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Science 10: Weather

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Contents

CONCEPT 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?

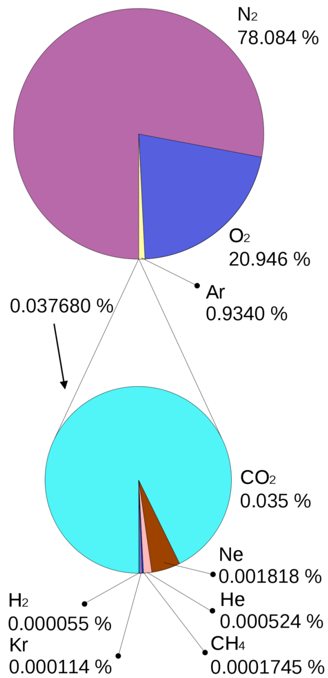

FIGURE 1.1
The composition of Earth's atmosphere.

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:

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

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:

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

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.

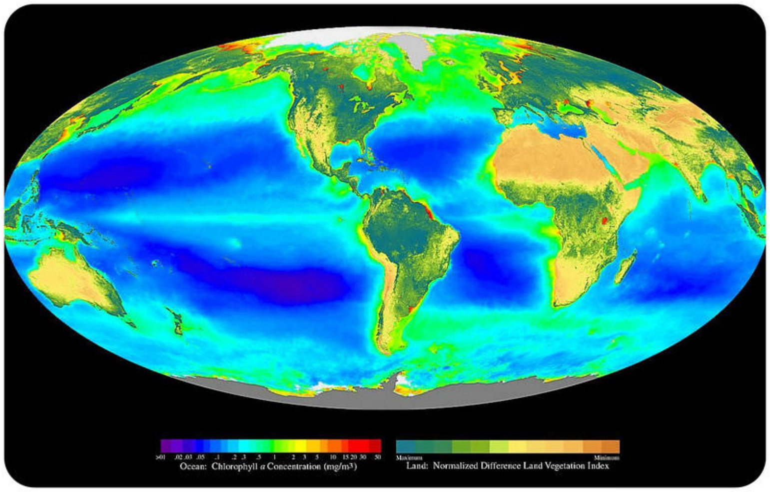

FIGURE 1.2
Chlorophyll indicates the presence of photosynthesizing plants as does the vegetation index.

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.

MEDIA
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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.

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?

Explore More

Use these resources to answer the questions that follow.

MEDIA
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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?

References

1. User:Mysid/Wikipedia. Composition of the atmosphere . Public Domain
2. Provided by the SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE. Satellite image of the plant coverage of the world . Public Domain

CONCEPT 2 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^oC per 1,000 m (3.6^oF 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** 2.1).

FIGURE 2.1
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.

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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.

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.

Explore More

Use this resource to answer the questions that follow.

MEDIA
Click image to the left or use the URL below.
URL: https://www.ck12.org/flx/render/embeddedobject/178110

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?

References

1. Ed Dunens. Picture of a temperature inversion . CC BY 2.0

CONCEPT 3 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.

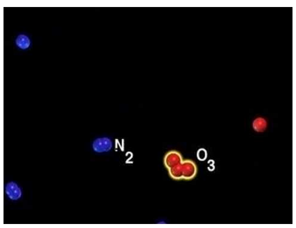
Because warmer, less dense air sits over cooler, denser air, air in the stratosphere is stable. As a result, there is little mixing of air within the layer. There is also little interaction between the troposphere and stratosphere for this reason.

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.



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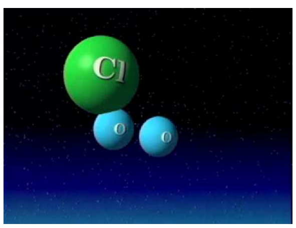

MEDIA

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Summary

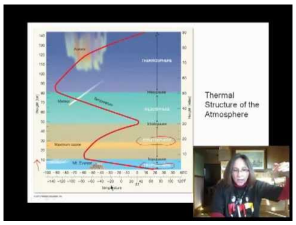
- There is little mixing between the troposphere, where all the turbulence is, and the stratosphere.
- Ozone gas protects life on Earth from harmful UV light, which damages cells.
- The ozone layer, in the stratosphere, has a higher concentration of ozone than other spots in the atmosphere.

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?

Explore More

Use this resource (watch up to 5:24) to answer the questions that follow.



MEDIA

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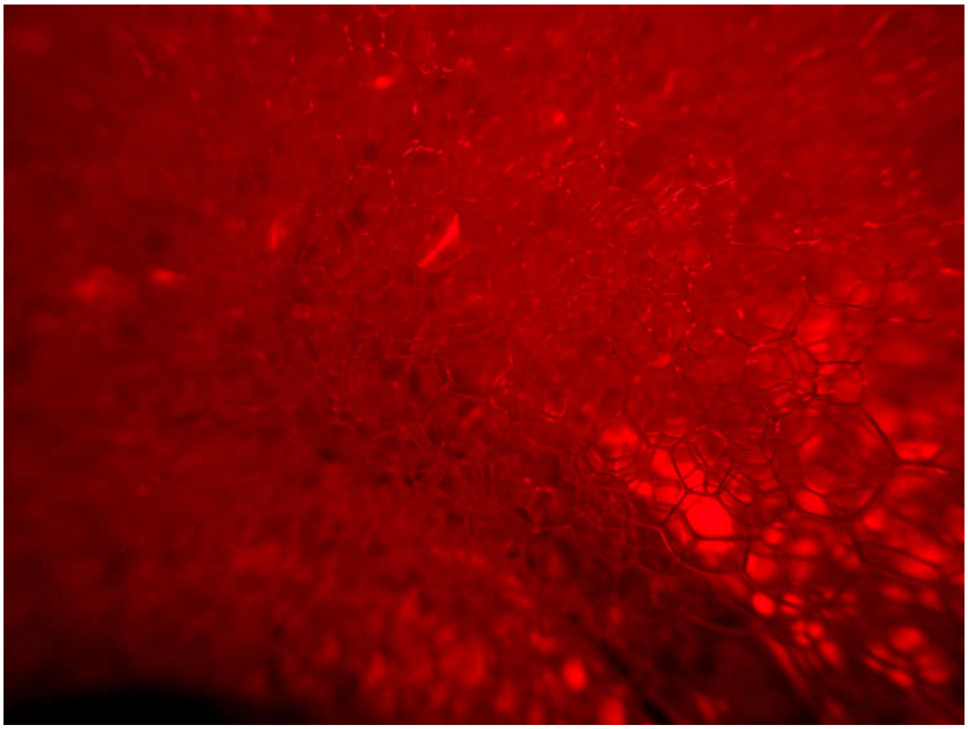
1. What does the figure tell you about what happens to air temperature when you climb a mountain?
2. What happens to temperature with altitude in the stratosphere?
3. Why does the stratosphere have that temperature gradient?
4. What tops the stratosphere?
5. What is the most important feature of the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

CONCEPT 4 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** 4.1). 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.

FIGURE 4.1
Although the mesosphere has extremely low pressure, it occasionally has clouds. The clouds in the photo are mesopheric clouds called **noctilucent clouds**.

MEDIA
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URL: https://www.ck12.org/flx/render/embeddedobject/186458

Summary

- The mesosphere has a very low density of gas molecules.
- Temperature decreases in the mesosphere with altitude because the heat source is the stratosphere.
- The mesosphere is no place for human life!

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?

Explore More

Use this resource to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/178114

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?

References

1. Jan Erik Paulsen. Noctilucent clouds in the mesosphere . CC BY 2.0

Concept 5 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** 5.1). 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.

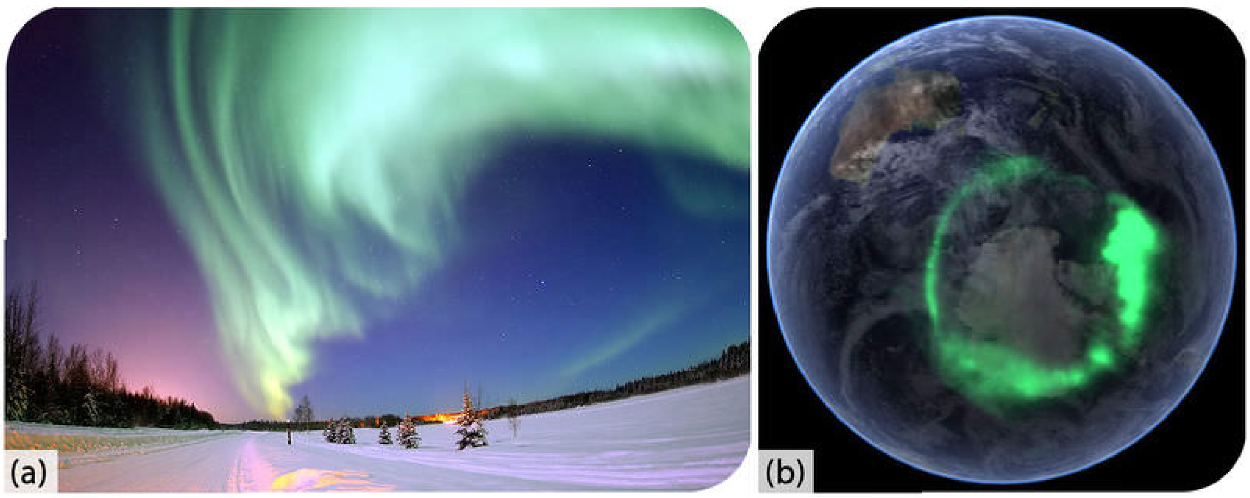

FIGURE 5.1

(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.

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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.

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?

Explore More

Use this resource to answer the questions that follow.

MEDIA

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URL: https://www.ck12.org/flx/render/embeddedobject/178116

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?

References

1. (a) Courtesy of Senior Airman Joshua Strang, United States Air Force; (b) Courtesy of NASA. Picture of the aurora borealis and aurora australis . Public Domain

CONCEPT 6 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** 6.1).

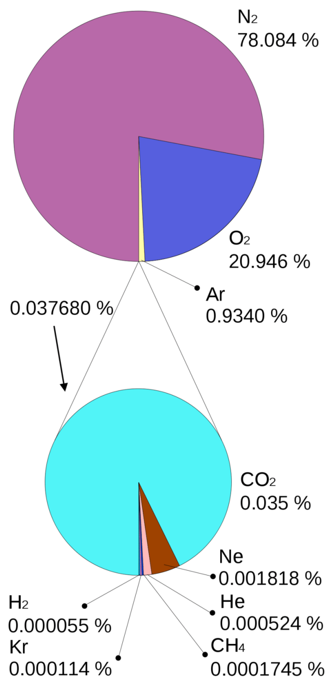

FIGURE 6.1

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

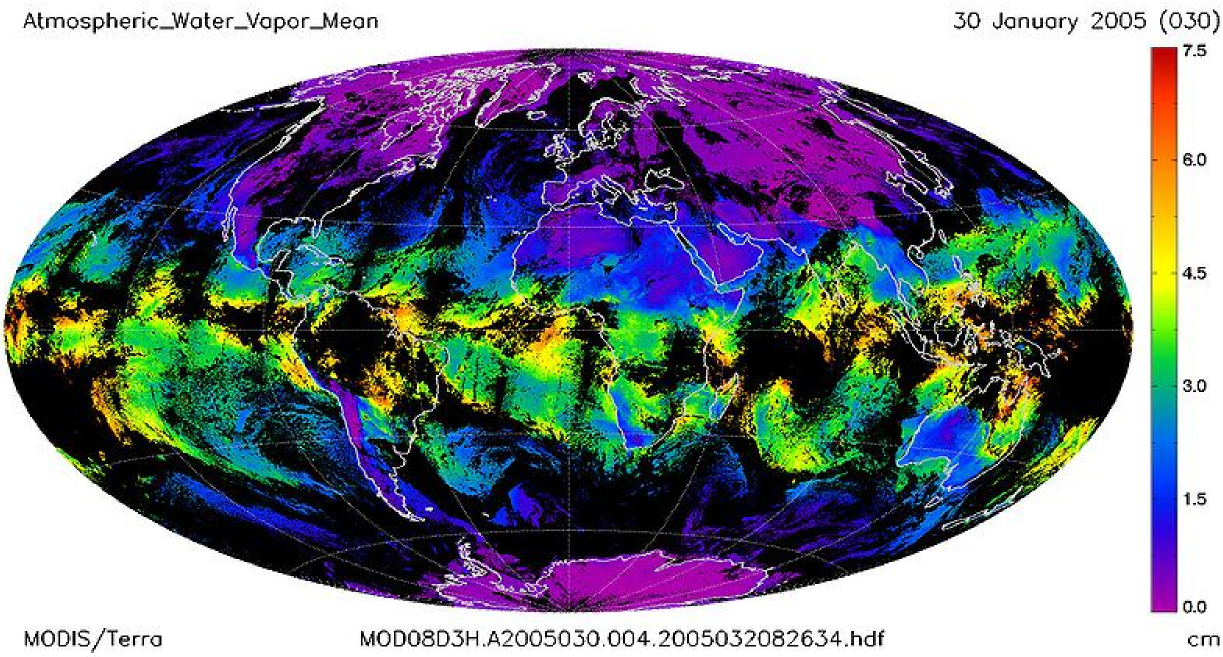

FIGURE 6.2

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

MEDIA

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URL: https://www.ck12.org/flx/render/embeddedobject/186442

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.

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?

Explore More

Use this resource to answer the questions that follow.

MEDIA
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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?

References

1. User:Mysid/Wikipedia. The composition of the atmosphere . Public Domain
2. Courtesy of MODIS/NASA. Map of the average atmospheric water vapor . Public Domain

CONCEPT 7 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.

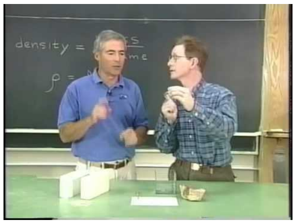
Pressure and Density

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** 7.1).

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.



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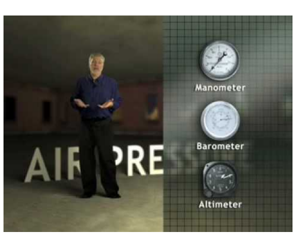
Pressure

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 7.1

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.



MEDIA

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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.

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?

Explore More

Use this resource to answer the questions that follow.

