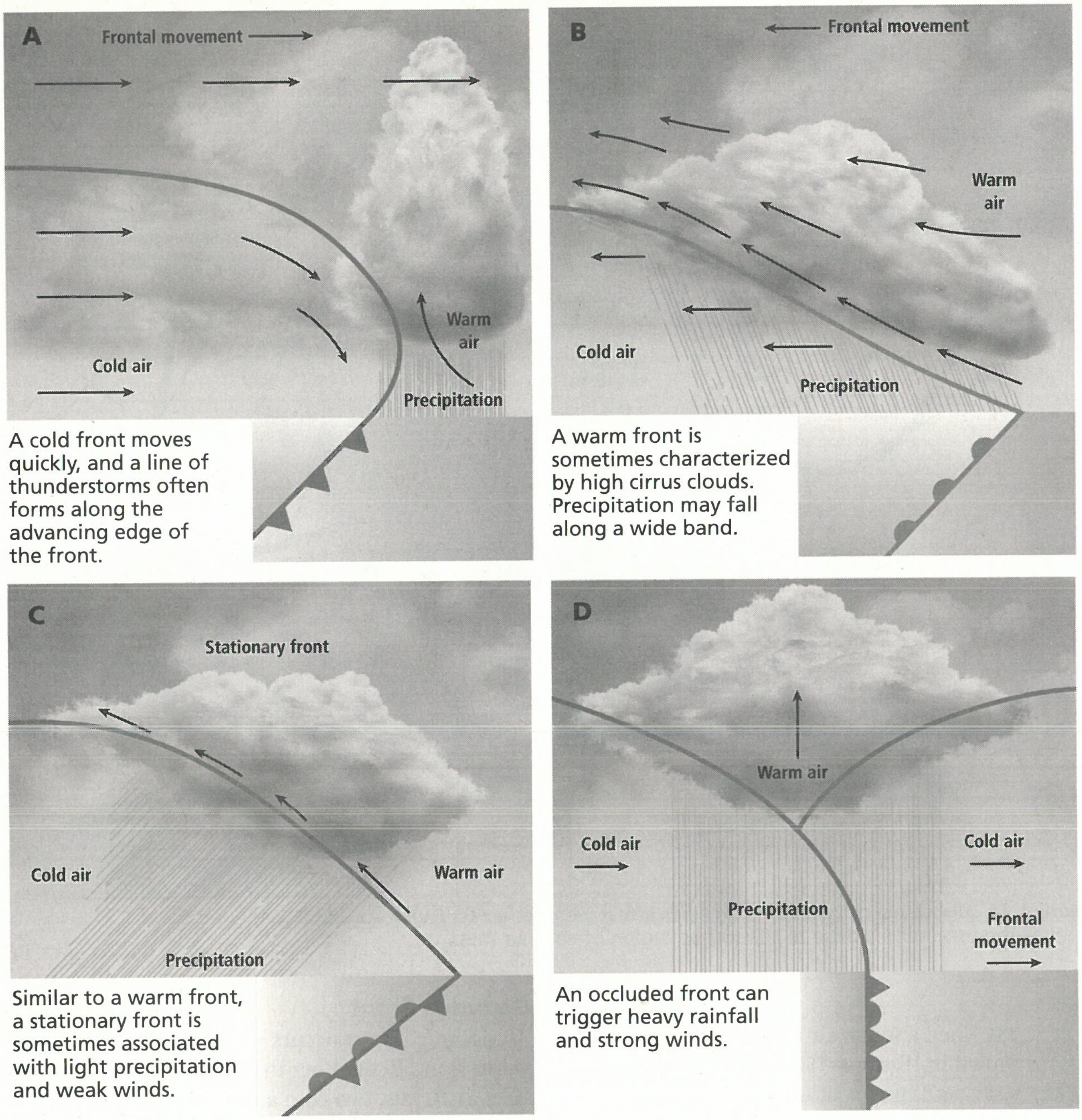


Figure 4-15 These diagrams show the structures of the four main types of fronts.

High-Pressure Systems

In the northern hemisphere, the Coriolis effect causes air in a high-pressure system to move in a clockwise direction, as shown in Figure 4-16A. The motion is reversed in the southern hemisphere: high-pressure systems south of the equator move in a counterclockwise direction. Regardless of latitude, the sinking air spreads out from the center when it reaches Earth's surface. High-pressure systems usually indicate fair weather because the air does not rise, cool, and condense into clouds.

Low-Pressure Systems

The air in low-pressure systems moves in a counterclockwise direction in the northern hemisphere, as shown in figure 4-16B, and in a clockwise direction in the southern hemisphere. The air rises toward the center and then up. Air from outside the system flows in to replace the rising air. Low-pressure systems are often associated with clouds and precipitation. A low-pressure system called a wave cyclone often affects the weather across large areas in the middle latitudes, including the mid-Atlantic states.

Weather Data

To forecast an advancing front or developing pressure system, meteorologists must first gather accurate weather data about temperature, air pressure, wind, and relative humidity, using a wide variety of instruments. Some of these instruments are illustrated in Figure 4-17. These data are obtained both close to Earth's surface and in the upper reaches of the troposphere.

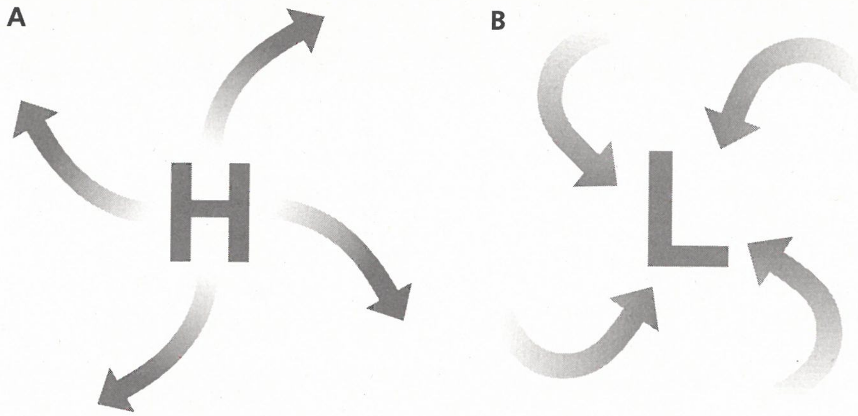


Figure 4-16 In the northern hemisphere, winds in a high-pressure system rotate in a clockwise direction (A), and winds in a low-pressure system rotate in a counterclockwise direction (B).

Surface Data

Thermometers are used to measure temperatures. Within some thermometers, the height of a liquid column of mercury or alcohol, which expands when heated, indicates the temperature. To measure air pressure, meteorologists use **barometers.** A mercury barometer contains a column of liquid mercury whose height marks the air pressure. An aneroid barometer contains a metal vacuum chamber that expands and contracts as air pressure changes.

An **anemometer** measures wind speed at Earth's surface. A commonly used anemometer has three cupped arms mounted on a vertical pole. Wind pushing against the cups causes the pole to rotate; wind speed can be determined by the rate of rotation.

Relative humidity is measured by a **hygrometer.** One common type of hygrometer, called a sling psychrometer, consists of two thermometers mounted side by side. The bulb of one thermometer is kept dry, so that thermometer records the true air temperature. The bulb of the second thermometer is kept wet by a cloth wick. The second thermometer records a lower temperature due to evaporation of water from the wick. Relative humidity can be determined from the difference between the wet-bulb and dry-bulb temperatures, in conjunction with a table like the *Relative Humidity* table in the *Earth Science Tables and Charts.* For example, consider a situation in which the dry-bulb temperature is 8°C and the wet-bulb temperature is 5°C. The difference between the wet-bulb and dry-bulb temperatures is 3°C. To determine the relative humidity, find the row in the table that corresponds to the dry-bulb temperature (8°C). Then find the column that corresponds to the difference between the wet-bulb and dry-bulb temperatures (3°C). The point where the row and the column intersect is the relative humidity of the air (62 percent). You can determine the dewpoint of the air by applying the same method to the *Dewpoint Temperatures* table in the *Earth Science Tables and Charts.* Relative humidity and dewpoint can also be measured by means of digital probes coupled to computers.

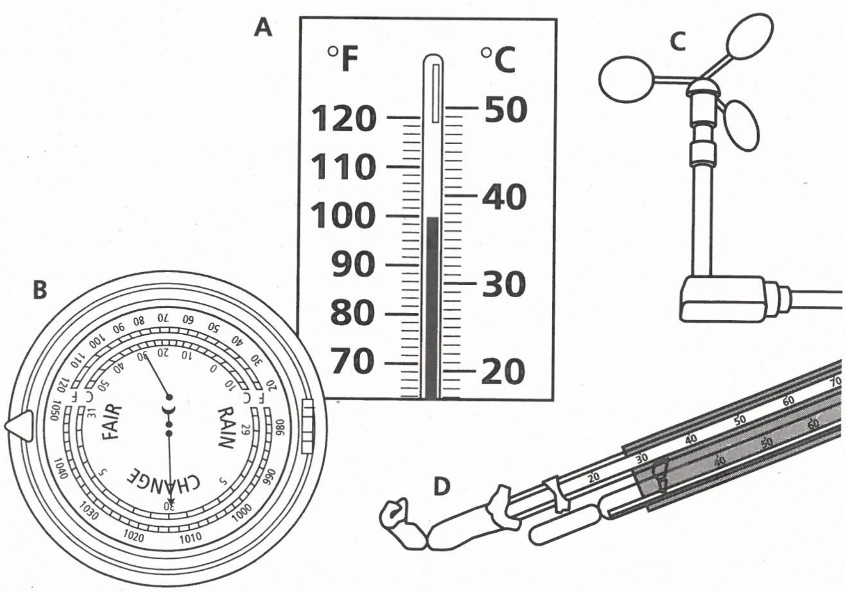


Figure 4-17 A thermometer (A), barometer (B), anemometer (C), and hygrometer (D) are commonly used weather instruments.

Automated Surface Observing System

To make accurate forecasts, meteorologists must compare and contrast current conditions involving several different weather variables. The measurements must be gathered at the same moment in time, and they must be gathered numerous times each day. To aid in this task, the U.S. National Weather Service has a network of approximately 1700 official weather-observing sites that measure and record weather variables at least every hour. An Automated Surface Observing System (ASOS) collects the data. This system includes the instruments described on the previous page, as well as rain gauges to measure the amount of precipitation and **ceilometers** to measure cloud heights and cloud cover.

Upper-Level Data

More complex technology is needed to gather data from the upper levels of the troposphere. Since weather near the surface is affected by changes in the upper atmosphere, such data are needed to ensure forecast accuracy.

