



Activity 2.1: Historical Climate Cycles

Grades 10 – 12

Description: Students interpret temperature reconstructions made using data from various sources (fossils, ice cores, tree rings) to understand historical climate cycles. They use this historical background to begin the discussion of how current changes in climate are different from what has happened in the past.

Materials:

- LCD projector
- Student worksheet handouts (one per student)
- Student graph handouts (one per group)

Time: One class period

National Science Education Standards:

A2.c Scientists rely on technology to enhance the gathering and manipulation of data. New techniques and tools provide new evidence to guide inquiry and new methods to gather data, thereby contributing to the advance of science.

D3.c Interactions among the solid Earth, the oceans, the atmosphere, and organisms have resulted in the ongoing evolution of the Earth system.

AAAS Benchmarks:

11C/H9 It is not always easy to recognize meaningful patterns of change in a set of data. Data that appear to be completely irregular may be shown by statistical analysis to have underlying trends or cycles. On the other hand, trends or cycles that appear in data may sometimes be shown by statistical analysis to be easily explainable as being attributable only to randomness or coincidence.

4B/H6 The Earth's climates have changed in the past, are currently changing, and are expected to change in the future, primarily due to changes in the amount of light reaching places on the Earth and the composition of the atmosphere. The burning of fossil fuels in the last century has increased the amount of greenhouse gases in the atmosphere, which has contributed to Earth's warming.

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?

Procedure

1. Begin the discussion with the question: Has the climate always been the way it is today?
 - If YES, then ask students, what about the ice ages, when it was much colder? Do you think there have been times when it was much hotter?
 - If NO, ask how it was different and how they know.



CHICAGO BOTANIC GARDEN

2. Once a variety of answers have been generated, ask:
 - What sources of information do we have to help us answer these questions?
 - What ways have researchers used to collect temperature data from the past? (Currently we have satellites and weather stations that constantly monitor temperature. In recent history, we used thermometers and historical records.)
 - What about before that? (We know about past climates from fossil records of plants, small insects, and pollen, ice cores, sea floor cores, geological patterns and formations, and even from looking at tree rings.) The science of studying past climates is called paleoclimatology.
3. Tell students that they are going to research different methods of identifying past temperature and then look at and interpret graphs of temperature reconstructed from a variety of different sources (ice cores, boreholes, tree rings, etc.).
4. Pass out the student handouts and Paleoclimate Reconstruction Graphs Part 1. The next two steps (5-6) can be done in whichever order works best for your class. You can either have students work to figure out the graphs in groups and then discuss, or you can go over the graphs as a class and then have students work in groups to answer the questions.
5. Break students into groups of two to three and have students work in groups to fill in the table and answer the questions.
6. Once students have finished, bring the class back together and project the graphs using an LCD projector. Have a whole class discussion about the graphs, what they mean and what they represent. Use the following notes to guide the discussion.

For detailed descriptions of the graphs used in this activity, please visit:

<http://www.globalchange.umich.edu/globalchange1/current/lectures/klings/paleoclimate/index.html>. For the purposes of this lesson, a summary is below:

Paleoclimate **reconstruction graph part I** shows the climate record as we currently understand it, and lists some of the techniques used to reconstruct past climate. Currently, we use instruments such as weather stations, thermometers, and satellite data. Past climate can be reconstructed by the remains of preserved organisms such as fossilized animals or plants and pollen. Sediment types and composition also provide information about past climates.

The right-hand column lists the techniques used to make the climate reconstruction shown on the left. In the ocean, we can find a nearly continuous climate record that goes back millions of years. This historical record consists of layers of plankton, pollen, and other sediments that collect on the ocean floor. The bottom panel of the figure shows 1 million years of climate data, which represents only about 1/50 of 1 percent of the Earth's lifetime. The green portions of the graph represent the portion of the graph that is expanded in each subsequent panel. So Graph B is an expanded representation of the green portion of Graph A.



Discussion

7. Start the discussion with the one-million-year time series (Graph A). Note that the record from the deep sea sediments shows cycles of alternating cold and warm periods with a period of about 100,000 years. Superimposed on this long-term cycle are multiple deviations on shorter time scales.
8. Now focus on the 150,000 years only (Graph B, representing the green portion of Graph A.) Explain to students that they are zooming in more and more closely to present day, and each graph is an expanded representation of the green portion of the previous graph. Graph B represents the glacial/interglacial features of two sets of ice core isotope measurements, one from Byrd Station in the Southern Hemisphere, and the other from Camp Century in the Northern Hemisphere.
9. The recent warming trend started approximately 15,000 years ago (Graph C, representing the green portion of Graph B). At this point in North America, glaciers retreated north past Michigan. This warming coincides with the development of human civilization. Also in Graph C, you may note a rapid cooling period that occurred around 10,000 years ago and lasted for approximately 700 years. This period was called the "Younger Dryas" after the non-woody dryas plant that covered much of the landscape during the colder time period.

