

## Activity 2.2: Historical Climate Cycles

### Grades 7 – 9

**Description:** This activity introduces students to the idea of historical climate cycles. In Part 1: Visualizing the climate from 400,000 B.C.E. to 10,000 C.E., students will interpret graphs of temperature data from the past 400,000 years to understand how Earth's climate has changed in the past.

#### Materials:

- Graph paper, butcher paper, or adding machine tape (at least 6 meters)
- Colored pencils
- Rulers
- Tape
- Copies of data tables
- Handouts for parts 1, 2, and 3

In Part 2: Graphing climate data from 10,000 to the present, students will graph data from 10,000 years ago to the present, and place key events in environmental and human history on the timeline to demonstrate the timeframe of historical climate change, and to begin to understand the relationships between humans and climate. Comparing this graph to the first graph highlights the increased rate of change.

Lastly, in Part 3: Explaining temperature variation, students will look at the graph of temperature over the past 400,000 years along with a graph of carbon dioxide concentration over 400,000 years. By analyzing these graphs together, students will draw the connection between carbon dioxide concentration and temperature.

**Total Time:** Three class periods

### National Science Education Standards

- 11.A.3e/f Use data manipulation tools and quantitative and representational methods to analyze measurements. Interpret and represent results of analysis to produce findings.
- 12.E.3a Analyze and explain large-scale dynamic forces, events, and processes that affect the Earth's land, water, and atmospheric systems.

### AAAS Benchmarks

- 11C/E2b Often the best way to tell which kinds of change are happening is to make a table or graph of measurements.
- 11C/M7 Cyclic patterns evident in past events can be used to make predictions about future events. However, these predictions may not always match what actually happens.
- 11C/M10 Trends based on what has happened in the past can be used to make predictions about what things will be like in the future. However, these predictions may not always match what actually happens.

### Common Core Math Standards

CCSS.Math.Content.5.G.A.1/2 Graph points on the coordinate plane to solve real-world and mathematical problems.



### Guiding Questions:

- How have average temperatures differed over the past 400,000 years?
- How do scientists reconstruct past climates?
- What are the connections between carbon dioxide concentration and temperature?

### Assessments

- Student worksheets
- Completed graph of temperature change over 10,000-year period

### Background Information

#### How are past temperatures determined from an ice core?

<http://www.scientificamerican.com/article.cfm?id=how-are-past-temperatures>

(Robert Mulvaney, glaciologist with the British Antarctic Survey)

The cornerstone of the success achieved by ice core scientists reconstructing climate change over many thousands of years is the ability to measure past changes in both atmospheric greenhouse gas concentrations and temperature. The measurement of the gas composition is direct: trapped in deep ice cores are tiny bubbles of ancient air, which we can extract and analyze using mass spectrometers. Temperature, in contrast, is not measured directly, but is instead inferred from the isotopic composition of the water molecules released by melting the ice cores.

Water is made up of molecules comprising two atoms of hydrogen and one atom of oxygen ( $\text{H}_2\text{O}$ ). But it's not that simple, because there are several isotopes (chemically identical atoms with the same number of protons, but differing numbers of neutrons, and therefore mass) of oxygen, and several isotopes of hydrogen. The isotopes of particular interest for climate studies are  $^{16}\text{O}$  (with 8 protons and 8 neutrons that make up 99.76 percent of the oxygen in water) and  $^{18}\text{O}$  (8 protons and 10 neutrons), together with  $^1\text{H}$  (with one proton and no neutrons, which is 99.985 percent of the hydrogen in water) and  $^2\text{H}$  (also known as deuterium (D), which has one proton and one neutron). All of these isotopes are termed 'stable' because they do not undergo radioactive decay.

Using sensitive mass spectrometers, researchers are able to measure the ratio of the isotopes of both oxygen and hydrogen in samples taken from ice cores, and compare the result with the isotopic ratio of an average ocean water standard known as SMOW (Standard Mean Ocean Water). The water molecules in ice cores are always depleted in the heavier isotopes (that is, the isotopes with the larger number of neutrons) and the difference compared to the standard is expressed as either  $^{18}\text{O}$  or D. Both of these values tell essentially the same story—namely, that there is less  $^{18}\text{O}$  and D during cold periods than there is in warm. Why is this? Simply put, it takes more energy to evaporate the water molecules containing a heavy isotope from the surface of the ocean, and, as the moist air is transported toward the poles and cools, the water molecules containing heavier isotopes are preferentially lost in precipitation. Both of these processes, known as fractionation, are dependent on temperature.



At a range of sites in the polar regions, scientists have measured a near linear relationship between  $^{18}\text{O}$  and D in samples of modern snowfall taken over several years and the mean annual temperature. This relationship can be used to calibrate the isotope ratio thermometer, although the calibration changes a little during ice age climates. Plotting either  $^{18}\text{O}$  or D with depth along the length of an ice core reveals the seasonal oscillations in temperature and researchers can also count annual layers in order to date them. From the very deepest ice cores reaching depths of more than three kilometers in the Antarctic ice sheet, we can clearly see the steady pulsing of the ice ages on a period of about 100,000 years. From a site called Dome C in Antarctica, we have recently reconstructed the climate spanning the last three quarters of a million years, and have shown seven ice ages, each interspersed with a warm interglacial climate such as the one we are living in today.

Also see: [http://earthobservatory.nasa.gov/Features/Paleoclimatology\\_IceCores/](http://earthobservatory.nasa.gov/Features/Paleoclimatology_IceCores/)

### **Natural Causes of Climate Change and How Today is Different**

Any changes to the Earth's climate system that affect how much energy enters or leaves the system alters Earth's radiative equilibrium and can force temperatures to rise or fall. These destabilizing influences are called climate forcings. Natural climate forcings include changes in the sun's brightness, Milankovitch cycles (small variations in the shape of Earth's orbit and its axis of rotation that occur over thousands of years), and large volcanic eruptions that inject light-reflecting particles as high as the stratosphere.

"Climate and the Earth's Energy Budget" by Rebecca Lindsey, January 14, 2009  
<http://earthobservatory.nasa.gov/Features/EnergyBalance/page1.php>

**Changes in the sun's brightness:** Satellite measurements spanning most of the globe have confirmed a distinct correlation between sea-surface temperatures and the eleven-year solar sunspot cycle. However, the effect is tiny, not even a tenth of a degree Celsius. Similarly weak but clear effects were detected in the atmosphere near the surface and, somewhat stronger, in the thin upper atmosphere. Average sunspot activity decreased after 1980, and on the whole, solar activity has not increased during the half-century since 1950. As for cosmic rays, they have been measured since the 1950s and likewise show no long-term trend. The continuing satellite measurements of the solar constant found it cycling within narrow limits, scarcely one part in a thousand. However, global temperatures continue to rise, and to accelerate at a record-breaking pace, resulting in a total of  $0.8^{\circ}$  Celsius of warming since the late 19th century. Beginning in the 1930s, scientists began to investigate whether increasing carbon dioxide emissions might be responsible for this increase in temperature, but it was not until the 1970s that scientists made the connection between human emissions and global warming, and not until the 1999 publication of the "hockey stick graph" by researcher Michael Mann was it broadly accepted.

