Atmospheric Processes

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CHAPTER 1 Atmospheric Processes

CHAPTER OUTLINE

Introduction

On the way to a rendezvous with the International Space Station, the space Shuttle Endeavor stood out against the layers of the atmosphere over the South Pacific. The orange lowest layer is the troposphere, which becomes the white stratosphere and then grades into the mesosphere. It's amazing that the properties of the atmosphere differ enough that they can show up as different colors in the sky.

1.1 Importance of the Atmosphere

- Describe Earth's atmosphere and explain the important roles it plays in sustaining life on Earth.

If Earth didn't have an atmosphere, would it always be cold?

This is a question commonly asked by 12-year-old girls being driven to school by their mothers. "Of course," the moms answer, "it would be extremely hot when the Sun is out and bitter cold when it's dark." Does this conversation sound familiar?

What Is the Atmosphere?

Earth's **atmosphere** is a thin blanket of gases and tiny particles —together called air. We are most aware of air when it moves and creates wind. Earth's atmosphere, along with the abundant liquid water at Earth's surface, are the keys to our planet's unique place in the solar system. Much of what makes Earth exceptional depends on the atmosphere. For example, all living things need some of the gases in air for life support. Without an atmosphere, Earth would likely be just another lifeless rock.

Let's consider some of the reasons we are lucky to have an atmosphere.

Gases Indispensable for Life on Earth

Without the atmosphere, Earth would look a lot more like the Moon. Atmospheric gases, especially carbon dioxide (CO_2) and oxygen (O_2), are extremely important for living organisms. How does the atmosphere make life possible? How does life alter the atmosphere?

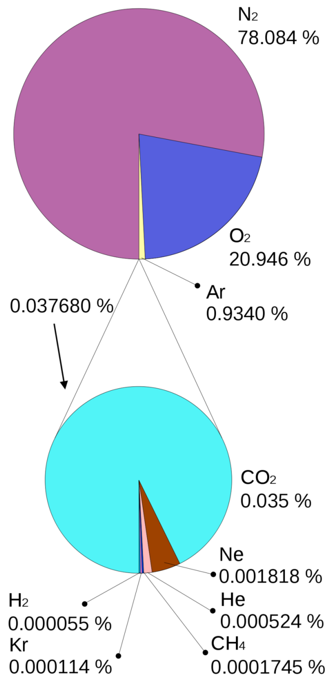


FIGURE 1.1
The composition of Earth's atmosphere.

Photosynthesis

In **photosynthesis**, plants use CO_2 and create O_2. Photosynthesis is responsible for nearly all of the oxygen currently found in the atmosphere.

The chemical reaction for photosynthesis is:

$6CO_2 + 6H_2O$ + solar energy $\rightarrow C_6H_{12}O_6$ (sugar) + $6O_2$

Respiration

By creating oxygen and food, plants have made an environment that is favorable for animals. In **respiration**, animals use oxygen to convert sugar into food energy they can use. Plants also go through respiration and consume some of the sugars they produce.

The chemical reaction for respiration is:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + useable energy

How is respiration similar to and different from photosynthesis? They are approximately the reverse of each other. In photosynthesis, CO_2 is converted to O_2 and in respiration, O_2 is converted to CO_2 (**Figure** 1.2).

Crucial Part of the Water Cycle

As part of the hydrologic cycle, water spends a lot of time in the atmosphere, mostly as water vapor. The atmosphere is an important reservoir for water.

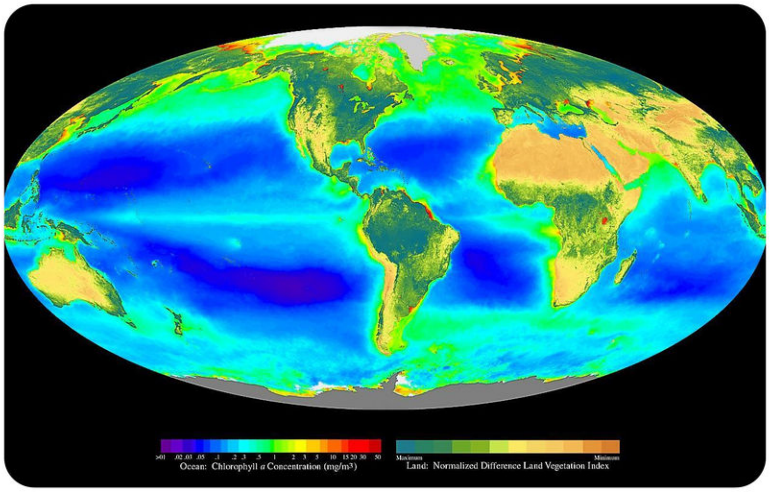


FIGURE 1.2
Chlorophyll indicates the presence of photosynthesizing plants as does the vegetation index.

Ozone Makes Life on Earth Possible

Ozone is a molecule composed of three oxygen atoms, (O_3). Ozone in the upper atmosphere absorbs high-energy **ultraviolet (UV) radiation** coming from the Sun. This protects living things on Earth's surface from the Sun's most harmful rays. Without ozone for protection, only the simplest life forms would be able to live on Earth. The highest concentration of ozone is in the ozone layer in the lower stratosphere.

Keeps Earth's Temperature Moderate

Along with the oceans, the atmosphere keeps Earth's temperatures within an acceptable range. Without an atmosphere, Earth's temperatures would be frigid at night and scorching during the day. If the 12-year-old in the scenario above asked why, she would find out. **Greenhouse gases** trap heat in the atmosphere. Important greenhouse gases include carbon dioxide, methane, water vapor, and ozone.

Provides the Substance for Waves to Travel Through

The atmosphere is made of gases that take up space and transmit energy. Sound waves are among the types of energy that travel though the atmosphere. Without an atmosphere, we could not hear a single sound. Earth would be as silent as outer space (explosions in movies about space should be silent). Of course, no insect, bird, or airplane would be able to fly, because there would be no atmosphere to hold it up.

Summary

- The atmosphere is made of gases that are essential for photosynthesis and respiration, among other life activities.
- The atmosphere is a crucial part of the water cycle. It is an important reservoir for water and the source of precipitation.
- The atmosphere moderates Earth's temperature because greenhouse gases absorb heat.

Explore More

Use these resources to answer the questions that follow.

https://www.youtube.com/watch?v=7XkH6NnUpFQ

1. What is the composition of the atmosphere?
2. What does the atmosphere do?
3. How are humans clanging the composition of the atmosphere?
4. What is the negative effect of that?
5. If Earth didn't have an atmosphere what would global temperatures be like?
6. Why don't you feel the air pressure of the air above you?

Explore More Answers

1. 78% nitrogen, 21% oxygen and the rest other gases such as carbon dioxide.
2. It provides us with the air we breathe, our changing weather, protects us from harmful solar radiation, protects us from space debris, it traps heat, which moderates the temperature.
3. Fossil fuel burning is adding carbon dioxide.
4. Too much carbon dioxide will trap more heat and warm the planet.
5. Hot when the sun is out and cold at night.
6. It always pushes on us from all sides but at the same time it is inside us pushing out.

Review

1. What gases are used and expelled by photosynthesis and respiration?
2. Where is the largest concentration of ozone and what value does it have?
3. How does the atmosphere keep Earth's temperature moderate?

Review Answers

1. Organisms that photosynthesize take in carbon dioxide and release oxygen. In respiration, organisms take in oxygen and release carbon dioxide.
2. Ozone is in the upper atmosphere in higher concentrations. It absorbs high energy ultraviolet radiation from the sun and protects life on Earth from those rays.
3. Greenhouse gases trap heat so that nights are not as cold and days are not as hot.

1.2 Composition of the Atmosphere

- Describe the composition of the atmosphere.

Did life evolve to match the atmosphere or is the fit just coincidence?

Life as we know it would not survive if there were no ozone layer to protect it from high energy ultraviolet radiation. Most life needs oxygen to survive. Nitrogen is also needed, albeit in a different form from that found in the atmosphere. Greenhouse gases keep the temperature moderate so that organisms can live around the planet. Life evolved to match the conditions that were available and to some extent changed the atmosphere to suit its needs.

Composition of Air

Several properties of the atmosphere change with altitude, but the composition of the natural gases does not. The proportions of gases in the atmosphere are everywhere the same, with one exception. At about 20 km to 40 km above the surface, there is a greater concentration of ozone molecules than in other portions of the atmosphere. This is called the **ozone layer**.

Nitrogen and Oxygen

Nitrogen and oxygen together make up 99% of the planet's atmosphere. Nitrogen makes up the bulk of the atmosphere, but is not involved in geological or biological processes in its gaseous form. Nitrogen fixing is described in the chapter Life on Earth. Oxygen is extremely important because it is needed by animals for respiration. The rest of the gases are minor components but sometimes are very important (**Figure** 1.3).

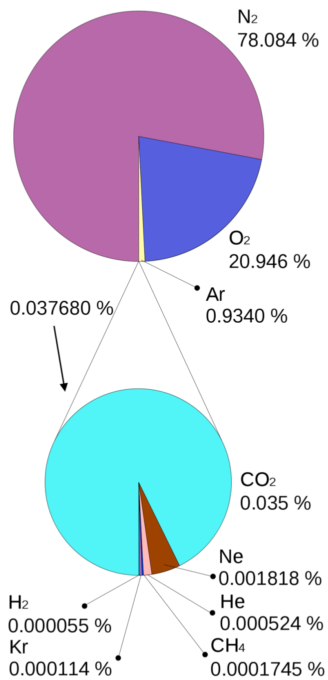


FIGURE 1.3

Nitrogen and oxygen make up 99% of the atmosphere; carbon dioxide is a very important minor component.

Water Vapor

Humidity is the amount of water vapor in the air. Humidity varies from place to place and season to season. This fact is obvious if you compare a summer day in Atlanta, Georgia, where humidity is high, with a winter day in Phoenix, Arizona, where humidity is low. When the air is very humid, it feels heavy or sticky. Dry air usually feels more comfortable. When humidity is high, water vapor makes up only about 4% of the atmosphere.

Where around the globe is mean atmospheric water vapor higher and where is it lower (**Figure** 1.4)? Why? Higher humidity is found around the equatorial regions because air temperatures are higher and warm air can hold more moisture than cooler air. Of course, humidity is lower near the polar regions because air temperature is lower.

Greenhouse Gases

Remember that greenhouse gases trap heat in the atmosphere. Important natural greenhouse gases include carbon dioxide, methane, water vapor, and ozone. CFCs and some other man-made compounds are also greenhouse gases.

Particulates

Some of what is in the atmosphere is not gas. Particles of dust, soil, fecal matter, metals, salt, smoke, ash, and other solids make up a small percentage of the atmosphere and are called **particulates**. Particles provide starting points

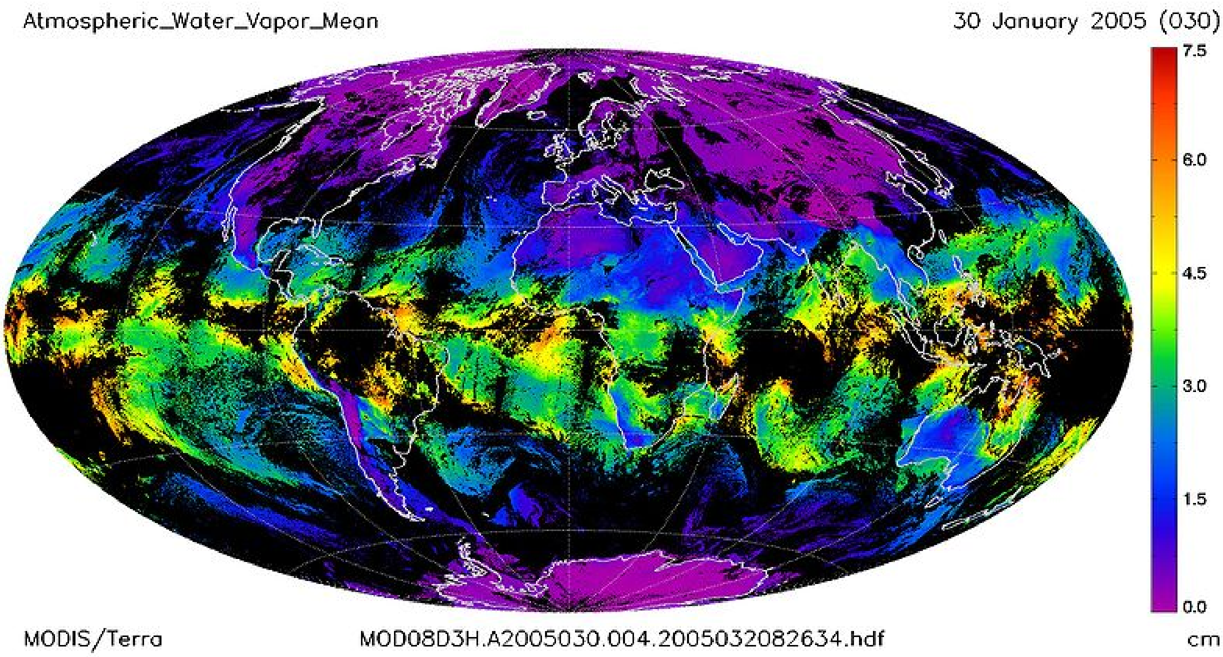


FIGURE 1.4

Mean winter atmospheric water vapor in the Northern Hemisphere when temperature and humidity are lower than they would be in summer.

(or nuclei) for water vapor to condense on and form raindrops. Some particles are pollutants.

Summary

- The major atmospheric gases are nitrogen and oxygen. The atmosphere also contains minor amounts of other gases, including carbon dioxide.
- Greenhouse gases trap heat in the atmosphere and include carbon dioxide, methane, water vapor, and ozone.
- Not everything in the atmosphere is gas; particulates are particles that are important as the nucleus of raindrops and snowflakes.

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=n_HlWovib3Y

1. What do we do with the nitrogen we breathe from the air around us?
2. What is the percent of each of the two most abundant gases in the atmosphere?
3. What is the most abundant gas in the remaining 1%? What are some of the other gases present?
4. Why is carbon dioxide important even though there is so little of it in the atmosphere?
5. How does oxygen get into the atmosphere?
6. What happens to the oxygen that is taken up in cellular respiration?

Explore More Answers

1. Nothing. We just breathe it in and out.
2. 78% nitrogen,21% oxygen
3. Argon is the most abundant remaining gas; the trace gases are carbon dioxide, hydrogen, krypton, methane, helium and neon
4. It is the most abundant greenhouse gas.
5. It is a byproduct of photosynthesis.
6. It burns the sugars for energy and releases carbon dioxide.

Review

1. What are the two major atmospheric gases and what roles do they play?
2. What are the important greenhouse gases?
3. What is humidity? If the humidity is 95% does that mean 95% of the air is water vapor?

Review Answers

1. Nitrogen and oxygen. Nitrogen is useful but not as a gas, only if it is fixed. Oxygen is used by animals for respiration.
2. Carbon dioxide is the most important; other important ones are methane, water vapor, ozone and CFCs.
3. The amount of water vapor in the air. No, it is the amount of the 4% of air that can be water vapor.

1.3 Pressure and Density of the Atmosphere

- Define air density and air pressure and explain how they change with increasing altitude.

Have your ears ever popped?

If your ears have ever "popped," you have experienced a change in air pressure. Ears "pop" because the air pressure is different on the inside and the outside.

Pressure and Density

The atmosphere has different properties at different elevations above sea level, or **altitudes**.

Density

The air density (the number of molecules in a given volume) decreases with increasing altitude. This is why people who climb tall mountains, such as Mt. Everest, have to set up camp at different elevations to let their bodies get used to the decreased air density (**Figure** 1.5).

Why does air density decrease with altitude? Gravity pulls the gas molecules towards Earth's center. The pull of gravity is stronger closer to the center, at sea level. Air is denser at sea level, where the gravitational pull is greater.

Pressure

Gases at sea level are also compressed by the weight of the atmosphere above them. The force of the air weighing down over a unit of area is known as its atmospheric pressure, or **air pressure**. Why are we not crushed? The molecules inside our bodies are pushing outward to compensate. Air pressure is felt from all directions, not just from above.

FIGURE 1.5
This bottle was closed at an altitude of 3,000 meters where air pressure is lower. When it was brought down to sea level, the higher air pressure caused the bottle to collapse.

At higher altitudes the atmospheric pressure is lower and the air is less dense than at lower altitudes. That's what makes your ears pop when you change altitude. Gas molecules are found inside and outside your ears. When you change altitude quickly, like when an airplane is descending, your inner ear keeps the density of molecules at the original altitude. Eventually the air molecules inside your ear suddenly move through a small tube in your ear to equalize the pressure. This sudden rush of air is felt as a popping sensation.

Summary

- Air density and pressure decrease with increasing altitude.
- Ears pop as air pressure inside and outside the ear equalizes.
- Gravity pulls more air molecules toward the center of the planet.

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=xJHJsA7bYGc

1. What force creates atmospheric pressure?
2. Where is atmospheric pressure greatest?
3. What is pressure? In what units is it expressed?
4. Why don't we collapse due to air pressure?

5. Why does the water stay in the glass when the card is on it?
6. Why couldn't we live without atmospheric pressure?

Explore More Answers

1. gravity
2. At Earth's surface.
3. pressure=force per unit area, SI units are pascals (Pa) or psi or pounds per square inch.
4. Air pressure transmits in all directions so the downward pressure is balanced by the force pushing up.
5. The card is a rigid membrane between the water and the air in the room. Air pressure pushes up on the card. Air pressure is not pushing down on the water because there is a vacuum on the top of the water. So the only downward force from the water is its weight, which is easily overcome by the air pressure from below the card.
6. We need it to breathe.

Review

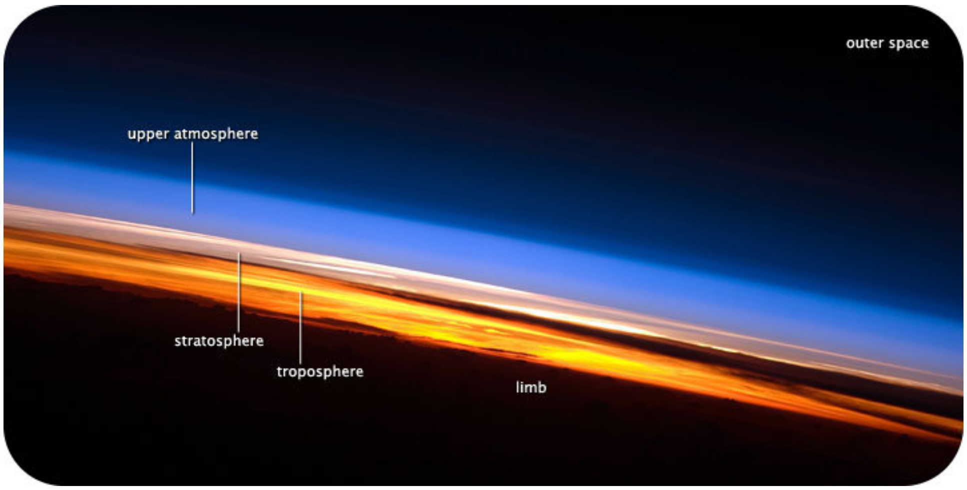
1. Why does air density decrease with increasing altitude?
2. Temperature also decreases with altitude. How does that relate to the change in air density?
3. Why are we not crushed by the weight of the atmosphere on our shoulders?

Review Answers

1. Air density decreases with increasing altitude because gravity pulls the molecules toward the center and the pull of gravity is less at higher altitudes.
2. Where there are fewer molecules there are fewer collisions between molecules. this lowers temperature.
3. Air pressure goes in all directions so the weight of air on us is balanced by the weight of air pushing upward.

1.4 Temperature of the Atmosphere

- Define temperature gradient.
- Explain the relationship between air temperature and the layers of Earth's atmosphere.
- Describe the relationship between air temperature and density.



Did you know that you can see the layers of the atmosphere?

The layers of the atmosphere appear as different colors in this image from the International Space Station.

Air Temperature

The atmosphere is layered, corresponding with how the atmosphere's temperature changes with altitude. By understanding the way temperature changes with altitude, we can learn a lot about how the atmosphere works.

Warm Air Rises

Why does warm air rise (**Figure** 1.6)? Gas molecules are able to move freely, and if they are uncontained, as they are in the atmosphere, they can take up more or less space.

- When gas molecules are cool, they are sluggish and do not take up as much space. With the same number of molecules in less space, both air density and air pressure are higher.
- When gas molecules are warm, they move vigorously and take up more space. Air density and air pressure are lower.

Warmer, lighter air is more buoyant than the cooler air above it, so it rises. The cooler air then sinks down, because it is denser than the air beneath it. This is convection, which was described in the chapter Plate Tectonics.

Temperature Gradient

The property that changes most strikingly with altitude is air temperature. Unlike the change in pressure and density, which decrease with altitude, changes in air temperature are not regular. A change in temperature with distance is called a **temperature gradient**.

FIGURE 1.6
Papers held up by rising air currents above a radiator demonstrate the important principle that warm air rises.

Layers

The atmosphere is divided into layers based on how the temperature in that layer changes with altitude, the layer's temperature gradient (**Figure** 1.7). The temperature gradient of each layer is different. In some layers, temperature increases with altitude and in others it decreases. The temperature gradient in each layer is determined by the heat source of the layer (See opening image).

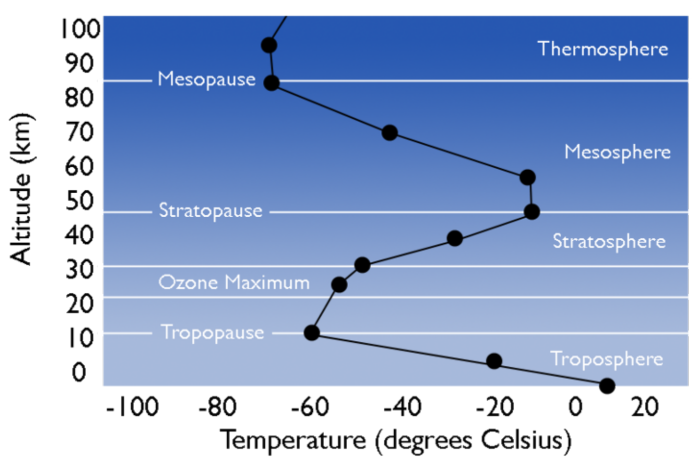
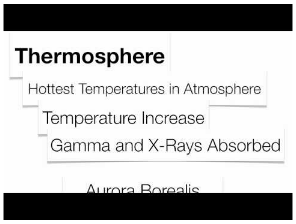


FIGURE 1.7
The four main layers of the atmosphere have different temperature gradients, creating the thermal structure of the atmosphere.

Most of the important processes of the atmosphere take place in the lowest two layers: the troposphere and the stratosphere.

This video is very thorough in its discussion of the layers of the atmosphere. Remember that the chemical composition of each layer is nearly the same except for the ozone layer that is found in the stratosphere **(8a)**: http://www.y outube.com/watch?v=S-YAKZoy1A0 (6:44).



MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/1600

Summary

- Warm air rises, cool air sinks. Warm air has lower density.
- Different layers of the atmosphere have different temperature gradients.
- Temperature gradient is the change in temperature with distance.

Explore More

Use this resource to answer the questions that follow

https://www.youtube.com/watch?v=VJkbad6RWtU Start at 4:41 to 6:50 unless you would like to review previous concepts.

1. What are atmospheric layers based on?
2. If the average July temperature at sea level in city A is 100-degrees and no other factors come into play except altitude, what will be the average July temperature at city B if it is at 5,000 feet?
3. What is the name of the outer boundary of the troposphere?
4. What is the temperature structure of the stratosphere?
5. What is the thickness of the stratosphere relative to the thickness of the troposphere?
6. What is the temperature structure of the mesosphere?
7. What are the major characteristics of the thermosphere?

Explore More Answers

1. Temperature
2. 82.5-degrees
3. the tropopause
4. It gets higher with altitude.
5. The troposphere is about 12km and the stratosphere is about 38 km so it is more than 3 times as thick.
6. It decreases with altitude.
7. The gases are low density, but they travel very fast. There is no well defined upper limit.

Review

1. What causes convection in the atmosphere?
2. Why do the different layers of the atmosphere have different temperature gradients?
3. What is temperature gradient?

Review Answers

1. Heat from Earth's surface warms the air and causes it to become less dense and rise. Air away from the surface cools and sinks.
2. The heat source is different in the different layers so the gradient is different; e.g. the heat source for the troposphere is Earth's surface so temperature decreases with distance fro the surface, but for the stratosphere is the sun so temperature increases with altitude.
3. The change in temperature with distance.

1.5 Troposphere

- Describe the characteristics and importance of the troposphere.
- Explain temperature inversion and its role in the troposphere.

Why is the troposphere important?

All of the wind, rain, and snow on Earth, as well as all of the air you breathe, is in the troposphere. The troposphere is the lowest and most important layer of the atmosphere. In this photo, a cumulonimbus cloud close to the surface over western Africa extends upward through the troposphere but does not pass into the stratosphere.

Temperature Gradient

The temperature of the **troposphere** is highest near the surface of the Earth and decreases with altitude. On average, the temperature gradient of the troposphere is 6.5^{o}C per 1,000 m (3.6^{o}F per 1,000 ft) of altitude.

Earth's surface is the source of heat for the troposphere. Rock, soil, and water on Earth absorb the Sun's light and radiate it back into the atmosphere as heat, so there is more heat near the surface. The temperature is also higher near the surface because gravity pulls in more gases. The greater density of gases causes the temperature to rise.

Notice that in the troposphere warmer air is beneath cooler air. This condition is unstable since warm air is less dense than cool air. The warm air near the surface rises and cool air higher in the troposphere sinks, so air in the troposphere does a lot of mixing. This mixing causes the temperature gradient to vary with time and place. The rising and sinking of air in the troposphere means that all of the planet's weather takes place in the troposphere.

Temperature Inversion

Sometimes there is a temperature **inversion**, in which air temperature in the troposphere increases with altitude and warm air sits over cold air. Inversions are very stable and may last for several days or even weeks. Inversions form:

- Over land at night or in winter when the ground is cold. The cold ground cools the air that sits above it, making this low layer of air denser than the air above it.
- Near the coast, where cold seawater cools the air above it. When that denser air moves inland, it slides beneath the warmer air over the land.

Since temperature inversions are stable, they often trap pollutants and produce unhealthy air conditions in cities (**Figure** 1.8).

FIGURE 1.8
Smoke makes a temperature inversion visible. The smoke is trapped in cold dense air that lies beneath a cap of warmer air.

At the top of the troposphere is a thin layer in which the temperature does not change with height. This means that the cooler, denser air of the troposphere is trapped beneath the warmer, less dense air of the stratosphere. Air from the troposphere and stratosphere rarely mix.

Summary

- In the troposphere warm air ordinarily sits below cooler air.
- With a temperature inversion, cold air sits below warm air and can't move.
- An inversion starts over land at night or in the winter, or near the coast.

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=CUuuYhg9iR4

1. What layer is all of Earth's surface in?
2. What is the thickness of the troposphere relative to the other layers? Where is the troposphere thickest and where is it thinnest?
3. Why does the troposphere contain most of the matter in the atmosphere?
4. Where is the warmest part of the troposphere and why?
5. What is a temperature inversion?
6. What is the environmental lapse rate?
7. How do scientists know the true environmental lapse rate in a column of air?

Explore More Answers

1. the troposphere
2. The troposphere is the thinnest layer. It is thickest near the equator and thinnest near the poles.
3. The atmosphere is much denser in the troposphere.
4. It is warmest near Earth's surface because heat builds up in the surface.
5. When it gets warmer rather than cooler with altitude in the troposphere.
6. It is the rate at which the atmosphere cools with altitude in the troposphere.
7. They measure the temperature through the troposphere with balloons.

Review

1. How does an inversion form at a coastal area?
2. What is the source of heat in the troposphere?
3. Describe the temperature gradient found in the troposphere.

Review Answers

1. Cold seawater cools the air above it. That air moves inland and since it is dense it slides beneath the warmer air.
2. Earth's surface
3. The temperature decreases with increasing altitude. This is because Earth's surface heats the base of the atmosphere. The warm atmosphere rises.

1.6 Stratosphere

- Describe the stratosphere and the ozone layer within it.
- Explain the ozone layer's importance to life on Earth.

The pilot says, "We are now at our cruising altitude of 30,000 feet." Why do planes fly so high?

That altitude gets them out of the troposphere and into the stratosphere. Although the arc that they must travel is greater the further from the surface they get, fuel costs are lower because there is less friction due to the lower air density. Also, there is little air turbulence, which makes the passengers happier.

Stratosphere

There is little mixing between the **stratosphere**, the layer above the troposphere, and the troposphere below it. The two layers are quite separate. Sometimes ash and gas from a large volcanic eruption may burst into the stratosphere. Once in the stratosphere, it remains suspended there for many years because there is so little mixing between the two layers.

Temperature Gradient

In the stratosphere, temperature increases with altitude. What is the heat source for the stratosphere? The direct heat source for the stratosphere is the Sun. The ozone layer in the stratosphere absorbs high energy ultraviolet radiation, which breaks the ozone molecule (3-oxygens) apart into an oxygen molecule (2-oxygens) and an oxygen atom (1-oxygen). In the mid-stratosphere there is less UV light and so the oxygen atom and molecule recombine to from ozone. The creation of the ozone molecule releases heat.

Because warmer, less dense air sits over cooler, denser air, air in the stratosphere is stable. As a result, there is little mixing of air within the layer. There is also little interaction between the troposphere and stratosphere for this reason.

The Ozone Layer

The **ozone layer** is found within the stratosphere between 15 to 30 km (9 to 19 miles) altitude. The ozone layer has a low concentration of ozone; it's just higher than the concentration elsewhere. The thickness of the ozone layer varies by the season and also by latitude.

Ozone is created in the stratosphere by solar energy. Ultraviolet radiation splits an oxygen molecule into two oxygen atoms. One oxygen atom combines with another oxygen molecule to create an ozone molecule, O_3. The ozone is unstable and is later split into an oxygen molecule and an oxygen atom. This is a natural cycle that leaves some ozone in the stratosphere.

The ozone layer is extremely important because ozone gas in the stratosphere absorbs most of the Sun's harmful ultraviolet (UV) radiation. Because of this, the ozone layer protects life on Earth. High-energy UV light penetrates cells and damages DNA, leading to cell death (which we know as a bad sunburn). Organisms on Earth are not adapted to heavy UV exposure, which kills or damages them. Without the ozone layer to absorb UVC and UVB radiation, most complex life on Earth would not survive long.

Summary

- There is little mixing between the troposphere, where all the turbulence is, and the stratosphere.
- Ozone gas protects life on Earth from harmful UV light, which damages cells.
- The ozone layer, in the stratosphere, has a higher concentration of ozone than other spots in the atmosphere.

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=OW-_qATBHgQ Watch to 5:24.