Evidence for this sudden cooling came from the study of ancient pollen grains found in sediments, which showed an abrupt change from pre- and post-glacial forests to glacial shrubs and then back again. This climate "jump" was also seen in ice core measurements of CO₂. The Younger Dryas provides dramatic evidence for rapid jumps in climate. *(Note that students will be reading a recently published article by NASA that links current climate changes to this type of rapid climate change.)*

10. Graph D shows the climate record of the past 1,000 years. At this time, the climate was relatively warm and dry (wine grapes were grown in England!). This was also the period that the Vikings ran out of room in Scandinavia and colonized Greenland, which was not icy at the time, as it is today). Unfortunately for the Vikings, the period of relatively mild climate was replaced by colder conditions during the famous "Little Ice Age," between 1250 and 1850, and Greenland became uninhabitable again.
11. The most recent 200 years are shown in Graph E and the end left-hand position of Graph D. During this time, global human activity significantly expanded and industrial revolution flourished, and temperatures continued to climb. (See also Graph 2 parts A and B.)
12. After this discussion, tell students that in addition to the methods shown in figure 1, scientists can also collect data on past climate from ice cores and tree rings. 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>



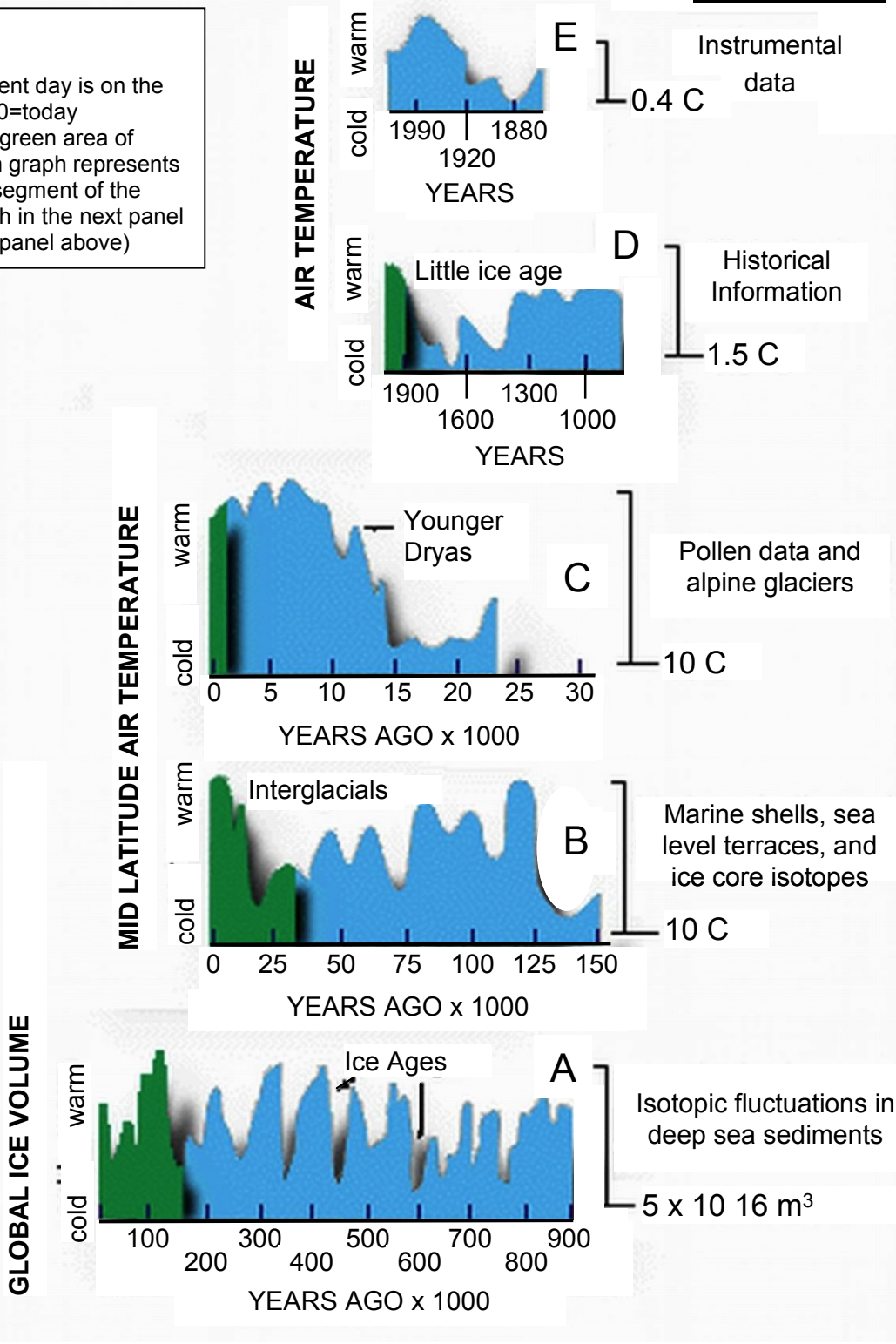
13. Next, hand out the Paleoclimate Graphs Part 2 and have students work in their groups together to answer the questions on the handout.
14. To close, discuss as a class how looking at past changes in climate can inform how we think about climate change today. Tell students that tomorrow they are going to do their own climate reconstruction by using tree cores to determine historical climates.
15. For homework, have students read the article, *Paleoclimate Record Points toward Potential Rapid Climate Changes* and revisit their class discussion. Students should write one to two paragraphs addressing the question: How looking at past changes in climate can inform how we think about climate change today?