MEDIA
Click image to the left or use the URL below.
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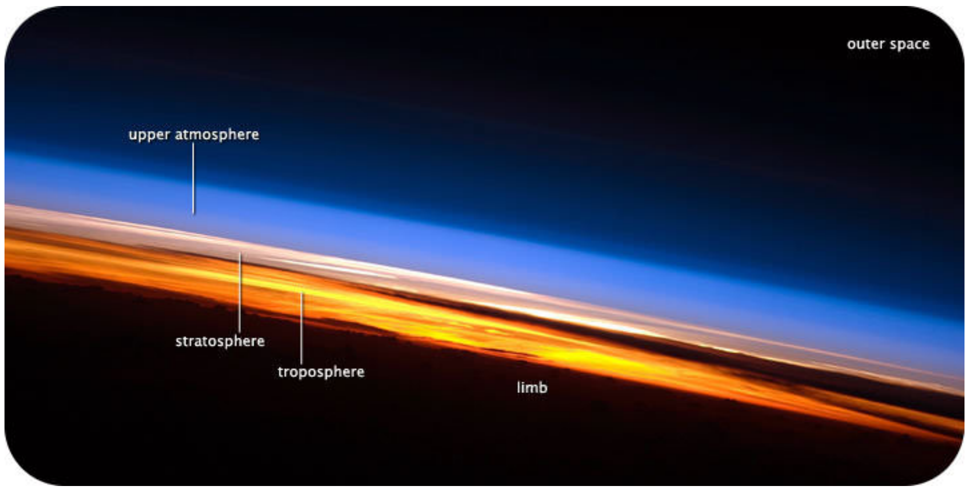
1. What force creates atmospheric pressure?
2. Where is atmospheric pressure greatest?
3. What is pressure? In what units is it expressed?
4. Why don't we collapse due to air pressure?
5. Why does the water stay in the glass when the card is on it?
6. Why couldn't we live without atmospheric pressure?

References

1. Andrew Gatt. Water bottle collapsing due to greater air pressure at lower altitudes . CC BY 2.0

CONCEPT 8 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** 8.1)? 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.

FIGURE 8.1
Papers held up by rising air currents above a radiator demonstrate the important principle that warm air rises.

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**.

Layers

The atmosphere is divided into layers based on how the temperature in that layer changes with altitude, the layer's temperature gradient (**Figure** 8.2). 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).

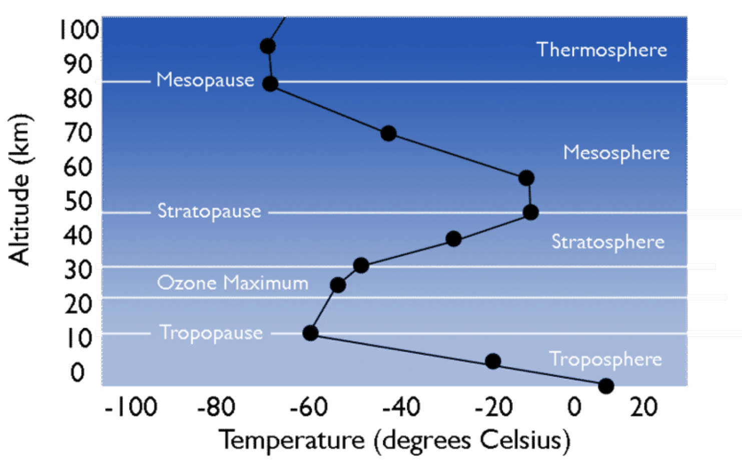
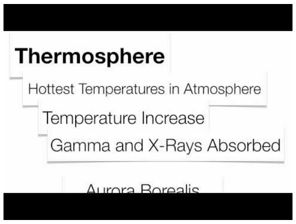


FIGURE 8.2
The four main layers of the atmosphere have different temperature gradients, creating the thermal structure of the atmosphere.

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.



MEDIA

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URL: https://www.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.

Review

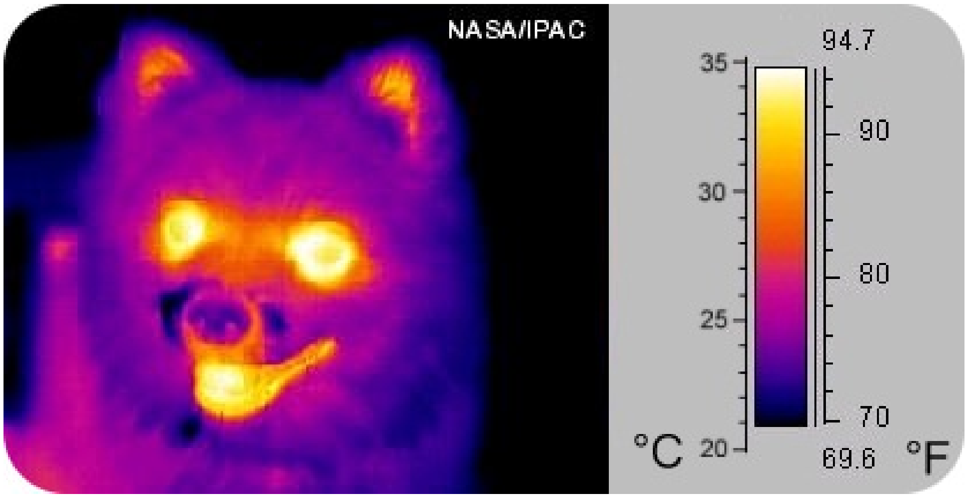
1. What causes convection in the atmosphere?
2. Why do the different layers of the atmosphere have different temperature gradients?
3. What is temperature gradient?

References

1. User:SCEhardt/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Convection_demo_with_radiator_and_papers.jpg . Public Domain
2. Sam McCabe. CK-12 Foundation . CC BY-NC 3.0

CONCEPT 9 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** 9.1). 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** 9.2). Ozone completely removes UVC, most UVB, and some UVA from incoming sunlight. O_2, CO_2, and H_2O also filter out some wavelengths.

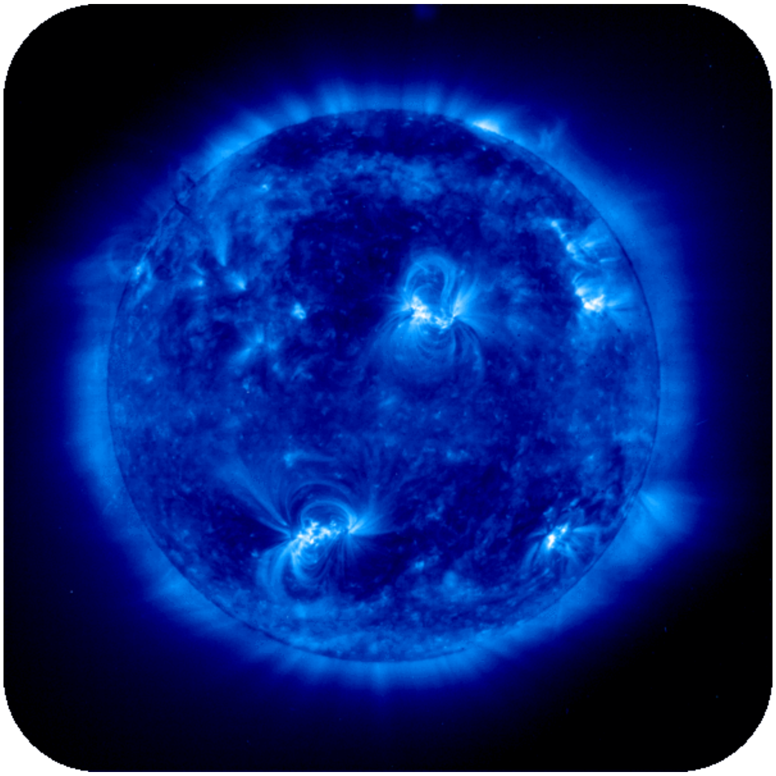


FIGURE 9.1
An image of the Sun taken by the SOHO spacecraft. The sensor is picking up only the 17.1 nm wavelength, in the ultraviolet wavelengths.

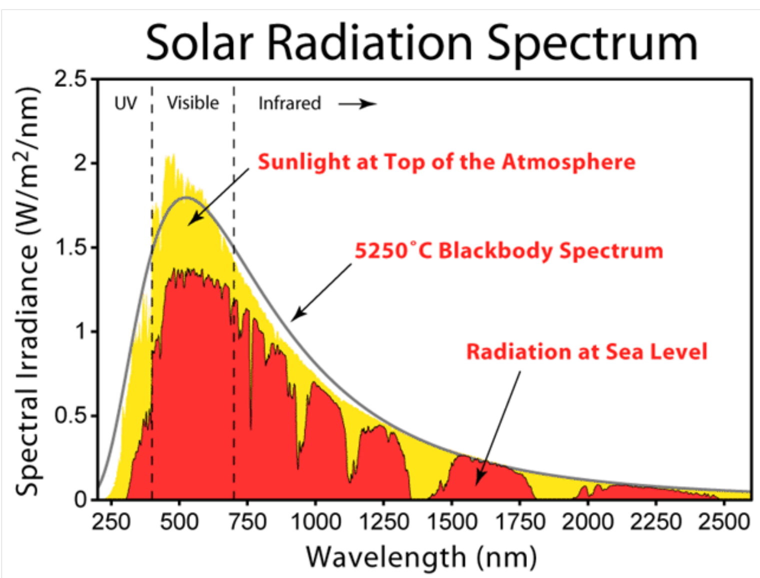
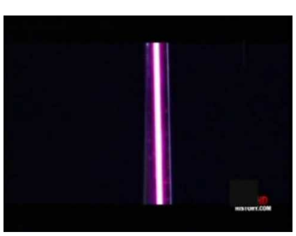


FIGURE 9.2
Atmospheric gases filter some wavelengths of incoming solar energy. Yellow shows the energy that reaches the top of the atmosphere. Red shows the wavelengths that reach sea level. Ozone filters out the shortest wavelength UV and oxygen filters out most infrared.



MEDIA
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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.

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** 9.2. What happens to the highest wavelengths of energy at Earth's surface?

Explore More

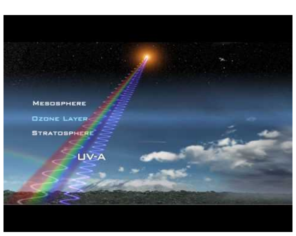
Use these resources to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: https://www.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?



MEDIA

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URL: https://www.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?

References

1. Courtesy of SOHO and NASA. Ultraviolet image of theSun . Public Domain
2. Courtesy of the US Government. The solar radiation spectrum . Public Domain

CONCEPT 10 Solar Energy and Latitude

- Describe the different amounts of solar energy that strike at different latitudes.

This is Antarctica. What season is this?

The Sun is always up, even in the middle of the night. That's the photo on the left. In the day, the Sun never gets too high in the sky. That's the photo on the right. So, this is summer. In the winter, it's just dark in Antarctica.

Energy and Latitude

Different parts of Earth's surface receive different amounts of sunlight (**Figure** 10.1). The Sun's rays strike Earth's surface most directly at the Equator. This focuses the rays on a small area. Near the poles, the Sun's rays strike the surface at a slant. This spreads the rays over a wide area. The more focused the rays are, the more energy an area receives, and the warmer it is.

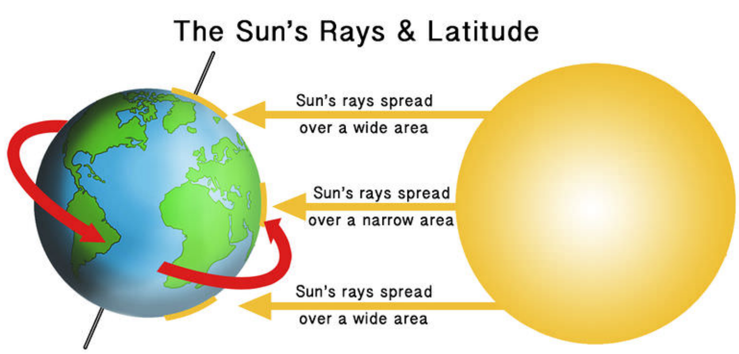


FIGURE 10.1
The lowest latitudes get the most energy from the Sun. The highest latitudes get the least.

The difference in solar energy received at different latitudes drives **atmospheric circulation**. Places that get more solar energy have more heat. Places that get less solar energy have less heat. Warm air rise, and cool air sinks. These principles mean that air moves around the planet. The heat moves around the globe in certain ways. This determines the way the atmosphere moves.

Summary

- A lot of the solar energy that reaches Earth hits the Equator.
- Much less solar energy gets to the poles.
- The difference in the amount of solar energy drives atmospheric circulation.

Review

1. The North Pole receives sunlight 24 hours a day in the summer. Why does it receive less solar radiation than the Equator?
2. What part of Earth receives the most solar radiation in a year? Why?
3. What makes the atmosphere move the way it does?

References

1. Laura Guerin. Diagram of latitude and energy received . CC BY-NC 3.0

CONCEPT 11 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** 11.1).

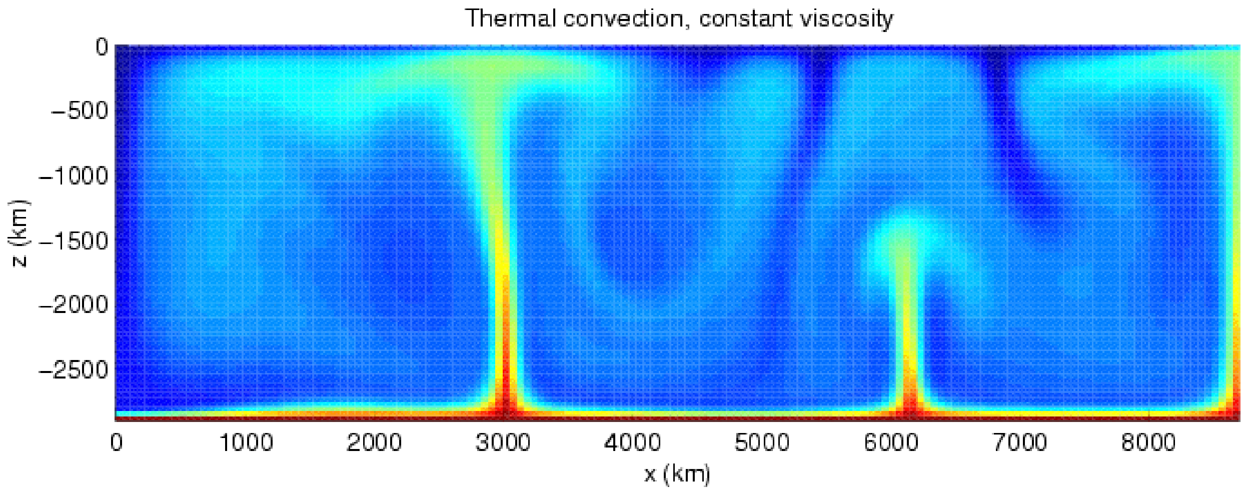


FIGURE 11.1

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

MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/186462

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.

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.

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?

