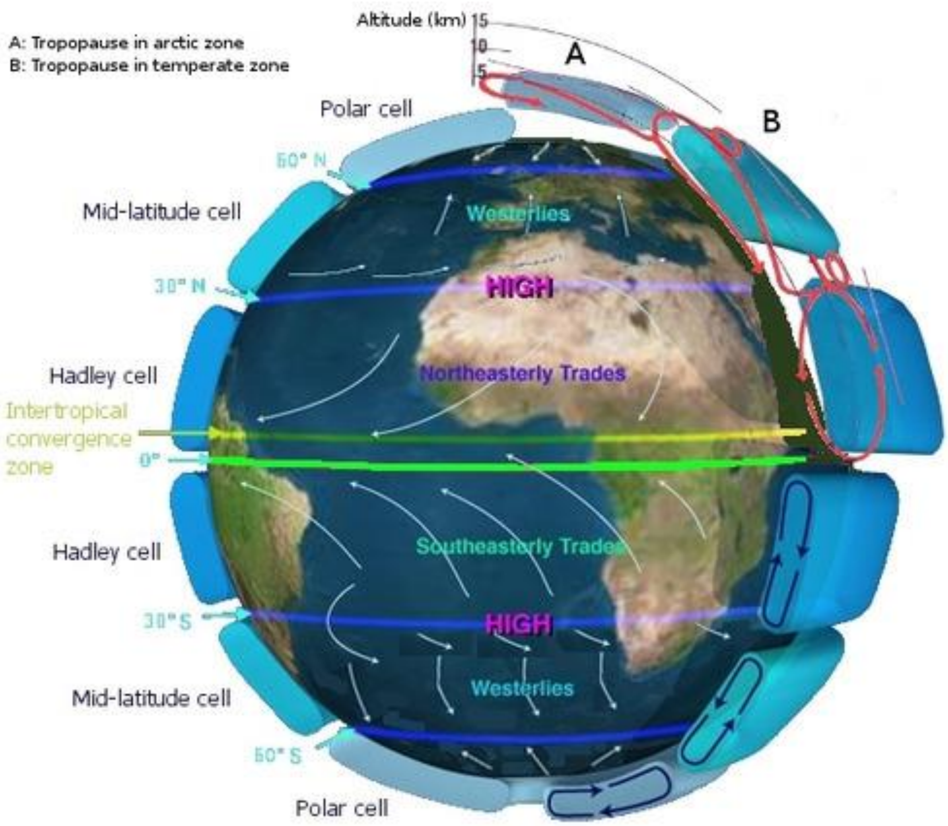
Why were winds so important to the early explorers?

Global Wind Belts

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 enabled commerce between people on opposite shores.

Global winds blow in belts encircling the planet. Notice that the locations of these wind belts correlate (go along with) 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 (see Figure below).



The direction of major wind belts.

Section 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 the Coriolis effect. So the air blows from northeast to the southwest. This belt is the trade winds, so called because at the time of sailing ships they were good for trade.
- In the Ferrel cell air should move south to north, but the winds actually blow from the southwest. This belt is also known as 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.

Check out this “real-time” Global Winds animation:

http://earth.nullschool.net/

This video lecture discusses the 3-cell model of atmospheric circulation and the resulting global wind belts and surface wind currents:

`http://www.youtube.com/watch?v=HWFDKdxK75E&feature=related (8:45)`

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.

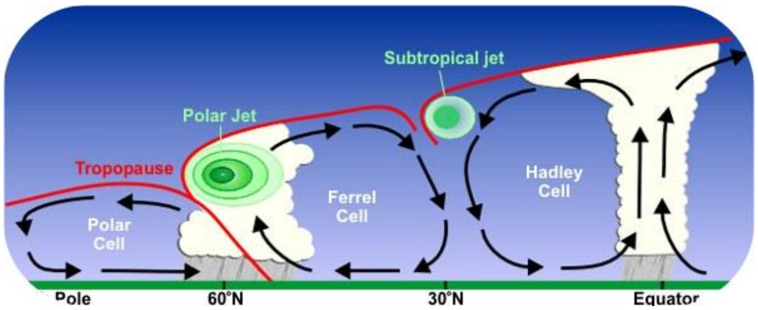
Polar Front

The polar front is the junction between the Ferrel and Polar cells. At this low pressure zone, relatively warm, moist air of the Ferrel 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 Polar Cell and Ferrel 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 below).

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.

Lesson 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.

Think like a Meteorologist

Use this resource to answer the questions that follow.

`http://www.youtube.com/watch?v=IWjeHtdpFjE`

1. Describe the process that creates wind?

2. What are monsoons? How are they created?

3. What are local and regional winds?

4. What are the global wind patterns?

5. In what direction does the Earth rotate?

6. What is the Coriolis effect?

7. What are the Westerlies?

8. Explain global wind patterns.

9. What is a jet stream? What is "the" jet stream?

10. Where on a circulation cell is there typically precipitation and where is there typically evaporation?

What is ozone and why are we concerned about a hole in the ozone?

Why can't the children in Punta Arenas go outside in the spring?

Children in Punta Arenas, Chile, the world's most southern city, look forward to spring as much as anyone who lives through a frigid, dark winter. But some years, the children are instructed not to go outside because the ozone hole has moved north and the UV radiation is too high.

Section 1: 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.

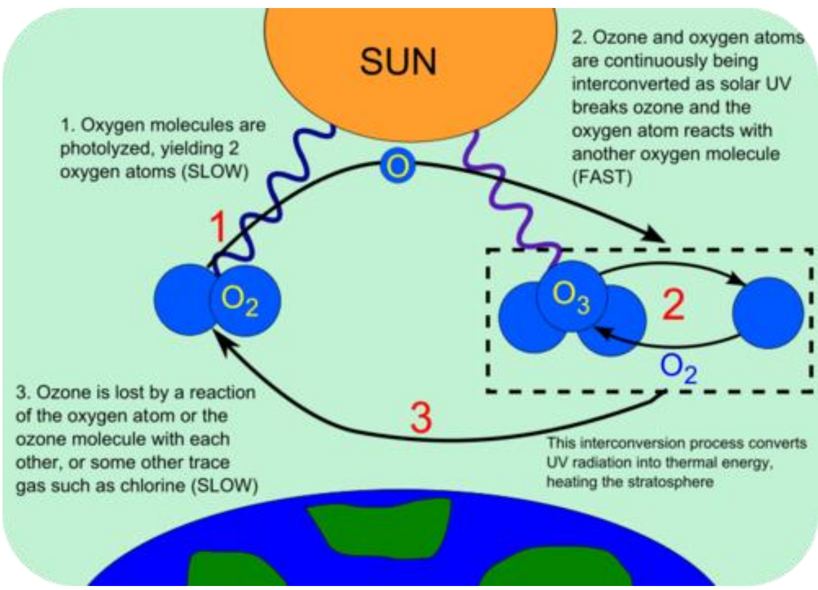
Ozone Keeps Earth's Temperature Moderate

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. Greenhouse gases trap heat in the atmosphere. Important greenhouse gases include carbon dioxide, methane, water vapor, and ozone.

Ozone Depletion

At this point you might be asking yourself, “Is ozone bad or is ozone good?” There is no simple answer to that question: It depends on where the ozone is located (see Figure below).

- In the troposphere, ozone is a pollutant.
- In the ozone layer in the stratosphere, ozone screens out high energy ultraviolet radiation and makes Earth habitable.



Solar energy breaks apart oxygen molecules into two oxygen atoms. (2) Ozone forms when oxygen atoms bond together as O_3. UV rays break apart the ozone molecules into one oxygen molecule (O_2) and one oxygen atom (O). These processes convert UV radiation into heat, which is how the Sun heats the stratosphere. (3) Under natural circumstances, the amount of ozone created equals the amount destroyed. When O_3 interacts with chlorine or some other gases the O_3 breaks down into $O_2$and O and so the ozone layer loses its ability to filter out UV.

