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]

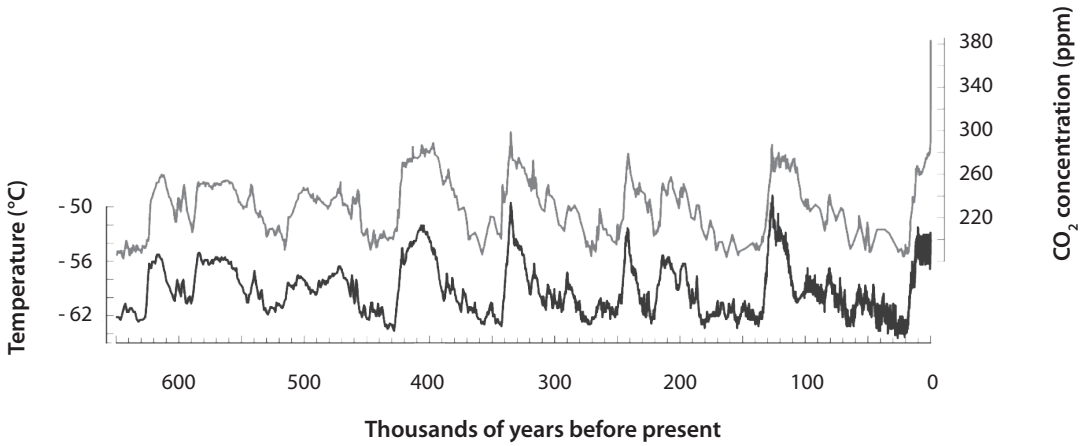
Methane makes up about 0.00017% of the atmosphere. An estimated 60% of methane emissions originate from fossil fuel production, rice cultivation, livestock, burning of biomass, and landfill emissions. [7] Natural sources include wetlands, permafrost, termites, oceans, wildfires, and soils. Atmospheric 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.

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Introduction

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>.

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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>.

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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/>.

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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.

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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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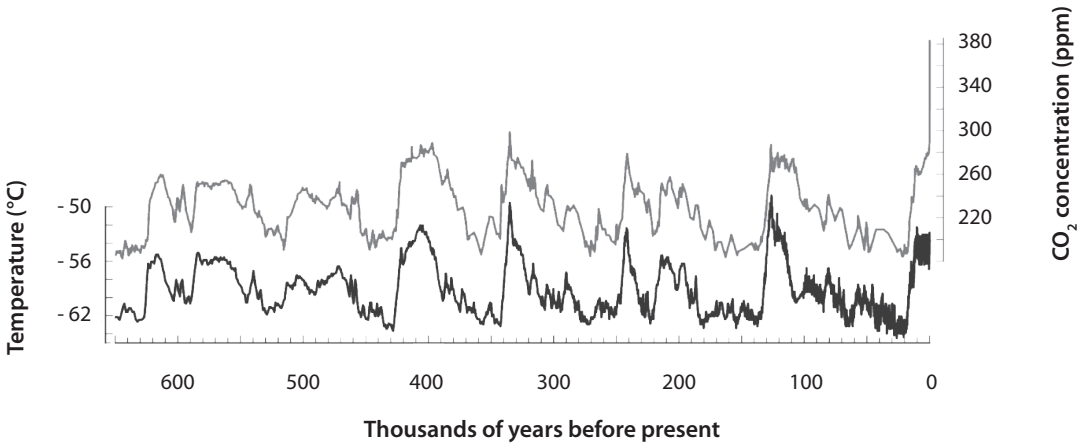
Student Reading

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.

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References

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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)

