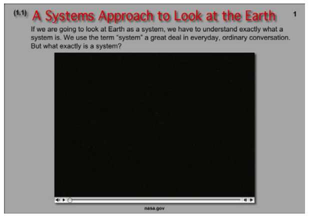
# A different way of understanding Earth

## A Systems Approach to Look at Earth

### 1.1

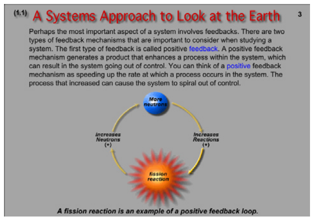



1.1.1

If we are going to look at Earth as a system, we have to understand exactly what a system is. We use the term "system" a great deal in everyday, ordinary conversation. But what exactly is a system?

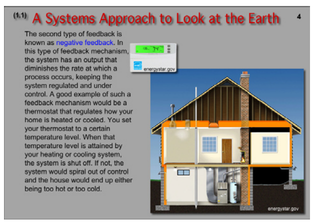

1.1.2

A system is a series of parts or pieces that work together in an interconnected manner. These interacting parts or pieces can be thought of as subsystems. A system has inputs and outputs of energy and matter. You can think of the inputs as what is necessary to sustain the system or keep the system going. The outputs are what the system produces.




1.1.3

Perhaps the most important aspect of a system involves what are termed feedbacks. There are two types of feedback mechanisms that are important to consider when studying a system. The first type of feedback is called positive feedback. A positive feedback mechanism generates a product that enhances a process within the system, which can result in the system going out of control. You can think of a positive feedback mechanism as speeding up the rate at which a process occurs in the system. The speeding up can cause the system to spiral out of control.




1.1.4

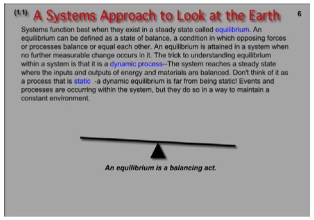
The second type of feedback is known as negative feedback. In this type of feedback mechanism, the system has an output that diminishes the rate at which a process occurs, keeping the system regulated and under control. A good example of such a feedback mechanism involves how a thermostat regulates how your home is heated or cooled. You set your thermostat to a certain temperature level. When that temperature level is attained by your heating or cooling system, the system is shut off. If not, the system would spiral out of control and the house would end up either being too hot or too cold.

## Notes

## Notes

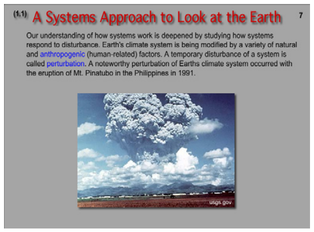

1.1.5

It is important to understand the idea that a positive feedback doesn't necessarily produce an outcome that is "good", nor does a negative feedback mechanism end up producing an outcome that is "bad".




1.1.6

Systems function best when they exist in a steady state called an equilibrium. An equilibrium can be defined as a state of balance, a condition in which opposing forces or processes exactly balance or equal each other. An equilibrium is attained in a system when no further measurable change occurs in it. The trick to understanding equilibrium within a system is that it is a dynamic process—the system reaches a steady state where the inputs and outputs of energy and materials are balanced. Don't think of it as a process that is static—a dynamic equilibrium is far from being static! Events and processes are occurring within the system, but they do so in a way to maintain a constant environment.



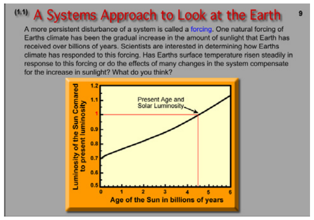

1.1.7

Our understanding of how systems work is deepened by studying how systems respond to disturbance. Earth's climate system is being modified by a variety of natural and anthropogenic factors. A temporary disturbance of a system is called perturbation. A noteworthy perturbation of Earth's climate system occurred with the eruption of Mt. Pinatubo in the Philippines in 1991.


1.1.8

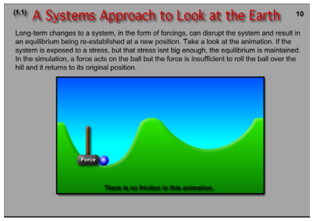
When Mt. Pinatubo erupted, it injected sulfur dioxide ($SO_2$) into the atmosphere. This $SO_2$ formed sulfate aerosol particles that prevented a small amount of sunlight from reaching Earth's surface. As a result, the surface temperature of the Earth dropped about 0.5 °C or 1 °F globally. Earth's climate system took about 3 years to fully recover from this perturbation.

# Notes



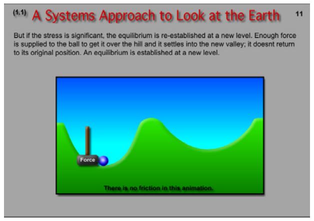

1.1.9

A more persistent disturbance of a system is called a forcing. One natural forcing of the Earth's climate has been the gradual increase in the amount of sunlight that Earth has received over billions of years. Scientists are interested in determining how Earth's climate has responded to this forcing. Has Earth's surface temperature risen steadily in response to this forcing or do the effects of many changes in the system compensate for this increase in sunlight? What do you think?




1.1.10

Long-term changes to a system, in the form of forcings, can disrupt the system and result in an equilibrium being re-established at a new position. Take a look at the animation. If the system is exposed to a stress, but that stress isn't big enough, the equilibrium is maintained. In the simulation below, a force acts on the ball. But the force is insufficient to roll the ball over the hill and it returns to its original position.



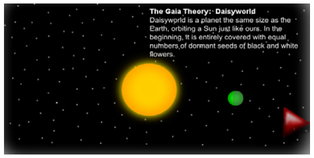

1.1.11

But if the stress is significant, the equilibrium is re-established at a new level. Enough force is supplied to the ball to get it over the hill and it settles into the new valley; it doesn't return to its original position. An equilibrium is established at a new level.

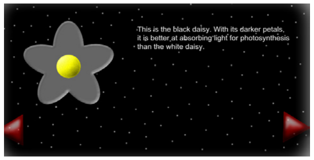

1.1.12

As you might imagine, understanding the response of the Earth system to forcing is a daunting challenge because the Earth system is very complex. A good place to begin our attempt to see if the natural systems can be self-regulating is to look at a system much simpler than that of Earth. James Lovelock, along with Andrew Watson, developed a very simple climate system for an imaginary planet, whose only life form is daisies, called Daisyworld. Let's see how Daisyworld operates.

## The Gaia Theory:  Daisyworld

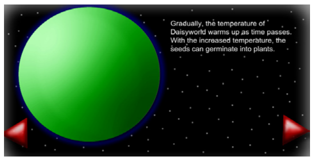


1) Daisyworld is a planet the same size as Earth, orbiting a Sun just like ours. In the beginning, it is entirely covered with equal numbers of dormant seeds of black and white flowers.

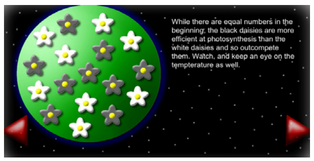


2)  This is the black daisy. With its darker petals, it is better at absorbing light for photosynthesis than the white daisy.

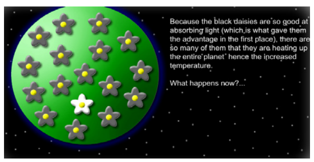
3)  This is the white daisy. Its white petals are better at reflecting light than the black daisy, so it can avoid overheating and dying.



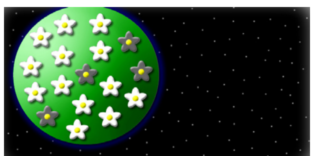
4)  Gradually, the temperature of Daisyworld warms up as time passes. With the increased temperature, the seeds can germinate into plants.



5)  While there are equal numbers in the beginning, the black daisies are more efficient at photosynthesis than the white daisies and so outcompete them. Watch, and keep an eye on the temperature as well.



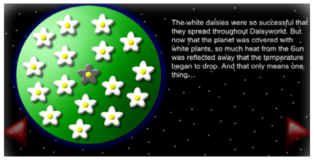
6)  Because the black daisies are so good at absorbing light (which is what gave them the advantage in the first place), there are so many of them that they are heating up the entire planet – hence the increased temperature. What happens now?...



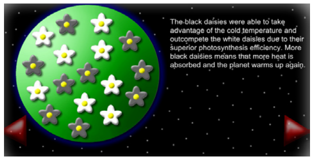
7)  Due to the high temperatures, the white daisies were able to outcompete the black daisies since they were better at reflecting away the Sun's light. So they do not overheat and die out.

# Notes

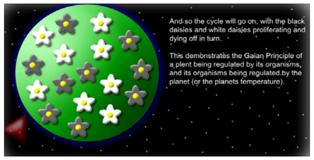
## Notes



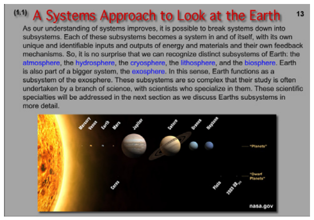
8) The white daisies were so successful that they spread throughout Daisyworld. But now that the planet was covered with white plants, so much heat from the Sun was reflected away that the temperature began to drop. And that only means one thing…



9) The black daisies were able to take advantage of the cold temperature and outcompete the white daisies due to their superior photosynthesis efficiency. More black daisies means that more heat is absorbed and the planet warms up again.



10) And so the cycle will go on, with the black daisies and white daisies proliferating and dying off in turn.
This demonstrates the Gaian Principle of a planet being regulated by its organisms, and its organisms being regulated by the planet (or the planet's temperature).




1.1.13
As our understanding of systems improves, it is possible to break systems down into subsystems. Each of these subsystems becomes a system in and of itself, with its own unique and identifiable inputs and outputs of energy and materials and their own feedback mechanisms. So, it is no surprise that we can recognize distinct subsystems of Earth: the atmosphere, the hydrosphere, the cryosphere, the lithosphere, and the biosphere. Earth is also part of a bigger system, the exosphere. In this sense, Earth functions as a subsystem of the exosphere. These subsystems are so complex that their study is often undertaken by a branch of science, which has scientists who specialize in the workings of each of them. These scientific specialties will be addressed in the next section as we discuss Earth's subsystems in more detail.


1.1.14
Summary
•Earth is composed of interacting subsystems. Outputs from one system may be inputs for another system.
•All systems have feedback loops, both positive and negative. Positive feedback loops tend to cause system processes to happen at a faster rate.

Negative feedback loops tend to keep a system in balance. (The terms positive and negative don't imply "good" or "bad".)

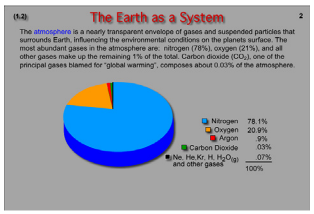
- Systems function best when they are in a steady state, or equilibrium.
- Perturbations are short-term disturbances to a system in equilibrium.
- Forcings are long-term disturbances to a system in equilibrium.
- Aerosols are solid particles that are released into the atmosphere; they tend to cause Earth to cool.
- Earth's subsystems include the atmosphere, hydrosphere, cryosphere, lithosphere, and biosphere.
- Earth is a subsystem of the exosphere.

# Notes

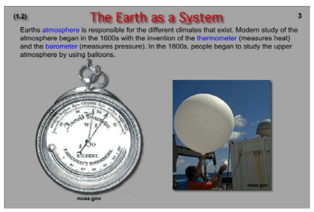
## Earth as a System

## 1.2


1.2.1
Earth can be thought of as being made of five subsystems: the atmosphere, hydrosphere, cryosphere, lithosphere, and biosphere. Earth is a planet that is part of a larger system called the exosphere. So you can think of Earth as a subsystem of the exosphere. To understand Earth as a system, we have to understand each of these subsystems, what they are made of, and how they interact.

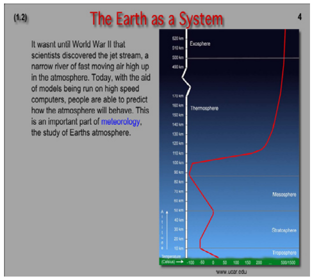



1.2.2
The atmosphere is a nearly transparent envelope of gases and suspended particles that surrounds Earth, influencing the environmental conditions on the planet's surface. The most abundant gases in the atmosphere are: nitrogen (78%), oxygen (21%); all other gases make up the remaining 1%. Carbon dioxide (CO2), one of the principal gases blamed for "global warming", composes about 0.03% of the atmosphere.




1.2.3
Earth's atmosphere is responsible for the planet's different climates. Modern study of the atmosphere began in the 1600s with the invention of the thermometer (measures heat) and the barometer (measures pressure). In the 1800s, people began to study the upper atmosphere by using balloons.

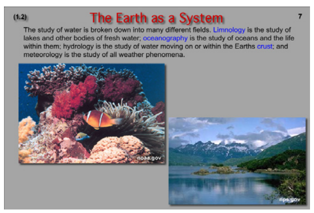
# Notes




1.2.4
It wasn't until World War II that scientists discovered the jet stream, a narrow river of fast moving air high up in the atmosphere. Today, with the aid of models being run on high speed computers, people are able to predict how the atmosphere will behave. This is an important part of meteorology, the study of Earth's atmosphere.


1.2.5
The atmosphere helps to keep Earth warm, shielding the surface from harmful radiation and circulating moisture. Changes in the atmosphere are responsible for: tornadoes, hurricanes, thunderstorms, lightning, rain, snow, warm days, blue skies, red sunsets, hail, sleet (snow days!), wind, dew, and fog.

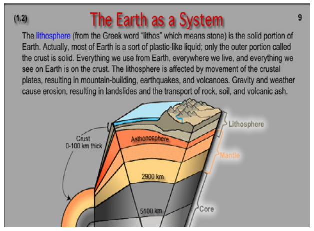
1.2.6
The hydrosphere includes all of the water regions at or near the surface of Earth. The surface of Earth has a lot of water on it, 350 million cubic miles of water covering 75% of the surface. Water is essential to support life; no water means no life! Earth's oceans have played an important role throughout history. They provide food, transportation, and recreation, all of which have been important in the development of society.




1.2.7
The study of water is broken down into many different fields. Limnology is the study of fresh water; oceanography is the study of oceans and the life within them; hydrology is the study of water within the Earth's crust; and meteorology is the study of the atmosphere, which transports large volumes of water.


1.2.8
The cryosphere is made up of water, like the hydrosphere, except that the cryosphere is always frozen. This permanent ice is located at the North and South Poles and at high elevations around the world. Recently people have used the cryosphere to study Earth's ancient past by analyzing the gases and other substances that are frozen in the ice.

# Notes

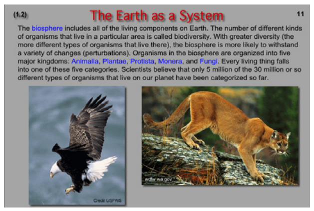



1.2.9

The lithosphere (from the Greek word "lithos" which means stone) is the solid portion of Earth. Actually, most of Earth is a sort of plastic-like liquid; only the outer portion called the crust is solid. Everything we use from Earth, everywhere we live, and everything we see on Earth is on the crust. The lithosphere is affected by movement of the crustal plates, resulting in mountain-building, earthquakes, and volcanoes. Gravity and weather cause erosion, resulting in landslides and the transport of rock, soil, and volcanic ash.

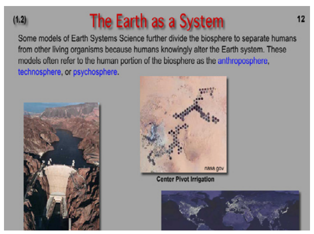
1.2.10

People first began studying the lithosphere, sometimes referred to as the geosphere, by looking at rocks: their color, texture, density, and chemical makeup. Geology is the study of the lithosphere and its processes. People depend on the lithosphere to obtain almost all of the materials used in today's world. Diamonds, gold, silver, coal, oil, stones for building, and natural gas all come from the lithosphere along with countless other products. People even depend on the lithosphere to-grow food.




1.2.11

The biosphere includes all of the living components on Earth. The number of different kinds of organisms that live in a particular area is called biodiversity. With greater diversity (the more different types of organisms that live there), the biosphere is more likely to withstand a variety of changes (perturbations). Organisms in the biosphere are organized into five major kingdoms: Animalia, Plantae, Protista, Monera, and Fungi. Every living thing falls into one of these five categories. Scientists believe 30 million different types of organisms live on our planet, and that only five million have been categorized so far.




1.2.12

Some models of Earth Systems Science further divide the biosphere to separate humans from other living organisms because humans knowingly alter the Earth system. These models often refer to the human portion of the biosphere as the anthroposphere, technosphere, or psychosphere.


1.2.13

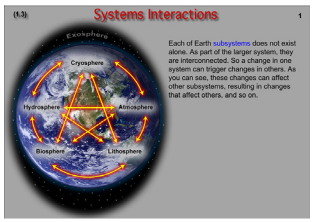
The exosphere, also known as the cosmosphere, is made up of everything outside of Planet Earth. Our solar system, star cluster, galaxy, galactic cluster, and universe are all parts of the exosphere. People have studied the exosphere for thousands of years using everything from the naked eye to high tech telescopes. With the beginning of the Space Age, studying the exosphere has been made much easier because we can now send instruments above Earth's atmosphere to see the exosphere unobstructed. The study of the exosphere, called astronomy, is probably the hardest sphere to study because generally we can't visit these distant places.


1.2.14

Summary

•The most abundant gas in Earth's atmosphere is nitrogen, followed by oxygen, argon, and carbon dioxide.
•Instruments are used to take direct measurements within the Earth system.
•Scientific disciplines focused on Earth's systems and subsystems include: meteorology and climatology (study of atmosphere--present and past); astronomy (study of the exosphere); limnology, hydrology, and oceanography (areas of study in the hydrosphere); geology (study of the lithosphere); biology (study of the biosphere); and glaciology (study within the cryosphere).
•The biosphere is broken down into five kingdoms.
•The effects of human activity in the Earth system are sometimes called the anthroposphere, technosphere, or psychosphere.
•The exosphere (outer space) is also known as the cosmosphere.

## 1.3 System Interactions

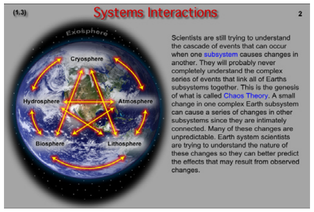



1.3.1

Each of Earth's subsystems does not exist alone. As part of the larger system, they are interconnected. So a change in one system can trigger changes in others. As you can see, these changes can affect other subsystems, resulting in changes that affect others, and so on.

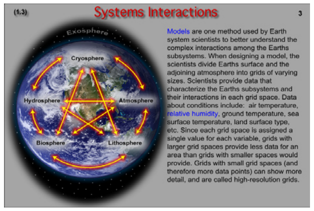
Notes

## Notes



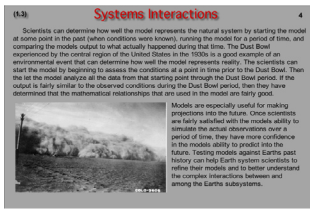

1.3.2

Scientists are still trying to understand the cascade of events that can occur when one subsystem causes changes in another. They will probably never completely understand the complex series of events that link all of Earth's subsystems together. This is the genesis of what is called Chaos Theory. A small change in one complex Earth subsystem can cause a series of changes in other subsystems since they are intimately connected. Many of these changes are unpredictable. Earth system scientists are trying to understand the nature of these changes so they can better predict the effects that may result from observed changes.




1.3.3

Models are one method used by Earth system scientists to better understand the complex interactions among the Earth's subsystems. When designing a model, the scientists divide Earth's surface and the adjoining atmosphere into grids of varying sizes. Scientists provide data that characterize the Earth's subsystems and their interactions in each grid space. Data about conditions include: air temperature, relative humidity, ground temperature, sea surface temperature, land surface type, etc. Since each grid space is assigned a single value for each variable, grids with larger grid spaces provide less data for an area than grids with smaller spaces would provide. Grids with small grid spaces (and therefore more data points) can show more detail, and are called high-resolution grids.

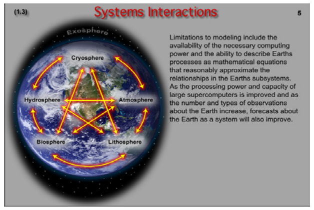



1.3.4

Scientists can determine how well the model represents the natural system by starting the model at some point in the past (when conditions were known), running the model for a period of time, and comparing the model's output to what actually happened during that time. The Dust Bowl experienced by the central region of the United States in the 1930s is a good example of an environmental event that can determine how well the model represents reality. The scientists can start the model by beginning to assess the conditions at a point in time prior to the Dust Bowl. Then they let the model analyze all the data from that starting point through the Dust Bowl period. If the output is fairly similar to the observed conditions during the Dust Bowl period, then they have determined that the mathematical relationships that are used in the model are fairly good.

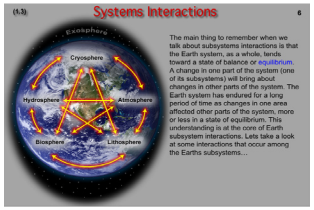
# Notes

Models are especially useful for making projections into the future. Once scientists are fairly satisfied with the model's ability to simulate the actual observations over a period of time, they have more confidence in the model's ability to predict into the future. Testing models against Earth's past history can help Earth system scientists to refine their models and to better understand the complex interactions between and among the Earth's subsystems.



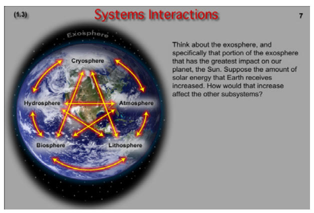

1.3.5

Limitations to modeling include the availability of the necessary computing power and the ability to describe Earth's processes as mathematical equations that reasonably approximate the relationships in Earth's subsystems. As the processing power and capacity of large supercomputers is improved and as the number and types of observations about Earth increase, forecasts about Earth as a system will also improve.



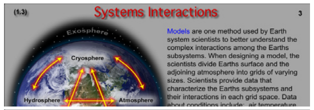

1.3.6

The main thing to remember when we talk about subsystems interactions is that the Earth system, as a whole, tends toward a state of balance or equilibrium. A change in one part of the system (one of its subsystems) will bring about changes in other parts of the system. The Earth system has endured for a long period of time as changes in one area affected other parts of the system, more or less in a state of equilibrium. This understanding is at the core of Earth subsystem interactions. Let's take a look at some interactions that occur among Earth's subsystems…




1.3.7

Think about the exosphere, and specifically that portion of the exosphere that has the greatest impact on our planet, the Sun. Suppose the amount of solar energy that Earth receives increased. How would that increase affect the other subsystems?





1.3 (Interactive screen)
Earth's systems interact with each other continuously. An event in one system can cause an effect felt in another system. Read the statement between the two red squares below. Drag the icon for each of the appropriate systems into the "Cause" and "Effect" squares. Click on "Check Answer" to see if you have set up the correct system interactions.

1.3.8 Rivers erode land.
1.3.9 Volcanoes release gases.
1.3.10 The Moon causes tides.
1.3.11 Rain causes plants to grow.
1.3.12 Hurricanes can cause beach erosion.
1.3.13 The presence of sunlight permits photosynthesis in plants.
1.3.14 Icebergs change the salinity of the oceans.
1.3.15 Humans construct mines to obtain coal.
1.3.16 Animals breathe oxygen.
1.3.17 Glaciers cut grooves in bedrock.
1.3.18 As an ice sheet melts, the oceans rise.
1.3.19 Increased solar energy can cause glaciers to melt.
1.3.20 Rainforests absorb large quantities of carbon dioxide.


1.3.21
Summary
•Earth is composed of interacting subsystems.
•Actions in one system can CAUSE an EFFECT felt in that system or other systems.
•It may be impossible to fully understand or accurately predict the complex events that occur within and among Earth's subsystems. This is the genesis of the Chaos Theory.
•A model, based on facts and research, is used in science to understand past events and to make predictions about future events.
•A change within one system in the Earth system can result in a shift of the equilibrium of other systems.

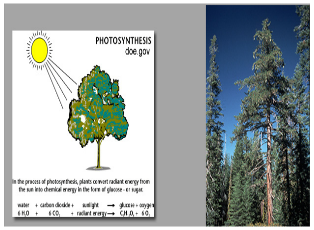
# Earth’s Grand Cycles

What are Grand Cycles?

## 2.1

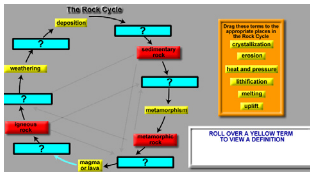

2.1.1

The Earth System relies on a series of processes that are essential in order for Earth to stay in equilibrium. These processes are often referred to as “grand cycles”. The grand cycles are a series of biogeochemical processes that occur in the Earth system. These biogeochemical processes recycle matter through the Earth system.




2.1.2

One example of a biogeochemical process would be the recycling of oxygen. For example, photosynthetic organisms release oxygen. Some oxygen is also recycled in the lithosphere as chemical reactions occur in the rocks and soil. All biogeochemical cycles involve a concept known as residence time. This is the length of time that a certain molecule remains in a particular form within the cycle. Residence time varies greatly in these cycles. Time frames may be as short as minutes to as long as millions of years. Click forward to investigate the Rock Cycle.



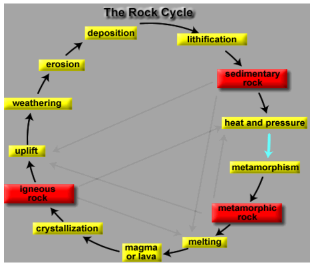

2.1.3

Below is a model of the rock cycle. It describes the formation of rocks and movement of rock material within the Earth System. Some of the terms associated with this diagram are missing. Drag the terms into the proper location in the rock cycle and then click on “Check Answer.” You’ll have three chances to get the terms in the correct locations.

Drag these terms to the appropriate places in the Rock Cycle.

crystallization
erosion
heat and pressure
lithification
melting
uplift

## Notes

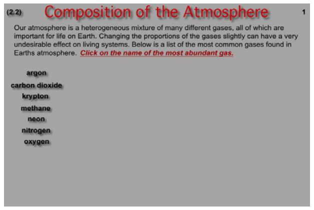



2.1.4

The rock cycle is a continuous process, represented in the diagram below by the changing arrows. Materials within the rock cycle have residence times that vary from months to millions of years. The remainder of this chapter examines some other grand cycles in more detail.

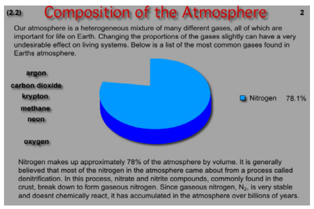
## Composition of the Atmosphere

## 2.2




2.2.1

Our atmosphere is a heterogeneous mixture of many different gases, all of which are important for life on Earth. Changing the proportions of the gases slightly can have a very undesirable effect on living systems. Below is a list of the most common gases found in Earth's atmosphere. Click on the name of the most abundant gas.



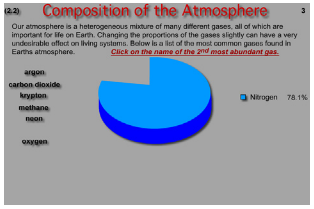

2.2.2

Our atmosphere is a heterogeneous mixture of many different gases, all of which are important for life on Earth. Changing the proportion of the gases slightly can have a very undesirable effect on living systems. Below is a list of the most common gases found in Earth's atmosphere.

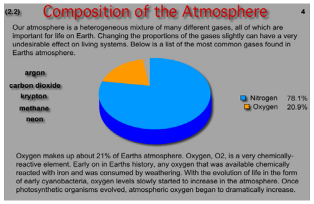
Nitrogen 78.1%

Nitrogen makes up approximately 78% of the atmosphere by volume. It is generally believed that most of the nitrogen in the atmosphere came about from a process called denitrification. In this process, nitrate and nitrite compounds, commonly found in the crust, break down to form gaseous nitrogen. Since gaseous nitrogen, $N_2$, is very stable and doesn't chemically react, it has accumulated in the atmosphere over billions of years.

# Notes



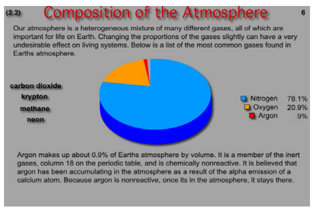

2.2.3
Our atmosphere is a heterogeneous mixture of many different gases, all of which are important for life on Earth. Changing the proportion of the gases slightly can have a very undesirable effect on living systems. Below is a list of the most common gases found in Earth's atmosphere. Click on the name of the second most abundant gas.




2.2.4
Our atmosphere is a heterogeneous mixture of many different gases, all of which are important for life on Earth. Changing the proportion of the gases slightly can have a very undesirable effect on living systems. Below is a list of the most common gases found in Earth's atmosphere.

Oxygen 20.9%

Oxygen makes up about 21% of Earth's atmosphere. Oxygen, $O_2$, is a very chemically-reactive element. Early on in Earth's history, any oxygen that was available chemically reacted with iron and was consumed by weathering. With the evolution of life in the form of early cyanobacteria, oxygen levels slowly started to increase in the atmosphere. Once photosynthetic organisms evolved, atmospheric oxygen began to dramatically increase.

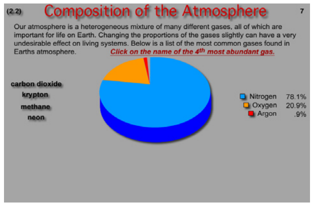



2.2.6
Our atmosphere is a heterogeneous mixture of many different gases, all of which are important for life on Earth. Changing the proportion of the gases slightly can have a very undesirable effect on living systems.

Argon 0.9%

Argon makes up about 0.9% of Earth's atmosphere by volume. It is a member of the inert gases, column 18 on the periodic table, and is chemically nonreactive. It is believed that argon has been accumulating in the atmosphere as a result of the alpha emission of a calcium atom. Because argon is nonreactive, once it's in the atmosphere, it stays there.

# Notes

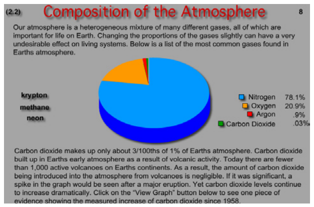



2.2.7

Our atmosphere is a heterogeneous mixture of many different gases, all of which are important for life on Earth. Changing the proportion of the gases slightly can have a very undesirable effect on living systems. Click on the name of the fourth most abundant gas.

Carbon dioxide 0.03%

Carbon dioxide makes up only about 3/100ths of 1% of Earth's atmosphere. Carbon dioxide built up in Earth's early atmosphere as a result of volcanic activity. Approximately 550 volcanic eruptions have occurred during the period of human history, and about 1300 eruptions are known to have occurred during the Holocene Period. The amount of carbon dioxide being introduced into the atmosphere from volcanoes is negligible. Yet, carbon dioxide levels are increasing dramatically. Click on the "View Graph" button below to see one piece of evidence showing the measured increase of carbon dioxide since 1958.



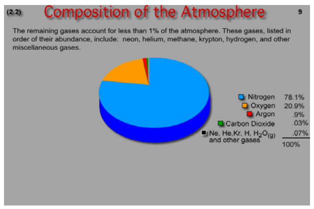

2.2.8

-Notice the steady increase in $CO_2$ levels

-What could cause this?

-Explain the differences in $CO_2$ levels between summer and winter.

Plants use carbon dioxide as they conduct photosynthesis, removing some of the carbon dioxide from the air. In temperate climates, many plants die back or lose their leaves during the fall, so photosynthesis is dramatically reduced in winter.




2.2.9

The remaining gases account for less than 1% of the atmosphere. These gases, listed in order of their abundance, include: neon, helium, methane, krypton, hydrogen, and other miscellaneous gases, including water vapor.

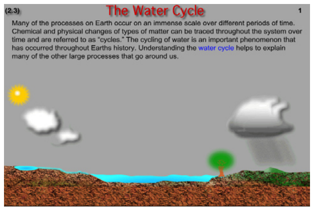
Ne, He, Kr, H, $H_2$0(g), and other gases ____________

100%

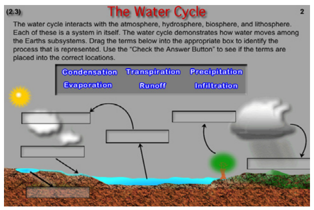

2.2.10
Summary
•Earth's atmosphere is composed of several gases. The most abundant is nitrogen, followed by oxygen, argon, and carbon dioxide.
•The composition of the atmosphere has changed over time, in response to natural chemical processes and the activities of the biosphere.
•Climate scientists understand that a change in the composition of the atmosphere can result in global climate change.

## The Water Cycle

## 2.3

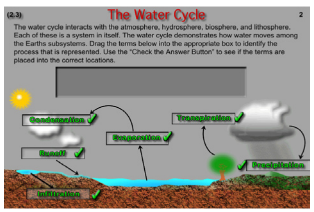



2.3.1
Many of the processes on Earth occur on an immense scale over different periods of time. Chemical and physical changes in matter can be traced throughout the system over time and are referred to as "cycles." The cycling of water is an important phenomenon that has occurred throughout Earth's history. Understanding the water cycle helps to explain many of the other processes that go on around us.



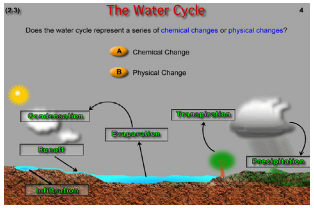

2.3.2
The water cycle interacts with the atmosphere, hydrosphere, biosphere, and lithosphere. Each of these is a system in itself. The water cycle demonstrates how water moves among Earth's subsystems. Drag the terms below into the appropriate box to identify the process that is represented. Use the "Check the Answer Button" to see if the terms are placed into the correct locations.

| | | |
|---|---|---|
| Condensation | Transpiration | Precipitation |
| Evaporation | Runoff | Infiltration |




2.3.4
Does the water cycle represent a series of chemical changes or physical changes?
A) Chemical Change
B) Physical Change

Notes




2.3.5
Does the water cycle represent a series of chemical changes or physical changes?

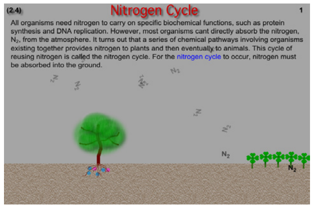
Water undergoes a series of physical changes. It simply changes phase between solid, liquid, and gas. Don't forget that water can also sublimate from glaciers and ice sheets by changing from a solid to a gas without going through the liquid phase.


2.3.6
Summary
•Very little new water enters the Earth system. Instead, almost all water has been recycled since Earth's formation.
•Several processes are involved in the natural recycling of water:
--Condensation – the conversion of gaseous water to liquid water
--Transpiration – the release of water vapor from plants
--Precipitation – movement of water from the atmosphere to Earth's surface
--Evaporation – changing from liquid water to gaseous water
--Runoff – draining of water from a solid surface
--Infiltration – movement of water into and below Earth's surface
--Sublimation – changing from solid water directly to gaseous water

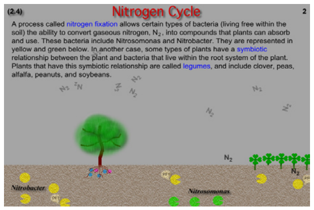
Notes

## The Nitrogen Cycle

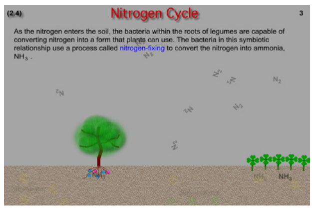
# 2.4



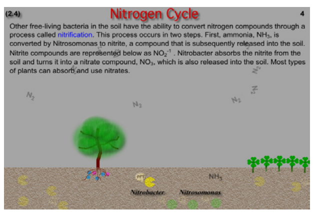

2.4.1
All organisms need nitrogen to carry on specific biochemical functions, such as protein synthesis and DNA replication. However, most organisms can't directly absorb nitrogen, $N_2$, from the atmosphere. A series of chemical pathways between organisms first provides nitrogen to plants, which are then consumed by animals. Re-use of nitrogen is called the nitrogen cycle. For the nitrogen cycle to occur, nitrogen must be absorbed into the ground from the air.



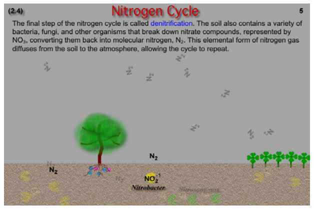

2.4.2
A process called nitrogen fixation allows certain types of bacteria (living free within the soil) the ability to convert gaseous nitrogen, $N_2$, into compounds that plants can absorb and use. These bacteria include <u>Nitrosomonas</u> and <u>Nitrobacter</u>. They are represented in green and yellow below. In another case, some types of plants have a symbiotic relationship between the plant and bacteria that live within the root system of the plant. Plants that have this symbiotic relationship are called legumes, and include clover, peas, alfalfa, peanuts, and soybeans.




2.4.3
As the nitrogen enters the soil, the bacteria within the roots of legumes are capable of converting nitrogen into a form that plants can use. The bacteria in this symbiotic relationship use a process called nitrogen-fixing to convert the nitrogen into ammonia, $NH_3$.

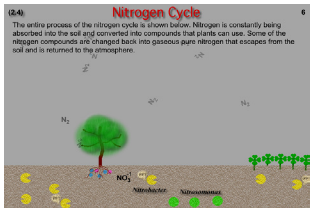



2.4.4
Other free-living bacteria in the soil have the ability to convert nitrogen compounds through a process called nitrification. This process occurs in two steps. First, ammonia, $NH_3$, is converted by Nitrosomonas to nitrite, a compound that is subsequently released into the soil. Nitrite compounds are represented below as $NO_2^{-1}$. Nitrobacter absorbs the nitrite from the soil and turns it into a nitrate compound, $NO_3$, which is also released into the soil. Most types of plants can absorb and use nitrates.




2.4.5

The final step of the nitrogen cycle is called denitrification. The soil also contains a variety of bacteria, fungi, and other organisms that break down nitrate compounds, represented by $NO_3$, converting them back into molecular nitrogen, $N_2$. This elemental form of nitrogen gas diffuses from the soil to the atmosphere, allowing the cycle to repeat.




2.4.6

The entire process of the nitrogen cycle is shown below. Nitrogen is constantly being absorbed into the soil and converted into compounds that plants can use. Some of the nitrogen compounds are changed back into gaseous pure nitrogen that escapes from the soil and is returned to the atmosphere.


2.4.7

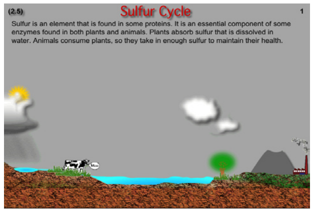
Summary

- Organisms need nitrogen for cellular processes such as protein synthesis and DNA replication.
- Nitrogen in the air (78% by volume) is pure nitrogen ($N_2$) which is chemically unavailable to most living things.
- Legumes (peas, clover, soybeans, peanuts, and alfalfa) have a symbiotic relationship with certain types of bacteria that live in their roots. This relationship allows legumes to fix nitrogen from the air into ammonia and enrich the soil.
- Nitrification is a process where bacteria living in the soil can convert gaseous $N_2$ into nitrogen compounds such as nitrites and nitrates that other organisms can use.
- Denitrification is a process through which some bacteria and fungi convert nitrogen compounds back to gaseous, pure nitrogen, $N_2$.

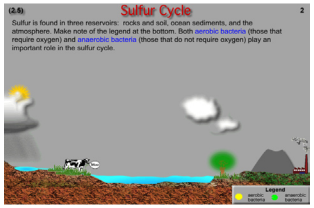
# Notes

## The Sulfur Cycle

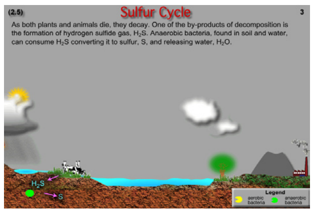
## 2.5



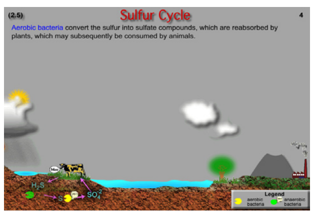

2.5.1
Sulfur is an element that is found in some proteins. It is an essential component of some enzymes found in both plants and animals. Plants absorb sulfur that is dissolved in water. Animals consume plants, so they take in enough sulfur to maintain their health.



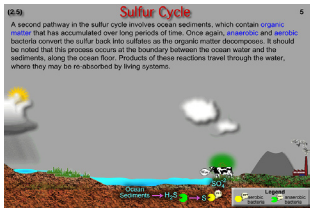

2.5.2
Sulfur is found in three reservoirs:  rocks and soil, ocean sediments, and the atmosphere. Make note of the legend at the bottom. Both aerobic bacteria (those that require oxygen) and anaerobic bacteria (those that do not require oxygen) play an important role in the sulfur cycle.




2.5.3
As both plants and animals die, they decay. One of the by-products of decomposition is the formation of hydrogen sulfide gas, $H_2S$. Anaerobic bacteria, found in soil and water, can consume $H_2S$ converting it to sulfur, S, and releasing water, $H_2O$.

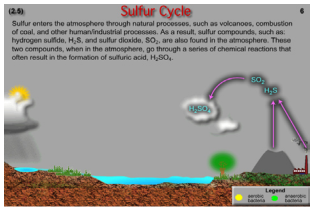



2.5.4
Aerobic bacteria convert the sulfur into sulfate compounds, which are reabsorbed by plants, which may subsequently be consumed by animals.



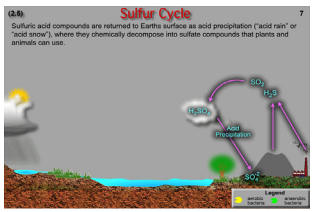

2.5.5

A second pathway in the sulfur cycle involves ocean sediments, which contain organic matter that has accumulated over long periods of time. Once again, anaerobic and aerobic bacteria convert the sulfur back into sulfates as the organic matter decomposes. It should be noted that this process occurs at the boundary between the ocean water and the sediments, along the ocean floor. Products of these reactions travel through the water, where they may be re-absorbed by living systems.



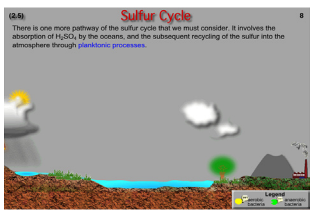

2.5.6

Sulfur enters the atmosphere through natural processes, such as volcanic eruptions, and through combustion of coal and other human/industrial processes. As a result, sulfur compounds, such as hydrogen sulfide, $H_2S$, and sulfur dioxide, $SO_2$, are also found in the atmosphere. These two compounds, when in the atmosphere, go through a series of chemical reactions that often result in the formation of sulfuric acid, $H_2SO_4$.



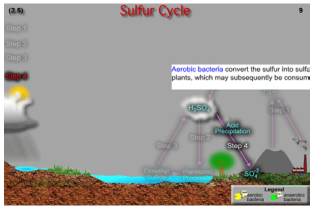

2.5.7

Sulfuric acid compounds are returned to Earth's surface as acid precipitation ("acid rain" or "acid snow"), where they chemically decompose into sulfate compounds that plants and animals can use.



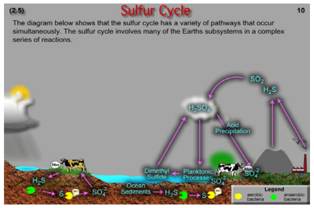

2.5.8

There is one more pathway of the sulfur cycle that we must consider. It involves the absorption of $H_2SO_4$ by the oceans, and the subsequent recycling of sulfur into the atmosphere through planktonic processes.




2.5.9
Step 1
Step 2
Step 3
Step 4

Acid precipitation
Dimethyl Sulfide
Planktonic Processes




2.5.10
The diagram below shows that the sulfur cycle has a variety of pathways that occur simultaneously. The sulfur cycle involves several of Earth's subsystems in a complex series of reactions.

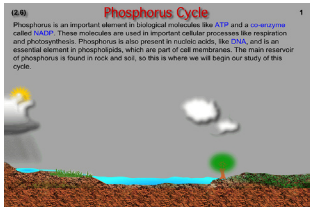

2.5.11
Summary

•Sulfur is an essential element for organisms to maintain their health.
•Plants can absorb sulfur compounds in solution, and animals get their sulfur by consuming plants.
•Sulfur is recycled as organisms decay.
•Both aerobic and anaerobic bacteria are involved in recycling sulfur.
•Several different pathways allow sulfur to be recycled. These pathways take place in the atmosphere, water, and underground.
•Humans add sulfur to the sulfur cycle by burning fossil fuels.

The Phosphorus Cycle

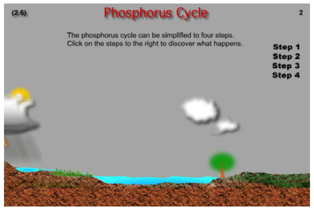
Notes

## 2.6




2.6.1

Phosphorus is an important element in biological molecules like ATP and a co-enzyme called NADP. These molecules are used in important cellular processes like respiration and photosynthesis. Phosphorus is also present in nucleic acids, like DNA, and is an essential element in phospholipids, which are part of cell membranes. The main reservoir of phosphorus is found in rock and soil, so this is where we will begin our study of this cycle.




2.6.2

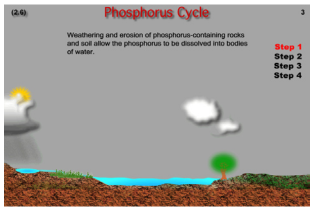
The phosphorus cycle can be simplified to four steps. Click on the steps to the right to discover what happens.

Step 1

Step 2

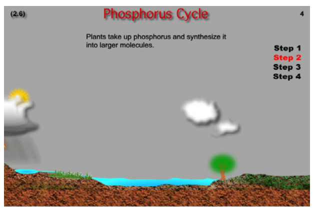
Step 3

Step 4



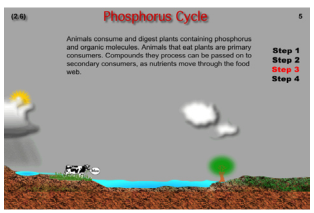

2.6.3

Weathering and erosion of phosphorus-containing rocks and soil allow the phosphorus to be dissolved into bodies of water.




2.6.4

Plants take up phosphorus and synthesize it into larger molecules.

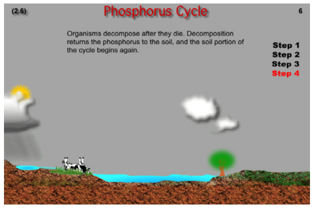



2.6.5

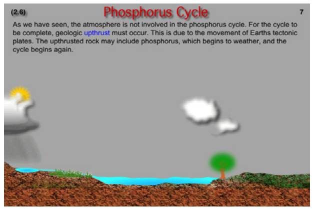
Animals consume and digest plants containing phosphorus and organic molecules. Animals that eat plants are primary consumers. Compounds they process can be passed on to secondary consumers, as nutrients move through the food web.

## Notes

Phosphorus and nitrogen compounds are often concentrated in some animals' waste. For example, waste from bats (called "guano") is high in phosphorus and nitrogen compounds. Because bat waste is often concentrated in the bottom of caves, it was relatively easy to mine this valuable resource and sell it to make commercial fertilizers. The economies of some Pacific island nations, like Nauru, were hinged to the sale of this mineral resource.




2.6.6
Organisms decompose after they die. Decomposition returns the phosphorus to the soil, and the soil portion of the cycle begins again.

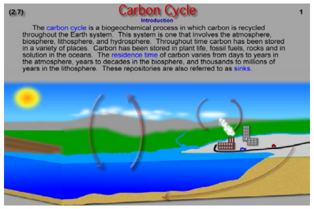



2.6.7
As we have seen, the atmosphere is not involved in the phosphorus cycle. For the cycle to be complete, new rocks must be exposed to the atmosphere, primarily due to the movement of Earth's tectonic plates. Newly-exposed rock may include phosphorus, which begins to weather, and the cycle begins again.


2.6.8
Summary
- Phosphorus is an important element for life on Earth. It is used to make biological molecules like ATP and NADP, that are needed to transfer energy within cells.
- The main reservoir for phosphorus is in rocks.
- The process can be summed up in four steps:
  - Phosphorus is released from rocks by weathering and erosion.
  - Plants use the phosphorus to make compounds they need.
  - Animals get phosphorus by consuming plants.
  - Organisms decompose, which recycles the phosphorus.