1. What does the figure tell you about what happens to air temperature when you climb a mountain?
2. What happens to temperature with altitude in the stratosphere?
3. Why does the stratosphere have that temperature gradient?
4. What tops the stratosphere?
5. What is the most important feature of the stratosphere and why?

Explore More Answers

1. As you climb the air temperature will decrease.
2. The stratosphere gets warmer with altitude.
3. The ozone layer radiates heat.
4. the stratopause
5. The stratosphere harbors the ozone layer, which protect life on Earth from harmful UV radiation.

Review

1. Why doesn't air mix between the troposphere and stratosphere?

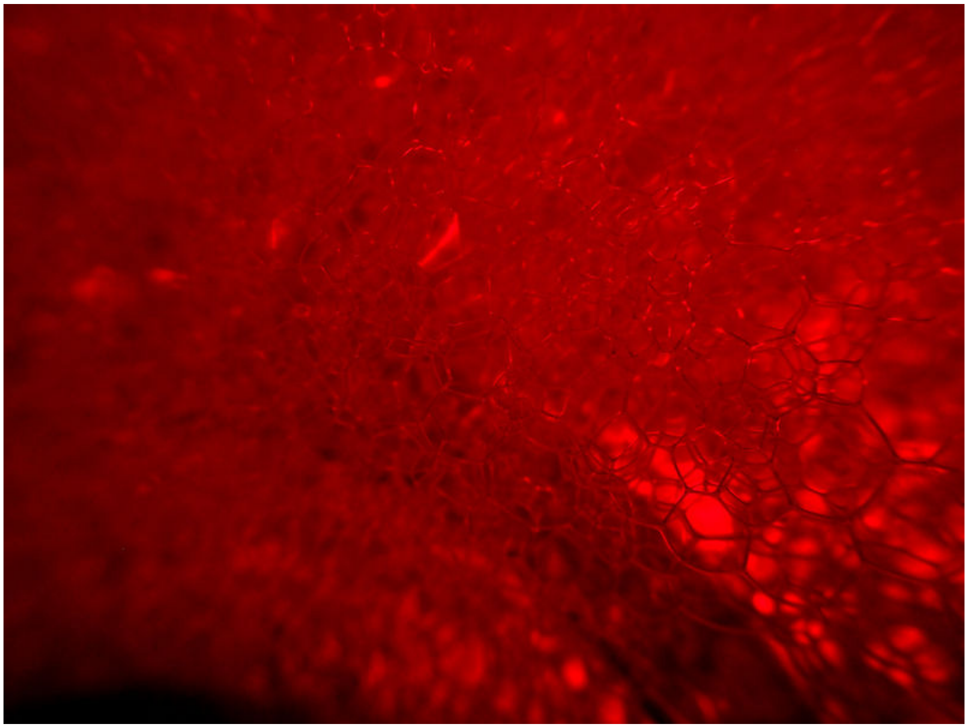
2. Why does one part of the stratosphere earn the name ozone layer?
3. What is the natural cycle that creates and destroys ozone molecules?

Review Answers

1. The stratosphere has warmer less dense air over the cooler denser air of the troposphere so they don't mix.
2. The concentration of ozone molecules is higher in that section of the stratosphere.
3. UV radiation splits the ozone molecule into an oxygen molecule and an oxygen atom. The oxygen atom combines with another oxygen molecule to create an ozone molecule.

1.7 Mesosphere

- Describe the mesosphere.



What can make your blood boil?

Believe it or not, if you were in the mesosphere without a space suit, your blood would boil! This is because the pressure is so low that liquids would boil at normal body temperature.

Mesosphere

Above the stratosphere is the **mesosphere**. Temperatures in the mesosphere decrease with altitude. Because there are few gas molecules in the mesosphere to absorb the Sun's radiation, the heat source is the stratosphere below. The mesosphere is extremely cold, especially at its top, about -90^{o}C (-130^{o}F).

Air Density

The air in the mesosphere has extremely low density: 99.9% of the mass of the atmosphere is below the mesosphere. As a result, air pressure is very low (**Figure** 1.9). A person traveling through the mesosphere would experience severe burns from ultraviolet light since the ozone layer, which provides UV protection, is in the stratosphere below. There would be almost no oxygen for breathing. And, of course, your blood would boil at normal body temperature.

Summary

- The mesosphere has a very low density of gas molecules.

FIGURE 1.9
Although the mesosphere has extremely low pressure, it occasionally has clouds. The clouds in the photo are mesopheric clouds called **noctilucent clouds**.

- Temperature decreases in the mesosphere with altitude because the heat source is the stratosphere.
- The mesosphere is no place for human life!

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=R5JFXb0lkLk

1. Where is the mesosphere?
2. What is the temperature gradient of the mesosphere?
3. What happens to a rock falling through space in the mesosphere? Why don't this happen in the thermosphere?

Explore More Answers

1. above the stratosphere
2. It gets colder with altitude.
3. Friction warms up the rock so much it begins to glow and then burn up. The gases in the thermosphere aren't dense enough to cause a shooting star.

Review

1. Why would a person get severe burns in the mesosphere?
2. Why would a person's blood boil in the mesosphere?
3. How can meteors burn in the mesosphere when the air density is so low?

Review Answers

1. The mesosphere is above the protective ozone layer so the person would be burned by high energy UV rays.
2. The pressure is so low that liquids boil at normal body temperature.
3. The air density is enough for an object traveling very fast to generate enough friction to burn.

1.8 Thermosphere and Beyond

- Describe the characteristics of the far outer atmosphere.
- Explain how aurora form.

How can people live in the thermosphere?

The inhabitants of the International Space Station and other space stations live in the thermosphere. Of course, they couldn't survive in the thermosphere environment without being inside the station or inside a space suit, but right now people are living that far from Earth's surface.

Thermosphere

The density of molecules is so low in the **thermosphere** that one gas molecule can go about 1 km before it collides with another molecule. Since so little energy is transferred, the air feels very cold (See opening image).

Ionosphere

Within the thermosphere is the **ionosphere**. The ionosphere gets its name from the solar radiation that ionizes gas molecules to create a positively charged ion and one or more negatively charged electrons. The freed electrons travel within the ionosphere as electric currents. Because of the free ions, the ionosphere has many interesting characteristics.

At night, radio waves bounce off the ionosphere and back to Earth. This is why you can often pick up an AM radio station far from its source at night.

Magnetosphere

The Van Allen radiation belts are two doughnut-shaped zones of highly charged particles that are located very high the atmosphere in the **magnetosphere**. The particles originate in solar flares and fly to Earth on the solar wind. Once trapped by Earth's magnetic field, they follow along the field's magnetic lines of force. These lines extend from above the Equator to the North Pole and also to the South Pole, then return to the Equator.

Aurora

When massive solar storms cause the Van Allen belts to become overloaded with particles, the result is the most spectacular feature of the ionosphere —the nighttime **aurora** (**Figure** 1.10). The particles spiral along magnetic field lines toward the poles. The charged particles energize oxygen and nitrogen gas molecules, causing them to light up. Each gas emits a particular color of light.

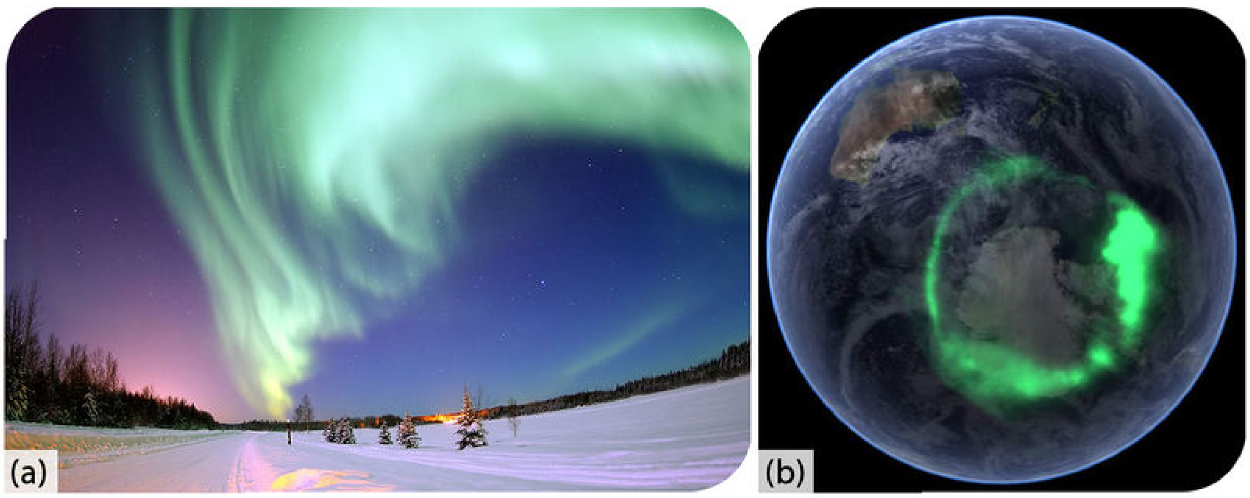


FIGURE 1.10

(a) Spectacular light displays are visible as the aurora borealis or northern lights in the Northern Hemisphere. (b) The aurora australis or southern lights encircles Antarctica.

What would Earth's magnetic field look like if it were painted in colors? It would look like the aurora! This QUEST video looks at the aurora, which provides clues about the solar wind, Earth's magnetic field and Earth's atmosphere.

Watch it at http://science.kqed.org/quest/video/illuminating-the-northern-lights/ .

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/116508

Exosphere

There is no real outer limit to the **exosphere**, the outermost layer of the atmosphere; the gas molecules finally become so scarce that at some point there are no more. Beyond the atmosphere is the solar wind. The **solar wind** is made of high-speed particles, mostly protons and electrons, traveling rapidly outward from the Sun.

Summary

- The solar wind is made of high speed particles from the Sun that travel through the solar system.
- The particles that create the aurora travel along Earth's magnetic field lines.
- Solar radiation ionizes gas molecules that travel as electric currents.

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=6i1CcfzowCU

1. Where is the thermosphere?
2. What is the temperature gradient of the thermosphere? What sub-layer is at the top of the thermosphere?
3. What are the two sources of ions in the ionosphere?
4. What creates the aurora?
5. How can people hear a radio station that is far from there location?

Explore More Answers

1. It is the layer above the mesosphere.
2. Temperature increases with altitude. The ionosphere is in the top portion of the thermosphere.
3. Protons and electrons from the sun stream toward Earth and get trapped in Earth's magnetic field. These ions spin around in the magnetic field. Ions are also produced from UV radiation by dissociating nitrogen and oxygen molecules.
4. The ions in the ionosphere spin toward the poles. The ions spiral through the magnetic field toward the poles and they interact with denser atmosphere.
5. Radio waves bounce off the ionosphere and return to Earth.

Review

1. How did the ionosphere get its name?
2. Why and when can you pick up AM radio stations far from their sources?
3. What causes the aurora and where in the atmosphere does it take place?

Review Answers

1. Solar radiation ionizes gas molecules to create positively and negatively charged ions.These ions act as electric currents.
2. Radio waves bounce off the ionosphere so they can wind up far from where they started.
3. The aurora occurs when ions spiraling along magnetic lines toward the poles energy gas molecules and cause them to light up.

1.9 Electromagnetic Energy in the Atmosphere

- Identify and define types of electromagnetic radiation.

Does cell phone use cause brain tumors?

Many studies have been done to see if the radio frequency radiation emitted by cell phones causes brain tumors. As yet the results have mostly shown no link, although one study seemed to show some connection. The largest amount of radiation comes when the phone first connects to a new cell phone tower, so avoid talking while driving —which is good for other reasons as well —or when the signal is poor and the phone must emit more radiation for it to work. There is a link between having a cell phone in your pocket and a decrease in bone density in the pelvis. What can cause these problems? What is electromagnetic radiation?

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** 1.11).

- The wavelengths humans can see are known as **visible light**. 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** 1.12). What objects can you think of that radiate visible light? Two include the Sun and a light bulb.

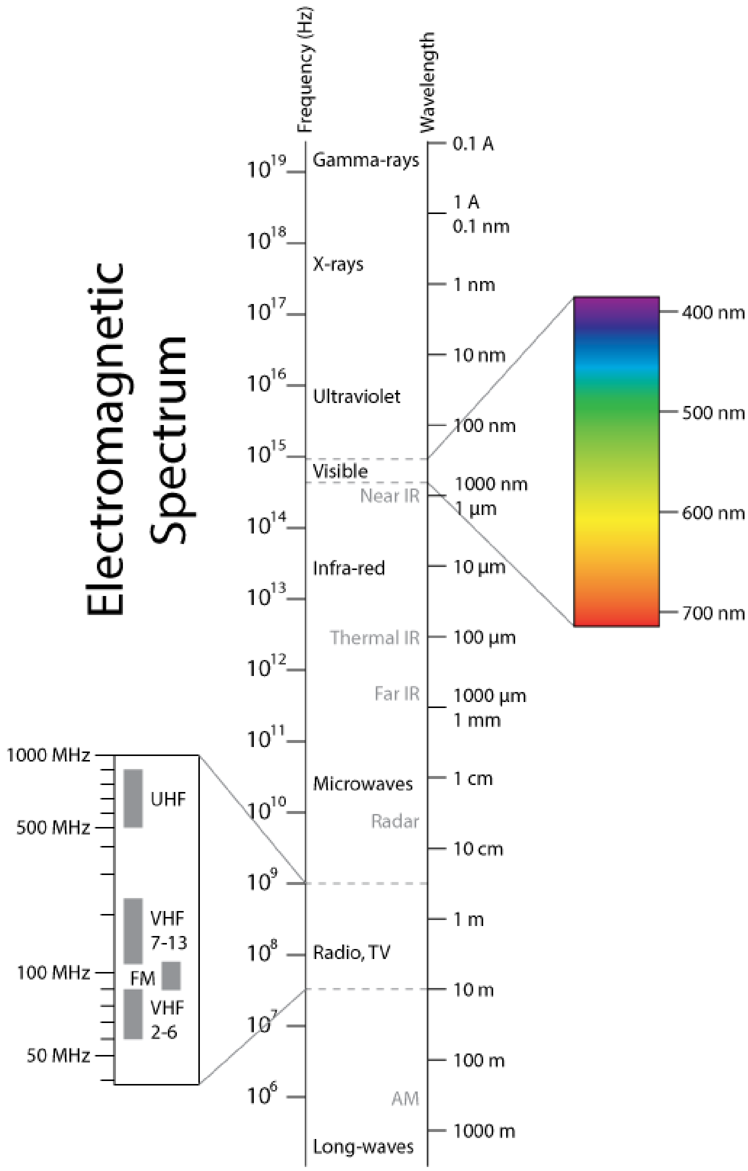


FIGURE 1.11
The electromagnetic spectrum; short wavelengths are the fastest with the highest energy.

- 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. **Albedo** is a measure of how well a surface reflects light. A surface with high albedo reflects a large percentage of light. A snow field has high albedo.

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

FIGURE 1.12
A prism breaks apart white light.

temperature.

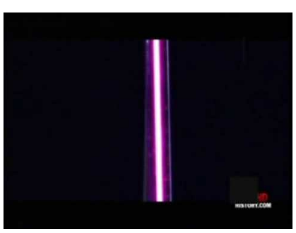
Summary

- Energy travels in waves with electrical and magnetic properties and so is called electromagnetic radiation.
- The wavelengths of visible light vary from long wavelength red to short wavelength violet. Infrared and ultraviolet wavelengths continue outward at longer and shorter wavelengths.
- The law of conservation of energy states that energy cannot be created or destroyed, it can only change forms.

Explore More

Use these resources to answer the questions that follow.

http://www.youtube.com/watch?v=kfS5Qn0wn2o



MEDIA
Click image to the left for use the URL below.
URL: http://gamma.ck12.org/flx/render/embeddedobject/1591

1. What is the electromagnetic spectrum?
2. What is the visible spectrum?
3. Why is the visible spectrum important?
4. What pattern is unique to hydrogen?
5. If a star emits that pattern what does it mean?

http://www.youtube.com/watch?v=QgzggbEQ2MY

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/1592

1. What is albedo?
2. How is albedo expressed?
3. What is the albedo of snow?
4. How is the Earth's albedo determined?
5. What does MODIS do?
6. What is the Earth's average temperature?
7. What happens when the rain forests are cut down?
8. What is the average albedo of the Earth?
9. What happens to albedo and temperature if snow melts?

Explore More Answers

- Electromagnetic Radiation

1. It is an immense scale used to measure the wavelengths of all kinds of radiation.
2. Visible light is a tiny portion of the electromagnetic spectrum. It is the part that humans can see.
3. Stars emit almost all o their light as visible light.
4. Hydrogen has red, light blue and deep blue.
5. This pattern always means that hydrogen is present in the light being emitted.

- Albedo

1. Albedo is a measure of reflectivity.
2. A percentage of total light reflected.
3. 85 to 90%
4. By satellite sensors and mathematical models.
5. They image the entire Earth every one to two days. It monitors changes over time.
6. about 15-degrees C
7. Darker soils are exposed and the average temperature increases up to 3-degrees C or 5.4-degrees F year round.
8. 0.3
9. Albedo decreases, more sunlight is absorbed and temperature increases.

Review

1. How is the light from the Sun different from the light from the Moon?
2. How does the energy that comes off a surface with high albedo differ from the energy that comes off a surface with low albedo?
3. How does a child kicking a soccer ball illustrate the law of conservation of energy?

Review Answers

1. The sun generates the electromagnetic energy, including the visible light we see. The moon reflects energy from the light of the sun.

2. A surface with high albedo reflects a large percentage of the light it receives; a surface with low albedo absorbs most of that energy.
3. The child has energy from food. She kicks the ball and converts that food energy first to potential energy when the foot is just poised and ready to kick the ball and then to kinetic energy when the foot transfers the energy into the ball. The energy is never lost just changed to different forms.

1.10 Temperature and Heat in the Atmosphere

- Explain the relationship between temperature and heat.

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

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

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.

Heat

Heat energy is transferred between physical entities. Heat is taken in or released when an object changes state, or changes from a gas to a liquid, or a liquid to a solid. This heat is called **latent heat**. When a substance changes state, latent heat is released or absorbed. A substance that is changing its state of matter does not change temperature. All of the energy that is released or absorbed goes toward changing the material's state.

For example, imagine a pot of boiling water on a stove burner: that water is at 100^{o}C (212^{o}F). If you increase the temperature of the burner, more heat enters the water. The water remains at its boiling temperature, but the additional energy goes into changing the water from liquid to gas. With more heat the water evaporates more rapidly. When water changes from a liquid to a gas it takes in heat. Since evaporation takes in heat, this is called evaporative cooling. Evaporative cooling is an inexpensive way to cool homes in hot, dry areas.

Substances also differ in their **specific heat**, the amount of energy needed to raise the temperature of one gram of the material by 1.0^oC (1.8^oF). Water has a very high specific heat, which means it takes a lot of energy to change the temperature of water. Let's compare a puddle and asphalt, for example. If you are walking barefoot on a sunny day, which would you rather walk across, the shallow puddle or an asphalt parking lot? Because of its high specific heat, the water stays cooler than the asphalt, even though it receives the same amount of solar radiation.

Summary

- Temperature the speed of vibration of the molecules that make up a substance. Heat is the energy transferred between physical entities.
- Latent heat is released or absorbed when a substance changes states.
- Specific heat is the amount of energy needed to raise the temperature of one gram of the material by 1.0^oC (1.8^oF).

Explore More

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=v1zOnyC4RgQ

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/1585

1. What is temperature?
2. What determines heat?
3. How is temperature measured? How does this work?
4. What is heat?
5. What is kinetic energy?
6. What does temperature measure?

Explore More Answers

1. Temperature is used to measure how hot or cold an object is. The amount of heat it gives off depends on temperature but is related to mass of the object.
2. Heat is determined by the temperature and the amount of the substance.
3. A thermometer is used to measure temperature. The fluid moves up or down the tube depending on the temperature of the substance.
4. Atoms and molecules move faster and they bounce around more.
5. The motion of atoms and molecules.
6. The average kinetic energy of a substance.

Review

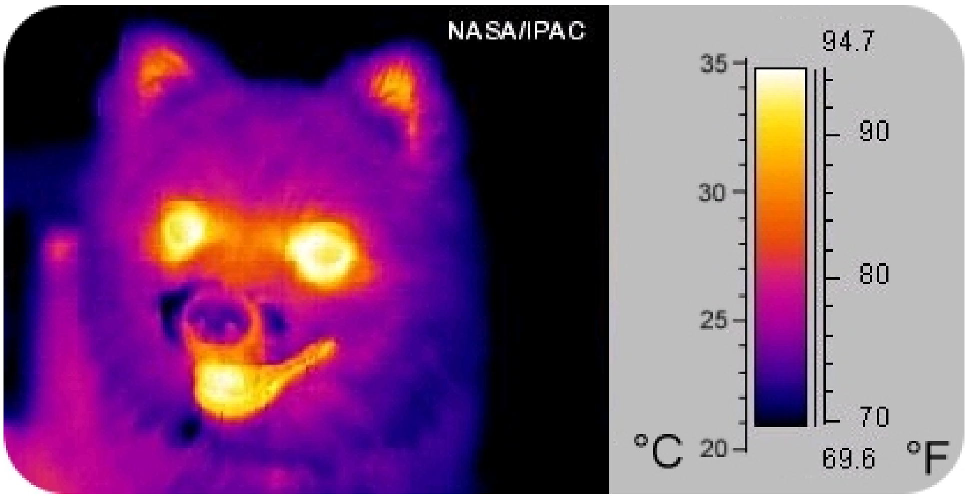
1. How does evaporative cooling work? Why do you think it is only effective in hot, dry areas?
2. What happens to the temperature of a substance as it changes state from liquid to solid? What happens to its latent heat?
3. As a substance changes state from liquid to solid, what happens to the molecules that make it up?

Review Answers

1. When water evaporates the change of state from liquid to gas takes in heat. This cools the region where the evaporation took place. It is only effective where water can evaporate, which is easier in dry places than in humid places.
2. The temperature of the substance doesn't change as it changes state. Latent heat is released or absorbed depending on whether the substance changes to a more or less organized state.
3. The molecules become more organized and less movable.

1.11 Solar Energy on Earth

- Describe different types of solar energy, including ultraviolet and infrared.



What's wrong with this dog?

Nothing! The sensor is detecting infrared radiation from the dog —in other words, heat. The Sun emits infrared radiation among other wavelengths too.

Energy From the Sun

Most of the energy that reaches the Earth's surface comes from the Sun (**Figure** 1.13). About 44% of solar radiation is in the visible light wavelengths, but the Sun also emits infrared, ultraviolet, and other wavelengths.

Ultraviolet

Of the solar energy that reaches the outer atmosphere, **ultraviolet (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.

Infrared

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

Some of the wavelengths of solar radiation traveling through the atmosphere may be lost because they are absorbed by various gases (**Figure** 1.14). Ozone completely removes UVC, most UVB, and some UVA from incoming sunlight. O_2, CO_2, and H_2O also filter out some wavelengths.

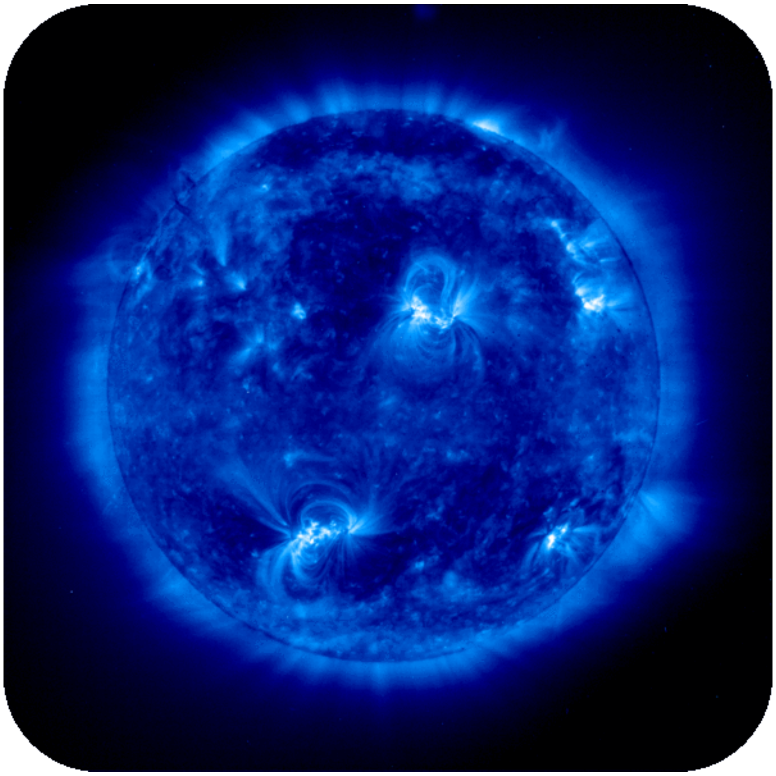


FIGURE 1.13
An image of the Sun taken by the SOHO spacecraft. The sensor is picking up only the 17.1 nm wavelength, in the ultraviolet wavelengths.

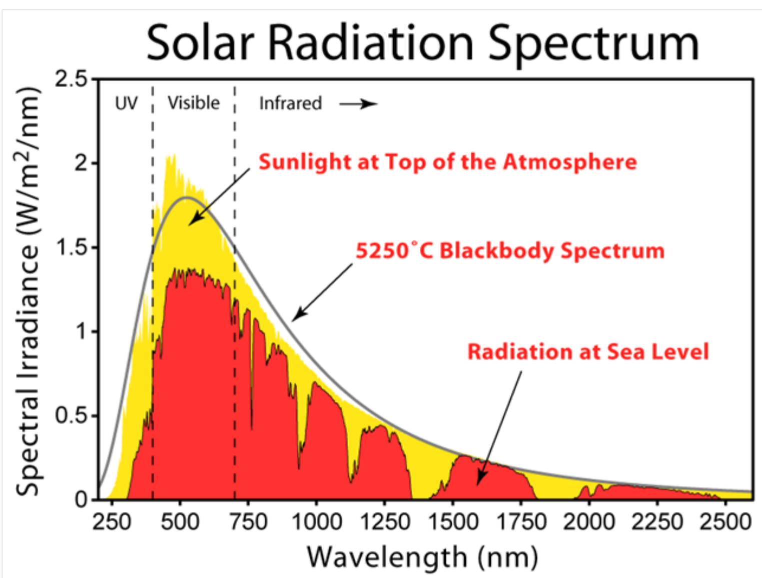


FIGURE 1.14
Atmospheric gases filter some wavelengths of incoming solar energy. Yellow shows the energy that reaches the top of the atmosphere. Red shows the wavelengths that reach sea level. Ozone filters out the shortest wavelength UV and oxygen filters out most infrared.

Summary

- Ultraviolet radiation has the highest energy; infrared the lowest.
- Ultraviolet is divided into three categories based on wavelength: UVC, with the highest energy, UVB, and UVA, with the lowest energy.
- Infrared has longer wavelengths than red light and is felt as heat.

Explore More

Use these resources to answer the questions that follow.

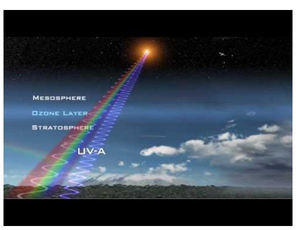
http://www.youtube.com/watch?v=i8caGm9Fmh0

MEDIA
Click image to the left for use the URL below.
URL: http://gamma.ck12.org/flx/render/embeddedobject/1586

1. What is infrared light?
2. How can we sense infrared light?
3. What can be used to see infrared light?
4. What happens to infrared radiation when it get to the Earth?
5. What heats the lower atmosphere?
6. What is the Earth's radiation budget? What happens if the radiation budget is out of balance?
7. What does near infrared measure?
8. What can studying infrared tell us abut the Earth?

Ultraviolet Waves

http://www.youtube.com/watch?v=QW5zeVy8aE0



MEDIA
Click image to the left for use the URL below.
URL: http://gamma.ck12.org/flx/render/embeddedobject/1587

1. What are ultraviolet waves?
2. What are three regions of ultraviolet waves?
3. Describe UVA.
4. What problem can UVB cause?
5. Why don't UVC rays reach the Earth?
6. What have scientists discovered with ultraviolet waves?

Explore More Answers

- Infrared

1. Infrared light are wavelengths of energy beyond visible red.
2. We sense it as heat.
3. We can use night vision goggles or infrared cameras.
4. Some is reflected off clouds and some is absorbed in the atmosphere. This warms the atmosphere and is emitted as long wave infrared radiation.

5. Solar radiation that is absorbd by the earth's surface, which warms it and it is emitted as long wave radiation. It warms the atmosphere. Greenhouse gases absorb the radiation and heats the lower atmosphere.
6. Energy entering, reflected, absorbed and emitted are the components. If they are out of balance, eventually climate will be changed.
7. Near infrared measures solar radiation from sun just beyond visible spectrum.
8. Vegetation patterns. Earth's system and energy budget; land cover.

- Ultraviolet

1. UV waves are high energy radiation beyond violet.
2. UVA, UVB, UVC
3. UVA is the lowest energy of the three. UVA is the closest to visible light and most of it reaches the surface.
4. UVB harmful rays that cause sunburn.
5. UVC: They are absorbed by the ozone layer.
6. Young hot stars emit these waves so scientists can study star formation. Some chemical substances interact with UV, which can be studied, as they are on Saturn. They study permanently shadowed craters on the moon.

Review

1. Why does more solar radiation of all wavelengths come into the exosphere than reaches Earth's surface?
2. Why does ultraviolet radiation, especially UVC, damage life?
3. Look at the **Figure** 1.14. What happens to the highest wavelengths of energy at Earth's surface?

Review Answers

1. Some wavelengths are filtered out by the atmosphere.
2. Ultraviolet is very high energy. UVC is the highest energy.
3. The highest wavelengths are filtered out by the atmosphere, particularly the ozone layer.

1.12 Heat Transfer in the Atmosphere

- Explain how conduction and convection work in the atmosphere.

What could cause such a spectacular, swirling funnel of air?

For many people, this sight is unfamiliar. It is a tornado. Tornadoes happen when heat is rapidly transferred between layers in the atmosphere.

Heat Transfer in the Atmosphere

Heat moves in the atmosphere the same way it moves through the solid Earth or another medium. What follows is a review of the way heat flows, but applied to the atmosphere.

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. This 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** 1.15).

What Drives Atmospheric Circulation?

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.