Paleoclimate Reconstruction Graphs Part 1

Notes

- 1) Current day is on the left, 0=today
- 2) The green area of each graph represents the segment of the graph in the next panel (the panel above)

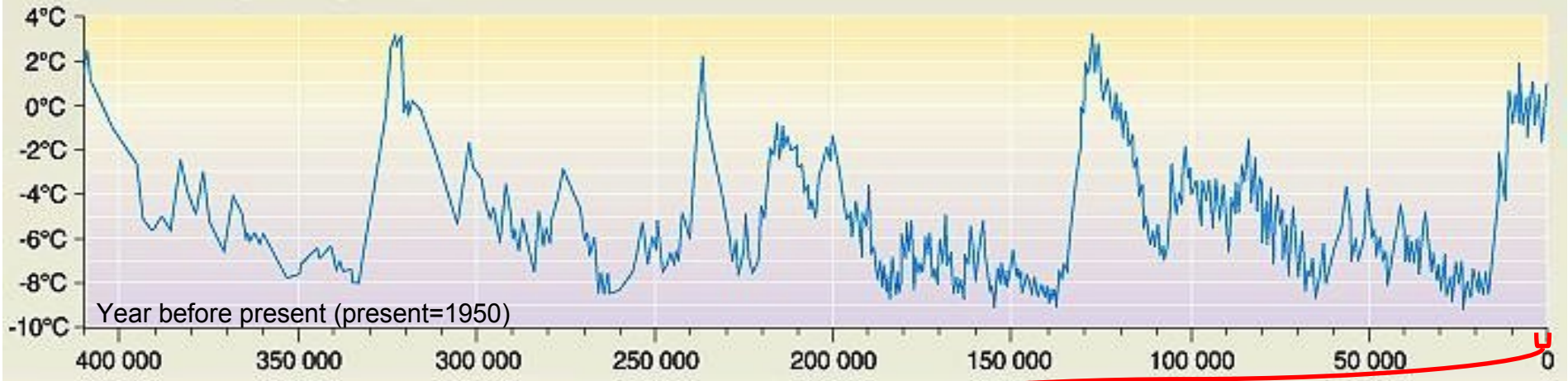
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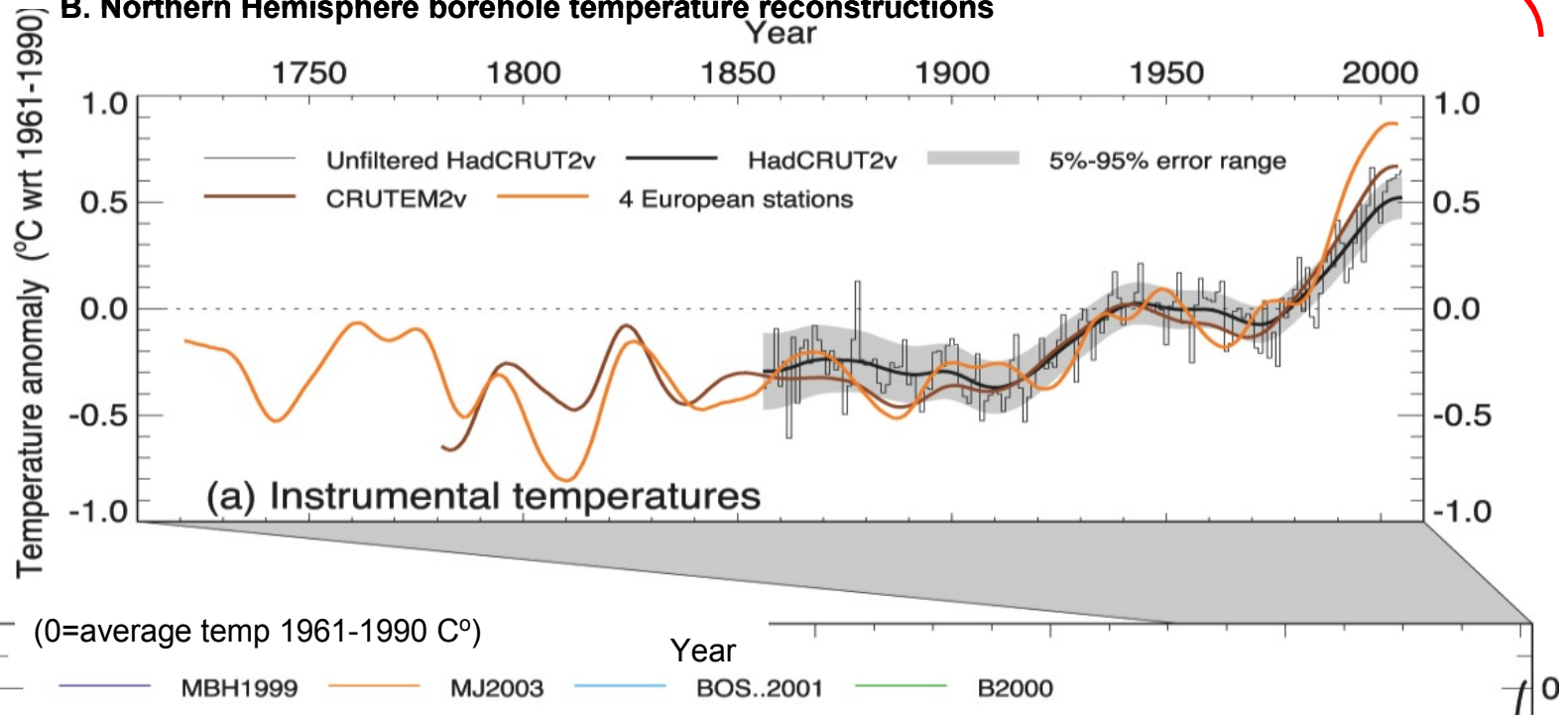
Paleoclimate Graphs Part 2



