Understanding Climate Change

Lesson plans for the classroom

by Holly Fretwell and Brandon Scarborough

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About the Authors

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Fretwell has co-authored curriculum for high school teachers on economic principles and climate change issues. She has completed a manuscript on public land management at PERC, the Property and Environment Research Center. She has presented papers promoting the use of markets in public land management and has provided congressional testimony on the state of US national parks and the future of the Forest Service. She has also published a children's book on climate change, *The Sky's Not Falling: Why It's OK to Chill About Global Warming* (World Ahead Media, 2007), to encourage parents, teachers, and kids to become critical thinkers.

Fretwell holds a B.A. in political science and an M.A. in resource economics from Montana State University.

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1 The Scientific Method

Introduction

Derived from the Latin word *scientia*, meaning knowledge, science is the ongoing process of learning through observation and testing.

The "scientific method" begins with the observation of a phenomenon. Based on that observation, a hypothesis is formed about the causes and/or consequences of the observed phenomenon. Scientists then devise experiments to test the hypothesis, collect and analyze data from the experiments, and reach conclusions.

Experimentation is designed to invalidate a hypothesis rather than prove it as true because an infinite number of alternate hypotheses would have to be tested to prove the absolute truth of any single hypothesis. Disproving a hypothesis decreases our confidence in its accuracy and expands our understanding of observed phenomena.

Even when testing appears to support a hypothesis, other scientists may challenge it by formulating an alternate hypothesis or testing method. In this way, science is an evolutionary learning process. While it gives us the best knowledge about the natural world that we have at a given time, our knowledge is continually expanding as new hypotheses are tested and new discoveries broaden our understanding. Amazing advances in technology continually improve our ability to observe and analyze the universe.

Just 600 years ago, conventional wisdom held that earth was at the center of the universe and that all the planets orbited around it. Only after Nicolaus Copernicus proposed otherwise did further research disprove that long-held theory. Today, we know that all planets in our solar system, including earth, revolve around the sun.

Sound science depends upon verifiable information and accurate testing methodologies. *If the theoretical assumptions underlying an experiment are inaccurate or the testing methods imprecise, the results of experimentation will be flawed*.

How does this relate to climate change? Our understanding of the natural world—including our climate—is evolving as a result of the scientific method. Although still incomplete, our scientific knowledge of climatology has increased tremendously in just the past few decades. However, hypotheses about climate change abound, and despite the popular media conception of consensus, the issues are far from settled. Due to the nature of the scientific method, no hypothesis can be proven absolutely true.

Lesson 1-A
The scientific method

1

Lesson 1-A

Theme

This lesson explores the scientific method and will help students to understand how hypotheses are tested and how theories are developed. It provides tools to generate hypotheses about climate change and methods to test them.

Purpose

This lesson introduces the scientific method and allows students to become familiar with the process of using it.

Description

Students will apply the scientific method to a real-world observation. They will develop a hypothesis and discuss ways to test it. The purpose of the lesson is to help students understand that science evolves and that knowledge is gained through the application of the scientific method.

Procedure

1 Ask your students to think about science. What *is* science?

> *Science is the evolutionary process of learning through observation and testing.*

2 Present *Visual 1.1: Science*. Discuss some of the scientific theories that were once believed to be true, but have since been revised or disproved.

> *For example, Galileo was convicted of suspicion of heresy for teaching that the sun, not earth, was at the center of our solar system (as originally formulated by Copernicus). Today, we know this to be true.*

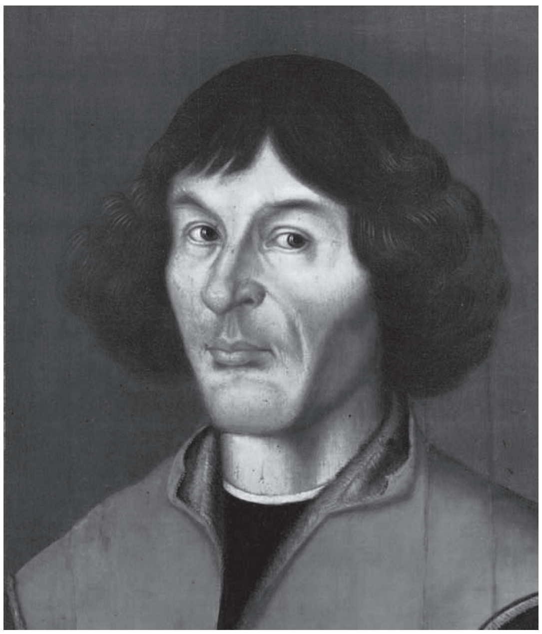
> *Scientific knowledge advances when scientists have the courage to question conventional ideas and to propose new theories supported by all the available evidence.*

3 Present *Visual 1.2: The scientific method*. Discuss the importance of the scientific method.

> *It is a process of making observations, forming hypotheses, testing the hypotheses, collecting data, and reaching conclusions. No hypothesis can be proven to be absolutely true; there will always be alternate hypotheses and testing methods that challenge a hypothesis' veracity.*

4 Hand out *Worksheet 1.1: The scientific method*. Have each student record a simple observation about the natural world (e.g., leaves are green; the grass is wet in the early morning). Have students follow the steps in *Visual 1.2: The scientific method* to develop a single-sentence hypothesis about why the observed phenomenon has occurred. It is not necessary for the hypothesis to be correct. Students will not be designing an experiment to test their hypothesis, but they should be able to identify at least three pieces of evidence that either support or refute their hypothesis.

Visual 1.1
Science



Nicolaus Copernicus

Is the earth the center of the universe?

Is the earth flat?

Are diseases caused by evil spirits?

Are natural disasters created by angry gods?

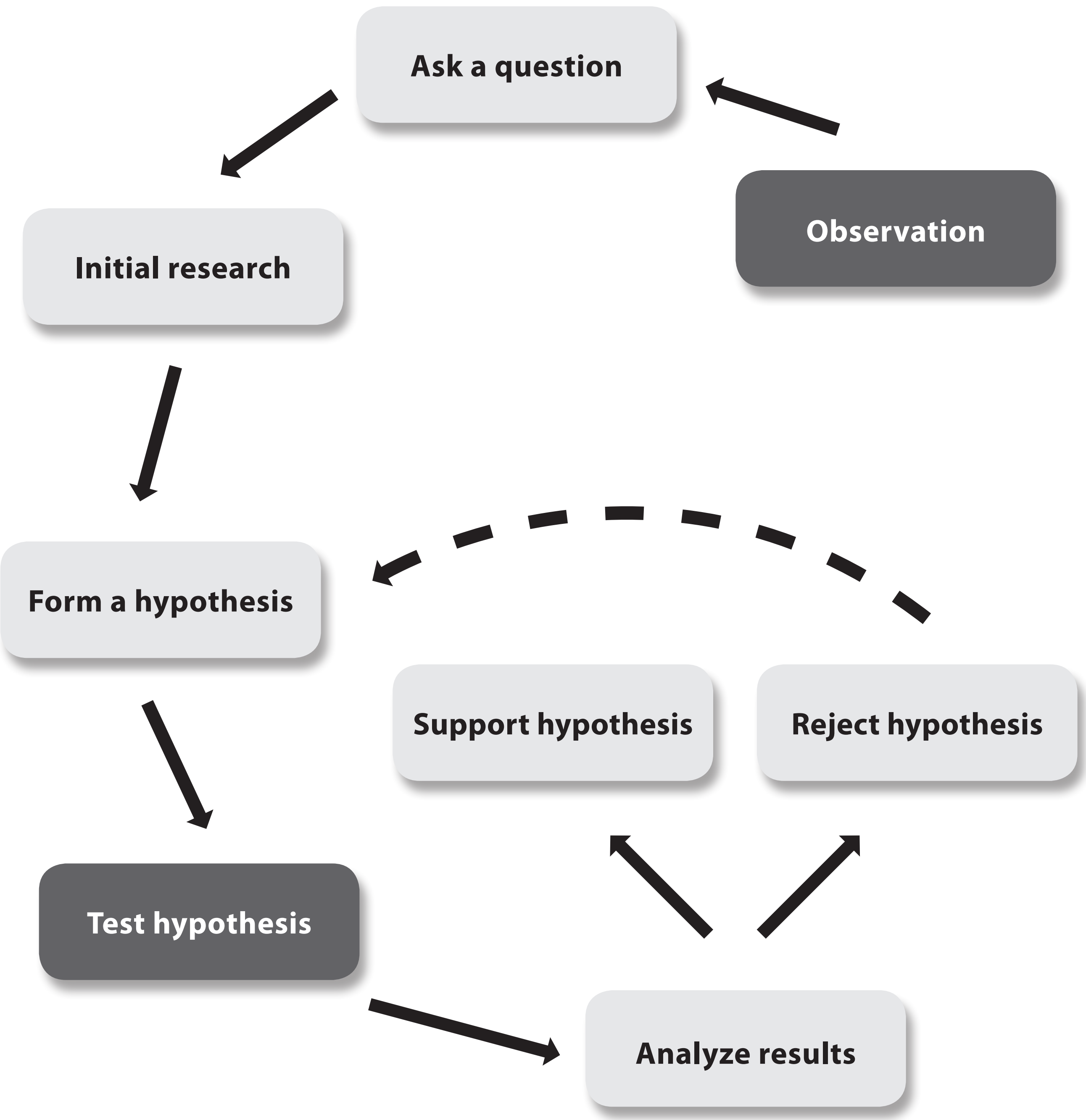
Does smoking pose a threat to your health?

Our history is full of examples where "common knowledge" was discarded in favor of more correct hypotheses.

1

Visual 1.2

Visual 1.2
The scientific method



Worksheet 1.1
The scientific method

Name:________________________

Observation: Make an observation about the natural world.

Ask a question: Form a question about your observation.

Initial research: Brainstorm some potential causes that might answer your question.

Form a hypothesis: Pose a possible answer to the question in the form of a statement.

List three pieces of evidence a scientific test might yield that would either support or refute your hypothesis:

Lesson 1-B

Climate change hypothesis

1

Lesson 1-B

Theme

Students have different ideas about climate change that they gather from various sources, not all of which have made conclusions based on proper scientific methods. Some students may believe that climate change is the result of human activity (i.e., that it is "anthropogenic"). Others may believe that climate change is a natural phenomenon. Still others may believe it to be the result of a combination of natural and anthropogenic factors.

Purpose

This lesson challenges students to think critically about climate change using the scientific method. It gives students the opportunity to explore their ideas and opinions, comparing them to alternate hypotheses.

Description

The class will organize a scientific investigation. Each student will take on the role of a scientist observing climate change and will employ the scientific method to develop and test a hypothesis about climate change.

Procedure

1 Engage your class in a discussion about their opinions about climate change and global warming, and ask them where they have obtained their information. Some questions to consider:

- What evidence suggests that our climate is changing?
- What observations have the students made?
- Are they convinced that the earth's climate is warming?
- Do they think that there are climate change skeptics within the scientific community?
- Do they believe that temperature change is the result of human activity? Are there other possible causes?
- How many students have watched movies or documentaries about climate change?
- How many students have read books or other research on the subject?
- Are there any students who have gleaned all they know about climate change from newspapers, TV, and radio?

2 Hand out *Worksheet 1.2: Climate change hypothesis*. Have students complete the worksheet individually, in the same manner as *Worksheet 1.1: The scientific method*. They may use any observation related to climate change.

3 Have each student present their hypothesis to the class. Discuss the different ideas proposed. Examples of hypotheses may include:

- Climate change is a natural, cyclical occurrence.
- Man-made emissions of carbon dioxide are responsible for climate change.
- There will be catastrophic consequences arising from climate change if we do not curtail greenhouse gas emissions.

4 Pick one of the students' hypotheses to use as a class example. Not all students need to agree with the hypothesis. Discuss how one might attempt to test it.

- What types of data and analyses would be useful to test the hypothesis?
  E.g., temperature data, weather pattern data, visual analysis of graphs, historical measures, human CO_2 emissions, etc.

- Where could such data be found?
  E.g., weather balloon temperature data from the troposphere, ice core samples, historical ground surface temperature records, etc.

- Is the testing method created by the class reliable (consistent in measurement) and valid (the best available approximation of the truth)? Would it provide useful results?

5 What conclusions can be made about the hypothesis based on the evidence or data available to the class?

Final Thought

It is important to re-evaluate prevailing ideas as more information becomes available. Critical thinking involves challenging our beliefs with alternate ideas. Science, which relies on the scientific method, is an ongoing process of forming new or alternate hypotheses, and then testing them to improve our knowledge of the natural world, including our climate.

Worksheet 1.2
Climate change hypothesis

Name:________________________

Observation: Make an observation about climate change.

Ask a question: Form a question about your observation.

Initial research: Brainstorm some potential causes that might answer your question.

Form a hypothesis: Pose a possible answer to the question in the form of a statement.

List three pieces of evidence a scientific test might yield that would either support or refute your hypothesis:

2 Correlation Is Not Causation

Introduction

Correlation is a systematic pattern that may emerge when we observe two variables over time. **Causation** means that there is a direct relationship between a change in one variable and a change in another variable.

Correlation does not imply causation because other unmeasured factors may be having an effect on one or both variables. A causative relationship between two variables can only be established by either proving or disproving a hypothesis using the scientific method.

When we observe a systematic pattern between two events or variables, we say that they are "correlated." A positive correlation exists when two variables move predictably in the same direction (e.g., both increase or both decrease), and a negative correlation exists when the two variables move predictably in opposite directions (e.g., one increases while the other decreases).

Correlation does not prove causation. To confirm causation, one must demonstrate that changes to one variable directly produce effects in the other. For example, we could observe the relationship between a rooster crowing and the sun rising and see that there is certainly a correlation between the two: the rooster crows while the sun rises. We could observe this systematic pattern on a daily basis, but we would not be able to conclude, for example, that the sun rises because the rooster crows. If we could prevent the rooster from crowing, we would observe that the sun still rises. Therefore, we have correlation but no causation among the two variables.

Correlation and climate

Carbon dioxide (CO_2) is the greenhouse gas most widely blamed for global warming and attendant weather disruptions, including intensified storms. Current atmospheric concentrations of carbon dioxide are higher now than they have been at any time in at least the last 650,000 years, according to the US Environmental Protection Agency. [1] In 2008 (and 1993), flooding ravaged the Midwestern United States after unusually heavy rains swelled rivers and burst levees. A number of newspaper reports noted that warmer air holds more moisture and thus unleashes heavier precipitation.

Higher levels of carbon dioxide and higher frequencies of catastrophic floods—two events that predictably occur together—are thus "correlated." But are they directly related? Did the higher levels of CO_2 cause the weather conditions that precipitated the floods? Remember, correlation does not imply causation.

The two events may seem to have a direct relationship, but one may actually have nothing to do with the other. Instead, one or more factors (variables) may cause the two events to occur simultaneously. For example, one of these variables could have been a delay in spring planting, which meant that there were fewer fields of crops to catch run-off, causing floods. Moreover, despite higher CO_2 levels in recent years, global temperatures are now expected to remain stable or even decline on average in certain regions. [2] This should prompt us to consider all possible factors when searching for any links between CO_2 and the earth's complex weather systems.

The scientific method helps us to differentiate between correlation and causation by testing hypotheses. Whether our hypotheses are confirmed or discredited, our knowledge and understanding of the world will be expanded through the process.

Learning about the atmosphere and its major components will improve students' understanding of the interplay between human actions and climate.

Atmosphere

The atmosphere is the blanket of air that surrounds earth and reaches upwards of 500 km into space (though about 99% of its mass exists within 31 km of earth's surface). This air is composed of multiple layers, each with varying temperatures, gas compositions, and densities. The atmosphere protects us from the sun's ultraviolet radiation, insulates us from extreme heat and cold, and plays a critical role in the cycling of carbon, water, and other components that are vital to life.

The dry atmosphere is primarily composed of nitrogen (78%) and oxygen (20.9%), with argon and other gases accounting for less than 1%. On its own, carbon dioxide accounts for only 0.038%. Other gases, including ozone, methane, and various natural and synthetic molecules, are also present, but comprise less than 0.0002% of the atmosphere. Water vapor is a small but important component of air that is found in differing amounts throughout the atmosphere—from just a trace in cold and arid regions to as much as 4% in tropical regions.

The troposphere is the layer of atmosphere closest to earth, extending from the surface to about 18 km at the equator and 6.5 km at the poles. It contains the air we breathe, our weather (including clouds), and most of the atmosphere's water vapor and other greenhouse gases.

Greenhouse gases

Although they comprise less than 5% of the atmosphere (when water vapor is included), greenhouse gases are critical to life on earth. Water vapor, CO_2, methane, ozone, nitrous oxide, and some human-made compounds affect surface and atmospheric temperatures by increasing the amount of heat energy that is captured.

Approximately 70% of the sun's energy (solar radiation) is absorbed by earth's surface, oceans, and atmosphere. The remaining 30% is reflected back into space. As solar radiation is absorbed at the earth's surface, infrared radiation is released back into the atmosphere. When this radiation comes in contact with greenhouse gases, a similar exchange of energy occurs: the gases both absorb and radiate energy. Part of this energy escapes into space and part of it radiates back toward earth's surface. As the concentration of greenhouse gases increases, the amount of heat energy radiating in the atmosphere increases, and more of that energy is likely to remain near the surface of the earth, causing temperatures there to increase.

The term "greenhouse effect" is a misnomer, however. The radiation of energy in the atmosphere is quite different from the warming dynamics in an actual greenhouse. In a greenhouse, heat becomes trapped because the glass restricts an exchange of air between the inside and the outside of the structure. The interaction between the sun's heat and greenhouse gases could be more accurately described as the "atmosphere" effect. In the atmosphere, greenhouse gases facilitate the mixing of air through the exchange of energy between space, the atmosphere, and earth's surface.

Water vapor is the most common greenhouse gas. Water vapor condenses into clouds, which can both warm and cool the planet. Clouds warm the planet by trapping heat near earth's surface. Alternatively, clouds cool the planet by reflecting the sun's radiation back into space. A multitude of other environmental factors, including wind and topography, also affect the impact of clouds on temperatures.

The primary source of water vapor in the atmosphere is evaporation from surface waters, including oceans, lakes, rivers, ponds, and even puddles and dew. Other sources include volcanic eruptions, forest fires, and the combustion of fossil fuels.

The atmosphere can only hold a finite amount of water. Once water vapor reaches a saturation point in the atmosphere, it condenses into clouds and water droplets, eventually precipitating back to the earth in the form of rain, sleet, hail, or snow. As temperatures increase, the atmosphere is able to hold more water before reaching the saturation point. Hence, water vapor concentrations generally increase with temperature. In other words, if temperatures remain constant, then increased evaporation or emissions of water vapor will have virtually no impact on atmospheric concentrations. Instead, more clouds will form and water will precipitate out of the atmosphere.

Water vapor is present in widely varying amounts around the globe depending on temperature, latitude, and altitude. Generally, the air above tropical regions contains more water vapor than the air above polar regions; the air at lower elevations contains more water vapor than the air at higher altitudes. [3] Estimating global average levels of water vapor has been difficult; in fact, the accuracy of such estimates is thought to be between 10% and 30%. [4] Despite our inability to accurately measure global levels, there is little doubt that water vapor is the most abundant and most important greenhouse gas in the atmosphere. [5] Moreover, there is significant evidence that water vapor levels have been increasing in recent decades. [6]

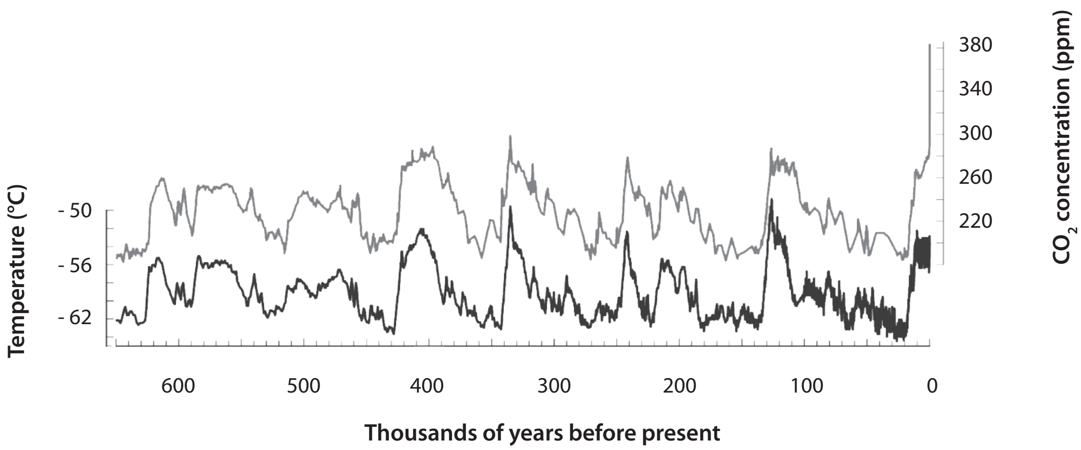
Methane makes up about 0.00017% of the atmosphere. An estimated 60% of methane emissions originate from fossil fuel production, rice cultivation, livestock, burning of biomass, and landfill emissions. [7] Natural sources include wetlands, permafrost, termites, oceans, wildfires, and soils. Atmospheric concentrations of methane have varied widely over time, but have remained relatively stable since 1998.

Carbon dioxide is the second most abundant greenhouse gas, though it only makes up approximately 0.038% of the total atmosphere. [8] Like water vapor, carbon and carbon dioxide are continuously cycling through the atmosphere, oceans, and land through both human and natural processes. Plants and other vegetation remove CO_2 from the atmosphere during photosynthesis. The carbon is then used to produce energy and biomass—the same biomass that is consumed by humans and other organisms. Plants, animals, and humans release CO_2 into the atmosphere through respiration and decay. Other natural sources of emissions include wildfires, volcanoes, and oceans, which also absorb significant amounts of CO_2 from the air. In total, natural sources of CO_2 make up roughly 96.2% of all CO_2 emissions into the air. The other 3.8% can be attributed directly to human activities, primarily deforestation and the burning of fossil fuels. [9]

Whether carbon dioxide emissions resulting from human actions have contributed to climate change is a matter of intense debate. The fact that the climate is always changing is often overlooked.

Earth's climate is driven by myriad factors, including solar activity, variations in the earth's orbit and rotation, and changes in ocean and wind currents. Current research is focused on the role of CO_2 and other greenhouse gases in climate change; however, scientists are also exploring other factors and, in doing so, are helping us to refine our understanding of the climate system.

Figure 2.1: Estimated temperature and carbon dioxide levels in Antarctica over the past 650,000 years



Source: Physics Institute, University of Bern, Switzerland. Adapted from Fretwell, Holly (2007). *The Sky's Not Falling: Why It's Okay to Chill about Global Warming*. World Ahead Media.

What does the evidence tell us?

It may appear that temperatures rise and fall in tandem with levels of carbon dioxide in the atmosphere. Look at Figure 2.1 above. The bottom line represents the estimated temperature in Antarctica over the past 650,000 years. The top line is the estimated level of carbon dioxide in the atmosphere over the same period.

The data were calculated by analyzing the composition of air bubbles trapped within ice cores. As snow falls and freezes year after year, air bubbles get trapped between layers. Scientists have drilled into the ice in Antarctic and Greenland and removed ice samples that date back hundreds of thousands of years. Some ice cores have measured nearly 3,050 meters deep.

Figure 2.1 illustrates two important points. First, it shows that climate changes over time. It has done so for hundreds of thousands of years and will continue to do so, regardless of human behavior.

Second, it shows that temperatures rose, on average, 800 years before carbon dioxide levels rose. Temperatures peaked and began to fall before carbon dioxide levels fell. [10] Thus, temperatures do not appear to have risen because of changes in atmospheric levels of CO_2. The relationship between these two variables demonstrates that correlation does not imply causation.

Figure 2.1 also shows that the climate on earth has been oscillating between glacial periods (ice ages) and interglacial periods of warming about every 100,000 years. The last ice age ended about 10,000 years ago, and we have been in a warming period since then.

References

1 Adam, David (2008, May 18). World Carbon Dioxide Levels Highest for 650,000 Years, Says US Report. *The Guardian*. <http://www.guardian.co.uk/environment/2008/may/13/carbonemissions.climatechange>.

2 National Oceanic and Atmospheric Administration (2008). *Carbon Dioxide, Methane Rise Sharply in 2007*. <http://www.noaanews.noaa.gov/stories2008/20080423_methane.html>.

Keenlyside, N.S., M. Latif1, J. Jungclaus, L. Kornblueh, and E. Roeckner (2008). Advancing Decadal-Scale Climate Prediction in the North Atlantic Sector. *Nature* 453 (May): 84–88.

3 Willett, K. M., N. P. Gillett, P. D. Jones, and P.W. Thorne (2007). Attribution of Observed Surface Humidity Changes to Human Influence. *Nature* 449: 710–12.

4 Chahine, Moustafa T. (1992). The Hydrological Cycle and Its Influence on Climate. *Nature* 359: 373–80.

5 Intergovernmental Panel on Climate Change [IPCC] (2007). *Climate Change 2007: The Physical Science Basis*. Intergovernmental Panel on Climate Change. <http://www.ipcc.ch/ipccreports/ar4-wg1.htm>.

6 IPCC (2007).

7 Intergovernmental Panel on Climate Change [IPCC] (2001). *Climate Change 2001: The Scientific Basis*. Contribution of Working Group I to the Third Assessment of the Intergovernmental Panel on Climate Change. Cambridge University Press.

4 National Oceanic and Atmospheric Administration (2008). *Trends in Atmospheric Carbon Dioxide - Mauna Loa*. <http://www.esrl.noaa.gov/gmd/ccgg/trends/>.

This CO_2 concentration (383.9 ppm) is the average of monthly mean CO_2 data for the period July 2007 to June 2008.

5 IPCC (2007).

6 Fischer, Hubertus, Martin Wahlen, Jesse Smith, Derek Mastroianna, and Bruce Deck (1999). Ice Core Records of Atmospheric Carbon Dioxide Around the Last Three Glacial Terminations. *Science* 283, 5408: 1712–14.

Lesson 2-A

Correlation and causation

Theme

Just because two events appear to occur simultaneously does not mean that one is linked to the other. In other words, correlation does not imply causation. In this lesson, students are taught how to use the scientific method to analyze the relationship between two variables.

Purpose

This lesson teaches students to view the natural world more objectively through the use of the scientific method.

Description

Students will analyze the relationship between two events and determine, by applying the scientific method, whether the occurrences are linked.

Procedure

1 Using *Visual 2.1: Correlation and causation*, discuss correlation as the relationship between two variables. When two events occur together, they are said to be correlated. Correlation does not prove that one event causes another. Testing and analysis are required to determine whether there is a causal relationship.

2 Hand out *Worksheet 2.1: Correlation is not causation*. Have the students work through this worksheet in pairs. *Worksheet 2.1 Answer Key* provides sample answers.

3 Have students present their best alternative hypotheses to the class.

4 Ask students whether they think there could be a causal relationship between the higher levels of CO_2 in the atmosphere and the massive floods in the Midwestern United States. It is important to remember that natural phenomena are complex, and no single hypothesis can explain them all.

5 Emphasize to students that correlation does not indicate causation. Point out that following the scientific method can help determine whether there is a causal link between two events.

Visual 2.1

Correlation and causation

Correlation

Correlation is a systematic pattern that may emerge when we observe two variables over time. It does not imply causation, however, because other unmeasured variables may be producing the result.

vs.

Causation means that there is a *direct* relationship between a change in one variable and a change in another variable. A causative relationship between two variables can only be established by either proving or disproving a hypothesis using the scientific method.

Causation

Worksheet 2.1
Correlation is not causation

Observation: Levels of carbon dioxide in the atmosphere have risen and the Midwestern United States has been hit by massive floods.

Hypothesis: Global warming, caused by higher levels of carbon dioxide in the atmosphere, has caused flooding in the Midwest.

Form three alternate hypotheses to explain the cause of the flooding in the Midwest.

1

2

3

Pick one of the three alternate hypotheses and briefly describe how you might test it. What data might be relevant?

If you were to test each of your alternative hypotheses and found evidence to support each, would this be sufficient to reject the hypothesis that global warming, caused by higher levels of carbon dioxide in the atmosphere, caused flooding in the Midwest?

Worksheet 2.1 Answer Key

Correlation is not causation

Observation: Levels of carbon dioxide in the atmosphere have risen and the Midwestern United States has been hit by massive floods.

Hypothesis: Global warming, caused by higher levels of carbon dioxide in the atmosphere, has caused flooding in the Midwest.

Form three alternate hypotheses to explain the cause of the flooding in the Midwest.