How Ozone is Destroyed

Human-made chemicals are breaking ozone molecules in the ozone layer. Chlorofluorocarbons (CFCs) are the most common, but there are others, including halons, methyl bromide, carbon tetrachloride, and methyl chloroform. CFCs were once widely used because they are cheap, nontoxic, nonflammable, and non-reactive. They were used as spray-can propellants, refrigerants, and in many other products.

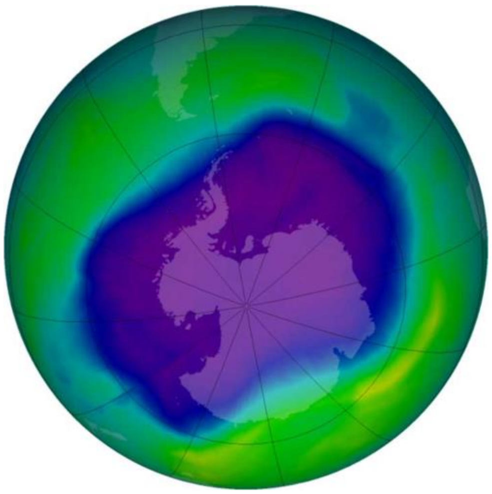
Once they are released into the air, CFCs float up to the stratosphere. Air currents move them toward the poles. In the winter, they freeze onto nitric acid molecules in polar stratospheric clouds (PSC) (see Figure below). In the spring, the sun's warmth starts the air moving, and ultraviolet light breaks the CFCs apart. The chlorine atom floats away and attaches to one of the oxygen atoms on an ozone molecule. The chlorine pulls the oxygen atom away, leaving behind an O_2 molecule, which provides no UV protection. The chlorine then releases the oxygen atom and moves on to destroy another ozone molecule. One CFC

molecule can destroy as many as 100,000 ozone molecules.

PSCs form only where the stratosphere is coldest, and are most common above Antarctica in the wintertime. PSCs are needed for stratospheric ozone to be destroyed.

Section 2: The Ozone Hole

Ozone destruction creates the ozone hole where the layer is dangerously thin (see Figure below). As air circulates over Antarctica in the spring, the ozone hole expands northward over the southern continents, including Australia, New Zealand, southern South America, and southern Africa. UV levels may rise as much as 20% beneath the ozone hole. The hole was first measured in 1981 when it was 2 million square km (900,000 square miles). The 2006 hole was the largest ever observed at 28 million square km (11.4 million square miles). The size of the ozone hole each year depends on many factors, including whether conditions are right for the formation of PSCs.



The September 2006 ozone hole, the largest observed (through 2011). Blue and purple colors show particularly low levels of ozone.

Find out how the ozone hole forms and view the hole over time on this National Geographic video:

`http://news.nationalgeographic.com/news/2008/11/081103-ozone-video-vin.html`

Ozone Loss in the North

Ozone loss also occurs over the North Polar Region, but it is not enough for scientists to call it a hole. Why do you think there is less ozone loss over the North Pole area? The region of low ozone levels is small because the atmosphere is not as cold and PSCs do not form as readily. Still, springtime ozone levels are relatively low. This low moves south over some of the world's most populated areas in Europe, North America, and Asia. At 40°N, the latitude of New York City, UV-B has increased about 4% per decade since 1978. At 55°N, the approximate latitude of Moscow and Copenhagen, the increase has been 6.8% per decade since 1978.

This video explains an importance of the stratospheric ozone layer to life on
Earth:

http://www.youtube.com/watch?v=I1wrEvc2URE&feature=related(1:52).

This NASA video discusses the ingredients of ozone depletion of Antarctica and the future of the ozone hole, including the effect of climate change:

http://www.youtube.com/watch?v=qUfVMogIdr8&feature=related (2:20).

Effects of Ozone Loss

Ozone loss effects on human health and environment include:

- Increases in sunburns, cataracts (clouding of the lens of the eye), and skin cancers. A loss of ozone of only 1% is estimated to increase skin cancer cases by 5% to 6%.
- Decreases in the human immune system’s ability to fight off infectious diseases.
- Reduction in crop yields because many plants are sensitive to ultraviolet light.
- Decreases in phytoplankton productivity. A decrease of 6% to 12% has been measured around Antarctica, which may be at least partly related to the ozone hole. The effects of excess UV on other organisms is not known.
- Whales in the Gulf of California have been found to have sunburned cells in their lowest skin layers, indicating very severe sunburns. The problem is greatest with light colored species or species that spend more time near the sea surface.

When the problem with ozone depletion was recognized, world leaders took action. CFCs were banned in spray cans in some nations in 1978. The greatest production of CFCs was in 1986, but it has declined since then. This will be discussed more in the next lesson.

Lesson Summary

- Ozone is a molecule made of 3 oxygen atoms. There is a layer of ozone in the stratosphere that absorbs harmful ultraviolet (UV) radiation.
- CFCs float up into the stratosphere where they break apart. The chlorine pulls an oxygen ion off of an ozone molecule and destroys it.
- The ozone hole is where there is less ozone than normal at that altitude. It forms in the spring.
- Ozone loss increases the amount of high-energy ultraviolet radiation that can strike Earth, causing ecological and health problems.

Think Like a Climatologist

1. What is ozone and why is it important? How do CFCs destroy ozone?
2. What is the ozone hole and where is it found? Is there an equivalent hole in the Northern Hemisphere?
3. What are some of the consequences of ozone loss that have been identified?

Practice

Use these resources to answer the questions that follow.

http://www.youtube.com/watch?v=xDOFJ5xoGmw

4. What is the purpose of the ozone?

5. Why is the ozone layer so fragile?

6. How much did ozone decrease between 1979 and 1993?

7. Which satellite was launched to study the ozone? When?

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

8. What caused this ozone loss?

Standard 3, Objective 2:
Describe elements of weather and the factors that cause them to vary from day to day.

Learning Objectives

- Identify the elements of weather and the instruments used to measure them (e.g., temperature—thermometer; precipitation—rain gauge or Doppler radar; humidity— hygrometer; air pressure—barometer; wind—anemometer; cloud coverage—satellite imaging).
- Describe conditions that give rise to severe weather phenomena (e.g., thunderstorms, tornados, hurricanes, El Niño/La Niña).
- Explain a difference between a low pressure system and a high pressure system, including the weather associated with them.
- Diagram and describe cold, warm, occluded, and stationary boundaries (weather fronts) between air masses.
- Design and conduct a weather investigation, use an appropriate display of the data, and interpret the observations and data.

What causes the change in the weather?

Now that we have looked at the atmosphere let's bring it a little closer to home and talk about weather. For an overview of air masses, see:

http://www.teachengineering.org/view_lesson.php?url=collection/cub_/lessons/cub_weather/cub_weather_lesson02.xml

Section 1: Air Masses

An air mass is a large body of air that has nearly the same temperature and humidity throughout. For example, an air mass might have cold dry air. Another air mass might have warm moist air. The conditions in an air mass depend on where the air mass formed.

Formation of Air Masses

Most air masses form over polar or tropical regions. They may form over continents or oceans. Air masses are moist if they form over oceans. They are dry if they form over continents. Air masses that form over oceans are called maritime air masses. Those that form over

Terms to know

- Weather
- Occluded Front
- Low Pressure System
- Stationary Front
- High Pressure System
- Air Masses
- Cold Front
- Warm Front

continents are called continental air masses. Figure 7.3 shows air masses that form over or near North America.

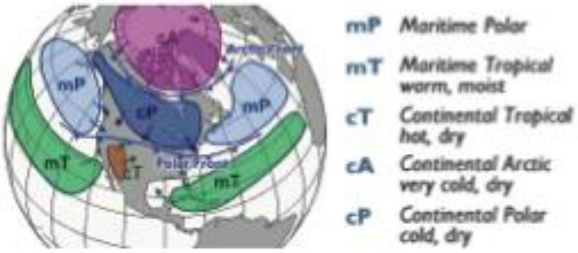


Figure 7.3 North American air masses.