American Institute of Physics, "Changing Sun, Changing Climate?"  
<http://www.aip.org/history/climate/solar.htm>, and "The Modern Temperature Trend"  
<http://www.aip.org/history/climate/20ctrend.htm>



**Milankovitch cycles:** The Milankovitch, or astronomical theory, of climate change is an explanation for changes in the seasons that result from changes in the Earth's orbit around the sun. The theory is named for Serbian astronomer Milutin Milankovitch, who calculated the slow changes in the Earth's orbit by careful measurements of the position of the stars, and through equations using the gravitational pull of other planets and stars. He determined that the Earth "wobbles" in its orbit. The Earth wobbles in space so that its tilt changes between about 22 and 25 degrees on a cycle of about 41,000 years. The Earth's "tilt" is what causes seasons, and changes in the tilt of the Earth can change the severity of the seasons. More "tilt" means more severe seasons—warmer summers and colder winters; less "tilt" means less severe seasons—cooler summers and milder winters.

The seasons can also be accentuated or modified by the degree of roundness of the orbital path around the sun, and the precession effect, the position of the solstices in the annual orbit. The Earth's orbit around the sun is not quite circular, which means that the Earth is slightly closer to the sun at some times of the year than others. The closest approach of the Earth to the sun is called perihelion, and it now occurs in January, making northern hemisphere winters slightly milder. This change in timing of perihelion is known as the precession of the equinoxes, and occurs in a period of 22,000 years. 11,000 years ago, perihelion occurred in July, making the seasons more severe than today. The "roundness", or eccentricity, of the Earth's orbit varies on cycles of 100,000 and 400,000 years, and this affects how important the timing of perihelion is to the strength of the seasons.

The combination of the 41,000-year tilt cycle and the 22,000-year precession cycles, plus the smaller eccentricity signal, affect the relative severity of summer and winter, and are thought to control the growth and retreat of ice sheets. While these factors do affect Earth's climate, orbital changes occur over tens and hundreds of thousands of years, and the climate system may also take thousands of years to respond to orbital forcing, so the rate and severity of current temperature trends cannot be attributed to these factors. In fact, according to recent Milankovitch cycle calculations, we should be entering a cooling period.

(Berger & Loutre. *An Exceptionally Long Interglacial Ahead?*

Science 23 August 2002, Vol. 297(5585))

Adapted from NOAA's description of the Astronomical Theory of Climate Change

<http://www.ncdc.noaa.gov/paleo/milankovitch.html>

**Volcanic Eruptions:** Volcanoes can affect climate. During major explosive eruptions, huge amounts of volcanic gas, aerosol droplets, and ash are injected into the stratosphere. Injected ash falls rapidly from the stratosphere. Most of it is removed within several days to weeks and has little impact on climate. But volcanic gases like sulfur dioxide can cause global cooling, while volcanic carbon dioxide, a greenhouse gas, has the potential to promote global warming. The most significant climate effects from volcanic injections into the stratosphere come from the conversion of sulfur dioxide to sulfuric acid, which condenses rapidly in the stratosphere to form fine sulfate aerosols. The aerosols increase the reflection of radiation from the sun back into space, cooling the Earth's lower atmosphere or troposphere. Several eruptions during the past century have caused a decline in the average temperature at the Earth's surface of up to half a



degree (Fahrenheit scale) for periods of one to three years. While sulfur dioxide released in contemporary volcanic eruptions has occasionally caused detectable global cooling of the lower atmosphere, the carbon dioxide released in contemporary volcanic eruptions has never caused detectable global warming of the atmosphere. All studies to date of global volcanic carbon dioxide emissions indicate that present-day subaerial and submarine volcanoes release less than one percent of the carbon dioxide released currently by human activities.

Adapted from the United States Geological Survey, “Volcanic Gas and Climate Change”  
<http://volcanoes.usgs.gov/hazards/gas/climate.php>

### **Why does it take so long to feel the impact, if CO<sub>2</sub> emissions are the cause?**

**The Oceans:** Oceans and climate are inextricably linked and oceans play a fundamental role in mitigating climate change by serving as both a major heat and carbon sink. Oceans are some of the Earth's biggest absorbers of heat, which can be seen in effects such as sea level rise, caused by the expansion of large bodies of water as they warm. The absorption goes on over long periods, as heat from the surface is gradually circulated to the lower reaches of the seas. In fact, the surface ocean currently absorbs between 80 and 90 percent of the heat from global warming. The change is most obvious in the top layer of the ocean, which has grown much warmer since the late 1800s. This top layer is now getting warmer at a rate of 0.2 degrees Fahrenheit per decade.

The ocean also acts as a carbon sink, so about one-fourth of the CO<sub>2</sub> emitted to the atmosphere from human activities has been absorbed into the oceans rather than staying in the atmosphere and contributing to the greenhouse effect. Air-sea gas exchange is a physio-chemical process, primarily controlled by the difference in gas concentrations between the air and the oceans, and an exchange coefficient, which determines how quickly a molecule of gas can move across the ocean-atmosphere boundary. It takes about one year to equilibrate CO<sub>2</sub> in the surface ocean with atmospheric CO<sub>2</sub>, so it is not unusual to observe large air-sea differences in CO<sub>2</sub> concentrations. The oceans contain a very large reservoir of carbon that can be exchanged with the atmosphere because the CO<sub>2</sub> reacts with water to form carbonic acid and its dissociation products. As atmospheric CO<sub>2</sub> increases, the interaction with the surface ocean will change the chemistry of the seawater, resulting in ocean acidification.

Evidence suggests that the past and current ocean uptake of human-derived (anthropogenic) CO<sub>2</sub> is primarily a physical response to rising atmospheric CO<sub>2</sub> concentrations. Whenever the partial pressure of a gas is increased in the atmosphere over a body of water, the gas will diffuse into that water until the partial pressures across the air-water interface are equilibrated. However, because the global carbon cycle is intimately embedded in the physical climate system, there exist several feedback loops between the two systems. For example, increasing CO<sub>2</sub> modifies the climate, which in turn affects ocean circulation and therefore ocean CO<sub>2</sub> uptake. Changes in marine ecosystems resulting from rising CO<sub>2</sub> and/or changing climate can also result in changes in air-sea CO<sub>2</sub> exchange. These feedbacks can change the role of the oceans in taking up atmospheric CO<sub>2</sub>, making it very difficult to predict how the ocean carbon cycle will operate in the future.