1. *Extensive land development has reduced the acreage of floodplains and wetlands that otherwise would have absorbed the heavy rains.*
2. *The El Nina effect, the result of cooler-than-normal ocean temperatures, increased snowfall. The snowmelt in spring subsequently swelled rivers.*
3. *A wet spring delayed farm plantings, which meant that there were fewer fields of crops to catch run-off.*

Pick one of the three alternate hypotheses and briefly describe how you might test it. What data might be relevant?

The El Nina effect, the result of cooler-than-normal ocean temperatures, increased snowfall. The snowmelt in spring subsequently swelled rivers.

Testing the El Nina effect would require data on ocean temperatures, as well as measurements of snowfall for various years. Data on the rise of rivers also would be needed to determine the impact on flooding.

If you were to test each of your alternative hypotheses and found evidence to support each, would this be sufficient to reject the hypothesis that global warming, caused by higher levels of carbon dioxide in the atmosphere, caused flooding in the Midwest?

No. Support for one hypothesis does not mean that another hypothesis is incorrect. More than one factor may be at play. However, the existence of flooding during periods when carbon dioxide levels were lower and temperatures were cooler would cast doubt on the global warming hypothesis.

Lesson 2-B

Correlation and causation in climate change

Theme

Students will learn about the atmosphere and the effect greenhouse gases have on climate. They will analyze the correlation between atmospheric levels of CO_2 and temperatures.

Purpose

The lesson teaches students to be cautious when interpreting data and not to assume that two events that occur simultaneously are causally related.

Description

Using the tools of scientific investigation, students will analyze the relationship between CO_2 emissions and global temperature change.

Procedure

1 Have students complete *Student Reading 2: Drivers of climate change*.

2 Review the concepts in *Visual 2.2: Atmosphere*, *Visual 2.3:Greenhouse gases*, *Visual 2.4: Greenhouse gases in the atmosphere*, and *Visual 2.5: Human CO_2 emissions*.

3 Working in small groups, have students complete *Worksheet 2.2: CO_2 and temperature correlation*.

4 Explore students' ideas about the relationship between temperature and atmospheric levels of CO_2. Have them share some of their conclusions.

5 Display *Visual 2.6: Climate variation* and talk about the correlation between atmospheric levels of CO_2 and temperature.

- Ask students if they think there is a causal relationship between CO_2 and temperature and, if so, ask them how they reached that conclusion.
- Because of the scale of the graph (650,000 years), it is difficult to see enough detail to determine whether one event precedes the other. Point out to students that changes in CO_2 levels occur about 800 years, on average, *after* changes in temperature. This was determined by analyzing the data that was used to construct the graph.

6 The timing of changes in CO_2 levels does not mean that higher temperatures cause a rise in atmospheric levels of carbon dioxide. There are many other factors affecting changes in both CO_2 levels and temperature. Provide examples to emphasize that correlation does not imply causation. Differentiate between:

- Events that may be coincident in correlation because of other factors causing both events, e.g., *ice cream sales and shark attacks increase during the summer*;
- Events that have some causality, e.g., *cooler temperatures and shorter days cause plants to undergo changes that cause leaves to change color*; and,
- Events that may have reverse causality (each event has an impact on the other), e.g, *rising temperatures increase water vapor and an increase in water vapor can cause temperatures to rise*.

Student Reading 2

Drivers of climate change

Atmosphere

The atmosphere is the blanket of air that surrounds earth and reaches upwards of 500 km into space (though about 99% of its mass exists within 31 km of earth's surface). This air is composed of multiple layers, each with varying temperatures, gas compositions, and densities. The atmosphere protects us from the sun's ultraviolet radiation, insulates us from extreme heat and cold, and plays a critical role in the cycling of carbon, water, and other components that are vital to life.

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Greenhouse gases

Although they comprise less than 5% of the atmosphere (when water vapor is included), greenhouse gases are critical to life on earth. Water vapor, CO_2, methane, ozone, nitrous oxide, and some human-made compounds affect surface and atmospheric temperatures by increasing the amount of heat energy that is captured.

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The term "greenhouse effect" is a misnomer, however. The radiation of energy in the atmosphere is quite different from the warming dynamics in an actual greenhouse. In a greenhouse, heat becomes trapped because the glass restricts an exchange of air between the inside and the outside of the structure. The interaction between the sun's heat and greenhouse gases could be more accurately described as the "atmosphere" effect. In the atmosphere, greenhouse gases facilitate the mixing of air through the exchange of energy between space, the atmosphere, and earth's surface.

Water vapor is the most common greenhouse gas. Water vapor condenses into clouds, which can both warm and cool the planet. Clouds warm the planet by trapping heat near earth's surface. Alternatively, clouds cool the planet by reflecting the sun's radiation back into space. A multitude of other environmental factors, including wind and topography, also affect the impact of clouds on temperatures.

The primary source of water vapor in the atmosphere is evaporation from surface waters, including oceans, lakes, rivers, ponds, and even puddles and dew. Other sources include volcanic eruptions, forest fires, and the combustion of fossil fuels.

The atmosphere can only hold a finite amount of water. Once water vapor reaches a saturation point in the atmosphere, it condenses into clouds and water droplets, eventually precipitating back to the earth in the form of rain, sleet, hail, or snow. As temperatures increase, the atmosphere is able to hold more water before reaching the saturation point. Hence, water vapor concentrations generally increase with temperature. In other words, if temperatures remain constant, then increased evaporation or emissions of water vapor will have virtually no impact on atmospheric concentrations. Instead, more clouds will form and water will precipitate out of the atmosphere.

Water vapor is present in widely varying amounts around the globe depending on temperature, latitude, and altitude. Generally, the air above tropical regions contains more water vapor than the air above polar regions; the air at lower elevations contains more water vapor than the air at higher altitudes. [1] Estimating global average levels of water vapor has been difficult; in fact, the accuracy of such estimates is thought to be between 10% and 30%. [2] Despite our inability to accurately measure global levels, there is little doubt that water vapor is the most abundant and most important greenhouse gas in the atmosphere. [3] Moreover, there is significant evidence that water vapor levels have been increasing in recent decades. [4]

Methane makes up about 0.00017% of the atmosphere. An estimated 60% of methane emissions originate from fossil fuel production, rice cultivation, livestock, burning of biomass, and landfill emissions. [5] Natural sources include wetlands, permafrost, termites, oceans, wildfires, and soils. Atmospheric concentrations of methane have varied widely over time, but have remained relatively stable since 1998.

Carbon dioxide is the second most abundant greenhouse gas, though it only makes up approximately 0.038% of the total atmosphere. [6] Like water vapor, carbon and carbon dioxide are continuously cycling through the atmosphere, oceans, and land through both human and natural processes. Plants and other vegetation remove CO_2 from the atmosphere during photosynthesis. The carbon is then used to produce energy and biomass—the same biomass that is consumed by humans and other organisms. Plants, animals, and humans release CO_2 into the atmosphere through respiration and decay. Other natural sources of emissions include wildfires, volcanoes, and oceans, which also absorb significant amounts of CO_2 from the air. In total, natural sources of CO_2 make up roughly 96.2% of all CO_2 emissions into the air. The other 3.8% can be attributed directly to human activities, primarily deforestation and the burning of fossil fuels. [7]

Whether carbon dioxide emissions resulting from human actions have contributed to climate change is a matter of intense debate. The fact that the climate is always changing is often overlooked.

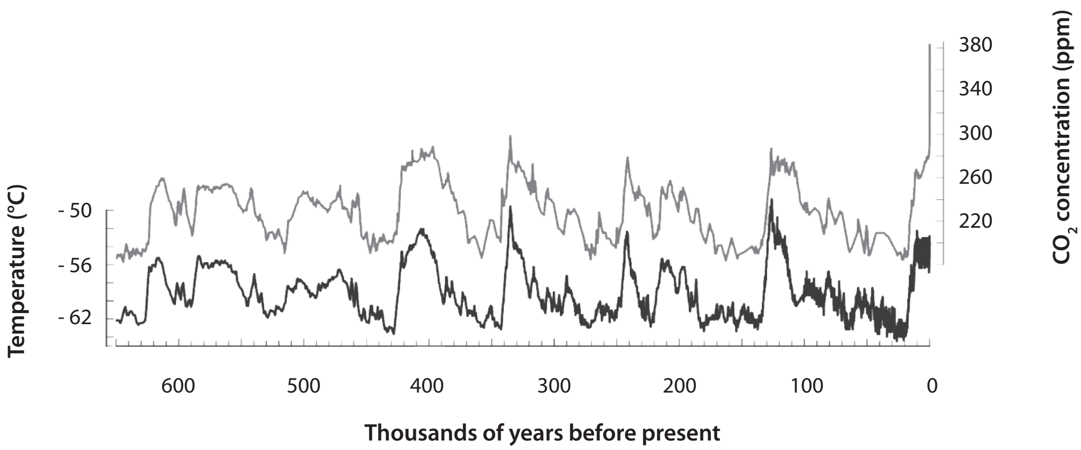
Earth's climate is driven by myriad factors, including solar activity, variations in the earth's orbit and rotation, and changes in ocean and wind currents. Current research is focused on the role of CO_2 and other greenhouse gases in climate change; however, scientists are also exploring other factors and, in doing so, are helping us to refine our understanding of the climate system.

What does the evidence tell us?

It may appear that temperatures rise and fall in tandem with levels of carbon dioxide in the atmosphere. Look at Figure 2.1. The bottom line represents the estimated temperature in Antarctica over the past 650,000 years. The top line is the estimated level of carbon dioxide in the atmosphere over the same period.

The data were calculated by analyzing the composition of air bubbles trapped within ice cores. As snow falls and freezes year after year, air bubbles get trapped between layers. Scientists have drilled into the ice in Antarctica and Green-

Figure 2.1: Estimated temperature and carbon dioxide levels in Antarctica over the past 650,000 years



Source: Physics Institute, University of Bern, Switzerland. Adapted from Fretwell, Holly (2007). *The Sky's Not Falling: Why It's Okay to Chill about Global Warming*. World Ahead Media.

land and removed ice samples that date back hundreds of thousands of years. Some ice cores have measured nearly 3,050 meters deep.

Figure 2.1 illustrates two important points. First, it shows that climate changes over time. It has done so for hundreds of thousands of years and will continue to do so, regardless of human behavior.

Second, it shows that temperatures rose, on average, 800 years before carbon dioxide levels rose. Temperatures peaked and began to fall before carbon dioxide levels fell. [8] Thus, temperatures do not appear to have risen because of changes in atmospheric levels of CO_2. The relationship between these two variables demonstrates that correlation does not imply causation.

Figure 2.1 also shows that the climate on earth has been oscillating between glacial periods (ice ages) and interglacial periods of warming about every 100,000 years. The last ice age ended about 10,000 years ago, and we have been in a warming period since then.

References

1 Willett, K. M., N. P. Gillett, P. D. Jones, and P.W. Thorne (2007). Attribution of Observed Surface Humidity Changes to Human Influence. *Nature* 449: 710–12.

2 Chahine, Moustafa T. (1992). The Hydrological Cycle and Its Influence on Climate. *Nature* 359: 373–80.

3 Intergovernmental Panel on Climate Change [IPCC] (2007). *Climate Change 2007: The Physical Science Basis*. Intergovernmental Panel on Climate Change. <http://www.ipcc.ch/ipccreports/ar4-wg1.htm>.

4 IPCC (2007).

5 Intergovernmental Panel on Climate Change [IPCC] (2001). *Climate Change 2001: The Scientific Basis*. Contribution of Working Group I to the Third Assessment of the Intergovernmental Panel on Climate Change. Cambridge University Press.

6 National Oceanic and Atmospheric Administration (2008). *Trends in Atmospheric Carbon Dioxide - Mauna Loa*. <http://www.esrl.noaa.gov/gmd/ccgg/trends/>.

This CO_2 concentration (383.9 ppm) is the average of monthly mean CO_2 data for the period July 2007 to June 2008.

7 IPCC (2007).

8 Fischer, Hubertus, Martin Wahlen, Jesse Smith, Derek Mastroianna, and Bruce Deck (1999). Ice Core Records of Atmospheric Carbon Dioxide Around the Last Three Glacial Terminations. *Science* 283, 5408: 1712–14.

Visual 2.2

Atmosphere

What is the

Atmosphere?

- Protects us from ultraviolet radiation and meteors
- Important part of the hydrologic and carbon cycles
- Insulates the planet from extreme temperatures

Components of the atmosphere

The atmosphere is comprised of water vapor and various natural and human-made gases. The dry atmosphere (what would remain if we could take all of the water vapor out of the air and remove the clouds) would consist of the following gases:

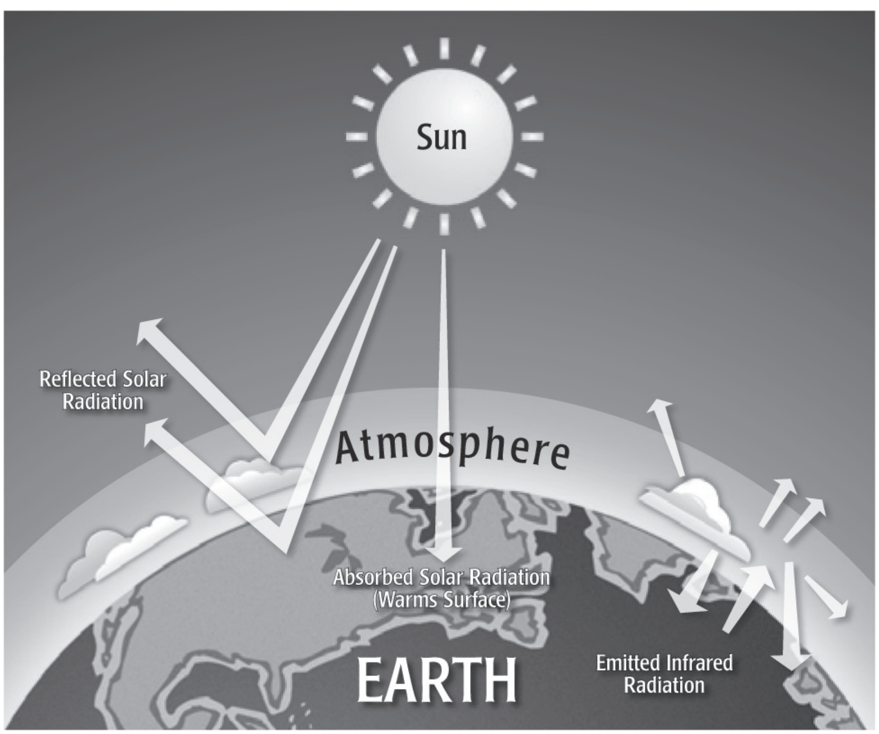
- 78.1% nitrogen
- 20.9% oxygen
- 0.9% argon
- 0.039% greenhouse gases (primarily carbon dioxide)

Visual 2.3
Greenhouse gases

Greenhouse gases are *critical* to life on earth

- They reduce the amount of energy and heat that escape into space, making the planet habitable.
- Atmospheric CO_2 and water vapor are part of the global carbon and hydrologic cycles.

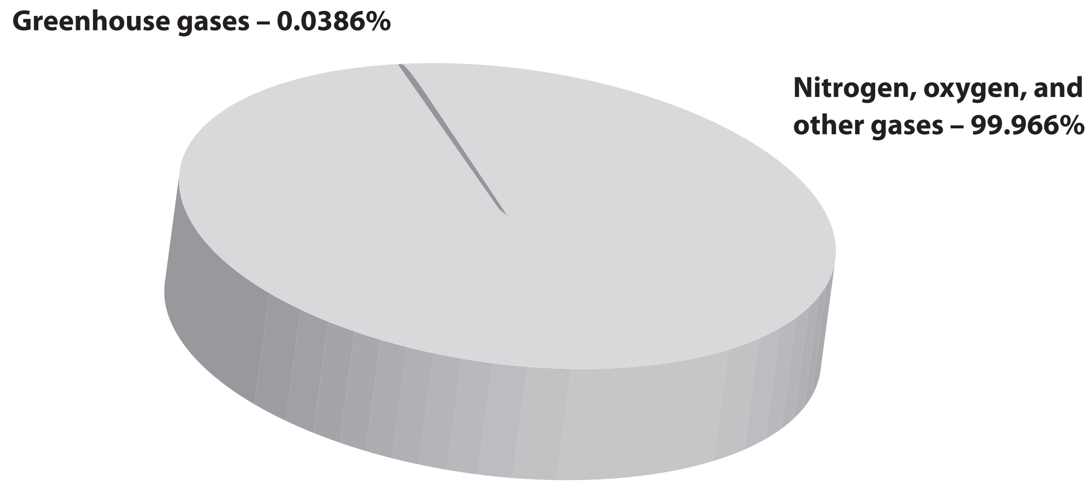
A simplified representation of the greenhouse effect



Source: Schneider, Nicholas (2008). *Understanding Climate Change*. Fraser Institute.

Visual 2.4
Greenhouse gases in the atmosphere

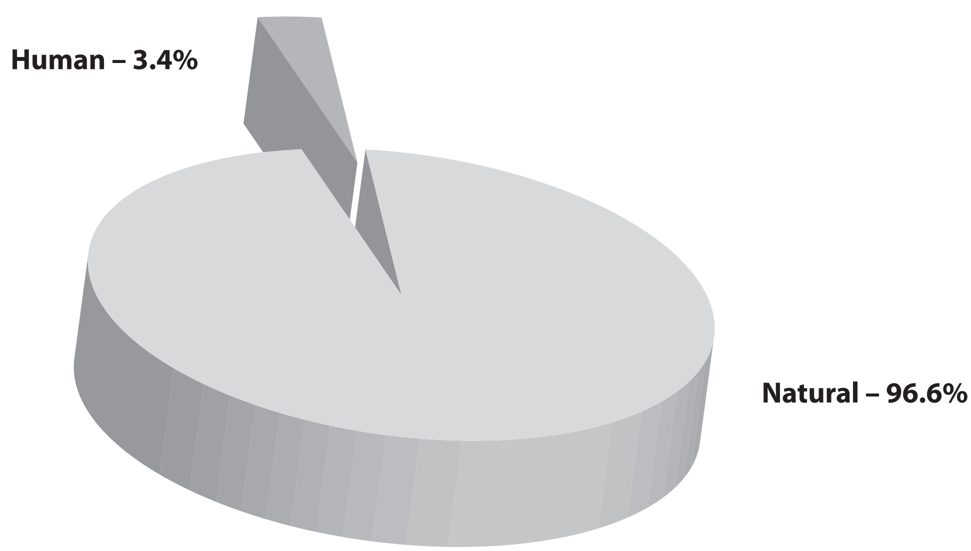
Greenhouse gases make up less than 1% of the dry atmosphere



Source: Blasing, T.J. (2008). *Recent Greenhouse Gas Concentrations*. Carbon Dioxide Information Analysis Center. <http://cdiac.esd.ornl.gov/pns/current_ghg.html>. Updated December 2008.

Visual 2.5
Human CO_2 emissions

Human emissions are a small part of total CO_2 emissions



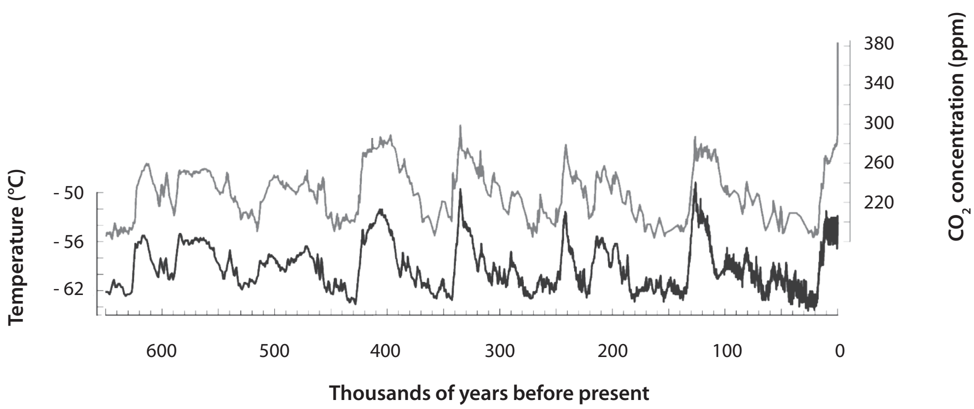
Source: Intergovernmental Panel on Climate Change [IPCC] (2007). *Climate Change 2007: The Physical Science Basis*. Intergovernmental Panel on Climate Change. <http://www.ipcc.ch/ipccreports/ar4-wg1.htm>.

Worksheet 2.2

CO_2 and temperature correlation

Looking at the graph below, what can you conclude about the relationship between atmospheric levels of carbon dioxide and temperature?

Estimated temperature and carbon dioxide levels in Antarctica over the past 650,000 years



Source: Physics Institute, University of Bern, Switzerland. Adapted from Fretwell, Holly (2007). *The Sky's Not Falling: Why It's Okay to Chill about Global Warming*. World Ahead Media.

Form two hypotheses that may explain the correlation between CO_2 and temperature.

1

2

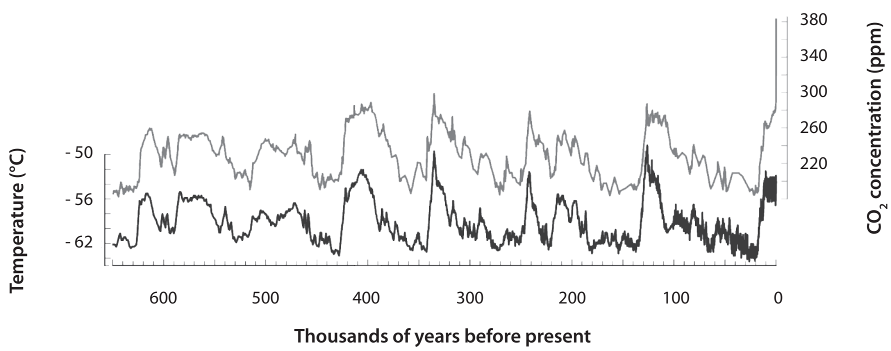
Worksheet 2.2 Answer Key

CO_2 and temperature correlation

Looking at the graph below, what can you conclude about the relationship between atmospheric levels of carbon dioxide and temperature?

There is a simple correlation between CO_2 levels and temperature in that they tend to increase and decrease in a similar pattern. In the natural world, many observable events are correlated. There are times when one event may directly or partially cause the other, in which case correlation does mean causation. Other times, the events are caused by external variables or they may be purely coincidental. The graph shows a correlation but does not provide enough evidence to determine causation. There is little doubt that humans have caused the increase in CO_2 levels in the last 100 years; however, it is unclear what effect, if any, this increase has had on temperatures.

Estimated temperature and carbon dioxide levels in Antarctica over the past 650,000 years



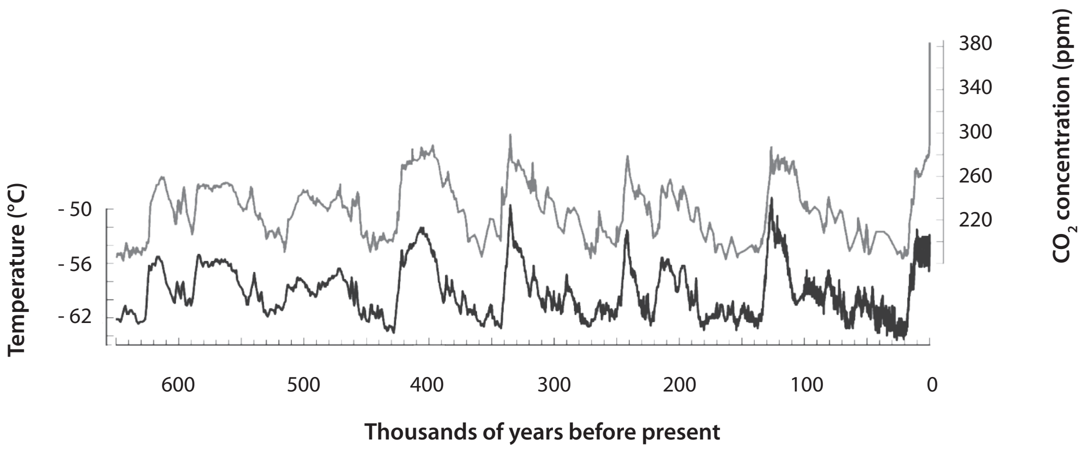
Form two hypotheses that may explain the correlation between CO_2 and temperature.

1. *Changes in atmospheric CO_2 levels cause changes in temperature. Rising CO_2 levels cause global temperatures to rise because of the greenhouse effect. Greenhouse gases, such as CO_2, can cause an increase in atmospheric temperatures by increasing the heat energy that is captured.*
2. *Changes in temperature cause changes in the level of atmospheric CO_2. As global temperatures rise, ocean temperatures also rise. Warmer oceans cannot retain as much CO_2, and thus emit more CO_2 into the atmosphere.*
3. *A third variable is affecting the changes in both CO_2 levels and temperature. Some external factor, such as changes in solar radiation (which may change plant distribution) or changes in photosynthesis (which can affect CO_2 uptake and emissions), is causing global temperatures, as well as atmospheric levels of CO_2, to change.*

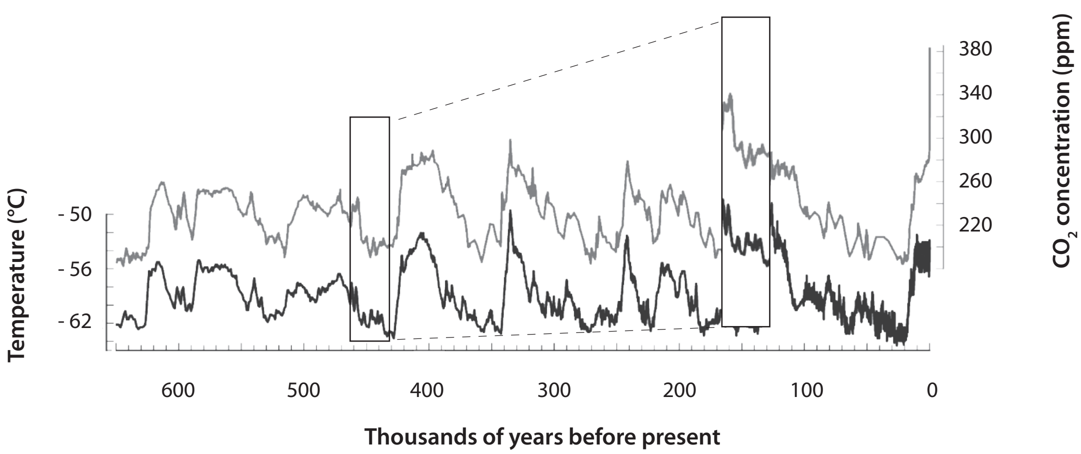
Visual 2.6

Climate variation

Temperatures on earth have increased and decreased throughout history



But CO_2 *follows* temperature change



Correlation is not causation!

Source: Physics Institute, University of Bern, Switzerland. Adapted from Fretwell, Holly (2007). *The Sky's Not Falling: Why It's Okay to Chill about Global Warming*. World Ahead Media.

3 The Carbon Cycle

Introduction

Carbon, the fourth most abundant element in our galaxy, is essential to life on earth. Virtually everything contains some form of carbon. Plants use carbon dioxide to produce energy for growth, and the human body is about 20% carbon by weight.

Carbon can be measured in various forms, including carbon dioxide (CO_2), methane (CH_4), and calcium carbonate ($CaCO_3$), which is found in rocks and aquatic shells. We can also measure organic carbon, which is found in organisms.

The carbon cycle is the movement of carbon in its different forms among various "pools." These pools include the atmosphere, the oceans, the terrestrial biosphere (vegetation and soils), and the geosphere (mineral soils, sediments, rock layers of earth's crust, and fossil fuels).

The total amount of carbon on earth and in the atmosphere is *constant*. However, the amount of carbon in the various pools and the time it takes for carbon to move from one pool to another varies widely.

Carbon is exchanged daily between the atmosphere and the biosphere, for example, when plants absorb CO_2 for photosynthesis. But it can take millions of years for carbon to move from the biosphere into the geosphere, a transfer that occurs during the formation of fossil fuels.

Pools that accumulate more carbon than they emit are referred to as carbon "sinks." For example, the oceans, the biosphere, and the atmosphere are carbon sinks because the total amount of carbon in each increases annually.

It has been hypothesized that increased levels of carbon in the atmosphere may be triggering warmer temperatures. To better understand why the atmosphere accumulates carbon, scientists focus on the exchanges or "flows" of carbon between the atmosphere and other pools.