Radiosondes

A **radiosonde** is a balloon-borne instrument that contains sensors to measure upper-level temperature, relative humidity, and air pressure. These measurements are transmitted by a radio signal to a ground station. By tracking the movements of the radiosonde, the station can determine wind speed and direction. Although radiosondes are widely used and give an accurate picture of the atmospheric conditions that affect surface weather, they are expensive.

Weather Radar

Radar is used to track areas of precipitation. A weather radar system includes a transmitter that emits electromagnetic waves through antennae. When these waves encounter large water droplets, they are reflected, producing an echo that is picked up by receiving antennae. Meteorologists use the elapsed time between transmission and echo reception to determine where rain is falling. Each radar system has a range roughly 400 km in diameter.

Doppler radar systems are similar to conventional radar systems, but have an added advantage. They can measure wind speeds associated with storms. Doppler radar is based on the **Doppler effect,** which is the change in wave frequency that occurs as the source of the waves moves toward or away from an observer. An ambulance siren, for example, sounds high-pitched as the ambulance approaches but then lowers in pitch as the ambulance passes. By plotting the echoes of radar signals, meteorologists can determine the speed at which raindrops are moving toward or away from the receiving antennae. Raindrops move horizontally because of wind; thus, Doppler radar data indicate wind speed. The ability to estimate wind speed is particularly important during severe weather events.

Satellites

Weather satellites orbit Earth high above the surface and regularly transmit images to weather stations. These images give meteorologists a good view of cloud cover—something radar cannot do. Satellites do not, however, track areas of precipitation. Data from satellites and radar are often used together to form a more complete forecast.

Some satellites use infrared imagery to detect differences in thermal energy on or near Earth's surface. These differences show up on an infrared image as different colors. A high, cold cloud, for example, will radiate thermal energy at a slightly different frequency than a low, warm cloud. By mapping the infrared images, meteorologists can determine a cloud's temperature and classification. In addition to information about clouds, infrared imagery is used to determine surface temperatures. This type of technology does not require visible light. Therefore, infrared imagery can provide temperature information both during the day and at night.

Atmospheric Cross Sections

Data from both surface and upper air measurements are often used to construct cross sections of the atmosphere. Such a cross section is basically a vertical slice of a particular part of the atmosphere, showing how properties such as temperature, wind speed, precipitation, and air pressure vary from the ground to the tropopause. By analyzing the cross sections, meteorologists can predict the probable movement of fronts, the jet stream, and areas of precipitation, among other things.

Weather Analysis

Weather data gathered from the various technologies discussed above are plotted on maps in the form of station models. A **station model** is a record of weather data for a particular location at a particular time. The symbols and numbers that appear in a station model are explained in Figure 4-18 and in *Weather Map Symbols* in the *Earth Science Tables and Charts.*

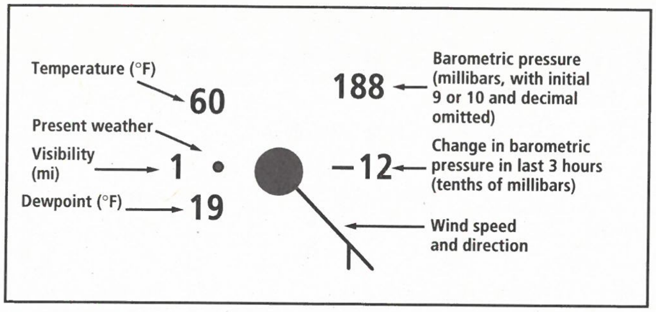


Figure 4-18 Meteorologists use station models to record weather data for a particular site at a particular time.

Synoptic Weather Maps

In contrast to station models, which describe weather conditions at specific places, synoptic weather maps show weather conditions on a national or global basis. These maps use isolines to represent atmospheric properties such as air pressure and temperature. Isolines are lines that connect points of equal or constant value. For example, a type of isoline called an isobar connects points of equal air pressure. Points of equal temperature are connected by isotherms. Once plotted on a synoptic weather map, these lines can be used to analyze weather patterns. Closely spaced isobars, for example, are evidence of a large pressure difference over a small area, which would cause strong winds. Isotherms show temperature differences and therefore indicate developing fronts. See Figure 4-19 on the next page for an example of a synoptic weather map.

Weather Forecasts

Forecasting the weather is a complex task that must take into account changes in numerous variables that occur throughout different levels of the troposphere. Meteorologists use mathematical equations to produce models that predict probable changes in atmospheric variables, such as temperature and density. Given the large amount of data that must be analyzed for a national or regional forecast, high-speed computers are used to calculate the models. The resulting forecast, which is based on numerical data, is called a **digital forecast.** Most meteorologists use digital forecasting to predict short-term changes in weather. Its accuracy depends on the amount of data available. More information results in increased accuracy. However, conflicting or different weather forecasts may be the result of using different weather models.

Analog Forecasts

For long-term forecasts covering months or seasons, meteorologists often use analog forecasting. An analog forecast compares current weather patterns to similar, or analogous, patterns that appeared in the past. Meteorologists then develop a long-term forecast based on the assumption that current events will develop in the same way that past events developed. Analog forecasting can offer a general description of the weather for a given month or season. But, unlike digital forecasting, it cannot offer an accurate forecast of the weather on a particular day.

Forecasting Accuracy

The accuracy of a forecast depends largely on the range of time it covers. Hourly forecasts can be made by examining current cloud and precipitation patterns, and then extrapolating these patterns one hour ahead. One- to three-day forecasts are more difficult to make because they cannot be based on the movement of clouds and precipitation, which can change drastically over the course of 24 hours. These forecasts must rely on data about large-scale weather systems and upper-level disturbances. While one- to three-day forecasts can predict the probability of sunshine or precipitation with a certain degree of accuracy, they cannot forecast exact temperatures or sky conditions at specific times. Modifications to general forecasts based on local factors can help improve forecast accuracy.

Long-Term Forecasts

Forecasting accuracy sharply decreases with time. A forecast for one week in advance is based on changes that occur throughout the atmosphere. Predictions can be made, but few details can be offered about exact weather conditions. A forecast in the two- to three-week range must largely rely on analogous events. Monthly and seasonal forecasts are based entirely on analogous events. In spite of the lower accuracy of long-term forecasting, awareness of certain weather patterns can assist communities in preparing for weather-related emergencies.

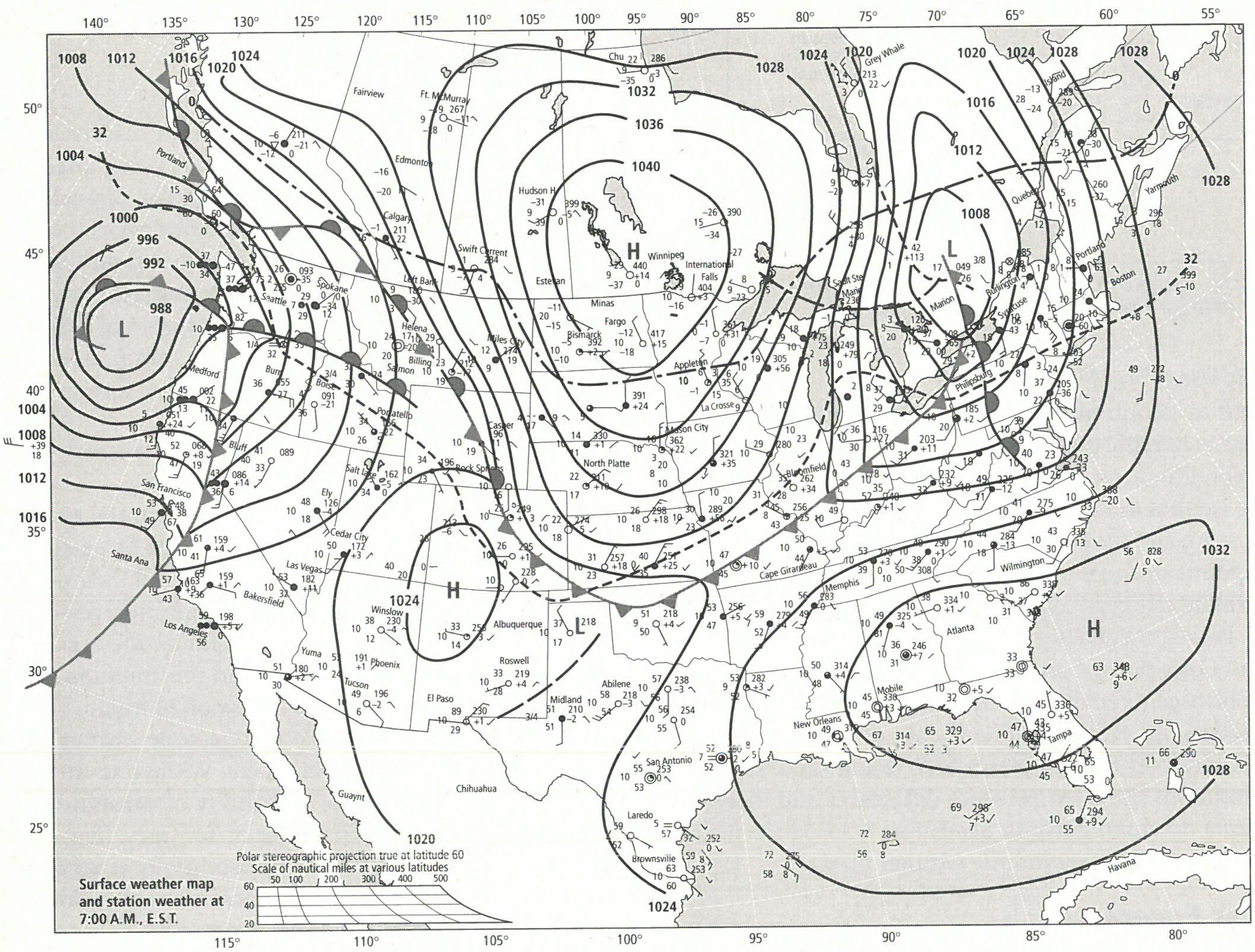


Figure 4-19 Information from station models is used to create a synoptic weather map, which shows the presence of fronts and atmospheric properties such as air pressure and temperature over a wide area for a specific time.

