GETTING TO THE CORE: THE LINK BETWEEN TEMPERATURE AND CARBON DIOXIDE

DESCRIPTION

This lesson plan gives students first-hand experience in analyzing the link between atmospheric temperatures and carbon dioxide (CO_2) concentrations by looking at ice core data spanning hundreds of thousands of years.

BACKGROUND

Since the start of the Industrial Revolution around 1750, people have burned large amounts of coal, oil, and natural gas to power their homes, factories, and vehicles. Today, most of the world relies on these fossil fuels for their energy needs. Burning fossil fuels releases CO_2, a heat-trapping gas, into the atmosphere, which is the main reason why the Earth's climate is getting warmer.

Heat-trapping gases are also called greenhouse gases. They exist naturally in the atmosphere, where they help keep the Earth warm enough for plants and animals to live—a phenomenon called the greenhouse effect. By adding more greenhouse gases to the atmosphere, however, people are contributing to an enhanced greenhouse effect and causing the atmosphere to trap more heat than it otherwise would.

The Earth's climate has changed many times before. There have been times when most of the planet was covered in ice, and there have also been much warmer periods. Over at least the last 650,000 years, temperatures and CO_2 levels in the atmosphere have increased and decreased in a cyclical pattern. The Earth's temperature has also experienced a similar cyclical pattern characterized by glacial and interglacial periods. During glacial periods (more commonly called ice ages), the Earth has experienced a widespread expansion of ice sheets on land. Intervals between ice ages, called interglacial periods, have brought higher temperatures. The Earth has been in an interglacial period for more than 11,000 years. Historically, temperature and CO_2 have followed similar patterns because the heating or cooling of Earth's surface can lead to changes in the concentrations of greenhouse gases in the atmosphere, which can then cause additional warming or cooling.

TIME: 60 minutes

LEARNING OBJECTIVES:

Students will:

- Understand the link between temperatures and CO_2 concentrations in the atmosphere
- Learn how to analyze patterns from the past and present
- Learn how past patterns can help to predict future scenarios

NATIONAL SCIENCE STANDARDS:

- Content Standard A: Science as inquiry
- Content Standard D: Earth and space science
- Content Standard E: Science and technology

ADAPTED FROM:

National Oceanic and Atmospheric Administration (NOAA): http://www.esrl.noaa.gov/gsd/outreach/education/poet/Global-Warming.pdf.

For hundreds of thousands of years, the concentration of CO_2 in the atmosphere stayed between 200 and 300 parts per million (ppm). Today, it's up to nearly 400 ppm (see graph at right), and the amount is still rising. Along with other greenhouse gases, this extra CO_2 is trapping heat and causing the climate to change.

Before people had thermometers, indeed before any temperatures were recorded, the Earth itself recorded clues about temperature, precipitation, atmospheric gases, and other aspects of the environment in the thick layers of ice that have accumulated in places like Greenland and Antarctica. To reveal these clues to the past, researchers drill into glaciers and