The oceans both absorb and emit the largest amounts of carbon on an annual basis. The oceans currently store an estimated 39 trillion metric tons of carbon. Each year, they release 90.6 billion metric tons of carbon while absorbing 92.2 billion metric tons. Thus, the net "sink" of the oceans is about 1.6 billion metric tons annually. [1] (For a sense of scale, Canada emits roughly 177 million metric tons of carbon annually from the combustion of fossil fuels.) [2]

The terrestrial biosphere is also a carbon sink. Forests and plants absorb carbon dioxide from the air during photosynthesis. Along with water and sunlight, plants convert CO_2 into sugars for energy and the production of leaves, bark, roots, and other forms of growth. Over time, carbon accumulates in plant tissues and soils.

Plants, trees, and soils are also sources of carbon emissions. Like humans and animals, plants release carbon (CO_2) into the atmosphere when they break down sugars for energy. Carbon is also released during plant decomposition. On average, the terrestrial biosphere (vegetation, soil, and detritus) absorbs 120 billion metric tons of carbon and emits 119.6 billion metric tons annually. [3]

Other important sources of carbon include the combustion of fossil fuels, volcanic activity, and wildfires. Land use changes, such as timber harvests and landscape clearing, are responsible for the emission of about 1.6 billion metric tons of carbon each year. The burning of fossil fuels creates another 6.4 billion metric tons of carbon emissions annually. Overall, human activities are responsible for about 1% of total carbon emissions into the atmosphere each year. [4]

The amount of carbon that remains in the atmosphere is primarily a function of total emissions less the amount absorbed by other pools. When the amount of carbon emitted into the atmosphere is greater than the amount absorbed, carbon levels in the atmosphere increase.

However, recent studies have found that these numbers do not add up as one would expect. The sum of all of the carbon emitted into the atmosphere minus the amount absorbed by the various pools is *not* equal to the amount of carbon that remains in the atmosphere; the amount of carbon remaining in the atmosphere is less than the difference between emissions and absorptions. Recent studies estimate that an amount equal to about 33% of human emissions of carbon is unaccounted for. [5]

Despite decades of research, our understanding of the global carbon cycle is incomplete. It is particularly challenging for scientists to quantify the amount of carbon exchanged between the various pools over time. Extensive use of computer modeling, satellite imagery, and ground measurements have improved our understanding, but precise measurements of carbon flows remain elusive.

This lack of understanding affects climate models and forecasts, resulting in inaccurate and unreliable predictions. Despite their unreliability, these same analyses and models are being used by governments to make policy decisions.

The limitations of climate models

The most complex climate models attempt to simulate various climate components such as the atmosphere, oceans, land, and ice. At the moment, climate models are the most comprehensive tool available for studying and simulating the interaction of diverse climate components and processes.

Though they are useful, climate models have important limitations. Even the most complex models cannot calculate every process in the climate, including many that are known to play important roles. Consequently, climate modelers must find ways to simplify and approximate many real-world physical relationships.

Evaluating the accuracy of climate models

Weather forecasts can be tested against actual observations to see if the model was accurate, but climate models often make predictions that span decades or longer, making it more difficult to confirm their accuracy. As a result, climate models are often tested by observing how closely they can simulate known past and present climate changes. The Intergovernmental Panel on Climate Change (IPCC) notes that since its last report in 2001, model performance has improved overall, but errors and biases remain. [6]

Temperature

Models can only simulate annual average temperatures in most regions of the world to within approximately 3° C of observations. [7] Averaging simulations across all models produces slightly better results, but errors in simulations involving polar regions are larger.

In addition, most models predict that increasing the atmospheric concentration of greenhouse gases will result in a strong warming in the troposphere around the tropics, and that the warming there will be greater than at the surface. However, since 1979, all but one weather balloon and satellite record have shown *less* warming in the tropical troposphere than at the surface. [8]

Precipitation

Models can simulate some large precipitation patterns on a regional scale, but individual models show substantial biases, especially in tropical regions.

Sea ice

When averaged across models, the simulation of observed sea ice coverage in the polar regions is reasonably similar to observations. However, the range of estimates among models exceeds 50% of the observed mean, and projections into the future remain uncertain. [9] Evaluations of the accuracy of the models are also limited by a shortage of real-world data for comparison.

Climate sensitivity

"Climate sensitivity" is the expected increase in global average temperature if the amount of carbon dioxide in the atmosphere were to double. Climate sensitivity is mostly influenced by feedback processes in the climate, which are difficult to estimate. Without the feedback process, a doubling of greenhouse gases would only raise average global temperatures in a climate model by about 1° C. [10] But because of the expected positive feedback processes, mainly from water vapor, most models project that global average temperatures would increase between 2° C and 4.5° C, with approximately 3° C being the most common estimate. [11]

Despite much research, the range of climate sensitivity estimates has not changed much over the past few decades. A major source of uncertainty is the difficulty of predicting the response of clouds to temperature increases.

Summary

Climate models are important for understanding and predicting possible climate changes, but the challenges of representing small-scale climate and weather processes, as well as the ongoing discrepancies between projected climate conditions and observations, are important limitations. Since models are used not only for making projections, but also for analyzing human influence on the current climate, it is important to understand their inherent uncertainties.

References

1 Intergovernmental Panel on Climate Change [IPCC] (2007). *Climate Change 2007: The Physical Science Basis*. Intergovernmental Panel on Climate Change. <http://www.ipcc.ch/ipccreports/ar4-wg1.htm>.

2 Marland, G., T.A. Boden, and R.J. Andres (2008). *Global, Regional, and National Fossil-Fuel CO_2 Emissions*. Carbon Dioxide Information Analysis Center. <http://cdiac.ornl.gov/trends/emis/overview.html>.

3 IPCC (2007).

4 IPCC (2007).

5 Houghton, J. T., G. J. Jenkins, and J.J. Ephraums (eds.) (1990). *Climate Change: The IPCC Scientific Assessment*. Cambridge University Press.

6 IPCC (2007).

7 IPCC (2007).

8 IPCC (2007).

9 IPCC (2007).

10 Rahmstorf, Stefan (2008). Anthropogenic Climate Change: Revisiting the Facts. In E. Zedillo, *Global Warming: Looking Beyond Kyoto* (Brookings Institution): 34–53. <http://www.pik-potsdam.de/~stefan/Publications/Book_chapters/Rahmstorf_Zedillo_2008.pdf>.

11 Rahmstorf (2008).

Lesson 3-A
The missing sink

Theme

Nearly everything on earth contains at least some carbon. Although there is a fixed amount of carbon in the earth and atmosphere, it is continuously cycled from one pool to another. Our ability to track flows of carbon between the various pools is limited by the complexity of the carbon cycle.

Purpose

To demonstrate that our lack of understanding concerning the carbon cycle diminishes the reliability of carbon tracking and climate modeling.

Description

Students will gain a basic understanding of carbon sources and exchanges. Using estimates of carbon stocks and flows, students will analyze data regarding various stocks and flows, and learn about the "missing sink" of carbon.

Procedure

1 Open a carbonated beverage in class. Ask students if they know what causes the bubbles.

> *Carbonation is the result of carbon dioxide dissolved in liquid under pressure. When the pressure is reduced (by opening the can or bottle), the carbon dioxide can no longer remain dissolved in the liquid and is released, creating bubbles of gas (CO_2).*

2 Show *Visual 3.1: The global carbon cycle* to demonstrate that carbon is everywhere and is always cycling from pool to pool.

3 Using *Visual 3.2: Forms of carbon*, explain that there are three forms of carbon: carbon dioxide (CO_2), methane (CH_4), and calcium carbonate ($CaCO_3$).

4 *Visual 3.3: The carbon cycle* describes the various attributes of the cycle. "Flows" refer to the movement of carbon between various pools. Some flows (also called "fluxes") are slow; for example, when carbon is held in the lower layers of the ocean and used in the formation of fossil fuels. Other flows are fast; for example, when carbon is exchanged between plants or animals and the atmosphere. Carbon is continuously moving between the oceans and the atmosphere. Explain that "sinks" are pools that absorb more carbon than they emit.

5 Refer again to *Visual 3.1: The global carbon cycle*. Review the different pools, sinks, and flows. Both carbon pools and flows are measured in billion metric tons (gigatons) of carbon. The arrows show how carbon flows between pools.

6 Hand out *Worksheet 3.1: Understanding the carbon cycle*. Review the description of the exercise using *Visual 3.4: Global carbon stocks and flows*. Have students complete the exercise in small groups.

7 Discuss the answers to each question. Explain the concept of the "missing sink." Tell students that the sum of all of the carbon emitted into the atmosphere minus the carbon absorbed by the various pools is not equal to the amount of carbon that remains in the atmosphere. The amount of carbon remaining in the atmosphere is *less* than the difference between emissions and absorptions. This difference is the missing sink. Emphasize that the missing sink is a scientific unknown, and is not a math or data error.

8 What does the missing sink reveal about current models of climate change?

> *Climate models are important for understanding and predicting possible climate changes, but they have a number of limitations. Scientists have used climate models to estimate the amount of carbon emitted into the atmosphere and the changing carbon levels in the atmosphere, oceans, and biosphere. However, the missing sink is still debated as our knowledge of it is uncertain.*

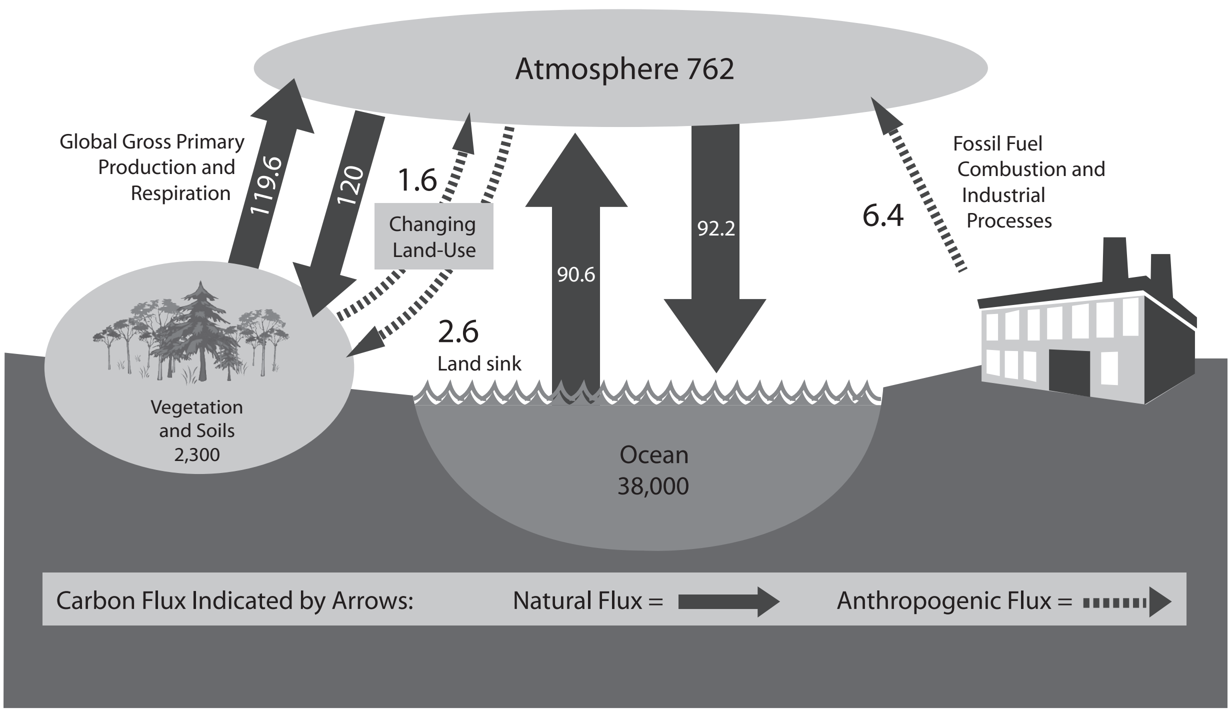
Final Thought

Remind students that science is a process of learning. The natural world may seem hopelessly complex, but that same complexity is what inspires scientists to develop and test new hypotheses. Each hypothesis advances our understanding of the world. Science is neither flawless nor absolute; it is simply the best knowledge we have at a given time. What we think we know today is susceptible to change in the future.

Visual 3.1

The global carbon cycle

The global carbon cycle



*Carbon fluxes are measured in billions of metric tons of carbon (GtC).
Source: Adapted from Intergovernmental Panel on Climate Change [IPCC] (2007). *Climate Change 2007: The Physical Science Basis*. Intergovernmental Panel on Climate Change. <http://www.ipcc.ch/ipccreports/ar4-wg1.htm>.

Visual 3.2
Forms of carbon

All carbon falls under 2 categories

Organic carbon

Found in living and dead organisms.

Hydrocarbons

Organic compounds made up of hydrogen and carbon, such as coal, natural gas, oil, and various fuels.

There are 3 forms of carbon

Carbon dioxide CO_2

Released through fossil fuel combustion, cement production, volcanic activity, respiration, decay of organic material, weathering, and certain changes in land use.

Absorbed by oceans and plants.

Methane CH_4

Mostly anthropogenic; sources include fossil fuel production, livestock, and waste management.

Calcium carbonate $CaCO_3$

Compounds made up of hydrogen and carbon, including coal, natural gas, and various fuels.

Visual 3.3

The carbon cycle

The carbon cycle

Carbon pools

Carbon reservoirs

- The atmosphere
- The oceans
- Terrestrial biosphere: living and dead vegetation and organic soils
- The geosphere: mineral soils, sediments, and rock layers of earth's crust; includes fossil fuels

Carbon sinks

Carbon reservoirs that absorb more than they emit

- Oceans, terrestrial biosphere, and the atmosphere

Carbon flows

The movement of carbon between various pools

Visual 3.4
Global carbon stocks and flows

Carbon stocks (storage) in billions of metric tons of carbon (GtC)

Carbonate rocks	65,000,000
Fossil fuels	3,700
Soils	~1,600
Vegetation and detritus	~700
Oceans	38,000
Atmosphere	762

Carbon flows (flux) in GtC

	Emissions	Absorption	Net
Oceans	90.6	92.2	- 1.6
Vegetation, soil, and detritus	119.6	120	- 0.4
Weathering		0.2	- 0.2
Fossil fuels	6.4		6.4
Land use changes	1.6		1.6
Missing sink		2.6	- 2.6
Net flux to the atmosphere			3.2

Sources: Oelkers, E. H., and D. R. Cole (2008). Carbon Dioxide Sequestration: A Solution to a Global Problem. *Elements* 4: 305–10.
Intergovernmental Panel on Climate Change [IPCC] (2007). *Climate Change 2007: The Physical Science Basis*. Intergovernmental Panel on Climate Change. <http://www.ipcc.ch/ipccreports/ar4-wg1.htm>.

Worksheet 3.1

Understanding the carbon cycle

Different types of carbon move through the earth and the atmosphere; some move rapidly, others very slowly. The total amount of carbon remains constant.

Inorganic carbon, such as bicarbonate and carbonate, is found in rocks and shells. Organic carbon is found in plants and animals. Carbon gases include carbon dioxide (CO_2), methane (CH_4), and carbon monoxide (CO).

The carbon cycle is the movement of carbon from one form to another. Carbon emissions are absorbed by the atmosphere, the oceans, and the biosphere.

Using the tables below, answer the questions on the following page. You may need a calculator for this exercise.

Carbon stocks (storage) in billions of metric tons of carbon (GtC)

Carbonate rocks	65,000,000
Fossil fuels	3,700
Soils	~1,600
Vegetation and detritus	~700
Oceans	38,000
Atmosphere	762

Carbon flows (flux) in GtC

	Emissions	Absorption	Net
Oceans	90.6	92.2	- 1.6
Land	119.6	120	- 0.4
Weathering		0.2	- 0.2
Fossil fuels	6.4		6.4
Land use changes	1.6		1.6
Missing sink		2.6	- 2.6
Net flux to the atmosphere			3.2

Sources: Oelkers, E. H., and D. R. Cole (2008). Carbon Dioxide Sequestration: A Solution to a Global Problem. *Elements* 4: 305–10.
Intergovernmental Panel on Climate Change [IPCC] (2007). *Climate Change 2007: The Physical Science Basis*. Intergovernmental Panel on Climate Change. <http://www.ipcc.ch/ipccreports/ar4-wg1.htm>.

Worksheet 3.1

Understanding the carbon cycle

1 Which of the carbon stocks is the largest?

2 What percentage of carbon stocks is held in oceans (approximately)?

3 Which of the carbon emissions sources is the largest? Which is the smallest?

4 Which carbon flow has the greatest net emissions? The greatest net absorption?

5 Which of the carbon flows are caused by human activity?

6 What is the sum of the net emissions of carbon that are caused by human activity?

7 What is the "missing sink"?

Worksheet 3.1 Answer Key

Understanding the carbon cycle

1 Which of the carbon stocks is the largest?

Carbonate rocks store 65,000,000 billion metric tons of carbon.

2 What percentage of carbon stocks is held in oceans (approximately)?

0.06 %. Total carbon storage is approximately 65,044,762 billion metric tons.

3 Which of the carbon emissions sources is the largest? Which is the smallest?

Largest: Land. Smallest: Land use changes.

4 Which carbon flow has the greatest net emissions? The greatest net absorption?

Greatest net emissions: Fossil fuels. Greatest net absorption: Missing sink.

5 Which of the carbon flows are caused by human activity?

Fossil fuels and land use changes.

6 What is the sum of the net emissions of carbon that are caused by human activity?

8 billion metric tons. (Fossil fuels, 6.4, plus land use changes, 1.6, equals 8 billion metric tons.)

7 What is the "missing sink"?

Carbon that has been released into the atmosphere is absorbed by the oceans, the biosphere, and the geosphere. However, the sum of all of the carbon emitted into the atmosphere minus the carbon absorbed by the various pools is not equal to the amount of carbon that remains in the atmosphere. The amount of carbon remaining in the atmosphere is less than the difference between emissions and absorptions. Recent studies estimate that an amount equal to about 33% of human emissions of carbon is unaccounted for.

Lesson 3-B

Weather forecasting

Theme

As much as scientists do know about weather and climate, weather forecasting still involves a lot of uncertainty and guesswork. Meteorologists analyze past and current atmospheric conditions to try to predict future weather. Using satellite data and computer models, they forecast future conditions. Changing forecasts and the proportion of inaccurate predictions are evidence that weather forecasting is imprecise.

Purpose

This lesson will demonstrate the challenges faced by meteorologists and climatologists when modeling and forecasting local weather and global climate conditions.

Description

Students will track weather forecasts for one week and examine the reliability of those forecasts. Measuring the rate of weather forecast errors can help students put complex climate change computer models in context with relatively simple weather prediction models. Compared to weather forecast models, climate change models, which are much more complex, have a much higher likelihood of error because far more variables are involved.

Procedure

1 Have students read *Student Reading 3: The limitations of climate models*. This will help students understand the difficulties surrounding climate modeling.

2 Hand out *Worksheet 3.2: Weather forecasts*. Using the worksheet, students will track weather forecasts for one week and examine the reliability of one-day predictions, three-day predictions, and weekly predictions. As the week progresses, students will compare the actual weather on each day to the forecast at the beginning of the week.

3 At the end of the week, have a class discussion about the accuracy of the weather forecasts. Have students compare forecasts from the different sources that were used by students to complete the assignment.

Final Thought

It is important for students to understand that predictions will never be 100% accurate. Although scientists know a lot about weather and forecasting, there are still many areas of uncertainty. Similarly, there is still a great deal of uncertainty about climate change.

3

Student Reading

Student Reading 3

The limitations of climate models

The most complex climate models attempt to simulate various climate components such as the atmosphere, oceans, land, and ice. At the moment, climate models are the most comprehensive tool available for studying and simulating the interaction of diverse climate components and processes.

Though they are useful, climate models have important limitations. Even the most complex models cannot calculate every process in the climate, including many that are known to play important roles. Consequently, climate modelers must find ways to simplify and approximate many real-world physical relationships.

Evaluating the accuracy of climate models

Weather forecasts can be tested against actual observations to see if the model was accurate, but climate models often make predictions that span decades or longer, making it more difficult to confirm their accuracy. As a result, climate models are often tested by observing how closely they can simulate known past and present climate changes. The Intergovernmental Panel on Climate Change (IPCC) notes that since its last report in 2001, model performance has improved overall, but errors and biases remain. [1]

Temperature

Models can only simulate annual average temperatures in most regions of the world to within approximately 3° C of observations. [2] Averaging simulations across all models produces slightly better results, but errors in simulations involving polar regions are larger.

In addition, most models predict that increasing the atmospheric concentration of greenhouse gases will result in a strong warming in the troposphere around the tropics, and that the warming there will be greater than at the surface. However, since 1979, all but one weather balloon and satellite record have shown *less* warming in the tropical troposphere than at the surface. [3]

Precipitation

Models can simulate some large precipitation patterns on a regional scale, but individual models show substantial biases, especially in tropical regions.

Sea ice

When averaged across models, the simulation of observed sea ice coverage in the polar regions is reasonably similar to observations. However, the range of estimates among models exceeds 50% of the observed mean, and projections into the future remain uncertain. [4] Evaluations of the accuracy of the models are also limited by a shortage of real-world data for comparison.

Climate sensitivity

"Climate sensitivity" is the expected increase in global average temperature if the amount of carbon dioxide in the atmosphere were to double. Climate sensitivity is mostly influenced by feedback processes in the climate, which are difficult to estimate. Without the feedback process, a doubling of greenhouse gases would only raise average global temperatures in a climate model by about 1° C. [5] But because of the expected positive feedback processes, mainly from water vapor, most models project that global average temperatures would increase between 2° C and 4.5° C, with approximately 3° C being the most common estimate. [6]

Despite much research, the range of climate sensitivity estimates has not changed much over the past few decades. A major source of uncertainty is the difficulty of predicting the response of clouds to temperature increases.

Summary

Climate models are important for understanding and predicting possible climate changes, but the challenges of representing small-scale climate and weather processes, as well as the ongoing discrepancies between projected climate conditions and observations, are important limitations. Since models are used not only for making projections, but also for analyzing human influence on the current climate, it is important to understand their inherent uncertainties.

References

1 Intergovernmental Panel on Climate Change [IPCC] (2007). *Climate Change 2007: The Physical Science Basis*. Intergovernmental Panel on Climate Change. <http://www.ipcc.ch/ipccreports/ar4-wg1.htm>.

2 IPCC (2007).

3 IPCC (2007).

4 IPCC (2007).

5 Rahmstorf, Stefan (2008). Anthropogenic Climate Change: Revisiting the Facts. In E. Zedillo, *Global Warming: Looking Beyond Kyoto* (Brookings Institution): 34–53. <http://www.pik-potsdam.de/~stefan/Publications/Book_chapters/Rahmstorf_Zedillo_2008.pdf>.

6 Rahmstorf (2008).

Worksheet 3.2

Weather forecasts

Using the form below, track weather forecasts for the coming week. You may use the weather forecasts from a TV newscast, radio station, newspaper, or website, but be consistent, i.e., use the same source throughout the assignment. Then answer the questions on the following page.

Weekly forecast on Monday **Date:**

	Monday (predicted)	Tuesday (predicted)	Wednesday (predicted)	Thursday (predicted)	Friday (predicted)
Temperature High					
Temperature Low					

Weekly forecast on Tuesday **Date:**

	Monday (actual)	Tuesday (predicted)	Wednesday (predicted)	Thursday (predicted)	Friday (predicted)
Temperature High					
Temperature Low					

Weekly forecast on Wednesday **Date:**

	Monday (actual)	**Tuesday (actual)**	Wednesday (predicted)	Thursday (predicted)	Friday (predicted)
Temperature High					
Temperature Low					

Weekly forecast on Thursday **Date:**

	Monday (actual)	**Tuesday (actual)**	**Wednesday (actual)**	Thursday (predicted)	Friday (predicted)
Temperature High					
Temperature Low					

Weekly forecast on Friday **Date:**

	Monday (actual)	**Tuesday (actual)**	**Wednesday (actual)**	**Thursday (actual)**	Friday (predicted)
Temperature High					
Temperature Low					

Worksheet 3.2
Weather forecasts

How accurate was Monday's weather prediction for each day of the week?

Monday:

Tuesday:

Wednesday:

Thursday:

Friday:

How did the weather predictions change over the course of the week compared to Monday's forecast?

4 Understanding Changes in Climate Conditions

Introduction

It has been proposed that increases in carbon dioxide (CO_2) emissions resulting from human activity are responsible for climate change. We know that CO_2, together with water vapor, ozone, methane, and other molecules in the atmosphere, helps to regulate temperatures on earth. We also know that the climate is always changing and that, regardless of human activity, it has undergone both abrupt and gradual swings in temperatures and atmospheric conditions. Within the past decade, our understanding of the climate has improved. However, there is still much that remains uncertain within the scientific community. A closer look at some of the factors that influence climate will put into perspective how difficult it is to model and understand past, current, and future changes in climate.

Over the past 100 years, the climate has undergone periods of both warming and cooling. During the late nineteenth century and early twentieth century, there were warnings of an impending ice age. In 1923, *Time* magazine stated, "[T]he discoveries of changes in the sun's heat and the southward advance of glaciers in recent years have given rise to conjectures of the possible advent of a new ice age." A decade later, the *New York Times* warned that the nation had entered its longest warming spell since 1776. [1]

Considering the complexity of our climate system, it is not surprising that forecasts change. As new information surfaces, we change the way we think about the natural world—including climate. In fact, many scientists who once thought human activities caused climate change are no longer certain that that is the case. On April 6, 2006, for example, 60 scientists signed a letter to Canadian Prime Minister Stephen Harper asserting that climate alarmism is unsupported by science. They wrote:

> Observational evidence does not support today's computer climate models, so there is little reason to trust model predictions of the future … Significant [scientific] advances have been made since the [Kyoto] Protocol was created, many of which are taking us away from a concern about increasing greenhouse gases. If, back in the mid-1990s, we knew what we know today about climate, Kyoto would almost certainly not exist, because we would have concluded it was not necessary. [2]

Even scientists who have worked with the United Nations Intergovernmental Panel on Climate Change (IPCC) are raising doubts about a climate crisis. In a January 2007 TV interview, scientist Richard Linden of the Massachusetts Institute of Technology said that fears of human-made climate change are "silly." [3]

In a 2007 *Wall Street Journal* article, atmospheric scientist John Christy, who declined his share of the Nobel Peace Prize awarded to the IPCC, noted that the climate system is so "extraordinarily complex" that it is "beyond the mastery of mere mortals." [4] He reminds us that the conditions we observe in today's climate have also existed in the past.

Historic climate change

The earth has warmed and cooled many times throughout history. (These cyclical patterns can be seen in Lesson 2, Figure 2.1.) Indeed, temperatures have been much higher in the past than they are today—as much as 10° C higher than temperatures have been at any time during the last century.

Past climate change is often discussed in the context of geologic time scales, as shifts have occurred over thousands or even tens of thousands of years. However, scientists have discovered that climate change is not always gradual. In fact, there is strong evidence that temperature changes can occur over the course of a few decades.

For example, it is estimated that temperatures in Greenland increased by 8° C to 16° C within a span of several decades about 15,000 years ago. Two decades after this rise in temperature, atmospheric levels of methane increased rapidly for about 50 years. Scientists believe that this was the result of an expansion of wetlands in tropical regions. [5]

During the last Glacial Maximum (about 21,000 years ago), ice covered all of Northern Europe and Canada, extending as far south as the Missouri River and as far east as New York. Since that time, temperatures have increased by an estimated 4º C to 7º C. [6] Only about 0.65º C of that warming has occurred during the last century. [7]

It is estimated that the earth is about 4.6 billion years old, but temperature records do not extend back that far. Consequently, scientists apply "proxies" (surrogate data) to estimate prehistoric temperatures. Proxies are constructed using fossils, sediment samples, and tree rings, as well as data from air bubbles found in ice cores in Antarctica and Greenland.

Based on such data, researchers have determined that rapid warming events typically have been followed by periods of gradual cooling that were triggered by accelerated glacial melt and the breakup of sea ice. The massive influx of fresh water into the north Atlantic Ocean is believed to have altered the patterns of ocean circulation, causing a cooling shift in the climate. Atmospheric CO_2 concentrations varied only slightly during these events—probably by less than 10 parts per million (ppm) during the warming periods and by 20 ppm during the cooling periods. [8] By comparison, CO_2 levels have increased by about 100 ppm during the last century, while temperatures have increased by only about 0.6° C. This evidence suggests that the correlation between rising temperatures and levels of CO_2 in the atmosphere is not causative.

During the Medieval Warm Period (c. 800-1300 CE), the earth was at least as warm as it is today. The warm temperatures of the time could not have been caused by the use of fossil fuels or by other human activities since people did not have cars or coal-burning power plants back then. After the Medieval Warm Period, temperatures dropped significantly, and the Little Ice Age, which lasted until the mid-nineteenth century, began.