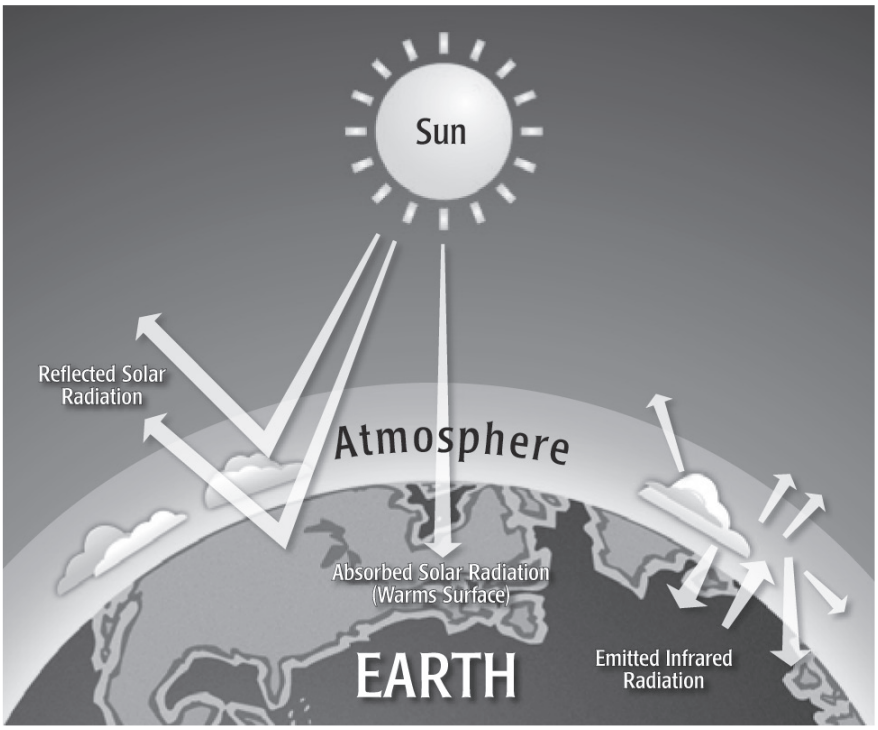
Visual 2.3

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

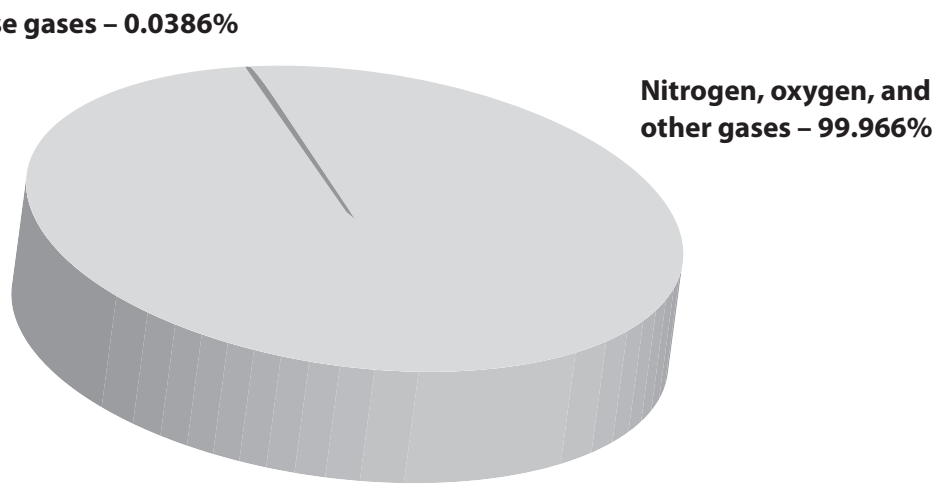


Source: Schneider, Nicholas (2008). *Understanding Climate Change*. Fraser Institute.

Visual 2.4

Greenhouse gases in the atmosphere

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



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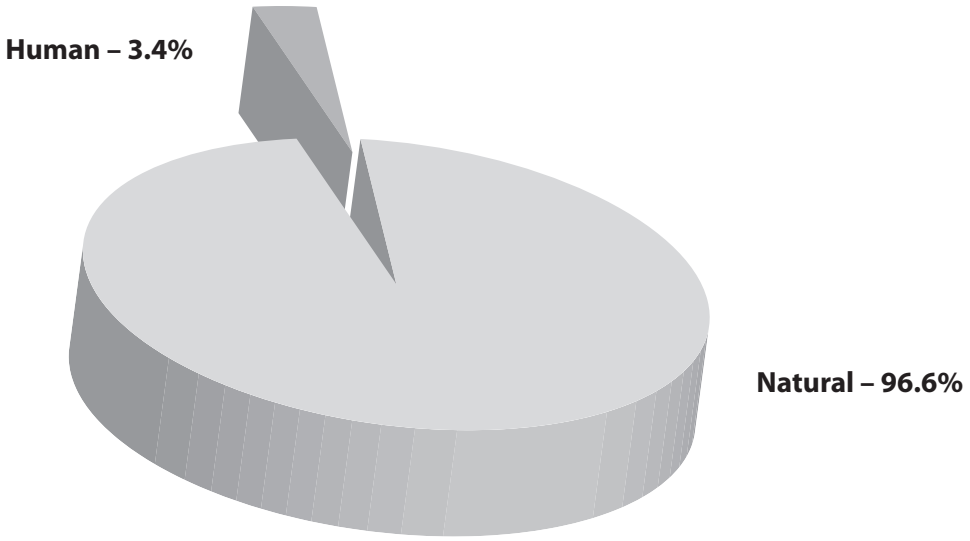
Visual 2.4

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



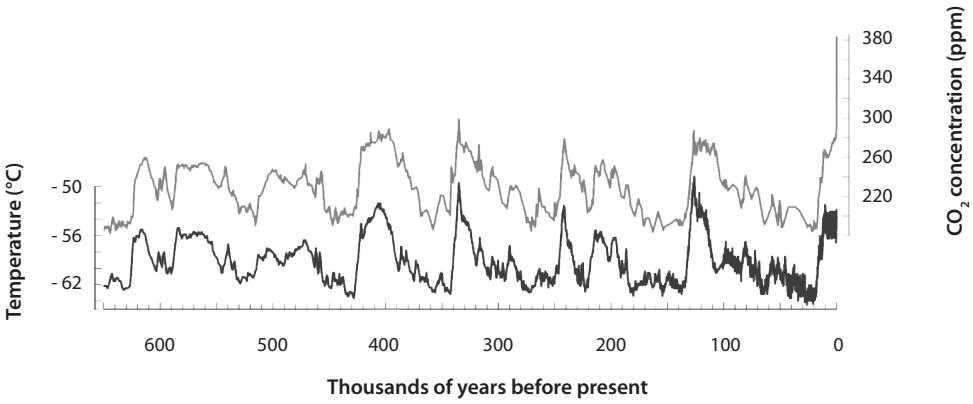
Source: Intergovernmental Panel on Climate Change [IPCC] (2007). *Climate Change 2007: The Physical Science Basis*. Intergovernmental Panel on Climate Change. <http://www.ipcc.ch/ipccreports/ar4-wg1.htm>.