A. Vostok Ice Core Data Temperature Reconstruction (temperature change from present, C°)



B. Northern Hemisphere borehole temperature reconstructions

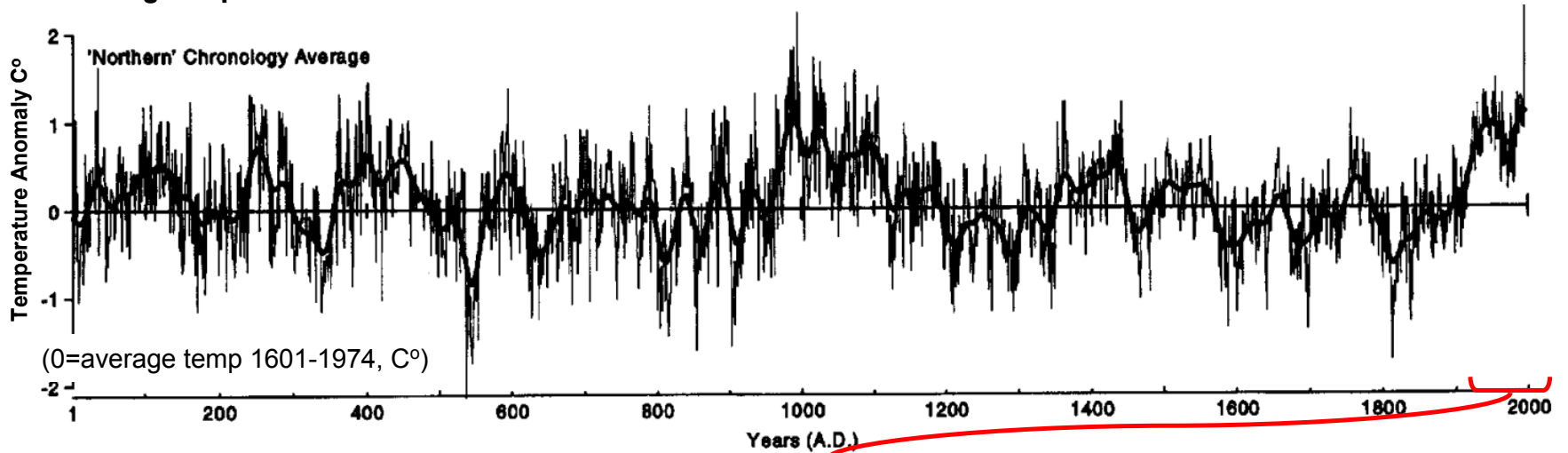


Graph A: Petit, J. R., J. Jouzel. Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature* 399, 429-436 (3 June 1999)
 Graph B: Figure 6.10 in the Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007 Solomon, S.,