When the earth began to warm again following the Little Ice Age, scientists began to track surface temperatures in the United States and elsewhere. [9] This data revealed a gradual warming trend that became more pronounced between 1900 and the 1940s, while carbon dioxide emissions resulting from human activity were low. Between the 1940s and the 1970s, temperatures actually declined slightly while carbon dioxide emissions caused by industrialization increased. This evidence suggests that CO_2 levels in the atmosphere cannot explain changes in climate.

Earth is not the only planet where temperatures are increasing. Mars, which is not affected by carbon dioxide emissions caused by human activity, has been warming, as well. [10] Scientists also believe that Jupiter, Neptune's moon, and even Pluto are warming, and that these warmer temperatures are probably the result of increases in the amount of energy given off by the sun. [11]

Drivers of climate change

The sun exerts the most significant influence on earth's climate. Thus, when we study climate change, it is important to consider the various factors that affect the amount of solar radiation that reaches the earth.

Incoming solar radiation

Changes in earth's orbit or orientation toward the sun alter the amount of energy the earth receives. Such a change can have a significant impact on earth's climate. In addition, the amount of energy the sun produces also changes, thereby altering the amount of energy that reaches earth. The surface and atmosphere of earth absorb an average of 240 watts of solar energy for every square meter of earth's surface area.

Variations in earth's orientation to the sun and its orbit around the sun are collectively known as the Milankovitch Cycles. There are three Milankovitch Cycles: eccentricity, obliquity, and precession (see Figures 4.1 and 4.2).

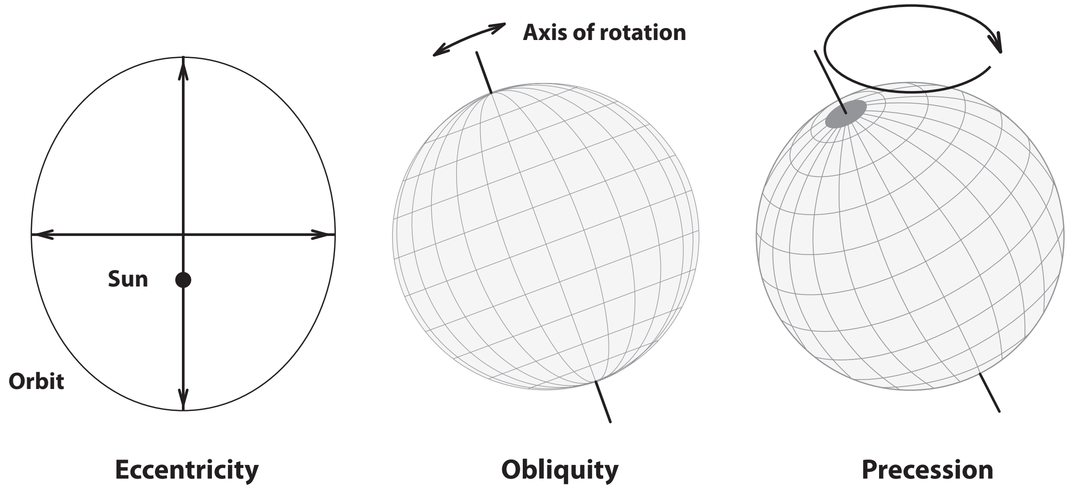
1 Eccentricity

Eccentricity is the shape of earth's orbit around the sun. This shape oscillates between less elliptical (nearly circular) and more elliptical (oval-shaped) over a cycle of about 100,000 years. We are currently in a period of low eccentricity, meaning that our orbit around the sun is more circular.

2 Obliquity

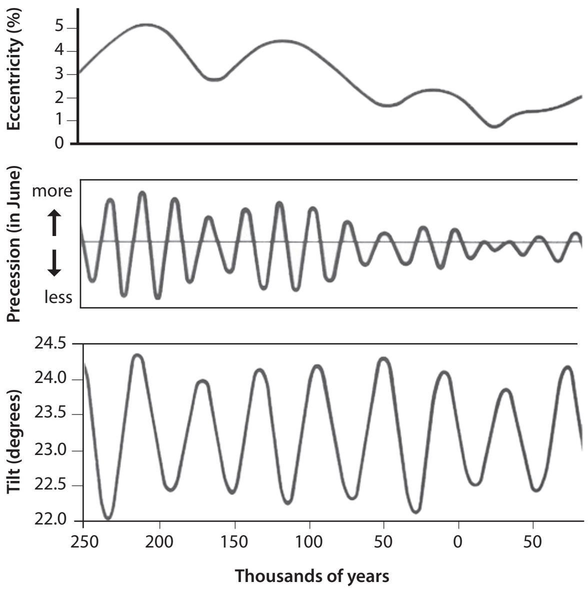
Obliquity refers to the tilt of earth's axis in relation to its plane of orbit around the sun. This tilt oscillates between about 22.1° and 24.5° over a cycle of 41,000 years. While obliquity does not change the total amount of solar energy the earth receives over time, it does alter the intensity of the summer and winter seasons at higher latitudes. As obliquity increases, the amount of solar radiation reaching higher latitudes intensifies during summer and lessens in intensity during winter months, thereby making summers warmer and winters colder. Currently, earth's axis of rotation is 23.5° and is declining, causing milder summers and winters at higher latitudes.

Figure 4.1: Milankovitch Cycles



Source: Riebeek, Holli (2006). *Paleoclimatology: Explaining the Evidence*. NASA. <http://earthobservatory.nasa.gov/Features/Paleoclimatology_Evidence/>.

Figure 4.2: Milankovitch Cycles over the past 250,000 years, with projections for the next 100,000 years



Source: Bagenal, Fran (2005). *Atmospheric Evolution*. University of Colorado. <http://lasp.colorado.edu/~bagenal/3720/CLASS20/20AtmosEvol1.html>.

3 Precession

Precession refers to changes in the orientation of earth's axis in space, a cycle that occurs over 19,000 to 23,000 years. Precession affects the time of year at which the earth is closest to or farthest away from the sun. Currently, we are closest to the sun in January and farthest away in July. As a result, our winters are relatively mild compared to winters during past ice ages.

Though we have discussed these three cycles in isolation, each cycle can have an impact on the effects of the other cycles. For example, earth's current obliquity may result in milder summers and winters, but changes in precession or eccentricity may lessen or intensify this effect.

There is widespread agreement among scientists that the Milankovitch Cycles have a significant impact on climate, one that is far greater than the impact of any human activity.

Reflected solar radiation

Albedo refers to the percentage of solar energy that is reflected by earth's atmosphere back into space. Albedo depends on a variety of factors, including the amount of water vapor (and other particles) in the atmosphere and the type of cloud cover. For example, warmer temperatures can increase atmospheric water vapor, which in turn can increase cloud cover. Denser cloud cover can increase the amount of solar radiation that is reflected back into space, causing a cooling effect. Alternatively, denser cloud cover can also lead to warmer temperatures by trapping heat closer to earth's surface.

About 30% of incoming solar radiation is reflected back into space, and two thirds of that amount is reflected by cloud cover and particles in the atmosphere, while the rest is reflected by earth's surface. Thus, particles in the atmosphere are partly responsible for keeping temperatures on earth lower. For example, the 1991 eruption of Mt. Pinatubo in the Philippines spewed an estimated 17 million tons of sulfur dioxide and ash particles into the atmosphere. By altering the amount of energy reaching earth's surface, the eruption had a profound impact on earth's climate, temporarily decreasing global average temperatures by about 0.5º C. [12]

Cosmic rays from other galaxies or other parts of our galaxy can also influence earth's climate. These cosmic rays collide with other molecules when they enter the atmosphere, creating ultra-small particles that can facilitate cloud formation. Over the past 100 years, scientists have recorded fewer cosmic rays and less cloud cover, meaning that more solar radiation has been able to reach the earth's surface.

Absorbed solar radiation

About 70% of solar radiation is absorbed by earth's surface and atmosphere and by clouds. Greenhouse gases can reduce the amount of infrared (heat) energy that is radiated by earth's surface, allowing more energy to remain in the lower atmosphere and at the surface. Without these gases, average global temperatures would be about -19º C instead of 14º C.

The amount of CO_2 in the atmosphere has varied widely over time. Current estimates suggest that CO_2 levels fluctuated between 180 ppm and 280 ppm throughout the 650,000 years leading up to the Industrial Revolution. Significant fluctuations in temperatures also occurred during that period.

Since 1850, atmospheric CO_2 levels have increased from about 265 ppm to 383 ppm (by volume). It is expected that CO_2 levels will continue to increase as developing nations such as China and India move through their own industrial revolutions.

Changes in land use affect the amount of energy absorbed by earth's surface and thus the amount of energy it radiates as heat. On a global scale, this effect is estimated to have increased surface temperatures by about 0.06º C over the last century. [13] On a local scale, the effects of land use changes can be much more significant. For example, densely populated urban areas absorb more heat energy than grassy fields or forests do, creating what is known as the "heat island effect." Annual mean temperatures in urban and suburban areas can be 1° C to 3° C greater than those in neighboring rural locations. [14]

Over the past few million years, earth's climate has fluctuated widely, along with temperatures and atmospheric compositions of greenhouse gases. These changes are the result of a multitude of factors, the complexity of which frustrates our ability to predict future climate conditions with accuracy.

References

1 Anderson, R. Warren, and Dan Gainor (2006). *Fire and Ice*. Business and Media Institute. <http://www.businessandmedia.org/specialreports/2006/fireandice/fireandice.asp>.

2 *Financial Post* (2006, April 6). Open Kyoto to Debate. <http://tinyurl.com/fpApr606>.

3 US Senate Committee on Environment and Public Works (2007). *MIT Climate Scientist Calls Fears of Global Warming 'Silly.'* <http://tinyurl.com/USSenComm>.

4 Christy, John (2007, November 1). My Nobel Moment. *Wall Street Journal*. <http://online.wsj.com/article/SB119387567378878423.html>.

5 Intergovernmental Panel on Climate Change [IPCC] (2007). *Climate Change 2007: The Physical Science Basis*. Intergovernmental Panel on Climate Change. <http://www.ipcc.ch/ipccreports/ar4-wg1.htm>.

6 IPCC (2007).

7 IPCC (2007).

8 Staufer, B., T. Blunier, A. Dällenbach, A. Indermühle, J. Schwander, T. F. Stocker, J. Tschumi, J. Chappellaz, D. Raynaud, C. U. Hammer, and H. B. Clausen (1998). Atmospheric CO_2 Concentration and Millennial-Scale Climate Change During the Last Glacial Period. *Nature* 392: 59–62.

9 NASA Goddard Institute for Space Studies [GISS] (2009). *GISS Surface Temperature Analysis*. <http://data.giss.nasa.gov/gistemp/graphs/>.

10 NASA (2005). Orbiter's Long Life Helps Scientists Track Changes on Mars. News release (September 16). <http://www.nasa.gov/home/hqnews/2005/sep/HQ_05274_Mars_Orbiter.html>.

11 Massachusetts Institute of Technology (2002). Pluto is Undergoing Global Warming, Researchers Find. News release (October 2). <http://web.mit.edu/newsoffice/2002/pluto.html>.

Goudarzi, Sara (2006, May 4). New Storm on Jupiter Hints at Climate Change. *Space*. <http://www.space.com/scienceastronomy/060504_red_jr.html>.

Massachusetts Institute of Technology (1998). MIT Researcher Finds Evidence of Global Warming on Neptune's Largest Moon. News release (June 24). <http://web.mit.edu/newsoffice/1998/triton.html>.

12 Self, Stephen, Jing-Xia Zhao, Rick E. Holasek, Ronnie C. Torres, and Alan J. King (1996). The Atmospheric Impact of the 1991 Mount Pinatubo Eruption. In *Fire and Mud: Eruptions and Lahars of Mount Pinatubo, Philippines* (United States Geological Survey). <http://pubs.usgs.gov/pinatubo/self/index.html>.

13 IPCC (2007).

14 US Environmental Protection Agency (2009). *What Is an Urban Heat Island?* <http://www.epa.gov/heatisland/about/index.htm>.

Lesson 4-A

Climate drivers

Theme

This lesson examines the primary drivers of climate change, including the absorption and reflection of solar radiation. It demonstrates that our climate is always changing.

Purpose

This lesson emphasizes that, even with advanced technology, there is still much that is uncertain about climate change. This lesson shows that there are natural forces that inevitably cause glacial periods as well as warming periods, irrespective of human activities.

Description

Students will read about the main drivers of climate change and examine a graph showing temperature changes in the United States between 1880 and 2005. Using this information, they will create hypotheses to explain those changes.

Procedure

1 Remind the class of the climate change hypotheses they constructed in *Lesson 1-B: Climate change hypothesis*. Ask students whether they think their hypotheses could be supported by our current understanding of climate change.

2 Let students know that beliefs about climate have changed over time. Some of these changes are illustrated in *Visual 4.1: News timelines*.

In the early 1900s, some people were concerned that the world was entering an ice age. By the 1930s and 1940s, the media reported that the world was warming, but by the 1970s, the focus was again on cooling. There have been cooling and warming trends throughout history. Over time, technology will improve, new data will become available, and better models will be designed to help us understand climate.

3 Have students use the scientific method to test their hypotheses. You may wish to refer back to *Visual 1.2: The scientific method*.

4 Hand out *Student Reading 4.1: Drivers of climate change* and *Worksheet 4.1: Temperature change*. Have students complete the reading and the worksheet.

5 Display *Visual 4.2: Correlation does not imply causation* and *Visual 4.3: US temperature change*. Ask students what evidence these graphs provide and what ideas are implied, but not supported, by the data. For example:

- How often has the climate changed?
- Does *Visual 4.3: US temperature change* show correlation and/or causation between CO_2 and temperature?

Point out that temperatures rose between 1900 and 1940, when CO_2 emissions were relatively low. Between 1940 and 1975, CO_2 emissions rose while temperatures declined.

6 Ask students to share their answers to question 4 from *Worksheet 4.1: Temperature change*. What factors are likely to cause climate change?

7 Note some factors that influence global temperatures:

- Incoming solar radiation is the amount of radiation that reaches earth. This is illustrated in *Visual 4.4: Incoming solar radiation*.
- Albedo is the percentage of solar radiation that is reflected by earth back into space. This is illustrated in *Visual 4.5: Albedo*.
- Absorbed solar radiation is defined in *Visual 4.6: Radiation absorbed*. Energy absorption is affected by chemical concentrations in the atmosphere and by land use changes (e.g., the “heat island effect”).

Visual 4.1
News timelines

A *Time* magazine timeline

“The discoveries of changes in the sun’s heat and the southward advance of glaciers in recent years have given rise to conjectures of the possible advent of a new ice age.”	“Gaffers who claim that winters were harder when they were boys and girls are quite right … weathermen have no doubt that the world, at least for the time being, is growing warmer.”	“Climatological Cassandras are becoming increasingly apprehensive, for the weather aberrations they are studying may be the harbinger of another ice age.”	“[S]cientists no longer doubt that global warming is happening, and almost nobody questions the fact that humans are at least partly responsible.”
September 10, 1923	January 2, 1939	June 24, 1974	April 9, 2001

A *New York Times* timeline

“MacMillan Reports Signs of New Ice Age”	“America in Longest Warm Spell Since 1776; Temperature Line Records a 25-Year Rise”	“Scientists Ponder Why World’s Climate is Changing; A Major Cooling Widely Considered to be Inevitable”	“Past Hot Times Hold Few Reasons to Relax About New Warming”
September 18, 1924	March 27, 1933	May 21, 1975	December 27, 2005

Source: Anderson, R. Warren, and Dan Gainor (2006). *Fire and Ice*. Business and Media Institute. <http://www.businessand-media.org/specialreports/2006/fireandice/fireandice.asp>.

Student Reading 4

Drivers of climate change

The sun has the most significant influence on earth's climate. Thus, when we study climate change, it is important to consider the various factors that affect the amount of solar radiation that reaches the earth.

Incoming solar radiation

Changes in earth's orbit or orientation toward the sun alter the amount of energy the earth receives. Such a change can have a significant impact on earth's climate. In addition, the amount of energy the sun produces also changes, thereby altering the amount of energy that reaches earth. The surface and atmosphere of earth absorb an average of 240 watts of solar energy for every square meter of earth's surface area.

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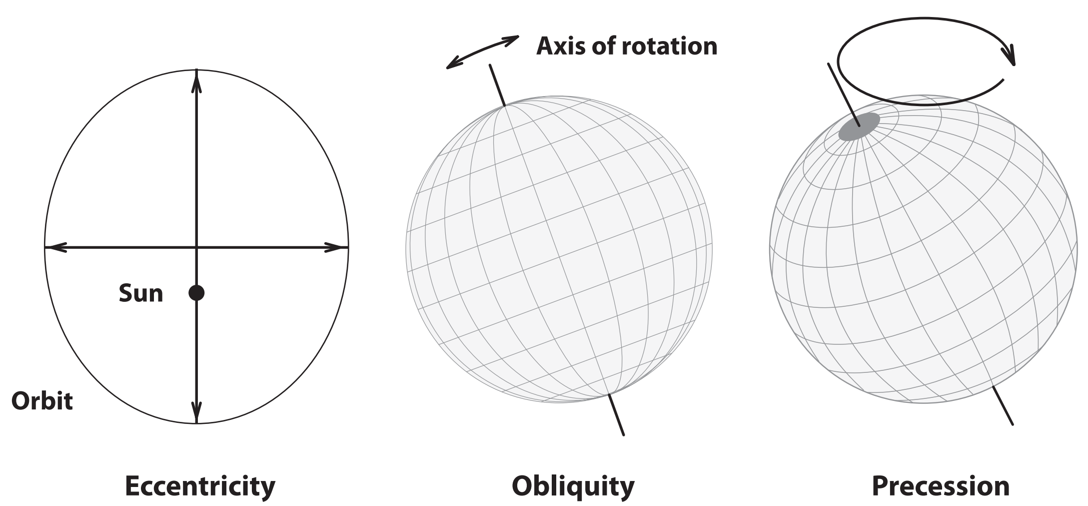
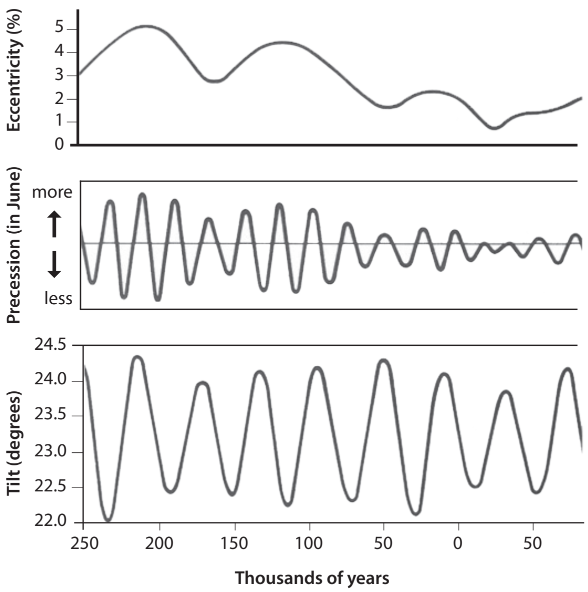
Obliquity refers to the tilt of earth's axis in relation to its plane of orbit around the sun. This tilt oscillates between about 22.1° and 24.5° over a cycle of 41,000 years. While obliquity does not change the total amount of solar energy the earth receives over time, it does alter the intensity of the summer and winter seasons at higher latitudes. As obliquity increases, the amount of solar radiation reaching higher latitudes intensifies during summer and lessens in intensity during winter months, thereby making summers

Figure 4.1: Milankovitch Cycles



Source: Riebeek, Holli (2006). *Paleoclimatology: Explaining the Evidence*. NASA. <http://earthobservatory.nasa.gov/Features/Paleoclimatology_Evidence/>.

Figure 4.2: Milankovitch Cycles over the past 250,000 years, with projections for the next 100,000 years



Source: Bagenal, Fran (2005). *Atmospheric Evolution*. University of Colorado. <http://lasp.colorado.edu/~bagenal/3720/CLASS20/20AtmosEvol1.html>.

warmer and winters colder. Currently, earth's axis of rotation is 23.5° and is declining, causing milder summers and winters at higher latitudes.

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Though we have discussed these three cycles in isolation, each cycle can have an impact on the effects of the other cycles. For example, earth's current obliquity may result in milder summers and winters, but changes in precession or eccentricity may lessen or intensify this effect.

There is widespread agreement among scientists that the Milankovitch Cycles have a significant impact on climate, one that is far greater than the impact of any human activity.

Reflected solar radiation

Albedo refers to the percentage of solar energy that is reflected by earth's atmosphere back into space. Albedo depends on a variety of factors, including the amount of water vapor (and other particles) in the atmosphere and the type of cloud cover. For example, warmer temperatures can increase atmospheric water vapor, which in turn can increase cloud cover. Denser cloud cover can increase the amount of solar radiation that is reflected back into space, causing a cooling effect. Alternatively, denser cloud cover can also lead to warmer temperatures by trapping heat closer to earth's surface.

About 30% of incoming solar radiation is reflected back into space, and two thirds of that amount is reflected by cloud cover and particles in the atmosphere, while the rest is reflected by earth's surface. Thus, particles in the atmosphere are partly responsible for keeping temperatures on earth lower. For example, the 1991 eruption of Mt. Pinatubo in the Philippines spewed an estimated 17 million tons of sulfur dioxide and ash particles into the atmosphere. By altering the amount of energy reaching earth's surface, the eruption had a profound impact on earth's climate, temporarily decreasing global average temperatures by about 0.5º C. [1]

Cosmic rays from other galaxies or other parts of our galaxy can also influence earth's climate. These cosmic rays collide with other molecules when they enter the atmosphere, creating ultra-small particles that can facilitate cloud formation. Over the past 100 years, scientists have recorded fewer cosmic rays and less cloud cover, meaning that more solar radiation has been able to reach the earth's surface.

Absorbed solar radiation

About 70% of solar radiation is absorbed by earth's surface and atmosphere and by clouds. Greenhouse gases can reduce the amount of infrared (heat) energy that is radiated by earth's surface, allowing more energy to remain in the lower atmosphere and at the surface. Without these gases, average global temperatures would be about -19º C instead of 14º C.

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Over the past few million years, earth's climate has fluctuated widely, along with temperatures and atmospheric compositions of greenhouse gases. These changes are the result of a multitude of factors, the complexity of which frustrates our ability to predict future climate conditions with accuracy.

References

1 Self, Stephen, Jing-Xia Zhao, Rick E. Holasek, Ronnie C. Torres, and Alan J. King (1996). The Atmospheric Impact of the 1991 Mount Pinatubo Eruption. In *Fire and Mud: Eruptions and Lahars of Mount Pinatubo, Philippines* (United States Geological Survey). <http://pubs.usgs.gov/pinatubo/self/index.html>.

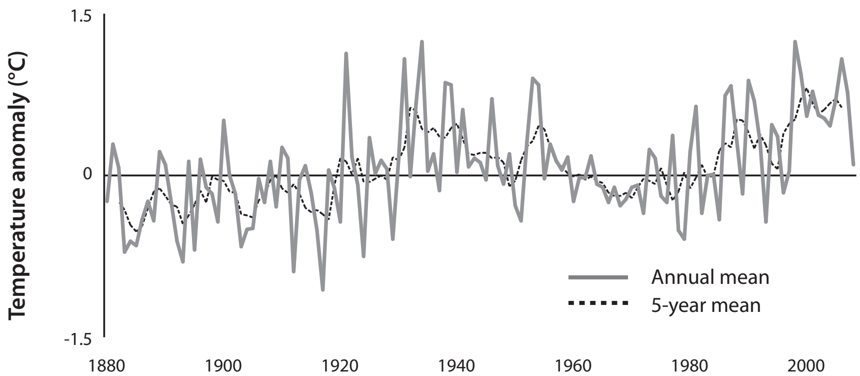
2 Intergovernmental Panel on Climate Change [IPCC] (2007). *Climate Change 2007: The Physical Science Basis*. Intergovernmental Panel on Climate Change. <http://www.ipcc.ch/ipccreports/ar4-wg1.htm>.

3 US Environmental Protection Agency (2009). *What Is an Urban Heat Island?* <http://www.epa.gov/heatisland/about/index.htm>.

Worksheet 4.1

Temperature change

Annual mean temperature change in the United States, 1880-2008



Source: NASA Goddard Institute for Space Studies (2009). *GISS Surface Temperature Analysis*. <http://data.giss.nasa.gov/gistemp/graphs/>.

Examine the graph above and answer the following questions:

1 What is the overall trend in temperatures indicated by the graph?

2 Is there any time period that diverges from the general trend in the graph?

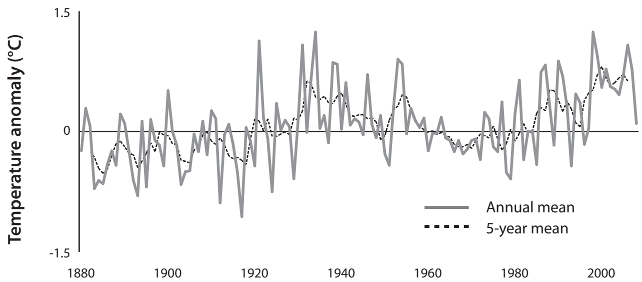
3 Create two hypotheses to explain why temperatures have generally increased since 1880.

4 Create a hypothesis to explain why temperatures were cooler between 1940 and 1970.

Worksheet 4.1 Answer Key

Temperature change

Annual mean temperature change in the United States, 1880-2008



Examine the graph above and answer the following questions:

1 What is the overall trend in temperatures indicated by the graph?

The general trend is that temperatures are increasing, but there are other smaller warming/cooling cycles within the larger trend.

2 Is there any time period that diverges from the general trend in the graph?

Between 1940 to 1970, temperatures declined.

3 Create two hypotheses to explain why temperatures have generally increased since 1880.

A. Energy from the sun has increased, resulting in warmer temperatures on earth.
B. It is part of a natural cycle—the climate is always changing.
C. There are fewer global pollutants in the air than there were 50 or 100 years ago, which means that more direct sunlight is reaching earth's surface.
D. Increased emissions from industrial development have amplified the greenhouse effect.
E. Milankovitch Cycles have created conditions for temperatures to increase.
F. Albedo has decreased, meaning less heat is reflected back into space.

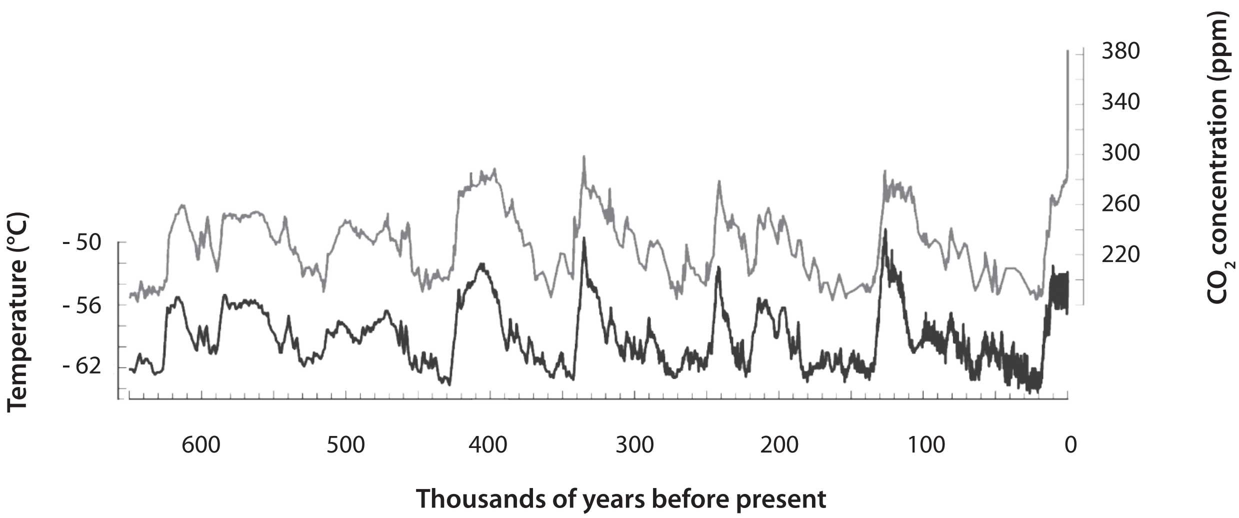
4 Create a hypothesis to explain why temperatures were cooler between 1940 and 1970.

A. Economies grew rapidly following the Great Depression and industrial emissions increased. The particulate matter emitted into the air reflected the incoming solar radiation and cooled the earth.
B. It is part of a natural cycle—the climate is always changing.

