CLIMATE CHANGE

Cary Sneider, Richard Golden, Florence Gaylen

Global Systems Science

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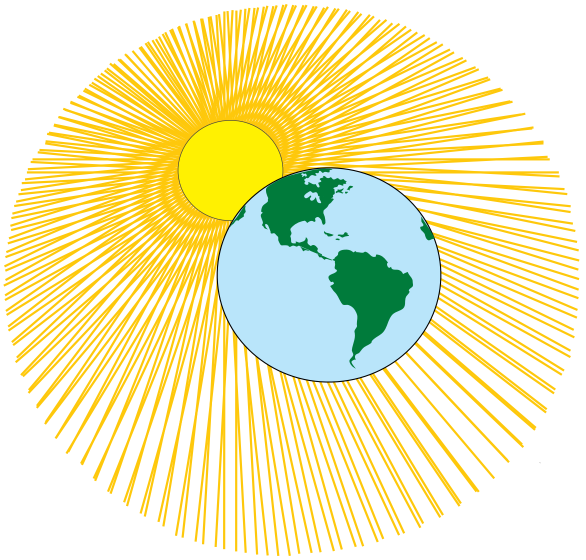

Global
Systems
Science

Climate Change

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Florence Gaylen

Contents

News and updates are available at the GSS website http://www.lhs.berkeley.edu/GSS/ in the "Staying Up To Date" section.

1. What Is the Greenhouse Effect?

Life on Earth is possible because our atmosphere keeps our planet warm. This warmth is due to the "greenhouse effect," which is a natural phenomenon.

Photo of New Guinea lowlands by Reginald Barrett.

Life on Earth would be impossible without the atmosphere. It contains oxygen and other gases essential for plants and animals. The atmosphere protects us from the Sun's harmful rays and acts like a blanket to keep our planet at a livable temperature. There is, however, some disturbing evidence that the heat-trapping property of our atmosphere is changing.

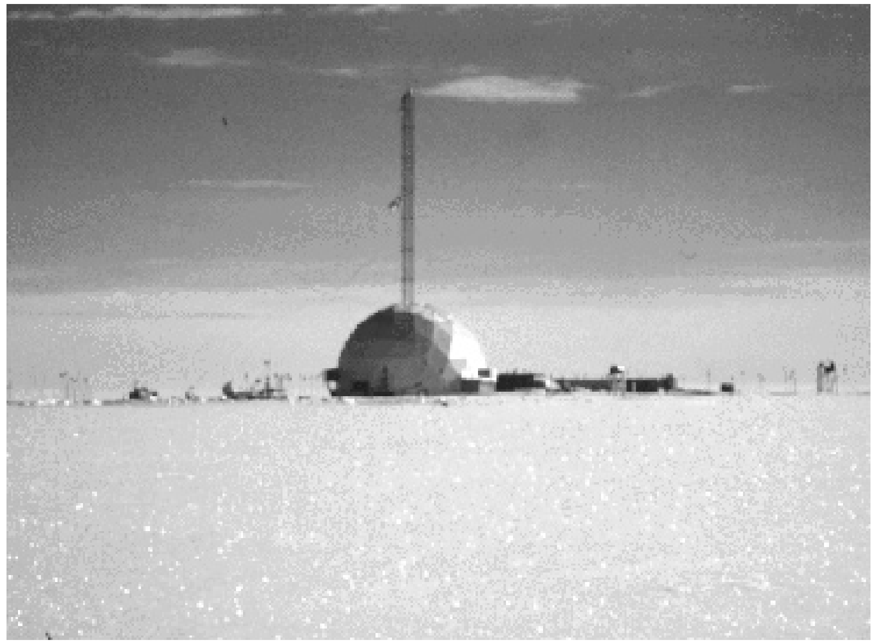
Changing Climate is about scientific research that is going on today. Research on our planet's climate is of such importance that whenever a new discovery is made, or a new theory is proposed, a story about it is carried in major newspapers. Among the most frequent topics appearing in the press during the past decade are *global warming* and the *greenhouse effect*.

Global warming refers to the fact that over the past century the average temperature of Earth has been gradually increasing. Nobody knows for certain if this trend will continue, and if it does, how much the temperature will rise. This is cause for concern because a further increase in Earth's temperature may disrupt global systems worldwide, with effects ranging from more intense storms and floods in some regions to droughts and heat waves in others.

Major changes are not expected to occur tomorrow, or the day after tomorrow, or possibly even within our lifetime. The issue is rather how our actions today will affect the world of our children and grandchildren.

Despite the importance of global warming, many people are not aware of it, or have misconceptions. For example, some people believe that global warming is caused by the "hole" in the ozone layer, while others think it's caused by black soot billowing from smokestacks. Neither is true. It's a little more complicated, and has to do with something called the "greenhouse effect."

The **greenhouse effect** is a natural phenomenon that makes our blue-green planet hospitable for life. The effect is caused by certain invisible gases—called greenhouse gases—in the atmosphere. Without those gases, which keep Earth warm, our planet would be a frigid ball of ice.

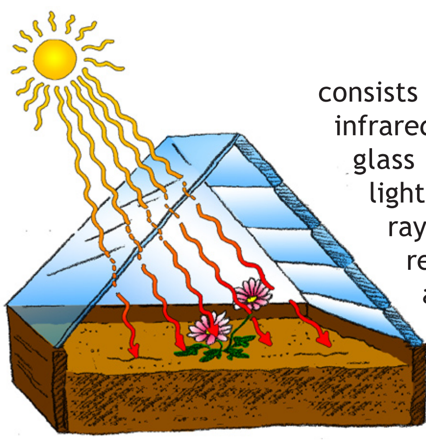


Research is taking place today at such far off places as this research station in Greenland where information on past climates is gathered by drilling down through layers of ice. A similar project is in progress on the opposite side of the world, in Antarctica.

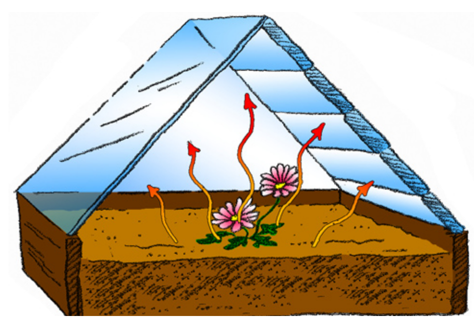
The reason many scientists believe the average temperature of Earth will continue to warm is because the concentration of greenhouse gases is increasing as a result of human activities. So, to understand the reasons why the globe may be warming up, and to predict what may happen in the future, we first have to understand the greenhouse effect.

Understanding the Greenhouse Effect

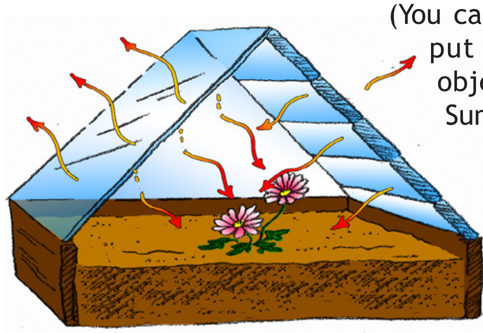
Most of Earth's atmosphere consists of nitrogen and oxygen. These gases allow sunlight to pass through them. They do not absorb heat from the Sun. However, the atmosphere also contains other gases that absorb heat. Sunlight warms them. Among these gases are carbon dioxide, water vapor, and methane, all of which existed in the atmosphere long before there were human beings, and are responsible for giving Earth a warm, comfortable climate. How do they do this? A simple greenhouse provides a clear analogy.



A. Sunlight consists of visible light and heat rays (called infrared energy). When sunlight falls on the glass window of a greenhouse, the visible light passes through, but some of the heat rays are absorbed, warming the glass. The rest of the heat rays pass through the glass and warms the soil and plants inside.



B. As the soil and plants warm, they give off heat (infrared energy). This heat energy is absorbed by the glass windows of the greenhouse, warming the interior even more. (You can feel heat energy if you put your hand next to any object that has been in the Sun all day.)



C. As the windows of the greenhouse warm, they also give off heat energy. Some of that energy escapes to the air outside, but some of it goes back into the greenhouse to warm the plants and soil even more.

The interior of the greenhouse gets warmer and warmer, until finally the amount of heat that escapes to the outside air equals the amount of heat flowing into the greenhouse from the Sun and the warm glass window.

You may be familiar with this effect when you enter a car that has been in the sunlight for a few hours with the windows closed. The glass windshield traps heat, so the air inside the car is warmer than the air outside the car.

Earth's Greenhouse Effect

There are two ways in which this effect in the greenhouse and car is different from what occurs in Earth's atmosphere. First, imagine you open the door to the greenhouse (or car). Warm air rushes out and is replaced by cooler air. This exchange of air is what cools the greenhouse. Can you imagine cooling Earth this way?

Second, in a greenhouse, the special heat-trapping material—the glass—is a solid surrounding the greenhouse. In the atmosphere, carbon dioxide, water vapor, and methane are spread thinly throughout the atmosphere.

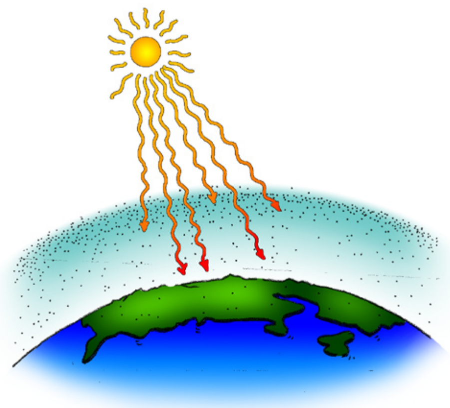
In other words, Earth heats up *like* a greenhouse, but it is not actually a greenhouse. Because the carbon dioxide, water vapor, and methane act like the glass in a greenhouse, they are called *greenhouse gases*.

The diagrams on this page illustrate the greenhouse effect in Earth's atmosphere. Compare it with the illustrations on the previous page to see how Earth's atmosphere system differs from an actual greenhouse.

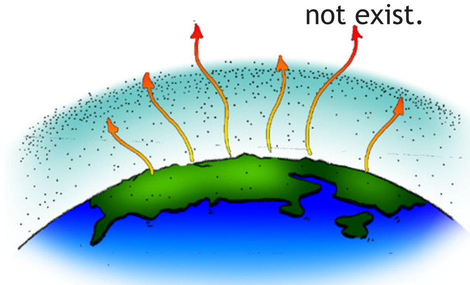
In a sense, the greenhouse gases act like a blanket, trapping heat energy near Earth's surface. These gases keep Earth's surface about 33°C (60°F) warmer than it would otherwise be.

If there were no greenhouse gases in our atmosphere, our entire planet would be so much colder than it is today—the oceans and all water would be completely frozen.

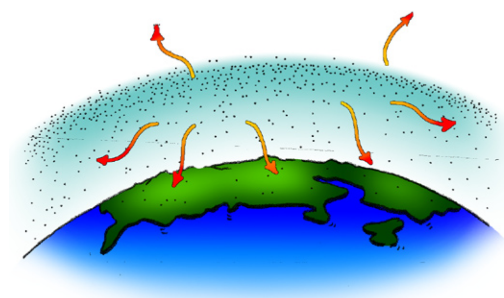
Liquid water was very important in the origin of life on Earth. If there were no greenhouse effect, it is likely that life—including us, of course—would not exist.



A. Energy from the Sun warms the atmosphere and the surface of Earth.



B. The warm soil, rocks, and water on Earth's surface give off heat energy, warming carbon dioxide and other greenhouse gases in Earth's atmosphere.



C. Some of the heat energy escapes from the atmosphere into space, but some of it returns to Earth to warm it further.

Who Discovered the Greenhouse Effect?

More than 100 years ago, Jean Fourier realized the atmosphere possessed heat-trapping properties. He coined the term *greenhouse effect* to refer to the idea that the atmosphere acted somewhat like the glass walls of a greenhouse, allowing sunlight to enter but preventing some of the heat energy escaping into space. This effect is due to the water vapor, methane, and carbon dioxide that exist naturally in the atmosphere.

For billions of years a certain level of carbon dioxide has been maintained in the atmosphere.

Carbon dioxide was *added* to the atmosphere naturally by volcanic action, animal respiration, and the decomposition and burning of forests. Carbon dioxide was also *removed* naturally from the atmosphere by absorption in the oceans, or it was incorporated into trees and other plant life. In this way a balance was maintained.

In 1896, the Swedish chemist Svante Arrhenius, who was familiar with Fourier's ideas, published an article with dire predictions.

Arrhenius knew the capacity of the atmosphere to trap heat was due to the greenhouse gases that existed naturally in the atmosphere. He was also aware the concentration of one of those gases, carbon dioxide (the same invisible gas that makes bubbles in soft drinks), was increasing. He decided this increase in carbon dioxide in the atmosphere was a result of the way merchandise was being produced —the industrial revolution was under way—irreversibly affecting society and the environment.

Hot lava from a volcano reaches the sea. In addition to hot lava and ash, volcanoes release huge quantities of carbon dioxide gas. Volcanoes have been a natural source of carbon dioxide on our planet for billions of years.

The *industrial revolution* is the name given to the changes in the production of goods and means of transportation that began when the steam engine substituted steam power for muscle power. In 1769 the first practical steam engine was patented by the Scottish instrument maker James Watt. Although no one knew it at the time, this invention started the industrial revolution.

Prior to the industrial revolution animals and men were the basic sources of energy. Inventions like the steam engine made large factories possible and changed the landscape of our country from farms and small towns to huge cities with industrial areas connected by rails and highways. By the time of Arrhenius, vast quantities of coal were routinely burned to provide energy to run factories. As a result, air pollution was becoming a problem throughout Europe.

Since human beings began burning fossil fuels, they have added more carbon dioxide to the atmosphere each year. In the refinery shown here, petroleum that was buried for millions of years is turned into gasoline and other fuels. When these fuels are burned, they release carbon dioxide gas. We can control air pollution to some extent with cleaner fuels or filters, but we cannot reduce production of carbon dioxide and the prospect of global warming, unless we burn less coal, oil, and gas.

Arrhenius realized that when coal burned it released not only thick black smoke; it also released the invisible gas, carbon dioxide. He also realized that vast quantities of carbon stored in the coal for millions of years was now being released into the atmosphere as CO_2.

Based on his knowledge of the properties of carbon dioxide, and Fourier's ideas about the greenhouse effect, Arrhenius predicted the concentration of carbon dioxide in Earth's atmosphere would eventually double, and when it did, the result would be an increase in average global temperatures of up to 5˚C (9˚F).

While the addition of just a few degrees may not seem like much compared with the natural greenhouse effect of 33˚C (60˚F), the effect of such a change on human society can make a huge difference.

For new material relating to this chapter, please see the GSS website "Staying Up To Date" page: http://lhs.berkeley.edu/gss/uptodate/2cc/2cc.html We invite you to send us new articles for the "Staying Up To Date" web page for this chapter. Articles may be from local newspapers, magazines, websites, or other sources that you think would be of interest to classrooms around the country. To send us articles please go to the link http://lhs.berkeley.edu/gss/uptodate/newarticle.html and find the "Submit New Article" button.

2. What Is Global Warming?

The worldwide drought of 1988, accompanied by tremendous forest fires, floods, and a super hurricane, caught people's attention. It was in the midst of that hot summer that James Hansen, a reputable NASA scientist, testified before Congress that he was "99% confident" the globe was heating up. Later, Hansen said the warming was probably due to an increased greenhouse effect, brought about by the production of huge amounts of carbon dioxide gas from burning fossil fuels in cars and power plants around the world.

In coming to his conclusion that Earth is warming, Hansen used data collected since 1866—when systematic temperature measurements began at a large number of sites around the world. A graph of the data he presented is on the next page. Each point on the graph represents the yearly average of the temperature taken at hundreds of sites around the world in that year. The average global temperature varies a lot from year to year but, overall, it is warmer today than it was 130 years ago.

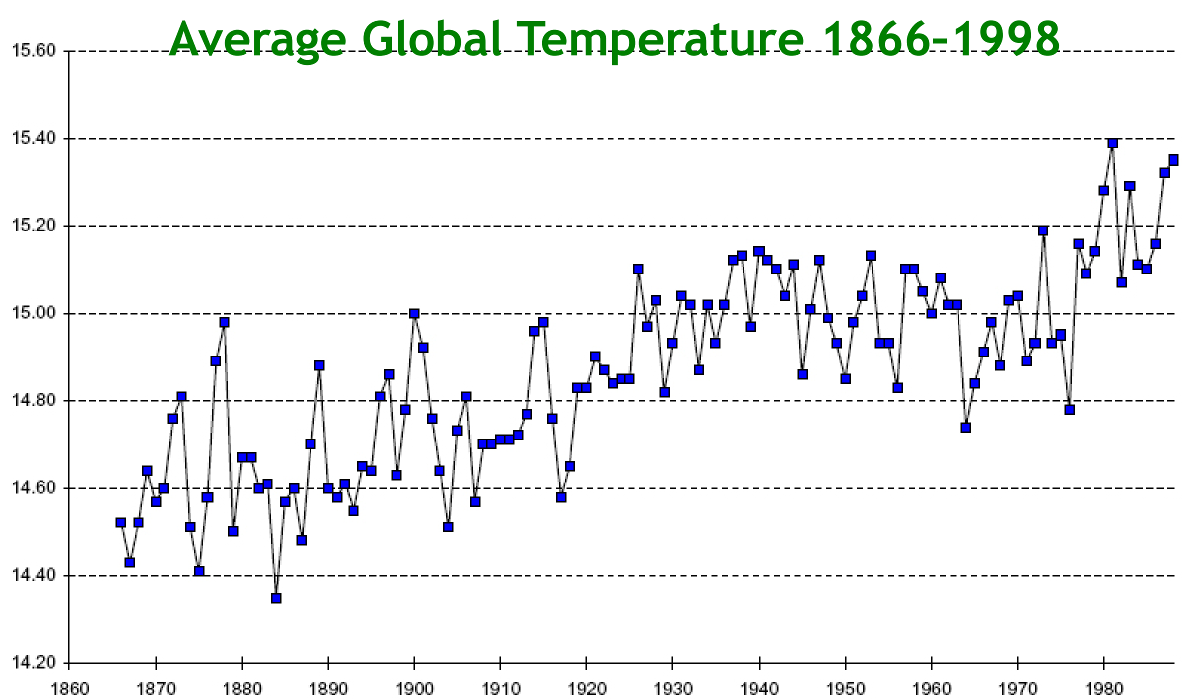
Climatologists—scientists who study long-term changes in weather patterns—are concerned about the prospect of global warming. Their predictions include rising sea levels, which would submerge coastal areas; increased droughts and forest fires; and floods. While some countries with cold climates would benefit from a warmer world, most countries would suffer serious disruption.

But not all climatologists agreed with James Hansen's conclusions. Scientists are skeptics. They demand hard evidence, carefully examined and tested, before they will accept a hypothesis and trust its conclusions. Such caution is a very important aspect of science, and controversy can continue for years or decades until a consensus of opinion is eventually reached. In the years since 1988 there have been many research studies conducted on global climate change.

According to the International Panel on Climate Change (IPCC), Svante Arrhenius was not far off the mark. The U.N. panel concluded that if we do not reduce the rate at which we burn fuels for energy in homes, industries, cars, and trucks, the amount of carbon dioxide in the atmosphere will double by the year 2100, causing the average global temperature to increase by 1°C to 3.5°C.

An increase of 1°C may not seem like much since we usually think in terms of weather—the day-to-day change in local conditions. However, the United Nations panel predicts a change in the *global climate*, which is the temperature of our entire planet averaged over 30 years. The report goes on to predict that a change in Earth's climate is likely to seriously affect the lives of people, plants, and animals.

The long time span is also difficult to grasp. It is hard for us to think a few months in advance, let alone worry about what may happen a 100 years from now. However, our children and grandchildren will have to live in that world. While people may well be able to adapt to the changing climate, plants and animals will have a much more difficult time.



Source: NASA Goddard Institute for Space Studies (http://www.giss.nasa.gov)

Investigation

How has the debate changed in the past 10 years?

Compare and contrast the information about global climate change as detailed in the newspaper articles on the next pages from 1989 and 1999. If you can, go to a library and search for other articles about global climate change. Look for evidence of consensus, as well as the comments of individual scientists.

QUESTIONS

Read the first newspaper story, and discuss the following questions.

2.1 Imagine you're in the audience in San Francisco when the scientists made their presentations. James Hansen is not quoted. Based on the descriptions in the article and earlier in this chapter what do you think he said?

2.2 What do Tim Barnett and James Hanson agree about?
What do they disagree about?

2.3 What does Tim Barnett mean by the statement, "Global averages [are] an absolutely bogus concept"?

2.4 On what basis does Thomas Karl disagree with Hanson? What does Hanson say about Karl's analysis?

2.5 Based on this article, as of 1989, did most scientists believe global warming was under way?

Now read the next newspaper, and discuss these questions.

2.6 Has the data collected between 1989 and 1999 more strongly supported Hanson or Karl and Barnett?

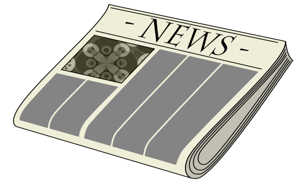
2.7 What disagreements are cited in this article?

2.8 Based on this article, as of 1999, did most scientists believe global warming was under way?

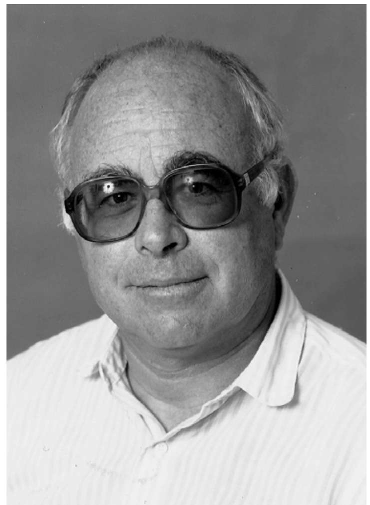
2.9 See if you can find a more recent article about the global warming controversy. What do most scientists believe today? What controversies are cited in the more recent article?

2.10 In your opinion, were Hansen's conclusions justified at the time?
Does the evidence support his views today?

In the news 1989



S.F. Forum on Global Warming Hears Heated Scientific Debate



Tim Barnett

James Hansen

By Charles Petit, *The San Francisco Chronicle*

Scientists differed sharply yesterday whether the greenhouse effect is already warming the planet—and a few doubted the widely believed forecasts of climate catastrophe in the next century.

At a meeting of the American Geophysical Union in San Francisco's Civic Auditorium, there was a rare public confrontation between a prominent scientist warning that global warming is already under way and threatens to wreak havoc in the next century, and other researchers who say it is too early to tell.

It is a controversy certain to heat up as scientists measure the shifting chemistry of the atmosphere, tune computer models of the world's ocean, clouds, and winds, and analyze unreliable temperature records from the last century.

James Hansen, director of the NASA Goddard Institute for Space Studies in New York, repeated the assertion he made to Congress a year ago that he is 99 percent certain that the globe will warm dramatically, by 3 to 9 degrees Fahrenheit, during the next century. This is a faster rise than any known in geologic history, and would make the Earth hotter than it has been in 100,000 years.

But a small band of researchers believe Hansen in particular, and many others, are making forecasts that go beyond the evidence.

Thomas R. Karl, of the National Oceanic and Atmospheric Administration research center in North Carolina, said Hansen's main contention that warming has already begun is not backed up by temperature records going back to 1850.

Last year Karl said that when temperatures dating back to the turn of the century are studied, and corrected for generally warmer readings in industrial areas, there is no long-term trend leading upward.

Climatologist Tim P. Barnett of the Scripps Institute of Oceanography in San Diego joined Karl in the criticism. His graphs and plots suggest that natural oscillations in global temperature are so large that they would conceal any signal that the warming had already begun.

Barnett took a hard shot at Hansen's use of global temperature averages as evidence for accuracy of computer predictions. Global averages, he said, are "an absolutely bogus concept . . . to be real blunt about it, to use Southern California surfer jargon, (use of) global averages sucks, guys." Barnett told the morning meeting of several hundred climate experts.

Hansen responded that his own analysis of the same data used by Karl not only confirms a global warming, but suggests the United States has warmed by up to half a degree in the past century. He said Karl "made an embarrassing mistake" in not using the data correctly.

Hansen got powerful support from a mathematician's detailed statistical analysis of variations in global temperatures for the past 100 years.

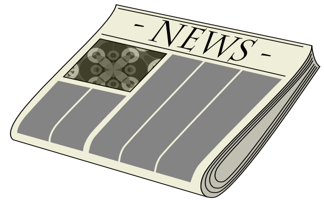
Statistically, the chances that the carbon dioxide is not causing warming are about 2 in 1 million, said David J. Thompson of the Mathematical Sciences Research Center at AT&T Bell Labs in New Jersey. "It looks like cause and effect to me," he said.

Greenhouse doubter Barnett said that he shares Hansen's view that the future does not look good. "Most scientists agree that if we put most of the stuff into the atmosphere (that is predicted), we will have a real climate problem . . . a climate regime that human civilization has never seen."

The session moderator, H. Frank Eden of the Joint Oceanographic Institutions, said, "We may not agree that we can already see the warming, but most of us believe in the general idea of the greenhouse effect."

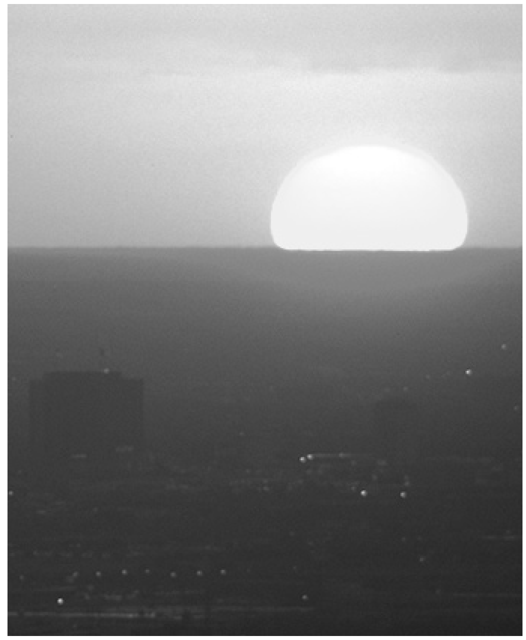
Excerpted from The San Francisco Chronicle, December 7, 1989, page A18

In the news 1999



Earth's Temperature Shot Skyward in 1998

By Richard Monastersky, *Science News*



Global temperatures in 1998 shattered the record high mark, making last year the warmest since at least 1860, and possibly since the end of the last millennium. El Niño deserves part of the credit, say climate scientists, but some researchers also see signs that people are helping to push temperatures into uncharted territory.

The World Meteorological Organization (WMO) in Geneva announced last month that the mean surface temperature of the globe in 1998 reached 0.58°C above a base line average for the period from 1961 through 1990. For climatologists, who worry about global changes in hundredths of a degree, last year's warmth stands out like a Himalayan peak.

"It's quite large. It represents several days' lengthening of the growing season," says David Parker of the United Kingdom Meteorological Office's Hadley Centre in Bracknell. The Hadley Centre and the University of East Anglia in Norwich supplied much of the analysis in the WMO statement, which includes data through mid-December. The British groups combine surface-temperature measurements made at more than 1,000 land meteorological stations with readings of sea-surface temperature from almost 2,000 ships and buoys.

A separate analysis, completed by NASA's Goddard Institute for Space Studies in New York, also has 1998 setting a temperature record by a wide margin, says James E. Hansen of the institute.

Climate researchers trace part of the heat to the El Niño ocean warming, which first started developing in mid-1997 in the Pacific. El Niño faded in May 1998, turning the tropical eastern Pacific cool, but temperatures remained elevated in many other ocean regions. In particular, the year brought "unprecedented warmth" to the Indian Ocean, according to WMO.

All the continents baked in 1998 except for northern parts of Europe and Asia. The southern United States faced extreme heat and drought during spring and summer. In central Russia, a June hot spell killed more than 100 people and fed large fires, WMO reports.

With El Niño now only a memory in the Pacific, Parker expects the globe to cool off in 1999, although probably not back to the 1961 to 1990 base line. The globe has warmed markedly during the past decade, so much so that 7 of the 10 warmest years on record occurred after 1990. All of the top 10 postdate 1983.

The recent warmth amplifies concerns that greenhouse gases are turning up Earth's thermostat, according to some researchers. A United Nations consensus panel* announced in 1995 that the balance of evidence suggests people are influencing climate. Now, says Parker, "the balance is tipping a bit further in that direction."

Greenhouse skeptics point out that the lower atmosphere up to 7 kilometers has not warmed over the last 20 years, since satellites started making measurements. These readings showed substantial warming in early 1998, but atmospheric temperatures later fell back to the 20-year average, says John Christy of the University of Alabama in Huntsville, who analyzes the satellite data.

Still, people are most concerned about Earth's surface, which has warmed by almost 0.7°C since the end of the 19th century, according to WMO. The hot spell of the past two decades may be unprecedented in the last 1,200 years, according to Jonathan T. Overpeck of the National Oceanic and Atmospheric Administration in Boulder, Colo., who discussed historical climate data last month at a meeting of the American Geophysical Union in San Francisco.

When Overpeck compiled work by scientists who have examined tree rings, glaciers, and sediments from lakes and oceans, he found no evidence for the existence of a global warm spell during the Medieval period—a time that climatologists once regarded a universally balmy. While Europe and Greenland were warm during this phase, South America, Antarctica, and Australia were not. Overall, he says, that time was not as warm as today.

* The International Panel on Climate Change (IPCC) includes approximately 2,500 scientists, including Tim Barnett and Thomas Karl.

Excerpted from Science News, *January 2, 1999, page*

Investigation

Caption Writers

These four images are related to consequences of climate change. Write a caption for each image to explain how it is related to the prediction that Earth is warming.