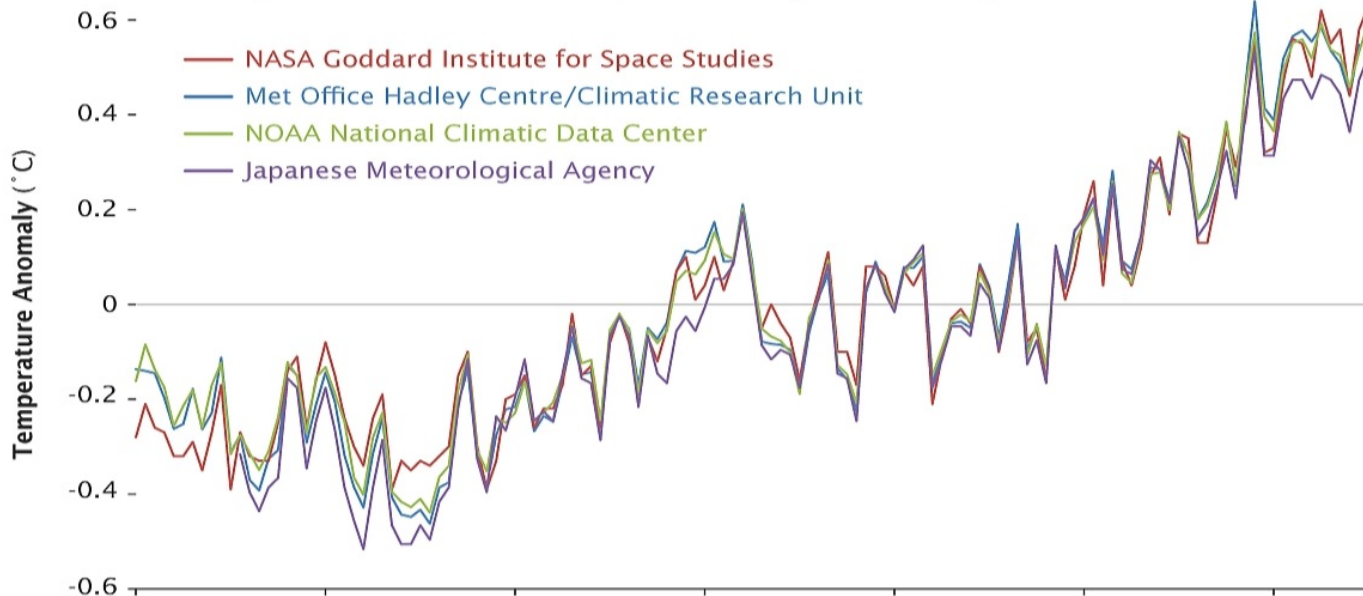
Paleoclimate Graphs Part 2 cont.

C. Tree Ring Temperature Reconstruction



Global Data from global temperature measures

Four independent records show nearly identical long-term warming trends.



Graph C: Briffa, Keith R. "Annual climate variability in the Holocene: interpreting the message of ancient trees." Quaternary Science Reviews 19 (2000): 87-105.

© (Graph D: NASA Earth Observatory, Robert Simmon. <http://www.giss.nasa.gov/research/news/20110113/>



Name _____ Class/Teacher _____

Student Handout: Using Paleoclimate Data to Interpret Changing Climates

Part 1

Use **Paleoclimate Reconstruction Graphs Part 1**, showing temperature reconstructions using instrumental data, historical records, pollen data, marine data, and deep sea sediment data, to fill out the following table and answer the questions.

Data Type	Time Scale	Trends before 1850	Trend after 1850	Data
Instrument	~1890-present	N/A	General warming trend since 1900	0.5 degree C increase in temp.
Historical				
Pollen and glaciers				
Marine shells/sea level terraces				
Deep sea sediment cores				

1. Were there any times in the past 400,000 years in which temperatures were warmer than today? If so, when?

2. Based upon the Paleoclimate Reconstruction Graphs Part 1, do you think climate can change rapidly (geologically speaking; remember that the Earth is 4,600,000,000 years old)? Give an example to support your answer.



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6. Look at the International Panel on Climate Change graph of borehole data (2B) from the U.S., Canada, Greenland, and Sweden. Does each data set follow a similar pattern? Explain why the graphs are not all exactly the same.

7. Compare the borehole graph (2B) with the graph of tree ring temperature reconstruction (2C). Describe any similarities and differences. What do you think are the causes of these similarities and differences?

