CHAPTER

13 Global Weather Dynamics

Getting Started

HOW IS EARTH DIFFERENT FROM THE MOON?

In this photograph of Earth taken from the Moon (Figure 1) perhaps the most obvious difference is the colour. Water, ice, air, and clouds contribute to the colour combination of blue and white and are responsible for the changing weather patterns on Earth.

Figure 1
Planet Earth is a unique place. This photograph of Earth was taken by astronauts from the Moon.

If you could watch Earth for several days from space, you would notice that the clouds continuously move. This dynamic motion provides one clue about the causes of weather changes on Earth: things are in motion.

With the continuous bombardment of solar energy hitting Earth every day, why isnÈt Earth much hotter than it is? Something happens to all that energy to allow the total amount of energy on Earth to remain fairly constant, in other words, Åin balance.Æ

To understand why the clouds and other components of EarthÈs features are in motion and why the energy is in balance, we need to consider what happens to the SunÈs energy that strikes Earth. In simple terms, this energy sets water and air in motion. But of course, weather dynamics, the study of how the motion of water and air causes weather patterns, is not quite as simple as that. This chapter explores what happens to the energy that hits the features on EarthÈs surface, namely, the atmosphere, land, water, and ice.

Reflect on your Learning

1. Why do you think the weather is warm in the summer and cold in the winter?
2. Why do you think that much of CanadaÈs weather travels from west to east?
3. Why do your ears pop in an elevator or airplane that ascends or descends rapidly?
4. Why do you think the coldest months of the year seem to come after the hours of daylight start to increase?
5. Why do you think rain or snow doesnÈt fall from all types of clouds?
6. What conditions do you think cause fog to form?
7. In January, itÈs warmer in St. JohnÈs, on the coast of Newfoundland, than in Ottawa, Ontario, which is farther south than St. JohnÈs. Why?

Throughout this chapter, note any changes in your ideas as you learn new concepts and develop your skills.

Try This Activity: Effects of Evaporation

As something cools, it loses energy; as it warms, it gains energy. But when liquids evaporate, do they cause their surroundings to become warmer or cooler? Think about how this question relates to weather before you follow the steps below.

Materials: apron, safety goggles, room-temperature water, rubbing alcohol in a dropper bottle, eye dropper

Rubbing alcohol is poisonous. Do not allow it to come in contact with your eyes or mouth. Do not inhale the fumes.

Rubbing alcohol is flammable. Do not put near an open flame.

¥ Put a drop of water on one index finger, and a drop of rubbing alcohol on the other index finger. Then hold both index fingers in the air and move them back and forth at the same rate.

(a) Describe what happens as you observe the liquids evaporate from your fingers. Compare how each finger feels. Explain your observations.

(b) Why do you think alcohol and water have different effects?

(c) Evaporation occurs on oceans and other bodies of water. Where does the energy come from for this evaporation?

(d) Clouds can form from condensation. Describe what you think happens to the temperature of the air when clouds form above an ocean.

¥ Using soap, wash any areas that came into contact with the rubbing alcohol.

13.1

A Closer Look at Earth

Figure 1

A globe is a three-dimensional model of Earth that is useful to refer to as you study weather dynamics. Globes are often tilted because the Earth itself is at an angle of 23.5¡ to the plane of its orbit around the Sun.

To begin our study of weather and changing weather patterns, we look at a worldwide, or global, view of Earth. A useful model to provide this view is a globe (Figure 1). The globe is tilted to represent EarthÕs tilt at an angle to an imaginary line between Earth and the Sun. Like Earth, the globe rotates on its axis, which is a line from the South Pole to the North Pole. A globe shows the oceans, continents, and countries of the world; some show major ocean and wind currents.

The main components of Earth that influence weather are the atmosphere, the land forms, and water in its various forms (solid, liquid, and vapour). If you look at a globe or a world map (Figure 2), you can see that a large portion of EarthÕs surface, about 70%, is covered by oceans. The remainder forms the continents. The atmosphere above the oceans and continents contains air, water vapour, and particles of dust and chemicals, all of which influence weather, especially when the atmosphere is in motion.

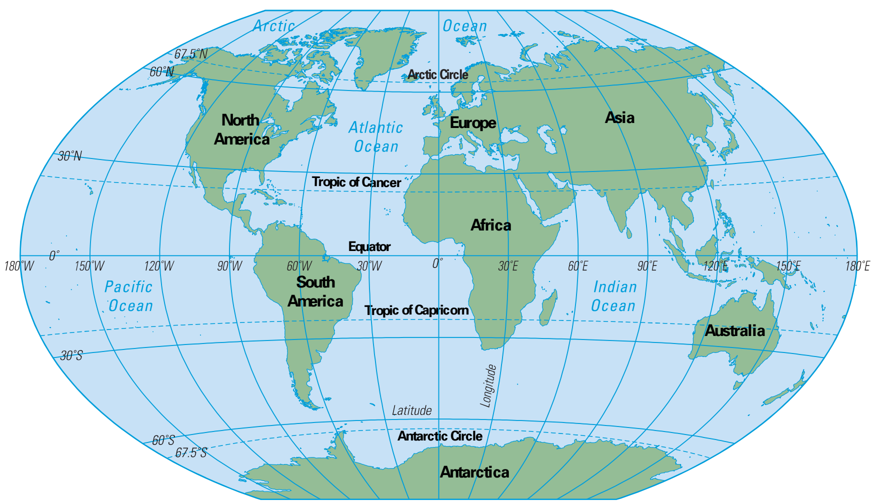


Figure 2

About 30% of EarthÕs surface is land; the rest consists of oceans and other bodies of water. The atmosphere extends above the surface to several hundred kilometres.

Comparing Weather and Climate

Before starting this unit, we should understand that weather and climate are different. Weather is the set of environmental conditions encountered from day to day. Climate is the set of environmental conditions averaged over many years. Consider a city located in southern Manitoba: its January climate is cold and fairly snowy and windy, with an average daytime high temperature of Ã12¡C. This information is the average of years of data. However, for a week in January, its weather could be mild, with daytime high temperatures of 6¡C, low winds, and sunny skies.

Work the Web

Visit www.science.nelson.com and follow the links for Science 10, 13.1. Find a site that has climate data for Canadian cities. Choose a city and graph the average monthly temperature and precipitation.

Global Geography

Longitude is the angle measured east or west from the 0¡ line, which passes through Greenwich, England. For example, the eastern tip of Cape Breton Island, Nova Scotia, is at 60¡ west longitude. Latitude is the angle measured north or south of the equator. For example, the border between the western Canadian provinces and the United States lies along the 49¡ north latitude line.

Notice the specially labelled latitudes on the map in Figure 2. The Tropic of Cancer, at 23.5¡ north latitude, is the most northerly location reached by the SunÕs vertical rays on the first day of summer, around June 21, each year. The Arctic Circle, at 66.5¡ north latitude, is the most northerly location reached by any of the SunÕs rays on the first day of winter, around December 21. The corresponding lines in the Southern Hemisphere are the Tropic of Capricorn and the Antarctic Circle.