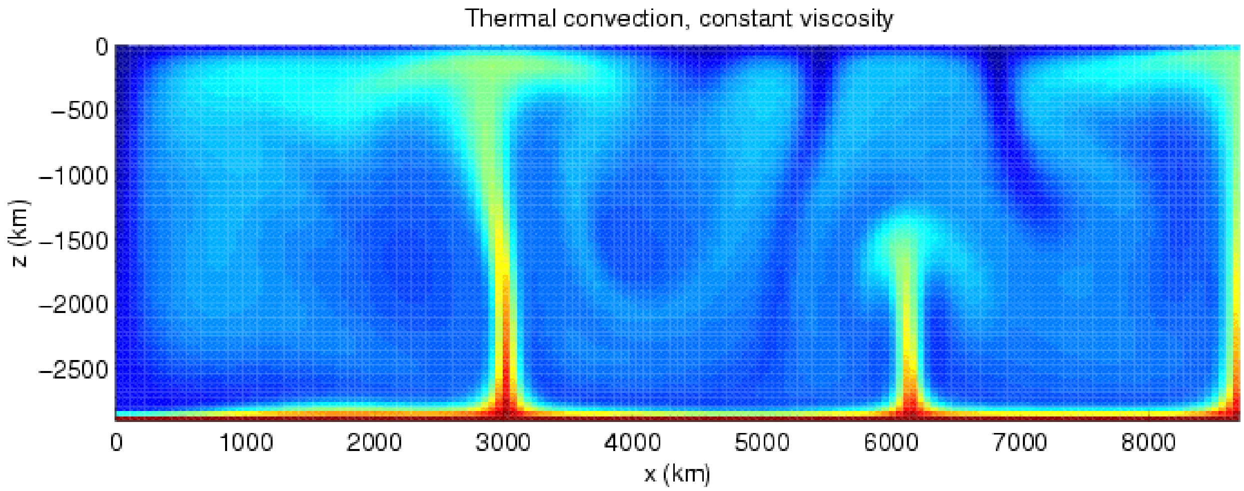


FIGURE 1.15
Thermal convection where the heat source is at the bottom and there is a ceiling at the top.

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

Summary

- In conduction, substances must be in direct contact as heat moves from areas of more heat to areas of less heat.
- In convection, materials move depending on their heat relative to nearby materials.
- The Equator receives more solar energy than other latitudes.

Explore More

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=ajQ3hm5JidU

MEDIA
Click image to the left for use the URL below.
URL: http://gamma.ck12.org/flx/render/embeddedobject/1599

1. What powers our weather?
2. What does heat cause?
3. How does the tilt of the Earth affect heating?
4. What causes wind?
5. What does water do with heat energy?

Explore More Answers

1. Energy in the form of heat from the sun.
2. Warm weather but also storms like tornadoes, hurricanes, blizzards and rain.
3. Energy from the sun is absorbed by the earth and converted to heat. But sunlight strikes unevenly because of the tilt. The uneven heating drives the weather.
4. The surface heats the air above it. This rises and cooler air moves in to take its place. This causes wind.
5. Water retains and releases heat energy from the Sun.

Review

1. What is moving in conduction? What is moving in convection?
2. Why do the poles receive less solar radiation than the Equator?
3. What drives atmospheric circulation?

Review Answers

1. In conduction, heat moves from areas of higher heat to lower heat by direct contact. In convection, material moves from areas of higher to lower heat.
2. The poles are dark for 6 months a year so they receive little solar radiation. When they do receive sunlight the sun is very low in the sky so the radiation is spread out over a large area.
3. Different regions receive different amounts of solar radiation. The places that receive the most are warmer so air rises and cooler air is drawn in.

1.13 Heat Budget of Planet Earth

- Explain Earth's heat budget and its relationship to solar radiation.

How does heat on Earth resemble a household budget?

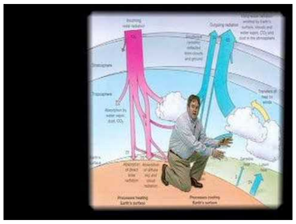
The heat left on Earth is heat in minus heat out. If more energy comes into the system than goes out of the system, the planet warms. If less energy goes into the system than goes out of the system, the planet cools. Replace the word "money" for "heat" and "on Earth" to "in your bank account" and you describe a household budget. Of course, Earth's heat budget is a lot more complex than a simple household budget.

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.

The basics of Earth's annual heat budget are described in this video: http://www.youtube.com/watch?v=mjj2i3hNQF0 (5:40).



MEDIA
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URL: http://gamma.ck12.org/flx/render/embeddedobject/1572

The Heat Budget

Because solar energy continually enters Earth's atmosphere and ground surface, is the planet getting hotter? The answer is no (although the next section contains an exception), 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? See the **Table** 1.1.

TABLE 1.1: The Amount of Incoming Solar Energy

	Day Length	Sun Angle	Solar Radiation	Albedo
Equatorial Region	Nearly the same all year	High	High	Low
Polar Regions	Night 6 months	Low	Low	High

Note: Colder temperatures mean more ice and snow cover the ground, making albedo relatively high.

This animation shows the average surface temperature across the planet as it changes through the year: Monthly Mean Temperatures at http://upload.wikimedia.org/wikipedia/commons/b/b3/MonthlyMeanT.gif .

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

Summary

- Incoming solar radiation is absorbed by atmospheric gases, reflected by clouds, or scattered.
- Much of the radiation that strikes the ground is radiated back into the atmosphere as heat.
- More solar radiation strikes the Equator than the poles.

Explore More

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=JFfD6jn_OvA

MEDIA
Click image to the left for use the URL below.
URL: http://gamma.ck12.org/flx/render/embeddedobject/1518

1. What does CERES measure?
2. What does the acronym CERES stand for?
3. What is the ideal radiation budget? Why?
4. How much of the Sun's radiation is reflected or absorbed by clouds.
5. What type of surfaces absorb the most energy?
6. Which regions are reflective?
7. What are scientists finding with CERES?
8. Why is the Earth warming?
9. What is a carbon footprint?
10. What happens to albedo when the ice caps melt?

Explore More Answers

1. CERES measures the amount of energy Earth receives and the amount it returns to space.
2. Clouds in the Earth's Radiant Energy System
3. The incoming and outgoing should be equal. An equal balance means that Earth's surface isn't cooling or warming from year to year.
4. About 50% is reflected or absorbed by clouds.
5. dark surfaces like oceans and rainforests
6. deserts and polar regions
7. Earth is warming up due to changes in the atmosphere.
8. There is an increase in greenhouse gases.
9. The carbon footprint is the amount of greenhouse gases created due to human activity.
10. Albedo decreases and more energy is absorbed.

Review

1. If the Sun suddenly started to emit more energy, what would happen to Earth's heat budget and the planet's temperature?
2. If more greenhouse gases were added to the atmosphere, what would happen to Earth's heat budget and the planet's temperature?
3. What happens to sunlight that strikes the ground?

Review Answers

1. More energy would reach the top oft he atmosphere and ore would cycle through the Earth system. Earth would become warmer.
2. Less energy could escape back into space and so the planet would become warmer.
3. The radiation converts to heat and is released into the atmosphere.

1.14 Greenhouse Effect

- Describe the greenhouse effect.
- Explain how human actions contribute to the greenhouse effect.

How does the atmosphere resemble a greenhouse?

To extend the growing season, many farmers use greenhouses. A greenhouse traps heat so that days that might be too cool for a growing plant can be made to be just right. Similar to a greenhouse, greenhouse gases in the atmosphere keep Earth warm.

The Greenhouse Effect

The exception to Earth's temperature being in balance is caused by greenhouse gases. But first the role of greenhouse gases in the atmosphere must be explained.

Greenhouse gases warm the atmosphere by trapping heat. Some of the heat that radiates out from the ground is trapped by greenhouse gases in the troposphere. Like a blanket on a sleeping person, greenhouse gases act as insulation for the planet. The warming of the atmosphere because of **insulation** by greenhouse gases is called the **greenhouse effect** (**Figure** 1.16). Greenhouse gases are the component of the atmosphere that moderate Earth's temperatures.

Greenhouse Gases

Greenhouse gases include CO_2, H_2O, methane, O_3, nitrous oxides (NO and NO_2), and chlorofluorocarbons (CFCs). All are a normal part of the atmosphere except CFCs. **Table** 1.2 shows how each greenhouse gas naturally enters the atmosphere.

TABLE 1.2: Greenhouse Gas Entering the Atmosphere

Greenhouse Gas	Where It Comes From
Carbon dioxide	Respiration, volcanic eruptions, decomposition of plant material; burning of fossil fuels
Methane	Decomposition of plant material under some conditions, biochemical reactions in stomachs
Nitrous oxide	Produced by bacteria
Ozone	Atmospheric processes
Chlorofluorocarbons	Not naturally occurring; made by humans

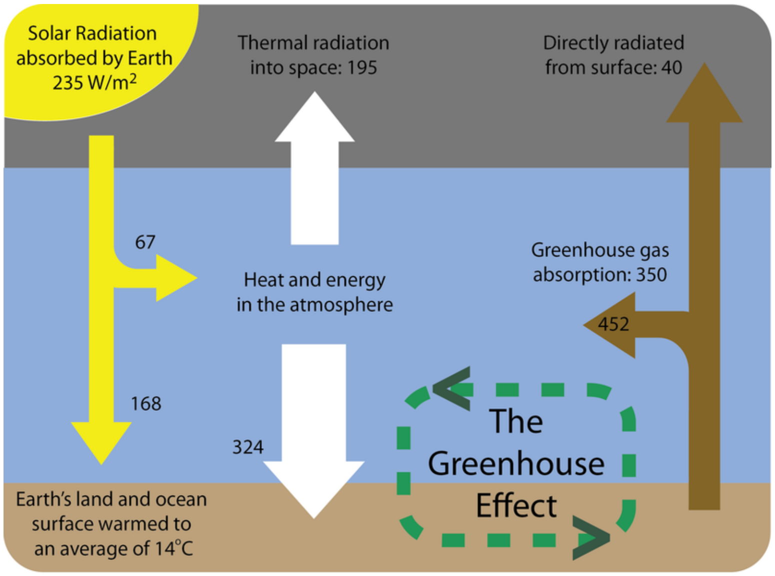


FIGURE 1.16
The Earth's heat budget shows the amount of energy coming into and going out of the Earth's system and the importance of the greenhouse effect. The numbers are the amount of energy that is found in one square meter of that location.

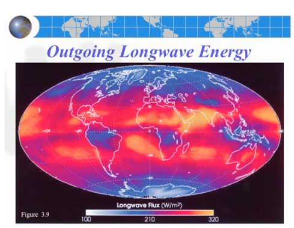
Different greenhouse gases have different abilities to trap heat. For example, one methane molecule traps 23 times as much heat as one CO_2 molecule. One CFC-12 molecule (a type of CFC) traps 10,600 times as much heat as one CO_2. Still, CO_2 is a very important greenhouse gas because it is much more abundant in the atmosphere.

Human Activity and Greenhouse Gas Levels

Human activity has significantly raised the levels of many of greenhouse gases in the atmosphere. Methane levels are about 2 1/2 times higher as a result of human activity. Carbon dioxide has increased more than 35%. CFCs have only recently existed.

What do you think happens as atmospheric greenhouse gas levels increase? More greenhouse gases trap more heat and warm the atmosphere. The increase or decrease of greenhouse gases in the atmosphere affect climate and weather the world over.

This PowerPoint review, *Atmospheric Energy and Global Temperatures*, looks at the movement of energy through the atmosphere: http://www.youtube.com/watch?v=p6xMF_FFUU0 (8:17).



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Summary

- Greenhouse gases include CO_2, H_2O, methane, O_3, nitrous oxides (NO and NO_2), and chlorofluorocarbons (CFCs).
- Tropospheric greenhouse gases trap heat in the atmosphere; greenhouse gases vary in their heat-trapping abilities.

- Levels of greenhouse gases in the atmosphere are increasing due to human activities.

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=ZzCA60WnoMk

1. What would the temperature of the surface be if the Earth did not have an atmosphere?
2. What does it mean to say that Earth is in radiative equilibrium?
3. What happens to the radiation emitted by Earth into space?
4. What are the most common greenhouse gases?
5. How do greenhouse gases react to incoming solar radiation and outgoing heat?
6. What do greenhouse gases do with the radiation they absorb? What happens to that?
7. What is greenhouse effect?
8. What happens to the surface of the Earth when there is an increase in greenhouse gases?

Explore More Answers

1. About 30-degrees C cooler.
2. The long wave radiation emitted into space equals the solar radiation absorbed by it.
3. About 10% escapes back into space; the rest is absorbed by clouds and greenhouse gases.
4. Water vapor and carbon dioxide
5. Short wave radiation from the sun passes through the greenhouse gases but long wave radiation is absorbed by them.
6. They re-emit it in all directions. About half escapes into space. The rest is directed back toward Earth's surface.
7. The long-wave radiation between Earth and the atmosphere cycles.
8. The temperature increases.

Review

1. If you were trying to keep down global temperature and you had a choice between adding 100 methane molecules or 1 CFC-12 molecule to the atmosphere, which would you choose and why?
2. What is the greenhouse effect?
3. How does Earth's atmosphere resemble a greenhouse?

Review Answers

1. One CFC molecule traps hundreds of times more heat than one methane molecule so go with adding 100 methane molecules.
2. Greenhouse effect is the warming of the atmosphere due to insulation by greenhouse gases.
3. Light comes in; some light is converted to heat, which is re radiated and the heat is trapped by the glass panels/atmosphere.

1.15 Circulation in the Atmosphere

- Explain why atmospheric circulation occurs.

Why do we say Earth's temperature is moderate?

It may not look like it, but various processes work to moderate Earth's temperature across the latitudes. Atmospheric circulation brings warm equatorial air poleward and frigid polar air toward the Equator. If the planet had an atmosphere that was stagnant, the difference in temperature between the two regions would be much greater.

Air Pressure Zones

Within the troposphere are convection cells (**Figure** 1.17). Air heated at the ground rises, creating a **low pressure zone**. Air from the surrounding area is sucked into the space left by the rising air. Air flows horizontally at top of the troposphere; horizontal flow is called **advection**. The air cools until it descends. When the air reaches the ground, it creates a **high pressure zone**. Air flowing from areas of high pressure to low pressure creates winds. The greater the pressure difference between the pressure zones, the faster the wind blows.

Warm air can hold more moisture than cool air. 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.

Wind

Air moving between large high and low pressure systems at the bases of the three major convection cells creates the global wind belts. These planet-wide air circulation systems profoundly affect regional climate. Smaller pressure

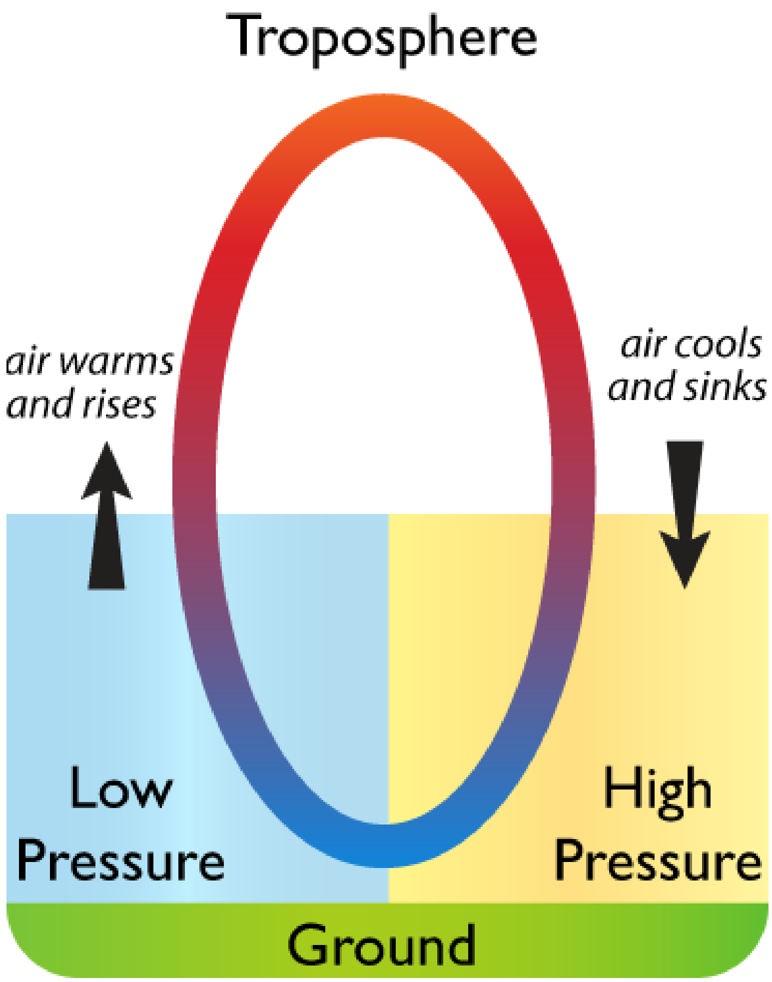


FIGURE 1.17
Warm air rises, creating a low pressure zone; cool air sinks, creating a high pressure zone.

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 .

Atmospheric Circulation

Two Convection Cells

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.

Plus Coriolis Effect

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.

Let's look at atmospheric circulation in the Northern Hemisphere as a result of the Coriolis effect (**Figure** 1.18). 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°N 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° and 30°N.

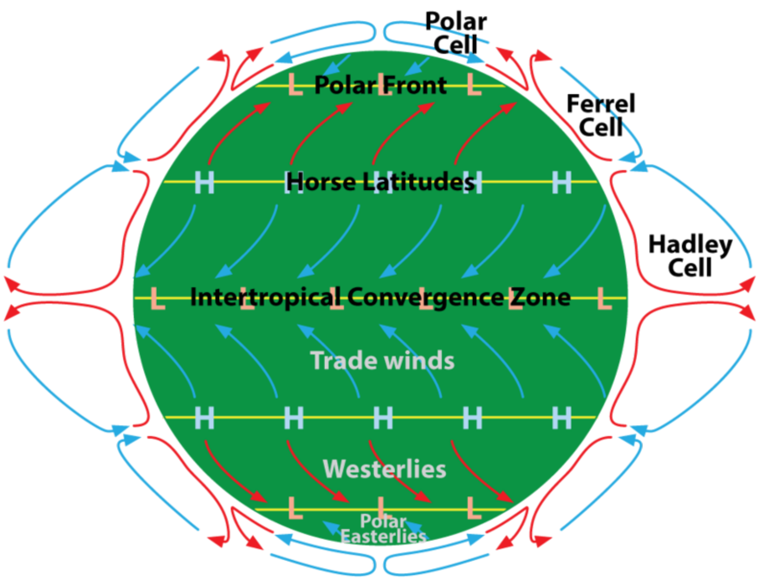


FIGURE 1.18
The atmospheric circulation cells, showing direction of winds at Earth's surface.

Equals Three Convection Cells

There are two more convection cells in the Northern Hemisphere. The Ferrell cell is between 30°N and 50° to 60°N. 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°N to 60°N and the North Pole, where cold air descends.

Plus Three in the Southern Hemisphere

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. The total number of atmospheric circulation cells around the globe is six.

Summary

- The atmosphere has six major convection cells, three in the northern hemisphere and three in the southern.
- Coriolis effect results in there being three convection cells per hemisphere rather than one.
- Winds blow at the base of the atmospheric convection cells.

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=Ye45DGkqUkE

1. What is the engine that drives atmospheric circulation?
2. What happens to air at the equator? Where does it go?
3. Why is there a lot of precipitation at the equator? What is the pressure?
4. What is the pressure at 30-degrees north and south and what type of climate is there?
5. What does Coriolis Effect do to the base of of the circulation cells? What is created?
6. In which direction to the winds curve north of the equator? South of the equator?
7. What happens to the air that sinks at the poles?

Explore More Answers

1. The intense heating of the equatorial areas.
2. Air at the equator rises upward, moves toward poles and then sinks at 30 N and S latitude, creating the Hadley circulation cells.
3. Warm moist air rises and cools so it can't hold as much moisture so it precipitates out. Air is rising so it is low pressure.
4. It is high pressure, which creates deserts.
5. It causes the winds to turn to create the Trade Winds and the prevailing westerlies.
6. It moves to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.
7. It moves toward the equator and bumps into air coming from the equator and rises, producing high precipitation belts at around 60-degrees north and south.

Review

1. Diagram and label the parts of a convection cell in the troposphere.
2. How many major atmospheric convection cells would there be without Coriolis effect? Where would they be?
3. How does Coriolis effect change atmospheric circulation?

Review Answers

1. See figure in text.
2. There would be two: Air would rise at the equator and sink at the poles so one would be in the Northern Hemisphere and one in the Southern Hemisphere.
3. Air moving toward the pole deflects to the right so it creates a smaller convection cell. In all three convection cells are created in each hemisphere.

1.16 Global Wind Belts

- Identify and define global winds.
- Explain how atmospheric circulation creates global winds, and how global winds influence climate.

Why were winds so important to the early explorers?

When Columbus sailed the ocean blue, and for centuries before and after, ocean travel depended on the wind. Mariners knew how to get where they were going and at what time of the year based on experience with the winds. Winds were named for their usefulness to sailors, such as the trade winds that facilitated commerce between people on opposite shores.

Global Wind Belts

Global winds blow in belts encircling the planet. Notice that the locations of these wind belts correlate with the atmospheric circulation cells. Air blowing at the base of the circulation cells, from high pressure to low pressure, creates the global wind belts.

The global wind belts are enormous and the winds are relatively steady (**Figure** 1.19).

The Global Winds

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

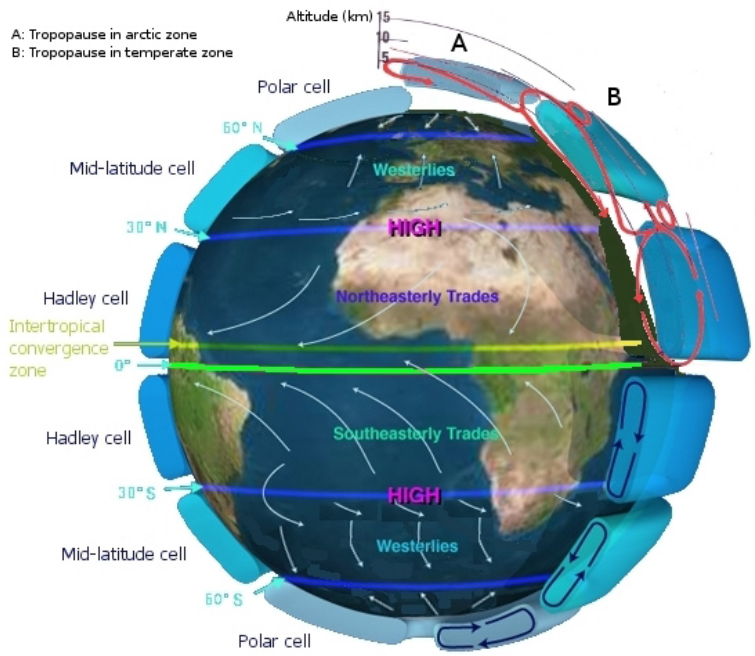
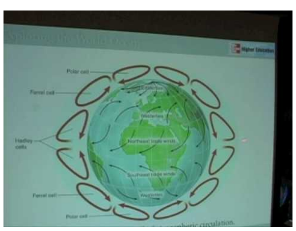


FIGURE 1.19
The major wind belts and the directions that they blow.

- 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.
- 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: http://www.youtube.com/watch?v=HWFDKdxK75E (8:45).



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Global Winds and Precipitation

The high and low pressure areas created by the six atmospheric circulation cells also determine in a general way the amount of precipitation a region receives. Rain is common in low pressure regions due to rising air. Air sinking in high pressure areas causes evaporation; these regions are usually dry. These features have a great deal of influence on climate.

Polar Front

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.

Jet Stream

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** 1.20).

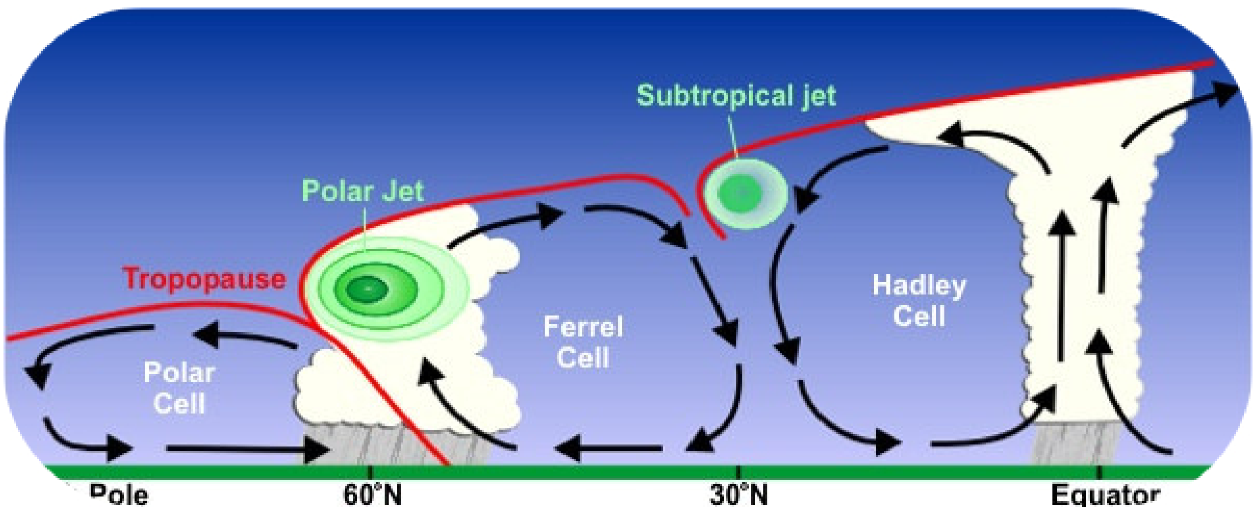


FIGURE 1.20

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°N and 50° to 75°N.

Summary

- Global winds blow from high to low pressure at the base of the atmospheric circulation cells.
- The winds at the bases of the cells have names: the Hadley cell is the trade winds, the Ferrel Cell is the westerlies, and the polar cell is the polar easterlies.
- Where two cells meet, weather can be extreme, particularly at the polar front.

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=UMI-UxSNJYg

1. What would wind at the surface do if Earth did not rotate?
2. At what latitudes are the three convection cells in the Northern and three in the Southern Hemisphere?
3. How are winds named?
4. What happens at the equator?
5. What creates the Trade Winds?
6. What happens to the air that sinks at the poles? What are the winds created?
7. Which winds are created as air moves from 30 to 60 degrees? Which way do those winds move in the northern and southern hemisphere?
8. What is the name of the zone at the equator? Is this a high or low pressure zone? Is there a lot of precipitation?
9. What is the name of the zone at 30-degrees? Is this a high or low pressure zone? Is there a lot of precipitation?
10. Why does the air that is sinking at 30-degrees north and south create deserts?
11. Which two air masses clash at the polar front?

Explore More Answers

1. It would flow from a high pressure at the poles to a low pressure at the equator.
2. 0 to 30, 30 to 60, 60 to 90 degrees north and south
3. By the direction they are coming from.
4. It gets a lot of sunlight so it is hot. Air rises and it is pushed north or south. As it rises it cools, moves to around 30 degrees and sinks.
5. Winds blow from around 30 degrees north and south of the equator toward the equator. Coriolis curves those winds right in the Northern Hemisphere and left in the Southern Hemisphere. These are the Trade Winds, Northeast and Southwest.
6. It moves toward 60-degrees north and south; these are the Polar Easterlies.
7. The prevailing westerlies; from west to east in both
8. It is the doldrums and is a low pressure zone so there is lots of precipitation.
9. It is the horse latitudes and is a high pressure zone so there is little precipitation.
10. The sinking air is dry and as it sinks it warms up.
11. Cold air from the polar regions and warmer air from toward the equator.

Review

1. What is a jet stream? What is "the" jet stream?
2. Why does a flight across the United States from San Francisco to New York City takes less time than the reverse trip?
3. Where on a circulation cell is there typically precipitation and where is there typically evaporation?

Review Answers

1. A jet stream is a fast flowing river of air where there is a large temperature difference between two air masses. "The" jet stream is where the polar cell and the Ferrel Cell meet so relatively warm and relatively cold air meet.
2. The westerly winds go from west to east at this latitude. They push an airplane from SF to NYC going in that direction but the airplane goes against them in the other direction.
3. Where air is rising i cools and loses precipitation. Where air is sinking it warms and there is evaporation.

1.17 Local Winds

- Describe the different types of local winds and explain how they are created.
- Explain how types of local winds influence climate.

How can they stand up?

When you try to walk against a 20 mile an hour wind it's not easy. Just standing up is like walking really fast!

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. Some local winds have very important effects on the weather and climate of some regions.

Land and Sea Breezes

Since water has a very high specific heat, it 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** blow from the cooler ocean over the warmer land in summer. Where is the high pressure zone and where is the low pressure zone (**Figure** 1.21)? 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** blow from the land to the sea in winter. Where is the high pressure zone and where is the low pressure zone? Some warmer air from the ocean rises and then sinks on land, causing the temperature over the land to become warmer.

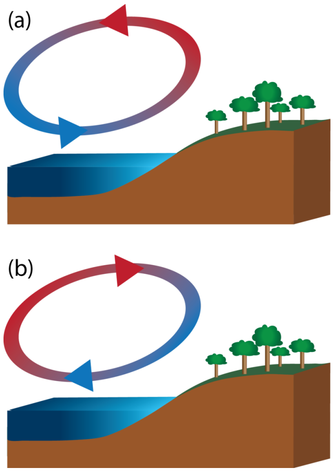


FIGURE 1.21
How do sea and land breezes moderate coastal climates?

Land and sea breezes create the pleasant climate for which Southern California is known. The effect of land and sea breezes are felt only about 50 to 100 km (30 to 60 miles) inland. This same cooling and warming effect occurs to a smaller degree during day and night, because land warms and cools faster than the ocean.

Monsoon Winds

Monsoon winds are larger scale versions of land and sea breezes; they blow from the sea onto the land in summer and from the land onto the sea in winter. Monsoon winds occur where very hot summer lands are next to the sea. Thunderstorms are common during monsoons (**Figure** 1.22).

FIGURE 1.22
In the southwestern United States relatively cool moist air sucked in from the Gulf of Mexico and the Gulf of California meets air that has been heated by scorching desert temperatures.

The most important monsoon in the world occurs each year over the Indian subcontinent. More than two billion residents of India and southeastern Asia depend on monsoon rains for their drinking and irrigation water. Back in the days of sailing ships, seasonal shifts in the monsoon winds carried goods back and forth between India and Africa.

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.

Katabatic Winds

Katabatic winds move up and down slopes, but they are stronger mountain and valley breezes. Katabatic winds form over a high land area, like a high plateau. The plateau is usually surrounded on almost all sides by mountains. In winter, the plateau grows cold. The air above the plateau grows cold and sinks down from the plateau through gaps in the mountains. Wind speeds depend on the difference in air pressure over the plateau and over the surroundings. Katabatic winds form over many continental areas. Extremely cold katabatic winds blow over Antarctica and Greenland.