Adapted from:

<http://www.pmel.noaa.gov/co2/story/Ocean+Carbon+Uptake>  
[http://www.education.noaa.gov/Climate/Carbon\\_Cycle.html](http://www.education.noaa.gov/Climate/Carbon_Cycle.html)  
<http://epa.gov/climatestudents/impacts/signs/oceans.html>  
[http://climate.nasa.gov/climate\\_reel/OceansClimateChange640360](http://climate.nasa.gov/climate_reel/OceansClimateChange640360)

**The Atmosphere:** Aerosols such as sulfates and black carbon (soot) can affect the heat balance of the planet. Sulfate aerosols are produced by the combustion of fossil fuels, while black carbon is produced by incomplete combustion of coal, biomass (wood, field residue, cow dung, etc.), and diesel fuel. The pollutants are thought to be the cause of *global dimming*, the gradual reduction in the amount of global direct irradiance at the Earth's surface observed for several decades from about 1960 through the early 1990s. The effect varied by location, but worldwide was estimated to be around four percent. However, since the early 1990s, there has been a lessening of these aerosols and some other types of air pollution, and a resultant lessening and reversal of global dimming. By 2005, global aerosols had dropped as much as 20 percent from the relatively stable level between 1986 and 1991.

Aerosol particles can cool the climate in two ways. Directly, sulfate aerosols reflect incoming solar radiation back to space. Indirectly, aerosols can increase the reflectivity of clouds by providing more nuclei on which water vapor can condense and form tiny cloud droplets. With more droplets to take up available water vapor, the droplets stay smaller and lighter in weight, and they fall less readily from the cloud as rain. The result is optically thicker clouds and decreased rainfall.

The combined effect of global dimming and warming may account for why one of the major impacts of a warmer climate—the spinning up of the water cycle of evaporation, more cloud formation and more rainfall—has not yet been observed. "Less sunlight reaching the surface counteracts the effect of warmer air temperatures, so evaporation does not change very much," said Gavin Schmidt of GISS, a co-author of the paper. "Increased aerosols probably slowed the expected change in the hydrological cycle."

However, aerosols also contribute to climate warming. Soot particles absorb solar radiation rather than reflecting it; thus, they warm the atmosphere and counter the cooling effects of reflective sulfate aerosols. By warming the atmosphere, soot can inhibit cloud formation and thus allow more sunlight to reach and warm the surface. The individual characteristics of real aerosols, which often contain both sulfate and soot, complicate global warming. The interactions and climate feedbacks of aerosols are very intricate, complicated, and controversial. The contribution of aerosols to global warming and cooling is not a new topic; aerosols have been included in global climate models for quite some time.

Adapted from:

[http://www.nasa.gov/centers/goddard/news/topstory/2007/aerosol\\_dimming.html](http://www.nasa.gov/centers/goddard/news/topstory/2007/aerosol_dimming.html)  
<http://education.arm.gov/outreach/publications/sgp/jul04.pdf>  
<http://www.geoengineeringwatch.org/global-dimming-2/>



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Wild, M. (2009). Global dimming and brightening: A review. *Journal of Geophysical Research: Atmospheres* (1984–2012), 114(D10).

### Additional Resources

- International Panel on Climate change explanation of human and natural causes of climate change. The short article includes descriptions of the different greenhouse gases, their sources and impacts, and compares those to the natural positive and negative radiative (heat) forcings. A graph of the comparison is included.  
<http://co2now.org/Know-the-Changing-Climate/Climate-System/ipcc-faq-human-natural-causes-climate-change.html>
- American Institute of Physics, “The Discovery of Global Warming. A comprehensive historical description of the investigation into climate and climate change, including influences on climate, climate data, theory, climate and society.”  
<http://www.aip.org/history/climate/index.htm#contents>
- Good video from NASA that explains the role of the ocean in absorbing the heat trapped by greenhouse gases in the atmosphere.  
[http://climate.nasa.gov/climate\\_reel/OceansClimateChange640360](http://climate.nasa.gov/climate_reel/OceansClimateChange640360)

### Vocabulary

- **ppm:** parts per million. Usually describes the concentration of a substance in a liquid or gas.
- **Ice core:** An ice core is a sample from an ice sheet, most commonly from the polar ice caps of Antarctica, Greenland, or from high mountain glaciers. As the ice forms, annual snowfall builds up layers from year to year, so lower layers are older than upper layers. An ice core contains ice formed over many years. Ice cores contain an abundance of information about climate. Particles and gases such as wind-blown dust, ash, bubbles of atmospheric gas and radioactive substances remain in the ice each year as it accumulates. The length of the record depends on the depth of the ice core and varies from a few years up to 800,000 years. The time resolution (i.e. the shortest time period which can be accurately distinguished) depends on the amount of annual snowfall, and reduces with depth as the ice compacts under the weight of layers accumulating on top of it. Upper layers of ice in a core correspond to a single year or sometimes a single season. Deeper into the ice the layers thin and annual layers become indistinguishable. An ice core from the right site can be used to reconstruct an uninterrupted and detailed climate record extending over hundreds of thousands of years, providing information on a wide variety of aspects of climate at each point in time.

### Procedure:

#### Part 1: Visualizing the climate from 400,000 to 10,000 years ago

1. Begin with a discussion with students about short/long periods of time. Ask them how we measure short periods of time. (They might say: seconds, or minutes, days, or even years.) How do we measure long periods of time? (They might say years or centuries.)
2. Review students’ earlier activities regarding weather. Ask them the following questions:
  - How far into the past did their data go?
  - Was that enough of a time frame to know whether the climate is changing? Why (not)?



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- Did the newspapers provide enough information to decide whether the climate is changing? Why or why not?
  - Do you think the climate has always been the same as it is today?
  - Even 400,000 years ago?
  - 100 million years ago?
  - Are there some other ways that we can know what the temperature was like in the distant past?
3. Tell students they will be looking at a data set that starts 400,000 years ago. They are going to use historical temperature data derived from ice cores going back 400,000 years to determine first if climate does change over time, and if so, how and how often. (You may wish to show the video *Drilling back to the Future: Climate Cues from Ancient ice on Greenland*. (available at CAMEL – Climate, adaptation, mitigation, E-learning): <http://www.camelclimatechange.org/resources/view/171210/?topic=65951>)
4. Hand out the sheet “Visualizing 400,000 Years of Climate Data.” In groups, or as a class, have students observe the graph and answer the questions. Depending on the level of your students, you may want to go project the graph and go over it as a class, to explain some of the more complex aspects:
- The scale on the Y-axis is the deviation from the global average temperature.
  - The 0 on the Y-axis represents the average global temperature between 1850 and 1900 (approx 14° C).
  - The scale on the X-axis represents geologic time, going back hundreds of thousands of years in the past. The numbers increase as you move to the left, representing how many years ago the dates are from the present.

When students have completed their work, ask the class:

- Does climate change over time?
- If there was change in the past, was it, in general, rapid or gradual?

You may want to stress that changes in temperature of even 1–2 degrees took tens of thousands of years to occur.

5. Finally, ask students to share their predictions of what they think the graph of climate from 10,000 years ago to the present will look like.