Explore More

Use this resource to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: https://www.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?

References

1. User:Harroschmeling/De.Wikipedia. Picture of convection cells in the atmosphere . Public Domain

CONCEPT 12 Heat Budget of Planet Earth

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

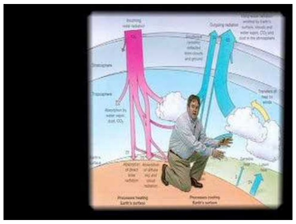
How does heat on Earth resemble a household budget?

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.



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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** 12.1.

TABLE 12.1: 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.

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.

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?

Explore More

Use this resource to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: https://www.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?

CONCEPT 13 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** 13.1). 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** 13.1 shows how each greenhouse gas naturally enters the atmosphere.

TABLE 13.1: 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

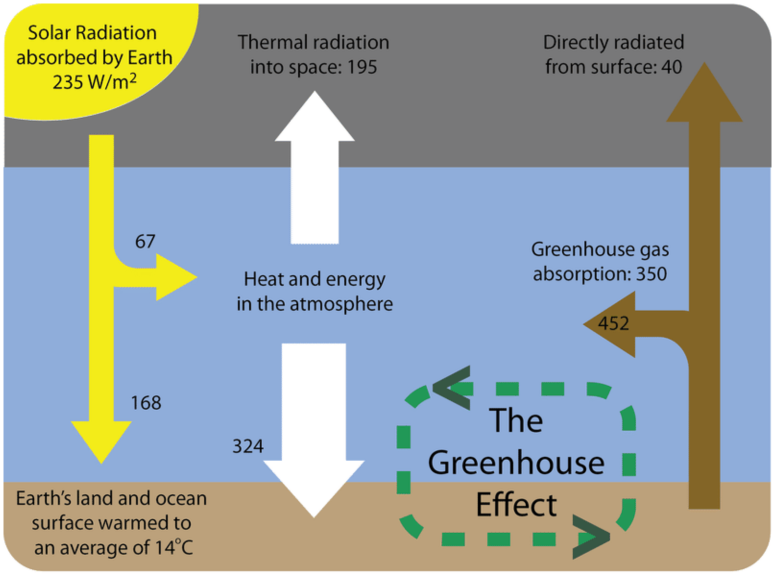


FIGURE 13.1

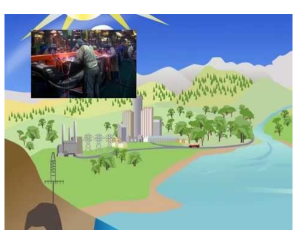
The Earth's heat budget shows the amount of energy coming into and going out of the Earth's system and the importance of the greenhouse effect. The numbers are the amount of energy that is found in one square meter of that location.

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.



MEDIA

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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.

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?

Explore More

Use this resource to answer the questions that follow.

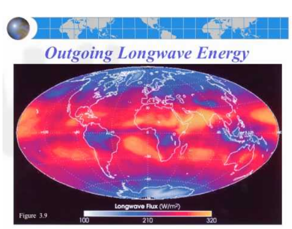
MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/160869

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?

Resources



MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/178121

References

1. Jodi So. Diagram of Earth's heat budget . CC BY-NC 3.0

CONCEPT 14 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** 14.1). 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.

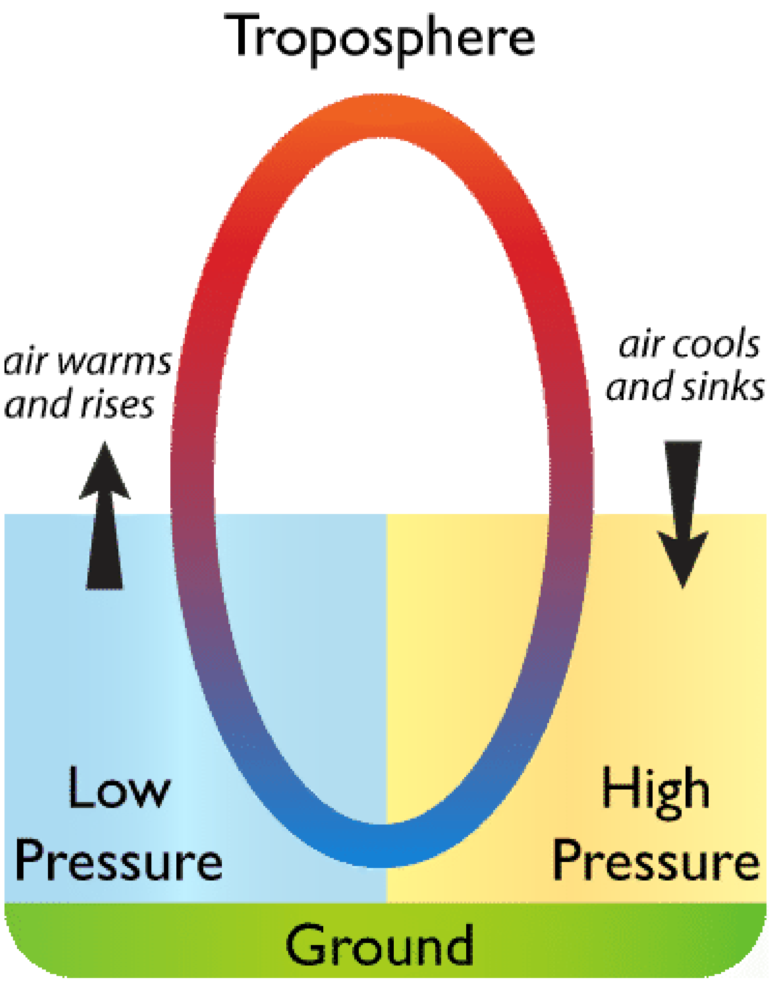


FIGURE 14.1
Warm air rises, creating a low pressure zone; cool air sinks, creating a high pressure zone.

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 systems create localized winds that affect the weather and climate of a local area.

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** 14.2). 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.

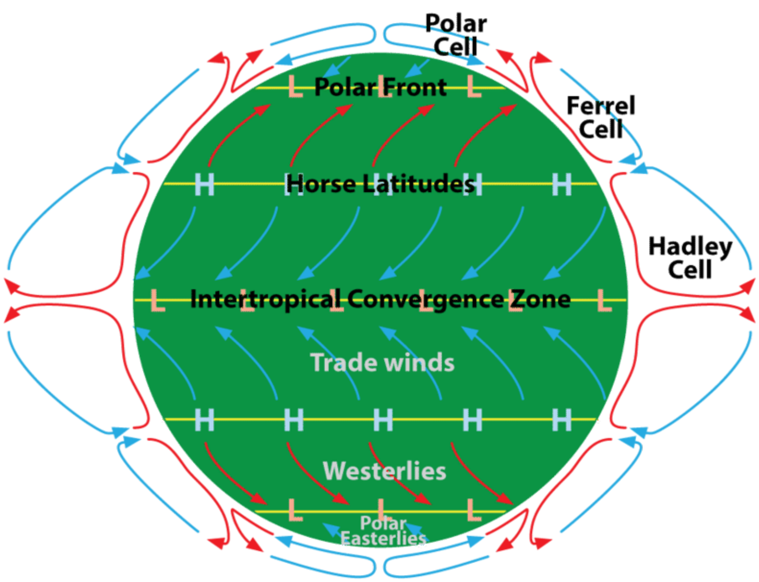


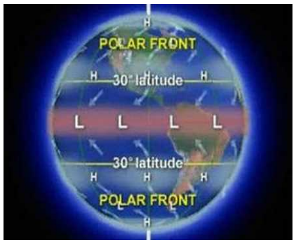
FIGURE 14.2
The atmospheric circulation cells, showing direction of winds at Earth's surface.

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.



MEDIA

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Summary

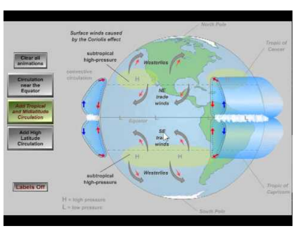
- The atmosphere has six major convection cells, three in the northern hemisphere and three in the southern.
- Coriolis effect results in there being three convection cells per hemisphere rather than one.
- Winds blow at the base of the atmospheric convection cells.

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?

Explore More

Use this resource to answer the questions that follow.



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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?

References

1. Hana Zavadska. Diagram of a convection cell creating low and high pressure zones . CC BY-NC 3.0

2. Zachary Wilson. Map of the atmospheric circulation cells . CC BY-NC 3.0

Concept 15 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** 15.1)? 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.

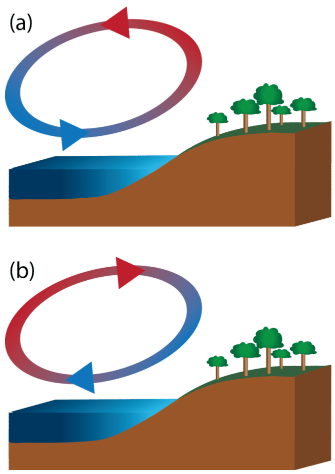


FIGURE 15.1
How do sea and land breezes moderate coastal climates?

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** 15.2).

FIGURE 15.2
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** 15.3), which creates many of the world's deserts.

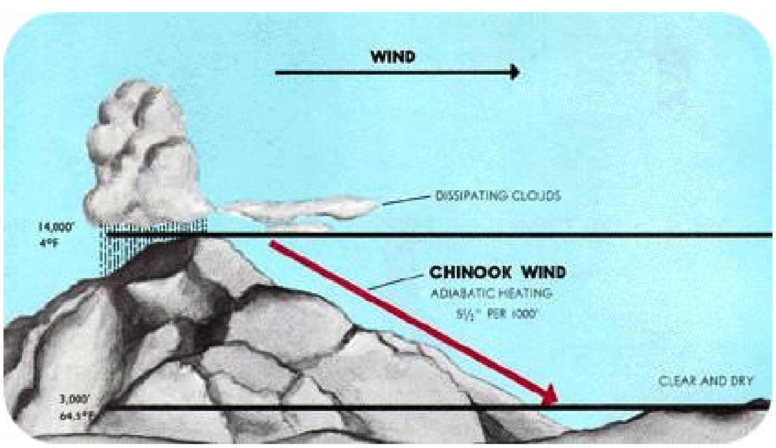


FIGURE 15.3

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** 15.4).

FIGURE 15.4
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** 15.5).

FIGURE 15.5
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** 15.6). A **haboob** forms in the downdrafts on the front of a thunderstorm.

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.

FIGURE 15.6
A haboob in the Phoenix metropolitan area, Arizona.

Summary

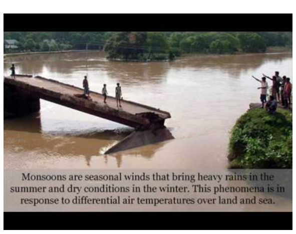
- Water has high specific heat, so its temperature changes very slowly relative to the temperature of the land. This is the reason for sea and land breezes and monsoon winds.
- The cause of all of these winds is the differential heating of Earth's surface, whether it's due to the difference in water 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.

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?

Explore More

Use these resources to answer the questions that follow.



MEDIA
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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?

MEDIA
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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?

References

1. Jodi So. Land and sea breezes blow in different directions if it is day or night . CC BY-NC 3.0
2. User:RyanW124/Wikipedia. Picture of a monsoon in the southwestern United States . Public Domain
3. Courtesy of US Federal Aviation Administration. Diagram of Chinnok winds . Public Domain
4. Courtesy of NASA. Satellite image of Santa Ana winds . Public Domain
5. Image copyright mikeledray, 2014. Santa Ana winds fuel wildfires in Southern California . Used under license from Shutterstock.com
6. User:Junebug172/Wikipedia. Picture of a haboob in Phoenix, Arizona . Public Domain

CONCEPT 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** 16.1).

The Global Winds

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

- 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.

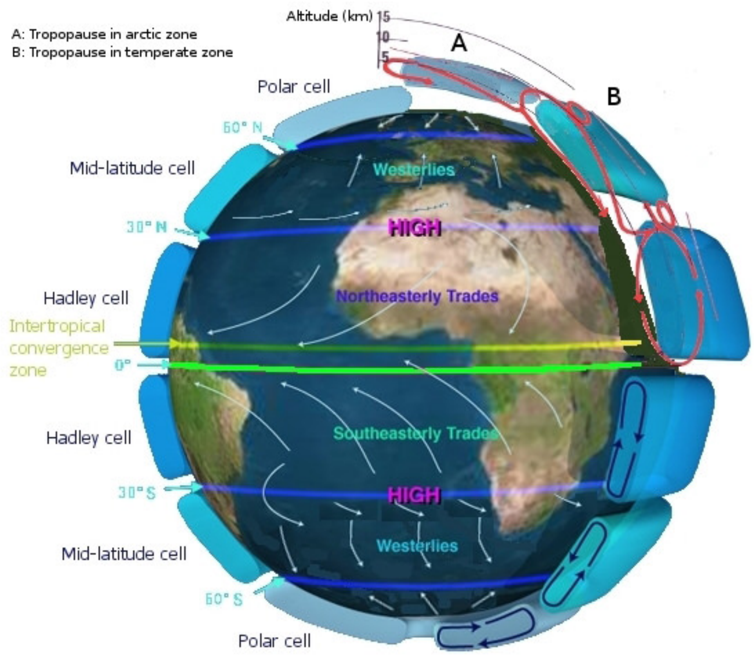
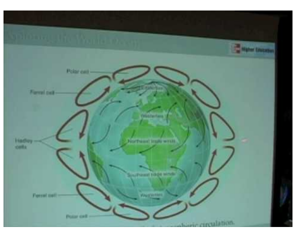


FIGURE 16.1
The major wind belts and the directions that they blow.

- 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.



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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** 16.2).

