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Atmosphere (Oceanography & Climate)

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Contents

CHAPTER 1 Layers of the Atmosphere

Lesson Objectives

- Describe how the temperature of the atmosphere changes with altitude.
- Outline the properties of the troposphere.
- Explain the role of the ozone layer in the stratosphere.
- Describe conditions in the mesosphere.
- Explain how the sun affects the thermosphere.

Vocabulary

- mesosphere
- ozone
- stratosphere
- temperature inversion
- thermosphere
- troposphere

Introduction

Earth's atmosphere is divided into four major layers. The layers are based on temperature.

Temperature of the Atmosphere

Air temperature changes as altitude increases. In some layers of the atmosphere, the temperature decreases. In other layers, it increases. You can see this in **Figure** 1.1. Refer to this figure as you read about the layers below.

Troposphere

The **troposphere** is the lowest layer of the atmosphere. In it, temperature decreases with altitude. The troposphere gets some of its heat directly from the sun. Most, however, comes from Earth's surface. The surface is heated by the sun and some of that heat radiates back into the air. This makes the temperature higher near the surface than at higher altitudes.

Properties of the Troposphere

Look at the troposphere in **Figure** 1.1. This is the shortest layer of the atmosphere. It rises to only about 12 kilometers (7 miles) above the surface. Even so, this layer holds 75 percent of all the gas molecules in the atmosphere. That's because the air is densest in this layer.

Mixing of Air

Air in the troposphere is warmer closer to Earth's surface. Warm air is less dense than cool air, so it rises higher in the troposphere. This starts a convection cell. Convection mixes the air in the troposphere. Rising air is also a main cause of weather. All of Earth's weather takes place in the troposphere.

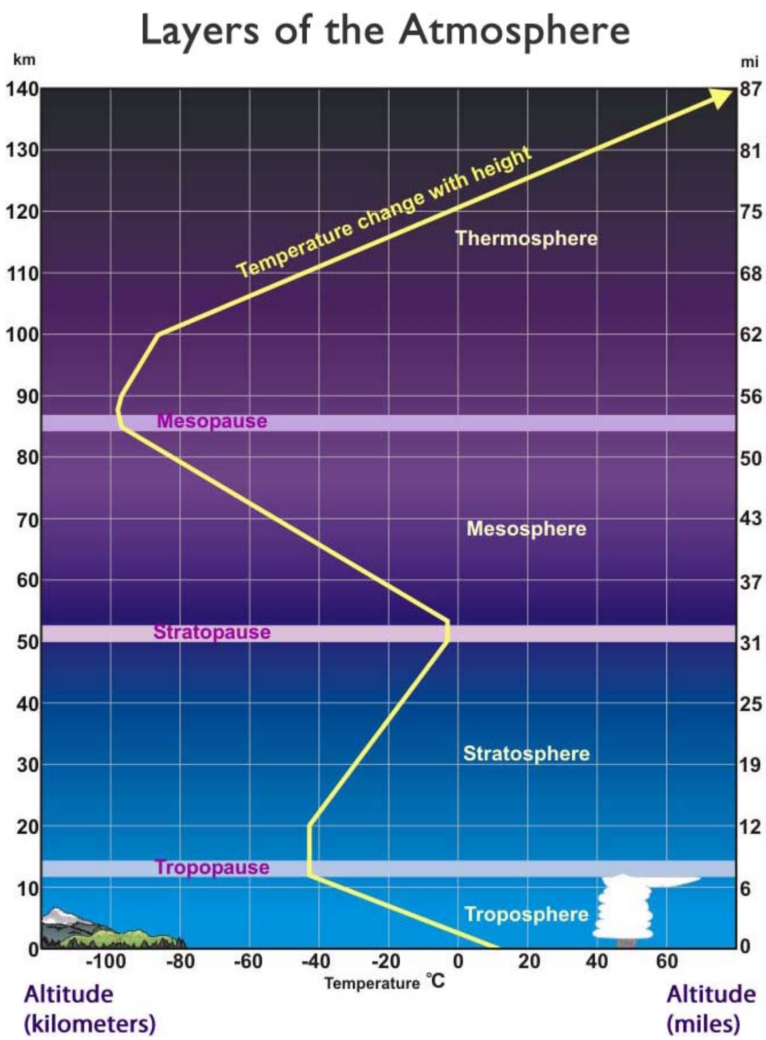


FIGURE 1.1

How does air temperature change in the layer closest to Earth?

Temperature Inversion

Sometimes air doesn't mix in the troposphere. This happens when air is cooler close to the ground than it is above. The cool air is dense, so it stays near the ground. This is called a **temperature inversion**. An inversion can trap air pollution near the surface. Temperature inversions are more common in the winter. Can you explain why?

Tropopause

At the top of the troposphere is a thin layer of air called the tropopause. You can see it in **Figure** 1.1. This layer acts as a barrier. It prevents cool air in the troposphere from mixing with warm air in the stratosphere.

Stratosphere

The **stratosphere** is the layer above the troposphere. The layer rises to about 50 kilometers (31 miles) above the surface.

FIGURE 1.2
Temperature Inversion and Air Pollution. How does a temperature inversion affect air quality?

Temperature in the Stratosphere

Air temperature in the stratosphere layer increases with altitude. Why? The stratosphere gets most of its heat from the sun. Therefore, it's warmer closer to the sun. The air at the bottom of the stratosphere is cold. The cold air is dense, so it doesn't rise. As a result, there is little mixing of air in this layer.

The Ozone Layer

The stratosphere contains a layer of ozone gas. **Ozone** consists of three oxygen atoms (O_3). The ozone layer absorbs high-energy UV radiation. As you can see in **Figure** 1.3, UV radiation splits the ozone molecule. The split creates an oxygen molecule (O_2) and an oxygen atom (O). This split releases heat that warms the stratosphere. By absorbing UV radiation, ozone also protects Earth's surface. UV radiation would harm living things without the ozone layer.

Stratopause

At the top of the stratosphere is a thin layer called the stratopause. It acts as a boundary between the stratosphere and the mesosphere.

Mesosphere

The **mesosphere** is the layer above the stratosphere. It rises to about 85 kilometers (53 miles) above the surface. Temperature decreases with altitude in this layer.

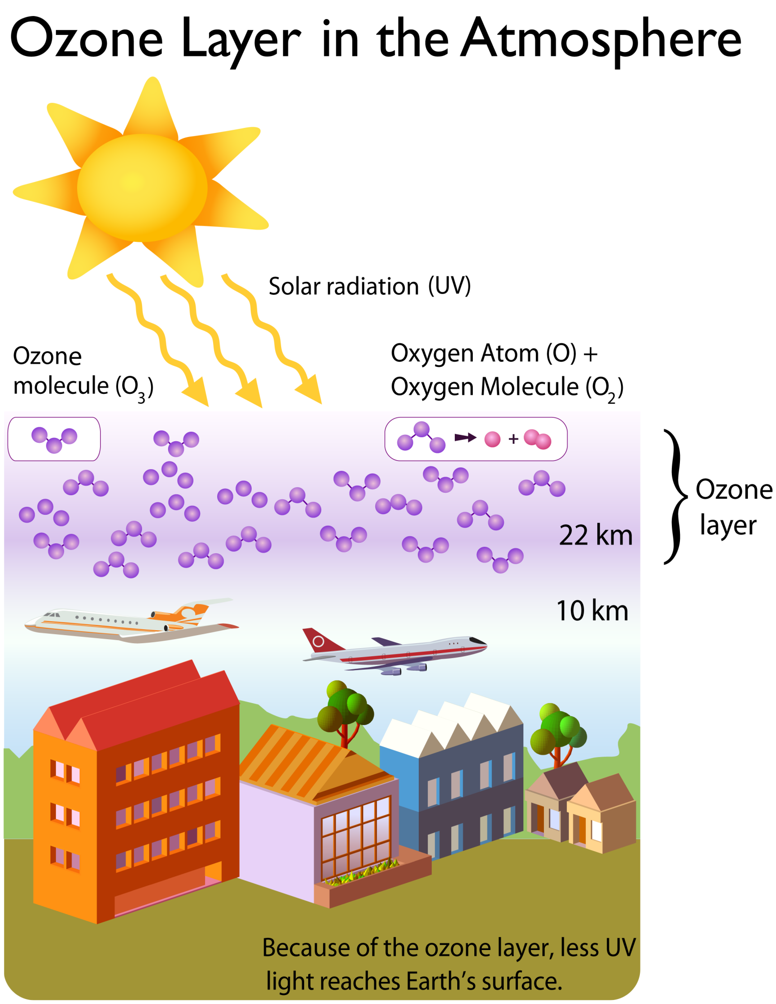


FIGURE 1.3
How does the ozone layer protect Earth

Temperature in the Mesosphere

There are very few gas molecules in the mesosphere. This means that there is little matter to absorb the sun's rays and heat the air. Most of the heat that enters the mesosphere comes from the stratosphere below. That's why the mesosphere is warmest at the bottom.