**Part 2: Graphing climate data from 10,000 years ago to the present**

1. Break the class up into six groups. Each group will be graphing a data set of temperature changes between 10,000 years ago and today. Students should use the following scale:

5 years = 0.25 cm

500 years = 25 cm



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This way, all data will be on the same scale. Groups with the 500-year averages (data sets 7, 8 and 9) will need four pieces of standard-sized paper to create their graph (they can tape pieces together or use butcher paper or poster board). Groups will also need a ruler with centimeter markings and colored pencils (depending on the size of your class and the number of points you want students to graph, you may want to give each group more than one data set).

The students' graphs should be set up in the same way as the graph on the handout, with a horizontal line at 0 to represent "current temperature." The y-axis needs to go from -2.1 to 1, with markings about every .1 degree, since most of the data is in decimal form and between 1 and -1.

2. Give students time to create their graphs and graph the data. They should use as much tape or graph paper as necessary to create a graph to scale.
3. Once students are done, have the groups line up in time order (students with data from 10,000 years ago should be at the front of the line). Have the first group of students tape their graph to the wall, have the second group of students add their graph to the first, continuing on until all the graphs have been taped together to create one long-term graph of temperature change.
4. **Optional:** Students can also add the events of human history to their graph(s). This will help students develop a connection between human actions and the climate.
5. Give students a few minutes to look over the graph. Have students write their reflections from the graphing activity on their handout.
6. Ask students what they noticed from the graph of the past 10,000 years as compared to the graph from the past 400,000 years. You may want to point out that in the 400,000-year graph, a temperature change of 1 or 2 degrees Celsius occurred over 10,000 years, but recently such a change happened in less than 100 years. Stress to students that the temperature is changing much faster now than it has in the past.
7. Ask students the same questions as at the beginning of the class?
  - Who thinks that the climate is changing? Why do you think that?
  - Has the climate always been the same as it is today?
  - What do you think has made the climate change in the past?
  - Is anything different about how the climate is changing today?
  - Ask students why they think climate is changing so quickly. Answers might include:
    - pollution
    - human impacts
    - increase in greenhouse gases

### Part 3: Explaining temperature variations

1. Part 3 will tie together the relationship between CO<sub>2</sub> and temperature that was introduced in earlier lessons.
2. Before distributing the handout for part 3, ask students what factors might explain the variation in temperature over the past 400,000 years. Write their answers on the board. If students do not mention greenhouse gases, remind them of the lessons and labs from earlier in the unit, and ask again.
3. Next, hand out the sheet “Explaining Temperature Variations.” Have students look at the two graphs and begin to answer the questions, alone, in groups, or as a whole class. Introduce (or review) the concept of ppm – parts per million. The data in the CO<sub>2</sub> graph is presented as ppmv, which stands for “parts per million by volume.”
4. Students may also need a bit of explanation regarding the years listed on the graph. On the graph, the CO<sub>2</sub> and temperature data end in 1950 (that is, “present” time is 1950). However, the data that they graphed in part 2 went to 2009. So their class graph is actually more complete than the graph on the handout. Lastly, a data point for CO<sub>2</sub> in 2010 (390 ppm) was added to the graph.
5. From the questions, students should develop the idea that carbon dioxide and temperature are closely related—they follow the same pattern. This is because an increase in CO<sub>2</sub> causes more energy to be kept on Earth, while a decrease in CO<sub>2</sub> allows more energy to escape into space.
6. Students should also understand that the increase in CO<sub>2</sub> in the recent past is caused mostly by an increase in fossil fuel use. Remind the students that since the industrial revolution (which began in 1790), fossil fuel use has been steadily increasing. Stress to students that the current levels of CO<sub>2</sub> are higher than at ANY point in the past 400,000 years!
7. The last question on the sheet asks students to predict what the CO<sub>2</sub> concentration and temperature will be in 2050. You may want to have students share their responses with the class. If students predict soaring CO<sub>2</sub> levels and temperatures, ask them what we can do **now** to prevent these levels from occurring.

### Extensions:

- It may help students to visualize the true changes in temperature by converting some of the temperatures from Celsius to Fahrenheit degrees. They can then visualize that the temperature changes on the graph are actually more drastic when in the Fahrenheit units with which students are familiar. The formula for converting from Celsius to Fahrenheit is:

$$F = 9/5C + 32$$



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- Students may wonder where the ancient data comes from. The data comes from making very deep (3,623-meter) cores in the ice in Antarctica. For more information, have students research the Vostok ice records.
- The timeline of human society also includes estimates of human population. You can have your students graph these data as well to see the exponential growth of the human population.

### Useful Websites

Paleomap project, Christopher Scotese, has helpful visuals and maps for visualizing climate history: <http://www.scotese.com/climate.htm>

On the cutting edge: Professional development for geoscience faculty also has many visuals and maps for climate change, and climate history:

<http://serc.carleton.edu/NAGTWorkshops/climatechange/visualizations/paleoclimate.html>

NOAA Paleoclimatology site:

A graph of historical climate, along with data on historical plant communities

<http://www.ncdc.noaa.gov/paleo/ctl/clisci100kb.html>

Additional data from the Vostok ice cores:

[http://www.ncdc.noaa.gov/paleo/icecore/antarctica/vostok/vostok\\_data.html](http://www.ncdc.noaa.gov/paleo/icecore/antarctica/vostok/vostok_data.html)

NASA GISS Surface Temperature Analysis has visualizations of climate data from 1880 to today: <http://data.giss.nasa.gov/gistemp/>

P.D. Jones, K.R. Briffa, T.P. Barnett, and S.F.B. Tett (1998), *The Holocene*, 8: 455-471.