Image A

Image B

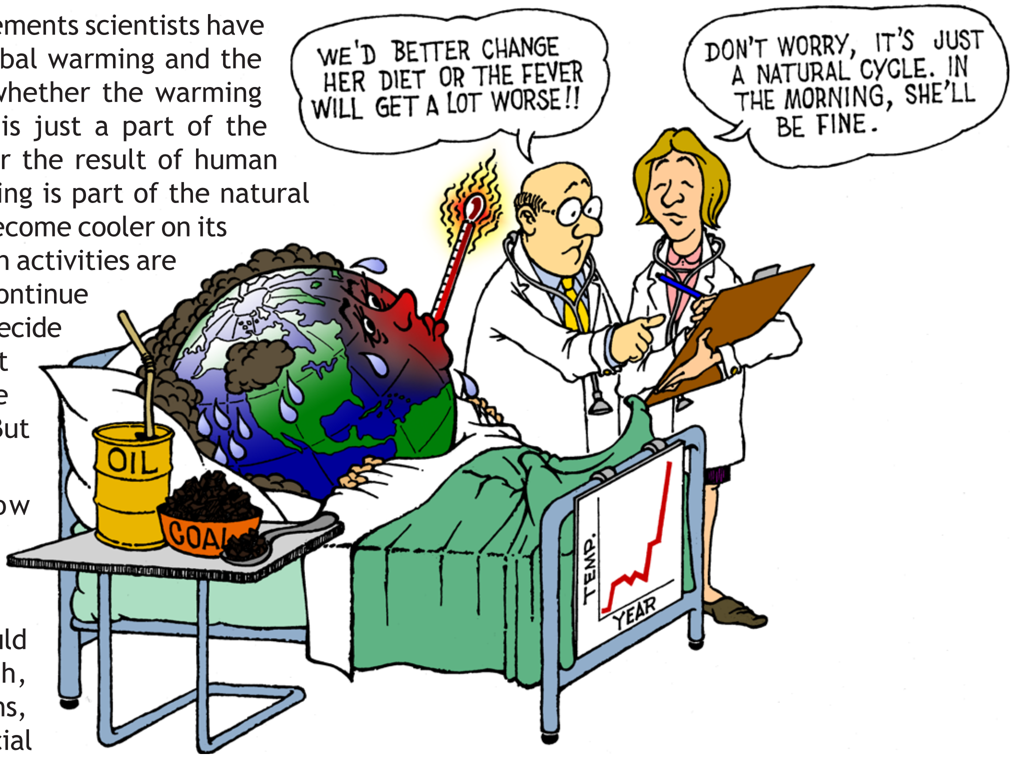
Image C

Image D

For new material relating to this chapter, please see the GSS website "Staying Up To Date" page: http://lhs.berkeley.edu/gss/uptodate/2cc/2cc.html We invite you to send us new articles for the "Staying Up To Date" web page for this chapter. Articles may be from local newspapers, magazines, websites, or other sources that you think would be of interest to classrooms around the country. To send us articles please go to the link http://lhs.berkeley.edu/gss/uptodate/newarticle.html and find the "Submit New Article" button.

3. What Is the Controversy About?

One of the disagreements scientists have about the theory of global warming and the greenhouse effect is whether the warming of Earth's atmosphere is just a part of the natural climate cycle or the result of human activities. If the warming is part of the natural cycle, then Earth may become cooler on its own. If, however, human activities are responsible, Earth will continue to warm, unless people decide to do something about it—primarily reduce the burning of fossil fuels. But change is not easy.



If scientists show convincing evidence that global climate change is actually occurring and that it would affect all life on Earth, policy makers—politicians, industry leaders, and social planners, among others—might consider ways of reducing fossil fuel use, and seek alternative energy sources. Policy makers want clear, definite answers. Scientists, however, are skeptics and expressing certainty is not necessarily the nature of scientific communication.

Scientists often challenge prevailing theories and widely accepted ideas. Even when all the evidence points in one direction, scientists are trained to shy away from absolute commitments, because something may have been overlooked. It seems unscientific to say "I'm absolutely certain," but quite acceptable to say "I'm 99% sure." About the best we can expect from scientists is *consensus*—the agreement of nearly everyone who works in a given field that something is probably true. And consensus about certain aspects of climate change was finally achieved at the end of 1995.

The Intergovernmental Panel on Climate Change (IPCC) Report: The Science of Climate Change

In December 1995, delegates from more than 116 countries met in Rome, Italy, to give final approval to a report on climate change that had been created during the previous five years by more than 2,500 scientists. The report was discussed line by line, and disagreements were argued and debated. The final report represents a broad consensus about climate change.

Overall, the IPCC report shows that many of the controversies about global warming have been resolved, while others still require further research.

The IPCC report is available on the Internet at http://www.unep.ch/ipcc/

What Is Known About Global Warming?

Scientists who have studied global climate change agree on each of these points.

1. The greenhouse gases currently in our atmosphere are responsible for keeping Earth warm. Without these gases, Earth would almost certainly be in the grip of the deepest ice age in its entire history. Life as we know it would be impossible.
2. The concentration of greenhouse gases is increasing. A measurement program started in 1956 shows that Arrhenius was correct, and carbon dioxide is building up in the atmosphere. Human activities are increasing the concentration of other greenhouse gases as well.
3. Theories, experiments, computer simulations, and observations of other planets converge on the prediction that if the concentration of greenhouse gases continues to rise, Earth will warm even more.

What Are the Controversial Issues?

Controversies, like those reported in the newspaper article on page 13, have been researched and debated by scientists over the past decade. Many of the questions are still unanswered. However, government officials and industry leaders still need to decide what to do, even before all the evidence is in. So it's especially important for them to keep informed about the latest research. To do that, they need to know what the issues are.

Understanding the questions scientists are trying to resolve is, in fact, important for everyone. Our individual actions may be affecting the climate, and climate change may be important to the well being of future generations. In addition, controversy in science provides a fascinating "window" on the nature of science. The controversies include the following questions.

- Is our planet getting warmer?
- Has the warming caused any noticeable effects so far?
- Is the warming observed this century part of a long-term natural cycle?
- What is the best explanation for the warming observed this century ?
- When will the concentration of greenhouse gases double?
- How warm will it get when greenhouse gases double?
- How will clouds and oceans affect the changing climate?
- Will the change in climate be gradual or rapid?
- How will life on Earth be affected by global warming?

As you read the latest reports on these controversies, imagine you are a government policy maker—a U.S. representative, senator, cabinet member, or even the president of the United States. Based on the latest information, what steps do you think are warranted? Strong, moderate, or no action?

- Strong actions to reduce greenhouse gases, such as adding a high federal tax on gasoline and oil. If, as intended, use of these fuels lessens, another result could be the loss of jobs by people in those industries.
- Moderate actions, such as giving income tax relief to those who conserve energy or plant trees.
- No action except for continued research.

Is Our Planet Getting Warmer?

The graph on page 15 shows the average yearly temperatures of the entire globe from 1866 to 1988. It was the primary evidence on which James Hansen based his conclusion that he was "99% confident" global warming was already under way. That single graph was the result of many years of work by the Goddard team and more than a 100 years of effort by meteorologists all over the globe.

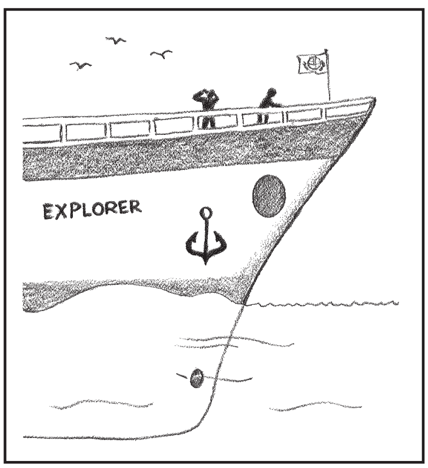
Hansen's team at Goddard did not simply average results non-critically. For example, they knew that sometimes a new thermometer might be installed at an observing station, or that the location of the thermometer might be moved. In some cases, cities might grow up around a weather observing station, and the decrease in the local foliage would cause warming near the thermometer. (This is called the *urban heat island* effect.) To avoid these problems, observers graphed results for each station over the entire length of the record, and these were compared with temperature measurements within a few hundred miles. "Jumps" in the data, or other "unreasonable" measurements could then be adjusted or eliminated before calculating overall averages.

Other scientists have looked critically at the result to see what might be wrong with it. For example, Patrick Michaels, a University of Virginia climatologist, found that a thermometer on St. Helena Island in the South Atlantic had been moved down a mountain slope in the 1970s. The change in location gave a false impression of rapid warming, said Michaels. Hansen investigated the claim, found it to be true, and made a correction. Because of such findings, the work of improving and updating the Goddard data continues to this day.

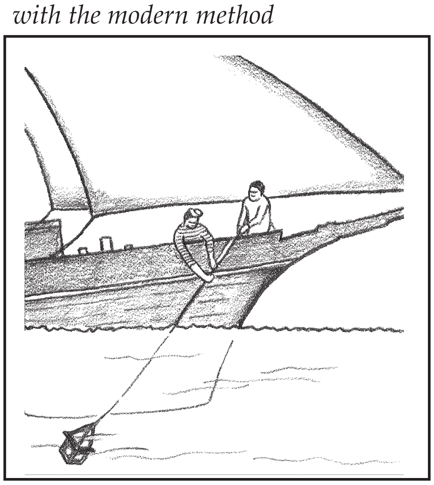
Hansen's conclusions were greatly strengthened when an independent group of scientists made a new survey of world temperatures since 1850. Philip Jones and Tom Wigley—climatologists at the University of East Anglia in Norwich, England—used different techniques to average the temperature measurements, and included many more measurements from the oceans. As an example of the kinds of corrections that Jones and Wigley needed to make when adding the marine measurements, they noted that before about 1940, ocean temperatures were measured by hauling up a sample of water in a canvas bucket and inserting a thermometer in the water. After 1940, thermometers were inserted in engine water-intake pipes. They found evaporation from the canvas bucket lowered the temperature, so they had to add 0.8°C to measurements made by the old method in order for both types of measurements to be comparable.

The IPCC report states that during the past century the average global surface temperature has increased by about 0.3°C to 0.6°C.

In summary, scientists have examined millions of temperature measurements taken around the world over the past century. Although there have been disagreements about the data, the great majority of scientists who study climate agree that the surface of our planet is warming.



Post-1940: Measuring ocean temperature with the modern method



Pre–1940: Measuring ocean temperature with a canvas bucket

Illustrations source: Philip D. Jones and M. L. Wigley, "Global Warming Trends," Scientific American, August 1990

Average Global Temperature Measurements

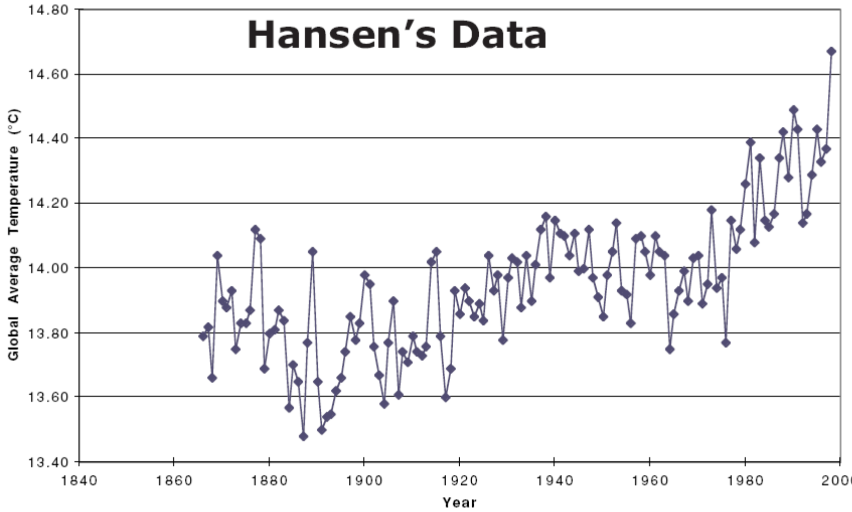
QUESTION 3.1

How much of a change in temperature is indicated by each data set?

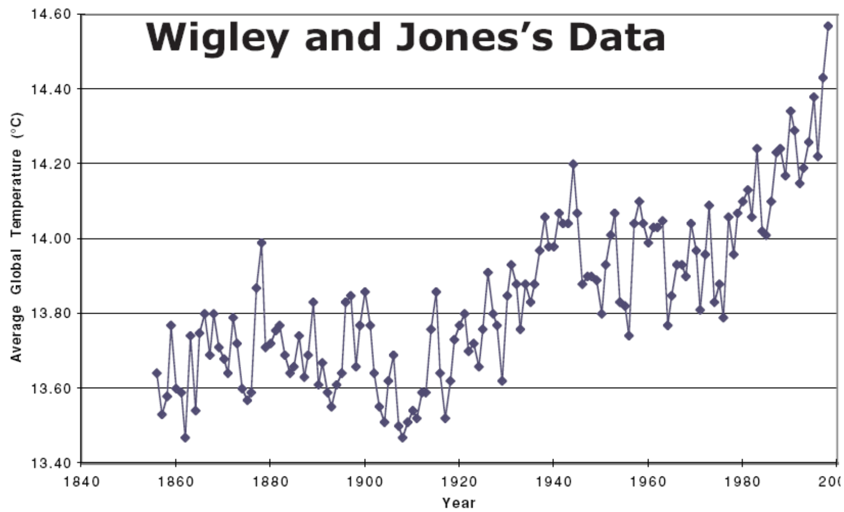
Are the same trends apparent in each one?

Are there significant differences?

Does the data support the conclusion by the IPCC that Earth is warming by about 0.3˚C to 0.6˚C?



Source: NASA Goddard Institute for Space Studies in New York (http://www.giss.nasa.gov)



Source: British Meteorological Office and University of East Anglia (http://www.cru.uea.ac.uk)

Has the Warming Caused Any Noticeable Effects So Far?

A variety of environmental changes have been observed by scientists around the globe. While it is still too early to say if the trends will continue, they do provide evidence of a gradually warming climate.

Glaciers

Most mountain glaciers are retreating. A photograph taken in 1849 of the Rhone Glacier in Gletsch, Switzerland, shows a huge river of ice slowly creeping down a mountain side. A photo of the same scene today shows a green valley with only a small portion of the glacier visible, halfway up the mountain. Similarly, glaciers in Alaska, Canada, and northern Russia are retreating. While a few glaciers, such as those in Scandinavia, continue to advance, most are gradually thawing.

Sea Level

According to the IPCC report, sea levels have risen by 10 to 25 cm over the past 100 years. It is very likely that the rise in sea level has resulted from the increase in temperature. First, water expands as it warms; and second, as glaciers on land melt, their water is added to the world's oceans.

Polar Ice

The permanent ice cover in the Arctic had shrunk by 14% in the past 20 years, according to a report in the December 3, 1999, issue of *Science*. Other data, collected by submarines, shows the Arctic ice sheet to be thinning. The continent of Antarctic appears to be warming even faster. In January 1996, the British Antarctic Survey reported five floating ice shelves, attached to the Antarctic Peninsula, had shrunk in the past 50 years. In 1999, a huge iceberg 38 miles long drifted into shipping lanes 200 miles south of the southernmost tip of South America. Scientists continue to monitor the ice sheets by satellite to learn if they are melting further.

Animal Behavior

In Europe, many species of butterflies are migrating further northward than usual, wrote Camille Parmesan and her colleagues in the June 10, 1999, issue of *Nature*. Two thirds of the 35 butterfly species they studied had migrated northward by 22 to 150 miles.

In addition to these careful studies there have been major climatic events that may be attributed to increasing temperatures. These include devastating storms and floods in Bangladesh in 1991, droughts and the resulting famines that have killed millions in sub-Saharan Africa, and heat waves such as the one that hit the East Coast of the United States in the summer of 1999.

While these trends and events provide *evidence* of a warming world, it is difficult for a scientists to conclude for certain that they are all *caused* by global warming. Climatologist Stephen Schneider illustrates this idea with the following example:

"Suppose you were trying to determine whether or not the total number of cars on the highways in a given urban area was increasing. You would have to count cars at a number of points throughout the area, and at different times of day, and then average the results. From day to day, the average number of cars will vary quite a bit, depending on a number of factors such as the day of the week, whether or not it is a holiday, or a special event like a World Series ball game. However, if the number of automobiles on the road were increasing over the years, you would expect to see a trend of increasing daily averages. If the trend is large enough, it will be noticeable despite the variations of large and small daily averages.

Rhone Glacier, Gletsch, Switzerland

1750

1950

September 2006

"Now suppose a major traffic jam occurs. You can trace the problem to an overturned truck that blocked a freeway, causing traffic tie-ups throughout the city. Was this major traffic jam caused by the increasing number of cars on the road? The answer is no—at least not directly. The gradual trend of an increasing number of cars on the road simply makes it more likely that a given event, such as an overturned truck, will result in a huge, citywide traffic jam.

"Similarly, the melting of glaciers, rising sea levels, changes in the behavior patterns of wildlife, hot spells, droughts, and forest fires—like traffic jams—provide evidence that our world is warming, although we cannot say for certain that any one of them is **caused** by global warming."

Is the Warming Observed Part of a Long-Term Natural Cycle?

Tim Barnett of the Scripps Institute of Oceanography in San Diego suggests natural oscillations in global temperature are so large that they would obscure any sign global warming had already begun. In other words, even if we accept the conclusions of the IPCC that Earth has warmed over the past century, in Barnett's view we cannot be sure the change is due to human activities.

How do we know about Earth's "natural oscillations"? A clue to past climate changes can be found in layers of ice near the North and South Poles. Since the ice does not melt in the Arctic and Antarctic regions, older layers are buried by newer layers. The deepest layers are compressed under the weight of the ice above, so they become very thin. Yearly layers can be seen and can be counted like annual rings on a tree.

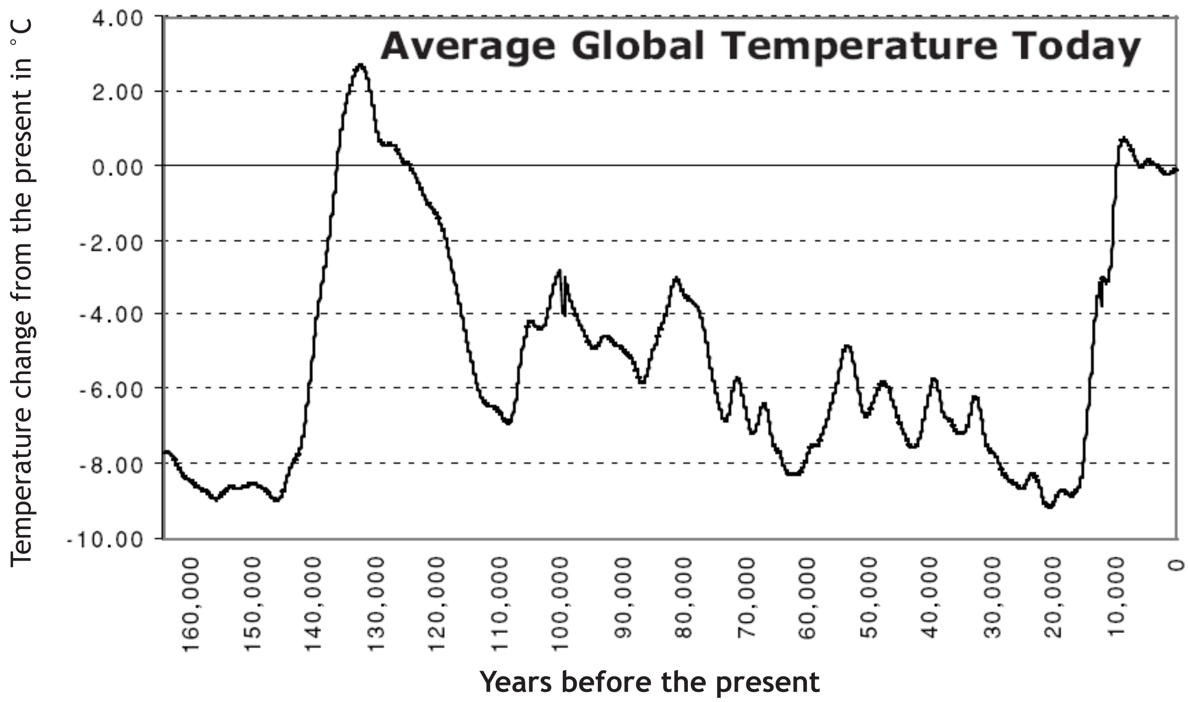
Over the past 20 years, many ice cores have been extracted from the Greenland ice sheet and from the deep ice of Antarctica. *Ice cores* are cylinders of ice cut by a drill shaped like a long tube. Each core is carefully dissected, one layer at a time.

The graph on the next page shows Earth's natural climate changes for the past 160,000 years. The horizontal line at "0" is the temperature today. It's easy to see what Barnett meant by "natural oscillations." Over the past 160,000 years, Earth's climate has varied a great deal. Furthermore, for most of that time it was a lot colder than it is now. That long period—from about 120,000 years ago to about 18,000 years ago—is the most recent "ice age." Although the average global temperature was at most 9°C colder than it is today, ice sheets up to two miles deep covered Canada and northern United States, reaching as far south as what is now New York state. Despite the cold, our ancestors thrived.

About 15,000 years ago Earth started to warm. Gradually, the great ice caps melted and sea levels rose worldwide by as much as 65 meters. The planet reached its current temperature about 10,000 years ago. During the most recent 10,000 years, called the Recent or Holocene Period, agriculture was developed and complex human civilizations gradually arose.

Studies of Earth's more distant past show there have been 17 warm interglacial periods over the past two million years. After each one, Earth gradually cooled again. Today, it's generally accepted that this pattern is caused by a regular cycle of changes in Earth's orbit and the tilt of its axis. Based on this theory, which accounts for past ice ages, Earth will be entering another ice age about 5,000 years in the future. But these very long-term cycles cannot explain the warming that has occurred in the past 100 years.

Yearly layers of ice can be counted like annual rings on a tree.



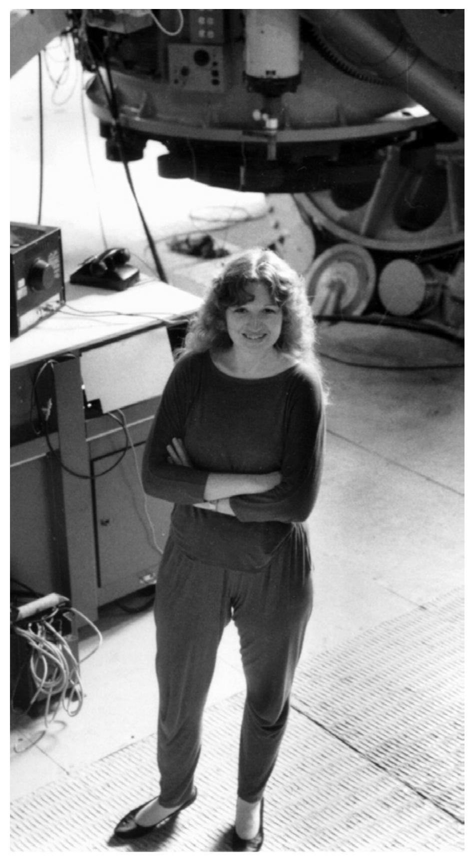
Source: Trends '93: A Compendium of Data on Global Change

What Is the Best Explanation for the Warming in the Past 100 Years?

Unlike ice ages, which take place over thousands of years, short-term changes in climate— such as the increase in temperature observed during the 1900s—are not well understood. For example, the graphs on page 15 show the global climate actually cooled from 1840 to 1970. This cannot be explained by the enhanced greenhouse effect, which would predict a continuous increase in temperature since the industrial revolution. Hansen and others note that although the greenhouse effect is important, it is probably not the only cause of climate change. Other factors may have caused some of the cooling. Volcanoes, for example, create huge clouds that persist for months, reflecting much of the Sun's energy back into space. However, no one has fully explained the cooling that took place from 1940 to 1970.

Other scientists have proposed theories about what they believe may have had a greater impact on the average global temperature than the greenhouse effect. One recent theory, put forward by several scientists, including Dr. Sallie Baliunas from Harvard University's Center for Astrophysics, is that most of the climate change observed in this century is due to changes in the Sun's activity.

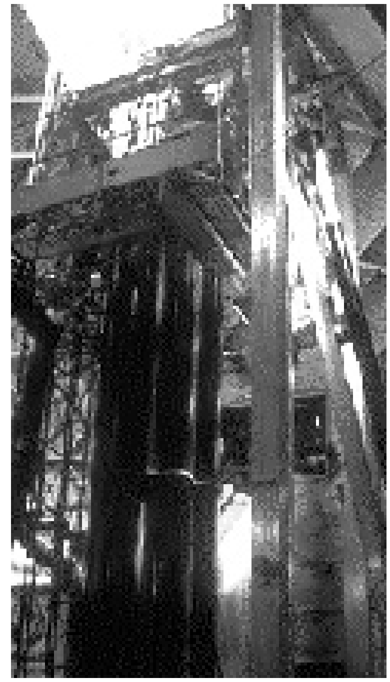
It has long been known that the Sun goes through a cycle about every 11 years, during which the number of sunspots increases and decreases. A *sunspot* is an area on the Sun that is a little cooler than the surrounding area; so it appears dark through a telescope. The 11-year cycle is not exactly the same every year. In some years the Sun is much more active than in other years.



Sallie Baliunas at Mt. Wilson Observatory. Photo courtesy of Sallie Baliunas.

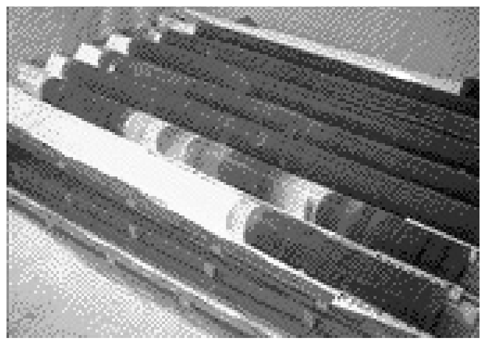
Baliunas and others claim these changes in solar activity affect Earth's climate, causing changes in the paths of storms, and the amount of cloud cover, rain, and snow. These changes naturally affect the planet's overall global temperature.

Support for the theory that the Sun has affected Earth's weather has been found deep in an ice core taken from the Greenland ice sheet. A team of scientists headed by Dr. Paul Mayewski from the University of New Hampshire counted annual layers of ice and snow, back to more than 160,000 years ago. One sign of climate change was the presence of dust in some layers. A greater concentration of dust suggested there must have been storms that year that carried the dust from areas where there was no snow to the Greenland ice sheet. The scientists found the concentration of dust varied with an 11-year cycle, supporting Baliunas's theory that solar activity affects Earth's climate.



Ice cores are extracted from the ice sheet by a large drill housed in a dome. (The outside of this dome near the middle of Greenland is shown on page 3.)

Although most scientists agree changes in the activity of the Sun affect Earth's climate, they differ sharply about how much the Sun has affected Earth's average temperature. Baliunas thinks as much as 94% of the global warming observed in this century may have been caused by the Sun. Others think the effect of the Sun is below 1%.



The ice cores are broken into lengths, 6–19 feet long, and hauled to the surface.

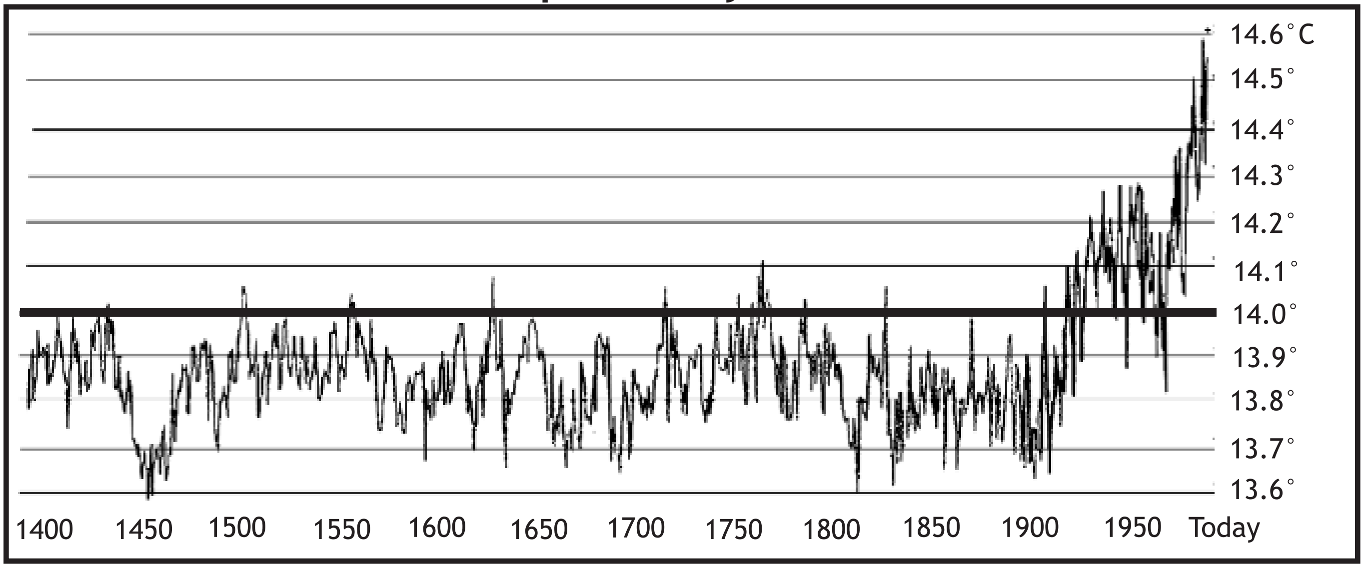
A detailed analysis of the average global climate in recent times by Michael Mann and Raymond Bradley of the University of Massachusetts and Malcolm Hughes of the University of Arizona. They combined data from several sources: ice cores from polar regions and from mountain glaciers; thicknesses of tree rings, and chemical analyses of layers of ancient corals (see Stevens in the Bibliography). For the most recent centuries the scientists used historical records, and the accurate instrument records such as those reported by Hansen and by Wigley and Jones (on page 20).

Mann said, "Our conclusion was that the warming of the past few decades appears to be closely tied to emission of greenhouse gases by humans and not any of the natural factors." (See Stevens in the Bibliography—New York Times; June 29, 1999).

Other researchers further support that conclusion: an analysis of ice cores shows current levels of carbon dioxide gas in the atmosphere are higher than at any time in the past 420,000 years (see Petit in the Bibliography). Efforts to use computer models to sort out the various factors affecting climate in the past 100 years determined that since the 1970s, global warming cannot be explained without a large impact from greenhouse gases. These studies strengthen the conclusion that human activities are contributing to global warming. (See Vinnikov in the Bibliography.)

Researchers cut and analyze sections of the ice cores as soon as they are removed. Workers wear "clean suits" over their warm clothing, so they do not contaminate the samples.

Annual temperature for the Northern Hemisphere over the past 600 years



Source: Mann, Bradley, Hughes

QUESTION 3.2. How does the graph on page 18 relate to the finding that current levels of carbon dioxide are higher now than at any time in the past 420,000 years?

When Will the Concentration of Greenhouse Gases Double?

It's difficult to imagine what your life will be like in five years—let alone in 30, 40, or 50 years, when you're bouncing grandchildren on your knee. But in order to take the predictions of climatologists seriously, that's what you need to do—think about how your actions today will affect the lives of your children and grandchildren.