Meteors in the Mesosphere

Did you ever see a meteor shower, like the one in **Figure** 1.4? Meteors burn as they fall through the mesosphere. The space rocks experience friction with the gas molecules. The friction makes the meteors get very hot. Many meteors burn up completely in the mesosphere.

Mesopause

At the top of the mesosphere is the mesopause. Temperatures here are colder than anywhere else in the atmosphere. They are as low as -100° C (-212° F)! Nowhere on Earth's surface is that cold.

FIGURE 1.4
Friction with gas molecules causes meteors to burn up in the mesosphere.

Thermosphere

The **thermosphere** is the layer above the mesosphere. It rises to 600 kilometers (372 miles) above the surface. The International Space Station orbits Earth in this layer as in **Figure** 1.5.

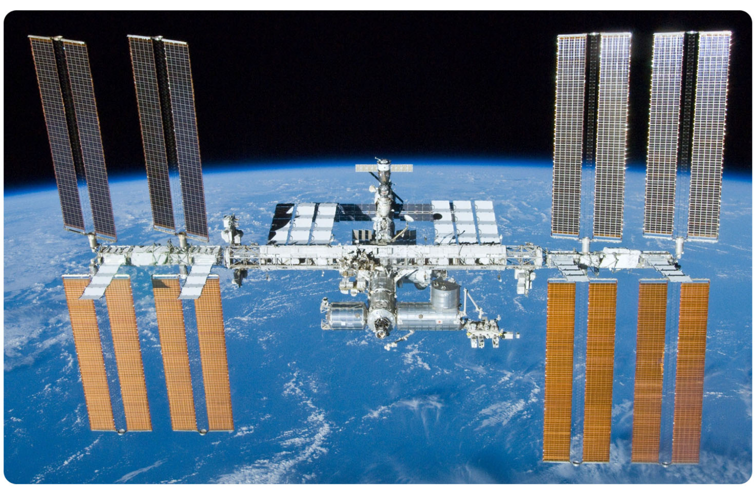


FIGURE 1.5
The International Space Station orbits in the thermosphere.

Temperature in the Thermosphere

Temperature increases with altitude in the thermosphere. Surprisingly, it may be higher than 1000° C (1800° F) near the top of this layer! The sun's energy there is very strong. The molecules absorb the sun's energy and are heated up. But there are so very few gas molecules, that the air still feels very cold. Molecules in the thermosphere gain or lose electrons. They then become charged particles called ions.

Northern and Southern Lights

Have you ever seen a brilliant light show in the night sky? Sometimes the ions in the thermosphere glow at night. Storms on the sun energize the ions and make them light up. In the Northern Hemisphere, the lights are called the northern lights, or aurora borealis. In the Southern Hemisphere, they are called southern lights, or aurora australis.

FIGURE 1.6
Glowing ions in the thermosphere light up the night sky.

Beyond the thermosphere the atmosphere gradually merges with outer space. This part of the atmopshere is sometimes called the exosphere. Gas molecules are very far apart, but they are really hot. Earth's gravity is so weak beyond the thermosphere that gas molecules sometimes just float off into space.

Lesson Summary

- Earth's atmosphere is divided into four major layers. The layers are based on temperature.
- The troposphere is the lowest layer. Temperature decreases with altitude in this layer. All weather takes place here.
- The stratosphere is the layer above the troposphere. Temperature increases with altitude in this layer. The ozone layer occurs here.
- The mesosphere is the layer above the stratosphere. Temperature decreases with altitude in this layer. Meteors burn up here.
- The thermosphere is the layer above the mesosphere. Temperature increases with altitude in this layer. The northern and southern lights occur here.
- Beyond the thermosphere, sometimes called the exosphere, air molecules are very far apart. They may escape Earth's gravity and float into space.

Lesson Review Questions

Recall

1. How does temperature change in the troposphere?

2. What is a temperature inversion?

3. Why is the ozone layer in the stratosphere important to life on Earth?

4. Where does the mesosphere get its heat?

Think Critically

5. How is a temperature inversion like the temperatures of the stratosphere and troposphere?

6. Explain why air mixes in the troposphere but not in the stratosphere.

7. Why is there a hole in the ozone layer? What do you think the consequences of that hole are?

Points to Consider

Energy from the sun is responsible for winds that blow in the troposphere.

- What is wind?
- How does energy cause winds to blow?

References

1. . MS-ES-15-12-Atmosphere-layers.
2. . MS-ES-15-13-Temperature-inversion.
3. . MS-ES-15-14-Ozone-layer.
4. . MS-ES-15-16-Meteor-shower.
5. . MS-ES-15-17-Space-station-in-thermosphere.
6. . MS-ES-15-18-Northern-lights.

Chapter 2 Energy in the Atmosphere

Lesson Objectives

- Describe how energy is transmitted.
- Describe the Earth's heat budget and what happens to the Sun's energy.
- Discuss the importance of convection in the atmosphere.
- Describe the greenhouse effect and why it is so important for life on Earth.

Vocabulary

- conduction
- convection
- electromagnetic waves
- greenhouse effect
- reflection
- temperature

Introduction

Wind, precipitation, warming, and cooling depend on how much energy is in the atmosphere and where that energy is located. Much more energy from the Sun reaches low latitudes (nearer the equator) than high latitudes (nearer the poles). These differences in the amount of solar radiation that reaches a given area in a given time – cause the winds, affect climate, and drive ocean currents. Heat is held in the atmosphere by greenhouse gases.

Energy, Temperature, and Heat

Energy

Energy travels through space or material. This is obvious when you stand near a fire and feel its warmth or when you pick up the handle of a metal pot even though the handle is not sitting directly on the hot stove. Invisible energy waves can travel through air, glass, and even the vacuum of outer space. These waves have electrical and magnetic properties, so they are called **electromagnetic waves**. The transfer of energy from one object to another through electromagnetic waves is known as radiation.

Different wavelengths of energy create different types of electromagnetic waves (**Figure** 2.1).

- The wavelengths humans can see are known as "visible light." These wavelengths appear to us as the colors of the rainbow. What objects can you think of that radiate visible light? Two include the Sun and a light bulb.
- The longest wavelengths of visible light appear red. Infrared wavelengths are longer than visible red. Snakes can see infrared energy. We feel infrared energy as heat.
- Wavelengths that are shorter than violet are called ultraviolet.