Chinook Winds (Foehn Winds)

Chinook winds (or **Foehn winds**) develop when air is forced up over a mountain range. This takes place, for example, when the westerly winds bring air from the Pacific Ocean over the Sierra Nevada Mountains in California. As the relatively warm, moist air rises over the windward side of the mountains, it cools and contracts. If the air is humid, it may form clouds and drop rain or snow. When the air sinks on the leeward side of the mountains, it forms a high pressure zone. The windward side of a mountain range is the side that receives the wind; the leeward side is the side where air sinks.

The descending air warms and creates strong, dry winds. Chinook winds can raise temperatures more than 20^{o}C (36^{o}F) in an hour and they rapidly decrease humidity. Snow on the leeward side of the mountain melts quickly. If precipitation falls as the air rises over the mountains, the air will be dry as it sinks on the leeward size. This dry, sinking air causes a **rainshadow effect** (**Figure** 1.23), which creates many of the world's deserts.

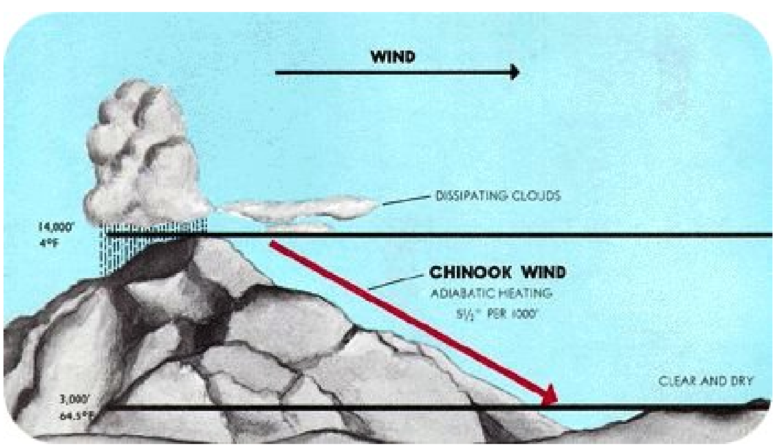


FIGURE 1.23

As air rises over a mountain it cools and loses moisture, then warms by compression on the leeward side. The resulting warm and dry winds are Chinook winds. The leeward side of the mountain experiences rainshadow effect.

Santa Ana Winds

Santa Ana winds are created in the late fall and winter when the Great Basin east of the Sierra Nevada cools, creating a high pressure zone. The high pressure forces winds downhill and in a clockwise direction (because of

Coriolis). The air pressure rises, so temperature rises and humidity falls. The winds blow across the Southwestern deserts and then race downhill and westward toward the ocean. Air is forced through canyons cutting the San Gabriel and San Bernardino mountains. (**Figure** 1.24).

FIGURE 1.24
The winds are especially fast through Santa Ana Canyon, for which they are named. Santa Ana winds blow dust and smoke westward over the Pacific from Southern California.

The Santa Ana winds often arrive at the end of California's long summer drought season. The hot, dry winds dry out the landscape even more. If a fire starts, it can spread quickly, causing large-scale devastation (**Figure** 1.25).

FIGURE 1.25
In October 2007, Santa Ana winds fueled many fires that together burned 426,000 acres of wild land and more than 1,500 homes in Southern California.

Desert Winds

High summer temperatures on the desert create high winds, which are often associated with monsoon storms. Desert winds pick up dust because there is not as much vegetation to hold down the dirt and sand. (**Figure** 1.26). A **haboob** forms in the downdrafts on the front of a thunderstorm.

FIGURE 1.26
A haboob in the Phoenix metropolitan area, Arizona.

Dust devils, also called whirlwinds, form as the ground becomes so hot that the air above it heats and rises. Air flows into the low pressure and begins to spin. Dust devils are small and short-lived, but they may cause damage.

Summary

- Water has high specific heat, so its temperature changes very slowly relative to the temperature of the land. This is the reason for sea and land breezes and monsoon winds.
- The cause of all of these winds is the differential heating of Earth's surface, whether it's due to the difference in water and land, the difference with altitude, or something else.
- Winds blow up and down slope, on and off land and sea, through deserts or over mountain passes.

Explore More

Use these resources to answer the questions that follow.

https://www.youtube.com/watch?v=1Qtf7M1s__w

1. What is the cause of monsoon winds? How is this the same or different from the cause of land and sea winds?
2. Why does wind blow from land to sea in winter?
3. Why does wind blow from sea to land in summer?
4. What causes the monsoon rain and winds?

https://www.youtube.com/watch?v=4pNQ4g4zOwY

1. Describe the movement of the Santa Ana winds through and outward from Southern California?
2. In which positions do high and low pressure cells need to be to generate these winds?
3. What causes the winds to blow from the east across Southern California?
4. What is the adiabatic process?
5. How does the adiabatic process work to create the Santa Ana Winds?
6. Why do fires often accompany the Santa Ana winds?

Explore More Answers

- Monsoon Winds

1. The cause is differential air temperatures over land and sea. This is also the cause of land and sea winds.
2. Land is cooler in winter so the air sinks, creating a high pressure. That air is pushed over the sea.
3. Land is warmer than the sea so the air rises and pulls in cooler air from the sea.
4. The low pressure causes rising air to cool and drop its moisture. The winds are strong because the temperature difference between the land and sea is so great.

- Santa Ana Winds

1. They blow from east to west across Los Angeles and into the Pacific toward and past the Channel Islands in the Pacific Ocean.
2. There must be a high pressure cell over the western US into the Pacific Ocean and a low pressure cell in the interior.
3. They are part of a high pressure cell that is circulating clockwise and the east to west portion goes from over Nevada through Southern California.
4. Pressure controls the temperature of an air parcel.
5. Air in the Great Basin has a moderate temperature. When the air goes up over the San Gabriel mountains there is less pressure and the air cools. The air is pushed into the LA Basin and it compresses and becomes hot. This is the Santa Ana winds.
6. The winds are strong and hot so if there's a spark or leftover campfire a fire can get out of control.

Review

1. How does the high specific heat of water result in the formation of sea and land breezes?
2. Describe the conditions that lead to Santa Ana winds.
3. How do Chinook winds lead to rainshadow effect?

Review Answers

1. Water has high specific heat so it maintains its temperature well. Land temperature varies much more by day and by season. When the temperature difference between land and sea is great, winds blow from the low pressure to the high pressure area.
2. In the late fall and winter the Great Basin cools, creating a high pressure. This forces winds downhill and through the mountain passes toward the Pacific Ocean. The descending air is hot and dry.
3. Air is forced over a mountain range. As it rises it cools and drops moisture. When it descends down the other side rising pressure increases the temperature and it gets dry.

1.18 Weather versus Climate

- Define weather and climate, and explain the relationship between them.

What's the weather like?

If someone across country asks you what the weather is like today, you need to consider several factors. Air temperature, humidity, wind speed, the amount and types of clouds, and precipitation are all part of a thorough weather report.

What is Weather?

All **weather** takes place in the atmosphere, virtually all of it in the lower atmosphere. Weather describes what the atmosphere is like at a specific time and place. A location's weather depends on:

- air temperature
- air pressure
- fog
- humidity
- cloud cover
- precipitation
- wind speed and direction

All of these characteristics are directly related to the amount of energy that is in the system and where that energy is. The ultimate source of this energy is the Sun.

Weather is the change we experience from day to day. Weather can change rapidly.

What is Climate?

Although almost anything can happen with the weather, **climate** is more predictable. The weather on a particular winter day in San Diego may be colder than on the same day in Lake Tahoe, but, on average, Tahoe's winter climate is significantly colder than San Diego's (**Figure** 1.27).

FIGURE 1.27
Winter weather at Lake Tahoe doesn't much resemble winter weather in San Diego even though they're both in California.

Climate is the long-term average of weather in a particular spot. Good climate is why we choose to vacation in Hawaii in February, even though the weather is not guaranteed to be good! A location's climate can be described by its air temperature, humidity, wind speed and direction, and the type, quantity, and frequency of precipitation.

The climate for a particular place is steady, and changes only very slowly. Climate is determined by many factors, including the angle of the Sun, the likelihood of cloud cover, and the air pressure. All of these factors are related to the amount of energy that is found in that location over time.

The climate of a region depends on its position relative to many things. These factors are described in the next sections.

Summary

- A region's weather depends on its air temperature, air pressure, humidity, precipitation, wind speed and direction, and other factors.
- Climate is the long-term average of weather.
- Weather can change in minutes, but climate changes very slowly.

Explore More

Use this resource to answer the questions that follow.

http://channel.nationalgeographic.com/channel/cosmos-a-spacetime-odyssey/videos/weather-versus-climate-change/

1. What is weather?
2. What is climate? What shapes climate?
3. What are the things that can change that will change climate?

4. What changes climate over time?
5. Where does the extra energy that is trapped by excess carbon dioxide go?

Explore More Answers

1. Weather is what the atmosphere does in the short term, hour to hour or day to day. It's chaotic and small changes in conditions can change the weather.
2. The long-term average of weather over a number of years. It is shaped by global forces that alter the energy balance in the atmosphere.
3. Changes in the sun, changes in the tilt of Earths axis, the amount of sunlight Earth reflects back to space, and the concentration of greenhouse gases.
4. A global force such as increasing atmospheric carbon dioxide.
5. It warms the air and warms the oceans.

Review

1. When you're in a cold place in December and you're planning a vacation for February, are you interested in a location's weather or climate? If it's a summer day and you want to take a picnic are you concerned with weather or climate?
2. What factors account for a location's weather?
3. If climate is the long-term average of weather, how can climate change?

Review Answers

1. Two months in advance you can only look at climate; a weather prediction will not be at all reliable. On a daily basis, you are interested in the weather.
2. air temperature, air pressure, fog, humidity, cloud cover, precipitation, wind speed direction
3. For climate to change there must be changes in a major factor that determines climate such as the angle of the sun, cloud cover, and air pressure.

1.19 Clouds

- Define humidity, and explain the relationship of humidity to cloud formation.
- Explain how clouds form and describe their influence on weather.
- Describe different types of clouds and fog.

Have you ever looked at the sky and found shapes in the clouds?

Clouds have a great effect on the weather and climate, but they can also be lovely (if they're not pouring rain on you). It's fun to sit and watch the clouds go by.

Humidity

Humidity is the amount of water vapor in the air in a particular spot. We usually use the term to mean **relative humidity**, the percentage of water vapor a certain volume of air is holding relative to the maximum amount it can contain. If the humidity today is 80%, it means that the air contains 80% of the total amount of water it can hold at that temperature. What will happen if the humidity increases to more than 100%? The excess water condenses and forms precipitation.

Since warm air can hold more water vapor than cool air, raising or lowering temperature can change air's relative humidity (**Figure** 1.28). The temperature at which air becomes saturated with water is called the air's **dew point**. This term makes sense, because water condenses from the air as dew if the air cools down overnight and reaches 100% humidity.

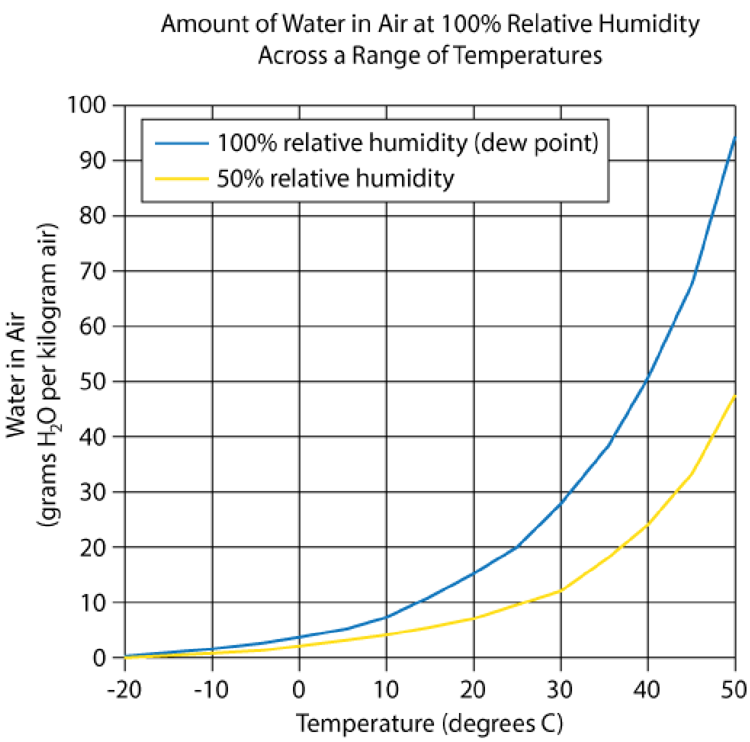


FIGURE 1.28
This diagram shows the amount of water air can hold at different temperatures. The temperatures are given in degrees Celsius.

Clouds

Water vapor is not visible unless it condenses to become a cloud. Water vapor condenses around a nucleus, such as dust, smoke, or a salt crystal. This forms a tiny liquid droplet. Billions of these water droplets together make a cloud.

Formation

Clouds form when air reaches its dew point. This can happen in two ways: (1) Air temperature stays the same but humidity increases. This is common in locations that are warm and humid. (2) Humidity remains the same, but temperature decreases. When the air cools enough to reach 100% humidity, water droplets form. Air cools when it comes into contact with a cold surface or when it rises.

Rising air creates clouds when it has been warmed at or near the ground level and then is pushed up over a mountain or mountain range or is thrust over a mass of cold, dense air.

Effects on Weather

Clouds have a big influence on weather:

- by preventing solar radiation from reaching the ground.
- by absorbing warmth that is re-emitted from the ground.
- as the source of precipitation.

When there are no clouds, there is less insulation. As a result, cloudless days can be extremely hot, and cloudless nights can be very cold. For this reason, cloudy days tend to have a lower range of temperatures than clear days.

Types of Clouds

Clouds are classified in several ways. The most common classification used today divides clouds into four separate cloud groups, which are determined by their altitude (**Figure** 1.29).

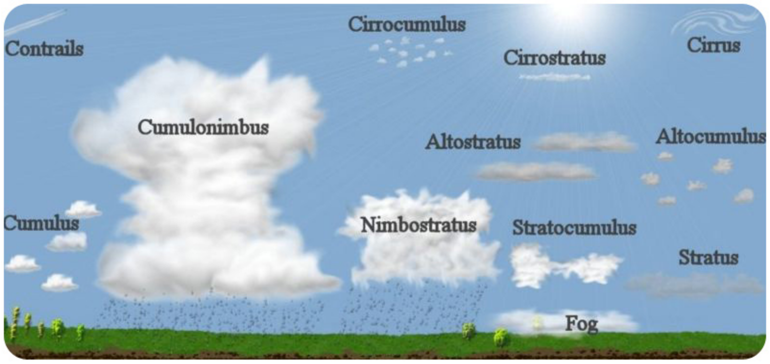


FIGURE 1.29
The four cloud types and where they are found in the atmosphere.

- High clouds form from ice crystals where the air is extremely cold and can hold little water vapor. Cirrus, cirrostratus, and cirrocumulus are all names of high clouds.
- Middle clouds, including altocumulus and altostratus clouds, may be made of water droplets, ice crystals or both, depending on the air temperatures. Thick and broad altostratus clouds are gray or blue-gray. They often cover the entire sky and usually mean a large storm, bearing a lot of precipitation, is coming.
- Low clouds are nearly all water droplets. Stratus, stratocumulus, and nimbostratus clouds are common low clouds. Nimbostratus clouds are thick and dark. They bring steady rain or snow.
- Vertical clouds, clouds with the prefix "cumulo-," grow vertically instead of horizontally and have their bases at low altitude and their tops at high or middle altitude. Clouds grow vertically when strong air currents are rising upward.

Precipitating clouds are nimbus clouds.

An online guide to cloud development and different cloud types from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/cld/home.rxml .

Fog

Fog (**Figure** 1.30) is a cloud located at or near the ground . When humid air near the ground cools below its dew point, fog is formed. Each type of fog forms in a different way.

- Radiation fog forms at night when skies are clear and the relative humidity is high. As the ground cools, the bottom layer of air cools below its dew point. Tule fog is an extreme form of radiation fog found in some regions.
- San Francisco, California, is famous for its summertime advection fog. Warm, moist Pacific Ocean air blows over the cold California current and cools below its dew point. Sea breezes bring the fog onshore.
- Steam fog appears in autumn when cool air moves over a warm lake. Water evaporates from the lake surface and condenses as it cools, appearing like steam.
- Warm humid air travels up a hillside and cools below its dew point to create upslope fog.

Fog levels are declining along the California coast as climate warms. The change in fog may have big ecological changes for the state.

FIGURE 1.30
(a) Tule fog in the Central Valley of California. (b) Advection fog in San Francisco. (c) Steam fog over a lake. (d) Upslope fog in Teresópolis city, Rio de Janeiro State, Brazil.

Learn more at http://www.kqed.org/quest/television/science-on-the-spot-science-of-fog .

MEDIA
Click image to the left for use the URL below.
URL: http://gamma.ck12.org/flx/render/embeddedobject/116506

Summary

- Air reaches its dew point when humidity increases or temperature decreases. Water droplets form when the air reaches 100% humidity.
- Clouds block solar radiation, absorb heat from the ground and are the source of snow and rain.
- Fog forms when there is a difference in temperature between the land and the air.

Making Connections

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/55524

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=FMagDRCpJ14

1. How are clouds categorized?
2. What are the four main cloud types?
3. Where do cirrus clouds form and what are they made of?
4. What do cirrus clouds indicate about the weather?
5. What do cumulus clouds look like? Where do they form?
6. What are stratiform clouds? Where do they form?
7. What are mid- and high-level stratus clouds called?
8. What do nimboform clouds do? What are the two common types?
9. What is unique about cumulonimbus clouds?

Explore More Answers

1. By their structural characteristics and the height in the atmosphere at which they develop.
2. cirro-form, cumulo=form, strato-form and nimbo-form
3. Cirrus clouds are high level clouds that form between 16,000 and 50,000 feet above the surface. They are made of tiny ice crystals.
4. They are indirect indicators of weather; they may accompany a strong jet stream and can precede surface fronts my more than a day or two.
5. They are fluffy white detached clouds that are formed between a few hundred and a few thousand feet.
6. They are a sheet or layer that has few features. They are primarily low but they can be found in the mid to upper levels of the atmosphere.
7. mid-level are alto stratus, high level are cirrostratus
8. Nimbo means rain; nimbostratus and cumulonimbus
9. They extend from the lower to the upper parts of the troposphere and they are thunderstorm clouds.

Review

1. Imagine a place with a daytime temperature of 45 degrees F. How will the nighttime temperature change if the sky is cloudy? How will it change if the sky is clear?
2. What set of conditions causes tule fog?
3. The low temperature a few degrees above freezing last night. Why is your car covered with frost this morning?

Review Answers

1. Clouds absorb warmth emitted from the ground so the nighttime temperature will not decrease as much if it is cloudy as if it is clear.
2. The ground is warm in the day but cools off at night. The air above that ground cools below its dew point and the water vapor within it condenses.
3. The local temperature on the car is colder than the air temperature so water vapor condenses and freezes on the car.

1.20 Precipitation

- Describe different types of precipitation and the conditions that create them.

Do you live in a place that gets lots of rain?

In some places it rains so much that people barely notice it. In others it rains so little that a rainy day is revered. Rain is not the only type of precipitation; see a few below.

Precipitation

Precipitation (**Figure** 1.31) is an extremely important part of weather. Water vapor condenses and usually falls to create precipitation.

Dew and Frost

Some precipitation forms in place. **Dew** forms when moist air cools below its dew point on a cold surface. **Frost** is dew that forms when the air temperature is below freezing.

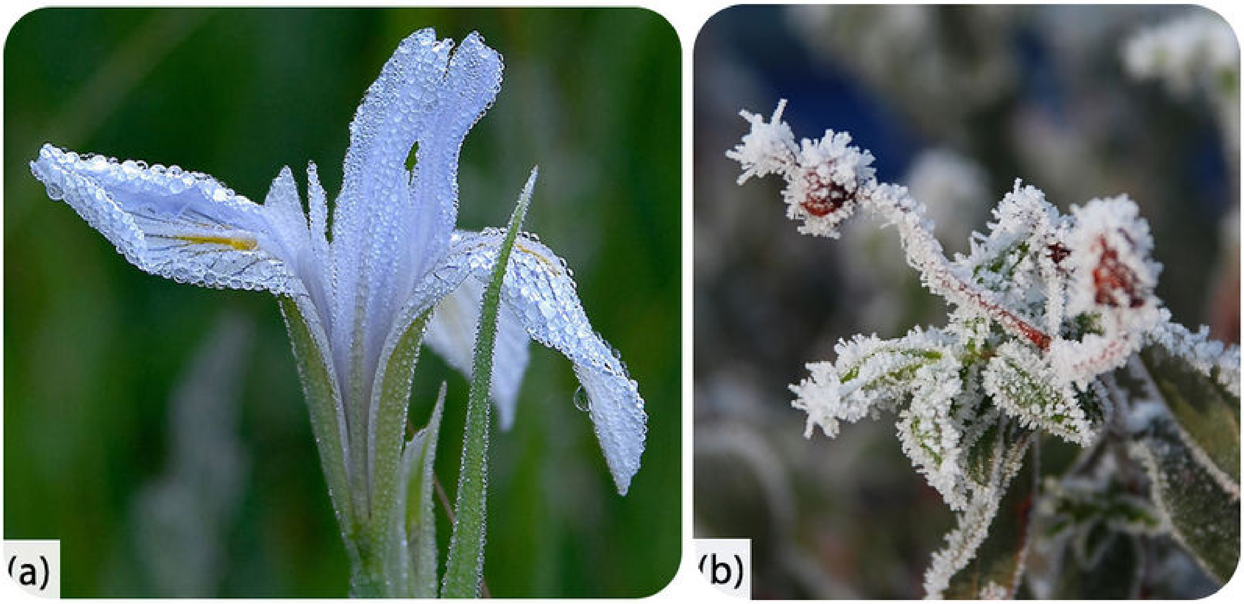


FIGURE 1.31
(a) Dew on a flower. (b) Hoar frost.

Precipitation From Clouds

The most common precipitation comes from clouds. **Rain** or snow droplets grow as they ride air currents in a cloud and collect other droplets (**Figure** 1.32). They fall when they become heavy enough to escape from the rising air currents that hold them up in the cloud. One million cloud droplets will combine to make only one rain drop! If temperatures are cold, the droplet will hit the ground as **snow**.

Other less common types of precipitation are **sleet** (**Figure** 1.33). Sleet is rain that becomes ice as it hits a layer of freezing air near the ground. If a frigid raindrop freezes on the frigid ground, it forms **glaze**. **Hail** forms in cumulonimbus clouds with strong updrafts. An ice particle travels until it finally becomes too heavy and it drops.

An online guide from the University of Illinois to different types of precipitation is seen here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/cld/prcp/home.rxml .

Summary

- A surface can be colder than the surrounding air, causing the air to cool below its dew point.
- Rain droplets caught up in air currents within a cloud get larger by the addition of condensed droplets until they are too heavy and they fall.
- If the ground is very cold, rain can freeze to become sleet or glaze.

Explore More

Use this resource to answer the questions that follow.

http://youtu.be/HKSGvD9X8sw?t=7m9s

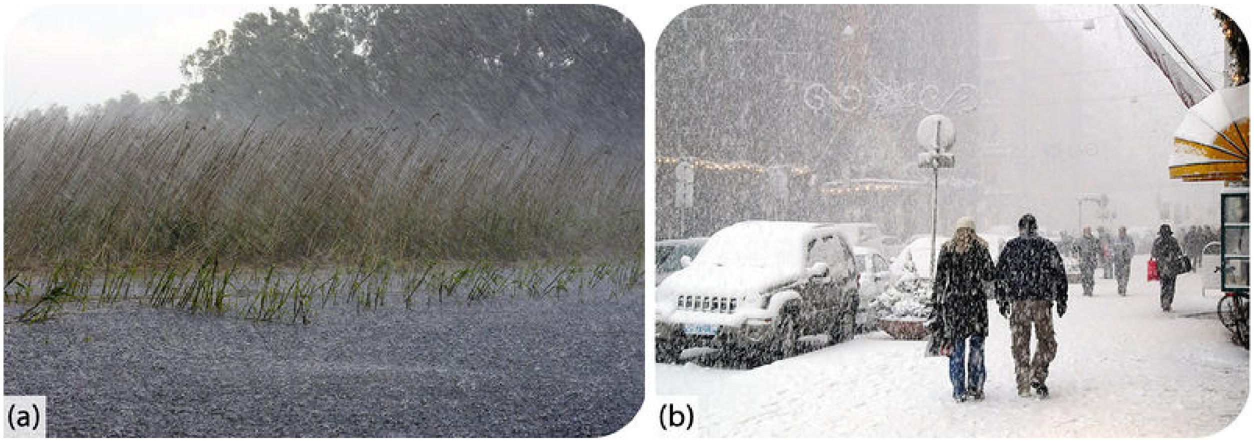


FIGURE 1.32
(a) Rain falls from clouds when the temperature is fairly warm. (b) Snow storm in Helsinki, Finland.

FIGURE 1.33
(a) Sleet. (b) Glaze. (c) Hail. This large hail stone is about 6 cm (2.5 inches) in diameter.

1. What is precipitation? What are the four main types?
2. What determines whether a bit of precipitation starts as water or ice? What determines what form it is in when it reaches the ground?
3. What does rain start out as and what does it end up as? Why?
4. Why is freezing rain solid when it reaches the surface?
5. What happens to sleet as it falls through the atmosphere?
6. How is hail different from sleet?
7. What does snow start as and what does it end as? What is the air temperature as it falls?

Explore More Answers

1. Anything that falls from a cloud. The types are rain, freezing rain, sleet and snow.

2. The air temperature in the cloud. The air temperature it falls through.
3. Rain may start out as liquid or ice but it falls through relatively warm air and ends up as liquid at the surface.
4. It freezes as it hits the ground because it is very cold near the ground.
5. It starts as ice, but it hits warm air and melts part way down, but then it hits a cold area near the ground and freezes into ice pellets.
6. Hail only forms during thunderstorms. It is a product of updrafts in the cloud. It grows larger with the addition of water as it cycles through the cloud.
7. It starts as snow and travels through cold air and remains as snow.

Review

1. Describe how raindrops form.
2. Why does hail only come from cumulonimbus clouds?
3. How does sleet form?

Review Answers

1. Droplets grow as they flow through a cloud. When the droplet is to heavy to remain in the cloud it falls.
2. For hail to form water coats ice crystals until it becomes too heavy and drops.
3. Sleet is rain that freezes in the cold air below the cloud. it hits the ground as ice.

1.21 Air Masses

- Explain how air masses form, move, and influence weather.

Why do these air balloons rise?

Warm air rises and cool air sinks. In a hot air balloon, a heater heats the air inside the balloon. When the weight of the warm air plus the balloon is less than the weight of the cooler air outside the balloon, the balloon will rise. Air masses work on the same principles, rising and falling when they confront an obstacle, such as another air mass.

What is an Air Mass?

An **air mass** is a batch of air that has nearly the same temperature and humidity (**Figure** 1.34). An air mass acquires these characteristics above an area of land or water known as its source region. When the air mass sits over a region for several days or longer, it picks up the distinct temperature and humidity characteristics of that region.

Air Mass Formation

Air masses form over a large area; they can be 1,600 km (1,000 miles) across and several kilometers thick. Air masses form primarily in high pressure zones, most commonly in polar and tropical regions. Temperate zones are ordinarily too unstable for air masses to form. Instead, air masses move across temperate zones, so the middle latitudes are prone to having interesting weather.

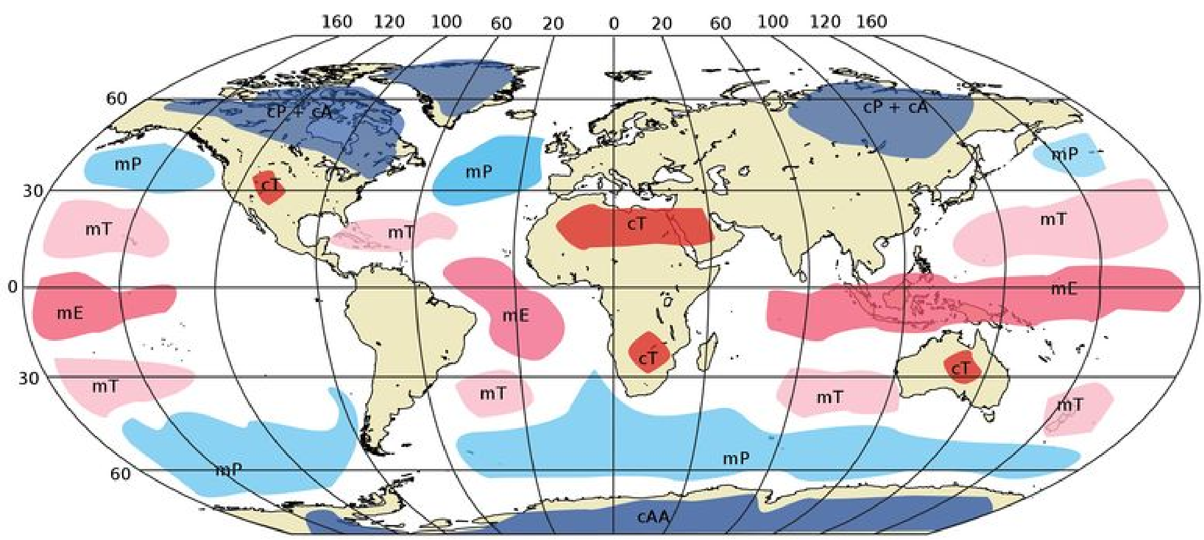


FIGURE 1.34

The source regions of air masses found around the world. Symbols: (1) origin over a continent (c) or an ocean (m, for maritime); (2) arctic (A), polar (P,) tropical (T), and equatorial (E); (3) properties relative to the ground it moves over: k, for colder, w for warmer.

What does an air mass with the symbol cPk mean? The symbol cPk is an air mass with a continental polar source region that is colder than the region it is now moving over.

Air Mass Movement

Air masses are slowly pushed along by high-level winds. When an air mass moves over a new region, it shares its temperature and humidity with that region. So the temperature and humidity of a particular location depends partly on the characteristics of the air mass that sits over it.

Storms

Storms arise if the air mass and the region it moves over have different characteristics. For example, when a colder air mass moves over warmer ground, the bottom layer of air is heated. That air rises, forming clouds, rain, and sometimes thunderstorms. How would a moving air mass form an inversion? When a warmer air mass travels over colder ground, the bottom layer of air cools and, because of its high density, is trapped near the ground.

Moderate Temperature

In general, cold air masses tend to flow toward the Equator and warm air masses tend to flow toward the poles. This brings heat to cold areas and cools down areas that are warm. It is one of the many processes that act to balance out the planet's temperatures.

Figures and animations explain weather basics at this USA Today site: http://www.usatoday.com/weather/wstorm0.htm .

An online guide from the University of Illinois about air masses and fronts is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/af/home.rxml .