SUBTOPIC C
THE NATURE OF STORMS

Covers National Science Content Standards UCP.1, UCP.2, UCP.3, UCP.4, UCP.5; A.1, A.2; D.1, D.2; E.1, E.2; F.6

Unifying Concepts and Processes

UCP.1	Systems, order, and organization
UCP.2	Evidence, models, and explanation
UCP.3	Change, constancy, and measurement
UCP.4	Evolution and equilibrium
UCP.5	Form and function

Science as Inquiry

A.1	Abilities necessary to do scientific inquiry
A.2	Understandings about scientific inquiry

Earth and Space Science

D.1	Energy in the Earth system
D.2	Geochemical cycles

Science and Technology

E.1	Abilities of technological design
E.2	Understandings about science and technology

Science in Personal and Social Perspectives

F.6	Science and technology in local, national, and global challenges

VOCABULARY

- air-mass thunderstorm
- sea-breeze thunderstorm
- frontal thunderstorm
- supercell
- downburst
- tornado
- Fujita tornado intensity scale
- tropical cyclone
- eye
- storm surge
- flash flood
- drought

Most of the weather you experience is relatively tame. The air outside might be cool or warm, but it presents no danger to life or property. In contrast, severe weather events such as thunderstorms, blizzards, tornadoes, and hurricanes can wreak havoc. In addition, recurring types of weather such as cold waves and droughts can cause as much damage as a powerful storm.

Thunderstorms

Thunderstorms develop when a cumulus cloud grows into a towering cumulonimbus cloud. For this to occur, certain atmospheric conditions must be present. Temperature and relative humidity must be at optimal levels for the storm to develop and precipitation to occur. For example, the cumulus cloud must be lifted by either the unequal heating of Earth's surface or by an advancing front. In addition, the lower atmosphere must contain an abundance of moisture. The "lift" provides the mechanism by which the cloud can reach its condensation point. The moisture then condenses and releases latent heat, which provides the thermal energy needed for the cloud to continue to grow. Finally, the air that surrounds the cloud must be unstable, or cooler than the cloud itself. Otherwise, the cloud will stop growing.

Factors That Affect Height

A cloud's rate of condensation lessens with altitude. Less latent heat is produced and the cloud cannot stay warmer than the surrounding air. This factor limits the height of most cumulonimbus clouds to roughly 18 000 m. Should the cloud encounter a layer of stable air, that, too, would stop its growth.

Air-Mass Thunderstorms

Meteorologists usually classify thunderstorms according to the factor that caused the air to rise. An **air-mass thunderstorm** rises because of the unequal heating of Earth's surface, which reaches its peak during mid-afternoon. For this reason, most air-mass thunderstorms occur in the afternoon or early evening.

A mountain thunderstorm is a type of air-mass thunderstorm that forms when air is lifted over a mountain. This process, which you read about earlier, is called orographic lifting. Another type of air-mass thunderstorm forms in the summer in tropical and subtropical coastal regions. These are **sea-breeze thunderstorms,** storms caused by sharp temperature gradients between air over land and air over water.

Frontal Thunderstorms

A **frontal thunderstorm,** the second main type of thunderstorm, usually forms as a result of an advancing cold front. The cold air rapidly pushes warm air up a steep slope, giving rise to the conditions necessary to form cumulonimbus clouds. A line of thunderstorms hundreds of kilometers in length can develop along the edge of the front. Unlike air-mass thunderstorms, cold-front thunderstorms can occur at any time. Their formation is not linked to the unequal heating of Earth's surface during the day.

Frontal thunderstorms also occasionally form along warm fronts. Normally, the gradual rise of air in a warm front works against the development of cumulonimbus clouds. However, if abundant moisture is present in the lower atmosphere and the air behind the front is unstable, a mild thunderstorm can form.

Thunderstorm Development

A thunderstorm usually goes through three distinct stages: the developing or cumulus stage, which is characterized by updrafts; the mature stage, which is characterized by updrafts and downdrafts; and the dissipation stage, which is characterized by the cessation of updrafts. These stages are illustrated in Figure 4-20.

Cumulus Stage

Air in a developing thunderstorm rises almost straight up, forming strong updrafts. The updrafts carry moisture to the top part of the cloud. Condensation occurs high in the atmosphere, and latent heat is released. Water droplets join together into larger droplets that fall as rain, cooling the air as they fall. This process marks the beginning of the storm's mature stage.

Mature Stage

The cooled air is now denser than the surrounding air. Being denser, it sinks rapidly toward the surface and produces strong downdrafts. Warm, moist air is still rising within the cloud, and the combined presence of updrafts and downdrafts creates a convection current. The current, in turn, causes turbulent surface winds. At this point in a thunderstorm's development, the volumes of air moving in updrafts and downdrafts are nearly equal.

Dissipation Stage

When downdrafts reach the ground, they spread out and cool both the surface and the air near the surface. In effect, this cuts off the storm's energy supply. The storm needs warm, moist air near the surface to sustain updrafts. The loss of warm air and the resulting cessation of updrafts mark the final stage of a thunderstorm. Precipitation no longer forms, but existing raindrops will continue to fall for a time. On average, most thunderstorms go through all three stages of development in roughly 30 minutes.

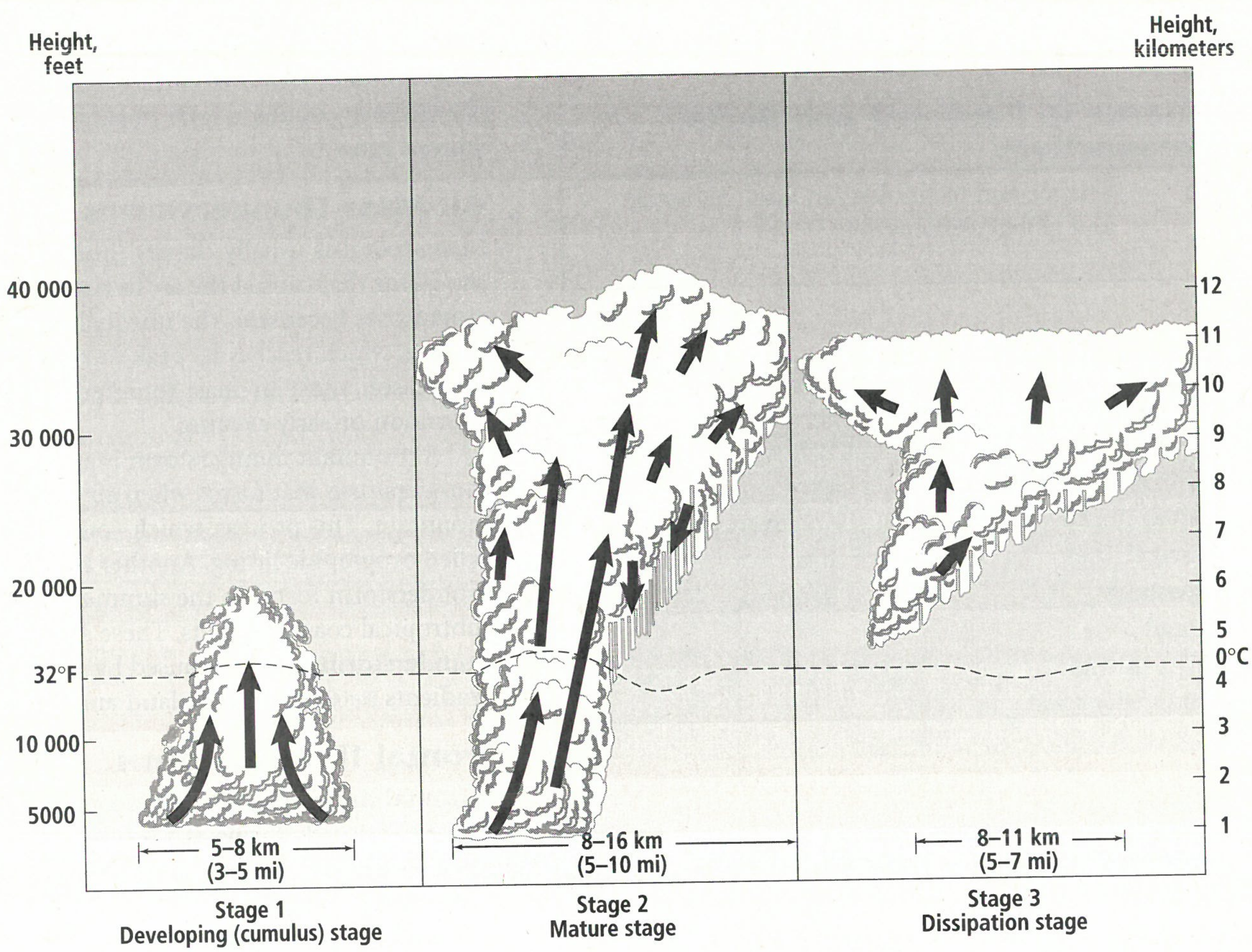


Figure 4-20 Air moves in different directions during each stage of thunderstorm development. Updrafts form in the cumulus stage. The mature stage has both updrafts and downdrafts. Updrafts stop in the dissipation stage.

Severe Thunderstorms

While all thunderstorms form under similar conditions, some are far more severe than others. The most powerful thunderstorms can produce devastating hail, swirling tornadoes, and surface winds of more than 160 km/h. Such destructive storms most often occur when a cold front continues to move over warm land that provides a steady supply of moisture. The resulting thunderstorms can last for days.

Supercells

Severe thunderstorms can also develop when an exceptionally large temperature gradient exists between the upper and lower parts of the storm. This increases the instability of the air, which in turn increases the storm's intensity by producing stronger updrafts and downdrafts. These conditions usually occur when cold fronts move with upper-level, low-pressure systems that contain pockets of cold air. The result can be a **supercell**—a self-sustaining, extremely violent storm with intense, rotating updrafts. The updrafts in a supercell can reach speeds as high as 240 km/h.

Only 10 percent of the estimated 100 000 thunderstorms that occur in the United States each year are considered severe, and only a handful of those develop into supercells. Although few in number, severe thunderstorms can cause billions of dollars in damage from lightning, strong winds, hail, floods, and tornadoes.

Lightning

Lightning is a hazard associated with all thunderstorms, regardless of their duration or intensity. Lightning is an electrical discharge caused by the rapid movement of air within a cumulonimbus cloud. Friction between updrafts and downdrafts causes some atoms near the ground or in the cloud to lose electrons. These atoms become positively charged. The separated electrons are then "picked up" by other atoms, which become negatively charged. Thus, positively and negatively charged regions of air exist in the storm, as shown in Figure 4-21. The electrical imbalance causes an invisible channel of negatively charged air to form between the cloud and the ground. As this channel nears the ground, it is met by a return stroke, which is a positively charged channel of ions. The return stroke, which surges upward toward the cloud, creates the brilliant illumination known as lightning.