The concentration of carbon dioxide in the atmosphere is increasing at the rate of half a percent per year. That's barely noticeable. But if that rate continues, about 100 years from now there will be twice as much carbon dioxide in the atmosphere than there was before the industrial revolution.

Although carbon dioxide is the most important greenhouse gas, it's only half the story. Other greenhouse gases (methane, nitrous oxides, and CFCs) contribute another half a percent per year in equivalent heat-trapping capacity.

The IPCC report envisions various scenarios, or possible futures. According to some scenarios, the amount of greenhouse gases in the atmosphere will grow even faster than it is growing now. This growth is caused by the increasing world population. As world population increases, so does the demand for food, energy, and manufactured goods. Much of this population growth is taking place in developing nations. As the people in these nations strive to have the same standard of living enjoyed by most people who live in industrialized nations, the amount of greenhouse gases in the atmosphere will increase even further. According to these projections, it seems likely that in the decades to come there will be even more greenhouse gas emissions than now. Finally, the destruction of rain forests, which is occurring around the world at an increasing rate, means that fewer trees will be around to absorb large quantities of carbon dioxide.

Other scenarios are more optimistic. If energy use can be cut back through conservation, less fossil fuels will be burned, and greenhouse gas emissions will be reduced. For example, new conservation technologies are being developed to light and heat homes in ways that use less energy; and cars are being developed that use gasoline more efficiently. Another factor would be the growth of alternative energy industries, including wind, solar, and geothermal power plants that do not emit greenhouse gases. Other scientists expect that, somehow, Earth's natural systems will adjust and the climate will not change significantly, even if the concentration of carbon dioxide continues to increase.

According to the IPCC report, "most emission scenarios indicate that, in the absence of mitigation policies [steps to reduce emissions], greenhouse gas emissions will continue to rise during the next century and lead to greenhouse gas concentrations that by the year 2100 are projected to change climate more than that projected for twice the pre-industrial concentrations of carbon dioxide."

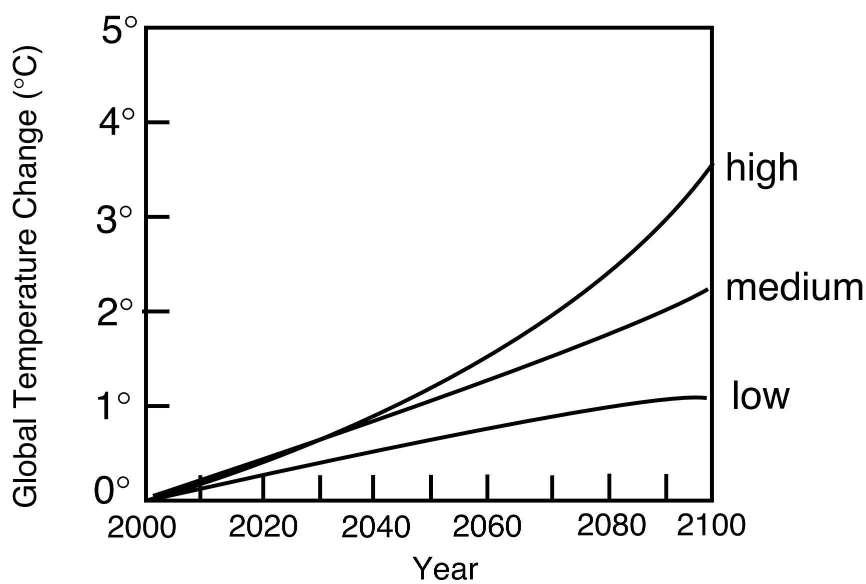
How Warm Will It Get When Greenhouse Gases Double?

Predictions of future climates are currently in the form of computer models. The computer models predict warming as greenhouse gases continue to increase. Climatologists try to make their models more realistic by including more factors. In the past five years, they have added the effect of *aerosols*—particles in the air emitted by cars and factories. Unlike the invisible greenhouse gases, aerosols are visible. Their effect on climate is much like a cloud of ash from a volcano. Aerosols cool the earth by reflecting some of the Sun's light back into space. The result is that instead of a 5°C increase expected by Arrhenius, only a 1° to 3.5°C increase in temperature is expected with a doubling of greenhouse gases in the atmosphere.

Predicting how warm it will get is very difficult. Imagine a time—perhaps when our children are grown—when new sources of power are developed which are "clean." They do not produce either greenhouse gases or aerosols. Aerosols have short lifetimes, since the particles settle within a few years. But greenhouse gases hang around for a very long time—as much as 500 years in the case of carbon dioxide. With the cooling effect of the aerosols gone, the atmosphere could heat very rapidly in less than a decade, causing even greater climate disruptions.

The scientists who designed these models acknowledge they do not have enough information about the effects of clouds and oceans in their calculations.

Projected average surface temperature for the next 100 years. *Source: The Science of Climate Change*

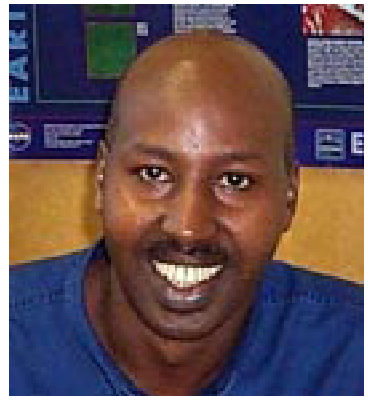


How Will Clouds and Oceans Affect the Changing Climate?

Clouds

If Earth becomes warmer because of the greenhouse effect, more water will evaporate from the oceans. Increased water vapor means more clouds, and clouds are very effective at reflecting sunlight. (Just think of the cooling effect of a cloud passing overhead on a hot day.) On the other hand, clouds can also warm Earth. Anyone who lives in the desert knows that you must dress warmly at night because the land cools off very rapidly. But if there are clouds overhead, they will absorb some of the heat radiated by Earth and send it back toward the ground. The only way to determine for sure how to enter clouds into the models is to study their effects in different parts of the world and in different seasons.

The study of clouds is a very active area for researchers today. Ali Omar is involved in a research project designed to answer some of these questions. He is one of the researchers studying the effects of clouds from a satellite launched in 2006. Named CALIPSO, the satellite is a joint project of the United States and France. It is equipped with a laser pointed towards Earth's surface. The satellite measures laser light that is reflected from cloud layers to determine where the cloud layers are located and how thick they are. It also measures infrared (heat) energy radiated into space. Scientists expect that data from the satellite and from ground-based measurements will enable them to determine whether the overall effect of the clouds is to cool or warm Earth's surface.



Ali Omar is assistant professor of Physics at Hampton University in Hampton, Virginia. When he was a young boy in Kenya he wanted to be a pilot, but his parents would not let him because they thought it was too dangerous. So, he decided he would learn how to build jet engines instead. He came to the United States to study aeronautical engineering. One of his required courses concerned how jet exhausts affect the atmosphere. That sparked his interest in environmental science. "Now," he says, "I'm kind of glad my parents did not allow me to become a pilot."

Oceans

Lynne Talley is a researcher at Scripps Institution of Oceanography in La Jolla, California, where she studies the role of ocean circulation in climate. She explained the importance of her research by posing an interesting question: "In February, you would not want to go swimming off the coast of Labrador (north of New England). The ocean surface temperature is only about 1°C. But Ireland is the same distance north of the equator, and water there is a much warmer 10°C. Why are they so different?" The difference, she said, is due to ocean currents. Labrador is bathed in frigid waters that come from the Arctic, while the coast of Europe is warmed by currents that come from the equator.

Lynne Talley of the Scripps Institution of Oceanography.

Talley said the temperature of the ocean changes far less than the temperature of the land. That affects the interaction between ocean circulation and world climate on different time scales, from a single day to hundreds of years. Let's start with *daily changes*. In the daytime the land heats quicker than the ocean, so the air above the land is warmer than the air above the ocean. Warmer air is less dense than cool air. Differences in air density can give rise to air movements. In some locations the difference is great enough for cool sea breezes to move landward, pushing the warmer air upward. At night the land cools off quickly, cooling the air just above it. When the air over the land becomes colder than the air over the sea, the winds reverse.

In order to predict the future of climate change, researchers are studying the ways that the ocean interacts with the atmosphere.

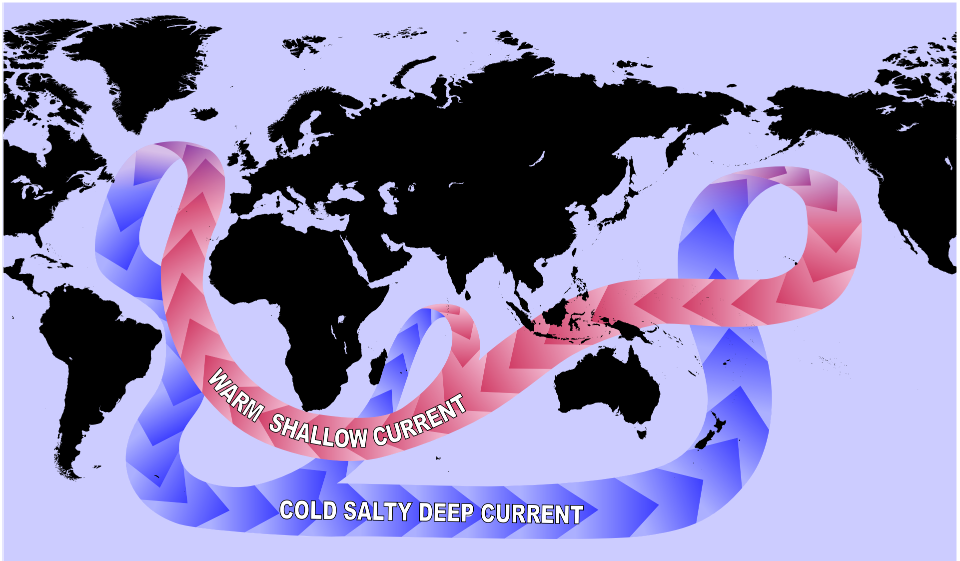
This description of how winds are created by the relative warming of land and sea also applies to the far stronger seasonal changes in Asia referred to as *monsoons*. In the summertime the land mass in Asia stays warmer than the sea. So, moist air moves from the ocean toward the land, bringing life-giving rains. In the winter, the ocean is warmer than the land, so the winds reverse, and people who live in Asia experience hot, dry weather.

Changes also occur *every few years*. The most intensively studied of those is El Niño—a weather condition in the Pacific Ocean that occurs every four to seven years. (El Niño means "The Child" in Spanish. It refers to the Christ Child since these weather conditions always occur around Christmas time.) During El Niño, normal winds and ocean currents reverse for several months, and extreme weather conditions can occur at other places in the world, ranging from droughts, forest fires, and floods to changes in the monsoons and trade winds. It is estimated that the 1982–83 El Niño event caused $8 billion dollars in damage and the death of 2,000 people worldwide. Estimates of the impact of the 1997–98 El Niño season are even greater, with property damage estimated in the $30 billion to $60 billion range, and as many as 21,000 lives lost (see Mackenzie in the Bibliography). While the cause of El Niño events is still not understood, scientists have determined that it involves the interaction of the ocean and atmosphere systems.

Over a period of hundreds of years, the ocean transports both heat energy and dissolved carbon dioxide in a current so huge it weaves through all of the world's oceans. It is sometimes called the "global ocean conveyor belt." Part of the driving force for this current is in the North Atlantic where salty water (which is already denser than fresh water) cools and becomes even denser. The cold, salty water sinks and begins a very long, deep journey around the world (as shown in the diagram on page 24) until it finally wells up somewhere in the Indian and Pacific, and maybe even around Antarctica. As it becomes part of a warm surface current, the water absorbs heat from the Sun and carbon dioxide from the air before it again sinks to the bottom of the Atlantic, several hundred years later. As pointed out by Talley, the precise course of the current is not thoroughly understood. However, the overall idea of long-term ocean circulation is well accepted by nearly all oceanographers today.

Some scientists are concerned global warming might cause enough melting of the Arctic and Greenland ice sheets for fresh water to flood the Atlantic, slowing or stopping the global conveyer belt. Some researchers reported evidence that the global conveyer belt had, in fact, stopped or weakened at least twice since the last ice age, suggesting that this may occur again if melting of the Arctic and Greenland ice sheets increases (see Ruhlemann in the Bibliography).

Until we have a better understanding of



Source: Climate System Modeling

The Global Conveyor Belt

A theory of how water circulates through the world's oceans over a period of several hundred years.

how the clouds and oceans interact with the atmosphere, we will not be able to predict accurately how much our planet will warm if the concentration of greenhouse gases doubles.

Will the Change in Climate Be Gradual or Rapid?

Analysis of layers of ice in Greenland provides an answer to this question. The record in the ice shows Earth started to emerge from the last ice age about 15,000 years ago. Then about 12,900 years ago, it suddenly cooled again. In the relatively short period of about 10 years, the temperature plunged 15°C, returning almost to ice-age temperatures. The cold period lasted for 13 centuries, until about 11,600 years ago, when, in just about a decade, Earth finally started to warm again. It has been relatively warm ever since. This cold period was also observed in the analysis of layers of ice from Antarctica, but was not quite so intense.

Why did the climate change over just one decade, then remain cold for 13 centuries, only to warm rapidly again? Scientists do not have certain answers to this question, but one popular theory is that the deep ocean current was "switched" off, and then "switched" back on again 13 centuries later. Here's how it may have happened.

We know the conveyor belt current makes a huge difference in the climate, and it is driven by changes in the temperature and salinity (saltiness) of the seawater. If the climate warmed too quickly, the warmer temperature could have caused a glacier to melt, flooding the North Atlantic with fresh water. The fresh water would float on top of the denser salty water, and stop the conveyor belt current from flowing. For the global ocean current to be "switched" back on, the ocean would have to become salty again. This could happen as the world cools in an ice age and less fresh water is added to the ocean. Eventually the ocean would become salty enough for the current to start flowing again and warm temperatures to return.

While we don't know for certain what will happen in the future, we do know abrupt changes in climate have occurred in the past, suggesting that they may occur in the future.

How Will Life on Earth Be Affected by Global Warming?

As far as local regions are concerned, no one knows for certain how life will be affected. According to climatologist Stephen Schneider, "It's still tough to be confident in projecting where and when it will be wetter and drier, how many floods might occur in the spring in California, or forest fires in Wyoming or Siberia in August."

Nonetheless, it is possible to make some reasonable predictions for life on the planet if an increase of a few degrees in global temperatures occurs. Predictions can be based on the observed differences between different regions of the globe today, or by studies of past conditions when the climate was known to be different from what it is today. Based on these studies, the IPCC made its most dramatic predictions: if current trends continue, the world of our grandchildren will be different from ours in several respects.

Rising sea levels

Because water expands when it's heated, and mountain glaciers drain to the ocean as they melt, the sea level will rise as the globe warms. Sea levels worldwide have already risen by 10 to 25 cm over the past century. If this trend continues, over the next 100 years they will rise by another 50 to 95 cm, and will continue to rise for the next several centuries.

Loss of coastal lands

In future decades more and more food will be necessary to sustain the world's growing population. Coastal plains are among the most fertile in the world. A rise in sea level would inundate some coastal areas. According to the IPCC report, "Estimated land losses range from 0.05% in Uruguay, 1% for Egypt, 6% for the Netherlands, and 17.5% for Bangladesh up to about 80% for the Majuro Atoll in the Marshall Islands." Areas in the United States threatened by sea level rise include areas of Florida, California, Louisiana, and other coastal areas.

Danger from storm surge

Because storms are caused by an exchange of heat energy between the oceans and atmosphere, global warming is expected to cause more intense storms. Moreover, higher sea levels increase damage from storms and floods. A large proportion of the world's population lives in coastal areas, and every few years tragedies occur when especially powerful storms buffet coastal areas with high winds and waves, causing billions of dollars in flood damage and killing thousands of people. In May, 1991, a storm hit Bangladesh with 270 kilometer per hour winds, flooded coastal plains, damaged more than a million homes, and killed an estimated 140,000 people. According to the IPCC report, 46 million people are currently in danger of coastal storm surges. An increase of 50 cm in sea level would increase the number of people at risk to 92 million, ignoring the effects of increasing world population. According to the IPCC report, "a rising sea level and the possibility of increased storm surges could threaten the survival of some small island states and coastal areas."

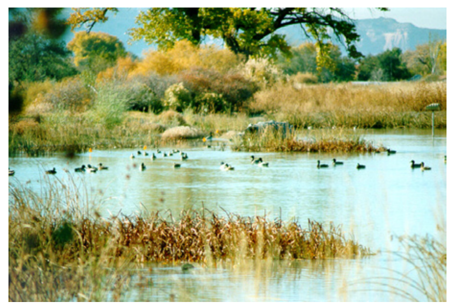
Loss of forests

Throughout the world, some forest preserves have been protected from logging or clearing. However, it may not be possible to protect forests from climate change. If global warming occurs at a pace faster than most species of trees can reestablish themselves, entire forest types may disappear and be replaced by new forest ecosystems.

Increased rainfall

Global warming will increase the rate of evaporation from oceans, and therefore increase rainfall worldwide. This will have a beneficial effect in some areas, but other areas would experience additional flooding and erosion.

Loss of wetlands



Saltwater marshes, mangrove ecosystems, coastal wetlands, sandy beaches, coral reefs and atolls, and river deltas are already impacted by the expansion of farms and cities. Those that remain would be further affected by a change in climate, with negative effects on the diversity of wildlife, freshwater supplies, fisheries, and tourism.

Increased desertification

Rainfall will increase in some areas, and decrease in others. Less rain is expected to fall in sub-Saharan Africa, South and Southeast Asia, and tropical Latin America. These areas would suffer losses in forested lands, reduced harvests, and expanded deserts.

Threats to human health

Illnesses caused by heat waves may increase as well as diseases such as malaria, dengue, and yellow fever, which are carried by insects. In addition, warmer weather and flooding would encourage the growth of organisms that cause salmonellosis, cholera, and giardiasis. Further health problems would be caused by shortages of food, fresh water, and increased air and water pollution.

Changes in agriculture

Overall, a higher concentration of carbon dioxide in the atmosphere will increase the growth of crops, but it will also increase the growth of weeds and insect pests. The greatest danger will be to the poorest people in the world, where available crops are just barely able to feed people today.

What Would You Do?

According to the scientific studies, what we do today will not affect our lives very much tomorrow or the next day. The greatest effect will be felt some years from now—by our children and grandchildren, and people living then. Is protecting the environment for future generations worth strong actions that might impact jobs today? Would moderate actions, such as conservation, recycling, and planting trees be better? Or is it best to take no action except continue to study the problem?

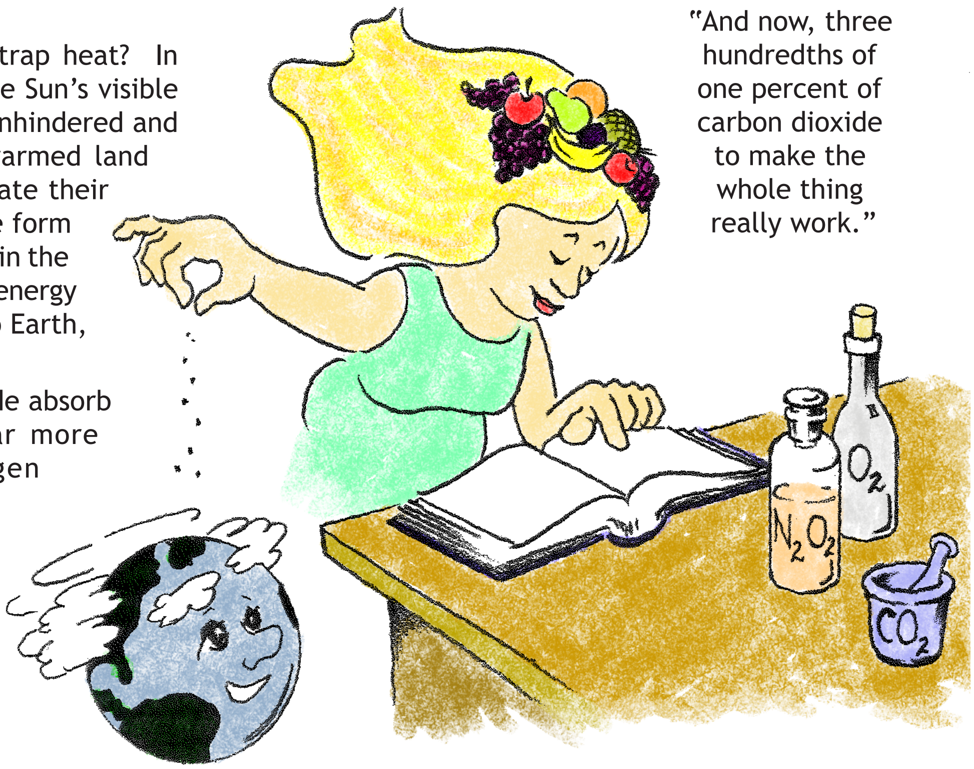
QUESTION 3.3. If you were a government decision maker, what would you do in the face of scientific controversy and the long time scales involved?

For new material relating to this chapter, please see the GSS website "Staying Up To Date" page:
http://lhs.berkeley.edu/gss/uptodate/2cc/2cc.html
We invite you to send us new articles for the "Staying Up To Date" web page for this chapter. Articles may be from local newspapers, magazines, websites, or other sources that you think would be of interest to classrooms around the country. To send us articles please go to the link http://lhs.berkeley.edu/gss/uptodate/newarticle.html and find the "Submit New Article" button.

4. What's So Special About CO_2?

How does carbon dioxide trap heat? In short, the atmosphere allows the Sun's visible light energy to pass through it unhindered and heat the ground. When the warmed land masses and seas cool, they radiate their energy back toward space in the form of infrared rays. Carbon dioxide in the air absorbs some of that infrared energy and sends a portion of it back to Earth, thus raising the temperature.

But *why* does carbon dioxide absorb infrared energy, while the far more abundant oxygen and nitrogen gases in the atmosphere do not? To fully explain how carbon dioxide and some other gases act to allow sunlight in and trap infrared energy we need to first find out how matter and energy interact.



"And now, three hundredths of one percent of carbon dioxide to make the whole thing really work."

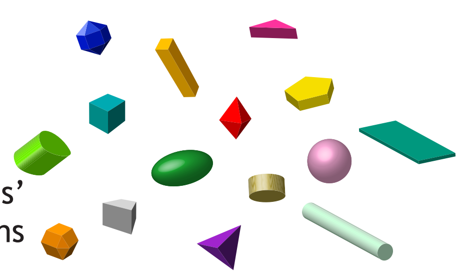
Matter

For thousands of years people have been observing nature and trying to reduce its complexities to simple, understandable terms. Many cultures recognized that everything was made up of just a few categories of matter. The ancient Greek, Aristotle, who lived 2,300 years ago, wrote that everything is made of different combinations of four basic ingredients: earth, air, water, and fire. For example, he thought wood was made of earth and fire. The process of burning let the "fire" out of the wood, leaving the black solid "earth" behind.

Aristotle's Idea

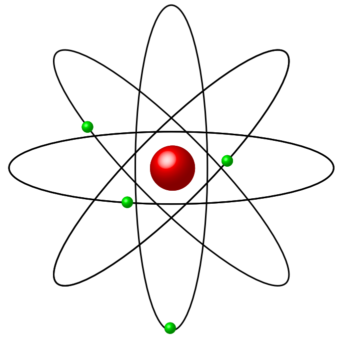
A different point of view was suggested by Democritus, a Greek philosopher who lived nearly a 100 years before Aristotle. He thought all things were made up of little indivisible particles ("atomos" in Greek), with nothing in between the particles.

Democritus' daring idea is very similar to the view virtually all scientists hold today, called the *particulate theory of matter*. According to this theory, all naturally occurring matter is made of only 92 different kinds of atoms. Materials made of only one kind of atom are called *elements*. An *atom* is the smallest unit of an element that still has the properties of that element. All atoms have the same general structure: a central *nucleus*, which has a positive electric charge, surrounded by negatively charged *electrons*.



Democritus' Atoms

Solar System View of an Atom



A "Cloud" of Electrons

Long ago, it was thought atoms were like little solar systems, with atoms whirling around the nucleus like planets around the Sun. As it is impossible to precisely locate any particle within an atom, today the image of a cloud is often used to show the unpredictable positions of the electrons.

Materials made of combinations of two or more elements are called *compounds*. The smallest unit of a compound is called a *molecule*. Carbon dioxide is a compound made of one carbon atom and two oxygen atoms; so its chemical symbol is CO_2.

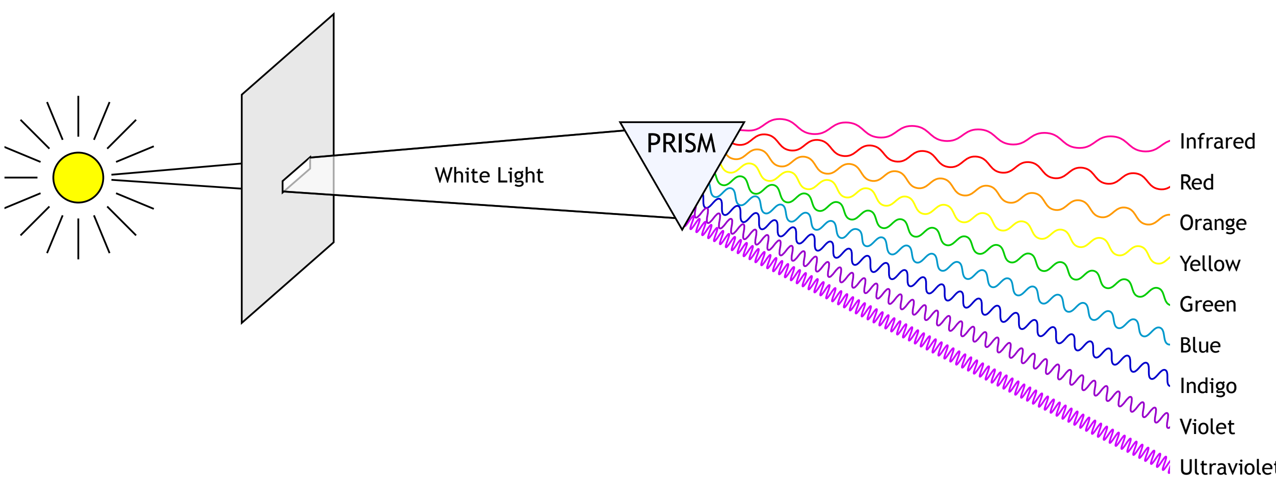
Scientists frequently draw diagrams of molecules showing how the different atoms inside them are arranged. However, none of these representations are intended to show what an atom or molecule "really" looks like, but rather, to represent various properties we know about them.

Understanding what is so special about CO_2 involves knowing about the interaction between matter and energy, so we'll next discuss energy.

Light Energy

Energy comes in many different forms, but for the purposes of understanding what's special about CO_2, it's most important to understand light and heat energy. First, we'll consider light.

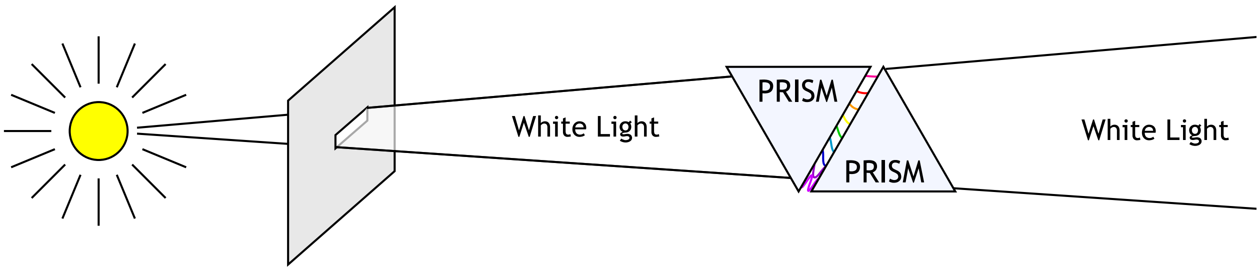
In the year 1666, at the age of 23, Isaac Newton began one of the first systematic investigations of light. He sent sunlight through a triangular piece of glass, called a *prism*, and found the effect to be "a very pleasing divertissement, to view the vivid and intense colors produced thereby." The glass prism cast elongated patches of light that were separated into bands of color: violet at one end, red at the other. In between was a continuous gradation of different colors. He noted the similarity of the pattern of colors to that of the rainbow. Newton named the pattern a *spectrum*.



Newton wondered where the colors came from. Did they come from the light or from the glass prism? He answered this question by inserting a second prism upside down into the beam. He found that if the prisms were close together, the colors combined again to form a bright beam of sunlight. Thus he concluded that the colors of the spectrum did not originate in the glass. His experiments showed that sunlight was composed of various colors and that the colors could be separated or combined with the help of a glass prism.

Investigation

Two Prisms



If you can borrow two prisms, you might try splitting a beam of light into its different colors, then combining the light again into a single beam—just as Isaac Newton did more than 300 years ago.

- Use the Sun or an electric light bulb for your source of light.
- Put a slit in a sheet of paper to create a single beam of light.
- Align the prism and then the second prism to create your spectrum and then turn the spectrum back into white light.

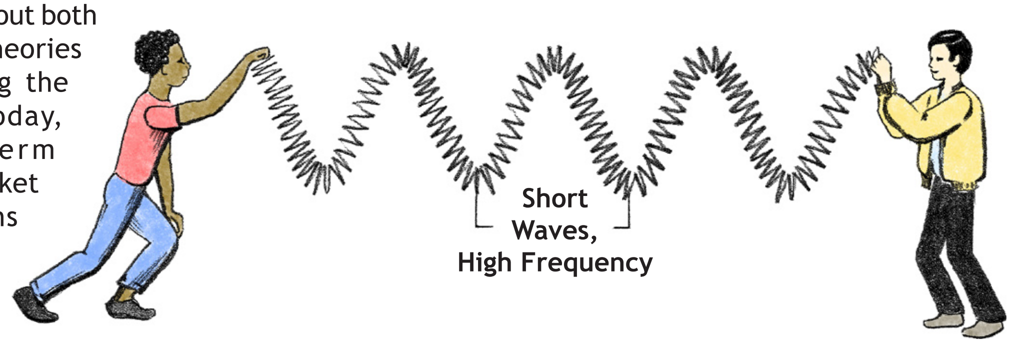
Two theories soon developed to explain the nature of these different colors: the particle theory and the wave theory of light. Newton favored the idea that each ray was composed of streams of tiny particles. He thought that some particles were blue and produced blue light, while other particles were red and produced red light.