Visual 4.2

Correlation does not imply causation

Estimated temperature and carbon dioxide levels in Antarctica over the past 650,000 years

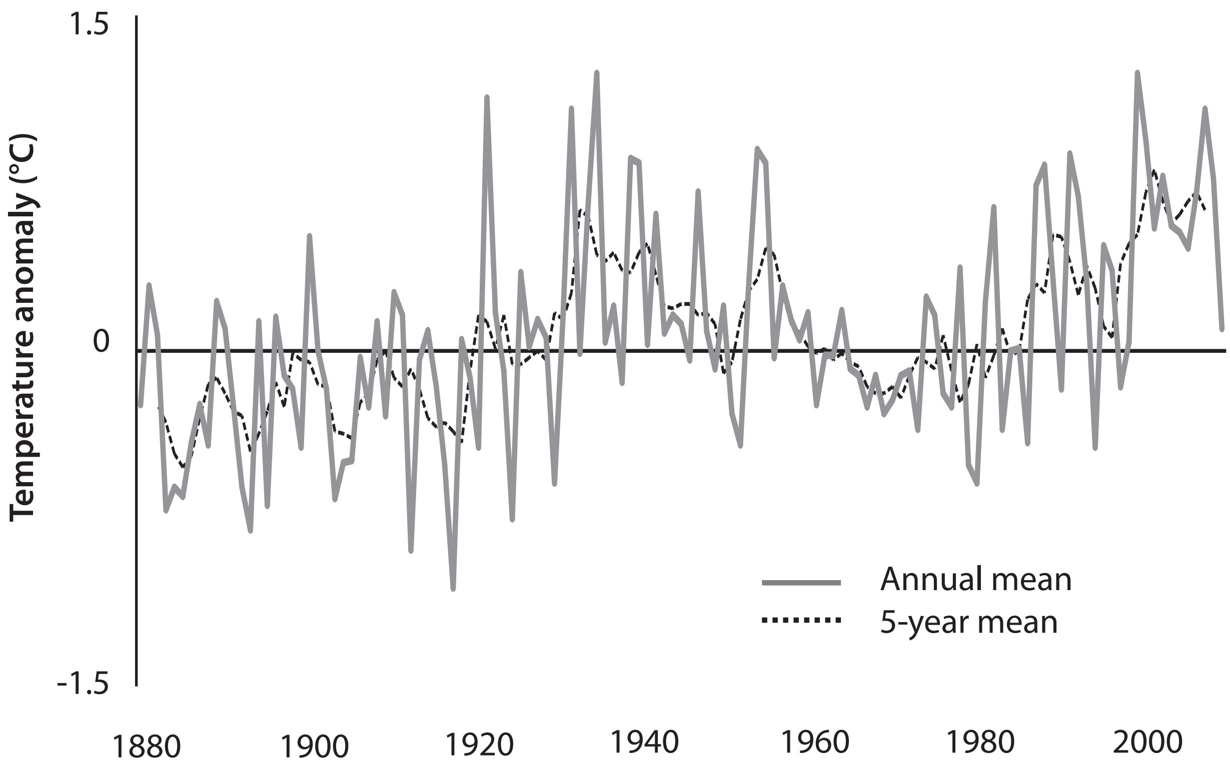


Source: Physics Institute, University of Bern, Switzerland. Adapted from Fretwell, Holly (2007). *The Sky's Not Falling: Why It's OK to Chill about Global Warming*. World Ahead Media.

Visual 4.3

US temperature change

Annual mean temperature change in the United States, 1880-2008



Source: NASA Goddard Institute for Space Studies (2009). *GISS Surface Temperature Analysis*. <http://data.giss.nasa.gov/gistemp/graphs/>.

Visual 4.4
Incoming solar radiation

The solar energy received on earth changes when the relationship between earth and the sun changes. Variations in earth's orientation to the sun and its orbit around the sun are collectively known as the **Milankovitch Cycles**, which are:

- **Eccentricity**: the shape of earth's orbit around the sun
- **Obliquity**: changes in the angle of earth's axis (tilt)
- **Precession**: the wobble of earth's tilt

Figure 1: Milankovitch Cycles

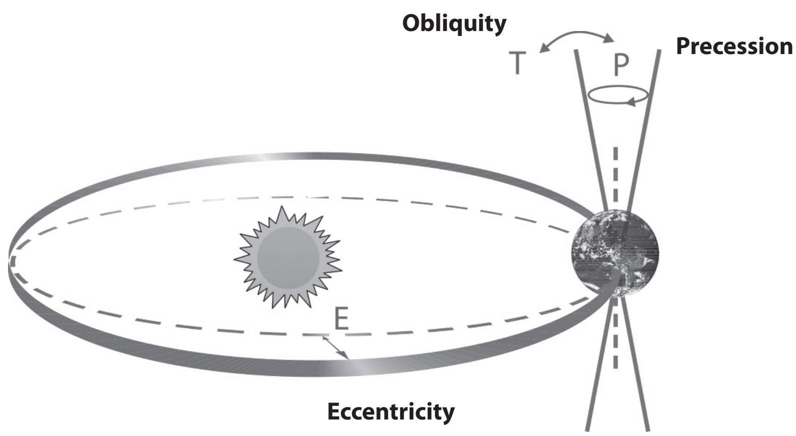
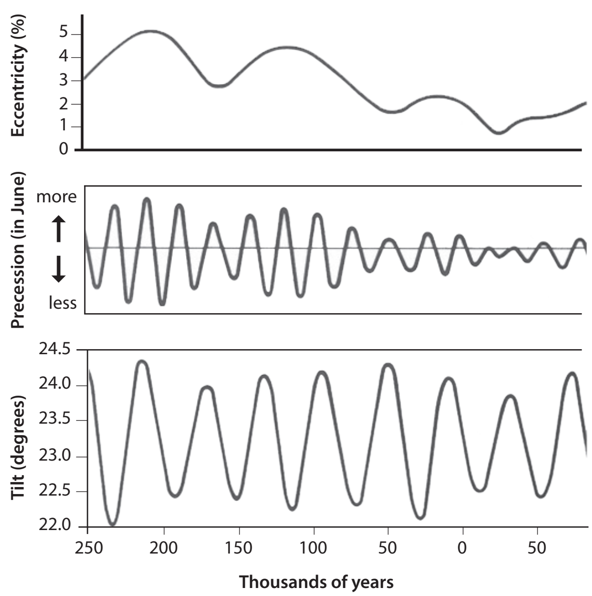


Figure 2: Milankovitch Cycles over the past 250,000 years, with projections for the next 100,000 years

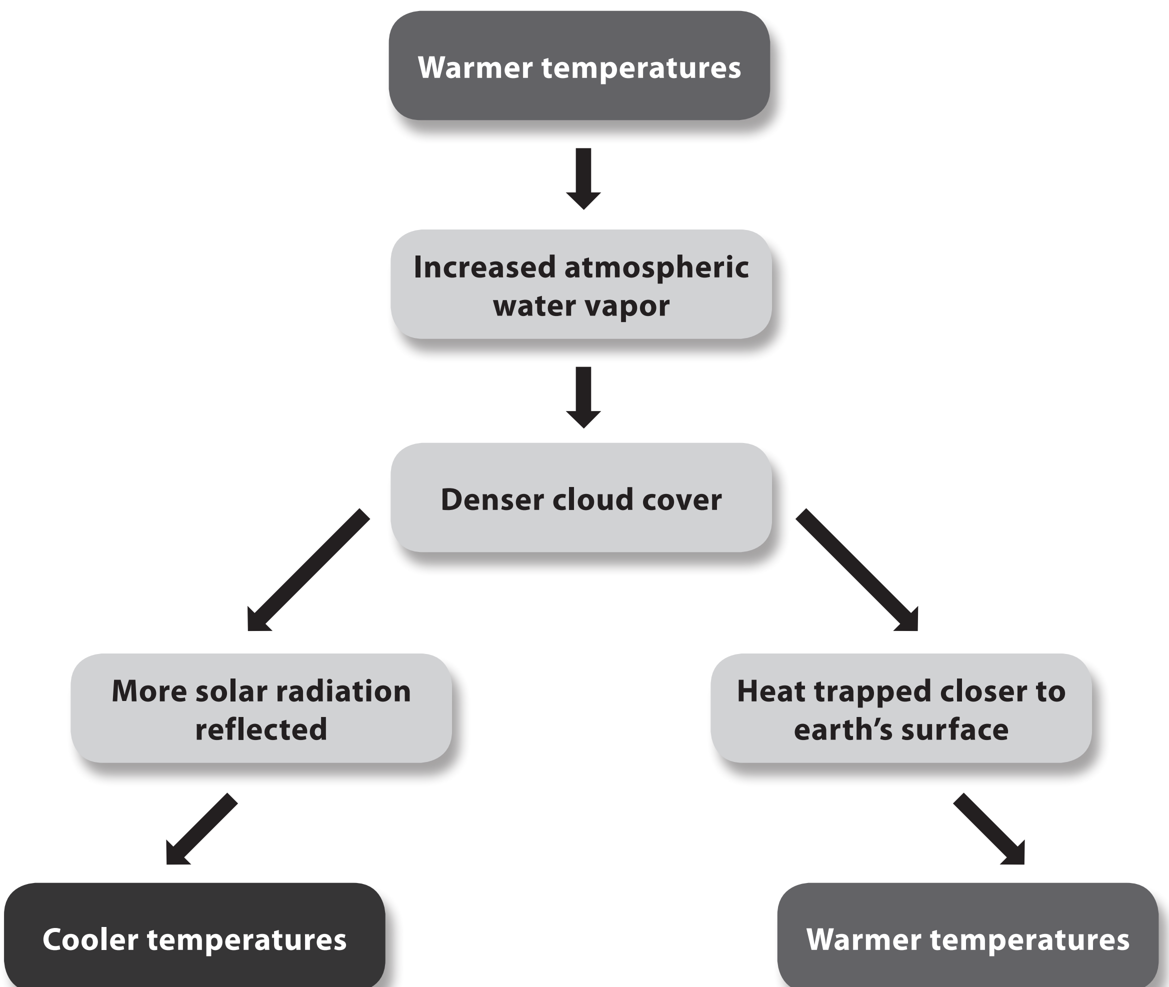


Source: Bagenal, Fran (2005). *Atmospheric Evolution*. University of Colorado. <http://lasp.colorado.edu/~bagenal/3720/CLASS20/20AtmosEvol1.html>.

Visual 4.5
Albedo

Albedo is the fraction of solar radiation reflected from earth back into space. Albedo depends upon a number of factors including:

- Water vapor
- Aerosols (particles in the air)
- Changes in cloud cover



Visual 4.6
Radiation absorbed

Land absorbs energy

- Changes in land use change the amount of energy absorbed by land

The "heat island effect"

- Annual mean temperatures in urban and suburban areas can be 1° C to 3° C higher than those in neighboring rural locations
- Displacing trees minimizes cooling from shade
- Buildings and streets can trap air and reduce air flow
- Vehicles, factories, and machines emit heat

4

Lesson 4-B

Lesson 4-B

Climate forces

Theme

The complexity of climate change stems from the innumerable forces that can impact local and global temperatures and climate over time. Some factors may have a warming effect while others may have a cooling effect. Researchers examine these factors for evidence to support or refute different hypotheses.

Purpose

This lesson emphasizes the importance of looking at a number of factors related to climate change, instead of narrowly focusing on CO_2. It will help students recognize that there is still much uncertainty regarding the role each factor plays in climate change.

Description

Students will complete a writing assignment to improve their understanding of the many variables that affect climate. In class, students will break off into groups and then analyze hypotheses about climate change. Two groups will be assigned to each hypothesis; one group will find evidence to support the hypothesis and the other group will find evidence to refute it.

Procedure

1 Talk with students about the different factors that impact global temperatures. Have students give examples of factors that may warm or cool temperatures. Organize their ideas into categories, e.g., incoming solar radiation, albedo, and radiated or absorbed heat energy.

2 Hand out *Worksheet 4.2: Climate forces*. This is a writing assignment that will help students learn how temperature responds to a variety of natural forces. Each student will write a paper discussing a variety of factors that impact climate and how each factor may affect global temperatures in the future. Discuss the various factors students wrote about in class.

3 Split the class into small groups (or students may work individually). Hand out *Worksheet 4.3: Hypothesis testing*. This is a group assignment that will help students learn how temperature and climate respond to a variety of factors, and increase their understanding of the difficulties surrounding climate analyses.

Choosing from the list below (or a list of your own), assign two groups to each hypothesis. One group will examine evidence that supports the hypothesis; the other group will gather evidence to refute it.

- CO_2 emissions from human activities are the main driver of climate change.
- Solar radiation is the most important driver of climate change.
- Cloud cover is likely to increase global temperatures.
- Cloud cover is likely to decrease global temperatures.

4 Have each group present their findings and answer the following questions.

- What was their goal?
- What data did they find to support their hypothesis?
- What data did they ignore?
- Given their findings, do they expect global temperatures to increase, decrease, or remain constant in the future?

Final Thought

It is important to consider many perspectives when analyzing an issue. People may get a biased view of an issue if they hear only one group's hypothesis. The information provided by a variety of sources is much more enlightening.

Worksheet 4.2

Climate forces

1 On a separate page, write a one-page paper discussing a variety of factors that may impact climate. You must discuss at least four factors, including each of the following:

- Solar radiation
- Cloud cover
- At least one of the Milankovitch Cycles

2 Provide global temperature forecasts for the next 5, 10, and 100 years, and justify your forecasts by citing various climate factors. How confident are you in your predictions?

Worksheet 4.3
Hypothesis testing

Working as a group, find evidence to support or reject the hypothesis highlighted below.

Be prepared to explain your findings to the class. Use the presentation summary below to organize your findings.

Hypothesis:

1 CO_2 emissions from human activities are the main driver of climate change.
2 Solar radiation is the most important driver of climate change.
3 Cloud cover is likely to increase global temperatures.
4 Cloud cover is likely to decrease global temperatures.

Presentation summary:

1 What was your goal?
2 What data supports your hypothesis?
3 What data contradicts your hypothesis?
4 According to your findings, what role, if any, does human activity play in climate change?
5 Given your findings, do you expect global temperatures to increase, decrease, or remain constant in the future?

5 Data Mining

Introduction

The purpose of this lesson is to help students better understand how data are presented and how data are used to test a hypothesis. Students will learn that data can be misused, whether by a selective use of data subsets or by graphing and charting tricks. They will also learn to evaluate information sources and how to improve their research and presentation methods.

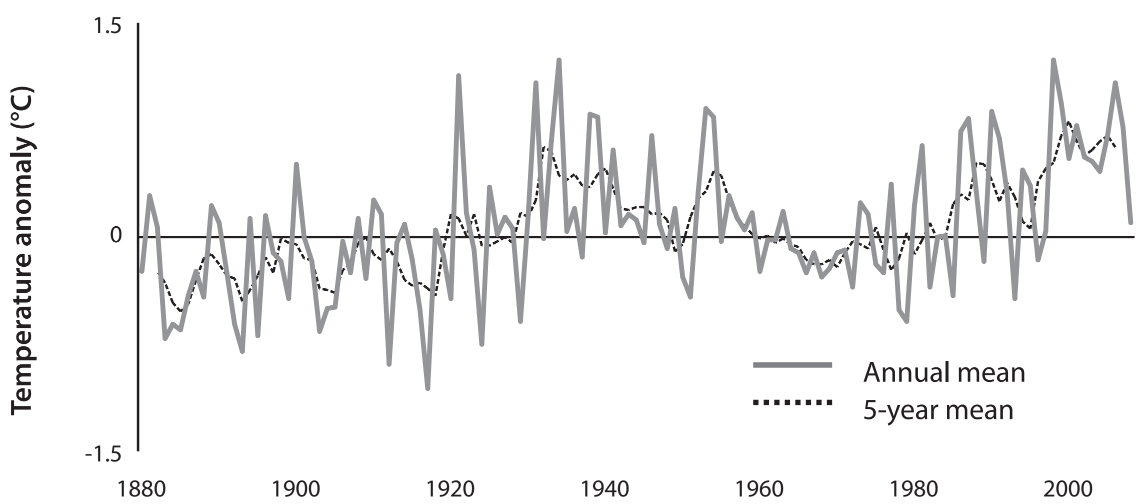
Advances in technology put more information at our fingertips than ever before. It is critical for students to be able to interpret graphs, charts, and tables accurately, and to recognize proper use of data.

In the past, there have been many presentations of data related to temperature and climate change that have told only part of the story. Through selective use of data, hypotheses that should have otherwise been rejected have gained popularity.

This lesson dispels current misconceptions by presenting a broad range of data on temperature, Arctic and Antarctic sea ice, and hurricane damage in the United States, some of which goes back as far as 450,000 years. This data comes from a variety of sources and is presented through a number of figures.

Figure 5.1: Annual mean temperature change in the United States, 1880-2008 shows surface temperatures in the United States since 1880.

Figure 5.1: Annual mean temperature change in the United States, 1880-2008

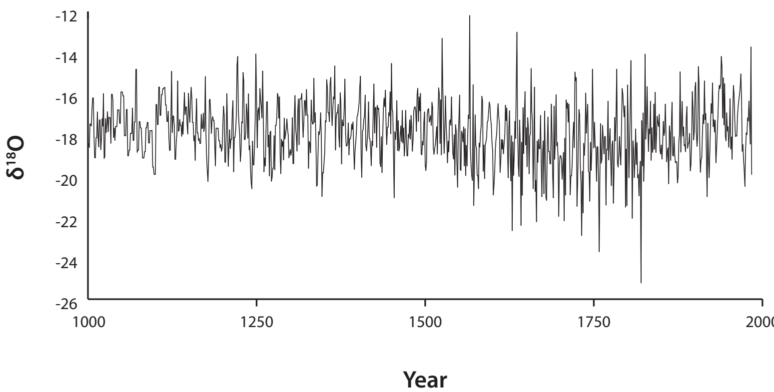


Source: NASA Goddard Institute for Space Studies, 2009.

The graph illustrates that temperatures have risen over time, except during a cooling period between 1940 and 1970 (a period during which CO_2 levels rose rapidly).

Figure 5.2: Quelccaya Glacier, Peru, temperature data, 1000-2000 offers a longer view of climate trends based on proxies from ice core data. The trend of rising temperatures after 1880 is still apparent, but the warming actually extends back to the late 1700s and early 1800s. This suggests that temperatures today are as warm as those nearly 1,000 years ago, long before the use of fossil fuels.

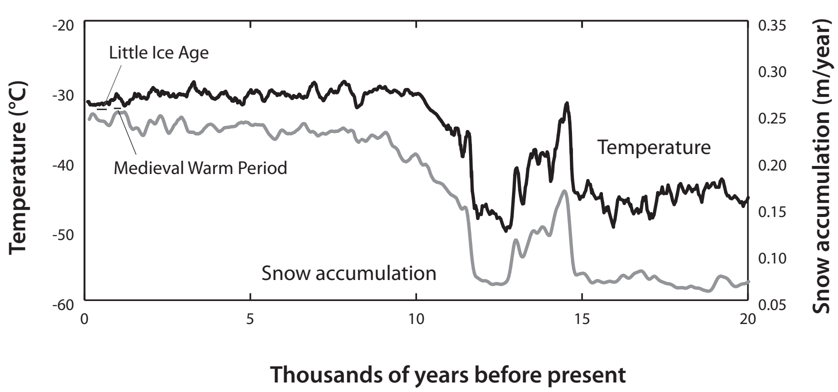
Figure 5.2: Quelccaya Glacier, Peru, temperature data, 1000-2000



Note: $\delta^{18}O$ is a measure of the ratio of stable isotopes $^{18}O : ^{16}O$. It is used as a proxy for temperature.

Source: Thompson, 1992.

Figure 5.3: Greenland Ice Sheet Project 2 ice core temperature and snow accumulation data (present to 20,000 years ago)



Source: Alley, 2000.

Figure 5.3 Greenland Ice Sheet Project 2 ice core temperature and snow accumulation data (present to 20,000 years ago) provides perspective on the scale of the most recent warming trend. Scientists have used data from ice cores in Greenland to estimate temperatures for the last 20,000 years. This graph shows that the earth has undergone significant climate changes in the past and that, at times, these changes happened quite abruptly. Also note how the Medieval Warm Period and Little Ice Age compare to past climate shifts. The most recent warming trend pales in comparison to past climate shifts.

Figure 5.4: Historical isotopic temperature record from the Vostok ice core (present to 450,000 years ago) is based on ice core data dating back 450,000 years. The longer time scale illustrates that abrupt temperature shifts have been common. Temperatures have soared higher than those recorded today and have plummeted to

5

Introduction

glacial levels as well, irrespective of human activities.

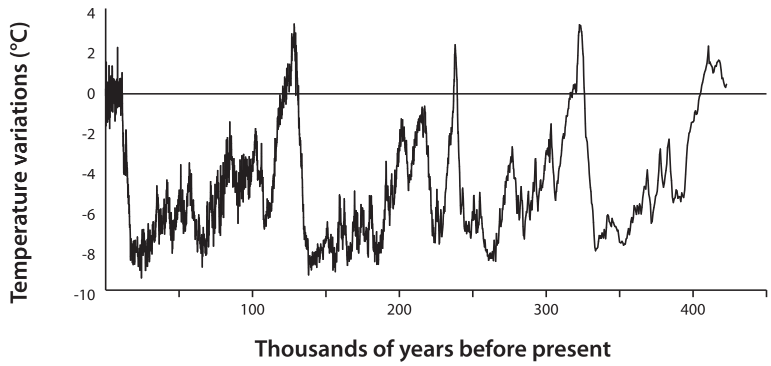
Taken together, Figures 5.1 through 5.4 illustrate how truncated data can be misleading. Manipulating the time span of trends can also be misleading.

Figures 5.5.1, 5.5.2, and 5.6 illustrate that data can also be misconstrued if relevant information about location is ignored. For example, many have pointed out that sea ice in the Arctic has been declining, but have neglected to note that Antarctic sea ice has actually been increasing, on average.

Data presentation concerning hurricane damage in the United States is also often incomplete. For example, it is often reported that climate change has increased the frequency and strength of hurricanes, and thus losses due to hurricanes. But a more thorough look at the data reveals otherwise.

Historically, population growth in North America has been highest in coastal regions. As more people have relocated to those areas, the risk of economic losses and fatalities from storms has increased. Taking these factors into account, it is easier to

Figure 5.4: Historical isotopic temperature record from the Vostok ice core (present to 450,000 years ago)



Source: Petit et al., 2000.

Figure 5.5.1: Ice extent anomalies in the Arctic, 1979-2009

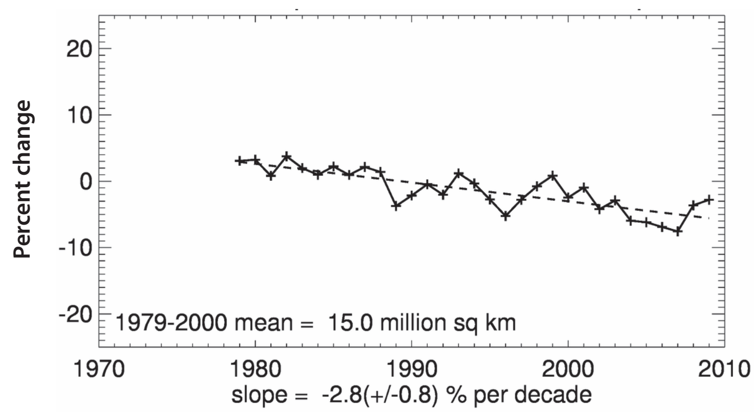
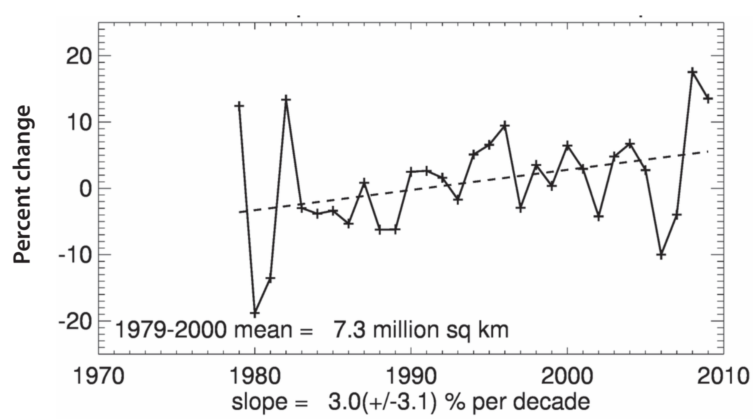


Figure 5.5.2: Ice extent anomalies in the Antarctic, 1979-2009



Source (for Figures 5.5.1 and 5.5.2): NSIDC, 2009.

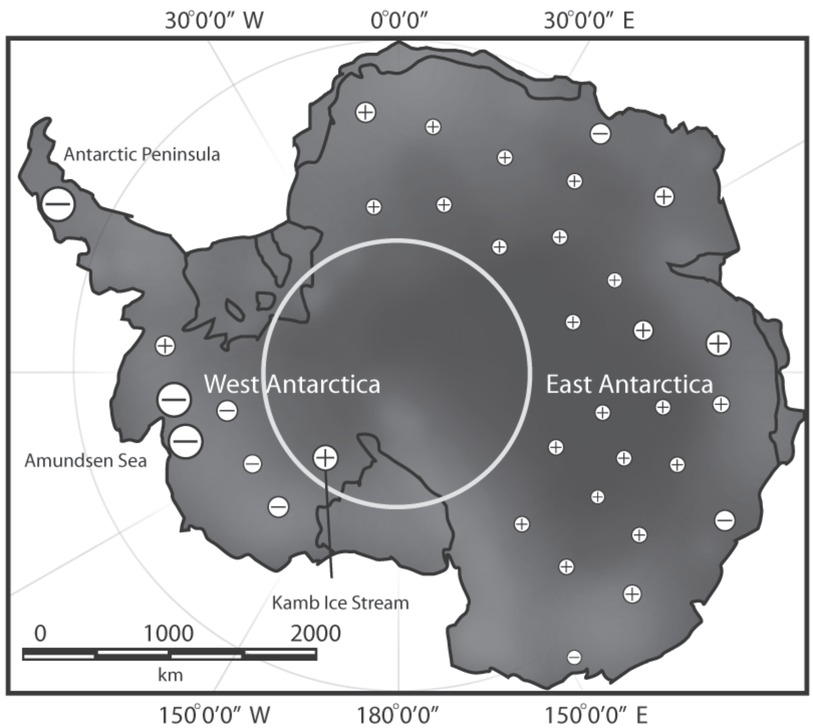
understand why a storm like Hurricane Katrina in 2005 would have a much larger effect than a storm of similar magnitude three decades ago. In other words, it is not the storms that have increased in intensity, but the level of destruction.

Figures 5.7 and 5.8, which both show the annual cost of hurricane damage in the United States from 1900 to 2005, demonstrate how the graphical representation of financial data can be misleading if the data are not normalized—that is, adjusted for changes in circumstances.

Figure 5.7: Total losses per year from Atlantic tropical cyclones adjusted for inflation to 2005 dollars, 1900-2005 shows that total losses due to hurricanes have increased dramatically since 1900, which may lead one to conclude that there has been an increase in the severity of storms. However, this increase in total losses is actually due to the growth of populations in coastal regions and the increased value of infrastructure and personal property in the area.

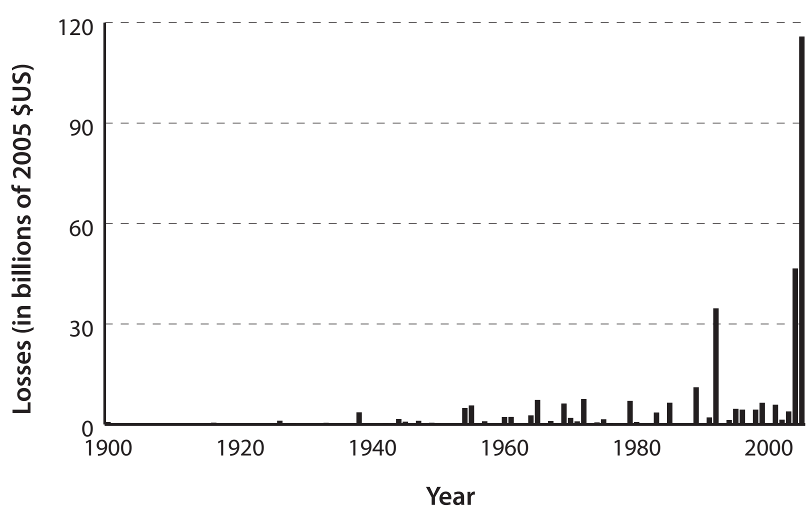
Figure 5.8: Normalized losses per year from Atlantic tropical cyclones, 1900-2005 "normalizes" the

Figure 5.6: Current areas of increasing and decreasing ice in Antarctica



Source: Vaughn, 2005.