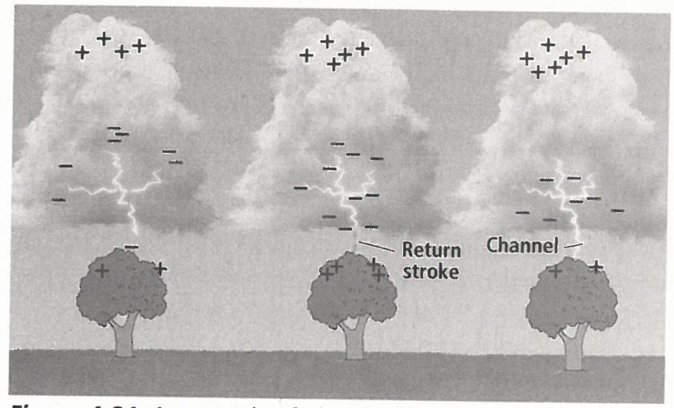


Figure 4-21 As a result of electrical imbalances in the air, negatively charged air moves toward the ground. A positively charged return stroke surges upward to meet it, causing the illumination known as lightning.

Hazards of Lightning

A lightning bolt heats the surrounding air to a temperature of 30 000°C—nearly five times greater than the temperature of the surface of the Sun. Thunder is produced by the rapid expansion and contraction of air caused by this intense heat.

Lightning causes hundreds of injuries and deaths each year. In addition, the 7500 wildfires sparked by lightning burn thousands of square kilometers of forests each year in the United States alone. Table 4-1 lists thunderstorm and lightning safety tips.

Table 4-1 Thunderstorm and Lightning Safety
When Thunderstorms Approach . . .
• Remember: If you can hear thunder, you are close enough to the storm to be struck by lightning. Go to a safe shelter immediately.
• Move to a sturdy building or car. Do not take shelter in small sheds, under isolated trees, or in convertible automobiles.
• If lightning is occurring and a sturdy shelter is not available, get inside a hard-topped automobile and keep the windows up.
• Get out of boats and away from water.
• Telephone lines and metal pipes can conduct electricity. Unplug appliances not necessary for obtaining weather information. Avoid using any electrical appliances. Use phones ONLY in an emergency.
If You Are Caught Outdoors and No Shelter Is Nearby . . .
• Find a low spot away from trees, fences, and poles. Make sure the place you choose is not subject to flooding.
• If you are in the woods, take shelter under the shorter trees.
• If you feel your skin tingle or your hair stand on end, squat low to the ground on the balls of your feet. Place your hands on your knees with your head between them. Make yourself the smallest target possible, and minimize your contact with the ground.

Source: NOAA

Strong Winds

Wind, another hazard associated with thunderstorms, can be exceptionally dangerous when downbursts occur. **Downbursts** are violent downdrafts that are concentrated in a small area. Normally, downdrafts spread out and disperse over a wide area when they reach the ground. These winds, however, sometimes fail to spread out and instead focus their fury in a small region, creating downbursts.

Downbursts that affect areas up to 5 km wide are called macrobursts. They can last up to 30 minutes and have wind speeds of 200 km/h. Downbursts that affect areas less than 3 km wide are called microbursts. They only last 10 minutes or less, but can reach wind speeds of 250 km/h. Microbursts in particular can cause extensive damage because they are difficult to detect in advance.

Hail

Hail is precipitation that falls as balls of ice. In the United States, it occurs most frequently in the interior portion of the country during spring. Because this region is heavily agricultural, hail often devastates entire crops.
It causes an estimated $1 billion in damage each year.

Two conditions cause hail to form in a thunderstorm. First, liquid water droplets are present in the upper reaches of the cloud, where temperatures are below freezing. These so-called supercooled water droplets freeze when they encounter ice pellets, and the ice pellets grow larger. Second, strong updrafts and downdrafts are present in the cloud. As the ice pellets are carried up and down by these winds, the pellets encounter more supercooled water droplets and continue to grow in layers. Eventually, the growing ice pellets become so heavy that they fall to the ground as hail.

Floods

Floods can occur when a slow-moving storm unleashes rain over a restricted region. This can happen if wind currents are weak, and the storm settles over an area for several days. An abundant supply of moisture throughout the atmosphere can cause even more rain to fall. In the United States, most thunderstorm-related deaths are related to floods.

Tornadoes

A **tornado** is a violent, whirling column of air that reaches the ground. Often sparked up supercells, tornadoes form when wind speed and wind direction change quickly with height. This process, known as wind shear, can cause a horizontal rotation of air in the lower atmosphere, as shown in Figure 4-22. Strong updrafts located near this rotation then tilt the twisting column of air vertically. The rate of rotation increases, removing air—and thus lowering air pressure—in the center of the column. The sharp pressure difference between the center and outer portions of the storm produces damaging winds.

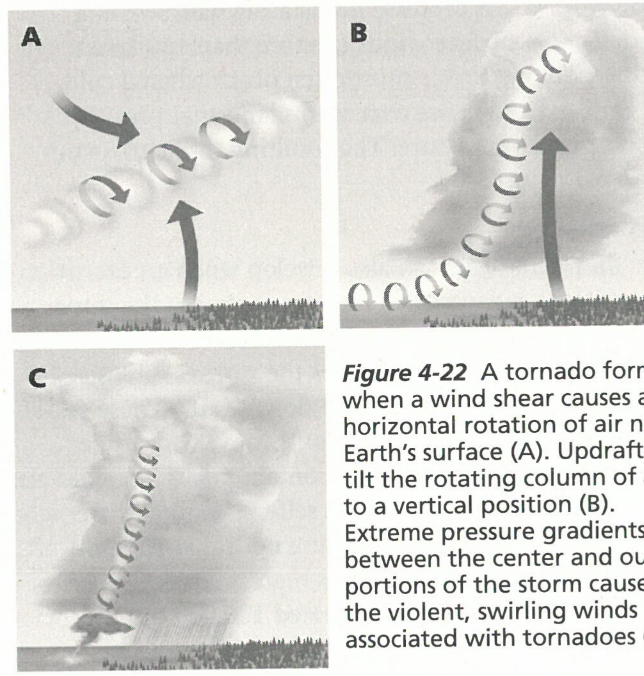


Figure 4-22 A tornado forms when a wind shear causes a horizontal rotation of air near Earth's surface (A). Updrafts tilt the rotating column of air to a vertical position (B). Extreme pressure gradients between the center and outer portions of the storm cause the violent, swirling winds associated with tornadoes (C).

Tornado Classification

The **Fujita tornado intensity scale** is used to classify tornadoes according to their path of destruction, wind speed, and duration. The scale is summarized in Table 4-2. The most powerful tornadoes can lift entire buildings and toss vehicles through the air.

Table 4-2 Fujita Tornado Intensity Scale

Weak tornadoes (F0 and F1)	80% of all tornadoes Path: up to 5 km Wind speed: 97 to 185 km/h Duration: 1–10 minutes +
Strong tornadoes (F2 and F3)	19% of all tornadoes Path: 24 km + Wind speed: 177 to 330 km/h Duration: 20 minutes +
Violent tornadoes (F4 and F5)	1% of all tornadoes Path: 80 km + Wind speed: > 322km/h Duration: 1 hour +

Tornado Distribution

Tornadoes usually form when polar air masses collide with tropical air masses. The large temperature gradients can spark a supercell that can, in turn, produce several tornadoes. In the United States, these conditions occur most frequently during spring in northern Texas, Oklahoma, Kansas, and Missouri, an area known as Tornado Alley.

Tornado Safety

More than 700 tornadoes strike the United States annually, causing an average of 80 deaths and 1500 injuries. The National Weather Service tracks these storms and issues advance warnings when possible. However, because tornadoes can develop quickly, it's best to seek shelter at the first sign of threatening weather. Table 4-3 includes other safety tips to follow in the event of a tornado.

Table 4-3 Tornado Safety
If a Warning Is Issued or If Threatening Weather Approaches . . .
• If you are in a home or building, move to a predesignated shelter, such as a basement.
• If an underground shelter is not available, move to an interior room or hallway on the lowest floor and get under a sturdy piece of furniture.
• Stay away from windows.
• Get out of automobiles.
• Do not try to outdistance a tornado in a car; instead, leave the car immediately.
• If you are caught outside or in a vehicle, lie flat in a nearby ditch or depression.
• Mobile homes, even when tied down, offer little protection from tornadoes and should be abandoned.

Source: NOAA

Tropical Cyclones

Tropical cyclones, some of the most powerful storms on Earth, are large, rotating, low-pressure storms that originate over tropical oceans. The storms get their tremendous energy from warm water. As ocean water evaporates, latent heat is stored and later released during condensation and precipitation. The air over the warm water is usually forced up by an existing weather disturbance; it then creates a low-pressure center at the ocean surface. Surface air rushes in to replace the rising air. The low-pressure system begins rotating counterclockwise in the northern hemisphere and clockwise in the southern hemisphere. The speed of rotation quickens as more air enters the system, rises, and releases energy through condensation. Air pressure continues to decrease in the storm's center. If these atmospheric conditions hold steady, the storm will grow in strength.

Distribution of Tropical Cyclones

Two factors are responsible for the formation of a tropical cyclone: warm water and a weather disturbance that causes air to rise. These factors are found in all tropical oceans except the cooler waters of the South Atlantic Ocean and the Pacific Ocean off the western coast of South America. In North America, tropical cyclones are known as hurricanes. They strike most frequently in late summer and early fall when tropical oceans contain the greatest amount of latent heat.

Movement of Tropical Cyclones

Wind currents guide tropical cyclones. The circulation of tropical high-pressure systems moves the storms west, then poleward. Prevailing westerlies take over in the midlatitudes. There, the movement of the storms becomes unpredictable due to the interaction of wind and weather systems.

Stages of Development

The first stage in the development of a tropical cyclone is a tropical disturbance, the spark that causes the air to rise. Atmospheric conditions must allow the rising air to be dispersed in the upper atmosphere for the storm to continue growing. The disturbance begins to rotate around an area of low pressure and reaches the next stage of development, a tropical depression. When wind speeds around the center exceed 65 km/h, the tropical depression is classified as a tropical storm. If air pressure continues to decrease and wind speeds reach 120 km/h, the tropical storm is considered a hurricane. At this point, the storm develops a calm center known as an **eye.** The strongest winds usually form a band called the eyewall that surrounds the eye. Figure 4-23 shows a cross-section of a hurricane. When a hurricane moves over land or colder water, it loses its source of energy (the tropical waters) and begins to fade. A hurricane frequently fluctuates in intensity as it interacts with other weather systems.