Between the Tropic of Cancer and the Tropic of Capricorn lies the large equatorial region often called the tropics. The polar regions are found north of the Arctic Circle and south of the Antarctic Circle. Between the tropics and the polar regions are the mid-latitude regions. Most of the populated areas of Canada lie in the mid-latitude region.

Challenge

1 Start collecting the five-day weather forecasts from a daily newspaper or another source (e.g., a web site). Store the forecasts so that you can analyze them as you learn more about weather forecasting.

2 Set up a portfolio of ideas and information so you can develop an understanding of what your weather-wise community will require. For example, which is more important to consider, the weather or the climate? Why?

3 Refer to the Nelson Science web site (www.science.nelson.com) to learn how to link your school to other schools where students are studying weather. Keep a record of how you accessed the network site.

Understanding Concepts

1. Describe todayÕs weather conditions for your area.
2. Describe the climate for your area at this time of year.
3. Use two or three adjectives to describe the following climates:
   (a) winter in CanadaÕs Arctic;
   (b) winter in Nova Scotia;
   (c) each of the seasons in your region.
4. List four or five decisions you have made in the past year that have depended on the weather.
5. Consult your atlas and state the latitude of
   (a) the equator;
   (b) the South Pole;
   (c) the southernmost land point in Canada;
   (d) your own area.
6. As you move from the equator to the poles (on a globe or Earth), what happens to the distance between the longitudinal lines?
7. Compare the following angles: the tilt of EarthÕs axis, the maximum latitude reached by the SunÕs vertical rays on the first day of summer, and the latitudinal angle separating the Arctic Circle from the North Pole. What do you notice?
8. Classify the following locations as being in the tropics, mid-latitude regions, or polar regions:
   (a) Greenland;
   (b) Thailand;
   (c) your own location.
9. Explain why climate should be considered when planning each of the following events:
   (a) a fireworks display;
   (b) the Winter Olympics at a mountain resort;
   (c) a charity run.

Exploring

10. Research what CanadaÕs astronauts have said about our planet as they viewed it from space. Are there any themes that emerge from their comments?
    (I) (J)

13.2

EarthÈs Energy Balance

Almost all the energy used on Earth to sustain life and cause our changing weather systems comes from the Sun. Different types of electromagnetic energy are emitted from the Sun, and they have different effects when they reach Earth. Without all this energy, plants would not grow, and the land, water, and air wouldnÈt stay warm enough for us to survive. But just enough energy is returned from Earth to space to keep the average surface temperature about 15¡C.

Transfer of Energy

Energy can be transferred from one place to another by four methods: radiation, conduction, convection, and advection. These methods of transferring energy, called heat transfer, all contribute to EarthÈs weather.

Radiation is the transfer of energy by means of waves. Unlike water waves and sound waves, radiation waves do not require a medium. This is why they can travel from the Sun, through space, and reach Earth. The energy that comes to us from the Sun reaches us by radiation. Visible light is one example of the many forms of energy that can travel through space. Other forms are infrared radiation, ultraviolet waves, and X rays. The set of waves that can travel through empty space at the speed of light is called the electromagnetic spectrum. Figure 1 shows these waves as well as some of their properties.

Did You Know?

A small portion of energy available on Earth comes from nuclear reactions in EarthÈs core.

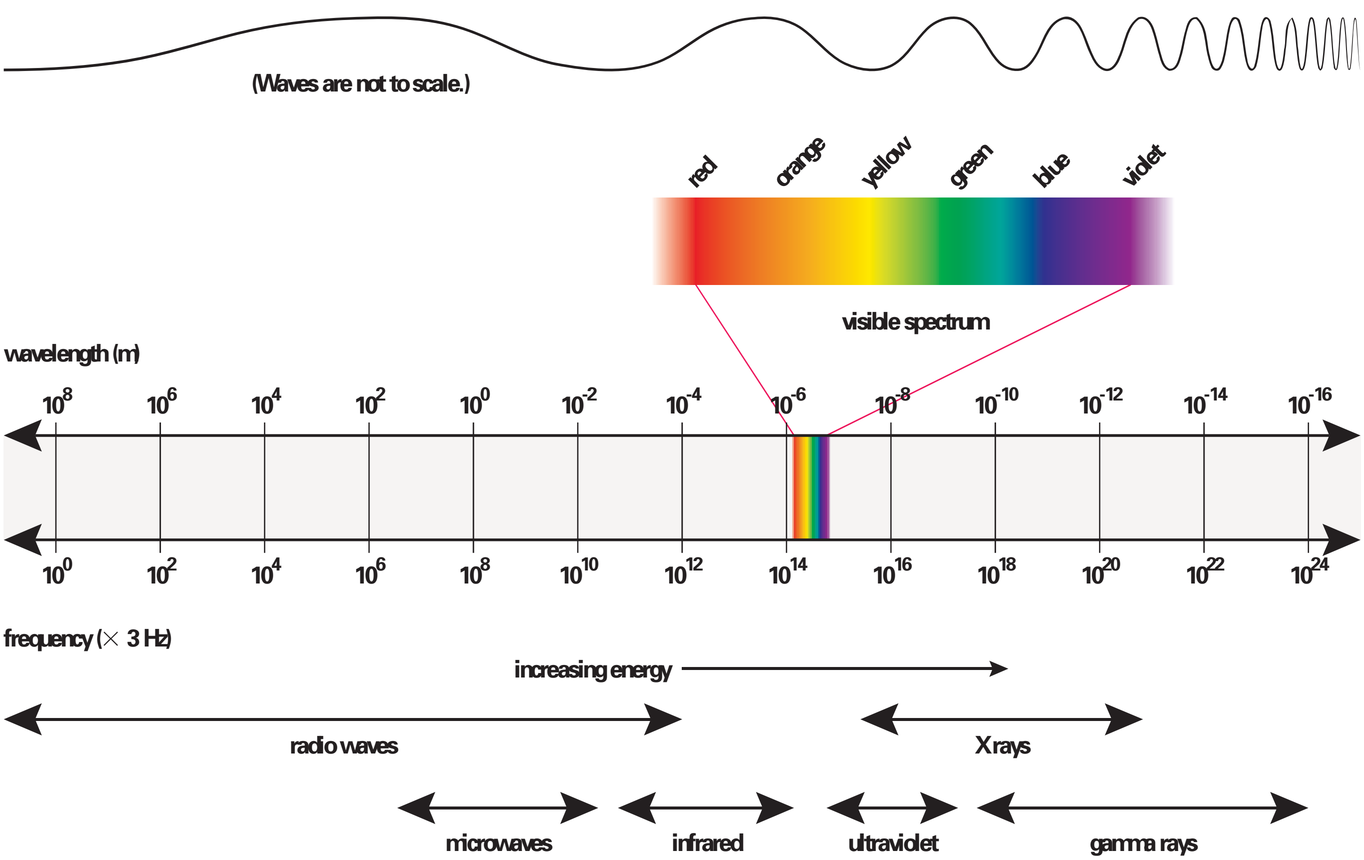


Figure 1

The electromagnetic spectrum consists of several types of waves, all of which travel at the speed of 300 000 km/s in a vacuum.