8. Compare the ice core graph (2A), the borehole graph (2B), and the tree ring reconstruction graph (2C). Explain why it is more difficult to identify patterns in the graphs that cover 2,000 years than in the ice core graph, which covers 400,000 years.

9. Consider the graph of direct global temperature measures (2D). What does this graph tell you about how climate is changing today? Explain how looking at paleoclimate temperature reconstructions can help as measures of temperature change from the recent past and present.



Paleoclimate Record Points Toward Potential Rapid Climate Changes

Patrick Lynch, NASA's Earth Science News Team 12.08.11

New research into the Earth's paleoclimate history by NASA's Goddard Institute for Space Studies director James E. Hansen suggests the potential for rapid climate changes this century, including multiple meters of sea level rise, if global warming is not abated.

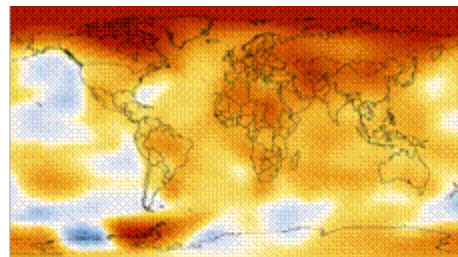
By looking at how the Earth's climate responded to past natural changes, Hansen sought insight into a fundamental question raised by ongoing human-caused climate change: "What is the dangerous level of global warming?" Some international leaders have suggested a goal of limiting warming to 2 degrees Celsius from pre-industrial times in order to avert catastrophic change. But Hansen said at a press briefing at a meeting of the American Geophysical Union in San Francisco on Tues, Dec. 6, that warming of 2 degrees Celsius would lead to drastic changes, such as significant ice sheet loss in Greenland and Antarctica.

Based on Hansen's temperature analysis work at the Goddard Institute for Space Studies, the Earth's average global surface temperature has already risen .8 degrees Celsius since 1880, and is now warming at a rate of more than .1 degree Celsius every decade. This warming is largely driven by increased greenhouse gases in the atmosphere, particularly carbon dioxide, emitted by the burning of fossil fuels at power plants, in cars and in industry. At the current rate of fossil fuel burning, the concentration of carbon dioxide in the atmosphere will have doubled from pre-industrial times by the middle of this century. A doubling of carbon dioxide would cause an eventual warming of several degrees, Hansen said.

In recent research, Hansen and co-author Makiko Sato, also of Goddard Institute for Space Studies, compared the climate of today, the Holocene, with previous similar "interglacial" epochs – periods when polar ice caps existed but the world was not dominated by glaciers. In studying cores drilled from both ice sheets and deep ocean sediments, Hansen found that global mean temperatures during the Eemian period, which began about 130,000 years ago and lasted about 15,000 years, were less than 1 degree Celsius warmer than today. If temperatures were to rise 2 degrees Celsius over pre-industrial times, global mean temperature would far exceed that of the Eemian, when sea level was four to six meters higher than today, Hansen said.



At the Earth's current rate of carbon dioxide increases in the atmosphere, the planet is likely to experience several degrees increase in average temperatures and large-scale changes such as ice sheet loss that could lead to several meters of sea level rise this century, NASA's James E. Hansen said in a recent paper. **Credit:** NASA's Scientific Visualization Studio



The average global surface temperature of Earth has risen by .8 degrees Celsius since 1880, and is now increasing at a rate of about .1 degree Celsius per decade. This image shows how 2010 temperatures compare to average temperatures from a baseline period of 1951-1980, as analyzed by scientists at NASA's Goddard Institute for Space Studies. **Credit:** NASA GISS



"The paleoclimate record reveals a more sensitive climate than thought, even as of a few years ago. Limiting human-caused warming to 2 degrees is not sufficient," Hansen said. "It would be a prescription for disaster."

Hansen focused much of his new work on how the polar regions and in particular the ice sheets of Antarctica and Greenland will react to a warming world.

Two degrees Celsius of warming would make Earth much warmer than during the Eemian, and would move Earth closer to Pliocene-like conditions, when sea level was in the range of 25 meters higher than today, Hansen said. In using Earth's climate history to learn more about the level of sensitivity that governs our planet's response to warming today, Hansen said the paleoclimate record suggests that every degree Celsius of global temperature rise will ultimately equate to 20 meters of sea level rise. However, that sea level increase due to ice sheet loss would be expected to occur over centuries, and large uncertainties remain in predicting how that ice loss would unfold.

Hansen notes that ice sheet disintegration will not be a linear process. This non-linear deterioration has already been seen in vulnerable places such as Pine Island Glacier in West Antarctica, where the rate of ice mass loss has continued accelerating over the past decade. Data from NASA's Gravity Recovery and Climate Experiment (GRACE) satellite is already consistent with a rate of ice sheet mass loss in Greenland and West Antarctica that doubles every ten years. The GRACE record is too short to confirm this with great certainty; however, the trend in the past few years does not rule it out, Hansen said. This continued rate of ice loss could cause multiple meters of sea level rise by 2100, Hansen said.