Hurricane Classification

The Saffir-Simpson hurricane scale, shown in Table 4-4, ranks hurricanes according to wind speed, air pressure in the center, and potential for property damage. Hurricanes in categories 1 and 2 cause minimal to moderate damage. Category 3 hurricanes are considered highly dangerous. Category 4 and 5 hurricanes are considered deadly.

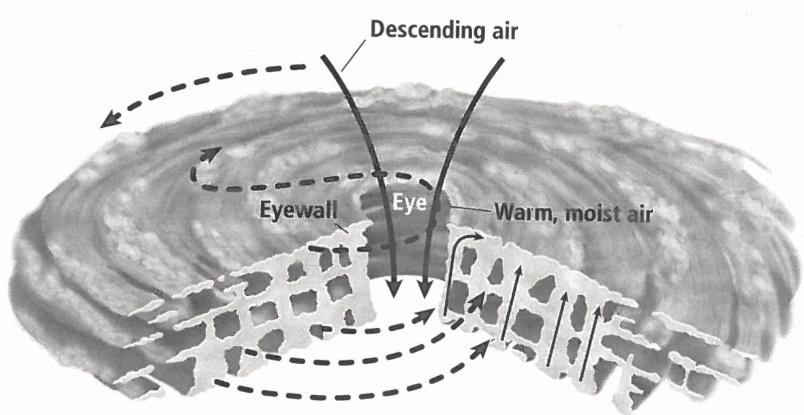


Figure 4-23 In this cross-section of a hurricane, dashed arrows indicate the direction in which the storm rotates. Thick, solid arrows indicate sinking air, and thin, solid arrows indicate moist, rising air.

Table 4-4 Saffir-Simpson Hurricane Scale

Scale number (category)	Sustained wind speed (km/h)	Damage	Examples of hurricanes and the states affected
1	119–153	Minimal	Florence, 1988 (LA) Charley, 1988 (NC)
2	154–177	Moderate	Kate, 1985 (FL Panhandle) Bob, 1991 (RI)
3	178–209	Extensive	Alicia, 1983 (N. TX) Emily, 1993 (NC Outer Banks)
4	210–250	Extreme	Andrew, 1992 (S. FL) Hugo, 1989 (SC)
5	>250	Catastrophic	Camille, 1969 (LA/MS) Labor Day Hurricane, 1935 (FL Keys)

Source: National Weather Service

Hurricane Hazards

Most of the damage associated with hurricanes is caused by strong winds. The most powerful winds are usually found in the eyewall, which is about 40 to 80 km wide. Wind speed decreases with distance from the eyewall. Still, winds of more than 60 km/h are commonly found hundreds of kilometers from the storm eye.

Storm Surges

The strong winds of hurricanes are a major factor in creating storm surges near coastal areas. **Storm surges** are mounds of ocean water driven by hurricane-force winds that wash over land. They can reach heights of 6 m above sea level and cause tremendous damage to property. Water damage from hurricanes is also common farther inland, where heavy rains can cause floods. To help reduce loss of life and property, the National Hurricane Center tracks the storms and issues advisory warnings in advance. In addition to the tips listed in Table 4-5, the National Weather Service often advises evacuation in the event of a strong hurricane. Evacuation advisories have saved countless lives. But given the unpredictability of a hurricane's movement, orders to evacuate can sometimes backfire. In 1999, more than 2 million people along the southeastern U.S. coast evacuated their homes in advance of Hurricane Floyd, causing a traffic jam that stretched for many miles. While some states such as North Carolina did sustain extensive storm damage, other states such as Florida were relatively untouched by Hurricane Floyd. A poll by the Florida International University indicated that the experience left many Floridians less willing to heed future evacuation advisories. In response, the National Weather Service has vastly improved its hurricane tracking models to avoid the sort of confusion that resulted from Hurricane Floyd.

Table 4-5 Hurricane Safety

- Turn the refrigerator to the maximum cold setting and open it only when necessary.
- Turn off all utilities if told to do so by authorities.
- Unplug small appliances.
- Turn off propane tanks.
- Fill bathtubs and large containers with water for sanitary purposes.

If Winds Become Strong . . .

- Stay away from windows and doors even if they are covered. Take refuge in a small interior room, closet, or hallway.
- Close all interior doors. Secure and brace external doors.
- If you are in a two-story house, go to an interior first-floor room, such as a bathroom or closet.
- If you are in a multiple-story building and away from water, go to the first or second floor and take refuge in a hall or other interior room away from windows.
- Lie on the floor under a table or other sturdy object.

Source: NOAA

Floods and Droughts

The types of severe weather discussed thus far seldom last for more than a day or two. Other types of severe weather, however, can impact an area for weeks or even months. Floods and droughts are types of recurring weather that, under certain conditions, can cause as much damage as a sudden, violent storm. Floods can be unleashed by a torrential downpour or by a mild storm that drops rain over a small area for a long time. **Flash floods** are local floods that are produced by a great volume of rainfall in a very short time. **Droughts** are extended periods of well-below-normal rainfall. They are usually caused by changes in wind currents that allow high-pressure systems to stall over land. The high pressure causes air to sink. Condensation cannot occur until the winds shift and the high-pressure system moves on.

SUBTOPIC D CLIMATE

Covers National Science Content Standards UCP.1, UCP.2, UCP.3, UCP.4, UCP.5; A.1, A.2; D.1, D.2; E.2; F.6

Unifying Concepts and Processes

UCP.1	Systems, order, and organization
UCP.2	Evidence, models, and explanation
UCP.3	Change, constancy, and measurement
UCP.4	Evolution and equilibrium
UCP.5	Form and function

Science as Inquiry

A.1	Abilities necessary to do scientific inquiry
A.2	Understandings about scientific inquiry

Earth and Space Science

D.1	Energy in the Earth system
D.2	Geochemical cycles

Science and Technology

E.2	Understandings about science and technology

Science in Personal and Social Perspectives

F.6	Science and technology in local, national, and global challenges

VOCABULARY

climatology	ice age
tropics	season
temperate zone	El Niño
polar zone	greenhouse effect
microclimate	global warming
heat island	

Climatology is the study of Earth's climate and the factors that affect past, present, and future climatic changes. As you learned earlier, climate describes the long-term weather patterns for a particular area. These patterns are based on data that are continually gathered from thousands of weather stations around the world. The data include daily high and low temperatures, amount of precipitation, wind speed and direction, humidity, and air pressure—all of which are averaged on a monthly or yearly basis for a period of at least 30 years. The resulting calculations give the normals, or standard climate values, for a location. Normals do not describe the weather on any given day, which can vary greatly from the norm. Rather, normals offer information about average weather over a long period of time.

Effects on Climate

Climates differ widely around the world. These climate variations are caused by latitude, topography, proximity to bodies of water, availability of moisture, global wind patterns, ocean currents, and air masses.

Latitude

Recall that the Sun's rays strike Earth's surface more directly near the equator than near the poles, as you saw in Figure 4-10 on page 72. As a result, the heating of Earth's surface and atmosphere by solar radiation varies with latitude. This variation in solar heating, in turn, gives rise to differences in climate. Figure 4-24 shows that Earth's surface is divided into five climate zones separated by lines of latitude. The **tropics,** located between 23.5° north and south latitude, receive the most intense solar radiation and thus are warm year-round. The two **temperate zones,** located between 23.5° and 66.5° north and south latitude, have moderate climates. The two **polar zones** extend from 66.5° north and south latitude to the poles. Because solar radiation strikes the polar zones at a low angle, they are nearly always cold.

Topographic Effects

Because of differences in specific heat, land heats up and cools down more rapidly than water does. This causes the climate of many coastal regions to be warmer in the winter and cooler in the summer than the climate of areas farther inland at the same latitude.

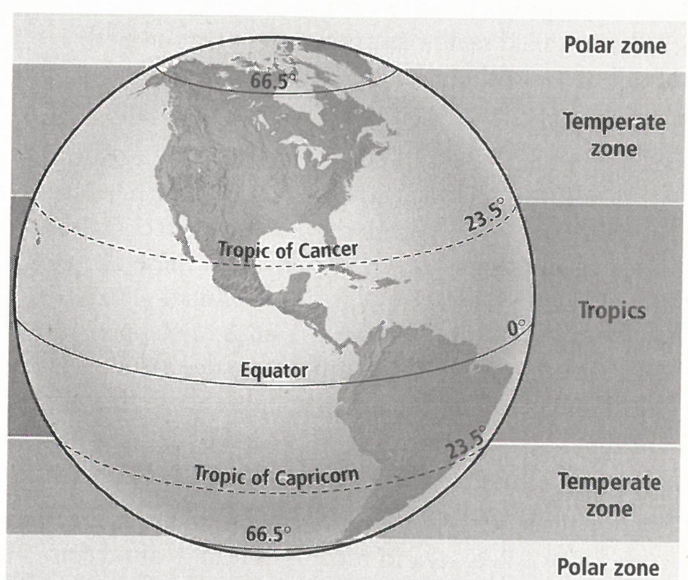


Figure 4-24 The intensity of solar radiation is greatest in the tropics and decreases steadily toward the poles.

Mountainous regions are generally cool because temperature decreases with height in the troposphere. Also, climate can vary on either side of a mountain. Remember that air often rises due to orographic lifting when it reaches a mountain. The rising air cools, water vapor in the air condenses, and rain falls. Hence, the climate on the windward side of the mountain is generally wet and cool. As the now-dry air descends over the leeward side of the mountain, it warms. Thus, the climate on the leeward side is generally dry and warm.

Air Masses

Air masses form over source regions with distinct characteristics. Refer to Figure 4-14 on page 75 to review the different air masses and their source regions in North America. The climate of those source regions, in turn, is heavily influenced by the air masses themselves. For example, an air mass that forms over tropical waters will dominate the weather of nearby islands, giving the islands a maritime tropical climate.

Climate Classification

To classify climates, most meteorologists use a modified version of the Koeppen classification system, which is based on vegetation and average monthly temperature and precipitation. The system, developed by Russian-born German climatologist Wladimir Koeppen (1846–1940), has six main divisions: tropical, dry, mild, continental, polar, and high-elevation.

Tropical Climates

Tropical climates are characterized by warm weather year round. They are heavily influenced by maritime tropical air. Annual levels of precipitation in wet zones can reach 600 cm. Tropical rain forests thrive on heat and moisture. Tropical wet-and-dry climates have dry winters caused by the seasonal presence of dry continental air masses. Grasslands called savannas are found in regions with a tropical wet-and-dry climate.