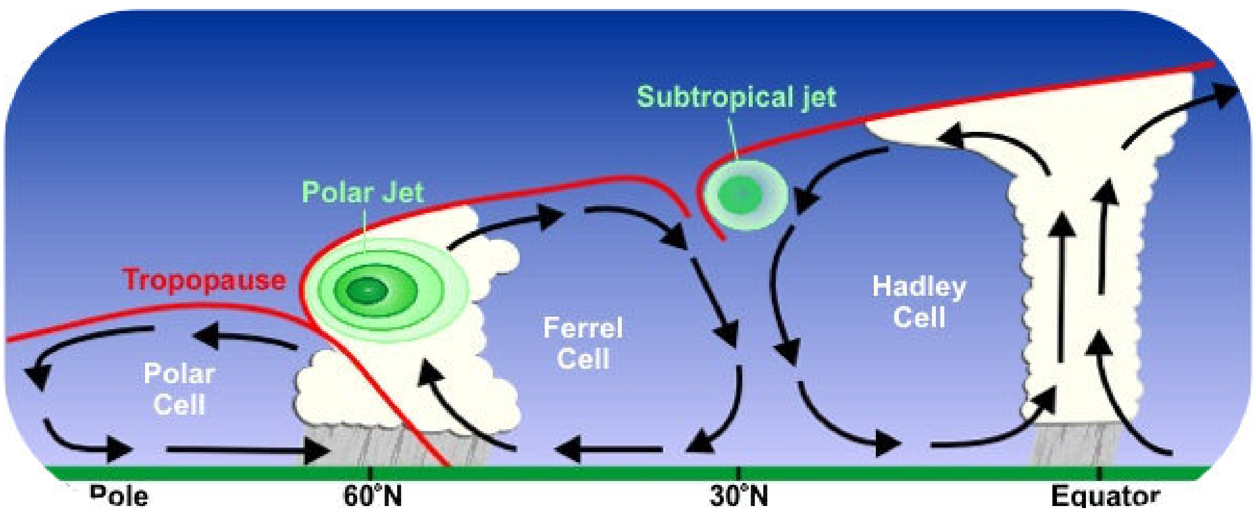
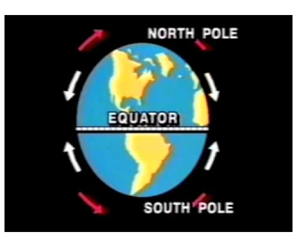


FIGURE 16.2
A cross section of the atmosphere with major circulation cells and jet streams. The polar jet stream is the site of extremely turbulent weather.

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.



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Summary

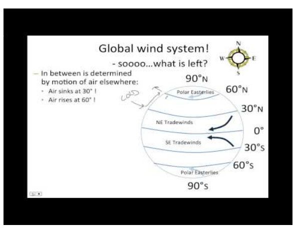
- Global winds blow from high to low pressure at the base of the atmospheric circulation cells.
- The winds at the bases of the cells have names: the Hadley cell is the trade winds, the Ferrel Cell is the westerlies, and the polar cell is the polar easterlies.
- Where two cells meet, weather can be extreme,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

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?

Explore More

Use this resource to answer the questions that follow.



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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?

References

1. Courtesy of NASA. Map of global wind belts . Public Domain
2. Courtesy of National Weather Service. Diagram of a jet stream . Public Domain

CONCEPT 17 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** 17.1).

FIGURE 17.1
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.

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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.

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?

References

1. Ridge Tahoe Resort Hotel. A snowboarder at Lake Tahoe . CC BY 2.0

Concept 18 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** 18.1). 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.

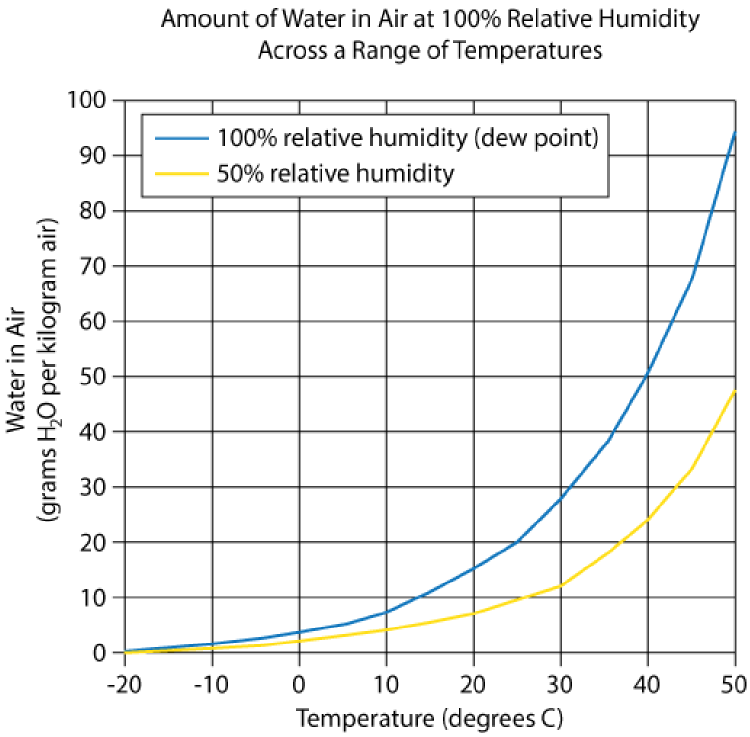

FIGURE 18.1
This diagram shows the amount of water air can hold at different temperatures. The temperatures are given in degrees Celsius.

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.

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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** 18.2).

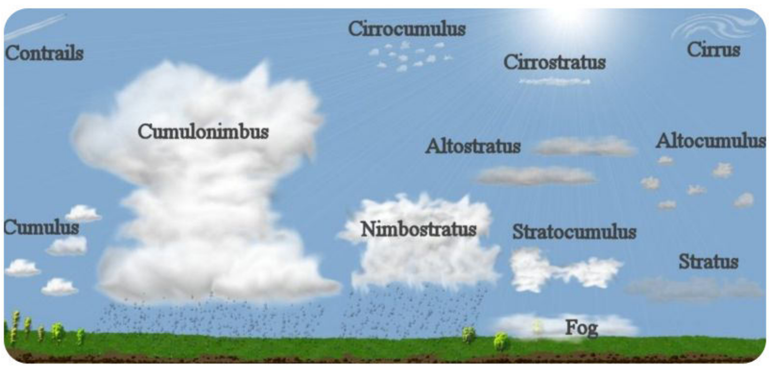

FIGURE 18.2
The four cloud types and where they are found in the atmosphere.

- 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.

Fog

Fog (**Figure** 18.3) 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.

FIGURE 18.3

(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.

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

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Summary

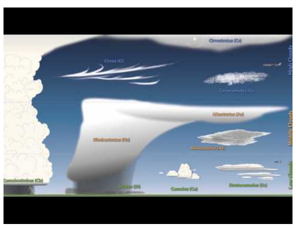
- Air reaches its dew point when humidity increases or temperature decreases. Water droplets form when the air reaches 100% humidity.
- Clouds block solar radiation, absorb heat from the ground and are the source of snow and rain.
- Fog forms when there is a difference in temperature between the land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

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?

Explore More

Use this resource to answer the questions that follow.



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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?

References

1. Zachary Wilson. Diagram showing the amount of water air and hold at different temperatures . CC BY-NC 3.0
2. Courtesy of Christopher M. Klaus, US Department of Energy. Picture showing classification of clouds . Public Domain
3. (a) Flickr:marya; (b) Jun Seita; (c) Image copyright Maxim Petrichuk, 2014; (d) Jorge Andrade. Pictures of tule, advection, steam, and upslope fog . (a) CC BY 2.0; (b) CC BY 2.0; (c) Used under license from Shutterstock.com; (d) CC BY 2.0

CONCEPT 19 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** 19.1) 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.

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** 19.2). 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**.

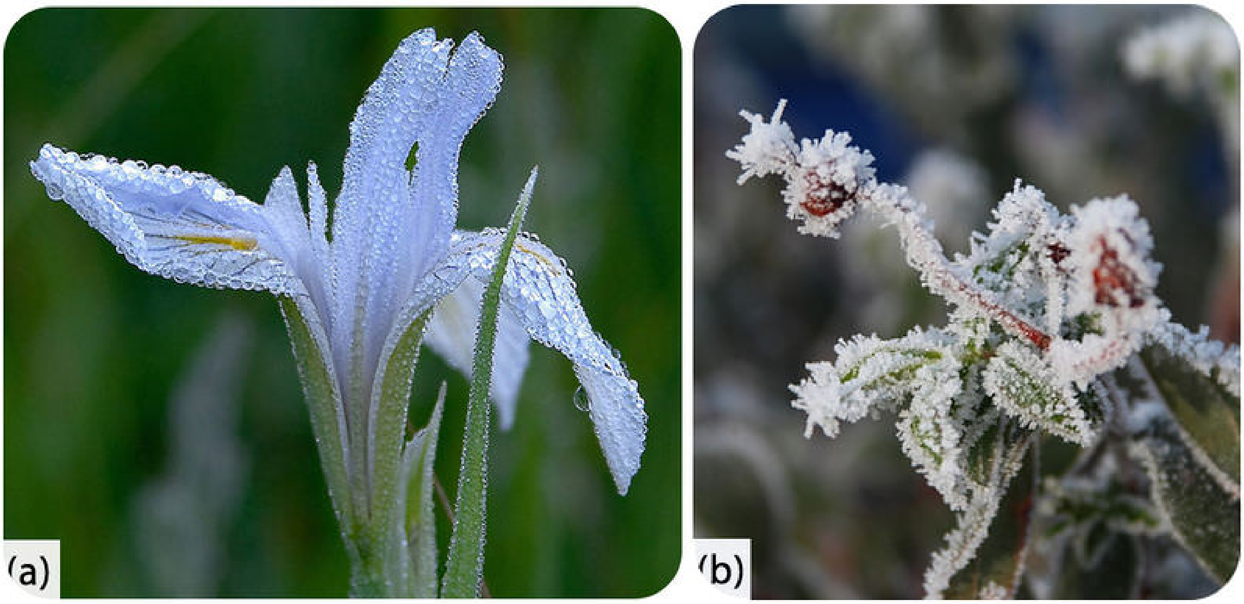

FIGURE 19.1
(a) Dew on a flower. (b) Hoar frost.

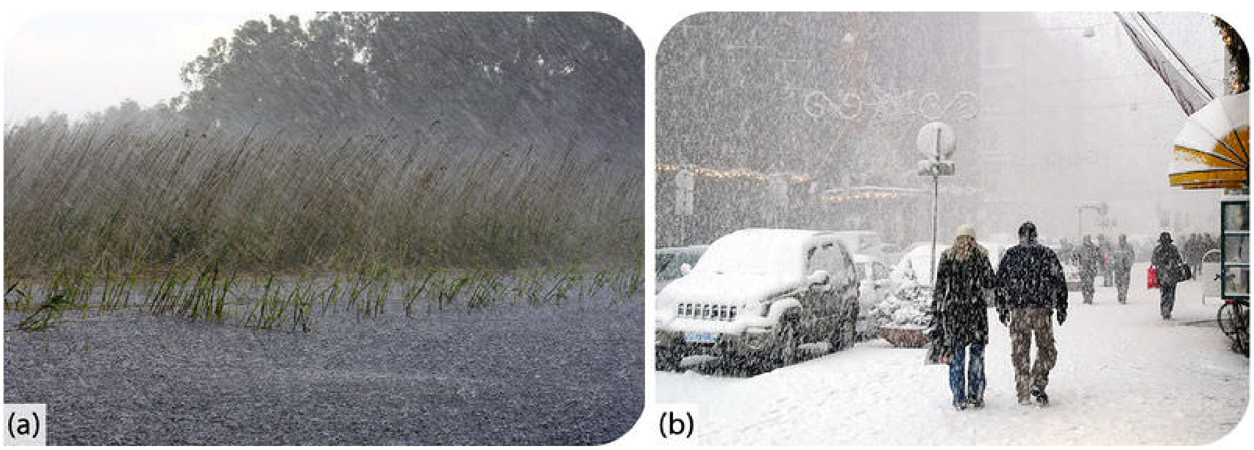

FIGURE 19.2
(a) Rain falls from clouds when the temperature is fairly warm. (b) Snow storm in Helsinki, Finland.

Other less common types of precipitation are **sleet** (**Figure** 19.3). 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.

FIGURE 19.3
(a) Sleet. (b) Glaze. (c) Hail. This large hail stone is about 6 cm (2.5 inches) in diameter.

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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.

Review

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

Explore More

Use this resource to answer the questions that follow.

MEDIA

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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?

References

1. (a) Courtesy of Jon Sullivan/PDPhoto.org; (b) Andy / Andrew Fogg. Dew and hoar frost on a flower . (a) Public Domain; (b) CC BY 2.0
2. (a) Image copyright Daniel Petrescu, 2014; (b) Image copyright col, 2014. Picture of a rain and snow storm . Used under licenses from Shutterstock.com
3. (a) User:Runningonbrains/Wikimedia Commons; (b) Lukas A, CZE; (c) Courtesy of the National Severe Storms Laboratory/US National Oceanic and Atmospheric Administration. Picture of sleet, glaze, and hail . Public Domain

Concept 20 Introduction to Weather

- Learn what factors make up weather.
- Understand what causes weather.

What's the weather like?

The United States is a big country. With two coasts and a large land mass in between, there's a chance for every kind of weather. In the next few sections we'll visit places that have the type of weather we're interested in studying.

What Is Weather?

All **weather** takes place in the atmosphere. Nearly all of it in the lower atmosphere. **Weather** refers to the conditions of the atmosphere at a given time and place. **Climate** is the average of weather over a long time.

Imagine your grandmother who lives in a distant place calls you up. She asks what your weather is like today. What would you say? Is it warm or cold? Sunny or cloudy? Calm or windy? Clear or rainy? What features of weather are important to mention?

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 what we experience from day to day, or minute to minute. Weather can change rapidly.

What Causes Weather?

Weather occurs because of unequal heating of the atmosphere. The source of heat is the Sun. The general principles behind weather can be stated simply:

- The Sun heats Earth's surface more in some places than in others.
- Where it is warm, heat from the Sun warms the air close to the surface. If there is water at the surface, it may cause some of the water to evaporate.
- Warm air is less dense, so it rises. When this happens, more dense air flows in to take its place. The flowing surface air is wind.
- The rising air cools as it goes higher in the atmosphere. If it is moist, the water vapor may condense. Clouds may form, and precipitation may fall.

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.

Review

1. Compare and contrast weather and climate.
2. What factors account for a location's weather?
3. Describe how unequal heating causes weather.

CONCEPT 21 Humidity

- Explain how humidity affects temperature.
- Understand humidity, relative humidity, and dew point.

Would you rather spend a summer day in Phoenix or in Houston?

People who live in Phoenix, Arizona, are told that summer isn't so bad because "it's a dry heat." What does that mean? Imagine that both Phoenix and Houston have a temperature of 90°F. In Phoenix, the relative humidity is 20%. In Houston, the relative humidity is 90%. So in Phoenix it feels like it's 90°. But in Houston it feels like it's 122! Of course in Phoenix in July, the average high temperature is 106°. That's hot, dry or not!

Humidity

Humidity is the amount of water vapor in the air. High humidity increases the chances of clouds and precipitation.

Relative Humidity

Humidity usually refers to **relative humidity**. This is the percent of water vapor in the air relative to the total amount the air can hold. How much water vapor can the air hold? That depends on temperature. Warm air can hold more water vapor than cool air (**Figure** 21.1).