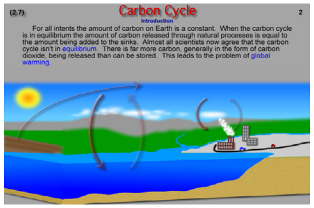
## The Carbon Cycle

# 2.7



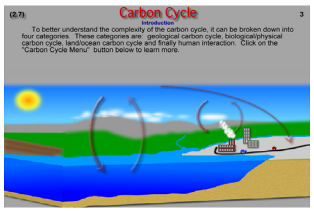

2.7.1

The carbon cycle is a biogeochemical process in which carbon is recycled throughout the Earth system. This cycle involves the atmosphere, biosphere, lithosphere, and hydrosphere. Throughout time, carbon has been stored in a variety of places. Carbon has been stored in plant life, fossil fuels, rocks, and in solution in the oceans. The residence time of carbon varies from days to centuries in the atmosphere, years to thousands of years (millennia) in the biosphere, and thousands to millions of years in the lithosphere. These repositories are also referred to as sinks.




2.7.2

For all intents, the amount of carbon on Earth is a constant. When the carbon cycle is in equilibrium the amount of carbon released through natural process is equal to the amount being added to the sinks. Almost all scientists now agree that the carbon cycle isn't in equilibrium. There is far more carbon, generally in the form of carbon dioxide, being released than can be stored. This leads to the problem of enhanced global warming.




2.7.3

The carbon cycle can be broken down into four categories. These categories are: geological carbon cycle, biological/physical carbon cycle, land/ocean carbon cycle, and finally, the effects of human interaction. Click on the "Carbon Cycle Menu" button below to learn more.

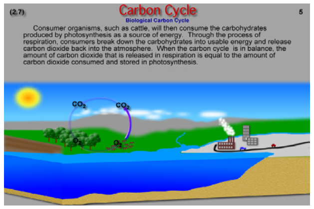
Global Carbon Cycle Menu

Biological

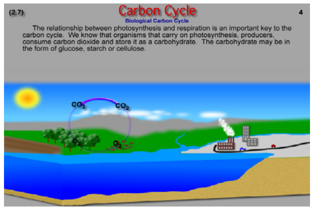
Geological

Land/Ocean

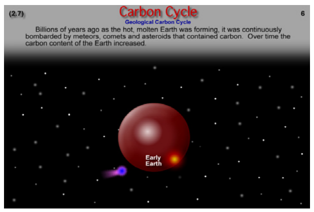
Human Role



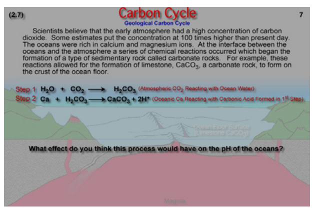

2.7.4
Biological Carbon Cycle
The balance between photosynthesis and respiration is an important key to the carbon cycle. Organisms that carry on photosynthesis, also known as producers, use carbon dioxide and store the resulting compounds as carbohydrates. These carbohydrates may be in the form of glucose, starch, or cellulose.




2.7.5
Biological Carbon Cycle
Primary consumers, such as cattle, eat plants and use the carbohydrates for their primary source of energy. Through the processes of digestion and cellular respiration, consumers break down carbohydrates, releasing energy and transforming the chemicals into other compounds. Cellular respiration releases carbon dioxide and water vapor back into the atmosphere. When this part of the carbon cycle is in balance (equilibrium), the amount of carbon dioxide that is released through respiration is equal to the amount of carbon dioxide consumed and stored in photosynthesis.




2.7.6
Geologic Carbon Cycle
Billions of years ago, meteors, comets, and asteroids that contained carbon bombarded the hot, molten Earth as it was forming. Over time, the carbon content of Earth increased.



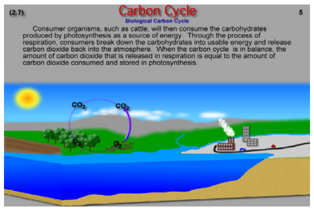

2.7.7
Geologic Carbon Cycle
Scientists have determined that Earth's early atmosphere had a high concentration of carbon dioxide. Some estimates put the concentration at 100 times higher than the present day concentration. However, $CO_2$ concentrations have not been higher than today's levels in the last 850,000 years.

The early oceans were rich in calcium and magnesium ions. A series of chemical reactions occurred at the interface between the atmosphere and the ocean surface, allowing the formation of carbonates that contributed to the formation of limestone, a sedimentary rock, on the ocean floor.

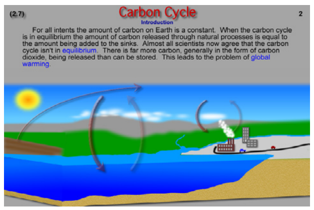
# Notes

Step 1: $H_2O + CO_2 \Rightarrow H_2CO_3$ (Atmospheric $CO_2$ reacting with ocean water)
Step 2: $Ca + H_2CO_3 \Rightarrow CaCO_3 + 2H^+$ (Oceanic Ca reacting with the carbonic acid formed in Step 1)

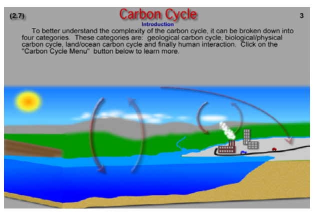
What effect do you think this process would have on the pH of the oceans?




2.7.8
Geological Carbon Cycle
You may know that Earth's crust is formed of large segments called plates, shown in gray below. These plates are moved around Earth's surface due to convection within the molten layers in the mantle. Note that new igneous rock is formed from volcanoes and at the mid-ocean ridges, while old igneous and sedimentary rocks are melted and recycled when they are forced downward at subduction zones around the world.

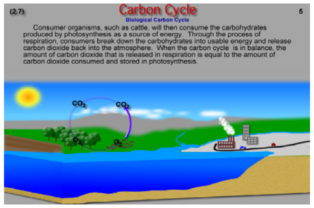



2.7.9
Geological Carbon Cycle
Water-logged limestone is melted as it is forced downward into the mantle. As a result, water vapor and carbon dioxide that were part of the limestone travel through the magma and are later released (as gases) into the atmosphere from erupting volcanoes. This very old carbon dioxide can react with water to eventually form carbonate rocks again. The geological part of the carbon cycle takes millions of years.




2.7.10
Land/ Ocean Carbon Cycle
Combustion of organic matter (fire) also adds carbon dioxide into the atmosphere. As a forest burns for a period of weeks or months, it releases carbon compounds (CO2, soot, etc.) that may have been stored for hundreds or thousands of years in the tissues of the trees. Therefore, burning of the world's rainforests is a particular concern because it releases large amounts of stored (sequestered) carbon into the atmosphere. Deforestation in some countries removes thousands of acres of forest per year.

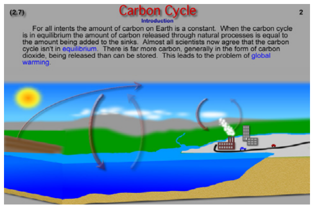
## Notes




2.7.11

Land/ Ocean Carbon Cycle

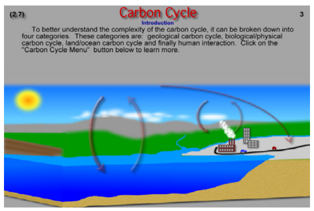
The amount of carbon stored in and released from the biosphere depends on the season. Earth's Northern Hemisphere has more land than ocean. Many land plants in the temperate regions drop their leaves and/or die back in autumn. This dead plant tissue rots through the winter and early spring, releasing carbon compounds into the air. In spring and summer, plant growth (photosynthesis) draws down the amount of carbon dioxide in the air. Those seasonal trends (dominated by the greater land mass in the Northern Hemisphere) are apparent in the graph below. The graph is known as the "Keeling Curve". It is named after Dr. Charles David Keeling, the researcher who began those measurements from the Mauna Loa Observatory in Hawai'i in 1958.




2.7.12

Land/ Ocean Carbon Cycle

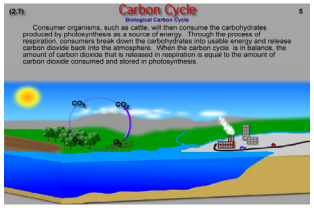
Likewise, the amount of carbon dioxide absorbed by the oceans and released back to the atmosphere depends on the temperature of the ocean water and the thickness of the mixed layer. As the temperature of the oceans increases, the amount of carbon dioxide that can be dissolved is reduced. As the surface waters warm, oceans may release more carbon dioxide than they store. The size of the arrows illustrates this relationship below.




2.7.13

Land/ Ocean Carbon Cycle

Where the ocean temperatures are cool, such as the Polar Regions, the amount of carbon dioxide being absorbed is greater than the amount released. This very cold, dense water sinks to the ocean bottom, transferring its carbon dioxide to the deepest parts of the ocean, where it may stay for decades to centuries. Eventually, over a long period of time, the deepwater resurfaces in areas where the ocean is warmer, releasing the carbon dioxide back to the atmosphere.

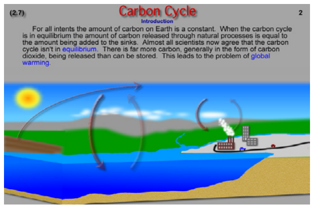



2.7.14

Land/ Ocean Carbon Cycle

Carbon dioxide in surface waters of much of the ocean is relatively short-lived compared to land, where it is stored for long periods of time in woody plants and in soil. Phytoplankton (floating photosynthetic organisms) in the oceans are quickly consumed and digested by zooplankton. The carbon dioxide taken up by the phytoplankton is returned to the atmosphere in a relatively short period of time.

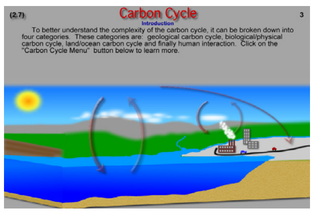
Some of the carbon compounds in the marine food web are incorporated into the tissues of larger animals, such as corals, shellfish, and the bones of mammals and birds. Tissues that do not decompose easily and are not recycled through the food web are added into the sediments, as the uneaten remains of organisms settle to the deep ocean floor. Over millions of years, this “long-term storage” of carbon compounds resulted in the formation of rocks containing coal, oil, and natural gas.




2.7.15

Human Role in the Carbon Cycle

As humans burn any fossil fuel (such as gasoline, natural gas, heating oil, or coal), we release carbon compounds into the atmosphere that had been stored for millions of years in Earth’s crust. This greatly exceeds the rate of natural release from these sinks. This practice increases the amount of greenhouse gases in the atmosphere, and is the basis for the term “anthropogenic warming”.

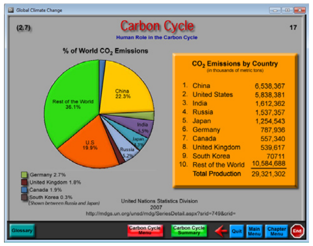



2.7.16

Human Role in the Carbon Cycle

Since the beginning of the Industrial Revolution, increased and widespread use of fossil fuels has dramatically increased the amount of carbon dioxide in the atmosphere. In the past 50 years, the number of people using technologies that are powered by fossil fuels has resulted in an exponential rate of growth in carbon emissions.

Notice that the light blue line is not the result of fuel combustion, but instead results from a chemical reaction that occurs as cement “cures”.




2.7.17
Human Role in the Carbon Cycle
(Table & pie chart with 2007 information)


Carbon Cycle Summary

•Carbon compounds, like other substances that are cycled through the Earth's systems, are stored in repositories referred to as sinks. The sinks are found in the atmosphere, biosphere, hydrosphere, and lithosphere.

•Earth's carbon content increased throughout its early history due to impacts of comets, meteors, and asteroids.

•Carbon content in the atmosphere has fluctuated during Earth's history.

•Carbon in the oceans can be stored in rocks or dissolved as carbon dioxide and carbonate compounds in ocean water.

•Carbon from rocks can be recycled into the atmosphere through volcanic eruptions.

•Photosynthesis and respiration are opposing reactions in the biosphere that recycle carbon through the atmosphere.

•Forests are carbon sinks that may exist for hundreds and thousands of years. Forest fires recycle carbon compounds into the atmosphere and soils.

•The Keeling Curve shows the seasonal trends and annual increases of atmospheric carbon dioxide. These changes are linked to the photosynthetic activity of land plants in the temperate regions of the Northern Hemisphere.

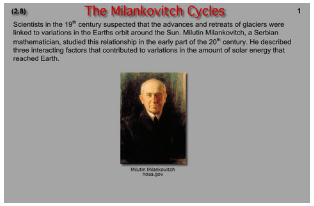
•Ocean water is a sink for carbon dioxide. However, warmer ocean water stores less carbon dioxide than cooler ocean water.

•Deep ocean sediments are a sink for carbon compounds.

•Humans release ancient carbon from its various sinks when we burn fossil fuels.

## The Milankovitch Cycles

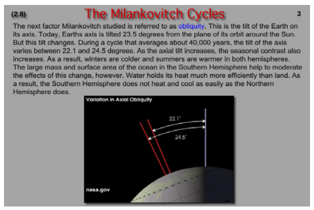
## 2.8




2.8.1
Scientists in the 19th century suspected that advances and retreats of glaciers were linked to variations in Earth's orbit around the Sun. Milutin Milankovitch, a Serbian mathematician, studied this relationship in the early part of the 20th century. He described three interacting factors that contributed to variations in the amount of solar energy that reached Earth.


2.8.2
The first factor to consider is precession. Think of a spinning top. As the top slows, it begins to wobble, and the upper point of the top begins to trace a circle. Over a few seconds, the top's axis traces a cone. A similar wobble occurs with Earth's axis. This is known as precession. Over many revolutions around the Sun, a gradual shift in the location in its orbit where Earth's axis would point toward or away from the Sun would occur.

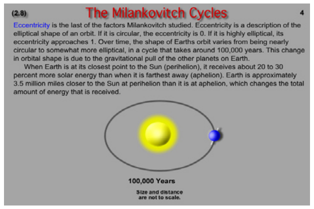
Precession of Earth's axis occurs over a period of approximately 26,000 years. Halfway through this cycle, 13,000 years from now, Earth's axis and Northern Hemisphere will point toward the Sun (still resulting in the Northern Hemisphere's summer) when Earth is in the part of its orbit that currently represents the winter solstice.




2.8.3
The next factor Milankovitch studied is referred to as obliquity. This refers to the tilt of Earth's axis. Today, Earth's axis is tilted 23.5 degrees from the plane of its orbit around the Sun. But this tilt changes. During a cycle that averages about 40,000 years, the tilt of the axis varies between 22.1 and 24.5 degrees. As the axial tilt increases, the seasonal contrast also increases. As a result, winters are colder and summers are warmer in both hemispheres.

The large mass and surface area of the ocean in the Southern Hemisphere help to moderate the effects of this change, however. Water holds its heat much more efficiently than land. As a result, the Southern Hemisphere does not heat and cool as easily as the Northern Hemisphere does.

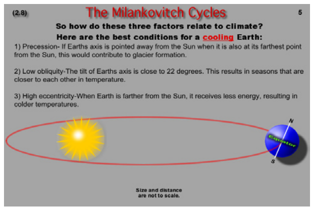
## Notes




2.8.4

Eccentricity is the last of the factors Milankovitch studied. Eccentricity is a description of the elliptical shape of an orbit. If it is circular, the eccentricity is 0. If it is highly elliptical, its eccentricity approaches 1. Over time, the shape of Earth's orbit varies from being nearly circular to somewhat more elliptical, in a cycle that takes around 100,000 years. This change in orbital shape is due to the gravitational pull of the other planets on Earth.

When Earth is at its closest point to the Sun (perihelion), it can receive up to 20 percent more solar energy than when it is farthest away (aphelion). Earth is approximately 3.5 million miles closer to the Sun at perihelion than it is at aphelion, which changes the total amount of energy that is received. When the orbit is more circular, the amount of energy received is more consistent throughout the year.



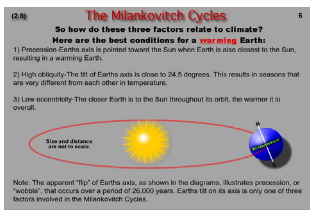

2.8.5

So how do these three factors relate to climate?
Here are the best conditions for a cooling Earth:

1) Precession- If Earth's axis is pointed away from the Sun when it is also at its farthest point from the Sun; this would contribute to glacier formation.

2) Low obliquity-The tilt of Earth's axis is close to 22 degrees. This results in seasons that are closer to each other in temperature.

3) High eccentricity-When Earth is farther from the Sun, it receives less energy, resulting in colder temperatures.




2.8.6

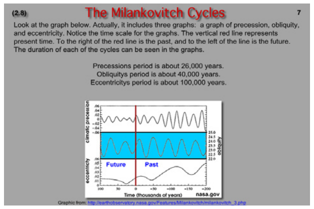
So how do these three factors relate to climate?
Here are the best conditions for a warming Earth:

1) Precession-Earth's axis is pointed toward the Sun when Earth is also closest to the Sun, resulting in a warming Earth.

2) High obliquity-The tilt of Earth's axis is close to 24.5 degrees. This results in seasons that are very different from each other in temperature.

3) Low eccentricity-The closer Earth is to the Sun throughout its orbit, the warmer it is overall.

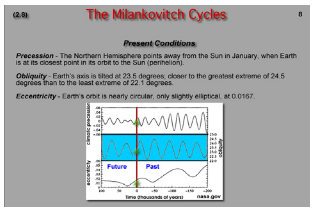
Note: The apparent "flip" of Earth's axis, as shown in the diagrams, illustrates precession, or "wobble", that occurs over a period of 26,000 years. Earth's tilt on its axis is only one of three factors involved in the Milankovitch Cycles.




2.8.7

Look at the graph below. Actually, it includes three graphs: a graph of precession, obliquity, and eccentricity. Notice the time scale for the graphs. The vertical red line represents present time. To the right of the red line is the past, and to the left of the line is the future. The duration of each of the cycles can be seen in the graphs.

Precession's period is about 26,000 years.
Obliquity's period is about 40,000 years.
Eccentricity's period is about 100,000 years.




2.8.8

Present Conditions

Precession: The Northern Hemisphere points away from the Sun in January, when Earth is at its closest point in its orbit to the Sun (perihelion).

Obliquity: Earth's axis is tilted at 23.5 degrees; closer to the greatest extreme of 24.5 degrees than to the least extreme of 22.1 degrees.

Eccentricity: Earth's orbit is nearly circular, only slightly elliptical, at 0.0167.

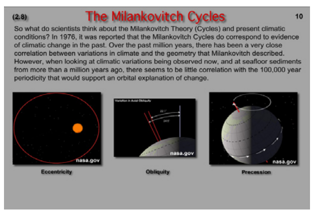

2.8.9

How do conditions now compare to those that would tend toward a cooling or warming Earth, based only on the factors Milankovitch considered?

Green box: (Present conditions)
Precession: The Northern Hemisphere points away from the Sun in January, when Earth is at its closest point in its orbit to the Sun (perihelion).
Obliquity: Earth's axis is tilted at 23.5 degrees; closer to the greatest extreme of 24.5 degrees than to the least extreme of 22.1 degrees.
Eccentricity: Earth's orbit is nearly circular, only slightly elliptical, at 0.0167.

Blue box: Best conditions for cooling of Earth:
Precession: The Northern Hemisphere points away from the Sun in January, when Earth is farthest from the Sun.
Low Obliquity: Earth's axis is tilted at close to 22 degrees, resulting in seasonal temperatures that are very similar to each other, so summers are not as warm as usual.
High Eccentricity: Earth's orbit is more elliptical, up to 0.058, putting Earth farther from the Sun for a longer period of time.

Red box: Best conditions for warming of Earth:
Precession: The Northern Hemisphere points toward the Sun in June, when Earth is closest to the Sun in its orbit.
High Obliquity: Earth's axis is tilted close to 24.5 degrees; this results in seasonal temperatures that are very different from each other in the Northern Hemisphere.
Low Eccentricity: Earth's orbit is nearly circular, 0.0034, keeping Earth closer to the Sun all year.




2.8.10

So what do scientists think about the Milankovitch Theory (Cycles) and present climatic conditions? In 1976, it was reported that the Milankovitch Cycles do correspond to evidence of climatic change in the past. Over the past million years, there has been a very close correlation between variations in climate and the geometry that Milankovitch described. However, when looking at climatic variations being observed now and at seafloor sediments from more than a million years ago, there seems to be little correlation with the 100,000 year periodicity that would support an orbital explanation of change.

Notes

Summary

2.8.11
Summary

•In the early years of the 20th century, Milutin Milankovitch proposed that Earth's climate is affected by three factors related to Earth's tilt and orbit around the Sun:

•Precession:
- •is a wobble of Earth's axis over a period of about 26,000 years
- •determines when Earth's axis is tilted toward or away from the Sun

•Obliquity
- • measure of the tilt of the axis, ranging from 22.1 to 24.5 degrees
- •changes over a period of about 40,000 years

•Eccentricity:
- •how elliptical Earth's orbit around the Sun is
- •changes over a period of about 100,000 years

•Evidence from deep-sea sediments correlates major climatic events over the past million years, but not before, to the Milankovitch Cycles.

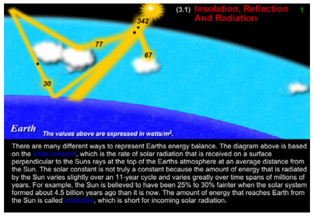
•Climatologists do not see a strong correlation between the Milankovitch Cycles and present climatic variations.

# Energy in Earth System

Insolation, Reflection, and Radiation

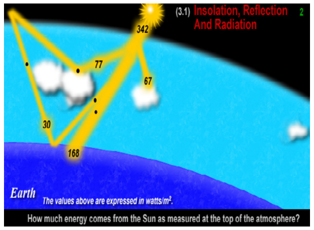
Notes

## 3.1




3.1.1

There are many different ways to represent Earth's energy balance. The diagram above is based on the solar constant, which is the rate of solar radiation that is received on a surface perpendicular to the Sun's rays at the top of Earth's atmosphere at an average distance from the Sun. The solar constant is not truly a constant because the amount of energy that is radiated by the Sun varies slightly over an 11-year cycle and varies greatly over time spans of millions of years. For example, the Sun is believed to have been 25% to 30% fainter when the Solar System formed about 4.5 billion years ago than it is now. The amount of energy that reaches Earth from the Sun is called insolation, which is short for incoming solar radiation.




3.1.2

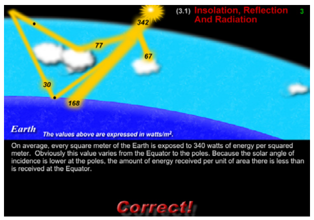
How much energy comes from the Sun as measured at the top of the atmosphere?

A. 30 watts/$m^2$

B. 168 watts/$m^2$

C. 342 watts/$m^2$

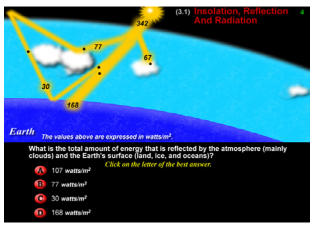
D. 70 watts/$m^2$




3.1.3

Correct choice C:

On average, every square meter of Earth is exposed to about 340 watts of energy. Obviously this value varies from the Equator to the poles. Because the solar angle of incidence is lower at the poles, the amount of energy received per unit of area there is less than is received at the Equator.




3.1.4

What is the total amount of energy that is reflected by Earth's atmosphere (mainly clouds) and from Earth's surface (land, ice, and oceans)?

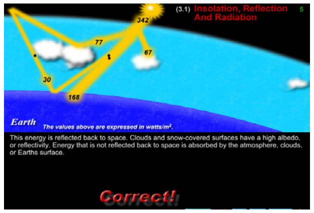
A. 107 watts/$m^2$

B. 77 watts/$m^2$

C. 30 watts/$m^2$

D. 168 watts/$m^2$

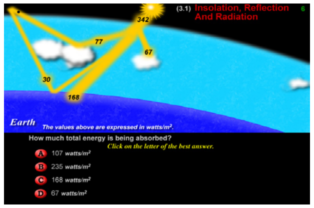
# Notes




3.1.5

Correct choice A:

This energy is reflected back to space. Clouds and snow-covered surfaces have a high albedo, or reflectivity. Energy that is not reflected back to space is absorbed by the atmosphere, clouds, or Earth's surface.




3.1.6

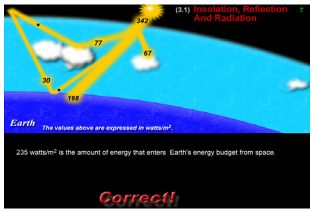
How much total energy is absorbed?

A. 107 watts/$m^2$

B. 235 watts/$m^2$

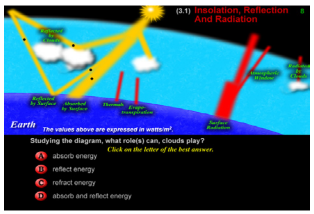
C. 168 watts/$m^2$

D. 67 watts/$m^2$




3.1.7

235 watts/$m^2$ is the amount of energy that enters Earth's energy budget from space.




3.1.8

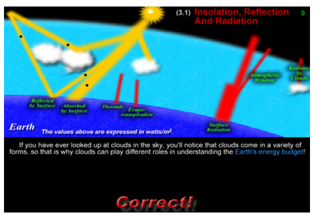
Studying the diagram, what role(s) can clouds play?

A. absorb energy

B. reflect energy

C. refract energy

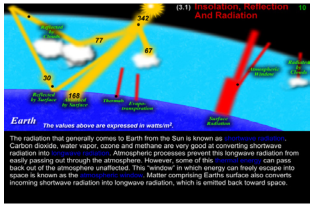
D. all of the above



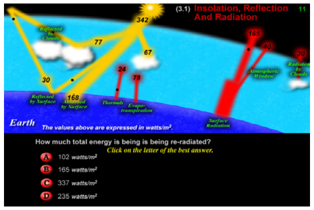

3.1.9

If you have ever looked up at clouds in the sky, you'll notice that clouds come in a variety of forms. That is why clouds can play different roles in Earth's energy budget!

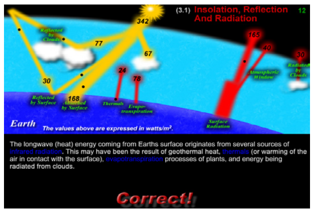
# Notes




3.1.10
The radiation that generally comes to Earth from the Sun is known as shortwave radiation. Carbon dioxide, water vapor, ozone, and methane are very good absorbers of longwave radiation. Their presence in air prevents some longwave radiation from easily passing out to space through Earth's atmosphere. However, some of this thermal energy can pass back out of the atmosphere unaffected. This "window", through which energy can freely escape into space, is known as the atmospheric window. Matter comprising Earth's surface also converts incoming shortwave radiation into longwave radiation, which is emitted back toward space.




3.1.11
How much total energy is being radiated?
A. 102 watts/m$^2$
B. 165 watts/m$^2$
C. 337 watts/m$^2$
D. 235 watts/m$^2$

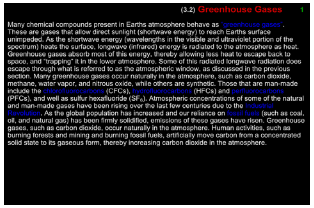



3.1.12
The longwave (heat) energy coming from Earth's surface originates from several sources of infrared radiation. This may have been the result of geothermal heat, thermals (or warming of the air in contact with the surface), evapotranspiration processes of plants, and energy being radiated from clouds.


3.1.13
Summary:
•Earth absorbs energy from the Sun in the form of shortwave radiation.
•Clouds can absorb, reflect, and radiate energy.
•Some of this energy remains within the Earth system, and some of it is radiated.
•The radiated energy is in the form of longwave radiation, which is heat energy.

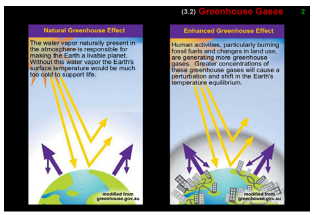
## Greenhouse Gases

## 3.2




### 3.2.1
### What are greenhouse gases?

Many chemical compounds present in Earth's atmosphere behave as "greenhouse gases". These are gases that allow direct sunlight (shortwave energy) to reach Earth's surface unimpeded. As the shortwave energy (wavelengths in the visible and ultraviolet portion of the spectrum) heats the surface, longwave (infrared) energy is radiated to the atmosphere as heat. Greenhouse gases absorb most of this energy, thereby allowing less heat to escape back to space, and "trapping" it in the lower atmosphere. Some of this radiated longwave radiation does escape through what is referred to as the atmospheric window, as discussed in the previous section. Many greenhouse gases occur naturally in the atmosphere, such as carbon dioxide, methane, water vapor, and nitrous oxide, while others are synthetic. Those that are man-made include the chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), as well as sulfur hexafluoride ($SF_6$). Atmospheric concentrations of some of the natural and man-made gases have been rising over the last few centuries due to the Industrial Revolution. As the global population has increased and our reliance on fossil fuels (such as coal, oil, and natural gas) has been firmly solidified, emissions of these gases have risen. Greenhouse gases, such as carbon dioxide, occur naturally in the atmosphere. Human activities, such as burning forests and mining and burning fossil fuels, artificially move carbon from a concentrated state to its gaseous form, thereby increasing carbon dioxide in the atmosphere.



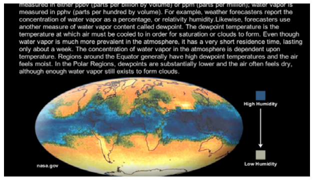

### 3.2.2
### Natural Greenhouse Effect

The water vapor naturally present in the atmosphere is responsible for making Earth a livable planet. Without this water vapor, Earth's surface temperature would be much too cold to support life.

## Notes

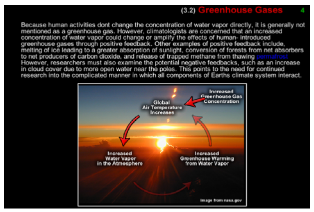
Enhanced Greenhouse Effect

Human activities, particularly burning fossil fuels and changes in land use, are generating more greenhouse gases. Greater concentrations of these greenhouse gases affect atmospheric temperatures and could cause a shift in the temperature equilibrium of Earth.



3.2.3

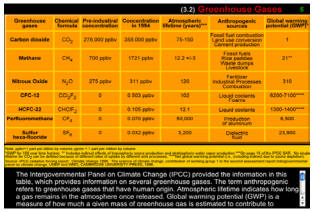
Most people are aware of the role that carbon dioxide plays as a greenhouse gas, but the most prevalent greenhouse gas is water vapor. Almost all greenhouse gas concentrations are measured in either ppbv (parts per billion by volume) or ppm (parts per million); water vapor is measured in pphv (parts per hundred by volume). For example, weather forecasters report the concentration of water vapor as a percentage, or relative humidity. Likewise, forecasters use another measure of water vapor content called dewpoint. The dewpoint temperature is the temperature at which air must be cooled to in order for saturation or clouds to form. Even though water vapor is much more prevalent in the atmosphere, it has a very short residence time, lasting only about a week. The concentration of water vapor in the atmosphere is  dependent upon temperature. Regions around the Equator generally have high dewpoint temperatures and the air feels moist. In the Polar Regions, dewpoints are substantially lower and the air often feels dry, although enough water vapor still exists to form clouds.



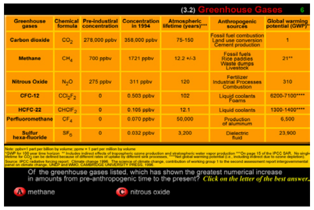

3.2.4

Because human activities don’t change the concentration of water vapor directly, it is generally not mentioned as a greenhouse gas. However, climatologists are concerned that an increased concentration of water vapor could  change or amplify the effects of human-introduced greenhouse gases through positive feedback. Other examples of positive feedback include: melting of ice leading to a greater absorption of sunlight, conversion of forests from net absorbers to net producers of carbon dioxide, and release of trapped methane from thawing permafrost. However, researchers must also examine the potential negative feedbacks, such as an increase in cloud cover due to more open water near the poles.  This points to the need for continued research into the complicated manner in which all components of Earth’s climate system interact.

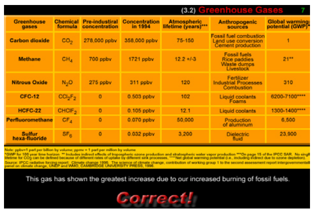
# Notes



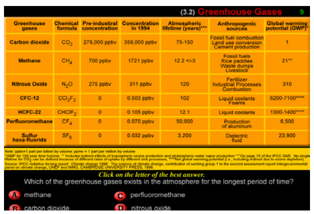

3.2.5
This table was produced by the Intergovernmental Panel on Climate Change (IPCC). The table provides information on several greenhouse gases. The term anthropogenic refers to greenhouse gases that have human origin. Atmospheric lifetime indicates how long a gas remains in the atmosphere once released. Global warming potential (GWP) is a measure of how much a given mass of greenhouse gas is estimated to contribute to increasing global temperatures. It is a relative scale, which compares the gas in question to that of the same mass of carbon dioxide. GWP is calculated over a specific time interval and the value of this must be stated whenever a GWP is quoted or else the value is meaningless.




3.2.6
Of the greenhouse gases listed, which has shown the greatest numerical increase in amounts from pre-anthropogenic time to the present?
A. methane
B. carbon dioxide
C. nitrous oxide
D. CFC-12

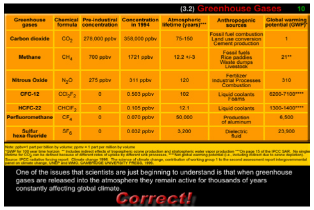



3.2.7
Carbon dioxide has shown the greatest increase due to our increased burning of fossil fuels.

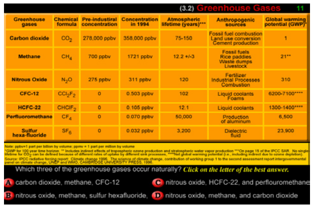



3.2.9
Click on the letter of the best answer.
Which of the greenhouse gases exists in the atmosphere for the longest period of time?
A. methane
B. carbon dioxide
C. perfluoromethane
D. nitrous oxide

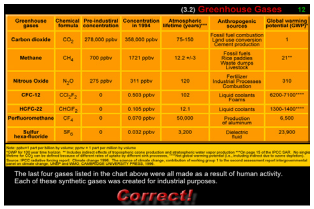
# Notes



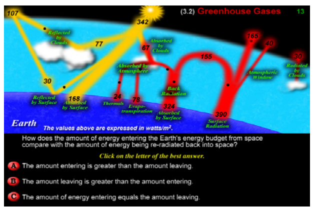

3.2.10
One of the issues that scientists are just beginning to understand is that when greenhouse gases are released into the atmosphere, some of them may remain active for thousands of years, constantly affecting global climate.



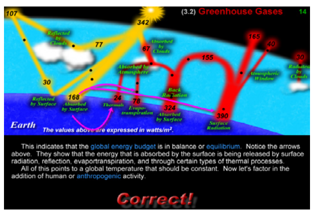

3.2.11
Which three of the greenhouse gases occur naturally? Click on the letter of the best answer.
A. carbon dioxide, methane, CFC-12
B. nitrous oxide, methane, sulfur hexafluoride
C. nitrous oxide, HCFC-22, and perfluoromethane
D. nitrous oxide, methane, carbon dioxide




3.2.12
The top three gases in the table occur naturally. The four gases listed at the bottom of the chart above were all made as a result of human activity. Each of those synthetic gases was created for industrial purposes.

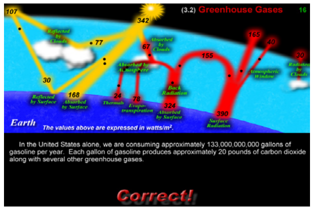



3.2.13
How does the amount of energy entering Earth's energy budget from space compare with the amount of energy leaving Earth at the top of the atmosphere?
A. The amount entering is greater than the amount leaving.
B. The amount leaving is greater than the amount entering.
C. The amount of energy entering equals the amount leaving.




3.2.14
This diagram indicates that the global energy budget as shown is in balance or equilibrium. Notice the arrows above. They show that the energy that is absorbed by the surface is being released by surface radiation, reflection, evaporation, and through certain types of thermal processes. All of this points to a global temperature that should be constant. Now factor in the addition of human, or anthropogenic, activity.

# Notes

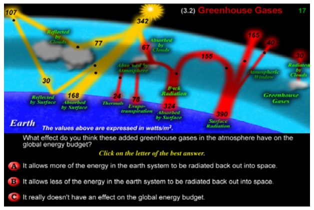



3.2.15
Humans have always had an impact on their local environment just like all other organisms. Since the earliest civilizations, humans have burned wood and other fuels for energy. Instead of burning wood as our primary energy source, we now use coal and petroleum. What effect do you think this has on the amount of greenhouse gases being emitted into the atmosphere?

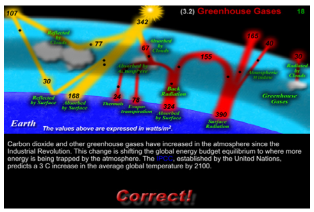
A. Increases the amount

B. Decreases the amount

C. The amount is remaining relatively constant.




3.2.16
In the United States alone, we consume approximately 133,000,000,000 (billion) gallons of gasoline per year. Each gallon of gasoline produces approximately 20 pounds of carbon dioxide along with several other greenhouse gases.

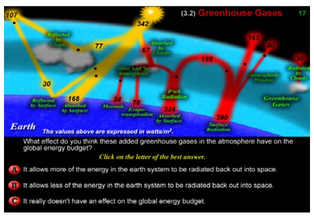



3.2.17
What effect do you think the addition of greenhouse gases to the atmosphere has on the global energy budget?

A. It allows more energy in the Earth system to be radiated to space.

B. It allows less of the energy in the Earth system to be radiated to space.

C. It really doesn't have an effect on the global energy budget.



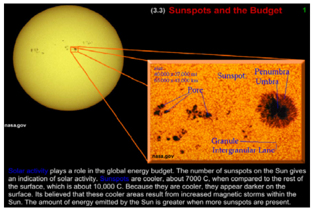

3.2.18
Carbon dioxide and other greenhouse gases have increased in the atmosphere since the Industrial Revolution. This change is shifting the global energy budget equilibrium to where more energy is being trapped by the atmosphere. The IPCC, established by the United Nations, predicts a 3 °C increase in the average global temperature by 2100.


3.2.19

Summary

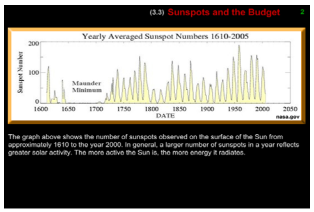
- Greenhouse gases are being added to the atmosphere by human activity.
- Increased greenhouse gases in the atmosphere prevent radiant energy from escaping the Earth system.
- Greenhouse gas molecules reside in the atmosphere for varying periods of time.

## 3.3 Sunspots and the Budget



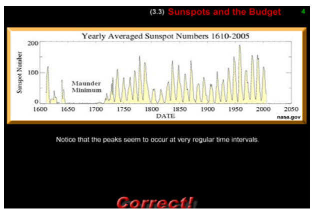

3.3.1

Solar activity plays a role in the global energy budget. The number of sunspots on the Sun gives an indication of solar activity. Sunspots are cooler, between 3,000 and 4,000 °C, when compared to the rest of the surface, which is about 6,000 °C. Because they are cooler, they appear darker on the surface. It's believed that these cooler areas result from increased magnetic storms within the Sun. As the number of sunspots increase, the total amount of energy emitted by the Sun increases as well, due to the increased magnetic fields associated with the sunspots.




3.3.2

The graph above shows the number of sunspots observed on the surface of the Sun from approximately 1610 to the year 2000. In general, a larger number of sunspots in a year reflects greater solar activity. The more active the Sun is, the more energy it radiates.




3.3.3

The peaks on the graph represent years of sunspot maximums. According to the graph, the greatest number of sunspots was observed in what year?

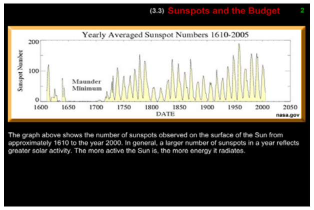
A. 1958

B. 1995

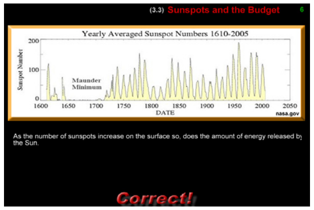
C. 1780

D. 1700

# Notes



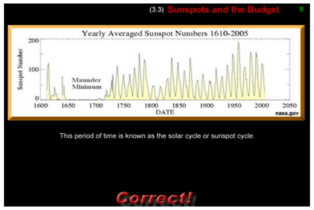

3.3.4
Also notice that the peaks seem to occur at regular time intervals.



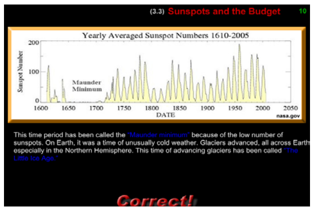

3.3.5
Was the amount of energy being given off by the Sun during 1958 greater than normal or less than normal? Click on the letter of the best answer.

A. Greater than normal

B. Less than normal




3.3.6
As the number of sunspots increases on the surface, so does the amount of energy released by the Sun.



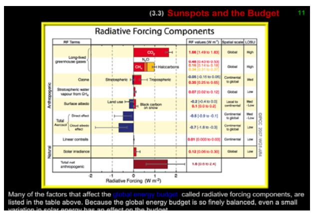

3.3.7
Approximately how many years occur between one sunspot minimum and the next minimum?

A. 11

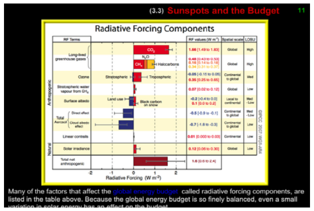
B. 25

C. 22

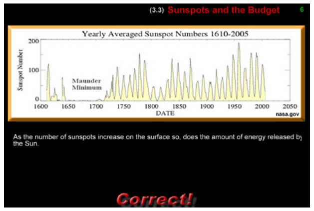
D. 50



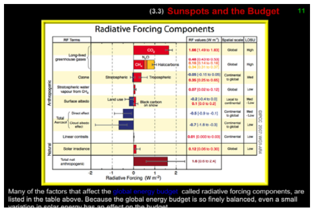

3.3.8
This period of time is known as the solar cycle or sunspot cycle.




3.3.9
During what 70-year period was sunspot activity very low?
A. 1790 to 1840
B. 1880 to 1920
C. 1645 to 1715
D. 1950 to 1990




3.3.10
This period has been called the "Maunder minimum" because of the low number of sunspots. On Earth, it was a time of unusually cold weather. Glaciers advanced, all across Earth, especially in the Northern Hemisphere. This time of advancing glaciers has been called "The Little Ice Age."



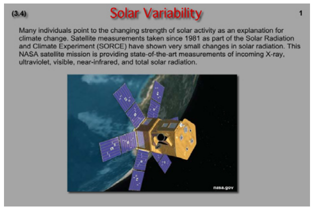

3.3.11
Many of the factors that affect the global energy budget, called radiative forcing components, are listed in the table above. Because the global energy budget is so finely balanced, even a small variation in solar energy has an effect on the budget.


3.3.12
Summary
•The number of sunspots gives an indication of the activity of the Sun.
•More sunspots equal more activity, which equals more energy being released by the Sun.
•The solar cycle, from solar minimum to solar minimum, is 11 years.
•Cycles of solar activity have an important, yet poorly understood, effect on the temperature of Earth.

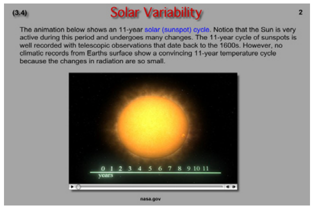
# Notes

## Solar Variability

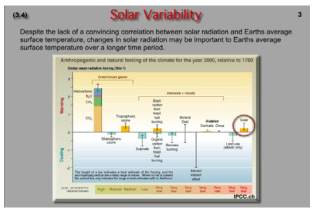
## 3.4



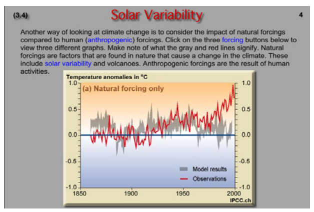

3.4.1
Many individuals point to the changing strength of solar activity as an explanation for climate change. Satellite measurements taken since 1981 as part of the Solar Radiation and Climate Experiment (SORCE) have shown very small changes in solar radiation. This NASA satellite mission is providing state-of-the-art measurements of incoming X-ray, ultraviolet, visible, near-infrared, and total solar radiation.



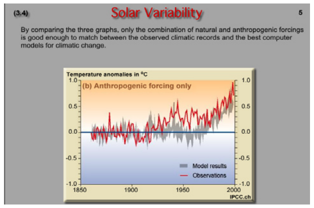

3.4.2
The animation below shows an 11-year solar (sunspot) cycle. Notice that the Sun is very active during this period and undergoes many changes. The 11-year cycle of sunspots is well recorded with telescopic observations that date back to the 1600s. However, no climatic records from Earth's surface show a convincing 11-year temperature cycle because the changes in radiation are so small.



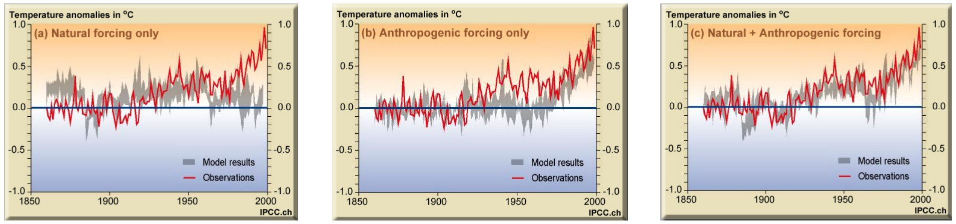

3.4.3
Despite the lack of a convincing correlation between solar radiation and Earth's average surface temperature, changes in solar radiation may be important to Earth's average surface temperature over a longer time period.

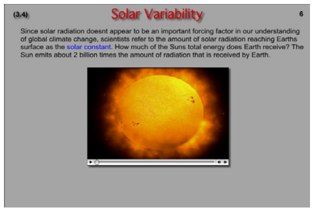



3.4.4
Another way of looking at climate change is to consider the impact of natural forcings compared to human (anthropogenic) forcings. Click on the three forcing buttons below to view three different graphs. Make note of what the gray and red lines signify. Natural forcings are factors that are found in nature that cause a change in the climate. These include solar variability and volcanoes. Anthropogenic forcings are the result of human activities.

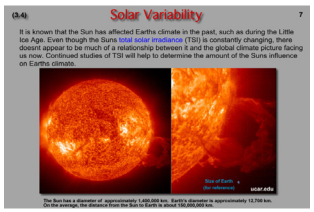



3.4.5
By comparing the three graphs, only the combination of natural and anthropogenic forcings is good enough to match the observed climatic records and the best computer models for climatic change.




3.4.6
Since solar radiation doesn't appear to be an important forcing factor in our understanding of global climate change, scientists refer to the amount of solar radiation reaching Earth's surface as the solar constant. How much of the Sun's total energy does Earth receive? The Sun emits about 2.2 billion times the amount of radiation that is received by Earth.



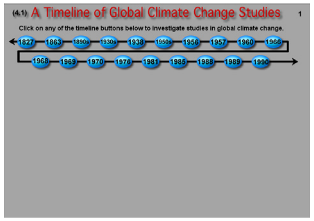

3.4.7
It is known that the Sun has affected Earth's climate in the past, such as during the Little Ice Age. Even though the Sun's total solar irradiance (TSI) is constantly changing, there doesn't appear to be much of a relationship between it and the global climate picture facing us now. Continued studies of TSI will help to determine the amount of the Sun's influence on Earth's climate.


3.4.8
Summary
•Records of the Sun's activity go back to the 1600s.
•Modern satellite observations of the Sun have revealed only very small changes in solar radiation.
•The influence of the Sun on Earth is nearly constant, varying slightly in strength over time.
•There are many factors (forcings) that influence Earth's global climate. Some of them, like the Sun, are natural. Others are the result of human activity (anthropogenic).