Dry Climates

Regions that have dry climates cover about 30 percent of Earth's land and include the major deserts, such as the Sahara and the Gobi. Warm, dry air, scant precipitation, and scarce vegetation are characteristic of these climates. The two subtypes of regions with dry climates are arid regions or deserts, and semiarid regions or steppes. Steppes are generally more humid than deserts; however, in all dry climates, rates of evaporation exceed those of precipitation.

Mild Climates

There are three subtypes of mild climates: humid subtropical, marine west coast, and mediterranean. Humid subtropical climates, such as those found in the southeastern United States, are influenced by subtropical high-pressure systems that form over warm oceans in the summer. Summers are warm and muggy, and winters are cool and dry. Oceans also influence marine west coast climates, found in parts of the western United States. Moist air from the ocean contributes to high levels of precipitation year-round with generally mild winters and cool summers. Mediterranean climates are common in areas surrounding the Mediterranean Sea. Because of the absence of cool ocean currents, these climates are characterized by warm summers.

Continental Climates

Continental climates, which include the climate found in the northeastern United States, are subdivided into warm summer, cool summer, and subarctic climates. All are influenced by both polar and tropical air masses. The collision of these air masses can cause sudden and extreme changes in weather. Temperature ranges are also extreme between summer and winter. In general, the presence of moist, tropical air in summer causes summers in regions with continental climates to be wetter than winters.

Polar Climates

Regions with polar climates are generally found above 66.5° latitude north and south of the equator. Average temperatures are below 10°C, so these regions are cold all year. The cold air, which holds less moisture than warm air, results in low rates of precipitation.

High-Elevation Climates

High-elevation climates are subtypes of polar climates found in mountainous regions. The cold conditions in these regions are caused by the general decrease in temperature that occurs with altitude in the troposphere. Regions with high-elevation climates may be located near the equator yet remain snow-covered throughout the year.

Microclimates

Microclimates are localized climates that differ from the regional climates in which they are found. A high-elevation climate, for example, is actually a microclimate in that it may be much colder than that of the surrounding area. Other types of microclimates exist in cities that have numerous skyscrapers and asphalt-covered streets and parking lots. The abundant asphalt and concrete materials store and then radiate heat into the air more efficiently than other types of surfaces, such as grass or water. Average temperatures in a city are thus higher than in surrounding rural areas, an effect known as an urban **heat island.** Heat islands also result in increased rates of precipitation because they cause extreme temperature differences with height that lead to the formation of clouds.

Climatic Changes

Scientific studies show that throughout Earth's geologic history, climate has constantly changed. Climate change, however, often takes place over long periods of time. Over the past 2 million years, for example, average global temperatures were alternately lower and higher than they are currently. During cold periods, glaciers covered much of Earth's surface. Periods of extensive glacial coverage are called **ice ages.** The last ice age ended about 10 000 years ago. In North America, glaciers spread from coast to coast and as far south as Indiana, as shown in Figure 4-25. As the glaciers retreated, they formed the Finger Lakes in central New York, among other features. Ice ages alternate with periods of higher temperatures called interglacial intervals. We are currently experiencing an interglacial interval.

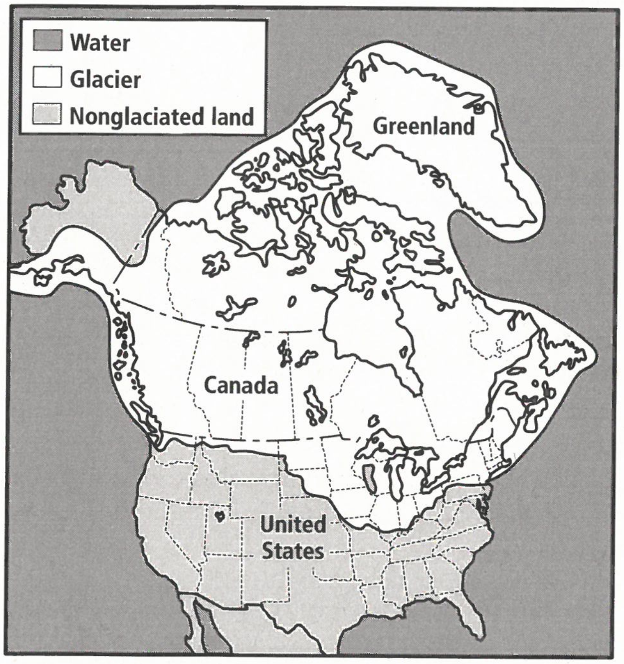


Figure 4-25 During the last ice age, glaciers spread into southern Indiana and from the west coast to the east coast of North America.

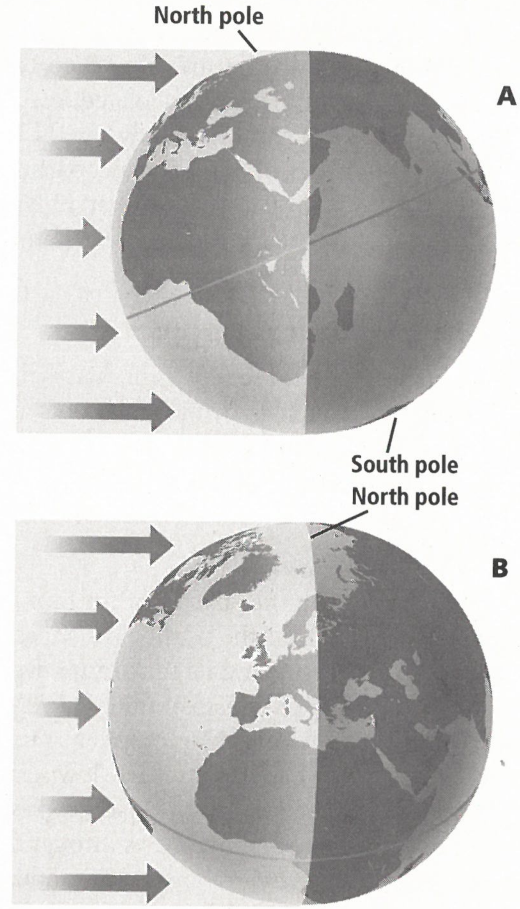


Figure 4-26 Summer occurs in the northern hemisphere when the north pole is tilted toward the Sun. At the same time, the south pole is pointed away from the Sun, and the southern hemisphere experiences winter (A). Neither pole is tilted toward the Sun during fall and spring (B).

Short-Term Changes in Climate

In contrast to long-term climatic changes, such as ice ages, other changes in climate happen routinely on a much shorter time scale. **Seasons,** for example, are short-term periods of climatic change caused by regular variations in daylight, temperature, and weather patterns. As shown in Figure 4-26, these variations exist because Earth is tilted on its axis and thus the intensity of solar radiation varies during the year as Earth revolves around the Sun. When the north pole is tilted toward the Sun, the northern hemisphere experiences the long hours of daylight and high temperatures of summer. Conversely, when the north pole is tilted away from the Sun, the northern hemisphere experiences the short hours of daylight and low temperatures of winter. The seasons are reversed in the southern hemisphere. During spring and fall, neither pole is tilted toward the Sun.

El Niño

El Niño, a warm ocean current that develops approximately every three to five years off the western coast of South America, also triggers short-term climatic changes. Normally, a high-pressure system off the northwestern coast of South America combines with air and ocean currents to create a cool, dry climate along much of the coast. Also, the trade winds in this area move west across the tropics, keeping warm water in the western Pacific Ocean. For reasons that are not fully understood, however, the high-pressure system and the trade winds sometimes weaken. Warm water rushes east toward the northwestern coast of South America, suddenly heating the air above the ocean. Fueled by this energy, convection currents grow stronger. Rates of precipitation increase dramatically. The cool, dry coastal area becomes wet and warm. Hot, moist air rises into the upper atmosphere and is carried by upper-level winds east across the tropics, causing global climatic changes. The jet stream, for example, shifts south in response to upper-level temperature gradients, bringing violent storms to California and the Gulf Coast, areas normally not affected by jet stream-driven storms.

To the east, hot, moist air dumps rain over areas that are usually dry. When its moisture is depleted, the air then causes droughts in areas that are normally wet. El Niño has caused floods, crop destruction, and famine, particularly in tropical regions where its impact is strongest. El Niño eventually weakens when the high-pressure system becomes reestablished.

Causes of Climatic Changes

Changes in climate can be caused by human activities, which will be discussed later, or by natural events. Natural events that contribute to climatic changes include variations in solar activity, changes in Earth's orbit, axis of rotation, and volcanic eruptions.

Variations in Solar Activity

Sunspots are dark spots on the surface of the Sun. Astronomers noticed long ago that the number of sunspots varies in a regular cycle, reaching its maximum every 11.2 years. In 1893, the English astronomer E. W. Maunder observed a strong causal relationship between sunspot activity and climate. A period of extremely low sunspot activity called the Maunder minimum closely corresponded to a period of extremely low temperatures throughout Europe. Additional studies later supported Maunder's observations. Increased solar activity appears to be linked to above-normal temperatures on Earth, while decreased solar activity coincides with below-normal temperatures.

Changes in Earth's Orbit

It is thought that Earth's orbit changes over the course of a 100 000-year cycle, becoming at times more elliptical, then more circular. Scientists hypothesize that these variations may lead to climatic changes. When its orbit is more elliptical, Earth passes closer to the Sun and global temperatures increase. When its orbit is more circular, Earth is farther from the Sun and global temperatures decrease.

Changes in Earth's Axis

The tilt of Earth's axis also varies from 22.1° to 24.5° during what is believed to be a 41 000-year cycle. According to one model, when the tilt angle is at its minimum, the temperature difference between winter and summer would decrease. Winters would be wetter and summers would be cooler. Additional snow would fall in polar regions. Because of the cooler summers, this snow would not melt, and glacial coverage would increase. Although the model is still under debate, changes in Earth's axis may be responsible for ice ages.

Changes in Earth's Wobble

As Earth rotates on its axis, it wobbles like a top. Over a span of 26 000 years, the wobble causes Earth's axis, which currently points toward the star Polaris, to point toward the star Vega then back to Polaris. By the year 14 000, Earth's axis will be pointed toward Vega. At that time, winter will occur in the northern hemisphere when Earth is farthest from the Sun, and summer will occur when Earth is closest to the Sun, the exact opposite of current conditions. The result will be warmer summers and colder winters.

Volcanic Activity

Another type of natural event, volcanic eruptions, can cause changes in climate by releasing large amounts of dust into the atmosphere. The dust, which can stay in the atmosphere for several years, acts like a screen that blocks solar radiation. The decrease in the amount of solar energy that reaches Earth's surface causes global temperatures to decrease. Within a year or two of a major eruption, temperatures rebound to normal.