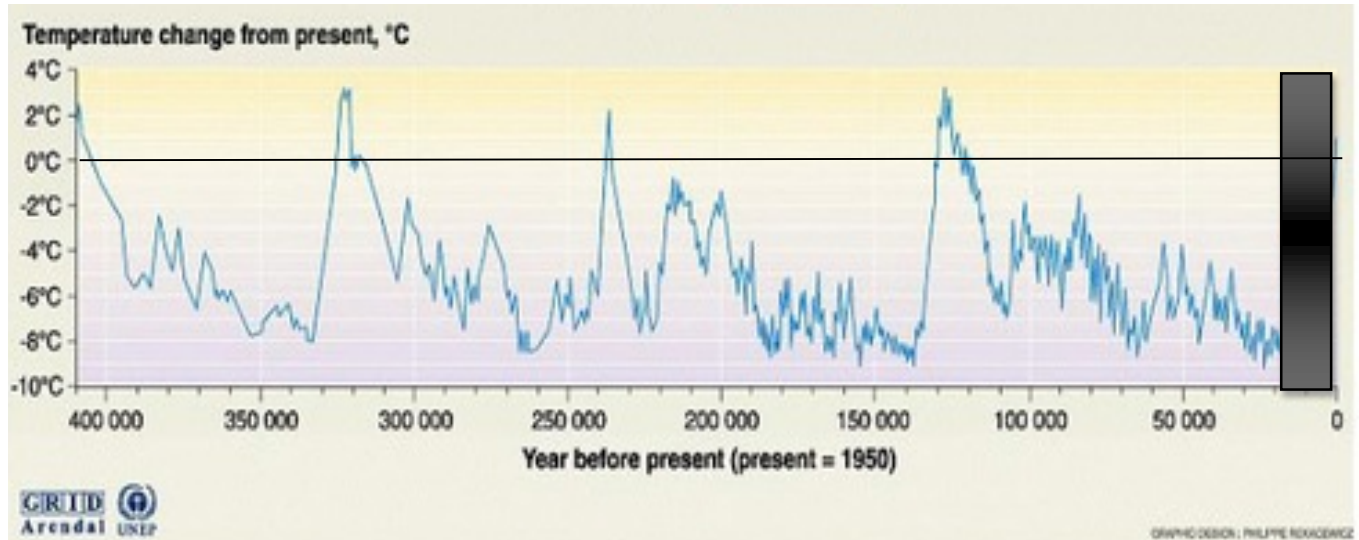
### NOTES:

Temperature deviation data\* taken from:

1. Jouzel J., C. Waelbroeck, B. Malaizé, M. Bender, J. R. Petit, N. I. Barkov, J. M. Barnola, T. King, V. M. Kotlyakov, V. Lipenkov, C. Lorius, D. Raynaud, C. Ritz and T. Sowers, 1996, Climatic interpretation of the recently extended Vostok ice records, *Climate Dynamics*, 12, 513-521.
2. NASA GISS Surface Temperature Analysis (GISTEMP), <http://data.giss.nasa.gov/gistemp/>  
Temperature deviations are calculated from the global mean for 1951–1980 (14.0 degrees -C)  
Timeline of human society data comes from multiple sources including *BigPicture*, *Small World*, <http://www.bigpicturesmallworld.com/funstuff/bigtime.shtml>
3. Graphs from: Petit, J.R., J. Jouzel, J., D. Raynaud, N.I. Barkov, J-M Barnola, I. Basile, M. Bender, J. Chappellaz, M. David, G. Delaygue, M. Delmotte, V.M. Kotlyakov, M. Legrand, V.Y. Lipenkov, C. Lorius, L. Pepin, C. C. Ritz, E. Saltzman, M. Stievenard, (1999). Climate and atmospheric history of the past 420 000 years from the Vostok ice core in Antarctica, *Nature*, 399, 429-436.

## Part 1: Visualizing 400,000 years of Climate Data

The graph below shows temperature data obtained from ice cores in Antarctica.



Source: J.F. Petit, J. Jouzel, et al. Climate and atmospheric history of the past 420 000 years from the Vostok ice core in Antarctica, *Nature* 399 (3 June), pp 429-436, 1999.

1. What type of data is shown on the x-axis? What are the units?
2. What type of data is shown on the y-axis? What are the units?
3. What do you think is meant by “temperature change from present?”
4. Where is “now” on the graph?
5. What do you think the line at 0 degrees Celsius represents?



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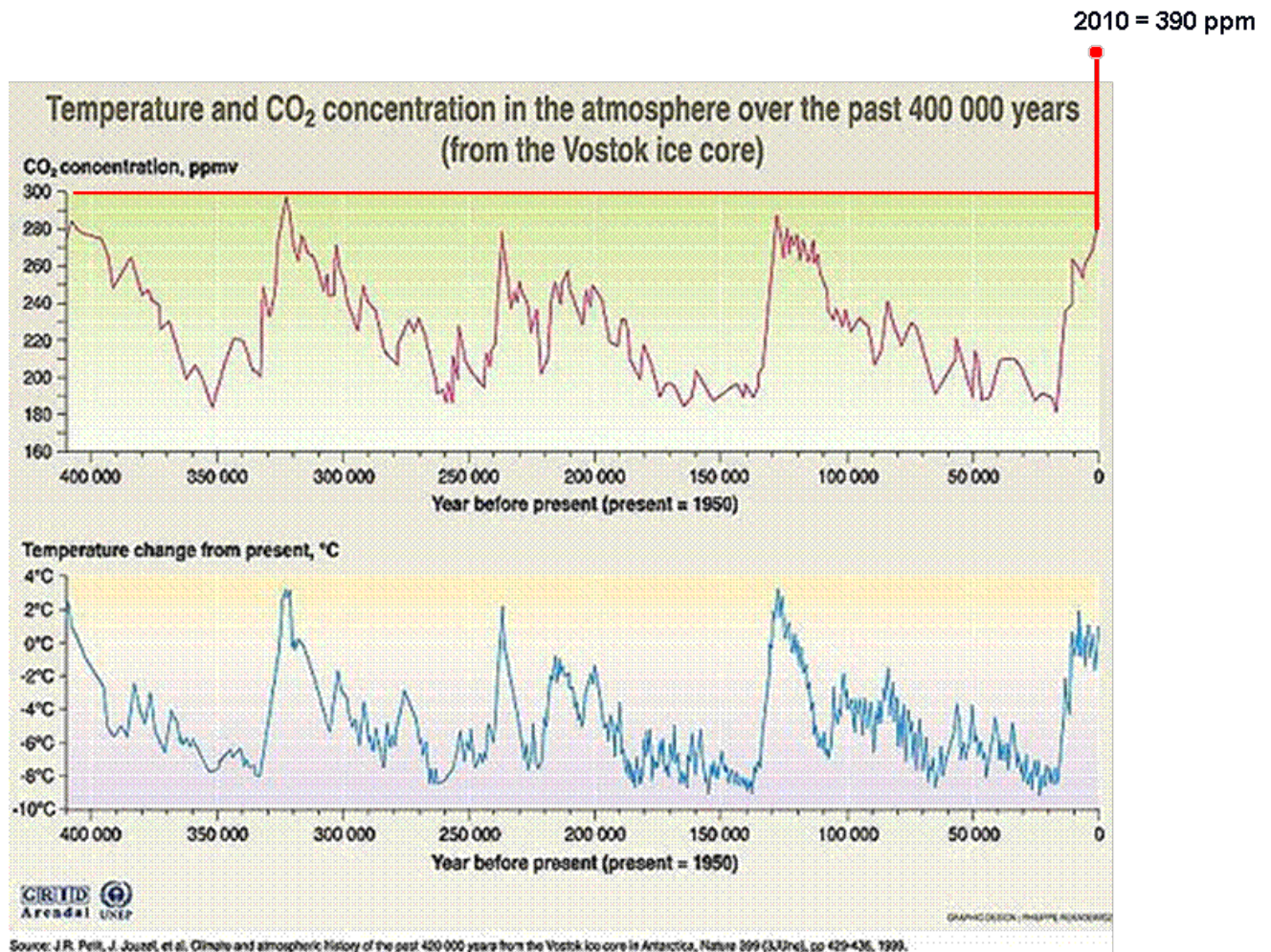
6. What does it mean when the temperature on the graph is a negative number?
7. Has climate changed over the past 400,000 years? How do you know?
8. Circle the coolest temperature(s) on the graph. Draw a box around the warmest temperature(s) on the graph.
9. How much did the temperature change between 320,000 and 260,000 years ago? How many years did it take for this temperature change to occur?
10. The last 10,000 years worth of data are not shown on the graph, because YOU will graph this data. What are your predictions for what the graph will look like over the past 10,000 years? (\*Note: the graph above only goes through 1950, but your data set goes through 2009).