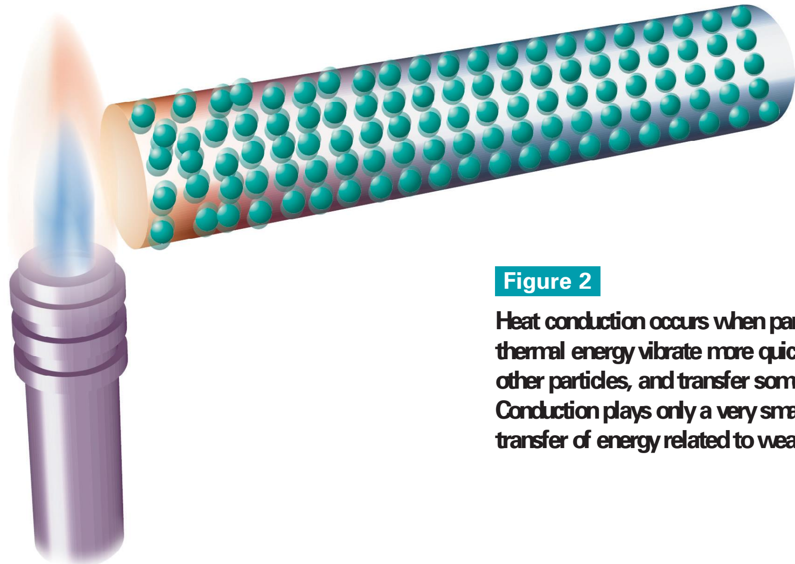


Figure 2

Heat conduction occurs when particles with greater thermal energy vibrate more quickly, collide with other particles, and transfer some energy to them Conduction plays only a very small role in the transfer of energy related to weather.

The other methods of energy transfer, require particles of matter. Conduction is the transfer of energy through the collision of particles (Figure 2). Although conduction occurs most easily in metals such as steel, it also occurs to a small extent in substances on Earth's surface, including rock, sand, soil, and water.

Convection and advection are the transfer of energy by the movement of particles in a fluid (Figure 3). A fluid is either a liquid (such as water) or a gas (such as the components of the atmosphere). Convection transfers energy vertically and advection transfers energy horizontally. Since weather systems depend on the movement of particles in the atmosphere and in the oceans, you will often apply the concepts of convection and advection as you understand weather systems.

These four methods of energy transfer help to maintain Earth's energy balance as well as distribute energy around the world.

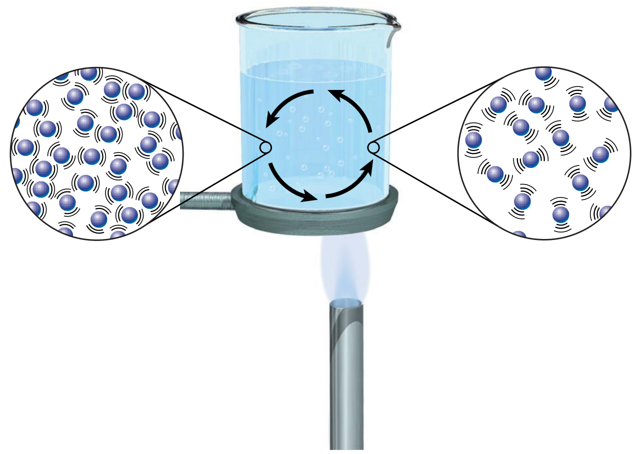


Figure 3

A convection current is set up when particles of a fluid gain energy. As their movement increases, they spread apart and that part of the fluid become less dense than the surroundings, and so it rises. The warm fluid is replaced by cooler fluid as the flow of the convection current begins.

Try This **Activity**

Observing Convection in Water

To illustrate convection in water, use cold water with some dark food colouring added and clear hot water.

Materials: apron, safety goggles, two beakers, hot water, cold water, dark food colouring

Hot water can scald you. Handle with care.

¥ Half fill a clear glass or plastic beaker with hot water and let the water settle. Very slowly and carefully, pour dyed cold water down the side of the beaker into the hot water.

(a) Observe what happens, then draw a sketch to explain what you observe.

¥ Reverse the process: add hot, clear water to cold, dyed water.

(b) Draw a sketch of your observations, and explain any differences between this step and the first one.

(c) Relate what happened in this activity to what you think happens to layers of water in oceans or layers of air in the atmosphere.

Reflection and Absorption of Energy

When the electromagnetic waves from the Sun reach Earth, some are reflected off the atmosphere and clouds back into space; some pass through the atmosphere and bounce off EarthÈs surface back into the atmosphere; and some get absorbed by the atmosphere, the ground, or the water at the surface. Figure 4 shows what percentages of solar radiation are reflected and absorbed. For the radiation that reflects off the atmosphere and the surface features of Earth, the portion of energy reflected depends on the albedo of the material. Clean snow has a high albedo; it reflects a large portion of incoming energy. Black soil has a low albedo; it absorbs more energy than it reflects.

Any object or material that absorbs energy and becomes warmer is called a heat sink. A heat sink holds energy in a similar way to how a kitchen sink holds water. Even though water has a higher albedo than land and soil (water reflects more solar energy than it absorbs), the oceans are good heat sinks. When solar energy hits water, the water begins to move Ä this is convection activity Ä and to transfer energy hundreds of metres deep into the oceans. Soil and rock are poor heat sinks. Heat is conducted very slowly into these materials.

An important property of all substances is their heat capacity, which is the measure of how much heat a substance requires to increase its temperature or how much heat it releases as its temperature decreases. Soil and rock are poor heat sinks; their heat capacity is low. As Figure 5 shows, water has a very high heat capacity, which means it can hold a lot of heat.

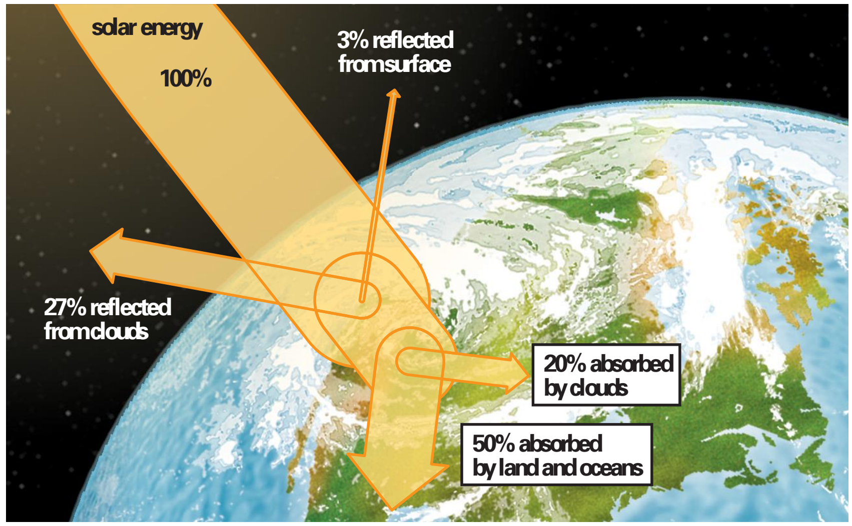


Figure 4

Some radiation that hits EarthÈs atmosphere reflects off particles in the atmosphere and clouds back into space. The rest passes through the atmosphere, hitting water, land, and ice.