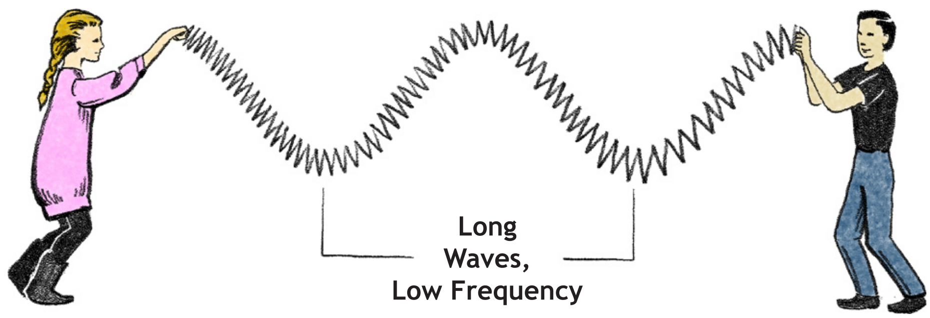
Other investigators performed experiments showing that light acted more like a wave. Their idea developed into the notion that blue light was composed of waves that were shorter, from crest to crest, than red light waves. The distance between wave crests was called the *wavelength*. Each of the colors of the visible spectrum had its own specific wavelength.

According to the wave model, light of a given wavelength has a corresponding frequency. *Frequency* can be thought of as speed of vibration, or how *frequently* a wave occurs in a certain period of time. Imagine making waves in a long spring, like a Slinky. Shaking your hand faster produces very short waves with high frequency. Shaking your hand slower produces longer waves at a lower frequency.

Wiggling your finger in water with fast and slow frequencies will produce similar results. Try it.

After many experiments and much discussion, it turned out both the particle and wave theories were useful in describing the properties of light. Today, scientists use the term *photon* to indicate a packet of light energy. Photons have properties of *both* waves and particles. For example, photons of blue and red light both appear to "bounce" off a mirror the way a ball bounces off of a wall. That suggests photons are like particles. On the other hand, when blue and red light rays pass through a prism, they are bent at different angles. This can be explained if the photons that carry blue light have shorter wavelengths and higher frequencies than the photons that carry red light. Other experiments indicate photons with higher frequency carry more energy.





Infrared (Heat) Energy

In order to understand the greenhouse effect it's important to know about *infrared energy*. Infrared energy was discovered more than 100 years ago when the English scientist Sir William Herschel used a prism to spread sunlight into a spectrum, and used a thermometer to measure the temperature in each color. He was amazed to find it was warm beyond the red end of the spectrum. He called the invisible form of energy, which could only be detected with the use of a thermometer, *infrared rays*.

If you have ever stood in front of a fire and felt its warmth, you have detected billions of infrared photons bombarding your skin. If someone or something gets between you and the source of infrared radiation, you can feel the radiation being blocked. Hold your hand near a rock or any other object that has been in bright sunlight for a while. You will feel the infrared waves as heat.

Objects that are warm radiate more infrared energy than objects that are cold. According to the molecular theory, this is because hot objects are composed of rapidly vibrating molecules. As the object cools, the molecules slow down. The energy from the vibrating molecules is converted to photons of infrared energy.

Warm objects that do not give off visible light can be "seen" with special instruments that detect infrared photons. Human beings and other animals, for example, radiate considerable infrared energy. The military makes use of infrared detectors in their night vision cameras and scopes. Some special photographic films are sensitive to infrared radiation and can take pictures of warm objects in the dark. Some snakes have sensors to "see" infrared light. This ability helps them locate prey at night.

Our skin nerve cells are not sensitive to visible light photons, but our eyes are supremely sensitive to them! The retina at the back of a human eyeball can distinguish photons of slightly different wavelengths and interpret them as different colors. As we lie on a beach, our eyes see the Sun's visible light energy, while our bodies feel its infrared energy.

It is now known that infrared energy is the same kind of energy as visible light, but the wavelength is longer. The wavelength (or color) of an object depends on its temperature. You can see this effect with a light bulb attached to a dimmer switch. A clear light bulb will allow you to see the thin metal filament inside the bulb. When the electricity begins to flow the filament will glow a dull red. As the dimmer is turned up the filament will get warmer and warmer. It will gradually turn from red to orange to yellow, and eventually it will become white hot.

Rays and Radiation

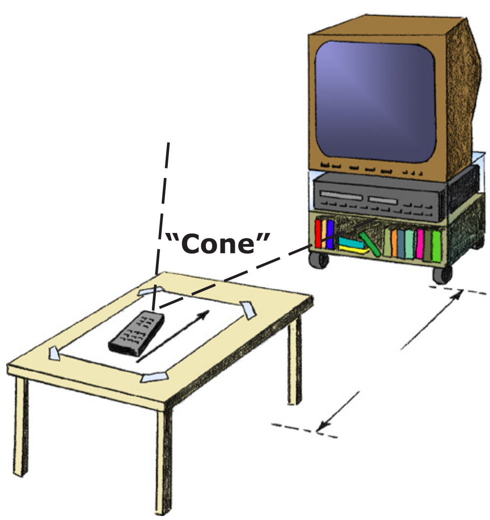
The terms *rays* and *radiation* can be applied to any form of energy which spreads out, or *radiates* from a source. Light rays are different from the particles that are emitted from radioactive minerals, although both can be referred to as radiation. Any kind of radiation, including sunlight, can be harmful in very large doses.

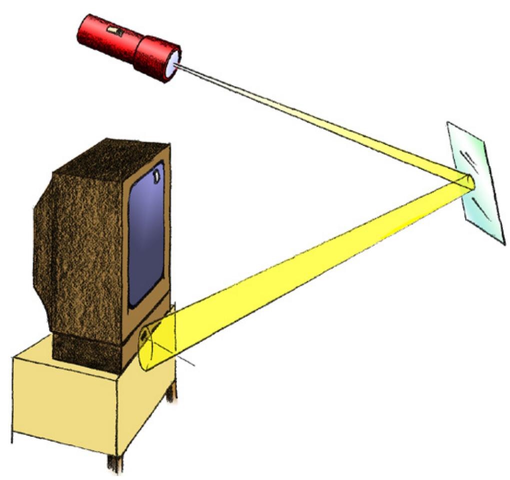
Investigation

Infrared Energy and Your TV

Wireless remote control devices for television sets and video cassette recorders use invisible beams of infrared radiation (IR) as the means of transferring the information from the device in the hand of the viewer to the controls within the sets. Try these experiments.

A. Measure the "cone" or area of infrared energy by putting the remote control device on a sheet of paper taped to a table. Move the table slowly away (and then closer) from the television. Mark the position where the device begins to work.





B. Even though you can't see it, the beam of infrared light will reflect off a wall or the ceiling just as a beam of visible light will reflect off a mirror. Try controlling your TV set by "bouncing" the beam around the room, instead of pointing it directly at the TV.

Carbon Dioxide—The Gatekeeper

Ideas about matter and energy come together as we return to the question, "What's so special about carbon dioxide?"

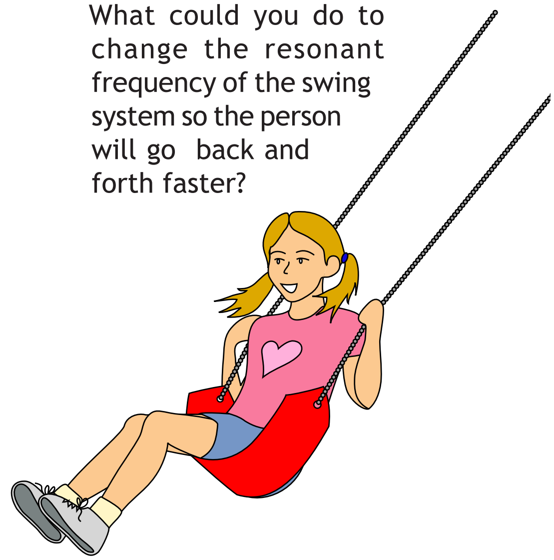
Carbon dioxide acts as a sort of gatekeeper. As we said at the beginning of this chapter, carbon dioxide allows visible light to pass right by but will absorb infrared energy. The key to understanding how it does this is a concept called *resonance*.

Imagine you are pushing your friend on a swing. If you want to get your friend to swing as high as possible, you need to time your pushes just right. If the swing goes back and forth once every second, you must push at a frequency of once per second. You must also give the push at just the right instant, when the swing is just about to go forward.

The right pushing speed required to transfer energy from one system (you) to another (the swinger) is called the *resonant frequency*. The following activity illustrates how resonant frequency is important when light energy interacts with molecules in the atmosphere.

QUESTION 4.1.

What could you do to change the resonant frequency of the swing system so the person will go back and forth faster?



Investigation

Why Do Some Molecules Absorb Infrared Energy?

A fascinating aspect of resonant frequency is that you can feel it. When you're pushing someone on a swing, you know when you have found the resonant frequency because you can feel your energy being transferred to the swing and the person on it. Each time you push, you can see the swing go higher and higher and higher.

Gas molecules in the atmosphere resonate when they are struck by a vibrating photon of light, but the molecules are so small, it is impossible for us to feel their resonant frequencies. In this investigation you will experiment with models of molecules that are millions of times larger than the real ones. You will use these models to see what happens when they are energized with different frequencies of vibration.

The models represent four different kinds of molecules found in the atmosphere: nitrogen, oxygen, carbon dioxide, and methane. The vibrations you will produce with your hands represent different frequencies of light.

Molecules are systems composed of different kinds of atoms connected by bonds. Many different kinds of materials can be used to create models of molecules, but not all of them will allow you to experiment with resonance.

Materials

- Strips of springy plastic, thin flexible rods, or long stiff springs to represent flexible molecular bonds. (Wooden materials such as Tinker toys or toothpicks are not flexible enough, so don't use them.)
- Styrofoam balls, rubber balls, or nuts and bolts to represent the atoms.
- Clock or watch with a second hand.

Experimental Procedure

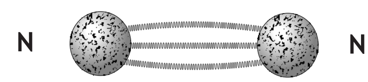
Using the materials make a model of nitrogen, oxygen, carbon dioxide, and methane (see next page). Test each model to determine its resonant frequency. For example, hold the carbon dioxide molecule by the central carbon atom and shake it up and down a few inches. Try a range of shaking speeds, or *frequencies*, from very slow (one shake per second) to very fast (seven or eight shakes per second).

See if you can find a frequency at which it is much easier to keep the model vibrating. It may dance around in a rhythmic way. If it does, it has absorbed the particular frequency of energy that you put into it. This frequency is called the *resonant frequency*.

Use the clock to time your shaking. Measure the resonant frequency by counting the number of vibrations in a five-second interval while your model is "dancing." Divide by five. Do as many trials as you need until you are convinced you have measured the resonant frequency of each model or until you are convinced you cannot find one.

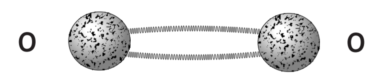
Nitrogen

Nitrogen makes up 78% of the atmosphere. Molecules of nitrogen gas are composed of two atoms of nitrogen (N) connected by a strong (short) triple bond.



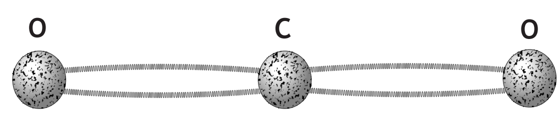
Oxygen

Oxygen makes up about 20% of the atmosphere. Molecules of oxygen gas are composed of two atoms of oxygen (O) connected by a strong (short) double bond.



Carbon Dioxide

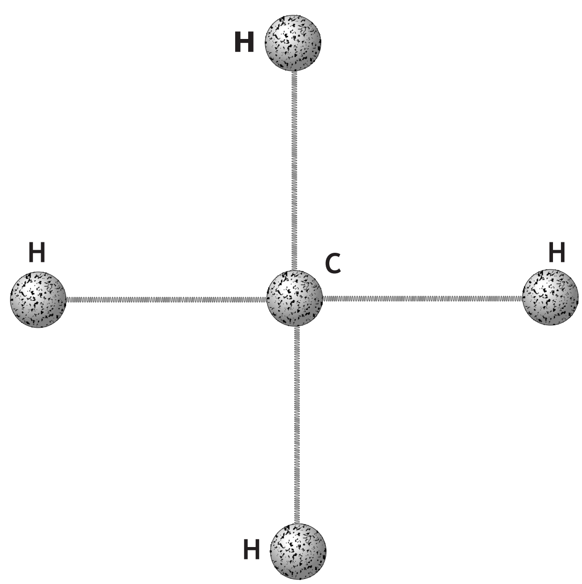
Carbon dioxide accounts for less than one percent of the atmosphere, but it makes a very important contribution to the greenhouse effect. Carbon dioxide molecules are composed of an atom of carbon (C) in the center, connected to two atoms of oxygen (O) with a weak (long) double bond.



Methane

For this experiment, all the atoms can be placed in a flat plane, as though they are lying on a table.

There is even less methane in the atmosphere than carbon dioxide, but it also makes a very important contribution to the greenhouse effect. Methane molecules are composed of a single carbon atom (C) in the middle, surrounded by four atoms of hydrogen (H), at equal distances, connected by weak (long) single bonds.



QUESTIONS

4.2 Which of the four molecules has the fastest resonant frequency?

Which has the slowest?

Which seem to have no resonant frequency?

4.3 If there are differences in resonant frequencies, why do you think they are different?

4.4 The behavior of these models are analogies to the behavior of real molecules of carbon dioxide, methane, oxygen, and nitrogen. From the observations of your models and their interactions with different frequencies of vibration, why do some gases in the atmosphere absorb infrared radiation while others don't?

The Resonant Frequencies of Real Molecules

In the previous experiment, you probably found some of your models responded to shaking at certain frequencies. If you vibrated your hand at the resonant frequency, the bonds between the atoms flexed in their natural rhythm, and the model absorbed your energy and "danced." That is a good analogy of how molecules in the atmosphere respond when they are struck by sunlight. In fact, everything that is free to move—from baseball bats and bridges to electric circuits—has its own resonant frequency. If energy that matches the resonant frequency is put into it, the object will absorb that energy and start to vibrate.

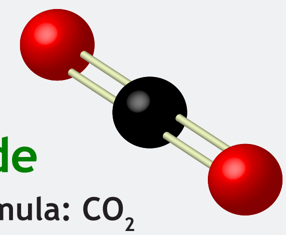
The resonant frequency of an object depends on its structure. When you tune a guitar by changing the tightness of a string, you are changing the structure so the string will vibrate at a different resonant frequency. Each model in your experiment probably has a different resonant frequency because each structure is different.

Now let's transfer this idea of resonance to real molecules. Molecules are far smaller than objects like bells and guitar strings; so the resonant frequencies of molecules are much, much faster. They resonate at speeds comparable to the frequency of light, which is over ten thousand trillion times a second!

Photons of visible light vibrate too fast to affect any of the molecules in the atmosphere. That is the reason visible light goes through air. However, photons of infrared energy vibrate at just the right frequency to transfer their energy to molecules of carbon dioxide and methane, which causes those molecules to vibrate. We experience this vibration as heat.

Gases that vibrate (and therefore heat up) when infrared energy passes through them are *greenhouse gases*. Oxygen and nitrogen are *not* greenhouse gases because they will not resonate at the frequencies of infrared energy. Carbon dioxide, methane, and water vapor *are* greenhouse gasses because they vibrate when they encounter infrared photons.

Carbon Dioxide



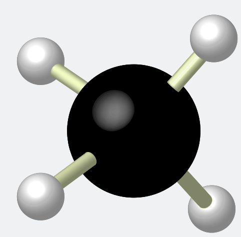
Chemical formula: CO_2

One atom of carbon—Two atoms of oxygen

Structural formula: O = C = O

The " = " represents a double chemical bond. Carbon always has four bonds. Oxygen always has two bonds.

Methane



Chemical formula: CH_4

One atom of carbon
Four atoms of hydrogen

Structural formula:

```
     H
     |
 H - C - H
     |
     H
```

Each " - " represents a single chemical bond. Carbon always has four bonds. Hydrogen always has one bond. A realistic three-dimensional structure for the methane molecule would show hydrogen atoms at the four corners of a tetrahedron.

Carbon Dioxide and Earth's Greenhouse Effect

As you know, molecules of carbon dioxide, methane, and other greenhouse gases vibrate when struck by infrared photons, while oxygen and nitrogen molecules do not. It is that property that allows greenhouse gases to keep our planet warm enough to sustain life.

It is important to remember Earth's greenhouse effect is not new. A certain amount of carbon dioxide, methane, and water vapor has been in the atmosphere for billions of years. If those gases were to suddenly disappear, our entire planet would enter the deepest, coldest ice age it has ever known, and most life would perish in a short time.

Global systems scientists are not worried about the natural greenhouse effect, but about an *increased* greenhouse effect due to human activities. It is therefore very important to find out how quickly the concentrations of greenhouse gases are increasing in the atmosphere.

Although water vapor produces most of the heating in our atmosphere, carbon dioxide is the most important of these gases because it is an unavoidable side effect of industrial society. Cars, trucks, and buses produce carbon dioxide whenever they burn gasoline. Most of the world's electrical power plants add huge amounts of carbon dioxide to the atmosphere every day as they consume trainloads of coal or oil. As developing countries modernize by building power plants and factories and more and more people have cars, more and more carbon dioxide is added to the atmosphere, increasing the greenhouse effect.

In 1957 a laboratory was set up to continuously monitor the amount of carbon dioxide in the atmosphere. Because carbon dioxide levels are very high in cities where there are many automobiles and factories, the laboratory had to be located as far from these sources as possible. An ideal location would be high in the atmosphere, far away from large cities and industrial regions.

Investigation

Getting a Piano to Sing to You

If you have access to a piano, try this experiment. Have a friend hold the "sustain pedal" down so that the strings are free to vibrate. Position your head above the strings and sing a musical note into the piano toward the sounding board beneath the strings. The sounding board will reflect the vibrations. Some of the strings will have natural resonant frequencies that match your input. Only those strings will vibrate. Listen for them. The piano will sing your note back to you.

For new material relating to this chapter, please see the GSS website "Staying Up To Date" page: http://lhs.berkeley.edu/gss/uptodate/2cc/2cc.html We invite you to send us new articles for the "Staying Up To Date" web page for this chapter. Articles may be from local newspapers, magazines, websites, or other sources that you think would be of interest to classrooms around the country. To send us articles please go to the link http://lhs.berkeley.edu/gss/uptodate/newarticle.html and find the "Submit New Article" button.

5. How Can We Measure Carbon Dioxide?

Mauna Loa Observatory, at 3,354 meters above sea level, on the Big Island of Hawaii.

For at least the past million years, hot lava has flowed from cracks in the Pacific Ocean bottom and slowly built the Hawaiian islands. The largest is the island of Hawaii, which is primarily composed of two volcanoes: Mauna Kea and Mauna Loa. If it is measured from its base on the ocean floor, Mauna Loa is the tallest mountain in the world. It rises about 6 kilometers through the ocean water and then continues to climb another 4 kilometers above sea level, where its summit is often shrouded in clouds.

Not far from the summit, a small cluster of buildings stands out sharply against the background of barren rock. At this altitude the air is cold and fresh. The nearest continental land mass is 4,831 km away. Far from local sources of contamination, it is a perfect site for a laboratory whose mission, since 1957, has been to monitor changes in the composition of Earth's atmosphere.

It was global systems scientist David Keeling who convinced government agencies it was important to monitor the concentration of carbon dioxide in the atmosphere and the summit of Mauna Loa was the best place in the world for this work. The continuous record of carbon dioxide—and which continues to be updated as you read these words—has become one of our most important data sets since it provides evidence the atmosphere is actually changing.

The oddly shaped buildings, antennas, and towers of the observatory seem like miniatures in a vast field of stark lava. Two of the buildings have domes that make them look like telescope housings, but there are no telescopes inside. Instead there are instruments that constantly sample the air above the mountain for evidence of change.

Following is an account of a field trip to the Mauna Loa Observatory. It is described for two reasons: to show how the concentration of carbon dioxide in the atmosphere is measured and recorded, and to introduce some of the people whose job it is to make those measurements.

Where the Air Is Clear

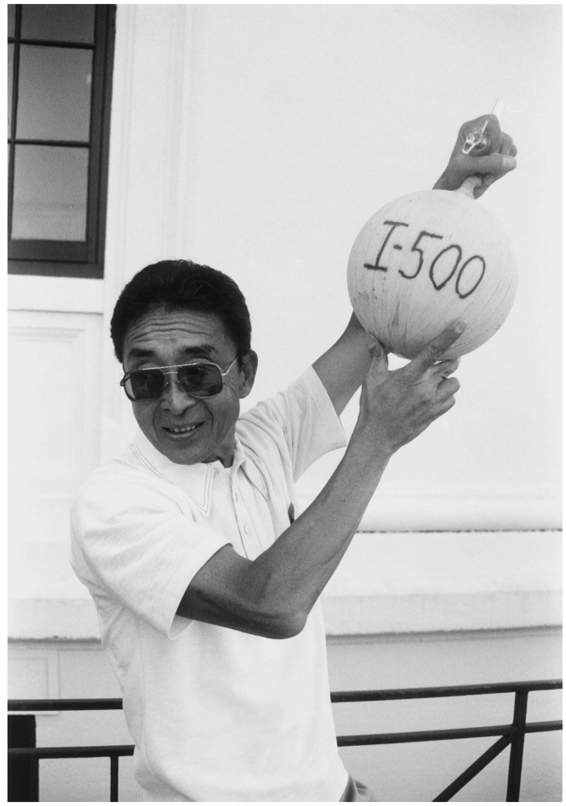
We were met by John Chin, who is in charge of the carbon dioxide monitoring project at the observatory, in Hilo, Hawaii.

We started by asking a few questions about how he became a scientist. He came to the United States when he was 12 or 13 years old. Speaking only Chinese at first, he had to work hard to keep up in the eighth grade in New York City. Eventually, he went to the University of Michigan, where he intended to study architecture. Less than excited by courses in the history of architecture, he changed his major to physics, which he enjoyed much more, and earned a bachelor's degree.

Chin's first job after finishing college was in a cement factory, testing the strength of samples of cement. Then, in 1960, he applied for a job at the Mauna Loa Observatory. Except for two years, when he worked on the space program for NASA in Huntsville, Alabama, his career has been at Mauna Loa.

Chin took us to a laboratory in the basement, where he demonstrated the method of air sampling that was used when the project began in 1957. He showed us a spherical glass flask covered with tape. The flask had a glass neck with a stopcock that could be opened to the air or closed to make an airtight seal. The flask held five liters of gas. In order to prepare the flask for use, the stopcock was opened and the flask was connected to an air pump. As much of the air as possible was pumped out of the flask; then the stopcock was closed to seal it.

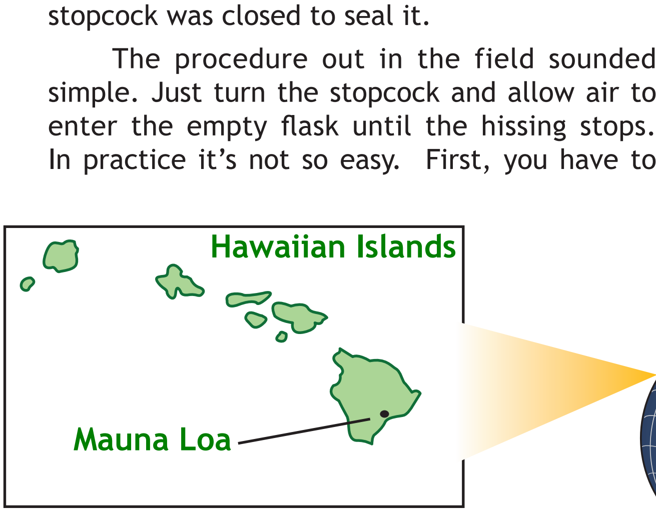
The procedure out in the field sounded simple. Just turn the stopcock and allow air to enter the empty flask until the hissing stops. In practice it's not so easy. First, you have to be sure you are facing away from any possible sources of contamination. That means avoiding cars and industrial exhaust. Chin said the really challenging part of the job is to hold your breath until the hissing stops, which may be as long as three minutes!



John Chin demonstrates a gas collection flask.

QUESTION 5.1. Why is it necessary to hold your breath when collecting gas samples?

Chin also demonstrated a newer device for collecting gas samples, which was introduced about 10 years ago. It fits into a suitcase. Inside the suitcase is a hollow tube that telescopes like a fishing rod, so air may be collected from 15 to 20 feet above ground. Since carbon dioxide is denser than most other gases in the air, it will stay close to the ground. The tall rod helps avoid most contamination from the immediate area. With the new equipment, Chin said he has to hold his breath only one minute.



The suitcase also contains a pump. The pump draws air in through the tube and pumps it into two glass flasks, pressurized at 1.5 times the normal pressure of the atmosphere at the surface. Chin is the only person who is allowed to take flask samples.

After the samples are taken, the flasks are sent to Boulder, Colorado, where the gas is analyzed. There, several methods are used to measure the concentration of carbon dioxide in a gas sample.

QUESTION 5.2.
Why are the glass flasks pressurized?

Why is no one but John Chin allowed to take flask samples?

The new device has a tall telescoping tube so the samples are not contaminated with ground sources of carbon dioxide.

John Chin demonstrates a new portable device for collecting samples of carbon dioxide. The device fits inside a suitcase.

To the Top of Mauna Loa

The trip to the observatory took about an hour and a half. There was no sign to mark the one-lane, winding road that led on mile after mile through desolate lava flows.

When we arrived at the station, we were greeted by Elmer Robinson, the director. He told us that he had earned bachelor's and master's degrees in meteorology. He had been drawn to meteorology "because it was always changing, always something new to learn."

Elmer Robinson, director of Mauna Loa Observatory.

Robinson said collecting and analyzing flasks of air at sea level is still important, but that today the flask method is primarily used to check the main system, which is housed at the observatory building just behind where he was standing. He gave us a quick overview of the whole process:

Step 1: Collect air sample. The air inlet for the monitoring experiments is on top of a huge 40-meter tower that dominates the small set of buildings. Pumps in the main building draw continuous air samples through several long, thin, plastic tubes, only about 0.6 cm in diameter. Tubes carrying air from the tower enter through the ceiling of the main building, bringing a continuous sample of air to the carbon dioxide monitoring equipment.

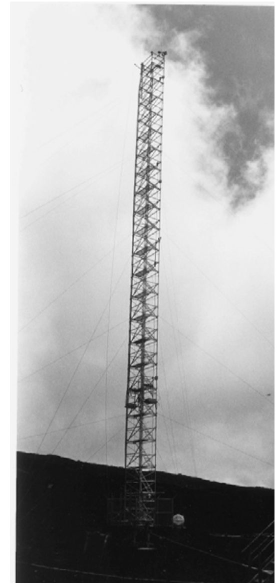
Step 2: Remove water from the sample. The air is pumped into a "freezer trap," which cools it to –79° C. That's cold enough to freeze all of the water vapor out of the sample, but not cold enough to freeze the carbon dioxide.

Step 3: Heat the air sample. The remaining air sample is pumped into a test chamber where it is exposed to infrared energy from a heating coil. The carbon dioxide in the air sample absorbs infrared energy, so the air warms.

Step 4: Measure heat absorbed by the air sample. The temperature of the air is then measured. The more carbon dioxide contained in a given sample, the warmer it gets. So, the temperature of the sample is a good measure of the concentration of carbon dioxide. The temperature of the air sample is measured electronically, and the data stored on magnetic tape. A record is also made on a paper chart recorder at the same time.

Step 5: Calibrate the equipment. Just to be certain the equipment is accurately measuring the amount of carbon dioxide in the air, prepared samples of gas are used to test the equipment every hour.

To calibrate the equipment, once every hour all the air is pumped out of the test chamber. Two samples of gas with known percentages of carbon dioxide are pumped into it, one at a time, from steel gas tanks. One sample has a higher percentage of carbon dioxide than the outside air, and one has a lower percentage of carbon dioxide. By comparing the temperature of the air sample from the atmosphere with the temperatures of the two prepared samples, the researchers can precisely measure the amount of carbon dioxide in the air.



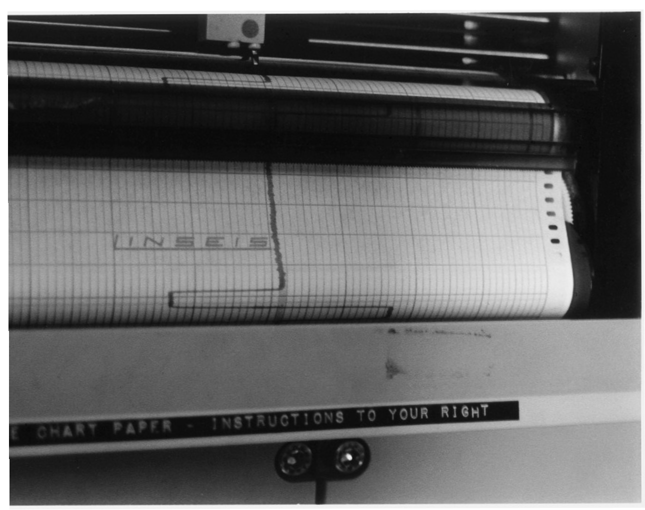
Tower for collecting air samples.

Data from the experiment are stored directly on magnetic tape cassettes for computer analysis. However, the results are also recorded on a strip chart recorder, as they were before the days of computers.

The strip charts are taken to the Hilo office once a week, where they are analyzed as an additional check ensuring the computers are operating properly.