**Part 2: Graphing 10,000 Years of Climate Data**

How does your class' graph of the past 10,000 years compare to the graph of the past 400,000 years. How are the graphs similar? How are they different?

### Part 3: Explaining Temperature Variations

The graph below shows carbon dioxide concentration and temperature data obtained from ice cores in Antarctica.



Look at the graphs above, on the bottom is the graph you saw (and helped to finish) in parts 1 & 2 of this activity.

1. In the top graph: what type of data is shown on the x-axis? What are the units?
2. In the top graph: what type of data is shown on the y-axis? What are the units?



CHICAGO BOTANIC GARDEN

3. How does the pattern in the first graph relate to the pattern in the second graph?
4. Why do you think the two patterns are related in this way?
5. The final point on the graph is from 1950, but the value for CO<sub>2</sub> concentration for 2010—390 ppm—is added to the graph. What was the change in CO<sub>2</sub> concentration between 1950 and 2010?
6. What do you think caused the increase in CO<sub>2</sub> concentration in the atmosphere between 1950 and 2010?
7. What do you expect will be the temperature change associated with this change in CO<sub>2</sub> concentration?



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8. **Prediction:** During this activity you have looked to the past 400,000 years of CO<sub>2</sub> and temperature. Now it is time to look to the future. What do you think the concentration of CO<sub>2</sub> in the atmosphere will be in the year 2050? What do you think the temperature will be in the year 2050? Explain your predictions. What role do we have in determining the CO<sub>2</sub> concentration and temperature in the year 2050?



# Average Temperature Deviation 500 Year Averages\* (10,000 BCE - 1852 CE)

Data Set 7

Year	DeltaT
-10,000-9501	-2.08
-9500-9001	-0.25
-9000-8501	-0.57
-8500-8001	-0.41
-8000-7501	-0.35
-7500-7001	-0.36
-7000-6501	-0.49
-6500-6001	-0.09

Data Set 8

Year	DeltaT
-6000-5501	-0.36
-5500-5001	-0.43
-5000-4501	-0.53
-4500-4001	-0.39
-4000-3501	-0.01
-3500-3001	0.06
-3000-2501	-0.14
-2500-2001	0.01

Data Set 9

Year	DeltaT
-2000-1501	-0.20
-1500-1001	-0.23
-1000-501	-0.65
-500-0	-0.51
0-499	-0.90
500-999	-0.46
1000-1499	-0.68
1500-1852	-0.35

## Average Temperature Deviation 5 Year Global Averages\* (1880 CE - 2009 CE)

Data Set 10

Year	5 Yr Avg.
1880-1884	-0.24
1885-1889	-0.31
1890-1894	-0.40
1895-1899	-0.14
1900-1904	-0.15
1905-1909	-0.22
1910-1914	-0.15
1915-1919	-0.19
1920-1924	-0.13

Data Set 11

Year	5 Yr Avg.
1925-1929	-0.08
1930-1934	-0.02
1935-1939	0.03
1940-1944	0.09
1945-1949	0.00
1950-1954	-0.02
1955-1959	0.00
1960-1964	-0.02
1965-1969	-0.06

Data Set 12

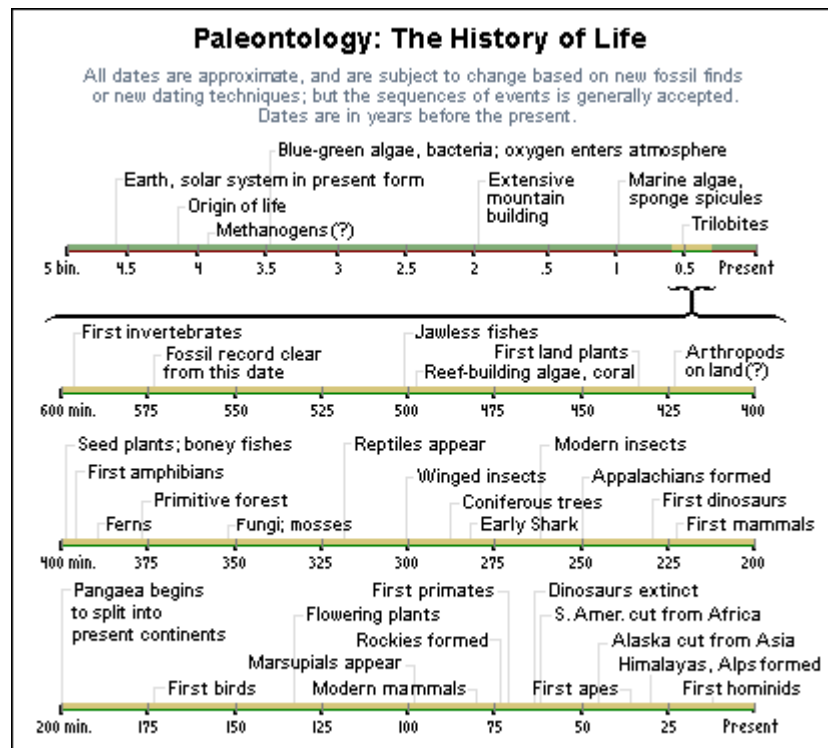
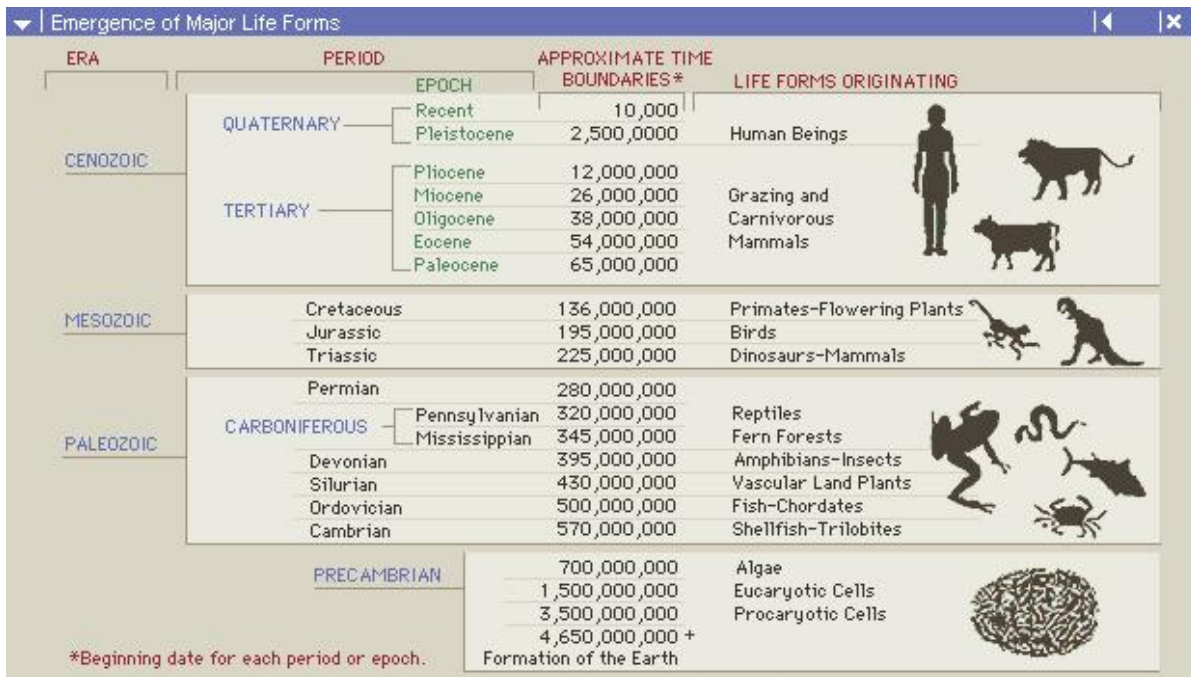
Year	5 Yr Avg.
1970-1974	0.00
1975-1979	0.02
1980-1984	0.24
1985-1989	0.26
1990-1994	0.30
1995-1999	0.46
2000-2004	0.58
2005-2009	0.68