An air mass takes on the conditions of the area where it forms. For example, a continental polar air mass has cold dry air. A maritime polar air mass has cold moist air. Which air masses have warm moist air? Where do they form?

Movement of Air Masses

When a new air mass goes over a region it brings its characteristics to the region. This may change the area’s temperature and humidity. Moving air masses cause the weather to change when they contact different conditions. For example, a warm air mass moving over cold ground may cause an inversion.

Why do air masses move? Winds and jet streams push them along. Cold air masses tend to move toward the equator. Warm air masses tend to move toward the poles. Coriolis Effect causes them to move on a diagonal. Many air masses move toward the northeast over the U.S. This is the same direction that global winds blow.

Section 2: Fronts

When cold air masses move south from the poles, they run into warm air masses moving north from the tropics. The boundary between two air masses is called a front. Air masses usually don’t mix at a front. The differences in temperature and pressure cause clouds and precipitation. Types of fronts include cold, warm, occluded, and stationary fronts.

Cold Fronts

A cold front occurs when a cold air mass runs into a warm air mass. This is shown in Figure above. The cold air mass moves faster than the warm air mass and lifts the warm air mass out of its way. As the warm air rises, its water vapor condenses. Clouds form, and precipitation falls. If the warm air is very humid, precipitation can be heavy. Temperature and pressure differences between the two air masses cause winds. Winds may be very strong along a cold front.

As the fast-moving cold air mass keeps advancing, so does the cold front. Cold fronts often bring sudden changes in the weather. There may be a thin line of storms right at the front that moves as it moves. In the spring and summer, these storms may be thunderstorms and tornadoes. In the late fall and winter, snow storms may occur. After a cold front passes, the cold air mass behind it brings cooler temperatures. The air is likely to be less humid as well.

Warm Fronts

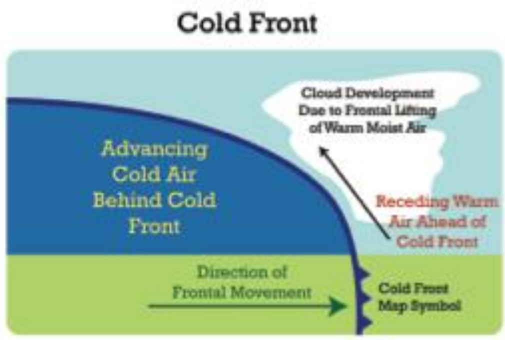
When a warm air mass runs into a cold air mass it creates a warm front. The warm air mass is moving faster than the cold air mass, so it flows up over the cold air mass. As the warm air rises, it cools, resulting in clouds and sometimes light precipitation. Warm fronts move slowly and cover a wide area. After a warm front passes, the warm air mass behind it brings warmer temperatures. The warm air is also likely to be more humid.

Occluded Fronts

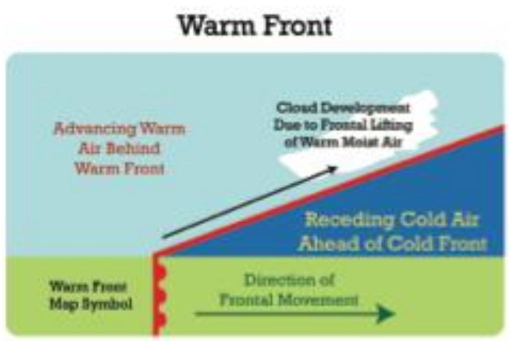
With an occluded front, a warm air mass becomes trapped between two cold air masses. The warm air is lifted up above the cold air as in Figure 7.6. The weather at an occluded front is especially fierce right at the occlusion. Precipitation and shifting winds are typical.

Stationary Fronts

Sometimes two air masses stop moving when they meet. These stalled air masses create a stationary front. Such a front may bring clouds and precipitation to the same area for many days.



Cold fronts often bring stormy weather.



Warm fronts generally bring cloudy weather.

Occluded Front

How does an occluded front differ from a warm or cold front?

Lesson Summary

- An air mass is a large body of air that has about the same conditions throughout. Air masses take on the conditions of the area where they form. Winds and air currents cause air masses to move. Moving air masses cause changes in the weather.
- A front forms at the boundary between two air masses. Types of fronts include cold, warm, occluded, and stationary fronts. Clouds, precipitation, and storms commonly occur along fronts.
- A cyclone is a system of winds that rotates around a center of low air pressure. An anticyclone is a system of winds that rotates around a center of high air pressure.

Think Like a Climatologist

1. What is an air mass?

2. Describe continental polar and maritime tropical air masses.

3. What causes air masses to move?

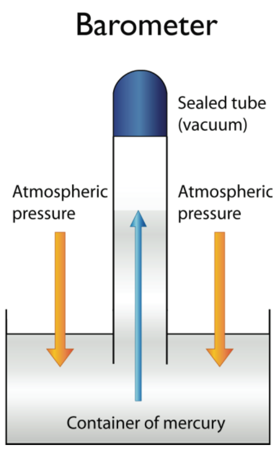
4. What is a front?

5. Define cyclone and anticyclone.

How do they Forecast the Weather?

Weather instruments measure weather conditions. One of the most important conditions is air pressure, which is measured with a barometer. Figure right shows how a barometer works. There are also a number of other commonly used weather instruments:

- A thermometer measures temperature.
- An anemometer measures wind speed.
- A rain gauge measures the amount of rain.
- A hygrometer measures humidity.
- A wind vane shows wind direction.
- A snow gauge measures the amount of snow.

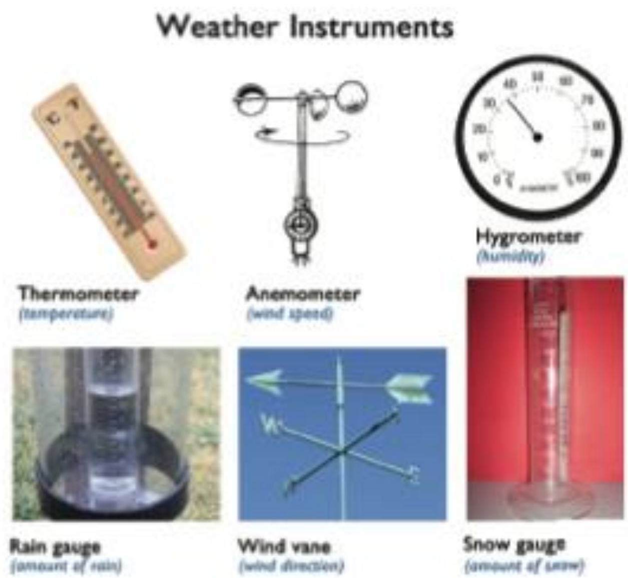


The greater the air pressure outside the tube, the higher the mercury rises inside the tube.

Weather instruments collect data from all over the world at thousands of weather stations. Many are on land but some float in the oceans on buoys.

There's probably at least one weather station near you. You can find out where at this link:

http://lwf.ncdc.noaa.gov/oa/climate/stationlocator.htm



Other weather devices are needed to collect weather data in the atmosphere. They include weather balloons, satellites, and radar.