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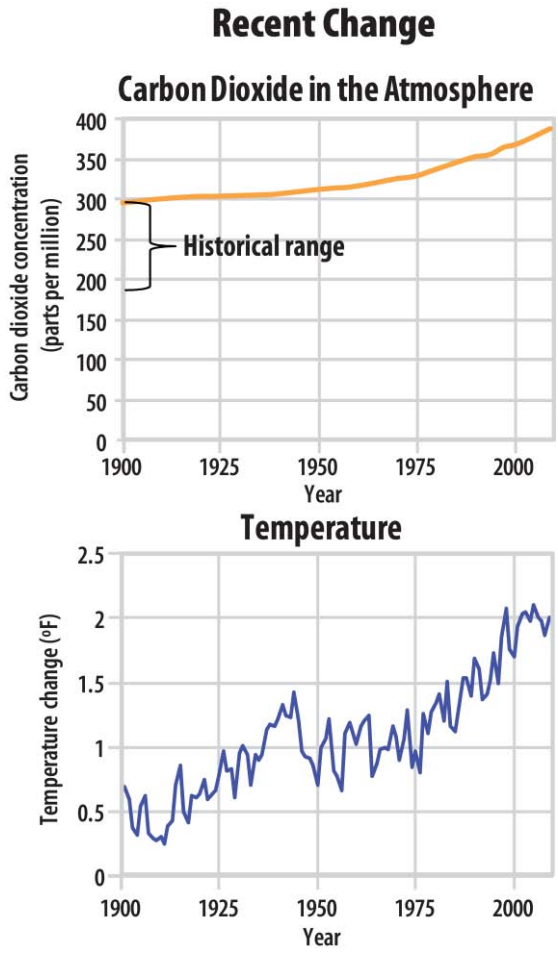
ice sheets and remove cylinder-shaped samples of ice called ice cores. Back in the laboratory, scientists can use chemical sampling techniques to determine the age of each layer of ice and the concentrations of different gases trapped in tiny air bubbles within the ice, which reveals the composition of the atmosphere in the past. They can also examine the water molecules in the ice itself to get information about historical temperatures. Trapped pollen and dust provide additional clues about the climate. Ice core records can go back hundreds of thousands of years, and they help scientists find out whether the rapid increase in CO_2 levels and temperature we are currently observing fits a natural pattern or not.

Investigating the Earth's air temperature and the amount of CO_2 in the atmosphere over a long time period helps us to better understand the Earth's carbon cycle (see the "Carbon Through the Seasons" lesson), its relationship to the greenhouse effect, and its role in regulating the Earth's climate.

MATERIALS

- A copy of the "Vostok, Antarctica, Ice Core Data" worksheet for each student
- A copy of "Vostok Data Instructions" for each student
- A copy of "Carbon Dioxide Concentration and Temperature Rate of Change" for each student
- A copy of the "Carbon Dioxide and Temperature Anomaly (398,000 BC to 400 BC)" graph for each student
- Graph paper (attached to the end of this lesson): two sheets per student
- Colored pencils



Source: U.S. EPA. *A Student's Guide to Global Climate Change*. http://www.epa.gov/climatechange/students.

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VOCABULARY

Carbon:
A chemical element that is essential to all living things. Carbon combines with other elements to form a variety of different compounds. Plants and animals are made up of carbon compounds, and so are certain minerals. Carbon combines with oxygen to make a gas called carbon dioxide.

Carbon cycle:
The movement and exchange of carbon through living organisms, the ocean, the atmosphere, rocks and minerals, and other parts of the Earth. Carbon moves from one place to another through various chemical, physical, geological, and biological processes.

Carbon dioxide (CO_2):
A colorless, odorless greenhouse gas. It is produced naturally when dead animals or plants decay, and it is used by plants during photosynthesis. People are adding carbon dioxide into the atmosphere, mostly by burning fossil fuels such as coal, oil, and natural gas. This extra CO_2 is the main cause of climate change.

Fossil fuel:
A type of fuel that forms deep within the Earth. Examples of fossil fuels include coal, oil, and natural gas. Fossil fuels are created over millions of years as dead plant and animal material becomes trapped and buried in layers of rock, and heat and pressure transform this material into a fuel. All fossil fuels contain carbon, and when people burn these fuels to produce energy, they create carbon dioxide.

Greenhouse effect:
Some of the energy radiated by the sun is converted to heat when it reaches the Earth. Some heat travels through the atmosphere and back out to space, while some is absorbed by atmospheric gases and radiated back to the Earth. The trapping and buildup of heat in the atmosphere near the Earth's surface is known as the greenhouse effect.

Greenhouse gas:
Also sometimes known as "heat-trapping gases," greenhouse gases are natural or manmade gases that trap heat in the atmosphere and contribute to the greenhouse effect. Greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide, and fluorinated gases.

Ice core:
A tube of ice that scientists drill out of a glacier or an ice sheet to learn about historical temperatures, gases that were present in the atmosphere in the past, and other information that provides clues about the climate.

Temperature anomaly:
A difference in temperature, compared with a particular baseline or reference point.

