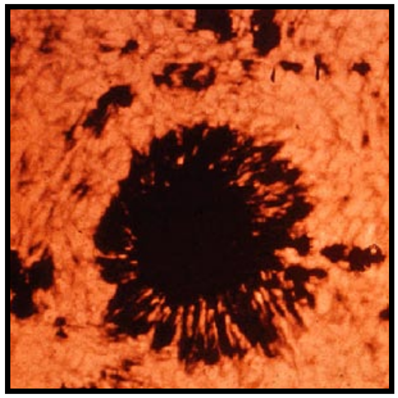
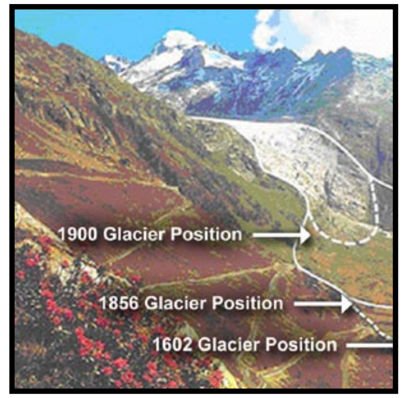
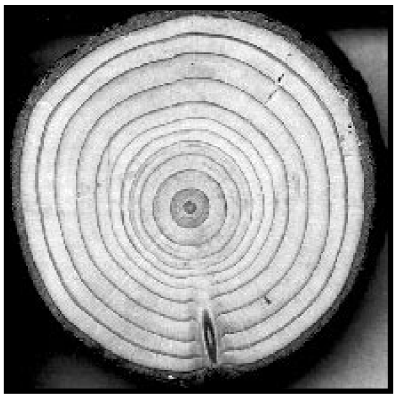
Climate Discovery Teacher's Guide

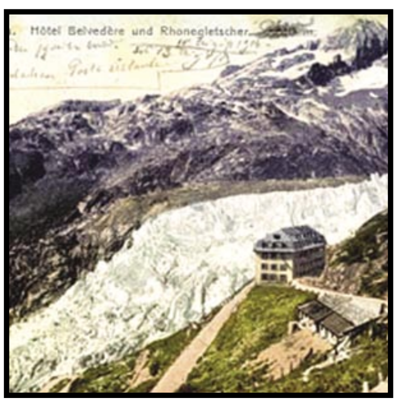






Unit: Paleoclimatology: Little Ice Age case study

Lessons for grades 5-8 that complement *Climate Discovery*, an exhibit at the National Center for Atmospheric Reseach, Boulder, Colorado



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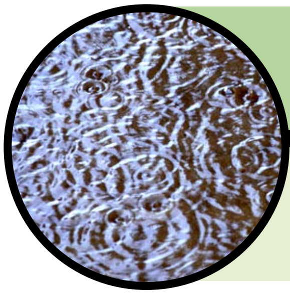
Introduction

Paleoclimatology is the science of reconstructing Earth's past climate. A paleoclimatologist's tools are natural sources such as ice cores and tree rings that contain important clues about past climate. They also use human records such as historical tree flowering and lake freezing dates, or artistic renderings and photographs of the environment, to indirectly measure climate conditions of the past.

In this unit, ***Paleoclimatology: Little Ice Age Case Study***, students will use various natural and human sources to better understand natural climate variability. Likewise, they will analyze two of the major contributors to climate variability and change: the solar cycle and extreme or persistent volcanic eruptions. In the unit's culminating lesson, students will compare and contrast solar, volcanic, and tree ring records from the Little Ice Age, 1350 to 1850 A.D., in order to draw conclusions about factors that contributed to this period's climate.

Throughout the Teacher Guide, we provide you with the necessary materials and science background information to allow you to confidently facilitate each lesson, as well as with additional resources should you or your students wish to learn more. We hope each Climate Discovery Unit will become an invaluable tool for you in your efforts to teach students about Earth's climate system.

We welcome your comments and suggestions about these materials. Please send them to us at the Office of Education and Outreach, National Center for Atmospheric Research, 1850 Table Mesa Drive, Boulder, CO 80305. We can also be reached by e-mail at erc@ucar.edu. We look forward to your feedback.



Differences between Climate and Weather

Unit: Little Ice Age
Lesson: 1

Materials & Preparation

Time:
- Introduction: 30 min
- Data collection: 10 minutes daily (for one or more weeks)
- Part 1 graphing/analysis: 45 min
- Part 2 graphing/analysis: 45 min

Materials for the Teacher:
- Thermometer
- A copy of the Weather Data Student Page for each day of data collection
- Overhead plot of average monthly temperature for your region (*see Advanced Preperation*)
- Overhead table of averaged climate data for region for period of data collection (average daily temperatures, minimums, maximums) (*see Advanced Preperation*)
- Internet access required

Materials for Students:
- Graph paper
- Pencils
- Colored pencils (recommended)
- Transparency (optional)

Source

Modified with permission from Project LEARN (http://www.ucar.edu/learn), a project of the University Corporation for Atmospheric Research (UCAR).

National Science Standards

Science as Inquiry: Content Standard A
Earth and Space Science: Content Standard D

Colorado Science Standards

- Science: 1, 4.2, 6
- Math: 3

Learning Goals

Students will
- Learn to collect and graph local weather data
- Understand the general distinctions between weather and climate
- Understand that daily weather measurements are highly variable compared to long-term climate data

What Students Do in this Lesson

Understanding and interpreting local weather data and understanding the relationship between weather and climate are important first steps to understanding larger-scale global climate changes. In this activity, students will collect weather data over several days or weeks, graph temperature data, and compare the temperature data collected with averaged climate data where they live.

Key Concepts

Weather is the current atmospheric conditions, including temperature, rainfall, wind, and humidity, while climate is the general weather conditions. Comparing daily temperature with averaged climate data, students will understand that weather is highly variable, but climate is not.

Scientists need a lot of data to average and understand regional climates or the "usual" conditions. To detect a change in climate, scientists need large amounts of data. They look for evidence of climate that existed long before humans made weather measurements. These climate records, including ice cores, lake bottom sediments, and tree rings, are called proxies. They are discussed in several of the activities that follow in this unit of the *Climate Discovery Teacher Guide*.

Differences between Climate and Weather

Advanced Preparation

- Familiarize yourself with the procedure for using your thermometers to collect atmospheric temperature data.
- Determine how long you want students to collect weather data (a week, month, or even all year). Depending on your regional climate, one week of data collection can be sufficient to illustrate weather variation (and may be more appropriate for younger students).
- Print and copy the Weather Data Student Page for data collection.
- Find climate data for your region: Climate data may be obtained from regional climatologists or local news stations. NOAA resources for locating regional climate data can also be found at: http://www.cdc.noaa.gov/PublicData/data_faq.html. However, as of the printing of this teacher guide, the simplest way we have found to locate regional climate data for locations within the North America, Europe, and major cities around the world is by visiting www.weather.com. At the main page, type your city name to get local weather, and then click "Averages" at the bottom of the page. Print the graph of monthly averages to show to the class when introducing Part 2 of this lesson. Then choose "Daily Averages" from the pull down menu at the top and select the month in which you are doing the activity. Use the average high, average low, and mean temperature values when plotting climate data in Part 2 of this lesson.

Directions

Part 1: Collecting Temperature Data

- Explain to students that they will collect temperature data to see how the temperature varies from day to day.
- Ask students to brainstorm what other aspects or characteristics of the weather might influence temperature (such as cloudiness, precipitation, and wind). Students will collect data about these factors too.
- Introduce students to the thermometer. Explain that each day a different pair of students will take the temperature measurement, and that because different people will be collecting data, it is important to collect the data the same way each time to be consistent. As a group, determine the procedure that students will follow each day to take measurements. (Observations should include the time of day and location. Care should be taken to ensure that body or building heat doesn't influence temperature measurements. Other considerations might include distance off the ground, number of measurements, length of time outside before measuring, etc.). Post these methods in a prominent classroom location.
- Record data for three days on the Weather Data Student Page to acclimate students to the observation methods. Once students appear comfortable with the data collection process, you may wish to have student pairs collect and share the data daily with the class.
- Have students create a graph of their weather data, adding to it each day (Y/vertical axis=temperature, X/horizontal axis=time/days). Help students to choose an appropriate range of values for their temperature axis based on their measurements. Graphing data helps students to identify patterns and relationships.
- If data is collected over several weeks, ask students to identify any patterns they see between the temperature data and the other weather elements measured (cloudiness, wind, precipitation).

Part 2: Comparing Student Data to Climate Data

- In a class discussion, ask the students if they think that their data is "typical" or representative of the weather for the period of time they have been monitoring. (The goal is for students to begin to understand that daily variations in weather are normal. Climate data, which describes "typical" weather, includes averages of decades of daily data.

- Show students the graph of average daily temperature over a year for your region. (See Advanced Preparation section above for help finding a graph.) Ask students what conclusions they can draw about climate from the graph. (Temperature is colder in winter, or warmer in summer, average temperatures and the amount of searsonal variation). Explain that this graph might help someone who is visiting the region to plan what sort of clothes to bring with them. For instance, if they are visiting in July, what should they bring? Would it help them to plan for tomorrow specifically?
- Compare the data from the climate graph to student weather data for the same time of year. To do this, students should plot climate temperature data points on their graphs with a different color and connect points with a line. If possible, have students also plot average maximum temperature and average minimum temperature on their graph. (Consider having students plot the data on overhead transparency using the same scale axes as the Part 1 graph so that the two graphs can be easily overlayed.)
- Discuss the differences between weather and climate:
    - Which is more variable: the daily temperature values or the average temperature values? Why?
    - Is the temperature data that the class collected warmer, cooler, or about the same as the average?
    - If you were asked to predict the temperature for tomorrow, which data would you find the most useful: the previous day's temperature, or the average temperature for that day?
    - If a scientist reported that your state was warmer last month than the same month a year ago, would you consider this to be evidence for climate change? Why or why not? (See Background Information.)

Extensions

- Do this exercise in cooperation with another school in a different geographic location comparing weather data.
- Set up a weather station at your school, collect data each day, and compare how aspects of the weather vary over the course of a school year.
- Participate in the GLOBE Program (www.globe.gov) in which students at schools around the world collect and share data about the environment.

ASSESSMENT

- Create your own simulated weather datasets. Ask students to examine the datasets and discuss: Which line on the graph is more variable: the daily values or the average values? Why?

Science Background Information

- When atmospheric scientists describe the "weather" at a particular time and place or the "climate" of a particular region, they describe the same characteristics: air temperature, type and amount of cloudiness, type and amount of precipitation, air pressure, and wind speed and direction. Why are the same characteristics used to describe both weather and climate? And why do we eagerly listen to the local weather forecaster but pay far less attention to predictions from the state climatologist?

    - **Weather** is the current atmospheric conditions, including temperature, rainfall, wind, and humidity at any given place. Weather is what is happening right now or likely to happen tomorrow or in the very near future.

Differences between Climate and Weather

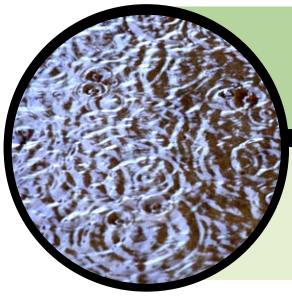
- **Climate** is sometimes referred to as "average" weather for a given area. The National Weather Service uses values such as temperature highs and lows and precipitation measures for the past thirty years to compile "average" weather for any given area. However, some atmospheric scientists consider "average" weather to be an inadequate definition. To more accurately portray the climatic character of an area, variations, patterns, and extremes must also be included. Thus, climate is the sum of all statistical weather information that helps describe a place or region.

Example of a climate temperature graph for Denver, CO showing change in average low and high temperature for each month (from weather.com)

- In the winter, we expect it to often be rainy in Portland, Oregon, sunny and mild in Phoenix, Arizona, and very cold and snowy in Buffalo, New York. But it would not be particularly startling to hear of an occasional January day with mild temperatures in Buffalo, rain in Phoenix, or snow in Portland. Meteorologists often point out that "climate is what you expect and weather is what you get." Or, as one middle school student put it, "Climate helps you decide what clothes to buy, weather helps you decide what clothes to wear."
- Scientists rely on large amounts of data over long timeframes to establish if the current weather patterns are usual. As weather measurements have only been made for 100-200 years, scientists look to records preserved in ice cores, tree rings, and sediment layers to identify how climate has varied in the past.
- Worldwide averages are used to describe global climate. Global climate is not easy to change. Regional averages may vary a bit, without causing a change in global climate. For instance, if the climate of Tunisia becomes warmer, and the climate of Mexico becomes cooler, the global average may not change. However, if regions warm more and are not balanced by other areas that cool, then global climate warms, as is the case over the past century.
- To investigate how climate may be changing due to human influences, scientists use weather data from as far back as the historical record goes (100-200 years). Detailed daily weather data are collected at surface weather stations throughout the world.
- Understanding and interpreting local weather data and understanding the relationship between weather and climate are important first steps to understanding larger-scale global climate changes.