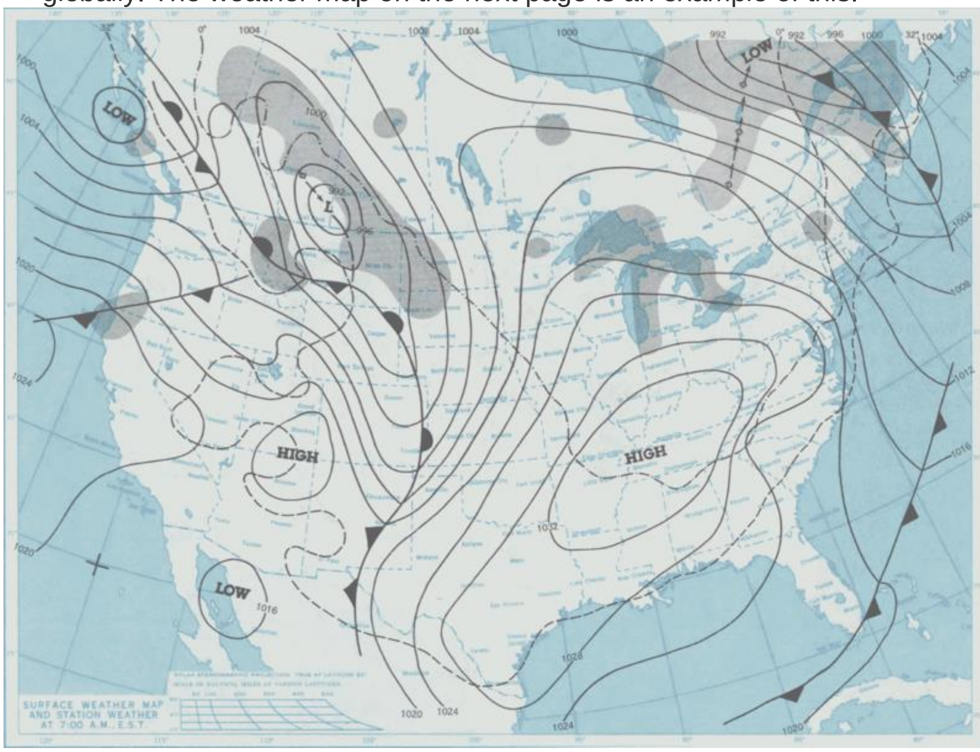
Weather stations contain many instruments for measuring weather conditions. The weather balloon will rise into the atmosphere until it bursts. As it rises, it will gather weather data and send it to the surface. Many weather satellites orbit Earth. They constantly collect and transmit weather data from high above the surface. A radar device sends out radio waves in all directions. The waves bounce off water in the atmosphere and then return to the sender. The radar data shows where precipitation is falling.

Section 1: Using computers to track the weather

What do meteorologists do with all that weather data? They use it in weather models. The models analyze the data and predict the weather. The models require computers. That's because so many measurements and calculations are involved.

Weather Maps

Because weather is an important part of everyday life, meteorologists use weather maps on the news to show what is happening nationwide or even globally. The weather map on the next page is an example of this.



Lesson Summary

- Weather is very complex. This makes it hard to predict. Certain "rules" can help. For example, low pressure brings stormy weather.
- Weather instruments measure weather factors. Weather stations collect data on Earth's surface. Weather balloons, satellites, and radar collect data in the atmosphere. Computer models analyze the data and help predict the weather.
- A shows the weather for a certain area. It can show actual or predicted weather. It may show a single weather condition or more than one.

Think Like a Meteorologist

1. Why is weather difficult to predict?

2. List three weather instruments, and state what they measure.

3. What is the role of weather balloons and weather satellites?

4. What does a weather map show?

How to read a weather map

http://www.ck12.org/earth-science/Weather-Maps/lecture/How-To-Read-A-Surface-Analysis-Of-A-Weather-Map/?referrer=featured_content

What Causes Severe Weather?

Sometimes weather can change drastically. Have you ever been out on a nice sunny day and suddenly you see large billowing clouds overhead? There are several types of severe weather than can happen around the globe. What is happening in your neighborhood?

Section 1: Thunderstorms

Thunderstorms form when ground temperatures are high, typically during late afternoons and early evenings in the summer.

Thunderstorms: Thunder and Lightning

- Thunderstorms can form individually or as part of a squall line along a cold front.
- Large amounts of energy collected within cumulonimbus clouds is released as electricity called lightning
- The rapid heating of the air surrounding a lightning strike produces a loud clap of thunder, which is a result of the rapidly expanding air.

Section 2: Tornadoes

Characteristics:

- Tornadoes form at the front of severe thunderstorms
- Tornadoes generally last only a few minutes
- When tornadoes form over water, they are referred to as waterspouts

Formation:

- Tornadoes are typically products of severe thunderstorms.
- As air in a thunderstorm rises, the surrounding air races in to fill the gap,
- This forms a funnel-shaped whirling column of air that extends down to the earth from the thundercloud.

Destruction:

- Damages a small area but can destroy everything it passes

- An average of 90 people are killed by tornadoes each year

Location:

- Tornadoes form during the spring where maritime tropical and continental polar air masses meet.

Section 3: Hurricanes

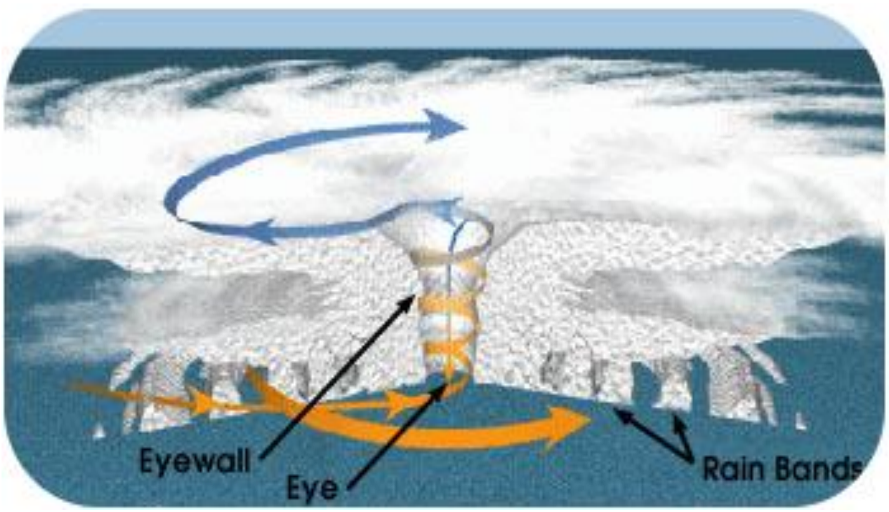
Hurricanes are special types of cyclones that form in the tropics. They are also referred to as tropical cyclones.

Hurricanes: Formation

- Hurricanes arise in the tropical latitudes in summer and autumn when sea surface temperatures are over 28ºC.
- Warm seas create a large humid air mass.
- Warm air rises and forms a low pressure cell called a tropical depression.
- Air begins to rotate around the low pressure.
- As air rises, water vapor condenses, releasing energy from latent heat.
- If wind shear is low, the storm will build into a hurricane within 2-3 day

Section 4: Blizzards

Blizzards are large snowstorms with high winds.



Conditions:

- Temperatures below -7º C (20º F); -12º C (10º 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.

Blizzards: Formation

- Occur across the middle latitudes and towards the poles
- Usually part of a mid-latitude cyclone
- Commonly occurs when the jet stream has traveled south and a cold, northern air mass comes into contact with a warmer, semitropical air mass.
- Pressure gradient between the low-pressure and high-pressure parts of the storm create strong winds

Blizzards: Lake-Effect Snow

- Lake effect snow occurs when an air mass reaches the leeward side of a lake. The air mass is very unstable and drops a tremendous amount of snow.

Section 5: Heat Waves and Droughts

Heat Wave:

- 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 9º F (5º C) above average.
- A high-pressure area sitting over a region with no movement is the likely cause of a heat wave.

Drought:

- When a region gets significantly less precipitation than normal for an extended period of time, it is in drought.
- Consequences to droughts include dust storms, blown over soil, and wildlife disturbance.

Lesson Summary

- A storm is an episode of severe weather. It is caused by a major disturbance in the atmosphere. Types of storms include thunderstorms, tornadoes, and hurricanes.
- A thunderstorm is a storm with heavy rains and lightning. It may also have hail and high winds. Thunderstorms are very common. They occur when the air is very warm and humid.
- A tornado is a storm with a funnel-shaped cloud. It has very strong, whirling winds. Tornadoes are small but powerful. They occur with thunderstorms and hurricanes.
- A hurricane is a large storm with high winds and heavy rains. Hurricanes develop from tropical cyclones. They form over warm ocean water. Much of the damage from hurricanes may be caused by storm surge.
- Winter storms develop from cyclones at higher latitudes. They include blizzards and lake-effect snow storms.