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INSTRUCTIONS

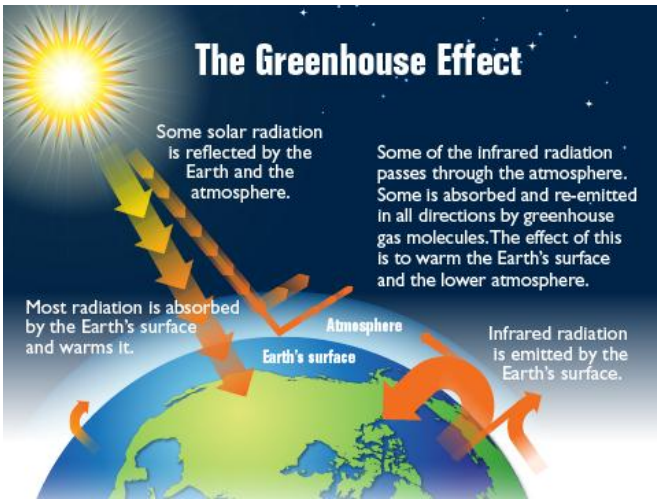
1. Explain to students that they will be using 400,000 years of ice core data to find clues about climate change. The data come from a research station called Vostok Station in Antarctica. Show students where the research station is located on a map. Explain to students that scientists at this remote research station gather ice cores that provide clues into the Earth's past—and present—climate. Discuss with students what ice cores are.
   [Answer: Ice cores are tubes of ice that are drilled out of glaciers or ice sheets. Ice cores provide scientists with information about historical temperatures, gases that were present in the atmosphere in the past, and other clues about the Earth's climate. Ice cores can date back many hundreds of thousands of years.]

2. Show the class a short video about the greenhouse effect from "Learn the Basics: Today's Climate Change" on EPA's *A Student's Guide to Global Climate Change* website (http://www.epa.gov/climatechange/students/basics/concepts.html). You can also demonstrate how the greenhouse effect works by diagramming it on the chalkboard, based on the example shown below. Discuss the greenhouse effect and the link between temperature and CO_2.

3. Hand out copies of the "Vostok, Antarctica, Ice Core Data" worksheets, two sheets of graph paper per student, and colored pencils. Discuss what is meant by a temperature anomaly.
   [Answer: Temperature anomaly means a departure from a reference value or long-term average. A positive anomaly indicates that the observed temperature was warmer than the reference value, while a negative anomaly indicates that the observed temperature was cooler than the reference value. For this data set, the reference value is -56 °C.]

4. Ask students to follow the instructions on the worksheet and to graph their results.

5. When students have finished their graphs, show them the "Carbon Dioxide Concentration and Temperature Anomaly (398,000 BC to 400 BC)" handout and discuss the following questions as a class:



The greenhouse effect is a process by which greenhouse gases keep the Earth warm by trapping heat before it can escape into outer space.

Image source: U.S. EPA. *Climate Change Indicators in the United States.*

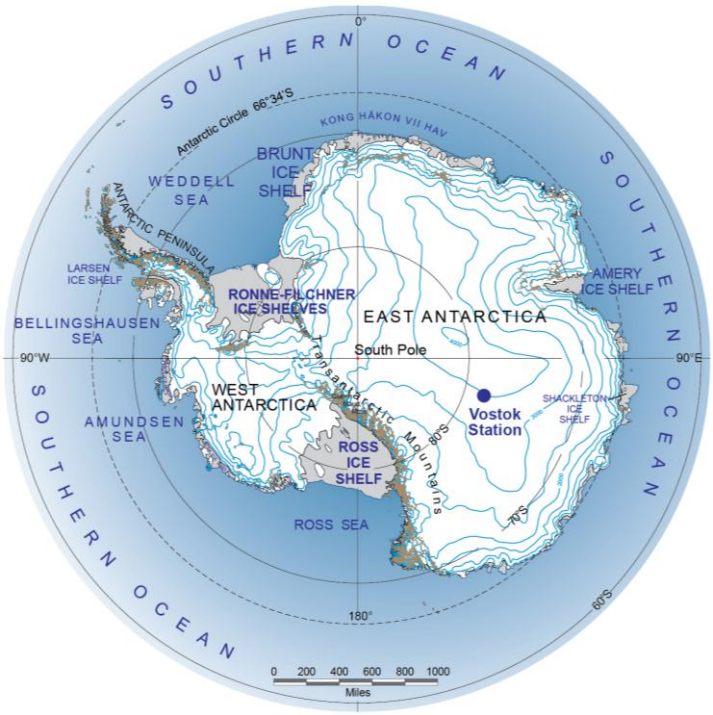
- What pattern(s) do you notice on the graphs?
  [Answer: A repeating cycle. When the carbon dioxide concentration goes up, temperature goes up. When the carbon dioxide concentration goes down, temperature goes down.]