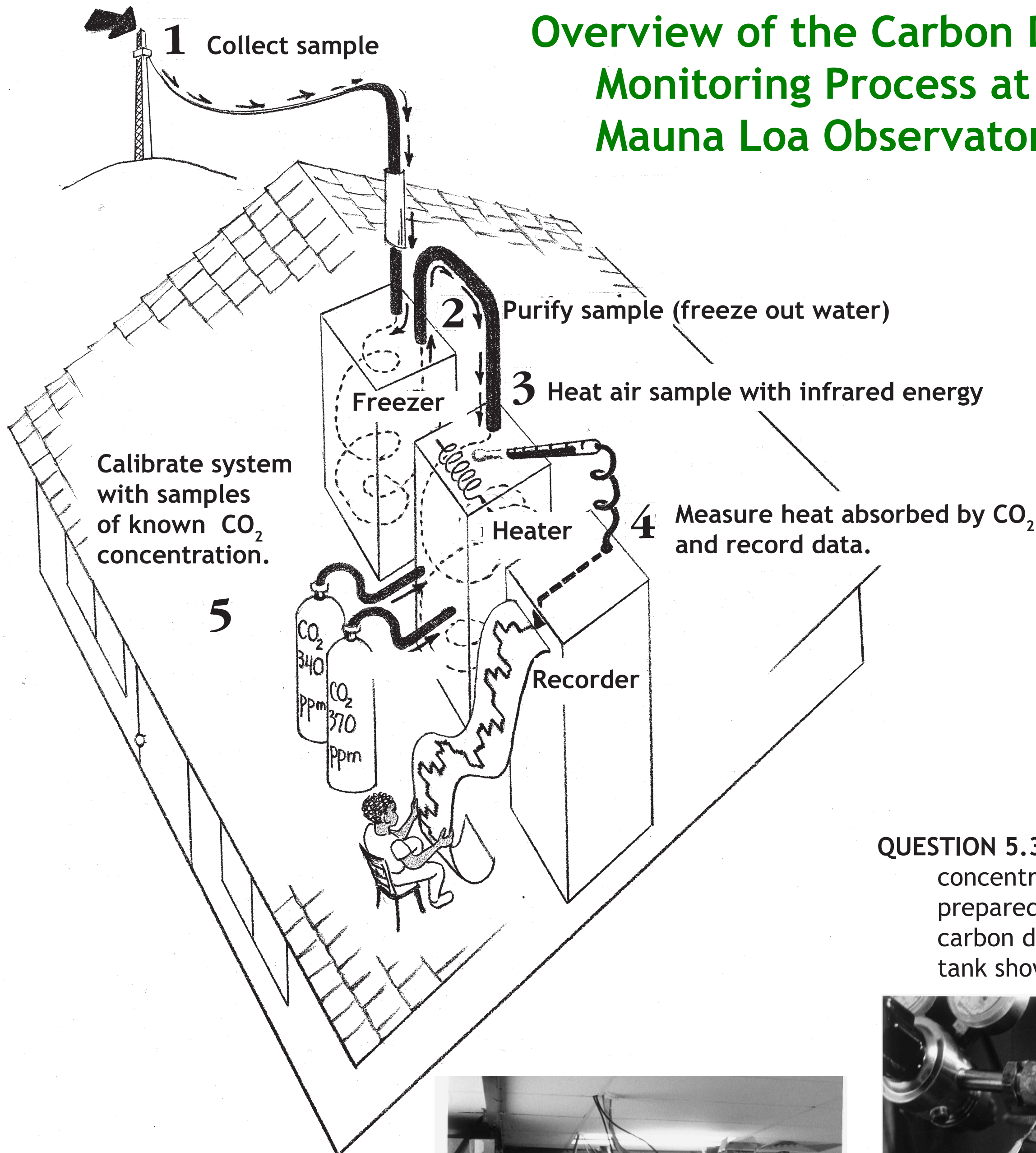
The chart paper rolls continuously through the recorder, while a pen marks the concentration of carbon dioxide in the test chamber. Reading the pen mark from top to bottom, we see a long line showing the concentration of carbon dioxide on the day we were there—353.7 parts per million. Where the line shifted to the left, it showed the concentration of gas from the tank on the previous page (340 ppm). Where the line shifted to the right, it showed the concentration of gas from another tank of prepared gas (370 ppm). After these calibration measurements, the equipment again measured samples from the air.

Elmer Robinson points out the magnetic tape recorder. The strip chart is below his hand and to the left.



Strip chart recorder.

Overview of the Carbon Dioxide Monitoring Process at Mauna Loa Observatory



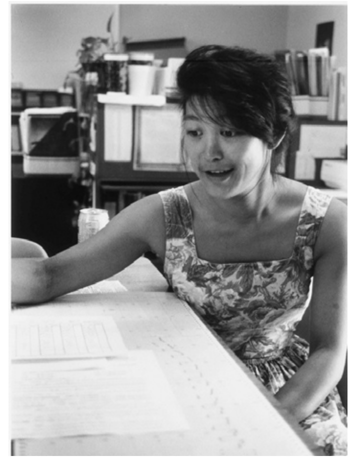
QUESTION 5.3. What is the concentration of the prepared sample of carbon dioxide in the tank shown below?

The air is first pumped into this freezer.

Air tubes from the tower enter through the ceiling.

Gas from these tanks is used to calibrate the equipment.

Back in the Hilo office, we talked with Tracy Yokoi, whose job it is to analyze the data from the strip chart recorder. She earned her bachelor's degree in biochemistry from the University of Hawaii and had just graduated two days before our interview.



Tracy Yokoi

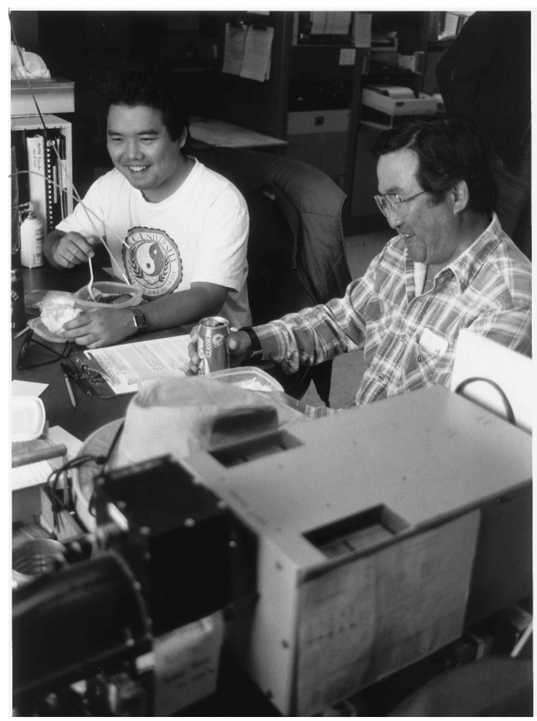
For Yokoi, work at Mauna Loa was not a career, but a student job where she worked a few hours a week. She said her real love was wet laboratory chemistry, "Where you mix chemicals and see things happen!"

Yokoi's desire to work in a different field of science is not due to lack of interest in her work at Mauna Loa. She knows the work is important, and even found data from Mauna Loa's carbon dioxide program in her ecology textbook. She said she had never heard of global warming, ozone depletion, or any of the other problems that the laboratory was set up to investigate before coming to work at Mauna Loa. Now she is not only aware of the problems, but wants to learn a lot more about them. Since school is over, she intends to learn as much as possible before beginning her new job as a wet laboratory chemist.

Living and Working on Top of a Mountain

Carbon dioxide monitoring is just one of the projects being conducted at the observatory. All the major factors that contribute to global climate change are being continuously monitored. These include the atmospheric concentrations of methane, nitrous oxide, chlorofluorocarbons (CFCs), and upper atmosphere ozone, as well as measurements of sunlight, especially ultraviolet energy.

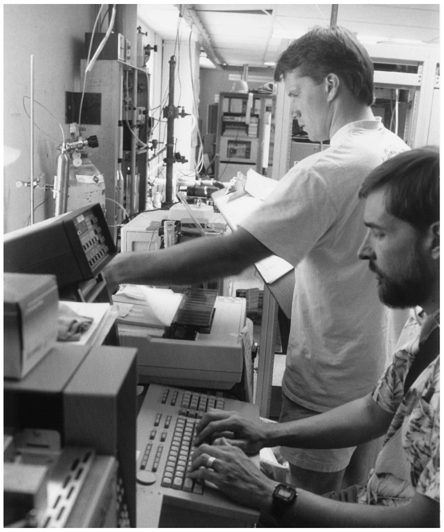
Because the trip up the mountain is so long, staff members drive up there only twice a week and when they do, they help take observations for all the different monitoring programs. Running those monitoring programs requires a team of 10 people, under Elmer Robinson's direction. Each individual is responsible for a program area. John Chin, for example, is responsible for the carbon dioxide program.



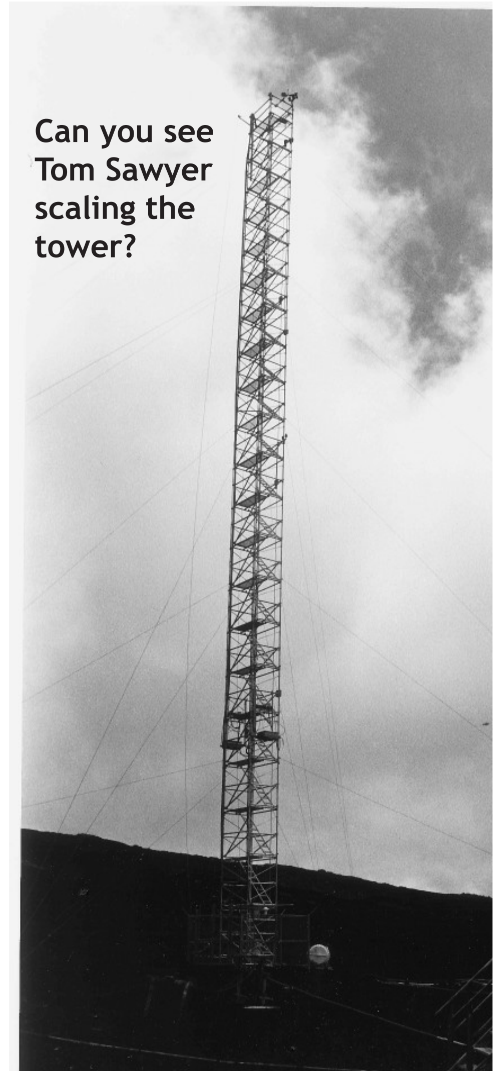
Darryl Funiyuki and Alan Yoshinaga (right)

We met two other members of the Mauna Loa team. Alan Yoshinaga, a chemist, runs the equipment that measures levels of methane and CFCs (chlorofluorocarbons). In Hilo, he runs a chemistry lab to measure the acidity of rain water from samples collected on the mountain. Darryl Funiyuki is an electrical engineer whose job is to keep all of the electronic equipment in working order. Both men have bachelor's degrees in their specialties.

In addition to the staff, there are frequent visitors from the federal agencies that coordinate the observations at Mauna Loa with those made at similar laboratories in Alaska, Samoa, the South Pole, and other stations. On the day we were there, Tom Sawyer and Arn Hayden from the National Oceanic and Atmospheric Administration (NOAA) laboratory in Boulder, Colorado, were installing new equipment for monitoring CFCs. Speaking with Hayden for a few minutes while he was taking a break, we learned he is a graduate student in mechanical engineering. After working for Westinghouse for a couple of years, he took his present job at NOAA, where he has lots of opportunity for on-the-job training.



Tom Sawyer and Arn Hayden (seated)



The people we met at Mauna Loa Observatory made it very clear to us just how interdisciplinary global systems science can be. We were not surprised that various staff members had skills in chemistry, meteorology, mechanical engineering, electrical engineering, biochemistry, and physics—but holding your breath for three minutes was a skill we did not expect scientists would need! One more skill was evident as we turned to take our last photograph of the day. That skill was demonstrated by Tom Sawyer who scaled the high tower in just a few minutes. At that altitude, where the air is so thin that walking a short distance can make you out of breath, his jaunt up the tower was quite an accomplishment.

Investigation

Sampling Carbon Dioxide

Discuss question 5.4 with your teammates and write down your prediction. Then determine whether or not you were right by first taking gas samples and then testing the samples to determine which has a greater concentration of carbon dioxide.

QUESTION 5.4

Which source do you think has a greater concentration of carbon dioxide: your breath, exhaust from a car, or the air in your classroom?

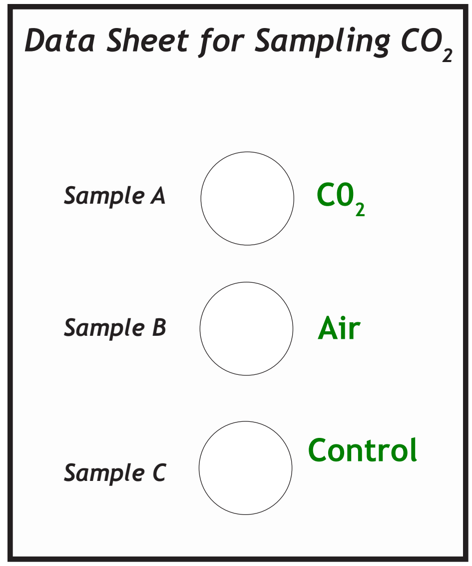
Materials

For each team of 3-4 students

- 5 clear vials
- Graduated cylinder (100 ml)
- Cup of water
- Bottle of Bromthymol Blue (BTB) solution
- Bottle of ammonia solution
- Eye dropper
- Straw
- Narrow-necked bottle (such as a wine bottle)
- 4 balloons of different colors with twist ties
- Teaspoon of baking soda
- 100 ml of vinegar
- 3 sheets of blank paper
- Piece of string, about 1/2 meter in length
- Twist-ties

Investigation (continued)

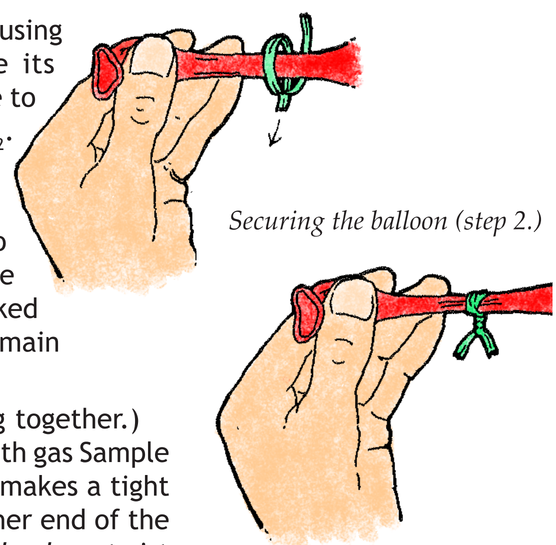
Part 1: Chemical Test for Carbon Dioxide



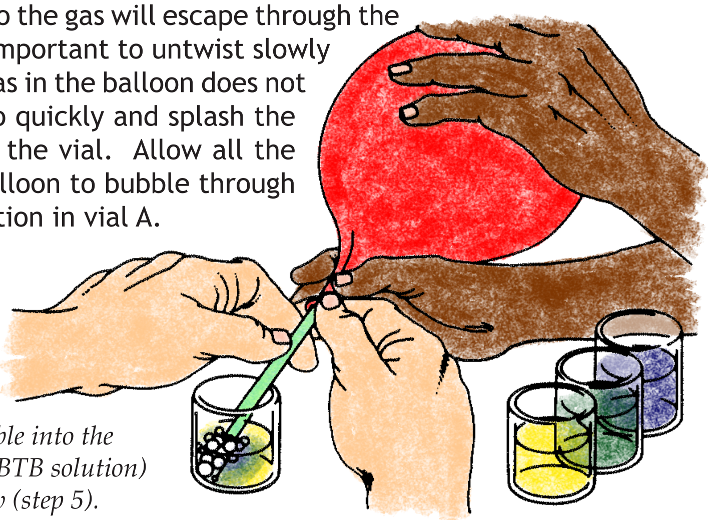
Use the blank sheets of paper to make data sheets for the three parts of the experiment.

Teams need to work together in this experiment, because most of the steps require more than one pair of hands.

1. **Make a sample of pure carbon dioxide (CO_2).** Use the graduated cylinder to pour 100 ml of vinegar into the narrow-necked bottle. Use a scrap of paper to make a funnel. With the funnel, put one teaspoon of baking soda into the bottle. Let the mixture bubble for 1 second to drive the air out; then slip a balloon over the neck of the bottle. The balloon should inflate to a 7–10 cm diameter. (If it doesn't, add more baking soda and try again.)
2. **Secure and measure Sample A (pure CO_2).** Twist the rubber neck of the balloon, and fasten it shut with a twist-tie. Record the color of the balloon on the first sheet of paper. Call it "Sample A." Measure the circumference of the balloon with a string.
3. **Make Sample B (room air).** Blow up a second balloon using a bicycle pump (do *not* use your breath). Measure its circumference with a string. Add more air or allow some to escape until it is the same size as the sample of pure CO_2. Secure the second balloon with a twist-tie. Record the color of the balloon on the data sheet under Sample B.
4. **Prepare the test vials.** Use the graduated cylinder to measure and pour 15 ml of BTB solution into each of three vials. Place the vials on the data sheet in the circles marked A, B, and C. Vial C is the control vial. This vial will remain untouched; no gas will be bubbled through it.
5. **Test Sample A.** (This step requires two people working together.) Insert the end of the straw into the neck of the balloon with gas Sample A. Wrap the neck of the balloon around the straw so it makes a tight seal, but do *not* remove the twist-tie yet! Insert the other end of the straw into the bottom of vial A. Remove the tie and *slowly* untwist the balloon so the gas will escape through the straw. It is important to untwist slowly so that the gas in the balloon does not come out too quickly and splash the liquid out of the vial. Allow all the gas in the balloon to bubble through the BTB solution in vial A.



Securing the balloon (step 2.)



Allow gas to bubble into the indicator liquid (BTB solution) through the straw (step 5).

What Is Happening?

BTB is a chemical indicator that changes from blue to yellow in the presence of an acid. When carbon dioxide is bubbled through the BTB solution, some of it dissolves and forms carbonic acid. The more carbon dioxide in a sample, the more carbonic acid will form in the solution, and the yellower the BTB will appear.

6. **Observe color changes.** Observe the color of the solution as you slowly bubble the gas through it. *What shades of colors does it pass through before reaching a final color when all of the gas has been bubbled through it?* Record the final color of the solution on the data sheet.

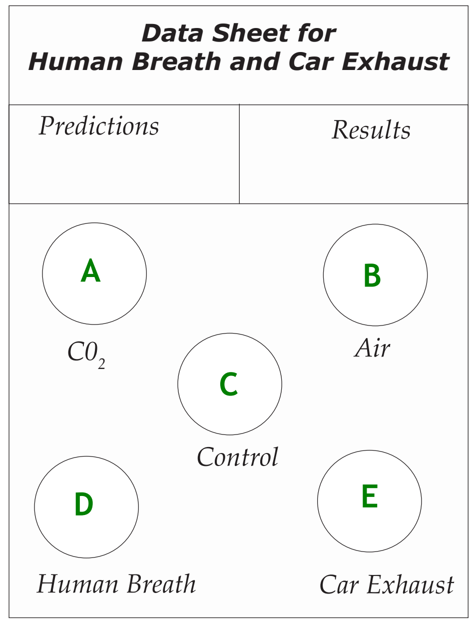
7. **Test Sample B.** Bubble Sample B from its balloon through the BTB solution in vial B. Compare its color with the blue of the control vial. Record the color of the solution on the data sheet. Save the solutions for later comparison.

8. **Draw conclusions.** Compare the colors of vials A, B, and C (the control). *What do your observations tell you about how BTB can be used as a chemical test for the concentration of carbon dioxide in a sample of gas?* Write your suggestions on the data sheet.

Part 2: Human Breath and Car Exhaust

1. **Predict.** On the data sheet, write your predictions by listing the four gas samples—human breath, pure CO_2, room air, and car exhaust— in order, from highest to lowest CO_2 concentration.

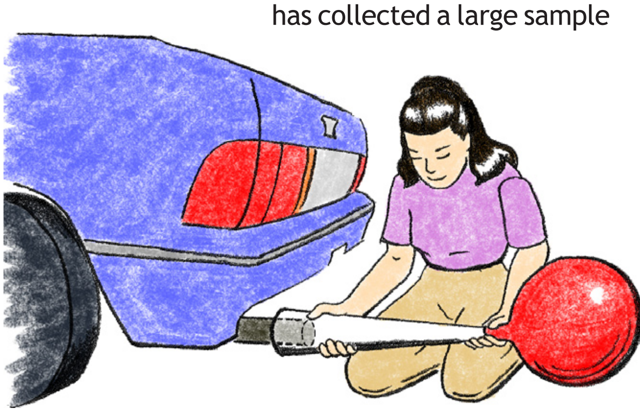
2. **Prepare test vials.** Make a data sheet as shown on this page. Position vials A, B, and C from the previous experiment on the new data sheet. Use the graduated cylinder to fill two additional vials with 15 ml of BTB solution. Place these on the circles for vials D and E.



3. **Collect Sample D—human breath.** One team member blows up a balloon and uses a string to measure its circumference until it is the same size as the other balloons. Twist the neck of the balloon and tie it so the gas does not escape. Record the color of the balloon as Sample D.

4. **Test Sample D.** As before, use the straw to bubble the gas in the balloon through the BTB solution in vial D. Observe any color changes and record them.

5. **Collect Sample E—Car Exhaust.** Go outdoors with your teacher to collect a sample of car exhaust. Each team needs a balloon, a string for measuring, and a twist-tie. Your teacher will provide a funnel made from a manila folder to channel gas from the exhaust pipe into your balloon. While your teacher starts the car, decide who in your team will actually collect the sample. **Stand in a safe area, where you will not be in danger of being hit by passing cars.** When your team member has collected a large sample of gas, allow some exhaust to escape, using the string to measure the circumference of the balloon so it is the same as the other balloons. If too much gas escapes, get another sample. Secure with a twist-tie.



6. **Test Sample E.** As before, use the straw to bubble the gas in the balloon through the BTB solution in vial E. Observe any color changes and record them.

7. **Record the results.** *What does the color of the five vials tell you about how the concentration of carbon dioxide in the four samples of gas?* Write your results on the data sheet. (Note: Keep the vials of BTB. You will need these solutions for the next part of the investigation.)

8. **Compare results with predictions.** In science, its useful to predict because we become aware of our expectations. It is just as valuable to prove yourself wrong as it is to confirm your predictions! Compare the results with your predictions. *Were you right or wrong?*

Part 3: Measuring Carbon Dioxide

Now we'll measure the percentage of carbon dioxide gas in each of the samples.

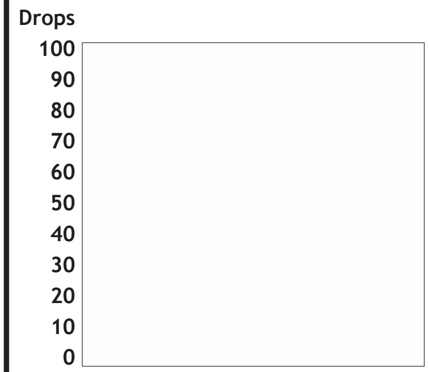
1. **Slowly add dilute ammonia to vial D, drop by drop.** Count the number of drops needed to return the solution in vial D to the same color as the control vial (C). Shake the contents of the vial when the solution is close to the blue color of the control vial to thoroughly mix the contents. When the solution remains the same deep blue of the control vial, record the number of drops. This process is called *titration*.
2. **Use the titration procedure on vials A, B, and E in the same way.** Add the ammonia last, drop by drop, to the vials that are very yellow in color. They may require up to 100 drops to turn them back to the same color as the control vial.

   Note: If the vial is about to overflow, pour the contents into a large, clean container, and continue adding drops. In that case, the color of the solution will become very pale.

   Add water to the BTB control vial so that the volumes of the two solutions are about the same; then you will be able to compare the color of the test solution with the color of the control vial.
3. **Analyze the results.** The number of drops of ammonia required to neutralize the solution is proportional to the concentration of carbon dioxide in the gas sample that was bubbled through the solution. For example, if it required 90 drops to neutralize the vial from Sample A (pre CO_2), then a sample that required 45 drops to neutralize had a concentration of about 50% CO_2. Write down the percentage concentration of carbon dioxide in each of the samples.
4. **Graph your results.** When you have finished testing vials A, B, D, and E, make a bar graph showing how many drops were required to turn each of these solutions back to the same color blue as the control vial. Be certain to label both axes of the graph.

   Note: *It is likely the sample of room air did not make any noticeable change when you bubbled it through a vial of BTB solution. This is because the chemical method of measuring the concentration of carbon dioxide is not sensitive enough for analyzing the small amounts of CO_2 in room air.*

Data Sheet for Measuring CO_2



	CO_2	Air	Control	Human	Car
Drops					
%					

QUESTIONS

5.5 If a gas sample is suspected to contain CO_2 but its presence is not indicated by the BTB test, what conclusion can you draw?

5.6 What does this experiment tell you about the concentration of CO_2 emitted in animal breath and vehicle exhaust? (Compare them.)

5.7 What additional information would you need to judge how much CO_2 animals and vehicles each contribute to the total atmospheric concentration of CO_2?

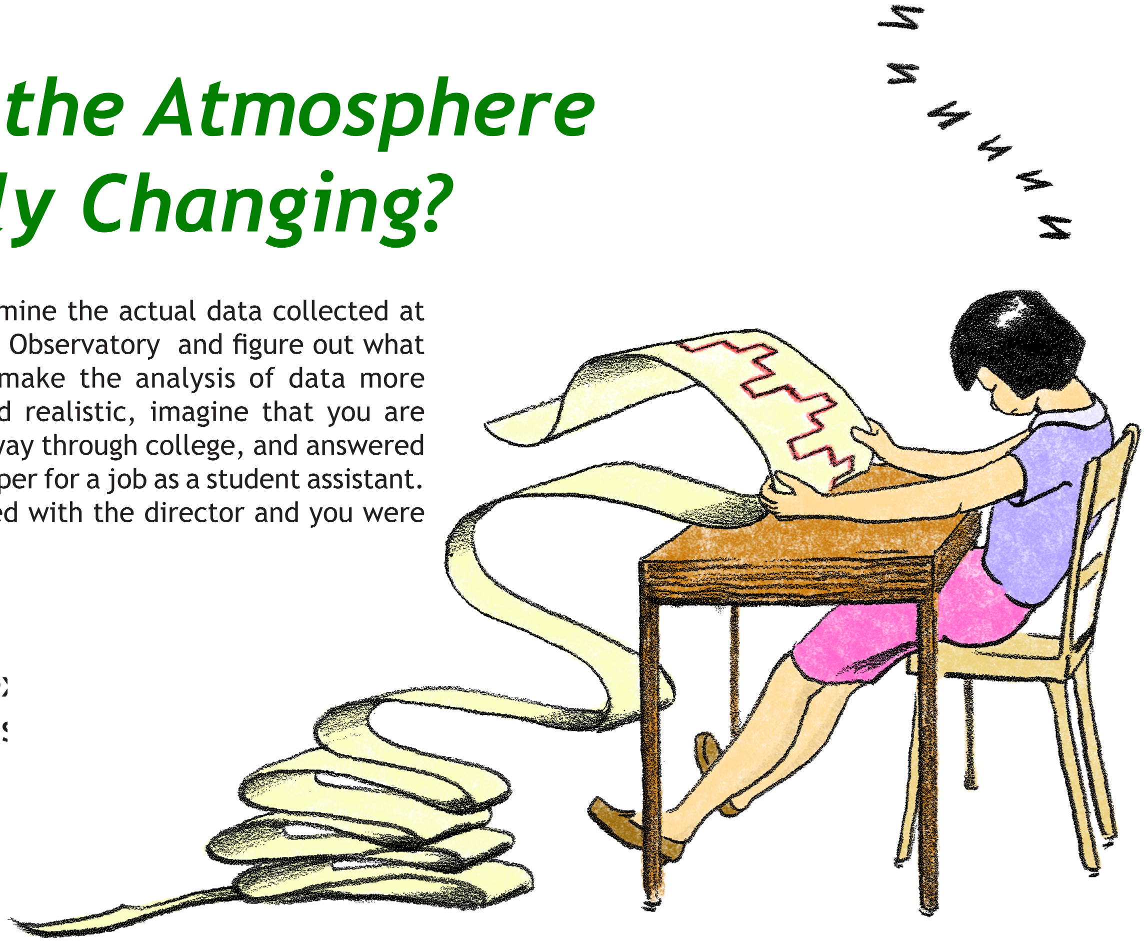
5.8 Currently there are about 180,000,000 gasoline-burning vehicles on the road in the United States alone. In the future, there is likely to be many more. How do you think this may affect the concentration of carbon dioxide gas in the atmosphere?

For new material relating to this chapter, please see the GSS website "Staying Up To Date" page: http://lhs.berkeley.edu/gss/uptodate/2cc/2cc.html We invite you to send us new articles for the "Staying Up To Date" web page for this chapter.

Articles may be from local newspapers, magazines, websites, or other sources that you think would be of interest to classrooms around the country. To send us articles please go to the link http://lhs.berkeley.edu/gss/uptodate/newarticle.html and find the "Submit New Article" button.

6. Is the Atmosphere Really Changing?

Let's examine the actual data collected at the Mauna Loa Observatory and figure out what it means. To make the analysis of data more interesting and realistic, imagine that you are working your way through college, and answered an ad in the paper for a job as a student assistant. You interviewed with the director and you were hired.



Investigation

The Findings from Mauna Loa

Carbon Dioxide in the Northern Hemisphere

As a student assistant, your job is to analyze data from the strip chart recorder and to find the average concentration of carbon dioxide for each month. It takes many hours of measuring, recording numbers, and calculating to find a monthly average from all that data! You have summarized the monthly data averages from two years in two columns as below.

Looking at the table you realize it is difficult to interpret. Having the data in a graph rather than a table would enable you—and your supervisor—to readily see if changes occur over time, if there is a pattern, or an unusual variation. So, you decide to plot the data on a graph before giving the information over to your supervisor. Plotting data for 2006 and 2007 will show you how the atmosphere changed.

On graph paper, plot the data shown. Create a line graph, with the dates along the bottom, from January 2006 to December 2007. To show the pattern clearly, choose a vertical scale that does not start from zero, but which ranges from the lowest to the highest measurements of carbon dioxide. Draw a line connecting the data points so you can see the pattern easily. Be sure to label the axes of your graph.

Investigation (continued)

Concentration of Carbon Dioxide in the Atmosphere at Mauna Loa

in Parts Per Million (PPM)

	2006	2007
Jan.	381.38	382.45
Feb.	382.03	383.68
Mar.	382.64	384.23
Apr.	384.62	386.26
May	384.95	386.39
June	384.06	385.87
July	382.29	384.39
Aug.	380.47	381.78
Sept.	378.67	380.73
Oct.	379.06	380.81
Nov.	380.15	382.33
Dec.	381.75	383.69

Sources: Scripps Institution of Oceanography (http://scrippsco2.ucsd.edu/data/in_situ_co2/monthly_mlo.csv) NOAA Earth System Research Laboratory (http:// www.esrl.noaa.gov/gmd/ccgg/trends)

QUESTIONS

6.1 What pattern is shown in the data?

6.2 During which months does the concentration of carbon dioxide seem to increase? How might you explain this increase?

6.3 During which months does the concentration of carbon dioxide seem to decrease? How might you explain this decrease?

6.4 During which months would you expect plants to be most actively growing? Would they be absorbing or releasing carbon dioxide when they are actively growing? Why?