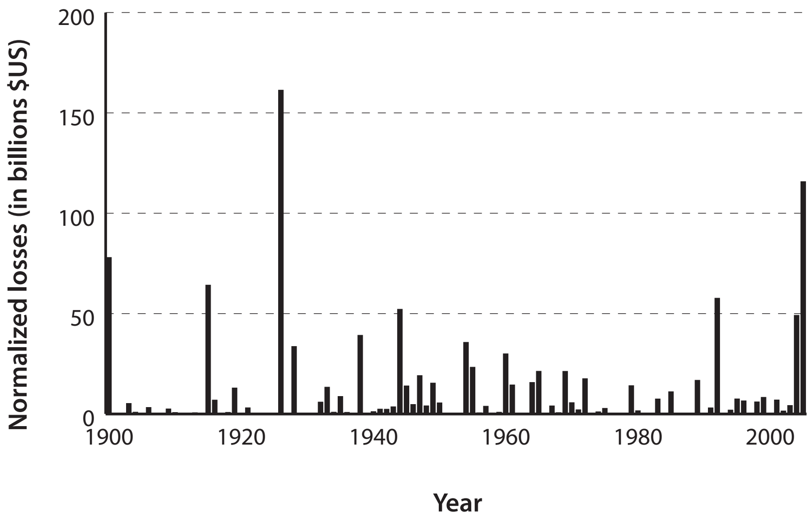
Figure 5.7: Total losses per year from Atlantic tropical cyclones, adjusted for inflation to 2005 dollars, 1900-2005



Source: Pielke et al., 2008.

cost figures, which means that the data are adjusted for the rise in population and property values. The normalized figure does not have the same visual implications as the previous figure, and suggests no patterning towards more severe hurricanes.

Figure 5.8: Normalized losses per year from Atlantic Tropical Cyclones, 1900-2005



Source: Pielke et al., 2008.

Furthermore, it is often reported that the number of storms occurring worldwide has increased in recent times. However, this claim does take into account all of the pertinent data. Over the past few decades, our ability to detect and monitor storms around the world has improved vastly. With the development of satellites and radar technologies, researchers now can detect storms that once were unaccounted for. Thus, the number of detected storms has increased, but the number of storms that make landfall has remained relatively constant.

References

Alley, R.B. (2000). *GISP2 Ice Core Temperature and Accumulation Data*. World Data Center for Paleoclimatology. <ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/greenland/summit/gisp2/isotopes/gisp2_temp_accum_alley2000.txt>.

NASA Goddard Institute for Space Studies (2009). *GISS Surface Temperature Analysis*. <http://data.giss.nasa.gov/gistemp/graphs/>.

NASA Goddard Space Flight Center (2002). Satellites Show Overall Increases in Antarctic Sea Ice Cover. News release (August 22). <http://www.gsfc.nasa.gov/news-release/releases/2002/02-128.htm>.

National Snow and Ice Data Center [NSIDC] (2009). *Sea Ice Index*. <http://nsidc.org/data/seaice_index/>, as of May 28, 2009.

Petit, J.R., D. Raynaud, C. Lorius, J. Jouzel, G. Delaygue, N.I. Barkov, and V.M. Kotlyakov (2000). *Historical Isotopic Temperature Record from the Vostok Ice Core*. Carbon Dioxide Information Analysis Center, US Department of Energy. <http://cdiac.ornl.gov/ftp/trends/temp/vostok/vostok.1999.temp.dat>.

Pielke, Roger A., Jr, Joel Gratz, Christopher W. Landsea, Douglas Collins, Mark A. Saunders, and Rade Musulin (2008). Normalized Hurricane Damage in the United States: 1900–2005. *Natural Hazards Review* 9, 1 (February): 29–42.

Thompson, L. (1992). *Quelccaya Ice Core Database*. World Data Center for Paleoclimatology. <http://www.ncdc.noaa.gov/paleo/icecore/trop/quelccaya/quelccaya_data.html>.

Vaughan, David G. (2005). Oceans: How Does the Antarctic Ice Sheet Affect Sea Level Rise? *Science* 308, 5730: 1877–78.

Lesson 5-A

Data mining

Theme

Different methods of data analysis and presentation can dictate the conclusions made about a hypothesis. This lesson will give students the tools to interpret data objectively. It will also explain the difference between "normative" and "positive" analyses. Various exercises will give students opportunities to apply what they have learned.

Purpose

This lesson will help students to better understand how researchers present their findings, and will illustrate how truncated data sets, missing information about raw numerical data, and data sets that have not been normalized can result in misleading conclusions.

Description

Students will analyze and interpret truncated sets of data. Afterwards, they will be shown a complete data set and asked to revise their interpretations. This lesson demonstrates how easily data can be manipulated, and it underscores the importance of examining alternate hypotheses.

Procedure

1 Discuss with students the difference between "normative" and "positive" analyses. Normative analysis describes the way one believes that something ought to be; it is based on personal value judgments. For example, statements such as "No one should smoke because it is bad for their health" and "Emissions of CO_2 should be decreased" reflect normative analysis. Positive analysis describes the way things actually are. Examples include statements such as "There are health risks associated with tobacco use" and "Canada emitted about 640 million metric tons of CO_2 in 2004."

When analyzing data, it is important to distinguish between how things are and how one would like things to be.

2 Display *Visual 5.1: US temperature change*, which shows that temperatures have generally risen since the late 1800s, with the exception of slight cooling period between 1940 and 1970. Ask students to draw conclusions from the data using positive analysis.

3 Tell the class that CO_2 levels have increased by about 36% since the Industrial Revolution. [1] Discuss the implications of this fact—does it support the hypothesis that higher levels of atmospheric CO_2 increase global temperatures?

4 Display *Visual 5.2: Quelccaya ice core data*. This graph shows that temperatures today are about as high as they were 1,000 years ago, long before the widespread use of fossil fuels. Ask students if this information changes what they think about the possibility of a link between fossil fuel use and climate change.

5 Display *Visual 5.3: Greenland ice core data*. Using ice cores from Greenland, researchers have been able to estimate temperatures for the past 20,000 years. Point out to students that the data presented in the previous two graphs were truncated data sets that were taken from the far left side of this graph. This graph offers perspective on the magnitude of the most recent warming trend. It shows that the earth has undergone significant climate changes in the past, and that sometimes these changes happened quite abruptly. Also compare the Medieval Warm Period and the Little Ice Age to past climate shifts. The most recent warming trend, which seemed significant in Visual 5.1, pales in comparison to past climate shifts. Based on this data, could one conclude that the most recent climate trend is catastrophic, as some claim?

6 *Visual 5.4: Vostok ice core data* presents temperature estimates for the past 450,000 years. Over the course of history, abrupt temperature shifts have not been uncommon. It is important to recognize that this pattern of warming and cooling has occurred regardless of human activities.

7 Hand out *Worksheet 5.1: Is there more to the story?* Have students read the worksheet and answer the questions.

8 Discuss students' answers to Worksheet 5.1.

9 Handout *Worksheet 5.2: The rest of the story* and answer the questions in class. Encourage discussion using Worksheet 5.2: Answer Key. Did any of the students change their opinion? Carefully work through each problem in the lesson and talk about the how the data presented in *Visual 5.1: US temperature change* may have affected the students' initial conclusions.

10 Display *Visual 5.5: Hurricane frequency 1970-2007*. This truncated data set makes it appear as though the number of category 4 and 5 hurricanes in the United States has increased over time. In fact, there were fewer such hurricanes between 1970 and 1990 than there were from 1944 to 1959 and from 1991 to 2007. This pattern can be seen in *Visual 5.6: Hurricane frequency, 1944-2007*, which reflects a more complete data set.

11 *Visual 5.7: US hurricane costs* shows that the costs arising from large storms hitting the United States have risen since the early 1900s. But this is not a result of warmer temperatures. This increase in losses is actually due to the growth of populations in coastal regions and the increased value of infrastructure and personal property in the areas where large storms are most likely to hit.

Visual 5.8: Normalized US hurricane costs adjusts the cost figures for the rise in population and property values. The normalized figure does not have the same visual implications as the previous figure, and suggests no patterning towards more severe hurricanes.

12 Emphasize that graphs do not always tell the whole story. Students should be cautious about jumping to conclusions and should be diligent when interpreting research reports. Discuss the importance of integrity in reporting research findings and the need for people to examine research from a variety of sources.

13 Have students work through *Worksheet 5.3: Hurricanes, 1970-2007* and then share their answers in class. Ask them to tell the class how they arrived at their conclusions.

14 Have students complete *Worksheet 5.4: Hurricanes, 1944-2007* and then share their answers with the class. Encourage discussion using Worksheet 5.4 Answer Key. If their answers to the questions in Worksheet 5.4 are different from their answers to Worksheet 5.3, ask them why they think they arrived at different conclusions. Explain that the first graph is based on a truncated data set, and thus offers a less complete picture of the data.

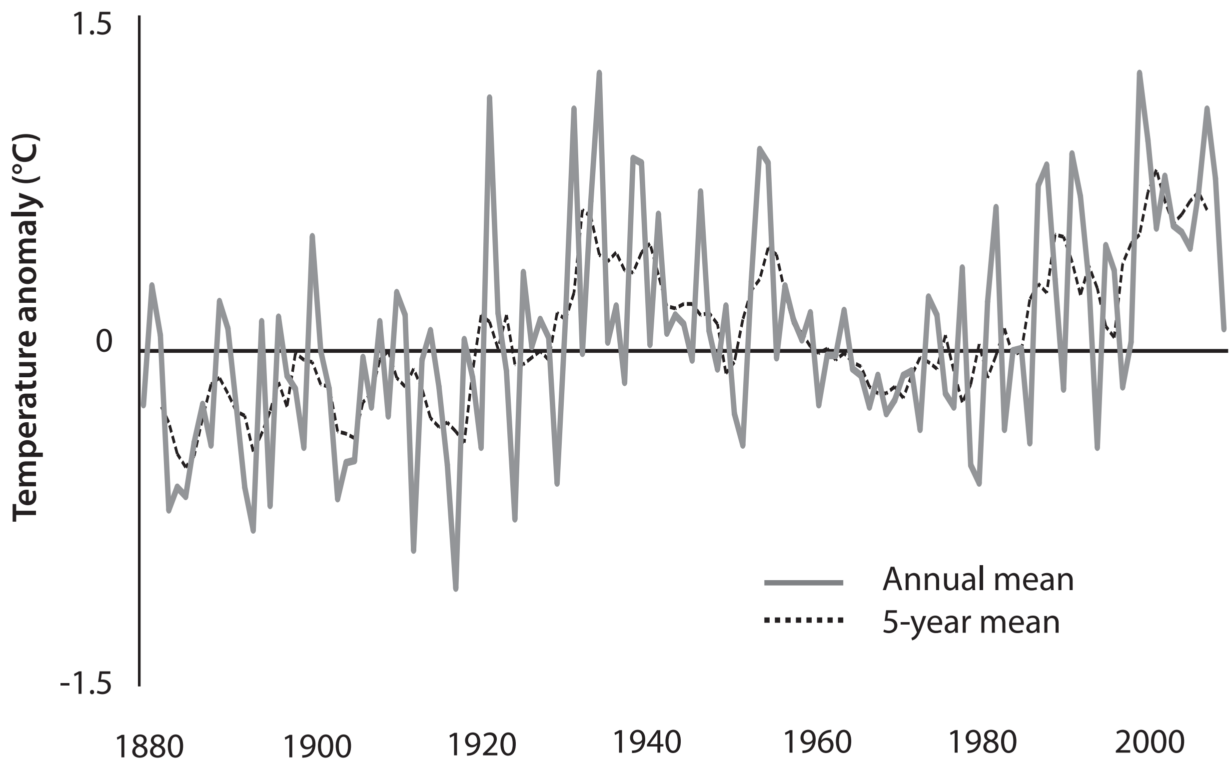
Reference

1 Schneider, Nicholas (2008). *Understanding Climate Change*. Fraser Institute.

Visual 5.1

US temperature change

Annual mean temperature change in the United States, 1880-2008

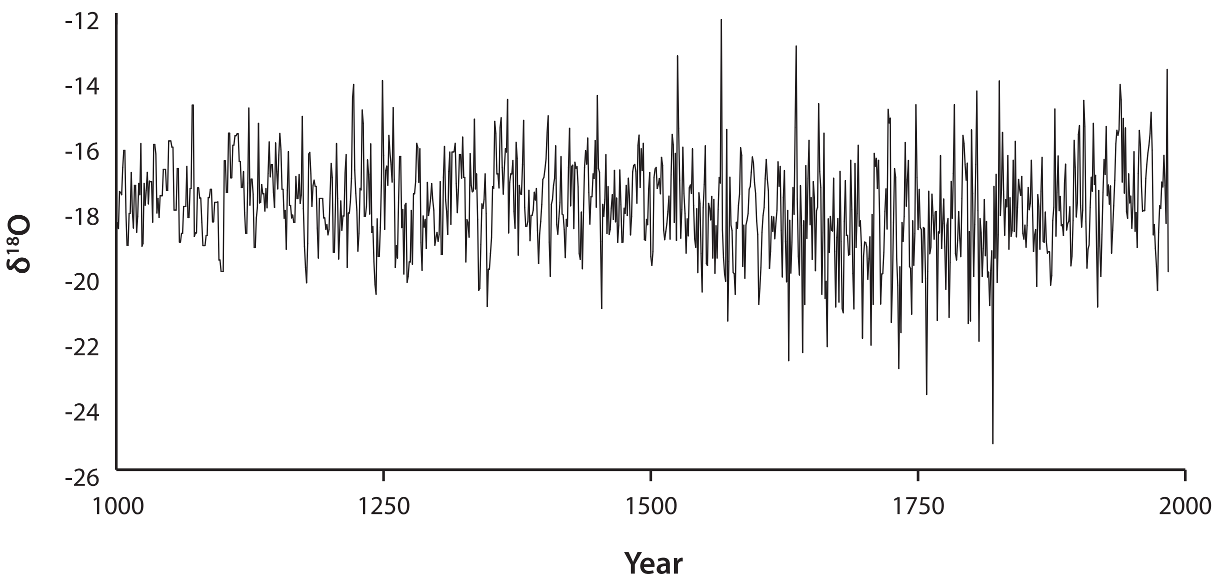


Source: NASA Goddard Institute for Space Studies (2009). *GISS Surface Temperature Analysis*. <http://data.giss.nasa.gov/gistemp/graphs/>.

Visual 5.2

Quelccaya ice core data

Quelccaya Glacier, Peru, temperature data, 1000-2000

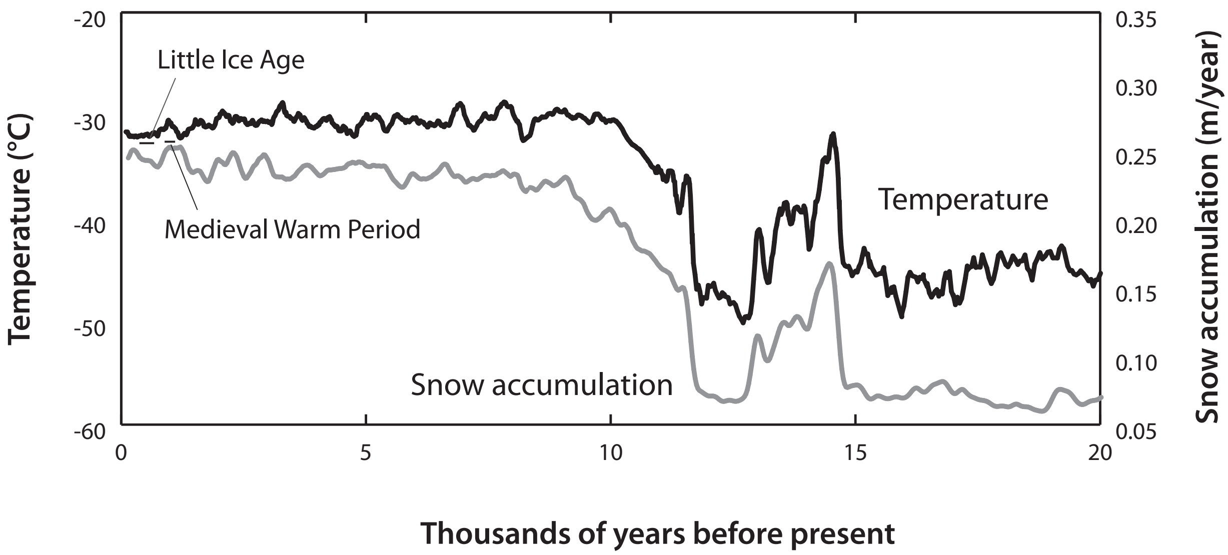


Note: $\delta^{18}O$ is a measure of the ratio of stable isotopes ^{18}O : ^{16}O. It is used as a proxy for temperature.
Source: Thompson, L. (1992). *Quelccaya Ice Core Database*. World Data Center for Paleoclimatology. <http://www.ncdc.noaa.gov/paleo/icecore/trop/quelccaya/quelccaya_data.html>.

Visual 5.3

Greenland ice core data

Greenland Ice Sheet Project 2 ice core temperature and snow accumulation data (present to 20,000 years ago)

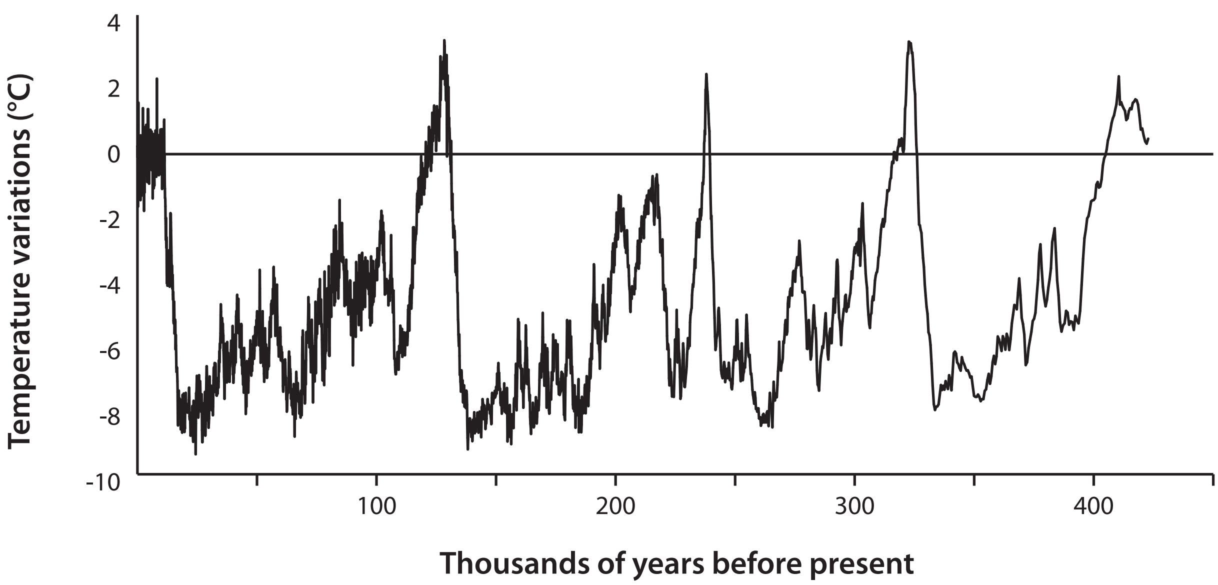


Source: Alley, R.B. (2000). *GISP2 Ice Core Temperature and Accumulation Data*. World Data Center for Paleoclimatology. <ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/greenland/summit/gisp2/isotopes/gisp2_temp_accum_alley2000.txt>.

Visual 5.4

Vostok ice core data

Historical isotopic temperature record from the Vostok ice core (present to 450,000 years ago)



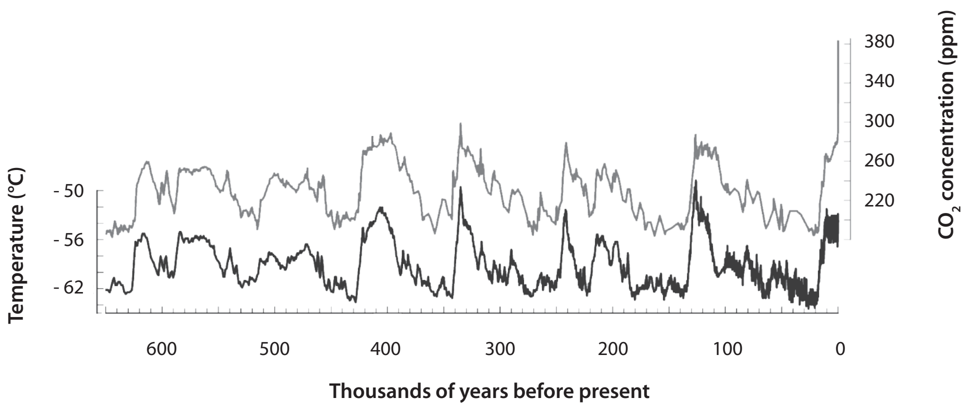
Source: Petit, J.R., D. Raynaud, C. Lorius, J. Jouzel, G. Delaygue, N.I. Barkov, and V.M. Kotlyakov (2000). *Historical Isotopic Temperature Record from the Vostok Ice Core*. Carbon Dioxide Information Analysis Center, US Department of Energy. <http://cdiac.ornl.gov/ftp/trends/temp/vostok/vostok.1999.temp.dat>.

Worksheet 5.1

Is there more to the story?

The following graph has been used widely to support the hypothesis that climate change is caused by human activities, including the use of fossil fuels.

Figure 5-A: Estimated temperature and carbon dioxide levels in Antarctica over the past 650,000 years



Source: Physics Institute, University of Bern, Switzerland. Adapted from Fretwell, Holly (2007). *The Sky's Not Falling: Why It's OK to Chill about Global Warming*. World Ahead Media.

Figure 5-A shows temperature changes and atmospheric levels of CO_2 for the past 650,000 years. The data used to construct this graph were collected from ice cores in Antarctica.

Referring to the graph, answer the following questions:

1 Is there a correlation between atmospheric levels of CO_2 and temperatures? Explain.

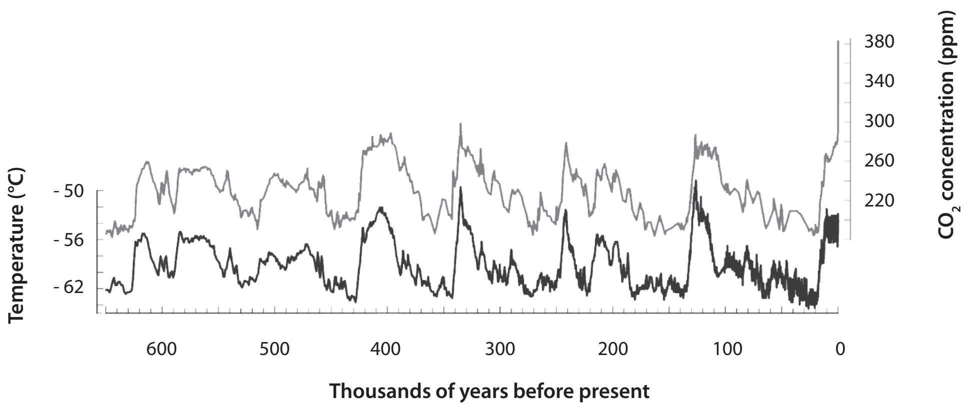
2 Is this evidence that emissions of CO_2 from human activities are causing climate change? Explain.

Worksheet 5.2

The rest of the story

The graph below is identical to Figure 5-A on Worksheet 5.1, but this worksheet includes additional information concerning the numerical data.

Figure 5-B: Estimated temperature and carbon dioxide levels in Antarctica over the past 650,000 years



Source: Physics Institute, University of Bern, Switzerland. Adapted from Fretwell, Holly (2007). *The Sky's Not Falling: Why It's OK to Chill about Global Warming*. World Ahead Media.

Though the graphs may appear to demonstrate otherwise, the raw data set used to construct Figures 5-A and 5-B shows that temperature changes occur about 800 years, on average, before atmospheric CO_2 levels change.

Using the additional information provided, answer the following questions:

1 Is there a correlation between atmospheric levels of CO_2 and temperatures? Explain.

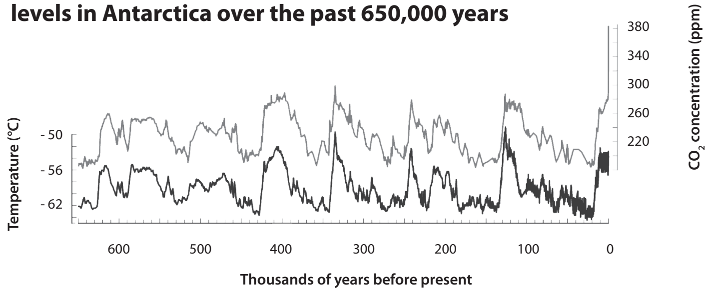
2 Is this evidence that emissions of CO_2 from human activities are causing climate change? Explain.

3 The data show that changes in temperature precede changes in CO_2. Is this sufficient evidence to conclude that changes in temperatures are causing changes in CO_2?

Worksheet 5.2 Answer Key

The rest of the story

Figure 5-B: Estimated temperature and carbon dioxide levels in Antarctica over the past 650,000 years



Using the additional information provided, answer the following questions:

1 Is there a correlation between atmospheric levels of CO_2 and temperatures? Explain.

There is a simple correlation between CO_2 levels and temperature as they tend to increase and decrease in a similar pattern. In the natural world, many observable events are correlated. There are times when one event may directly or partially cause the other, in which case correlation does mean causation. Other times, the correlated events could be caused by some external variable or may be purely coincidental. Figure 5-B shows a correlation but does not provide enough evidence to determine causation. It is true that human activities have led to an increase in CO_2 levels in the last 100 years, but it is unclear what effect, if any, this has had on temperatures.

2 Is this evidence that emissions of CO_2 from human activities are causing climate change? Explain.

No. Correlation is not causation. It is possible that one factor is causing the other, but it is also possible that external factors are affecting both CO_2 levels and temperature. Given the historic lag of CO_2 changes behind temperature changes, it is unlikely that changes in CO_2 alone are causing changes in temperatures. Atmospheric CO_2 levels, however, may still have an impact on the rate of temperature change (as evidenced by the slow decline in temperatures over time while CO_2 levels remain relatively high).

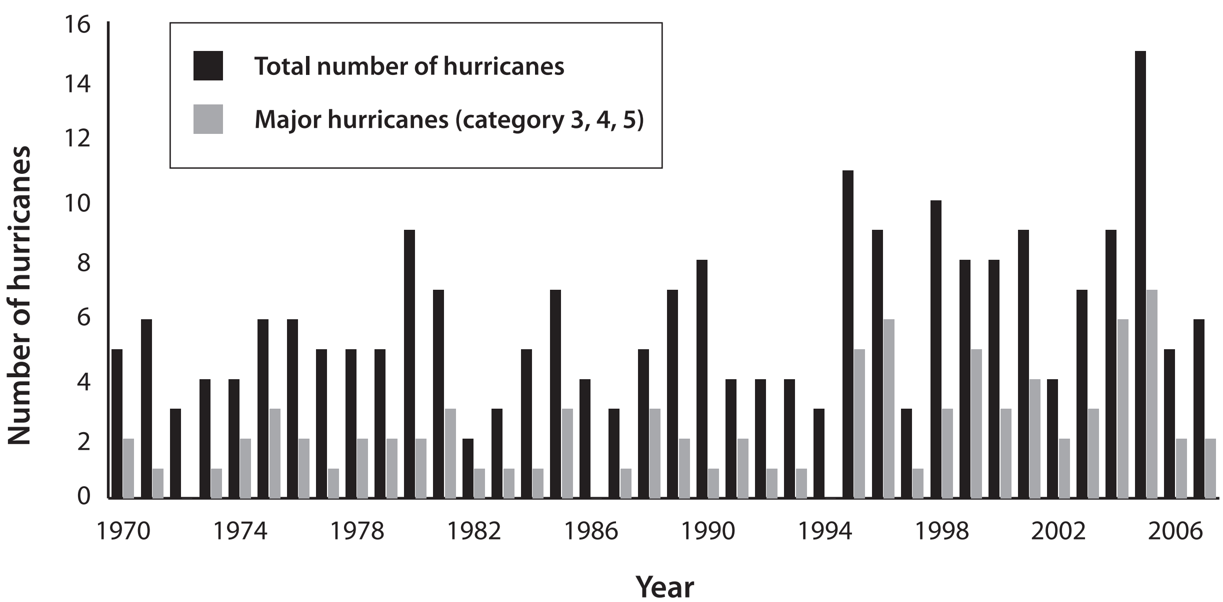
3 The data show that changes in temperature precede changes in CO_2. Is this sufficient evidence to conclude that changes in temperatures are causing changes in CO_2?