Can you think of some objects that appear to radiate visible light, but actually do not? The moon and the planets do not emit light of their own; they reflect the light of the Sun. **Reflection** is when light (or another wave) bounces back from a surface. Some surface are better at reflecting light than others, while other surface are better at absorbing

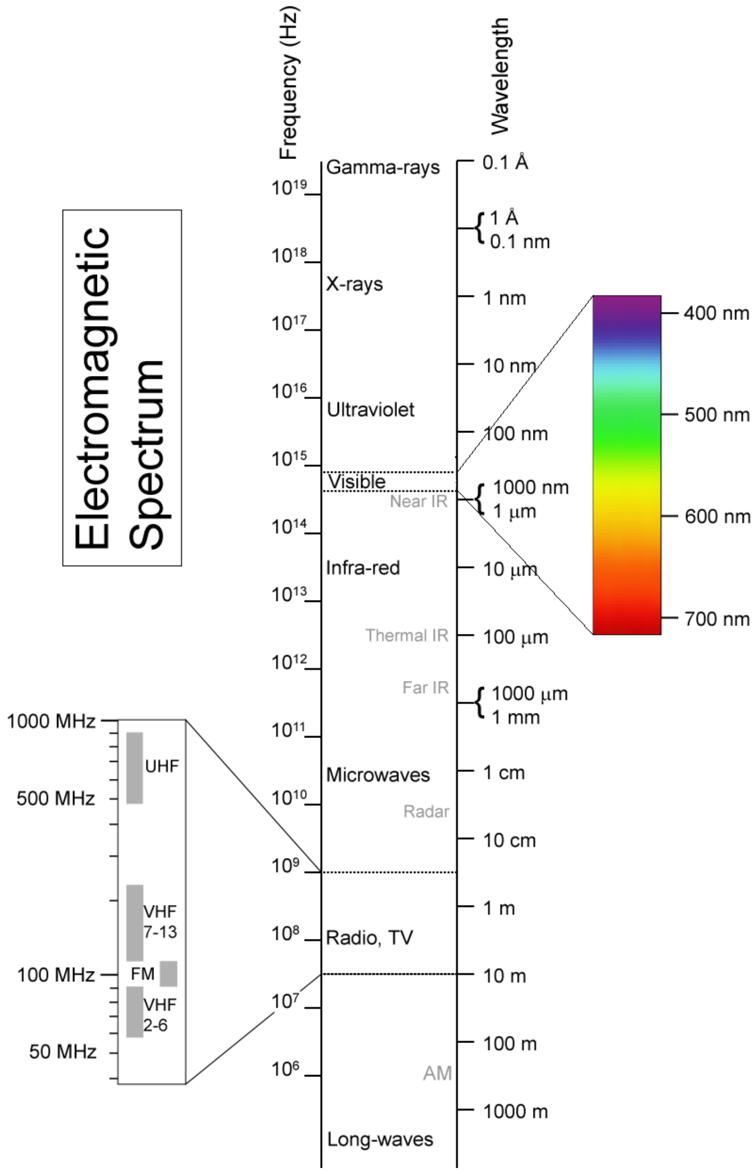


FIGURE 2.1

The electromagnetic spectrum; short wavelengths are the fastest with the highest energy.

light. For example a snow field is better at reflecting light while a forest is better at absorbing light. Can you explain why?

One important fact to remember is that energy cannot be created or destroyed – it can only be changed from one form to another. This is such a fundamental fact of nature that it is a law: the law of conservation of energy.

In photosynthesis, for example, plants convert solar energy into chemical energy that they can use. They do not create new energy. When energy is transformed, some nearly always becomes heat. Heat transfers between materials easily, from warmer objects to cooler ones. If no more heat is added, eventually all of a material will reach the same temperature.

Temperature

Temperature is a measure of how fast the atoms in a material are vibrating. High temperature particles vibrate faster than low temperature particles. Rapidly vibrating atoms smash together, which generates heat. As a material cools down, the atoms vibrate more slowly and collide less frequently. As a result, they emit less heat. What is the difference between heat and temperature?

- Temperature measures how fast a material's atoms are vibrating.
- Heat measures the material's total energy.

Which has higher heat and which has higher temperature: a candle flame or a bathtub full of hot water?

- The flame has higher temperature, but less heat, because the hot region is very small.
- The bathtub has lower temperature but contains much more heat because it has many more vibrating atoms. The bathtub has greater total energy.

Energy From the Sun

Most of the energy that reaches the Earth's surface comes from the Sun (**Figure** 2.2). About 44% of solar radiation is in the visible light wavelengths, but the Sun also emits infrared, ultraviolet, and other wavelengths.

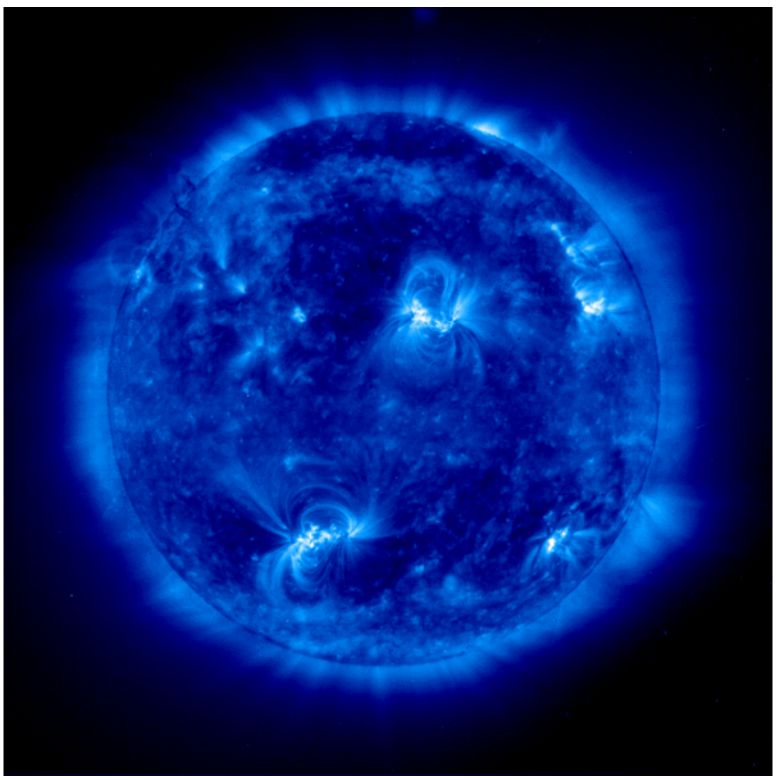


FIGURE 2.2
An image of the sun taken by the SOHO spacecraft. The sensor is picking up only the 17.1 nm wavelength, in the ultraviolet wavelengths.

When viewed together, all of the wavelengths of visible light appear white. But a prism or water droplets can break the white light into different wavelengths so that separate colors appear (**Figure** 2.3).

Of the solar energy that reaches the outer atmosphere, UV wavelengths have the greatest energy. Only about 7% of solar radiation is in the UV wavelengths. The three types are:

- UVC: the highest energy ultraviolet, does not reach the planet's surface at all.
- UVB: the second highest energy, is also mostly stopped in the atmosphere.
- UVA: the lowest energy, travels through the atmosphere to the ground.

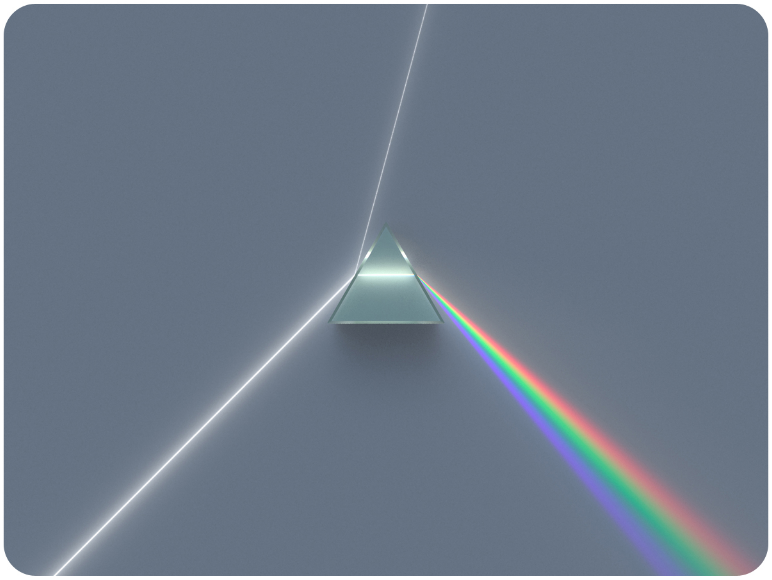


FIGURE 2.3
A prism breaks apart white light.