Think Like a Scientist

1. Define storm. List three types of storms.

2. Why do thunderstorms occur?

3. What is lightning? What causes it?

4. Where is tornado alley? Why do so many tornadoes occur there?

5. Where do hurricanes form? Where do they get their energy?

What are short-term climate changes?

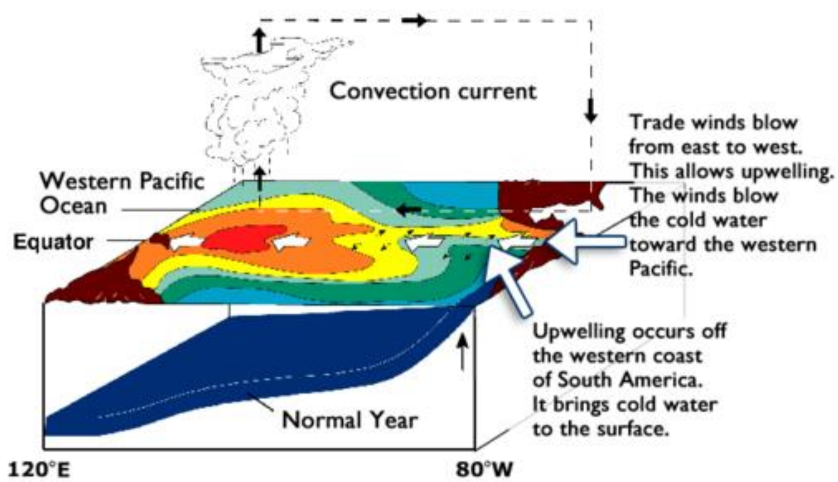
El Niño and La Niña bring about dramatic changes in climate for a year or two. In some locations one brings rain and the other brings drought. In California, for example, El Niño years are full of snow and rain. La Niña years tend towards drought. These variations can bring tremendous changes to living creatures. Humans are also affected; for example, erosion from storms may be very high some years.

Short-Term Climate Change

You've probably heard of El Niño and La Niña. These terms refer to certain short-term changes in climate. The changes are natural and occur in cycles, lasting from days to years. El Niño and La Niña are not the only short-term climate changes. Others include the Pacific decadal oscillation and the North Atlantic oscillation. El Niño and La Niña are the most noticeable and discussed.

Section 1: El Niño and La Niña

To understand El Niño and La Niña, you first need to know what happens in normal years. This is shown in the Figure below.



This diagram represents the Pacific Ocean in a normal year. North and South America are the found at the lower left and upper right of the image.

El Niño

During an El Niño, the western Pacific Ocean is warmer than usual. This causes the trade winds to change direction. The winds blow from west to east instead of east to west. This is shown in Figure below. The change in the trade winds also causes the jet streams to be north of their normal location. The warm water travels east across the equator, too. Warm water piles up along the western coast of South America. This prevents upwelling. Why do you think this is true?

These changes in water temperature, winds, and currents affect climates worldwide. The changes usually last a year or two. Some places get more rain than normal. Other places get less. In many locations, the weather is more severe.

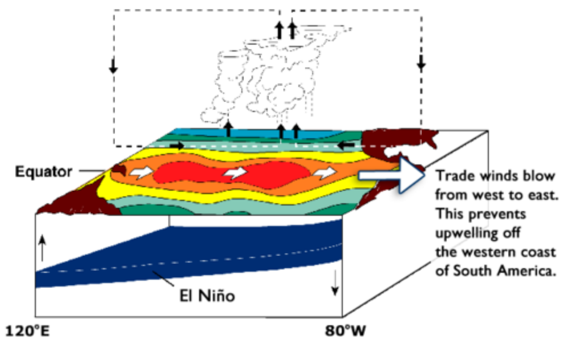


Image El Nino Year

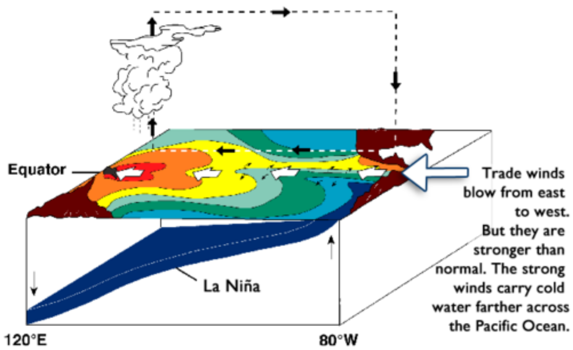
How do you think El Niño affects climate on the western coast of South America?

This ABC News video explores the relationship of El Niño to global warming. El Niño is named as the cause of strange weather across the United States in the winter of 2007 in this video:

http://www.youtube.com/watch?v=5uk9nwtAOio&feature=related (3:33).

La Niña

La Niña generally follows El Niño. It occurs when the Pacific Ocean is cooler than normal (see the figure on the following page). The trade winds are like they are in a normal year. They blow from east to west.



But in a La Niña the winds are stronger than usual. More cool water builds up in the western Pacific. These changes can also affect climates worldwide.

Image La Nina year

How do you think La Niña affects climate on the western coast of South America?

Some scientists think that global warming is affecting the cycle of El Niño and La Niña. These short-term changes seem to be cycling faster now than in the past. They are also more extreme.

An online guide to El Niño and La Niña events from the University of Illinois is found

here:http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/eln/home.rxml

El Niño and La Niña are explained in a National Geographic vides found at National Geographic Video, Natural disaster, Landslides, and More: El Niño

How Has Earth's Climate Changed?

- Explain differences between weather and climate and the methods used to investigate evidence for changes in climate (e.g., ice core sampling, tree rings, historical temperature measurements, changes in the extent of alpine glaciers, changes in the extent of Arctic sea ice).
- Explain how Earth's climate has changed over time and describe the natural causes for these changes (e.g., Milankovitch cycles, solar fluctuations, plate tectonics).
- Describe how human activity influences the carbon cycle and may contribute to climate change.
- Explain the differences between air pollution and climate change and how these are related to society's use of fossil fuels.

Terms to know

- Weather
- Carbon Cycle
- Climate
- Fossil Fuels

Sometimes you hear about what the weather is like in an area. You also hear about what the climate is like in an area. What is the difference?

Section 1: Weather vs. Climate

Weather

- Weather describes what the atmosphere is like at a specific time and place.
- Weather is made up of factors including air temperature, pressure, fog, humidity, cloud cover, precipitation, and wind.
- Most of the time, the weather is different every day.

Climate

- The climate of a region is the long-term average weather of a particular spot. It is often more predictable than the weather.
- The climate usually changes slowly, and is usually affected by factors like the angle of the Sun and the amount of cloud cover in the region.
- The weather changes all the time. It can change in a matter of minutes. Changes in climate occur more slowly. They also tend to be small changes. But even small changes in climate can make a big difference for Earth and its living things.

How Earth's Climate Has Changed

Earth's climate has changed many times. It's been both hotter and colder than it is today.

The Big Picture

Over much of Earth's past, the climate was probably a little warmer than it is today. But ice ages also occurred many times. An ice age is a period when temperatures are cooler than normal. This causes glaciers to spread to lower latitudes. Scientists think that ice ages occurred at least six times over the last billion years alone. How do scientists learn about Earth's past climates?