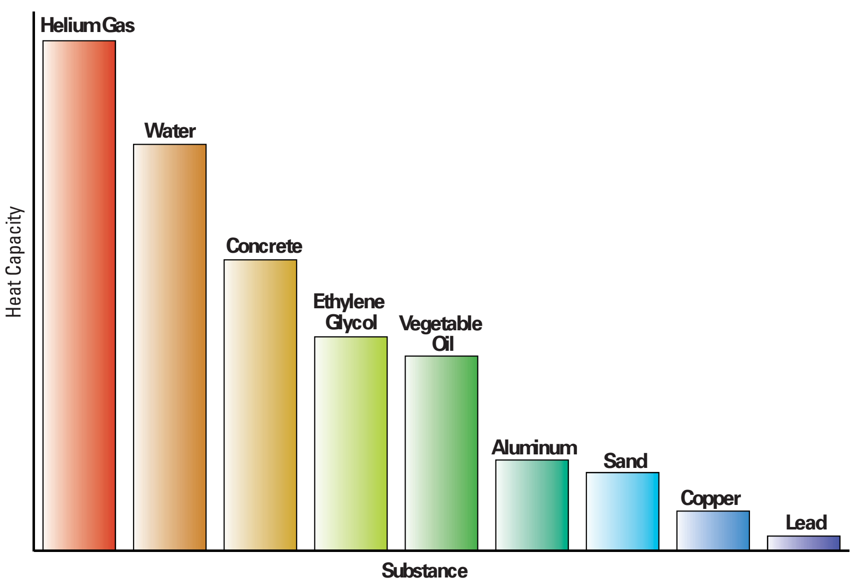


Figure 5

Heat capacities of common substances. To calculate the heat capacities of different substances, scientists use the same mass of each substance, yielding what is called the specific heat capacities measured in J/(kgÓC¡). Metals tend to have low specific heat capacities.

Try This Activity: Comparing Heat Capacities

Which of the following can heat up a 500 g sample of room-temperature water the most: 200 g of rock at 100¡C, 200 g of steel at 100¡C, or 200 g of water at 100¡C?

(a) Design and carry out an investigation to K answer this question. (The masses should be equal, but they donÈt have to be 200 g.)

¥ Before carrying out the activity, get your teacherÈs approval, and ensure that you have included all necessary safety precautions. Be sure to observe all precautions when doing the activity.

(b) Use your findings to explain what you know about the heat capacity of substances.

Understanding Concepts

1. Explain why conduction, convection, and advection cannot occur in space.
2. Which part of the electromagnetic spectrum
   (a) allows us to see?
   (b) is used in ovens?
   (c) is used to take images of your teeth?
3. Does warm water rise or fall in cold water? Explain why this happens.
4. Explain why convection does not occur in solids.
5. Explain why rocks and soil are poor heat sinks.
6. List the following in order of highest to lowest albedo: dirty snow, clean snow, ocean water, an evergreen forest.
7. Two clouds are about the same size. One appears light in colour, and the other appears dark because it blocks more sunlight. Which would be a better heat sink? Why?
8. Describe what would happen to the temperature on Earth if the amount of energy reflected back to space
   (a) increased to 80%;
   (b) decreased to 5%.

Making Connections

9. ÅNight-visionÆ goggles, cameras, and displays in cars detect infrared radiation emitted by objects that have higher temperatures than their surroundings. What types of things can be seen by night-vision devices?
10. If the polar ice caps melted, how would this affect the overall albedo of Earth? What effect would you expect this to have on the global climate?

Exploring

11. Find out how EarthÈs albedo compares with the albedos of the other planets in the solar system. What patterns, if any, do you observe?

Challenge

2 How much heat a city absorbs from solar radiation depends on its albedo. What factors might change the albedo of a city?

3 When it is 9:00 a.m. in Sudbury, it is 10:00 a.m. in Sydney and 7:00 a.m. in Medicine Hat. When you want to communicate with students in other parts of Canada, how will you work with time differences?

SKILLS HANDBOOK: K Planning an Investigation

The Atmosphere

Earth's atmosphere may not be as easy to see as all the water and ice in the world, but it is very important for life as well as weather systems. Every time you see clouds in the sky, feel wind in your face, or even take a breath, you experience an effect of the atmosphere.

The atmosphere is the blanket of air and moisture that surrounds Earth. Most dense at sea level, where the molecules are pressed together by the weight of the air above, the atmosphere becomes less dense as the height above sea level increases. About 500 km up, there are hardly any molecules, and the vacuum of space begins.

Near Earth's surface, the atmosphere consists mainly of nitrogen (78%), oxygen (21%), and small amounts of other gases, such as argon, carbon dioxide, and water vapour (Figure 1).

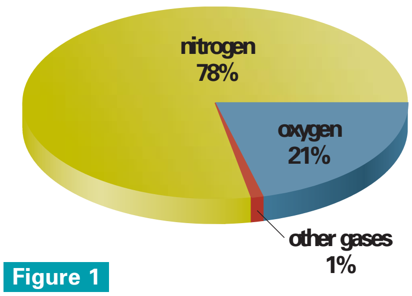


Figure 1

Besides nitrogen and oxygen, the atmosphere contains small amounts of water vapour, argon, carbon dioxide, neon, helium, krypton, hydrogen, and ozone.

Atmospheric Layers

The atmosphere consists of several layers, each with distinct properties. Figure 2 shows these layers as well as their typical temperatures and altitude and the locations of clouds, aircraft, and spacecraft. Altitude is the height above sea level, usually measured in metres (m) or kilometres (km). (Altitude can also be called elevation.) All the layers are thicker above the equator than above the poles. The air at the equator is warmer, so it expands and takes up more space than the cold air at the poles.

The troposphere is the atmospheric layer closest to Earth's surface, up to an altitude of about 16 km at the equator and as low as 8 km at the poles. It contains most of the atmosphere's moisture and is responsible for most of our weather systems. As the altitude above Earth's surface increases, the temperature in the troposphere decreases.

Try This Activity: Modelling the Density of the Atmosphere

To get an idea of how the force of gravity acting on the atmosphere causes the air to be most closely packed (densest) at the ground, use a simple model of donut-shaped disc magnets.

Materials: five or six disc magnets, a pencil

- Place five or six disc magnets onto a vertical pencil so that they repel each other (Figure 2). Observe the spacing of the magnets. Sketch what you see.

(a) Explain your observations of the distances between the magnets.

(b) Explain how this model relates to the relationship between the density of the atmosphere and the distance above Earth's surface.