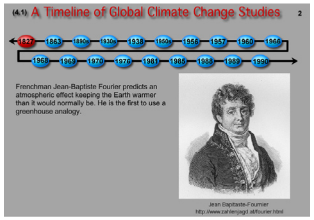
# Historical Perspective

## A Timeline of Global Climate Change Studies

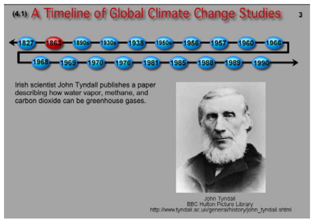
### 4.1



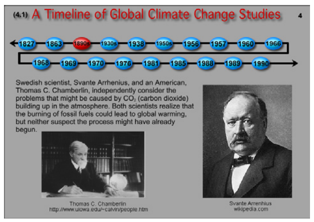

4.1.1
Click on any of the timeline buttons below to investigate studies in global climate change.



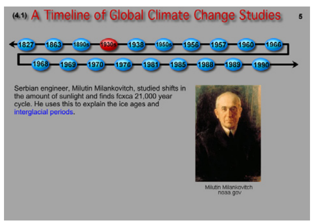

4.1.2 (1827)
Frenchman Jean-Baptiste Fourier predicts an atmospheric effect keeping Earth warmer than it would normally be. He is the first to use a greenhouse analogy.




4.1.3 (1863)
Irish scientist, John Tyndall, publishes a paper describing how water vapor, methane, and carbon dioxide can be greenhouse gases.

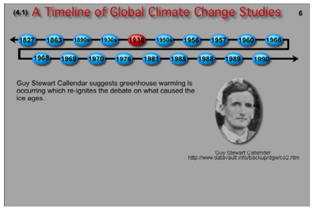



4.1.4 (1890s)
Swedish scientist, Svante Arrhenius, and an American, Thomas C. Chamberlin, independently consider the problems that might be caused by $CO_2$ building up in the atmosphere. Both scientists realize that the burning of fossil fuels could lead to global warming, but neither suspects the process might have already begun.

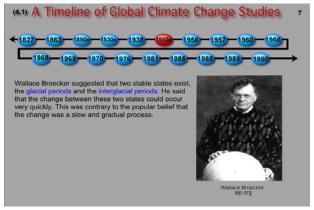



4.1.5 (1930s)
Serbian engineer, Milutin Milankovitch, studied shifts in the amount of sunlight and finds a 21,000-year cycle. He uses this to explain the ice ages and interglacial periods.

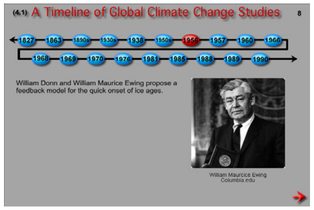
# Notes



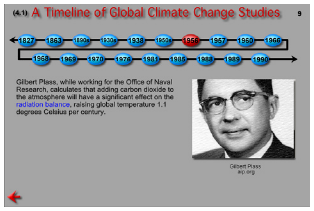

4.1.6 (1938)
Guy Stewart Callendar suggests greenhouse warming is occurring, which re-ignites the debate on what caused the Ice Ages.



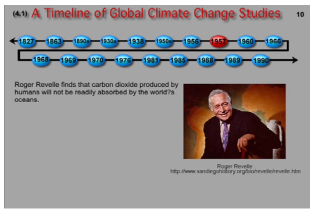

4.1.7 (1950s)
Wallace Broecker suggested that two stable states exist, the glacial periods and the interglacial periods. He said that the change between these two states could occur very quickly. This was contrary to the popular belief that the change was a slow and gradual process.



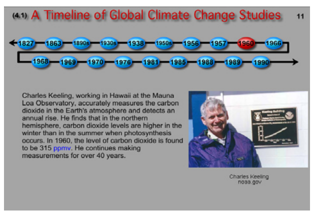

4.1.8 (1956a)
William Donn and William Maurice Ewing propose a feedback model for the quick onset of ice ages.




4.1.9 (1956b)
Gilbert Plass, while working for the Office of Naval Research, calculates that adding carbon dioxide to the atmosphere will have a significant effect on the radiation balance, raising global temperature 1.1 degrees Celsius per century.

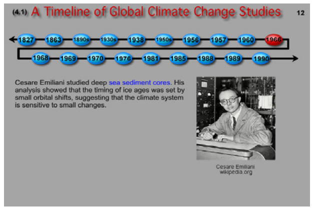



4.1.10 (1957)
Roger Revelle finds that carbon dioxide produced by humans will not be readily absorbed by the world's oceans.

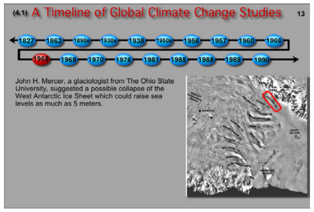



4.1.11 (1960)
Charles Keeling, working in Hawaii at the Mauna Loa Observatory, accurately measures the carbon dioxide in Earth's atmosphere and detects an annual rise. He finds that carbon dioxide levels are higher in the winter than in the summer when photosynthesis occurs. In 1960, the level of carbon dioxide is found to be 315 ppmv. He continues taking measurements for over 40 years.

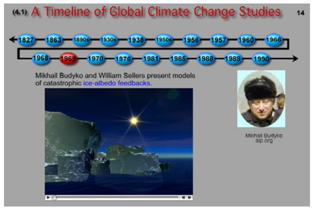
# Notes



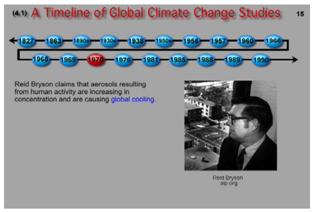

4.1.12 (1966)
Cesare Emiliani studied deep seafloor sediment cores. His analysis showed that the timing of ice ages was set by small orbital shifts, suggesting that the climate system is sensitive to small changes.



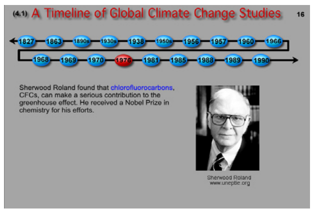

4.1.13 (1969)
John H. Mercer, a glaciologist from The Ohio State University, suggested a possible collapse of the West Antarctic Ice Sheet which could raise sea levels by as much as 5 meters.



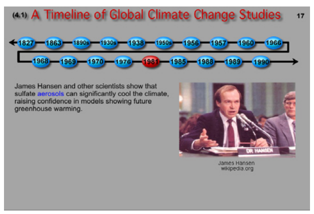

4.1.14 (1969)
Mikhail Budyko and William Sellers present models of catastrophic ice-albedo feedbacks.




4.1.15 (1970)
Reid Bryson claims that aerosols resulting from human activity are increasing in concentration and are causing global cooling.

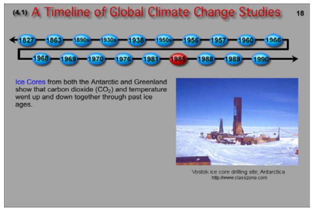



4.1.16 (1976)
Sherwood Roland found that chlorofluorocarbons, CFCs, make a serious contribution to the greenhouse effect. He received a Nobel Prize in chemistry for his efforts.

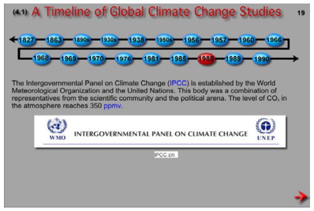



4.1.17 (1981)
James Hansen and other scientists show that sulfate aerosols can significantly cool the climate, raising confidence in models showing future greenhouse warming.

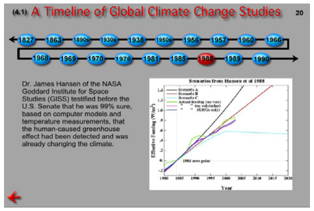
## Notes



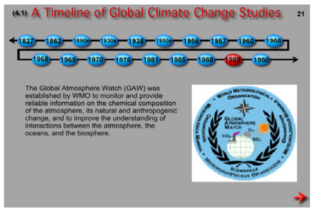

4.1.18 (1985)
Ice cores from both Antarctica and Greenland show that carbon dioxide ($CO_2$) and temperature went up and down together through past ice ages.



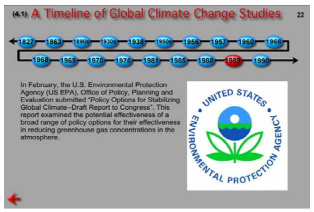

4.1.19 (1988a)
The Intergovernmental Panel on Climate Change (IPCC) is established by the World Meteorological Organization (WMO) and the United Nations (UN). This Panel includes representatives from both the scientific community and the political arena.
The level of $CO_2$ in the atmosphere reaches 350 ppmv.




4.1.20 (1988b)
Dr. James Hansen of the NASA Goddard Institute for Space Studies (GISS) testified before the U.S. Senate that he was 99% sure, based on computer models and temperature measurements, that the human-caused greenhouse effect had been detected and was already changing the climate.



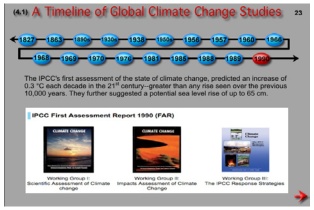

4.1.21 (1989a)
The Global Atmosphere Watch (GAW) was established by the World Meteorological Organization (WMO) to monitor and provide reliable information on the chemical composition of the atmosphere, its natural and anthropogenic change, and to improve the understanding of interactions between the atmosphere, the oceans, and the biosphere.



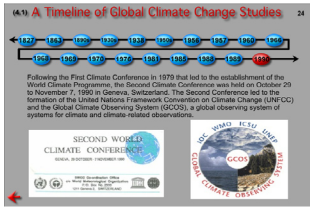

4.1.22 (1989b)
In February, the U.S. Environmental Protection Agency (US EPA), Office of Policy, Planning, and Evaluation submitted "Policy Options for Stabilizing Global Climate--Draft Report to Congress". This report examined the potential effectiveness of a broad range of policy options for their effectiveness in reducing greenhouse gas concentrations in the atmosphere.

4.1.23 (1989c)
Fossil-fuel and other U.S. industries formed an organization called the Global Climate Coalition to tell politicians and the public that climate science is too uncertain to justify action.

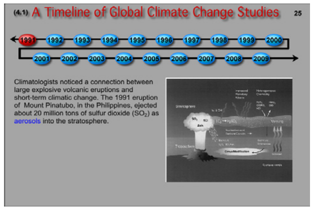
# Notes




4.1.23 (1990a)
The IPCC's first assessment of the state of climate change predicted an increase of 0.3 °C each decade in the 21$^{st}$ century--greater than any rise seen over the previous 10,000 years. They further suggested a potential sea level rise of up to 65 cm.

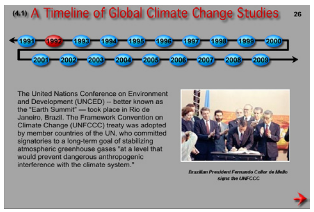



4.1.24 (1990b)
Following the First Climate Conference in 1979 that led to the establishment of the World Climate Programme, the Second Climate Conference was held from October 29 to November 7, 1990 in Geneva, Switzerland. The Second Conference led to the formation of the United Nations Framework Convention on Climate Change (UNFCCC) and the Global Climate Observing System (GCOS) to monitor climate-related observations.

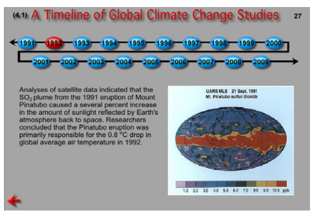



4.1.25 (1991)
Climatologists noticed a connection between large explosive volcanic eruptions and short-term climatic change. The 1991 eruption of Mount Pinatubo, in the Philippines, ejected about 20 million tons of sulfur dioxide ($SO_2$) as aerosols into the stratosphere.

<u>Pop-up note for aerosols:</u>
Sulfer dioxide from the cloud is transformed into sulfuric acid (H2SO4). The sulfuric acid quickly condenses, producing aerosol particles which linger in the atmosphere for long periods of time. The aerosols create a dense, optically bright haze layer that reflects some of the Sun's incoming radiation.



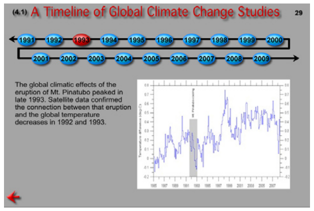

4.1.26 (1992a)
The United Nations Conference on Environment and Development (UNCED)—better known as the "Earth Summit"–took place in Rio de Janeiro, Brazil. The Framework Convention on Climate Change (UNFCCC) treaty was adopted by member countries of the UN, who committed signatories to a long-term goal of stabilizing atmospheric greenhouse gases "at a level that would prevent dangerous anthropogenic interference with the climate system."



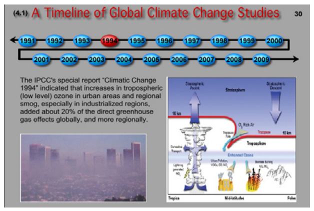

4.1.27 (1992b)
Analyses of satellite data indicated that the $SO_2$ plume from the 1991 eruption of Mount Pinatubo caused a several percent increase in the amount of sunlight reflected by Earth's atmosphere back to space. Researchers concluded that the Pinatubo eruption was primarily responsible for the 0.8 °C drop in global average air temperature in 1992.

# Notes

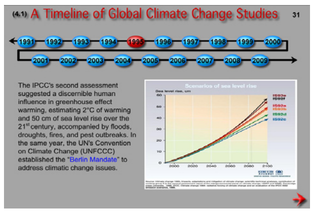

4.1.28 (1993a)
Researchers who study Greenland ice cores determined that great climate changes can occur in the span of a single decade.




4.1.29 (1993b)
The global climatic effects of the eruption of Mt. Pinatubo peaked in late 1993. Satellite data confirmed the connection between that eruption and the global temperature decreases in 1992 and 1993.




4.1.30 (1994)
The IPCC's special report "Climatic Change 1994" indicated that increases in tropospheric (low-level) ozone in urban areas and regional smog, especially in industrialized regions, added about 20% of the direct greenhouse gas effects globally, and more regionally.

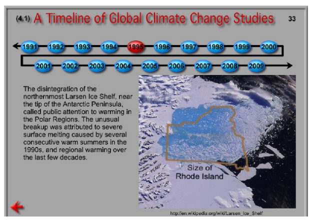



4.1.31 (1995a)
The IPCC's second assessment suggested a discernible human influence in greenhouse effect warming, estimating 2 °C of warming and 50 cm of sea level rise over the 21$^{st}$ century, accompanied by floods, droughts, fires, and pest outbreaks. In the same year, the UN's Framework Convention on Climate Change (UNFCCC) established the "Berlin Mandate" to address climatic change issues.

Pop-up Note:

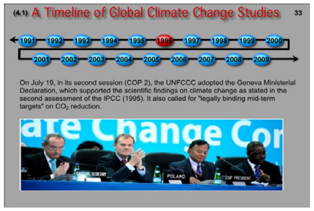
Berlin Mandate - a two year Analytical and Assessment Phase (AAP) established in the UNFCCC's first annual meeting held in Berlin, Germany in 1995.

This targeted a set of comprehensive actions by December 1997 to address climatic change issues.

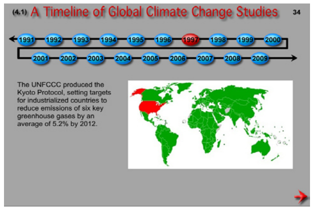



4.1.32 (1995b)
The disintegration of the northernmost Larsen Ice Shelf, near the tip of the Antarctic Peninsula, called public attention to warming in the Polar Regions. The unusual breakup was attributed to severe surface melting caused by several consecutive warm summers in the 1990s, and regional warming over the last few decades.

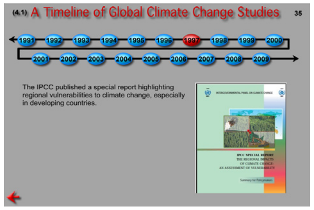
# Notes



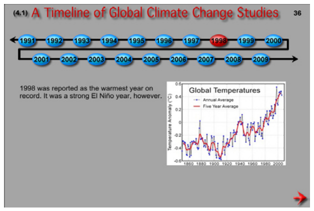

4.1.33 (1996)
On July 19, in its second session (COP 2), the UNFCCC adopted the Geneva Ministerial Declaration, which supported the scientific findings on climate change as stated in the second assessment of the IPCC (1995). It also called for "legally binding mid-term targets" on $CO_2$ reduction.



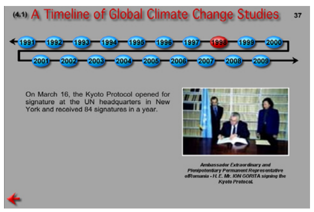

4.1.34 (1997a)
The UNFCCC produced the Kyoto Protocol, setting targets for industrialized countries to reduce emissions of six key greenhouse gases by an average of 5.2% by 2012.



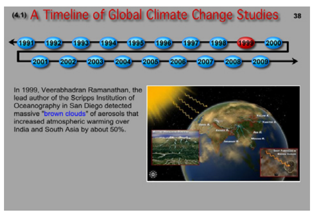

4.1.35 (1997b)
The IPCC published a special report highlighting regional vulnerabilities to climate change, especially in developing countries.




4.1.36 (1998a)
1998 was reported as the warmest year on record. However, it was a strong El Niño year.




4.1.37 (1998b)
On March 16, the Kyoto Protocol opened for signature at the UN headquarters in New York and received 84 signatures in a year.

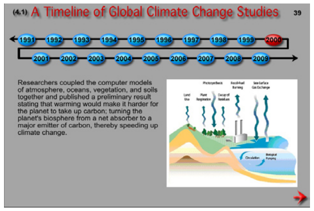



4.1.38 (1999a)
In 1999, Veerabhadran Ramanathan, of the Scripps Institution of Oceanography in San Diego, was the lead author on a paper describing massive "brown clouds" of aerosols that increased atmospheric warming over India and South Asia by about 50%.

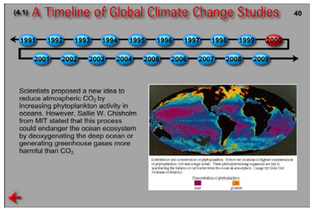
Pop-up Note:

Brown Clouds - Soot-filled aerosol clouds that may contribute to atmospheric warming as much as greenhouse gases do by absorbing the Sun's energy and then releasing it to the surrounding air as heat.

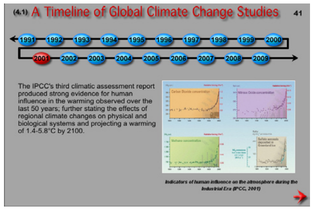
# Notes



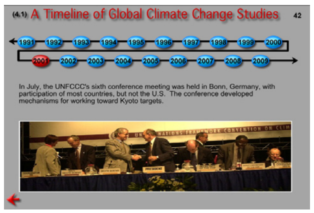

4.1.39 (2000a)
Researchers were able to include mathematical descriptions of Earth's atmosphere, oceans, vegetation, and soils into computer models, creating more robust "coupled models" of Earth's climate system. Published preliminary results showed that warming would make it harder for the planet to take up carbon; turning the planet's biosphere from a net absorber to a major emitter of carbon, and thereby speeding up climate change.



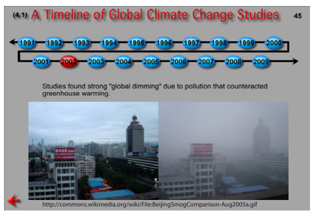

4.1.40 (2000b)
Phil Boyd and Cliff Law reported on the test of their idea of releasing iron in the Southern Ocean to reduce atmospheric $CO_2$ by increasing phytoplankton activity in oceans. However, Sallie W. Chisholm from MIT argued that this process could endanger the ocean ecosystem by de-oxygenating the deep ocean or by generating greenhouse gases more harmful than $CO_2$.



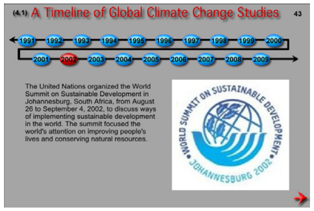

4.1.41 (2001a)
The IPCC's third climatic assessment report produced strong evidence for human influence in the warming observed over the last 50 years; further stating the effects of regional climate changes on physical and biological systems and projecting a warming of 1.4-5.8 °C by 2100.




4.1.42 (2001b)
In July, the UNFCCC's sixth conference meeting was held in Bonn, Germany, with participation of most countries, but not the U.S. The conference developed mechanisms for working toward Kyoto targets.

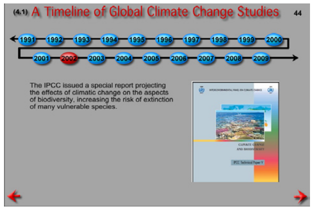



4.1.45 (2001c)
Gerry Stanhill and S. Cohen (2001) coined the term "global dimming" to describe the effect of pollutants and aerosols that reduced the amount of sunlight received at Earth's surface.



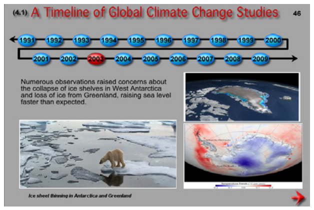

4.1.43 (2002a)

The United Nations organized the World Summit on Sustainable Development in Johannesburg, South Africa, from August 26 to September 4, 2002, to discuss ways of implementing sustainable development in the world. The summit focused the world's attention on improving people's lives and conserving natural resources.



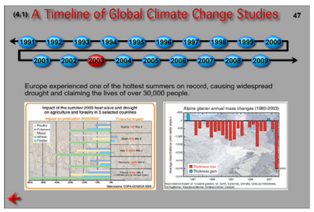

4.1.44 (2002b)

The IPCC issued a special report projecting the effects of climatic change on biodiversity, increasing the risk of extinction of many vulnerable species.



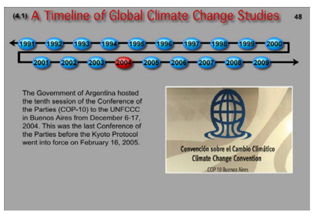

4.1.46 (2003a)

Numerous observations raised concerns about the collapse of ice shelves in West Antarctica and loss of ice from Greenland, which would raise sea level faster than expected.



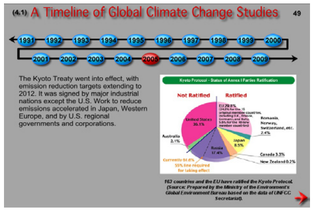

4.1.47 (2003b)

Europe experienced one of the hottest summers on record, causing widespread drought and claiming the lives of over 30,000 people.

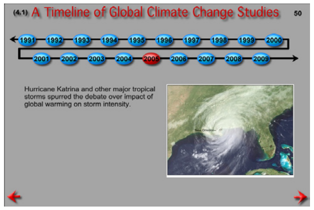



4.1.48 (2004)

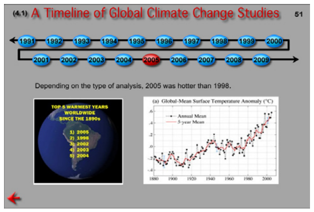
The Government of Argentina hosted the tenth session of the Conference of the Parties (COP-10) to the UNFCCC in Buenos Aires from December 6-17, 2004. This was the last Conference of the Parties before the Kyoto Protocol went into force on February 16, 2005.



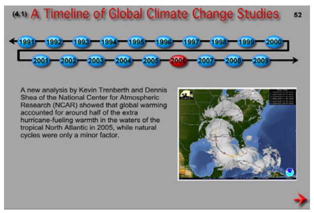

4.1.49 (2005a)
The Kyoto Treaty went into effect, with emission reduction targets extending to 2012. It was signed by major industrial nations except the U.S.A. Meanwhile, work to reduce emissions accelerated in Japan, Western Europe, and by regional governments and corporations in the U.S.A.



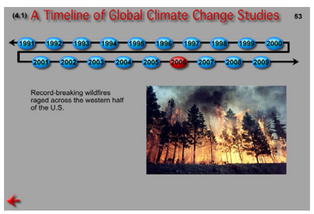

4.1.50 (2005b)
Hurricane Katrina and other major tropical storms spurred the debate over impact of global warming on storm intensity.




4.1.51 (2005c)
Depending on the type of analysis, 2005 was hotter than 1998.

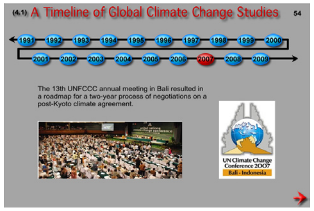



4.1.52 (2006a)
A new analysis by Kevin Trenberth and Dennis Shea of the National Center for Atmospheric Research (NCAR) showed that global warming accounted for around half of the extra hurricane-fueling warmth in the waters of the tropical North Atlantic in 2005, while natural cycles were only a minor factor.

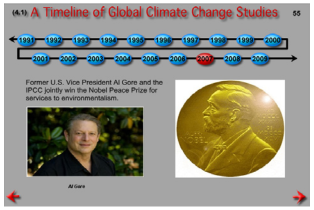



4.1.53 (2006b)
Record-breaking wildfires raged across the western half of the U.S.

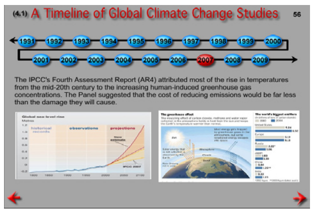
# Notes



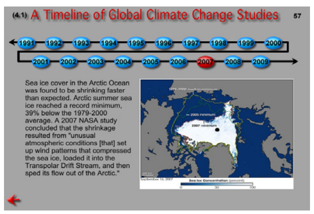

4.1.54 (2007a)
The 13th UNFCCC annual meeting in Bali resulted in a roadmap for a two-year process of negotiations on a post-Kyoto climate agreement.



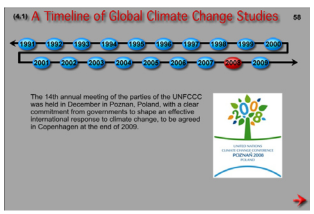

4.1.55 (2007b)
Former U.S. Vice President Al Gore and the IPCC jointly win the Nobel Peace Prize for services to environmentalism.



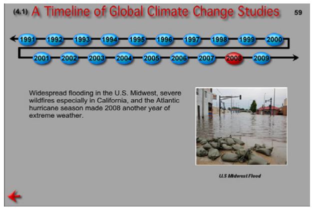

4.1.56 (2007c)
The IPCC's Fourth Assessment Report (AR4) attributed most of the rise in temperatures from the mid-20th century to the increasing human-induced greenhouse gas concentrations. The Panel suggested that the cost of reducing emissions would be far less than the damage they will cause.



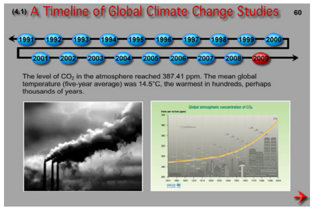

4.1.57 (2007d)
Sea ice cover in the Arctic Ocean was found to be shrinking faster than expected. Arctic summer sea ice reached a record minimum, 39% below the 1979-2000 average. A 2007 NASA study concluded that the shrinkage resulted from "unusual atmospheric conditions [that] set up wind patterns that compressed the sea ice, loaded it into the Transpolar Drift Stream, and then sped its flow out of the Arctic."



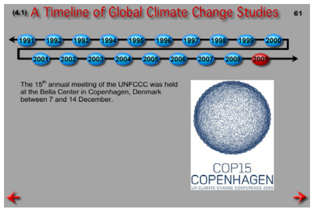

4.1.58 (2008a)
The 14th annual meeting of the parties of the UNFCCC was held in December in Poznań, Poland, with a clear commitment from governments to shape an effective international response to climate change, to be agreed in Copenhagen at the end of 2009.



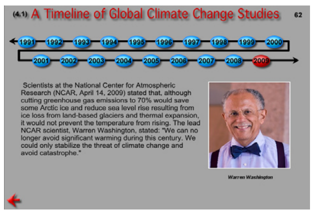

4.1.59 (2008b)
Widespread flooding in the U.S. Midwest, severe wildfires especially in California, and the Atlantic hurricane season made 2008 another year of extreme weather.




4.1.60 (2009a)
The level of $CO_2$ in the atmosphere reached 387.41 ppm. The mean global temperature (five-year average) was 14.5 °C, the warmest in hundreds, perhaps thousands of years.




4.1.61 (2009b)
The 15th annual meeting of the UNFCCC was held at the Bella Center in Copenhagen, Denmark, between December 7-14.

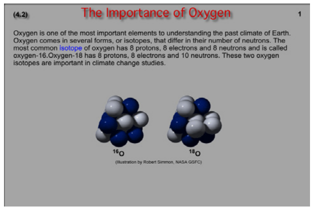



4.1.62 (2009c)
Scientists at the National Center for Atmospheric Research (NCAR, April 14, 2009) stated that, although cutting greenhouse gas emissions to 70% would save some Arctic ice and reduce sea level rise resulting from ice loss from land-based glaciers and thermal expansion, it would not prevent the temperature from rising. The lead NCAR scientist, Warren Washington, stated: "We can no longer avoid significant warming during this century. We could only stabilize the threat of climate change and avoid catastrophe."

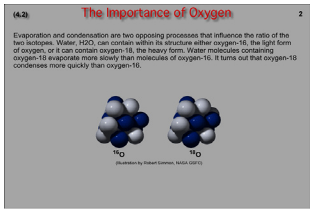
## Notes

# The Importance of Oxygen

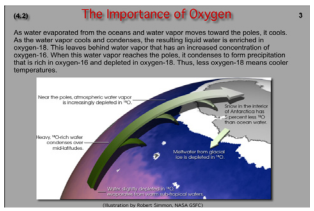
## 4.2



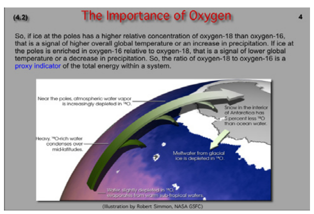

4.2.1
Oxygen is one of the most important elements in understanding the past climate of Earth. Oxygen comes in several forms, or isotopes, that differ in their number of neutrons. The most common isotope of oxygen has 8 protons, 8 electrons, and 8 neutrons and is called oxygen-16. Oxygen-18 has 8 protons, 8 electrons, and 10 neutrons. These two oxygen isotopes are important in climate change studies.




4.2.2
Evaporation and condensation are two opposing processes that influence the ratio of the two isotopes. Water, H2O, can contain within its structure either oxygen-16, the light form of oxygen, or it may contain oxygen-18, the heavy form. Very rarely, water molecules may also contain an intermediate isotope, oxygen-17. Water molecules containing oxygen-18 evaporate more slowly and condense more quickly than molecules with oxygen-16.

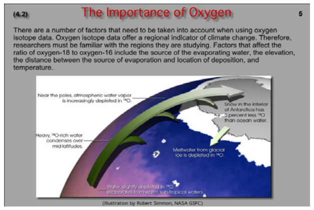



4.2.3
Water cools as it evaporates from the oceans and as water vapor moves toward the poles. As the water vapor cools and condenses, the resulting liquid water is enriched in oxygen-18. This leaves behind water vapor that has an increased concentration of oxygen-16. When this water vapor reaches the poles, it condenses to form precipitation that is richer in oxygen-16 and depleted in oxygen-18. Thus, less oxygen-18 in the snow means cooler temperatures.




4.2.4
So, if ice at the poles has a higher relative concentration of oxygen-18 than oxygen-16, that is a signal of higher overall global temperature or an increase in precipitation. If ice at the poles is enriched in oxygen-16 relative to oxygen-18, that is a signal of lower overall global temperature or a decrease in precipitation. So, the ratio of oxygen-18 to oxygen-16 is a proxy indicator of the total energy within a system.

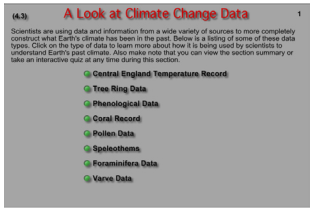
Notes




4.2.5

There are a number of factors that need to be considered when using oxygen isotope data. Oxygen isotope data offer a regional indicator of climate change. Therefore, researchers must be familiar with the regions they are studying. Factors that affect the ratio of oxygen-18 to oxygen-16 include the source of the evaporating water, the elevation, the distance between the source of evaporation and the location of deposition, and temperature.

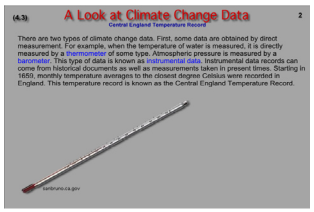
## 4.3 A Look at Climate Change Data




4.3.1

Scientists use data and information from a wide variety of sources to more completely construct what Earth's climate has been in the past. Below is a listing of some of these data types. Click on the type of data to learn more about how it is being used by scientists to understand Earth's past climate. Also make note that you can view the section summary or take an interactive quiz at any time during this section.

- Central England Temperature Record
- Tree Ring Data
- Phenological Data
- Coral Record
- Pollen Data
- Speleothems
- Foraminifera Data
- Varve Data

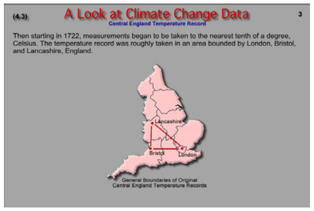



4.3.2

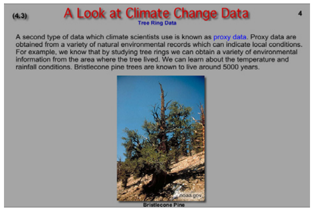
Central England Temperature Record

There are two types of climate change data. First, some data are obtained by direct measurement. For example, the temperature of water can be directly measured using a thermometer of some type. Atmospheric pressure is measured using a barometer. These types of data are known as instrumental data. Instrumental data records can come from historical documents as well as from measurements taken in present times. Starting in 1659, monthly temperature averages, to the closest degree Celsius, were recorded in England. This temperature record is known as the Central England Temperature Record.

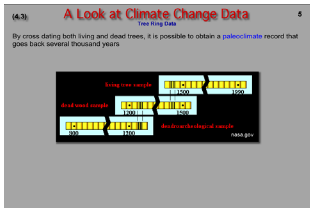
# Notes



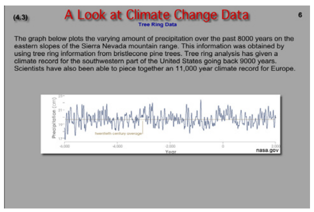

4.3.3
Then starting in 1722, measurements were taken to the nearest tenth of a degree Celsius. The temperature record was taken in an area roughly bounded by London, Bristol, and Lancashire, England.



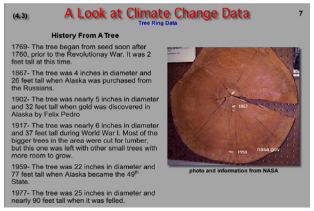

4.3.4
Tree Ring Data
A second type of data which climate scientists use is known as proxy data. Proxy data are obtained from a variety of natural environmental records that indicate local conditions. For example, we know that by studying tree rings, we can obtain a variety of environmental information about the area where the tree lived, such as temperature and rainfall conditions. Bristlecone pine trees are known to live around 5000 years.




4.3.5
By cross-dating both living and dead trees, it is possible to obtain a paleoclimate record that goes back several thousand years.

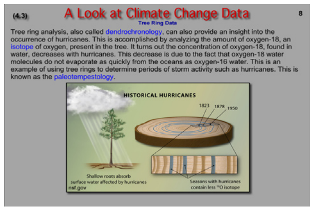



4.3.6
The graph below plots the varying amounts of precipitation over the past 8000 years on the eastern slopes of the Sierra Nevada mountain range. This information was obtained using tree ring information from bristlecone pine trees. Tree ring analysis has given a climatic record for the southwestern part of the United States going back 9000 years. Scientists have also been able to construct an 11,000-year climate record for Europe using tree ring data.



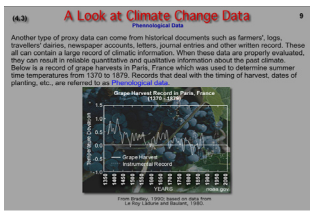

4.3.7

1769- The tree began from seed soon after 1760, prior to the U.S. Revolutionary War. It was 2 feet tall at this time.
1867- The tree was 4 inches in diameter and 26 feet tall when Alaska was purchased from Russia.
1902- The tree was nearly 5 inches in diameter and 32 feet tall when gold was discovered in Alaska by Felix Pedro.
1917- The tree was nearly 6 inches in diameter and 37 feet tall during World War 1. Most of the bigger trees in the area were cut for lumber, but this one was left with other small trees with more room to grow.
1959- The tree was 22 inches in diameter and 77 feet tall when Alaska became the 49th U.S. state.
1977- The tree was 25 inches in diameter and nearly 90 feet tall when it was felled.




4.3.8

Tree ring analysis, also called dendrochronology, can also provide an insight into the occurrence of hurricanes. This is accomplished by analyzing the amount of oxygen-18, an isotope of oxygen, present in the tree. The concentration of oxygen-18, found in water, decreases with hurricanes. This decrease is due to the fact that oxygen-18 water molecules do not evaporate as quickly from the oceans as oxygen-16 water. This is an example of using tree rings to determine periods of storm activity such as hurricanes. This is known as paleotempestology.

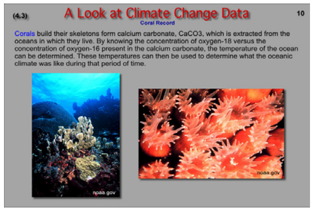



4.3.9

Phenological Data

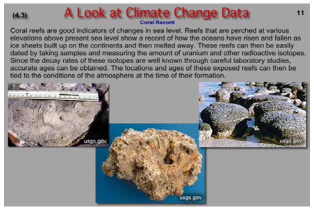
Another type of proxy data can come from historical documents such as farmers' logs, travelers' diaries, newspaper accounts, letters, journal entries, and other written records. All of these may contain details about climatic information. When these data are properly evaluated, they can provide reliable quantitative and qualitative information about past climate. Below is a record of grape harvests in Paris, France, which was used to determine summertime temperatures from 1370 to 1879. Records that deal with the timing of harvests, dates of planting, etc., are referred to as phenological data.

# Notes



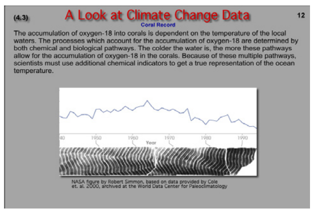

4.3.10
Coral Record

Corals build their skeletons from calcium carbonate, $CaCO_3$, which is extracted from the oceans in which they live. By knowing the concentration of oxygen-18 versus the concentration of oxygen-16 present in the calcium carbonate, the temperature of the ocean, at the time the corals were alive, can be determined.



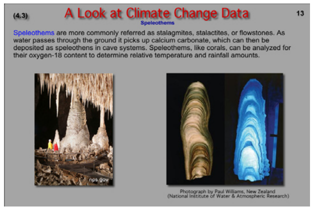

4.3.11
Coral reefs are good indicators of changes in sea level. Reefs are found only in areas of the oceans where water temperatures and sunlight allow coral to survive. Therefore, reefs that are perched at elevations above present sea level show that sea level was higher in the past. The locations and ages of these exposed reefs indicate the conditions at the time of their formation.

Reefs can be easily dated by taking samples and measuring the amounts of uranium and other radioactive isotopes. Accurate ages can be obtained because the decay rates of specific isotopes have been established through careful laboratory studies.




4.3.12
There are both biological and chemical pathways that account for the presence of oxygen-18 in corals. Incorporation of oxygen-18 (O-18) into the stony skeletons of coral polyps is dependent upon the temperature of the local waters. For example, more oxygen-18 is present when corals live in colder water. However, because there are multiple pathways for O-18 to be included in coral structures, scientists must use additional chemical indicators to get a true representation of the ocean temperature.

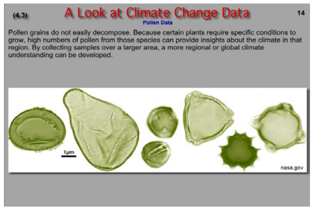
# Notes




4.3.13

Speleothems

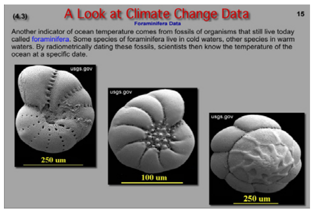
Speleothems are more commonly referred to as stalagmites, stalactites, or flowstones. As water passes through the ground, it picks up calcium carbonate, which can then be deposited as speleothems in cave systems. Speleothems, like corals, can be analyzed for their oxygen-18 content to determine relative temperature and rainfall amounts.




4.3.14

Pollen Data

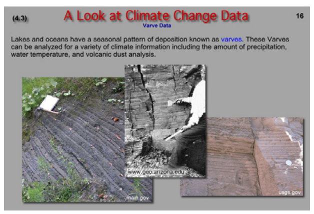
Pollen grains do not easily decompose. Because certain plants require specific conditions to grow, high numbers of pollen from those species can provide insights about the climate in that region. By collecting samples over a larger area, a more regional or global climate understanding can be developed.




4.3.15

Foraminifera Data

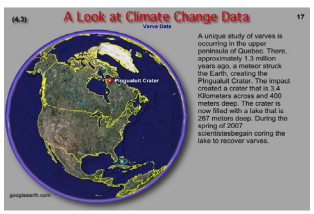
Another indicator of ocean temperature comes from fossils of organisms that still live today, called foraminifera. Some species of foraminifera survive best in colder waters; other species survive better in warmer water. Oxygen isotopes once again serve as a proxy for temperature of the surface waters. Then, by radiometrically-dating these fossils, scientists can determine the temperature of the ocean at a specific date.




4.3.16

Varve Data

A seasonal pattern of deposition occurs in lakes and oceans, producing features known as varves, which can be analyzed for a variety of climatic information. For example, scientists can gain insights into the amount of precipitation, water temperature, and volcanic dust in the sediments.




4.3.17

A unique study of varves is occurring in the upper peninsula of Quebec. Approximately 1.3 million years ago, a meteor struck Earth, creating the Pingualuit Crater. The impact crater is 3.4 kilometers across and 400 meters deep. The crater is now filled with a lake that is 267 meters deep. During the spring of 2007, scientists began coring the lake bed to recover varves.

# Notes


4.3.18
Because of its location, the lake has basically remained undisturbed by humans. Scientists are excited by the prospect that the varves may provide an uninterrupted climate history that could go back 1.3 million years. The depth of the lake makes scientists confident that none of the varves have been erased by glacier activity through time.

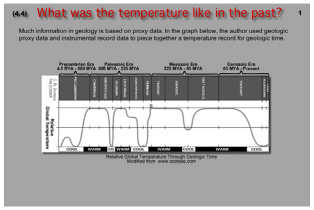

4.3.19
Climate Data Summary
Climatologists, like any other scientists, must have reliable data to make judgments. Usable data can come from a wide variety of sources. These sources include instrumental data from devices such as thermometers, barometers, and hygrometers. However, reliable instrumental data only goes back about 200-300 years. As scientists study past climates in an effort to be able to predict future climates, they must turn to proxy data to extend their timelines back into the distant past. Sources of such proxy data include: dendrochronology (tree rings), pollen analysis (palynology), coral reefs, speleothems, analysis of varves, and historical records. The greater the number of independent lines of data that show the same basic trends, the stronger the scientific case.


4.3.20
Summary
• Climate scientists use two types of data. Instrumental data records rely on making direct measurements such as temperature, mass, volume, humidity, and pressure. According to internationally recognized procedures, the measuring instruments must be properly installed in suitable places, carefully maintained, and conscientiously observed.
• Scientists also gather data from time periods when direct measurements were not made. This type of data is called proxy data. Proxy data, like instrumental data, must subscribe to internationally recognized procedures of analysis and be calibrated against accurate, known standards. The science of paleoclimatology relies on a wide variety of proxy data to obtain information about Earth's past climate.
• Proxy data are used in a variety of applications beyond paleoclimatology. Direct measurements are limited by the technology that we possess as a given time. Think of proxy data as a way of indirectly measuring a condition by drawing inferences based on sound science.

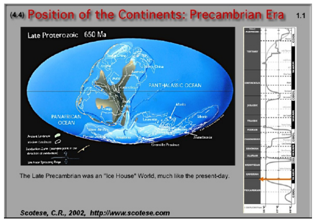
# Notes

## What was Earth’s temperature like in the past?

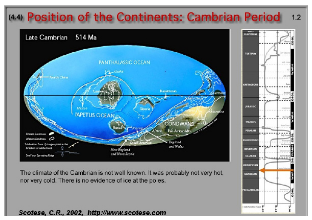
## 4.4



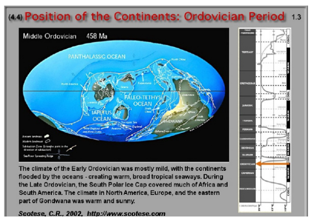

4.4.1
Much information in geology is based on proxy data. In the graph below, the author used geologic proxy data and instrumental record data to construct a temperature record for geologic time.



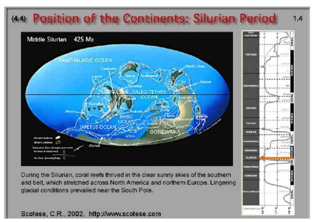

4.4.1.1 Position of the Continents: Precambrian Era
The Late Precambrian was an “Ice House” world, much like the present-day.




4.4.1.2 Position of the Continents: Cambrian Period
The climate of the Cambrian is not well known. It was probably not very hot, nor very cold. There is no evidence of ice at the poles.

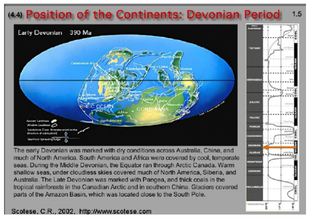



4.4.1.3 Position of the Continents: Ordovician Period
The climate of the Early Ordovician was mostly mild, with the continents flooded by the oceans—creating warm, broad tropical seaways. During the Late Ordovician, the South Polar ice cap covered much of Africa and South America. The climate in North America, Europe, and the eastern part of Gondwana was warm and sunny.



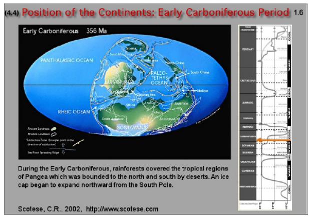

4.4.1.4 Position of the Continents: Silurian Period
During the Silurian, coral reefs thrived in the clear sunny skies of the southern arid belt, which stretched across North America and northern Europe. Lingering glacial conditions prevailed near the South Pole.

## Notes



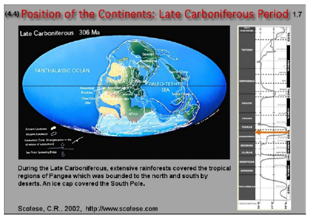

4.4.1.5 Position of the Continents: Devonian Period

The early Devonian was marked with dry conditions across Australia, China, and much of North America. South America and Africa were covered by cool, temperate seas. During the Middle Devonian, the Equator ran through Arctic Canada. Warm shallow seas, under cloudless skies covered much of North America, Siberia, and Australia. The Late Devonian was marked with Pangea, and thick coals in the tropical rainforests in the Canadian Arctic and in southern China. Glaciers covered parts of the Amazon Basin, which was located close to the South Pole.



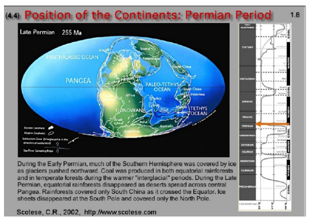

4.4.1.6 Position of the Continents: Early Carboniferous Period

During the Early Carboniferous, rainforests covered the tropical regions of Pangea, which was bounded to the north and south by deserts. An ice cap began to expand northward from the South Pole.




4.4.1.7 Position of the Continents: Late Carboniferous Period

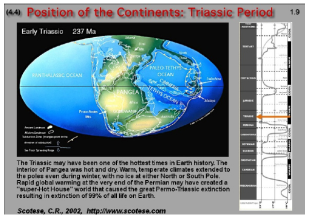
During the Late Carboniferous, extensive rainforests covered the tropical regions of Pangea, which was bounded to the north and south by deserts. An ice cap covered the South Pole.