The remaining solar radiation is the longest wavelength, infrared. Most objects radiate infrared energy, which we feel as heat (**Figure** 2.4).

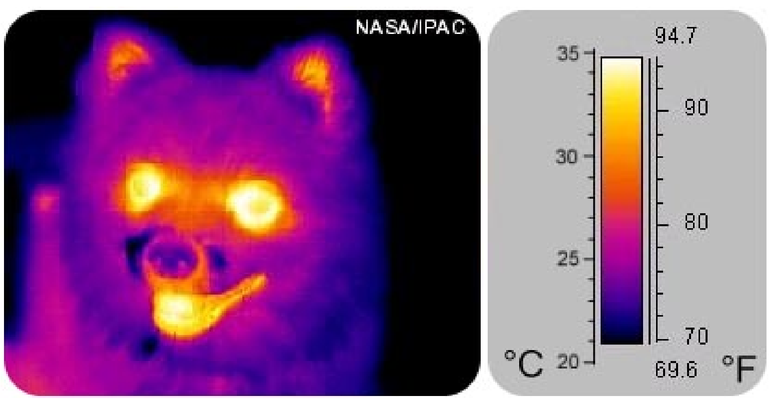


FIGURE 2.4
An infrared sensor detects different amounts of heat radiating from a dog.

Some of the wavelengths of solar radiation traveling through the atmosphere may be lost because they are absorbed by various gases. Ozone completely removes UVC, most UVB and some UVA from incoming sunlight. O_2, CO_2 and H_2O also filter out some wavelengths.

Solar Radiation on Earth

Different parts of the Earth receive different amounts of solar radiation. Which part of the planet receives the most solar radiation? The Sun's rays strike the surface most directly at the equator.

Different areas also receive different amounts of sunlight in different seasons. What causes the seasons? The seasons are caused by the direction Earth's axis is pointing relative to the Sun.

The Earth revolves around the Sun once each year and spins on its axis of rotation once each day. This axis of rotation is tilted 23.5^o relative to its plane of orbit around the Sun.

Northern Hemisphere Summer

The North Pole is tilted towards the Sun and the Sun's rays strike the Northern Hemisphere more directly in summer (**Figure** 2.5). At the summer solstice, June 21 or 22, the Sun's rays hit the Earth most directly along the Tropic of Cancer (23.5^{o}N); that is, this area receives the most solar energy because the sun is directly over head the longest, also giving the Northern Hemisphere their longest day of the year. When it is summer solstice in the Northern Hemisphere, it is winter solstice in the Southern Hemisphere.

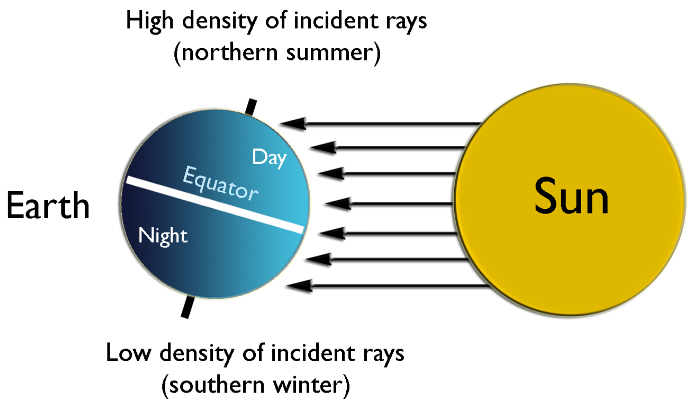


FIGURE 2.5
Summer solstice in the Northern Hemisphere.

Northern Hemisphere Winter

Winter solstice for the Northern Hemisphere happens on December 21 or 22. The tilt of Earth's axis points away from the Sun (**Figure** 2.6). Light from the Sun is spread out over a larger area, so that area isn't heated as much. With fewer daylight hours in winter, there is also less time for the Sun to warm the area. When it is winter in the Northern Hemisphere, it is summer in the Southern Hemisphere.

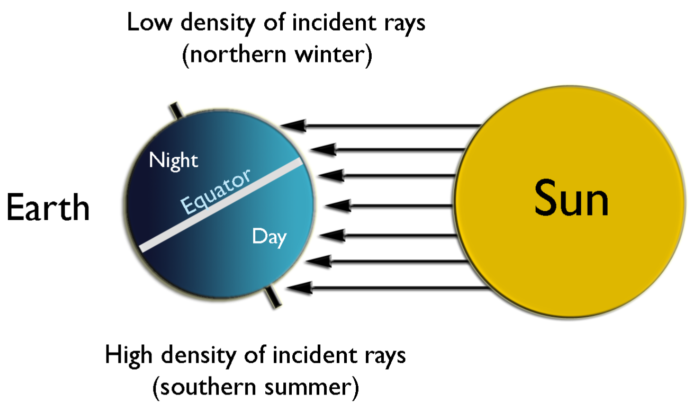


FIGURE 2.6
In Southern Hemisphere summer, the Sun

Equinox

Halfway between the two solstices, the Sun's rays shine most directly at the equator, called an "equinox" (**Figure** 2.7). The daylight and nighttime hours are exactly equal on an equinox. The autumnal equinox happens on September 22 or 23 and the vernal or spring equinox happens March 21 or 22 in the Northern Hemisphere.

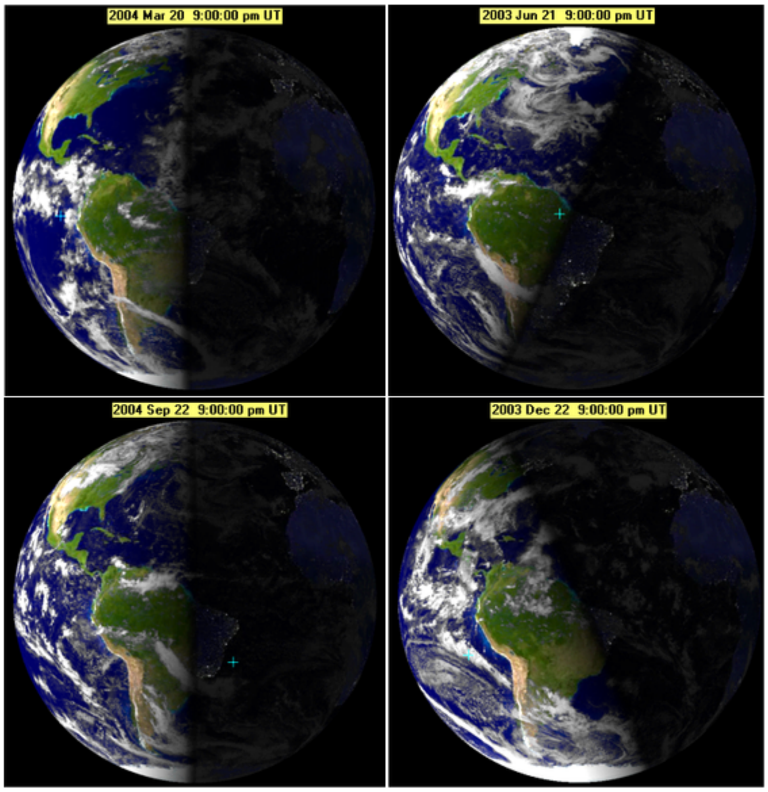


FIGURE 2.7
Where sunlight reaches on spring equinox, summer solstice, vernal equinox, and winter solstice. The time is 9:00 p.m. Universal Time, at Greenwich, England.

Heat Transfer in the Atmosphere

Heat moves in the atmosphere the same way it moves through the solid Earth (think back to Plate Tectonics and what moves the plates).

Radiation is the transfer of energy between two objects by electromagnetic waves. Heat radiates from the ground into the lower atmosphere.

In **conduction**, heat moves from areas of more heat to areas of less heat by direct contact. Warmer molecules vibrate rapidly and collide with other nearby molecules, transferring their energy. In the atmosphere, conduction is more effective at lower altitudes where air density is higher; transfers heat upward to where the molecules are spread further apart or transfers heat laterally from a warmer to a cooler spot, where the molecules are moving less vigorously.