6.5 During which months would you expect leaves to be falling, and annual plants to be dying? Would plants absorb or release carbon dioxide when they lose their leaves, die, and decay?

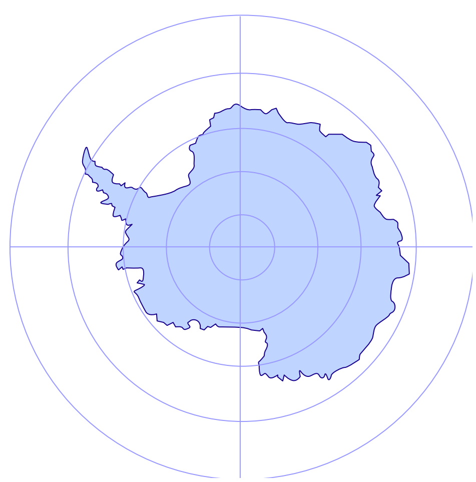
6.6 Does the data support a connection between plant growth cycles and atmospheric concentration of carbon dioxide or some other causes? Explain your ideas.

The Findings from the South Pole: Carbon Dioxide in the Southern Hemisphere

"Hold it!" you might say. "Carbon dioxide levels seem to vary with the seasons. However, Mauna Loa is in Earth's Northern Hemisphere. When we are having summer in the Northern Hemisphere, people who live in the Southern Hemisphere are having winter. I wonder if the yearly variation in the concentration of carbon dioxide is the same in the Southern Hemisphere as it is here on Mauna Loa?"

Before reporting your data, you log onto the computer and look for a file of data from a Southern Hemisphere station also assigned to monitor carbon dioxide concentration. Got it! There is a carbon dioxide monitoring station at the South Pole! According to the computer log, the South Pole observing station is on an ice- and snow-covered plateau over a mile and a half above sea level, and about 7 miles from the pole.

The South Pole station is at the center of the continent of Antarctica, where longitude lines cross. Data was collected in flasks and sent to a laboratory for analysis, except during 1960 to 1963, when a continuous sampling station was set up. Data collection continues today by the flask sampling method.



Investigation (conclusion)

QUESTIONS

Predict what you think the graph of carbon dioxide concentration measured at the South Pole and plotted each month will look like.

6.7. Will the graph be similar to or different from the Mauna Loa graph? Explain.

6.8. Will it be a straight line, with no peaks and valleys of carbon dioxide concentration?

6.9. If peaks and valleys do occur, will they occur at the same times as at Mauna Loa?

6.10. Will there be as big a difference between the maximum and minimum concentration at the South Pole as at Mauna Loa?

Plot the South Pole data from the table below. Use the same chart that you used to plot the data from Mauna Loa. Use X's to plot the points so you can distinguish them from the Mauna Loa data. Draw a smooth line through the data points so you can see the pattern easily. Compare the results with your from the predictions.

6.11. Which of your predictions were correct?

6.12. Were you surprised by any patterns in the data? If so, by what?

6.13. How can you explain your findings?

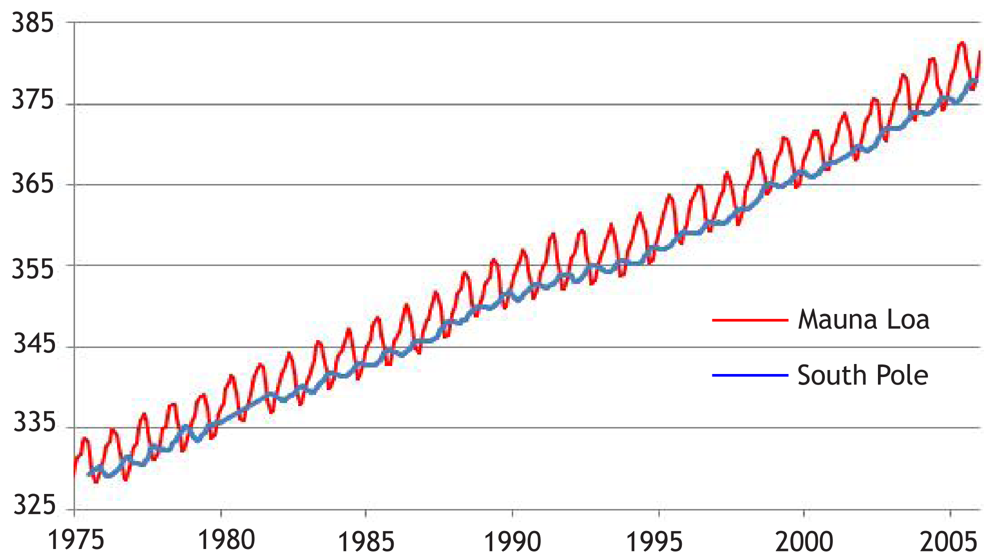
Concentration of CO_2 in the Atmosphere at the South Pole in Parts Per Million (ppm)

	2006	2007
Jan.	377.81	379.16
Feb.	377.54	379.23
Mar.	377.53	379.20
Apr.	377.75	379.51
May	377.93	379.83
June	378.29	380.21
July	378.79	380.62
Aug.	379.19	381.11
Sept.	379.23	381.43
Oct.	379.25	381.59
Nov.	379.28	381.54
Dec.	379.36	381.58

Source: Scripps Institution of Oceanography (http://scrippsco2.ucsd.edu/data/spo.html)

Monthly concentrations of carbon dioxide in air

collected from stations at Mauna Loa and the South Pole, measured in parts per million (ppm)



Source: Adapted from http://tamino.wordpress.com/2007/06/20/latest-trends-in-co2

Results from the Past 30 Years

Look again at your graph of the concentration of carbon dioxide during 2006 and 2007. *In addition to the seasonal changes in the level of carbon dioxide, can you also detect a trend?* To observe this trend over a longer period of time, let's look at the findings Mauna Loa station and the South Pole for the period 1975 to 2005.

QUESTIONS

6.14 Refer to the graph on this page and estimate the average concentration of carbon dioxide in the atmosphere during the year 1975. How many parts per million (ppm) were measured that year?

6.15 Estimate the average concentration of carbon dioxide in the atmosphere during 2005. How many ppm were measured that year?

6.16 By what percentage has the carbon dioxide concentration increased since 1975? (Percentage equals the increase in ppm divided by ppm in 1975, times 100.)

Seasonal Changes

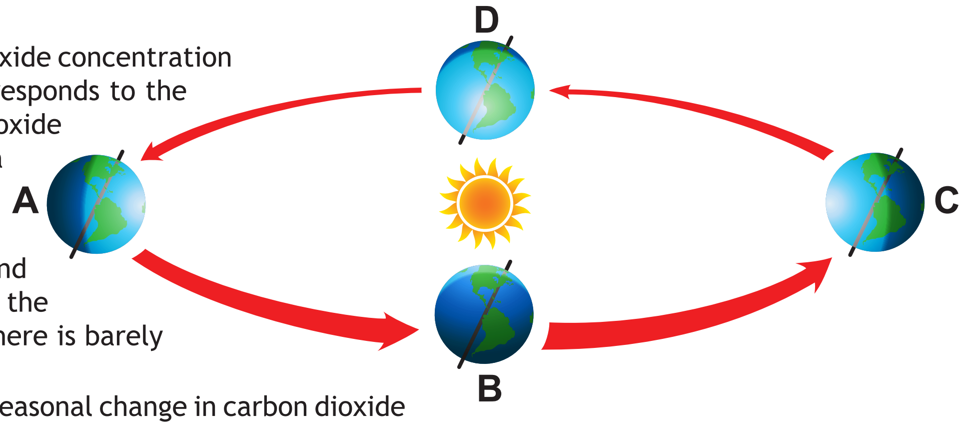
It appears there is a natural yearly change in the concentration of carbon dioxide. The data from Mauna Loa shows the concentration of carbon dioxide in the Northern Hemisphere increases slowly most of the year, but decreases rapidly in the summer. Data from the South Pole shows a similar pattern but with two important differences:

1) The peak in carbon dioxide concentration at the South Pole corresponds to the minimum of carbon dioxide concentration at Mauna Loa.
2) The difference between the peaks and valleys is much less at the South Pole. In fact, there is barely any decrease at all.

QUESTION 6.17

What seasons would be experienced by a resident in the United States when the Earth is at point A, B, C, and D?

What seasons would be experienced by a resident of Australia at the same points?



One explanation for the seasonal change in carbon dioxide concentration is the cycle of plant growth. First, consider late spring and summer in the Northern Hemisphere, when plants are growing rapidly. Rapid growth means that they must make leaves, stems, roots, and other plant tissues through the process of *photosynthesis*. In this process, the plants take in carbon dioxide and water vapor through tiny openings, or *stomata*, in their leaves. Inside the plant cells, the carbon is extracted from carbon dioxide and combined with hydrogen from water to provide food for the plant and to form new plant tissue. Light energy drives this chemical reaction; thus the name *photosynthesis* (*photo* meaning light and *synthesis* meaning the combination of materials to form new substances).

When some plants die or become dormant in the fall and winter, they stop absorbing carbon dioxide. As the dead parts decompose, they return carbon dioxide to the atmosphere. Carbon again combines with oxygen and is released in the form of carbon dioxide. Carbon dioxide continues building up in the air until late spring, when the rate of new plant growth exceeds the rate of old plant decay. Carbon dioxide is removed from the atmosphere until fall, when the rate of decay again equals the rate of growth. This exchange between foliage and air accounts for the annual change in the concentration of carbon dioxide that is recorded at Mauna Loa each year.

The process of fall die-off and spring revival is similar in the Southern Hemisphere. However, when people who live in the Northern Hemisphere experience summer, those in the Southern Hemisphere are feeling the cold of winter. That's why the maximum concentration of carbon dioxide in the air of Earth's Southern Hemisphere is shifted by about six months from that of the Northern Hemisphere.

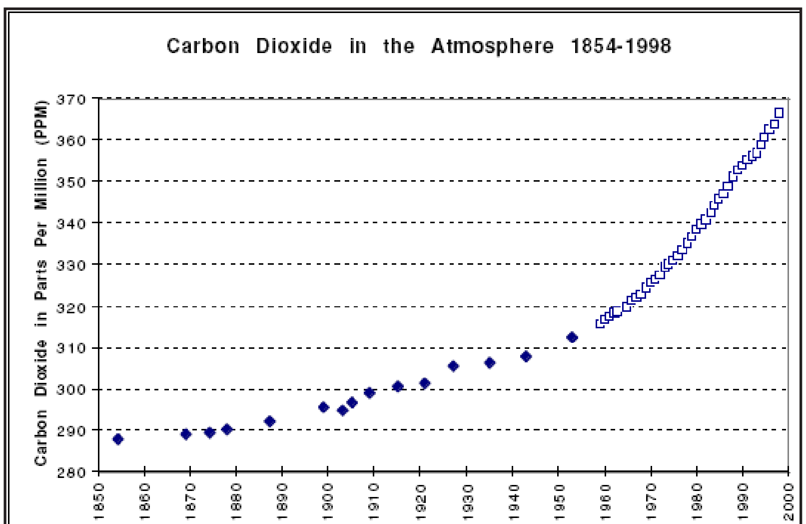
Another difference is in the amount of carbon dioxide extracted by plants in the Southern Hemisphere. Since there is less land area in the Southern Hemisphere, there are fewer plants. Compare the land and sea areas in the portions of the globe shown here.

Are Humans Changing the Atmosphere?

To determine how much industrial activity has changed the composition of Earth's atmosphere, we must look back further, to the beginning of the industrial age.

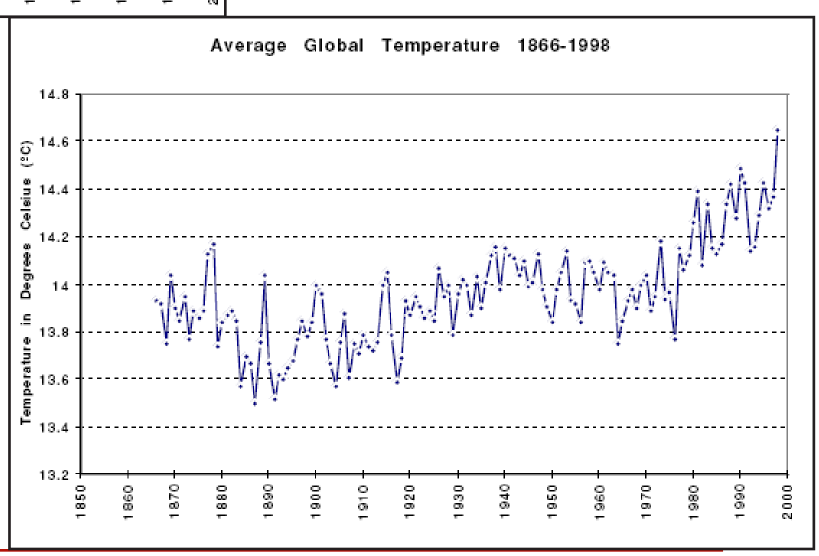
We can learn about past climates by analyzing cores of ancient layers of ice drilled from the ice sheets near the poles. It is also possible to use the same ice cores to measure the amount of CO_2 that was present in the atmosphere. This is done by placing a sample of ice from a given layer, representing a particular year, into a chamber. The air is pumped out of the chamber. The ice is crushed, so bubbles trapped in the ice are broken, releasing ancient air trapped inside for thousands of years. Instruments are used to determine the precise concentration of carbon dioxide in the atmosphere when that layer of ice was formed.

The bubbles of air trapped in the ice cores from Greenland, Antarctica, and other sites around the world have been analyzed. As can be seen in the top graph on this page, the concentration of carbon dioxide in the year 1854 was about 288 ppm. During the period known as the Industrial Revolution, the concentration of carbon dioxide climbed to almost 370 ppm. The present rate of increase of carbon dioxide is 50 times faster than at any time in the past.



Sources: 1880 to 1953 filled-in diamonds—Neftel et al., Trends '93, pp 11-14. (http://cdiac.esd.ornl.gov/ftp/trends/co2/siple2.013) 1958 to 1998 open squares—Mauna Loa Observatory, Hawaii

The bottom graph shows the average temperature of Earth since 1866. Scientists like James Hansen (see Chapter 1), who believe the increase in the average global temperature is caused in large part by the increase in carbon dioxide from the burning of fossil fuels, point out that both graphs are heading upward. They say that confirms the prediction of the greenhouse effect. Scientists who disagree say the increase in world temperatures may be due to other factors. They also note the cooling trend, between 1939 and 1976, which is not consistent with the predictions of the global warming theory.



QUESTION 6.18. Compare the top and bottom graphs. In your opinion, are these results consistent with the theory of global warming and the greenhouse effect, or do they refute the theory? Can any definite conclusions be drawn from these graphs? What would it take to convince you that Hansen is definitely right, or definitely wrong?

Source: NASA Goddard Institute for Space Studies (http://www.giss.nasa.gov)

Testing the Evidence

Scientists are rarely satisfied with evidence from only one source. Ice cores preserved bubbles of old air. Where else might bubbles of old air be found? One answer was in the hollow buttons of Civil War uniforms. Some of them were sealed so well that they preserved the air inside for 130 years. Scientists removed the air from the buttons and measured the carbon dioxide concentration. In other cases old glass bottles that had been sealed for 100 years or more were carefully opened and the air inside was analyzed. Information gathered from these different sources all indicated that the concentration of carbon dioxide had increased from about 280 parts per million before the industrial revolution to more than 360 parts per million today.

Investigation

What Are the Human-Caused Sources of Carbon Dioxide?

It appears true that the concentration of carbon dioxide in the atmosphere is much higher today than it was before the industrial revolution. The change from day to day and year to year is not that much, but over decades the change becomes noticeable.

Where did that additional carbon dioxide come from? One way carbon dioxide is added to the atmosphere is when people burn fossil fuels. Nearly all the electricity used in this country comes from power plants where trainloads of fossil fuels are burnt every day. Fossil fuels are burned in cars, ships, and airplanes. They are burned in houses to heat air and water. They are burned in factories to melt metals and fashion millions of objects used by people every day. You only have to look around you to see the continual burning of fossil fuels.

In the past 100 years, the rate at which our society has added carbon dioxide to the atmosphere has grown tremendously, but many of these changes go unnoticed, in part because they have taken place slowly in comparison with a human lifetime, and in part because we quickly adapt to changes.

Have you ever gone back to an old neighborhood after being away for a few years and been surprised at the differences, while those living there hardly notice the changes? Recognizing change is an important skill. Sometimes changes go unnoticed for a long time, until all of a sudden, things seem very different.

The purpose of this investigation is to enable you to recognize the vast number of changes over the past 100 years that, taken together, are responsible for the increased concentration of carbon dioxide in the atmosphere.

You can also find out how much CO_2 is produced by countries through data resources such as World Resources Institute (http://wri.org/) which collects and disseminates such data. For example, see data of "Carbon Dioxide Emissions" by country and by economic sector as of 2005, contains data from year 2001. http://earthtrends.wri.org/pdf_library/data_tables/cli2_2005.pdf. You can even find out per capita emission of CO_2 by using the WRI data in conjunction with population data from a source such as the International Data Base (http://www.census.gov/ipc/www/idbnew.html) or the CIA World Fact Book (https://www.cia.gov/cia/publications/factbook/fields/2119.html)

How Has San Francisco Changed During the 20th Century?

Comparing pictures is one way to recognize changes that have taken place over a long span of time. Look carefully at the pictures on the next page. The top picture shows San Francisco just after the turn of the 19th century. The bottom picture shows the same scene in the 1990s.

How Has the Area Where You Live Changed?

Most cities, large and small, have a local historical society that preserves old photographs of their city or town. Perhaps you have a relative who has such pictures. Try to obtain an old photograph and go to the site today to observe the changes. If you can, take a new photograph of the scene so you can show the pictures to others. If photographs are not available, interview the oldest resident you can meet with and get an idea of what your community was like years ago.

QUESTION 6.19

For the two pictures of San Francisco on the next page, make a list of the changes that you see. Discuss how each change might make a difference in the amount of carbon dioxide that is released into the atmosphere.

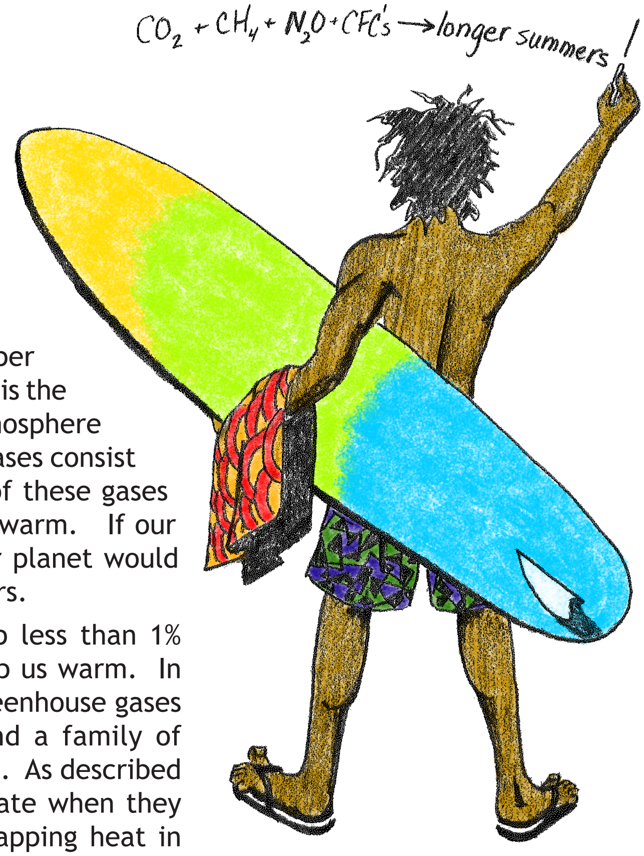
Multiply the changes on your list by the thousands of communities across the nation. Which of these changes do you think contributed most to the amount of carbon dioxide in the atmosphere? Rank the changes in order from greatest to least contributions to Earth's changing atmosphere, and state why you ranked them as you did.

San Francisco from Telegraph Hill at the beginning of the 20th century.

San Francisco from Telegraph Hill at the end of the 20th century.

For new material relating to this chapter, please see the GSS website "Staying Up To Date" page: http://lhs.berkeley.edu/gss/uptodate/2cc/2cc.html We invite you to send us new articles for the "Staying Up To Date" web page for this chapter. Articles may be from local newspapers, magazines, websites, or other sources that you think would be of interest to classrooms around the country. To send us articles please go to the link http://lhs.berkeley.edu/gss/uptodate/newarticle.html and find the "Submit New Article" button.

7. What Are the Greenhouse Gases?

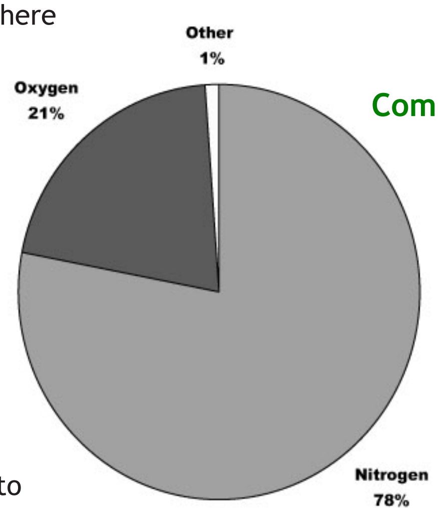


The Composition of Earth's Atmosphere

Ninety percent of the gases that make up our atmosphere are in the *troposphere*—the lowest and densest part of the atmosphere which extends 10–12 kilometers above the surface. The *stratosphere*, which extends up to about 60 kilometers, contains most of the rest of the atmospheric gases. While the very thin upper reaches of our atmosphere extend even further, it is the composition of gases in the lower part of the atmosphere that has the greatest effect on climate. These gases consist almost entirely of nitrogen and oxygen. Both of these gases are important for life, but they do not keep us warm. If our atmosphere consisted of these gases alone, our planet would be nearly as cold, and perhaps as lifeless, as Mars.

But the greenhouse gases—which make up less than 1% of the entire atmosphere—absorb heat and keep us warm. In addition to carbon dioxide and methane, the greenhouse gases include water vapor, nitrous oxide, ozone, and a family of gases called chlorofluorocarbons (CFCs for short). As described in Chapter 4, molecules of all these gases vibrate when they encounter infrared photons. They warm up, trapping heat in Earth's atmosphere.

Measurements made at Mauna Loa in Hawaii, the South Pole, and other sites around the world show the atmosphere is changing. In the opinion of the vast majority of atmospheric scientists, this increase in the atmospheric concentration of greenhouse gases will gradually bring about widespread changes in Earth's climate. Although the extent, timing, and impact of these changes in various regions of the world are uncertain, the climate changes that have taken place in recent history—such as the "dust bowl" droughts that plagued the United States in the 1930s—illustrate that small changes in the average global temperature can have major and sometimes devastating impacts on life. It is therefore very important for us to have a clear picture of the sources of these gases and their relative contributions to the predicted global warming.



Composition of Earth's Atmosphere

At present the atmosphere contains		
Nitrogen	N_2	78%
Oxygen	O_2	21%
And less than 1% of the following		
Argon	Ar	
*Water Vapor	H_2O	
*Carbon Dioxide	CO_2	
Neon	Ne	
*Ozone	O_3	
Helium	He	
*Methane	CH_4	
Krypton	Kr	
Hydrogen	H_2	
*Nitrous Oxide	N_2O	
Carbon monoxide	CO	
Sulfur dioxide	SO_2	
Xenon	Xe	
Nitrogen Dioxide	NO_2	
Ammonia	NH_3	
*Chlorofluorocarbons	CFCs	
***Greenhouse Gases**	*Source: Our Changing Planet, pages 68-69, and 293-304*	

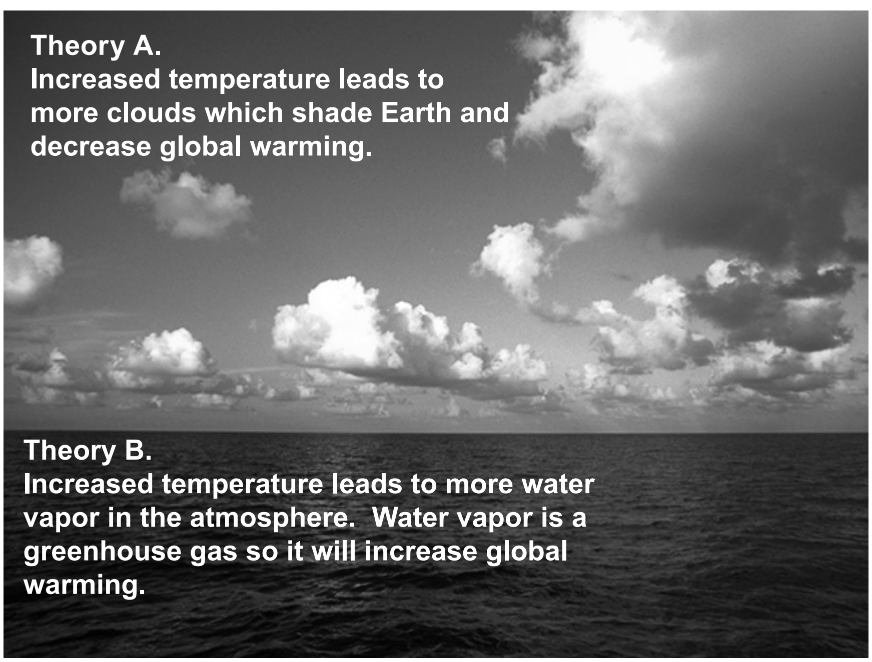
The Greenhouse Gases

Water Vapor (H_20)

Many people believe the plume of visible steam from a boiling kettle is water vapor. However, steam and water vapor are not the same. Steam consists of large water droplets suspended in the air, while *water vapor* is an invisible gas. Like carbon dioxide and methane, water vapor resonates at the frequency of infrared energy, so it traps heat in the atmosphere.

The amount of water vapor in the air at any one place is highly variable. Its concentration changes hour by hour and from place to place, ranging from up to 4% in tropical rain forests, down to a few tens of parts per million in the dry, frigid air of the Antarctic.

Water vapor is produced when sunlight falls on rivers, oceans, and other bodies of liquid water. As the water warms, its molecules move faster and faster, until some finally escape, forming a gas that mixes with the air. Water vapor is also released by the leaves of plants as part of their life processes.



Feedback *occurs when the output of a system automatically controls the input. In the case of global warming, the output is increased global temperature.*

Theory A is an example of negative *feedback, in which a little warming leads to cooling, so the climate system returns to normal.*

Theory B is an example of positive *feedback, in which a little warming leads to more warming, so the climate system is disturbed more and more.*

The concentration of water vapor is called *humidity.* On a warm, "sticky" day the air contains a lot of water vapor. Warmer air is able to hold a greater concentration of water vapor. That is the reason dew forms in the early morning hours, when the air cools and water vapor condenses. The water vapor reenters the atmosphere later in the morning, when sunlight warms the air and evaporates the droplets of dew.

Water vapor has always played an important role in the natural greenhouse effect. Unlike the other greenhouse gases, most water vapor is *not* added to the atmosphere by human activities. However, it is of special interest to scientists because its effect may change as a result of human activities. Two theories have been proposed. One suggests water vapor will increase the effect of the warming, the other suggests it will form clouds and cool Earth. At this writing, no one knows for certain which will happen.

Carbon Dioxide (CO_2)

Carbon dioxide seems to be the world's favorite gas. It is loved by soda pop and beer drinkers. It's bubbles put the fizz in champagne. Carbon dioxide makes baked goods "rise." It is the most important of the greenhouse gases. Carbon dioxide has some strange properties. At low temperatures it can be compressed into a white solid we call *dry ice*. At room temperature, the cold solid dry ice changes back into a gas without melting into a liquid form, which is called *sublimation.*

Carbon dioxide bubbles out of the ground in soda springs. It explodes in vast quantities out of volcanoes. Animals and plants release it as they use oxygen for respiration. Carbon dioxide is released in forest fires. Decay of rotting plants and animals produces carbon dioxide. Without carbon dioxide to trap infrared energy, our planet would be about 33°C cooler than it is now, and it is questionable whether life ever would have evolved.

During tree growth, carbon is collected from the atmosphere and incorporated in the plant tissue we call "wood." About half of each firewood log is composed of carbon (by weight). When the log is burned, most of the carbon is released from the wood in the form of carbon dioxide gas. James Watt's first steam engine used wood as a fuel. The steam engine signalled the beginning of a process in which humans beings add significant amounts of carbon dioxide to the atmosphere.

Burning wood in steam engines certainly contributed to air pollution in those early days, but the amount of carbon dioxide added to the air was not that large. The carbon was simply recycled from the air to the wood, and then back again when the wood was burned. But when the most frequently used fuel was changed from wood to coal, the change in the atmosphere began in earnest. That is because coal is composed of carbon from plants that died millions of years ago. When coal is burned, it releases carbon dioxide into the atmosphere.

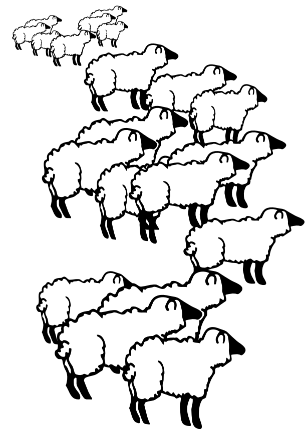
More and more coal was burned throughout the world in the 19th and early 20th centuries. Then people found oil, It was easier to extract from the ground, transport, and use than coal. Like coal, oil consists of the partly decayed remains of plants and animals. Today, most of the energy used to power our transportation, run our factories, heat our homes, and produce electricity comes from oil. But all of these benefits are not without costs to the environment.

Every piece of wood, every pound of coal, every gallon of oil burned releases carbon dioxide. Just one gallon of gasoline burned in a car's engine adds about 10 kilograms of carbon in the form of carbon dioxide to the atmosphere. Each year, five tons of carbon in the form of carbon dioxide—roughly equivalent to the mass of a single large elephant—is added to the atmosphere for every man, woman, and child living in the United States.

The concentration of carbon dioxide in the atmosphere is now 25% higher than it was before the extensive forest clearing and the industrial development that began nearly 200 years ago. That percentage is currently rising at a rate of half a percent per year.

Methane (CH_4)

Methane (swamp gas) is produced when plant material decays without oxygen. The largest sources of natural methane are swamps and marshes where fallen plants are decaying in the underwater mud.



Like carbon dioxide, methane absorbs infrared energy. In fact, one molecule of methane is 20 to 30 times better at absorbing infrared energy than a molecule of carbon dioxide.