Additional Resources

- Web Weather for Kids (http://www.ucar.edu/educ_outreach/webweather/)
- The Globe Program (http://www.globe.gov/)
- Project SkyMath (http://my.unidata.ucar.edu/content/staff/blynds/Skymath.html)
- National Weather Service (http://iwin.nws.noaa.gov/iwin/graphicsversion/main.html)
- United States Climate at a Glance (http://www.ncdc.noaa.gov/oa/climate/research/cag3/cag3.html)
- The Weather Channel (www.weather.com)



Differences between Climate and Weather

Name ______________________

Date __________ Class ______________

WEATHER DATA

Date: ____________ **Time:** ____________ **Location:** ______________________

Data collected by (names): ____

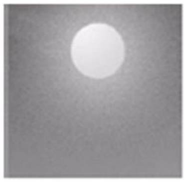
The temperature is: [°C] [°F]

C= (**F**-32) / 1.8
F= (1.8 x **C**) +32

Other things we noticed about the weather that may affect temperature:

Cloudiness *(Circle one.)*

No clouds



Clear (clouds in less than 10%)

Isolated clouds (10-25% of sky covered)

Scattered clouds (25-50% of sky covered)

Broken clouds (50-90% of sky covered)

No blue sky showing (100% of sky covered)

Precipitation

- ☐ Heavy Rain
- ☐ Light Rain
- ☐ Light Snow falling
- ☐ Heavy Snow falling
- ☐ Hail
- ☐ Other _______________

Wind

- ☐ Completely calm
- ☐ Light breeze (Wind felt on face. Leaves rustle.)
- ☐ Moderate breeze (Flags flap a little, Small branches and leaves move.)
- ☐ Strong breeze (Wind whistles, umbrellas turn inside out, bushes sway.)
- ☐ Gale (It's difficult to walk in the wind, tree twigs breaking)

Natural Records of Change: Working with Indirect Evidence of Past Climates

Unit: Little Ice Age
Lesson: 2

Materials & Preparation

Time:
- Preparation: 10 minutes
- Teaching: 45 minutes

Materials for the Teacher:
- Overhead projector
- Overhead transparency of p.4 of this lesson
- Chalk or white board
- Examples of tree rings or fossils to show to the class (optional)

Materials for Students:
- Colored pencils, markers, or crayons (6 colors per pair of students)
- Pencil
- Paper
- Student Page 1 and 2

National Science Standards
- Earth and Space Science: Content Standard D
- Science in Personal and Social Perspectives: Content Standard F
- History and Nature of Science: Content Standard G

Colorado Science Standards
- Science: 4.2, 5d, 6d

Learning Goals
Students will
- Learn that evidence of climate change is found in the natural world (indirect evidence) and human observations (direct evidence).
- Learn that indirect evidence can be interpreted if you know how the natural system that generated the indirect evidence works.
- Scientists study how natural systems are influenced in the modern world in order to interpret indirect evidence and understand how they were influenced by past climate change.
- Understand that scientists use data from many sources to understand past climates and climate change.

What Students Do in this Lesson
Students play a dice game to explore the differences between direct and indirect evidence. Student pairs roll dice and record the numbers rolled as a series of colors instead of numbers. Other pairs of students try to crack the color code to figure out the sequence of numbers rolled. In this way, students gain an understanding of how indirect evidence of climate change can be interpreted. In conclusion, the class discusses the various records made by humans and indirect evidence found in nature that can be studied to understand how climate has varied through time.

Key Concepts
- Scientists collect data from many sources to identify, understand, and interpret past changes in Earth's climate.
- Natural records of climate change, such as tree rings, ice cores, pollen and ocean sediments offer indirect evidence of climate change. They require knowledge of how the natural recorder works.
- Records made by humans , such as artwork, harvest records, and accounts of changing seasons, are more direct, but can be incomplete.

Natural Records of Change: Working with Indirect Evidence of Past Climates

Advanced Preparation

- Read and review the lesson plans and associated science background information provided.
- Familiarize yourself with the different types of climate recorders shown on the overhead (p.4).

Introducing the Lesson

- Explain that clues to how the climate has changed exist in the natural world in tree rings, Arctic and Antarctic ice, and layers of sediments on the seafloor and lake bottoms. Discuss why these data are indirect evidence of past climate.
- Explain to students that in this activity they will assume the role of scientists viewing and interpreting data. They will record indirect evidence of events that happened. They will learn what is involved in accurately interpreting indirect evidence.
- Give students an overview of the activity: First they will, in pairs, generate the indirect evidence that will be interpreted by another group.

Facilitating the Lesson

- Divide students into pairs and provide each pair with a copy of Student Page 1 (Direct Evidence Secret Key) and Student Page 2 (Indirect Evidence Record).
- Provide each student pair with one die. Instruct them to roll the die and record the series of numbers they rolled in order on the Record of Direct Evidence (Student Page 1, Step #1). Have students repeat this process for 20 rolls of the die.
- Instruct students to choose a color to represent each number (1-6) on their Secret Key (Student Page 1, Step #2) and mark that color in the box next to the number. Tell students that the color key should be kept secret from other student pairs.
- Then instruct students to record the colors that correspond to the sequence of numbers rolled (as they chose in their Key) on the Indirect Evidence Record (Student Page 2, Step #3). Do not write the numbers on the Indirect Evidence Record (Student Page 2)!
- Have two pairs join together making a group of four. Tell the pairs of students that their goal is to decode each other's keys without speaking a word or looking at the Secret Key (Student Page 1).
- To figure out which color corresponds to which number, one pair watches (and takes notes) while the other pair continues to roll the die and place a color along their remaining squares in the Indirect Evidence Record (Student Page 2, Step #4).
- Once one pair has the key decoded, and has identified which numbers were rolled in order on the Indirect Evidence Record (Step #5), allow them to check the key. Then the pairs switch roles.

Summarizing and Reflecting

- Tell students that the natural world leaves indirect evidence of climate change. Scientists study how things in the natural world are affected by changes in temperature so that they can decode indirect evidence left behind by these natural things. Show the class the overhead transparency that highlights various types of evidence and discuss the many different types of indirect evidence that scientists investigate to understand past climate. Then discuss the direct evidence that they use (records made by humans). Discuss the benefits and limitations of each.

Science Background Information

Paleoclimatology: The science of reconstructing climate history.

Scientists interested in climate change do not have methods for directly measuring ancient conditions. Thus, they collect indirect evidence of climate change, known as "proxy" data. Each source of data may respond to different conditions in the local and global environment. Humans recorded observations of weather because it has been very important throughout our history. By combining data from various historical sources, scientists develop a broad understanding of climate change over hundreds of years for specific regions of the world. Nature and humans have created records of climate change. For example:

Nature's records of climate change (proxy data):

- Tree rings
- Location (elevation and latitude) of environmentally sensitive plant and animal life
- Ice layers in glaciers
- Pollen
- Ocean and lake sediments

Human records of climate change:

- Records of harvest production
- Records of the cost of basic foodstuffs
- Artistic renderings of the environment
- Photographs
- Records of annual social events based on natural phenomena (such as harvest celebrations)
- Records of the timing of tree flowering and lake freezing

Extensions

- Have students develop their own secrete code for others to decode.

Additional Resources

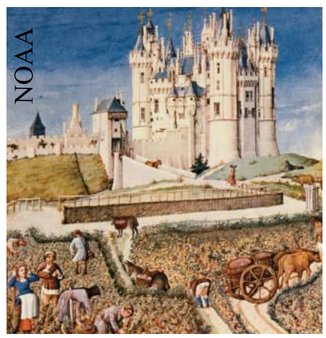
- What is Paleoclimatology?
  http://www.ngdc.noaa.gov/paleo/primer.html
- Influence of Climate Change on Human Society
  http://www2.sunysuffolk.edu/mandias/lia/index.html
- Importance of art to science
  http://www.mit.edu:8001/people/davis/EncycEnv.html
- Kuntsthistoridche Museum, houses several Brueghel paintings
  http://www.khm.at/homeE3.html.

Natural Records of Change: Working with Indirect Evidence of Past Climates

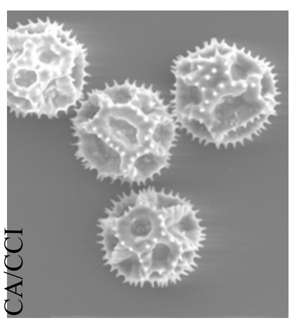
Tree rings: Yearly records of variability in temperature and water

When seasons change: Records of when trees flower and when lakes freeze

Ice Cores: Yearly variations in volcanic ash, temperature as recorded by isotope ratios



Food! Records of harvest production, celebrations, and the cost of food



Pollen: Indicates what plants grew where. If we know their growing conditions, we can interpret climate of the area.

Artwork: Paintings and photographs of people and places provide records of climate.

Ocean and lake sediments: Records of plankton, isotopes, color, decomposition, etc.

Note: Use for summarizing. Print on transparency and share with overhead.

Working with Indirect Evidence: 1

Name ______________________

Date __________ Class __________

Direct Evidence Secret Key (*Don't let other groups see this page!*)

Data collected by (names): ______________________

*1. Roll the die 20 times. Record the **number** of each roll on the timeline below. Your first roll is marked next to "start".*

Record of Direct Evidence (numbers only!)

Start | | | | | | | | | | | | | | | | | | | | | Finish

2. Decide which colors you would like to represent each number of the die. Create a key with the colors and numbers below.

Key:

	Number	Color
1		
2		
3		
4		
5		
6		

Working with Indirect Evidence: 2

Name ____________________

Date __________ Class ____________

The Indirect Evidence Record

Data collected by (names): ________________________________

3. Color the boxes below based on the number of each roll in your Record of Direct Evidence *and the key on the other page. For example, if blue is the color you chose for the number two and you roll a two, you would color the square blue. Your first roll is the box next to "start". DO NOT WRITE THE NUMBER!*

Record of Indirect Evidence (Colors only!)

Start | | | | | | | | | | | | | | | | | | | | Finish

4. ***Decoding the key!*** *Your teacher will assign you to work with another pair of students. Let the other pair of students watch as you roll the die and color in the boxes below. How many rolls of the die will it take for them to crack your color code? Keep rolling the die and filling in colors until they think they have it figured out. Don't tell them what colors are used for each number.*

5. ***The secret code is...***

To the other pair of students: Have you cracked the code of these data recorders? If so, fill out below what you think the ***numbers*** *are along the timeline that are represented by each color. Then, compare with your classmates' key.*

Start | | | | | | | | | | | | | | | | | | | | Finish

Living During the Little Ice Age

Unit: Little Ice Age
Lesson: 3

Materials & Preparation

Time:
- Preparation: 10 minutes
- Teaching: 30 minutes

Materials for the Teacher:
- White/black board and markers/chalk
- Overhead transparency of graphs (p.3)

Materials for Student Pairs:
- Student pages 1 – 3
- Pencil and paper

National Science Standards
- Science as Inquiry: Content Standard A
- Earth and Space Science: Content Standard D
- Science in Personal and Social Perspectives: Content Standard F

Colorado Science Standards
- Science: 1, 3.2, 4.1, 4.2, 6

Learning Goals
Students will:
- Understand the nature of the Little Ice Age (1350-1850 A.D.)
- Understand how historical records of crops, economics, and famine, as well as art, document climatic changes during the Little Ice Age.
- Interpret and compare data using graphs.

What Students Do in this Lesson
Students brainstorm what the living conditions during the period known as the Little Ice Age (1350-1850) might have been like. Then students study information about lifestyles, the economy, crop yields, and human and livestock mortality during the Little Ice Age. They compare, and discuss what they have learned.

Key Concepts
- The Little Ice Age was a period of unusually cool conditions between the years of 1300 and 1850 A.D.
- Humans experienced increased illness and famine during the Little Ice Age.
- Livestock survival and crop productivity decreased.
- Cost of food increased due to shortages and low crop yields.
- The Little Ice Age was preceded and followed by periods of warmer climates.

Living During the Little Ice Age

Advanced Preparation

- Copy student page 1 (one per student) (Or make one overhead of this page.)
- Copy student pages 2 and 3 (enough for groups of 3 – 4 to each get one of the 2 pages)
- Make an overhead of page 3 of this lesson.

Facilitating the Lesson

- Explain to students that in this lesson they will study how people living in Northern Europe were effected by climate change a few hundred years ago. Show them this area of Europe on a map.
- Tell students that between 1300 and 1850 many parts of the world experienced repeated unusually cool conditions that scientists have called the "Little Ice Age." During these cooler times, winters were longer and colder than normal, and summers were shorter and cooler.
- Ask students what they think the living conditions would have been like during this time, and list student ideas on the board. They should understand that people living during the Little Ice Age, would have been affected by:
    - Decreases in plant growth
    - Crop failures and reduced productivity of plants and animals they used for food
    - Increased death of humans and livestock due to famine and illness
- Have students answer questions on Student Page 1. *Does this painting describe weather? Does this painting describe climate? Was it always colder then? What information might make this evidence more clear?*
- Provide student pairs with either student page 2 or 3 and ask the students to answer the questions as they study the information on their student page.
- Bring the students together to share the documented effects of the Little Ice Age. Discuss their conclusions while looking at the overhead of all graphs shown together and have each student answer the following: *How does the cost of grain change? In which years was there high livestock mortality?*

Science Background Information

The Little Ice Age (1350-1850) was a period of particularly harsh climate conditions across most parts of the world. Most of the documents that record information about the Little Ice Age come from Northern Europe because extensive records were kept. A combination of decreased solar activity and numerous large volcanic eruptions cooled Earth's climate. Cooling caused glaciers to advance and stunted tree growth. Livestock died, harvests failed, and humans suffered from increased famine and disease. The Little Ice Age illustrates changes to climate that occur when the Sun is less active and cooling of Earth is exacerbated by volcanic eruptions. Many other examples of climate change due to natural forces exist including the "year without a summer" which followed the 1815 eruption of Tambora, in Indonesia. At an earlier time, Europe experienced a warm period which may have helped the Vikings to settle Greenland. In order to understand the current climate change debate, one must understand the natural events and cycles that play an important role in determining climate on Earth.