Heat transfer by movement of heated materials is called **convection**. Heat that radiates from the ground initiates convection cells in the atmosphere (**Figure** 2.8).

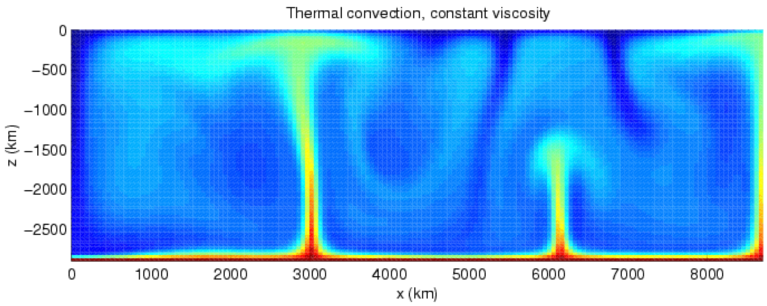


FIGURE 2.8
Thermal convection where the heat source is at the bottom and there is a ceiling at the top.

Heat at Earth's Surface

About half of the solar radiation that strikes the top of the atmosphere is filtered out before it reaches the ground. This energy can be absorbed by atmospheric gases, reflected by clouds, or scattered. Scattering occurs when a light wave strikes a particle and bounces off in some other direction.

About 3% of the energy that strikes the ground is reflected back into the atmosphere. The rest is absorbed by rocks, soil, and water and then radiated back into the air as heat. These infrared wavelengths can only be seen by infrared sensors.

Because solar energy continually enters Earth's atmosphere and ground surface, is the planet getting hotter? The answer is no because energy from Earth escapes into space through the top of the atmosphere. If the amount that exits is equal to the amount that comes in, then average global temperature stays the same. This means that the planet's heat budget is in balance. What happens if more energy comes in than goes out? If more energy goes out than comes in?

To say that the Earth's heat budget is balanced ignores an important point. The amount of incoming solar energy is different at different latitudes. Where do you think the most solar energy ends up and why? Where does the least solar energy end up and why?

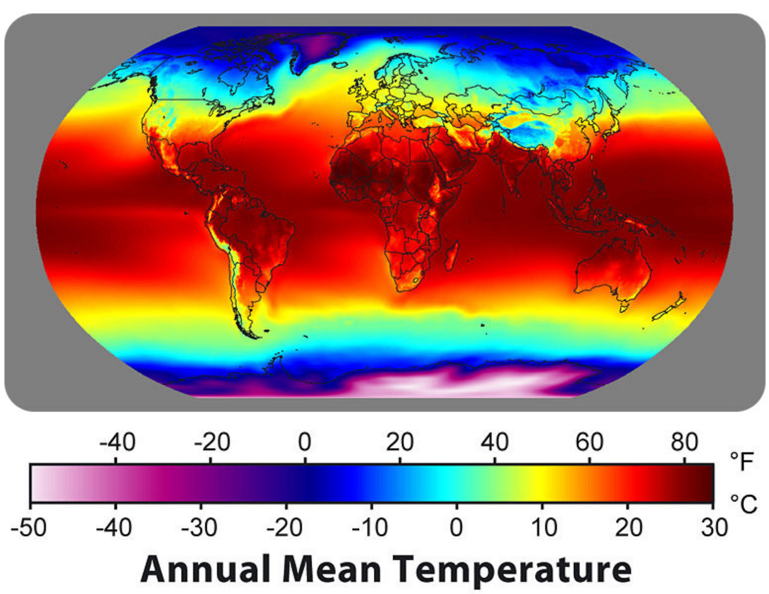


FIGURE 2.9
The average annual temperature of the Earth, showing a roughly gradual temperature gradient from the low to the high latitudes.

The difference in solar energy received at different latitudes drives atmospheric circulation.

Lesson Summary

- All materials contain energy, which can radiate through space as electromagnetic waves. The wavelengths of energy that come from the Sun include visible light, which appears white but can be broken up into many colors.
- Ultraviolet waves are very high energy. The highest energy UV, UVC and some UVB, gets filtered out of incoming sunlight by ozone.
- More solar energy reaches the low latitudes and the redistribution of heat by convection drives the planet's air currents.

Review Questions

1. Give a complete description of these three categories of energy relative to each other in terms of their wavelengths and energy: infrared, visible light, and ultraviolet.
2. Why do the polar regions reflect more solar energy than tropical regions?
3. How much sunlight does the North Pole get on June 21? How much does the South Pole get on that same day?
4. What is the difference between conduction and convection?
5. What is a planet's heat budget? Is Earth's heat budget balanced or not?
6. On a map of average annual temperature, why are the lower latitudes so much warmer than the higher latitudes?

Points to Consider

- How does the difference in solar radiation that reaches the lower and upper latitudes explain the way the atmosphere circulates?
- How does the atmosphere protect life on Earth from harmful radiation and from extreme temperatures?
- What would the consequences be if the Earth's overall heat budget were not balanced?

References

1. . EarSci-1503-02.png.
2. . EarSci-1503-03.png.
3. . EarSci-1503-04.jpg.
4. . EarSci-1503-05.jpg.
5. . HS-ES-Rev-15-Northern_Summer.png.
6. . HS-ES-Rev-15-Northern_Winter.png.
7. . EarSci-1503-08.png.
8. . HS-ES-15-23-Convection-snaps.
9. . EarSci-1503-09.jpg.

CHAPTER 3 The Importance, Composition & Properties of the Atmosphere

Lesson Objectives

- Explain why Earth's atmosphere is important.
- Describe the composition of the atmosphere.
- List properties of the atmosphere.

Vocabulary

- air pressure
- altitude

Introduction

Why is Earth the only planet in the solar system known to have life? The main reason is Earth's atmosphere. The atmosphere is a mixture of gases that surrounds the planet. We also call it air. The gases in the air include nitrogen, oxygen, and carbon dioxide. Along with water vapor, air allows life to survive. Without it, Earth would be a harsh, barren world.

Why the Atmosphere Is Important

We are lucky to have an atmosphere on Earth. The atmosphere supports life, and is also needed for the water cycle and weather. The gases of the atmosphere even allow us to hear.

The Atmosphere and Living Things

Most of the atmosphere is nitrogen, but it doesn't do much. Carbon dioxide and oxygen are the gases in the atmosphere that are needed for life.

- Plants need carbon dioxide for photosynthesis. They use sunlight to change carbon dioxide and water into food. The process releases oxygen. Without photosynthesis, there would be very little oxygen in the air.
- Other living things depend on plants for food. These organisms need the oxygen plants release to get energy out of the food. Even plants need oxygen for this purpose.

The Atmosphere and the Sun's Rays

The atmosphere protects living things from the sun's most harmful rays. Gases reflect or absorb the strongest rays of sunlight. **Figure** 3.1 models this role of the atmosphere.

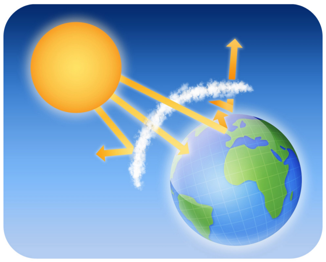


FIGURE 3.1
The atmosphere shields Earth from harmful solar rays.

The Atmosphere and Earth's Temperature

Gases in the atmosphere surround Earth like a blanket. They keep the temperature in a range that can support life. The gases keep out some of the sun's scorching heat during the day. At night, they hold the heat close to the surface, so it doesn't radiate out into space.

The Atmosphere and Earth's Water

Figure 3.2 shows the role of the atmosphere in the water cycle. Water vapor rises from Earth's surface into the atmosphere. As it rises, it cools. The water vapor may then condense into water droplets and form clouds. If enough water droplets collect in clouds they may fall as rain. This how freshwater gets from the atmosphere back to Earth's surface.