Figure 2

Gravity exerts a downward force, or pull, on the top magnet, but magnetic repulsion also exerts an upward force, or push, on it.

Where the troposphere ends is a thin boundary called the tropopause. At this level, the temperature no longer decreases with increasing altitude. In fact, the temperature rises because the tropopause contains a little more ozone, which absorbs ultraviolet radiation from the Sun, causing a temperature increase. The higher temperature of the tropopause helps to keep the molecules of the next higher layer separate from the troposphere.

Above the tropopause is the stratosphere, a dry atmospheric layer from about 12 km to 50 km that contains higher concentrations of ozone than any other layer. The ozone here helps protect Earth from much of the harmful ultraviolet radiation from the Sun, and its presence explains why the temperature of the stratosphere increases as the altitude increases. (Although ozone in the stratosphere is helpful, ozone near the ground is harmful.)

The middle layer in the atmosphere is called the mesosphere (meso means middle). With the exception of ozone and water vapour concentrations, the composition of the atmosphere up to and including the mesosphere is very similar. Here, the temperature and density of the gases are extremely low. This layer extends from about 50 km to 80 km.

Above the mesosphere is the thermosphere, where the density remains low but molecules have higher energy, producing higher temperatures than in the mesosphere. In the thermosphere, the highest-energy electromagnetic waves from the Sun (e.g., X rays) are absorbed, which increases the temperature. The thermosphere extends from about 80 km to about 500 km. The thermosphere is also called the ÅionosphereÆ because in this layer, high-energy radiation from the Sun causes particles to become electrically charged ions. The ions produce the beautiful light displays called auroras, the Northern Lights and the Southern Lights.

Above the thermosphere is the exosphere, the thin outermost layer of the atmosphere. From the point of view of space travel, the exosphere can be called space because there are so few particles there, and what particles there are (mainly hydrogen) are spread out.

Notice in Figure 3 that the temperature of the atmosphere is different at different altitudes. The change of temperature over a distance is called a temperature gradient. The temperature gradient of the troposphere is about Ã6¡C per 1000 m. Beyond the troposphere, the temperature gradient in each layer becomes less uniform.

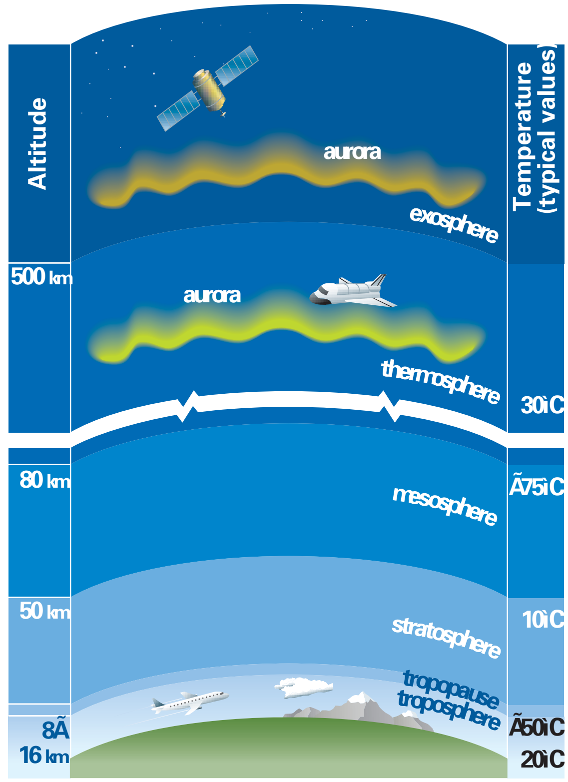


Figure 3

The atmosphere consists of six main layers, starting with the troposphere near the ground.

Did You Know?

If the width of your science textbook represented EarthÌs diameter, the troposphere would be thinner than a human hair.

Supporting Life

Life as we know it would not be possible without the atmosphere. Oxygen and nitrogen in the atmosphere are needed to support life, and carbon dioxide is needed for green plants to thrive. Ozone in the upper atmosphere absorbs ultraviolet radiation, protecting us from this harmful radiation from the Sun. The atmosphere plays a role in the water cycle, which supplies EarthÌs surface with water. And it offers us protection from most of the meteors coming our way, since most of them vaporize due to the frictional effects when they speed through the atmosphere.

The atmosphere also helps to keep the average temperature within a life-supporting range. Gases such as water vapour and carbon dioxide trap energy in the form of heat radiated from the ground. And the atmosphere circulates air to help maintain a fairly constant balance of energy around the world.

Atmospheric Pressure

Atmospheric pressure is the pressure the air exerts as gravity pulls it toward the centre of Earth. It is greatest at sea level, where the molecules are closest together. At higher altitudes, atmospheric pressure decreases. Atmospheric pressure at a particular altitude also depends on other factors, such as whether the air is rising or falling. Thus, there are two variations to consider: vertical and horizontal.

Pressure gradient is a measure of the amount the atmospheric pressure changes across a set distance. Pressure gradients can be vertical or horizontal. Figure 4(a) shows that the atmospheric pressure decreases rapidly as the altitude above sea level increases. Mountain climbers and aircraft designers are among the many people who need to know the effects of low atmospheric pressure at high altitudes. Figure 4(b) shows a way of representing horizontal pressure gradients using lines of constant pressure. The gradient is greatest where the lines are closest together. These types of lines are used on weather maps to designate high- and low-pressure areas and to predict strengths and directions of winds.

Notice in Figure 4 that atmospheric pressure is stated in kilopascals (kPa). Since kilo means 1000, 1 kPa = 1000 Pa. Thus, a pressure of 100 kPa is the same as 100 000 Pa. To get an idea of how much pressure this is, imagine an average-size student wearing flat shoes and standing on one foot. The pressure of the shoe on the floor would be about 100 kPa. Now imagine the same student holding a 1 kg bag of sugar; the pressure of the shoe on the floor would increase to about 102 kPa.

The most common instrument used to measure atmospheric pressure is the aneroid barometer. (The word ÅaneroidÆ means Åwithout liquid.Æ As shown in Figure 5, this instrument consists of an enclosed container with thin metal walls that are sensitive to pressure changes. A needle attached to the container indicates the pressure.