Additional Resources

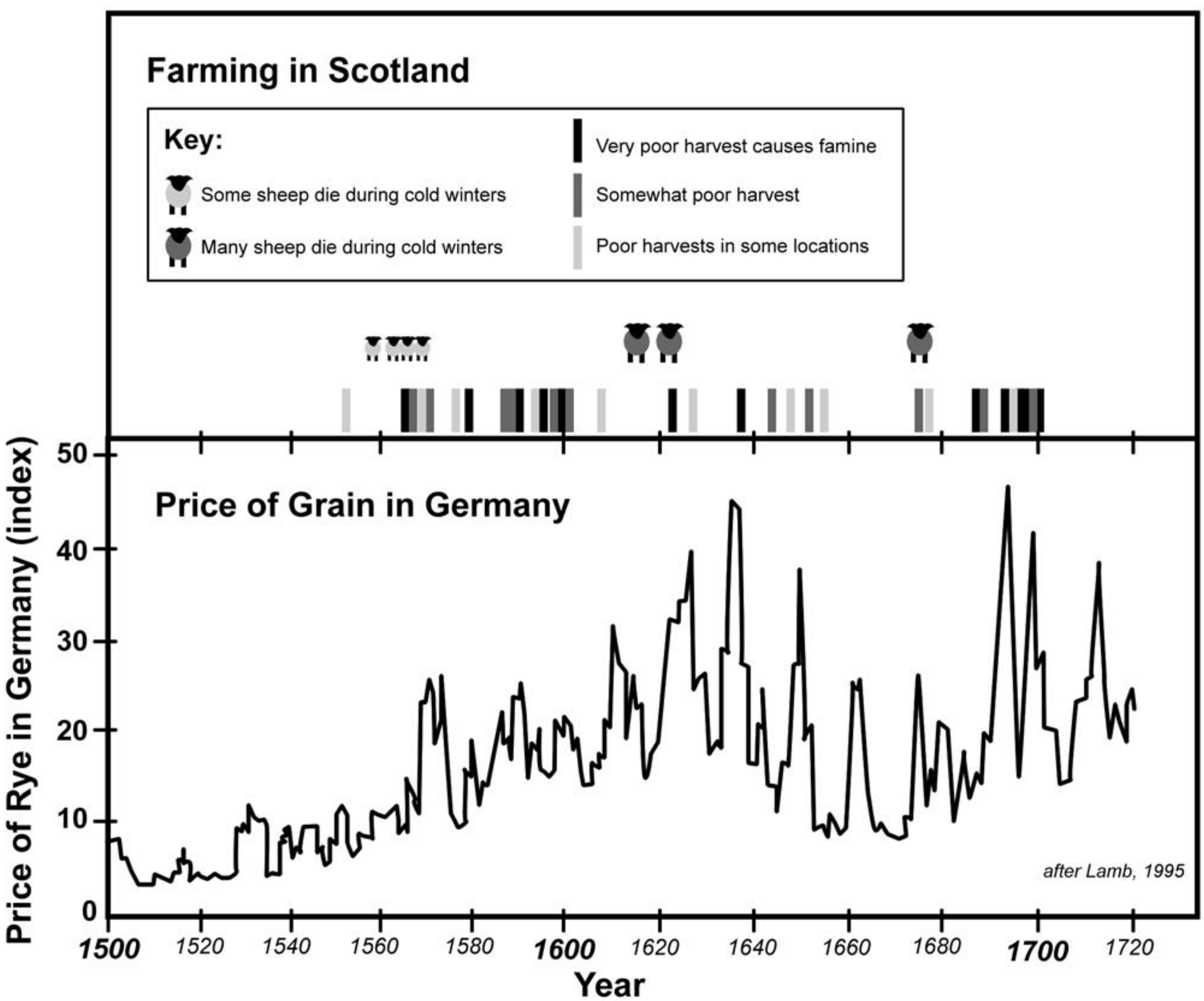
- Little Ice Age: UC San Diego http://calspace.ucsd.edu/virtualmuseum/climatechange2/04_3.shtml
- Suffolk Community College: http://www2.sunysuffolk.edu/mandias/lia/index.html

Wrap up questions:

How does the cost of grain in Germany change between 1500 and 1700?

In what times was there less food to eat in Scotland?

How is climate related to grain in Germany and farming in Scotland?



Instructor: Copy onto overhead transparency

Page #1: Living During the Little Ice Age

Name ____________________

Date __________ Class ____________________

A Typical Winter Day During the Little Ice Age

This scene, captured by the artist Peter Bruegel the Elder during 1565, depicts people engaged in a wide range of activities.

- How do you think the painting shows the effects of weather or climate?
- Do you think that artwork is based on reality or fiction? Explain your answer.
- What additional information would you like to have in order to know if the artwork represents the real weather or climate conditions of the time?

Page #2: Living During the Little Ice Age

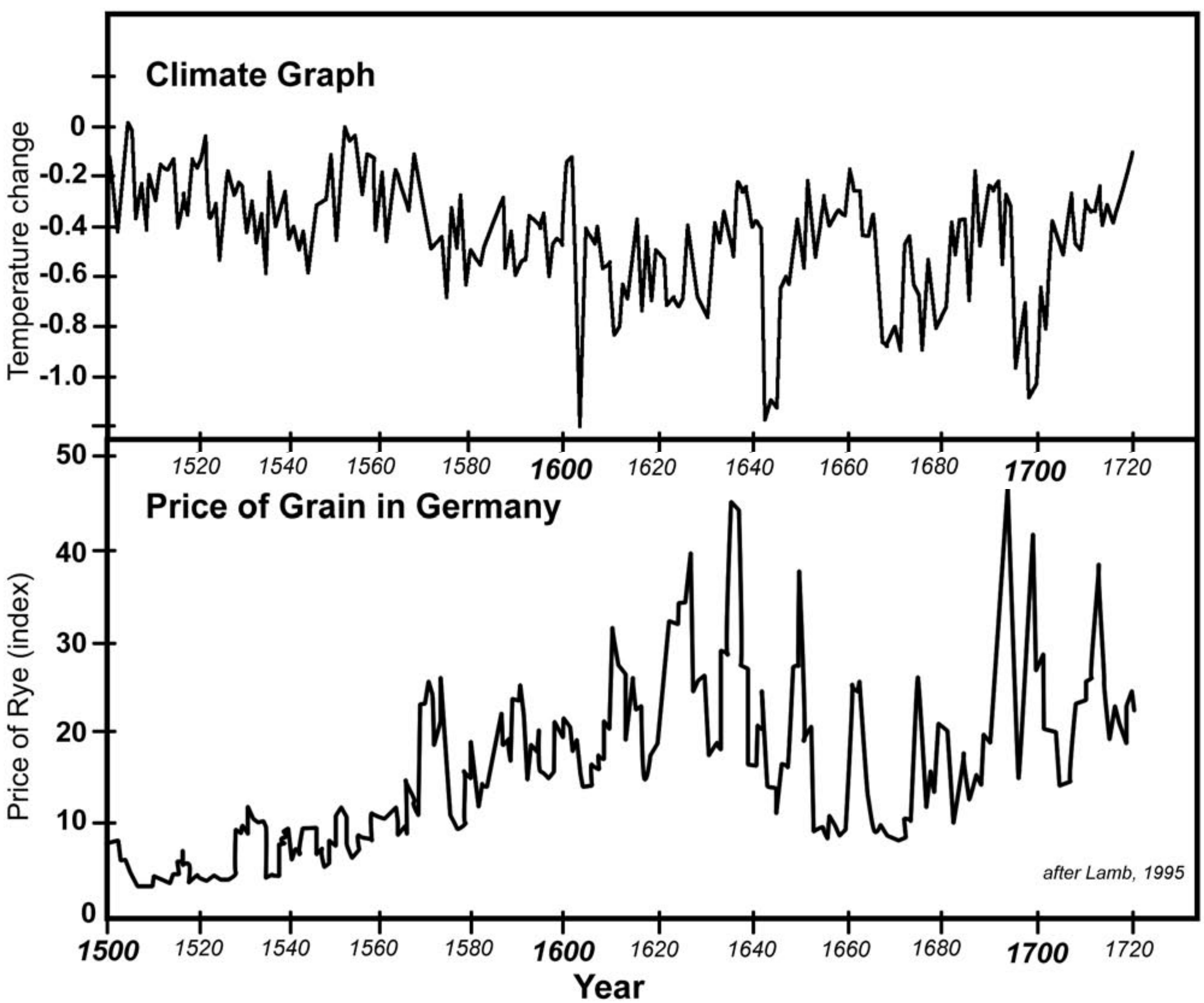
Name ____________________

Date __________ Class __________

Cost of Grain in Germany during 1500 to 1700

Study the graph in order to answer the following questions:

- How does the cost of grain change in Germany between 1500 to 1700?
- Are there years when grain is inexpensive and other years when it is expensive?
- What do you think might cause changes in the price of the grain?



Climate (top) and cost of rye in Germany (bottom) from 1500-1720

Page #3: Living During the Little Ice Age

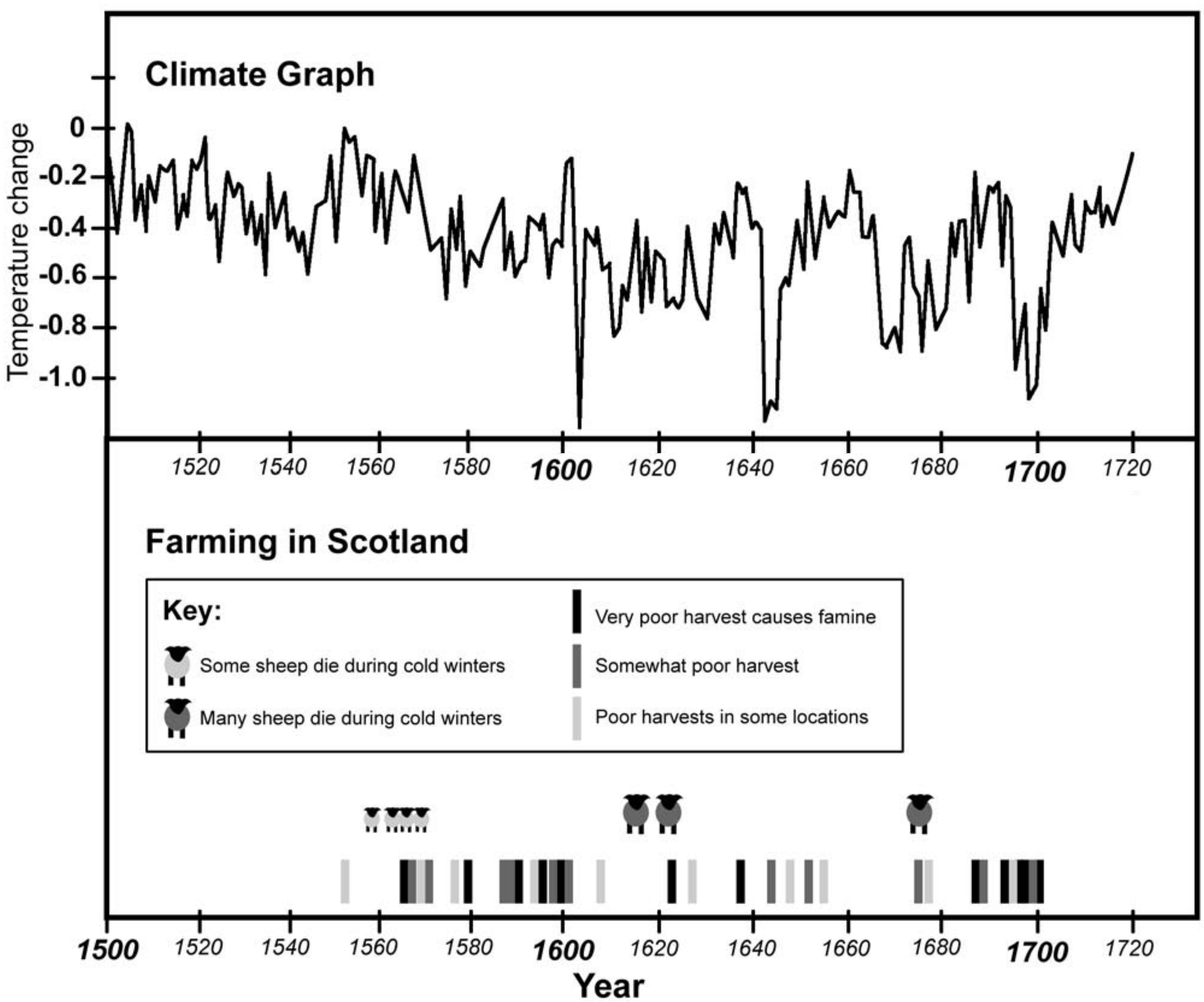
Name ____________________

Date __________ Class ____________

Mortality of People and Livestock in Scotland (1500-1700)

Study the graph to find answers to the following questions

- In which years do you think life in Scotland was very difficult due to lack of food?
- What conditions can cause the death of sheep?
- What conditions do you think might cause a poor harvest?
- How do you think that the death of sheep and a poor harvest combine to affect the conditions for people living in Scotland?
- What happens to the death rate of humans when food is unavailable?
- Which occurs first: harsh winter conditions, death of sheep, poor harvest, or famine? Why do you think so?



Climate (top) and health of sheep and crops in Scotland (bottom) from 1500-1700 (after Lamb, 1995)

Where Have All the Glaciers Gone?

Unit: Little Ice Age
Lesson: 4

Materials & Preparation

Time:
- Preparation: 20 minutes
- Teaching: 45 minutes

Materials for the Teacher:
- Overhead projector
- Overhead Transparencies of page 4 and 5 of this lesson and Venn diagram (Student Page 2)
- Examples of glacial till or striated rocks to show students (optional)

Materials for Student Pairs:
- Student Page 1
- Student Page 2 (Venn Diagram)
- Pencil

Materials for Individual Students:
- Student Page 3 (optional assignment)

National Science Standards
- Science as Inquiry: Content Standard A
- Earth and Space Science: Content Standard D
- Science in Personal and Social Perspectives: Content Standard F

Colorado Science Standards
- Science: 1, 4.2b, 4.4c, 5d, 6c

Learning Goals
Students will
- Understand that scientists examine evidence from around the world in order to understand global climate change.
- Understand that records of climate change exist.
- Describe photographs, interpreting changes in glaciers over time.
- Explain changes in climate over time based on interpretations of data and photographs.

What Students Do in this Lesson
In this lesson, students examine images of alpine glaciers to develop an understanding of how glaciers respond to climate change. They record, discuss, and interpret their observations. They consider explanations for changes in the size and position of glaciers from around the world. They develop an understanding that the melting (retreat) of glaciers is occurring simultaneously on different continents around the world, and, thus, they represent evidence of global climate change.

Key Concepts
- The position and size of alpine glaciers changes over time.
- 100 years ago the Rhone Glacier (and most others) were much larger.
- Natural and human made landmarks allow one to judge the change in size and extent of the glaciers over time.
- By comparing historical and present-day images, we can better understand climate change.
- Glaciers around the world are melting, indicating that Earth's climate is warming.

Where Have All the Glaciers Gone?