Summary

- An air mass has roughly the same temperature and humidity.
- Air masses form over regions where the air is stable for a long enough time that the air can take on the characteristics of the region.
- Air masses move when they are pushed by high level winds.

Explore More

Use this resource to answer the questions that follow. https://www.youtube.com/watch?v=zAEEqEF-KZ4 Watch to 3:31.

1. What is an air mass?
2. Where do continental air masses form and what are their characteristics?
3. Where do maritime air masses form and what are their characteristics?
4. Where do polar air masses form and what are their characteristics?
5. Where do tropical air masses form and what are their characteristics?
6. What are the four air mass types and what are their major characteristics?
7. What happens when one air mass overtakes another air mass? what does this do to the weather?
8. How large can an air mass be?

Explore More Answers

1. An air mass is a large body of air that is more or less consistent in its temperature and humidity.
2. Continental air masses form over land and are dry
3. Maritime air masses form over the oceans and are moist.
4. Polar air masses form over the high latitudes and are cold.
5. Tropical air masses form over the low latitudes and are warm.
6. 1) Continental Polar: cold and dry; Continental Tropical: warm and dry; Maritime Polar: cool and moist; Maritime Tropical: warm and moist.
7. One air mass is pushed out of the way. It can make the weather unsettled, stormy or even violent.
8. Up to 3 million square miles.

Review

1. How do the movements of air masses moderate temperature?
2. Why do air masses form mostly in high pressure areas?
3. What is the relationship between air masses and storms?

Review Answers

1. Cold air masses flow toward the Equator and warm air masses flow toward the Poles so this moderates temperature.
2. High pressure zones are stable enough that air can sit in one spot for a while.
3. If the air mass and the ground it goes over are different in temperature a storm can form. If two air masses have different temperatures a storm can form.

1.22 Weather Fronts

- Define different types of fronts.
- Explain how fronts create changes in weather.

How is a meteorological front like a military front?

In military usage, a front is where two opposing forces meet. This bayonet charge of French soldiers is opposing the Germans along the Western Front during World War I. How does a weather front resemble this?

Fronts

Two air masses meet at a **front**. At a front, the two air masses have different densities and do not easily mix. One air mass is lifted above the other, creating a low pressure zone. If the lifted air is moist, there will be condensation and precipitation. Winds are common at a front. The greater the temperature difference between the two air masses, the stronger the winds will be. Fronts are the main cause of stormy weather.

There are four types of fronts, three moving and one stationary. With cold fronts and warm fronts, the air mass at the leading edge of the front gives the front its name. In other words, a cold front is right at the leading edge of moving cold air and a warm front marks the leading edge of moving warm air.

Stationary Front

At a **stationary front** the air masses do not move (**Figure** 1.35). A front may become stationary if an air mass is stopped by a barrier, such as a mountain range. A stationary front may bring days of rain, drizzle, and fog. Winds usually blow parallel to the front, but in opposite directions. After several days, the front will likely break apart.

Cold Fronts

When a cold air mass takes the place of a warm air mass, there is a **cold front** (**Figure** 1.36).

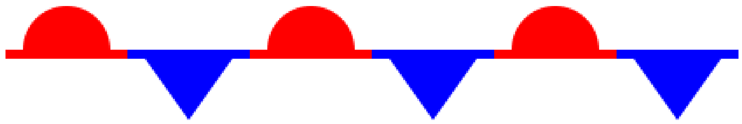


FIGURE 1.35
The map symbol for a stationary front has red domes for the warm air mass and blue triangles for the cold air mass.

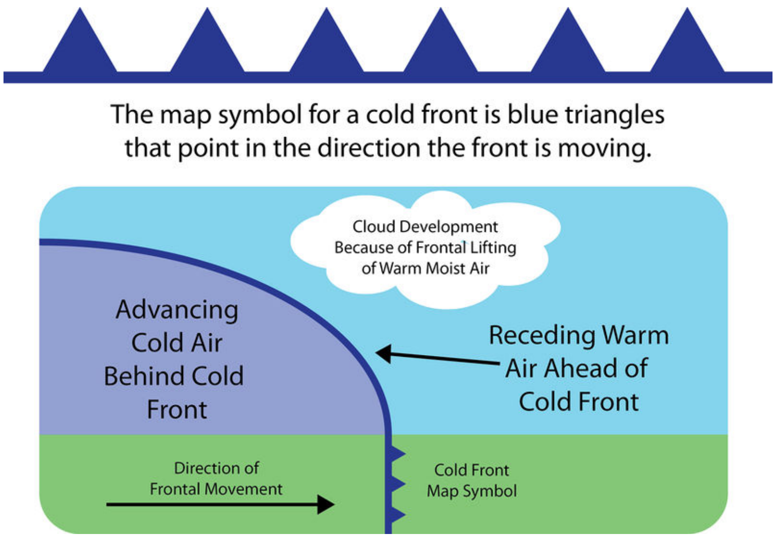


FIGURE 1.36
The cold air mass is dense, so it slides beneath the warm air mass and pushes it up.

Imagine that you are standing in one spot as a cold front approaches. Along the cold front, the denser, cold air pushes up the warm air, causing the air pressure to decrease (**Figure** 1.36). If the humidity is high enough, some types of cumulus clouds will grow. High in the atmosphere, winds blow ice crystals from the tops of these clouds to create cirrostratus and cirrus clouds. At the front, there will be a line of rain showers, snow showers, or thunderstorms with blustery winds (**Figure** 1.37). A **squall line** is a line of severe thunderstorms that forms along a cold front. Behind the front is the cold air mass. This mass is drier, so precipitation stops. The weather may be cold and clear or only partly cloudy. Winds may continue to blow into the low pressure zone at the front.

The weather at a cold front varies with the season.

- Spring and summer: the air is unstable so thunderstorms or tornadoes may form.
- Spring: if the temperature gradient is high, strong winds blow.
- Autumn: strong rains fall over a large area.
- Winter: the cold air mass is likely to have formed in the frigid arctic, so there are frigid temperatures and heavy snows.

Warm Fronts

At a **warm front**, a warm air mass slides over a cold air mass (**Figure** 1.38). When warm, less dense air moves over the colder, denser air, the atmosphere is relatively stable.

Imagine that you are on the ground in the wintertime under a cold winter air mass with a warm front approaching. The transition from cold air to warm air takes place over a long distance, so the first signs of changing weather appear long before the front is actually over you. Initially, the air is cold: the cold air mass is above you and the warm air mass is above it. High cirrus clouds mark the transition from one air mass to the other.

FIGURE 1.37
A squall line.

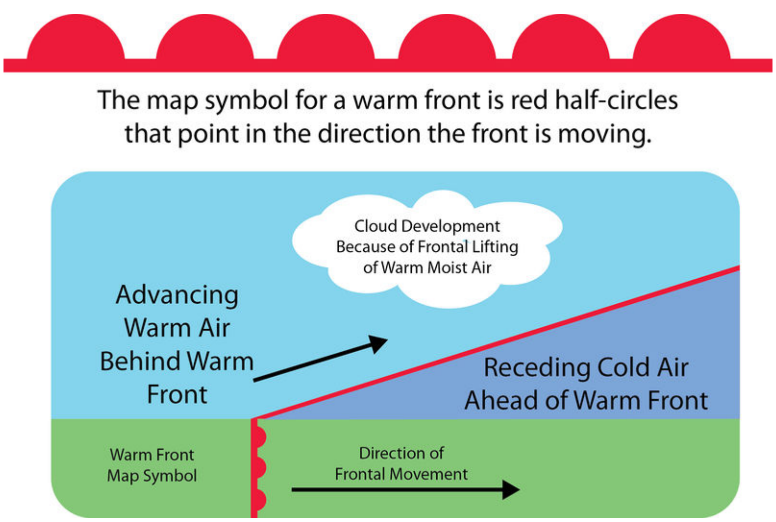


FIGURE 1.38
Warm air moves forward to take over the position of colder air.

Over time, cirrus clouds become thicker and cirrostratus clouds form. As the front approaches, altocumulus and altostratus clouds appear and the sky turns gray. Since it is winter, snowflakes fall. The clouds thicken and nimbostratus clouds form. Snowfall increases. Winds grow stronger as the low pressure approaches. As the front gets closer, the cold air mass is just above you but the warm air mass is not too far above that. The weather worsens. As the warm air mass approaches, temperatures rise and snow turns to sleet and freezing rain. Warm and cold air mix at the front, leading to the formation of stratus clouds and fog (**Figure** 1.39).

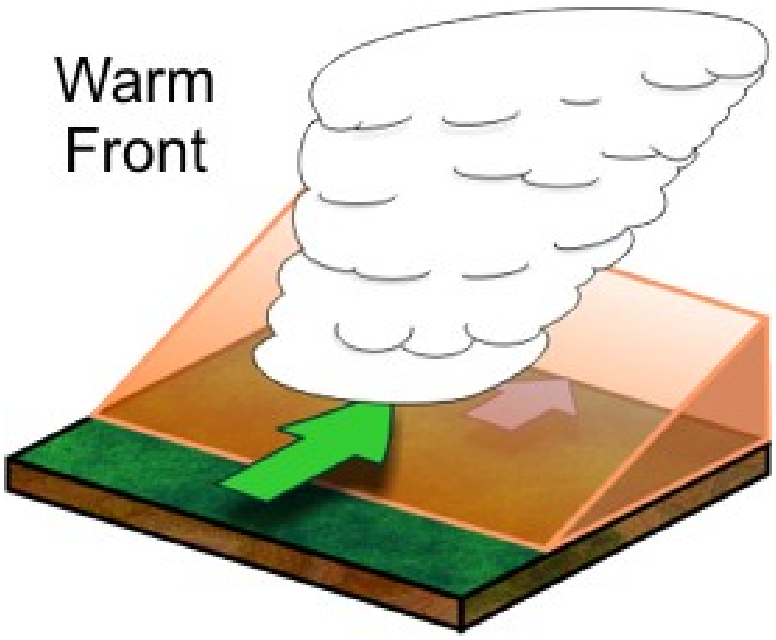


FIGURE 1.39
Cumulus clouds build at a warm front.

Occluded Front

An **occluded front** usually forms around a low pressure system (**Figure** 1.40). The occlusion starts when a cold front catches up to a warm front. The air masses, in order from front to back, are cold, warm, and then cold again.

FIGURE 1.40
The map symbol for an occluded front is mixed cold front triangles and warm front domes.

Coriolis effect curves the boundary where the two fronts meet towards the pole. If the air mass that arrives third is colder than either of the first two air masses, that air mass slip beneath them both. This is called a cold occlusion. If the air mass that arrives third is warm, that air mass rides over the other air mass. This is called a warm occlusion (**Figure** 1.41).

The weather at an occluded front is especially fierce right at the occlusion. Precipitation and shifting winds are typical. The Pacific Coast has frequent occluded fronts.

Summary

- Much of the weather occurs where at fronts where air masses meet.

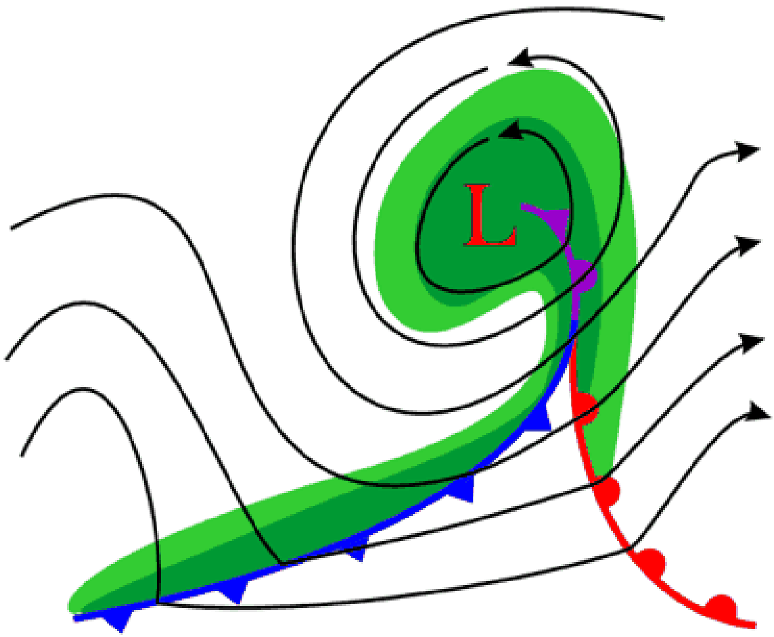


FIGURE 1.41

An occluded front with the air masses from front to rear in order as cold, warm, cold.

- In a warm front a warm air mass slides over a cold air mass. In a cold front a cold air mass slides under a warm air mass.
- An occluded front has three air masses, cold, warm, and cold.

Explore More

Use this resource to answer the questions that follow.

http://youtu.be/zAEEqEF-KZ4?t=3m30s

1. What are fronts?
2. What happens when a maritime tropical air mass moves of the ocean toward a continental polar air mass and why?
3. What is a warm front? Why is it called a warm front?
4. How does a cold front get its name?
5. What happens in a cold front? What type of weather does it produce and why?
6. What happens in a stationary front?
7. When does an occluded front form? What type of weather happens?

Explore More Answers

1. The boundaries between air masses.
2. The maritime air mass is warmer so the air rises over the top of the polar air mass. The water vapor condenses the air mass has cooled and precipitation is likely.
3. A front in which a warm moist air mass rises over a cool dry air mass. It is called a warm front because the warm air mass advances.
4. The cold air mass moves forward.
5. The advancing cold air pushes the warm air upward. Cold fronts produce brief heavy precipitation; brief because the front moves quickly.

6. A warm and cold front meet but they do not move.
7. An occluded front happens when a cold front overtakes a warm front. The weather can be like cold or warm fronts.

Review

1. What characteristics give warm fronts and cold fronts their names?
2. How does Coriolis effect create an occluded front?
3. Describe the cloud sequence that goes along with a warm front.

Review Answers

1. The name of a front comes is due to the air mass that is advancing; e.g. a cold front forms when the cold air mass is advancing.
2. Coriolis effect curves the boundary where the two fronts meet, creating the occlusion.
3. First there are high cirrus clouds that become thicker until cirrostratus clouds form. As the front approaches, altocumulus and altostratus clouds appear and the sky turns gray. Snow or rain fall. Thicker nimbostratus clouds form and snowfall increases. When the warm front is above the snow turns to sleet and freezing rain and eventually stratus clouds and fog form.

1.23 Thunderstorms

- Explain how thunderstorms form, grow, and produce lightning and thunder.

What lives fast and dies young?

That describes most thunderstorms. Thunderstorms can be very intense but may last for only a matter of minutes. They're fun (and dangerous) while they're active, though.

Thunderstorms

Thunderstorms are extremely common. Worldwide there are 14 million per year —that's 40,000 per day! Most drop a lot of rain on a small area quickly, but some are severe and highly damaging.

Thunderstorm Formation

Thunderstorms form when ground temperatures are high, ordinarily in the late afternoon or early evening in spring and summer. The two figures below show two stages of thunderstorm buildup (**Figure** 1.42).

Growth

As temperatures increase, warm, moist air rises. These updrafts first form cumulus and then cumulonimbus clouds. Winds at the top of the troposphere blow the cloud top sideways to make the anvil shape that characterizes a cloud as a thunderhead. As water vapor condenses to form a cloud, the latent heat makes the air in the cloud warmer than the air outside the cloud. Water droplets and ice fly up through the cloud in updrafts. When these droplets get heavy enough, they fall.

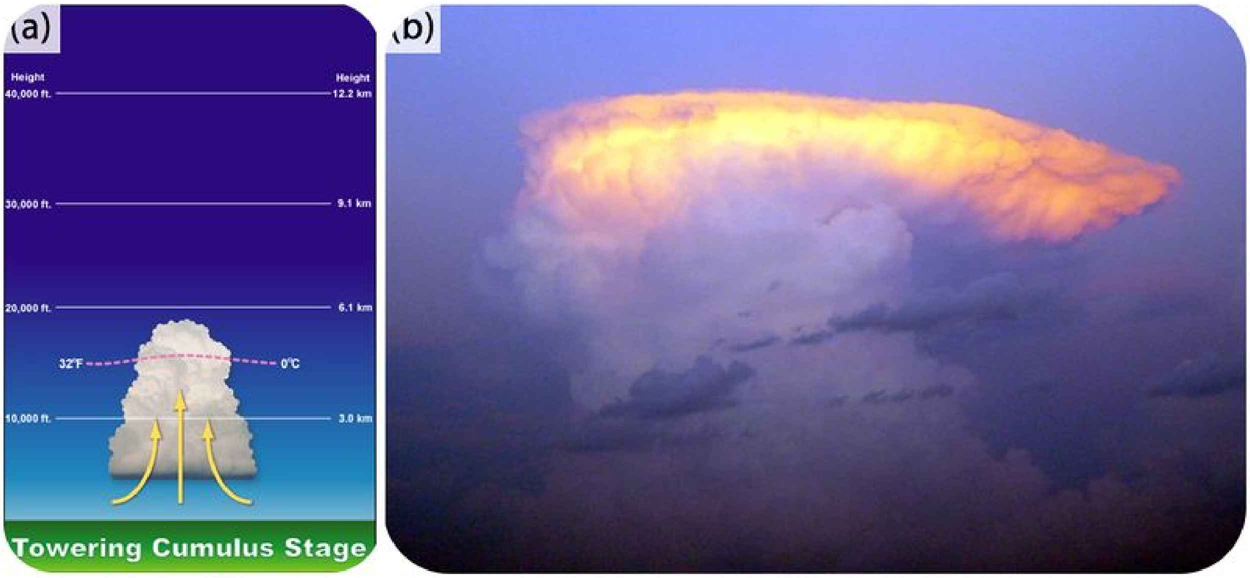


FIGURE 1.42
(a) Cumulus and cumulonimbus clouds. (b) A thunderhead.

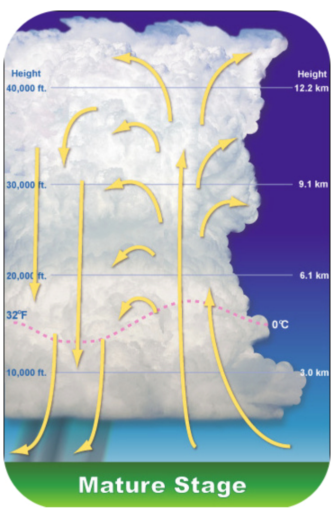


FIGURE 1.43
A mature thunderstorm with updrafts and downdrafts that reach the ground.

This starts a downdraft, and soon there is a convection cell within the cloud. The cloud grows into a cumulonimbus giant. Eventually, the drops become large enough to fall to the ground. At this time, the thunderstorm is mature, and it produces gusty winds, lightning, heavy precipitation, and hail (**Figure** 1.43).

The End

The downdrafts cool the air at the base of the cloud, so the air is no longer warm enough to rise. As a result, convection shuts down. Without convection, water vapor does not condense, no latent heat is released, and the thunderhead runs out of energy. A thunderstorm usually ends only 15 to 30 minutes after it begins, but other thunderstorms may start in the same area.

Severe Thunderstorms

With severe thunderstorms, the downdrafts are so intense that when they hit the ground, warm air from the ground is sent upward into the storm. The warm air gives the convection cells more energy. Rain and hail grow huge before gravity pulls them to Earth. Severe thunderstorms can last for hours and can cause a lot of damage because of high winds, flooding, intense hail, and tornadoes.

Squall Lines

Thunderstorms can form individually or in squall lines along a cold front. In the United States, squall lines form in spring and early summer in the Midwest, where the maritime tropical (mT) air mass from the Gulf of Mexico meets the continental polar (cP) air mass from Canada (**Figure** 1.44).

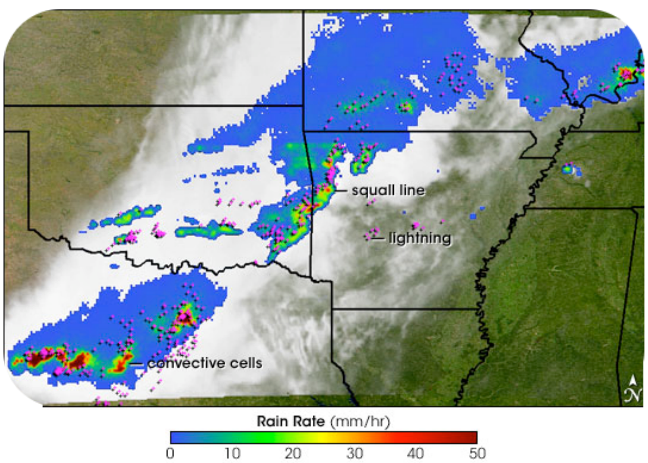


FIGURE 1.44
Cold air from the Rockies collided with warm, moist air from the Gulf of Mexico to form this squall line.

Lightning and Thunder

So much energy collects in cumulonimbus clouds that a huge release of electricity, called **lightning**, may result (**Figure** 1.45). The electrical discharge may be between one part of the cloud and another, two clouds, or a cloud and the ground.

Lightning heats the air so that it expands explosively. The loud clap is **thunder**. Light waves travel so rapidly that lightning is seen instantly. Sound waves travel much more slowly, so a thunderclap may come many seconds after the lightning is spotted.

Damage

Thunderstorms kill approximately 200 people in the United States and injure about 550 Americans per year, mostly from lightning strikes. Have you heard the common misconception that lightning doesn't strike the same place twice? In fact, lightning strikes the New York City's Empire State Building about 100 times per year (**Figure** 1.46).

FIGURE 1.45
Lightning behind the town of Diamond Head, Hawaii.

FIGURE 1.46
Lightning strikes some places many times a year, such as the Eiffel Tower in Paris.

An online guide to severe storms from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/svr/home.rxml .

Summary

- Thunderstorms grow where ground temperatures are extremely high.
- Convection in the cloud causes raindrops or hailstones to grow. Downdrafts ultimately end convection.
- Squall lines are long lines of thunderstorms that form along a cold front.

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=OUkoCWVxNRQ

1. Describe the temperature gradient in the troposphere, tropopause and stratosphere?
2. What causes the flat top of a thunder cloud?
3. What is rising in a thunderstorm? What is sinking?
4. Where do the tornadoes form relative to the thundercloud?
5. What is the gust front?
6. What are downbursts?
7. How does hail form?
8. What are the stages of a thunderstorm?

Explore More Answers

1. In the troposphere it gets colder with altitude; it's flat in the troposphere; it's gets warmer in the stratosphere.
2. It can't grow higher because it's warmer above.
3. Warm air is rising in updrafts; cold air is sinking in downdrafts.
4. The tornadoes are in about the middle of the cloud.
5. It is the leading edge of the rain-cooled gusty air preceding a thunderstorm.
6. Air drops where the rain has significantly cooled it and it hits the ground rapidly.
7. In updrafts and downdrafts air, ice crystals add more material until the crystal is so large it falls. If it is ice it falls as hail.
8. cumulus, mature, dissipating

Review

1. Why are thunderstorms so common?
2. What is the energy source that feeds a thunderstorm?
3. What causes a thunderstorm to end?

Review Answers

1. Thunderstorms are common because there are many circumstances when conditions are right with high ground temperatures.
2. Heat from the ground, which of course came from the sun, feeds a thunderstorm.
3. Thunderstorms end when downdrafts cool down the base of the cloud and convection shuts down.

1.24 Tornadoes

- Explain how and where tornadoes form.
- Describe how the severity of tornadoes is measured and the damage they can cause.

Who killed the Wicked Witch of the East?

Dorothy's house flies up in a tornado to the magical land of Oz. When the tornado ends, the house it falls on the witch. Dorothy becomes a hero for killing the tyrannical witch, but despite that yearns for home. In the real world, tornadoes do kill, but houses don't usually fly, and wicked witches usually avoid tornadoes.

Tornadoes

Tornadoes, also called twisters, are fierce products of severe thunderstorms (**Figure** 1.47). As air in a thunderstorm rises, the surrounding air races in to fill the gap. This forms a tornado, a funnel-shaped, whirling column of air extending downward from a cumulonimbus cloud.

A tornado lasts from a few seconds to several hours. The average wind speed is about 177 kph (110 mph), but some winds are much faster. A tornado travels over the ground at about 45 km per hour (28 miles per hour) and goes about 25 km (16 miles) before losing energy and disappearing (**Figure** 1.48).

FIGURE 1.47
The formation of this tornado outside Dimmit, Texas, in 1995 was well studied.

FIGURE 1.48
This tornado struck Seymour, Texas, in 1979.

Damage

An individual tornado strikes a small area, but it can destroy everything in its path. Most injuries and deaths from tornadoes are caused by flying debris (**Figure** 1.49). In the United States an average of 90 people are killed by tornadoes each year. The most violent two percent of tornadoes account for 70% of the deaths by tornadoes.

Location

Tornadoes form at the front of severe thunderstorms. Lines of these thunderstorms form in the spring where where maritime tropical (mT) and continental polar (cP) air masses meet. Although there is an average of 770 tornadoes annually, the number of tornadoes each year varies greatly (**Figure** 1.50).

April 2011

In late April 2011, severe thunderstorms pictured in the satellite image spawned the deadliest set of tornadoes in more than 25 years. In addition to the meeting of cP and mT mentioned above, the jet stream was blowing strongly

FIGURE 1.49
Tornado damage at Ringgold, Georgia in April 2011.

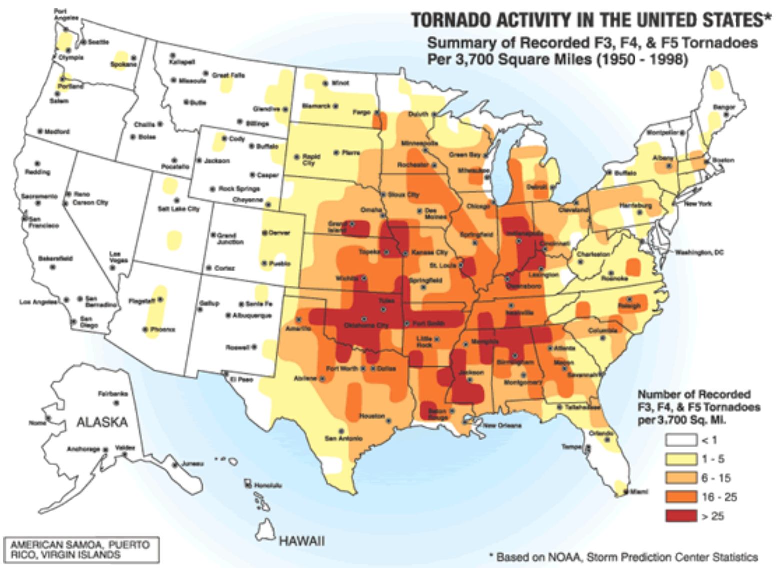


FIGURE 1.50
The frequency of F3, F4, and F5 tornadoes in the United States. The red region that starts in Texas and covers Oklahoma, Nebraska, and South Dakota is called Tornado Alley because it is where most of the violent tornadoes occur.

in from the west. The result was more than 150 tornadoes reported throughout the day (**Figure** 1.51).

The entire region was alerted to the possibility of tornadoes in those late April days. But meteorologists can only predict tornado danger over a very wide region. No one can tell exactly where and when a tornado will touch down. Once a tornado is sighted on radar, its path is predicted and a warning is issued to people in that area. The exact path is unknown because tornado movement is not very predictable.

Tornado catchers capture footage inside a tornado on this National Geographic video: http://ngm.nationalgeographic.com/ngm/0506/feature6/multimedia.html .

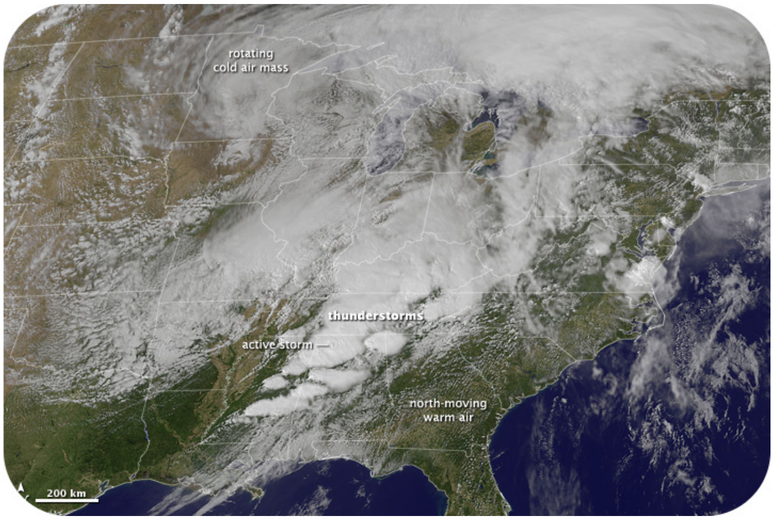


FIGURE 1.51
April 27-28, 2011. The cold air mass is shown by the mostly continuous clouds. Warm moist air blowing north from the Atlantic Ocean and Gulf of Mexico is indicated by small low clouds. Thunderstorms are indicated by bright white patches.

Fujita Scale

The intensity of tornadoes is measured on the Fujita Scale (see **Table** 1.3), which assigns a value based on wind speed and damage.

TABLE 1.3: The Fujita Scale (F Scale) of Tornado Intensity

F Scale	(km/hr)	(mph)	Damage
F0	64-116	40-72	Light - tree branches fall and chimneys may collapse
F1	117-180	73-112	Moderate - mobile homes, autos pushed aside
F2	181-253	113-157	Considerable - roofs torn off houses, large trees uprooted
F3	254-333	158-206	Severe - houses torn apart, trees uprooted, cars lifted
F4	333-419	207-260	Devastating - houses leveled, cars thrown
F5	420-512	261-318	Incredible - structures fly, cars become missiles
F6	>512	>318	Maximum tornado wind speed

Summary

- A tornado is a whirling funnel of air extending down from a cumulonimbus cloud.
- The Fujita scale measures tornado intensity based on wind speed and damage.
- Tornadoes can only be predicted over a wide region.

Making Connections

MEDIA

4. Where does a supercell thunderstorm get its power?
5. What happens when a thunderstorm can finally form in spite of the cap?
6. The meeting of which air masses causes thunderstorms in the spring?
7. Which factor increases the chance of powerful thunderstorms and tornadoes?
8. Why might global warming produce more thunderstorms and tornadoes?

Explore More Answers

1. The updrafts rotate and develop a supercell that can develop a tornado.
2. Instability, the propensity to accelerate rising upwards, and wind shear, the change of direction and wind speed with height.
3. The rising air twists and this feeds back into the thunderstorm and can intensify this motion.
4. The cap thousands of feet above the ground suppresses the development of thunderstorms. This increases the amount of energy that collects and so the instability.
5. It rises very quickly and explosively, which maximizes the strength of the updraft and the chance of forming volcanoes.
6. Cold dry air from Canada and warm moist air from the Gulf of Mexico meet.
7. The temperature difference between the two air masses.
8. With more warmth there is more energy in the system, which can create more storms.