Ice and ocean sediment cores from the polar regions indicate that temperatures at the poles during previous epochs – when sea level was tens of meters higher – is not too far removed from the temperatures Earth could reach this century on a "business as usual" trajectory.

"We don't have a substantial cushion between today's climate and dangerous warming," Hansen said. "Earth is poised to experience strong amplifying feedbacks in response to moderate additional global warming."

Detailed considerations of a new warming target and how to get there are beyond the scope of this research, Hansen said. But this research is consistent with Hansen's earlier findings that carbon dioxide in the atmosphere would need to be rolled back from about 390 parts per million in the atmosphere today to 350 parts per million in order to stabilize the climate in the long term. While leaders continue to discuss a framework for reducing emissions, global carbon dioxide emissions have remained stable or increased in recent years.

Hansen and others noted that while the paleoclimate evidence paints a clear picture of what Earth's earlier climate looked like, but that using it to predict precisely how the climate might change on much smaller timescales in response to human-induced rather than natural climate



change remains difficult. But, Hansen noted, the Earth system is already showing signs of responding, even in the cases of "slow feedbacks" such as ice sheet changes.

The human-caused release of increased carbon dioxide into the atmosphere also presents climate scientists with something they've never seen in the 65 million year record of carbon dioxide levels – a drastic rate of increase that makes it difficult to predict how rapidly the Earth will respond. In periods when carbon dioxide has increased due to natural causes, the rate of increase averaged about .0001 parts per million per year – in other words, one hundred parts per million every million years. Fossil fuel burning is now causing carbon dioxide concentrations to increase at two parts per million per year.

"Humans have overwhelmed the natural, slow changes that occur on geologic timescales," Hansen said.

<http://www.nasa.gov/topics/earth/features/rapid-change-feature.html>



Paleoclimate Resources on the Web

NASA Paleoclimatology

http://earthobservatory.nasa.gov/Features/Paleoclimatology/paleoclimatology_intro.php

This site explains the ways that researchers use the earth (oxygen isotopes in rocks and soils), the oceans (bottom sediment, fossil chemistry), and ice (polar ice core isotopes, dust, volcanic ash), as proxy data for temperature.

Paleoclimate data that can be used to generate climate reconstructions from a variety of NASA and other government research projects data sources:

<http://globalchange.nasa.gov/KeywordSearch/Keywords.do?Portal=GCMD&KeywordPath=Parameters%7CPALEOCLIMATE%7CPALEOCLIMATE+RECONSTRUCTIONS&MetadataType=0&lbnode=mdlbl>

Rimfrost Climate Data Graphing Tool

<http://www.rimfrost.no/>

Here you can visualize temperature data over 250 years at over 1100 locations throughout the world, as well as carbon dioxide emissions and ice core data.

NOAA Paleoclimatology

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

This site is a collection of all the different types of paleoclimate data. It provides links and access to data from around the world.

Paleomap Project

<http://www.scotese.com/climate.htm>

This site provides climate visualizations for different periods throughout the Earth's history. It also provides concrete examples of indicators for different climate times (e.g. if a geologist finds coal, bauxite, and laterite in a sediment, they are looking at what used to be a wet, warm climate).

University of Michigan Global Change Paleoclimate Website

<http://www.globalchange.umich.edu/globalchange1/current/lectures/klings/paleoclimate/>

This site provides an overview and detailed descriptions of the different methods used to reconstruct temperatures including:

- Isotopic Geochemical Studies: the study of rock isotopic ratios, ice core bubbles, deep sea sediments, etc.
- Dendochronology: the study of tree rings
- Pollen Distribution: the study of plant types and prevalence from pollen found in sediments, ice, rocks, caves, etc.
- Lake Varves: (like dendochronology, but with lake sediments; a varve is an annual layer of mud in the sediment)
- Coral Bed Rings
- Fossils: Studies of geological settings, etc.
- Historical documents, paintings, evidence of civilizations, etc.

**Teacher Answer Key****Student Handout: Using Paleoclimate Data to Interpret Changing Climates****Part 1**

Use **Paleoclimate Reconstruction Graphs Part 1**, showing temperature reconstructions using instrumental data, historical records, pollen data, marine data, and deep sea sediment data, to fill out the following table and answer the questions.