In swamps, methane gas bubbles to the surface soon after it is produced. However, large pockets of methane gas can become trapped between layers of soil and rock. Gas trapped in this way is called *natural gas*. Huge pockets of natural gas are often found near deposits of oil. Initially, the natural gas was seen as a waste product. However, people found the gas could be piped to homes and industries and used as fuel. Some of the methane added to the atmosphere each year by human activities comes from leaky gas pipes.

However, most of the methane added to the atmosphere every year comes from agricultural activities. For example, the soil in which rice plants grow must be covered with water. The hollow stem of the rice plant serves as a pipe through which the methane produced by the decaying matter beneath the water escapes into the air. With many new rice paddies constructed to feed the world's growing population, the amount of methane in the atmosphere is increasing rapidly.

Domesticated cattle, sheep, goats, and camels produce methane in their digestive systems. One cow produces approximately one-half pound of methane per day. There are estimated to be 3.3 billion domesticated animals in the world. Their population has increased as human societies have grown.

Microbes in the guts of termites also produce methane. One of the arguments against the practice of cutting rain forests is that the increase in termite activity that occurs when trees are cut may add significant quantities of methane to the atmosphere.

About 10% of all methane produced is the result of burning wood. Wood is still burned as a primary fuel in some parts of the world. The gas is also released during coal mining operations and landfills.

Can an Ice Cube Burn?

Yes, if it's a cube of ice-like material taken from the tundra in the Arctic. When organic material decays in the frozen wastes of the Arctic, the methane can sometimes get trapped in little cage-like structures of ice crystals. The same phenomenon can happen in the sediments on the shores of the Arctic Sea. When the ice crystals melt, methane is released and can burn. One of the concerns of scientists is, if the tundra and the Arctic Seas warm, large quantities of the frozen methane could be released, significantly adding to the concentration of greenhouse gases in the atmosphere.

QUESTION 7.1. Would release of methane from Arctic Sea be an example of positive or negative feedback? Explain.

Nitrous Oxide (N_2O)

Nitrous oxide is another greenhouse gas. It is produced naturally by microbes in the soil and from the burning of wood in forest fires. About one third of the nitrous oxide in the atmosphere is the result of human activities. The increase in concentration comes from the large-scale use of chemical fertilizers and the burning of fossil fuels for energy, primarily in automobiles.

The concentration of nitrous oxide is increasing at the rate of about 0.2% per year. Although its rate of increase is relatively small, it is a cause for concern because nitrous oxide is 250 times more efficient than carbon dioxide in absorbing infrared energy. In addition, nitrous oxide breaks down slowly. Once it is in the atmosphere, a molecule may have a lifetime of more than 150 years.

Recently, scientists at the University of California at San Diego identified an industrial source of nitrous oxide. They found the process of manufacturing an acid, from which nylon is made, gives off nitrous oxide. For every kilogram of nylon produced, a kilogram of nitrous oxide is generated and enters the atmosphere. That process alone accounts for one tenth of the increase of nitrous oxide released into the atmosphere each year.

Chlorofluorocarbons (CFCs)

Chlorofluorocarbons are gases that contain chlorine, fluorine, and carbon. In contrast to the other greenhouse gases that have always been present to some extent in the atmosphere, there is no natural source of CFCs. They are completely a product of the chemical industry, and were developed for use in refrigerators, air conditioners, and as a cleaning fluid in certain industries.

In January 1999, the concentration of CFC-11 was measured to be 260 parts per trillion (ppt), and CFC-12 was measured at 528 ppt. A few hundred parts per trillion may not seem like a lot, but CFCs have a fantastic capacity to trap infrared energy. Each CFC molecule can trap between 17,000 and 20,000 times the energy that is absorbed by a single molecule of carbon dioxide. In all, the family of CFC gases accounts for about 12% of the greenhouse warming observed in recent years.

CFCs were increasing in the atmosphere at a rate of about 7% per year until 1993, when an international agreement (the Montreal Protocol) called for industrial nations to stop using these gases. The primary reason for this treaty was that CFCs were known to destroy ozone in the stratosphere. But the treaty also had a beneficial effect helping reduce CFCs in the lower atmosphere, where it acted as a greenhouse gas. Due to the Montreal Protocol, new refrigerators and air conditioners must now use different gases. However, since it takes 50 to 100 years for CFC molecules to break down, the CFCs already in the atmosphere will remain with us for a very long time.

Ozone (O_3)

A "normal" oxygen molecule in the atmosphere consists of two oxygen atoms linked together by chemical bonds. An ozone molecule is a temporary partnership of three oxygen atoms. Ozone is formed when an energy source such as ultraviolet radiation from the Sun, an electrical spark, or lightning breaks the bonds between oxygen atoms in a "normal" oxygen molecule, creating individual oxygen atoms. An individual oxygen atom (O) can combine with an oxygen molecule (O_2) to produce a molecule of ozone gas with three atoms of oxygen (O_3).

Ultraviolet light striking normal oxygen molecules in the upper atmosphere has resulted in the *ozone layer*, which is a slight concentration of ozone gas (about 12 parts per billion) about 30 to 40 kilometers above Earth's surface. It does not consists of ozone alone; there is, however, a slight increase in the concentration of ozone at that level. People who have heard about the "hole in the ozone layer" often mistake this problem with the cause of global warming. Actually, ozone in the upper atmosphere has very little to do with global warming. So it's important to describe the role that ozone plays in both the upper and lower atmosphere.

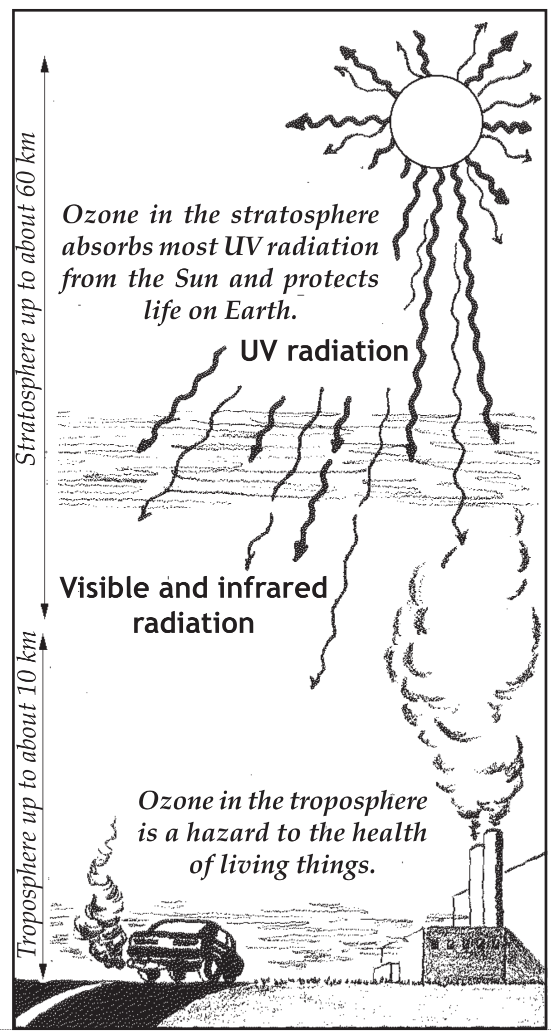
In the Stratosphere High above the surface of Earth, ozone shields living things from the lethal effects of the Sun's ultraviolet radiation.

The ozone layer permits living organisms to live on land. Without this important gas, life would be restricted to the oceans.

In the 1980s it was discovered that CFC gases produced by the chemical industry have gradually drifted into the upper atmosphere where these gases have begun to destroy the ozone layer. Scientists are concerned that if the trend continues, people and animals will be exposed to more of the Sun's ultraviolet radiation, and will be more likely to contract melanoma, a deadly form of skin cancer, and cataracts, a disease that clouds the cornea of the eye.

In the Troposphere Since ozone absorbs infrared energy, it functions as a greenhouse gas when it is in the lower atmosphere, where it intercepts infrared energy from Earth's surface. Ozone is one of the components of urban smog, and because of its poisonous chemical properties, it is considered a serious health hazard. The amount of ozone varies widely, but the average concentration of this gas is increasing in urban areas. Automobile exhaust accounts for about 75% of the ozone production in the troposphere.

We *want* ozone in the upper atmosphere to block harmful ultraviolet rays from the Sun, but we *don't* want it near Earth's surface, where it poisons living things and acts as an added greenhouse gas. Both ozone gas and CFCs act as greenhouse gases in the lower atmosphere.



Summary of the Gases That Contribute to the Increased Greenhouse Effect

Greenhouse Gas	Resulting from Human Activities	Average Time in Atmosphere	Current Contribution to Increased Greenhouse Effect
Carbon Dioxide	Fossil fuel burning, deforestation	50–200 years	60%
Methane	Cattle, rice paddies, landfills, gas leaks, mining, termites	10 years	15%
Nitrous Oxide	Fossil fuel burning, fertilizers	150 years	5%
Chlorofluorocarbons	Refrigerators, aerosols, air conditioners, electronics production, foam blowing of plastics	60–100 years	12%
Ozone	Automobile exhausts, electrical generation	Weeks to months in the lower atmosphere	8%

Source: Our Changing Planet, page 304

All Together Now!

Discussions about the problem of potential global climate change very often focus on the increase in atmospheric carbon dioxide. The burning of fossil fuels is so much a part of our lives that the production of carbon dioxide is easily evident. However, the other greenhouse gases are becoming increasingly important. As the chart below shows, the additional concentration of carbon dioxide in the air due to human activities accounts for about 60% of the increased greenhouse effect, while all the other greenhouse gases together account for about 40% of the effect. Together, these gases create the current concern about global warming because they are all increasing.

You may be wondering why water vapor is not included in the chart. As you know, water vapor is a potent greenhouse gas. For billions of years water vapor has helped keep the atmosphere warm enough for life. Although water vapor may be increasing as a result of a warming climate, it is not added to the atmosphere by human activities, and scientists do not know for sure what its effect on the climate will ultimately be. The chart includes only those gases that are contributing to the ***increased*** greenhouse effect.

Why Is the Concentration of Greenhouse Gases Increasing?

The increase in greenhouse gases can be attributed to three major factors: population growth, industrialization, and deforestation.

Population Growth

At the start of the 20th century there were 1.6 billion people worldwide. Now there are 6 billion people on Earth. The world's population is exploding. According to projections, there may be 8.5 billion by the year 2025. Each person added to the world's population increases the human activities that are responsible for the growing levels of greenhouse gases.

Industrialization

While population is a major factor in creating an increase in the concentration of greenhouse gases, the main cause is industrialization—the growing number of automobiles, power plants, and factories that burn fossil fuels. Although the United States accounts for only 5% of the world's population, because of its high level of industrialization, it produces more greenhouse gases than any other country in the world. However, as developing countries become more and more industrialized, the burning of fossil fuels is increasing worldwide.

Deforestation

Forests are not only valuable as homes for the world's wildlife; they also absorb vast quantities of carbon dioxide from the atmosphere. When trees grow, they absorb carbon dioxide from the air and store the carbon in wood and leaves. As forests are burned to create farmland and residential areas, the carbon stored in the trees reenters the atmosphere. While forests are increasing in some areas, such as the Northeastern United States, worldwide forest cover is rapidly decreasing. According to the Worldwatch Institute, "Almost half the forests that once covered the Earth are gone, and deforestation is expanding and accelerating. The health and the quality of remaining forests are declining."

For new material relating to this chapter, please see the GSS website "Staying Up To Date" page: http://lhs.berkeley.edu/gss/uptodate/2cc/2cc.html
We invite you to send us new articles for the "Staying Up To Date" web page for this chapter. Articles may be from local newspapers, magazines, websites, or other sources that you think would be of interest to classrooms around the country. To send us articles please go to the link http://lhs.berkeley.edu/gss/uptodate/newarticle.html and find the "Submit New Article" button.

8. What Are Governments Doing About Climate Change?

What Is the United States Doing?

A Commitment to Research

In 1988, when talk of global warming hit the front pages, George Bush was running for president. He promised, if elected, the problem would be high on his agenda. In 1989, he took an important step by establishing the U.S. Global Change Research Program. The USGCRP is a long-term, coordinated program will set goals.

1. Address key uncertainties about changes in the Earth system, both natural and human-induced
2. Monitor, understand, and predict global change
3. Provide a sound scientific basis for national and international decision-making on global change issues

The USGCRP is the largest global change research program in the world. Under this program, it has been possible to coordinate the work of dozens of agencies supporting hundreds of research projects involving thousands of scientists. Presidents Bush and Clinton and the members of Congress have continuously given this program a high priority. Its proposed budget for 2000 is $1.78 billion.

While there has been agreement that the U.S. government should support research on climate change, debates continue to echo in the halls of Congress about what *actions* the government should undertake to reduce the emission of greenhouse gases.

Questions About Action

President Bill Clinton and Vice President Al Gore have made a strong commitment to environmental protection. In 1993, President Clinton ordered the Department of Energy and the Environmental Protection Agency to work together in drafting a plan for reducing greenhouse gas emissions to no more than the amount produced by our country in 1990 and to accomplish this by the year 2000.

The two agencies drafted for the president a Climate Change Action Plan and Assessment, which proposed 50 actions to reduce the emission of greenhouse gases and to assess how well the United States is doing in slowing further climate change. Most of the actions involved energy conservation, and industries in the United States were requested to cooperate on a voluntary basis. Congress was asked to appropriate funds to carry out the plan.

In November 1993, a Congressional hearing was conducted to consider the president's plan. The people asking questions are members of Congress—not scientists. They ask and expect the scientists to give them answers they can understand. Here are excerpts from that hearing.

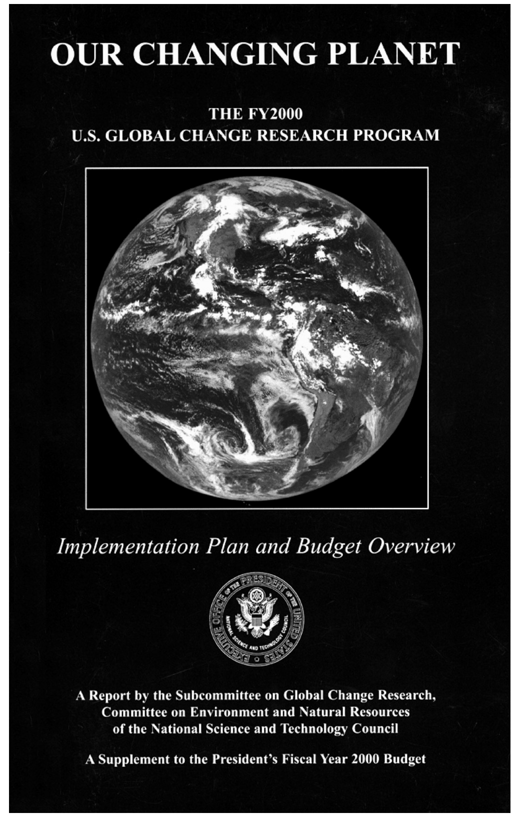
Hearing

Before the Committee on Science, Space, and Technology

U.S. House of Representatives

ONE HUNDRED THIRD CONGRESS

Tuesday, November 16, 1993

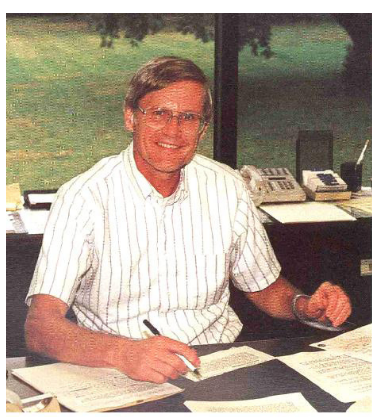


David Minge,
U.S. Representative from Minnesota

Rep. David Minge

MINGE: I guess I'm always somewhat of a skeptic of things, and I recall that about 30 years ago there were articles that were appearing from various scholars indicating that we were going to have a return to the Ice Age, and one would be probably well advised not to invest in Canadian or North Dakota farmland because who knew how long it would be before the ice would return. And I'm interested that now we're talking about global warming. To what extent can you say that there's clearly a consensus in the scientific community that global warming is what is occurring and that we are not simply experiencing a shift in climate that is of a temporary duration and a decade from now we'll be talking about the Ice Age again?

Jerry Mahlman, director, Geophysical Fluid Dynamics Laboratory, National Oceanic Atmospheric Administration, Princeton, N.J.



Jerry Mahlman

MAHLMAN: In the early seventies, there was a great deal of press attention to the comments of a few that we have to be prepared for the onset of the next Ice Age. Many neglected to point out that would be on the order of 5 to 15 thousand years from now, and the press gave it a lot of attention, to the bewilderment of many of us, because by that time, in 1967, the fundamentals of the greenhouse effect had been calculated, by first principles, and many of us were already concerned about this problem at that time.

So I think that the reminiscence about Ice Age apocalyptic statements is really kind of what actually happened at that time. So, to me, the issue remains that we have to think about global warming on the shorter time scale, namely, over the next century.

You asked the question about the virtually one degree Fahrenheit global mean surface increase we've seen over the past century: is that unambiguously attributable to the greenhouse effect? I think the honest answer is it's quite likely that it is so, but what we do not know is whether or not the one degree Fahrenheit warming is due, and only due, to greenhouse warming. We do know that the climate fluctuates naturally, as you quite properly pointed out. The evidence suggests that one degree Fahrenheit variation over a century is clearly at the outer limits of what we would expect in natural fluctuation of climate to do without being forced by something, greenhouse gases or changed solar constant, or whatever.

So I've sometimes said that if it were a civil court case, the global mean temperature record would probably be convicted on the basis of preponderance of evidence. If it were a criminal court case, I could visualize a hung jury with eleven saying yes and one saying no.

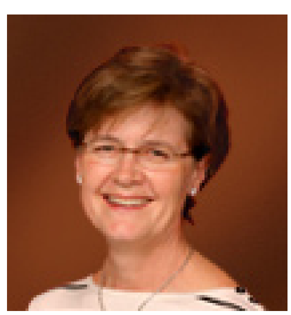
MINGE: Are there credible or respected scientists or academicians that disagree with the global warming hypothesis or theory that we're discussing this morning?

MAHLMAN: There is essentially no one who disagrees with the global warming hypothesis. It is foolish to do so and none of the credible scientists are that foolish, in the sense that we do know that if you increase carbon dioxide in the atmosphere, you increase the ability of the gas, the atmospheric gas, to absorb radiation and that produces a warming effect.

All of the controversy, all of the arguments, is: how does that warming effect play out in the climate system? There have been skeptics who have said that they're not sure that the models are correct—an appropriate skepticism, I might add—and they have been seeking contrary hypotheses that, in effect, could make it go away.

And the trouble with those hypotheses is that they're depending on mechanisms to cancel out another mechanism. It's a bit like trying to cure a hot foot by putting a bag of ice on your head; on the average you might not change your temperature, but something else happens when the system is trying to adjust itself. So that even the more noted skeptics realize that some of their contrary hypotheses, if carried out, would also be indicative of substantial changes in the climate system. In other words, the system, to avoid responding the way that the greenhouse theories say, would have do something else very tricky and effect a climate change in itself, in my personal opinion.

CHAIRMAN: Thank you, Dr. Mahlman . . . Now we'll hear from Dr. Susan Tierney, Assistant Secretary for Policy, Planning, and Evaluation at the U.S. Department of Energy.



Susan Tierney

TIERNEY: Let me start with the Administration's overview. First, we think this plan is a robust, credible plan. It is the most specific plan that has been prepared to date by any country in the world. We are pleased that it meets the President's commitment to reduce the country's greenhouse gas emissions to their 1990 level by the year 2000.

It has been no small achievement to figure out how to do that. Without the Climate Change Action Plan, emissions of the major greenhouse gases (carbon dioxide, methane, nitrous oxides, and hydrofluorocarbons) are projected to grow by about 7 percent between 1990 and 2000.

The plan will attain the emission reduction goal by implementing nearly 50 specific actions that touch every sector of the economy. It leverages a modest government expenditure—about $1.9 billion between 1994 and 2000—which stimulates over $60 billion over the same period in private sector investment in energy efficiency, renewable energy, and other technologies that help reduce greenhouse gas emissions. These investments, in turn, pay substantial dividends to consumers and firms in the form of reduced energy costs—over $60 billion in reduced costs between 1994 and 2000, with continuing cost savings of over $200 billion between 2001 and 2010.

Hearing (continued)

These energy efficiency improvements are especially cost-effective methods to reduce greenhouse gas emissions—in fact, most of the emission reductions in the plan can be achieved at a profit for U.S. firms and consumers.

For example, the plan will allow workers the option of taking either employer-paid parking or its cash value as increased income instead—providing a financial incentive to take public transportation or car pool.

Through this plan, the United States will aggressively promote more recycling, more efficient transportation systems, more reductions in harmful methane emissions from mining and agriculture. The plan protects forest resources that store carbon taken from the atmosphere. And it establishes a program to monitor the results of the plan and modify it if necessary to adapt to changing circumstances.

The entire transcript is available from the U.S. Government Printing Office and from large libraries.

QUESTION 8.1. How would you judge the scientists' answers?

Can you summarize, in your own words, what each scientist is saying?

Has the Action Plan Been Carried Out?

According to the White House Council on Environmental Quality, most of the recommended actions to reduce greenhouse gases are voluntary, and a great many U.S. companies have responded very positively to these recommendations. For example, the Green Lights program, which was started under the Bush administration and expanded under the Clinton administration, encourages companies to install energy efficient lighting in place of the lighting systems they now use. While the installation is expensive, the new lights would pay for themselves in lower electric bills within a couple of years. More than a thousand companies have signed up to overhaul their lighting systems. Such programs are very promising since electricity generation accounts for more than a third of the greenhouse gas emissions in the United States.

Another successful program has been an effort by the Environmental Protection Agency (EPA) to certify electrical equipment that use a minimum amount of energy with an "Energy Star" label. The public has responded very positively to this program by purchasing the energy-efficient products in preference to those that do not have the "Energy Star" label.

However, the positive gains made by programs such as Green Lights and Energy Star have been offset by Americans' choices of cars and driving habits. Approximately one third of the greenhouse gases emitted from the United States is from motor vehicles. Over the years, new technologies have improved gas mileage so that an average passenger car gets 28 miles per gallon. However, light trucks, vans, and sport utility vehicles, which average only 20 miles per gallon, have become increasingly popular in recent years. The result is that Americans are burning more fuel per mile than just a few years ago.

An additional problem is a change in driving habits. Speed limits have recently increased in most states, and higher speeds means reducing miles per gallon still further. A van that gets 20 miles per gallon at 55 mph gets only 16 miles per gallon if driven at 65 mph. Speeding up to 75 means that the driver can go only 13 miles on a gallon of gas. And to make matters worse, Americans are driving more than ever before.

Looking to the future, there is still a chance that improvements in auto technology can help reduce greenhouse gas emissions. General Motors, Ford, Toyota, and other companies are developing cars that are lighter in weight and that are powered by both a gasoline engine and an electric motor. The first of these to reach the marketplace is the Toyota Prius, which can travel 66 miles on one gallon of gas. In addition, the President's proposed budget for fiscal year 2000 includes $264 million to continue a government-sponsored program to develop a family car capable of 80 miles per gallon. That would mean a two-thirds reduction in carbon dioxide emissions.

Update, April 14, 1999

The debates in our nation's capitol continued throughout the 1990s. In general, funds for research were supported, but other actions were hard-fought battles.

In April 1999, a hearing took place in the U.S. House of Representatives before the Subcommittee on Energy and the Environment of the Committee on Science. The hearing was about the President's $4.142 billion climate change proposal. There was broad agreement about spending nearly half of the funds on research, but a great deal of disagreement about spending the balance. These requests were for grants to states and localities for equipment to reduce air pollution; tax reductions for companies that would invest in new equipment to reduce their emission of greenhouse gases; funds to support the development of new energy efficient technologies; and money for the conservation of forests and farmlands.

In his opening statement, Subcommittee Chairman Ken Calvert, representing Riverside County, California, said:

Representative Ken Calvert

"Gentlemen, as much as I enjoy your company, I am sad to say that I cannot find anything in this budget proposal that is much different from the request the Congress, in large part rejected last year—with the exception being the U.S. Global Change Research Program . . .

"I note that some of the programs within the climate change budget are 'voluntary.' Programs such as Energy Star and Green Lights have reduced energy consumption and emissions in the United States. However, I question whether coordination of these voluntary programs—which subsidize rich private sector firms—is really a proper role for the Federal Government, especially when the private sector could be doing those things without taxpayer funds, and whether this money could be better spent elsewhere—like protecting the Social Security Trust Fund."

Speaking in support of the proposal, Neal Lane, assistant to the president for Science and Technology, responded:

"I believe, as do most scientists who have carefully studied this problem, that we need to confront this growing challenge now. The evidence is compelling that emissions of greenhouse gases from human activities are amplifying the Earth's natural greenhouse effect and warming the planet's surface. Computer models suggest that such warming is likely to lead to further climate disruptions and ecological impacts as sea levels rise, patterns of precipitation change, atmospheric and ocean currents shift, and plants and animals migrate.

Neal Lane

"So, the question facing us is—what specific constructive steps do we take? First, it requires a sustained and enhanced commitment to energy research, development and deployment. It is critical that we begin our long-term efforts in this area sooner rather than later, because the consequences of our near-term technology choices are themselves significant and long-lasting. The longer we continue on a 'business as usual' path, the greater the degree of warming, the faster the rate of climate change, and the more severe the negative effects for human and ecological systems . . .

"Mr. Chairman, doing nothing is the high risk option. What is at stake is the health and well-being of our children and future generations, as well as our environmental quality and global stability."

Who Decides What to Do?

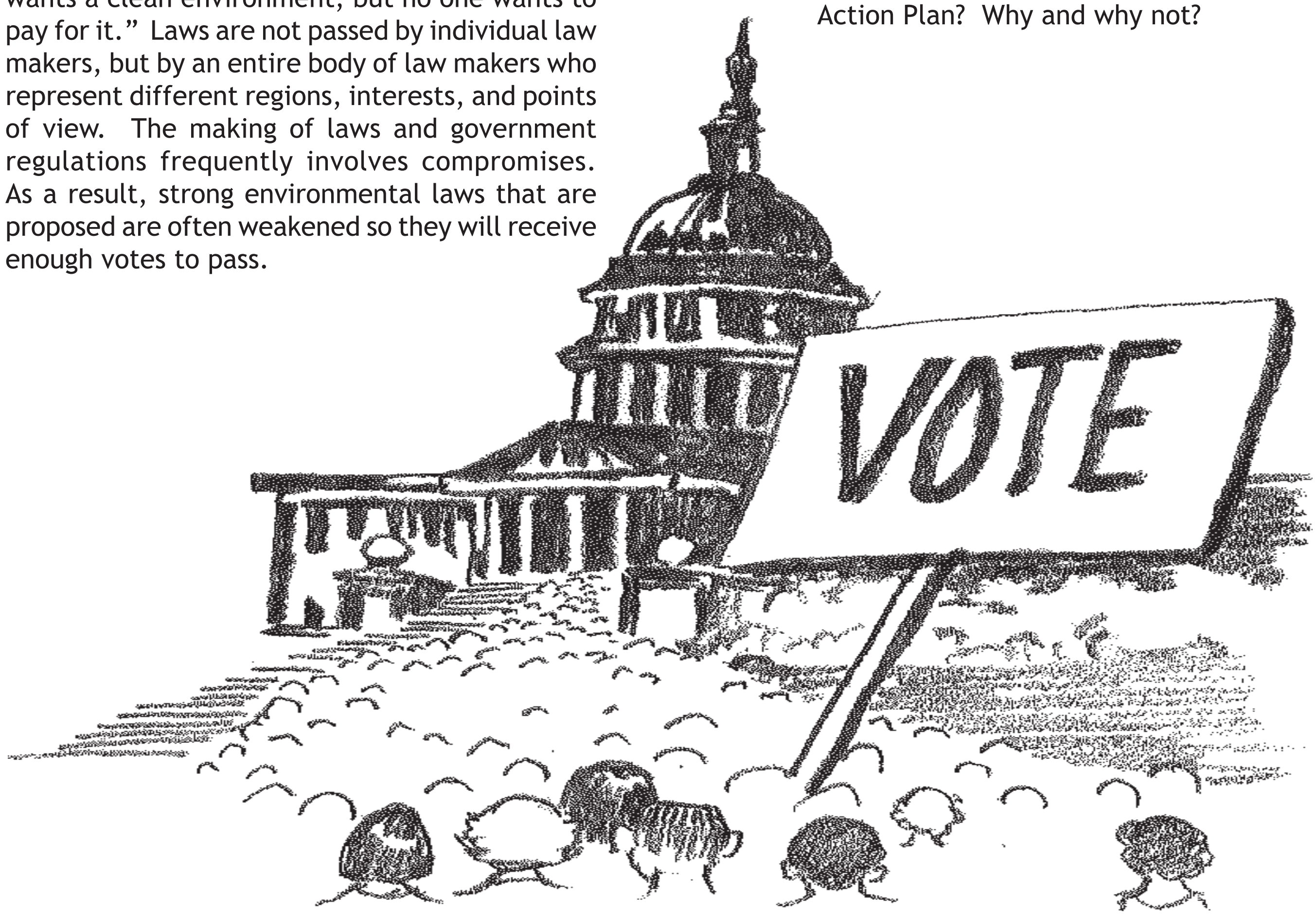
It is up to us to decide what to do about climate change. In part, we make these decisions through our elected representatives. Since 1988 there has been a firm commitment to continue research, but an ongoing debate in Congress about whether the government should offer tax credits or other incentives to industry to develop more energy efficient technology.

QUESTION 8.2.

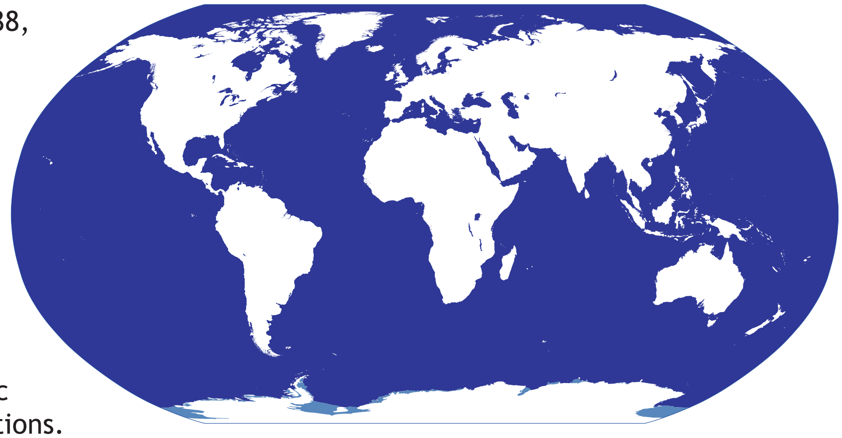
Think about your state and region.