The Greenhouse Effect

As was mentioned before, human activities can also affect climate. Before exploring this topic, you'll first need to understand the greenhouse effect. The **greenhouse effect** is the natural heating of Earth's surface caused by certain atmospheric gases such as water vapor and carbon dioxide. These so-called greenhouse gases absorb and radiate infrared energy, as shown in Figure 4-27. The greenhouse effect helps maintain surface temperatures at an optimal level. Life on the planet could not exist without this natural phenomenon.

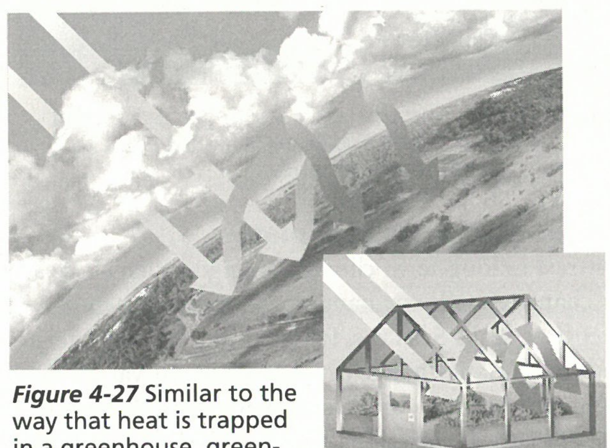


Figure 4-27 Similar to the way that heat is trapped in a greenhouse, greenhouse gases in Earth's atmosphere absorb infrared radiation emitted by the surface. The energy is then released to warm the atmosphere.

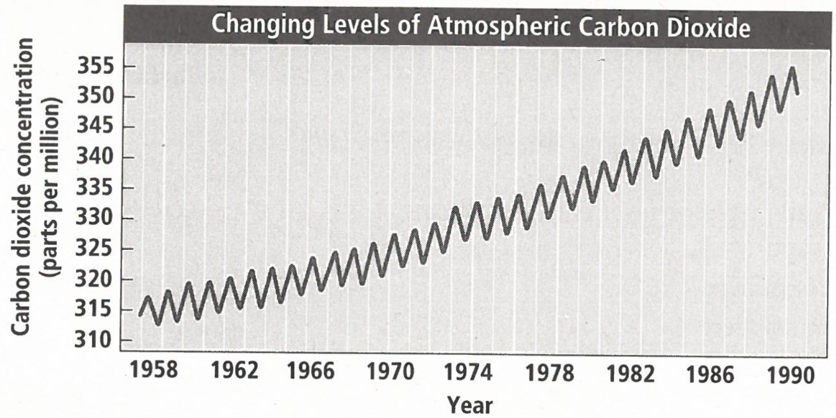


Figure 4-28 Levels of atmospheric carbon dioxide are steadily increasing. This increase may be due to human activities, such as the burning of fossil fuels and deforestation.

Global Warming

Most scientists believe that an increase in the amount of greenhouse gases could increase the absorption of infrared radiation and cause **global warming,** which is a rise in global temperatures. As Figure 4-28 shows, levels of atmospheric carbon dioxide have been steadily increasing over the past 200 years. Mounting evidence indicates that this increase is linked to human activities, such as the burning of fossil fuels in vehicles and power plants, which release carbon dioxide into the air. Also, the mass removal of large tracts of trees, known as deforestation, increases levels of atmospheric carbon dioxide. Like all plants, trees remove carbon dioxide from the air during photosynthesis. When trees are cut down, rates of photosynthesis decrease and less carbon dioxide is removed from the air.

Effects of Global Warming

Even a small rise in global temperatures could lead to widespread climatic changes. Polar ice caps might melt, sea level would then increase, and coastal areas, including major ports such as Seattle, could be flooded. Deserts may spread, and the intensity and frequency of severe storms might increase.

Global warming is a controversial issue. Although Earth's surface temperature has increased slightly in the last 100 years, some scientists hypothesize that this increase was caused by natural events, such as those discussed earlier. Other scientists, citing a growing body of evidence, argue that levels of atmospheric carbon dioxide must be decreased to combat global warming. Government regulations that limit and monitor carbon dioxide emissions are a step in this direction. Individuals can help, too, by reducing their consumption of fossil fuels. This can be accomplished in a number of ways, such as carpooling, turning off lights and appliances when they are not in use, and recycling.

QUESTIONS FOR SUBTOPIC A

Type A

Some questions may require the use of the *Earth Science Tables and Charts.*

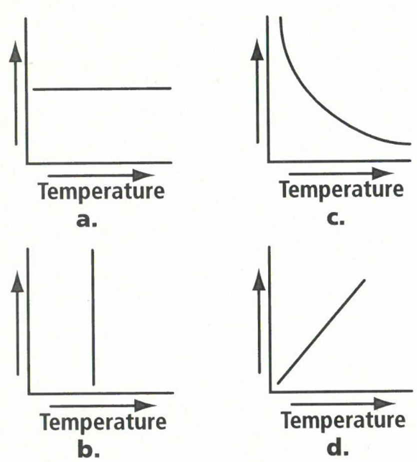
1. Which atmospheric layer contains the most water vapor?
- **a.** mesosphere
- **b.** stratosphere
- **c.** troposphere
- **d.** thermosphere

2. Compared to land, water changes temperature
- **a.** more slowly because water has a lower specific heat.
- **b.** more slowly because water has a higher specific heat.
- **c.** more quickly because water has a lower specific heat.
- **d.** more quickly because water has a higher specific heat.

3. What causes wind?
- **a.** differences in humidity
- **b.** differences in elevation
- **c.** differences in rates of condensation
- **d.** differences in air pressure

Type B

Base your answers to questions 4 and 5 on the graphs below.



4. Which graph represents the relationship between air density and air temperature?

5. Which graph represents the relationship between air pressure and air temperature?

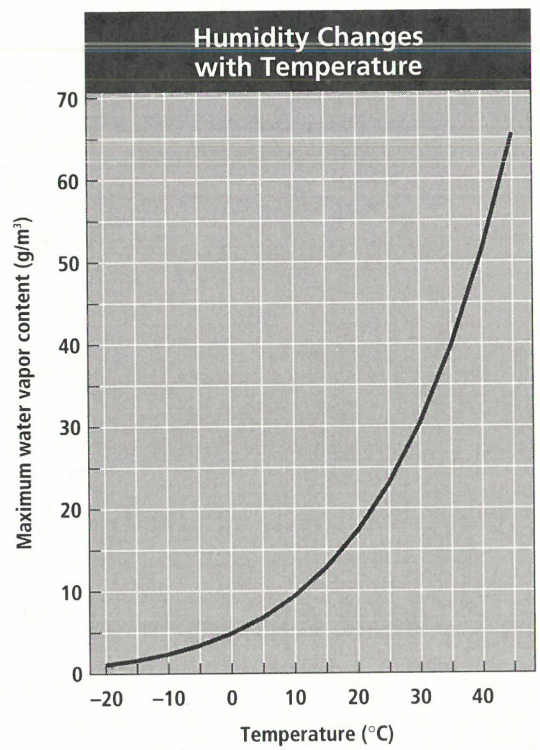
Type C

Base your answer to question 6 on the newspaper article below.

> **Legislation Protects Ozone**
>
> The governor of New York signed environmental legislation that restricts the use of ozone-depleting chemicals in refrigeration systems, air-conditioners, and fire extinguishers.
>
> The law limits, and in some cases bans, the sale of chlorofluorocarbons (CFCs), which have been found to contribute to the destruction of Earth's ozone layer. This layer protects life on Earth's surface from the Sun's dangerous ultraviolet rays.

6. Explain how CFCs destroy ozone molecules.

Base your answers to questions 7 and 8 on the graph below, which shows how much water vapor air can hold at different temperatures.



7. How much water vapor can 1 cubic meter of air hold at 20°C? If a sample of air had a relative humidity of 30 percent at 20°C, how much water vapor could a cubic meter of that air hold?

8. Which action would release more water as precipitation: cooling 1 cubic meter of saturated air from 45°C to 40°C, or cooling the same volume of saturated air from 10°C to –20°C?

QUESTIONS FOR SUBTOPIC B

Type A

Some questions may require the use of the *Earth Science Tables and Charts.*

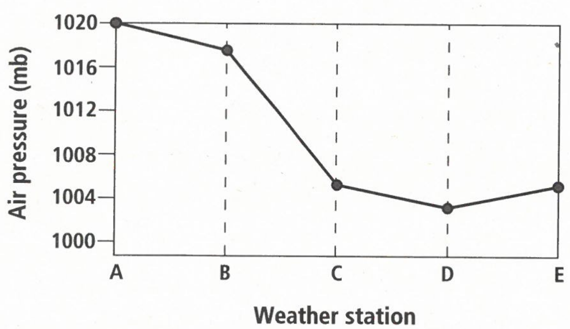
9. A sling psychrometer shows a dry-bulb reading of 14°C and a wet-bulb reading of 9°C. What are the dewpoint and relative humidity, respectively?

a. −10°C and 16%
b. −10°C and 50%
c. 4°C and 16%
d. 4°C and 50%

10. Which type of air mass is most likely to form over the North Atlantic Ocean?

a. maritime polar
b. maritime tropical
c. continental polar
d. continental tropical

11. The graph below shows the air pressure recorded at the same time at five weather stations in the United States. The stations are located at the same latitude, and the distance between adjacent locations is 250 km.



Wind speed is most likely greatest between which two weather stations?

a. A and B
b. B and C
c. C and D
d. D and E

12. What type of weather would you predict if the moisture content of the air increases and air pressure then decreases?

a. sunny and fair
b. cold and windy
c. partly cloudy with skies becoming clear
d. cloudy with a chance of precipitation

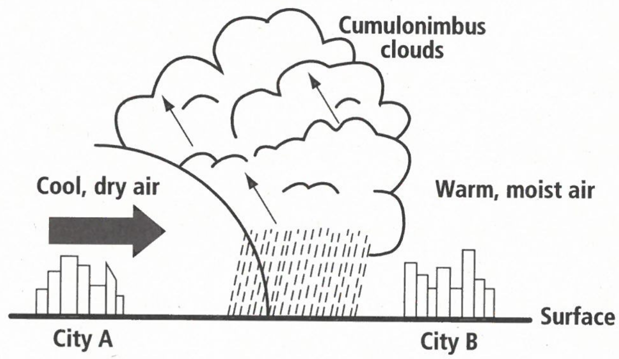
13. What does weather radar track?

a. precipitation
b. air pressure
c. temperature
d. cloud height

Type B

Some questions may require the use of the *Earth Science Tables and Charts.*

Base your answers to questions 14–16 on the diagram of a weather front below.