- How many peaks (top) can you identify? How many troughs (bottom)?
  [Answer: Five peaks and four troughs.]

- What is the approximate number of years in one complete cycle? (Hint: A cycle is the time between two peaks or between two troughs.)
  [Answer: 100,000 years.]

- Do peaks represent glacial (cold) periods, or do troughs? How do you know?
  [Answer: Troughs, because the temperature is at its lowest.]

Location of Vostok Station in Antarctica



6. Now pass out copies of the "Carbon Dioxide Concentration and Temperature Rate of Change" worksheet. Explain that temperature anomaly values in the first table (398,000 BC to 400 BC) use a different reference value from the temperature anomaly values in the second table (1901 to 2011).

   - Ask students if choosing a different reference value would change the shape of the trend. Why or why not?
     [Answer: No, even if a new reference point is used, the shape and direction of the trend or repeating pattern would stay the same. The overall pattern would just shift up or down.]

7. Ask students to use the "Vostok, Antarctica, Ice Core Data" worksheet and their graphs to fill in the blank boxes in the first table ("48,000 BC to 400 BC") on the "Carbon Dioxide Concentration and Temperature Rate of Change" worksheet. Then ask them to finish filling in the second table ("1901 to 2011"), which has been partially populated with more recent data from another source. When students are finished, ask them the following questions regarding the parts of the table that they filled in:

   - How many years of data are shown in the "48,000 BC to 400 BC" table?
     [Answer: About 47,600 years.]

   - How many years of data are shown in the "1901 to 2011" table?
     [Answer: 110 years.]

   - Ask students if either table, both tables, or neither table show a warming trend. Explain.
     [Answer: Both. CO_2 concentrations increase and temperature anomaly increases. Both increase at a greater rate more recently.]

   - What trend, upward or downward, are we currently experiencing?
     [Answer: Upward for both CO_2 concentration and temperature anomaly.]

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- What is the change in the temperature anomaly between 1901 and 2011?
  [Answer: Approximately 0.68 ^{o}C.]
- In 1971, the globally averaged CO_2 concentration was approximately 330 ppm. If the CO_2 concentration in 2000 was about 384 ppm, calculate the average rate of increase per year.
  [Answer: Approximately 1.5 ppm per year.]
- What is happening to the rate of change for CO_2 concentrations and temperature anomaly over time?
  [Answer: The rate of change increases. This is another way of saying that if you graphed the results, the slope of the line would become steeper over time.]

EXTENSION

Let students see first-hand how scientists are working in the field to collect ice cores. As a class activity or as a homework assignment, ask students to watch a video about ice core sampling in Antarctica. (See http://www.youtube.com/watch?v=TDOQIkiIL9Q&feature=related or http://www.youtube.com/watch?v=Kr02VF3ralc&feature=related.) Ask students to write a paragraph explaining how examining ice cores helps scientists better understand today's climate.