Advanced Preparation

- Read and review the lesson plan and the science background information.
- Copy overheads onto transparencies (Page 4 and 5, and Venn Diagram from Student Page 2)
- Make copies of student pages, one per student.
- Gather additional images of glaciers or bookmark appropriate Internet sites such as the National Snow and Ice Data Center (http://nsidc.org).

Introducing the Lesson

- Begin the lesson by explaining the characteristics of an alpine or mountain glacier (See Background Information, page 3).
- Ask students how they would predict glaciers would be affected by climate change (i.e., warming climate causes glaciers to melt and cooling climate causes glaciers to grow).
- Based on their prediction, ask students if they can think of a way to use glaciers to understand if climate has changed over the past 100 years. Tell students that in this lesson they will compare photographs of glaciers from the past century.

Facilitating the Lesson

- Show students Overhead #1 (page 4) and introduce students to a map of Switzerland and the small mountain town of Gletsch, below the Furka Pass. Explain to students that if they were to visit Gletsch, Switzerland, they would see very steep mountains, a small rural town, and a narrow winding road through the mountains. If possible, search online for a current aerial photo of the area.
- Explain that students will receive two images of the Rhone Glacier, which sits above Gletsch, one from 1906 and one from 2003.
- Ask students to make careful observations of each image. Model how to use the Venn diagram to compare and contrast the images.
- Pair students and distribute to each team a set of images of the Rhone glacier and Venn diagram.
- Allow students time to examine the images and complete the Venn diagram, recording similarities and difference between the past and present images of the glacier.

Summarizing and Reflecting

- Have each team share one or more observation they made about the two images of the Rhone Glacier.
- Record team observations on an overhead copy of the Venn diagram.
- Ask students to identify one or two of the most likely reasons for changes in the size and position of the glacier (i.e., glaciers respond to long term changes in climate and current warming has caused melting).
- Ask students how they know that the retreating Rhone Glacier is due to climate change. What additional evidence might they need? (I.e., evidence from other glaciers in other places worldwide).
- Display Overhead #2 (page 5) to show retreat of glaciers of the world as evidence.

Extensions or Homework

- Introduce the Boulder Glacier images as an additional class assignment or as homework. Boulder Glacier is in Glacier National Park, MT (http://www.nps.gov/glac/). Have students apply their knowledge and experience with the Rhone Glacier to their study of the Boulder Glacier.

Where Have All the Glaciers Gone?

- Map the recession of a specific glacier. Use aerial photographs and topographic maps to delineate the present and past positions of glaciers.

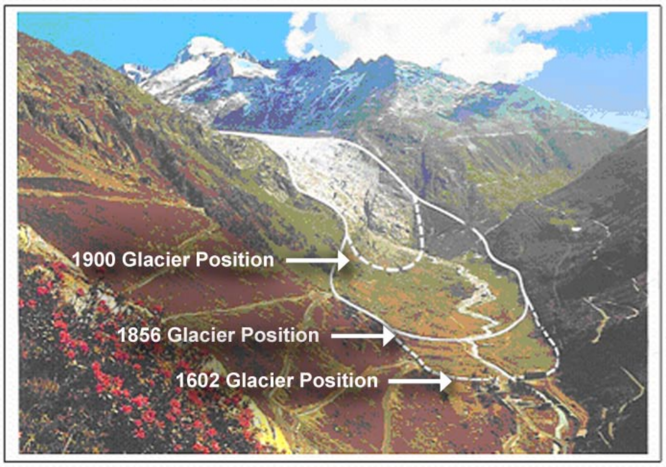
Background Information

What is an alpine glacier?

Glaciers are large masses of ice. The ice forms from snowfall that accumulates over long periods of time (many years). Most glaciers form where snowfall is high and temperatures are cool, even in summer. Thus, glaciers tend to be found either near the poles or at high altitudes on the slopes of high mountains. Glaciers in mountains are the focus of this lesson. They are called alpine glaciers.

How do glaciers respond to changes in the climate?

Alpine glaciers are particularly susceptible to shifts in climate. Glaciers respond to long term changes in the Earth's climate. Global temperature is determined by Earth's energy budget, that is, the amount of solar energy received and retained by our planet. The amount of this energy controls the average global temperature. If the average temperature on Earth increases, alpine glaciers melt. They appear to move to higher altitudes up the valley (see example below). The opposite is true as well. Small decreases in the average annual temperature cause glaciers to increase in size as increased snowfall at high altitude causes glacial ice to flow downhill. In the last several hundred years, most glaciers in the world have retreated, resulting from an increase in average annual global temperature.



How do we know alpine glaciers move?

One identifying characteristic of glaciers is that their ice flows slowly over time. The ice is able to flow because it is under considerable pressure from the immense weight of overlying ice. Glaciers move slowly down a valley over time as more ice is added to their upslope end. As a glacier melts, or retreats, piles of rock called moraines, eskers, drumlins are left behind in the valley.

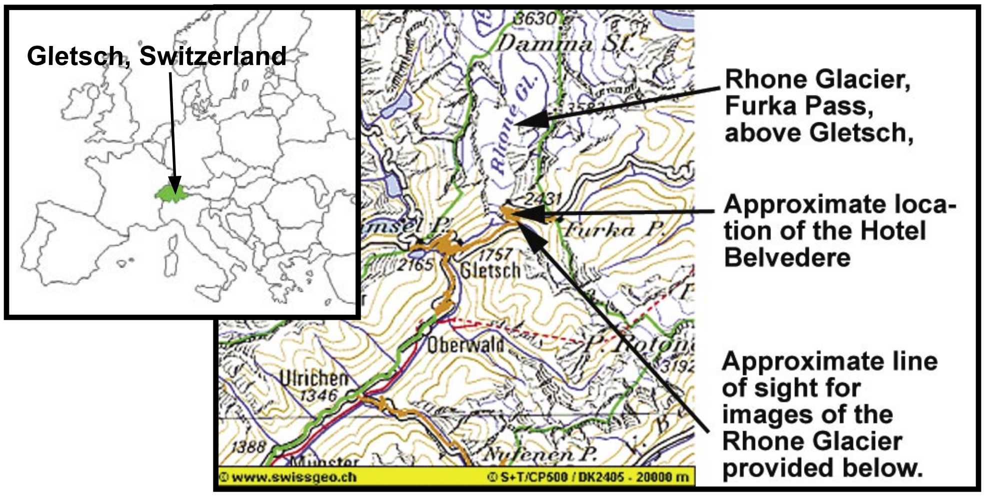
Additional Resources

- The National Snow and Ice Data Center http://nsidc.org
- Glacier National Park http://www.nps.gov/glac/

Where Have All the Glaciers Gone?

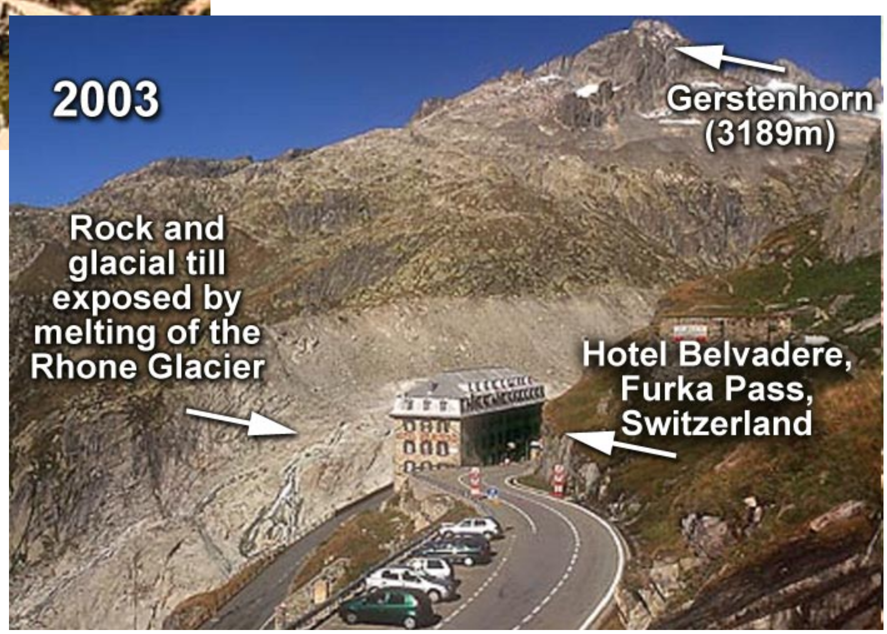
Overhead #1: Rhone Glacier Information

- Maps at right:
  Topographic map of the region surrounding the Rhone Glacier and small map of location within Europe.



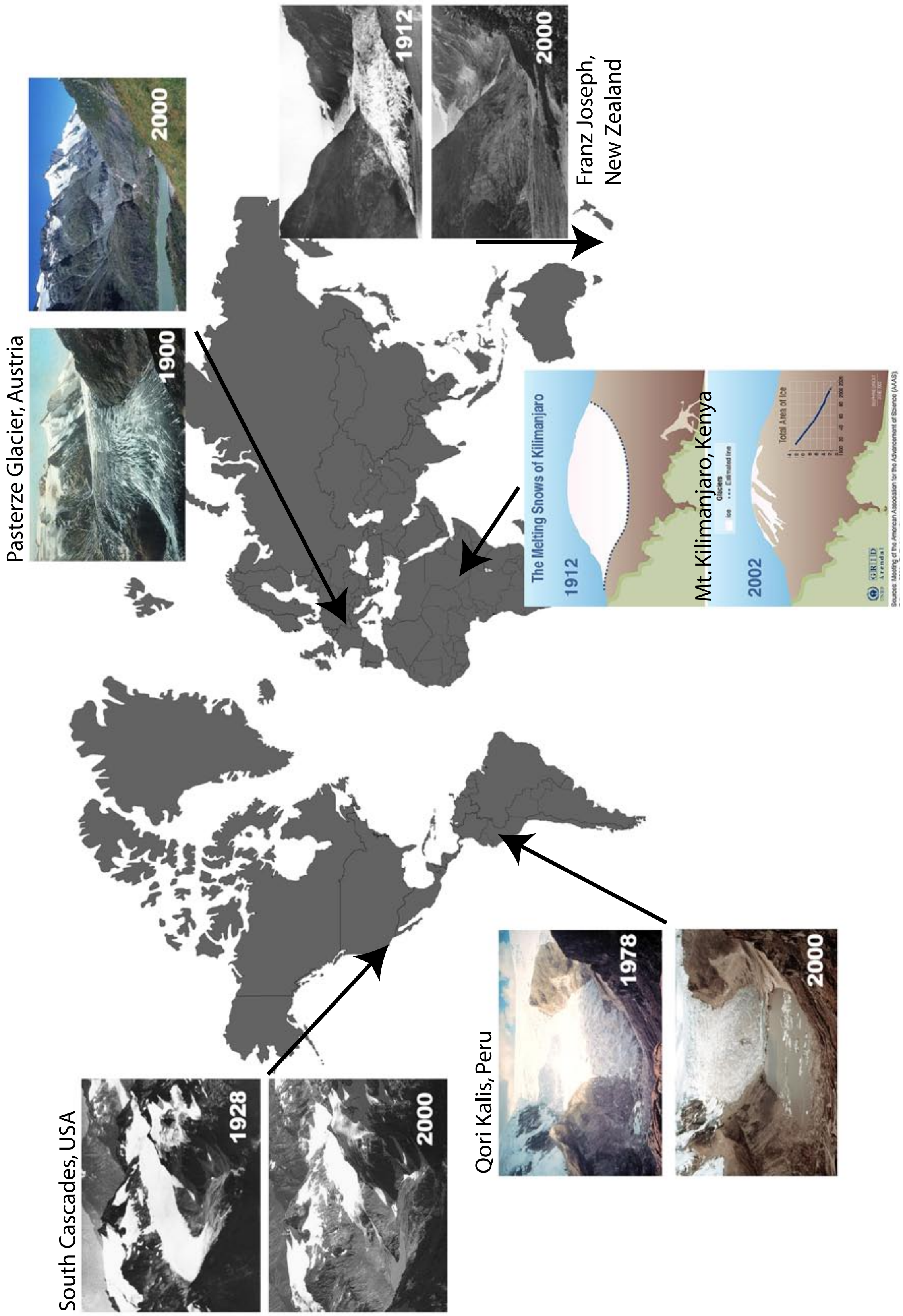
- Painting at left:
  Date: Approximately 1906
  Location: Furka Pass above Gletsch, Switzerland
  Description: This image shows the Rhone glacier behind the Hotel Belvedere in about the year 1906. The glacier is located near the town of Gletsch and the Furka Pass in northeastern Switzerland. The glacier has experienced extensive melting over the past century.

- Photograph at right:
  Date: 2003
  Location: Furka Pass above Gletsch, Switzerland
  Description: By 2003 the Rhone glacier has melted, exposing the valley floor scraped free of soil and carving the U-shaped valley formerly filled with ice. Recent increases in mean annual global temperature are responsible for the change.



Where Have All the Glaciers Gone?

Overhead #2:
Images of Global Glacial Retreat



Page #1: Where Have All the Glaciers Gone?