14. Which type of weather front is shown?

a. warm front
b. cold front
c. occluded front
d. stationary front

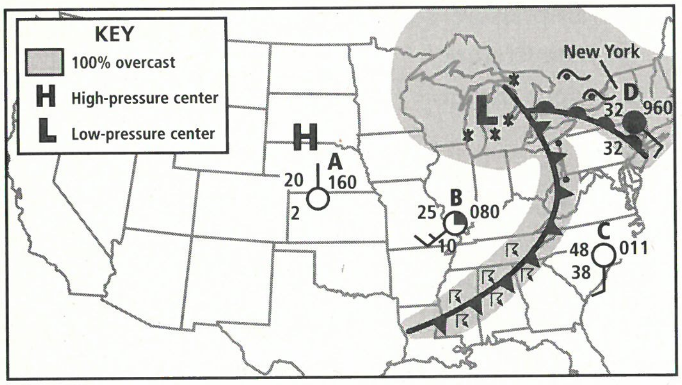
15. What type of weather is associated with the cumulonimbus clouds?

a. thunderstorms
b. sunny skies
c. mild precipitation
d. droughts

16. Which statement best describes the movement of warm air in the front?

a. It rises sharply above the cool air.
b. It rises slowly above the cool air.
c. It sinks under the cool air.
d. It stalls.

Base your answers to questions 17 and 18 on the weather map below.



17. What weather conditions are shown at location D?

a. cloudy skies with light snow

b. cloudy skies with freezing rain

c. saturated air with no precipitation

d. partly cloudy skies with rain showers

18. What type of weather front has entered New York State?

a. warm

b. cold

c. stationary

d. occluded

Type C

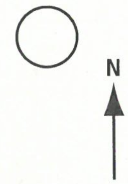
Base your answers to questions 19–21 on the table below. Some questions may require the use of the *Earth Science Tables and Charts.*

Air temperature	**21°C**
Barometric pressure	**993.1 mb**
Wind direction	**from the east**
Wind speed	**25 knots**

19. State the air temperature in degrees Fahrenheit.

20. *a* Write the barometric pressure as it would appear on a station model.
b Convert the barometric pressure from millibars to inches.

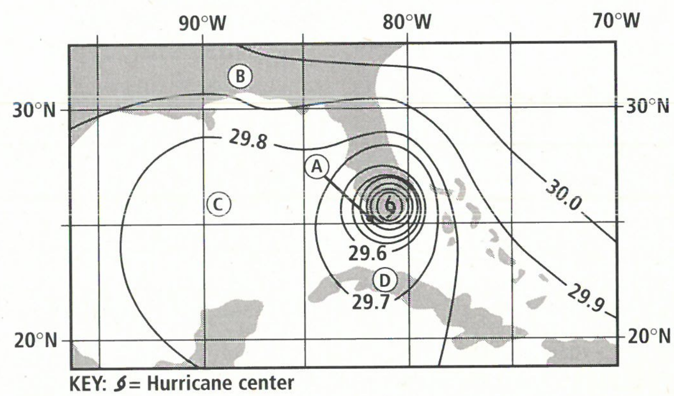
21. Use the data from the table to draw a line with feathers to indicate wind speed. Draw your line on the station model below.



QUESTIONS FOR SUBTOPIC C

Type A

Base your answer to question 22 on the weather map below. The map shows a hurricane located over southern Florida. The isobars connect points of equal air pressure.



22. At which location are the winds of this hurricane the strongest?

a. A

b. B

c. C

d. D

23. A tornado has a wind speed of 290 km/h and a path of destruction 48 km wide. How would the tornado be classified according to the Fujita tornado intensity scale?

a. F0 or F1

b. F1 or F2

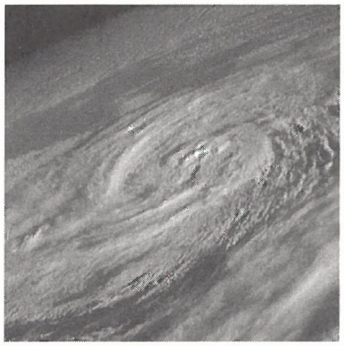
c. F2 or F3

d. F4 or F5

24. Droughts are extended periods of
- **a.** above-normal temperatures.
- **b.** below-normal temperatures.
- **c.** above-normal rainfall.
- **d.** below-normal rainfall.

Type B

Base your answers to questions 25–27 on the satellite image below.



25. What would you expect to find in the center of this storm?
- **a.** a cold, dry air mass
- **b.** a warm, dry air mass
- **c.** an area of high pressure
- **d.** an area of low pressure

26. Where is the storm located?
- **a.** in the northern hemisphere because the storm is rotating in a clockwise direction
- **b.** in the northern hemisphere because the storm is rotating in a counterclockwise direction
- **c.** in the southern hemisphere because the storm is rotating in a clockwise direction
- **d.** in the southern hemisphere because the storm is rotating in a counterclockwise direction

27. Over which area did the storm likely originate?
- **a.** polar continental land
- **b.** polar ocean
- **c.** tropical continental land
- **d.** tropical ocean

Type C

Base your answers to questions 28 and 29 on the following information: A tornado is moving toward a city at a speed of 210 km/h. The tornado is currently located 250 km from the city.

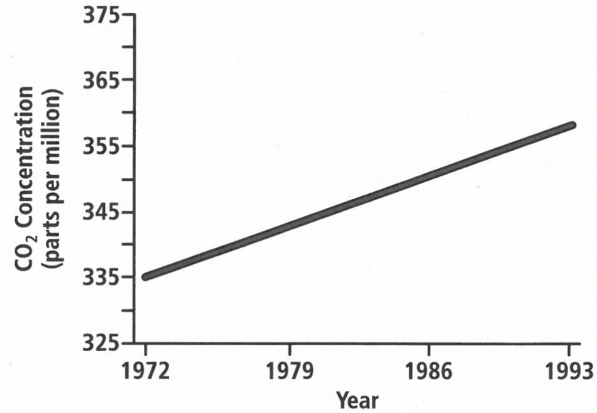
28. How much time do residents have to prepare for the storm?

29. What safety measures can be taken to lessen property damage and loss of life?

QUESTIONS FOR SUBTOPIC D

Type A

Base your answer to question 30 on the graph below, which shows the average annual concentration of carbon dioxide in Earth's atmosphere from 1972 to 1993.



30. What is a likely effect of the change in average carbon dioxide concentration?
- **a.** a decrease in the average wavelength of solar radiation
- **b.** a decrease in the thickness of Earth's atmosphere
- **c.** an increase in the absorption of infrared radiation by Earth's atmosphere
- **d.** an increase in the thickness of Earth's glaciers

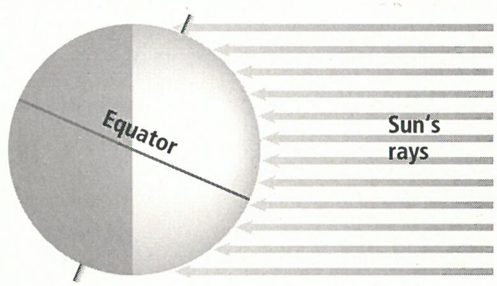
31. Most scientists believe that an increase in the level of atmospheric carbon dioxide may cause an increase in global temperatures. This belief is based on the fact that carbon dioxide is a
- **a.** good absorber of infrared radiation.
- **b.** poor absorber of infrared radiation.
- **c.** good reflector of ultraviolet radiation.
- **d.** poor reflector of ultraviolet radiation.

32. What is the first stage in the formation of El Niño?
- **a.** Convection currents strengthen.
- **b.** The jet stream shifts south.
- **c.** Trade winds weaken.
- **d.** Precipitation increases.

33. Temperatures in Washington, D.C., are likely to be
- **a.** higher than those in the surrounding countryside.
- **b.** lower than those in the surrounding countryside.
- **c.** drier than those in the surrounding countryside.
- **d.** the same as those in the surrounding countryside.

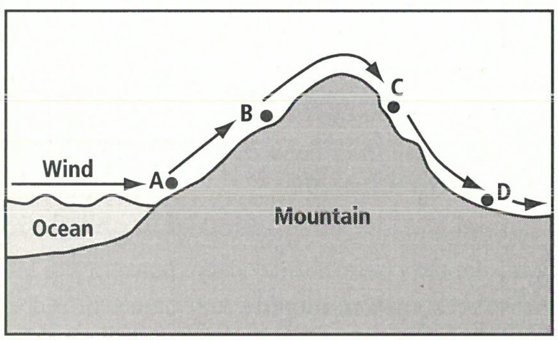
Type B

34. According to the diagram, which season is it in the northern hemisphere?



a. fall
b. winter
c. spring
d. summer

Base your answers to questions 35 and 36 on the diagram below, which shows the flow of air over a mountain.

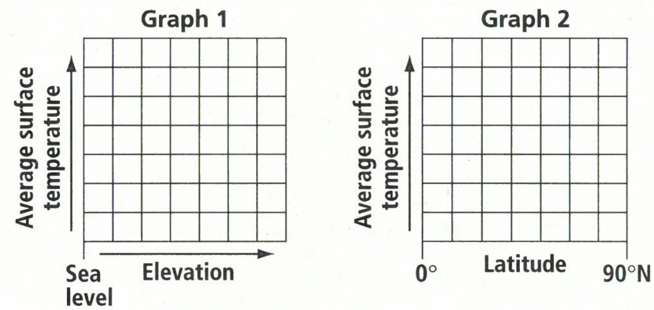


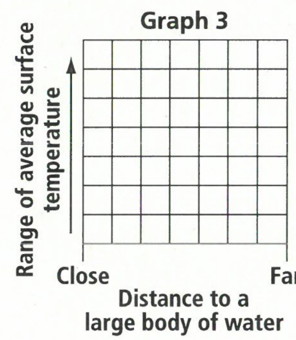
35. Which location is likely to receive the most precipitation?
a. A
b. B
c. C
d. D

36. Where would a desert most likely form?
a. A
b. B
c. C
d. D

Type C

Some questions may require the use of the *Earth Science Tables and Charts.*





37. On Graph 1, draw a line to show the relationship between average surface temperature and elevation.

38. On Graph 2, draw a line to show the general relationship between average surface temperature and latitude.

39. On Graph 3, draw a line to show the relationship between range of average surface temperature and distance to a large body of water.