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VOSTOK, ANTARCTICA, ICE CORE DATA

NAME: _____ **DATE:** _____

Carbon Dioxide Concentration and Temperature Anomaly Data
(398,000 BC to 400 BC)

Year (BC)	CO_2 concentration (ppm)	CO_2 concentration rounded to nearest whole number	Temperature anomaly (°C)	Temperature anomaly (°C) rounded to nearest tenth of a degree
398,000	278		-1.64	
388,000	255.2		-5.34	
378,000	245.9		-4.88	
368,000	229.7		-5.42	
358,000	206.4		-5.8	
348,000	193		-7.64	
338,000	220.4		-7.44	
328,000	234.2		-4.9	
318,000	271.8		-0.12	
308,000	256.3		-3.32	
298,000	241.9		-3.08	
288,000	240.2		-6	
278,000	207.7		-6.17	
268,000	231.4		-5.95	
258,000	184.7		-8.3	
248,000	203.9		-6.52	
238,000	230.4		-2.12	
228,000	245.2		-6.15	
218,000	212.2		-4.31	
208,000	244.6		-3.07	
198,000	242.6		-2.68	
188,000	231.4		-6.49	
178,000	213.2		-6.34	
168,000	197.9		-7.01	
158,000	204.4		-6.25	
148,000	191.9		-7.34	
138,000	192.3		-8.99	

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Carbon Dioxide Concentration and Temperature Anomaly Data
(398,000 BC to 400 BC)

Year (BC)	CO_2 concentration (ppm)	CO_2 concentration rounded to nearest whole number	Temperature anomaly (°C)	Temperature anomaly (°C) rounded to nearest tenth of a degree
128,000	263.4		1.47	
118,000	265.2		-0.86	
108,000	245.7		-5.53	
98,000	225.9		-3.45	
88,000	208		-4.69	
78,000	221.8		-3.66	
68,000	227.4		-7.84	
58,000	210.4		-6.53	
48,000	190.4		-5.18	
38,000	209.1		-6.91	
28,000	205.4		-7.95	
18,000	189.2		-7.62	
8,000	261.6		-0.28	
400	284.7		0	

Data source: National Oceanic and Atmospheric Administration (NOAA): www.esrl.noaa.gov/gsd/outreach/education/poet/Global-Warming.pdf.

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VOSTOK DATA INSTRUCTIONS

Instructions for Filling Out the "Vostok, Antarctica, Ice Core Data" Worksheet

1. In the space provided in column three, round the carbon dioxide (CO_2) concentration to the nearest whole number.

2. In the space provided in column five, round the temperature anomaly to the nearest tenth of a degree.

Instructions for Plotting the Graphs

1. You will create two graphs: one for CO_2 concentration and one for temperature anomaly.

2. On both graphs, your x-axis will represent years. Start with 400,000 BC on the left and number as far as the the year 0 on the right, counting by intervals of 10,000 years. Label the axis.

3. On the first graph, the y-axis on the left side of the paper will represent the CO_2 concentration using units of parts per million (ppm). Begin with 100 ppm at the lower end, and number up to 400 ppm, counting by intervals of 10 ppm. Label the axis.

4. On the second graph, the y-axis on the left side of the paper will represent the temperature anomaly in degrees Celsius (°C). Begin with -10.0 °C at the lower end and number up to 2.0 °C, counting by intervals of 0.5 °C. Label the axis.

5. Using different colored pencils, plot the points for CO_2 concentration and temperature anomaly.

6. Write a title on each graph.

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CARBON DIOXIDE CONCENTRATION AND TEMPERATURE RATE OF CHANGE

NAME: _____ **DATE:** _____

48,000 BC to 400 BC
Length of time: ____ years

Variable	Value in 48,000 BC	Value in 400 BC	Change	Rate of change per year
CO_2 concentration (ppm)				
Temperature anomaly (^oC)				

1901 to 2011
Length of time: ____ years

Variable	Value in 1901	Value in 2011	Change	Rate of change per year
CO_2 concentration (ppm)	296.1 ppm	391.6 ppm		
Temperature anomaly (^oC)	-0.16 ^oC	0.51 ^oC		

Data source: U.S. EPA, *Climate Change Indicators in the United States*: http://www.epa.gov/climatechange/science/indicators/.

CO_2 concentrations are from Antarctica (1901) and Hawaii (2011).
Temperature anomaly is a global average.