Review

1. What causes the tornadoes of Tornado Alley?
2. How does the Fujita scale resemble the scales for assessing earthquake intensity? Which does it most resemble?
3. What circumstances led to the intensity of tornado activity in April 2011?

Review Answers

1. Tornado Alley is where the maritime tropical and continental polar air masses meet in the spring. This generates a lot of thunderstorms and so a lot of tornadoes.
2. The Fujita scale is a mathematical scale (not logarithmic) that is based on damage noted. It is most like the Modified Mercalli scale of measuring earthquake intensity.
3. The meeting of the cP and mT air masses and the jet stream blowing strongly from the west.

1.25 Mid-Latitude Cyclones

- Describe mid-latitude cyclones and explain how and where they form.

Where were you on Halloween 2011?

If you live along the northeastern United States you may remember Halloween being postponed in 2011. A large and atypically early nor'easter dropped as much as 32 inches of snow, caused over three million people to lose power, and brought on 39 deaths. Like hurricanes, nor'easters are cyclones, but they form much further north.

Mid-Latitude Cyclones

Cyclones can be the most intense storms on Earth. A **cyclone** is a system of winds rotating counterclockwise in the Northern Hemisphere around a low pressure center. The swirling air rises and cools, creating clouds and precipitation.

Mid-latitude cyclones form at the polar front when the temperature difference between two air masses is large. These air masses blow past each other in opposite directions. Coriolis effect deflects winds to the right in the Northern Hemisphere, causing the winds to strike the polar front at an angle. Warm and cold fronts form next to each other. Most winter storms in the middle latitudes, including most of the United States and Europe, are caused by mid-latitude cyclones (**Figure** 1.52).

The warm air at the cold front rises and creates a low pressure cell. Winds rush into the low pressure and create a rising column of air. The air twists, rotating counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. Since the rising air is moist, rain or snow falls.

Mid-latitude cyclones form in winter in the mid-latitudes and move eastward with the westerly winds. These two- to five-day storms can reach 1,000 to 2,500 km (625 to 1,600 miles) in diameter and produce winds up to 125 km (75 miles) per hour.

Nor'easters

Mid-latitude cyclones are especially fierce in the mid-Atlantic and New England states, where they are called **nor'easters** because they come from the northeast. About 30 nor'easters strike the region each year. (**Figure** 1.53).

An online guide to mid-latitude cyclones from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/cyc/home.rxml .

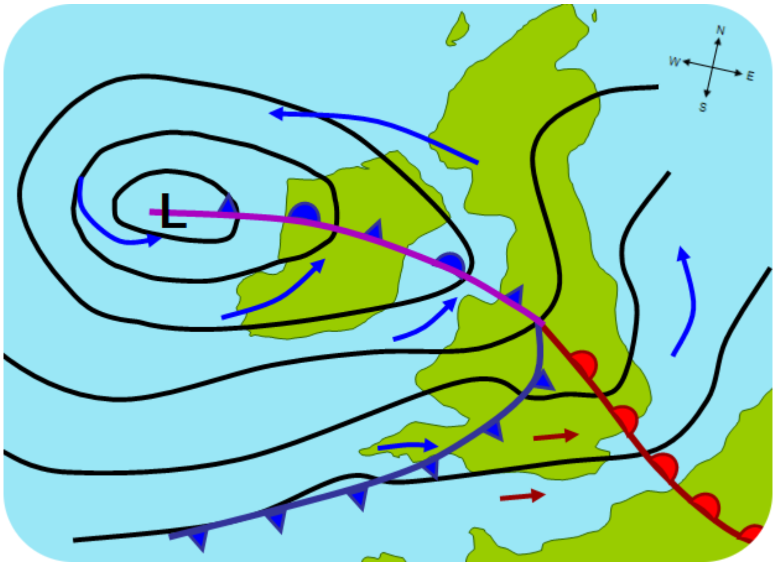


FIGURE 1.52
A hypothetical mid-latitude cyclone affecting the United Kingdom. The arrows point the wind direction and its relative temperature; L is the low pressure area. Notice the warm, cold, and occluded fronts.

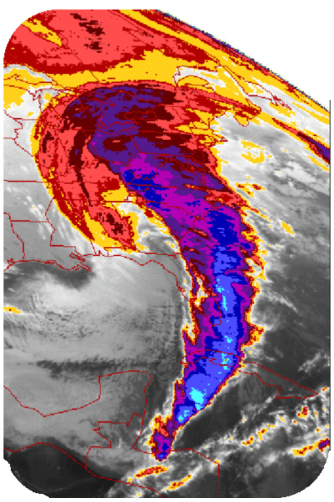


FIGURE 1.53
The 1993 "Storm of the Century" was a nor'easter that covered the entire eastern seaboard of the United States.

Summary

- A cyclone is a system of winds rotating counter-clockwise (in the Northern Hemisphere) around an area of low pressure.
- A mid-latitude cyclone forms at the polar front when the temperature difference between air masses is very large.
- Nor'easters are mid-latitude cyclones that come from the northeast.

Explore More

Use this resource to answer the questions that follow.

http://www.slideshare.net/lschmidt1170/midlatitude-cyclones

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/4745

1. What is at the center of a midlatitude cyclone?
2. What does the low pressure cell do?
3. What types of air masses are typically involved?
4. What does a mature midlatitude cyclone have?
5. Where is the heaviest precipitation located in a midlatitude cyclone?

Explore More Answers

1. At the center is a low pressure cell as much as 1000 miles across.
2. It produces converging counterclockwise wind flow.
3. Relatively cool air from the higher latitudes and relatively warm air from the subtropcs.
4. It has a cool sector and a warm sector, separated by a cold front and a warm front.
5. The heaviest rain hits when the warm air gives way to the cold air at the cold front.

Review

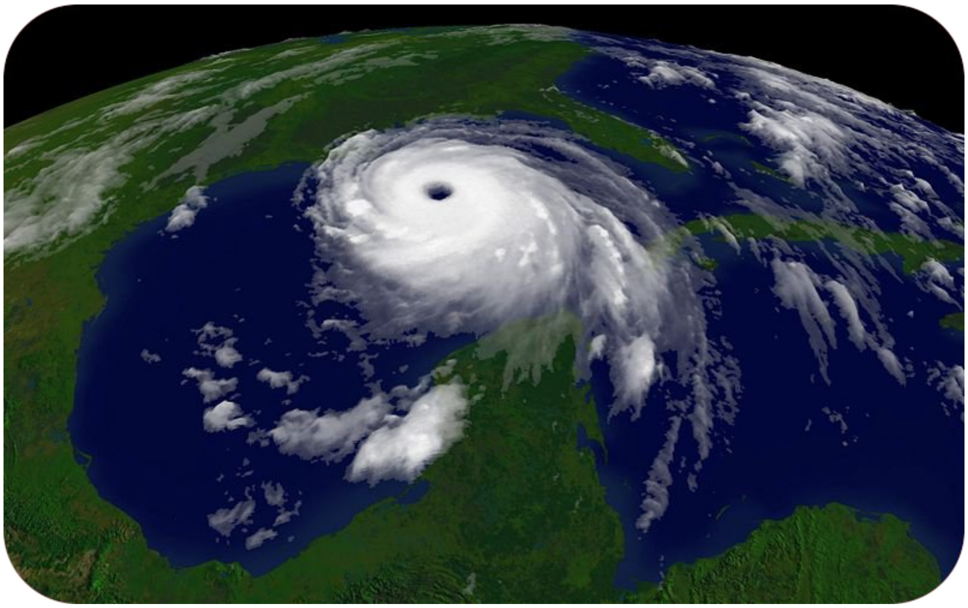
1. Describe the circumstances that result in a nor'easter.
2. What is a cyclone?
3. What are the motions of air in a mid-latitude cyclone?

Review Answers

1. Nor'easters are mid-latitude cyclones that come off the Atlantic.
2. A cyclone is a system of winds rotating counterclockwise in the Northern Hemisphere around a low pressure center.
3. In a mid-latitude cyclone the air masses blow past each other in opposite directions and Coriolis deflects the winds.

1.26 Hurricanes

- Explain how and where hurricanes form.
- Describe how hurricanes are measured and the damage that they can cause.



Why did New Orleans Mayor Ray Nagin call Hurricane Katrina "...a storm that most of us have long feared," as it approached New Orleans?

Hurricane Katrina nears its peak strength as it travels across the Gulf of Mexico. Hurricane Katrina was the most deadly and the most costly of the hurricanes that struck in the record-breaking 2005 season.

Hurricanes

Hurricanes —called typhoons in the Pacific —are also cyclones. They are cyclones that form in the tropics and so they are also called tropical cyclones. By any name, they are the most damaging storms on Earth.

Formation

Hurricanes arise in the tropical latitudes (between 10^o and 25^oN) in summer and autumn when sea surface temperature are 28^oC (82^oF) or higher. The warm seas create a large humid air mass. The warm air rises and forms a low pressure cell, known as a **tropical depression**. Thunderstorms materialize around the tropical depression.

If the temperature reaches or exceeds 28^oC (82^oF), the air begins to rotate around the low pressure (counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere). As the air rises, water vapor condenses, releasing energy from latent heat. If wind shear is low, the storm builds into a hurricane within two to three days.

Hurricanes are huge and produce high winds. The exception is the relatively calm eye of the storm, where air is rising upward. Rainfall can be as high as 2.5 cm (1") per hour, resulting in about 20 billion metric tons of water released daily in a hurricane. The release of latent heat generates enormous amounts of energy, nearly the total annual electrical power consumption of the United States from one storm. Hurricanes can also generate tornadoes.

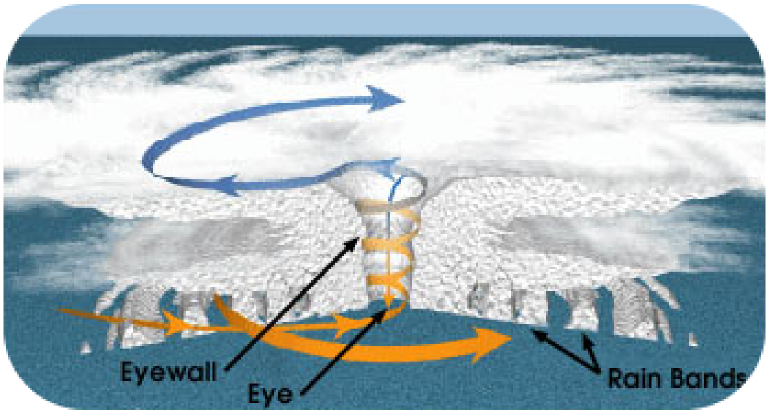


FIGURE 1.54
A cross-sectional view of a hurricane.

Hurricanes move with the prevailing winds. In the Northern Hemisphere, they originate in the trade winds and move to the west. When they reach the latitude of the westerlies, they switch direction and travel toward the north or northeast. Hurricanes may cover 800 km (500 miles) in one day.

Saffir-Simpson Scale

Hurricanes are assigned to categories based on their wind speed. The categories are listed on the Saffir-Simpson hurricane scale (**Table** 1.4).

TABLE 1.4: Saffir-Simpson Hurricane Scale

Category	Kph	Mph	Estimated Damage
1 (weak)	119-153	74-95	Above normal; no real damage to structures
2 (moderate)	154-177	96-110	Some roofing, door, and window damage, considerable damage to vegetation, mobile homes, and piers
3 (strong)	178-209	111-130	Some buildings damaged; mobile homes destroyed
4 (very strong)	210-251	131-156	Complete roof failure on small residences; major erosion of beach areas; major damage to lower floors of structures near shore
5 (devastating)	>251	>156	Complete roof failure on many residences and industrial buildings; some complete building failures

Damage

Damage from hurricanes comes from the high winds, rainfall, and storm surge. Storm surge occurs as the storm's low pressure center comes onto land, causing the sea level to rise unusually high. A storm surge is often made worse by the hurricane's high winds blowing seawater across the ocean onto the shoreline. Flooding can be devastating, especially along low-lying coastlines such as the Atlantic and Gulf Coasts. Hurricane Camille in 1969 had a 7.3 m (24 foot) storm surge that traveled 125 miles (200 km) inland.

Hurricane Katrina

The 2005 Atlantic hurricane season was the longest, costliest, and deadliest hurricane season so far. Total damage from all the storms together was estimated at more than $128 billion, with more than 2,280 deaths. Hurricane Katrina was both the most destructive hurricane and the most costly (**Figure** 1.55).

FIGURE 1.55
Flooding in New Orleans after Hurricane Katrina caused the levees to break and water to pour through the city.

News about Hurricane Katrina from the New Orleans Times-Picayune: http://www.nola.com/katrina/graphics/flashflood.swf .

An animation of a radar image of Hurricane Katrina making landfall is seen here: http://upload.wikimedia.org/wikipedia/commons/9/97/Hurricane_Katrina_LA_landfall_radar.gif .

NASA's short video, "In Katrina's Wake": http://www.youtube.com/watch?v=HZjqvqaLltI .

Hurricanes are explored in a set of National Geographic videos found at National Geographic Video: http://video.nationalgeographic.com/video/environment/environment-natural-disasters/hurricanes . At this link, watch the following videos:

- "Hurricanes 101" is an introduction to the topic.
- "How Katrina Formed" looks at the history of Hurricane Katrina as it formed and passed through the Gulf coast.

- Follow that up with “Doomed New Orleans,” which explores how the devastation to the city is a man-made disaster.
- “The Hurricane Ike of 1900” looks at what happened in the days when there was little warning before a hurricane hit a coastal city.

Lots of information about hurricanes is found in this online guide from the University of Illinois: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/hurr/home.rxml .

Summary

- Hurricanes are actually tropical cyclones because they originate in the tropical latitudes.
- The damage hurricanes cause is due largely to storm surge, but high wind speeds and rain also cause damage.
- Hurricane Katrina was so damaging because the levees that protected New Orleans broke.

Making Connections

Multimedia

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/53634

Explore More

Use this resource to answer the questions that follow.

http://video.nationalgeographic.com/video/news/katrina-formation

1. What was the temperature of the Atlantic Ocean off the Bahamas?
2. What does the air above that warm water do?
3. Where does the heat come from to take the storm to the next step?
4. How does the storm then grow?
5. What is the cycle that is formed?
6. How does the cyclonic storm form?
7. What happens to most severe tropical storms?
8. What did Katrina do in Florida?
9. What happened to the storm in the Gulf of Mexico?
10. What was the category, wind speed and storm surge of the hurricane that hit the Gulf coast?
11. Why did Katrina weaken after hitting land?

Explore More Answers

1. 85-degrees F
2. It becomes warm and then rises and condenses to form a system of thunderstorms?
3. Condensation of water vapor to liquid water, that change of state, releases heat, which warms the atmosphere.
4. That warm air rises and cooler air must come to the center to take its place.
5. Warm water gives energy to the atmosphere, which continues to build the storm.
6. The incoming air begins to circulate and forms a center.

7. The spin out their lives in the open ocean.
8. The Category 1 storm glanced of the tip of Florida and headed into the Gulf of Mexico.
9. The water in the Gulf was 87-degrees F so as the storm traveled over that water the storm grew more intense. It became a Category 5.
10. Katrina was a category 4 with wind speeds of 155 mph and storm surge 20 feet high. It was the most destructive storm to hit the land in 36 years.
11. The storm gets energy from warm water and it was cut off from the warm Gulf.

Review

1. What is the difference between a hurricane and a mid-latitude cyclone?
2. How does a hurricane form? Where does the storm get its energy?
3. Under what circumstances does a hurricane die?

Review Answers

1. A hurricane forms in the tropics, but a mid-latitude cyclone forms in the mid-latitudes.
2. When sea surface temperatures are high in the tropics a low pressure cell forms and generates thunderstorms. If there is enough energy the air rotates around the low pressure and energy is generated from the latent heat released as warm water vapor changes state to liquid water.
3. A hurricane dies when it can no longer get energy from warm sea water, which is when it moves north over colder water or over land.

1.27 Blizzards

- Describe the conditions that define blizzards and explain how blizzards form.

What would cause a snow day in Greece?

Sometimes a snowstorm strikes a location that's usually snow-free. When that happens, for some reason air masses are not behaving normally. Usually an atypical snow is fun for the people who live there, especially since everything usually gets shut down —including schools!

Blizzards

A **blizzard** is distinguished by certain conditions:

- Temperatures below –7°C (20°F); –12°C (10°F) for a severe blizzard.
- Winds greater than 56 kmh (35 mph); 72 kmh (45 mph) for a severe blizzard.
- Snow so heavy that visibility is 2/5 km (1/4 mile) or less for at least three hours; near zero visibility for a severe blizzard.

Formation

Blizzards happen across the middle latitudes and toward the poles, usually as part of a mid-latitude cyclone. Blizzards are most common in winter, when the jet stream has traveled south and a cold, northern air mass comes into contact with a warmer, semitropical air mass (**Figure** 1.57). The very strong winds develop because of the pressure gradient between the low-pressure storm and the higher pressure west of the storm. Snow produced by the storm gets caught in the winds and blows nearly horizontally. Blizzards can also produce sleet or freezing rain.

FIGURE 1.56
A blizzard obscures the Capitol in Washington, DC.

FIGURE 1.57
Blizzard snows blanket the East Coast of the United States in February 2010.

Lake-Effect Snow

In winter, a continental polar air mass travels down from Canada. As the frigid air travels across one of the Great Lakes, it warms and absorbs moisture. When the air mass reaches the leeward side of the lake, it is very unstable and it drops tremendous amounts of snow. This **lake-effect snow** falls on the snowiest metropolitan areas in the United States: Buffalo and Rochester, New York (**Figure** 1.58).

Summary

- Blizzards are often part of a mid-latitude cyclone where the jet stream brings cold air into contact with warm moist air.
- The difference in pressure between the air masses brings about strong winds.
- Cold polar air absorbs moisture as it travels over the Great Lakes and then dumps it as snow downwind to create lake-effect snow.

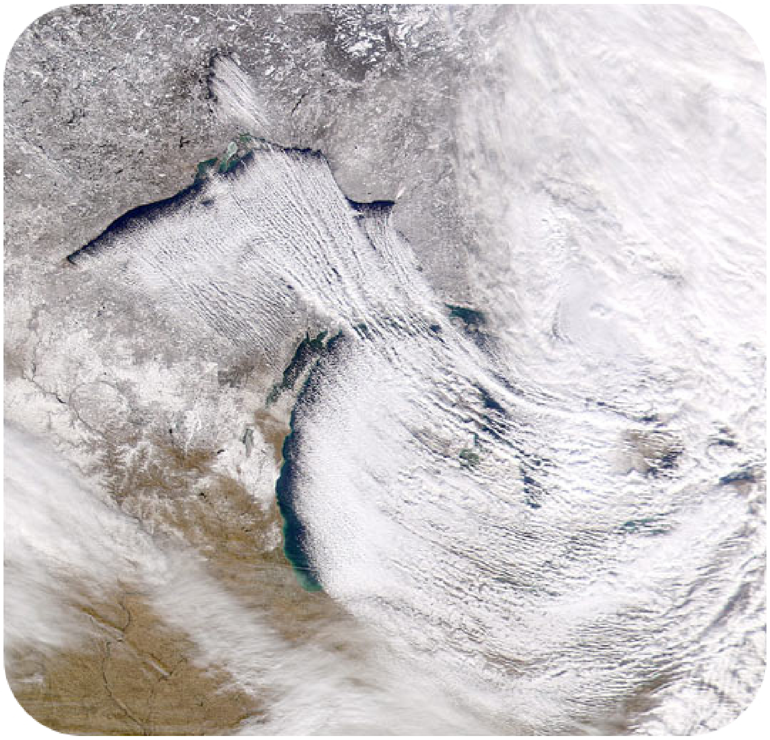


FIGURE 1.58
Frigid air travels across the Great Lakes and dumps lake-effect snow on the leeward side.

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=KFK7kXBLwy0

1. How are blizzards the same as snowstorms?
2. What types of air masses meet and what do they do to form a snowstorm?
3. When does a snowstorm become a blizzard?
4. When do blizzards usually happen?
5. Where do blizzards usually occur in the U.S.?
6. How can you survive a blizzard?

Explore More Answers

1. Blizzards start out as snowstorms. They have cold air at Earth's surface, lots of moisture and lift.
2. Cold polar air meets with moist tropical air. The warm air rises over the cold air and then it snows.
3. Winds of 35 mph or more for at least 3 hours, visibility of less than 1/4 mile.
4. After a lengthy period of cold weather.
5. Across the middle of the country but they can get as far south as Texas or as far east as Maine.
6. Stay indoors or if you have to go out dress warmly, keep car gas tank full, keep blanket in car. Buy emergency supplies. Take warnings seriously.

Review

1. Under what circumstances does a blizzard form?

2. What causes lake-effect snow?
3. What is a blizzard?

Review Answers

1. They happen in the mid latitudes and toward the poles, usually as part of a mid-latitude cyclone. The jet stream is south so a cold northern air mass contacts a warmer wetter air mass. The two air masses generate strong winds.
2. Cold Canadian air travels across a relatively warm lake. The air cools and absorbs moisture. When it reaches the leeward side of teh lake it cools and drops a bunch of moisture as snow.
3. A blizzard has temperatures below 20-degrees F with high winds greater than 35 mph and such heavy snow that there is very little or no visibility.

1.28 Heat Waves and Droughts

- Describe the causes of heat waves and droughts.

Why are these children playing in a fire hydrant?

The deadliest weather phenomena are not blizzards or hurricanes but heat waves. People who live in areas where the weather is usually not hot may not have air conditioning. Children have a way of finding a solution to a problem that usually involves fun.

Heat Waves

A **heat wave** is different depending on its location. According to the World Meteorological Organization a region is in a heat wave if it has more than five consecutive days of temperatures that are more than 9°F (5°C) above average.

Heat waves have increased in frequency and duration in recent years. The summer 2011 North American heat wave brought record temperatures across the Midwestern and Eastern United States. Many states and localities broke records for temperatures and for most days above 100°F.

Causes

A high pressure cell sitting over a region with no movement is the likely cause of a heat wave.

What do you think caused the heat wave in the image below (**Figure** 1.59)? A high pressure zone kept the jet stream further north than normal for August.

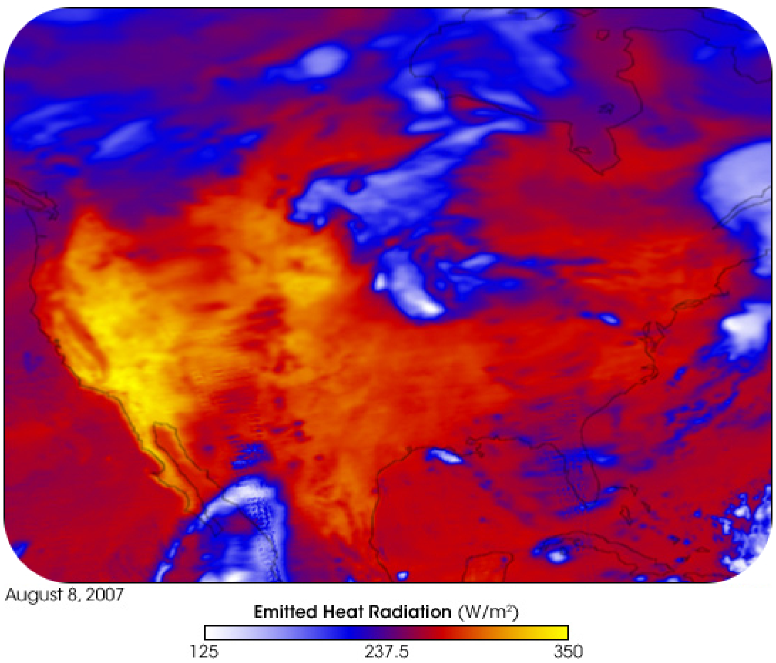


FIGURE 1.59
A heat wave over the United States as indicated by heat radiated from the ground. The bright yellow areas are the hottest and the blue and white are coolest.

Droughts

Droughts also depend on what is normal for a region. When a region gets significantly less precipitation than normal for an extended period of time, it is in drought. The Southern United States is experiencing an ongoing and prolonged drought.

Drought has many consequences. When soil loses moisture it may blow away, as happened during the Dust Bowl in the United States in the 1930s. Forests may be lost, dust storms may become common, and wildlife are disturbed. Wildfires become much more common during times of drought.

Summary

- It's hard to define a heat wave or a drought because these phenomena depend are deviations from normal conditions in a region.
- A heat wave is caused when a warm high-pressure cell sits over a region.
- Drought may have extremely severe consequences depending on its duration and intensity.

Explore More

Use these resources to answer the questions that follow.

http://channel.nationalgeographic.com/channel/videos/record-breaking-heat-waves-explained/

1. What is the difference between record breaking heat waves in the past and now?
2. Between 2000 and 2009 in the U.S., how did heat waves stack up against cold events?
3. What evidence is indisputable?
4. How does Professor Demming figure out what the cause of the heat is?
5. When was carbon dioxide last as high in the atmosphere?
6. Where does the carbon dioxide come from?
7. Why does carbon dioxide increase Earth's temperature?
8. How much warmer has the world gotten in the past 140 years?

Explore More Answers

1. In the past heat records were broken but an equal number of cold records were broken. Now most records broken are heat records.
2. There were twice as many hot as cold events.
3. The world is getting hotter.
4. He collects gases from high in the atmosphere, particularly carbon dioxide.
5. Millions of years ago.
6. burning fossil fuels
7. It's a greenhouse gas that traps heat and re-emits some of it downward to warm the surface.
8. 1.5 degrees

Review

1. How is a heat wave defined?
2. How is a drought defined?
3. How does the position of the jet stream cause a heat wave?

Review Answers

1. A heat wave is more than five consecutive days of temperature that are more than 9°F (5°C)above average.
2. Drought is when a region gets significantly less rainfall than normal.
3. If a high pressure zone keeps the jet stream further north than usual the regions that are under warm tropical air that should be under cold dry air will increase.

1.29 Collecting Weather Data

- Describe how scientists collect information about weather.

Can you forecast your health?

You can use a thermometer to better understand your health just like a meteorologist uses one to better understand the weather. A thermometer will help you forecast your health just as it will help to forecast the weather. Other tools, like barometers, also help with weather forecasting.

Collecting Weather Data

To make a weather forecast, the conditions of the atmosphere must be known for that location and for the surrounding area. Temperature, air pressure, and other characteristics of the atmosphere must be measured and the data collected.

Thermometer

Thermometers measure temperature. In an old-style mercury thermometer, mercury is placed in a long, very narrow tube with a bulb. Because mercury is temperature sensitive, it expands when temperatures are high and contracts when they are low. A scale on the outside of the thermometer matches up with the air temperature.

Some modern thermometers use a coiled strip composed of two kinds of metal, each of which conducts heat differently. As the temperature rises and falls, the coil unfolds or curls up tighter. Other modern thermometers measure infrared radiation or electrical resistance. Modern thermometers usually produce digital data that can be fed directly into a computer.

Barometer

Meteorologists use **barometers** to measure air pressure. A barometer may contain water, air, or mercury, but like thermometers, barometers are now mostly digital.

A change in barometric pressure indicates that a change in weather is coming. If air pressure rises, a high pressure cell is on the way and clear skies can be expected. If pressure falls, a low pressure cell is coming and will likely bring storm clouds. Barometric pressure data over a larger area can be used to identify pressure systems, fronts, and other weather systems.

Weather Stations

Weather stations contain some type of thermometer and barometer. Other instruments measure different characteristics of the atmosphere, such as wind speed, wind direction, humidity, and amount of precipitation. These instruments are placed in various locations so that they can check the atmospheric characteristics of that location (**Figure** 1.60). Weather stations are located on land, the surface of the sea, and in orbit all around the world.

FIGURE 1.60
A land-based weather station.

According to the World Meteorological Organization, weather information is collected from 15 satellites, 100 stationary buoys, 600 drifting buoys, 3,000 aircraft, 7,300 ships, and some 10,000 land-based stations.

Radiosondes

Radiosondes measure atmospheric characteristics, such as temperature, pressure, and humidity as they move through the air. Radiosondes in flight can be tracked to obtain wind speed and direction. Radiosondes use a radio to communicate the data they collect to a computer. Radiosondes are launched from about 800 sites around the globe twice daily to provide a profile of the atmosphere. Radiosondes can be dropped from a balloon or airplane to make measurements as they fall. This is done to monitor storms, for example, since they are dangerous places for airplanes to fly.

Radar

Radar stands for Radio Detection and Ranging (**Figure** 1.61). A transmitter sends out radio waves that bounce off the nearest object and then return to a receiver. Weather radar can sense many characteristics of precipitation: its location, motion, intensity, and the likelihood of future precipitation. Doppler radar can also track how fast the precipitation falls. Radar can outline the structure of a storm and can be used to estimate its possible effects.

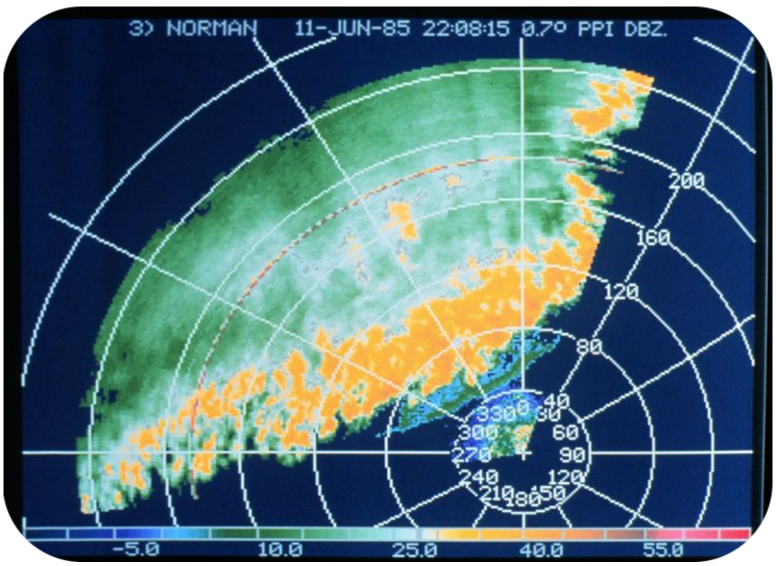


FIGURE 1.61
Radar view of a line of thunderstorms.

Satellites

Weather satellites have been increasingly important sources of weather data since the first one was launched in 1952. Weather satellites are the best way to monitor large-scale systems, such as storms. Satellites are able to record long-term changes, such as the amount of ice cover over the Arctic Ocean in September each year.

Weather satellites may observe all energy from all wavelengths in the electromagnetic spectrum. Visible light images record storms, clouds, fires, and smog. Infrared images record clouds, water and land temperatures, and features of the ocean, such as ocean currents (**Figure** 1.62).

An online guide to weather forecasting from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/fcst/home.rxml .

Summary

- Various instruments measure weather conditions: thermometers measure air temperature, and barometers measure air pressure.
- Satellites monitor weather and also help with understanding long-term changes in climate.
- Radar is used to monitor precipitation.