Humidity and Heat

People often say, "it's not the heat but the humidity." Humidity can make a hot day feel even hotter. When sweat evaporates, it cools your body. But sweat can't evaporate when the air already contains as much water vapor as it can hold. The **heat index** (**Figure** 21.2) is a measure of what the temperature feels like because of the humidity.

Dew Point

You've probably noticed dew on the grass on a summer morning. Why does dew form? Remember that the land heats up and cools down fairly readily. So when night comes, the land cools. Air that was warm and humid in the daytime also cools over night. As the air cools, it can hold less water vapor. Some of the water vapor condenses on the cool surfaces, such as blades of grass. The temperature at which water vapor condenses is called the **dew point**. If this temperature is below freezing, ice crystals of frost form instead of dew (**Figure** 21.3). The dew point occurs at 100 percent relative humidity. Can you explain why?

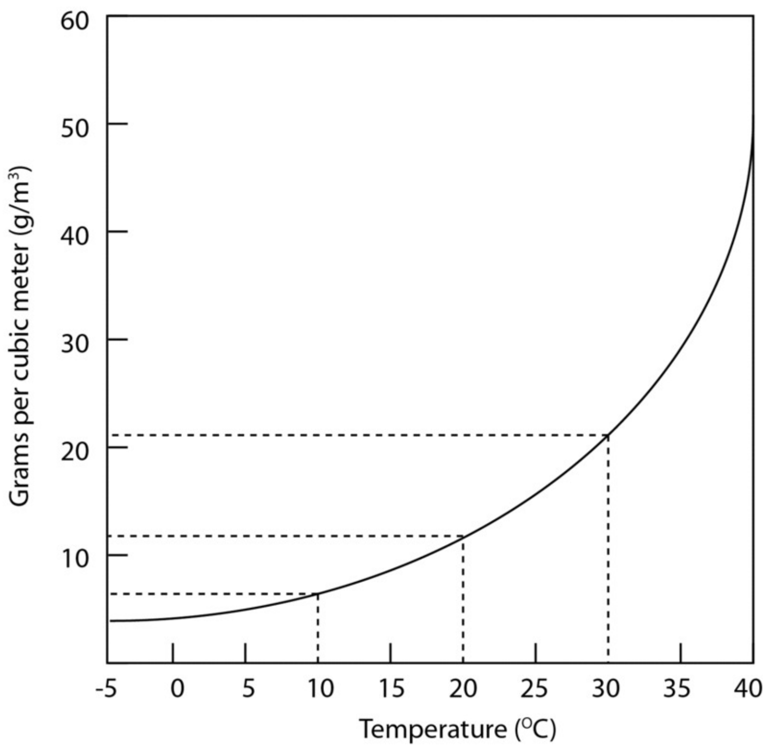

FIGURE 21.1
How much water vapor can the air hold when its temperature is 40° C?

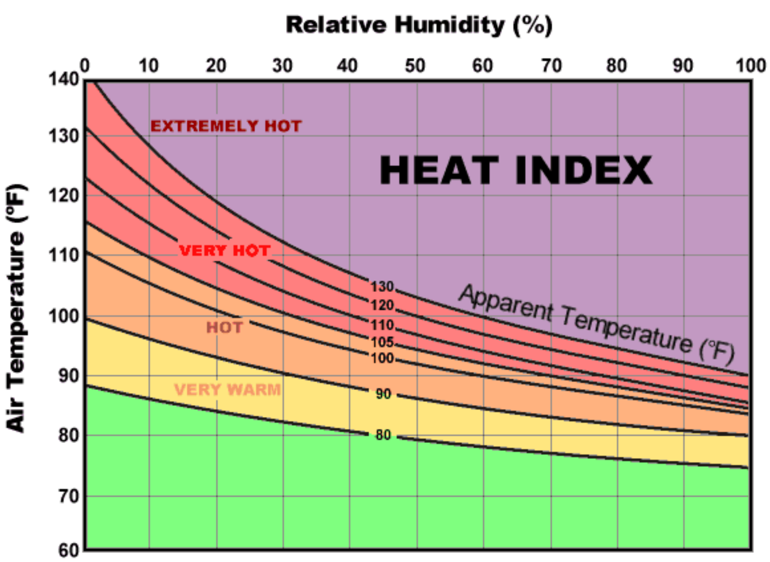

FIGURE 21.2
How hot does it feel when the air temperature is 90°F? It depends on the humidity.

Summary

- Air reaches its dew point when humidity increases or temperature decreases.
- Water droplets form when the air reaches 100% humidity. If the temperature is cold enough, frost will form.
- Relative humidity is how the air feels at its temperature and humidity.

FIGURE 21.3
The grass on the left is covered with dew. The grass on the right is covered with frost. The difference is the temperature of the grass.

Review

1. What is humidity? What is relative humidity?
2. Explain what heat index is.
3. Why does water come out of the air at its dew point?

Explore More

Use the resource below to answer the questions that follow.

MEDIA
Click image to the left or use the URL below.
URL: https://www.ck12.org/flx/render/embeddedobject/116783

1. What is humidity?
2. What is water vapor?
3. What is absolute humidity?
4. What two factors does relative humidity consider?
5. What are you likely to see when the humidity is 100%?

References

1. Jodi So. Graph showing water vapor capacity and temperature . CC BY-NC 3.0
2. Courtesy of National Weather Service, NOAA. Graph of apparent temperature based on air temperature and humidity . Public Domain
3. Left: Jordan McCullough; Right: Adrian Byrne (Flickr:Byrnsey). Dew and frost form due to the dew point . CC BY 2.0

CONCEPT 22 Fog

- Describe different types of fog.

Where is the most famous fog in the U.S.?

San Francisco, the city by the bay, is known for its fog. There's an old joke: "I spent the coldest winter of my life in San Francisco one summer." That's because of the fog! There is a big difference in temperature between the two sides of the city. On the Pacific side, where there is fog, temperatures are low. On the bay side, where there isn't fog, temperatures are much higher.

Fog

Fog (**Figure** 22.1) is a cloud on the ground. Fog forms when humid air near the ground cools below its dew point. Each type of fog forms in a different way.

- **Radiation fog** forms at night. Skies are clear, and the relative humidity is high. The ground cools as temperature goes down. Air near the ground cools below its dew point. Tule fog is an extreme form of radiation fog. This type of fog strikes the Central Valley of California in winter.
- **Advection fog** is famous in San Francisco, California. Warm, moist air comes in from the Pacific Ocean. The air blows over the cold California current. When the air cools below its dew point, fog forms. 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. As the water vapor cools, it condenses. The fog appears 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 22.1
(a) Tule fog in the Central Valley of California. (b) Advection fog in San Francisco. (c) Steam fog over a lake in Algonquin Park, Canada. (d) Upslope fog around the peak of Sanqing Mountains in China.

MEDIA
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Summary

- Fog forms when there is a difference in temperature between the land and the air.

Review

1. Why does fog form?
2. What makes tule fog distinctive?
3. Compare and contrast the different types of fog.

References

1. (a) marya (Flickr:emdot); (b) Flickr:different2une; (c) Flickr:3rdparty!; (d) Jordan (Flickr:jshansen). Pictures of tule, advection, steam, and upslope fog . CC BY 2.0

CONCEPT 23 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** 23.1). 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.

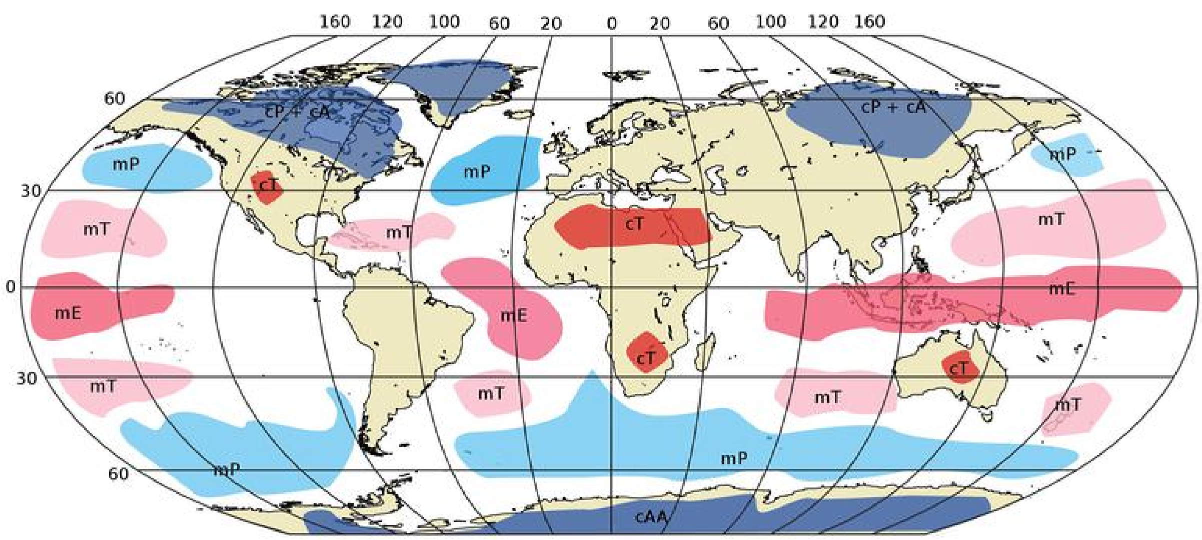

FIGURE 23.1

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.

MEDIA

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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.

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?

Explore More

Use this resource (watch up to 3:31) and answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/178134

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?

References

1. Courtesy of NASA. Map of air masses found around the world . Public Domain

CONCEPT 24 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** 24.1). 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** 24.2).

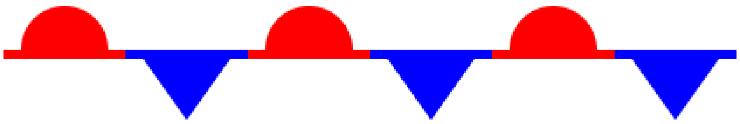


FIGURE 24.1
The map symbol for a stationary front has red domes for the warm air mass and blue triangles for the cold air mass.

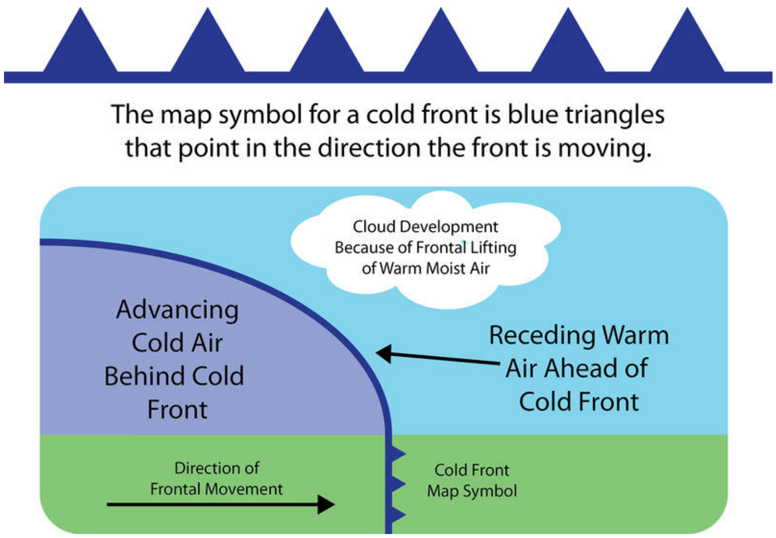


FIGURE 24.2
The cold air mass is dense, so it slides beneath the warm air mass and pushes it up.

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** 24.2). 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** 24.3). 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** 24.4). 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 24.3
A squall line.

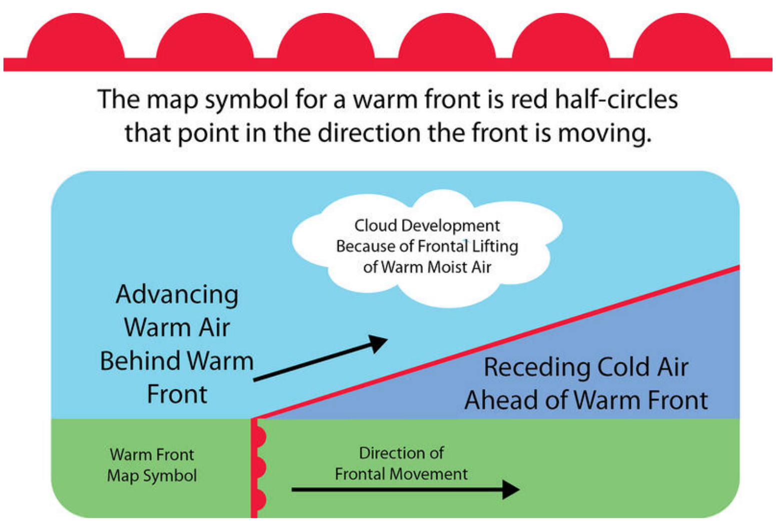


FIGURE 24.4
Warm air moves forward to take over the position of colder air.

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** 24.5).

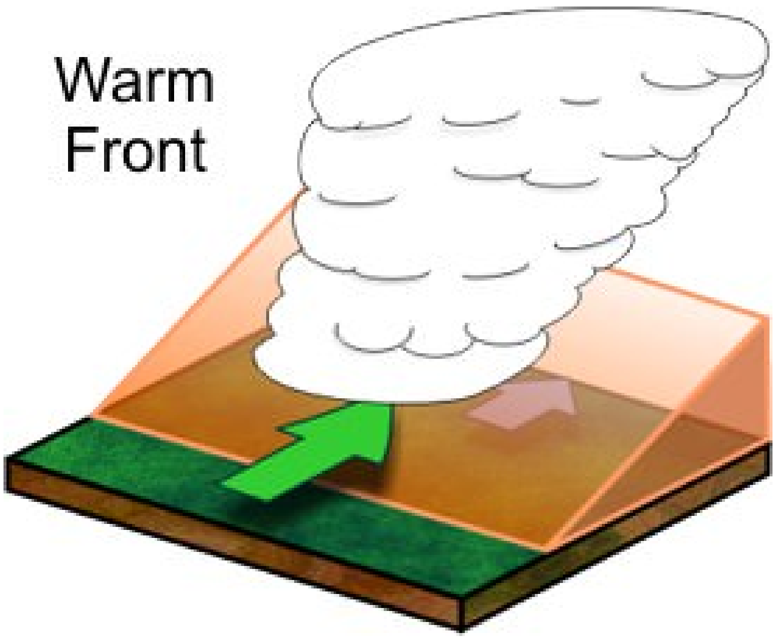


FIGURE 24.5
Cumulus clouds build at a warm front.

Occluded Front

An **occluded front** usually forms around a low pressure system (**Figure** 24.6). 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 24.6
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** 24.7).

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.