Data Type	Time Scale	Trends before 1850	Trend after 1850	Data
Instrument	~1880-present	NA	General warming trend since 1900	0.5 degree C increase in temp.
Historical	~900-1900	Cooler temperatures between ~1300-1650	NA	1.5 degree C change in temp.
Pollen and glaciers	~3000-24,000 years ago	Much cooler 15-20 thousand yrs. Ago, then warmer, with a few cooler dips	NA	10 degree C change in temperature
Marine shells/sea level terraces	~27,000-150,000 years ago	There are medium peaks and dips about every 40,000 yrs with smaller dips in between and a cooling trend that ends about 20,000 years ago.	NA	10 degree C change in temperature
Deep sea sediment cores	~150,000-900,000 years ago	There are fairly regular deep peaks and dips about every 100,000 years	NA	Data is measured by the volume of ice/glaciers

1. Were there any times in the past 400,000 years in which temperatures were warmer than today? If so, when?

Yes there were at least three times that it was warmer than it is today, approximately 200,000, 300,000, and 400,000 years ago. In between these times, there were colder periods.

2. Based upon the Paleoclimate Reconstruction Graphs Part 1, do you think climate can change rapidly (geologically speaking; remember that the Earth is 4,600,000,000 years old)? Give an example to support your answer.

It seems like it can change quickly, geologically speaking. One example is about 15,000 years ago (Illustrated in Graph C), when the temperature changed approximately 5-6 degrees C in only a few thousand years.



Teacher Answer Key

3. Is there similarity among the temperature curves from reconstructions of different data? Reference the graphs to explain your answer

There is similarity in the curves in different reconstructions from data. For example both graphs E and D show a dip in temperature around 1800, and both graphs B and C show dips about 15,000 years ago, and then a steep increase between 15,00 and 10,000 years ago.

However, they are not exactly the same. One of the reasons is that you can see more detail in the peaks and dips in temperature on the graphs that represent smaller amounts of time. Another may be that data was collected in different locations and temperature variation might have been different around the world. A final reason might be that some types of data and reconstructions are more accurate than others.

Part 2

Use **Paleoclimate Graphs Part 2**, showing temperature reconstructions of the Vostok ice cores (2A) and IPCC boreholes (2B), and tree rings (2C) and direct temperature measures (2D), to answer the following questions:

4. Consider the Vostok Ice Core graph (2A). Describe any patterns you see referencing the time scale of those patterns (e.g. every 100,000 years, every 10,000 years).

There are large temperature peaks about every 100,000 years. These peaks tend to come quickly geographically speaking, and then taper more slowly downward again. During the cooler times there are smaller temperature increases about every 10,000 years, but there is an overall cooling trend until you get to the next 100,000 year spike.

5. Based on the historical patterns you identified above, where in the cycle of temperature increase/decrease should we be today? Support your answer with data.

It looks like we should be getting close to the top of one of those temperature spikes. If you look at the Vostok data, it looks like we might be entering a cooling trend at the very end, but it's not entirely clear. If you look at the more recent temperature reconstructions, the borehole, it is clear that at least since about 1800, there has been a steep warming trend. This is reflected both in the tree ring data and in direct temperature measurements.

6. Look at the International Panel on Climate Change graph of borehole data (2B) from the U.S., Canada, Greenland, and Sweden. Does each data set follow a similar pattern? Explain why the graphs are not all exactly the same.

Each does follow basically the same trend. They are not all the same because they were taken from different locations and temperature variation can be different at different locations. They also may be different because they are temperature reconstructions, not actual measurements, so the methods of reconstruction may have been different.



Teacher Answer Key

7. Compare the borehole graph (2B) with the graph of tree ring temperature reconstruction (2C). Describe any similarities and differences. What do you think are the causes of these similarities and differences?

They follow generally the same pattern, with a slight increase between 800 and 1000 CE and then a decrease between 1000 and about 1800, then increasing again. There may be differences because they are two different types of temperature reconstructions. Tree growth is affected by things other than temperature, so that may also explain differences between the tree ring and borehole reconstructions.

8. Compare the ice core graph (2A), the borehole graph (2B), and the tree ring reconstruction graph (2C). Explain why it is more difficult to identify patterns in the graphs that cover 2,000 years than in the ice core graph, which covers 400,000 years.

It is more difficult to identify patterns in graphs that cover shorter time frames because daily temperature variation is expected, so you need many, many, data points over longer periods of time to identify any consistent changes in temperature over time.

9. Consider the graph of direct global temperature measures (2D). What does this graph tell you about how climate is changing today? Explain how looking at paleoclimate temperature reconstructions can help as measures of temperature change from the recent past and present.

Graph 2D shows that though there are fluctuations, temperature has been increasing steadily for the past about 650 years, and has increased about 1 degree C since then. It indicates that the climate is getting warmer. Looking at longer term trends in temperature helps us predict that temperature could be expected to change in the future, and by looking at patterns, we can see whether or not it is changing in the ways that we might expect, or if something different is happening.