Do you think voters would support programs like the Climate Change Action Plan? Why and why not?

The objections to federal programs to reduce the emission of greenhouse gases usually revolve around money. As some have observed, "Everyone wants a clean environment, but no one wants to pay for it." Laws are not passed by individual law makers, but by an entire body of law makers who represent different regions, interests, and points of view. The making of laws and government regulations frequently involves compromises. As a result, strong environmental laws that are proposed are often weakened so they will receive enough votes to pass.



What Is the World Doing About Climate Change?



In an effort to learn more about Earth's climate the United Nations, in 1988, established the Intergovernmental Panel on Climate Change (IPCC). The Panel formed several working groups: two groups comprising 2,500 scientists from around the world, who would coordinate scientific research on climate change, and decide what measures should be taken; and a third group, consisting primarily of economists who would examine the economic and societal impacts of various actions. It is fair to say the work of the IPCC convinced political leaders in countries around the world that climate change could have serious consequences, and they needed to talk about what could and should be done.

The Earth Summit, 1992

In 1992, top government officials from more than 150 countries met under United Nations sponsorship in Rio de Janeiro, Brazil, to discuss environmental and economic issues, including climate change. Because this was the largest international convention ever held—more than 25,000 people attended—it is known as the Earth Summit.

One of the most important results of this extraordinary meeting was a draft treaty, called the United Nations Framework Convention on Climate Change (FCCC). The treaty acknowledged the need for all nations to participate in efforts to slow global warming. Reaching an agreement as to how to proceed, however, would be no easy matter and was left to be addressed at future meetings.

President George Bush directed the U.S. delegates to the Earth Summit to make sure that the language in the treaty avoided any firm commitments that might weaken the U.S. economy. Other countries, as you can imagine, pressed for measures that met their own objectives. A significant concern was the economic inequity between the industrialized nations and the developing countries. Nevertheless, progress was made after much discussion and an agreement or treaty on broad basic principles was reached.

A treaty does not become legally binding unless it is signed by authorized representatives of the participating nations and then ratified by the law-making body of each country. In the United States, President Bush signed the FCCC treaty, which was ratified by the Senate in October 1992. Around the world, 179 governments have ratified the treaty.

The Kyoto Protocol, 1997

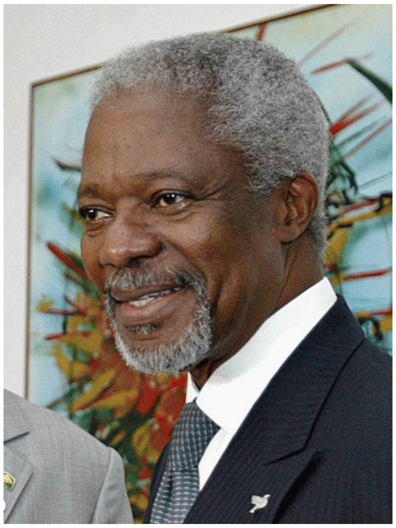
Each year, since the FCCC was drafted, representatives from countries around the world held meetings to determine exactly how and when the agreement should be implemented. When the delegates met in Kyoto, Japan, in December 1997, the objective was to set legally binding limits on the emissions of greenhouse gases resulting from human activities.

Back in Rio, in 1992, the signers of the FCCC acknowledged that industrialized nations are primarily responsible for the increasing atmospheric concentration of greenhouse gases. Developed countries, therefore, would need not only to take measures to curtail future increases in emissions but also to cut back, over a period of time, to earlier levels. The signers also recognized the developing countries had a relatively low per capita greenhouse gas emission. However, as the developing countries would become more industrialized, their share of greenhouse gases emissions would increase. Therefore, finding an equitable balance to satisfy the needs of both developed and developing nations became, and remained, the difficult task faced by the participants in the Kyoto meeting.

In addition to the political agendas policy makers of each country have, there are business interests that try to influence the outcomes of the meetings. Oil-producing nations and the fossil fuel industries share economic interests that strongly influence their outlook on just what measures should be taken. In short, the issues, influences, and consequences are complex, and progress was slow in Kyoto. Nevertheless, a significant agreement—the Kyoto Protocol—was eventually reached. According to the Kyoto Protocol, the United States would reduce its emissions of greenhouse gases 7 percent below 1990 levels by the year 2012. Similarly, other industrialized nations agreed to mandatory reductions. Developing nations, however, were not required to reduce or limit their emissions of greenhouse gases.

Immediately after the Kyoto Conference, President Clinton issued the following statement:

> "I am very pleased that the United States has reached an historic agreement with other nations of the world to take unprecedented action to address global warming. This agreement is environmentally strong and economically sound. It reflects a commitment by our generation to act in the interests of future generations.
>
> "No nation is more committed to this effort than the United States. In Kyoto, our mission was to persuade other nations to find common ground so we could make realistic and achievable commitments to reduce greenhouse gas emissions. That mission was accomplished . . .
>
> "There are still hard challenges ahead, particularly in the area of involvement by developing nations. It is essential that these nations participate in a meaningful way if we are to truly tackle this global environmental challenge. But the industrialized nations have come together, taken a strong step, and that is real progress."



Secretary General of the United Nations Kofi Annan of Ghana

Continued Discussions, Buenos Aires, 1998

Deciding just how to implement the Kyoto agreement continued at the November 1998 meeting in Buenos Aires. The meeting opened with a message of greetings to the delegates from the Secretary General of the United Nations Kofi Annan of Ghana.

"The Kyoto Protocol is the most far-reaching agreement on environment and sustainable development ever adopted. Drawing on the best available science, and on new concepts in international law and diplomacy such as the precautionary principle, the protocol offers a new, more sustainable path for industrial economies. Its adoption demonstrates just how far the community of nations has come in accepting responsibility for its shared stewardship of the Earth. The next step is to translate this written agreement into reality by signing and ratifying it quickly, so that it enters into force within two or three years.

"Here in Buenos Aires, you have launched the post-Kyoto process, a process as significant and challenging as those that produced the Protocol and Convention. Our destination may be agreed, but now you must determine the best way to get us there.

"We need to ensure that emission reductions are cost-effective while ensuring that domestic action remains paramount. We must also figure out the best way to transfer climate-friendly technologies to developing countries.

"We need much more scientific research, data collection, training and public outreach. And we need to expand and strengthen the Convention's mechanisms for sharing information and reporting on national actions and programs.

"We all know that, despite the agreement at Kyoto, countries still hold differing perspectives on the way forward. I am confident that the political will exists to find common ground and move forward."

Differing views and proposals were considered, and eventually the Buenos Aires plan of action was adopted. Deadlines for finalizing work on the Kyoto Protocol were agreed to, as well as how to overcome barriers in transferring environmentally friendly technologies—such as those encouraged in the U.S. Green Lights program—to developing countries. Still, not all the wrinkles were ironed out. In October 1999, the next scheduled international conference took place in Bonn, Germany. Even then, there were still issues to resolve.

Debates in the U.S. Congress

In the United States, the Kyoto Protocol received mixed reviews. President Clinton signed the agreement. However, in order to have the force of law, it must be ratified by two-thirds of the 100 members of the Senate. Various views were expressed. Sen. Joseph Lieberman of Connecticut issued the following statement.

"I commend President Clinton and Vice President Gore for their moral and political leadership in addressing the threat of global climate change. In signing the Kyoto Protocol today, the president and vice president are in sync with the American people who support action on global warming because they care about the kind of world we leave to our children and because they want the cleaner air that will come with implementing this treaty.

"It is essential that the United States be a full player at the negotiating table in order to influence future decisions that will be made about emissions trading and other market-based programs which we fought hard to include in the Kyoto agreement.

Sen. Joseph Lieberman

"By signing the agreement, the Administration confers on the United States the authority and credibility it needs to continue its leadership role in shaping and implementing these programs and in persuading the developing nations to become a part of the solution.

"At the same time, no binding obligations will be placed on American companies as a result of the agreement. The Administration has said it will require meaningful participation by developing countries before seeking ratification of the treaty by the Senate.

"The Kyoto Protocol is not a complete agreement; it is only a beginning. But it establishes the goals and describes the mechanisms for dealing with global warming.

"I am proud that our country has now signed onto the global effort to protect our Earth's irreplaceable natural environment."

Sen. Lieberman's views, however, were not shared by a majority of senators. The main stumbling block was the absence of a requirement for developing countries to reduce greenhouse gas emissions. Recognizing that he lacked the support of two-thirds of the Senators, President Clinton decided not to submit the treaty for ratification at that time.

Rep. James Sensenbrenner Jr.

The possible effect of the treaty was also discussed in the House of Representatives. On April 14, 1999, at a House hearing about the Fiscal Year Climate Change Budget, Chairman James Sensenbrenner Jr. of Wisconsin stated: "As I have said on many occasions, I believe this U.N. treaty to be seriously flawed—so flawed, in fact, that it cannot be salvaged. In short, the treaty is based on immature science, costs too much, leaves too many procedural questions unanswered, is grossly unfair because developing countries are not required to participate, and will do nothing to solve the speculative problem it is intended to solve."

QUESTION 8.3. Try to imagine yourself in the shoes of a senator. You are elected by people in your state to carry out the social policies you promised during your campaign. Once on the job, you are guided by letters and telephone calls from voters, and you listen to experts and lobbyists. But you will be the one to vote on the Kyoto Protocol.

What would you do?

Why?

For new material relating to this chapter, please see the GSS website "Staying Up To Date" page:
http://lhs.berkeley.edu/gss/uptodate/2cc/2cc.html
We invite you to send us new articles for the "Staying Up To Date" web page for this chapter. Articles may be from local newspapers, magazines, websites, or other sources that you think would be of interest to classrooms around the country. To send us articles please go to the link http://lhs.berkeley.edu/gss/uptodate/newarticle.html and find the "Submit New Article" button.

9. *What Do You Think About Global Climate Change?*

We have considered actions by the U.S. government and other governments to slow global climate change. It's important to recognize, however, that it is not just government officials who can make a difference. Every person in the world contributes to the changing atmosphere, and people in industrialized countries like the United States contribute the most. Therefore, it's important for all of us to be aware of how we affect the climate and to decide what each of us, as individual citizens, wants to do about it.

In this chapter you will be asked to examine your own understanding and opinions about global climate change in four key areas: science and technology, economics, politics, and ethics; then, to examine your actions—the choices that you make as a citizen and a consumer. You will not be told what to believe, but rather to decide if your actions are consistent with your understanding and beliefs.

Science & Technology: What Do We Know About Climate Change?

It is up to scientists and engineers to study climate change, to predict its impact, and to figure out ways to cope in a warmer world. It is up to you, as a responsible citizen, to follow this research as it is reported on television, in newspapers and magazines.

Monitoring the Environment

The U.S. government sponsors scientific research stations all over the world to measure the state of the atmosphere and the current levels of greenhouse gases. The network of monitoring stations also includes satellites that keep track of the temperature of the atmosphere and oceans, the condition of sea ice around the poles, and the amount of radiation coming from the Sun. A number of federal agencies are responsible for collecting the data and making them available to the public.

Predicting the Effects of Global Warming

The first predictions of global warming by Arrhenius, 100 years ago, were based on a theory of how the Earth-atmosphere system might react to changes due to the industrial age. Since that time, a great many scientists and engineers have made detailed studies to improve the theory and construct computer models of the Earth-atmosphere system.

These models cannot predict what will occur in small regions of the world, but they all agree that major changes in climate will result over the next century if greenhouse gases continue to build up in the atmosphere. In recent years the accuracy of these models has been improved by adding the effects of aerosols—fine particles released into the air by power plants, cars, and factories. These models have been tested by comparing them with past climate changes. Further research is needed to take into account the role of clouds and the ocean.

Reducing the Emission of Greenhouse Gases

Energy conservation is currently the cheapest way to reduce the emission of greenhouse gases. If everyone were careful about using energy, we could reduce the emission of greenhouse gases and save money. Engineers are developing more efficient refrigerators and also more efficient appliances for lighting and heating. The aim of these efforts is to reduce the need to burn fossil fuels and to keep carbon dioxide locked in the ground a little longer. Development of alternative energy sources such as wind, solar, and safe nuclear energy are other projects that engineers are working on.

Finding Ways of Coping in a Warmer World

Even if the government undertakes a strong program to reduce the emission of greenhouse gases, they will still build up in the atmosphere, but more slowly than if we do nothing. In the meantime, we can greatly expand efforts of scientists and engineers who are exploring ways to cope with a warmer world. For example, since plants need carbon dioxide for photosynthesis, most plants grow better in an atmosphere that is rich in carbon dioxide. The problem is to find food plants that will produce nutritious crops and do better than the weeds and insects, which also will do better with more CO_2.

Some scientists are studying ways to help wildlife adjust to changes in habitat as the climate changes. These efforts may help endangered species establish new colonies, or provide "migration corridors" where land development is halted or restricted so that the animals can migrate on their own.

QUESTION 9.1. Briefly summarize your answers to these questions.

What do we know about climate change?

Is it really occurring?

What will it mean?

Why should I care?

Why is it important to continue learning about the science and technology of climate change in the future?

Economics:
What Are the Costs Associated with Climate Change?

We can't know if the first humans to discover how to control fire were appreciated by their fellow cave dwellers. What is certain is that from then on the use of fire became an important aspect of social policy. As a result, fewer people died from cold and attack by animals. Later, the ability to control fire led to the development of cooking, the extraction and use of metals, and many other processes that form the basis of civilization.

The invisible by-product of fire—carbon dioxide—had long been ignored. Today the heat from fossil fuels and its carbon dioxide production is so much a part of our industrial way of life that any attempt to reduce the production of the gas will change our lives in profound ways.

Even in earlier times, when wood was used for heating and cooking, energy had its cost. It required work to cut and haul the wood to where it was to be burned. Where populations grew quickly, forested areas were stripped, and people had to go further to obtain wood. Switching to coal and then to oil and natural gas was a response to the need for a continuing supply of fuel that was plentiful and cheap. The choice of which fuel to use and how much energy to produce has always been an economic choice, decided by balancing the benefits of that energy with its costs.

QUESTION 9.2

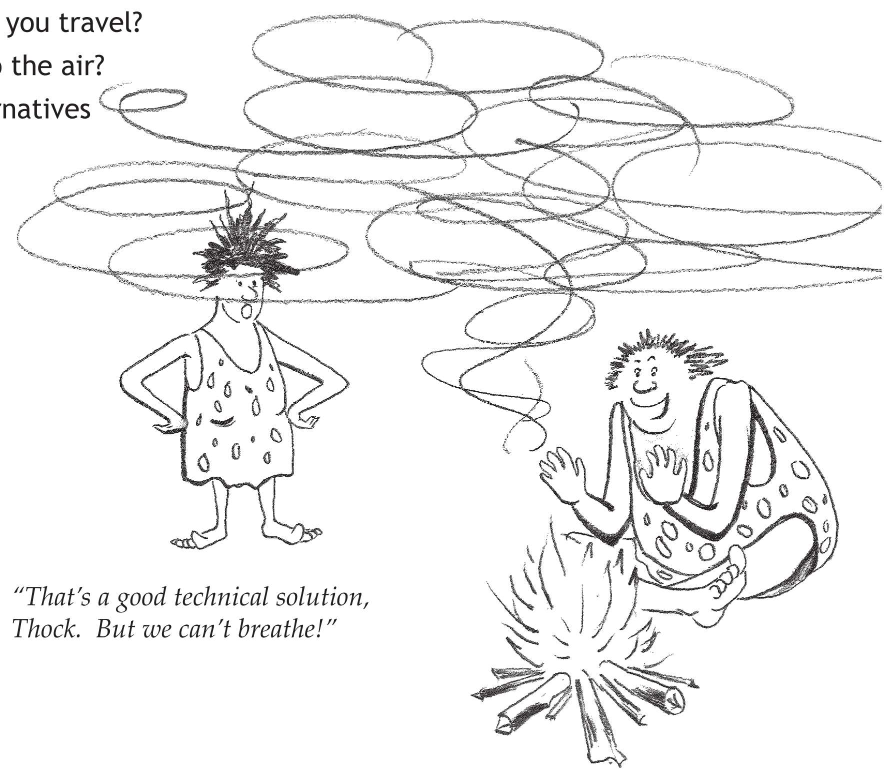
What kind of fuel is used in your home?

What kind of fuel is used in your school?

What kind of fuel is used when you travel?

Do these add carbon dioxide to the air?

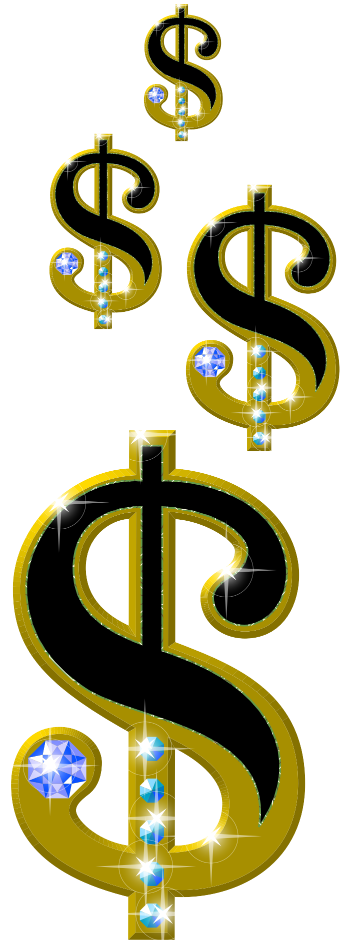
Are there any economical alternatives available to you?



"That's a good technical solution, Thock. But we can't breathe!"

Estimating the Costs of Global Warming

The fuels we use may be the cheapest ones available. In the long run, however, they may actually be very costly. If they contribute to global warming, what would be the real cost to us or our children? Estimating costs is very difficult because we cannot accurately predict the effects of global warming. However, we can imagine various possible scenarios. For example, if sea levels rise, it may become necessary to build seawalls and dikes, or to resettle large groups of people around the world. We can estimate the costs of these actions, as well as the increased costs of health care for the elderly in the case of long spells of hot weather, and the costs to agriculture of droughts or floods.



Consider the case of San Francisco Bay. During the most recent Ice Age, which was only about 5°C cooler than now, water levels were 200 feet lower than now. San Francisco Bay was a meadow. When the climate warmed, glaciers melted and the volume of seawater expanded, filling San Francisco Bay to its present level. If the globe warms further, scientist predict the sea level will continue to rise, flooding the low-lying areas of San Francisco, Oakland, Berkeley, and other cities that ring the Bay.

If sea levels rose by 10 feet over the next century, $48 billion worth of structures would be destroyed in the San Francisco Bay Area alone, according to researchers. Partial protection could be provided by seawalls at a cost of more than $1 billion, plus $100 million annually for maintenance. The researchers recommend prohibiting future construction in low-lying areas (see Barnum in the Bibliography).

The potential economic problems are even worse for people who live on islands. Many of these concerns were expressed on September 27 and 28, 1999, at a United Nations special session on climatic threats to island nations. Delegates pointed out the tremendous impact on their economies due to the loss of fresh water, reduced land for agriculture, damage from increased storms, and loss of trade and tourism.

QUESTION 9.3

What are the most likely economic impacts of climate change if people continue to use energy the way it is used now?

When will this impact be felt?

Who will it affect?

Do you think it will have an impact on your life or on your children's lives?

What might be done now to reduce global warming without seriously damaging today's economy?

The Costs of Reducing Emissions of Greenhouse Gases

Spending now to save money later is rarely a popular choice. For example, people could substantially cut their monthly electric bills by replacing all their regular incandescent bulbs with compact fluorescent bulbs. The compact fluorescent bulbs last much longer, but they cost more, so many people are not willing to make the switch.

Industries that burn large amounts of coal or oil could switch to natural gas, which burns more efficiently, produces more heat energy, and releases less carbon dioxide per unit of energy produced. But switching from coal or oil to natural gas requires expensive equipment. Not all companies can afford the new equipment.

Increased taxes on fuels to discourage their use is also an unpopular choice in the United States. In Europe, high fuel taxes support trains and other mass transit systems. However, increasing the cost of fuels too rapidly could cause some businesses to fail and employees to lose their jobs. Unfortunately, any method to reduce the release of greenhouse gases will have a negative impact on the people who currently extract and sell these fuels, or transport them to where they are needed.

Political Choices: What Will It Take to Do Something About Climate Change?

It is helpful to keep in mind that environmental issues are not new in national politics. In just about every presidential campaign politicians have talked about the environment. When Adlei Stevenson, then-governor of Illinois, was a candidate for president in 1956, he said:

> "We travel together on a little spaceship, dependent upon its vulnerable reserves of air and soil, committed for our safety to its security and peace, preserved from annihilation only by the care, the work, and I will say, the love we give our fragile craft."

In recent years, environmental issues have become more important in election campaigns because political polls show there is strong support for protection of the environment among U.S. voters. However, politicians with even the best of intentions often encounter difficulties when trying to pass laws or regulations that protect the environment.

QUESTION 9.4

What are the greatest challenges faced by law makers?

If you were a member of Congress, what would your position on climate change be?

How would you respond to the President's Action Plan on Climate Change?

Would you vote to ratify the Kyoto Protocol?

How would you convince the voters in your state that you made the right choice?

Ethical Dilemmas: What's the Right Thing to Do?

Another way to see the controversy about climate change is from the point of view of *ethics*—a set of moral principles or values that guide our decisions.

Although nearly all climatologists predict that Earth will continue to warm in the coming decades—a warmer climate will not make the planet uninhabitable. The human race has already demonstrated it can exist under extreme temperature conditions. The cultural adaptations we make—like changes in clothing and home structures—allow us to adapt. However, many plant and animal species may not survive. A polar bear cannot unbutton its coat or move to a colder climate if the Arctic summer becomes warmer over the next few decades.

Other problems that could result from global climate change include rising sea levels, increased storm surge, loss of forests and coastal lands, increased rainfall and floods in some areas and desertification in other areas, as well as threats to human health and agriculture.

Your thoughts about these effects of global warming reflect your ethical code. Do you believe we should slow the burning of fossil fuels to reduce the likelihood of global warming? And if you do, what about the people who work in the fossil fuel industries? Will there be other opportunities for these people to find employment, or will the entire economy suffer? In short, how can we balance the demands of the present against our concerns for the future? As Congressional hearings and international forums illustrate, it is not an easy task.

From time to time politicians manage to gather support for social policies because they are able to convince people the policies are based on important ethical principles, even if those policies are expensive to implement. This approach is being taken by Tuiloma Neroni Slade, a representative from the island nation of Samoa to the United Nations. He is trying to convince industrialized nations to reduce their use of fossil fuels. He said,

> "Climate change is already taking effect in terms of some of the life support systems. For instance, in the Maldives, there is infiltration of freshwater reserves by sea water. In many places, there is a degree of brackishness in the drinking water. You can see this in the Caribbean. You can certainly see this in the Pacific. Fresh water reserves have been contaminated. Whether it is the storm surge or the sea rising, the [salt] waters get into the fresh water.
>
> "Climate change is the type of global issue not of our making, so it raises questions of equity and ethics."

When we think of our world, we can picture it as it appears on a globe—a collection of continents and nations separated by oceans, or, we can see it from the viewpoint of an astronaut, with areas of land, oceans, and swirling clouds.

Image source: NASA

QUESTION 9.5

What is your opinion?

What are the ethical issues that come to mind when you think about climate change?

What do you believe is your moral duty to others?

What do you believe is your moral duty to the society you live in?

What do you believe is your moral duty to the wider world community?

What do you believe is your moral duty to our Earth?

QUESTION 9.6. How does each point of view help us understand our home planet and how it is changing?

Personal Opinion Essay

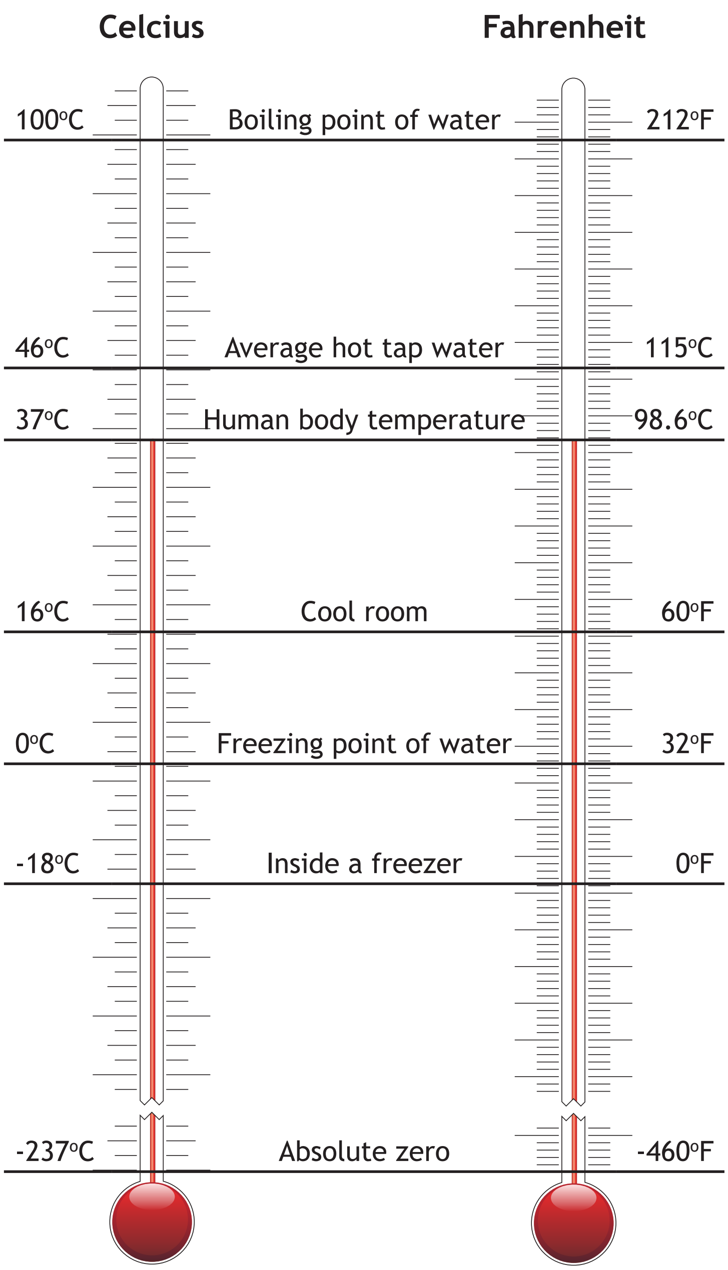
Write an essay describing your *personal* position on global climate change. The essay should be written according to the format and length requirements set by your teacher. In preparing to write your essay, please do the following:

1. Draw a line down the center of a sheet of paper. On the left, list the most important points you want to make.
2. On the right side, list any arguments that people who disagree with you might make.
3. Decide what actions you could take that would reflect your position regarding global climate change. List these on the bottom or back side of the paper.
4. Share your ideas with a classmate. Find out what he or she thinks, and discuss the points on which you agree and differ.
5. Make an outline of your essay. Decide on the order in which to present your main points so that your opinion is clear and logical. Under each main point, explain your opinion and why you disagree with people who might hold an opposite view. End the essay with what actions you and others might take (or not take) that reflect your opinions on this subject. Choose a title that captures your most important idea or conclusion.

For new material relating to this chapter, please see the GSS website "Staying Up To Date" page: http://lhs.berkeley.edu/gss/uptodate/2cc/2cc.html We invite you to send us new articles for the "Staying Up To Date" web page for this chapter. Articles may be from local newspapers, magazines, websites, or other sources that you think would be of interest to classrooms around the country. To send us articles please go to the link http://lhs.berkeley.edu/gss/uptodate/newarticle.html and find the "Submit New Article" button.

Converting Celsius and Fahrenheit Temperature Scales

Celsius (or centigrade) is the temperature scale used by scientists, while Fahrenheit is the scale used by most nonscientists in the United States. Since this book is about global systems *science*, we have used the Celsius scale throughout. However, it is very easy to convert from one scale to the other.



Conversion Formulas

$$F^\circ = C^\circ \times 5/9 + 32$$

$$C^\circ = (F^\circ - 32) \times 9/5$$

For example, the average global temperature of the whole Earth in 1991 was 15.39°C. To find out what that temperature is on the Fahrenheit scale, multiply 15.39 by 9, divide by 5, and add 32. The average global temperature in 1991 on the Fahrenheit scale was 59.7°F.

The theory that heat is the motion of molecules leads to the concept of absolute zero. As matter loses more and more heat, molecular motion slows down until at some point molecular motion stops. The temperature at which that point is predicted to occur is called *absolute zero*. Although very cold temperatures have been reached in laboratories, absolute zero has never been achieved, and it is probably impossible to do so.

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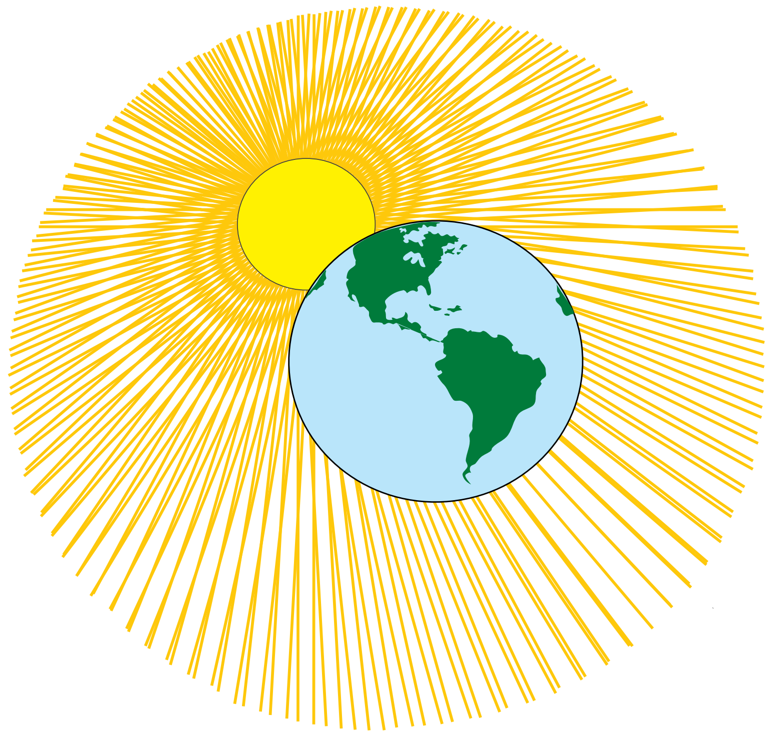

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