Name ______________________________

Date ____________ Class ____________

Directions

- Compare and contrast the two images below.
- What features of the landscape remain unchanged?
- What changes occurred in the landscape between 1906 and 2003
- **Use the Venn diagram to record your observations.**

The Rhone Glacier and the Hotel Belvedere in **1906**

The Rhone Glacier and the Hotel Belvedere in **2003**

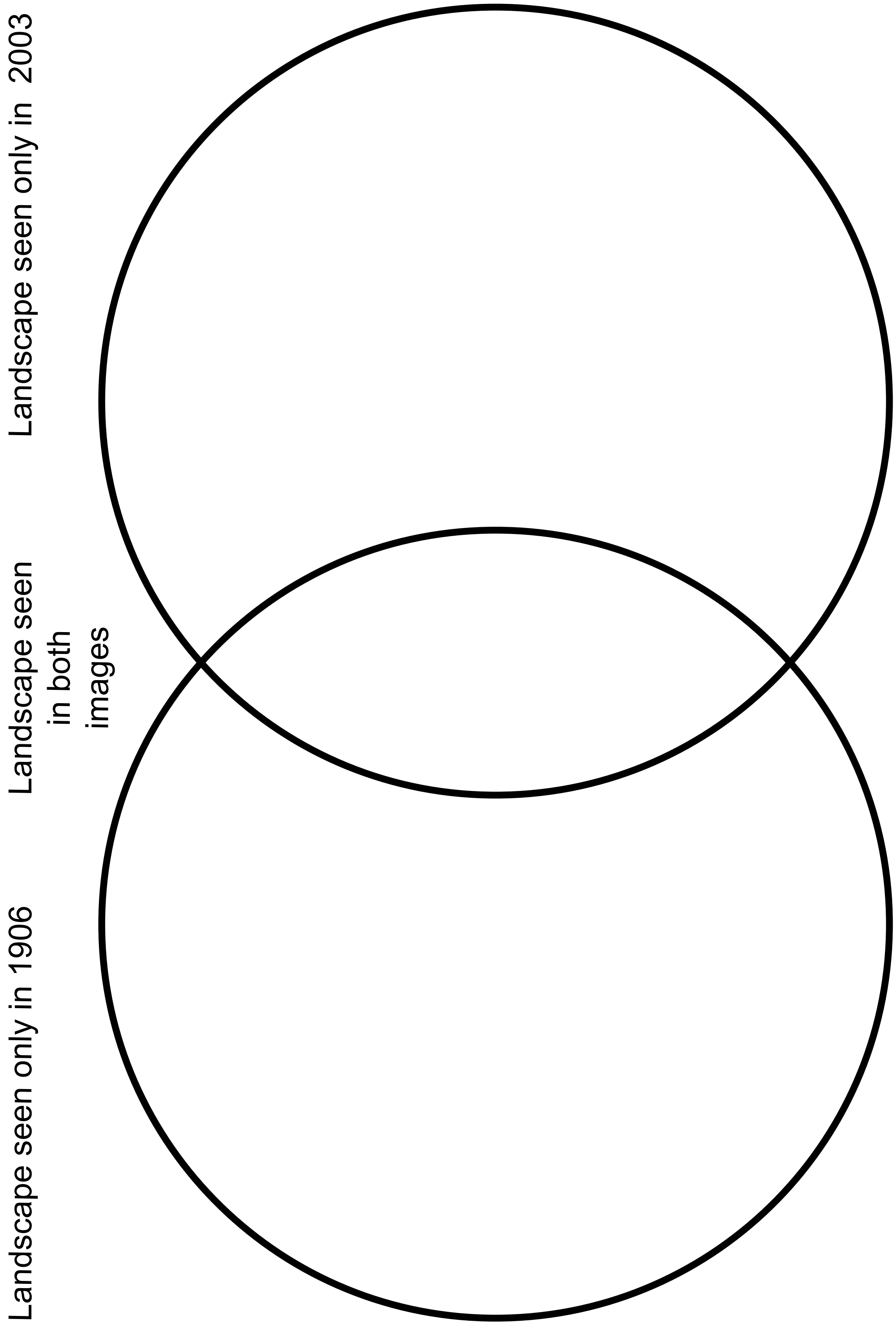
Page #2: Where Have All the Glaciers Gone?

Name ____________________

Date __________ Class ____________

Directions

- Use the 1906 and 2003 pictures of the Rhone Glacier to complete this Venn diagram.



Page #3: Where Have All the Glaciers Gone?

Name ______________________

Date __________ Class ______________

The two photographs below were taken from the same position in Glacier National Park, Montana of the Boulder Glacier. The one on the left was taken in 1932 and the one on the right was taken in 1988.

Directions

- Compare and contrast the two images of the Boulder Glacier shown below.
- Create your own Venn diagram and use it to list the similarities and differences between the images.

Answer the following questions on a separate sheet of lined paper

- What evidence in the photographs indicates that the images are from the same location?
- How much time has passed between the taking of the first and the second photograph?
- What changes occurred to the landscape between 1932 and 1988? Be specific.
- Imagine that you took both of these photographs. You took the first while you were 10 years old and vacationing with your parents. You took the second picture when you retired and took a trip to the National Park. Write a postcard describing each visit to the area. What might you have done? What clothing or supplies did you bring?

1932

1988

Trees: Recorders of Climate Change

Unit: Little Ice Age
Lesson: 5

Materials & Preparation

Time:
- Preparation: 20 minutes
- Teaching: Part A: 20 min, Part B: 30-40 min

Materials for the Teacher:
- Overhead projector
- Overhead transparency of tree rings (page 5)

Materials for the Class:
- Copies of simulated tree cores (page 6-7)

Materials for Individual Students:
- *Student Page*
- Tree "cookie"
- Magnifying glass *(optional)*
- Metric ruler (mm)
- Pencil

National Science Standards
- Science as Inquiry: Content Standard A
- Earth and Space Science: Content Standard D
- History and Nature of Science: Content Standard G

Colorado Science Standards
- Science: 1, 4.2b, 6d

Learning Goals
Students will
- Identify seasonal and annual growth in a cross section of a tree.
- Understand that thickness of a tree ring is affected by environmental conditions.
- Understand that evidence of past climates is recorded in series of tree rings.
- Learn to interpret past climate conditions from tree ring thickness.
- Collect and analyze tree ring data, testing a hypothesis and drawing conclusions.

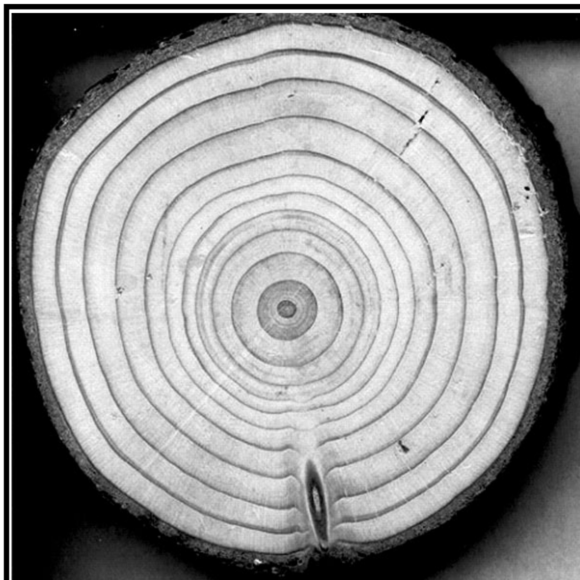
What Students Do in this Lesson
Students are introduced to tree rings by examining a cross section of a tree, also known as a "tree cookie." They discover how tree age can be determined by studying the rings and how ring thickness can be used to deduce times of optimal growing conditions. Next they investigate simulated tree rings applying the scientific method to explore how climatic conditions varied during the Little Ice Age.

Key Concepts
- During each growing season (spring and summer), trees produce new wood in a ring on the outside of the tree trunk located just inside the bark.
- Wood made during the first part of the growing season is light in color and wood made late in the growing season is dark in color.
- A series of concentric rings form during consecutive years of growth. Age is determined by counting the number of rings, oldest to youngest, from the center to the bark.
- A single tree ring is an indicator of growing conditions over a single growing season. A thicker ring may indicate a longer growing season or more water availability depending on the environment and tree species.
- A set of many consecutive tree rings provides information on climate trends during a tree's lifetime.

Trees: Recorders of Climate Change

Advanced Preparation

- Prepare a cross-section through a tree trunk (tree "cookie") for each student (0.5-1" thick and 4-6" diameter is ideal). Contact a local tree trimming service and ask for cuttings or order tree cross-sections from a classroom supply company (allow several weeks for delivery).
- Copy page 5 onto transparency for use during Part A.
- Copy simulated tree cores and cut them apart (You may wish to provide several copies of each simulated tree core.) The dates will need to be kept with each core.
- Place simulated tree cores at stations around the room with signs that indicate the time range.
- Copy Student Page for each student.



A simple, yet elegant picture of tree rings from a very young balsam fir (*Abies balsamea*)
Source: Henri Grissino-Meyer
http://web.utk.edu/~grissino/gallery

Facilitating the Lesson: Part A

- Familiarize students with their tree "cookie" cross-section.
    - Explain that trees produce rings as they grow each spring and summer.
    - Ask students to describe the tree ring colors. Is there a pattern to the light and dark rings? Explain that wood made during the first part of the growing season is light in color and wood made late in the growing season is darker. A light and a dark band together are the growth during one year.
- Explain to students that the study of the ages of tree rings is called *dendrochronology* ("dendro" is Latin for tree and chronology is the study of a time sequence).
    - Ask students how old their tree was when it was cut. (Students should count the light/dark couplets of rings to estimate age.)
    - Ask students which rings they think are youngest. Which are the oldest? (There may be multiple hypotheses suggested by your students. If so, discuss the likelihood of each hypothesis, leading students to understand that the outer ring is, in fact, the youngest.)
    - If the time that the tree was cut is known, have students count backwards to find the ring that represents the student's year of birth.
- Explain to students that past climates can be interpreted based on how the tree rings formed. This is called *dendroclimatology*.
    - Ask students if all the rings are the same thickness. They will likely notice that some rings are thicker than others. This can be for many reasons, but mainly the variations in ring thickness relate to growing conditions. In high latitude areas, tree growth is limited by the length of the growing season, which is controlled by temperature. In other environments, tree growth is greatly controlled by water availability.
    - Tree ring thickness can vary from year to year. Review with students that thick rings indicate a "good" growing season, narrow rings indicate a shorter or dryer growing season. Ask students to

identify which year had the best growing season.

- Tell students that there are two ways to study tree rings. Scientists can use cross-sections, but this is typically only done if the tree has died, because the process kills the tree. Instead, scientists usually take cores from living trees to study the rings. When a tree is cored, a small cylinder of wood is pulled out, smaller than the diameter of a drinking straw. Coring does not harm the tree. The rings can be studied from the cylindrically-shaped core. (Show overhead transparency of tree coring: page 5.)

Facilitating the Lesson: Part B

- Show students the simulated tree rings that they will use for this activity. They are made to look like tree cores (except they are flat). The simulated tree rings group the light colored and darker band so that each interval along the simulated tree ring core indicates a year's growth.
- Explain that the simulated tree ring samples are based on data from trees from high northern latitudes where the length of the growing season controls ring thickness. Since the length of the growing season is based on the temperature, thick rings will form when the climate is warmer and thin rings will form when the climate is cooler. The simulated rings cover a period from about 1402 to 1960.
- Pass out Student Pages and rulers and familiarize students with the directions before beginning. Students will make a hypothesis (or do this as a class), collect data, and make interpretations.
    - Instruct students to develop a *hypothesis* about the climate over the total time interval. Explain that the class will test the hypothesis by collecting data from tree rings. After studying the tree ring data, they will either accept the hypothesis or reject the hypothesis.
    - *Data collection*: Instruct students to visit each station and measure the total thickness of the tree rings for each time interval in millimeters (model this procedure for students), recording the thickness in the appropriate place in the data table on the Student Page.
    - *Data analysis*: Instruct students to divide their measurement for each time interval by the number of years in each interval to get average ring thickness for each time interval. Record this in the table.
    - *Interpretation*: Have students answer the thought questions on their student page and discuss answers as a group.
- In summary, describe that paleoclimatologists use a variety of "proxies" to interpret past climate. These proxies indicate the relative temperature but are an indirect record of it. Ask students if they think that the tree rings are a source of direct or indirect evidence of past climates.

Background Information

Dendrochronology: The study of the growth of tree rings
Dendroclimatology: The study of the relationship between climate and tree growth in an effort to reconstruct past climates

The growth layers of trees, called rings, preserve an interesting record of environmental conditions over the lifespan of the tree. They record evidence of environmental events such as floods, droughts, insect attacks, forest fires, lightning strikes, and even earthquakes. Many consecutive tree rings also record longer term and more subtle changes in climate over time.

Each year, new wood grows on the outside of the tree trunk, just under the bark. A year's growth is called a tree ring. Each tree ring is made of a band of light colored wood produced early in the growing season (spring and early summer) and a dark colored band produced late in the season (late summer and early fall). Counting the rings of a tree will determine its age.

Scientists seldom cut down a tree to analyze its rings. Instead, core samples are extracted using a borer that's screwed into the tree and pulled out, bringing with it a cylinder of wood about 4 millimeters in diameter. The hole in the tree is then sealed to prevent disease (see images of this process on page 5).

Tree rings are an example of climate proxy data, providing indirect evidence of past climates. Scientists can use tree-ring patterns to reconstruct regional patterns of climatic change. The amount of tree growth depends upon various local environmental conditions. At high latitudes, the amount of tree growth is mostly controlled by temperature. Trees grow thicker rings when the growing season is longer and narrower rings when the growing season is shorter. The length of the growing season is related to the climate, namely the temperature. If the rings are a consistent thickness throughout the tree, the climate likely did not vary over the lifespan of the tree.

The simulated tree rings used in the second part of this activity were developed based on the results of a study by Briffa et al. (2001) in which the ring patterns of 387 trees from northern latitudes were used to interpret temperature variations over the past 600 years. Since the thickness of the simulated tree rings is based on the results from many trees, it shows an average trend. Typically, climatologists require at least 30 years of data to establish understanding of climate. To understand changes in climate requires even more data. Generally, dendroclimatologists use large databases of tree ring data to compare the records of many trees, and interpret when, where, and how quickly climates have changed.

Extensions

- Take a field trip to take core samples from local trees with a core tool and then analyze the tree rings.