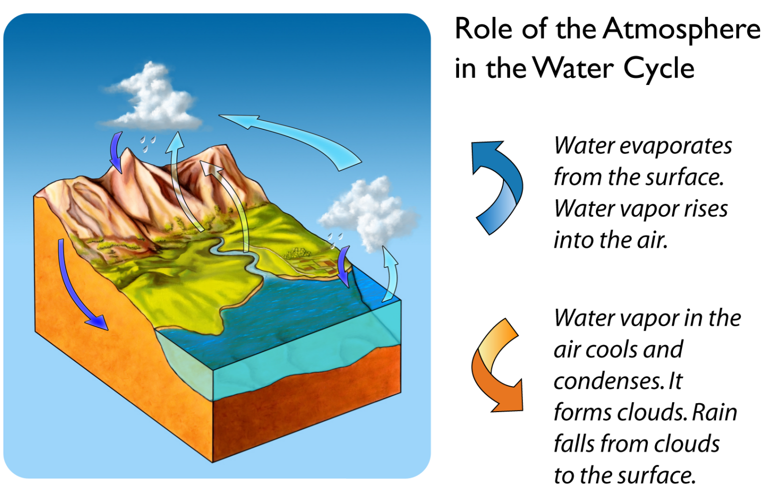


FIGURE 3.2
The atmosphere is a big part of the water cycle. What do you think would happen to Earth

The Atmosphere and Weather

Without the atmosphere, there would be no clouds or rain. In fact, there would be no weather at all. Most weather occurs because the atmosphere heats up more in some places than others.

The Atmosphere and Weathering

Weather makes life interesting. Weather also causes weathering. Weathering is the slow wearing down of rocks on Earth's surface. Wind-blown sand scours rocks like sandpaper. Glaciers of ice scrape across rock surfaces like a file. Even gentle rain may seep into rocks and slowly dissolve them. If the water freezes, it expands. This eventually causes the rocks to crack. Without the atmosphere, none of this weathering would happen.

The Atmosphere and Sound

Sound is a form of energy that travels in waves. Sound waves can't travel through empty space, but they can travel through gases. Gases in the air allow us to hear most of the sounds in our world. Because of air, you can hear birds singing, horns tooting, and friends laughing. Without the atmosphere, the world would be a silent, eerie place.

Composition of Air

Air is easy to forget about. We usually can't see it, taste it, or smell it. We can only feel it when it moves. But air is actually made of molecules of many different gases. It also contains tiny particles of solid matter.

Gases in Air

Figure 3.3 shows the main gases in air. Nitrogen and oxygen make up 99 percent of air. Argon and carbon dioxide make up much of the rest. These percentages are the same just about everywhere in the atmosphere.

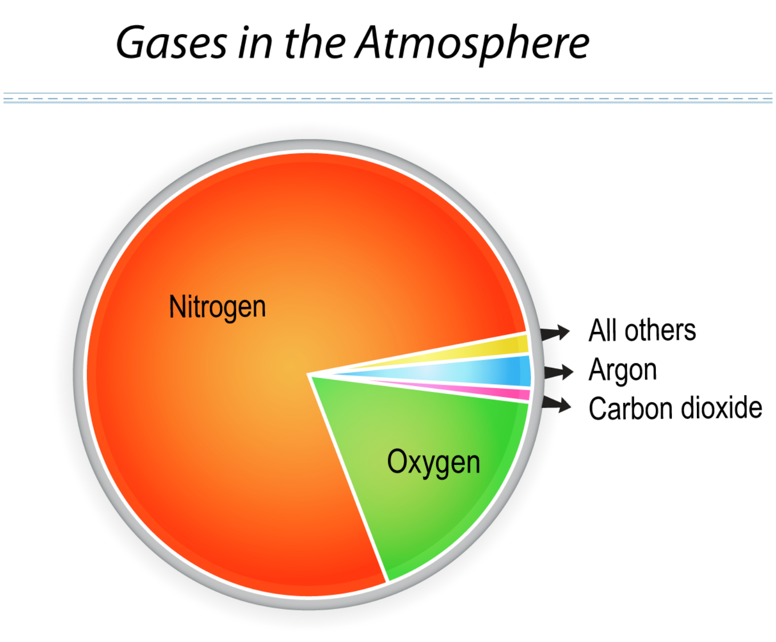


FIGURE 3.3
This graph identifies the most common gases in air.

Air also includes water vapor. The amount of water vapor varies from place to place. That's why water vapor isn't included in **Figure** 3.3. It can make up as much as 4 percent of the air.

Particles in the Air

Air includes many tiny particles. The particles may consist of dust, soil, salt, smoke, or ash. Some particles pollute the air and may make it unhealthy to breathe. But having particles in the air is very important. Tiny particles are needed for water vapor to condense on. Without particles, water vapor could not condense. Then clouds could not form and Earth would have no rain.

Properties of Air

We usually can't sense the air around us unless it is moving. But air has the same basic properties as other matter. For example, air has mass, volume and, of course, density.

Density of Air

Density is mass per unit volume. Density is a measure of how closely molecules are packed together. The closer together they are, the greater the density. Since air is a gas, the molecules can pack tightly or spread out.

The density of air varies from place to place. Air density depends on several factors. One is temperature. Like other materials, warm air is less dense than cool air. Since warmer molecules have more energy, they are more active. The molecules bounce off each other and spread apart. Another factor that affects the density of air is altitude.

Altitude and Density

Altitude is height above sea level. The density of air decreases with height. There are two reasons. At higher altitudes, there is less air pushing down from above. Also, gravity is weaker farther from Earth's center. So at higher altitudes, air molecules can spread out more. Air density decreases. You can see this in **Figure** 3.4.

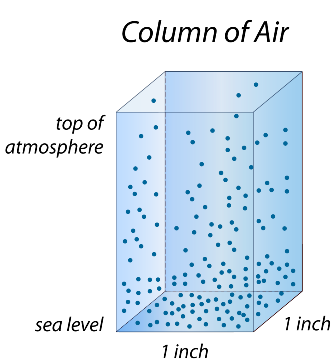


FIGURE 3.4

This drawing represents a column of air. The column rises from sea level to the top of the atmosphere. Where does air have the greatest density?

Air Pressure

Because air is a gas, its molecules have a lot of energy. Air molecules move a lot and bump into things. For this reason, they exert pressure. **Air pressure** is defined as the weight of the air pressing against a given area.

At sea level, the atmosphere presses down with a force of about 1 kilogram per square centimeter (14.76 pounds per square inch). If you are standing at sea level, you have more than a ton of air pressing against you. Why doesn't the pressure crush you? Air presses in all directions at once. Other molecules of air are pushing back.

Altitude and Air Pressure

Like density, the pressure of the air decreases with altitude. There is less air pressing down from above the higher up you go. Look at the bottle in **Figure** 3.5. It was drained by a hiker at the top of a mountain. Then the hiker screwed the cap on the bottle and carried it down to sea level. At the lower altitude, air pressure crushed it. Can you explain why?

FIGURE 3.5
At sea level, pressure was greater outside than inside the bottle. The greater outside pressure crushed the bottle.

Lesson Summary

- Gases in the atmosphere are needed by living things. They protect life from the sun's harmful rays. They also keep temperatures in a range that can support life. Gases in air play a major part in the water cycle, weather, and weathering. They are also needed to transmit most sounds.
- Nitrogen and oxygen make up about 99 percent of the air. Argon and carbon dioxide make up much of the rest. The air also contains water vapor. The amount of water vapor varies from place to place.
- Air has mass and volume. It also has density and exerts pressure. Both the density and pressure of air decrease with altitude.

Lesson Review Questions

Recall

1. State how living things interact with the atmosphere.

2. What role does the atmosphere play in the water cycle?

3. Why does weathering on Earth's surface depend on the atmosphere?

4. Describe the composition of air.

Think Critically

5. Explain how and why the density of air changes with altitude.

6. Review **Figure** 3.5 and its caption. What would the bottle look like if the hiker hadn't screwed on the cap before returning to sea level? Explain your answer.