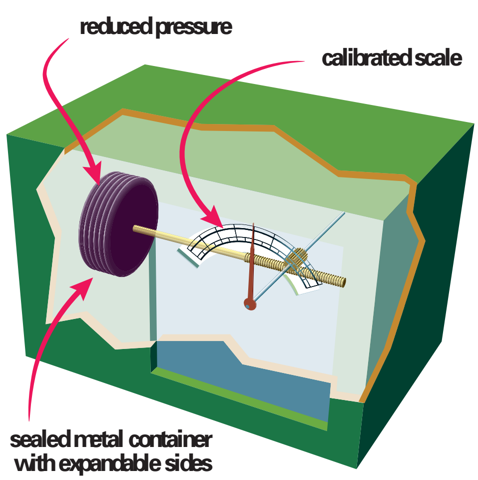
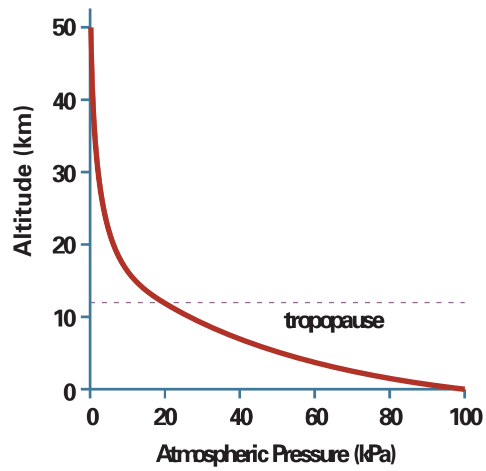
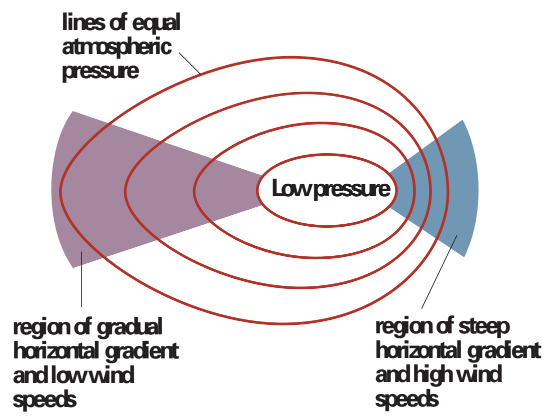


Figure 4

At ground level, the average atmospheric pressure is approximately 100 kPa. The pressure decreases at higher altitudes. Pressure varies from the average of each altitude.



(a) Vertical pressure gradients



(b) Horizontal pressure gradients

Figure 5

The design of an aneroid barometer: as air pressure drops, the container expands, moving the bar attached to the needle. Some barometers indicate the atmospheric pressure on a scale; others simply indicate the type of weather to expect as the atmospheric pressure changes.

Exploring the Atmosphere

Scientists use various methods to study the atmosphere. To observe features high in the atmosphere, say up to 30 km, they launch balloons that carry a radiosonde, an instrument with electronic sensors that measure temperature, atmospheric pressure, and water vapour (Figure 6). Data are sent back to ground stations using radio signals. The balloons are also tracked by ground-based radar systems to measure wind speed and direction. Other methods are described in Chapter 14.

Figure 6
Weather balloons are launched regularly from many locations to keep track fo the changing conditions in the atmosphere. This one is being launched from a Canadian weather station.

Challenge

3 Atmospheric pressure is not stated in kilopascals in some countries, such as the United States. What other units are used? How can you convert them to kilopascals?

Understanding Concepts

1. Using dots to represent molecules of nitrogen, oxygen, and other components of the atmosphere, draw a diagram to show how the spacing between the molecules changes as altitude in the troposphere increases.
2. Explain why the altitude of the tropopause is lower above the poles than above the equator.
3. Which atmospheric layer do you expect you must learn more about before you understand weather systems. Why?
4. Using the temperature gradient of the troposphere, estimate the temperature of the air outside an airplane flying at an altitude of 10 km when the air temperature at ground level is
   (a) 20¡C;
   (b) 0¡C.
5. Explain why the temperature of the stratosphere is higher than the temperature of the tropopause.
6. Explain why atmospheric pressure is lower at the top of a mountain than in the valley below.
7. Suppose that todayÕs weather map shows lines indicating equal pressure 5 mm apart in eastern Manitoba and 8 mm apart in western Manitoba. Explain which area has the higher pressure gradient.
8. Convert:
   (a) 101.3 kPa to pascals;
   (b) 99 900 Pa to kilopascals;
   (c) a change of atmospheric pressure of 0.3 kPa to pascals.
9. Which type of pressure gradient influences
   (a) convection of atmospheric gases?
   (b) advection of atmospheric gases?

Exploring

10. Research the use of an altimeter. Orally describe what you (I) discover to the class.
11. Research the causes and effects of altitude sickness, and then answer the following: if you were climbing a high mountain, such as Mount Everest, what could you do to reduce the effects of altitude sickness?
12. Some early balloonists risked their lives to find out more about the atmosphere. Pick two (e.g., James Glaisher and Robert Coxwell from England; Marie Elizabeth Thible and Teisserenc de Bort from France), and research their exploits. Create a poster with their pictures, if possible, and brief biographies.

SKILLS HANDBOOK: (I) General Research

13.6

Prevailing Wind Patterns

Of the many features we call weather, winds are one of the most important. A wind is a movement of air in the atmosphere. Some winds are local or regional, which means they occur in fairly small areas. But major wind patterns cover much larger areas. Winds that affect large areas are called prevailing winds. Since they affect weather around the world, we study them first. Later in the unit, we will explore some local and regional winds.

The Coriolis Effect

Earth's rotation causes anything that moves long distances, such as prevailing winds, to appear to change direction. The apparent change of direction of a moving object in a rotating system is called the Coriolis effect, after Gaspard de Coriolis, the French mathematician who first analyzed it.

To understand why the Coriolis effect causes a moving object to appear to change direction, imagine trying to slide a puck on a frictionless, rotating platform (Figure 1). In diagram (a), you are at position A, and the platform is not rotating. You slide the puck toward your friend at B. The puck slides in a straight line and your friend stops it. In diagram (b), the platform is rotating counterclockwise, and the point of view is from above the platform. Again you slide the puck toward your friend at B. This time, however, your friend misses the puck because the platform has rotated. Diagram (c) shows the same situation as in (b), this time from the point of view of A. Now the puck appears to curve toward the right, and of course your friend misses the puck. The puck actually travelled in a straight line; it just appeared to veer, or twist, to the right.

The situation in Figure 1(c) resembles what happens in the Northern Hemisphere. When viewed from a point above the North Pole, Earth rotates eastward, or counterclockwise. Thus, objects or particles in motion in the Northern Hemisphere appear to move toward the right. In the Southern Hemisphere, moving objects appear to move toward the left. Although Earth is still rotating eastward, viewed from a point above the South Pole the rotation is clockwise. The Coriolis effect is noticed least at the equator and most near the poles.

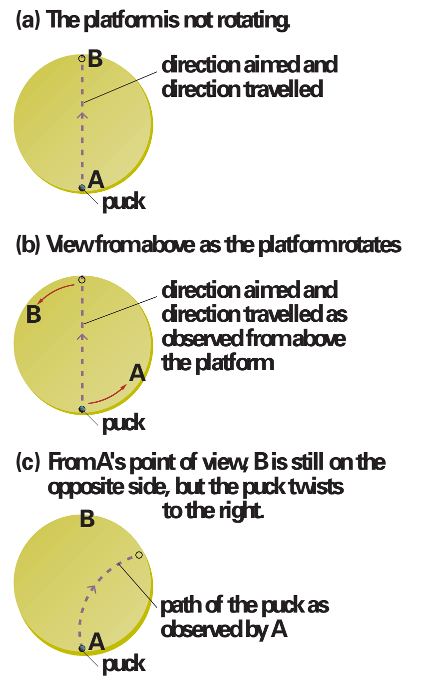


Figure 1

Sliding a puck on a platform illustrates the Coriolis effect.