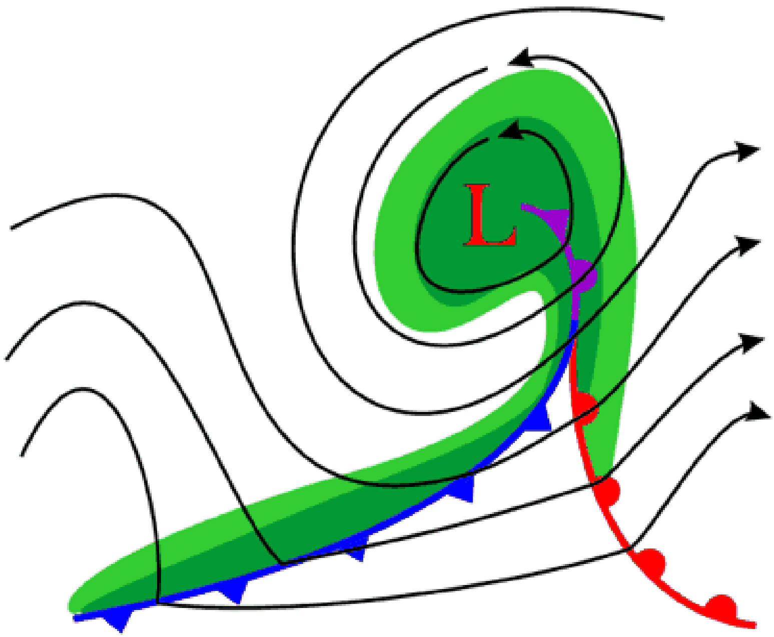
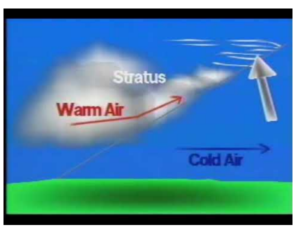


FIGURE 24.7
An occluded front with the air masses from front to rear in order as cold, warm, cold.



MEDIA
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Summary

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

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.

Explore More

Use this resource to answer the questions that follow.

MEDIA
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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?

References

1. User:-xfi-/Cs.Wikipedia. Symbol for a stationary front . Public Domain
2. Jodi So. Diagram of a cold front . CC BY-NC 3.0
3. Courtesy of the National Oceanic and Atmospheric Administration. Picture of a squall line . Public Domain
4. Jodi So. Diagram of a warm front . CC BY-NC 3.0
5. User:Mouagip/Wikimedia Commons, based on image from the US National Oceanic and Atmospheric Administration. Cumulus cloud build at a warm front . Public Domain
6. User:-xfi-/Cs.Wikipedia. Symbol for an occluded front . Public Domain
7. Courtesy of the National Weather Service/NOAA. Diagram of an occluded front . Public Domain

CONCEPT 25 Thunderstorms

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

What lives fast and dies young?

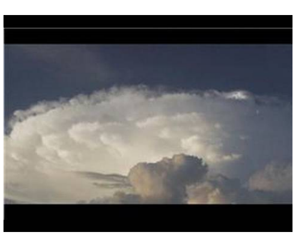
That describes most thunderstorms. Thunderstorms can be very intense but may last for only a matter of minutes. They're fun (and dangerous) while they're active, though.

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** 25.1).



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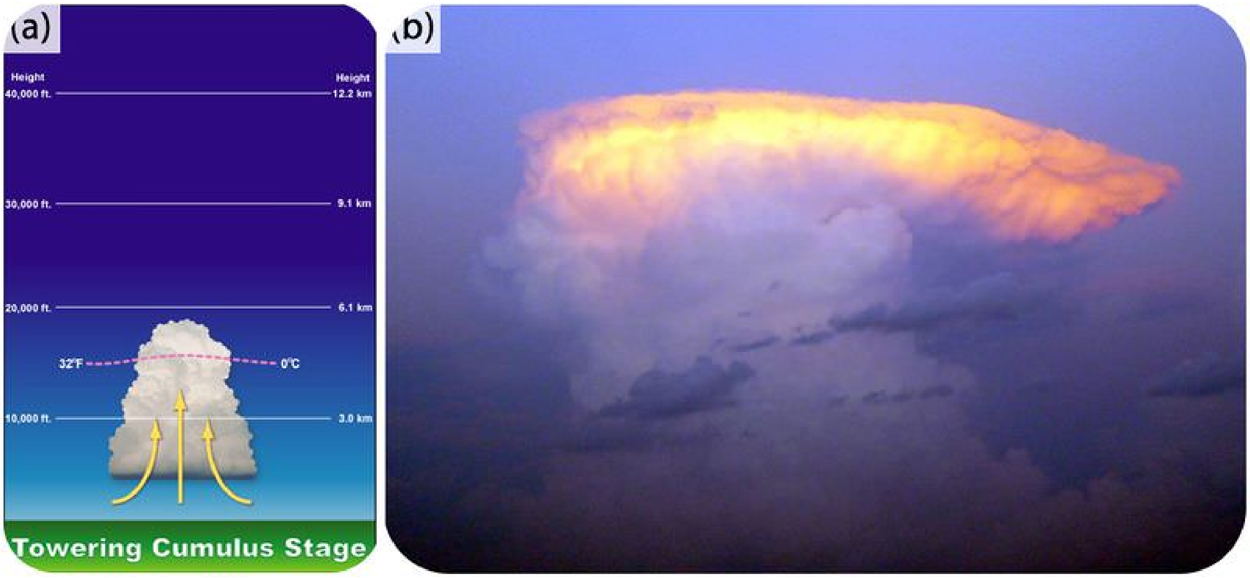


FIGURE 25.1
(a) Cumulus and cumulonimbus clouds. (b) A thunderhead.

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.

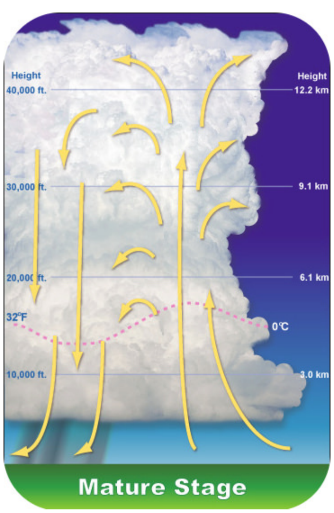


FIGURE 25.2
A mature thunderstorm with updrafts and downdrafts that reach the ground.

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** 25.2).

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** 25.3).

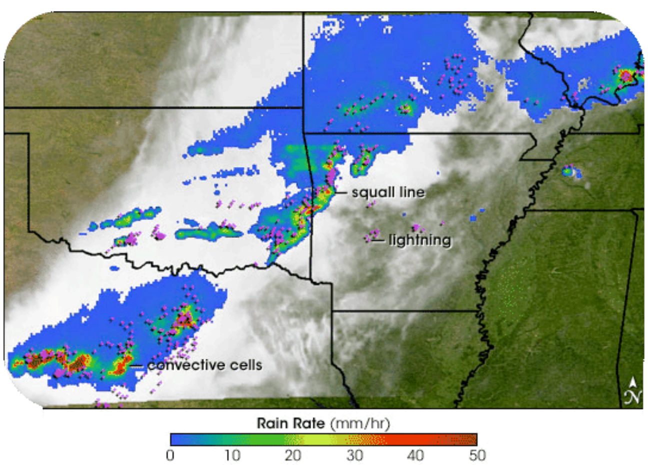


FIGURE 25.3
Cold air from the Rockies collided with warm, moist air from the Gulf of Mexico to form this squall line.

Lightning and Thunder

So much energy collects in cumulonimbus clouds that a huge release of electricity, called **lightning**, may result (**Figure** 25.4). 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.

FIGURE 25.4
Lightning behind the town of Diamond Head, Hawaii.

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** 25.5).

FIGURE 25.5
Lightning strikes some places many times a year, such as the Eiffel Tower in Paris.

Summary

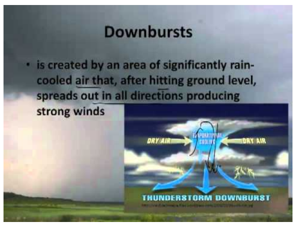
- Thunderstorms grow where ground temperatures are extremely high.
- Convection in the cloud causes raindrops or hailstones to grow. Downdrafts ultimately end convection.
- Squall lines are long lines of thunderstorms that form along a cold front.

Review

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

Explore More

Use this resource to answer the questions that follow.



MEDIA

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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?

References

1. (a) Courtesy of the US National Oceanic and Atmospheric Administration; (b) User:MONGO/Wikimedia Commons. Cumulus and cumulonimbus clouds, and a thunderhead . Public Domain
2. Courtesy of National Oceanic and Atmospheric Administration. Diagram of a mature thunderstorm . Public Domain
3. Courtesy of Hal Pierce (SSAI/NASA GSFC). Map of a squall line . Public Domain
4. Flickr:poorboy1225. Bolt of lightning . CC BY 2.0
5. M. G. Loppé. Multiple lighting bolts strike the Eiffel Tower of Paris . Public Domain

CONCEPT 26 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** 26.1). 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** 26.2).

FIGURE 26.1
The formation of this tornado outside Dimmit, Texas, in 1995 was well studied.

FIGURE 26.2
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** 26.3). 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** 26.4).

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 26.3
Tornado damage at Ringgold, Georgia in April 2011.

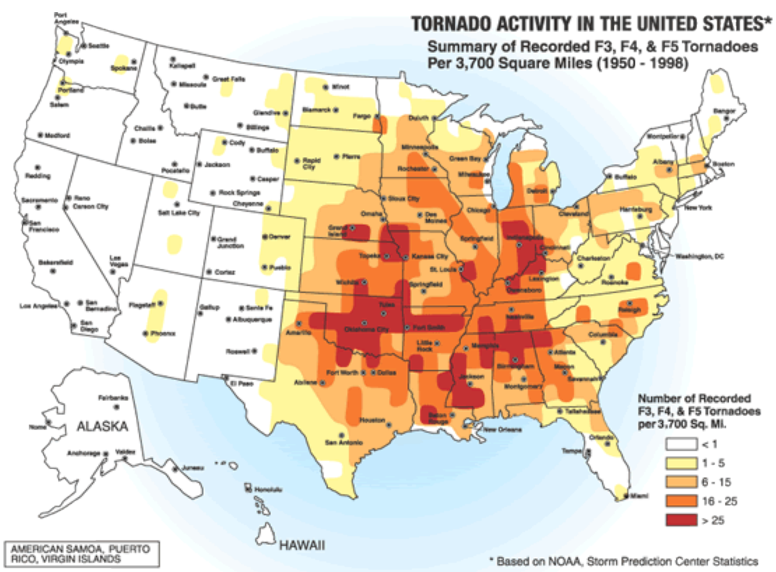


FIGURE 26.4
The frequency of F3, F4, and F5 tornadoes in the United States. The red region that starts in Texas and covers Oklahoma, Nebraska, and South Dakota is called Tornado Alley because it is where most of the violent tornadoes occur.

in from the west. The result was more than 150 tornadoes reported throughout the day (**Figure** 26.5).

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.

Fujita Scale

The intensity of tornadoes is measured on the Fujita Scale (see **Table** 26.1), which assigns a value based on wind speed and damage.

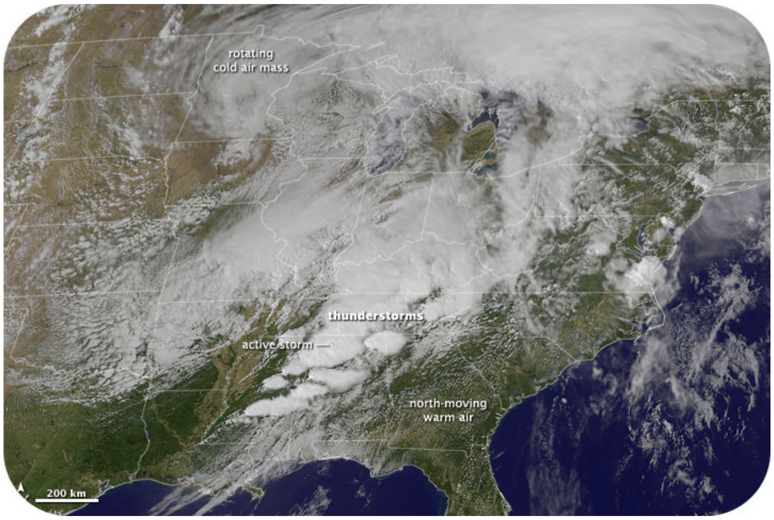


FIGURE 26.5
April 27-28, 2011. The cold air mass is shown by the mostly continuous clouds. Warm moist air blowing north from the Atlantic Ocean and Gulf of Mexico is indicated by small low clouds. Thunderstorms are indicated by bright white patches.

TABLE 26.1: 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

MEDIA
Click image to the left or use the URL below.
URL: https://www.ck12.org/flx/render/embeddedobject/186485

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.

MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/178139

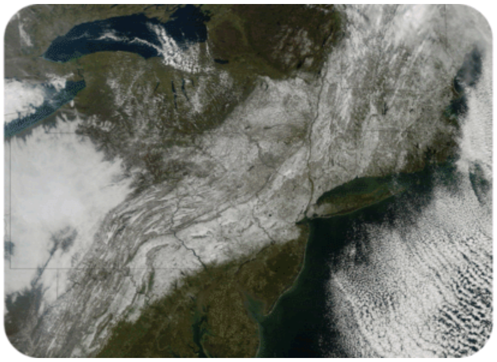
1. Why do tornadoes form from supercells?
2. What two elements are present in a thunderstorm that will form a tornado?
3. What are winds doing within a thunderstorm to create a tornado?
4. Where does a supercell thunderstorm get its power?
5. What happens when a thunderstorm can finally form in spite 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?

References

1. Courtesy of Harald Richter, US National Oceanic and Atmospheric Administration. Pictures of the formation of a tornado . Public Domain
2. Courtesy of National Severe Storms Laboratory/US National Oceanic and Atmospheric Administration. Picture of a tornado . Public Domain
3. Courtesy of National Weather Service. Damage caused by a tornado . Public Domain
4. Courtesy of the US Federal Emergency Management Agency. Frequency map of tornadoes in the United States . Public Domain
5. Courtesy of GOES Project Science team/NASA's Earth Observatory. Satellite image of tornado spree in 2011 . Public Domain

CONCEPT 27 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** 27.1).

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** 27.2).