\*Data 1880-2009 from NASA (<http://data.giss.nasa.gov/gistemp/>)

<b>Date</b>	<b>Event</b>
<b>- 360,000</b>	Human ancestors first use fire
<b>- 100,000</b>	Human ancestors migrate out of Africa
<b>- 40,000</b>	Human use complex language
<b>- 30,000</b>	Neanderthals die out
<b>- 25,000</b>	Last ice age
<b>- 12,000</b>	Agricultural revolution – human population reaches 10 million people
<b>- 10,000</b>	Dogs are domesticated
<b>- 3000</b>	Pyramids are built in Egypt – human population reaches 50 million people
<b>- 1000</b>	Humans use an alphabet – human population reaches 150 million
<b>1</b>	Humans use the abacus – human population reaches 200 million
<b>1500</b>	The first printing press is invented – human population reaches 500 million
<b>1600</b>	The first microscope and telescope are used – human population reaches 600 million; Little Ice Age
<b>1850</b>	The industrial revolution begins – human population reaches 1 billion
<b>1940</b>	The first computers were used – human population reaches 2.5 billion
<b>1950</b>	Humans watch television
<b>1969</b>	Humans land on the moon
<b>2000</b>	Humans use the internet – human population reaches 6 billion



## CHICAGO BOTANIC GARDEN

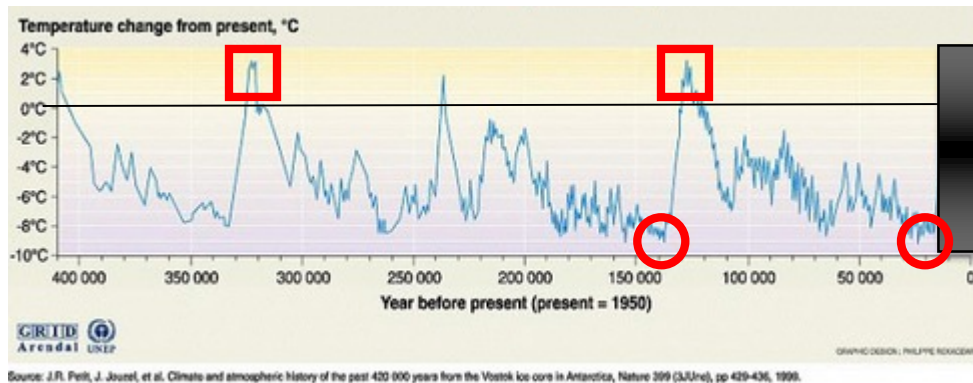


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**Answer key**

**Part 1: Visualizing 400,000 years of climate data**

The graph below shows temperature data obtained from ice cores in Antarctica.



1. What type of data is shown on the x-axis? What are the units?  
Time, years before present
2. What type of data is shown on the y-axis? What are the units?  
Temperature change from present, Celsius degrees
3. What do you think is meant by “temperature change from present?”  
The difference between the Earth’s average temperature at some time in the past and “today’s” (1950) average temperature
4. Where is “now” on the graph?  
“Now” is on the far right side of the graph, though the data ends in 1950.
5. What do you think the line at 0 degrees Celsius represents?  
This line represents the current average temperature of Earth (1950).
6. What does it mean when the temperature on the graph is a negative number?  
This means that the temperature at this point in the past was lower than it is today.
7. Has climate changed over the past 400,000 years? How do you know?  
Yes, climate has changed. The line on the graph goes up and down over the course of the 400,000 years.
8. Circle the coolest temperature on the graph. Draw a box around the warmest temperature on the graph.



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9. How much did the temperature change between 320,000 and 260,000? How many years did it take for this temperature change to occur?

About 10.5 degrees ( $2.5 - (-8)$ ). This change took 80,000 years to occur.

10. The last 10,000 years worth of data are not shown on the graph, because YOU will graph this data. What are your predictions for what the graph will look like over the past 10,000 years? (\*Note: the graph above only goes through 1950, but your data set goes through 2009).

Answers will vary based on students' predictions.