No. The graph alone does not provide sufficient information to conclude that temperature changes are causing changes in CO_2 levels.

Visual 5.5

Hurricane frequency, 1970-2007

Number of hurricanes and major hurricanes (category 3, 4, 5), Atlantic Basin, 1970-2007



Source: Unisys (2008). *Atlantic Tropical Storm Tracking by Year*. Unisys Weather. <http://weather.unisys.com/hurricane/atlantic/index.html>.

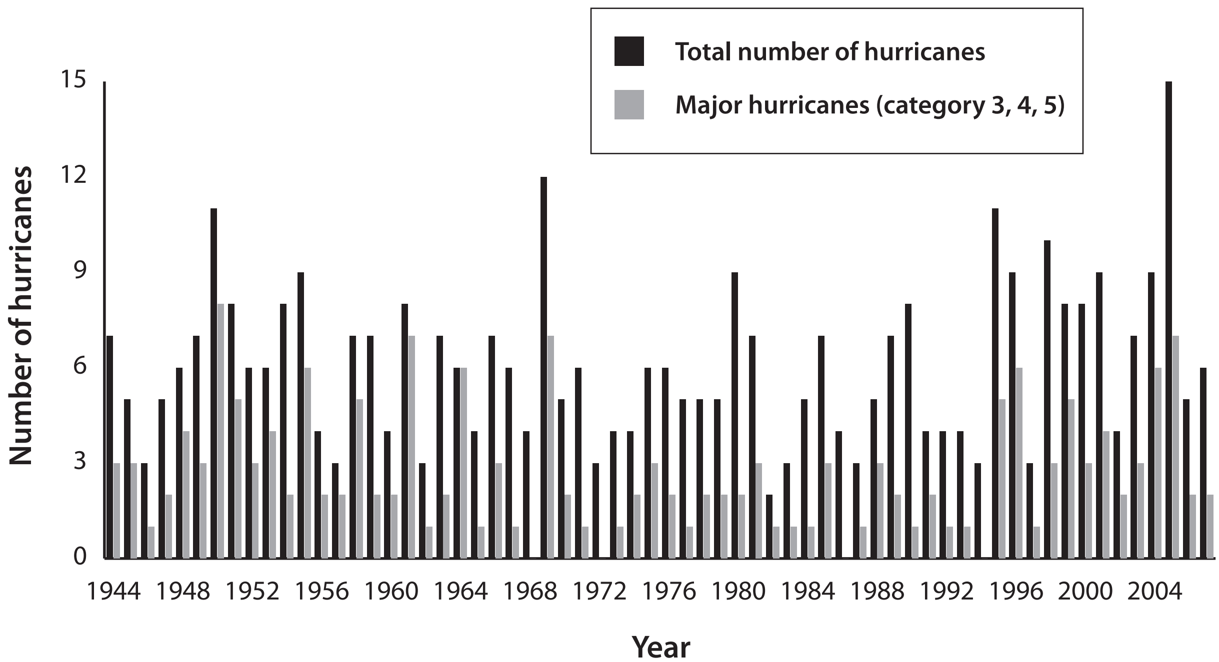
5

Visual 5.5

Visual 5.6

Hurricane frequency, 1944-2007

Number of hurricanes and major hurricanes (category 3, 4, 5), Atlantic Basin, 1944-2007

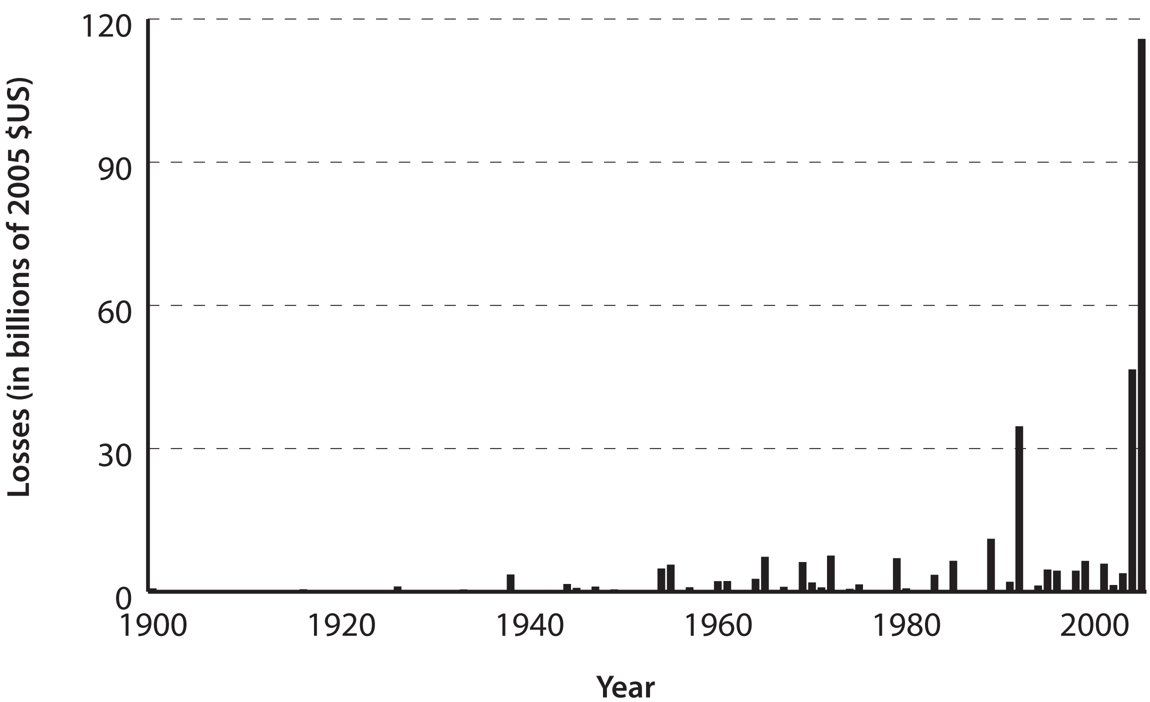


Source: Unisys (2008). *Atlantic Tropical Storm Tracking by Year*. Unisys Weather. <http://weather.unisys.com/hurricane/atlantic/index.html>.

Visual 5.7

US hurricane costs

Total losses per year from Atlantic tropical cyclones, adjusted for inflation to 2005 dollars, 1900-2005

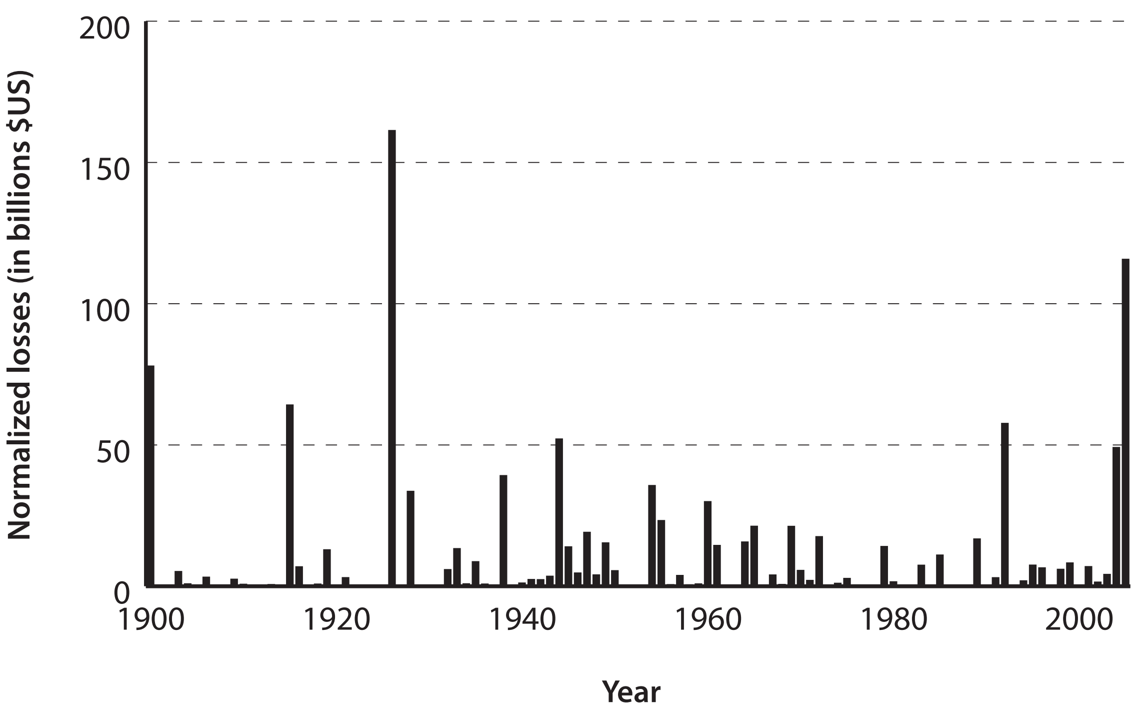


Source: Pielke, Roger A., Jr, Joel Gratz, Christopher W. Landsea, Douglas Collins, Mark A. Saunders, and Rade Musulin (2008). Normalized Hurricane Damage in the United States: 1900–2005. *Natural Hazards Review* 9, 1 (February): 29–42.

Visual 5.8

Normalized US hurricane costs

Normalized losses per year from Atlantic tropical cyclones, 1900-2005

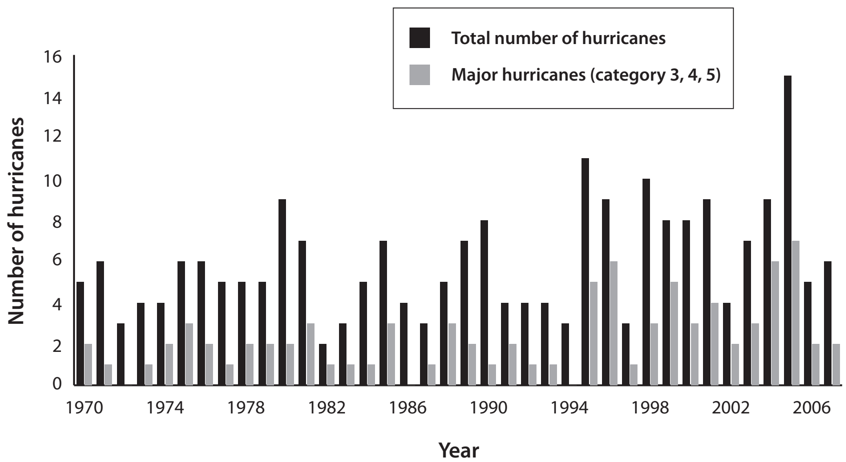


Source: Pielke, Roger A., Jr, Joel Gratz, Christopher W. Landsea, Douglas Collins, Mark A. Saunders, and Rade Musulin (2008). Normalized Hurricane Damage in the United States: 1900–2005. *Natural Hazards Review* 9, 1 (February): 29–42.

Worksheet 5.3

Hurricanes, 1970-2007

Number of hurricanes and major hurricanes (category 3, 4, 5), Atlantic Basin, 1970-2007



Source: Unisys (2008). *Atlantic Tropical Storm Tracking by Year*. Unisys Weather. <http://weather.unisys.com/hurricane/atlantic/index.html>.

This graph shows the frequency of hurricanes in the Atlantic Basin. Category 1 hurricanes are the least powerful, with wind speeds between 119 and 153 km per hour. Category 2 and 3 hurricanes carry wind speeds from 154 to 209 km per hour. Category 4 and 5 hurricanes, such as Hurricane Katrina in 2005, have wind speeds of 210 km per hour and greater.

1 Has the number of hurricanes in the Atlantic Basin increased over time?

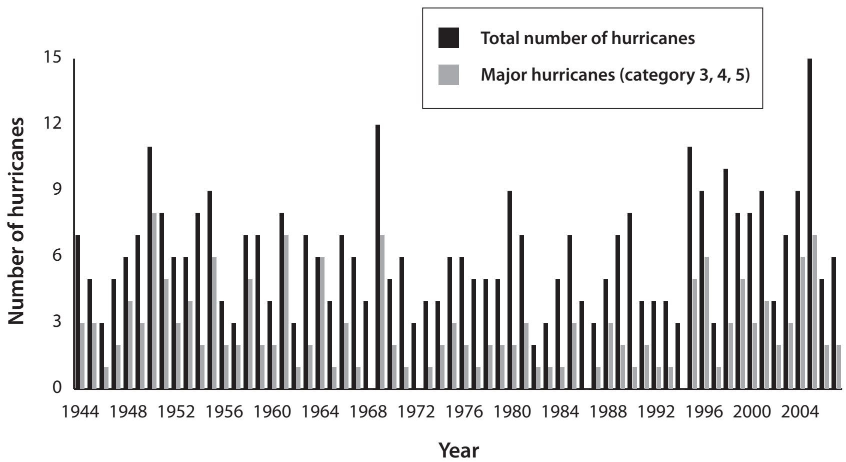
2 Have hurricanes in the Atlantic Basin become stronger over time?

3 Does this data support the hypothesis that climate change caused by human activities has affected the intensity and frequency of hurricanes?

Worksheet 5.4

Hurricanes, 1944-2007

Number of hurricanes and major hurricanes (category 3, 4, 5), Atlantic Basin, 1944-2007



Source: Unisys (2008). *Atlantic Tropical Storm Tracking by Year*. Unisys Weather. <http://weather.unisys.com/hurricane/atlantic/index.html>.

5

Worksheet 5.4

This graph shows the frequency of hurricanes in the Atlantic Basin. Category 1 hurricanes are the least powerful, with wind speeds between 119 and 153 km per hour. Category 2 and 3 hurricanes carry wind speeds from 154 to 209 km per hour. Category 4 and 5 hurricanes, such as Hurricane Katrina in 2005, have wind speeds of 210 km per hour and greater.

1 Has the number of hurricanes in the Atlantic Basin increased over time?

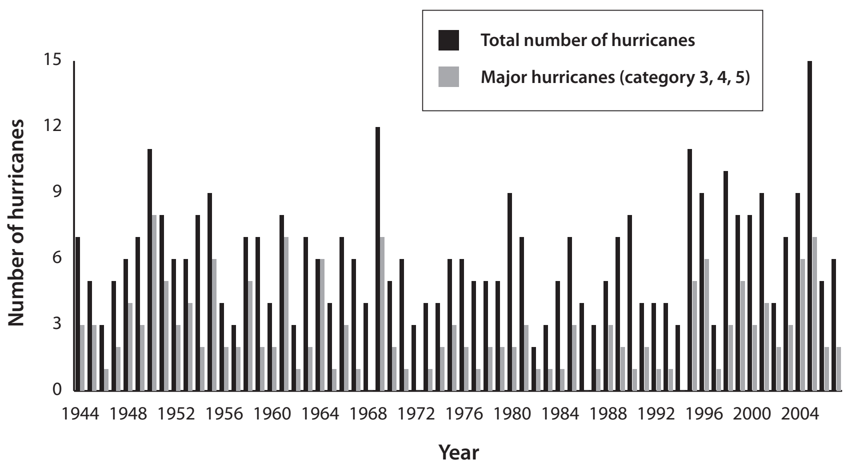
2 Have hurricanes in the Atlantic Basin become stronger over time?

3 Does this data support the hypothesis that climate change caused by human activities has affected the intensity and frequency of hurricanes?

Worksheet 5.4 Answer Key

Hurricanes, 1944-2007

Number of hurricanes and major hurricanes (category 3, 4, 5), Atlantic Basin, 1944-2007



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Worksheet 5.4 Answer Key

This graph shows the frequency of hurricanes in the Atlantic Basin. Category 1 hurricanes are the least powerful, with wind speeds between 119 and 153 km per hour. Category 2 and 3 hurricanes carry wind speeds from 154 to 209 km per hour. Category 4 and 5 hurricanes, such as Hurricane Katrina in 2005, have wind speeds greater than 211 km per hour.

1 Has the number of hurricanes in the Atlantic Basin increased over time?

It appears as though the number of hurricanes may be slightly up, but the number of major hurricanes is slightly down.

2 Have hurricanes in the Atlantic Basin become stronger over time?

No. The number of major hurricanes has decreased slightly over time.

3 Does this data support the hypothesis that climate change caused by human activities has affected the intensity and frequency of hurricanes?

No. This data does not provide enough evidence to demonstrate a correlative or causative relationship between hurricanes and climate change.

Lesson 5-B

Climate forces

Theme

This lesson demonstrates that it is possible to mislead an audience using various graphing techniques, even if the same data are used.

Purpose

This lesson illustrates that the very same set of data can be manipulated graphically in various ways, suggesting various conclusions. It teaches students to think critically when interpreting graphs.

Description

Students will analyze and interpret three graphs that show temperature trends. Though each graph looks very different, they are all based on the same data set. Students will learn that they need to be cautious when interpreting graphs.

Procedure

1 Break the class into small groups. Hand out one of the three temperature anomaly charts to each group.

2 Explain that temperature data are often reported as "anomaly values," that is, the amount by which temperatures deviate from the average. For example, if the average temperature between 1950 and 2000 was 10° C, and the average temperature in 1988 was 11° C, then the reported temperature anomaly would be 1° C for that year.

3 Give each group five to 10 minutes to discuss their temperature anomaly graph. Each group will determine what the graph shows them about temperatures over time.

4 Display the temperature anomaly graphs one at a time. Have each group explain their conclusions about whether temperatures are changing over time based on the data provided by their graph. Point out the differences in conclusions among the groups.

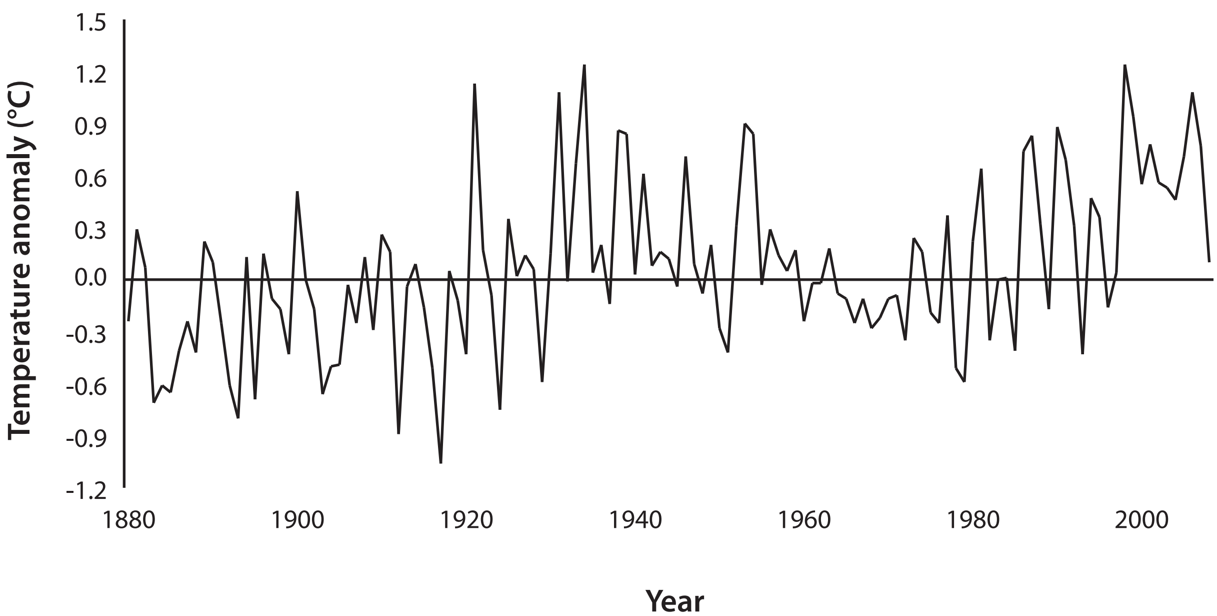
5 When all groups are finished, tell students that all three graphs represent the same data. The only difference is the temperature scale on the left side of the diagram and the use of a line graph instead of data points. Altering the scales of a graph can be a powerful tool that students should learn to recognize.

6 Ask students to explain why researchers who have access to the same data may present their findings in a way that could lead their respective audiences to different conclusions.

Visual 5.9

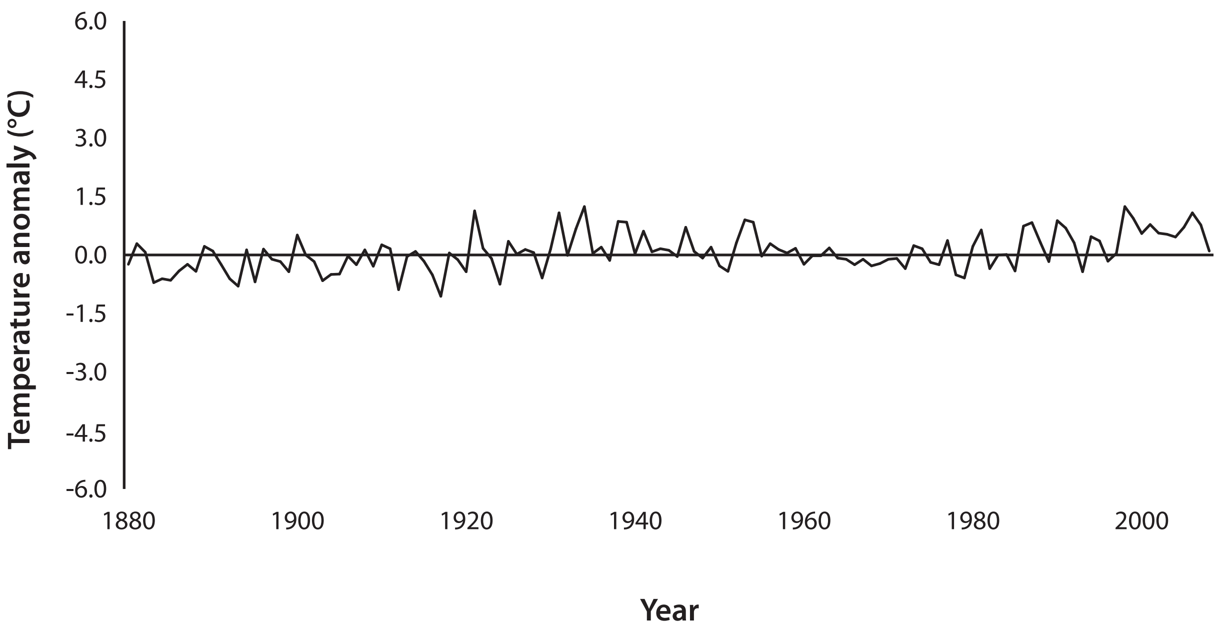
Temperature anomaly - Location 1

Temperature anomaly, Location 1, 1880-2008



Visual 5.10
Temperature anomaly - Location 2

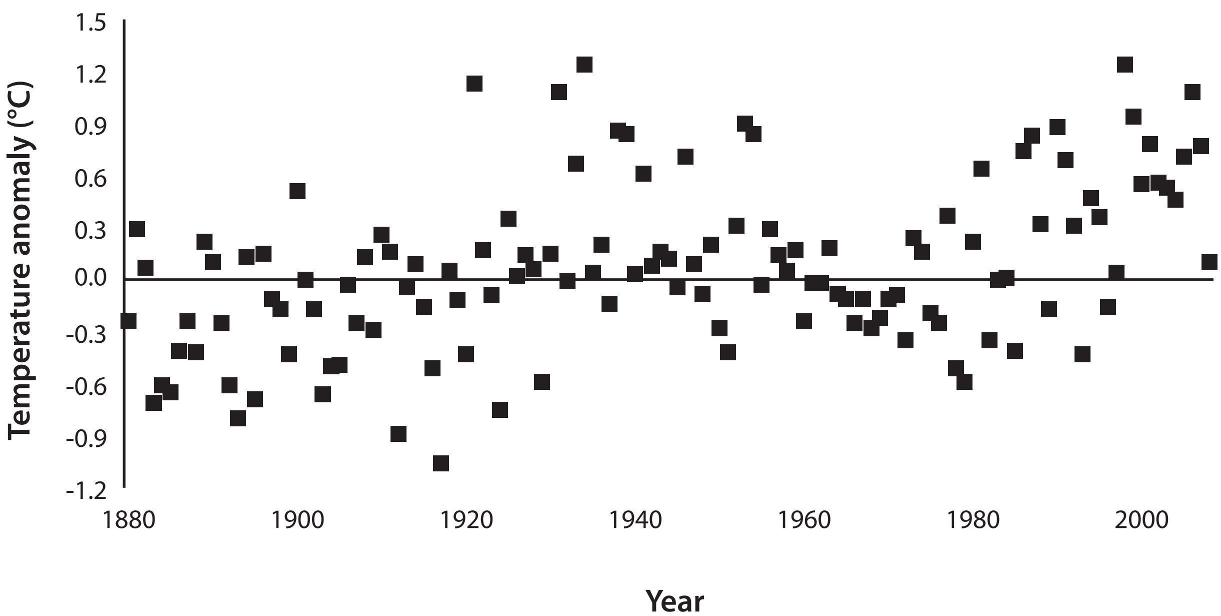
Temperature anomaly, Location 2, 1880-2008



Visual 5.11

Temperature anomaly - Location 3

Temperature anomaly, Location 3, 1880-2008



6 Choices

Introduction

What would you do with a birthday gift of $100? The money could be spent in a number of ways, but it could only be spent once. That means that trade-offs would have to be made: if you bought one item for $100, then you would not be able to do anything else with that birthday money.

Economics examines how people make choices. It reminds us that choices are necessary because most resources are scarce. The amount of money people have is limited, and the goods we can buy and the resources needed to make them are finite.

Many economists say nothing is truly free. Even the air we breathe, although abundant, is not free and limitless. The air, like most everything else, is not an isolated resource—it can be affected both positively and negatively by our actions. Thus, we pay for it indirectly through the cost of emissions controls on autos, factories, and many other sources of emissions, for example.

In 2004, eight of the world's most distinguished economists were invited to participate in the Copenhagen Consensus project. As part of the project, this panel of experts was asked to evaluate how they would allocate scarce resources to enhance human well-being. The panel was asked to consider the various challenges facing the world and answer the question, "What would be the best ways of advancing global welfare, and particularly the welfare of developing countries, supposing that an additional $50 billion of resources were at governments' disposal?"

The panel categorized the various opportunities according to the benefits that would come as a result of each dollar spent. Bad opportunities were those for which a dollar spent provided less than a dollar's worth of benefits. Fair opportunities returned at least one dollar for each dollar spent. Good opportunities had a return greater than dollar for dollar. The panel then listed the opportunities in order of return (see Table 6.1, pg. 96).

Interestingly, addressing climate change was found to be a "bad opportunity," and was placed at the bottom of the list.

It is often believed that governments can solve our environmental and social problems. It is important to understand, however, that even government resources are limited. Even the wealthiest countries cannot afford to do everything. We must weigh the expected costs and benefits of our decisions.

Table 6.1: Global priority list from the Copenhagen Consensus 2004, in descending order of desirability

	Challenge	Opportunity
Very good opportunities	Diseases	Control of HIV/AIDS
	Malnutrition	Provision of micro-nutrients
	Subsidies/Trade	Trade liberalization
	Diseases	Control of malaria
Good opportunities	Malnutrition	Development of new agricultural activities
	Sanitation/Water	Small-scale water technology for livelihoods
	Sanitation/Water	Community-managed water supply and sanitation
	Sanitation/Water	Research on water productivity for agriculture
	Government	Lowering the cost of starting a new business
Fair opportunities	Migration	Lowering barriers to migration for skilled workers
	Malnutrition	Improving infant and child nutrition
	Malnutrition	Reducing the prevalence of low birth weight
	Diseases	Scaled-up basic health services
Bad opportunities	Migration	Guest worker programs for the unskilled
	Climate	Optimal carbon tax ($25-$300)
	Climate	The Kyoto Protocol
	Climate	Value-at-risk carbon tax ($100-$450)

Source: Copenhagen Consensus (2004). *Copenhagen Consensus 2004*. Copenhagen Consensus Center. <http://www.copenhagenconsensus.com/Home-1.aspx>.

Around the world, there are many proposals to reduce carbon emissions, each of which would require trade-offs. Several questions should be asked to help determine the efficacy of such proposals, including:

1 What are the expected benefits of the proposal?

2 What are the expected costs of the proposal?

3 What are the trade-offs?

4 Could financial resources be better spent on other programs?

CO_2 emissions are both natural and the by-product of human activities, and it is true that human activities have increased CO_2 levels. However, we still do not know what impact, if any, these emissions have had or will have on the climate. Nor are we certain that reducing levels of CO_2 in the atmosphere will have any effect on the climate.