4.4.1.8 Position of the continents: Permian Period

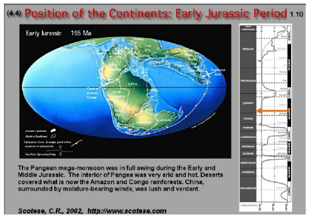
During the Early Permian, much of the Southern Hemisphere was covered by ice as glaciers pushed northward. Coal was produced in both equatorial rainforests and in temperate forests during the warmer "Interglacial" periods. During the Late Permian, equatorial rainforests disappeared as deserts spread across central Pangea. Rainforests covered South China as it crossed the Equator. Ice sheets disappeared at the South Pole and covered only the North Pole.

# Notes



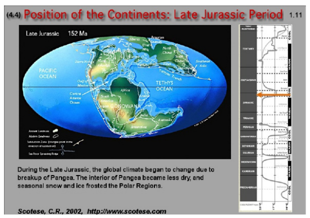

4.4.1.9 Position of the Continents: Triassic Period

The Triassic may have been one of the hottest times in Earth history. The interior of Pangea was hot and dry. Warm, temperate climates extended to the Poles even during winter, with no ice at either the North or South Pole. Rapid global warming at the very end of the Permian may have created a super-"Hot House" world that caused the great Permo-Triassic extinction—an extinction of 99% of all life on Earth.



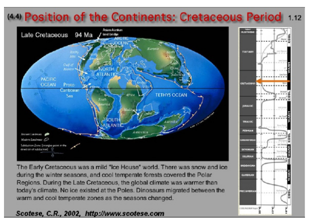

4.4.1.10 Position of the Continents: Jurassic Period

The Pangean mega-monsoon was in full swing during the Early and Middle Jurassic. The interior of Pangea was very arid and hot. Deserts covered what is now the Amazon and Congo rainforests. China, surrounded by moisture-bearing winds, was lush and verdant.




4.4.1.11 Position of the Continents:

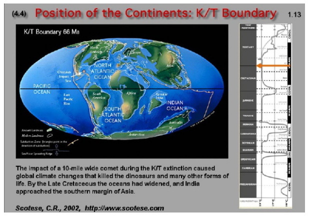
During the Late Jurassic, the global climate began to change due to breakup of Pangea. The interior of Pangea became less dry, and seasonal snow and ice frosted the Polar Regions.



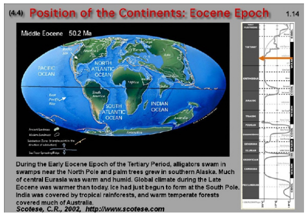

4.4.1.12 Position of the Continents: Cretaceous Period

The Early Cretaceous was a mild "Ice House" world. There was snow and ice during the winter seasons, and cool temperate forests covered the Polar Regions. During the Late Cretaceous, the global climate was warmer than today's climate. No ice existed at the Poles. Dinosaurs migrated between the warm temperate and cool temperate zones as the seasons changed.

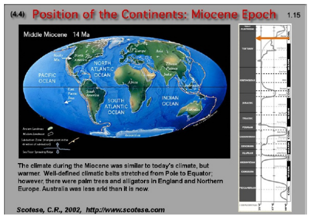
## Notes



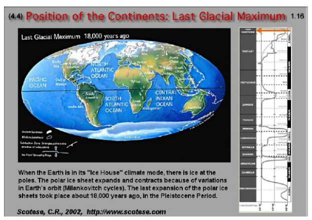

4.4.1.13 Position of the Continents: K/T Boundary
The impact of a 10-mile-wide comet or asteroid during the K/T extinction caused global climate changes that killed the dinosaurs and many other forms of life. By the Late Cretaceous the oceans had widened, and India approached the southern margin of Asia.



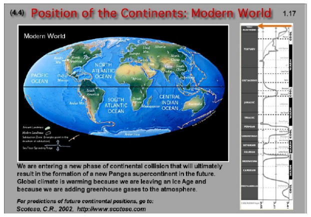

4.4.1.14 Position of the Continents: Eocene Epoch
During the Early Eocene Epoch of the Tertiary Period, alligators swam in swamps near the North Pole and palm trees grew in southern Alaska. Much of central Eurasia was warm and humid. Global climate during the Late Eocene was warmer than today. Ice had just begun to form at the South Pole. India was covered by tropical rainforests, and warm temperate forests covered much of Australia.




4.4.1.15 Position of the Continents: Miocene Epoch
The climate during the Miocene Epoch of the Tertiary Period was similar to today's climate, but warmer. Well-defined climatic belts stretched from Pole to Equator; however, there were palm trees and alligators in England and Northern Europe. Australia was less arid than it is now.



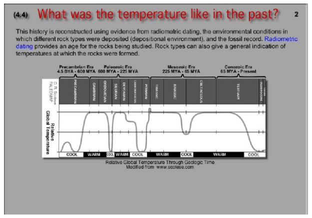

4.4.1.16 Position of the Continents: Last Glacial Maximum
When the Earth is in its "Ice House" climate mode, there is ice at the poles. The polar ice sheet expands and contracts because of variations in Earth's orbit (Milankovitch cycles). The last expansion of the polar ice sheets took place about 18,000 years ago, in the Pleistocene Epoch.




4.4.1.17 Position of the Continents: Modern World

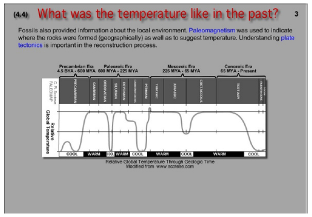
We are entering a new phase of continental collision that will ultimately result in the formation of a new Pangea supercontinent in the future. Global climate is warming because we are leaving an Ice Age and because we are adding greenhouse gases to the atmosphere.

For predictions of future continental positions, go to:
http://www.scotese.com/



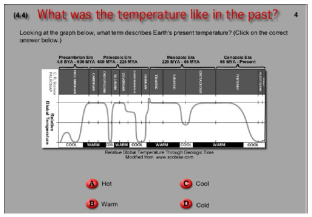

4.4.2

This history is reconstructed using evidence from radiometric dating, the environmental conditions in which different rock types were deposited (depositional environment), and the fossil record. Radiometric dating provides an age for the rocks being studied. Rock types can also give a general indication of temperatures at which the rocks were formed.




4.4.3

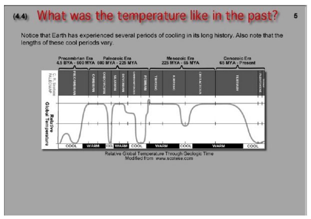
Fossils also provided information about the local environment. Paleomagnetism was used to indicate where the rocks were formed (geographically) as well as to suggest temperature. Understanding plate tectonics is important in the reconstruction process.




4.4.4

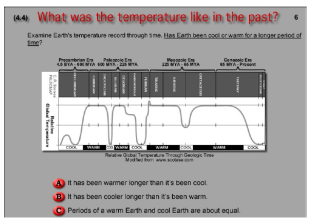
Looking at the graph below, what term describes Earth's present temperature? (Click on the correct answer below.)

A. Hot
B. Warm
C. Cool
D. Cold




4.4.5

Notice that Earth has experienced several periods of cooling in its long history. Also note that the lengths of these cool periods vary.



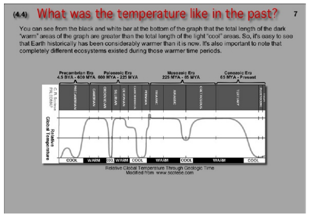

4.4.6

Examine Earth's temperature record through time. Has Earth been cool or warm for a longer period of time?

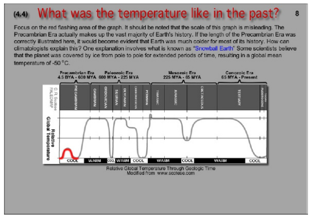
A. It has been warmer longer than it's been cool.
B. It has been cooler longer than it's been warm.
C. Periods of a warm Earth and cool Earth are about equal.

# Notes

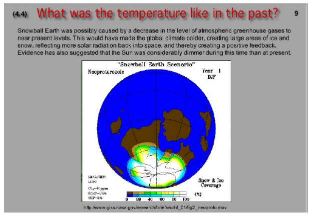
# Notes



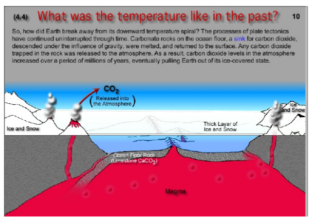

4.4.7
You can see from the black and white bar at the bottom of the graph that the total length of the dark "warm" areas of the graph are greater than the total length of the light "cool" areas. So, it's easy to see that Earth historically has been considerably warmer than it is now. It's also important to note that completely different ecosystems existed during those warmer time periods.




4.4.8
Focus on the red flashing area of the graph. It should be noted that the scale of this graph is misleading. The Precambrian Era actually makes up the vast majority of Earth's history. If the length of the Precambrian Era was correctly illustrated here, it would become evident that Earth was much colder for most of its history. How can climatologists explain this? One explanation involves what is known as "Snowball Earth." Some scientists believe that the planet was covered by ice from pole to pole for extended periods of time, resulting in a global mean temperature of -50 °C.

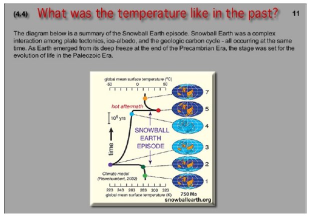



4.4.9
Snowball Earth was possibly caused by a decrease in the level of atmospheric greenhouse gases to near present levels. This would have made the global climate colder, creating large areas of ice and snow, reflecting more solar radiation back into space, and thereby creating a positive feedback. Evidence has also suggested that the Sun was considerably dimmer during this time than at present.



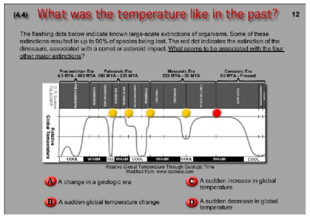

4.4.10
So, how did Earth break away from its downward temperature spiral? The processes of plate tectonics have continued uninterrupted through time. Carbonate rocks on the ocean floor, a sink for carbon dioxide, descended under the influence of gravity, were melted, and returned to the surface. Any carbon dioxide trapped in the rock was released to the atmosphere. As a result, carbon dioxide levels in the atmosphere increased over a period of millions of years, eventually pulling Earth out of its ice-covered state.

## Notes




4.4.11

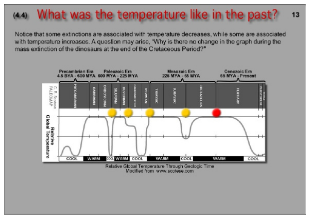
The diagram below is a summary of the Snowball Earth episode. Snowball Earth was a complex interaction among plate tectonics, ice-albedo, and the geologic carbon cycle—all occurring at the same time. As Earth emerged from its deep freeze at the end of the Precambrian Era, the stage was set for the evolution of life in the Paleozoic Era.




4.4.12

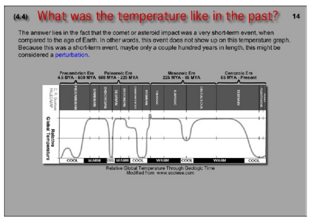
The flashing dots below indicate known large-scale extinctions of organisms. Some of these extinctions resulted in up to 90% of species being lost. The red dot indicates the extinction of the dinosaurs, associated with a comet or asteroid impact. What seems to be associated with the four other major extinctions?

A. A change in a geologic era
B. A sudden global temperature change
C. A sudden increase in global temperature
D. A sudden decrease in global temperature



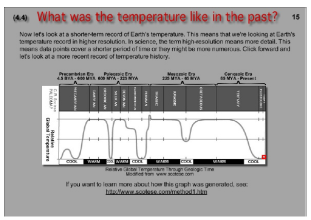

4.4.13

Notice that some extinctions are associated with temperature decreases, while some are associated with temperature increases. A question may arise, "Why is there no change in the graph during the mass extinction of the dinosaurs at the end of the Cretaceous Period?"




4.4.14

The answer lies in the fact that the comet or asteroid impact was a very short-term event, when compared to the age of Earth. In other words, this event does not show up on this temperature graph. Because this was a short-term event, maybe only a couple hundred years in length, this might be considered a perturbation.

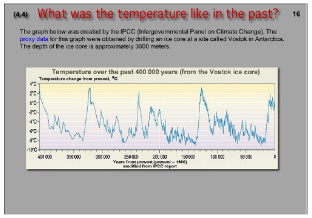



4.4.15

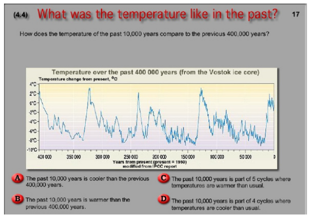
Now let's look at a shorter-term record of Earth's temperature. This means that we're looking at Earth's temperature record in higher resolution. In science, the term high-resolution means more detail. This means data points cover a shorter period of time or they might be more numerous. Click forward and let's look at a more recent record of temperature history.

If you want to learn more about how this graph was generated, see: http://www.scotese.com/method1.htm

# Notes

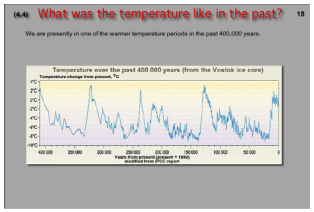



4.4.16
The graph below was created by the IPCC (Intergovernmental Panel on Climate Change). The proxy data for this graph were obtained by drilling an ice core at a site called Vostok in Antarctica. The depth of the ice core is approximately 3600 meters.

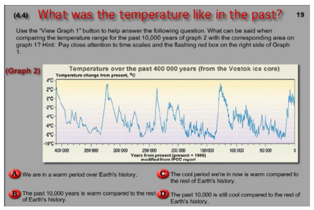



4.4.17
How does the temperature of the past 10,000 years compare to the previous 400,000 years?

A. The past 10,000 years is cooler than the previous 400,000 years.
B. The past 10,000 years is warmer than the previous 400,000 years.
C. The past 10,000 years is part of 5 cycles where temperatures are warmer than usual.
D. The past 10,000 years is part of 4 cycles where temperatures are cooler than usual.

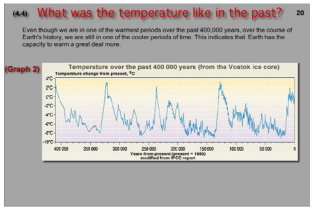



4.4.18
We are presently in one of the warmer temperature periods in the past 400,000 years.



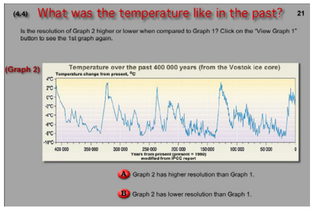

4.4.19
Use the "View Other Graph" button to help answer the following question. What can be said when comparing the temperature range for the past 10,000 years of graph 2 with the corresponding area on graph 1? Hint: Pay close attention to time scales and the flashing red box on the right side of Graph 1.

A. We are in a warm period of Earth's history.
B. The past 10,000 years is warm compared to the rest of Earth's history.
C. The cool period we're in now is warm compared to the rest of Earth's history.
D. The past 10,000 years was still cool compared to the rest of Earth's history.




4.4.20

Even though we are in one of the warmest periods over the past 400,000 years, over the course of Earth's history, we are still in one of the cooler periods of time. This indicates that Earth has the capacity to warm a great deal more.

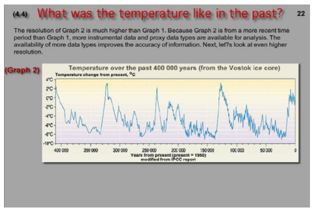



4.4.21

Is the resolution of Graph 2 higher or lower when compared to Graph 1? Click on the "View Other Graph" button to see the first graph again.

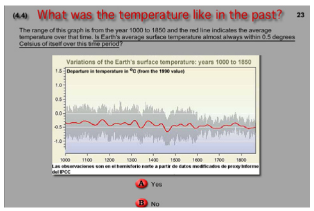
A. Graph 2 has higher resolution than Graph 1.

B. Graph 2 has lower resolution than Graph 1.




4.4.22

The resolution of Graph 2 is much higher than Graph 1. Because Graph 2 is from a more recent time period than Graph 1, more instrumental data and proxy data types are available for analysis. The availability of more data types improves the accuracy of information. Next, let's look at even higher resolution.

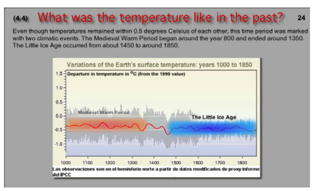



4.4.23

The range of this graph is from the year 1000 to 1850 and the red line indicates the departure in temperature in °C (from the 1990 value). Is Earth's average surface temperature almost always within 0.5 degrees Celsius of itself over this time period?

A. Yes

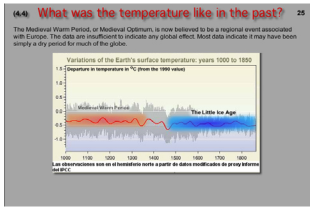
B. No



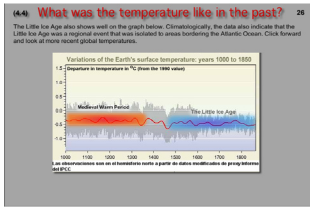

4.4.24

Even though temperatures remained within 0.5 degrees Celsius of each other, this time period was marked with two climatic events. The Medieval Warm Period began around the year 800 and ended around 1350. The Little Ice Age, also in the Northern Hemisphere, occurred from about 1450 to around 1850.

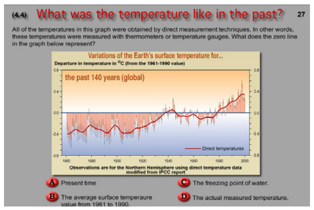
# Notes




4.4.25
The Medieval Warm Period, or Medieval Optimum, is now believed to be a regional event associated with Europe. The data are insufficient to indicate any global effect. Most data indicate it may have been simply a dry period for much of the globe.

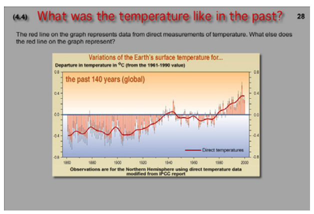



4.4.26
The Little Ice Age also shows well on the graph below. Climatologically, the data also indicate that the Little Ice Age was a regional event that was isolated to areas bordering the Atlantic Ocean. Click forward to look at more recent global temperatures.



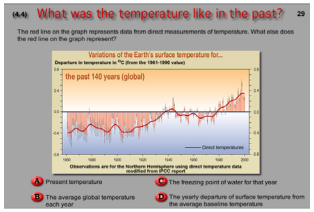

4.4.27
All of the temperatures in this graph were obtained by direct measurement techniques. In other words, these temperatures were measured with thermometers or temperature gauges. What does the zero line in the graph below represent?

A. Present time
B. The average surface temperature value from 1961 to 1990
C. The freezing point of water
D. The actual measured temperature




4.4.28
The gray zero line is the average of the surface temperature around the world from 1961 to 1990. It is used as a baseline to compare all temperature departures.

## Notes




4.4.29

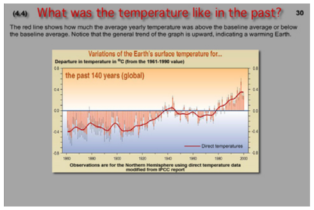
The red line on the graph represents data from direct measurements of temperature. What else does the red line on the graph represent?

A. Present temperature

B. The average global surface temperature each year

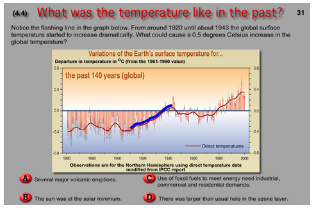
C. The freezing point of water for that year

D. The yearly departure of surface temperature from the average baseline temperature




4.4.30

The red line shows how much the average yearly temperature was above the baseline average or below the baseline average. Notice that the general trend of the graph is upward, indicating a warming Earth.




4.4.31

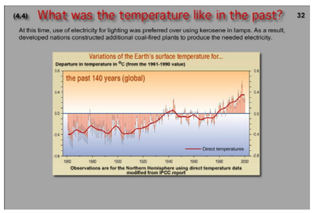
Notice the flashing line in the graph below. From around 1920 until about 1943, the global surface temperature started to increase dramatically. What could cause a 0.5 °C increase in the global temperature?

A. Several major volcanic eruptions

B. The Sun was at a solar minimum.

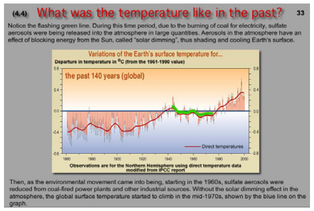
C. Use of fossil fuels to meet energy needs: industrial, commercial, and residential demands

D. There was larger than usual hole in the ozone layer.




4.4.32

At this time, use of electricity for lighting was preferred over using kerosene in lamps. As a result, developed nations constructed additional coal-fired power plants to produce the needed electricity.




4.4.33

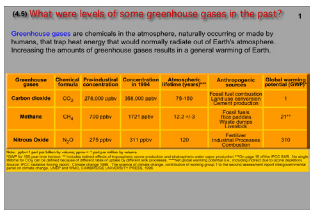
Notice the flashing green line. During this time period, due to the burning of coal for electricity, sulfate aerosols were being released into the atmosphere in large quantities. Aerosols in the atmosphere have an effect of blocking energy from the Sun, called "solar dimming", thus shading and cooling Earth's surface.
Then, as the environmental movement came into being, starting in the 1960s, sulfate aerosols were reduced from coal-fired power plants and other industrial sources. Without the solar dimming effect in the atmosphere, the global surface temperature started to climb in the mid-1970s, shown by the blue line on the graph.


4.4.34

Summary

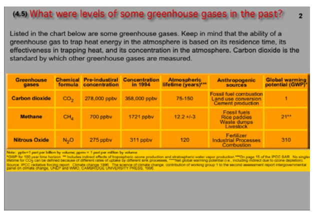
·Using both direct measurements from the past 100+ years and proxy data from earlier time periods, scientists have learned that the temperature of Earth has fluctuated several degrees.
·Many of these large temperature swings led to mass extinctions.
·The past 5 million years represent one of Earth's cooler times.
·Although we are currently in a cool period (historically), the temperature of Earth is now rising.
·Earth's temperature began to rise in the mid-1800s, occurring at the same time as the Industrial Revolution.
·In the mid-1900s, Earth's temperature started to rise at a new rate.

## 4.5 What were levels of some greenhouse gases in the past?




4.5.1

Greenhouse gases are chemicals in the atmosphere, whether naturally-occurring or made by humans, that trap heat energy that would normally radiate out of Earth's atmosphere. Increasing the amounts of greenhouse gases results in a general warming of Earth.

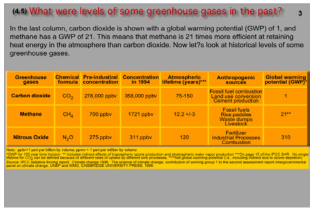



4.5.2

Information about some greenhouse gases is provided below. Keep in mind that the ability of a greenhouse gas to trap heat energy in the atmosphere is based on its residence time, its effectiveness in trapping heat, and its concentration in the atmosphere. Carbon dioxide is the standard by which other greenhouse gases are measured.

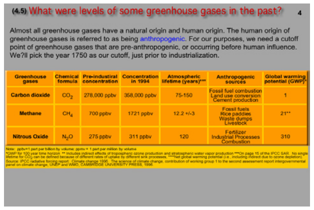
## Notes

# Notes



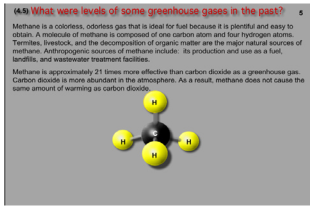

4.5.3

In the last column, carbon dioxide is shown with a global warming potential (GWP) of 1, and methane has a GWP of 21. This means that methane is 21 times more efficient at retaining heat energy in the atmosphere than carbon dioxide. Now let's look at historical levels of some greenhouse gases.




4.5.4

Almost all greenhouse gases have a natural origin and human origin. The human origin of greenhouse gases is referred to as being anthropogenic. For our purposes, we need a cutoff point of greenhouse gases that are pre-anthropogenic, or occurring before human influence. We'll pick the year 1750 as our cutoff, just prior to industrialization.

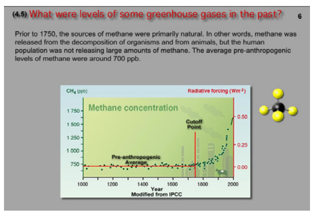



4.5.5

Methane

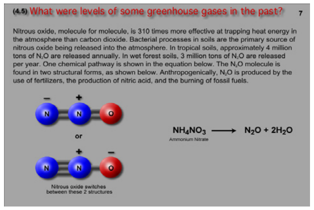
Methane is a colorless, odorless gas that is ideal for fuel because it is plentiful and easy to obtain. A molecule of methane is composed of one carbon atom and four hydrogen atoms. Termites, livestock, and the decomposition of organic matter are the major natural sources of methane. Anthropogenic sources of methane include: its production and use as a fuel, rice paddies, landfills, and wastewater treatment facilities.

Methane is approximately 21 times more effective than carbon dioxide as a greenhouse gas. But carbon dioxide is more abundant in the atmosphere. As a result, methane does not cause the same amount of warming as carbon dioxide.




4.5.6

Prior to 1750, the sources of methane were primarily natural. In other words, methane was released from the decomposition of organic matter and from animals, but the human population was not releasing large amounts of methane. The average pre-anthropogenic levels of methane were around 700 ppb.

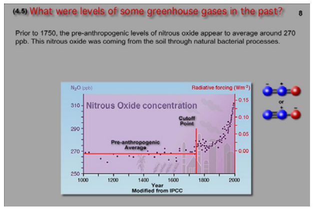



4.5.7

Nitrous oxide

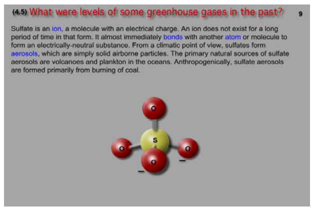
Nitrous oxide, molecule for molecule, is 310 times more effective at trapping heat energy in the atmosphere than carbon dioxide. Bacterial processes in soils are the primary source of nitrous oxide being released into the atmosphere. Approximately 4 million tons of $N_2O$ are released annually from tropical soils. Another 3 million tons of $N_2O$ are released per year from wet forest soils.

One chemical pathway is shown in the equation below. The $N_2O$ molecule is found in two structural forms, as shown below. Anthropogenically, $N_2O$ is produced by the use of fertilizers, the production of nitric acid, and the burning of fossil fuels.




4.5.8

Prior to 1750, the pre-anthropogenic levels of nitrous oxide were around 270 ppb. This nitrous oxide was coming from the soil through natural bacterial processes.

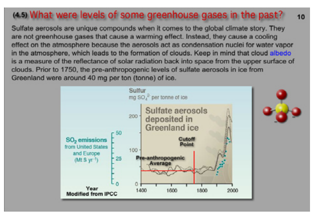



4.5.9

Sulfate aerosols

Sulfate is an ion, an atom or molecule with an electrical charge. An ion does not exist for a long period of time in that form. It almost immediately bonds with another atom or molecule to form an electrically-neutral substance.

From a climatic point of view, sulfates form aerosols, which are simply solid airborne particles. The primary natural sources of sulfate aerosols are volcanoes and plankton in the oceans. Anthropogenically, sulfate aerosols are added primarily from burning of coal.




4.5.10

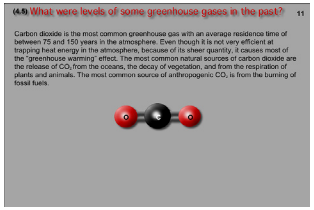
Sulfate aerosols are unique compounds when it comes to the global climate story. They are not greenhouse gases that cause a warming effect. Instead, they cause a cooling effect on the atmosphere because the aerosols act as condensation nuclei for water vapor in the atmosphere, which leads to the formation of clouds. Keep in mind that cloud albedo is a measure of

# Notes

## Notes

the reflectance of solar radiation back into space from the upper surface of clouds.

Prior to 1750, the pre-anthropogenic levels of sulfate aerosols in ice from Greenland were around 40 mg per tonne (1.1 U.S. tons) of ice.

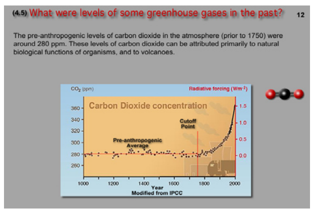



4.5.11

Carbon dioxide

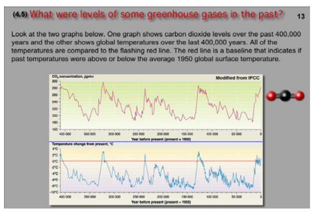
Carbon dioxide is the most common greenhouse gas with an average residence time of between 75 and 150 years in the atmosphere. However, approximately 20% of the $CO_2$ in the air will remain there for up to 1000 years. Even though it is not very efficient at trapping heat energy in the atmosphere, because of its sheer quantity, it causes most of the "greenhouse warming" effect.

The most common natural sources of carbon dioxide are the release of $CO_2$ from the oceans, the decay of organic matter, and from the respiration of plants and animals. The most common source of anthropogenic $CO_2$ is from the burning of fossil fuels.



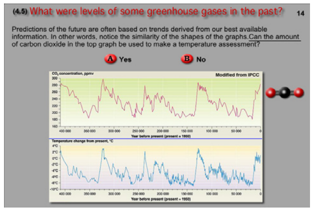

4.5.12

The pre-anthropogenic levels of carbon dioxide in the atmosphere (prior to 1750) were around 280 ppm. These levels of carbon dioxide can be attributed primarily to natural biological functions of organisms, including decay, and to volcanic eruptions.




4.5.13

Look at the two graphs below. One graph shows carbon dioxide levels over the past 400,000 years and the other shows global temperatures over the last 400,000 years. All of the temperatures are compared to the flashing red line. The red line is a baseline that indicates if past temperatures were above or below the present average global surface temperature.

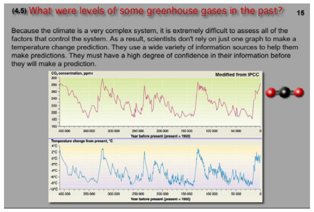



4.5.14

Predictions of the future are often based on trends derived from our best available information. Notice the similarity of the shapes of the graphs. Can the amount of carbon dioxide in the top graph be used to make a temperature assessment?

A. Yes

B. No




4.5.15

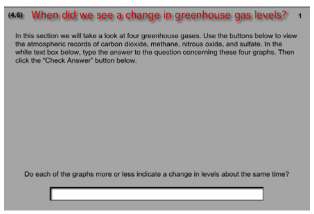
Because the climate is a very complex system, it is extremely difficult to assess all of the factors that control the system. As a result, scientists don't rely on just one graph to make a temperature change prediction. They use a wide variety of information sources to help them make predictions. They must have a high degree of confidence in their information before they will make a prediction.


4.5.16

Summary

- Not all greenhouse gases are equal, gram for gram, at warming Earth.
-The effectiveness of a greenhouse gas at trapping heat in the atmosphere is determined by its abundance, its residence time, and how well it traps heat.
-The top three greenhouse gases are: carbon dioxide, methane, and nitrous oxide.
-Sulfate aerosols released into the atmosphere can cool Earth because they contribute to cloud formation.
-There are both naturally-occurring sources and human-produced sources of greenhouse gases. Human-produced sources are referred to as anthropogenic.
-Levels of greenhouse gases in the atmosphere can be used to roughly determine temperature change trends in the atmosphere.

## 4.6 When did we see a change in greenhouse gas levels?



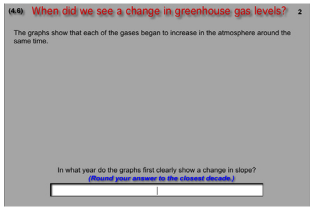

4.6.1

In this section we will take a look at four greenhouse gases. Use the buttons below to view the atmospheric records of carbon dioxide, methane, nitrous oxide, and sulfate aerosols. In the white text box below, type the answer to the question concerning these four graphs. Then click the "Check Answer" button below.

Do each of the graphs more or less indicate a change in levels about the same time?

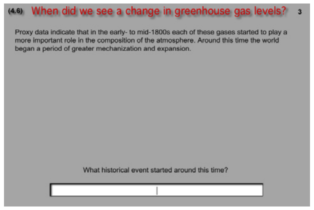
Notes

# Notes

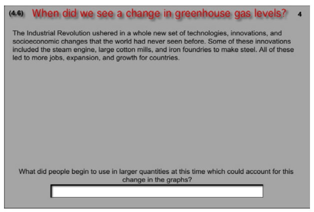



4.6.2
Yes, the graphs show that each of the gases began to increase in the atmosphere <u>around the same time.</u>

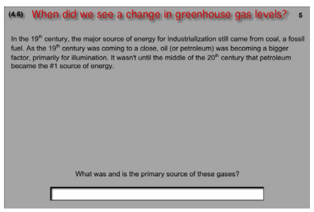
In what decade do you think the graphs first clearly show a change in slope?



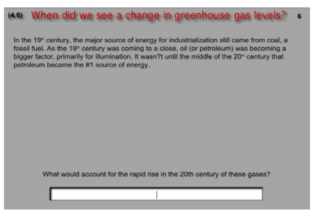

4.6.3
Proxy data indicate that in the early- to mid-1800s each of these gases started to play a more important role in the composition of the atmosphere. Around this time, the world began a period of greater mechanization and expansion.
What historical event started around this time?



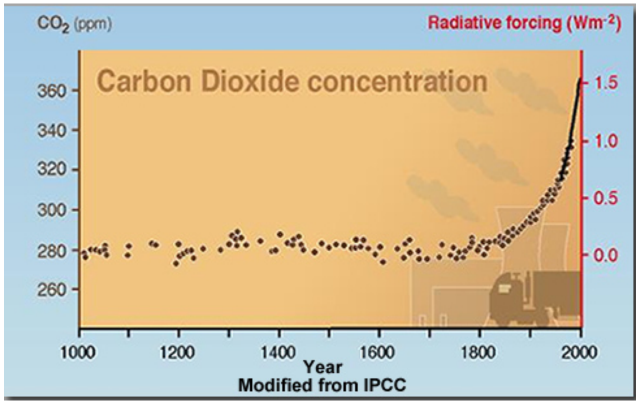

4.6.4
The Industrial Revolution ushered in a whole new set of technologies, innovations, and socioeconomic changes that the world had never seen before. Some of these innovations included the steam engine, large cotton mills, and iron foundries to make steel. All of these led to more jobs, expansion, and growth for countries.
People used considerably more ____ as a result of this tremendous increase in mechanization.



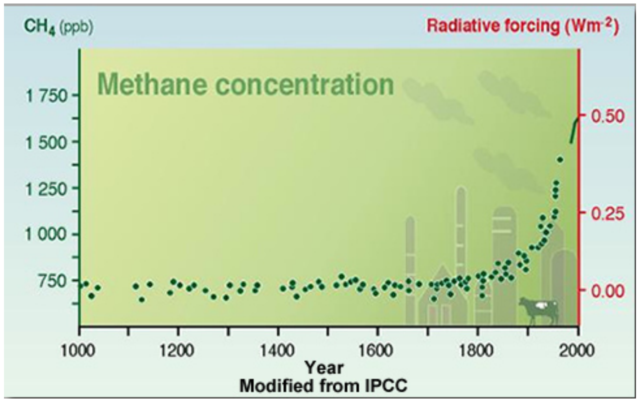

4.6.5
In the 19th century, the major source of energy for industrialization still came from coal, a fossil fuel. As the 19$^{th}$ century was coming to a close, oil (or petroleum) was becoming a bigger factor, primarily for illumination. It wasn't until the middle of the 20$^{th}$ century that petroleum became the primary source of energy.
What was and is the primary source of these gases?



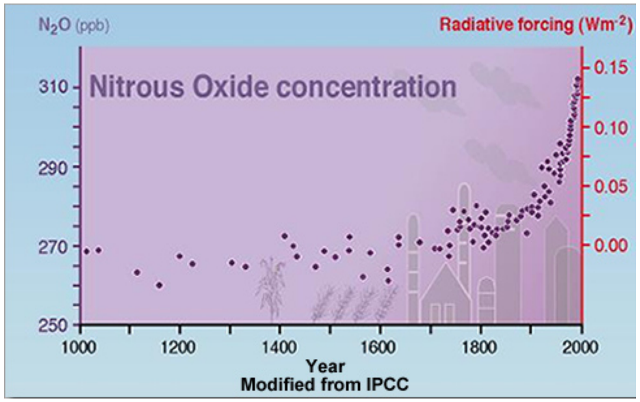

4.6.7
After 1950, the demand for automobiles resulted in increased demand for gasoline, which is made from petroleum--a fossil fuel.



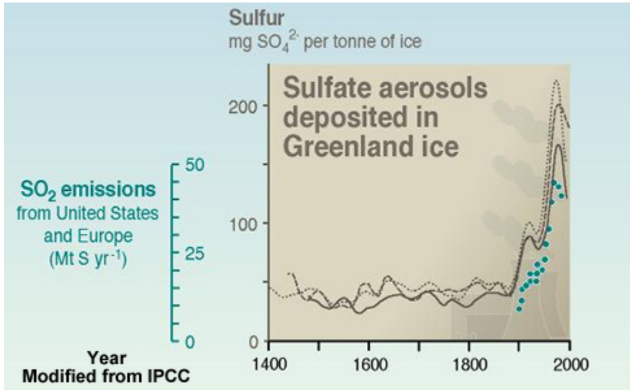
$CO_2$ (ppm)
Radiative forcing (Wm-2)
Carbon Dioxide concentration
360
340
320
300
280
260
1.5
1.0
0.5
0.0
1000
1200
1400
1600
1800
2000
Year
Modified from IPCC

$CH_4$ (ppb)
Radiative forcing (Wm-2)
Methane concentration
1 750
1 500
1 250
1 000
750
0.50
0.25
0.00
1000
1200
1400
1600
1800
2000
Year
Modified from IPCC

$N_2O$ (ppb)
Radiative forcing (Wm-2)
Nitrous Oxide concentration
310
290
270
250
0.15
0.10
0.05
0.00
1000
1200
1400
1600
1800
2000
Year
Modified from IPCC

Sulfur
mg $SO_4^{2-}$ per tonne of ice
Sulfate aerosols deposited in Greenland ice
200
100
0
$SO_2$ emissions
from United States and Europe
(Mt S yr-1)
50
25
0
1400
1600
1800
2000
Year
Modified from IPCC

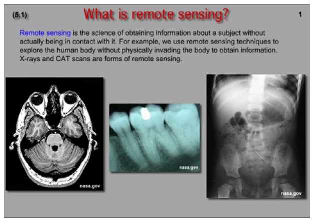

Notes

# Remote Sensing

What is remote sensing?

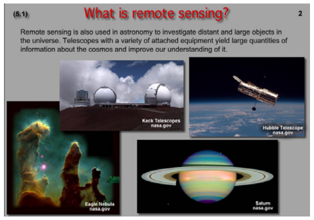
## Notes

## 5.1



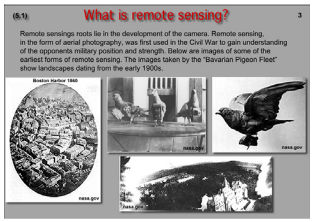

5.1.1

Remote sensing is the science of obtaining information about a subject without actually being in contact with it. For example, we use remote sensing techniques to explore the human body without physically invading the body to obtain information. X-rays and CAT scans are forms of remote sensing.



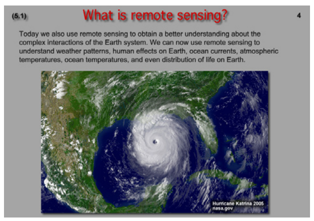

5.1.2

Remote sensing is also used in astronomy to investigate distant and large objects in the universe. Telescopes with a variety of attached equipment yield large quantities of information about the cosmos and improve our understanding of it.




5.1.3

Remote sensing's roots lie in the development of the camera. Remote sensing, in the form of aerial photography, was first used in the U.S. Civil War to gain understanding of the opponent's military position and strength. Below are images of some of the earliest forms of remote sensing. The images taken by the "Bavarian Pigeon Fleet" show landscapes dating from the early 1900s.



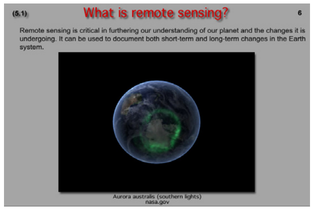

5.1.4

Today, we also use remote sensing to obtain a better understanding about the complex interactions of the Earth system. We can now use remote sensing to understand weather patterns, human effects on Earth, ocean currents, atmospheric temperatures, ocean temperatures, and even distribution of life on Earth.


5.1.5

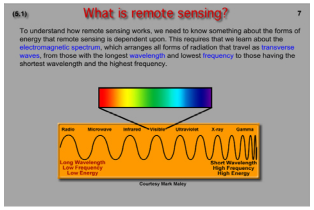
Click on the play button (triangle in the lower left) to gain a better understanding of the techniques used in remote sensing today. (While watching this video, keep in mind that not all objects are necessarily in scale with each other.)

## Notes



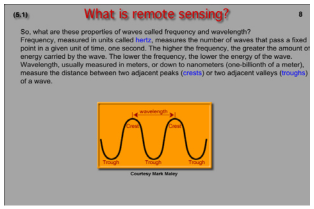

5.1.6

Remote sensing is critical in furthering our understanding of our planet and the changes it is undergoing. It can be used to document both short-term and long-term changes in the Earth system.




5.1.7

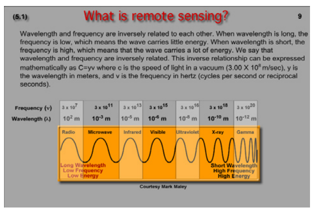
To understand how remote sensing works, we need to know something about the forms of energy that remote sensing is dependent upon. This requires that we learn about the electromagnetic spectrum, which arranges all forms of radiation that travel as transverse waves, from those with the longest wavelength and lowest frequency to those having the shortest wavelength and the highest frequency.




5.1.8

So, what are these properties of waves called frequency and wavelength? Frequency, measured in units called hertz, measures the number of waves that pass a fixed point in a given unit of time, one second. The higher the frequency, the greater the amount of energy carried by the wave. The lower the frequency, the lower the energy of the wave.

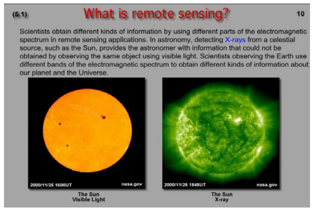
Wavelength, usually measured in meters, or down to nanometers (one-billionth of a meter), measure the distance between two adjacent peaks (crests) or two adjacent valleys (troughs) of a wave.



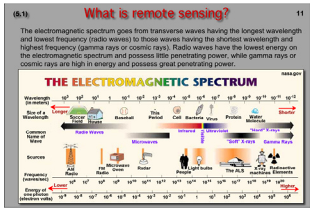

5.1.9

Wavelength and frequency are inversely related to each other. When wavelength is long, the frequency is low, which means the wave carries little energy. When wavelength is short, the frequency is high, which means that the wave carries a lot of energy.

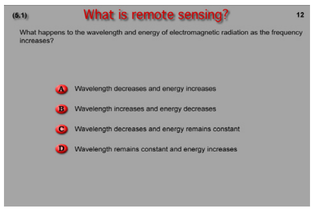
This inverse relationship can be expressed mathematically as $C = \lambda v$ where C is the speed of light in a vacuum ($3.00 \times 10^8$ m/sec), $\lambda$ is the wavelength in meters, and v is the frequency in hertz (cycles per second or reciprocal seconds).



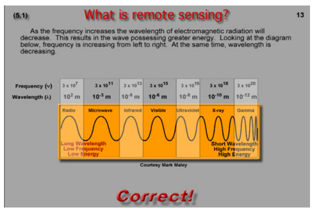

5.1.10
Scientists obtain different kinds of information by using different parts of the electromagnetic spectrum in remote sensing applications. In astronomy, detecting X-rays from a celestial source, such as the Sun, provides the astronomer with information that could not be obtained by observing the same object using visible light. Scientists who observe Earth use different bands of the electromagnetic spectrum to obtain different kinds of information about our planet and the Universe.




5.1.11
The electromagnetic spectrum goes from transverse waves having the longest wavelength and lowest frequency (radio waves) to those waves having the shortest wavelength and highest frequency (gamma rays or cosmic rays). Radio waves have the lowest energy on the electromagnetic spectrum and possess little penetrating power, while gamma rays or cosmic rays are high in energy and possess great penetrating power.




5.1.12
What happens to the wavelength and energy of electromagnetic radiation as the frequency increases?
A) Wavelength decreases and energy increases.
B) Wavelength increases and energy decreases.
C) Wavelength decreases and energy remains constant.
D) Wavelength remains constant and energy increases.




5.1.13
Correct!
As the frequency increases, the wavelength of electromagnetic radiation will decrease. This results in the wave possessing greater energy. Looking at the diagram below, frequency increases from left to right. At the same time, wavelength decreases.

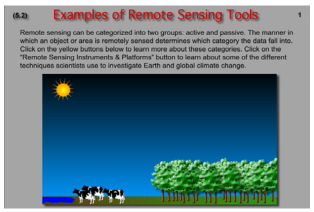
## Notes


5.1.15
Ground truthing helps to ensure that data collected by a satellite are accurate and reliable. Since a satellite views such a large area at one time, it is important for scientists to visit a site that a satellite images. This often can lead scientists to unique places.

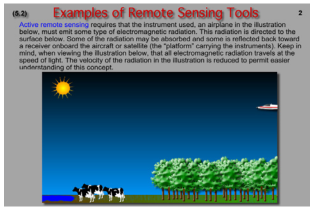

5.1.16
Summary:
•Remote sensing allows us to get a global perspective on Planet Earth, and how the Earth is changing.
•It depends upon transverse waves that travel at a speed of light, $3.00 \times 10^8$ m/sec.
•All forms of radiation that travel at the speed of light can be characterized by specific wavelengths and frequencies.
•In the diagram of the electromagnetic spectrum, types of radiation are shown from left to right along a continuum from longest wavelength and lowest frequency (radio waves) to shortest wavelength and highest frequency (gamma radiation).
•The higher the frequency of a wave, the higher the energy. Likewise, the lower the frequency of the wave, the lower the energy.

## Examples of Remote Sensing Tools

## 5.2

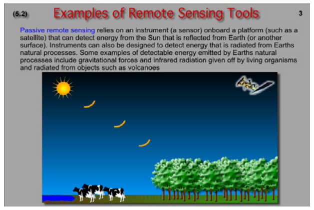



5.2.1
Remote sensing can be categorized into two types: active and passive. The manner in which an object or area is remotely sensed determines which category the data fall into. Click on the yellow buttons below to learn more about these categories. Click on the "Remote Sensing Instruments & Platforms" button to learn about some of the different techniques scientists use to investigate Earth and global climate change.



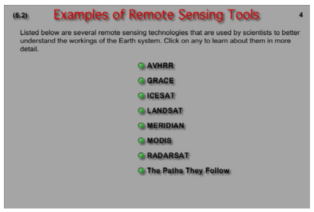

5.2.2

Active remote sensing requires that the device used (onboard an airplane in the illustration below) must transmit some type of electromagnetic radiation. This radiation is directed to the surface below. Some of the radiation may be absorbed and some is reflected back toward a receiver (or sensor) onboard the aircraft or satellite (the "platform" carrying the instruments). Keep in mind, when viewing the illustration below, that all electromagnetic radiation travels at the speed of light. The velocity of the radiation in the illustration is reduced to permit easier understanding of this concept.



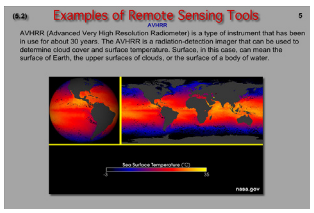

5.2.3

Passive remote sensing relies on an instrument (a sensor) onboard a platform (such as a satellite) that can detect energy that is naturally reflected or emitted from Earth (or another surface). Instruments can also be designed to detect energy and forces that are generated on Earth. Some examples of detectable energy emitted by Earth's natural processes include gravitational forces and infrared radiation given off by living organisms and radiated from objects such as volcanoes.