Observed Wind Patterns

When Christopher Columbus sailed from Europe across the Atlantic Ocean to North America in 1492, he took advantage of two important prevailing winds: the northeast trade winds to go westward and the mid-latitude westerlies to sail back to Europe. These prevailing winds, and several others, are shown in Figure 2.

- Between 60¡ latitude and the poles, surface winds tend to flow from east to west. These are called the polar easterlies.
- Between 30¡ and 60¡ latitude, surface winds tend to flow from west to east. These are called the mid-latitude westerlies.
- Suface winds near the equator (0¡ latitude) tend to flow from east to west. North of the equator, these winds are called the northeast trade winds, and south of the equator, they are called the southeast trade winds.
- Jet streams are high-speed winds in the upper regions of the troposphere, often around the mid-latitudes. They tend to move from west to east and steer most of the major weather systems, such as low-pressure and high-pressure systems.

Figure 2

This map shows the major large-scale prevailing winds. Study the map carefully to discover several important patterns that will help you understand properties of these winds.

Try This
Activity Twisting Winds

This activity will help you visualize why winds twist to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.

Materials: Bristol board, a compass, scissors, a metre stick, a pencil, a pointer, a small stack of large-size paper

Handle the compass and scissors with care.

¥ Use the compass to draw a circle (with a diameter of 30 cm to 40 cm) on the Bristol board. Cut out the circle and label the centre ÅNorth PoleÆand the outside edge the Åequator.ÆAlso draw a counterclockwise arrow near the equator and label it Ådirection of EarthÌs rotation.Æ

¥ Place Earth flat on the small stack of extra paper, and poke the pointer through the Bristol board at the North Pole. Position the metre stick next to the pointer so that the metre stick divides Earth in two.

¥ While a student slowly but steadily rotates Earth counterclockwise, have another student draw a line along the metre stick at a constant speed from the equator toward the North Pole, then from the North Pole to the equator (Figure 3). Use an arrow to label the direction of the line.

(a) Does the line twist to the left or right?

¥ Repeat the process for the Southern Hemisphere using the reverse side of the Bristol board, but this time rotate Earth clockwise.

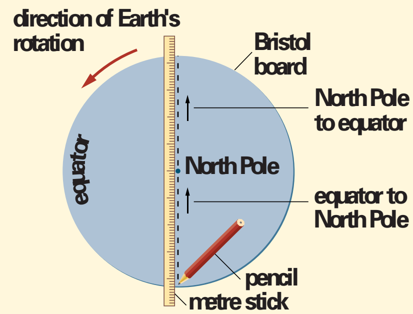
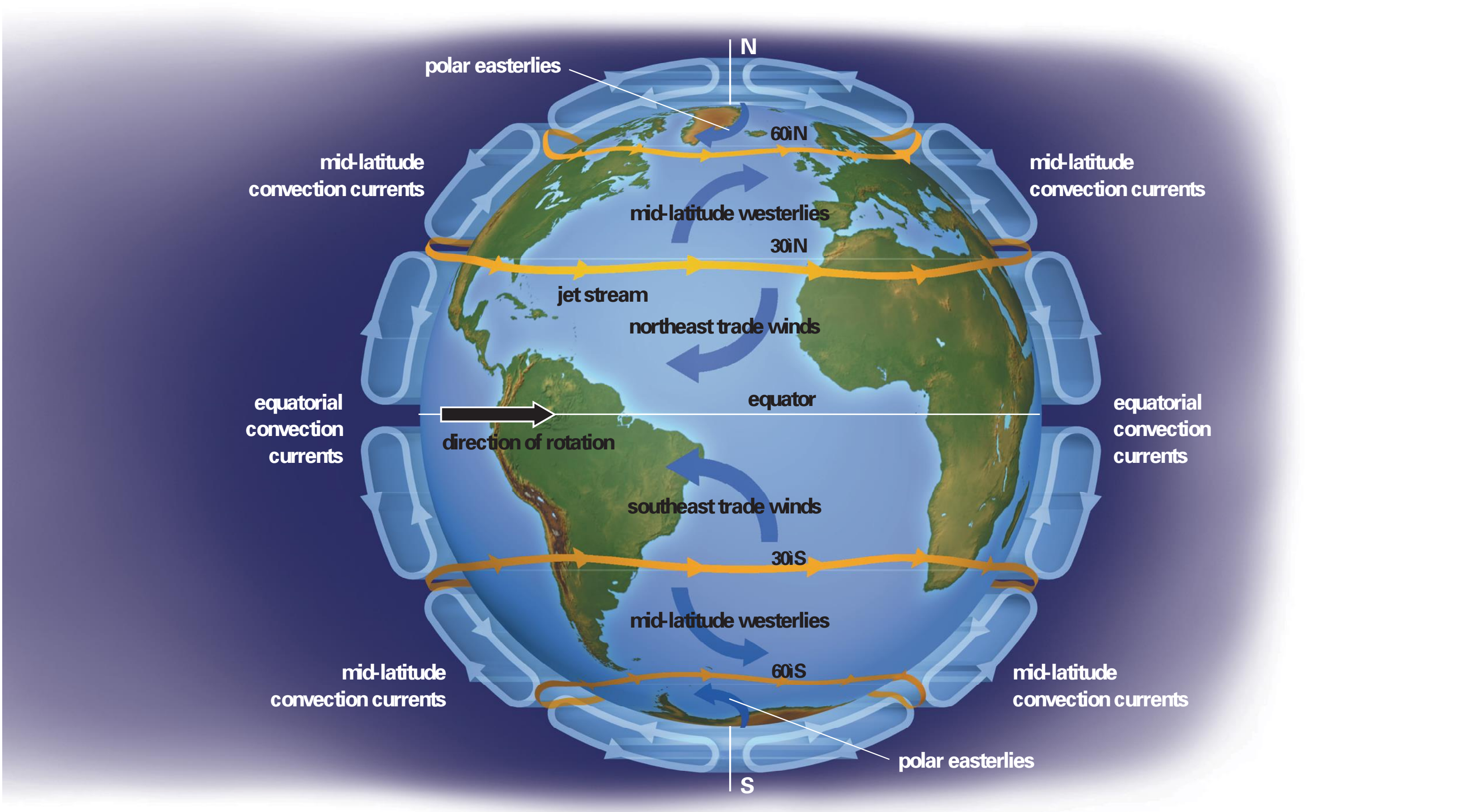


Figure 3
In this model, the moving pencil represents the wind moving first northward from the equator to the North Pole, then southward from the North Pole to the equator.



Causes of Prevailing Winds

Prevailing winds are caused by a combination of convection currents and EarthÈs eastward rotation. The explanations given here focus on the Northern Hemisphere.