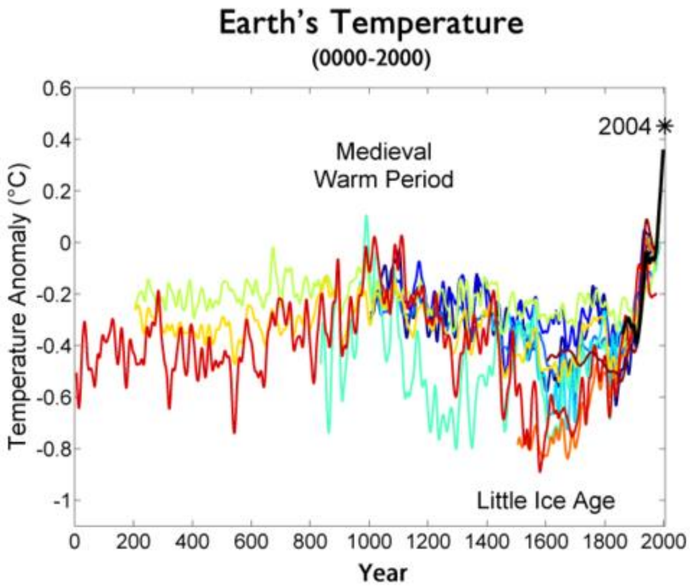
Pleistocene Ice Age

The last major ice age took place in the Pleistocene. This epoch lasted from 2 million to 14,000 years ago. Earth's temperature was only 5° C (9° F) cooler than it is today. But glaciers covered much of the Northern Hemisphere. In the Figure right, you can see how far south they went. Clearly, a small change in temperature can have a big impact on the planet. Humans lived during this ice age.

Pleistocene Glaciers. Chicago would have been buried under a glacier if it existed during the Pleistocene.

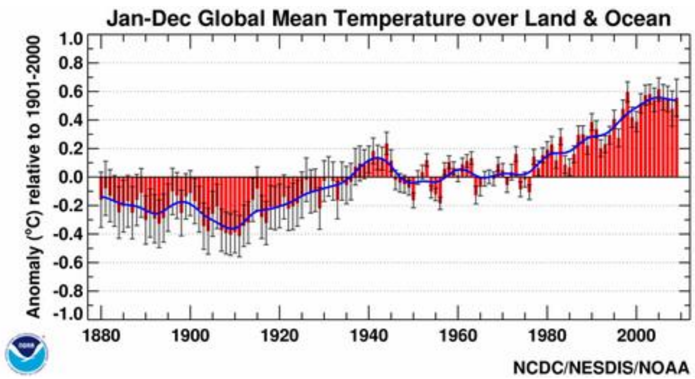
Earth’s Recent Temperature

Since the Pleistocene, Earth’s temperature has
risen. Figure below shows how it changed over just the last 2000 years.
There were minor ups and downs. But each time, the anomaly (the
difference from average temperature) was less than 1° C (1.8° F).



Earth

Since the mid-1800s, Earth has warmed up quickly. Look at
the Figure below. The 14 hottest years on record occurred since 1900.
Eight of them occurred since 1998. This is what is usually meant
by global warming.


Jan-Dec Global Mean Temperature over Land & Ocean
Anomaly (°C) relative to 1901-2000
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
1880
1900
1920
1940
1960
1980
2000
NCDC/NESDIS/NOAA

Standard 3, Objective 3: Examine the natural and human-caused processes that cause Earth's climate to change over intervals of time ranging from decades to millennia.

Natural processes caused early climate change. Human beings may be contributing to current climate change.

What Causes Climate Change?

- Several natural processes may affect Earth's temperature. They range from sunspots to Earth's wobble.
- Sunspots are storms on the sun. When the number of sunspots is high, the sun gives off more energy than usual. This may increase Earth's temperature.
- Plate movements cause continents to drift. They move closer to the poles or the equator. Ocean currents also shift when continents drift. All these changes affect Earth's temperature.
- Plate movements trigger volcanoes. A huge eruption could spew so much gas and ash into the air that little sunlight would reach the surface for months or years. This could lower Earth's temperature.
- A large asteroid hitting Earth would throw a lot of dust into the air. This could block sunlight and cool the planet.
- Earth goes through regular changes in its position relative to the sun. Its orbit changes slightly. Earth also wobbles on its axis. Both of these changes can affect Earth's temperature.

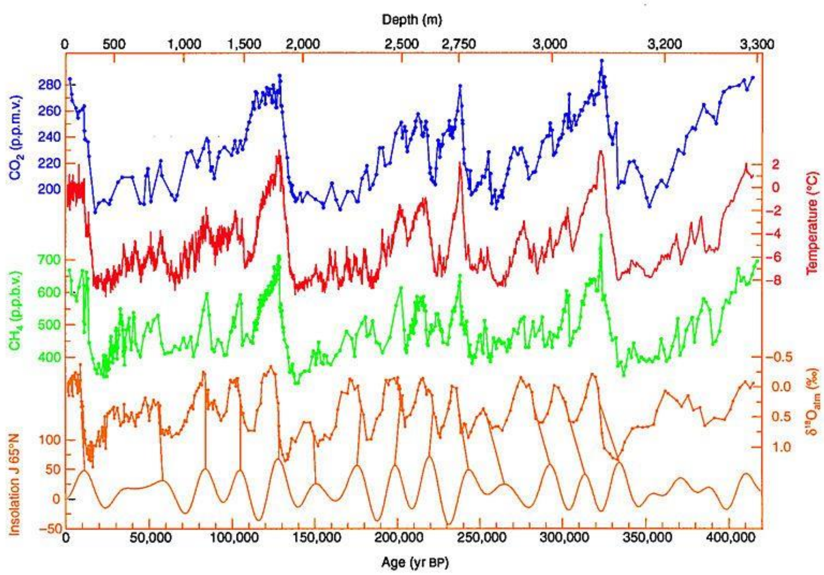


Image Vostok Ice Core. Why do the blue, green and red lines go in the same direction at the same time?

This is a complicated graph, but extremely interesting. The data are from the 3600 meter-long Vostok ice core, which gave climate scientists an unprecedented look into the history of Earth's climate. The red line is temperature. You can see that carbon dioxide and methane are correlated with temperature. When these greenhouse gases are high, temperature is high. This holds true for the 440,000 years revealed in the core.

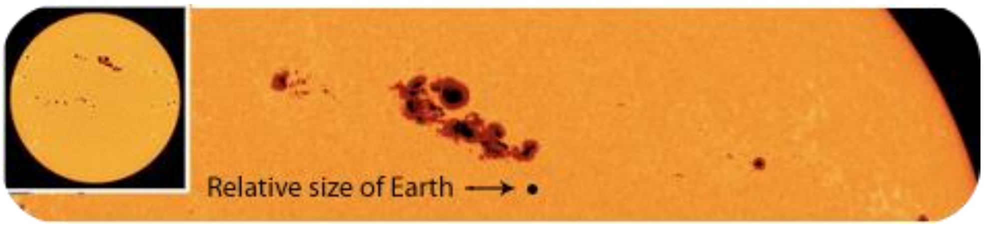
Section 1: Causes of Long-term Climate Change

Many processes can cause climate to change. These include changes:

- In the amount of energy the Sun produces over years.
- In the positions of the continents over millions of years.
- In the tilt of Earth's axis and orbit over thousands of years.
- That are sudden and dramatic because of random catastrophic events, such as a large asteroid impact.
- In greenhouse gases in the atmosphere, caused naturally or by human activities.

Solar Variation

The amount of energy the Sun radiates is variable. Sunspots are magnetic storms on the Sun's surface that increase and decrease over an 11-year cycle (Figure below). When the number of sunspots is high, solar radiation is also relatively high. But the entire variation in solar radiation is tiny relative to the total amount of solar radiation that there is, and there is no known 11-year cycle in climate variability. The Little Ice Age corresponded to a time when there were no sunspots on the Sun.



Sunspots on the face of the Sun.

Plate Tectonics

Plate tectonic movements can alter climate. Over millions of years as seas open and close, ocean currents may distribute heat differently. For example, when all the continents are joined into one supercontinent (such as Pangaea), nearly all locations experience a continental climate. When the continents separate, heat is more evenly distributed.
Plate tectonic movements may help start an ice age. When continents are located near the poles, ice can accumulate, which may increase albedo and lower global temperature. Low enough temperatures may start a global ice age.

Plate motions trigger volcanic eruptions, which release dust and CO2 into the atmosphere. Ordinary eruptions, even large ones, have only a short-term effect on weather (Figure below). Massive eruptions of the fluid lavas that create lava plateaus release much more gas and dust, and can change climate for many years. This type of eruption is exceedingly rare; none has occurred since humans have lived on Earth.

An eruption like Sarychev Volcano (Kuril Islands, Japan) in 2009 would have very little impact on weather.