5.2.4

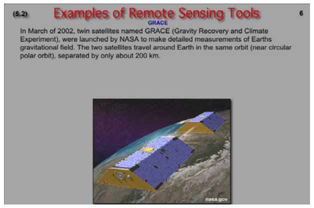
Listed below are several platforms (objects such as ships, planes, and satellites) that carry instruments (such as cameras, sounders and radiometers) used by scientists to better understand the workings of the Earth system. Click on any to learn about them in more detail.



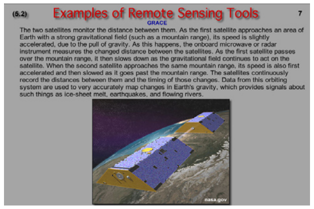

5.2.5

AVHRR (Advanced Very High Resolution Radiometer) is a type of instrument that has been in use for about 30 years. The AVHRR is a radiation-detection imager that can be used to determine cloud cover and surface temperature. Surface, in this case, can mean the surface of Earth, the upper surfaces of clouds, or the surface of a body of water.

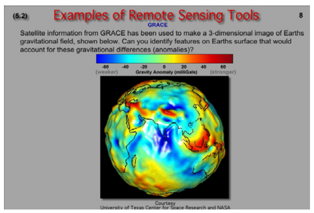
# Notes



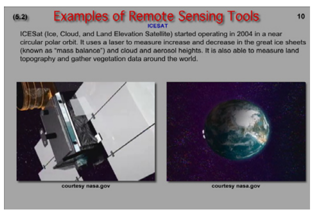

5.2.6
In March of 2002, twin satellites named GRACE (Gravity Recovery and Climate Experiment), were launched by NASA to make detailed measurements of Earth's gravitational field. The two satellites travel around Earth in the same orbit (near-circular polar orbit), separated by only about 200 km.




5.2.7
The two satellites monitor the distance between them. As the first satellite approaches an area of Earth with a strong gravitational field (such as a mountain range), its speed is slightly accelerated, due to the pull of gravity. As this happens, the onboard microwave or radar instrument measures the changed distance between the satellites. As the first satellite passes over the mountain range, it slows as the gravitational field continues to act on the satellite. When the second satellite approaches the same mountain range, its speed is also first accelerated and then slowed as it goes past the mountain range. The satellites continuously record the distances between them and the timing of those changes. Data from this orbiting system are used to very accurately map changes in Earth's gravity, which provides signals about such things as ice-sheet melt, earthquakes, and flowing rivers.

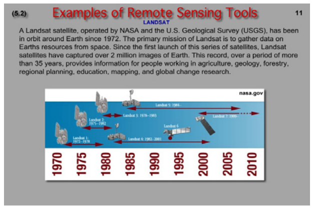



5.2.8
Satellite information from GRACE has been used to make a 3-dimensional image of Earth's gravitational field, shown below. Can you identify features on Earth's surface that would account for these gravitational differences (anomalies)?



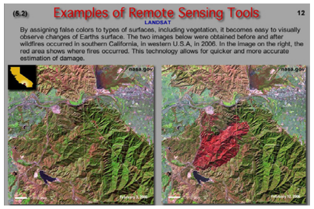

5.2.10
ICESat (Ice, Cloud, and Land Elevation Satellite) started operating in 2004 in a near-circular polar orbit. It uses a laser to measure increases and decreases in the great ice sheets (known as "mass balance") as well as cloud and aerosol heights. It is also able to measure land topography and gather vegetation data around the world.

## Notes



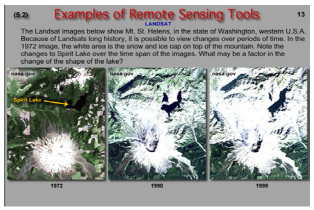

5.2.11

A Landsat satellite, operated by NASA and the U.S. Geological Survey (USGS), has been in orbit around Earth since 1972. The primary mission of Landsat is to gather data on Earth's resources from space. Since the first launch of this series of satellites, Landsat satellites have captured over 2 million images of Earth. This record, over a period of more than 35 years, provides information for people working in agriculture, geology, forestry, regional planning, education, mapping, and global change research.



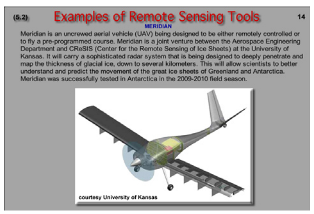

5.2.12

By assigning false colors to types of surfaces, including vegetation, it becomes easy to visually observe changes of Earth's surface. The two images below were obtained before and after wildfires occurred in southern California, in western U.S.A, in 2006. In the image on the right, the red area shows where fires occurred. This technology allows for quicker and more accurate estimation of damage.




5.2.13

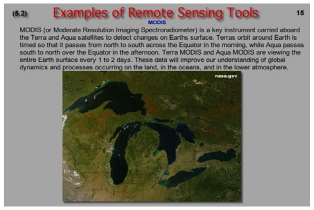
The Landsat images below show Mt. St. Helens, in the state of Washington, western U.S.A. Because of Landsat's long history, it is possible to view changes over periods of time. In the 1972 image, the white area is the snow and ice cap on top of the mountain. Note the changes to Spirit Lake over the time span of the images. What may be a factor in the change of the shape of the lake?



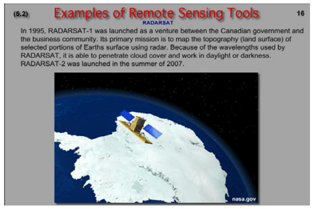

5.2.14

Meridian is an uncrewed aerial vehicle (UAV) that is being designed to be either remotely controlled or to fly a pre-programmed course. Meridian is a joint venture between the Aerospace Engineering Department and CReSIS (Center for the Remote Sensing of Ice Sheets) at the University of Kansas. It will carry a sophisticated radar system that is being designed to deeply penetrate and map the thickness of glacial ice, down to several kilometers. This will allow scientists to better understand and predict the movement of the great ice sheets of Greenland and Antarctica. Meridian was successfully tested in Antarctica in the 2009-2010 field season.

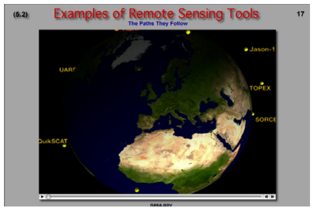
# Notes




5.2.15
MODIS (or Moderate Resolution Imaging Spectroradiometer) is a key instrument for detecting chages on Earth's surface that is carried aboard both the Terra and Aqua satellites. Terra's orbit around Earth is timed so that it passes from north to south across the Equator in the morning, while Aqua passes south to north over the Equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth surface every 1 to 2 days. These data will improve our understanding of global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere.




5.2.16
In 1995, RADARSAT-1 was launched as a venture between the Canadian government and the business community. Its primary mission is to use radar to map the shape (topography) of selected areas of Earth's surface. Because of the wavelengths used by RADARSAT, it is able to penetrate cloud cover and work in daylight or darkness. RADARSAT-2 was launched in the summer of 2007.



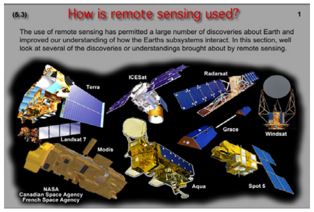

5.2.17
The Paths They Follow


5.2.18
Summary
-Active remote sensing requires an instrument that transmits a signal that is reflected from an object or surface being studied, back to the sensor in the instrument panel.
-In passive remote sensing, the sensing instrument detects energy that is naturally released or reflected.
-Groundtruthing is a method in which scientists go to the location of a remotely sensed area to ensure the information, or interpretation of the information, from remote sensors is accurate.
-Scientists use many different remote sensing instruments.
-AVHRR uses a radar signal to map surface temperatures around Earth.
-GRACE is a pair of satellites that work together to map gravitational changes on Earth.
-ICESat uses a laser beam to measure ice sheet mass, clouds, and aerosols.

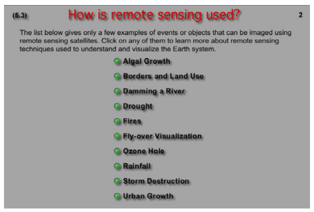
## Notes

-Landsat uses reflected solar energy to map the resources of Earth.
-Meridian is a remotely controlled (or pre-programmed) uncrewed aircraft being designed to use radar to map the ice sheets of Greenland and Antarctica.
-MODIS is a system of instruments that provide almost real-time images of Earth's surface.
-RADARSAT uses radar, which can penetrate clouds and does not require light, to map the shape (topography) of Earth.

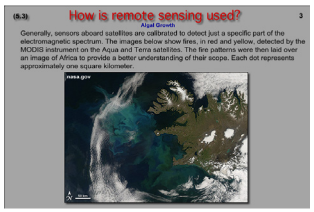
## 5.3 How is Remote Sensing Used?



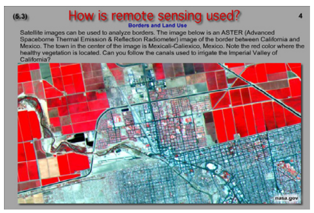

5.3.1
The use of remote sensing has permitted a large number of discoveries about Earth and improved our understanding of how the Earth's subsystems interact. In this section, we'll look at several of the discoveries or understandings brought about by remote sensing.



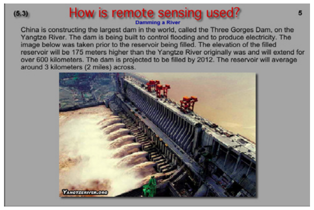

5.3.2
The list below gives only a few examples of events or objects that can be imaged using remote sensing satellites. Click on any of them to learn more about remote sensing techniques used to understand and visualize the Earth system.




5.3.3
Algal Growth
The image below was captured by MODIS on the Aqua satellite. It shows a bloom of phytoplankton in the North Atlantic Ocean around Iceland. The growth of these tiny organisms is the result of abundant nutrients that built up over the winter months. With the advent of long daylight hours in the summer months, the phytoplankton start to reproduce at prodigious rates.



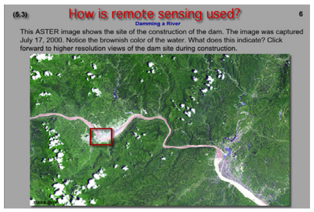

5.3.4
Borders and Land Use
Satellite images can be used to analyze borders. The image below is an ASTER (Advanced Spaceborne Thermal Emission & Reflection Radiometer) image of the border between California and Mexico. The town in the center of the image is Mexicali-Caliexico, Mexico. Note the red color where the healthy vegetation is located. Can you follow the canals used to irrigate the Imperial Valley of California?




5.3.5

Damming a River

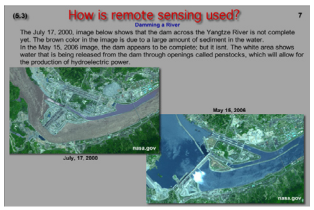
China is constructing the largest dam in the world, called the Three Gorges Dam, on the Yangtze River. The dam is being built to control flooding and to produce electricity. The image below was taken prior to the reservoir being filled. The elevation of the filled reservoir will be 175 meters higher than the Yangtze River originally was and will extend for over 600 kilometers. The dam is projected to be filled by 2012. The reservoir will average around 3 kilometers (2 miles) across.




5.3.6

Damming a River

This ASTER image shows the site of the construction of the dam. The image was captured July 17, 2000. Notice the brownish color of the water. What does this indicate? Click forward to see higher resolution views of the dam site during construction.

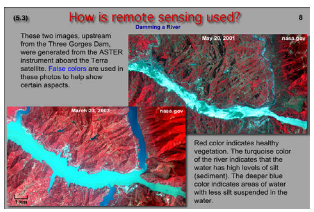



5.3.7

Damming a River

The July 17, 2000, image below shows that the dam across the Yangtze River is not complete yet. The brown color in the image is due to a large amount of sediment in the water.

In the May 15, 2006 image, the dam appears to be complete; but it isn't. The white area shows water that is being released from the dam through openings called penstocks, which will allow for the production of hydroelectric power.

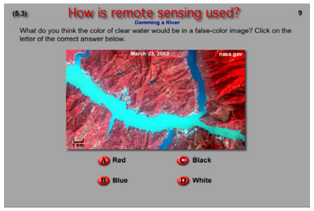



5.3.8

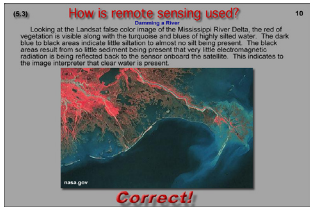
Damming a River

These two images, upstream from the Three Gorges Dam, were generated from the ASTER instrument aboard the Terra satellite. False colors are used in these photos to help show certain aspects.

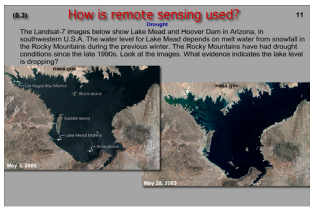
Red color indicates healthy vegetation. The turquoise color of the river indicates that the water has high levels of silt (sediment). The deeper blue color indicates areas of water with less silt suspended in the water.



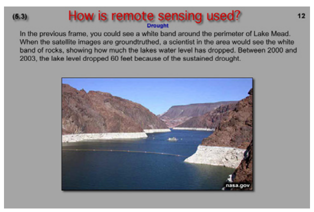

5.3.9
Damming a River
What do you think the color of clear water would be in a false-color image? Click on the letter of the correct answer below.
A) Red
B) Blue
C) Black
D) White




5.3.10
Damming a River
Looking at the false color image of the Mississippi River delta, the red color (vegetation) is visible along with the turquoise and blues of highly-silted water. The dark blue to black areas indicate little siltation to almost no silt being present. The black areas result from so little sediment being present that very little electromagnetic radiation is being reflected back to the sensor onboard the satellite. This indicates to image interpreter that clear water is present.

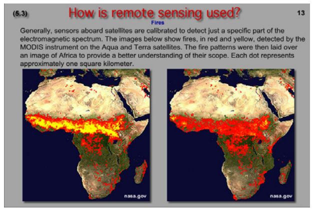



5.3.11
Drought
The Landsat-7 images below show Lake Mead and Hoover Dam in Arizona, in southwestern U.S.A. The water level for Lake Mead depends on melt water from snowfall in the Rocky Mountains during the previous winter. The Rocky Mountains have had drought conditions since the late 1990s. Look at the images. What evidence indicates the lake level is dropping?




5.3.12
Drought
In the previous frame, you could see a white band around the perimeter of Lake Mead. When the satellite images are groundtruthed, a scientist in the area would see the white band of rocks, showing how much the lake's water level has dropped. Between 2000 and 2003, the lake level dropped 60 feet because of the sustained drought.

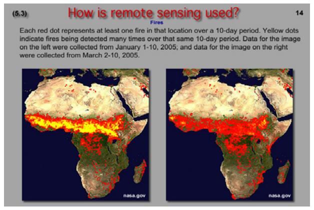
# Notes




5.3.13

Fires

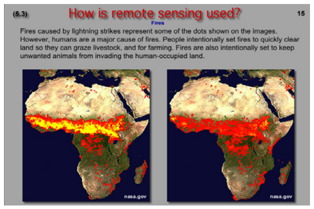
Generally, sensors aboard satellites are calibrated to detect just a specific part of the electromagnetic spectrum. The images below show fires, in red and yellow, detected by the MODIS instrument on the Aqua and Terra satellites. The fire patterns were then laid over an image of Africa to provide a better understanding of their scope. Each dot represents approximately one square kilometer.




5.3.14

Fires

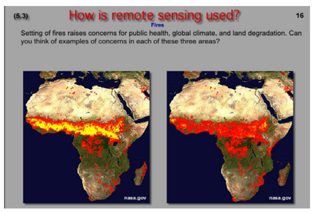
Each red dot represents at least one fire in that location over a 10-day period. Yellow dots indicate fires being detected many times over that same 10-day period. Data for the image on the left were collected from January 1-10, 2005; and data for the image on the right were collected from March 2-10, 2005.




5.3.15

Fires

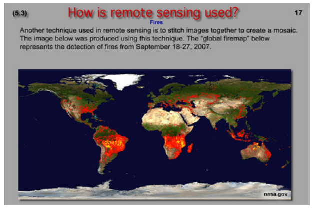
Fires caused by lightning strikes represent some of the dots shown on the images. However, humans are a major cause of fires. People intentionally set fires to quickly clear land so they can graze livestock, and for farming. Fires are also intentionally set to keep unwanted animals from invading the human-occupied land.




5.3.16

Fires

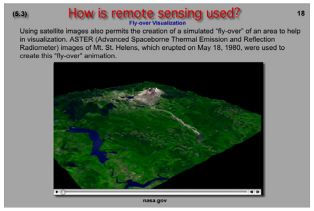
Setting of fires raises concerns for public health, global climate, and land degradation. Can you think of examples of concerns in each of these three areas?




5.3.17

Fires

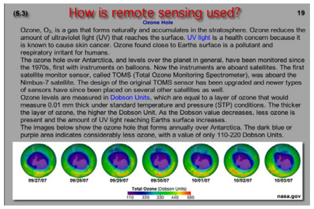
Another technique used in remote sensing is to stitch images together to create a mosaic. The image below was produced using this technique. The "global firemap" below represents the detection of fires from September 18-27, 2007.




5.3.18

Fly-over Visualization

Using satellite images also permits the creation of a simulated "fly-over" of an area to help in visualization. ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) images of Mt. St. Helens, which erupted on May 18, 1980, were used to create this "fly-over" animation.




5.3.19

Ozone Hole

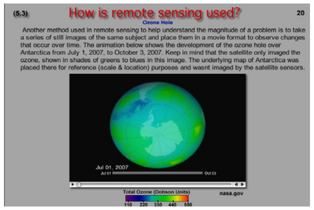
Ozone, $O_3$, is a gas that forms naturally and accumulates in the stratosphere. Ozone reduces the amount of ultraviolet light (UV) that reaches Earth's surface. UV light is a health concern because it is known to cause skin cancer. Ozone found close to Earth's surface is a pollutant and respiratory irritant for humans.

The ozone hole over Antarctica, and levels over the planet in general, have been monitored since the 1970s, first with instruments on balloons. Now the instruments are onboard satellites. The first satellite monitor sensor, called TOMS (Total Ozone Monitoring Spectrometer), was onboard the Nimbus-7 satellite. The design of the original TOMS sensor has been upgraded and newer types of sensors have since been placed on several other satellites as well.

Ozone levels are measured in Dobson Units, which are equal to a layer of ozone that would measure 0.01 mm thick under standard temperature and pressure (STP) conditions. The thicker the layer of ozone, the higher the Dobson Unit. As the Dobson value decreases, less ozone is present and the amount of UV light reaching Earth's surface increases.

The images below show the ozone hole that forms annually over Antarctica. The dark blue or purple area indicates low levels of ozone, with a value of only 110-220 Dobson Units.

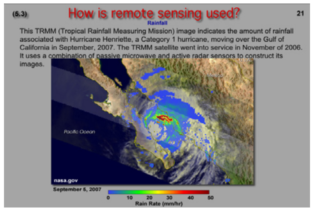
# Notes




5.3.20

Ozone Hole

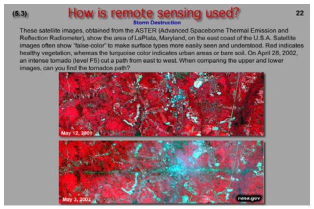
Another method used in remote sensing to help understand the magnitude of a problem is to take a series of still images of the same subject and place them in a movie format to observe changes that occur over time. The animation below shows the development of the ozone hole over Antarctica from July 1, 2007, to October 3, 2007. Keep in mind that the satellite only imaged the ozone, shown in shades of greens to blues in this image. The underlying map of Antarctica was placed there for reference (scale & location) purposes, and wasn't imaged by the satellite sensors.




5.3.21

Rainfall

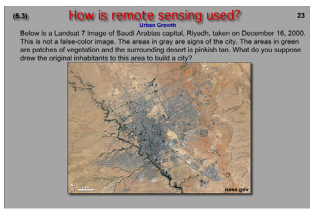
This TRMM (Tropical Rainfall Measuring Mission) image indicates the amount of rainfall associated with Hurricane Henriette, a Category 1 hurricane, as it moved over the Gulf of California in September, 2007. The TRMM satellite went into service in November of 2006. It uses a combination of passive microwave and active radar sensors to construct its images.




5.3.22

Storm Destruction

These satellite images, obtained from the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), show the area of LaPlata, Maryland, on the east coast of the U.S.A. Satellite images often show "false-color" to make surface types more easily seen and understood. Red indicates healthy vegetation, whereas the turquoise color indicates urban areas or bare soil. On April 28, 2002, an intense tornado (level F5) cut a path from east to west. When comparing the upper and lower images, can you find the tornado's path?




5.3.23

Urban Growth

Below is a Landsat 7 image of Saudi Arabia's capital, Riyadh, taken on December 16, 2000. This is not a false-color image. The areas in gray are signs of the city. The areas in green are patches of vegetation and the surrounding desert is pinkish tan. What do you suppose drew the original inhabitants to this area to build a city?

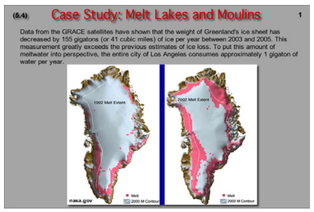
# Notes

Summary

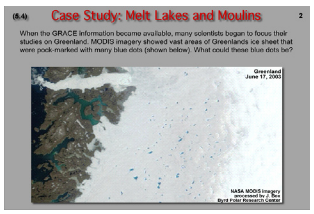
5.3.24
Summary
-Remote sensing is used in a wide variety of ways to help us understand the Earth system.
-False-color imagery can be used to make different surface types more apparent.
-Both living and nonliving things can be detected using satellite remote sensing.
-Computer programs can convert large volumes of remotely-sensed data into a visual format that can be more easily understood.
-Animations can be created using a series of satellite images.
-Many types of remote sensing instruments are used to analyze Earth and space.
-Each remote sensing instrument is designed to detect specific wavelengths.

## Case Study: Melt lakes and moulins

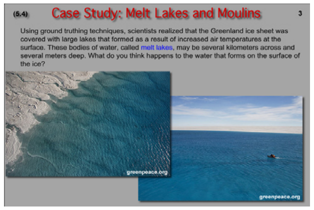
## 5.4



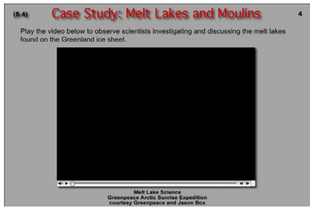

5.4.1
Data from the GRACE satellites have shown that the weight of Greenland's ice sheet has decreased by 155 gigatons (or 41 cubic miles) of ice per year between 2003 and 2005. This measurement greatly exceeds the previous estimates of ice loss. To put this amount of meltwater into perspective, the entire city of Los Angeles, California, consumes approximately 1 gigaton of water per year.



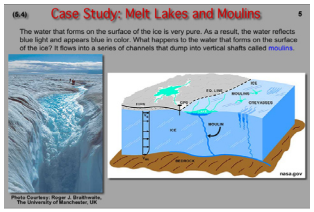

5.4.2
When the GRACE information became available, many scientists began to focus their studies on Greenland. MODIS imagery showed vast areas of Greenland's ice sheet that were pock-marked with many blue dots (shown below). What could these blue dots be?



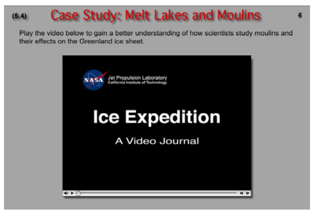

5.4.3
Using ground truthing techniques, scientists realized that the Greenland ice sheet was covered with large lakes that formed as a result of increased air temperatures at the surface. These bodies of water, called melt lakes, may be several kilometers across and several meters deep. What do you think happens to the water that forms on the surface of the ice?



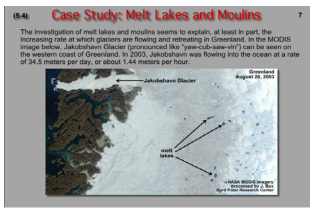

5.4.4
Play the video below to observe scientists investigating and discussing the melt lakes found on the Greenland ice sheet.




5.4.5
The water that forms on the surface of the ice is very pure. As a result, the water reflects blue light and appears blue in color. What happens to the water that forms on the surface of the ice? It flows into a series of channels that dump into vertical shafts called moulins (pronounced like moo-lawns').




5.4.6
Play the video below to gain a better understanding of how scientists study moulins and their effects on the Greenland ice sheet.




5.4.7
The investigation of melt lakes and moulins seems to explain, at least in part, the increasing rate at which glaciers are flowing and retreating in Greenland. In the MODIS image below, Jakobshavn Glacier (pronounced like "yaw'-cub-saw-vin") can be seen on the western coast of Greenland. In 2003, Jakobshavn was flowing into the ocean at a rate of 34.5 meters per day, or about 1.44 meters per hour.

# Notes

Summary

5.4.8

Summary

-Measurements from satellite images have shown that the amount of ice in southern and central Greenland is rapidly decreasing.

-Melt lakes form as water collects in various places on the surface of the ice sheet.

-Moulins are thought to provide a drainage pathway to the base of the glacier, where water can lubricate the boundary between the ice and rock.

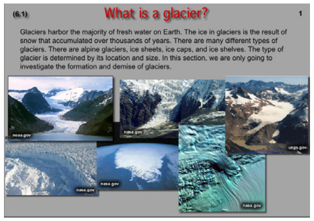
- The lubricated boundary, along with other factors, allows the glacier to flow at alarmingly fast rates into the ocean.

# Glacial Evidence

What is a Glacier?

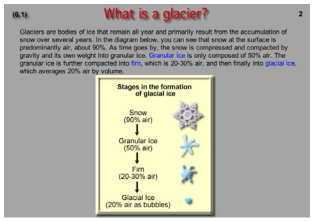
## Notes

## 6.1



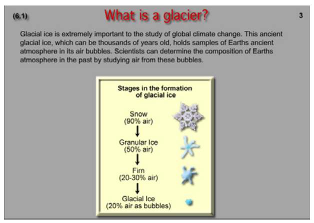

6.1.1

The majority of Earth's freshwater is trapped, as ice, in the polar ice sheets. Ice sheets are the result of snow that accumulated over hundreds of thousands of years. While it takes a very long time to build an ice sheet, new studies suggest that they can disappear (or get smaller) quite quickly. Ice sheets like Greenland and Antarctica are composed of glaciers (that drain ice from the ice sheet interior out to the ocean), ice shelves (glacier ice that extends, and is floating, on top of the ocean), and ice caps (small areas of ice that are separate from the ice sheet as a whole). Types of glaciers are determined by their location, size and temperature. [In this section, we are only going to investigate the formation and demise of glaciers.]




6.1.2

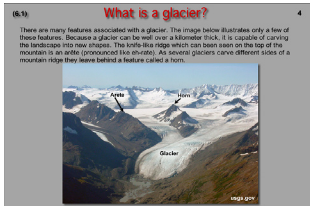
Glaciers are bodies of ice that remain all year and are large enough to flow because of their weight. They result from the accumulation of snow over several years. In the diagram below, you can see that snow at the surface is predominantly air, about 90%. As time goes by, the snow is compressed and compacted by gravity and its own weight into granular (round-shaped) snow. Granular snow is only composed of 50% air. The granular snow is further compacted into firn, which is 20-30% air, and then finally into glacier ice, which averages 20% air by volume.




6.1.3

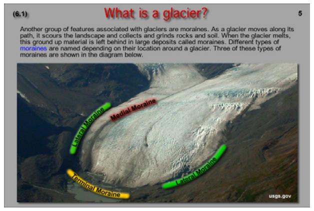
Ice is extremely important to the study of global climate change. Ancient ice, which can be thousands of years old, holds samples of Earth's ancient atmosphere in its air bubbles. Scientists can determine the composition of Earth's atmosphere in the past by studying air from these bubbles.

# Notes




6.1.4

There are many features associated with a glacier. The image below illustrates only a few of these features. Because a glacier can be well over a kilometer thick, its weight is capable of carving the landscape into new shapes, in particular smooth-sided U-shaped valleys. The knife-like ridge which can been seen on the top of the mountain is an arête (pronounced like eh-rate'), and forms from two adjacent glaciers. As several glaciers carve different sides of a mountain ridge, they leave behind a feature called a horn.

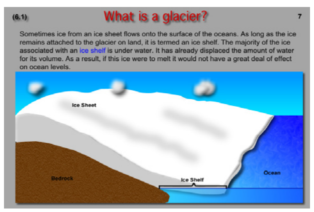



6.1.5

Another group of features associated with glaciers are moraines. As a glacier moves along its path, it scours the landscape and collects and grinds rocks and soil. When the glacier melts, this ground-up material is left behind in large deposits called moraines. Different types of moraines are named depending on their location around a glacier. Three types of moraines are shown in the diagram below.


6.1.6

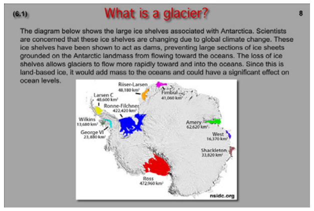
Ice masses around the world can be classified according to their size and location. A very large mass of ice that covers an extensive land mass is referred to as an ice sheet. Ice sheets cover both Antarctica and Greenland, the latter of which is shown below. These sheets of ice are often anchored to bedrock and may be several kilometers thick.



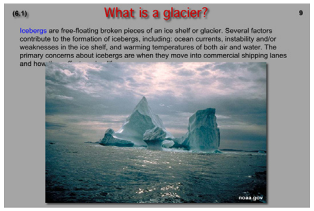

6.1.7

Sometimes ice from an ice sheet flows onto the surface of the oceans. As long as the ice remains attached to the glacier on land, it is termed an ice shelf. The majority of the ice associated with an ice shelf is under water. It has already displaced the amount of water for its volume. As a result, when ice from ice shelves melts, it does not affect sea level.

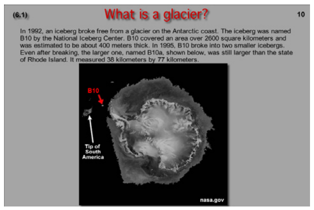
## Notes



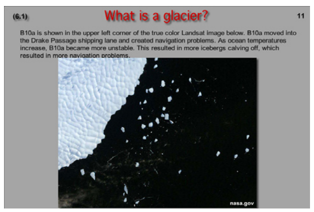

6.1.8
The diagram below shows the large ice shelves around Antarctica. Scientists are concerned that these ice shelves are changing due to global climate change. These ice shelves have been shown to act as dams, preventing large sections of ice sheets grounded on the Antarctic landmass from flowing toward the ocean. The loss of ice shelves allows glaciers to flow more rapidly toward and into the ocean. Since glaciers are land-based ice, they would add mass to the oceans and would have a significant effect on ocean levels.




6.1.9
Icebergs are free-floating broken pieces of an ice shelf or glacier. Several factors contribute to the formation of icebergs, including: ocean currents, instability and/or weaknesses in the ice shelf, and warming temperatures of both air and water. The primary concerns about icebergs are when they move into commercial shipping lanes and how they affect marine life.

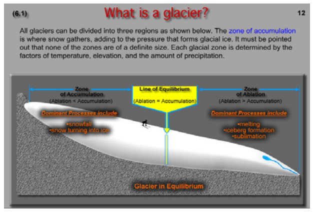



6.1.10
In 1992, an iceberg broke free from a glacier on the Antarctic coast. The iceberg was named B10 by the National Iceberg Center. B10 covered an area over 2600 square kilometers and was estimated to be about 400 meters thick. In 1995, B10 broke into two smaller icebergs. Even after breaking, the larger one, named B10a, shown below, was still larger than the state of Rhode Island. It measured 38 kilometers by 77 kilometers.



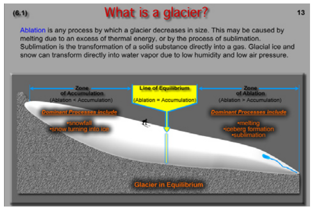

6.1.11
B10a is shown in the upper left corner of the true color Landsat image below. B10a moved into the Drake Passage shipping lane and created navigation problems. As ocean temperatures increase, B10a became unstable. This resulted in more icebergs calving off, which resulted in more navigation problems.

## Notes



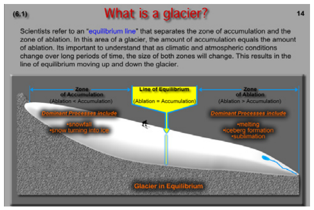

6.1.12

All glaciers can be divided into two zones as shown below. The zone of accumulation is where snow accumulates, whereas the ablation zone is where snow and ice melt. It must be pointed out that none of the zones are of a definite size. Each glacial zone is determined by the factors of temperature, elevation, and the amount of precipitation.



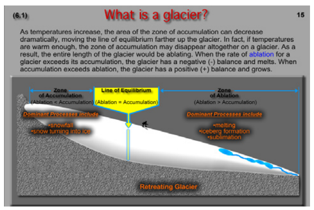

6.1.13

Ablation is any process by which a glacier decreases in size. This may be caused by melting due to an excess of thermal energy, or by the process of sublimation. Sublimation is the transformation of a solid substance directly into a gas. Glacial ice and snow can transform directly into water vapor due to low humidity and low air pressure.




6.1.14

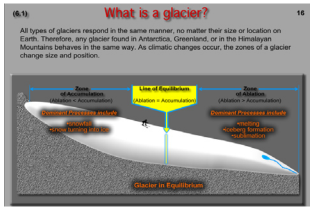
Scientists refer to an "equilibrium line" that separates the zone of accumulation and the zone of ablation. In this area of a glacier, the amount of accumulation equals the amount of ablation. It's important to understand that as climatic and atmospheric conditions change over long periods of time, the size of both zones will change. This results in the line of equilibrium moving up and down the glacier.




6.l.15

As temperatures increase, the area of the zone of accumulation can decrease dramatically, moving the line of equilibrium farther up the glacier. In fact, if temperatures are warm enough, the zone of accumulation may disappear altogether on a glacier. As a result, the entire length of the glacier would be ablating. When the rate of ablation for a glacier exceeds its accumulation, the glacier has a negative (-) balance and loses mass (decreases in size and/or thickness). When accumulation exceeds ablation, the glacier has a positive (+) balance and adds mass, increasing in size and/or thickness.

# Notes



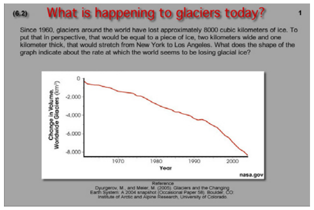

6.1.16
All types of glaciers respond in the same manner, no matter their size or location on Earth. Therefore, any glacier found in Antarctica, Greenland, or in the Himalayan Mountains behaves in the same way. As climatic changes occur, the zones of a glacier change size and position.


6.1.17
Summary
- Glaciers are moving masses of ice that last from season to season. They are a force that can reshape the landscape.
- A glacier forms when snow accumulates over long periods of time and is progressively converted into granular snow, firn, and finally, glacier ice. The amount of air trapped in these different forms also decreases progressively.
- The trapped air in the ice provides scientists with samples of Earth's ancient atmosphere.
- Movement of glaciers has created many recognizable features on Earth's surface, including: U-shaped valleys, moraines, arêtes, and horns.
- Ice masses are defined by their size and location, and include: mountain (alpine) glaciers, ice sheets, ice caps, and ice shelves.
- Ice shelves extend into the ocean from land. They displace water as they move into the ocean, so their melt has little additional effect on sea level.
- Ablation refers to the processes that reduce the size of a glacier, making it appear to retreat or recede. Examples include: melting, calving (breaking off chunks), and sublimation.
- The relative size of the zones of ablation and accumulation determine whether the glacier is advancing (gaining mass) or retreating (losing mass), and is driven by changes in climate.

## Notes

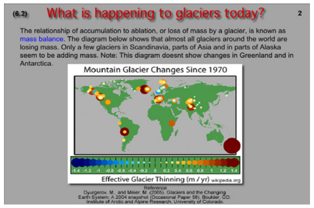
# What is happening to glaciers today?

## 6.2



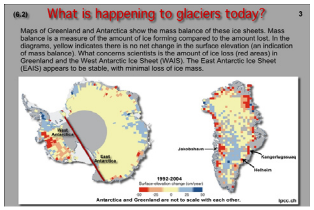

6.2.1

According to NASA's Earth Observatory website, glaciers around the world have lost approximately 8000 cubic kilometers of ice since 1960. To put that in perspective, that would be equal to a piece of ice, two kilometers wide and one kilometer thick, that would stretch from New York to Los Angeles. What does the shape of the graph indicate about the rate at which the world seems to be losing glacial ice?




6.2.2

The relationship of a glacier's accumulation (addition of mass) to ablation (loss of mass) is known as mass balance. The diagram below shows that almost all glaciers around the world are losing mass. Only a few glaciers in Scandinavia, parts of Asia, and in parts of Alaska seem to be adding mass. Note: This diagram doesn't show changes in Antarctica.




6.2.3

Maps of Greenland and Antarctica show the mass balance of these ice sheets. Mass balance is a measure of the amount of ice forming compared to the amount lost. In the diagrams, yellow indicates there is no net change in the surface elevation (an indication of mass balance). What concerns scientists is the amount of ice loss (red areas) in Greenland and the West Antarctic Ice Sheet (WAIS). The East Antarctic Ice Sheet (EAIS) appears to be stable, with minimal loss of ice mass.


6.2.4

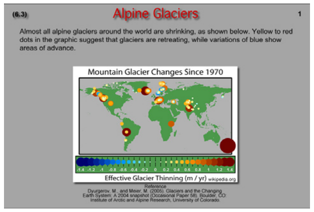
Summary

- Glacial volume around the world is generally declining.
- The rate at which glaciers are melting appears to be on the rise.
- Mass balance is the difference between accumulation and ablation on a glacier, usually calculated annually.

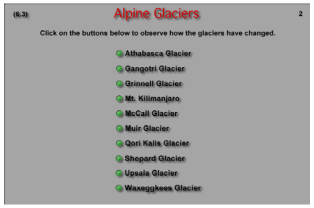
# Notes

## Alpine Glaciers

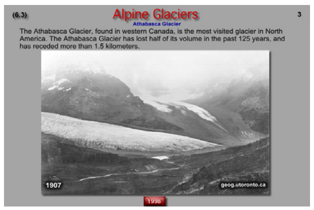
## 6.3



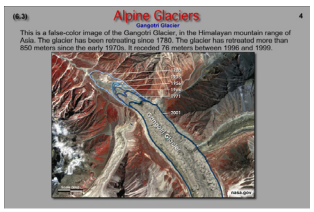

6.3.1
Almost all alpine glaciers around the world are shrinking, as shown below. Yellow to red dots in the graphic suggest that glaciers are retreating, while variations of blue show areas of advance.



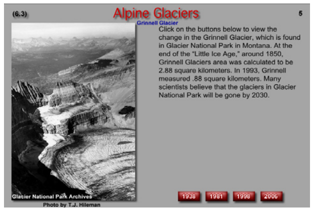

6.3.2
Click on the buttons below to observe how the glaciers have changed.
- Athabasca Glacier
- Gangotri Glacier
- Grinnell Glacier
- Mt. Kilimanjaro
- McCall Glacier
- Muir Glacier
- Qori Kalis Glacier
- Shepard Glacier
- Upsala Glacier
- Waxeggkees Glacier




6.3.3
Athabasca Glacier
The Athabasca Glacier, found in western Canada, is the most visited glacier in North America. The Athabasca Glacier has lost half of its volume in the past 125 years, and has receded more than 1.5 kilometers.



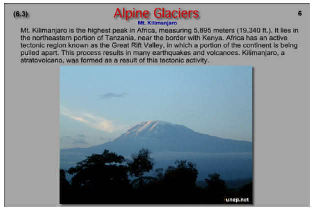

6.3.4
Gangotri Glacier
This is a false-color image of the Gangotri Glacier, in the Himalayan mountain range of Asia. The glacier has been retreating since 1780. The glacier has retreated more than 850 meters since the early 1970s. It receded 76 meters between 1996 and 1999.




6.3.5

Grinnell Glacier

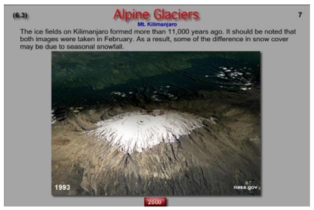
Click on the buttons below to view the change in the Grinnell Glacier, which is found in Glacier National Park in Montana. At the end of the "Little Ice Age," around 1850, Grinnell Glacier's area was calculated to be 2.88 square kilometers. In 1993, Grinnell measured 0.88 square kilometers. Many scientists believe that the glaciers in Glacier National Park will be gone by 2030.




6.3.6

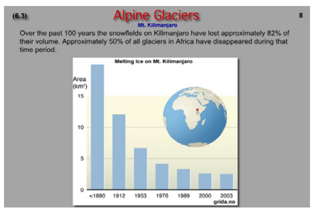
Mt. Kilimanjaro

Mt. Kilimanjaro is the highest peak in Africa, measuring 5,895 meters (19,340 ft.). It lies in the northeastern portion of Tanzania, near the border with Kenya. Africa has an active tectonic region known as the Great Rift Valley, in which a portion of the continent is being pulled apart. This process results in many earthquakes and volcanoes. Kilimanjaro, a stratovolcano, was formed as a result of this tectonic activity.



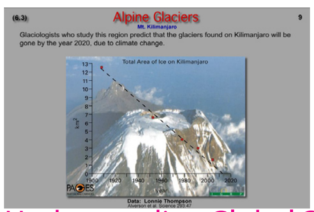

6.3.7

The ice fields on Kilimanjaro formed more than 11,000 years ago. It should be noted that both images were taken in February. As a result, some of the difference in snow cover may be due to seasonal snowfall.




6.3.8

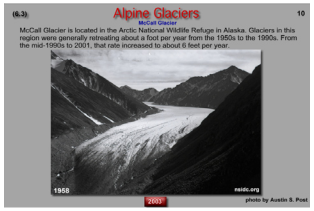
Over the past 100 years, the snowfields on Kilimanjaro have lost approximately 82% of their volume. Approximately 50% of all glaciers in Africa have disappeared during that time period.



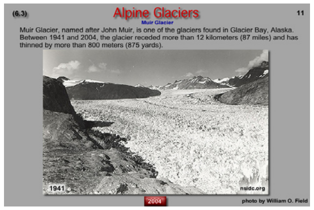

6.3.9

Glaciologists who study this region predict that the glaciers found on Kilimanjaro will be gone by the year 2020, due to climate change.

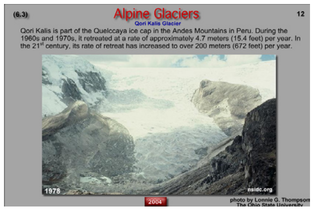
# Notes



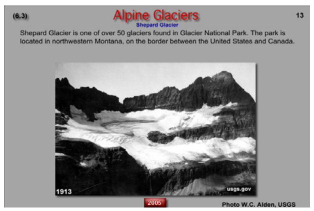

6.3.10
McCall Glacier
McCall Glacier is located in the Arctic National Wildlife Refuge in Alaska. Glaciers in this region were generally retreating about a foot per year from the 1950s to the 1990s. From the mid-1990s to 2001, that rate increased to about 6 feet per year.




6.3.11
Muir Glacier
Muir Glacier, named after John Muir, is one of the glaciers found in Glacier Bay, Alaska. Between 1941 and 2004, the glacier receded more than 12 kilometers (8.7 miles) and has thinned by more than 800 meters (875 yards).

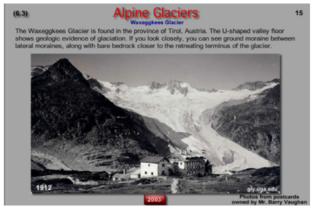



6.3.12
Qori Kalis Glacier
Qori Kalis is part of the Quelccaya ice cap in the Andes Mountains in Peru. During the 1960s and 1970s, it retreated at a rate of approximately 4.7 meters (15.4 feet) per year. In the 21st century, its rate of retreat has increased to over 200 meters (672 feet) per year.




6.3.13
Shepard Glacier
Shepard Glacier is one of over 50 glaciers found in Glacier National Park. The park is located in northwestern Montana, on the border between the United States and Canada.


6.3.14
Upsala Glacier
Upsala Glacier is found in Argentina's los Glaciares National Park. It is retreating at a rate of approximately 200 meters per year. Between the mid-1960s and the mid-1990s, Upsala Glacier retreated approximately 4 kilometers.



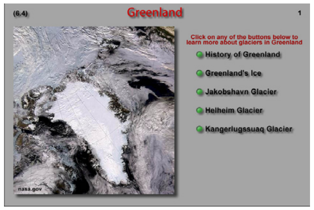

6.3.15
Waxeggkees Glacier
The Waxeggkees Glacier is found in the province of Tirol, Austria. The U-shaped valley floor shows geologic evidence of glaciation. If you look closely, you can see ground moraine between lateral moraines, along with bare bedrock closer to the retreating terminus of the glacier.


6.3.16
Summary
- Almost all alpine glaciers around the world are losing mass, decreasing in area and thickness.
- The graph to the right shows how the volume of glacial ice around the world is decreasing.

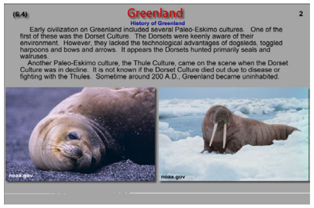
# Notes

## Greenland

### 6.4

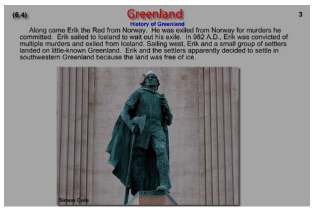



6.4.1
Click on any of the buttons below to learn more about glaciers in Greenland.
- History of Greenland
- Greenland's Ice
- Jakobshavn Glacier
- Helheim Glacier
- Kangerdlugssuaq Glacier



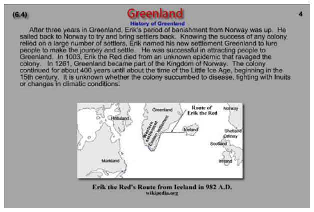

6.4.2
History of Greenland
Greenland's early civilization included several Paleo-Eskimo cultures. One of the first of these was the Dorset Culture. The Dorsets were keenly aware of their environment. However, they lacked the technological advantages of dogsleds, toggled harpoons, and bows and arrows. It appears the Dorsets hunted primarily seals and walruses.

Another Paleo-Eskimo culture, the Thule Culture, arose when the Dorset Culture was in decline. It is not known if the Dorset Culture died out due to disease or fighting with the Thules. Sometime around 200 A.D. (C.E. or "Common Era"), Greenland became uninhabited.

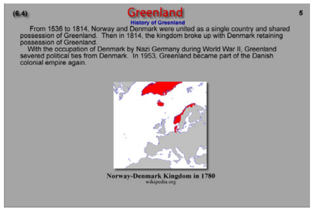



6.4.3
Along came Erik the Red from Norway. He was exiled from Norway for murders he committed. Erik sailed to Iceland to wait out his exile. In 982 C.E., Erik was convicted of multiple murders and was also exiled from Iceland. Sailing west, Erik and small group of settlers landed on little-known Greenland. Erik and the settlers apparently decided to settle in southwestern Greenland because the land was free of ice.

# Notes

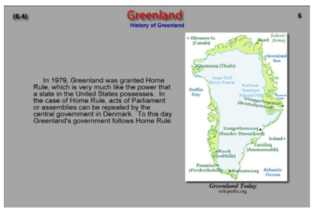



6.4.4
When Erik's period of banishment from Norway ended, he sailed back to Norway to bring more settlers to Greenland. Erik named his new settlement Greenland to lure people to make the journey and settle. He was successful in attracting people to Greenland. In 1003, Erik the Red died from an unknown epidemic that ravaged the colony. In 1261, Greenland became part of the kingdom of Norway. The colony continued for about 400 years until about the time of the Little Ice Age, beginning in the 15th century. It is unknown whether the colony succumbed to disease, fighting with Inuits, or changes in climatic conditions.