Solar energy strikes most directly near the equator, heating the air, the land, and the water. The warmed air begins to form a convection current, called the equatorial convection current (Figure 2). The warm air rises and expands, leaving behind an area of lower pressure. When the rising air reaches the tropopause, it moves northward. Around 30¡ latitude, it has become colder and more dense, so it sinks down toward EarthÈs surface, creating an area of high pressure there. Air at the surface moves away from this area of high pressure toward the low-pressure area at the equator. This moving surface air twists to the right as it moves south, causing the northeast trade winds.

At 30¡ latitude, some of the descending air from the equatorial convection current is deflected northward, away from the high-pressure area toward an area of low pressure around 60¡ latitude. This low-pressure area is formed by another convection current, the mid-latitude convection current, as it begins rising where its warm air meets cold polar air. The surface air moving north toward the area of low pressure becomes part of this convection current. The air twists to the right as it flows northward, causing the mid-latitude westerlies.

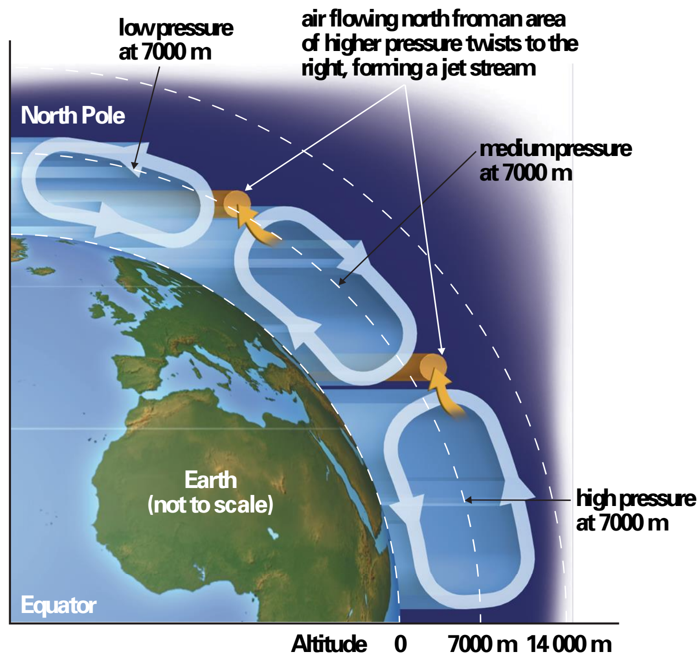
Near the North Pole, the air is cold and dense, so it sinks, creating a high-pressure area at the surface. The surface air moves southward, away from this high-pressure area. At the same time, it twists to the right, causing the polar easterlies.

When the polar air reaches a latitude of about 60¡ it meets the rising warmer air from the mid-latitude convection currents. As the rising air nears the tropopause, its motion completes the convection currents shown in Figure 2, with some air moving toward the equator and the rest toward the North Pole.

To understand how the jet streams form, consider the atmospheric pressure at an altitude of 7000 m. At this altitude above the equator, there is still 7000 m of troposphere on top because warm air rises high. At an altitude of 7000 m above the 30¡ north latitude, there may be only 5000 m of troposphere above, which means that the pressure here is lower than at the same altitude above the equator. Since air moves from higher pressure to lower pressure, air at the 7000 m altitude at the equator moves northward while twisting to the right. This results in a high-altitude, eastward-flowing wind, the jet stream, around 30¡ latitude. A second jet stream may occur near 60¡ north latitude where, at 7000 m, the pressure is even lower than at 30¡ north latitude. (Farther north the temperature is lower, so the air at 30¡ latitude, while cool, is warmer than the air at 60¡ latitude.) The same thing can happen: the air moves from higher pressure to lower pressure, sometimes forming another jet stream. Figure 4 shows formation of the jet streams.

Figure 4

In the Northern Hemisphere, jet streams form in the upper troposphere when air moves from high-pressure areas toward low-pressure areas while at the same time twisting to the right.



Prevailing winds, including the jet streams, are affected by the changing seasons. For one thing, they change latitudes. A simple way to remember this is the saying, Åwinds follow the Sun.ÆFor example, in the Northern Hemisphere, the northeast trade winds move southward, closer to the equator, as the SunÈs direct rays hit south of the equator during winter.

Effects of Prevailing Winds

Prevailing winds help to distribute large amounts of solar energy from the equator to the colder parts of the world. Because convection currents are involved in many of these winds, there is also a return flow of colder air southward. The prevailing winds also carry moisture, helping to cause a variety of precipitation such as snow and rain. To understand the effects of winds, you must remember that rising air tends to be warm and moist, while falling air tends to be cool and dry. Let us look at several effects of winds in the Northern Hemisphere.

Near the equator, wherever the two sets of equatorial convection currents (one in the Northern Hemisphere and one in the Southern) meet and rise, weather tends to be cloudy and rainy. At about 30¡ north latitude, the cool, falling air is dry, creating desert-like conditions. If you look at a globe or map of the world, you will find large deserts near this latitude, for example, the Gobi Desert in Asia, the Sahara Desert in Africa, and the Mojave, Great Basin, and Sonoran Deserts in North America.

At about 60¡ north latitude, two air systems meet and rise, creating unsettled conditions of cloud and precipitation. Winds and storms are stronger in winter because the Arctic region receives no sunlight, so it gets cold rapidly. This produces a larger temperature difference between the polar regions and the equator, which causes greater pressure differences and stronger winds.

Jet stream winds have an important influence on weather systems, as you will learn in the next chapter.

Work the Web

The katabatic wind in Antarctica is the most powerful wind in the world. Visit www.science.nelson.com and follow the Science 10, 13.6 links to find out more about katabatic and anabatic winds. Sketch the flow of air in katabatic and anabatic winds.

Understanding Concepts

1. In the Northern Hemisphere
   (a) in what general direction does energy flow?
   (b) in what general direction does warm air flow?
   (c) toward which side do winds tend to twist?
2. Using Figure 4 as a reference, explain the cause of each of the following in the Southern Hemisphere:
   (a) the southeast trade winds;
   (b) the mid-latitude westerlies;
   (c) the polar easterlies;
   (d) the jet stream(s).
3. (a) Along which latitude in the Southern Hemisphere are deserts likely to be found? Explain why this happens.
   (b) Refer to a globe or world map to find the names of three or four Southern Hemisphere deserts.

Making Connections

4. If you were a pilot flying from Tokyo, Japan, to Vancouver, B.C., what would you do to minimize the time required to complete the flight? Why?

Exploring

5. (I) Find a reference that shows the routes across the Atlantic Ocean taken by Columbus in 1492. Explain how the routes he took relate to the prevailing winds.
6. (J) Research more about jet streams to find out when and how they were discovered. Report briefly on what you discover to the class.
7. Have you ever felt you were Åin the doldrums?ÆLook up doldrums in the dictionary, then explain how the psychological meaning relates to the geographical meaning.

Challenge

1 How could you measure wind speed and direction?
2 How will you design your community to counteract potential wind hazards? How could you reduce turbulence around buildings and the effects of blowing snow?
3 Which prevailing wind or winds do you think would be worthwhile to include in your network data?