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VOSTOK, ANTARCTICA, ICE CORE DATA—ANSWER KEY

Carbon Dioxide Concentration and Temperature Anomaly Data
(398,000 BC to 400 BC)

Year (BC)	CO_2 concentration (ppm)	CO_2 concentration rounded to nearest whole number	Temperature anomaly (°C)	Temperature anomaly (°C) rounded to nearest tenth of a degree
398,000	278	**278**	-1.64	**-1.6**
388,000	255.2	**255**	-5.34	**-5.3**
378,000	245.9	**246**	-4.88	**-4.9**
368,000	229.7	**230**	-5.42	**-5.4**
358,000	206.4	**206**	-5.8	**-5.8**
348,000	193	**193**	-7.64	**-7.6**
338,000	220.4	**220**	-7.44	**-7.4**
328,000	234.2	**234**	-4.9	**-4.9**
318,000	271.8	**272**	-0.12	**-0.1**
308,000	256.3	**256**	-3.32	**-3.3**
298,000	241.9	**242**	-3.08	**-3.1**
288,000	240.2	**240**	-6	**-6**
278,000	207.7	**208**	-6.17	**-6.2**
268,000	231.4	**231**	-5.95	**-6**
258,000	184.7	**185**	-8.3	**-8.3**
248,000	203.9	**204**	-6.52	**-6.5**
238,000	230.4	**230**	-2.12	**-2.1**
228,000	245.2	**245**	-6.15	**-6.2**
218,000	212.2	**216**	-4.31	**-4.3**
208,000	244.6	**245**	-3.07	**-3.1**
198,000	242.6	**243**	-2.68	**-2.7**
188,000	231.4	**231**	-6.49	**-6.5**
178,000	213.2	**213**	-6.34	**-6.3**
168,000	197.9	**198**	-7.01	**-7**
158,000	204.4	**204**	-6.25	**-6.3**
148,000	191.9	**192**	-7.34	**-7.3**
138,000	192.3	**192**	-8.99	**-9**
128,000	263.4	**263**	1.47	**1.5**

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Carbon Dioxide Concentration and Temperature Anomaly Data
(398,000 BC to 400 BC)

Year (BC)	CO_2 concentration (ppm)	CO_2 concentration rounded to nearest whole number	Temperature anomaly (°C)	Temperature anomaly (°C) rounded to nearest tenth of a degree
118,000	265.2	**265**	-0.86	**-0.9**
108,000	245.7	**246**	-5.53	**-5.5**
98,000	225.9	**226**	-3.45	**-3.5**
88,000	208	**208**	-4.69	**-4.7**
78,000	221.8	**222**	-3.66	**-3.7**
68,000	227.4	**227**	-7.84	**-7.8**
58,000	210.4	**210**	-6.53	**-6.5**
48,000	190.4	**190**	-5.18	**-5.2**
38,000	209.1	**209**	-6.91	**-6.9**
28,000	205.4	**205**	-7.95	**-8**
18,000	189.2	**189**	-7.62	**-7.6**
8,000	261.6	**262**	-0.28	**-0.3**
400	284.7	**285**	0	**0**

Data source: National Oceanic and Atmospheric Administration (NOAA): www.esrl.noaa.gov/gsd/outreach/education/poet/Global-Warming.pdf.