Points to Consider

In this lesson, you read that air density and pressure change with altitude. The temperature of the air also changes with altitude. Air temperature measures the heat energy of air molecules.

- What heats the atmosphere? Where does air get its energy?
- What causes the atmosphere to lose energy and become cooler?

References

1. . MS-ES-15-01-Solar-rays.
2. . MS-ES-15-02-Role-of-the-atmosphere.
3. . MS-ES-15-03-Gases-in-the-atmosphere.
4. . MS-ES-15-04-Column-of-air.
5. . MS-ES-15-05-Bottle-at-sea-level.

CHAPTER 4 Air Movement

Lesson Objectives

- List the properties of the air currents within a convection cell.
- Describe how high and low pressure cells create local winds.
- Discuss how global convection cells lead to the global wind belts.

Vocabulary

- high pressure zone
- jet stream
- land breeze
- low pressure zone
- sea breeze

Introduction

A few basic principles go a long way toward explaining how and why air moves: Warm air rising creates a **low pressure zone** at the ground. Air from the surrounding area is sucked into the space left by the rising air. Air flows horizontally at top of the troposphere. The air cools until it descends. Where it reaches the ground, it creates a **high pressure zone**. Air flowing from areas of high pressure to low pressure creates winds. Warm air can hold more moisture than cold air. Air moving at the bases of the three major convection cells in each hemisphere north and south of the equator creates the global wind belts.

Air Pressure and Winds

Within the troposphere are convection cells (**Figure** 4.1).

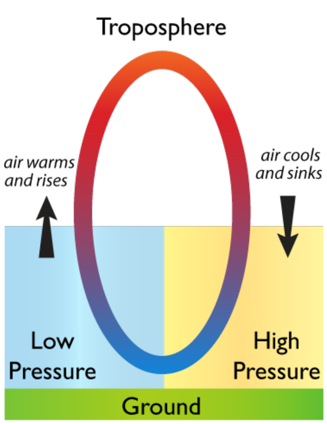


FIGURE 4.1
Warm air rises, creating a low pressure zone; cool air sinks, creating a high pressure zone.

Air that moves horizontally between high and low pressure zones makes wind. The greater the pressure difference between the pressure zones the faster the wind moves.

Convection in the atmosphere creates the planet's weather. When warm air rises and cools in a low pressure zone, it may not be able to hold all the water it contains as vapor. Some water vapor may condense to form clouds or precipitation. When cool air descends, it warms. Since it can then hold more moisture, the descending air will evaporate water on the ground.

Air moving between large high and low pressure systems creates the global wind belts that profoundly affect regional climate. Smaller pressure systems create localized winds that affect the weather and climate of a local area.

An online guide to air pressure and winds from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/fw/home.rxml.

Local Winds

Local winds result from air moving between small low and high pressure systems. High and low pressure cells are created by a variety of conditions.

Land and Sea Breezes

Water maintains its temperature well, so water heats and cools more slowly than land. If there is a large temperature difference between the surface of the sea (or a large lake) and the land next to it, high and low pressure regions form. This creates local winds.

- **Sea breezes** form during the day along coastal areas. Air blows from the cooler ocean over the warmer land. Where is the high pressure zone and where is the low pressure zone? (**Figure** 4.2). Sea breezes blow at about 10 to 20 km (6 to 12 miles) per hour and lower air temperature much as 5 to 10^{o}C (9 to 18^{o}F).
- **Land breezes** form at night along coastal areas. Air blows from the cooler land to the warmer sea. Where is the high pressure zone and where is the low pressure zone? Why do these breezes change from day to night? Remember the land warms and cools faster than the land.

Mountain and Valley Breezes

Temperature differences between mountains and valleys create mountain and valley breezes. During the day, air on mountain slopes is heated more than air at the same elevation over an adjacent valley. As the day progresses, warm air rises and draws the cool air up from the valley, creating a valley breeze. At night the mountain slopes cool more quickly than the nearby valley, which causes a mountain breeze to flow downhill.

Atmospheric Circulation

Because more solar energy hits the equator, the air warms and forms a low pressure zone. At the top of the troposphere, half moves toward the North Pole and half toward the South Pole. As it moves along the top of the troposphere it cools. The cool air is dense and when it reaches a high pressure zone it sinks to the ground. The air is sucked back toward the low pressure at the equator. This describes the convection cells north and south of the equator.

If the Earth did not rotate, there would be one convection cell in the northern hemisphere and one in the southern with the rising air at the equator and the sinking air at each pole. But because the planet does rotate, the situation is more complicated. The planet's rotation means that the Coriolis Effect must be taken into account. Coriolis Effect was described in the Earth's Oceans chapter.

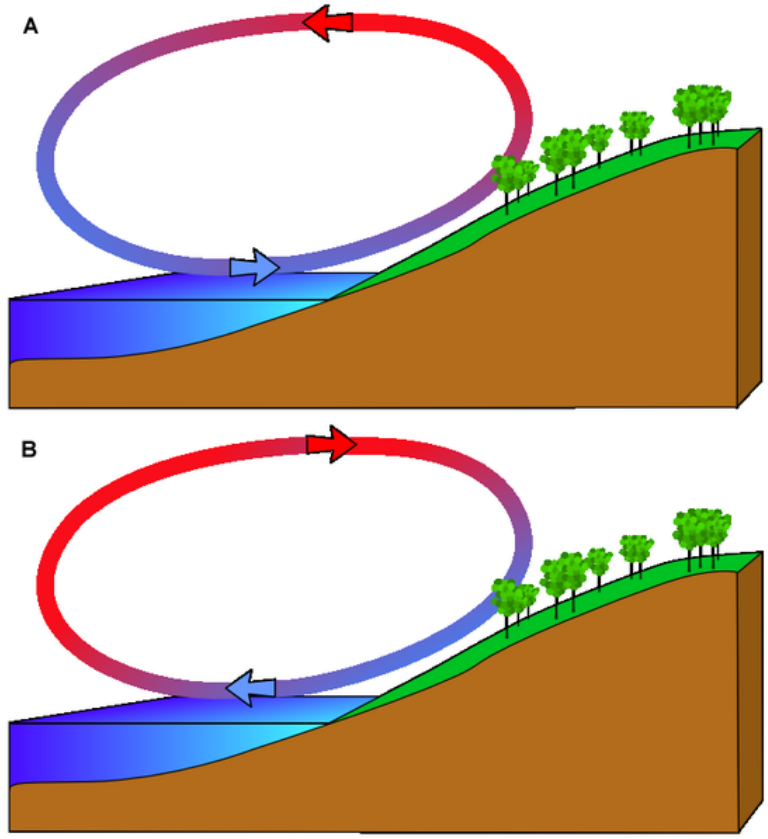


FIGURE 4.2
How do sea and land breezes moderate coastal climates?

Let's look at atmospheric circulation in the Northern Hemisphere as a result of the Coriolis Effect (**Figure** 4.3). Air rises at the equator, but as it moves toward the pole at the top of the troposphere, it deflects to the right. (Remember that it just appears to deflect to the right because the ground beneath it moves.) At about 30^oN latitude, the air from the equator meets air flowing toward the equator from the higher latitudes. This air is cool because it has come from higher latitudes. Both batches of air descend, creating a high pressure zone. Once on the ground, the air returns to the equator. This convection cell is called the Hadley Cell and is found between 0^o and 30^oN.

There are two more convection cells in the Northern Hemisphere. The Ferrell cell is between 30^oN and 50^o to 60^oN. This cell shares its southern, descending side with the Hadley cell to its south. Its northern rising limb is shared with the Polar cell located between 50^oN to 60^oN and the North Pole, where cold air descends.

There are three mirror image circulation cells in the Southern Hemisphere. In that hemisphere, the Coriolis Effect makes objects appear to deflect to the left.

Global Wind Belts

Global winds blow in belts encircling the planet. The global wind belts are enormous and the winds are relatively steady (**Figure** 4.4). These winds are the result of air movement at the bottom of the major atmospheric circulation cells, where the air moves horizontally from high to low pressure.