Milankovitch Cycles

The most extreme climate of recent Earth history was the Pleistocene. Scientists attribute a series of ice ages to variation in the Earth's position relative to the Sun, known as Milankovitch cycles.

The Earth goes through regular variations in its position relative to the Sun:

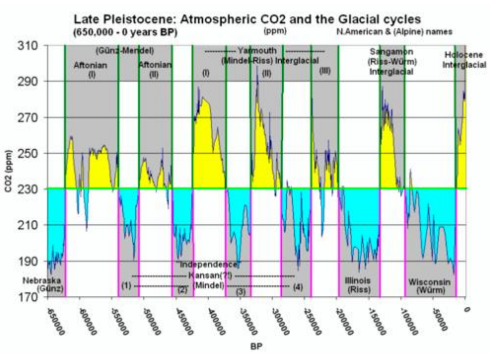
1. The shape of the Earth's orbit changes slightly as it goes around the Sun. The orbit varies from more circular to more elliptical in a cycle lasting between 90,000 and 100,000 years. When the orbit is more elliptical, there is a greater difference in solar radiation between winter and summer.
2. The planet wobbles on its axis of rotation. At one extreme of this 27,000 year cycle, the Northern Hemisphere points toward the Sun when the Earth is closest to the Sun. Summers are much warmer and winters are much colder than now. At the opposite extreme, the Northern Hemisphere points toward the Sun when it is farthest from the Sun. This results in chilly summers and warmer winters.
3. The planet’s tilt on its axis varies between 22.1o and 24.5o. Seasons are caused by the tilt of Earth's axis of rotation, which is at a 23.5o angle now. When the tilt angle is smaller, summers and winters differ less in temperature. This cycle lasts 41,000 years.

When these three variations are charted out, a climate pattern of about 100,000 years emerges. Ice ages correspond closely with Milankovitch cycles. Since glaciers can form only over land, ice ages only occur when landmasses cover the polar regions. Therefore, Milankovitch cycles are also connected to plate tectonics.

Changes in Atmospheric Greenhouse Gas Levels

Since greenhouse gases trap the heat that radiates off the planet’s surfaces, what would happen to global temperatures if atmospheric greenhouse gas levels decreased? What if greenhouse gases increased? A decrease in greenhouse gas levels decreases global temperature and an increase raises global temperature.

Greenhouse gas levels have varied throughout Earth history. For example, CO2 has been present at concentrations less than 200 parts per million (ppm) and more than 5,000 ppm. But for at least 650,000 years, CO2 has never risen above 300 ppm, during either glacial or interglacial periods (Figure below).



CO2 levels during glacial (blue) and interglacial (yellow) periods. Are CO2 levels relatively high or relatively low during interglacial periods? Current carbon dioxide levels are at 387 ppm, the highest level for the last 650,000 years. BP means years before present.

Natural processes add and remove CO2 from the atmosphere.

Processes that add CO2:

- volcanic eruptions
- decay or burning of organic matter.

Processes that remove CO2:

- absorption by plant and animal tissue.

When plants are turned into fossil fuels, the CO_2 in their tissue is stored with them. So CO_2 is removed from the atmosphere. What does this do to Earth's average temperature?

What happens to atmospheric CO_2 when the fossil fuels are burned? What happens to global temperatures?

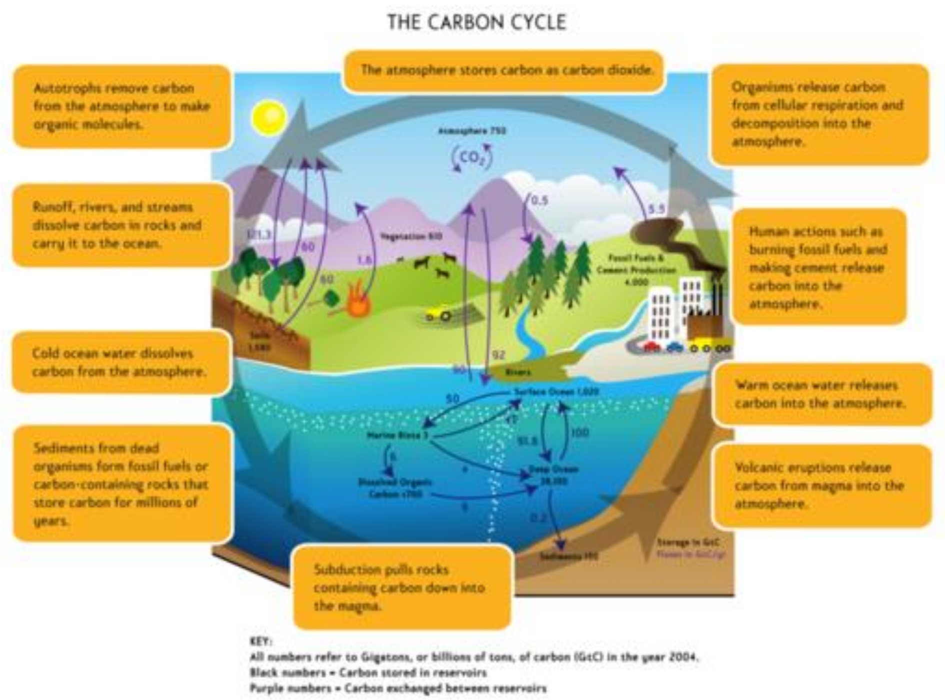
Lesson Summary

- The positions of continents, the sizes of oceans and the amount of volcanic activity that takes place are all ways that plate tectonics processes can affect climate.
- Milankovitch cycles affect the way Earth relates to the sun due to the shape of the planet's orbit, its axial tilt, and its wobble.
- Atmospheric greenhouse gas levels correlate with average global temperatures.

How are Fossil Fuels Formed?

Fossil fuels are made from plants and animals that lived hundreds of millions of years ago. The plants used energy from the Sun to form energy-rich carbon compounds. As the plants and animals died, their remains settled onto the ground and at the bottom of the sea. Layer upon layer of organic material was laid down. Eventually, the layers were buried very deeply. They experienced intense heat and pressure. Over millions of years, the organic material turned into fossil fuels.

Fossil fuels are compounds of carbon and hydrogen, called hydrocarbons



Section 1: Human Actions Impact the Carbon Cycle

Humans have changed the natural balance of the carbon cycle because we use coal, oil, and natural gas to supply our energy demands. Fossil fuels are a sink for CO_2 when they form, but they are a source for CO_2 when they are burned.

The equation for combustion of propane, which is a simple hydrocarbon looks like this (Figure below):

$$\underset{\text{propane}}{C_3H_8} + \underset{\text{oxygen}}{5\,O_2} \rightarrow \underset{\text{carbon dioxide}}{3\,CO_2} + \underset{\text{water}}{4\,H_2O}$$

Propane combustion formula.

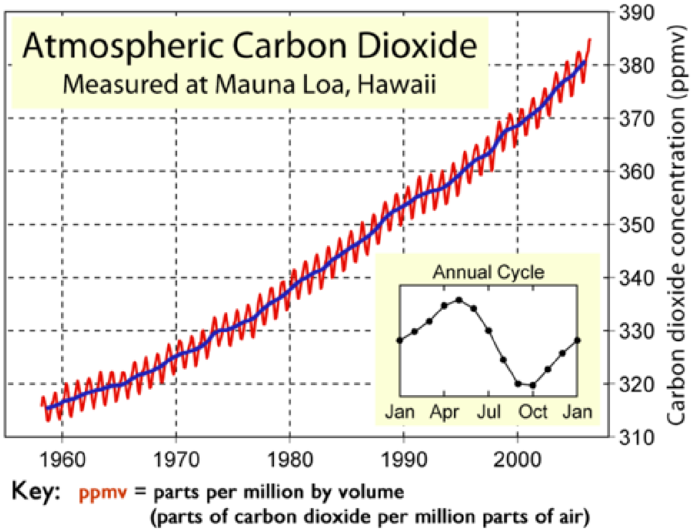
The equation shows that when propane burns, it uses oxygen and produces carbon dioxide and water. So when a car burns a tank of gas, the amount of CO_2 in the atmosphere increases just a little. Added over millions of tanks of gas and coal burned for electricity in power plants and all of the other sources of CO_2, the result is the increase in atmospheric CO_2 seen in the graph above.