Additional Resources

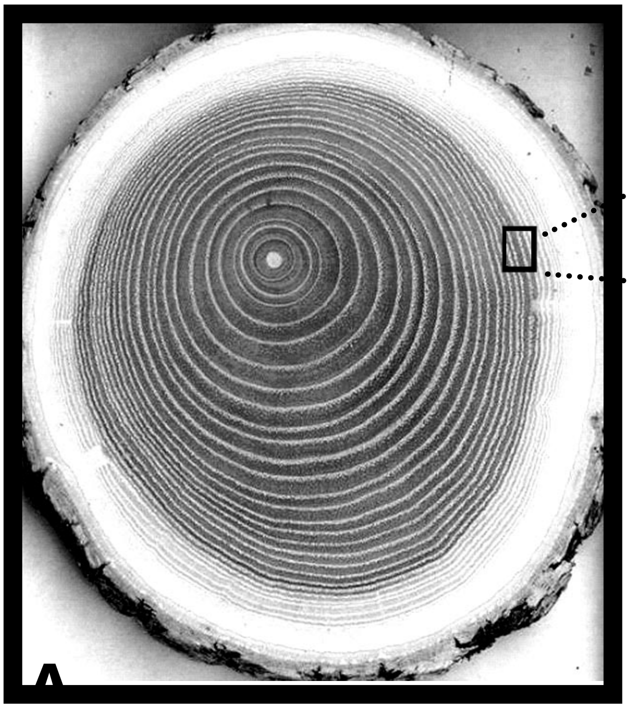
- Project LEARN: http://www.ucar.edu/learn
- Tree Rings: A Study of Climate Change (NASA) http://vathena.arc.nasa.gov/curric/land/global/treestel.html
- Trees as Indicators of Climate Change, by Keith Briffa: http://www.cru.uea.ac.uk/cru/annrep94/trees
- Tree Rings: A cursory look at these well-known features, by Paul James: http://www.microscopy-uk.net/mag/artjan02/treering.html
- Briffa, et al., 2001, Low-frequency temperature variations from a northern tree ring density network, Journal of Geophysical Research, Vol. 106, no. D3, pp. 2929-2941.

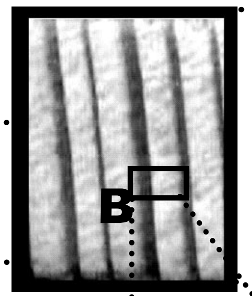
- Sources of tree cross-sections:
    - NOAA Tree Ring Slide Set: http://www.ngdc.noaa.gov/paleo/slideset/tree_rings.html
    - Science Kit & Boreal Laboratories http://sciencekit.com/default.asp
    - Carolina Biological Supply Company http://www.carolina.com/

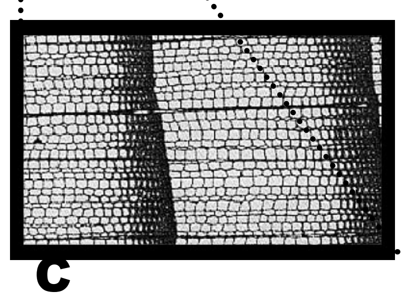
Trees: Recorders of Climate Change

Note: Copy this page onto transparency for use with overhead projector.

TREE RINGS







Images of tree rings at different levels of magnification

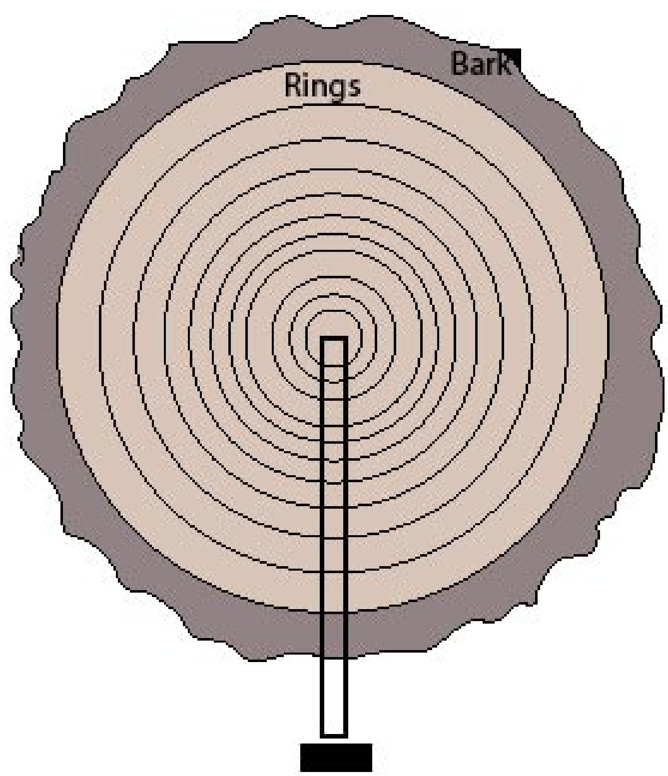
A. Large cross-section (Henri Grissino-Meyer http://web.utk.edu/~grissino/gallery)

B. Close up of rings (Caspar Amman, NCAR)

C. Close up of cells (Caspar Amman, NCAR)

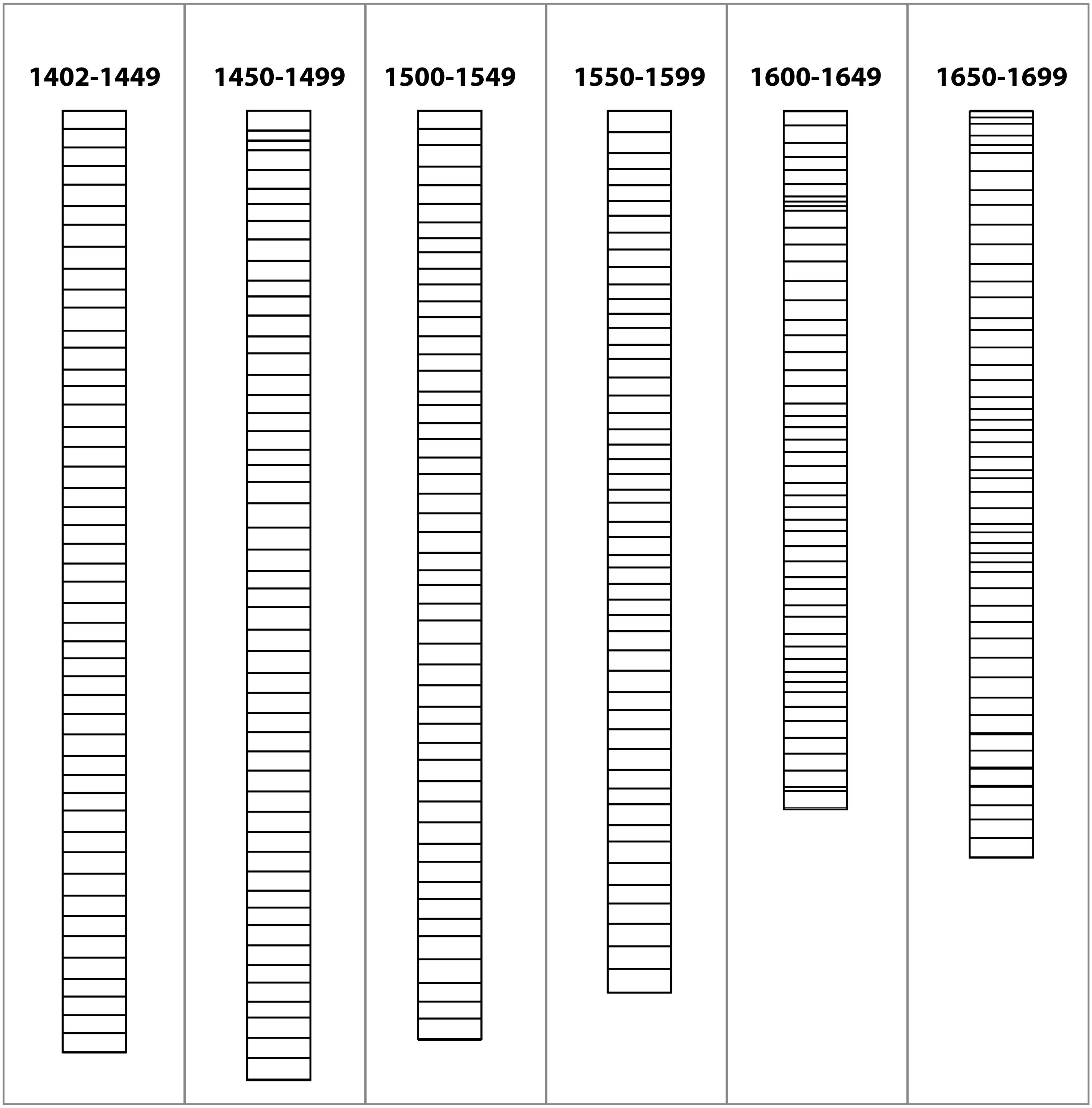
TREE CORING

Image: NOAA

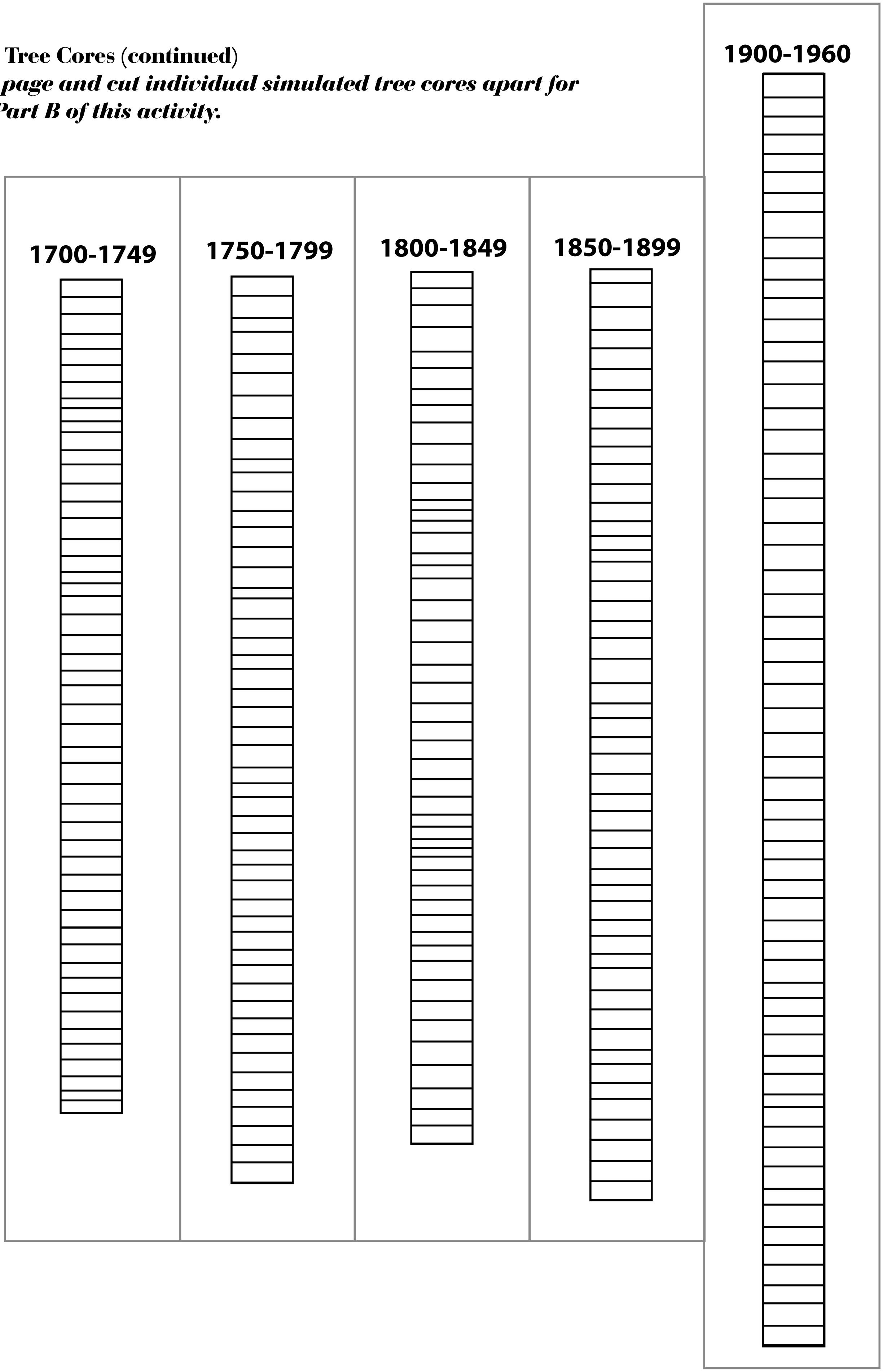


Simulated Tree Cores

Copy this page (and the following page) and cut individual simulated tree cores apart for use with Part B of this activity.



Simulated Tree Cores (continued)
Copy this page and cut individual simulated tree cores apart for use with Part B of this activity.



Trees: Recorders of Climate Change

Name ______________________________

Date ____________ Class ______________

The Question: Has the climate changed over the last 600 years?

Make a hypothesis.
A hypothesis is a statement about how something works or how something happened. Based on the question above, make your own hypothesis. Write it in the space below.

____

____

Collect and analyze tree ring data!

1. Measure the total length of the tree ring core at each station. Make your measurements in millimeters. Write each measurement into the "total thickness" column of the table.
2. Fill in the number of years of each time interval in the "number of years" column.
3. Divide each "total thickness" measurement by the "number of years" to get the average ring thickness for each time interval. Use at least one decimal place (example: 2.3).

Time intervals	Number of years	Total Thickness (mm)	Average ring thickness
Example	50	200	200/50=4
1402-1449			
1450-1499			
1500-1549			
1550-1599			
1600-1649			
1650-1699			
1700-1749			
1750-1799			
1800-1849			
1850-1899			
1900-1960			

What's does it all mean? Answer these questions on the back of this page.

1. Based on ring thickness data, can you accept your hypothesis, or reject it?
2. Based on the ring thickness data, would you speculate that some intervals were warmer or cooler than others? If so, which was the warmest interval? Which was the coolest interval?
3. How certain are you of your interpretations? Would you like to see more evidence? If so, what type of evidence and from what time interval?
4. Doing research often brings up more research questions. What's sorts of questions would you want to look into for future research? List at least two questions.
5. Why do climatologists need at least 30 years of data to describe climate?