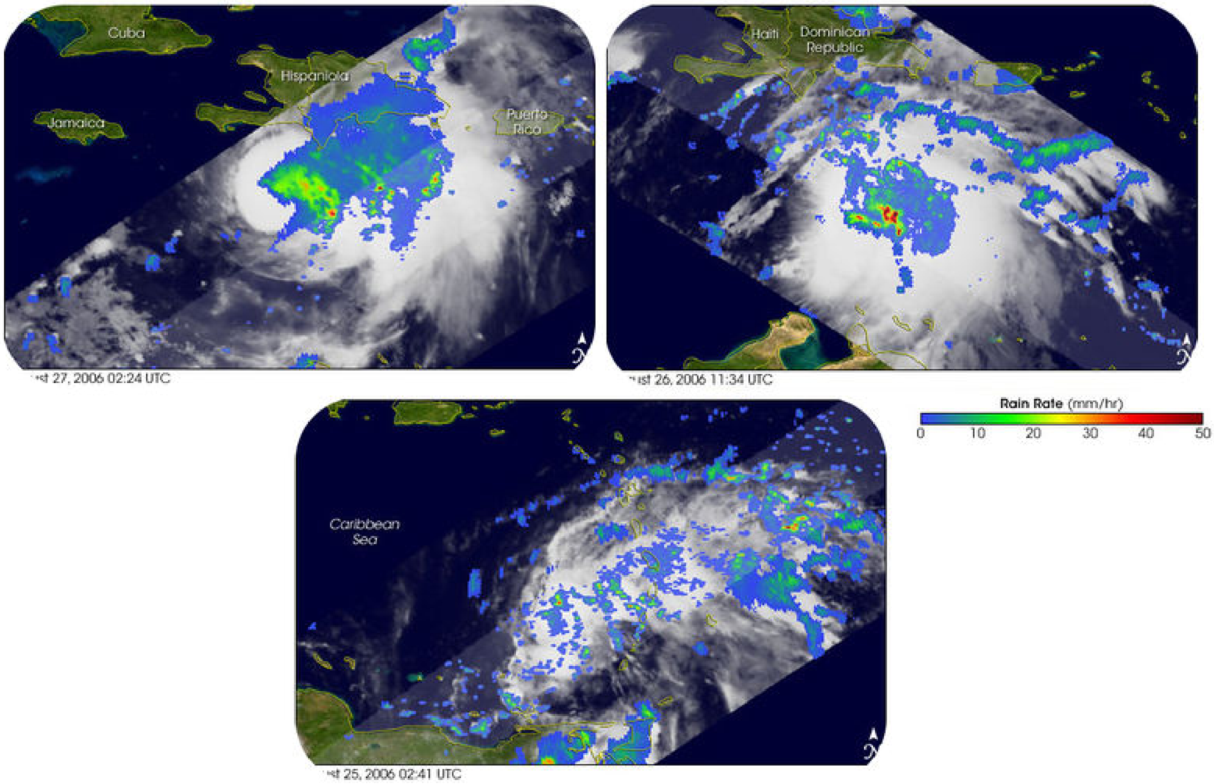


FIGURE 1.62
Infrared data superimposed on a satellite image shows rainfall patterns in Hurricane Ernesto in 2006.

Making Connections

MEDIA
Click image to the left for use the URL below.
URL: http://gamma.ck12.org/flx/render/embeddedobject/54872

Explore More

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=RTkPlhc3k-0

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/1577

1. What is contemporary weather forecasting based on?
2. What do radisonde balloons do?
3. What data do satellites collect?
4. What data is collected by radar?
5. List other ways weather data is collected.

Explore More Answers

1. Bringing together a huge amount of statistics and quickly processing the data.
2. Radiosonde balloons gather data from the upper atmosphere.
3. Satellites that show cloud and snow patterns
4. Radar for precipitation outlines and patterns.
5. ground weather stations, both manned and automatic; weather aircraft; weather ships; automatic weather buoys

Review

1. What can a barometer tell you about the coming weather?
2. Weather prediction is now much better than it was 30 years ago. Can you figure out why?
3. Since there are weather satellites, why do you think weather forecasters still use radiosondes?

Review Answers

1. A barometer measures air pressure and can be used to indicate what weather is coming. Higher pressure indicates clear skies; lower pressure indicates a possible storm.
2. Technology is far more advanced; weather satellites collect information much more effectively than other indicators.
3. Radiosondes can provide a profile; satellites stay at one altitude.

1.30 Predicting Weather

- Explain how meteorologists forecast the weather.

Does a picnic bring rain?

Weather forecasts are better than they ever have been. According to the World Meteorological Organization (WMO), a 5-day weather forecast today is as reliable as a 2-day forecast was 20 years ago. Now there's no excuse to be rained out on a picnic!

Numerical Weather Prediction

The most accurate weather forecasts are made by advanced computers, with analysis and interpretation added by experienced meteorologists. These computers have up-to-date mathematical models that can use much more data and make many more calculations than would ever be possible by scientists working with just maps and calculators. Meteorologists can use these results to give much more accurate weather forecasts and climate predictions.

In Numerical Weather Prediction (NWP), atmospheric data from many sources are plugged into supercomputers running complex mathematical models (**Figure** 1.63). The models then calculate what will happen over time at various altitudes for a grid of evenly spaced locations. The grid points are usually between 10 and 200 kilometers apart. Using the results calculated by the model, the program projects weather further into the future. It then uses these results to project the weather still further into the future, as far as the meteorologists want to go. Once a forecast is made, it is broadcast by satellites to more than 1,000 sites around the world.

NWP produces the most accurate weather forecasts, but as anyone knows, even the best forecasts are not always right.

Weather prediction is extremely valuable for reducing property damage and even fatalities. If the proposed track of a hurricane can be predicted, people can try to secure their property and then evacuate (**Figure** 1.64).

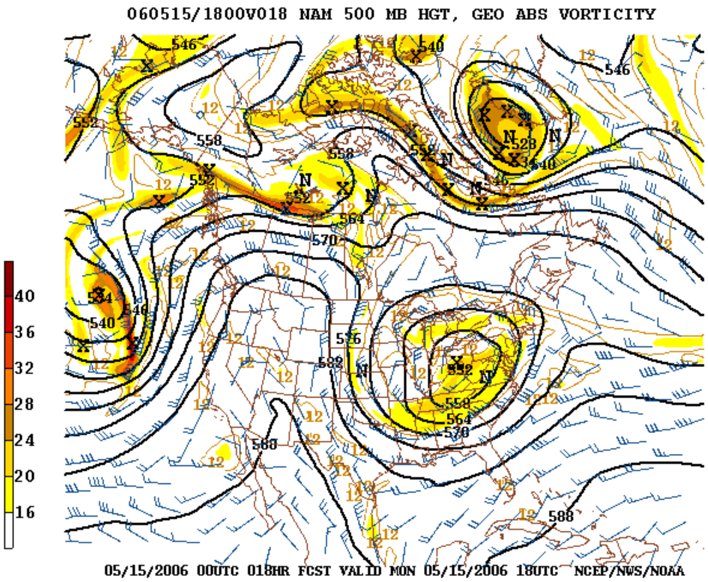


FIGURE 1.63
A weather forecast using numerical weather prediction.

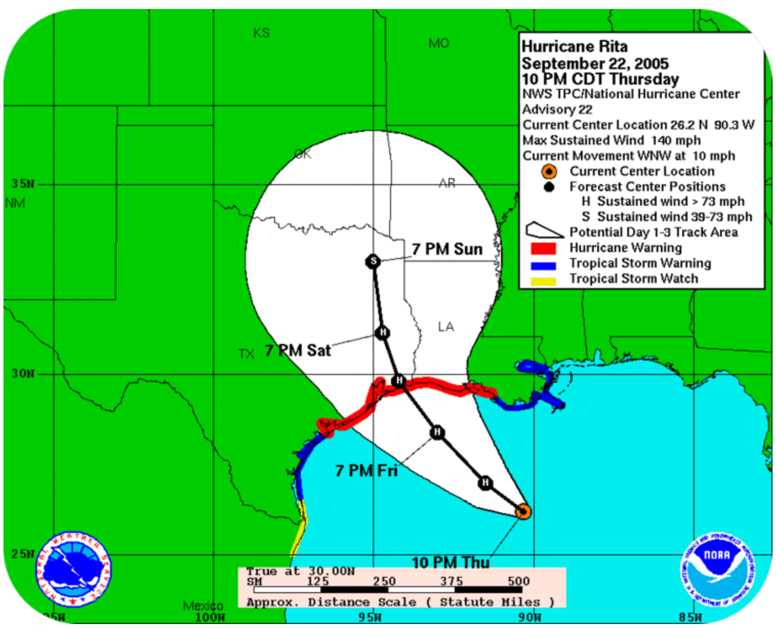


FIGURE 1.64
By predicting Hurricane Rita's path, it is likely that lives were saved.

Summary

- Meteorologists use computers to crank data through mathematical models to forecast the weather.
- Numerical weather prediction calculates what will happen to conditions horizontally and vertically over an area.
- Weather forecasts can go further into the future than ever.

Making Connections

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/54870

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=214h-SyMpe8

1. Explain how scientists monitor weather above Earth.
2. What does GIFTS stand for?
3. What does GIFTS do?
4. How will GIFTS be better than weather balloons?
5. How does gifts collect so much data?
6. What is remote sensing?
7. How does GIFTS sense water vapor?
8. What sort of predictions about hurricanes will scientists be able to make with GIFTS?
9. What winds will GIFTS be able to sense?

Explore More Answers

1. Geostationary satellites orbits Earth at about the same speed that Earth rotates. It collects weather data as it hovers over the same point on Earth. There is a network of these satellites.
2. Geostationary Imaging Fourier Transform Spectrometer
3. It is an instrument to be flown in a geostationary satellite. It provides a complete picture of the upper atmosphere conditions.
4. Balloons are far apart and rise only twice per day but GIFTS will give the same data every 10 seconds everywhere, over land and over the sea.
5. It uses infrared digital camera technology with several thousand times more sensors.
6. Staying away from something and knowing it's state.
7. The infrared camera senses the amount of heat the water vapor radiates.
8. Predict formation and intensity of storms, how much rain will fall and how severe the winds will be.
9. steering winds

Review

1. What is numerical weather prediction?
2. Even with numerical weather prediction, meteorologists have a difficult time predicting the path of a hurricane more than a day or two into the future. Why?
3. One popular online weather prediction site goes 10 days out and another goes 15 days out. Why the discrepancy?

Review Answers

1. In numerical weather prediction many sources of atmospheric data are crunched in supercomputers that can calculate what will happen over time across a grid.

2. Hurricanes don't always behave predictably. It is a chaotic system.
3. The additional five days it not very accurate. One site values accuracy and the other values the ability to predict further into the future.

1.31 Weather Maps

- Describe the information depicted on weather maps.
- Analyze weather maps.

What can a weather map tell you about the weather?

A lot! A weather map indicates all sorts of things to let you know the forecast. It also may have some cute graphics associated with it.

Weather Maps

Weather maps simply and graphically depict meteorological conditions in the atmosphere. Weather maps may display only one feature of the atmosphere or multiple features. They can depict information from computer models or from human observations.

On a weather map, important meteorological conditions are plotted for each weather station. Meteorologists use many different symbols as a quick and easy way to display information on the map (**Figure** 1.65).

Once conditions have been plotted, points of equal value can be connected by isolines. Weather maps can have many types of connecting lines. For example:

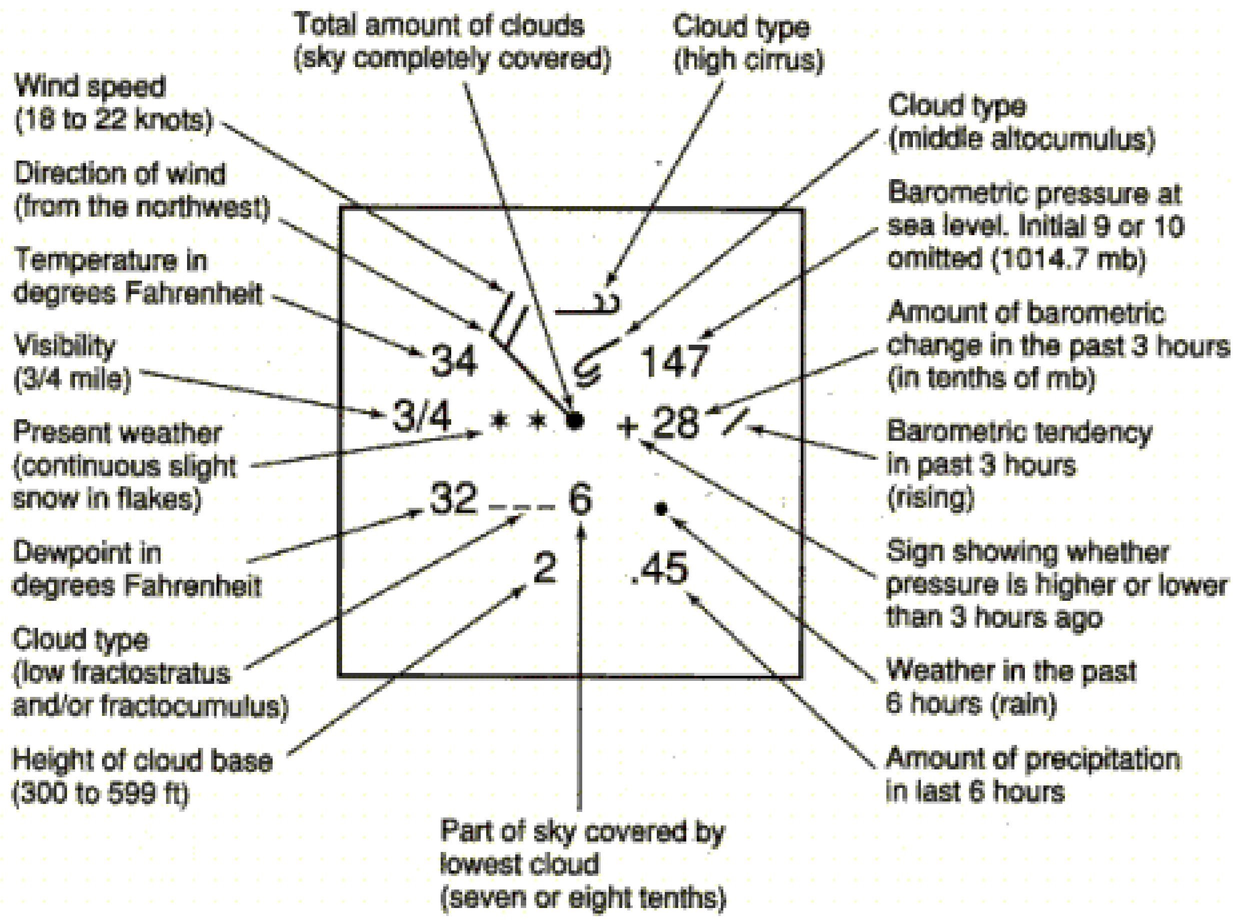


FIGURE 1.65

Explanation of some symbols that may appear on a weather map.

- Lines of equal temperature are called **isotherms**. Isotherms show temperature gradients and can indicate the location of a front. In terms of precipitation, what does the 0^oC (32^oF) isotherm show?

An animation on how to contour isotherms is seen here: Contouring isotherms https://courseware.e-education.psu.edu/public/meteo/meteo101demo/Examples/Shockwave/contouring0203.dcr .

- **Isobars** are lines of equal average air pressure at sea level (**Figure** 1.66). Closed isobars represent the locations of high and low pressure cells.

- **Isotachs** are lines of constant wind speed. Where the minimum values occur high in the atmosphere, tropical cyclones may develop. The highest wind speeds can be used to locate the jet stream.

Surface weather analysis maps are weather maps that only show conditions on the ground (**Figure** 1.67).

An online guide about to how to read weather maps from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/maps/home.rxml .

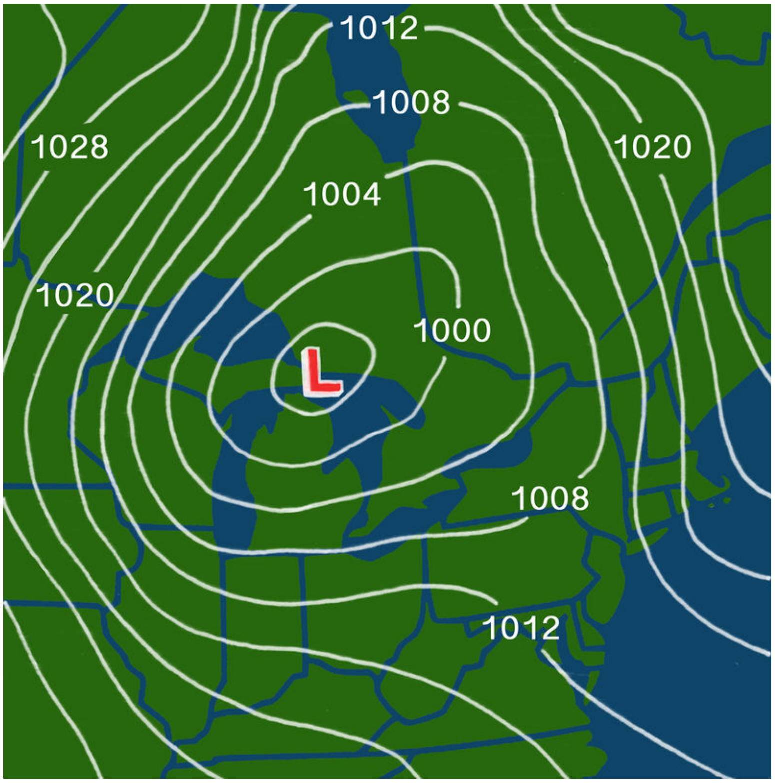


FIGURE 1.66
Isobars can be used to help visualize high pressure (H) and low pressure (L) cells.

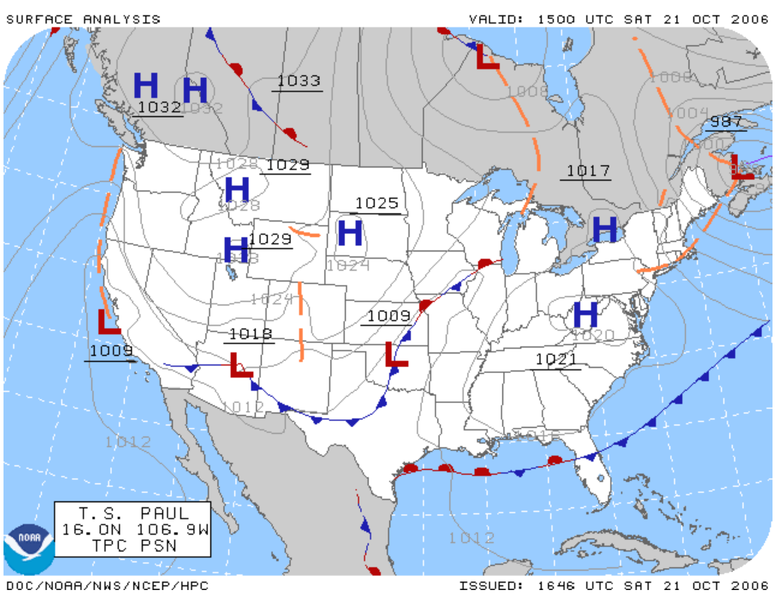


FIGURE 1.67
Surface analysis maps may show sea level mean pressure, temperature, and amount of cloud cover.

More about remote sensing of weather is discussed in this online guide: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/rs/home.rxml .

Summary

- Weather maps graphically depict weather conditions.

- Isotherms are lines of constant temperature; isobars are lines of constant pressure; isotachs are lines of constant wind speed.
- Isobars indicate pressure cells.

Explore More

Use these resources to answer the questions that follow.

https://www.youtube.com/watch?v=bd7DcVnrSL8

1. What is an isoline map?
2. What do isobars join?
3. What is the difference in air pressure between isolines on an American weather map?
4. How are high pressure areas identified on a weather map? What does that look like in real life?
5. How are low pressure areas identified on a weather map? What does that look like in real life?
6. If the H weren't on a weather map, how could you still tell there was a high pressure? How could you identify a low pressure?
7. What is a front? How does a front appear on a weather map?
8. What symbolizes a cold front on a weather map?
9. What symbolizes a warm front on a weather map?
10. What symbolizes a stationary front on a weather map?
11. What symbolizes an occluded front on a weather map?
12. How does wind blow relative to high and low pressure cells?
13. What does it mean when the the isolines are close together?

Explore More Answers

1. A map made of lines that join points of equal value.
2. Isobars join points of equal air pressure.
3. 4 mb
4. A letter H. IRL it looks like clear skies and little wind.
5. A letter L. IRL it looks like high winds, clouds and rain.
6. In a high pressure, the isolines form a circle and the numbers on the isolines rise toward the center. In a low pressure, the numbers on the isolines decrease toward the center.
7. A front is where two air masses meet. It is a line with circles or triangles attached.
8. A blue line with triangles indicating the direction of movement.
9. A red line with circles pointing in the direction of movement.
10. Alternating warm and cold front symbols.
11. A purple line with triangles and semi-circles.
12. Wind blows into low pressure cells and away from high pressure cells.
13. The wind is strong.

Review

1. What is the purpose of isolines on a weather map?
2. Define isobar, isotach, and isotherm.
3. How are high and low pressure cells indicated on a weather map?

Review Answers

1. Isolines indicate points that have equal value.
2. Isobars: lines of equal pressure at sea level; isotach: lines of constant wind speed; isotherm: lines of equal temperature
3. High are indicated by an H and low by an L.

1.32 Effect of Latitude on Climate

- Describe how latitude influences a region's climate, particularly its average temperature.

Where do you want to go on vacation?

If you live in a frigid climate you may want to go to lower latitudes for your mid-winter vacation. If you live in the desert, you may like to spend part of your summer at higher latitudes. Different climates are found at different latitudes.

Latitude

Many factors influence the climate of a region. The most important factor is latitude because different latitudes receive different amounts of solar radiation.

- The Equator receives the most solar radiation. Days are equally long year-round and the Sun is just about directly overhead at midday.
- The polar regions receive the least solar radiation. The night lasts six months during the winter. Even in summer, the Sun never rises very high in the sky. Sunlight filters through a thick wedge of atmosphere, making the sunlight much less intense. The high albedo, because of ice and snow, reflects a good portion of the Sun's light.

Temperature with Latitude

It's easy to see the difference in temperature at different latitudes in the **Figure** 1.68. But temperature is not completely correlated with latitude. There are many exceptions. For example, notice that the western portion of South America has relatively low temperatures due to the Andes Mountains. The Rocky Mountains in the United

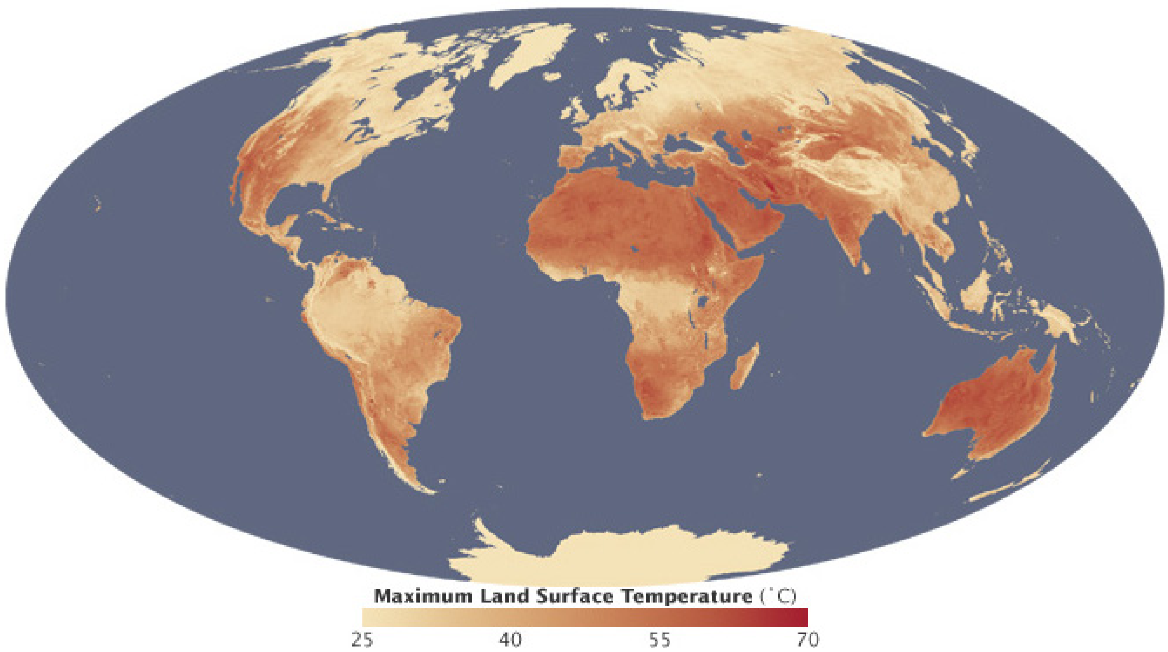


FIGURE 1.68
The maximum annual temperature of the Earth, showing a roughly gradual temperature gradient from the low to the high latitudes.

States also have lower temperatures due to high altitudes. Western Europe is warmer than it should be due to the Gulf Stream.

Summary

- The amount of solar radiation received by the planet is greatest at the Equator and lessens toward the poles.
- At the poles the Sun never rises very high in the sky and sunlight filters through a thick wedge of atmosphere.
- Latitude is not the only factor that determines the temperature of a region, as can be seen in the striped map above.

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=d1W2k6JksQY

1. Why does less solar radiation reach the poles?
2. What are the mean annual temperatures at the equator? What are they at the south pole?
3. How does latitude affect precipitation?
4. Where are the regions of rising air?
5. Where are the regions of sinking air?
6. Why are the Sahara and the deserts of the American Southwest at about the same latitude?
7. Why are there lots of forests at 60-degrees latitude? Why is this a stormy region?

8. How can the north and south poles be called deserts? Why is there snow there?

Explore More Answers

1. The same amount of solar radiation gets spread out over a larger area due to the curvature of the earth.
2. At the equator they are higher than 80-degrees F and at the south pole they are below -40-degrees F.
3. Air convects all over Earth. Where air is rising, there is more precipitation. Where air is sinking, there is less precipitation.
4. At the equator and at around 60-degrees north and south of the equator.
5. At the poles and at around 30-degrees north and south of the equator.
6. It is around 30-degrees latitude and it is where air is sinking.
7. Air is rising and so there is a lot of precipitation. It is a stormy region because very cold air from the poles meets warmer wetter air from the equator.
8. They get very little precipitation because air is sinking. When they do get precipitation it is snow and it never melts.

Review

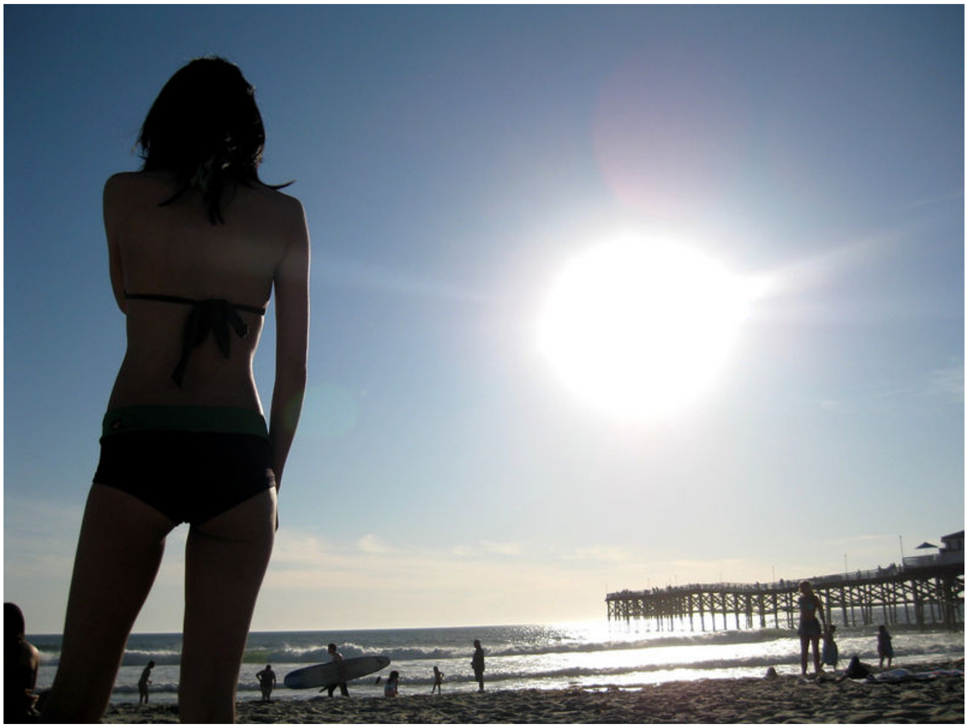
1. Why do the poles receive so much less solar radiation than the Equator considering that it's light for six months at the poles?
2. Why is latitude considered the most important factor in determining temperature?
3. Look at a map of geological features and look at the temperature map to try to determine why some of the exceptions exist. What's the realtively cool blob north of India?

Review Answers

1. It is also dark for six months a year at the poles. Also, the Sun never rises very high so the sunlight must filter through a thick wedge of atmosphere and it also must spread over a larger area.
2. The amount of solar radiation a location receives is the most important determinant of what the climate will be.
3. The Himalaya mountains are a location that is cooler than it should be just based on latitude.

1.33 Effect of Atmospheric Circulation on Climate

- Explain how major climate traits correlate with the positions of the atmospheric circulation cells.



Does it really never rain in California like the song says?

In California, the predominant winds are the westerlies blowing in from the Pacific Ocean, which bring in relatively cool air in summer and relatively warm air in winter. The winds do bring rain, quite a bit in northern California, but in San Diego there are only 10 inches a year on average.

Atmospheric Circulation Cells

The position of a region relative to the circulation cells and wind belts has a great affect on its climate. In an area where the air is mostly rising or sinking, there is not much wind.

The ITCZ

The **Intertropical Convergence Zone (ITCZ)** is the low pressure area near the Equator in the boundary between the two Hadley Cells. The air rises so that it cools and condenses to create clouds and rain (**Figure** 1.70). Climate along the ITCZ is therefore warm and wet. Early mariners called this region the doldrums because their ships were often unable to sail due to the lack of steady winds.

The ITCZ migrates slightly with the season. Land areas heat more quickly than the oceans. Because there are more land areas in the Northern Hemisphere, the ITCZ is influenced by the heating effect of the land. In Northern Hemisphere summer, it is approximately 5° north of the Equator, while in the winter it shifts back and is approximately at the Equator. As the ITCZ shifts, the major wind belts also shift slightly north in summer and south in winter, which causes the wet and dry seasons in this area (**Figure** 1.71).