Global Wind Belts

Let's look at the global wind belts in the Northern Hemisphere.

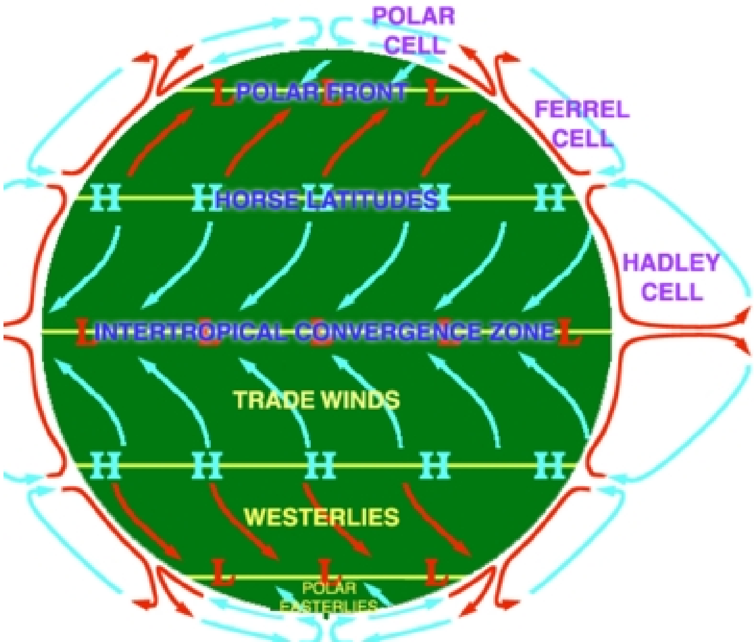


FIGURE 4.3

The atmospheric circulation cells, showing direction of winds at Earth's surface.

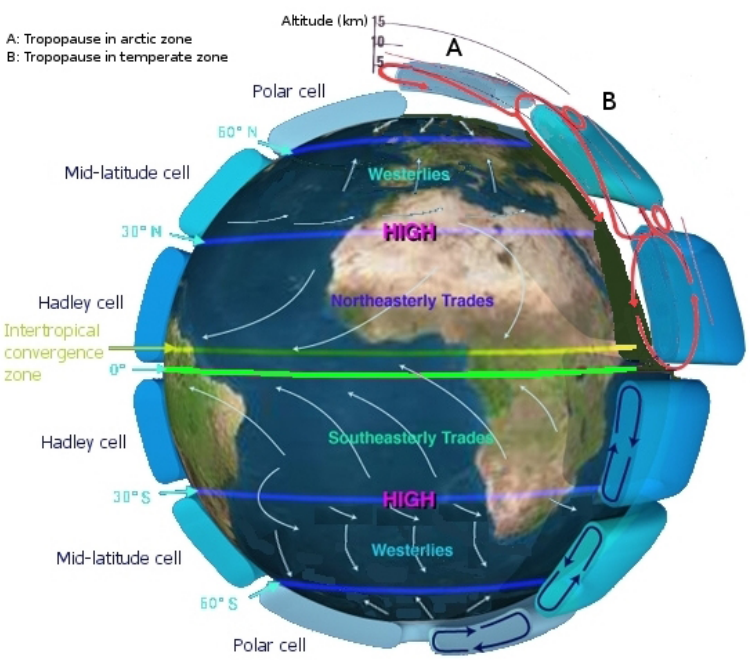


FIGURE 4.4

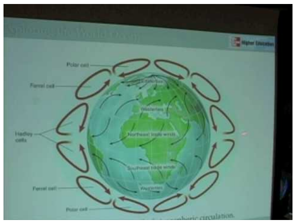
The major wind belts and the directions that they blow.

- In the Hadley cell air should move north to south, but it is deflected to the right by Coriolis. So the air blows from northeast to the southwest. This belt is the trade winds, so called because at the time of sailing ships they were good for trade.
- In the Ferrel cell air should move south to north, but the winds actually blow from the southwest. This belt is the westerly winds or westerlies. Why do you think a flight across the United States from San Francisco to New York City takes less time than the reverse trip?

- In the Polar cell, the winds travel from the northeast and are called the polar easterlies

The wind belts are named for the directions from which the winds come. The westerly winds, for example, blow from west to east. These names hold for the winds in the wind belts of the Southern Hemisphere as well.

This video lecture discusses the 3-cell model of atmospheric circulation and the resulting global wind belts and surface wind currents **(5a)**: http://www.youtube.com/watch?v=HWFDKdxK75E&feature=related (8:45).



MEDIA

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Global Winds and Precipitation

Besides their effect on the global wind belts, the high and low pressure areas created by the six atmospheric circulation cells determine in a general way the amount of precipitation a region receives. In low pressure regions, where air is rising, rain is common. In high pressure areas, the sinking air causes evaporation and the region is usually dry.

Polar Fronts and Jet Streams

The polar front is the junction between the Ferrell and Polar cells. At this low pressure zone, relatively warm, moist air of the Ferrell Cell runs into relatively cold, dry air of the Polar cell. The weather where these two meet is extremely variable, typical of much of North America and Europe.

The polar **jet stream** is found high up in the atmosphere where the two cells come together. A jet stream is a fast-flowing river of air at the boundary between the troposphere and the stratosphere. Jet streams form where there is a large temperature difference between two air masses. This explains why the polar jet stream is the world's most powerful (**Figure** 4.5).

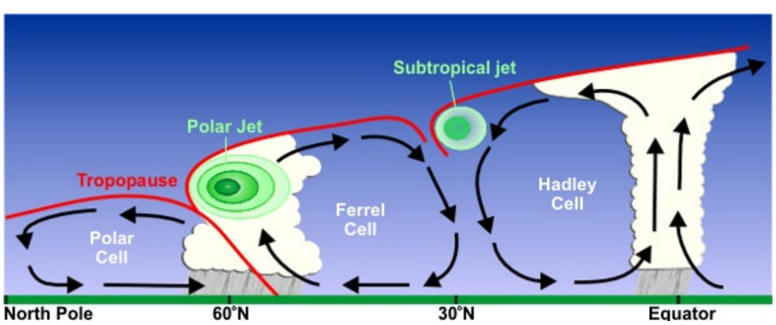

FIGURE 4.5

A cross section of the atmosphere with major circulation cells and jet streams. The polar jet stream is the site of extremely turbulent weather.

Jet streams move seasonally just as the angle of the Sun in the sky moves north and south. The polar jet stream, known as "the jet stream," moves south in the winter and north in the summer between about 30^oN and 50^o to 75^oN.

Lesson Summary

- Winds blow from high pressure zones to low pressure zones. The pressure zones are created when air near the ground becomes warmer or colder than the air nearby.
- Local winds may be found in a mountain valley or near a coast.
- The global wind patterns are long-term, steady winds that prevail around a large portion of the planet.
- The location of the global wind belts has a great deal of influence on the weather and climate of an area.

Review Questions

1. Draw a picture of a convection cell in the atmosphere. Label the low and high pressure zones and where the wind is.

2. Under what circumstances will winds be very strong?

3. Given what you know about global-scale convection cells, where would you travel if you were interested in experiencing warm, plentiful rain?

4. Describe the atmospheric circulation for two places where you are likely to find deserts, and explain why these regions are relatively warm and dry.

5. Why does the Coriolis Effect cause air to appear to move clockwise in the Northern Hemisphere? When does Coriolis Effect cause air to appear to move counterclockwise?

6. Sailors once referred to a portion of the ocean as the doldrums. This is a region where there is frequently no wind, so ships would become becalmed for days or even weeks. Where do you think the doldrums might be relative to the atmospheric circulation cells?

Points to Consider

- How do local winds affect the weather in an area?
- How do the global wind belts affect the climate in an area?
- What are the main principles that control how the atmosphere circulates?

References

1. . HS-ES-Rev-15-27-Pressurezones.png.
2. . EarSci-1504-02.png.
3. . EarSci-1504-08.jpg.
4. . EarSci-1504-09.jpg.
5. . HS-ES-15-35-Jet-cross-section.jpg.