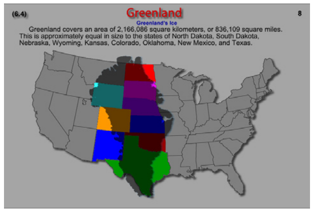

6.4.5
From 1536 to 1814, Norway and Denmark were united as a single country and shared possession of Greenland. Then in 1814, the kingdom broke up. Denmark retained possession of Greenland.

Greenland severed political ties with Denmark during World War II when Nazi Germany occupied Denmark. In 1953, Greenland became part of the Danish Empire again.

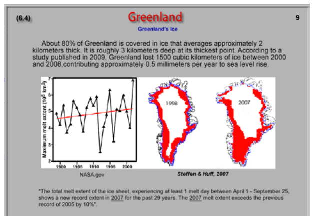



6.4.6
In 1979, Greenland was granted Home Rule, which is very much like the power that a state in the United States possesses. In the case of Home Rule, acts of Parliament or assemblies can be repealed by the central government in Denmark. To this day, Greenland's government follows Home Rule.


6.4.7
This section focuses on three of Greenland's glaciers. Jakobshavn (Yaw'-cub-saw-vin) Glacier is found on the west coast of Greenland. Kangerdlugssuaq (Cang-gerd-loose'-wak) and Helheim (hell-hyme) Glaciers are found on the east coast.

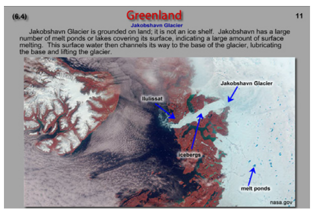



6.4.8
Greenland's Ice
Greenland covers an area of 2,166,086 square kilometers, or 836,109 square miles. This is approximately equal in size to the states of North Dakota, South Dakota, Nebraska, Wyoming, Kansas, Colorado, Oklahoma, New Mexico, and Texas.




6.4.9
About 80% of Greenland is covered by ice that averages approximately 2 kilometers thick. It is roughly 3 kilometers deep at its thickest point. According to a study published in 2009, Greenland lost 1500 cubic kilometres of ice between 2000 and 2008, contributing approximately 0.5 millimeters per year to sea level rise.
"The total melt extent of the ice sheet, experiencing at least 1 melt day be tween April 1 - September 25, shows a new record extent in 2007 for the past 29-years. The 2007 melt extent exceeds the previous record of 2005 by 10%." (It is the caption for the graphic, but it is important information.)

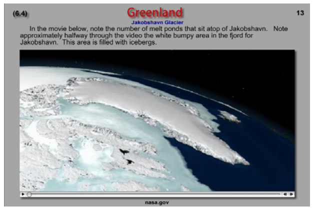

6.4.10
Jakobshavn Glacier
Jakobshavn Glacier is located near a little town in western Greenland called Ilulissat. In the past few years, Jakobshavn Glacier has been one of the fast moving glaciers in Greenland. At its front, it is moving ~30 m/day!




6.4.11
Jakobshavn Glacier is grounded on land; it is not an ice shelf. Jakobshavn has a large number of melt ponds or lakes covering its surface, indicating seasonal melting. Surface water flows downslope and channels its way to the base of the glacier, temporarily lubricating the base and lifting the glacier.

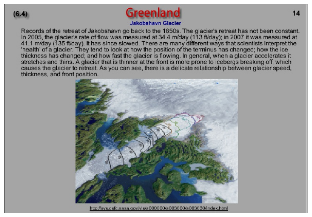

6.4.12

The town of Ilulissat can be seen in the background in the photo on the left. The photo on the right shows the meltwater and crevasses through which water is making its way to the bottom of the glacier.




6.4.13

In the movie below, note the number of melt ponds on the surface of Jakobshavn. Note approximately halfway through the video the white bumpy area in the fjord for Jakobshavn. This area is filled with icebergs.




6.4.14

Records of the retreat of Jakobshavn go back to the 1850s. The glacier's retreat has not been constant. In 2005, the glacier's rate of flow was measured at 34.4 m/day (113 ft/day); in 2007 it was measured at 41.1 m/day (135 ft/day). It has since slowed. There are many different ways that scientists interpret the 'health' of a glacier. They tend to look at how the position of the terminus has changed; how the ice thickness has changed; and how fast the glacier is flowing. In general, when a glacier accelerates it stretches and thins. A glacier that is thinner at the front is more prone to icebergs breaking off, which causes the glacier to retreat. As you can see, there is a delicate relationship between glacier speed, thickness, and front position.


6.4.15

Helheim Glacier

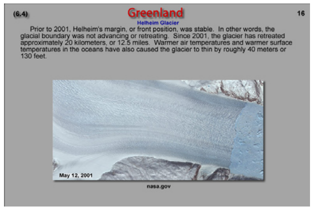
Helheim Glacier, located in eastern Greenland, is another outlet glacier draining the Greenland ice sheet. At its front, it is currently flowing at a rate of approximately 24 meters (78.7 feet) per day. Prior to 2001, it was flowing at a rate of 19 meters (62.3 feet) per day. Between 2003-5, when it sped up, it was flowing at 32 meters per day. It has since slowed down.

Jakobshavn Glacier

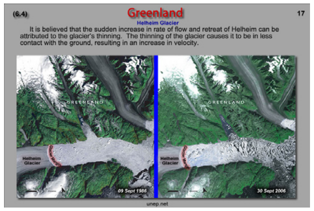
Kangerdlugssuaq Glacier

Helheim Glacier

# Notes



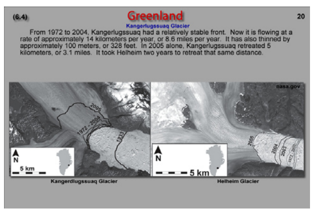

6.4.16
As shown in the images below, the glacier retreated roughly 20 kilometers (km), or 12.5 miles between 2001 and 2005. Since the 2005 minimum, the glacier has advanced about 1.5 km. Warmer air temperatures and warmer surface temperatures in the oceans have also caused the glacier to thin by roughly 40 meters or 130 feet.




6.4.17
It is believed that the sudden increase in rate of flow and retreat of Helheim can be attributed to the glacier's thinning. The thinning of the glacier causes it to be in less contact with the ground, resulting in an increase in velocity.


6.4.18
Kangerdlugssuaq Glacier is also an outlet glacier draining the Greenland ice sheet. It drains approximately 4% of the area of Greenland annually.


6.4.19
Like other glaciers in Greenland, Kangerdlugssuaq Glacier is losing mass. What makes Kangerdlugssuaq unique is how fast and how suddenly it is experiencing change.




6.4.20
From 1972 to 2004, Kangerdlugssuaq had a relatively stable front. Now it is flowing at a rate of approximately 14 kilometers per year, or 10.4 miles per year. It has also thinned by approximately 100 meters, or 328 feet. In 2005 alone, Kangerdlugssuaq retreated 5 kilometers, or 3.1 miles. It took Helheim two years to retreat that same distance.

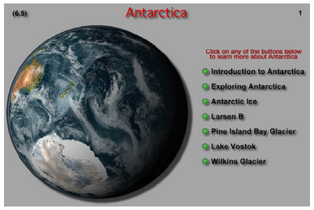
Notes

Summary

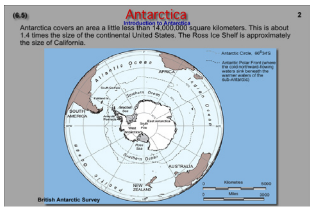
6.4.21
- Several large glaciers in southern and central Greenland are retreating.
- Several large glaciers in Greenland are moving faster now than they were ten years ago. Jakobshavn, Helheim, and Kangerdlugssuaq have doubled or tripled their flow speeds.
- The retreat of the glaciers appears to be caused by a combination of factors, including warmer air.
- Some glaciers that are loosely grounded in the surrounding seas are thinning, resulting in mass loss. This loss of mass makes them more buoyant, and they lose their grounding, which in turn, allows them to retreat faster.

## Antarctica

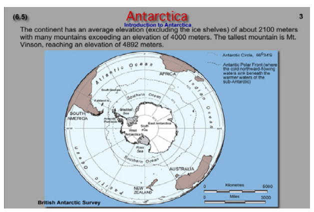
## 6.5




6.5.1
Click on any of the buttons below to learn more about Antarctica.
- Introduction to Antarctica
- Exploring Antarctica
- Antarctic Ice
- Larsen B
- Pine Island Glacier
- Lake Vostok
- Wilkins Ice Shelf

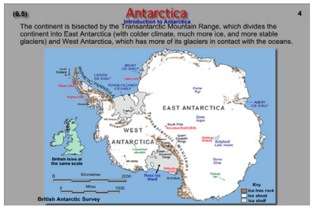



6.5.2
Introduction to Antarctica
The area of Antarctica is a little less than 14,000,000 square kilometers. This is about 1.4 times the size of the continental United States. The Ross Ice Shelf is approximately the size of California.

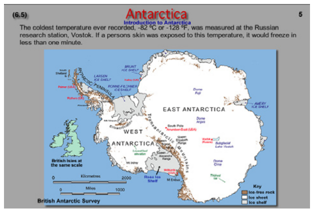



6.5.3
The continent has an average elevation (excluding the ice shelves) of about 2100 meters with many mountains exceeding an elevation of 4000 meters. The tallest mountain is Mt. Vinson, reaching an elevation of 4892 meters.

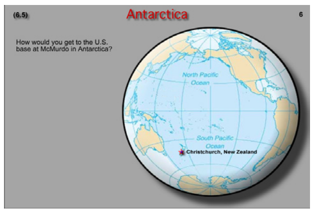
# Notes



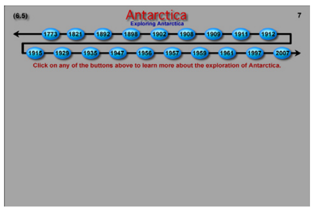

6.5.4
The continent is bisected by the Transantarctic Mountain Range, which divides the continent into East Antarctica (with colder climate, much thicker ice, and more stable glaciers) and West Antarctica, which is comprised of the Ross and Weddell Seas, a comparatively small land mass between them, and the Antarctic Peninsula. During the IGY (1957-58) scientists learned that parts of the West Antarctic Ice Sheet (WAIS) are below sea level.



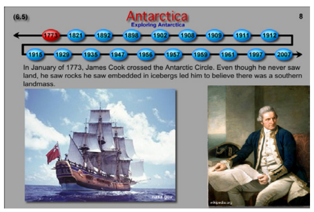

6.5.5
The coldest temperature ever recorded, -82 ºC or -128 ºF, was measured at the Russian research station, Vostok. If a person's skin was exposed to this temperature, it would freeze in less than one minute.




6.5.6
How would you get to the U.S. research station at McMurdo in Antarctica?

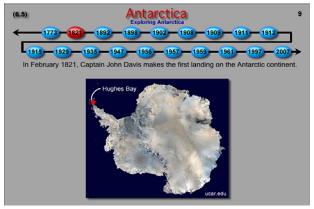



6.5.7
Exploring Antarctica
Click on any of the buttons above to learn more about the exploration of Antarctica.

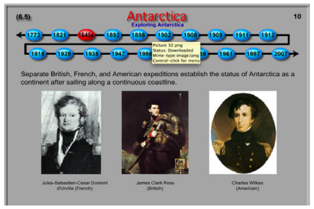



6.5.8 (1773)
In January of 1773, James Cook crossed the Antarctic Circle. Even though he never saw land, rocks he saw embedded in icebergs led him to believe there was a southern landmass.

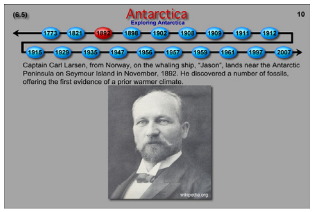
## Notes



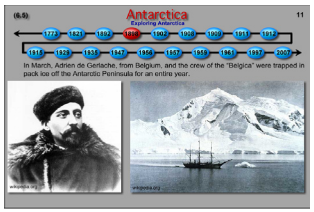

6.5.9 (1821)
In February 1821, Captain John Davis made the first landing on the Antarctic continent.




6.5.10 (1840s)
Separate British, French, and American expeditions establish the status of Antartica as a continent after sailing along its continuous coastline.



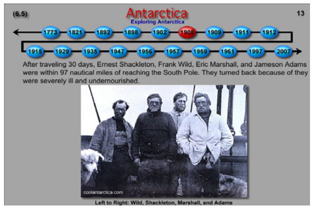

6.5.11 (1892)
Captain Carl Larsen, from Norway, on the whaling ship, "Jason", landed near the Antarctic Peninsula on Seymour Island in November, 1892. He discovered a number of fossils, offering the first evidence of a prior warmer climate.



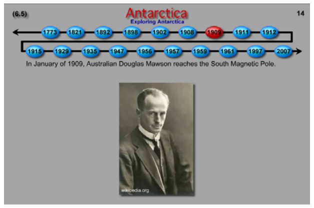

6.5.12 (1898)
In March, Adrien de Gerlache, from Belgium, and the crew of the "Belgica" were trapped in pack ice off the Antarctic Peninsula for an entire year.


6.5.13 (1902)
Captain Robert F. Scott, from the United Kingdom, leads his first Antarctic expedition to the South Pole, with Ernest Shackleton and Edward Wilson. They turned back after traveling for two months because they were suffering from scurvy and snow blindness. They reached 82 oS and traveled 3100 kilometers roundtrip.

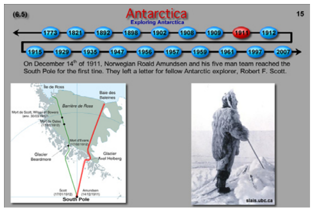
# Notes



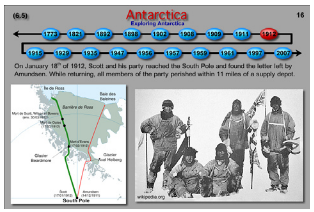

6.5.14 (1908)
After traveling 30 days, Ernest Shackleton, Frank Wild, Eric Marshall, and Jameson Adams were within 97 nautical miles of reaching the South Pole. They turned back because they were severely ill and undernourished.



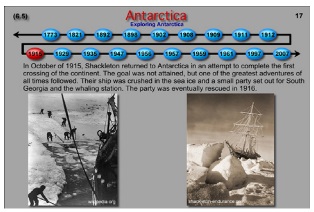

6.5.15 (1909)
In January of 1909, Australian Douglas Mawson reached the South Magnetic Pole.




6.5.16 (1911)
On December 14th of 1911, Norwegian Roald Amundsen and his five-man team reached the South Pole for the first time. They left a letter for fellow Antarctic explorer, Robert F. Scott.

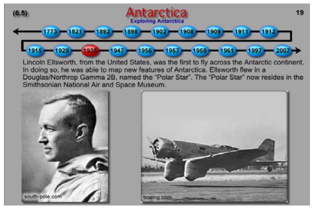



6.5.17 (1912)
On January 18th of 1912, Scott and his party reached the South Pole and found the letter left by Amundsen. While returning, all members of the party perished within 11 miles of a supply depot.

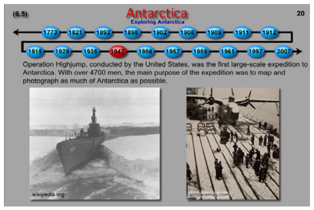



6.5.18 (1915)
In October of 1915, Shackleton returned to Antarctica in an attempt to complete the first crossing of the continent. The goal was not attained, but one of the greatest adventures of all times followed. Their ship was crushed in the sea ice and a small party set out for South Georgia and the whaling station. The party was eventually rescued in 1916.

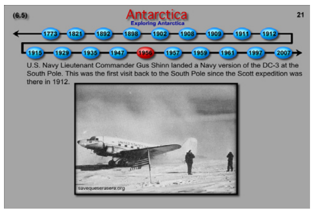

6.5.19 (1929)
Richard E. Byrd and three others from the United States became the first to fly over the South Pole in a Ford Tri-motor airplane.



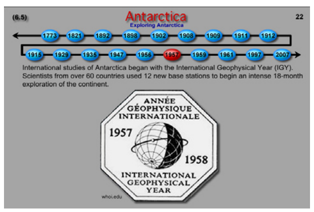

6.5.20 (1935)
Lincoln Ellsworth, from the United States, was the first to fly across the Antarctic continent. In doing so, he was able to map new features of Antarctica. Ellsworth flew in a Douglas/Northrop Gamma 2B, named the "Polar Star". The "Polar Star" now resides in the Smithsonian National Air and Space Museum.




6.5.21 (1947)
Operation Highjump, conducted by the United States, was the first large-scale expedition to Antarctica. With over 4700 men, the main purpose of the expedition was to map and photograph as much of Antarctica as possible.




6.5.22 (1956)
U.S. Navy Lieutenant Commander Gus Shinn landed a Navy version of the DC-3 at the South Pole. This was the first visit back to the South Pole since the Scott expedition was there in 1912.

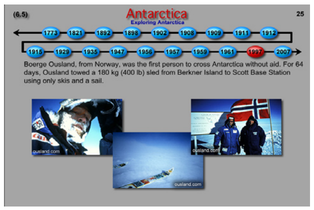



6.5.23 (1957)
International studies of Antarctica began with the International Geophysical Year (IGY). Scientists from over 60 countries used 12 new base stations to begin an intense 18-month exploration of the continent.

# Notes

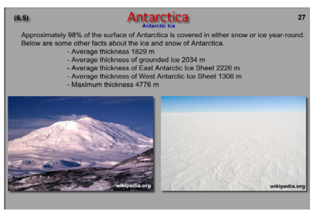

6.5.24 (1959)
In December, 1959, the twelve leading nations participating in the IGY signed the "Antarctic Treaty" in Washington, DC. The treaty was framed as an agreement so the continent "shall continue forever to be used exclusively for peaceful purposes".


6.5.25 (1961)
The Antarctic Treaty entered into force on June 23, 1961. It guarantees that territory south of 60º South latitude will be used only for peaceful and scientific purposes. The 46 countries that are now party to the treaty represent about two-thirds of the world's population.



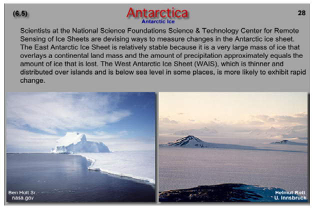

6.5.26 (1997)
Boerge Ousland, from Norway, was the first person to cross Antarctica without aid. For 64 days, Ousland towed a 180 kg (400 lb) sled from Berkner Island to Scott Base Station using only skis and a sail.


6.5.27 (2007)
The fourth International Polar Year (IPY) ran from 2007-2009, spanning two years to allow coverage of a full annual cycle in both the Arctic and Antarctic.

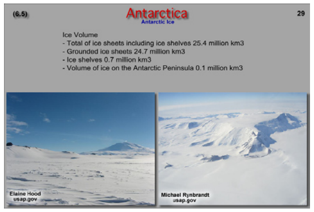



6.5.28
Antarctic Ice
Approximately 98% of the surface of Antarctica is covered in either snow or ice year-round. Below are some other facts about the ice and snow of Antarctica:
- Average thickness 1829 m
- Average thickness of grounded ice 2034 m
- Average thickness of East Antarctic Ice Sheet 2226 m
- Average thickness of West Antarctic Ice Sheet 1306 m
- Maximum thickness 4776 m

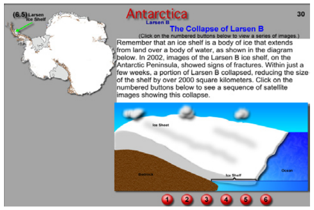
# Notes



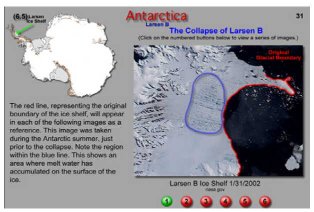

6.5.29
Scientists at the National Science Foundation's Science & Technology Center for Remote Sensing of Ice Sheets are devising ways to measure changes in the Antarctic ice sheet. The East Antarctic Ice Sheet is relatively stable because it is a very large mass of ice that overlays a continental land mass and the amount of precipitation approximately equals the amount of ice that is lost. The West Antarctic Ice Sheet (WAIS), which is thinner and distributed over islands and is below sea level in some places, is more likely to exhibit rapid change.




6.5.30
Ice Volume
- Total of ice sheets including ice shelves: 25.4 million $km^3$
- Grounded ice sheets: 24.7 million $km^3$
- Ice shelves: 0.7 million $km^3$
- Volume of ice on the Antarctic Peninsula: 0.1 million $km^3$

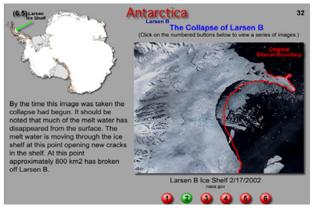



6.5.31
Larsen B
The Collapse of Larsen B
(Click on the numbered buttons below to view a series of images.)
Remember that an ice shelf is a body of ice that extends from land over a body of water, as shown in the diagram below. In 2002, images of the Larsen B ice shelf, on the Antarctic Peninsula, showed signs of fractures. Within just a few weeks, a portion of Larsen B collapsed, reducing the size of the shelf by over 2000 square kilometers. Click on the numbered buttons below to see a sequence of satellite images showing this collapse.

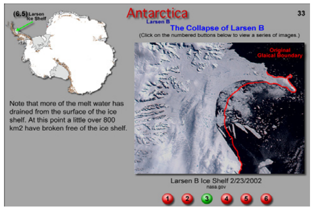



6.5.32
The Collapse of Larsen B
(Click on the numbered buttons below to view a series of images.)
The red line, representing the original boundary of the ice shelf, will appear in each of the following images as a reference. This image was taken during the Antarctic summer, just prior to the collapse. Note the region within the blue line. This shows an area where melt water has accumulated on the surface of the ice.

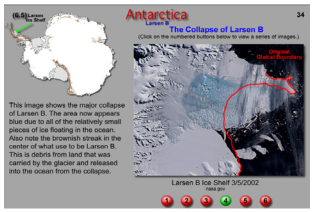
# Notes



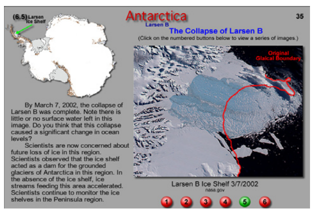

6.5.33 (Button 2)
By the time this image was taken, the collapse had begun. It should be noted that much of the melt water has disappeared from the surface. The melt water is moving through the ice shelf at this point, opening new cracks in the shelf. At the time of this image, approximately 800 km2 had broken off Larsen B.



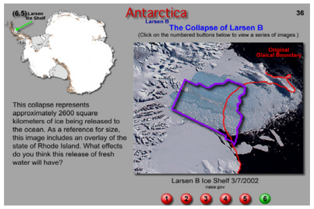

6.5.34 (Button 3)
Note that more of the melt water has drained from the surface of the ice shelf. At this point, a little over 800 km$^2$ of ice had broken free of the ice shelf.




6.5.35 (Button 4)
This image shows the major collapse of Larsen B. The area now appears blue due to all of the relatively small pieces of ice floating in the ocean. Also note the brownish streak in the center of what used to be Larsen B. This was debris from land that was carried by the glacier and released into the ocean from the collapse.

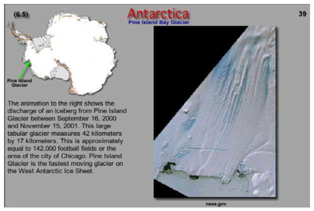



6.5.36 (Button 5)
By March 7, 2002, the collapse of Larsen B was complete. Note there is little or no surface water left in this image. Do you think that this collapse caused a significant change in ocean levels?
Scientists are now concerned about future loss of ice in this region. Scientists observed that the ice shelf acted as a dam for the grounded glaciers of Antarctica in this region. In the absence of the ice shelf, ice streams feeding this area accelerated. Scientists continue to monitor the ice shelves in the Peninsula region.

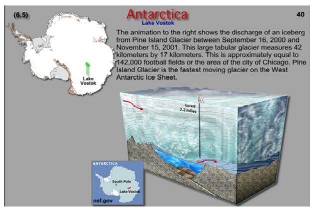



6.5.37 (Button 6)
This collapse represents approximately 2600 square kilometers of ice being released to the ocean. As a reference for size, this image includes an overlay of the state of Rhode Island. What effects do you think this release of fresh water will have?


6.5.38
The collapse of Larsen B can be traced to two factors. The first factor is the general warming of the Southern Ocean surrounding Antarctica, causing the ice shelf to melt from the bottom. The second factor is the accumulation of glacial meltwater on the surface of the shelf. This water, using the natural crevasses found in the ice, flows down through the ice, weakening its structure, resulting in the collapse of the shelf. Play the movie below to see these melt ponds.

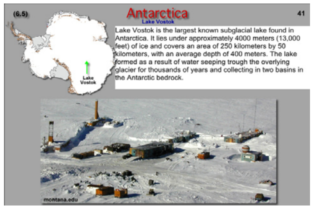



6.5.39
Pine Island Glacier
The Pine Island Glacier is the largest glacier on the West Antarctic Ice Sheet, representing approximately 10% of the ice there. It is roughly 2500 meters thick, grounded on bedrock that is 1500 meters below sea level. Scientists are concerned about Pine Island Glacier because it is the major corridor for ice from the interior of the West Antarctic Ice Sheet. Loss of this glacier and its damming effect on the continent's ice could cause a dramatic rise in sea level in the future.

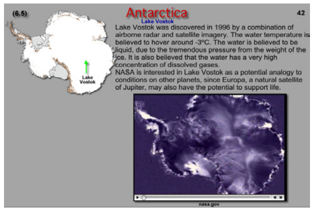



6.5.40
Pine Island Glacier
The animation to the right shows the discharge of an iceberg from Pine Island Glacier between September 16, 2000 and November 15, 2001. This large tabular glacier measured 42 kilometers by 17 kilometers. This is approximately equal to 142,000 football fields, or the area of the city of Chicago. Pine Island Glacier is the fastest moving glacier on the West Antarctic Ice Sheet.

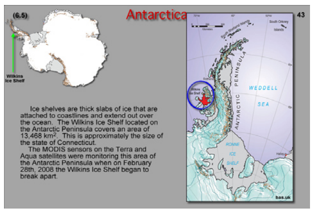
# Notes




6.5.41
Lake Vostok
Lake Vostok is the largest known subglacial lake found in Antarctica. It lies under approximately 4000 meters (13,000 feet) of ice and covers an area of 250 kilometers by 50 kilometers, with an average depth of 400 meters. The lake formed as a result of water seeping through the overlying glacier for thousands of years and collecting in two basins in the Antarctic bedrock.

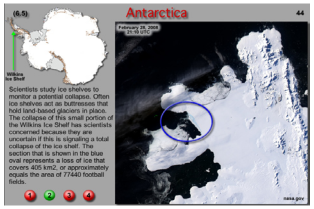



6.5.42
Lake Vostok
The Russians have retrieved an ice core that is over 3500 meters long and approximately 600,000 years old. They stopped drilling roughly 100 meters short of reaching the lake surface because microbial life may exist there. If so, precautions are being evaluated to prevent the environment from being contaminated by modern microbes when the lake's surface is reached. In the meantime, the borehole has been filled with a combination of chemicals to prevent the hole from freezing until a suitably cautious plan is approved.




6.5.43
Lake Vostok was discovered in 1996 by a combination of airborne radar and satellite imagery. The water temperature is believed to hover around -3 ºC. The water is believed to be liquid, due to the tremendous pressure from the weight of the ice. It is also believed that the water has a very high concentration of dissolved gases.
NASA is interested in Lake Vostok as a potential analogy to conditions on other planets, since Europa, a natural satellite of Jupiter, may also have the potential to support life.


6.5.45
Wilkins Ice Shelf
Ice shelves are thick slabs of ice that extend out over the ocean from land-based ice. In 2007, the Wilkins Ice Shelf located on the Antarctic Peninsula covered an area of 14,358 km$^2$, approximately the size of the state of Connecticut.
MODIS sensors on the Terra and Aqua satellites had been monitoring this area of the Antarctic Peninsula when on February 28th, 2008, the Wilkins Ice Shelf began to break apart. By the beginning of 2009, only a narrow ice bridge remained.



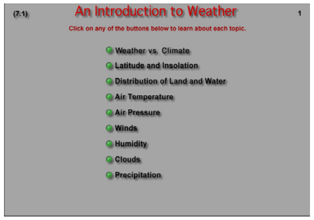

6.5.46
Scientists study ice shelves to monitor a potential collapse. Often ice shelves act as buttresses that hold land-based glaciers in place. The collapse of this small portion of the Wilkins Ice Shelf concerned scientists because they were uncertain if it signaled an impending total collapse of the ice shelf. The section that is shown in the blue oval represents a loss of ice that covers 405 $km^2$, or approximately the area of 77,440 football fields.


6.5.45
Summary
- Antarctica is 1.4 times the size of the continental United States.
- The average elevation of Antarctica is 2100 meters, with an average ice thickness of about 1800 meters.
- The Transantarctic Mountain Range divides Antarctica into two distinctive regions. Many of the glaciers in the West Antarctic are in contact with the ocean. East Antarctica is the coldest, highest, driest, and windiest place on Earth.
- Many people have studied and explored Antarctica over the past 200 years.
- In 2002 a section of ice, known as Larsen B, broke off from West Antarctica. This large piece of ice had acted as a dam, slowing the glaciers that fed the ice shelf.
- Part of the Pine Island Glacier collapsed in West Antarctica in 2001. This glacier is the fastest moving glacier in Antarctica, and is under scrutiny for rapid potential change.
- Lake Vostok lies under 4,000 meters of ice on East Antarctica. Precautions are being taken in case life exists in the lake.

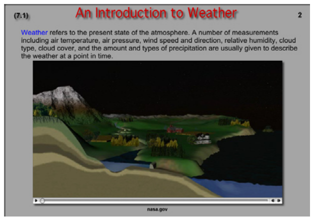
# Meteorological Evidence
An Introduction to Weather

Notes

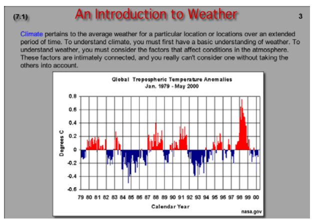
## 7.1




7.1.1
Click on any of the buttons below to learn about each topic.
Weather vs. Climate
Latitude and Insolation
Distribution of Land and Water
Air Temperature
Air Pressure
Winds
Humidity
Clouds
Precipitation

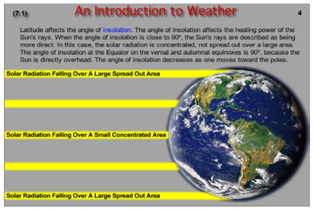



7.1.2
Weather vs. Climate
Weather refers to the present state of the atmosphere. A number of measurements including:  air temperature, air pressure, wind speed and direction, relative humidity, cloud type, cloud cover, and the amount and types of precipitation are usually given to describe the weather at a point in time.




7.1.3
Climate pertains to the average weather for a particular location or locations over an extended period of time. To understand climate, you must first have a basic understanding of weather. To understand weather, you must consider the factors that affect conditions in the atmosphere. These factors are intimately connected, and you really can't consider one without taking the others into account.

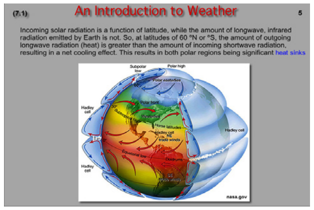
# Notes




7.1.4

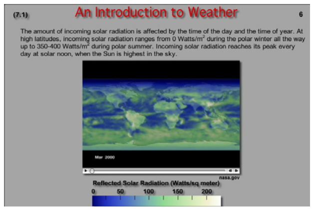
Latitude and Insolation

Latitude affects the angle of insolation. The angle of insolation affects the heating power of the Sun's rays. When the angle of insolation is close to 90°, the Sun's rays are described as being more direct. In this case, the solar radiation is concentrated, not spread out over a large area. The angle of insolation at the Equator on the vernal and autumnal equinoxes is 90°, because the Sun is directly overhead. The angle of insolation decreases as one moves toward the poles.




7.1.5

Incoming solar radiation is a function of latitude, while the amount of longwave, infrared radiation emitted by Earth is not. So, at latitudes of 60 °N or °S, the amount of outgoing longwave radiation (heat) is greater than the amount of incoming shortwave radiation, resulting in a net cooling effect. This results in both polar regions being significant heat sinks.



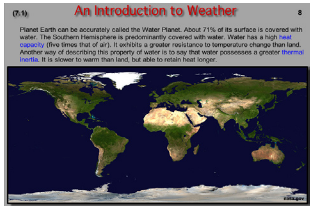

7.1.6

The amount of incoming solar radiation is affected by the time of day and the time of year. At high latitudes, incoming solar radiation ranges from 0 Watts/$m^2$ during the polar winter all the way up to 350-400 Watts/$m^2$ during polar summer. Incoming solar radiation reaches its peak every day at solar noon, when the Sun is highest in the sky.


7.1.7

Clouds also affect incoming solar radiation, and their effects vary. First, clouds reflect about 20% of incoming radiation back to space, due to their relatively high albedo. This can be viewed as a surface cooling effect, because the energy is not absorbed and emitted as heat. However, clouds also absorb some incoming solar radiation, which is then radiated both back into space and toward Earth's surface, moderating temperatures. At the poles, however, clouds tend to dampen the daily variation in temperature (highs and lows) because they prevent some energy from reaching the surface. But they also prevent heat energy from radiating back to space.

Notes




7.1.8

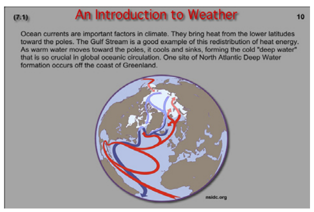
Distribution of Land and water

Planet Earth can be accurately called the Water Planet. About 71% of its surface is covered with water. The Southern Hemisphere is predominantly covered with water. Water has a high heat capacity (five times that of air). It exhibits a greater resistance to temperature change than land. Another way of describing this property of water is to say that water possesses a greater thermal inertia. It is slower to warm than land, but able to retain heat longer.


7.1.9

The dynamics change when snow and ice are considered. A thick layer of sea ice limits the warming and moisture influence of the oceans on the near-surface atmosphere in the winter. It acts like a blanket of insulation on the surface of the ocean. Sea ice has a high albedo, .70, which means that it reflects 70% of the incident radiation from Earth's surface back to space. Typically, sea ice is covered by a layer of snow, which has an even higher albedo, sometimes greater than 0.82. This means the majority of the radiation that reaches the surface of sea ice and snow cover is reflected from the surface. More importantly, albedo over ice- and snow-covered surfaces changes seasonally. The angle of the Sun's rays and surface melting are important determining factors.

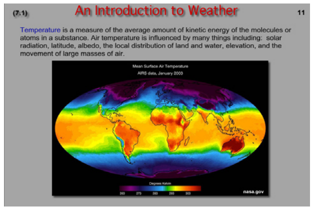
Open water has a very low albedo of 0.08, reflecting only 8% of incoming radiation, and absorbing 92% of the radiation that reaches the water surface! Having more open water in the Arctic Ocean allows more exchange of heat and moisture with the atmosphere, affecting cloudiness and increasing the amount of solar energy that can be absorbed and radiated back into the atmosphere as heat.



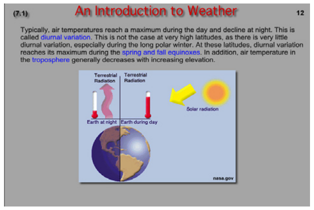

7.1.10

Ocean currents are important factors in climate. They bring heat from the lower latitudes toward the poles. The Gulf Stream is a good example of this redistribution of heat energy. As warm water moves toward the poles, it cools and sinks, forming the cold "deep water" that is so crucial in global oceanic circulation. One site of North Atlantic Deep Water formation occurs off the coast of Greenland.

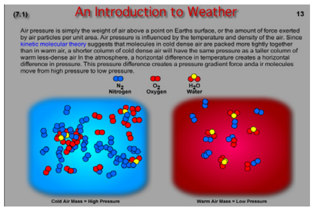
# Notes




7.1.11
Air Temperature
Temperature is a measure of the average amount of kinetic energy of the molecules or atoms in a substance. Air temperature is influenced by many things including:  solar radiation, latitude, albedo, the local distribution of land and water, elevation, and the movement of large masses of air.

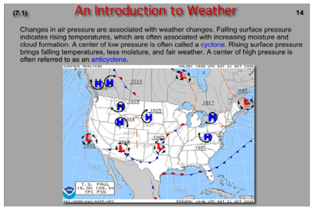



7.1.12
Typically, air temperatures reach a maximum during the day and decline at night. This is called diurnal variation. This is not the case at very high latitudes, as there is very little diurnal variation, especially during the long polar winter. At these latitudes, diurnal variation reaches its maximum during the spring and fall equinoxes. In addition, air temperature in the troposphere generally decreases with increasing elevation.



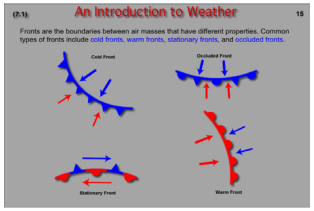

7.1.13
Air Pressure
Air pressure is simply the weight of air above a point on Earth's surface, or the amount of force exerted by air particles per unit area. Air pressure is influenced by the temperature and density of the air. Since the kinetic molecular theory suggests that molecules in cold dense air are packed more tightly together than in warm air, a shorter column of cold dense air will have the same pressure as a taller column of warm less-dense air, defined as the gravitational force (weight) of the atmospheric column above a point per unit area.
Pressure is due to the concentration of particles per unit area. The particles in warm air are spread farther apart, so there are fewer of them per unit of volume. As a result, warmer air has lower pressure and colder air has higher pressure.
Cold Air Mass = High Pressure
Warm Air Mass = Low Pressure
In the atmosphere, a horizontal difference in temperature creates a horizontal difference in pressure. This pressure difference creates a pressure gradient force since air molecules move from high pressure to low pressure.

# Notes



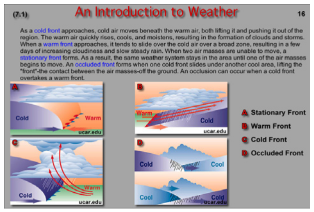

7.1.14

Changes in air pressure are associated with weather changes. When low pressure air moves into a region, it typically brings an area of higher temperatures, increased moisture, and clouds. A center of low pressure is often called a cyclone. When high pressure air moves into an area, it brings brings lower temperatures, decreased moisture, and fair weather. A center of high pressure is often referred to as an anticyclone.



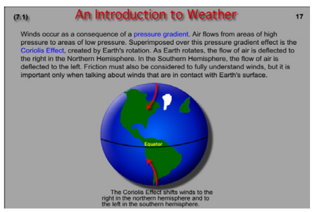

7.1.15

Fronts are the boundaries between air masses that have different properties. Common types of fronts include cold fronts, warm fronts, stationary fronts, and occluded fronts.



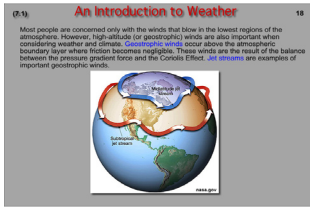

7.1.16

As a cold front approaches, cold air moves beneath the warm air, both lifting it and pushing it out of the region. The warm air quickly rises, cools, and moistens, resulting in the formation of clouds and storms. When a warm front approaches, it tends to slide over the cold air over a broad zone, resulting in a few days of increasing cloudiness and slow steady rain. When two air masses are unable to move, a stationary front forms. As a result, the same weather system stays in the area until one of the air masses begins to move. An occluded front forms when one cold front slides under another cool area, lifting the "front"-the contact between the air masses-off the ground. The occlusion occurs when the cold front overtakes the warm front.

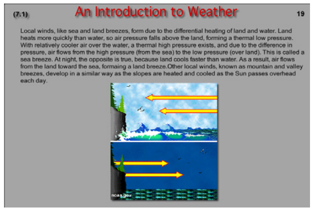



7.1.17

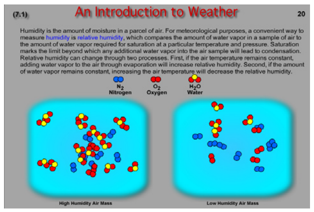
Winds occur as a consequence of a pressure gradient. Air accelerates from areas of high pressure to areas of low pressure. Superimposed over this pressure gradient effect is the Coriolis Effect, created by Earth's rotation. As Earth rotates, the flow of air is deflected to the right in the Northern Hemisphere. In the Southern Hemisphere, the flow of air is deflected to the left. Friction must also be considered to fully understand winds, but it is important only when talking about winds that are in contact with Earth's surface.




7.1.18
Most people are concerned only with the winds that blow in the lowest regions of the atmosphere. However, high- altitude (or geostrophic) winds are also important when considering weather and climate. Geostrophic winds occur above the atmospheric boundary layer where friction becomes negligible. These winds are the result of the balance between the pressure gradient force and the Coriplis Effect. Jet streams are examples of important geostrophic winds.



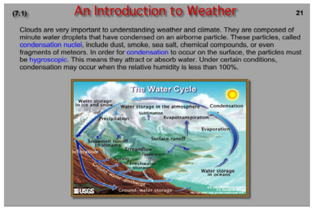

7.1.19
Local winds, like sea and land breezes, form due to the differential heating of land and water. Land heats more quickly than water, so air pressure falls above the land, forming a thermal low pressure. With relatively cooler air over the water, a thermal high pressure exists, and due to the difference in pressure, air flows from the high pressure (from the sea) to the low pressure (over land). This is called a sea breeze. At night, the opposite is true, because land cools faster than water. As a result, air flows from the land toward the sea, forming a land breeze. Other local winds, known as mountain and valley breezes, develop in a similar way as the slopes are heated and cooled as the Sun passes overhead each day.



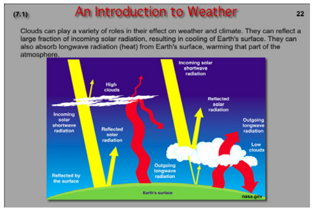

7.1.20
Humidity is the amount of moisture in a parcel of air. For meteorological purposes, a convenient way to measure humidity is relative humidity, which compares the actual amount of water vapor in a sample of air to the maximum amount of water vapor required for saturation at a particular temperature and pressure. Saturation marks the limit beyond which any additional water vapor into the air sample will lead to condensation.

Relative humidity can change through two processes. First, if the air temperature remains constant, adding water vapor to the air through evaporation will increase relative humidity. Second, if the amount of water vapor remains constant, increasing the air temperature will decrease the relative humidity.

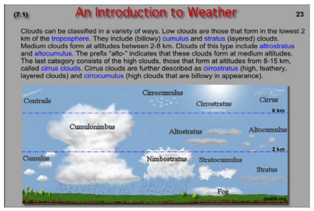
## Notes



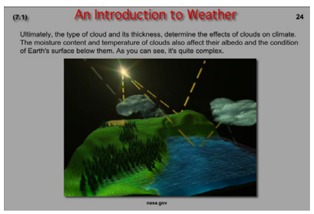

7.1.21
Clouds are very important to understanding weather and climate. They are composed of minute water droplets that have condensed on an airborne particle. These particles, called condensation nuclei, include: dust, smoke, sea salt, chemical compounds, or even fragments of meteors. In order for condensation to occur on the surface, the particles must be hygroscopic. This means they attract or absorb water. Under certain conditions, condensation may occur when the relative humidity is less than 100%.




7.1.22
Clouds can play a variety of roles in their effect on weather and climate. They can reflect a large fraction of incoming solar radiation, resulting in cooling of Earth's surface. They can also absorb longwave radiation (heat) from Earth's surface, warming that part of the atmosphere.

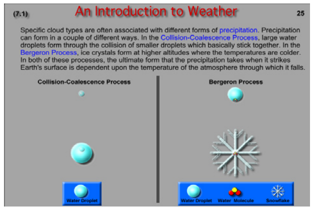



7.1.23
Clouds can be classified in a variety of ways. Low clouds are those that form in the lowest 2 km of the troposphere. They include (billowy) cumulus and stratus (layered) clouds. Medium clouds form at altitudes between 2-8 km. Clouds of this type include altostratus and altocumulus. The prefix "alto-" indicates that these clouds form at medium altitudes. The last category consists of the high clouds, those that form at altitudes from 8-15 km, called cirrus clouds. Cirrus clouds are further described as cirrostratus (high, feathery, layered clouds) and cirrocumulus (high clouds that are billowy in appearance).




7.1.24
Ultimately, the type of cloud and its thickness determine the effects of clouds on climate. The moisture content and temperature of clouds also affect their albedo and the condition of Earth's surface below them. As you can see, it's quite complex.

# Notes




7.1.25

Precipitation

Specific cloud types are often associated with different forms of precipitation. Precipitation can form in a couple of different ways. In the Collision-Coalescence Process, large water droplets form through the collision of smaller droplets which basically stick together. In the Bergeron Process, ice crystals form at higher altitudes where the temperatures are colder. In both of these processes, the ultimate form that the precipitation takes when it strikes Earth's surface is dependent upon the temperature of the atmosphere through which it falls.


7.1.26

This combination of events results in the many different types of precipitation that fall upon Earth, from rain to snow, hail, sleet, and freezing rain.


7.1.27

SUMMARY (page 1)

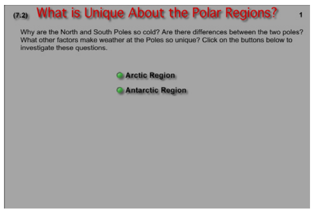
- It is important to remember that weather describes the current conditions of the atmosphere, whereas climate describes the conditions of the atmosphere over a long period of time.
- The angle at which the Sun's rays strike Earth varies with latitude. As latitude increases, the angle of insolation and the absorption of solar radiation decreases.
- The oceans and atmosphere store and transport energy.
- Clouds play a major role in reflecting energy away from Earth. They also trap energy close to Earth's surface, acting as insulation.
- Ocean currents transport heat energy toward the poles.
- Cold air is more dense than warm air. As a result, cold air masses tend to be high pressure areas and sink, while less-dense warm air masses tend to be low pressure areas that rise. Pressure is a function of both density and temperature.

## Notes


7.1.28
Summary (page 2)
- High pressure areas tend to bring lower temperatures, decreased moisture, and fair weather.
- Low pressure areas tend to bring an area of warmer temperatures, increased cloudiness, and precipitation.
- There are four types of weather fronts: cold fronts, warm fronts, stationary fronts, and occluded fronts.
- The Coriolis Effect is caused by Earth's rotation on its axis. This causes wind belts in the Northern Hemisphere to be shifted to the right, while wind belts in the Southern Hemisphere are deflected to the left.
- Humidity is a measure of the amount of water vapor in a sample of air.
- The energy transfer that occurs within the water cycle is an important factor in determining weather conditions.
- Cloud types can be used to predict future weather.

### What is Unique About the Polar Regions?

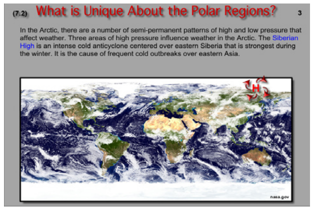
## 7.2




7.2.1
Why are the North and South Poles so cold? Are there differences between the two poles? What other factors make weather at the Poles so unique? Click on the buttons below to investigate these questions.

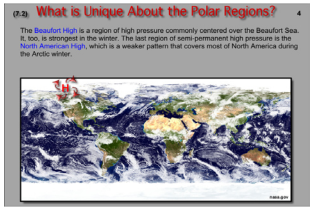

7.2.2
Both the North and South Poles are affected by a polar vortex. The polar vortex is a persistent large-scale cyclonic circulation pattern in the mid- to upper-troposphere and stratosphere, centered over the pole. The Arctic polar vortex is not symmetrical and features an elongated area of low pressure, called a trough, which extends over eastern North America.

# Notes



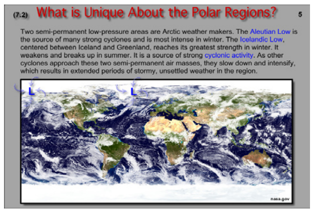

7.2.3

In the Arctic, there are a number of semi-permanent patterns of high and low pressure that affect weather. Three areas of high pressure influence weather in the Arctic. The Siberian High is an intense cold anticyclone centered over eastern Siberia that is strongest during the winter. It is the cause of frequent cold outbreaks over eastern Asia.