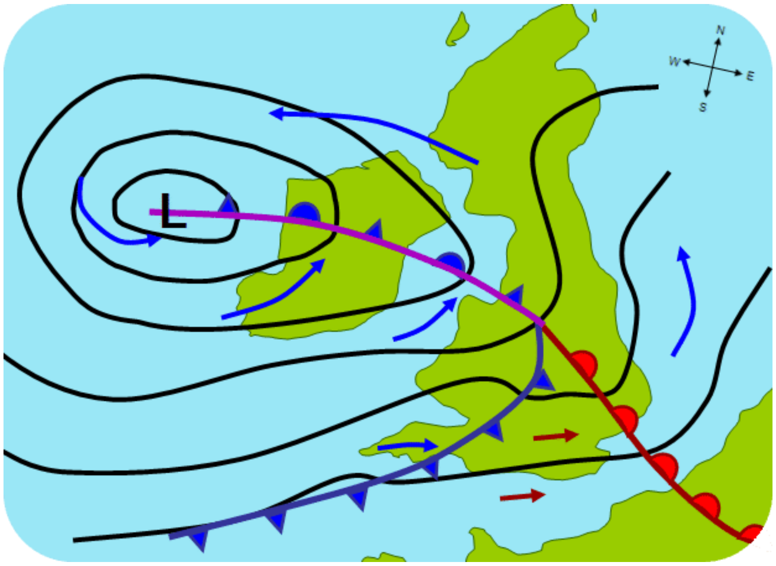


FIGURE 27.1
A hypothetical mid-latitude cyclone affecting the United Kingdom. The arrows point the wind direction and its relative temperature; L is the low pressure area. Notice the warm, cold, and occluded fronts.

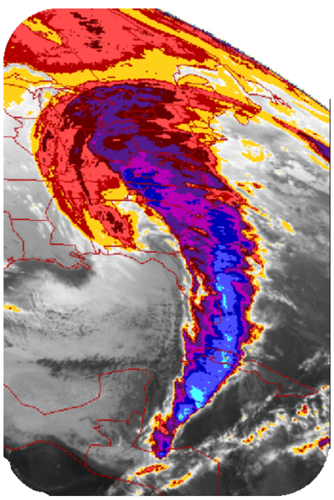


FIGURE 27.2
The 1993 "Storm of the Century" was a nor'easter that covered the entire eastern seaboard of the United States.

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.

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?

Explore More

Use this resource to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/4745

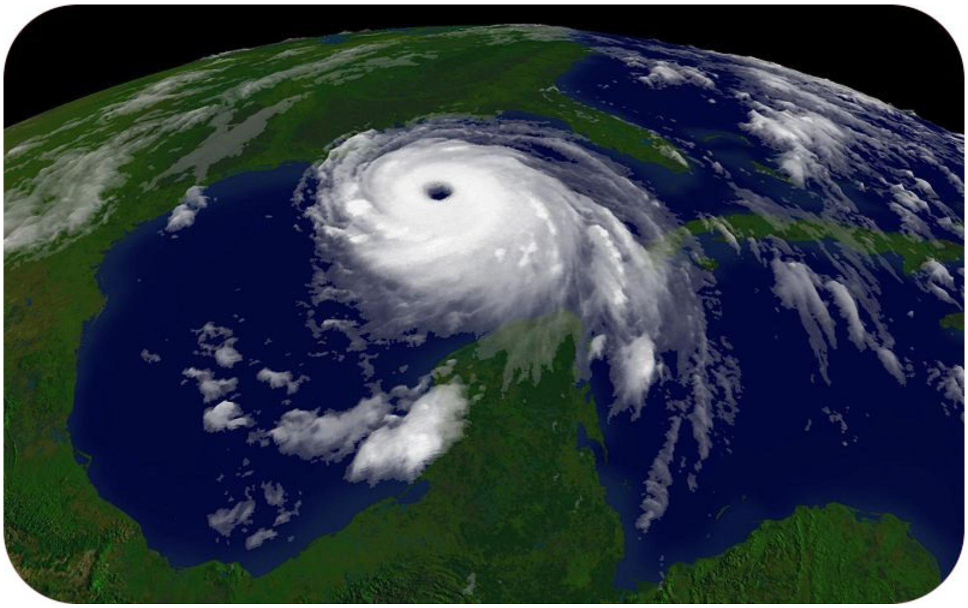
1. What is at the center of a midlatitude cyclone?
2. What does the low pressure cell do?
3. What types of air masses are typically involved?
4. What does a mature midlatitude cyclone have?
5. Where is the heaviest precipitation located in a midlatitude cyclone?

References

1. User:MichaelBillington/Wikipedia. A hypothetical mid-latitude cyclone affecting the United Kingdom . Public Domain
2. Courtesy of NASA. The 1993 "Storm of the Century'' was a nor'easter that covered the entire eastern seaboard of the United States . Public Domain

CONCEPT 28 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.

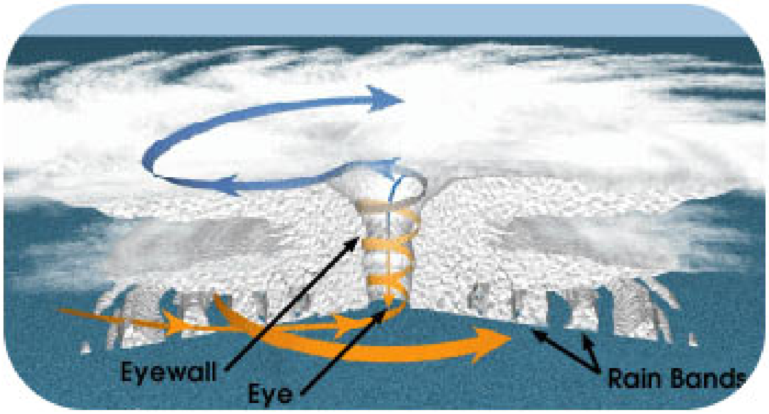


FIGURE 28.1
A cross-sectional view of a hurricane.

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.

MEDIA
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Saffir-Simpson Scale

Hurricanes are assigned to categories based on their wind speed. The categories are listed on the Saffir-Simpson hurricane scale (**Table** 28.1).

TABLE 28.1: 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

TABLE 28.1: (continued)

Category	Kph	Mph	Estimated Damage
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.

The End

Hurricanes typically last for 5 to 10 days. The winds push them to the northwest and then to the northeast. Eventually a hurricane will end up over cooler water or land. At that time the hurricane's latent heat source shut downs and the storm weakens. When a hurricane disintegrates, it is replaced with intense rains and tornadoes.

There are about 100 hurricanes around the world each year, plus many smaller tropical storms and tropical depressions. As people develop coastal regions, property damage from storms continues to rise. However, scientists are becoming better at predicting the paths of these storms and fatalities are decreasing. There is, however, one major exception to the previous statement: Hurricane Katrina.

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** 28.2).

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.

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?

FIGURE 28.2
Flooding in New Orleans after Hurricane Katrina caused the levees to break and water to pour through the city.

3. Under what circumstances does a hurricane die?

Resources

MEDIA
Click image to the left or use the URL below.
URL: https://www.ck12.org/flx/render/embeddedobject/178141

References

1. Courtesy of US National Oceanic and Atmospheric Administration. A cross-sectional view of a hurricane . Public Domain
2. Courtesy of Petty Officer 2nd Class Kyle Niemi, US Coast Guard. Flooding in New Orleans after Hurricane Katrina hit . Public Domain

CONCEPT 29 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** 29.2). 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 29.1
A blizzard obscures the Capitol in Washington, DC.

FIGURE 29.2
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** 29.3).

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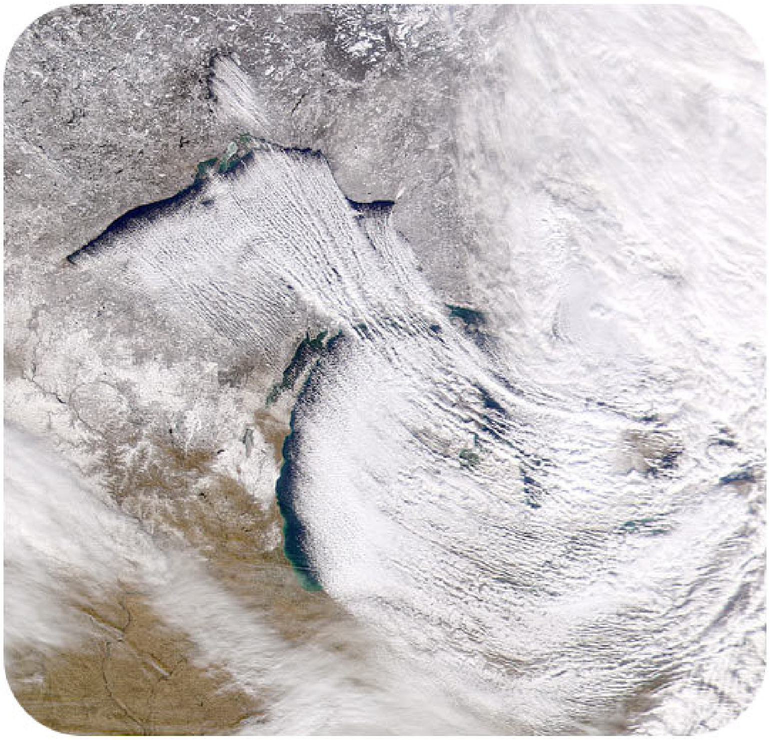

FIGURE 29.3
Frigid air travels across the Great Lakes and dumps lake-effect snow on the leeward side.

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.

Review

1. Under what circumstances does a blizzard form?
2. What causes lake-effect snow?
3. What is a blizzard?

Explore More

Use this resource to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/178143

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?

References

1. Official Navy Page. Blizzard in Washington D.C. . CC BY 2.0
2. Courtesy of Jeff Schmaltz, NASA/MODIS Rapid Response Team. Satellite image of snow and blizzard over the East Coast in 2010 . Public Domain
3. Courtesy of SeaWiFS Project and NASA/Goddard Space Flight Center. Satellite image of lake-effect snow . Pubic Domain

Concept 30 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** 30.1)? A high pressure zone kept the jet stream further north than normal for August.

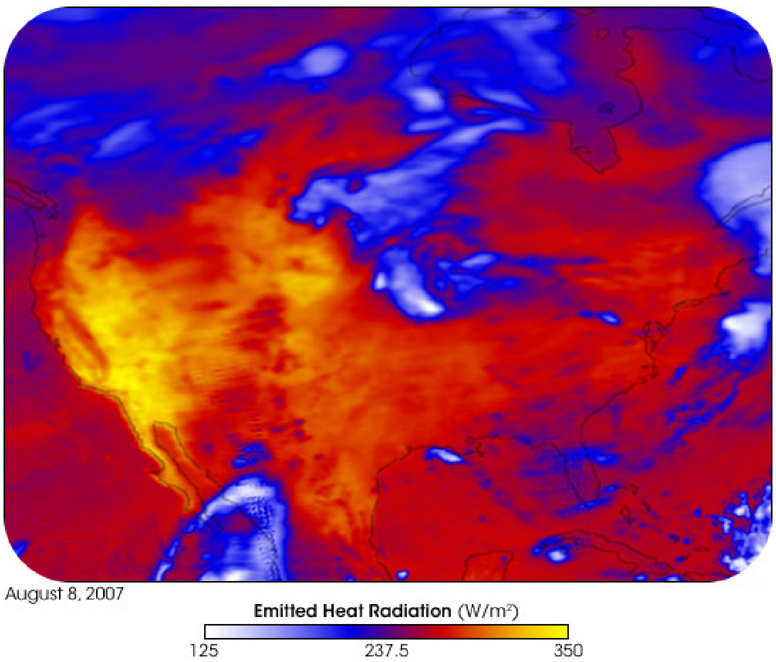

FIGURE 30.1
A heat wave over the United States as indicated by heat radiated from the ground. The bright yellow areas are the hottest and the blue and white are coolest.

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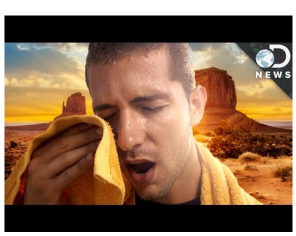

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Droughts

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.

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?

References

1. Courtesy of Jesse Allen, NASA/NASA's Earth Observatory. Satellite image of a heat wave . Public Domain

CONCEPT 31 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** 31.1). Weather stations are located on land, the surface of the sea, and in orbit all around the world.

FIGURE 31.1
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** 31.2). 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.

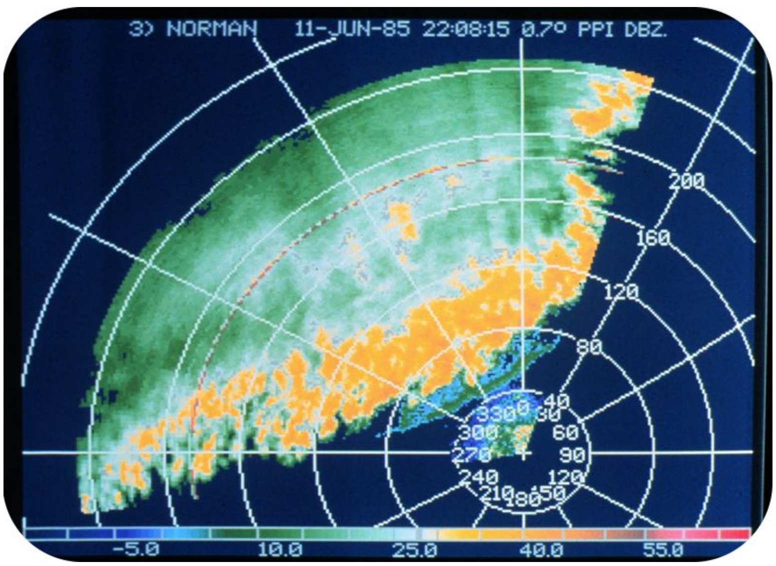

FIGURE 31.2
Radar view of a line of thunderstorms.

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** 31.3).