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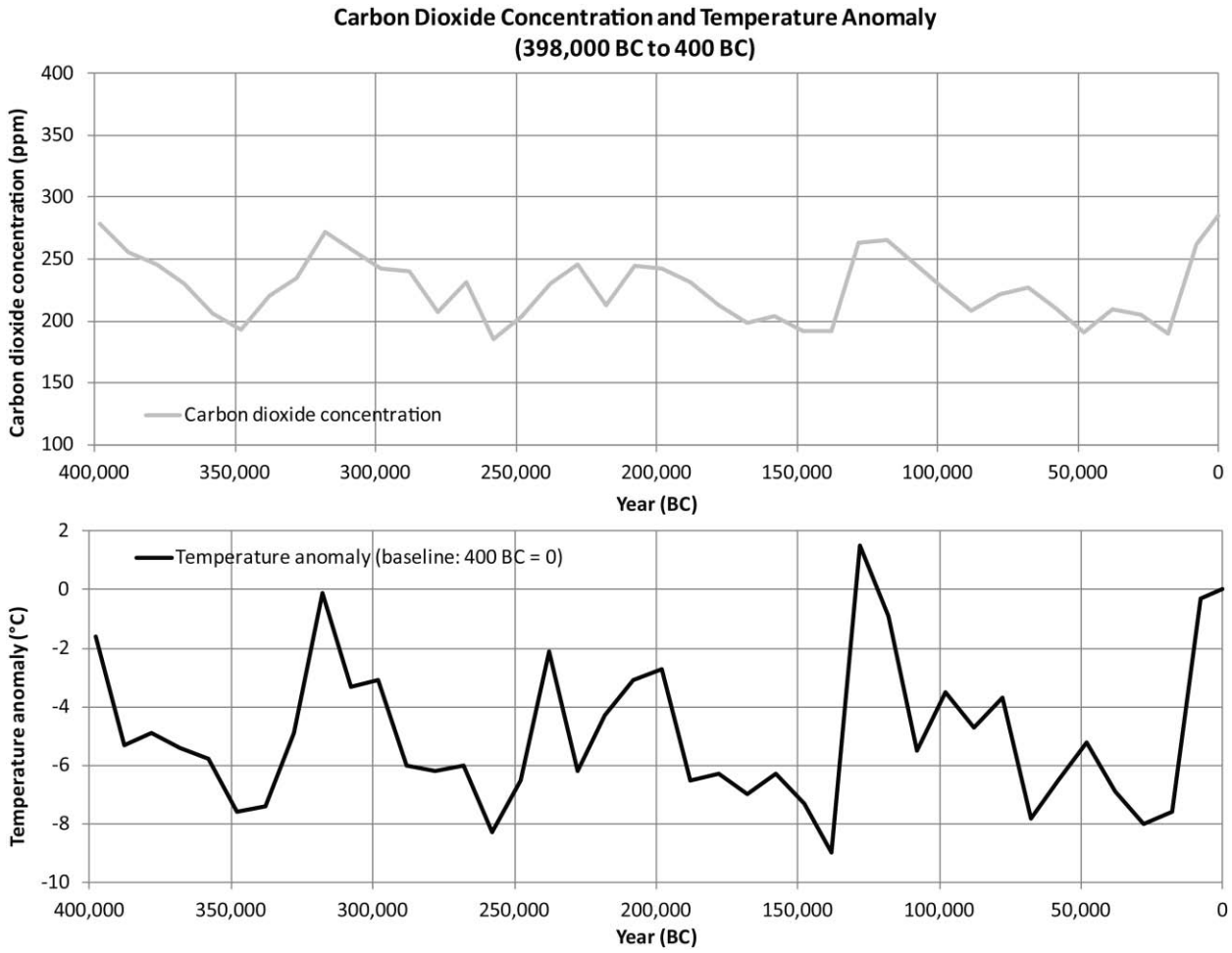

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CARBON DIOXIDE CONCENTRATION AND TEMPERATURE RATE OF CHANGE—ANSWER KEY

48,000 BC to 400 BC
Length of time: 47,600 years

Variable	Value in 48,000 BC	Value in 400 BC	Change	Rate of change per year
CO_2 concentration (ppm)	190.4 ppm	284.7 ppm	+94.3 ppm	94.3 ppm / 47,600 years = 0.0020 ppm per year
Temperature anomaly (°C)	-5.18 °C	0 °C	+5.18 °C	5.18 °C / 47,600 = 0.00011 °C per year

1901 to 2011
Length of time: 110 years

Variable	Value in 1901	Value in 2011	Change	Rate of change per year
CO_2 concentration (ppm)	296.1 ppm	391.6 ppm	+95.5 ppm	95.5 ppm / 110 years = 0.868 ppm per year
Temperature anomaly (°C)	-0.16 °C	0.51 °C	+0.67 °C	0.67 °C / 110 years = 0.0061 °C per year

Data source: U.S. EPA, *Climate Change Indicators in the United States*: http://www.epa.gov/climatechange/science/indicators/.

CO_2 concentrations are from Antarctica (1901) and Hawaii (2011). Temperature anomaly is a global average.

NAME: _____ TITLE: _____ DATE: _____