The second largest source of atmospheric CO_2 is deforestation (Figure below). Trees naturally absorb CO_2 while they are alive. Trees that are cut down lose their ability to absorb CO_2. If the tree is burned or decomposes, it becomes a source of CO_2. A forest can go from being a carbon sink to being a carbon source.

This forest in Mexico has been cut down and burned to clear forested land for agriculture.

Section 2: Causes of Global Warming

Recent global warming trends. Figure below shows the increase in carbon dioxide since 1960. Carbon dioxide is a greenhouse gas. It's one of several gasses in the air. This has created a greater greenhouse effect.

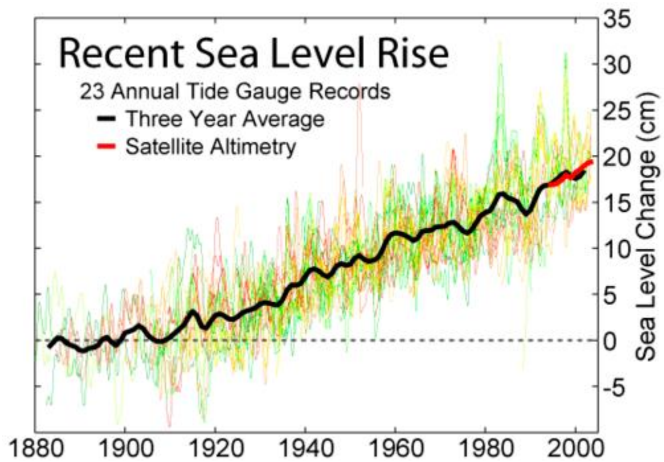


How much more carbon dioxide was in the air in 2005 than in 1960?

Effects of Global Warming

As Earth has gotten warmer, sea ice has melted. This has raised the level of water in the oceans. Figure below shows how much sea level has risen since 1880.

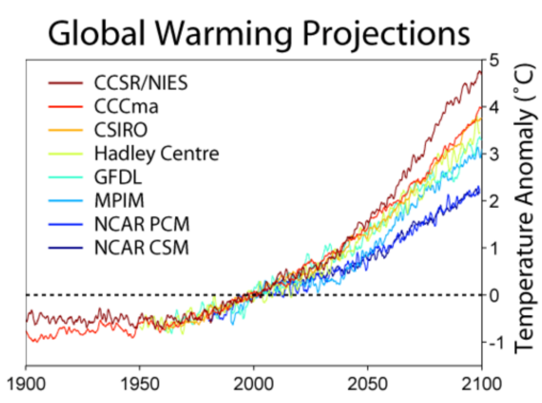
How much did sea level rise between 1880 and 2000?



Other effects of global warming may include more extreme weather. Many living things may not be able to adjust to the changing climate. For example, coral reefs are dying out in all the world's oceans due to climate change and other factors.

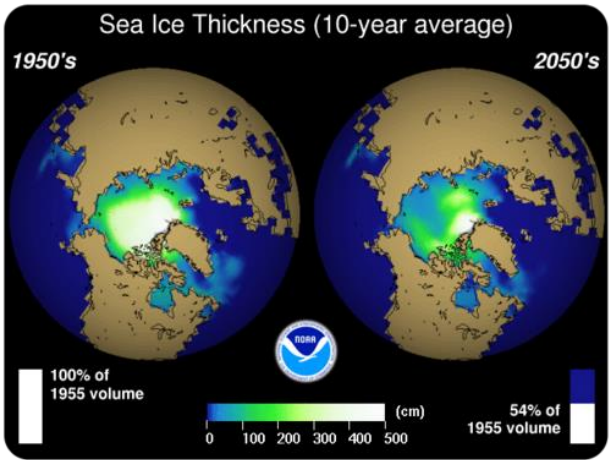
How Will Climate Change in the Future?

Look at the projections in Figure below. The temperature in 2100 may be as much as 5° C (9° F) higher than it was in 2000. A 5° C decrease in temperature led to the Pleistocene ice age. How might a 5° C increase in temperature affect Earth in the future?



Projections of several different models are shown here. They all predict a warmer future.

One effect of higher temperatures will be more melting of sea ice. The figure below shows how much less sea ice there may be in 2050 if temperatures keep going up. This would cause sea level to rise even higher. Some coastal cities could be under water. Millions of people would have to move inland. How might other living things be affected?

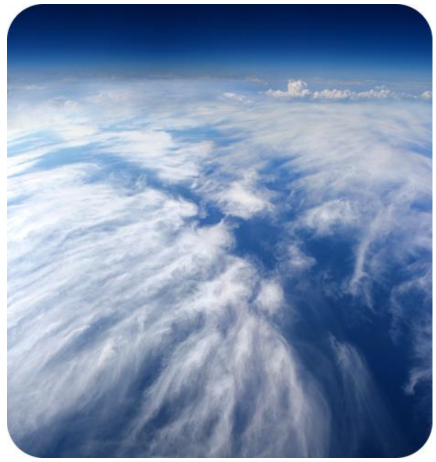


In the 2050s, there may be only half as much sea ice as there was in the 1950s.

Why is the atmosphere important?

Well, it contains all of the air that we breathe. The atmosphere also has other roles and functions, so when we interfere with the atmosphere, we interfere with some important biological processes. And this can have consequences.

The Atmosphere



The atmosphere plays an important part in maintaining Earth's freshwater supply. It is part of the water cycle. It refills lakes and rivers with precipitation. The atmosphere also provides organisms with gases needed for life. It contains oxygen for cellular respiration and carbon dioxide for photosynthesis.

Section 3: Air Pollution

Earth's atmosphere is vast. However, it has been seriously polluted by human activities. Air pollution consists of chemical substances and particles released into the atmosphere, mainly by human actions. The major cause of outdoor air pollution is the burning of fossil fuels. Power plants, motor vehicles, and home furnaces all burn fossil fuels and contribute to the problem (see Table below). Ranching and using chemicals such as fertilizers also cause air pollution. Erosion of soil in farm fields and construction sites adds dust particles to the air as well. Fumes from building materials, furniture, carpets, and paint add toxic chemicals to indoor air.

Pollutant	Example/Major Source	Problem
Sulfur oxides (SOx)	Coal-fired power plants	Acid Rain
Nitrogen oxides (NOx)	Motor vehicle exhaust	Acid Rain
Carbon monoxide (CO)	Motor vehicle exhaust	Poisoning
Carbon dioxide (CO2)	All fossil fuel burning	Global Warming
Particulate matter (smoke, dust)	Wood and coal burning	Respiratory disease, Global Dimming

Pollutant	Example/Major Source	Problem
Mercury	Coal-fired power plants, medical waste	Neurotoxicity
Smog	Coal burning	Respiratory problems; eye irritation
Ground-level ozone	Motor vehicle exhaust	Respiratory problems; eye irritation

In humans, air pollution causes respiratory and cardiovascular problems. In fact, more people die each year from air pollution than automobile accidents. Air pollution also affects ecosystems worldwide by causing acid rain, ozone depletion, and global warming. Ways to reduce air pollution from fossil fuels include switching to nonpolluting energy sources (such as solar energy) and using less energy. What are some ways you could use less energy?

Acid Rain

All life relies on a relatively narrow range of pH, or acidity. That's because protein structure and function are very sensitive to pH. Air pollution can cause precipitation to become acidic. Nitrogen and sulfur oxides, mainly from motor vehicle exhaust and coal burning, create acids when they combine with water in the air. The acids lower the pH of precipitation, forming acid rain. If acid rain falls on the ground, it may damage soil and soil organisms. If it falls on plants, it may kill them (see Figure below). If it falls into lakes, it lowers the pH of the water

and kills aquatic organisms.