7.2.4

The Beaufort High is a region of high pressure commonly centered over the Beaufort Sea. It, too, is strongest in the winter. The last region of semi-permanent high pressure is the North American High, which is a weaker pattern that covers most of North America during the Arctic winter.



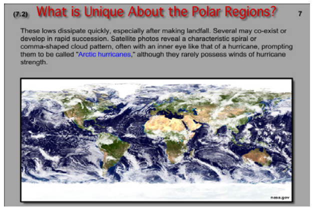

7.2.5

Two semi-permanent low-pressure areas are Arctic weather makers. The Aleutian Low is the source of many strong cyclones and is most intense in winter. The Icelandic Low, centered between Iceland and Greenland, reaches its greatest strength in winter. It weakens and breaks up in summer. It is a source of strong cyclonic activity. As other cyclones approach these two semi-permanent air masses, they slow down and intensify, which results in extended periods of stormy, unsettled weather in the region.

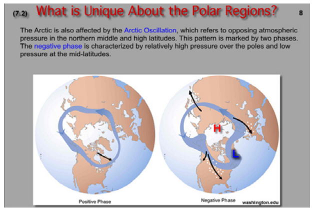

7.2.6

Shorter episodes of low-pressure conditions also affect weather in the Arctic. These polar lows are small, in comparison to the semi-permanent Aleutian and Icelandic lows. These smaller lows are usually only several hundred kilometers in diameter and typically possess strong winds. They form beneath cold upper-level troughs when frigid Arctic air flows southward over warm open water. They develop rapidly, reaching their peak strength in 12-24 hours, and are of short duration, lasting only 1-2 days.

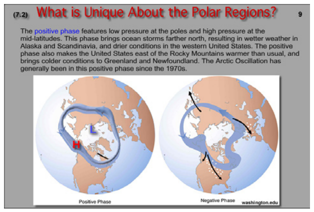
# Notes




7.2.7
These lows dissipate quickly, especially after making landfall. Several may co-exist or develop in rapid succession. Satellite photos reveal a characteristic spiral or comma-shaped cloud pattern, often with an inner eye like that of a hurricane, prompting them to be called "Arctic hurricanes," although they rarely possess winds of hurricane strength.




7.2.8
The Arctic is also affected by the Arctic Oscillation, which refers to opposing atmospheric pressure in the northern middle and high latitudes. This pattern is marked by two phases. The negative phase is characterized by relatively high pressure over the poles and low pressure at the mid-latitudes.



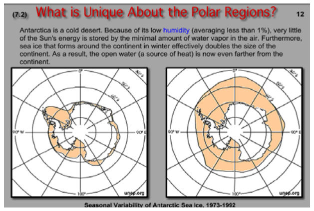

7.2.9
The positive phase features low pressure at the poles and high pressure at the mid-latitudes. This phase brings ocean storms farther north, resulting in wetter weather in Alaska and Scandinavia, and drier conditions in the western United States. The positive phase also makes the United States east of the Rocky Mountains warmer than usual, and brings colder conditions to Greenland and Newfoundland. The Arctic Oscillation has generally been in this positive phase since the 1970s.


7.2.10
What about Antarctica? Like the Arctic region, Antarctica also possesses a polar vortex. The Antarctic polar vortex is more symmetrical than the Arctic polar vortex. This results in cloud, wind, and weather patterns that are unique to Antarctica.

# Notes

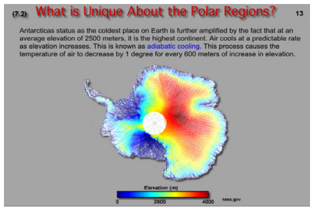

7.2.11

Antarctic weather varies dramatically from the interior of the continent to the coast. Because of the size of the continent, much of the interior of Antarctica does not benefit from the moderating effect of the oceans. Furthermore, the formation of additional sea ice around the continent in winter puts open water even farther from the interior. With 98% of its surface perennially covered by ice and snow, most of the Sun's radiation is reflected, rather than absorbed.



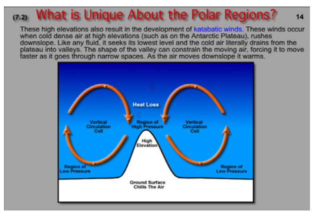

7.1.12

Antarctica is a cold desert. Because of its low humidity (averaging less than 1%), very little of the Sun's energy is stored by the minimal amount of water vapor in the air. Furthermore, sea ice that forms around the continent in winter effectively doubles the size of the continent. As a result, the open water (a source of heat) is now even farther from the continent.




7.2.13

Antarctica's status as the coldest place on Earth is further amplified by the fact that at an average elevation of 2500 meters, it is the highest continent. Air cools at a predictable rate as elevation increases. This is known as adiabatic cooling. This process causes the temperature of air to decrease by 1 degree C. for every 600 meters of increase in elevation.

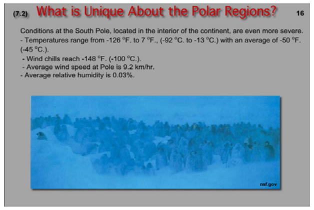



7.2.14

These high elevations also result in the development of katabatic winds. These winds occur when cold dense air at high elevations (such as on the Antarctic Plateau), rushes downslope. Like any fluid, it seeks its lowest level and the cold air literally drains from the plateau into valleys. The shape of the valley can constrain the moving air, forcing it to move faster as it goes through narrow spaces. As the air moves downslope it warms.

# Notes


7.2.15
All of these factors combine to make Antarctica the coldest, highest, windiest, driest, and iciest continent on Earth.
By the numbers....
- Coldest: The annual average temperature of the polar plateau is -58 °F. (-50 °C.).
- Highest: The average elevation of the continent is 2500 meters.
- Windiest: Wind speeds can reach 320 km/hr along Commonwealth Bay due to katabatic winds.
- Driest: The continent averages less than 5 cm/yr of liquid precipitation equivalent.
- Iciest: Ice covers 98% of the continent, and reaches a thickness of 4,775 m on Wilkes Land.



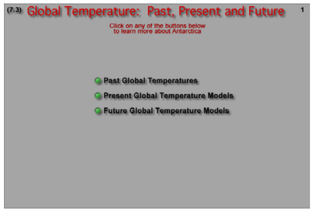

7.2.16
Conditions at the South Pole, located in the interior of the continent, are even more severe.
- Temperatures range from -126 °F. to 7 °F., (-92 °C. to -13 °C.) with an average of -50 °F. (-45 °C.).
- Wind chills reach -148 °F. (-100 °C.).
- Average wind speed at the South Pole is 9.2 km/hr.
- Average relative humidity is 0.03%.


7.2.17
Summary
The North Pole and South Pole have similarities and differences.
Similarities:
Both poles are in areas of expansive snow and ice, experience bitterly cold temperatures, and sunlight (or darkness) for months at a time.
Differences:
- The North Pole is in the Arctic Ocean, which is surrounded by land. Changing amounts of sea ice from year to year affect the Arctic climate, because open water absorbs more solar energy, which is re-radiated into the atmosphere. The biosphere at the North Pole is represented by the polar marine food web.
- The South Pole is located on a large continent that is 98% covered by snow and ice. The ice sheet at the Pole has a high albedo, low heat con-

ductivity, lower heat capacity, and high average elevation. The biosphere is represented by scientists on the surface of the ice sheet and microbes in the ice and rock.

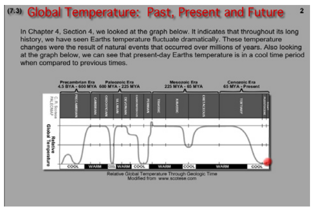
## Global Temperature: Past, Present and Future

7.3

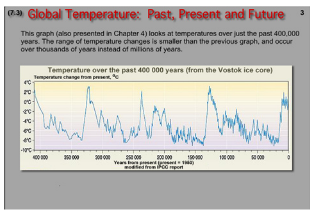



Click on any of the buttons below to learn more about each topic.

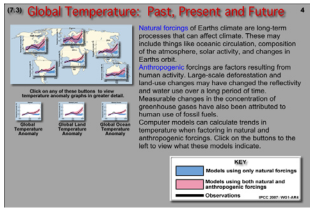
- Past Global Temperatures
- Present Global Temperature Models
- Future Global Temperature Models




7.3.2
In Chapter 4, Section 4, we looked at the graph below. It indicates that throughout its long history, we have seen Earth's temperature fluctuate dramatically. These temperature changes were the result of natural events that occurred over millions of years. Also looking at the graph below, we can see that present-day Earth's temperature is in a cool time period when compared to previous times.




7.3.3
This graph (also presented in Chapter 4) looks at temperatures over just the past 400,000 years. The range of temperature changes is smaller than the previous graph, and occur over thousands of years instead of millions of years.




7.3.4

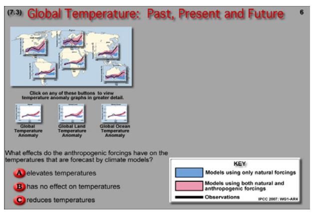
Natural forcings of Earth's climate are long-term processes that can affect climate. These may include things like oceanic circulation, composition of the atmosphere, solar activity, and changes in Earth's orbit.

Anthropogenic forcings are factors resulting from human activity. Large-scale deforestation and land-use changes may have changed the reflectivity and water use over a long period of time. Measurable changes in the concentration of greenhouse gases have also been attributed to human use of fossil fuels.

Computer models can calculate trends in temperature when factoring in natural and anthropogenic forcings. Click on the buttons to the left to view what these models indicate.

Click on any of these buttons to view temperature anomaly graphs in greater detail.

Global Temperature Anomaly
Global Land Temperature Anomaly
Global Ocean Temperature Anomaly

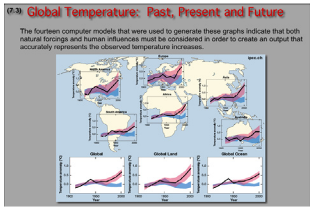



7.3.6

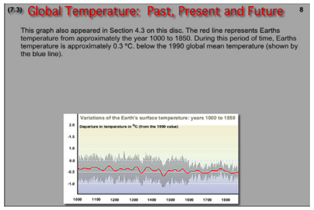
The black line represents the observed temperatures, averaged for each continent, the global land surface, the global ocean surface, and the entire globe. The blue area shows the range of model outputs when only natural forcings are used in the computer model equations. The pink area shows the range of model outputs when both natural and anthropogenic forcings are used in the computer models.

Outputs from computer models that use _____ forcings are best able to reproduce the observed temperature changes.

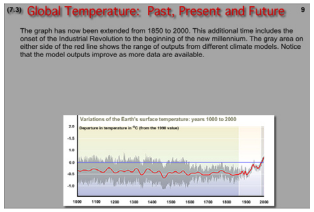
A) only natural
B) only anthropogenic
C) both natural and anthropogenic



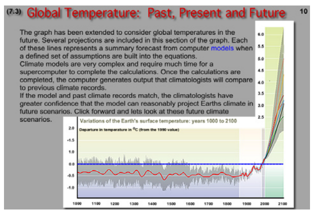

7.3.7
The fourteen computer models that were used to generate these graphs indicate that both natural forcings and human influences must be considered in order to create an output that accurately represents the observed temperature increases.




7.3.8 *(in the Future section)
This graph also appeared in Section 4.3 on this disc. The red line represents Earth's temperature from approximately the year 1000 to 1850. During this period of time, Earth's temperature is approximately 0.3 ºC. below the 1990 global mean temperature (shown by the blue line).




7.3.9
The graph has now been extended from 1850 to 2000. This additional time includes the onset of the Industrial Revolution to the beginning of the new millennium. The gray area on either side of the red line shows the range of outputs from different climate models. Notice that the model outputs improve as more data are available.

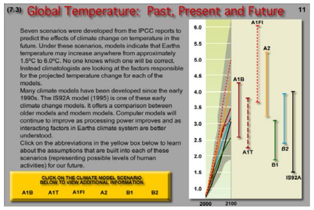



7.3.10
The graph has been extended to consider global temperatures in the future. Several projections are included in this section of the graph. Each of these lines represents a summary forecast from computer models when a defined set of assumptions are built into the equations.

Climate models are very complex and require much time for a supercomputer to complete the calculations. Once the calculations are completed, the computer generates output that climatologists will compare to previous climate records.

If the model and past climate records match, the climatologists have greater confidence that the model can reasonably project Earth's climate in future scenarios. Click forward and let's look at these future climate scenarios.

# Notes

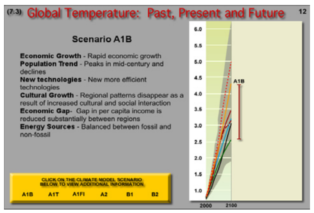



7.3.11

Seven scenarios were developed from the IPCC reports, to predict the effects of climate change on temperature in the future. Under these scenarios, models indicate that Earth's temperature may increase anywhere from approximately 1.5 ºC to 6.0 ºC by the year 2100. No one knows which scenario will be more correct. Instead climatologists are looking at the factors responsible for the projected temperature change for each of the models.

Many climate models have been developed since the early 1990s. The IS92A model (1995) is one of these early climate change models. It offers a comparison between older models and modern models. Computer models will continue to improve as processing power improves and as interacting factors in Earth's climate system are better understood.

Click on the abbreviations in the yellow box below to learn about the assumptions that are built into each of these scenarios (representing possible levels of human activities) for our future.




7.3.12

Scenario A1B

Economic Growth - Rapid economic growth

Population Trend – Peaks in mid-century and declines

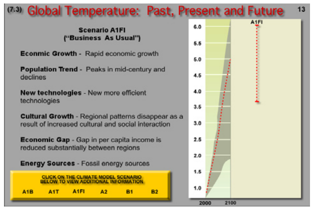
New technologies – New, more-efficient technologies

Cultural Growth – Regional patterns disappear as a result of increased cultural and social interaction

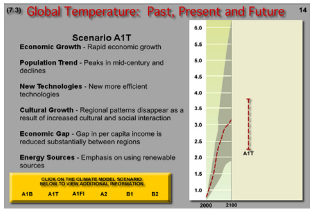
Economic Gap – Gap in per capita income is reduced substantially between regions

Energy Sources – Balanced between fossil and non-fossil

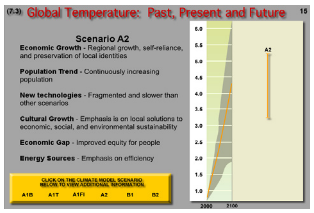
# Notes



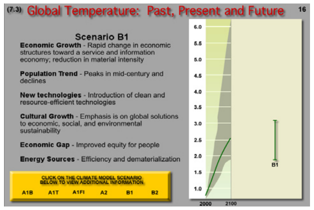

7.3.13
Scenario A1FI
(“Business  As Usual”)
Econmic Growth – Rapid economic growth
Population Trend – Peaks in mid-century and declines
New technologies – New, more-efficient technologies
Cultural Growth – Regional patterns disappear as a result of increased cultural and social interaction
Economic Gap – Gap in per capita income is reduced substantially between regions
Energy Sources – Fossil energy sources



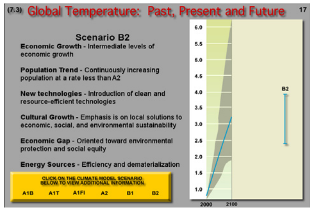

7.3.14
Scenario A1T
Economic Growth – Rapid economic growth
Population Trend – Peaks in mid-century and declines
New Technologies – New, more-efficient technologies
Cultural Growth – Regional patterns disappear as a result of increased cultural and social interaction
Economic Gap – Gap in per capita income is reduced substantially between regions
Energy Sources – Emphasis on using renewable sources



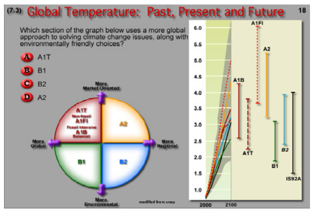

7.3.15
Scenario A2
Economic Growth – Regional growth, self-reliance, and preservation of local identities
Population Trend – Continuously increasing population
New technologies – Fragmented and slower than other scenarios
Cultural Growth – Emphasis is on local solutions to economic, social, and environmental sustainability
Economic Gap – Improved equity for people
Energy Sources – Emphasis on efficiency




7.3.16
Scenario B1
Economic Growth – Rapid change in economic structures toward a service and information economy; reduction in material intensity
Population Trend – Peaks in mid-century and declines
New technologies – Introduction of clean and resource-efficient technologies
Cultural Growth – Emphasis is on global solutions to economic, social, and environmental sustainability
Economic Gap – Improved equity for people
Energy Sources – Efficiency and dematerialization

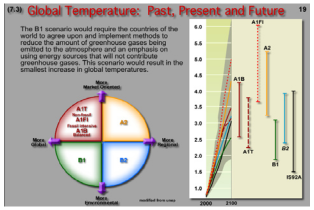



7.3.17
Scenario B2
Economic Growth – Intermediate levels of economic growth
Population Trend – Continuously increasing population at a rate less than A2
New technologies – Introduction of clean and resource-efficient technologies
Cultural Growth – Emphasis is on local solutions to economic, social, and environmental sustainability
Economic Gap – Oriented toward environmental protection and social equity
Energy Sources – Efficiency and dematerialization

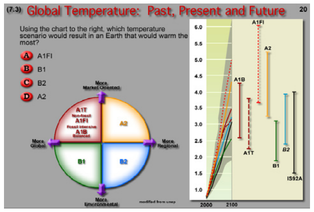



7.3.18
Which section of the graph below uses a more global approach to solving climate change issues, along with environmentally-friendly choices?
A) red
B) green
C) orange
D) red

## Notes

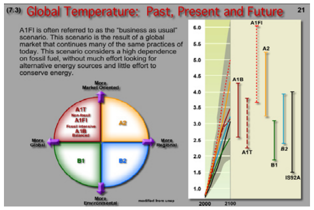



7.3.19
The B1 scenario (in the green quadrant) would require the countries of the world to agree upon and implement methods to reduce the amount of greenhouse gases being emitted to the atmosphere and an emphasis on using energy sources that will not contribute greenhouse gases. This scenario would result in the smallest increase in global temperatures.




7.3.20
Using the chart to the right, which temperature scenario would result in an Earth that would warm the most?

A) A1FI
B) B1
C) B2
D) A2




7.3.21
A1FI is often referred to as the “business as usual” scenario. This scenario is the result of a global market that continues many of the same practices of today. This scenario considers a high dependence on fossil fuel, without much effort looking for alternative energy sources and little effort to conserve energy.


7.3.22
Summary

-Earth’s climate has changed dramatically over very long periods of time (millions of years).
-Fossils and other types of evidence indicate that climate has also changed dramatically over periods of thousands of years.
- Scientists develop climate projections by creating scenarios for change, based on facts such as energy consumption patterns, economic growth, and population trends. Computer models are programmed and then run to see how well they reconstruct known climate events of the past. If they predict the past well, then scientists have more confidence about how well the model might predict the future.
- According to the Intergovernmental Panel on Climate Change (IPCC)

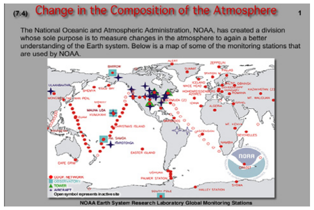
Notes

reports, computer models project that Earth's temperature may increase from 2 ºC. to 6 ºC. by end of the 21st century.

-Assumptions about a range of priorities are built into the computer models in order to consider the most likely temperature changes that may occur in the 21st century.

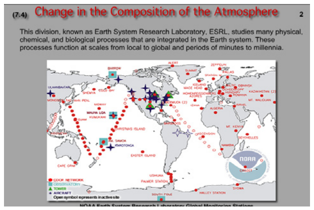
## Change in the Composition of the Atmosphere

### 7.4



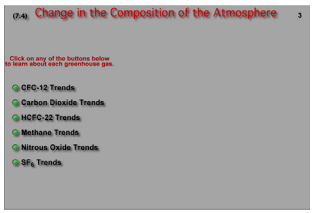

7.4.1

The National Oceanographic and Atmospheric Administration, NOAA, has created a division whose sole purpose is to measure changes in the atmosphere, to gain a better understanding of the Earth system. Below is a map of some of the monitoring stations that are used by NOAA.



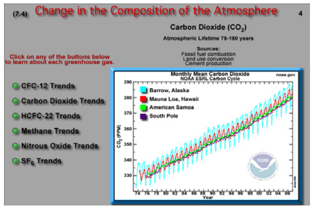

7.4.2

This division, known as Earth System Research Laboratory, ESRL, studies many physical, chemical, and biological processes that are integrated in the Earth system. These processes function at scales from local to global and periods of minutes to millennia.



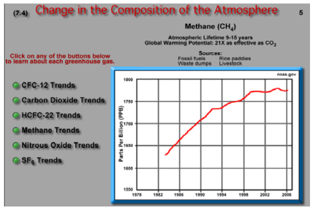

7.4.3 Click on any of the buttons below to learn about each greenhouse gas.

- CFC-12 Trends
- Carbon Dioxide Trends
- HCFC – 22 Trends
- Methane Trends
- Nitrous Oxide Trends
- $SF_6$ Trends



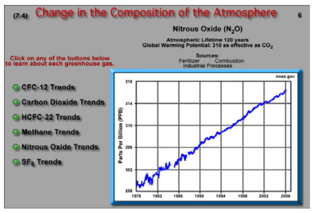

7.4.4
Carbon Dioxide ($CO_2$)
Atmospheric Lifetime: 75-150 years

Sources:
Fossil fuel combustion
Land use conversion
Cement production




7.4.5
Methane ($CH_4$)
Atmospheric Lifetime: 9 – 15 years
Global Warming Potential: 21X as effective as $CO_2$

Sources:
Fossil fuels Rice paddies
Waste dumps Livestock

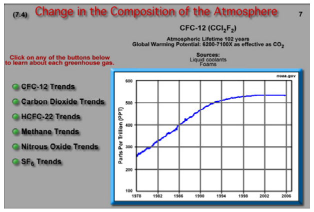



7.4.6
Nitrous Oxide ($N_2O$)

Atmospheric Lifetime: 120 years
Global Warming potential: 310X as effective as $CO_2$

Sources:
Fertilizer Combustion
Industrial Processes

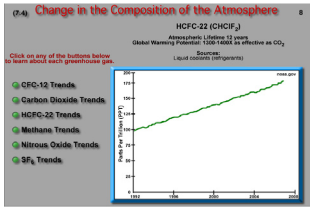
# Notes




7.4.7
CFC – 12 ($CCl_2F_2$)

Atmospheric Lifetime:  102 years
Global Warming Potential: 6200-7100X as effective as $CO_2$

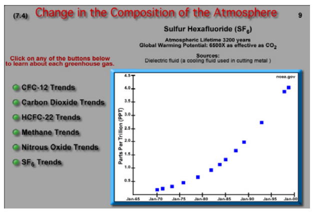
Sources:
Liquid coolants
Foams




7.4.8
HCFC-22 ($CHClF_2$)

Atmospheric Lifetime:  12 years
Global Warming Potential: 1300-1400X as effective as $CO_2$

Sources:
Liquid coolants (refrigerants)




7.4.9
Sulfur Hexafluoride ($SF_6$)

Atmospheric Lifetime:  3200 years
Global Warming Potential:  6500X as effective as $CO_2$

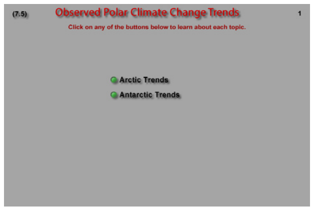
Sources:
Dielectric fluid (a cooling fluid used in cutting metal)

Notes


7.4.10
Summary
-NOAA is just one of many agencies or institutions that monitor the composition of Earth's atmosphere.
- Concentrations of major greenhouse gases have been on the increase for many years.
- Greenhouse gases are measured as a very small percentage of the gases in Earth's atmosphere.
- Greenhouse gases are usually measured in parts per million or parts per billion by volume.
- Greenhouse gases have different residence times in the atmosphere and different potential to help Earth retain heat energy.
- Greenhouse gas concentrations have been increasing due to human activity and natural processes.

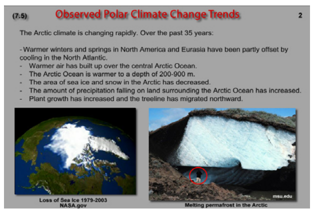
## Observed Polar Climate Change Trends

## 7.5




7.5.1
Click on one of the buttons below to learn about that topic.

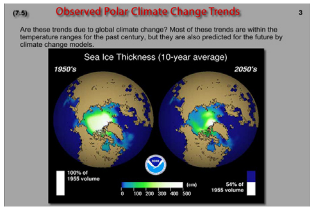
- Arctic Trends
- Antarctic Trends



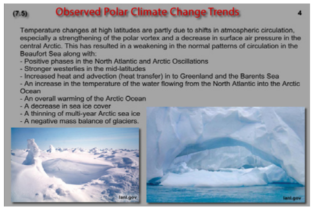

7.5.2
The Arctic climate is changing rapidly. Over the past 35 years:

- Warmer winters and springs in North America and Eurasia have been partly offset by cooling in the North Atlantic.
- Warmer air has built up over the central Arctic Ocean.
- The Arctic Ocean is warmer to a depth of 200-900 m.
- The area of sea ice and snow in the Arctic has decreased.
- The amount of precipitation falling on land surrounding the Arctic Ocean has increased.
- Plant growth has increased and the treeline has migrated northward.

# Notes



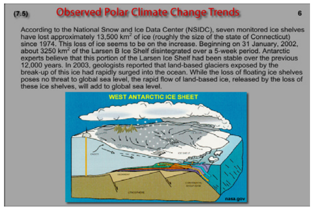

7.5.3
Are these trends due to global climate change? Most of these trends are within those observed within the temperature ranges for the past century, but they are also predicted for the future by climate change models.



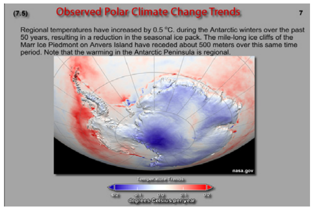

7.5.4
Temperature changes at high latitudes are partly due to shifts in atmospheric circulation, especially a strengthening of the polar vortex and a decrease in surface air pressure in the central Arctic. This has resulted in a weakening in the normal patterns of circulation in the Beaufort Sea along with:

- Positive phases in the North Atlantic and Arctic Oscillations
- Stronger westerlies in the mid-latitudes
- Increased heat and advection (heat transfer) to Greenland and the Barents Sea
- An increase in the temperature of the water flowing from the North Atlantic into the Arctic Ocean
- An overall warming of the Arctic Ocean
- A decrease in sea ice cover
- A thinning of multi-year Arctic sea ice
- A negative mass balance of glaciers.

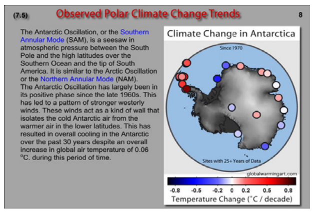

7.5.5 (Antarctic Trends)
Accurately describing the situation in the Antarctic is more difficult due to the lack of good weather data prior to 1957--the First International Geophysical Year (IGY). Whereas temperature data from the Arctic region come from many weather stations, there are only about 100 weather stations in the Antarctic that can provide data over the past 50 years. Considering the vast size of the Antarctic continent, the distribution of those 100 weather stations gives us a very limited dataset on which to base predictions.




7.5.6
According to the National Snow and Ice Data Center (NSIDC), seven monitored ice shelves have lost approximately 13,500 km$^2$ of ice (roughly the size of the state of Connecticut) since 1974. This loss of ice seems to be on the increase. Beginning on January 31, 2002, about 3250 km$^2$ of the Larsen B Ice Shelf disintegrated over a 5-week period. Antarctic experts believe that this portion of the Larsen Ice Shelf had been stable over the previous 12,000 years. In 2003, geologists reported that land-based glaciers exposed by the break-up of this ice had rapidly surged into the ocean. While the loss of floating ice shelves poses no threat to global sea level, the rapid flow of land-based ice, released by the loss of these ice shelves, will add to global sea level.

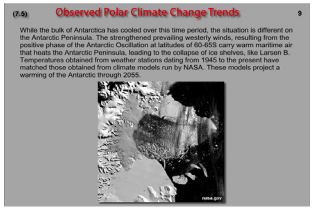



7.5.7
Regional temperatures have increased by 0.5 ºC. during the Antarctic winters over the past 50 years, resulting in a reduction in the seasonal ice pack. The mile-long ice cliffs of the Marr Ice Piedmont on Anvers Island have receded about 500 meters over this same time period. Note that the warming in the Antarctic Peninsula is regional.



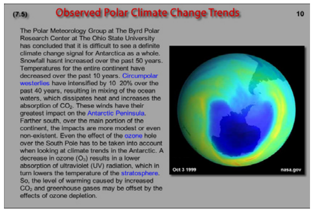

7.5.8
The Antarctic Oscillation, or the Southern Annular Mode (SAM), is a see-saw in atmospheric pressure between the South Pole and the high latitudes over the Southern Ocean and the tip of South America. It is similar to the Arctic Oscillation or the Northern Annular Mode (NAM).

The Antarctic Oscillation has largely been in its positive phase since the late 1960s. This has led to a pattern of stronger westerly winds. These winds act as a kind of wall that isolates the cold Antarctic air from the warmer air in the lower latitudes. This has resulted in overall cooling in the Antarctic over the past 30 years despite an overall increase in global air temperature of 0.06 ºC. during this period of time.



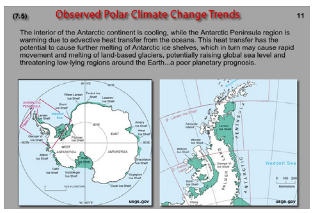

7.5.9

While the bulk of Antarctica has cooled over this time period, the situation is different on the Antarctic Peninsula. The strengthened prevailing westerly winds, resulting from the positive phase of the Antarctic Oscillation at latitudes of 60-65 ºS carry warm, maritime air that heats the Antarctic Peninsula, leading to the collapse of ice shelves, like Larsen B. Temperatures obtained from weather stations dating from 1945 to the present have matched those obtained from climate models run by NASA. These models project a warming of the Antarctic through 2055.




7.5.10

The Polar Meteorology Group at The Byrd Polar Research Center at The Ohio State University has concluded that it is difficult to see a definite climate change signal for Antarctica as a whole. Snowfall hasn't increased over the past 50 years. Temperatures for the entire continent have decreased over the past 10 years. Circumpolar westerlies have intensified by 10 – 20% over the past 40 years, resulting in mixing of the ocean waters, which dissipates heat and increases the absorption of $CO_2$. These winds have their greatest impact on the Antarctic Peninsula. Farther south, over the main portion of the continent, the impacts are more modest or even non-existent. Even the effect of the ozone hole over the South Pole has to be taken into account when looking at climate trends in the Antarctic. A decrease in ozone ($O_3$) results in a lower absorption of ultraviolet (UV) radiation, which in turn lowers the temperature of the stratosphere. So, the level of warming caused by increased $CO_2$ and greenhouse gases may be offset by the effects of ozone depletion.




7.5.11

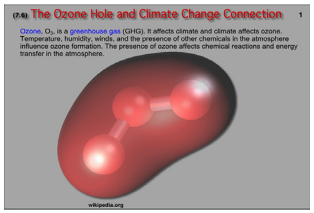
The interior of the Antarctic continent is cooling, while the Antarctic Peninsula region is warming due to advective heat transfer from the oceans. This heat transfer has the potential to cause further melting of Antarctic ice shelves, which in turn may cause rapid movement and melting of land-based glaciers, potentially raising global sea level and threatening low-lying regions around the Earth...a poor planetary prognosis.

## Notes


7.5.12
Summary
- The climate in the Arctic region is changing. The Arctic Ocean is warming, permafrost is thawing, and precipitation in the region is decreasing.
- The climate in the Antarctic region is also changing. Ice shelves on the Antarctic Peninsula have collapsed, temperatures on the shoreline are increasing, and weather patterns are changing.
- Stronger positive feedback loops (phases) are now the controlling factors in these regions.
- Even though the statements above may seem to indicate a doomsday outlook, it should be noted that some natural processes may reduce the predicted effects of global climate change. These natural processes are not yet fully understood by scientists.

## The Ozone Hole and Climate Change Connection

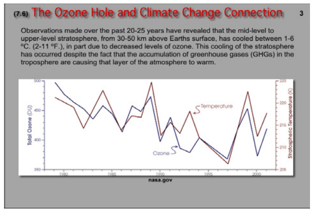
## 7.6



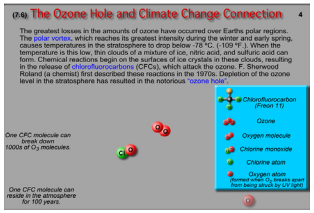

7.6.1
Ozone, $O_3$, is a greenhouse gas (GHG). It affects climate, and climate affects ozone. Temperature, humidity, winds, and the presence of other chemicals in the atmosphere influence ozone formation. The presence of ozone affects chemical reactions and energy transfer in the atmosphere.


7.6.2
Ozone generates heat in the atmosphere in two ways. Ozone absorbs ultraviolet (UV) radiation from the Sun as well as long-wave or infrared (IR) radiation from the troposphere. Reduced levels of ozone in the stratosphere result in lower temperatures at that altitude and more UV passing through to Earth's surface.

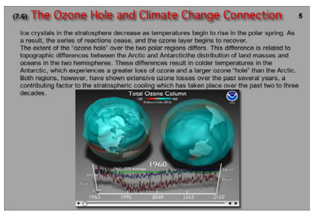
# Notes




7.6.3
Observations made over the past 20-25 years have revealed that the mid-level to upper-level stratosphere, from 30-50 km above Earth's surface, has cooled between 1-6 ºC. (2-11 ºF.), in part due to decreased levels of ozone. This cooling of the stratosphere has occurred despite the fact that the accumulation of greenhouse gases (GHGs) in the troposphere is causing that layer of the atmosphere to warm.



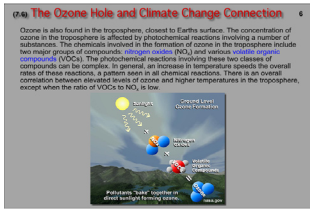

7.6.4
The greatest losses in the amounts of ozone have occurred over Earth's polar regions. The polar vortex, which reaches its greatest intensity during the winter and early spring, causes temperatures in the stratosphere to drop below -78 ºC (-109 ºF). When the temperature is this low, thin clouds of a mixture of ice, nitric acide, and sulfuric acid can form. Chemical reactions begin on the surfaces of ice crystals in these clouds, resulting in the release of chlorofluorocarbons (CFCs), which attack the ozone. F. Sherwood Roland (a chemist) first described these reactions in the 1970s. Depletion of the ozone level in the stratosphere has resulted in the notorious Antarctic "ozone hole".




7.6.5
Ice crystals in the stratosphere decrease as temperatures begin to rise in the polar spring. As a result, the series of reactions cease, and the ozone layer begins to recover.

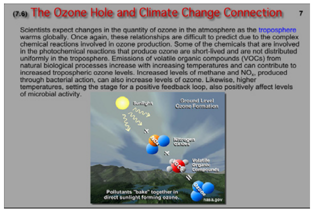
The extent of the "ozone hole" over the two polar regions differs. This difference is related to topographic differences between the Arctic and Antarctic—the distribution of land masses and oceans in the two hemispheres. These differences result in colder temperatures in the Antarctic, which experiences a greater loss of ozone and a larger ozone "hole" than the Arctic. Both regions, however, have shown extensive ozone losses over the past several years, a contributing factor to the stratospheric cooling which has taken place over the past two to three decades.

# Notes



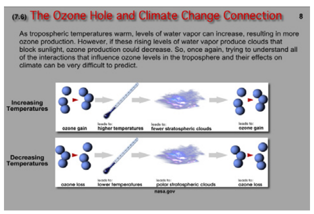

7.6.6

Ozone is also found in the troposphere, closest to Earth's surface. The concentration of ozone in the troposphere is affected by photochemical reactions involving a number of substances. The chemicals involved in the formation of ozone in the troposphere include two major groups of compounds: nitrogen oxides (NOx) and various volatile organic compounds (VOCs). The photochemical reactions involving these two classes of compounds can be complex. In general, an increase in temperature speeds the overall rates of these reactions, a pattern seen in all chemical reactions. There is an overall correlation between elevated levels of ozone and higher temperatures in the troposphere, except when the ratio of VOCs to NOx is low.



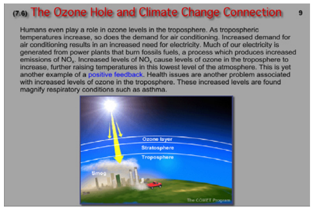

7.6.7

Scientists expect changes in the quantity of ozone in the atmosphere as the troposphere warms globally. Once again, these relationships are difficult to predict due to the complex chemical reactions involved in ozone production. Some of the chemicals that are involved in the photochemical reactions that produce ozone are short-lived and are not distributed uniformly in the troposphere. Emissions of volatile organic compounds (VOCs) from natural biological processes increase with increasing temperatures and can contribute to increased tropospheric ozone levels. Increased levels of methane and NOx, produced through bacterial action, can also increase levels of ozone. Likewise, higher temperatures, setting the stage for a positive feedback loop, also positively affect levels of microbial activity.

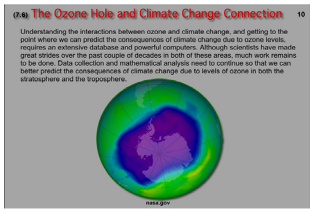



7.6.8

As tropospheric temperatures warm, levels of water vapor can increase, resulting in more ozone production. However, if these rising levels of water vapor produce clouds that block sunlight, ozone production could decrease. So, once again, trying to understand all of the interactions that influence ozone levels in the troposphere and their effects on climate can be very difficult to predict.




7.6.9
Humans even play a role in ozone levels in the troposphere. As tropospheric temperatures increase, so does the demand for air conditioning. Increased demand for air conditioning results in an increased need for electricity. Much of our electricity is generated from power plants that burn fossils fuels, a process which produces increased emissions of NOx. Increased levels of NOx cause levels of ozone in the troposphere to increase, further raising temperatures in this lowest level of the atmosphere. This is yet another example of a positive feedback. Health issues are another problem associated with increased levels of ozone in the troposphere. These increased levels also magnify respiratory conditions such as asthma.




7.6.10
Understanding the interactions between ozone and climate change, and getting to the point where we can predict the consequences of climate change due to ozone levels, requires an extensive database and powerful computers. Although scientists have made great strides over the past couple of decades in both of these areas, much work remains to be done. Data collection and mathematical analysis need to continue so that we can better predict the consequences of climate change due to levels of ozone in both the stratosphere and the troposphere.

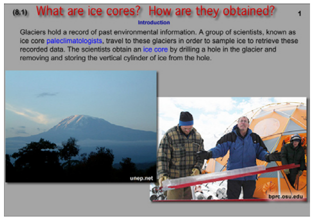

7.6.11
Summary
- Ozone is a greenhouse gas.
- Ozone in the stratosphere helps to block ultraviolet light from the Sun.
- Ozone in the troposphere is a pollutant that causes respiratory problems for some people.
- As Earth's temperature increases, ozone quantities also increase through natural processes.
- Stratospheric ozone is depleted by human activity through introduction of chlorofluorocarbon compounds, which are completely synthetic, into the atmosphere.
- The interactions of ozone in the atmosphere are very complicated.

# Ice Core Evidence

What are ice cores? How are they obtained?

Notes

## 8.1

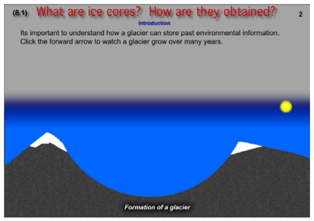



8.1.1

What are ice cores? How are they obtained?

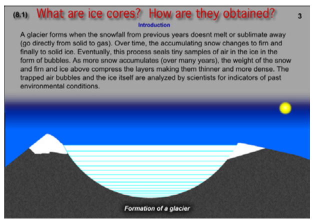
Introduction

Glaciers hold a record of past environmental information. A group of scientists, known as ice core paleoclimatologists, travel to these glaciers in order to sample ice to retrieve these recorded data. The scientists obtain an ice core by drilling into the glacier and removing and storing the vertical cylinder of ice from the drill.




8.1.2

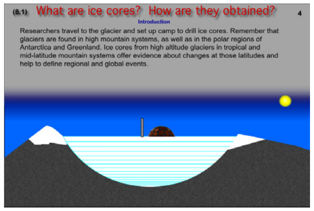
It's important to understand how a glacier can store past environmental information. Click the forward arrow to watch a glacier grow over many years.




8.1.3

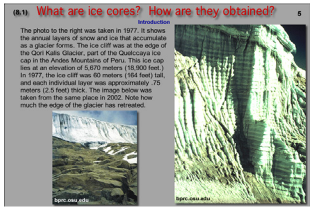
A glacier forms when the snowfall from previous years doesn't melt or sublimate away (go directly from solid to gas). Over time, the accumulating snow changes to firn and finally to solid ice. Eventually, this process seals tiny samples of air in the ice in the form of bubbles. As more snow accumulates (over many years), the weight of the snow and firn and ice compress the lower layers, making them thinner and more dense. The trapped air bubbles and the ice itself are analyzed by scientists for indicators of past environmental conditions.

# Notes



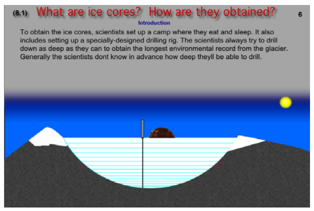

8.1.4

Researchers travel to the glacier and set up camp to drill ice cores. Remember that glaciers are found in high mountain systems, as well as in the polar regions of Antarctica and Greenland. Ice cores from high altitude glaciers in tropical and mid-latitude mountain systems offer evidence about changes at those latitudes and help to define regional and global events.



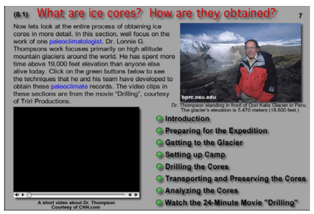

8.1.5

The photo to the right was taken in 1977. It shows the annual layers of snow and ice that accumulate as a glacier forms. The ice cliff was at the edge of the Qori Kalis Glacier, part of the Quelccaya ice cap in the Andes Mountains of Peru. This ice cap lies at an elevation of 5,670 meters (18,900 feet). In 1977, the ice cliff was 60 meters (164 feet) tall, and each individual layer was approximately .75 meters (2.5 feet) thick. The image below was taken from the same place in 2002. Note how much the edge of the glacier has retreated.




8.1.6

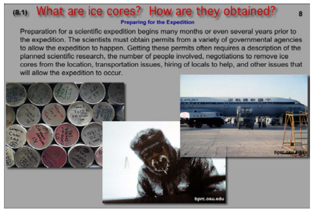
To obtain the ice cores, scientists set up a camp where they eat and sleep. It also includes setting up a specially-designed drilling rig. The scientists always try to drill as deep as they can, to obtain the longest environmental record from the glacier. Generally the scientists don't know in advance how deep they'll be able to drill.




8.1.7

Now let's look at the entire process of obtaining ice cores in more detail. In this section, we'll focus on the work of one paleoclimatologist. Dr. Lonnie G. Thompson's work focuses primarily on high altitude mountain glaciers around the world. He has spent more time above 19,000 feet elevation than anyone else alive today. Click on the green buttons below to see the techniques that he and his team have developed to obtain these paleoclimate records. The video clips in these sections are from the movie "Drilling", courtesy of Triri Productions.

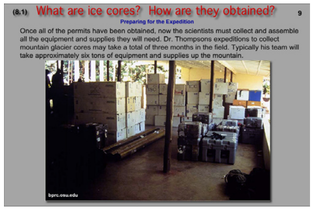
# Notes




8.1.8

Preparing for the Expedition

Preparation for a scientific expedition begins many months or even several years prior to the expedition. The scientists must obtain permits from a variety of governmental agencies to allow the expedition to happen. Getting these permits often requires a description of the planned scientific research, the number of people involved, negotiations to remove ice cores from the location, transportation issues, hiring local people to help, and other issues that will allow the expedition to occur.

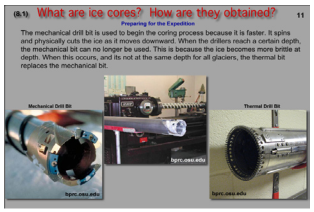



8.1.9

Once all of the permits have been obtained, now the scientists must collect and assemble all the equipment and supplies they will need. Dr. Thompson's expeditions to drill mountain glacier cores may take a total of three months in the field. Typically his team will take approximately six tons of equipment and supplies up the mountain.


8.1.10

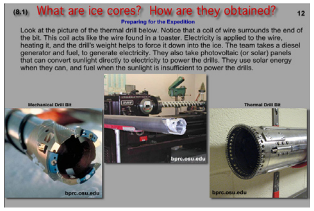
Dr. Thompson uses two types of hollow drill bits to obtain the ice cores. The picture in the center below shows the machine shop at Byrd Polar where they make the drill bits. Each ice core is approximately 11 cm (4 inches) in diameter.



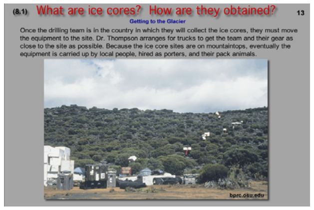

8.1.11

The mechanical drill bit is used to begin the coring process because it is faster. It spins and physically cuts the ice as it moves downward. When the drillers reach a certain depth, the mechanical bit can no longer be used. This is because the ice becomes more brittle at depth. When this occurs, and it's not at the same depth for all glaciers, the thermal bit replaces the mechanical bit.

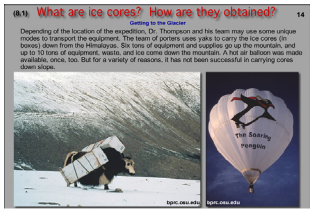
## Notes



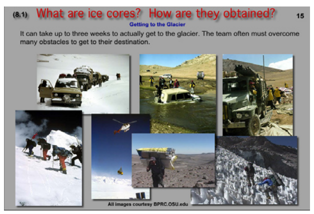

8.1.12
Look at the picture of the thermal drill below. Notice that a coil of wire surrounds the end of the bit. This coil acts like the wire found in a toaster. Electricity is applied to the wire, heating it, and the drill's weight helps to force it down into the ice. The team takes a diesel generator and fuel, to generate electricity. They also take photovoltaic (or solar) panels that can convert sunlight directly to electricity to power the drills. They use solar energy when they can, and fuel when the sunlight is insufficient to power the drills.




8.1.13
Getting to the Glacier
Once the drilling team is in the country in which they will collect the ice cores, they must move the equipment to the site. Dr. Thompson arranges for trucks to get the team and their gear as close to the site as possible. Because the ice core sites are on mountaintops, eventually the equipment is carried up by local people, hired as porters, and their pack animals.

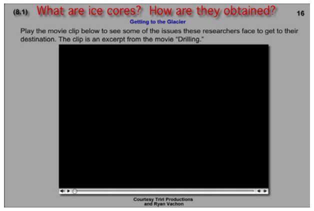



8.1.14
Depending of the location of the expedition, Dr. Thompson and his team may use some unique modes to transport the equipment. The team of porters uses yaks to carry the ice cores (in boxes) down from the Himalayas. Six tons of equipment and supplies go up the mountain, and up to 10 tons of equipment, waste, and ice come down the mountain. A hot air balloon was made available, once, too. But for a variety of reasons, it has not been successful in carrying cores down slope.

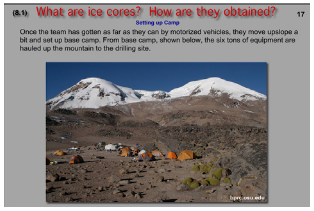



8.1.15
It can take up to three weeks to actually get to the glacier. The team often must overcome many obstacles to get to their destination.