Blooming Thermometers

Unit: Little Ice Age
Lesson: 6

Materials & Preparation

Time:
- Preparation: 20 minutes
- Teaching time: 45 minutes

Materials for the Teacher:
- Overhead projector
- Overhead of images of cherry blossoms (p.4)

Materials for Students:
- Student Page
- Pencil
- Ruler
- Eraser
- Paper

National Science Standards
- Science as Inquiry: Content Standard A
- Earth and Space Science: Content Standard D
- Science in Personal and Social Perspectives: Content Standard F

Colorado Science Standards
- Science: 1, 4.2b, 6c
- Geography: 6

Learning Goals
Students will
- Understand that many natural phenomena respond to seasonal weather changes.
- Understand that the timing of seasonal changes and reactions of these natural phenomena will change as climate changes over long periods of time.
- Natural and human records help us to recreate the history of climate based on records of seasonal change.
- Cool spring temperatures occurred in the 11th-14th and 16th centuries according to records of when plants bloomed each spring.

What Students Do in this Lesson
In this lesson students develop an understanding of the relationship between natural phenomena, weather, and climate change: the study known as "phenology." In addition, they learn how cultural events are tied to the timing of seasonal events. First, students brainstorm a list of natural phenomena that occur annually in response to changes in seasonal weather changes. Next, they receive cultural and historical information regarding the Japanese springtime festival of Hanami, celebrating the appearance of cherry blossoms. Students plot and interpret average bloom date data from over the past 1100 years.

Key Concepts
- Biological phenomena respond rapidly to changes in weather as seasons change throughout the year.
- Gradual shifts in the timing of these seasonal biological responses occur as gradual changes in the climate occur over decades and centuries.
- Human records of events such as the blooming of cherry blossoms help to illustrate climate change over centuries.
- Spring temperatures were cool and blossoms appeared later than usual in April from 1100 to 1400 AD and in 1600 AD.

Blooming Thermometers

Advanced Preparation

- Make copies of the Student Page, one per student.
- Copy the *Cherry Blossom Overhead Images* (page 4) onto transparency.

Introducing the Lesson

- Ask students to brainstorm how they know that seasons are changing. What changes? Is it just the temperature? Do other phenomena react to the change in weather? How? (Examples: Leaves turning color, harvesting crops, flowers blooming, air conditioning turned on, heat turned on, etc.)
- Discuss the following:
    - Do the phenomena that the class brainstormed happen at exactly the same time each year?
    - What might cause the timing to be different?
    - If the climate were to cool or warm, how would these phenomena be affected?

Facilitating the Lesson

- Explain that in this lesson, the students will investigate data about one phenomenon that is affected by changing seasons: the blooming of cherry blossoms.
- Show images of the festival and blossoms (see overhead on page 4). Explain that each spring the Japanese celebrate the appearance of cherry blossoms (sakura) with the festival of Hanami.
- Explain that records have been kept of the first appearance of cherry blossoms and scientists have used these records to understand climate variations. In this lesson, the class will do the same.
- Discuss what students would expect to happen to bloom timing if the climate were cooler or warmer.
- Distribute the Student Page and explain the concept of "mean blossom date." The data from each century is averaged. That is why there is a decimal place in the date (average day in the month) for each century. Because the data is averaged, small variations in bloom time are not present. Additionally, one year's blossom date is also an average because not all trees bloom at exactly the same time.
- Have each student create a graph of blossom date versus time. (Their resulting graphs should resemble the graph on page 4 of this lesson plan.) Students are instructed to make a bar graph. If students are not familiar with bar graphs, show examples from outside this lesson. Point out that the graph on the student page has a y-axis with the largest number on the bottom and the smallest at the top.
- Once students have created graphs, ask them to answer the thought questions listed on the Student Page.
- Review student responses to the thought questions and discuss the nature of indirect evidence, and how survival has historically been tied to seasons and climate.

Extension

- Have students identify a local event that occurs regularly and in response to seasonal change and review historical records of that event if available. (Examples may include: melting ice from a pond, presence of migratory birds, blooming flowers, monarch butterfly migrations, etc.)
- Participate in the GLOBE Program, which involves students in collection of phenology data (globe.gov).
- Have students do background research about phenology.

Blooming Thermometers

Background Information

Biological Events and Climate Change

The study of climate change includes *phenology*. Phenology is the study of biological events that change in response to their environment. The word takes it's meaning from "phenomenon." For example, bird migration is a phenomenon associated with climate and season. Likewise, the appearance of flowers, such as cherry blossoms, is a response to the local weather and climate. On an annual basis, many biological events respond to weather, whereas over long periods of time the phenomena shift gradually, earlier or later in the year, in response to climate.

For hundreds of years, the Japanese have held a celebration each spring called Hanami in honor of the appearance of cherry blossoms (sakura). Originally a social event reserved for the nobility, it has evolved into one that most Japanese share. Ancient documents record the date of past festivals and scientists have been able to use this information to calculate the mean annual blossom date for cherry trees over the past 1100 years. The change in the bloom dates provides insight into past changes in climate.

The early appearance of blossoms indicates a mild winter and warmer climate whereas a late blossom date indicates longer, harsher winters and a cooler climate. The table and graph below indicate the mean blooming date each century for the years 900 to 1956 for cherry trees in the city of Kyoto, Japan.

Based on the bloom data (in table below), a relatively warm climate during the 10th and 11th centuries gave way to cooler conditions in the 12th-15th centuries. The climate warmed during the 16th century, cooled during the 17th century, and has been relatively warm since.

Additional Resources

- Japanese Festival, Hanami: http://www.tjf.or.jp/eng/ge/ge11hana.htm
- Annual Blossom Forecast: http://www.jma.go.jp/JMA_HP/jma/jma-eng/sakura/sakura.htm
- Images of Cherry Blossoms
    - http://www.ktv.co.jp/hanami/2003/index_english.html
    - http://www3u.kagoya.net/~tanimoto/hanami/sakura.htm

Blooming Thermometers

Cherry Blossom Overhead

Instructor: Copy onto transparency for use with an overhead projector.

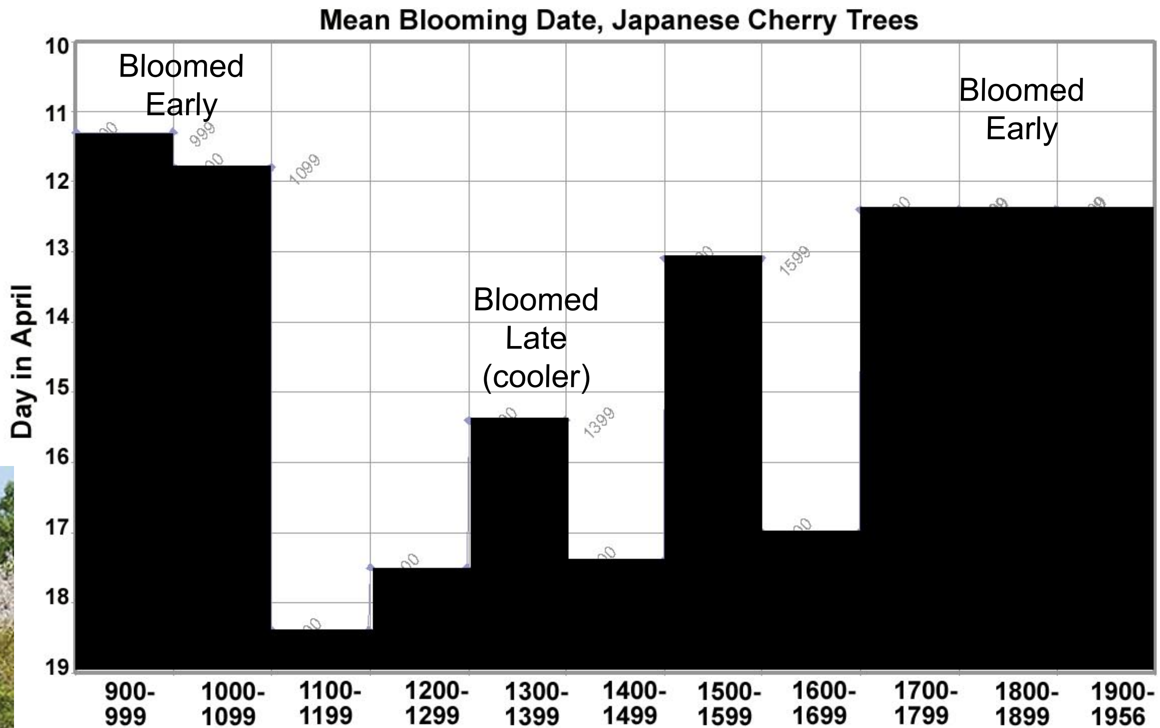


Table 1. Mean Blooming Dates by century, from H. Arakawa, Journal of Meteorology, December 1956

Century	Mean Blooming Date
900-999	April 11.3
1000-1099	April 11.8
1100-1199	April 18.4
1200-1299	April 17.5
1300-1399	April 15.4
1400-1499	April 17.4
1500-1599	April 13.1
1600-1699	April 17
1700-1799	April 12.4
1800-1899	April 12.4
1900-1956	April 12.4

Cherry blossoms

People attending the festival of Hanami

Blooming Thermometers

Name ______________________________

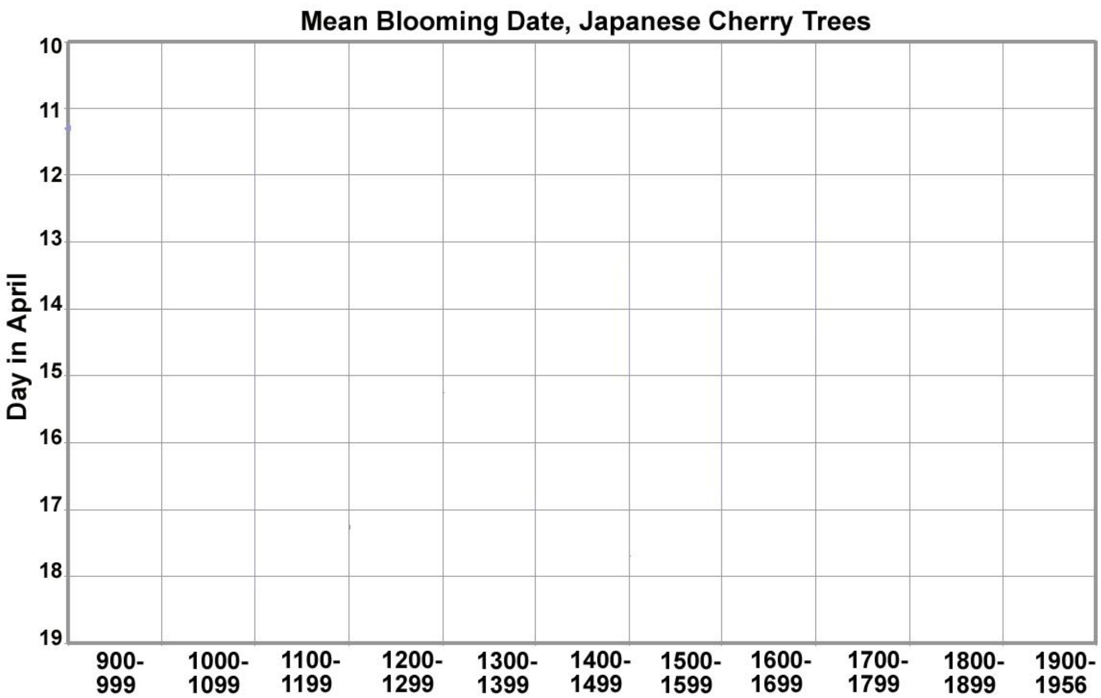
Date __________ Class ______________

The data in the table below indicate the mean blooming dates of cherry trees in Kyoto, Japan during each century between 900 and 1956.

Make a bar graph:

- Use the data below to make a bar graph of Mean Blooming Date versus Century. A bar graph has a bar for each category (time period). The height of the bar depends on the bloom date.

Century	Mean Blooming Date
900-999	April 11.3
1000-1099	April 11.8
1100-1199	April 18.4
1200-1299	April 17.5
1300-1399	April 15.4
1400-1499	April 17.4
1500-1599	April 13.1
1600-1699	April 17
1700-1799	April 12.4
1800-1899	April 12.4
1900-1999	April 12.4

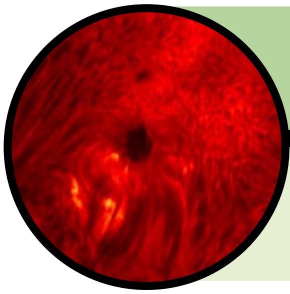


Answer the following questions based upon your graph.

- In what century did the cherry blossoms appear earliest in April? ____________________
- In what century did the cherry blossoms appear latest in April? ____________________
- What environmental conditions, weather and climate, might cause cherry blossoms to appear late or early? _______________________
- Do you think the date that a flower appears is a good indication of the regional climate? Explain your answer. ____

  ____
- The changes in bloom date may have been caused by global climate change. What additional data would you need to investigate this statement?______________________________________

  ____



Sunspots and Climate

Unit: Little Ice Age
Lesson: 7

Materials & Preparation

Time:
- Preparation: 10 min
- Teaching: 60 min

Materials for the Teacher:
- Overhead projector
- Transparencies of the Sun (page 4)

Materials for Students:
- Pencil
- Ruler
- Student Page 1
- Student Page 2

National Science Standards
- Science as Inquiry: Content Standard A
- Earth and Space Science: Content Standard D

Colorado Science Standards
- Science: 1, 4.4, 6

Student Goals
Students will
- Understand that the Sun has features called sunspots.
- Understand that the number and location of sunspots changes over time.
- Learn through graphing data that the number of sunspots varies over time with a regular pattern.
- Learn through graph interpretation that when the temporal pattern of sunspots has been disrupted in the past, there has been climate change on Earth.

What Students Do in this Lesson
As an introduction, students identify sunspots on images of the Sun, discovering that the number, location, and size of spots is not always the same. During the first part of the activity, students make a graph that shows how the number of sunspots has changed over the past 30 years. Interpreting their graphs, students discover that there is a regular pattern to the number of sunspots (the 11-year sunspot cycle). During the second part of the activity, students interpret a graph of sunspot data from the coldest part of the Little Ice Age (Maunder Minimum). Students discover that the regular pattern of sunspots was disrupted in the past and this had an effect on the climate of our planet.

Key Concepts
- The Sun has features called sunspots that change in number and location over time.
- People have been keeping detailed records of the number of sunspots for hundreds of years.
- The number of sunspots waxes and wanes with a regular periodicity of 11 years; this is called the solar cycle.
- The solar cycle has been disrupted in the past, causing climate change on Earth (during the Little Ice Age, for example).