Given the uncertainty surrounding the impact of CO_2 on the climate, it is difficult to know what the benefits of any CO_2 emissions reduction policy would be.

There is a range of estimates for emission reduction costs under the Kyoto Protocol. One often-cited estimate is that it would cost US$180 billion annually for the next 100 years for all developed nations. [1]

The high costs and uncertain benefits of emission reduction proposals need to be weighed against other spending choices. For example, at a cost of about $3 billion per year, the annual death toll from malaria, currently one million people, could be reduced by 75% by 2085. [2] Malaria is still so prevalent in Africa that it consumes nearly half of all clinic services on the continent. [3]

Furthermore, it is estimated that 1.1 billion people in the world lack access to potable water. The World Health Organization (WHO) estimates that an investment of $37.5 billion over the next 10 years would reduce by half the proportion of people currently living without access to safe drinking water. [4]

Poverty is also a significant problem worldwide, particularly in developing countries. For example, three-quarters of the population in Sub-Saharan Africa in 2001 were living below the international poverty level of US$2.15 a day. [5]

By contrast, the median family income in Canada is CA$63,600, or CA$174 a day. [6] Canada's greater wealth brings with it much higher living standards—and greater CO_2 emissions. The average Canadian emits about 19 metric tons of CO_2 each year. The average for all of Africa is 1.16 metric tons per person each year. [7]

In Kenya, more than half of the population (about 300 million people) do not have access to safe drinking water, the majority of houses have dirt floors, and only 15% of homes are connected to an electricity grid. [8]

Highly developed nations send CO_2 into the atmosphere by producing and using energy. That energy use provides innumerable benefits worldwide. These benefits include advances in medicine, which save lives and improve the health of people everywhere, and developments in agricultural technologies, which have vastly improved the quality and quantity of food, reducing famine around the world.

As our incomes rise, we can afford to spend resources on improving the world. In doing so, we can act responsibly by prioritizing the use of resources based on the greatest return.

References

1 Lomborg, Bjørn (2007). *Perspective on Climate Change*. Prepared statement, given before the Subcommittee on Energy and Air Quality and the Subcommittee on Energy and Environment of the Congressional Committee on Science and Technology, March 21, 2007. <http://energycommerce.house.gov/cmte_mtgs/110-eaq-hrg.032107.Lomborg-testimony.pdf>, as of January 7, 2007.

2 Goklany, Indur M. (2007). *The Improving State of the World*. CATO Institute.

3 Grabowsky, Mark (2008). The Billion-Dollar Malaria Moment. *Nature* 451 (February 28): 1051–52. <http://www.nature.com/nature/journal/v451/n7182/full/4511051a.html>.

4 World Health Organization (2002). Choosing Interventions to Reduce Specific Risks. In *The World Health Report 2002: Reducing Risks, Promoting Healthy Life*. <http://www.who.int/whr/2002/chapter5/en/index5.html>.

5 United Nations Development Programme (2005). *Investing in Development: A Practical Plan to Achieve the Millennium Development Goals*. <http://www.unmillenniumproject.org/reports/index_overview.htm>, as of March 6, 2008.

6 Statistics Canada (2009). *Median Total Income, by Family Type, by Census Metropolitan Area*. Last updated February 11, 2009. <http://www40.statcan.gc.ca/l01/cst01/famil107a-eng.htm>.

7 Energy Information Administration (2005). *International Carbon Dioxide Emissions and Carbon Intensity*. <http://www.eia.doe.gov/emeu/international/carbondioxide.html>, as of January 25, 2008.

8 United Nations Development Programme (2005). *Millennium Development Goals in Kenya: Needs and Costs*. <http://www.un-kenya.org/MDGsKenya/MDGNeedsAssessment.pdf.>

Lesson 6-A
Choices

Theme

Economics is about choices and trade-offs. Because we live in a world with limited resources, it is important to understand that we cannot have everything we desire. How we use resources involves trade-offs; we need to choose between the options available to us.

Purpose

This lesson will help students understand the importance of trade-offs and of evaluating the costs and benefits of proposals to address climate change.

Description

Students will imagine that they have received a birthday gift of $100 and will decide how they would like to spend the money. This will help students understand the need to make choices or trade-offs.

Procedure

1 Hand out *Worksheet 6.1: Birthday money*. Have students imagine that they were given $100 for their birthday. Using the first column on the handout, students will list in order of preference the items they would like to buy with that $100 (saving is an acceptable use of the money). In the second column, students will write the estimated cost of each item they would like to purchase.

2 Have students think about how their priorities would change if the price per liter of gas increased by $1? By $3? Increases in fuel costs impact virtually every product and service since we often have to transport items around the world both during the manufacturing process and afterwards, when the items are ready to be sold.

3 In the third column, have students increase the price of their desired items by 30% (multiply the price of each item by 1.3). Students should then circle the items they can still afford and intend to buy. Have students discuss what they had to give up. Ask them to think about the impact price increases have on households.

4 Pose this question to the class: if $100 was given to the class instead of to each individual, how would they determine how to spend the money? On the board, write the various items students believe should be bought with the $100. Discuss methods that could be used to determine how the money should actually be spent.

This is essentially what governments do. They have a limited amount of resources and an unlimited number of demands from their constituents. It is up to politicians and other government personnel to determine how those resources will be used. Money and resources used in one way will no longer be available to be used in another way.

5 To put this into perspective, have students think about what their families can afford to buy compared to households across the world. Work through *Visual 6.1: Global household budgets*, discussing the differences in the incomes of people around the world. Encourage students to think about what it would mean for families in Ecuador or Chad if their household costs increased—what might these families have to give up to afford the same amount of food? Have them fill out *Worksheet 6.2: Rising energy prices and unseen consequences* and discuss their answers.

6 Explain that the policy decisions made here in Canada and the United States have an impact on global prices. Energy, for example, is an input in food production. When energy prices rise, the cost of food production also increases, thus increasing the cost to the consumer. Policies aimed at reducing carbon emissions, such as a carbon tax, will increase the price of energy and thus may have far-reaching effects beyond our own borders.

Worksheet 6.1

Birthday money

Name ____________________________

Imagine that you have received a birthday gift of $100. Think about how you would like to spend the money. In the column on the left, list in order of preference the items you might buy (savings is an acceptable choice). In the second column, write the approximate price of the item. In the third column, increase the price of each item by 30% (multiply each price by 1.3). Then circle the items you can still afford and intend to buy.

	Purchase preference	Price	Adjusted price
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			
12.			

Visual 6.1
Global household budgets

The average family in **Ecuador**

Weekly household expenditures: **$36.15**

Weekly income: **$54.75**

The average family in **Chad**

Weekly household expenditures: **$6.68**

Weekly income: **$11.17**

The average family in **Canada**

Weekly household expenditures: **$373.45**

Weekly income: **$673.94**

Maps: Central Intelligence Agency (2008). *The World Factbook: Reference Maps*. <https://www.cia.gov/library/publications/the-world-factbook/docs/refmaps.html>.

*Current 2005 US dollars.
Household expenditures include: shelter, food, clothing, utilities, health care, transportation, appliances, furniture, linens, toiletries, electronics, and entertainment.

Source: World Bank (2008). *World Development Indicators Online*. World Bank. Calculations by authors.

Worksheet 6.2

Rising energy prices and unseen consequences

Use the information provided in *Visual 6.1: Global household budgets* to answer the following questions and fill in the table below.

A How much money do these families have left over once they cover their household costs?

B What percentage of their income do these families spend on household costs?

C How much money would each family have left over if household costs increased by 5% due to rising energy costs?

D How much money would each family have left over if household costs increased by 10% due to rising energy costs?

E If household costs increased by 10%, what percentage of their income would each family have to spend on household costs?

	A.	B.	C.	D.	E.
Ecuador					
Chad					
Canada					

What "extras" do you think these families could purchase with the money left over after they have covered their household costs?

With less money left over, what opportunities would these families have to forgo, in terms of savings and investment?

Worksheet 6.2 Answer Key

Rising energy prices and unseen consequences

Use the information provided in *Visual 6.1: Global household budgets* to answer the following questions and fill in the table below.

A How much money do these families have left over once they cover their household costs?

B What percentage of their income do these families spend on household costs?

C How much money would each family have left over if household costs increased by 5% due to rising energy costs? = *income - (household spending x 1.05)*

D How much money would each family have left over if household costs increased by 10% due to rising energy costs? = *income - (household spending x 1.10)*

E If household costs increased by 10%, what percentage of their income would each family have to spend on household costs? $= \frac{\textit{household spending x 1.10}}{\textit{weekly income}}$

6

Worksheet 6.2 Answer Key

	A.	B.	C.	D.	E.
Ecuador	$18.60	66%	$16.79	$14.99	73%
Chad	$4.49	60%	$4.16	$3.82	66%
Canada	$300.49	55%	$411.73	$451.87	61%

What "extras" do you think these families could purchase with the money left over after they have covered their household costs?

They could pay taxes and mandatory deductions, pay interest on loans, add it to their savings, invest in their businesses, pay for education, invest the money for a return, etc.

With less money left over, what opportunities would these families have to forgo, in terms of savings and investment?

They would have less money to put toward education, business investments, and interest income from savings, etc.

Lesson 6-B

Policy trade-offs

Theme

This lesson introduces students to the task policy makers face in deciding how to address climate change.

Purpose

This lesson illustrates the fact that policy makers cannot please everyone, and that they must consider the wishes of various stakeholders when they make decisions.

Description

In this lesson, students will form their own policy recommendations by considering the potential costs and benefits of various proposals. Students will identify the constituents who would benefit and those who would be harmed by their policy recommendations.

Procedure

1 Display *Visual 6.2: Policy choices* and give students some background information on the origins of the table. Note where climate challenges were ranked. Tell students about some of the policy recommendations that have been put forward to address climate change. Currently, most climate change policies focus largely on reducing emissions of CO_2.

- Under a *cap-and-trade* scheme, the government sets an overall limit (a cap) on CO_2 emissions. Based on that cap, quotas are imposed on individual sources of emissions, such as utilities and factories. The government allocates "allowances" to each facility that represents the volume of their quota. A facility that can reduce its emissions to a level below its quota can sell its allowances to others for whom the cost of emission reductions is greater than the cost of purchasing credits (trade).
- Alternatively, the government may impose *carbon taxes* on emitters based on each ton of CO_2 emitted, or may tax the sale of energy in the form of gas or electricity, for example. In either case, the cost of goods and services would increase.

2 Discuss with students the costs of emissions regulations. Stricter emissions regulations would increase the price of most products. Remind students about the birthday money and of the items they had to forgo when the price of goods increased.

3 Have students discuss popular conceptions about the benefits of reducing CO_2 emissions. In light of the knowledge they have gained from these climate change lessons, do they believe that these benefits are realistic or possible? What trade-offs have to be made when CO_2 reduction policies are put into place?

4 Distribute *Worksheet 6.3: Policy choices*. Put students in small groups and have them discuss what they would do about climate change if they were policy makers.

5 Ask students to share their recommendations with the class. As each group reports its findings, write each policy recommendation on the board. Note which constituents would benefit and which would be adversely affected by each recommendation. Show students that even when sound science is the foundation of policy, there will always be winners and losers. Sometimes politicians focus on appeasing certain groups in order to further their political careers and interests, and ignore optimal policies as a result. In some cases, the politicians who are trying to create the most optimal policy are vilified in the media by groups who would be the "losers" if that policy were implemented.

6 There are costs associated with every policy decision. Have the class think about what could be done with the billions of dollars that are being spent on combating climate change. *Visual 6.3: The Millennium Development Goals* offers an overview of the development goals set by the United Nations for the UN Millennium Project. The UN has set out eight development goals, to be achieved by 2015, that would enhance human well-being. These goals are certainly viable alternatives to spending money on climate initiatives.

Before any decisions are made, however, a cost-benefit analysis should be considered. A brief economic analysis of the costs and benefits of the Millennium Development Goals is presented in *Visual 6.4: Costs and benefits of meeting the MDG by 2015*.

There are other alternatives available to us in addition to these goals. *Visual 6.5: Alternative actions* suggests some other actions we could take in place of the Millennium Development Goals.

Final Thought

It is important for students to understand that resources are limited. We cannot do everything; trade-offs must be made. This is as true for governments as it is for individuals. In addition, values are subjective and vary considerably among people. This is one reason why it is difficult for politicians to prioritize the many, often conflicting, demands of constituents.

Visual 6.2

Policy choices

Global priority list from the Copenhagen Consensus 2004, in descending order of desirability

	Challenge	Opportunity
Very good opportunities	Diseases	Control of HIV/AIDS
	Malnutrition	Provision of micro-nutrients
	Subsidies/Trade	Trade liberalization
	Diseases	Control of malaria
Good opportunities	Malnutrition	Development of new agricultural activities
	Sanitation/Water	Small-scale water technology for livelihoods
	Sanitation/Water	Community-managed water supply and sanitation
	Sanitation/Water	Research on water productivity for agriculture
	Government	Lowering the cost of starting a new business
Fair opportunities	Migration	Lowering barriers to migration for skilled workers
	Malnutrition	Improving infant and child nutrition
	Malnutrition	Reducing the prevalence of low birth weight
	Diseases	Scaled-up basic health services
Bad opportunities	Migration	Guest worker programs for the unskilled
	Climate	Optimal carbon tax ($25-$300)
	Climate	The Kyoto Protocol
	Climate	Value-at-risk carbon tax ($100-$450)

Source: Copenhagen Consensus (2004). *Copenhagen Consensus 2004*. Copenhagen Consensus Center. <http://www.copenhagenconsensus.com/Home-1.aspx>.

Worksheet 6.3

Policy choices

You are an elected official and your job is to design a policy that will address your constituents' concerns about climate change. Your policy recommendation must consider (1) the science of climate change, (2) the costs and benefits of the policy, and (3) the constituents involved. One member of your group will present your policy recommendation to the class.

Stakeholders are the individuals and groups that will have an interest in the policies you design. The following is a list of stakeholders you must consider when designing your policy.

- **Taxpayers**, some of whom may be concerned about climate change, but none of whom want their tax dollars to be wasted.
- **Oil companies** that are concerned about their public image and higher energy costs.
- **Alternative energy suppliers** that want subsidies to help lower the higher costs of their products. (Lower costs would help them to increase their market share.)
- **Environmental groups** that advocate dramatic reductions in CO_2, irrespective of the costs.
- **Low-income households** that cannot afford higher energy prices.

Scientific considerations:

Policy recommendation:

Costs and benefits:

Who will benefit from your policy? Who will pay the costs?

Visual 6.3

The Millennium Development Goals

The UN's ***Millennium Development Goals*** *(MDG) to be achieved by 2015*

1 **Eradicate extreme poverty and hunger**

1. Reduce extreme poverty by half
2. Reduce hunger by half

2 **Achieve universal primary education**

1. Universal primary schooling

3 **Promote gender equality and empower women**

1. Equal male-female enrollment in primary schools
2. Increase women's share of paid employment
3. Equal male-female representation in parliaments

4 **Reduce child mortality**

1. Reduce mortality of children aged five years old and younger by two thirds
2. Provide measles immunizations

5 **Improve maternal health**

1. Reduce maternal mortality by three quarters

6 **Combat HIV/AIDS, malaria, and other diseases**

1. Halt and reverse spread of HIV/AIDS
2. Halt and reverse spread of malaria
3. Halt and reverse spread of tuberculosis

7 **Ensure environmental sustainability**

1. Reverse loss of forests
2. Reduce proportion of people without improved drinking water by half
3. Reduce proportion of people without sanitation by half
4. Improve the lives of slum-dwellers

8 **Develop a global partnership for development**

1. Provide access to affordable essential medicines and new technologies
2. Improve the trade prospects of developing countries

Visual 6.4

Costs and benefits of meeting the MDG by 2015

Costs

- In low-income countries: **US$149 billion**
- In all countries: **US$189 billion**

Benefits

- Lifting **500 million** people out of extreme poverty (people living on less than US$1 per day)
- Feeding **300 million** near-starving people
- Saving **30 million** children who would die before age five
- Saving the lives of **2 million** mothers
- Supplying **350 million** people with clean drinking water
- Providing **650 million** people with basic sanitation
- Ensuring that **hundreds of millions** more women and girls will go to school, have access economic and political opportunity, and have greater security and safety

Source: United Nations Development Programme (2005). *Investing in Development: A Practical Plan to Achieve the Millennium Development Goals*. <http://www.unmillenniumproject.org/reports/index_overview.htm>.

Visual 6.5

Alternative actions

Alternative ACTIONS

Malaria

- Cost: $3 billion per year
- Benefit: Reduce malaria deaths by 75%, from 1 million to 250,000 people by 2085

Agricultural productivity

- Cost: $5 billion per year
- Benefit: Increase agricultural productivity so as to erase any climate change-caused agricultural decreases

Coastal area protection

- Cost: $1 billion per year
- Benefit: Protect land from a 0.5-meter rise in sea levels by 2100

Source: Goklany, Indur M. (2007). *The Improving State of the World*. CATO Institute.

References

Adam, David (2008, May 18). World Carbon Dioxide Levels Highest for 650,000 Years, Says US Report. *The Guardian*. <http://www.guardian.co.uk/environment/2008/may/13/carbonemissions.climatechange>.

Alley, R.B. (2000). *GISP2 Ice Core Temperature and Accumulation Data*. World Data Center for Paleoclimatology. <ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/greenland/summit/gisp2/isotopes/gisp2_temp_accum_alley2000.txt>.

Anderson, R. Warren, and Dan Gainor (2006). *Fire and Ice*. Business and Media Institute. <http://www.businessandmedia.org/specialreports/2006/fireandice/fireandice.asp>.

Bagenal, Fran (2005). *Atmospheric Evolution*. University of Colorado. <http://lasp.colorado.edu/~bagenal/3720/CLASS20/20AtmosEvol1.html>.

Blasing, T.J. (2008). *Recent Greenhouse Gas Concentrations*. Carbon Dioxide Information Analysis Center. <http://cdiac.esd.ornl.gov/pns/current_ghg.html>. Updated December 2008.

Bond, G., W. Showers , M. Cheseby, R. Lotti, P. Alsami, P. de Menocal, P. Priore, H. Cullen, I. Hajdas, and G. Bonani (1997). A Pervasive Millennial-Scale Cycle in North Atlantic Holocene and Glacial Climates. *Science* 278, 5431: 1257–66.

Caldeira, Ken, A.K. Jain, and Martin I. Hoffert (2003). Climate Sensitivity, Uncertainty and the Need for Energy without CO_2 Emissions. *Science* 299, 5615: 2052–54.

Central Intelligence Agency [CIA] (2008). *The World Factbook: Reference Maps*. <https://www.cia.gov/library/publications/the-world-factbook/docs/refmaps.html>.

Chahine, Moustafa T. (1992). The Hydrological Cycle and Its Influence on Climate. *Nature* 359: 373–80.

Christy, John (2007, November 1). My Nobel Moment. *Wall Street Journal*. <http://online.wsj.com/article/SB119387567378878423.html>.

Copenhagen Consensus (2004). *Copenhagen Consensus 2004*. Copenhagen Consensus Center. <http://www.copenhagenconsensus.com/Home-1.aspx>.

Energy Information Administration [EIA] (2005). *International Carbon Dioxide Emissions and Carbon Intensity*. <http://www.eia.doe.gov/emeu/international/carbondioxide.html>, as of January 25, 2008.

Financial Post (2006, April 6). Open Kyoto to Debate. <http://tinyurl.com/fpApr606>.

Fischer, Hubertus, Martin Wahlen, Jesse Smith, Derek Mastroianna, and Bruce Deck (1999). Ice Core Records of Atmospheric Carbon Dioxide Around the Last Three Glacial Terminations. *Science* 283, 5408: 1712–14.

Fretwell, Holly (2007). *The Sky's Not Falling: Why It's OK to Chill about Global Warming*. World Ahead Media.

Goklany, Indur M. (2007). *The Improving State of the World*. CATO Institute.

Goudarzi, Sara (2006, May 4). New Storm on Jupiter Hints at Climate Change. *Space*. <http://www.space.com/scienceastronomy/060504_red_jr.html>.

Grabowsky, Mark (2008). The Billion-Dollar Malaria Moment. *Nature* 451 (February 28): 1051–52. <http://www.nature.com/nature/journal/v451/n7182/full/4511051a.html>.

Houghton, J. T., G. J. Jenkins, and J.J. Ephraums (eds.) (1990). *Climate Change: The IPCC Scientific Assessment*. Cambridge University Press.

Intergovernmental Panel on Climate Change [IPCC] (2001). *Climate Change 2001: The Scientific Basis*. Contribution of Working Group I to the Third Assessment of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Intergovernmental Panel on Climate Change [IPCC] (2007). *Climate Change 2007: The Physical Science Basis*. Intergovernmental Panel on Climate Change. <http://www.ipcc.ch/ipccreports/ar4-wg1.htm>.

Kaleita, Amy (2009). *Sense and Sequestration: The Carbon Sequestration Cycle Explained*. Pacific Research Institute. <http://liberty.pacificresearch.org/docLib/20070202_2006_Carbon_seq.pdf>.

Keenlyside, N.S., M. Latif1, J. Jungclaus, L. Kornblueh, and E. Roeckner (2008). Advancing Decadal-Scale Climate Prediction in the North Atlantic Sector. *Nature* 453 (May): 84–88.

King, David A. (2004). Climate Change Science: Adapt, Mitigate, or Ignore? *Science* 303, 5655: 176–77.

Lomborg, Bjørn (2007). *Perspective on Climate Change*. Prepared statement, given before the Subcommittee on Energy and Air Quality and the Subcommittee on Energy and Environment of the Congressional Committee on Science and Technology, March 21, 2007. <http://energycommerce.house.gov/cmte_mtgs/110-eaq-hrg.032107.Lomborg-testimony.pdf>, as of January 7, 2007.

Marland, G., T.A. Boden, and R.J. Andres (2008). *Global, Regional, and National Fossil-Fuel CO_2 Emissions*. Carbon Dioxide Information Analysis Center. <http://cdiac.ornl.gov/trends/emis/overview.html>.

Massachusetts Institute of Technology [MIT] (1998). MIT Researcher Finds Evidence of Global Warming on Neptune's Largest Moon. News release (June 24). <http://web.mit.edu/newsoffice/1998/triton.html>.

Massachusetts Institute of Technology [MIT] (2002). Pluto is Undergoing Global Warming, Researchers Find. News release (October 2). <http://web.mit.edu/newsoffice/2002/pluto.html>.

NASA (2005). Orbiter's Long Life Helps Scientists Track Changes on Mars. News release (September 16). <http://www.nasa.gov/home/hqnews/2005/sep/HQ_05274_Mars_Orbiter.html>.

NASA Goddard Institute for Space Studies (2009). *GISS Surface Temperature Analysis*. <http://data.giss.nasa.gov/gistemp/graphs/>.

NASA Goddard Space Flight Center (2002). Satellites Show Overall Increases in Antarctic Sea Ice Cover. News release (August 22). <http://www.gsfc.nasa.gov/news-release/releases/2002/02-128.htm>.

National Center for Policy Analysis [NCPA] (2008). *A Global Warming Primer*. <http://www.ncpa.org/pdfs/GlobalWarmingPrimer.pdf>.

National Oceanic and Atmospheric Administration (2008). *Trends in Atmospheric Carbon Dioxide - Mauna Loa*. <http://www.esrl.noaa.gov/gmd/ccgg/trends/>.

National Snow and Ice Data Center [NSIDC] (2009). *Sea Ice Index*. <http://nsidc.org/data/seaice_index/>, as of May 28, 2009.

Oelkers, E. H., and D. R. Cole (2008). Carbon Dioxide Sequestration: A Solution to a Global Problem. *Elements* 4: 305–10.

Petit, J.R., D. Raynaud, C. Lorius, J. Jouzel, G. Delaygue, N.I. Barkov, and V.M. Kotlyakov (2000). *Historical Isotopic Temperature Record from the Vostok Ice Core*. Carbon Dioxide Information Analysis Center, US Department of Energy. <http://cdiac.ornl.gov/ftp/trends/temp/vostok/vostok.1999.temp.dat>.

Pielke, Roger A., Jr, Joel Gratz, Christopher W. Landsea, Douglas Collins, Mark A. Saunders, and Rade Musulin (2008). Normalized Hurricane Damage in the United States: 1900–2005. *Natural Hazards Review* 9, 1 (February): 29–42.

Rahmstorf, Stefan (2008). Anthropogenic Climate Change: Revisiting the Facts. In E. Zedillo, *Global Warming: Looking Beyond Kyoto* (Brookings Institution): 34–53. <http://www.pik-potsdam.de/~stefan/Publications/Book_chapters/Rahmstorf_Zedillo_2008.pdf>.

Riebeek, Holli (2006). *Paleoclimatology: Explaining the Evidence*. NASA. <http://earthobservatory.nasa.gov/Features/Paleoclimatology_Evidence/>.

Robinson, Arthur B., Noah E. Robinson, and Willie Soon (2007). *Environmental Effects of Increased Atmospheric Carbon Dioxide*. Oregon Institute of Science and Medicine. <http://www.oism.org/pproject/s33p36.htm>.

Schneider, Nicholas (2008). *Understanding Climate Change*. Fraser Institute.

Self, Stephen, Jing-Xia Zhao, Rick E. Holasek, Ronnie C. Torres, and Alan J. King (1996). The Atmospheric Impact of the 1991 Mount Pinatubo Eruption. In *Fire and Mud: Eruptions and Lahars of Mount Pinatubo, Philippines* (United States Geological Survey). <http://pubs.usgs.gov/pinatubo/self/index.html>.

Statistics Canada (2009). *Median Total Income, by Family Type, by Census Metropolitan Area*. Last updated February 11, 2009. <http://www40.statcan.gc.ca/l01/cst01/famil107a-eng.htm>.

Staufer, B., T. Blunier, A. Dällenbach, A. Indermühle, J. Schwander, T. F. Stocker, J. Tschumi, J. Chappellaz, D. Raynaud, C. U. Hammer, and H. B. Clausen (1998). Atmospheric CO_2 Concentration and Millennial-Scale Climate Change During the Last Glacial Period. *Nature* 392: 59–62.

Stocker, Thomas (2007). From Polar Ice Cores to Better Climate Models? *IPRC Climate* 7, 1: 13–15.

Thompson, L. (1992). *Quelccaya Ice Core Database*. World Data Center for Paleoclimatology. <http://www.ncdc.noaa.gov/paleo/icecore/trop/quelccaya/quelccaya_data.html>.

Unisys (2008). *Atlantic Tropical Storm Tracking by Year*. Unisys Weather. <http://weather.unisys.com/hurricane/atlantic/index.html>.

United Nations Development Programme (2005). *Investing in Development: A Practical Plan to Achieve the Millennium Development Goals*. <http://www.unmillenniumproject.org/reports/index_overview.htm>, as of March 6, 2008.

United Nations Development Programme (2005). *Millennium Development Goals in Kenya: Needs and Costs*. <http://www.un-kenya.org/MDGsKenya/MDGNeedsAssessment.pdf>.

US Environmental Protection Agency (2009). *What Is an Urban Heat Island?* <http://www.epa.gov/heatisland/about/index.htm>.

US Senate Committee on Environment and Public Works (2007). *MIT Climate Scientist Calls Fears of Global Warming 'Silly.'* <http://tinyurl.com/USSenComm>.

Vaughan, David G. (2005). Oceans: How Does the Antarctic Ice Sheet Affect Sea Level Rise? *Science* 308, 5730: 1877–78.

Willett, K. M., N. P. Gillett, P. D. Jones, and P.W. Thorne (2007). Attribution of Observed Surface Humidity Changes to Human Influence. *Nature* 449: 710–12.

World Bank (2008). *World Development Indicators*. World Bank.

World Data Center for Paleoclimatology (2005). *Quelccaya Ice Cap, Peru Data*. NOAA Satellite and Information Service. <http://www.ncdc.noaa.gov/paleo/icecore/trop/quelccaya/quelccaya_data.html>.

World Health Organization (2002). Choosing Interventions to Reduce Specific Risks. In *The World Health Report 2002: Reducing Risks, Promoting Healthy Life*. <http://www.who.int/whr/2002/chapter5/en/index5.html>.

Useful Resources

Energy Information Administration (EIA). <http://www.eia.doe.gov/iea/>.

Waghorn, G.C., and S.L. Woodward (2004). *Ruminant Contributions to Methane and Global Warming—A New Zealand Perspective*. Presented at the Science of Changing Climates—Impact on Agriculture, Forestry and Wetlands, University of Alberta, Edmonton, July 20-23, 2004.

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