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.

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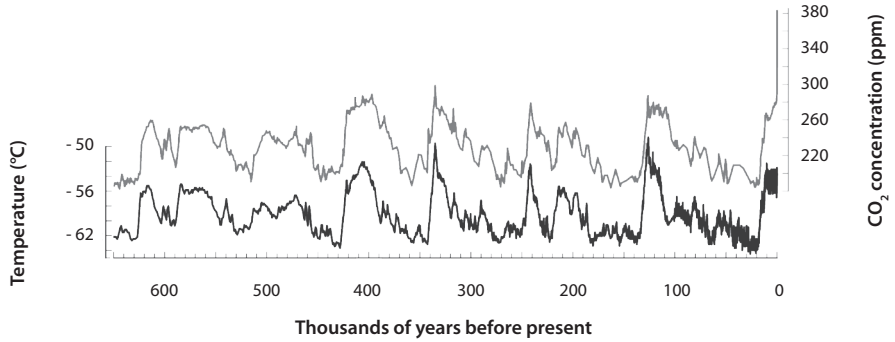
Worksheet 2.2 Answer Key

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

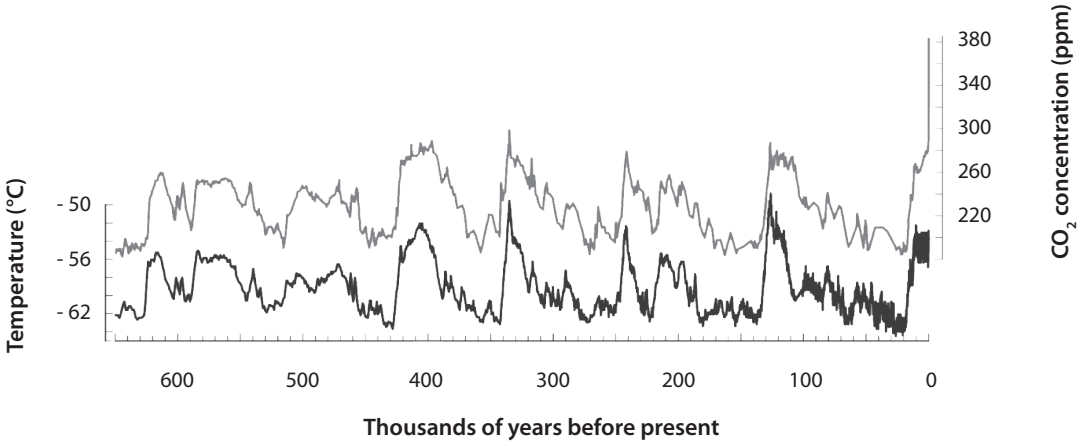


Form two hypotheses that may explain the correlation between CO_2 and temperature.

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



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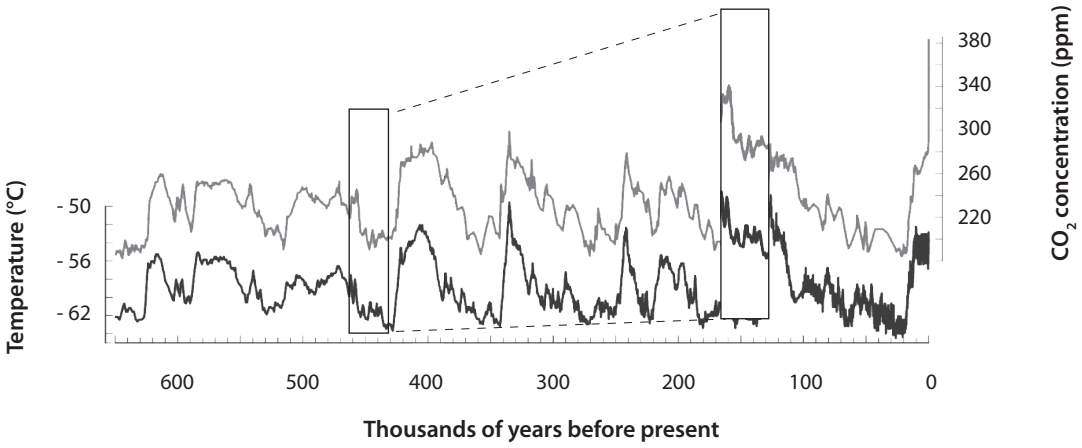
Visual 2.6

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.