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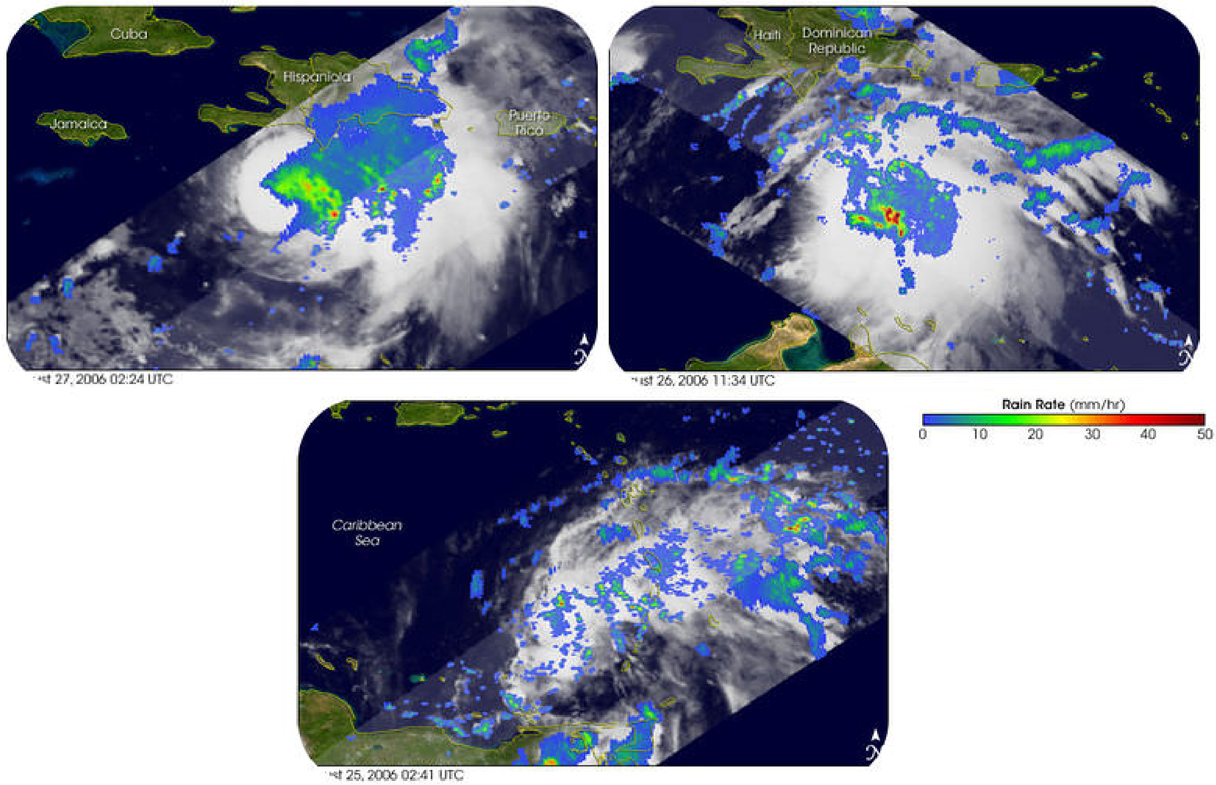

FIGURE 31.3

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

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.

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?

Explore More

Use this resource to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.
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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.

References

1. User:CambridgeBayWeather/Wikipedia. A land-based weather station . Public Domain
2. Courtesy of US National Oceanic and Atmospheric Administration. Radar view of a line of thunderstorms . Public Domain
3. Courtesy of Hal Pierce (SSAI/NASA GSFC). Infrared view from a satellite of a hurricane . Public Domain

CONCEPT 32 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** 32.1). 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** 32.2).

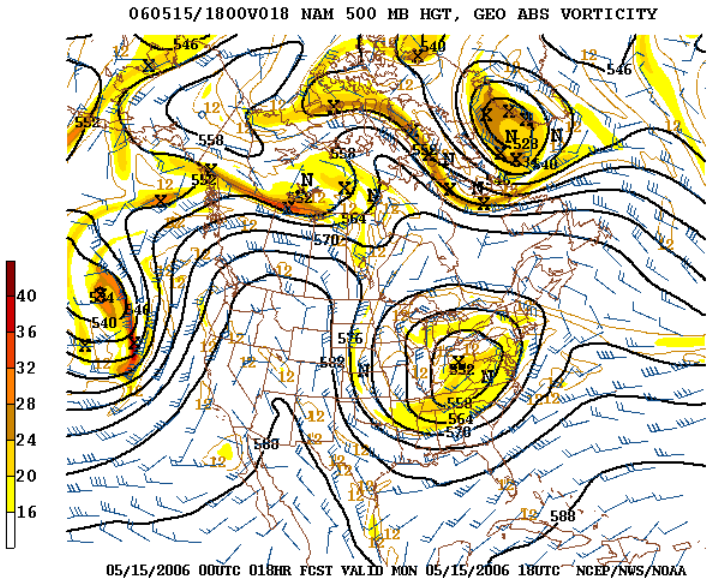


FIGURE 32.1

A weather forecast using numerical weather prediction.

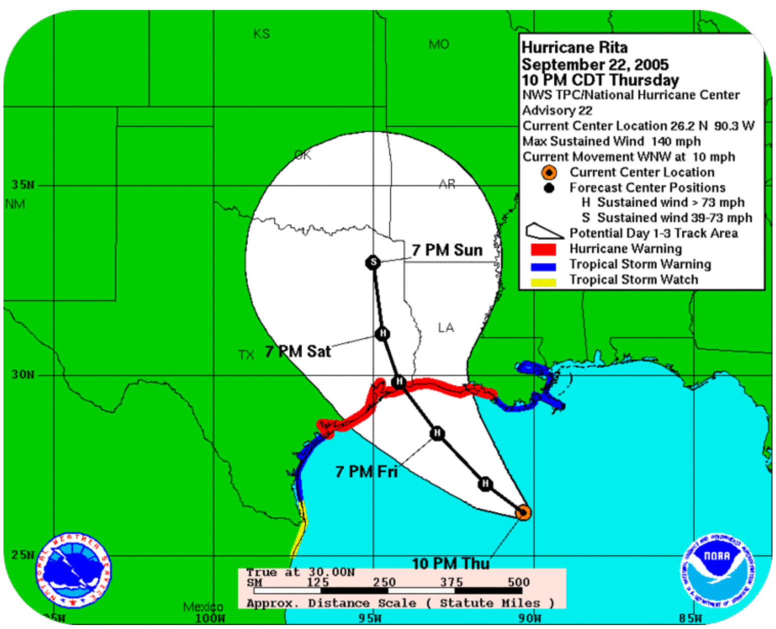


FIGURE 32.2

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.

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?

Explore More

Use this resource to answer the questions that follow.

MEDIA

Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/178227

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?

References

1. Courtesy of National Weather Service/US National Oceanic and Atmospheric Administration. Map of a weather forecast . Public Domain
2. Courtesy of US National Oceanic and Atmospheric Administration. Weather prediction for Hurricane Rita . Public Domain

CONCEPT 33 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** 33.1).

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:

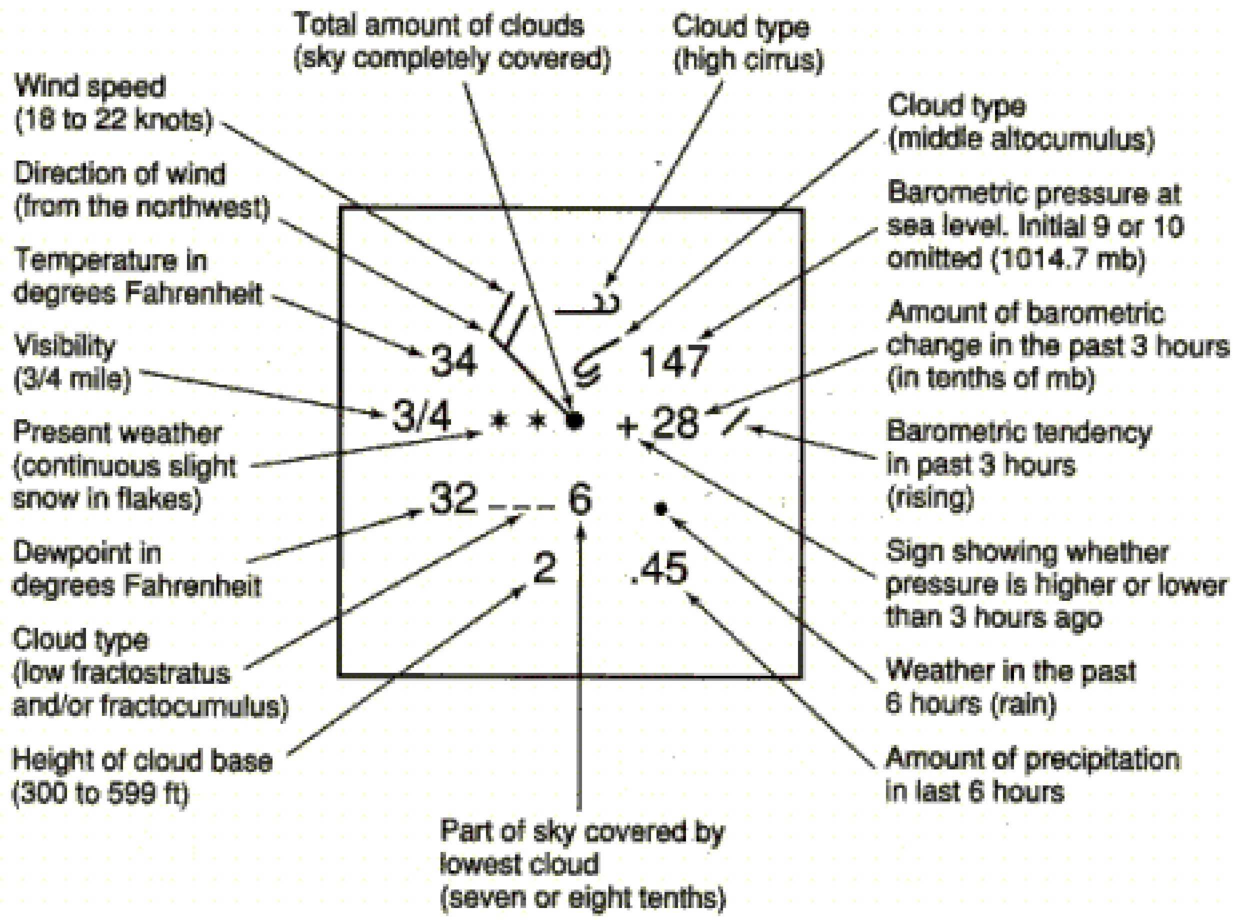


FIGURE 33.1
Explanation of some symbols that may appear on a weather map.

- 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?
- **Isobars** are lines of equal average air pressure at sea level (**Figure** 33.2). 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** 33.3).

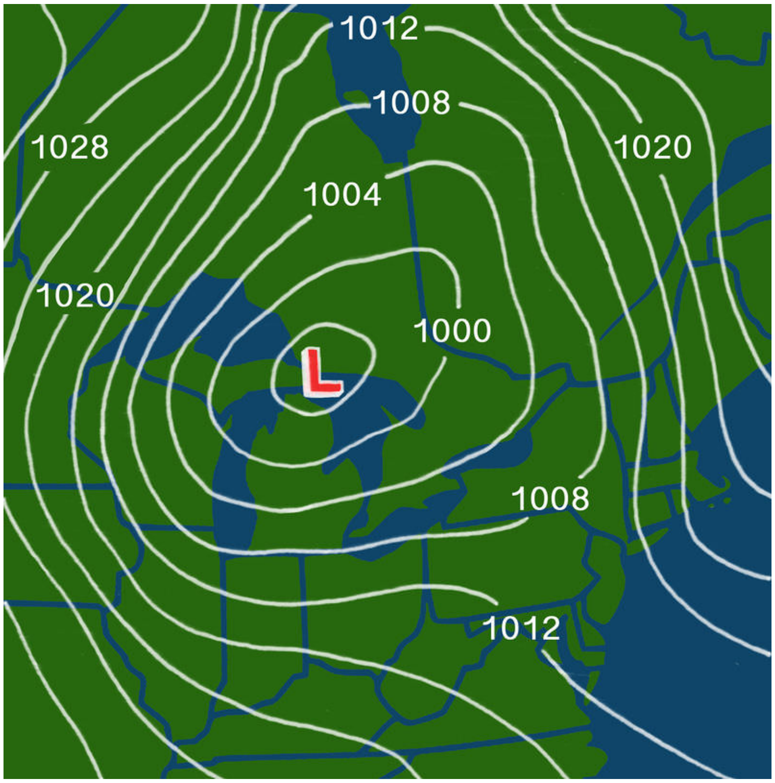


FIGURE 33.2
Isobars can be used to help visualize high pressure (H) and low pressure (L) cells.

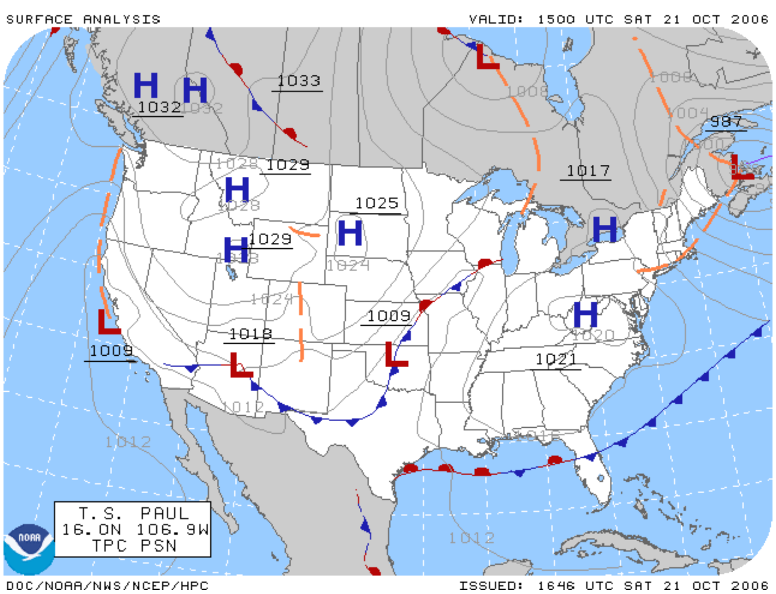
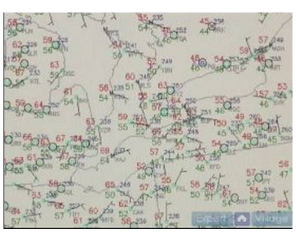


FIGURE 33.3
Surface analysis maps may show sea level mean pressure, temperature, and amount of cloud cover.



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Summary

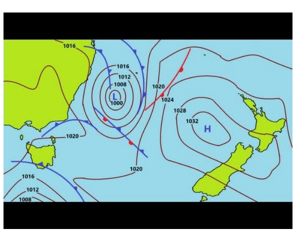
- Weather maps graphically depict weather conditions.
- Isotherms are lines of constant temperature; isobars are lines of constant pressure; isotachs are lines of constant wind speed.
- Isobars indicate pressure cells.

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?

Explore More

Use this resource to answer the questions that follow.



MEDIA
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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?

References

1. Courtesy of the US National Oceanic and Atmospheric Administration. Explanation of a weather readout . Public Domain
2. Laura Guerin. Weather map with isobars . CC BY-NC 3.0
3. Courtesy of US National Oceanic and Atmospheric Administration. Weather map showing air pressure, temperature, and cloud cover . Public Domain