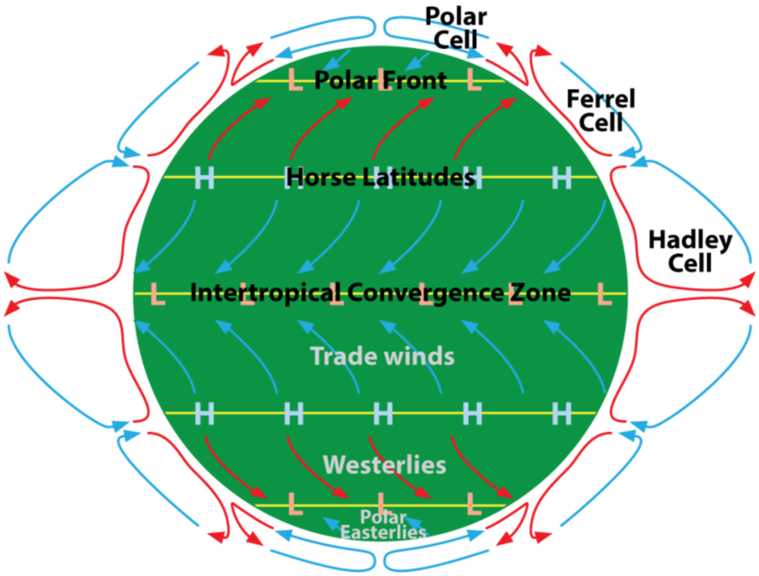


FIGURE 1.69
The atmospheric circulation cells and their relationships to air movement on the ground.

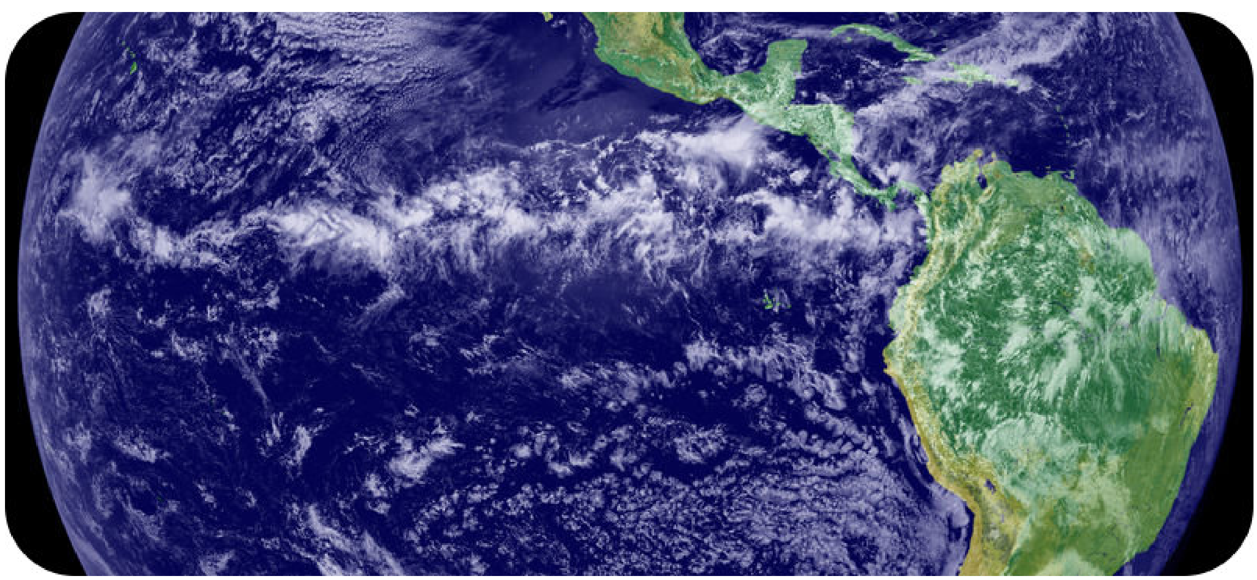


FIGURE 1.70
The ITCZ can easily be seen where thunderstorms are lined up north of the Equator.

Hadley Cell and Ferrell Cell Boundary

At about 30°N and 30°S, the air is fairly warm and dry because much of it came from the Equator, where it lost most of its moisture at the ITCZ. At this location the air is descending, and sinking air warms and causes evaporation.

Mariners named this region the horse latitudes. Sailing ships were sometimes delayed for so long by the lack of wind that they would run out of water and food for their livestock. Sailors tossed horses and other animals over the

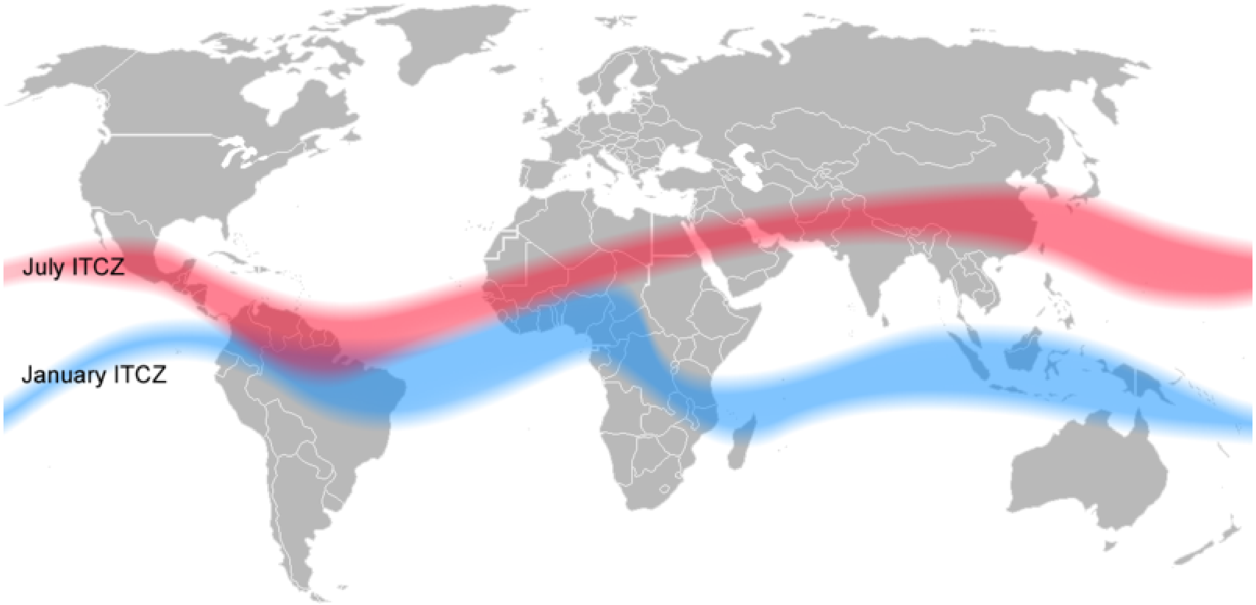


FIGURE 1.71
Seasonal differences in the location of the ITCZ are shown on this map.

side after they died. Sailors sometimes didn't make it either.

Ferrell Cell and Polar Cell Boundary

The polar front is around 50° to 60°, where cold air from the poles meets warmer air from the tropics. The meeting of the two different air masses causes the polar jet stream, which is known for its stormy weather. As the Earth orbits the Sun, the shift in the angle of incoming sunlight causes the polar jet stream to move. Cities to the south of the polar jet stream will be under warmer, moister air than cities to its north. Directly beneath the jet stream, the weather is often stormy and there may be thunderstorms and tornadoes.

Prevailing Winds

The prevailing winds are the bases of the Hadley, Ferrell, and polar cells. These winds greatly influence the climate of a region because they bring the weather from the locations they come from. Local winds also influence local climate. For example, land breezes and sea breezes moderate coastal temperatures.

Summary

- High and low pressure zones related to the atmospheric circulation cells are important in determining a region's climate.
- Prevailing winds influence the climate of a region because they bring in weather from the upwind area.
- Boundaries between cells are often known for winds and stormy weather due to the contact of different air masses.

Explore More

Use this resource to answer the questions that follow.

http://earthguide.ucsd.edu/eoc/middle_school_t/teachers/earth/sp_atmosphere/p_atmo_circulation_composite.html

1. What is the atmosphere?
2. How are winds named?
3. What happens when surface winds converge?
4. What occurs when surface winds diverge?
5. What is the ITCZ?
6. How does the ITCZ change with the seasons?
7. What is air pressure?
8. How does atmospheric pressure vary by latitude?

Explore More Answers

1. The envelope of air that moves about Earth.
2. Winds are named for the direction they come from.
3. Where surface winds converge air rises.
4. Where surface winds diverge air sinks.
5. The Intertropical Convergence Zone is an irregular boundary where the north and south tradewinds converge. The ITCZ moves toward the equator during winter and northward in the summer.
6. Atmospheric pressure is the force exerted on the ground by the mass of the overlying air column.
7. Areas near the equator and near 60 degrees have lower pressure, but areas at around 30 degrees and the poles have higher pressure.

Review

1. What are prevailing winds and how do they affect climate?
2. What is the ITCZ? How does its location affect weather?
3. Where is there not much wind?

Review Answers

1. The prevailing winds are at the bases of the major convection cells. They bring weather from the locations they come from.
2. The Intertropical Convergence Zone is a low pressure area near the equator that moves a bit north of the equator in the summer and to the equator in the winter. As it shifts the major wind belts shift also.
3. Where air is sinking or rising, where the major convection cells meet, has little wind.

1.34 Effect of Continental Position on Climate

- Define marine and continental climates, and explain how continental position and ocean currents affect climate.

What causes San Francisco's famous fog?

The California Current travels from the north and brings cold water to the region just offshore. The warm Mediterranean climate of coastal California contrasts with the cold water offshore and forms advection fog, which blows off the shore and up to a few miles inland. Fog under the Golden Gate Bridge is a common sight in the City by the Bay.

Continental Position

When a particular location is near an ocean or large lake, the body of water plays an extremely important role in affecting the region's climate.

- A **maritime climate** is strongly influenced by the nearby sea. Temperatures vary a relatively small amount seasonally and daily. For a location to have a true maritime climate, the winds must most frequently come off the sea.
- A **continental climate** is more extreme, with greater temperature differences between day and night and between summer and winter.

The ocean's influence in moderating climate can be seen in the following temperature comparisons. Each of these cities is located at 37^{o}N latitude, within the westerly winds (**Figure** 1.72).

The climate of San Francisco is influenced by the cool California current and offshore upwelling. Wichita has a more extreme continental climate. Virginia Beach, though, is near the Atlantic Ocean. Why is the climate there less influenced by the ocean than is the climate in San Francisco? Hint: Think about the direction the winds are going at that latitude. The weather in San Francisco comes from over the Pacific Ocean while much of the weather in Virginia comes from the continent.

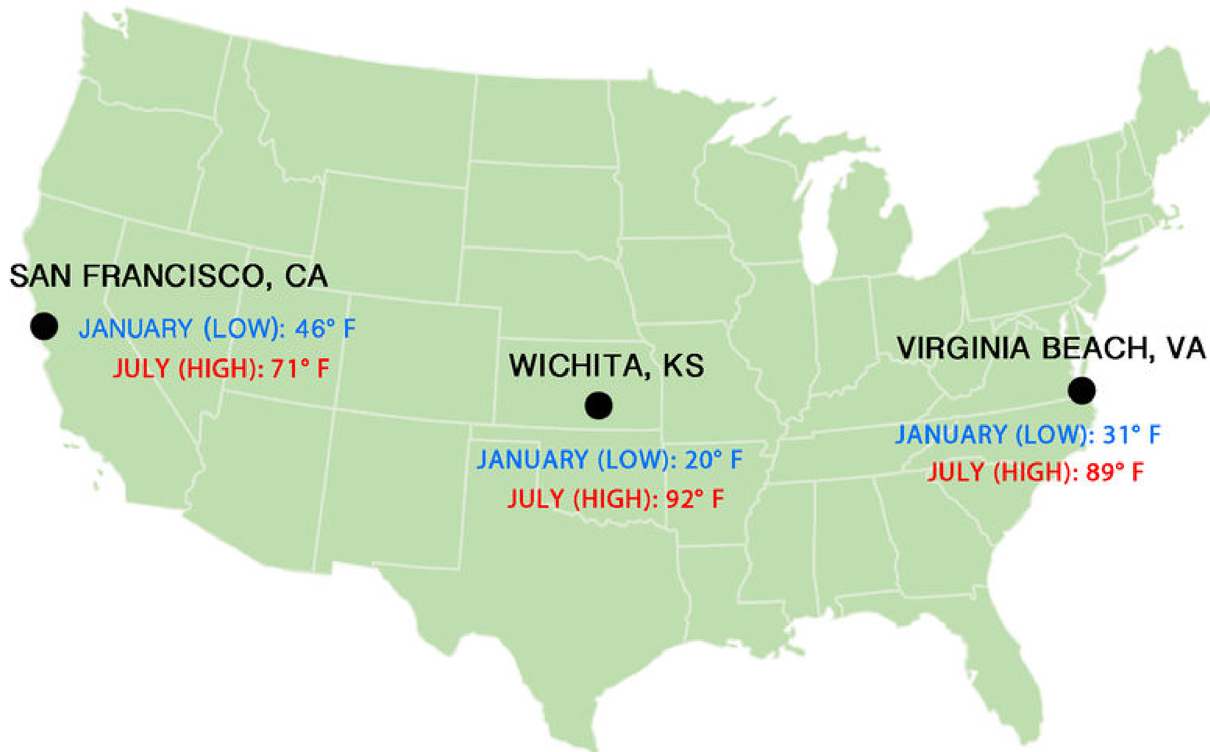


FIGURE 1.72
How does the ocean influence the climate of these three cities?

Ocean Currents

The temperature of the water offshore influences the temperature of a coastal location, particularly if the winds come off the sea. The cool waters of the California Current bring cooler temperatures to the California coastal region. Coastal upwelling also brings cold, deep water up to the ocean surface off of California, which contributes to the cool coastal temperatures. Further north, in southern Alaska, the upwelling actually raises the temperature of the surrounding land because the ocean water is much warmer than the land. The important effect of the Gulf Stream on the climate of northern Europe is described in the chapter Water on Earth.

Summary

- A maritime climate is influenced by a nearby ocean. A continental climate is influenced by nearby land.
- The temperature of offshore currents affect nearby land areas.
- A maritime climate is less extreme than a continental climate because the ocean moderates temperatures.

Explore More

Use this resource to answer the questions that follow.

http://www.watchmojo.com/index.php?id=6521

Multimedia

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/60968

1. What does the temperature depend on across the U.S.?
2. What influences the weather in California?
3. What is the temperature variation between the coast and inland in the summer? Where is the warmer weather?
4. What is the temperature variation between the coast and inland in the winter?
5. How much rainfall does the redwood forest receive?
6. California is good for beach bums and snow bunnies, but can they both be happy at the same time in the state?

Explore More Answers

1. Temperature depends on the position within the U.S. and distance from the pacific Ocean.
2. The Pacific Ocean.
3. Approximately 25-degrees F with the warmer temperatures in the inland areas.
4. Approximately 7-degrees F.
5. over 100 inches per year
6. It is possible that beaches will be warm enough for visits when there is still spring and early summer snow for skiing.

Review

1. If upwelling stopped off of California, how would climate be affected?
2. From which direction would weather come to a city at 65-degrees north?
3. Why is the climate of San Francisco so different from the climate of Virginia Beach when both are near an ocean?

Review Answers

1. Upwelling cools off the water off the coast so it cools down the coastal areas.
2. At that latitude weather would come from the east.
3. The prevailing winds at that latitude are from west to east so SF gets a much greater influence from the pacific than Virginia Beach does fro the Atlantic.

1.35 Effect of Altitude and Mountains on Climate

- Explain how altitude and mountain ranges affect climate.
- Define rainshadow effect.

Are they worms crawling across the landscape?

This image shows the difference in climate between mountain ranges and the surrounding lands.

Altitude and Mountain Ranges

Air pressure and air temperature decrease with altitude. The closer molecules are packed together, the more likely they are to collide. Collisions between molecules give off heat, which warms the air. At higher altitudes, the air is less dense and air molecules are more spread out and less likely to collide. A location in the mountains has lower average temperatures than one at the base of the mountains. In Colorado, for example, Lakewood's (5,640 feet) average annual temperature is 62^{o}F (17^{o}C), while Climax Lake's (11,300 feet) is 42^{o}F (5.4^{o}C).

Mountain ranges have two effects on the climate of the surrounding region:

- rainshadow effect, which brings warm, dry climate to the leeward side of a mountain range (**Figure** 1.73).
- separation in the coastal region from the rest of the continent. Since a maritime air mass may have trouble rising over a mountain range, the coastal area will have a maritime climate but the inland area on the leeward side will have a continental climate.

FIGURE 1.73
The Bonneville Salt Flats are part of the very dry Great Basin of the Sierra Nevada of California. The region receives little rainfall.

Five factors that Affect Climate takes a very thorough look at what creates the climate zones. The climate of a region allows certain plants to grow, creating an ecological biome: http://www.youtube.com/watch?v=E7DLLxrrBV8 (5:23).

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/1588

Summary

- Collisions between molecules increase temperature: where air is denser, the air temperature is higher.
- Rainshadow effect occurs on the leeward side of a mountain range.
- Maritime air may become stuck on the windward side of a mountain range and so is unable to bring cooler air further inland.

Explore More

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=yuvy4nLtWk4

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/1589

1. What happens when wind crashes into a mountain range?
2. What weather occurs on the windward side of a mountain?
3. What is the climate on the windward side of the mountain relative to the leeward side of the mountain?
4. What are rain shadow deserts?
5. Describe the characteristics seen on the windward side of the Sierra Nevada Mountains.
6. Describe the characteristics see on the leeward side of the Sierra Nevada Mountains.

Explore More Answers

1. It rises, expands, cools and condenses.
2. The air rises so there are clouds and rain.
3. The climate on the windward side of the mountain is much cooler and wetter than on the leeward side, where it is warmer and drier.
4. The region is so dry that it is a desert.
5. On the windward side of the Sierra Nevada, to the west, the wind rises and so it condenses and rain falls. There are forests and lakes with lots of rain and snow in winter.
6. The difference is stark. It is very dry and there are sand dunes. There is not a great deal of vegetation.

Review

1. Why does an increase in altitude cause a change in temperature?

2. What is rainshadow effect?
3. Besides rainshadow effect, how else do mountains affect weather downwind?

Review Answers

1. At sea level the gas molecules are packed closer together so they are more likely to collide and the air is warmer. At higher altitudes there is less gravity so the molecules are not packed so closely together and they do not collide as much.
2. Rainshadow effect is when air goes over a mountain and drops its moisture on the windward side, plus as it descends on the leeward side it arms and is able to hold more moisture so it evaporates rather than precipitates water.
3. A mountain range can separate air from the rest of the country, especially dense air that can't climb over the mountain range.

1.36 Climate Zones and Biomes

- Define biome and microclimate.
- Describe the major climate zones and explain how they relate to biomes.

How do plants that evolved without any genetic interaction end up being so similar?

Organisms evolve to fit the conditions they are in. There are only so many ways to minimize the use of water, so plants in arid climates evolve very similar structures for that purpose. There are many instances of parallel evolution in widely separated organisms.

Climate Zones and Biomes

The major factors that influence climate determine the different climate zones. In general, the same type of climate zone will be found at similar latitudes and in similar positions on nearly all continents, both in the Northern and Southern Hemispheres. The exceptions to this pattern are the climate zones called the continental climates, which are not found at higher latitudes in the Southern Hemisphere. This is because the Southern Hemisphere land masses are not wide enough to produce a continental climate.

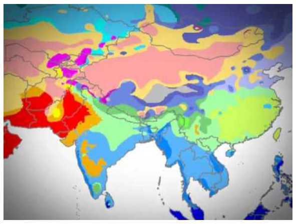
Classification

Climate zones are classified by the Köppen classification system. This system is based on the temperature, the amount of precipitation, and the times of year when precipitation occurs. Since climate determines the type of vegetation that grows in an area, vegetation is used as an indicator of climate type.

Biomes

A climate type and its plants and animals make up a **biome**. The organisms of a biome share certain characteristics around the world, because their environment has similar advantages and challenges. The organisms have adapted to that environment in similar ways over time. For example, different species of cactus live on different continents, but they have adapted to the harsh desert in similar ways.

The similarities between climate zones and biome types are displayed in this video: http://www.youtube.com/watch?v=Z_THTbynoRA (1:01).



MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/1580

Major Climate Groups

The Köppen classification system recognizes five major climate groups. Each group is divided into subcategories. Some of these subcategories are forest, monsoon, and wet/dry types, based on the amount of precipitation and season when that precipitation occurs (**Figure** 1.74).

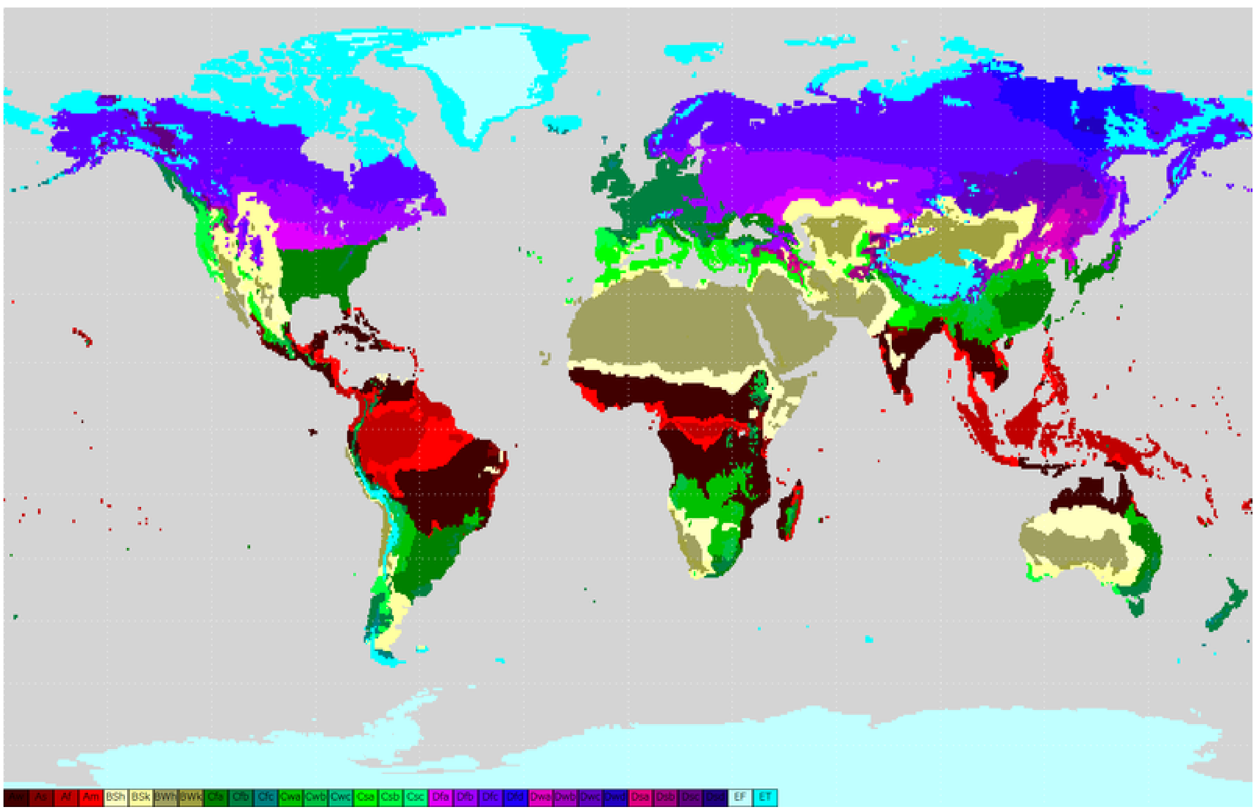


FIGURE 1.74

This world map of the Köppen classification system indicates where the climate zones and major biomes are located.

Tropical Moist Climates

Tropical moist climates are found in a band about 15^o to 25^o N and S of the Equator (**Figure** 1.74).

- Temperature: Intense sunshine. Each month has an average temperature of at least 18^oC (64^oF).
- Rainfall: Abundant, at least 150 cm (59 inches) per year.

The main vegetation for this climate is the tropical rainforest.

Dry Climates

Dry climates have less precipitation than evaporation.

- Temperature: Abundant sunshine. Summer temperatures are high; winters are cooler and longer than in tropical moist climates.
- Rainfall: Irregular; several years of drought are often followed by a single year of abundant rainfall. Dry climates cover about 26% of the world's land area.

Low latitude deserts are found at the Ferrell cell high pressure zone. Higher latitude deserts occur within continents or in rainshadows. Vegetation is sparse but well adapted to the dry conditions.

Moist Subtropical Mid-latitude

Moist subtropical mid-latitude climates are found along the coastal areas in the United States.

- Temperature: The coldest month ranges from just below freezing to almost balmy, between -3^oC and 18^oC (27^o to 64^oF). Summers are mild, with average temperatures above 10^oC (50^oF). Seasons are distinct.
- Rainfall: There is plentiful annual rainfall.

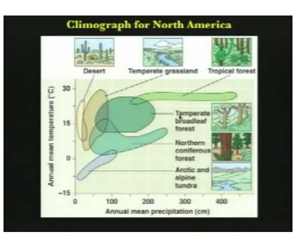
Continental Climates

Continental climates are found in most of the North American interior from about 40°N to 70°N.

- Temperature: The average temperature of the warmest month is higher than 10°C (50°F) and the coldest month is below -3°C (27°F).
- Precipitation: Winters are cold and stormy (look at the latitude of this zone and see if you can figure out why). Snowfall is common and snow stays on the ground for long periods of time.

Trees grow in continental climates, even though winters are extremely cold, because the average annual temperature is fairly mild. Continental climates are not found in the Southern Hemisphere because of the absence of a continent large enough to generate this effect.

This "Ecosystem Ecology" video lecture at U.C. Berkley outlines the factors that create climate zones and consequently the biomes: http://www.youtube.com/watch?v=3tY3aXgX4AM (46:46).



MEDIA

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URL: http://gamma.ck12.org/flx/render/embeddedobject/1581

Polar Climates

Polar climates are found across the continents that border the Arctic Ocean, Greenland, and Antarctica.

- Temperature: Winters are entirely dark and bitterly cold. Summer days are long, but the Sun is low on the horizon so summers are cool. The average temperature of the warmest month is less than 10^{o}C (50^{o}F). The annual temperature range is large.
- Precipitation: The region is dry, with less than 25 cm (10 inches) of precipitation annually; most precipitation occurs during the summer.

Microclimates

When climate conditions in a small area are different from those of the surroundings, the climate of the small area is called a **microclimate**. The microclimate of a valley may be cool relative to its surroundings since cold air sinks. The ground surface may be hotter or colder than the air a few feet above it, because rock and soil gain and lose heat readily. Different sides of a mountain will have different microclimates. In the Northern Hemisphere, a south-facing slope receives more solar energy than a north-facing slope, so each side supports different amounts and types of vegetation.

Altitude mimics latitude in climate zones. Climates and biomes typical of higher latitudes may be found in other areas of the world at high altitudes.

Summary

- A biome is a climate zone and the plants and animals that live in it.
- The Koppen classification system divides climates into five major types and many subtypes based on temperature and humidity characteristics.
- A microclimate has different climate conditions from the surrounding regions.

Explore More

Use this resource to answer the questions that follow.

http://science.howstuffworks.com/life/biomes-videos-playlist.htm [CK-12: Put in all 5 parts]

1. What is a biome?
2. How are biomes related to latitude?
3. Why are members of a biome similar even if the landmasses have not been connected for millions of years?
4. What defines a desert? Are all deserts hot?
5. How are cacti adapted to the desert?
6. Why is a desert bloom so spectacular?
7. What are some of the strategies desert animals use for surviving in the desert?
8. How do ectothermic {cold-blooded) animals live in the desert?
9. What is a savannah?
10. How do large herbivores protect the environment they live in?
11. Why do herbivores live in large groups?
12. Why are some animals nocturnal?
13. What are the temperate biomes? What is the difference between the two?
14. What do deciduous trees do?
15. Why is a deciduous forest a difficult environment to adapt to?
16. Why do temperate grasslands have lower biodiversity than the deciduous forest?

17. Why do grassland animals dig burrows?

Explore More Answers

1. A biome is a a major ecological community that ecosystems with similar climate and organisms.
2. Biomes are related to climate zones, which are related to latitude.
3. Certain types of plants can life in a biome and the characteristics of those plants affect the herbivores and carnivores that live in the biome.
4. All deserts have low precipitation, but they can be hot or cold or something in between.
5. They have extensive root systems to collect surface rainfall and reach distant water sources. They store water in stems roots or leaves. Leaves are sharp spines to deter herbivores, and leaves have waxy coverings to protect water.
6. Seeds can remain dormant for years but if enough water falls they will bloom.
7. Some are nocturnal, they have small body and long appendages for more cooling, fur and feathers has light color to reflect heat.
8. They alternate time in sun with time in shade or underground.
9. A savannah is a grassland with shrubs and trees, with low precipitation and high temperatures.
10. They eat bushes and trees when they are small so they do not take over the land.
11. As protection from predators.
12. To escape the heat of the day.
13. grasslands and deciduous forests; the amount of moisture makes the difference between the two. Temperate deciduous forests get a lot of rainfall while grasslands get much less.
14. They lose their leaves in winter and grow them in summer.
15. It is hot in summer and cold in winter.
16. It can be very dry.
17. There are no trees to live in or nest in.

Review

1. How does a biome relate to a climate zone?
2. How does a region develop its own microclimate?
3. Where do you think dry climates are located? Where are subtropical climates located?

Review Answers

1. The organisms that can live in an area are determined by the climate zone.
2. the region is somehow different fro the surrounding region so its climate will differ from the rest.
3. Dry climates are located where there is a high pressure cell due to global atmospheric circulation or on the leeward side of mountains.

Summary

The layers of the atmosphere are divided by their temperature gradients. The lowest layer is the troposphere, where all weather takes place. The next layer is the stratosphere, which contains the protective ozone layer. The density of the gases decreases with altitude and generally so does temperature. More solar energy strikes at the Equator and this is what drives the global winds. Warm air rises, moves poleward, and then sinks when it meets with air moving toward the Equator. The result is six atmospheric circulation cells, three in each hemisphere. Local differences in temperature also create winds. Where the air is stable for at least a few days, the conditions of the land or water beneath the air alter the air and so creates an air mass. Interactions between air masses bring about a lot of weather; for example, the thunderstorms and tornadoes that form along a front. Weather prediction is much better than it was in past years, due in part to the information gleaned from satellites. Climate is the long-term average of weather. The climate of a location depends on its latitude, position relative to the atmospheric circulation cells, position on a continent, altitude, and position relative to mountains. Where climate is roughly the same, there is a climate zone. The organisms that live within a climate zone create a unique biome.

1.37 References

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