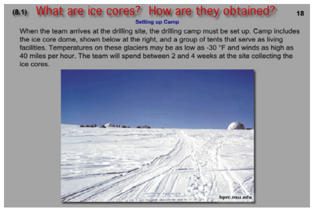
# Notes



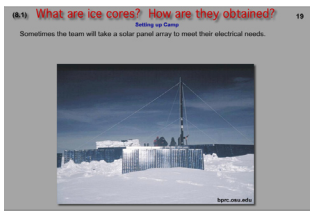

8.1.16
Play the movie clip below to see some of the issues these researchers face to get to their destination. The clip is an excerpt from the movie "Drilling."




8.1.17
Setting up Camp
Once the team has gotten as far as they can by motorized vehicles, they move upslope a bit and set up base camp. From base camp, shown below, the six tons of equipment are hauled up the mountain to the drilling site.

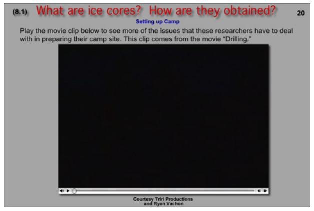



8.1.18
When the team arrives at the drilling site, the drilling camp must be set up. Camp includes the ice core dome, shown below at the right, and a group of tents that serve as living facilities. Temperatures on these glaciers may be as low as -30 °F and winds as high as 40 miles per hour. The team will spend between 2 and 4 weeks at the site collecting the ice cores.



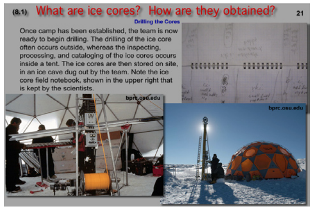

8.1.19
Sometimes the team will take a solar panel array to meet their electrical needs.

# Notes




8.1.20

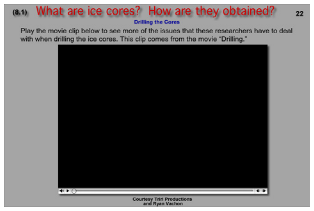
Play the movie clip below to see more of the issues that these researchers have to deal with in preparing their camp site. This clip comes from the movie "Drilling."




8.1.21

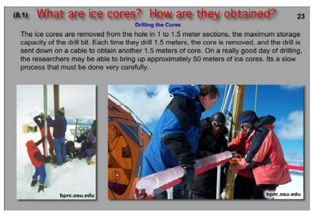
Drilling the Cores

Once camp has been established, the team is now ready to begin drilling. The drilling of the ice core often occurs outside, whereas inspecting, processing, and cataloging of the ice cores occurs inside a tent. The ice cores are then stored on site, in an ice cave dug out by the team. Note the ice core field notebook, shown in the upper right, that is kept by the scientists.



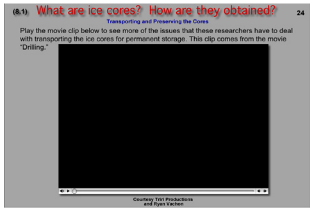

8.1.22

Play the movie clip below to see more of the issues that these researchers have to deal with when drilling the ice cores. This clip comes from the movie "Drilling."



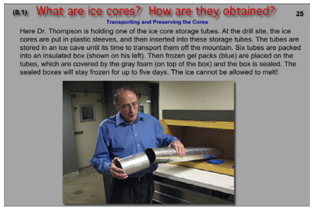

8.1.23

The ice cores are removed from the hole in 1 to 1.5 meter sections, the maximum storage capacity of the drill bit. Each time they drill 1.5 meters, the core is removed, and the drill is sent down on a cable to obtain another 1.5 meters of core. On a really good day of drilling, the researchers may be able to bring up approximately 50 meters of ice cores. It's a slow process that must be done very carefully.

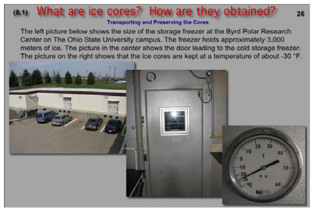



8.1.24
Transporting and Preserving the Cores

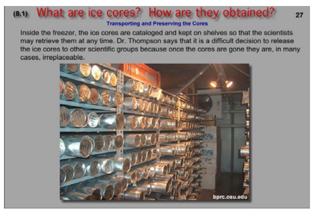
Play the movie clip below to see more of the issues that these researchers have to deal with to transport the ice cores for permanent storage. This clip comes from the movie "Drilling."




8.1.25
Here Dr. Thompson is holding one of the ice core storage tubes. At the drill site, the ice cores are put in plastic sleeves, and then inserted into these storage tubes. The tubes are stored in an ice cave until it's time to transport them off the mountain. Six tubes are packed into an insulated box (shown on his left). Then frozen gel packs (blue) are placed on the tubes, which are covered by the gray foam (on top of the box) and the box is sealed. The sealed boxes will stay frozen for up to five days. The ice cannot be allowed to melt!

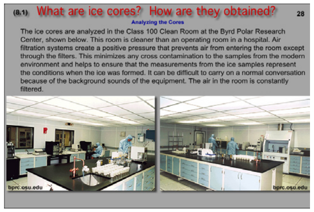



8.1.26
The left picture below shows the size of the storage freezer at the Byrd Polar Research Center on The Ohio State University campus. The freezer holds approximately 7,000 meters of ice. The picture in the center shows the door leading to the cold storage freezer. The picture on the right shows that the ice cores are kept at a temperature of about -30 °F.



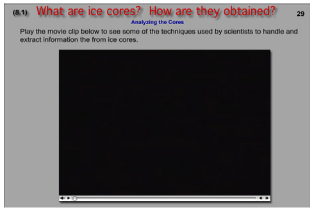

8.1.27
Inside the freezer, the ice cores are cataloged and kept on shelves so that the scientists may retrieve them at any time. Dr. Thompson says that it is a difficult decision to release the ice cores to other scientific groups because once the cores are gone they are, in many cases, irreplaceable.

# Notes




8.1.28
Analyzing the Cores

The ice cores are analyzed in the Class 100 Clean Room at the Byrd Polar Research Center, shown below. The air in this room is cleaner than that found in an operating room in a hospital. Air filtration systems create a positive pressure that prevents air from entering the room except through the filters. This minimizes any cross contamination to the samples from the modern environment and helps to ensure that the measurements from the ice samples represent the conditions when the ice was formed. It can be difficult to carry on a normal conversation because of the background sounds of the equipment. The air in the room is constantly filtered.



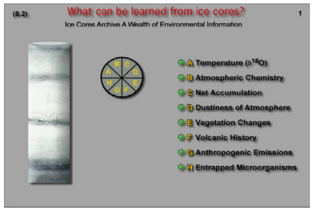

8.1.29
Play the movie clip below to see some of the techniques used by scientists to handle and extract information from the ice cores.


8.1.30
Summary
-A paleoclimatologist is a scientist who studies the past climate conditions of Earth.
-An ice core is a cylinder of ice removed from a glacier. It records the accumulation of snow, ice, and atmospheric conditions over a long period of time.
-An ice core provides evidence to describe past climates, called paleoclimates.
-Samples of the atmosphere are contained in the bubbles within the ice cores.
-Ice cores have been obtained from the ice sheets and glaciers of Greenland and Antarctica, and from many mountain glaciers around the world.
-Obtaining an ice core sample is a time-consuming and difficult process.
-Scientists are trying to obtain as many ice cores samples as possible before the glaciers in key locations are gone.

Notes

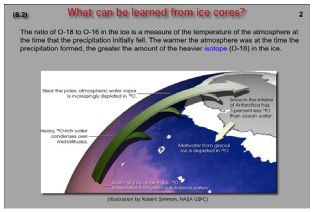
## What can be learned from an ice core?

## 8.2



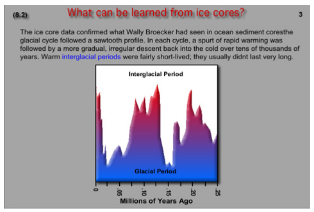

8.2.1
Ice Cores Archive a Wealth of Environmental Information

- A Temperature ($\delta^{18}O$)
- B Atmospheric Chemistry
- C Net Accumulation
- D Dustiness of Atmosphere
- E Vegetation Changes
- F Volcanic History
- G Anthropogenic Emissions
- H Entrapped Microorganisms

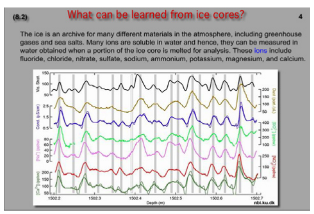



8.2.2
What can be learned from ice cores?

The ratio of (O-18) to (O-16) in the ice is a measure of the temperature of the atmosphere at the time that the precipitation initially fell. The warmer the atmosphere was at the time the precipitation formed, the greater the amount of the heavier isotope (O-18) in the ice.

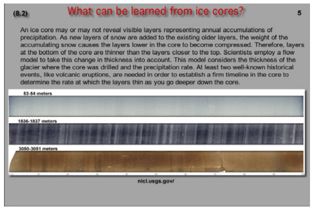



8.2.3
The ice core data confirmed what Wally Broecker had seen in ocean sediment cores—the glacial cycle followed a sawtooth profile. In each cycle, a spurt of rapid warming was followed by a more gradual, irregular descent back into the cold over tens of thousands of years. Warm interglacial periods were fairly short-lived; they usually didn't last very long.



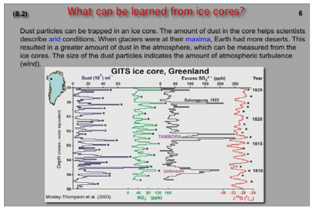

8.2.4
The ice is an archive for many different materials in the atmosphere, including greenhouse gases and sea salts. Many ions are soluble in water and hence, they can be measured in water obtained when a portion of the ice core is melted for analysis. These ions include fluoride, chloride, nitrate, sulfate, sodium, ammonium, potassium, magnesium, and calcium.

# Notes



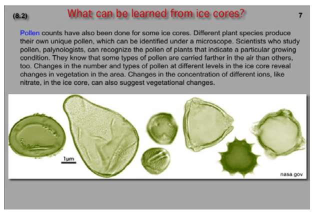

8.2.5

An ice core may or may not reveal visible layers representing annual accumulations of precipitation. As new layers of snow are added to the existing older layers, the weight of the accumulating snow causes the layers lower in the core to become compressed. Therefore, layers at the bottom of the core are thinner than layers closer to the top. Scientists employ a flow model to take this change in thickness into account. This model considers the thickness of the glacier where the core was drilled and the precipitation rate. At least two well-known historical events, like volcanic eruptions, are needed in order to establish a firm timeline in the core to determine the rate at which the layers thin as you go deeper down the core.



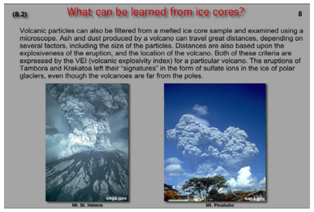

8.2.6

Dust particles can be trapped in an ice core. The amount of dust in the core helps scientists describe arid conditions. When glaciers were at their maxima, Earth had more deserts. This resulted in a greater amount of dust in the atmosphere, which can be measured from the ice cores. The size of the dust particles indicates the amount of atmospheric turbulence (wind).



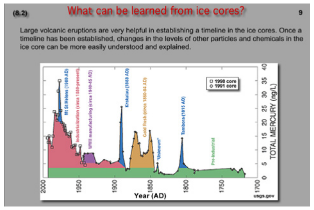

8.2.7

Pollen counts have also been done for some ice cores. Different plant species produce their own unique pollen, which can be identified under a microscope. Scientists who study pollen, palynologists, can recognize the pollen of plants that indicate a particular growing condition. They know that some types of pollen are carried farther in the air than others, too. Changes in the number and types of pollen at different levels in the ice core reveal changes in vegetation in the area. Changes in the concentration of different ions, like nitrate, in the ice core, can also suggest vegetational changes.



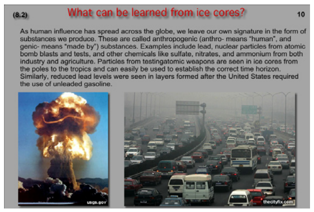

8.2.8

Volcanic particles can also be filtered from a melted ice core sample and examined using a microscope. Ash and dust produced by a volcano can travel great distances, depending on several factors, including the size of the particles. Distances are also based upon the explosiveness of the eruption, and the location of the volcano. Both of these criteria are expressed by the VEI (volcanic explosivity index) for a particular volcano. The eruptions of Tambora and Krakatoa left their "signatures" in the form of sulfate ions in the ice of polar glaciers, even though the volcanoes are far from the poles.



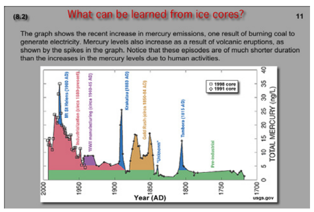

8.2.9

Large volcanic eruptions are very helpful in establishing a timeline in the ice cores. Once a timeline has been established, changes in the levels of other particles and chemicals in the ice core can be more easily understood and explained.




8.2.10

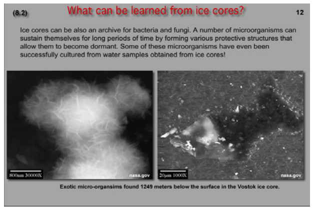
As human influence has spread across the globe, we leave our own signature in the form of substances we produce. These are called anthropogenic (anthropo- means "human", and genic- means "made by") substances. Examples include lead, nuclear particles from atomic bomb blasts and tests, and other chemicals like sulfate, nitrates, and ammonium from both industry and agriculture. Particles from testing atomic weapons are seen in ice cores from the poles to the tropics and can easily be used to establish the correct time horizon. Similarly, reduced lead levels were seen in layers formed after the United States required the use of unleaded gasoline.




8.2.11

The graph shows the recent increase in mercury emissions, one result of burning coal to generate electricity. Mercury levels also increase as a result of volcanic eruptions, as shown by the spikes in the graph. Notice that these episodes are of much shorter duration than increases in mercury levels due to human activities.

# Notes




8.2.12

Ice cores can be also an archive for bacteria and fungi. A number of microorganisms can sustain themselves for long periods of time by forming various protective structures that allow them to become dormant. Some of these microorganisms have even been successfully cultured from water samples obtained from ice cores!


8.2.13

Summary

-The ratios of oxygen-18 to oxygen-16 isotopes in an ice core sample can be used to assess the relative temperature of paleoclimates compared to the present.

-The study of ice layers, atmospheric chemistry, volcanic activity, human-created emissions, and dust in the ice cores provide a reliable timescale for temperatures obtained from the ice cores.

-The study of ice layers, atmospheric chemistry, volcanic activity, human-created emissions, and dust in the ice cores gives scientists an insight into climatic conditions of the past.

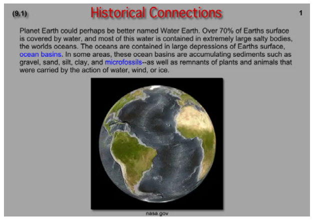
-Evidence trapped in ice cores offers insight into different types of organisms that lived in the past.

-Ice cores are rich archives of both natural and man-made events.

# Oceanographic Evidence
Historical Connections

Notes

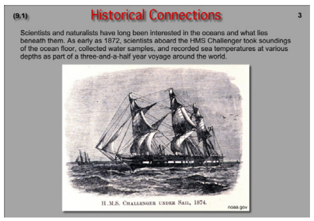
## 9.1



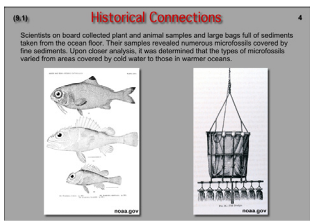

9.1.1
Historical Connections

Planet Earth could perhaps be better named the Water Planet. Over 70% of Earth's surface is covered by water, and most of this water is contained in extremely large salty bodies, the world's oceans. The oceans are contained in large depressions, the ocean basins. In some areas, the ocean basins are accumulating sediments such as stones, sand, silt, clay, and microfossils, as well as remnants of plants and animals that were carried by the action of water, wind, or ice.


9.1.2
Seafloor sediments tell a story of Earth's past climate history. Paleoclimatologists, scientists who are interested in past climate, study cores taken from the ocean floor to try to understand the story these sediments tell.



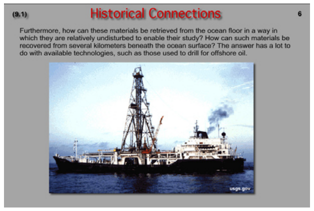

9.1.3
Scientists and naturalists have long been interested in the oceans and what lies beneath them. As early as 1872, scientists aboard the HMS Challenger took soundings of the ocean floor, collected water samples, and recorded sea temperatures at various depths as part of a three-and-a-half year voyage around the world.




9.1.4
Scientists on board collected plant and animal samples and large bags full of sediments taken from the ocean floor. Their samples revealed numerous microfossils covered by fine sediments. Upon closer analysis, it was determined that the types of microfossils varied in areas covered by cold water compared to those in warmer oceans.

# Notes


9.1.5
In addition to the sediments that build up over time, a steady rain of dust, plants, and animal skeletons settles on the ocean floor year after year. Consistent with the Law of Superposition, the new materials fall on top of older materials. With time, these layers of sediment form a vertical timeline that can represent millions of years of the Earth's past.



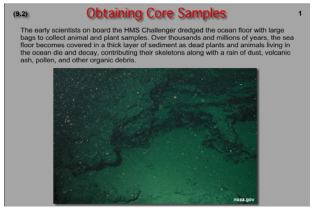

9.1.6
How can these materials be retrieved from the ocean floor so that they are relatively undisturbed? How can materials be recovered from several kilometers beneath the ocean surface? The answer has a lot to do with available technologies, such as those used to drill for offshore oil.


9.1.7
Summary
-Approximately 70% of Earth's surface is covered by water.
-A large amount of data concerning Earth's past climate is stored in sediments such as stones, sand, silt, and clay. Oceanographers use the term "muds" to include silt plus clay.
-Scientists study evidence from the oceans using a variety of techniques. One of these is by taking a vertical core of sediment from the ocean floor.
-One of the first attempts to study the ocean floor was done from the HMS Challenger in the late 1800s.
-Scientists on the HMS Challenger brought up samples of the ocean floor along with plant and animal specimens to be studied.
-Sediments are deposited on the ocean floor according to the Law of Superposition, which states that the new material is deposited on top of older material.

# Notes

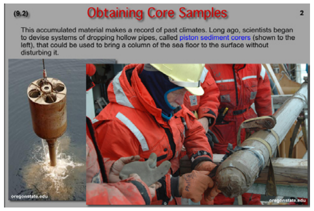
## Obtaining Core Samples in the Oceans

## 9.2

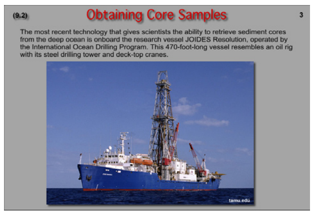



9.2.1
Obtaining Core Samples

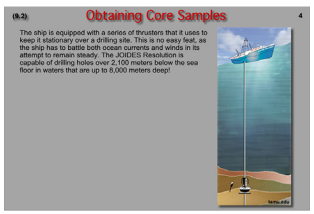
Over thousands and millions of years, the sea floor becomes covered in a thick layer of sediment as dead plants and animals that were living in the ocean die and decay, contributing their skeletons along with a rain of dust, volcanic ash, pollen, and other organic debris. The early scientists on board the HMS Challenger dredged the ocean floor with large bags to collect animal and plant samples.



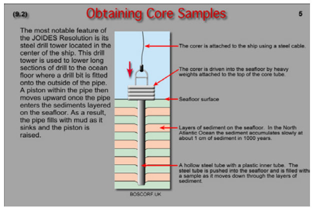

9.2.2
This accumulated material makes a record of past climates. Long ago, scientists began to devise systems of dropping hollow pipes, called piston sediment corers (shown to the left), that could be used to bring a column of the sea floor to the surface without disturbing the layers in it.




9.2.3
The most recent technology that gives scientists the ability to retrieve sediment cores from the deep ocean is onboard the research vessel JOIDES Resolution, operated by the International Ocean Drilling Program. This 470-foot-long vessel resembles an oil rig with its steel drilling tower and deck-top cranes.




9.2.4
The ship is equipped with a series of thrusters that it uses to keep it stationary over a drilling site. This is no easy feat, as the ship has to battle both ocean currents and winds in its attempt to remain steady. The JOIDES Resolution is capable of drilling holes over 2,100 meters below the sea floor in waters that are up to 8,000 meters deep!




9.2.5
The most notable feature of the JOIDES Resolution is its steel drill tower located in the center of the ship. This drill tower is used to lower long sections of drill pipe to the ocean floor where a drill bit is fitted onto the outside of the pipe. A piston within the pipe then moves upward once the pipe enters the sediments layered on the seafloor. As a result, the pipe fills with mud as it sinks and as the piston is raised.

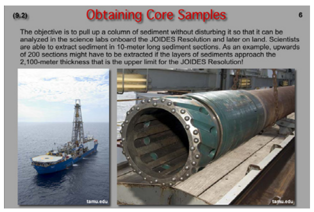
In the diagram:
The corer is attached to the ship using a steel cable.

The corer is driven into the seafloor by heavy weights attached to the top of the core tube.

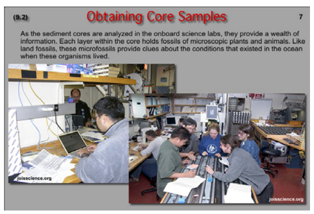
Seafloor surface

Layers of sediment on the seafloor. In the North Atlantic Ocean, the sediment accumulates slowly at about 1 cm of sediment in 1000 years.

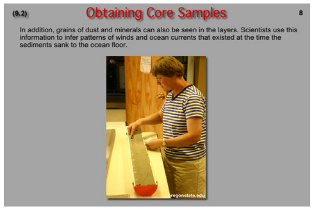
A hollow steel tube with a plastic inner tube. The steel tube is pushed into the seafloor and is filled with a sample as it moves down through the layers of sediment.




9.2.6
The objective is to obtain a column of sediment without disturbing it so that it can be analyzed in the science labs onboard the JOIDES Resolution and later on land. Scientists are able to extract sediment in 10-meter-long sections. As an example, upwards of 200 sections might have to be extracted if the layers of sediments approach the 2,100-meter thickness that is the upper limit for the JOIDES Resolution.




9.2.7
As the cores are analyzed in the onboard science labs, they provide a wealth of information. Each layer within the core holds fossils of microscopic plants and animals. Like land fossils, these microfossils provide clues about the conditions that existed in the ocean when these organisms lived.

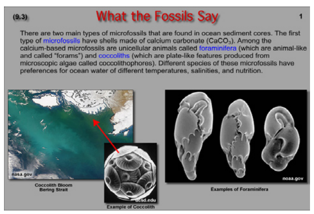



9.2.8
In addition, grains of dust and minerals can also be seen in the layers. Scientists use this information to infer patterns of winds and ocean currents that existed at the time the sediments sank to the ocean floor.


9.2.9
Summary
-Scientists aboard the HMS Challenger obtained samples of the ocean bottom by dragging bags along the ocean floor and then bringing them to the surface for analysis.
-The next technology for retrieving samples of the ocean floor was called a piston sediment corer. It used long hollow pipes to collect a cylindrical core of the ocean floor sediment.
-Next large ships were designed and built to drill deep into the ocean floor to obtain (and store) cores that total more than 2000 meters (2 km) in length.
-No matter how these cores are obtained, they go back to a laboratory where they are analyzed for microfossils, sediment type, and chemicals. They are also age-dated.
-Scientists can use the cores to reconstruct past climatic conditions, including wind patterns and ocean currents.

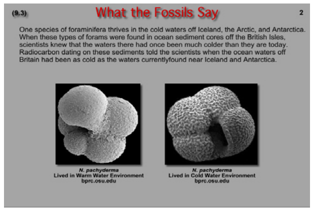
## What the Fossils Say

## 9.3



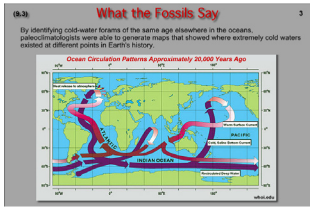

9.3.1
There are two main types of microfossils that are found in ocean sediment cores. The first type of microfossils have shells made of calcium carbonate ($CaCO_3$). Among the calcium-based microfossils are unicellular animal-like organisms called foraminifera (often called "forams") and coccoliths (which are plate-like features produced from microscopic algae called coccolithophores). Different species of these microfossils have preferences for ocean water of different temperatures, salinities, and nutrition.

# Notes



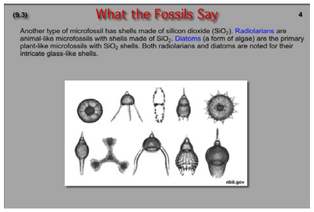

9.3.2

One species of foraminifera thrives in the cold waters off Iceland, the Arctic, and Antarctica. When these types of forams were found in ocean sediment cores off the British Isles, scientists knew that the waters there had once been much colder than they are today. Radiocarbon dating on these sediments told the scientists when the ocean waters off Britain had been as cold as the waters currently found near Iceland and Antarctica.



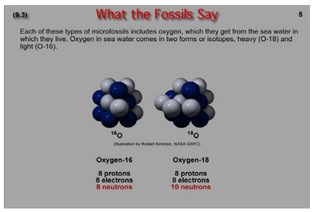

9.3.3

By identifying cold-water forams of the same age elsewhere in the oceans, paleoclimatologists were able to generate maps that showed where extremely cold waters existed at different points in Earth's history.



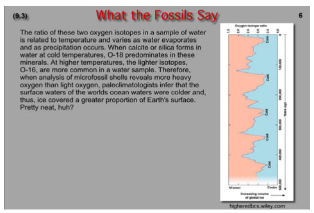

9.3.4

Another type of microfossil has shells made of silicon dioxide ($SiO_2$). Radiolarians are animal-like microfossils with shells made of $SiO_2$. Diatoms (a form of algae) are the primary plant-like microfossils with $SiO_2$ shells. Both radiolarians and diatoms are noted for their intricate glass-like shells.




9.3.5

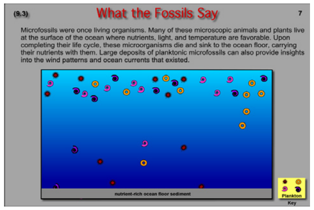
Each of these types of microfossils includes oxygen, which they get from the sea water in which they live. Oxygen in seawater comes in two forms, or isotopes: heavy (O-18) and light (O-16).



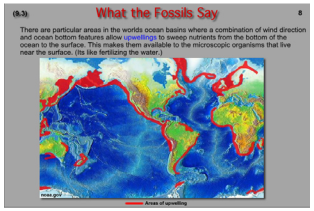

9.3.6

The ratio of these two oxygen isotopes in a water sample is related to temperature and varies as water evaporates and precipitation occurs. When calcite or silica forms in water at cold temperatures, O-18 predominates in these minerals. At higher temperatures, the lighter isotopes, O-16, are more common in a water sample. Therefore, when analysis of microfossil shells reveals more heavy oxygen than light oxygen, paleoclimatologists infer that the surface waters of the world's ocean waters were colder and, thus, ice covered a greater proportion of Earth's surface. This is remarkable, isn't it?

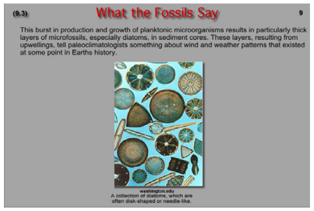
# Notes




9.3.7
Microfossils were once living organisms. Many of these microscopic animals and plants live at the surface of the ocean where nutrients, light, and temperature are favorable. Upon completing their life cycle, these microorganisms die and sink to the ocean floor, carrying their nutrients with them. Large deposits of planktonic microfossils can also provide insights into the wind patterns and ocean currents that existed.




9.3.8
There are particular areas in the world's ocean basins where a combination of wind direction and ocean bottom features allow upwellings to sweep nutrients from the bottom of the ocean to the surface. This makes them available to the microscopic organisms that live near the surface. (It's like fertilizing the water.)

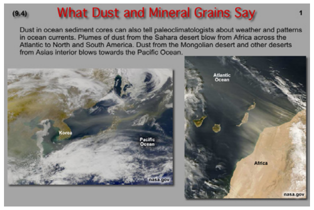



9.3.9
The resulting burst in production and growth of planktonic microorganisms leaves particularly thick layers of microfossils, especially diatoms, in sediment cores. These layers, that indicate upwelling areas, tell paleoclimatologists something about wind and weather patterns that existed at some point in Earth's history.

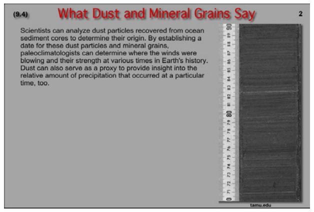

9.3.10
Summary
-The remains of micro-organisms that settled to the sea floor became microfossils. They are part of the seafloor sediments that provide much information about Earth's past.
-Microfossils often differ in the chemical composition of their shells. They are usually either calcium-based or silicon-based.
-Forams (animal-like microfossils) and coccolithophores have very recognizable calcium-based shells.
-Some forams provide clues to the temperature of the surface water of the oceans by the direction that the shell coiled.
-Scientists can also examine the ratio of O-18 and O-16 in the shells of fossils (including microfossils) to help determine the temperature of the surface waters at the time the organisms were alive.
-Upwelling returns nutrients from the sea floor to the surface along many coastlines of the world, and enriches the next generation of planktonic micro-organisms.

## What Dust and Mineral Grains Say

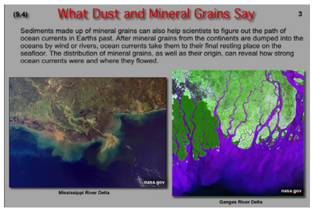
# 9.4




9.4.1
Dust in ocean sediment cores can also tell paleoclimatologists about weather and patterns in ocean currents. Plumes of dust from the Sahara desert blow from Africa across the Atlantic to North and South America. Dust from the Mongolian desert and other deserts from Asia's interior blows toward the Pacific Ocean.




9.4.2
Scientists can analyze dust particles recovered from ocean sediment cores to determine their origin. By establishing a date for these dust particles and mineral grains, paleoclimatologists can determine where the winds were blowing, and their strength, at various times in Earth's history. Dust can also serve as a proxy to provide insight into the relative periods of drought that occurred in the region at a particular time, too.




9.4.3
Sediments made up of mineral grains can also help scientists to determine the path of ocean currents in Earth's past. After mineral grains from the continents are dumped into the oceans by wind or rivers, ocean currents take them to their long-term resting place on the seafloor. The distribution of mineral grains, as well as their origin, can reveal how strong ocean currents were and where they flowed.

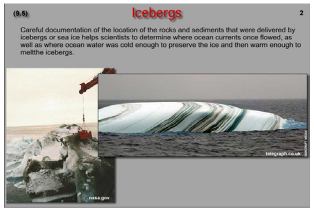

9.4.4
Summary
-Dust from land surfaces can be stored in the ocean floor sediment.
-Analysis of the dust and minerals from ocean sediments helps scientists to understand wind patterns and precipitation amounts at that time.
-Sediments from rivers that are deposited on the ocean floor also provide information about wind and ocean currents.

# Notes

## Icebergs

### 9.5


9.5.1
Ocean currents can also carry icebergs and sea-ice floes from their point of origin near the poles toward the lower latitudes. When these icebergs or sea ice melt, rocks and sediments embedded in them sink to the ocean floor and may be found later in sediment cores. This is known as “ice-rafted debris.”

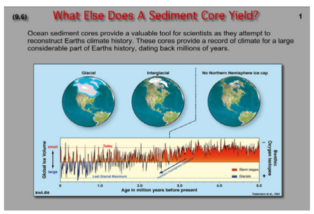



9.5.2
Careful documentation of the location of the rocks and sediments that were delivered by icebergs or sea ice helps scientists to determine where ocean currents once flowed, as well as where ocean water was cold enough to preserve the ice and then warm enough to melt the icebergs.


9.5.3
Summary
-Glaciers often contain sediment scoured from Earth’s surface.
-When glaciers release icebergs into the oceans, they eventually melt and deposit their sediment load on the ocean floor. Similarly, sea ice also carries and then releases sediment.
-Ice-rafted debris in a seafloor sediment core provides information about the source of the sediments or rocks, as well as the distance and direction it was transported.

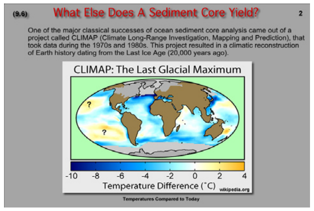
### 9.6

## What Else Does a Sediment Core Yield?

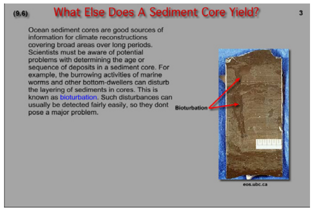



9.6.1
Ocean sediment cores provide a valuable tool for scientists as they attempt to reconstruct Earth’s climate history. These cores provide a record of climate for a considerable part of Earth’s history, dating back millions of years.

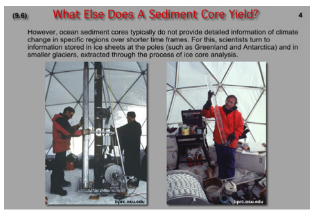
# Notes




9.6.2
One of the major classical successes of ocean sediment core analysis came out of a project called CLIMAP (Climate Long-Range Investigation, Mapping and Prediction), that obtained data during the 1970s and 1980s. This project resulted in a climatic reconstruction of Earth history dating from the Last Ice Age (20,000 years ago).




9.6.3
Ocean sediment cores are good sources of information for climate reconstructions covering broad areas over long periods. Scientists must be aware of potential problems with determining the age or sequence of deposits in a sediment core. For example, the burrowing activities of marine worms and other bottom-dwellers can disturb the layering of the sediments in cores. This is known as bioturbation. Such disturbances can usually be detected fairly easily, so they don't pose a major problem.




9.6.4
However, ocean sediment cores typically do not provide detailed information of climate change in specific regions over shorter time frames. For more detail, scientists study ice cores (shown below) for the climate record that is archived in layers of ice. This record may be obtained from ice sheets in the polar regions (such as Greenland and Antarctica) or from mountain glaciers in the tropical and mid-latitude regions.

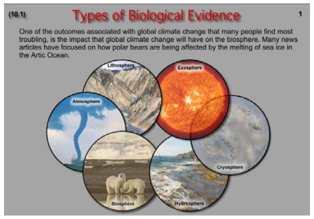

9.6.5
Summary
-Analyses of ocean sediment cores have enabled scientists to reconstruct ancient climates dating back millions of years.
-When studying ocean cores, scientists may detect disturbances to the core sample caused by marine life. This alteration of the originally deposited sediments by marine life is called bioturbation.
-Any paleoclimatic information that is obtained from ocean cores needs to be compared to a variety of other sources. (such as ice cores, tree rings, etc.)

# Biological Evidence

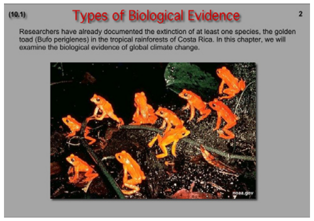
Notes

## Types of Biological Evidence

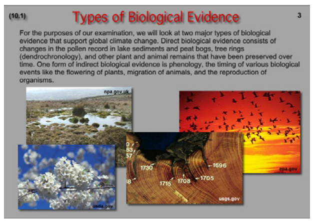
### 10.1




10.1.1
Types of Biological Evidence
Introduction
One of the outcomes associated with global climate change that many people find most troubling is the impact that global climate change will have on the biosphere. Many news articles have focused on how polar bears are being affected by the melting of sea ice in the Arctic Ocean.




10.1.2
In this chapter, we will examine the biological evidence of global climate change. Some species are particularly vulnerable. The golden toad (Bufo periglenes) was once abundant in a small region of the tropical cloud forests of Costa Rica. However, it has not been seen since May 15, 1989, and has been classified by the International Union for Conservation of Nature (IUCN) as an extinct species. Climate change may not be the direct cause of this extinction, since amphibian populations are declining generally. But animals that are adapted to mountain tops have "no where to go" as the climate warms.




10.1.3
For the purposes of our examination, we will look at two major types of biological evidence related to global climate change. Examples of direct biological evidence include: changes in the pollen record in lake sediments and peat bogs, tree rings (dendrochronology), and other plant and animal remains that have been preserved over time. One form of indirect biological evidence is phenology, the timing of various biological events, like the flowering of plants, migration of animals, and the reproduction of organisms.

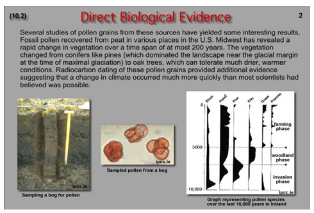

10.1.4
Summary
-Almost all spheres of the Earth system will be affected by global climate change because of their interactions with each other.
-Some species of organisms are more vulnerable than others to the impact of global climate change.
-Direct biological evidence comes from analyzing the changes in the form or populations of organisms over time, whether prehistoric or recent.
-Indirect biological evidence is derived from studying the species' behavior (climbing, burrowing, defenses, etc.) and/or the timing of cyclical activities (blooming of plants, seasonal migrations, seed development, etc.).

## Direct Biological Evidence

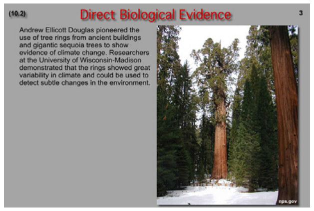
## 10.2


10.2.1
Direct Biological Evidence

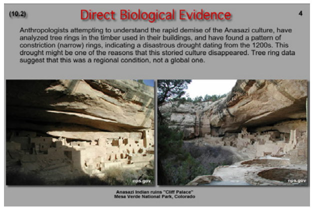
Lake sediments and peat bogs provide ideal environments for the preservation of pollen grains. The lack of oxygen in layers of lake sediments and the acidic conditions of peat bogs keep the pollen grains from decomposing.



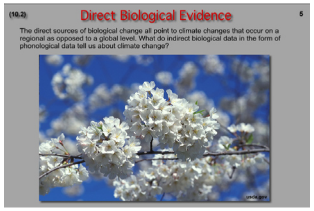

10.2.2
Several studies of pollen grains from these environments have yielded some interesting results. Fossil pollen recovered from peat in various places in the U.S. Midwest has revealed a rapid change in vegetation over a time span of at most 200 years. The vegetation changed from conifers like pines (which dominated the landscape near the glacial margin at the time of maximal glaciation) to oak trees, which can tolerate much drier and warmer conditions, including fires. Radiocarbon dating of these pollen grains provided additional evidence suggesting that a change in climate occurred much more quickly than most scientists had believed was possible.




10.2.3
Andrew Ellicott Douglas pioneered the use of tree rings from ancient buildings and gigantic sequoia trees to show evidence of climate change. Researchers at the University of Wisconsin-Madison demonstrated that the rings showed great variability in climate and could be used to detect subtle changes in the environment.




10.2.4
Anthropologists attempting to understand the rapid demise of the Anasazi culture, have analyzed tree rings in the timber used in their buildings, and have found a pattern of constriction (narrow) rings, indicating a disastrous drought dating from the 1200s. This drought might be one of the reasons that this storied culture disappeared. Tree ring data suggest that this was a regional condition, not a global one.



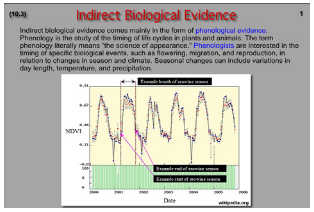

10.2.5
The direct sources of biological change all point to climate changes that occur on a regional as opposed to a global level. What do indirect biological data in the form of phenological data tell us about climate change?


10.2.6
Summary
-Some organisms that are preserved in specific types of environments can provide a great deal of information to scientists.
-Pollen grains preserved over the last 200 years have shown how the environment has changed in a relatively short time.
-The study of tree rings provides information about past climatic conditions.
-By studying the trees that ancient civilizations used to construct buildings, scientists are gaining an understanding of climatic conditions that may have contributed to the downfall of some civilizations.

## Indirect Biological Evidence

# Notes

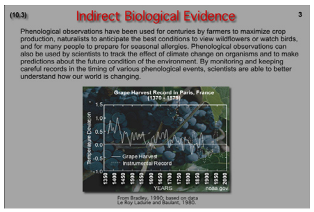
## 10.3




10.3.1
Indirect Biological Evidence

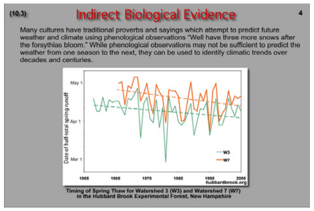
Indirect biological evidence comes mainly in the form of phenological evidence. Phenology is the study of the timing of life cycles in plants and animals. The term phenology literally means "the science of appearance." Phenologists are interested in the timing of specific biological events, such as budburst, flowering, migration, and reproduction, in relation to changes in season and climate. Seasonal changes can include variations in day length, temperature, and precipitation.


10.3.2
Many events herald the arrival of spring. Some of these springtime phenological events that interest scientists include: flowering, leaf unfolding, insect emergence, and bird, fish, and mammal migration. You might even know examples of phenological evidence that have been established in local lore, such as the date the swallows return to San Juan Capistrano, when the forsythia flowers, and so forth.

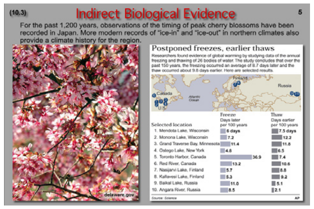



10.3.3
Phenological observations have been used for centuries by farmers to maximize crop production, by naturalists to anticipate the best conditions to view wildflowers or watch birds, and to allow people to prepare for seasonal allergies. Phenological observations can also be used by scientists to track the effect of climate change on organisms and to make predictions about the future condition of the environment. By monitoring and keeping careful records on the timing of various phenological events, scientists are able to better understand how our world is changing.

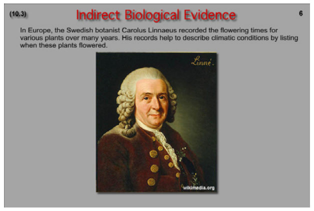
## Notes



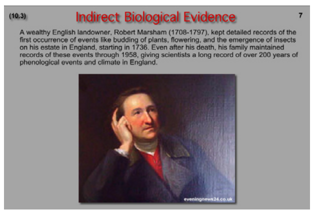

10.3.4
Many cultures have proverbs and sayings that attempt to predict future weather and climate using phenological observations. An example is: "We'll have three more snows after the forsythias bloom." While phenological observations may not be sufficient to predict the weather from one season to the next, they can be used to identify climatic trends over decades and centuries.



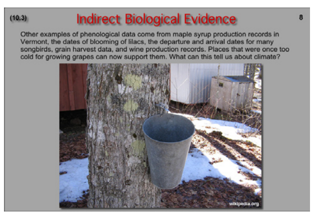

10.3.5
For the past 1,200 years, observations of the timing of peak cherry blossoms have been recorded in Japan. More modern records of "ice-in" and "ice-out" in northern Europe also provide a climate history for that region.




10.3.6
In Europe, the Swedish botanist Carolus Linnaeus recorded the flowering times for various plants over many years. He even proposed a clock garden, based on his observations of the time of day that different flowers open. His records help to describe climatic conditions by listing when these plants flowered.

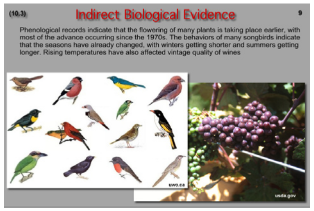



10.3.7
A wealthy English landowner, Robert Marsham (1708-1797), kept detailed records of the first occurrence of events like budding of plants, flowering, and the emergence of insects on his estate in England, starting in 1736. Even after his death, his family maintained records of these events through 1958, giving scientists a long record of over 200 years of phenological events and climate in England.



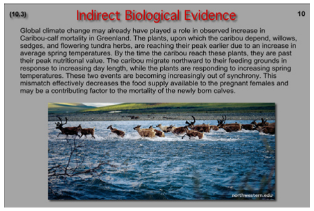

10.3.8
Other examples of phenological data come from maple syrup production records in Vermont, the dates of blooming of lilacs, the departure and arrival dates for many songbirds, grain harvest data, and wine production records. Places that were once too cold for growing grapes can now support them. What can this tell us about climate?

# Notes




10.3.9

Phenological records indicate that the flowering of many plants is taking place earlier, with most of the advance occurring since the 1970s. The behaviors of many songbirds indicate that the seasons have already changed, with winters getting shorter and summers getting longer. Rising temperatures have also affected vintage quality of wines.




10.3.10

Global climate change may already have played a role in observed increase in mortality of caribou calves in Greenland. The plants upon which the caribou depend (willows, sedges, and flowering tundra herbs) reach their peak growth earlier due to an increase in average spring temperatures. By the time the caribou arrive in the area where these plants grow, they are past their peak nutritional value.

The caribou migrate northward to their feeding grounds in response to increasing day length (a function of Earth's orbit around the Sun), while the plants are responding to increasing spring temperatures. These two events are becoming increasingly out of synchrony. This "trophic mismatch" effectively decreases the food supply available to the pregnant females and may be a contributing factor to the mortality of the newly-born calves.


10.3.11

Summary

-Scientists study the timing of seasonal behaviors to gain a better understanding of climatic conditions over long periods of time. This branch of science is known as phenology.

-The timing of flowering, leaf unfolding, emergence of insects, and the migration of animals can help scientists to understand changes in climatic conditions.

-Grape harvest records have been kept for several centuries around the world. These records can point to global climate change over time.

-Looking at the freeze-thaw records for lakes or ponds can also provide scientists with important climatic information.

-One of the longest phenological records involves observations of the emergence of cherry blossoms.

-Carolus Linnaeus was the first scientist to publish his record of phenological observations in Europe. Robert Marsham also recorded observations in England in the 1800s.

-The return of migrating songbirds in the spring also represents a type of phenological evidence concerning climatic conditions.

## Notes

# What are Some Potential Trends for the Future?

## 10.4


### 10.4.1
What are Some Potential Trends for the Future?

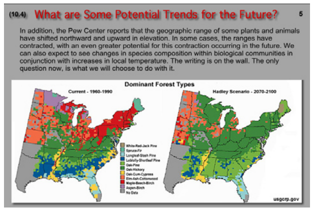
Changes in the timing of biological events have the potential to adversely affect humans. The existence of many plants depends upon animal-mediated pollination. Flowering plants and their pollinators co-evolved. Factors that keep the timing of flowering in synchrony with the availability of particular animal pollinators are complex and unknown. It is quite possible that peak plant flowering times and pollinator availability could get out of synchrony—flowers would be opening before pollinating agents are available. This could have disastrous effects on agriculture.


### 10.4.2
Data from eastern Maryland show that flowering time has advanced by nearly a month since the 1920s, based upon the weight of beehives. The weight of beehives can be used as a proxy of flowering time. Hive weight, which is dependent upon the amount of honey the bees make, goes up when the flowers that bees depend upon are open.


### 10.4.3
During the winter, bees eat the honey they've stored and vibrate their wings to generate heat. If the temperature of the hive is not maintained at a minimal level, the eggs laid by the queen will die and the colony must start over. If this occurs, peak flowering may occur before there are enough worker bees available to take advantage of the situation. Then the bees in the hive may not be able to make enough honey to survive until the next year. Hive weight would be reduced. Eventually, yields of crops that depend upon bees for pollination could also decrease due to the lack of pollinators, threatening the supplies of fruits and vegetables.

# Notes


10.4.4
The Pew Center on Global Climate Change released a report in June, 2009, documenting the scientific evidence on the observed effects of climate change in the United States. For example, the timing of important biological events, including the flowering of plants and the breeding times of animals, has shifted, and these changes have occurred in conjunction with changes in the U.S. climate.




10.4.5
In addition, the Pew Center reports that the geographic ranges of some plants and animals have shifted northward, and upward in elevation. In some cases, the ranges have contracted, with an even greater potential for this contraction occurring in the future. We can also expect to see changes in species composition within biological communities in conjunction with increases in local temperature. The writing is on the wall. The only question now is, "What we will choose to do with it?"


10.4.6
Summary
-The activities of some organisms, such as bees and birds, are important to humans. Climatic change can affect the behavior of these organisms. This change, in turn, can have an adverse effect on human activities.
-Some studies indicate that biological communities are shifting their range as a result of climate change.