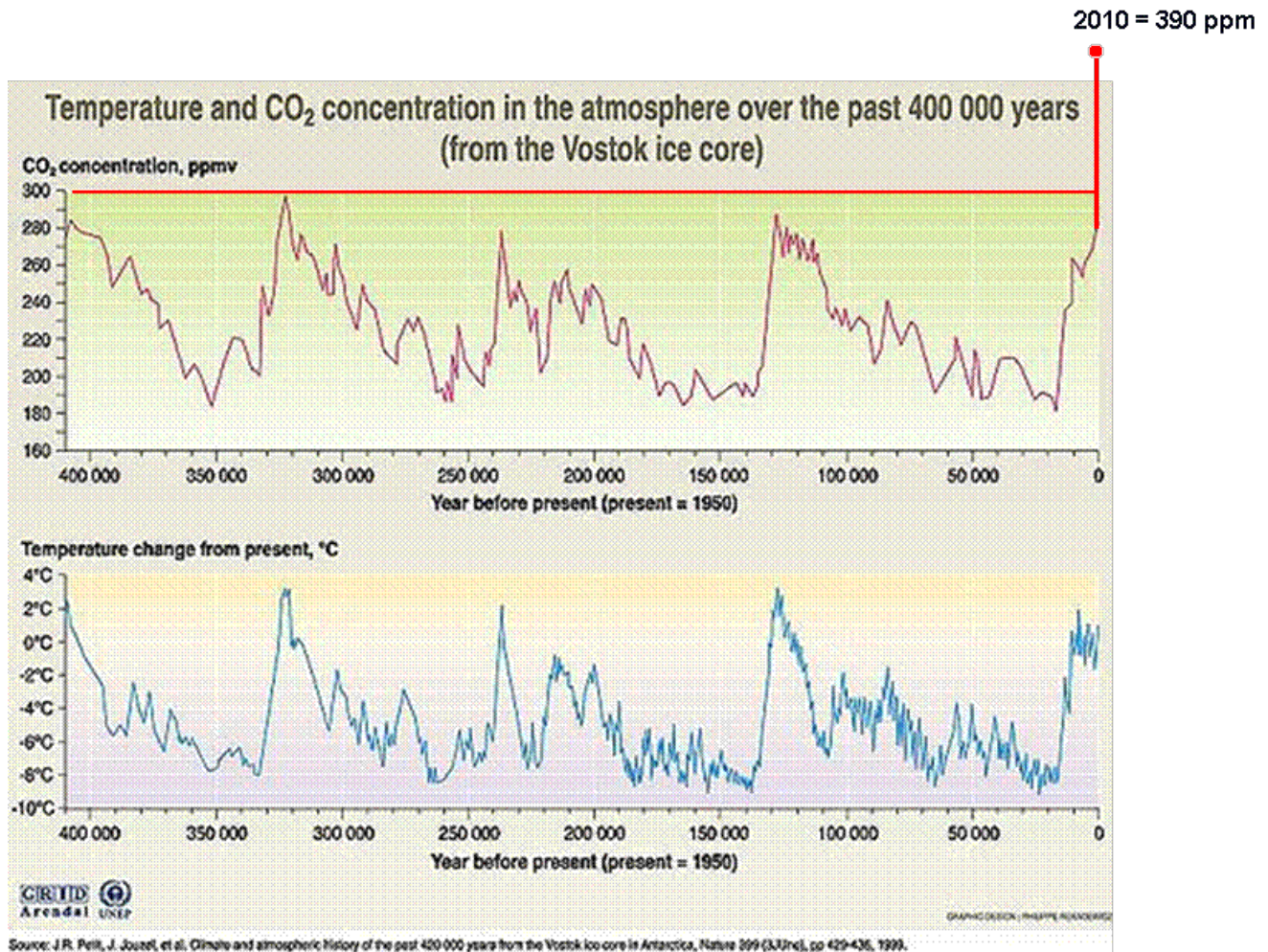
## Part 2: Graphing 10,000 years of climate data

How does your class' graph of the past 10,000 years compare to the graph of the past 400,000 years. How are the graphs similar? How are they different?

Answers will vary. Students may note that the graphs represent different amounts of time, different changes in temperature, and are different sizes but that temperature changes in both cases. They may note that temperature change seems to occur more rapidly in the graph of the past 10,000 years.

### Part 3: Explaining Temperature Variations

The graph below shows carbon dioxide concentration and temperature data obtained from ice cores in Antarctica.



Look at the graphs above, on the bottom is the graph you saw (and helped to finish) in parts 1 & 2 of this activity.

1. In the top graph: what type of data is shown on the x-axis? What are the units?  
Time, years before present.
2. In the top graph: what type of data is shown on the y-axis? What are the units?  
Carbon dioxide concentration. The units are PPMV, or parts per million by volume.
3. How does the pattern in the first graph relate to the pattern in the second graph?  
Answers will vary, but students should note a similar pattern in both graphs.



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4. Why do you think the two patterns are related in this way?  
*Answers will vary, but students may note that changes in carbon dioxide cause changes in temperature, since carbon dioxide is a greenhouse gas.*
5. The final point on the graph is from 1950, but the value CO<sub>2</sub> concentration for 2010 – 390 ppm – is added to the graph. What was the change in CO<sub>2</sub> concentration between 1950 and 2010?  
*Approximately 120 ppm (270-390)*
6. What do you think caused the increase in CO<sub>2</sub> concentration in the atmosphere between 1950 and 2010?  
*Answers will vary, students may mention an increase in fossil fuel use.*
7. What do you expect will be the temperature change associated with this change in CO<sub>2</sub> concentration?  
*Answers will vary.*
8. **Prediction:** During this activity you have looked to the past 400,000 years of CO<sub>2</sub> and temperature. Now it is time to look to the future. What do you think the concentration of CO<sub>2</sub> in the atmosphere will be in the year 2050? What do you think the temperature will be in the year 2050? Explain your predictions. What role do we have in determining the CO<sub>2</sub> concentration and temperature in the year 2050?  
*Answers will vary.*



**Mass Extinctions Tied to Past Climate Changes:** *Fossil and temperature records over the past 520 million years show a correlation between extinctions and climate change*  
Adapted from an article by David Biello, *Scientific American*, October 24, 2007

Looking at both the fossil record and temperatures from the same time periods shows that a global warming trend is bad for the number of different species on Earth. 251 million years ago, an estimated 70 percent of land plants and animals died. At the same time, 84 percent of ocean life died. This event is known as the Permian extinction. The cause for this mass extinction is unknown. However, it is known that this period was an extremely warm one. A new study of the temperature and fossil records over the past 520 million years shows that extinctions like these have happened several times. Global warming is often linked with the planet-wide die-offs.

"There have been three major greenhouse phases in the time period we analyzed and the peaks in temperature of each coincide with mass extinctions," says ecologist Peter Mayhew. Dr. Mayhew led the research to examine the fossil and temperature records. "The fossil record and temperature data already existed but nobody had looked at the connection between them."

Scientists compared the number of different sea organisms living during a given time period and the temperature at those times. The data show that eras with relatively high concentrations of greenhouse gases had far fewer numbers of species. Mayhew indicated that it appears that greenhouse periods led to a low variety of species.

This discovery raises concern about the future of species currently in existence on Earth. Global temperatures continue to rise to levels similar to those seen during the Permian era. It is thought that as the Earth and seas warm, many species will not be able to survive in their changed habitats.

However, we cannot definitely say that global warming was the cause of the Permian extinctions, or that all mass extinctions are associated with warmer worlds. During the cooling at the end of the Ordovician period, about 430 million years ago, the planet saw the disappearance of 60 percent of different groups of marine organisms. But scientists argue that the evidence of a link between climate change and mass extinctions is reason to be concerned for the future. There needs to be more study of the historic connection between a warmer world and the loss of species. Mayhew says, "That will help us decide if this is really a worry for the next generation or if the threat is merely a distant future threat."