Graphing Sunspot Cycles

Advanced Preparation

- Copy overhead (page 4) onto transparency and familiarize yourself with the images.
- Copy Student Page 1 *(Graphing Sunspots)* and Student Page 2 *(Sunspots and Climate)* for each student.

Introducing the Lesson

- Tell students that they should never look directly at the Sun. (This can cause blindness.)
- Show students the transparency images of the Sun using the overhead projector. Describe how pictures like this are taken. (They are not photographs; the data is collected by a remote sensing instrument called MDI that is on the SOHO spacecraft and made into a representation or image that looks like a photograph.)
- Start with the upper left picture (A, courtesy of spaceweather.com). This shows a very large sunspot and quite a few smaller ones. To provide a sense of scale, there is a small dot to indicate the size of Earth as compared with the sunspots (point this out to students).
- Look at the other images on the transparency (B-D) and see if members of the class can find sunspots. All three of these images show the Sun on different days of July 2005. The date and time are in the lower left of each image. (All three images courtesy of NASA SOHO.)
- Discuss the following as a class:
    - Do the number of spots stay the same? Brainstorm ideas about why the number of visible sunspots might change over time. There are two reasons why this might be: 1) we are not always looking at the same side of the Sun, because the Sun rotates and Earth orbits, thus the number of spots we can see can vary with the time of day over a few days or weeks (example: compare images B-D); 2) the number of sunspots can change over weeks, months, years (example: compare image A with the others) .
    - Are all the spots the same? Notice that some spots are large and others are small.
    - Tell students that scientists have been observing the number of spots on the sun for hundreds of years. In this lesson they will investigate this data to see if there is a pattern to the number of spots.

Facilitating the Lesson: Part A

- Pass out *Student Page 1: Graphing Sunspot Data*.
- Describe to students that listed in the data table on the student page is the average number of sunspots for each year. Scientists take the size and number of sunspots into account in their observations as well as the side of the Sun they can view and the technology used to collect the sunspot data.
- Have students graph the points and answer the interpretation questions at the bottom of the student page.
- Discuss the answers to the interpretation questions, especially the pattern of the sunspot numbers. Describe that the pattern they are seeing is called the Solar Cycle. This cycle also correlates with other types of phenomena such as solar storms and other changes in space weather.

Facilitating the Lesson: Part B

- In this part of the lesson students examine a graph of sunspot data from 1630 to 1770. Ask students to predict the type of pattern they would expect to see in the number of sunspots, based on their knowledge of sunspots built during Part A of this lesson.
- Hand out Student Page 2: *Sunspots and Climate*
- Review Student Page directions with the class. Discuss how to interpret a graph.
- After students have had a chance to work individually on their answers to the questions on the Student Page,

Graphing Sunspot Cycles

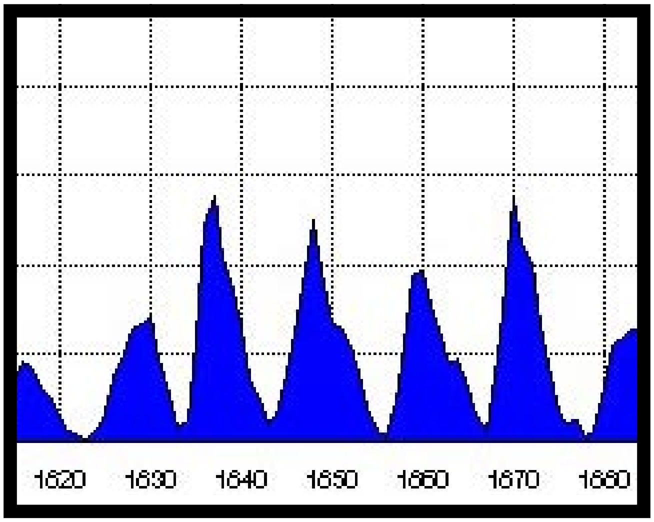
discuss answers as a group. Students have hopefully recognized that the climate cooled when there were few sunspots. This period of time (1645-1715) was called the Maunder Minimum. It was the coldest period of the Little Ice Age. (See *Background* below.)

Extensions
Take a look at sunspots WITHOUT LOOKING AT THE SUN! To do this safely, you will need to project an image of the Sun through either a pair of binoculars, a telescope, or a device called a Sunspotter onto a piece of white paper or a white wall. For more information about how to safely look at sunspots with your class, see the websites listed in the *Additional Resources* section below. Additonally, consider taking a field trip to a local observatory, if possible.

Science Background Information
When viewed through a telescope, sunspots have a dark central region surrounded by a somewhat lighter region. The dark area is slightly cooler than the surrounding area. This cool area is likely related to a strong magnetic field around the sunspot. Sunspots typically last anywhere from a few days to a few months.

People have been observing and keeping records of sunspots for hundreds of years. In 1612, Galileo proved there were spots on the Sun. He used a telescope to look at the Sun (not directly!). At the time, telescopes (and other optics) were very recent innovations and were allowing scientists such as Galileo to discover new aspects of our planet and space. Galileo's discovery was highly controversial at the time because the spots he found were viewed as imperfections. Many of his 17th century colleagues did not believe the Sun could be imperfect!

Over time, scientists have noticed a pattern in the number of sunspots. About every 11 years the number of sunspots reaches a high and then decreases again. This is known as the Solar Cycle. Other sorts of solar activity are related to this cycle as well, such as solar flares, which tend to occur on areas of the Sun near sunspots. The year 2011 will be a solar maximum, making 2006 and 2015 close to solar minimums.



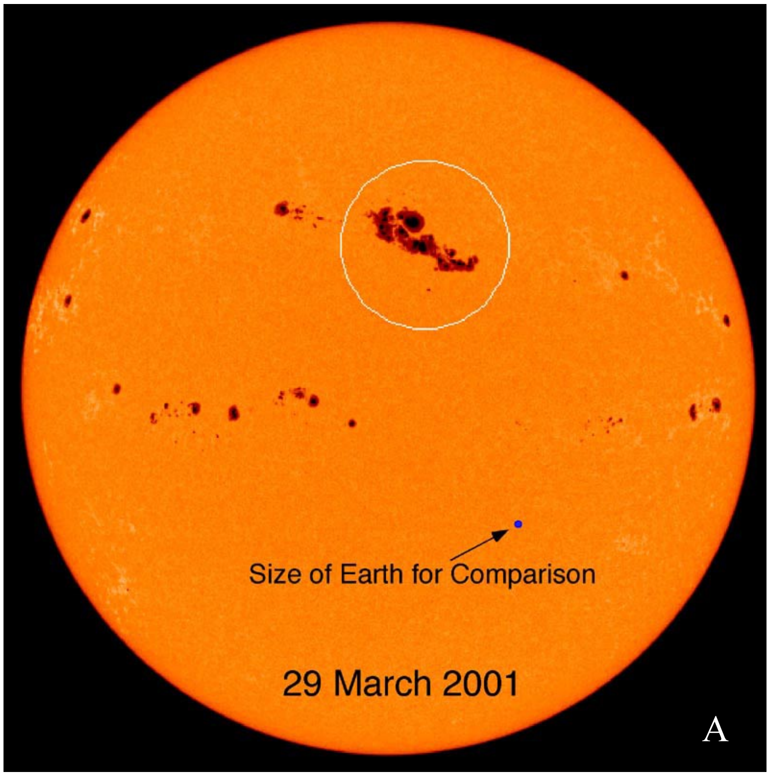
Graph of sunspot numbers showing the repreating pattern of the 11-year solar cycle.

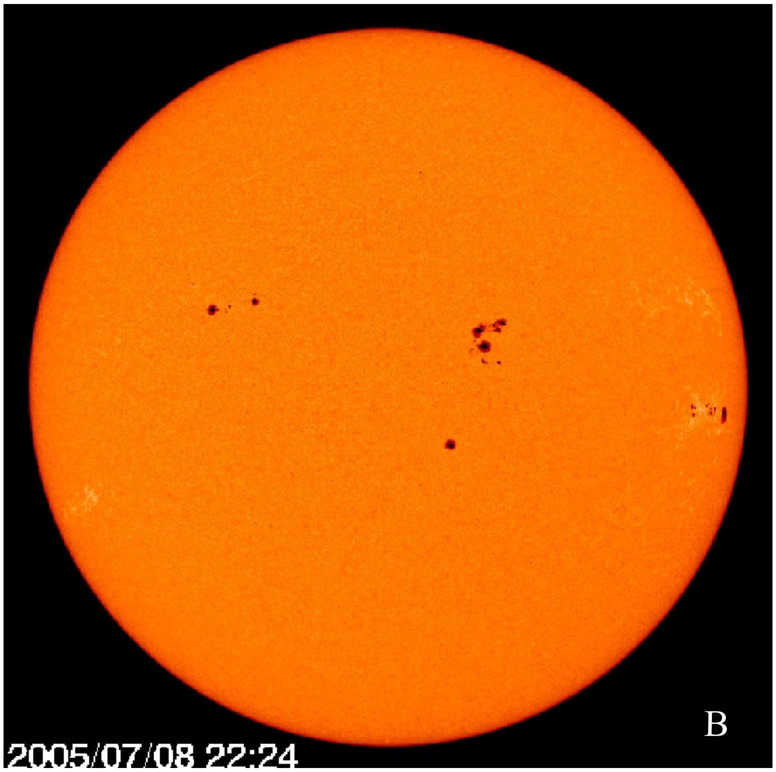
When the Sun has fewer sunspots, it gives off less energy. This results in less energy making its way to Earth, and our planet cools. More than 300 years ago, when the climate was cooler for a time called the "Little Ice Age," people noticed there were no sunspots for several decades. This possible correlation between the number of sunspots and temperature is what students should find on the graph on Student Page 2.

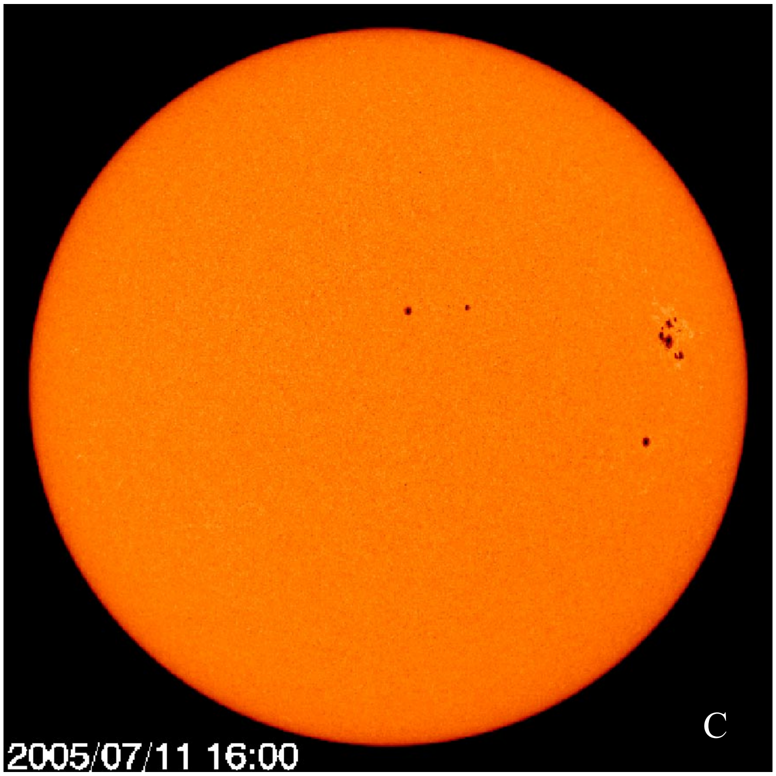
Additional Resources
- Windows to the Universe http://www.windows.ucar.edu
- Resources for safely looking at sunspots:
    - Tips about Safe Sunwatching http://www.spaceweather.com/sunspots/doityourself.html
    - Information about Sunspotters http://scientificonline.com/product.asp_Q_pn_E_3112800

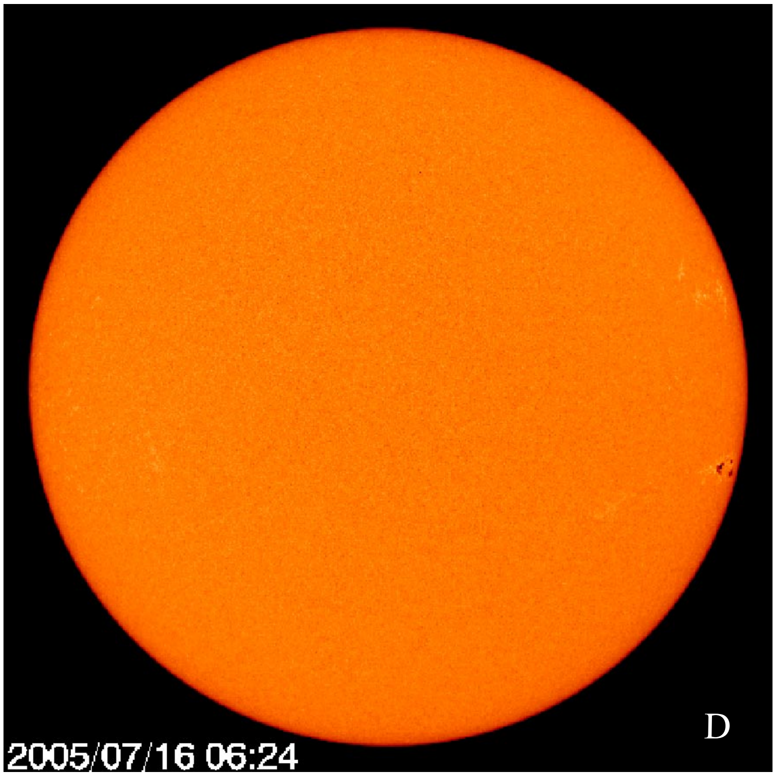
Graphing Sunspot Cycles

Instructor: Copy the following images of the Sun onto overhead transparency. See introduction for details about images.









Page 1: Graphing Sunspots

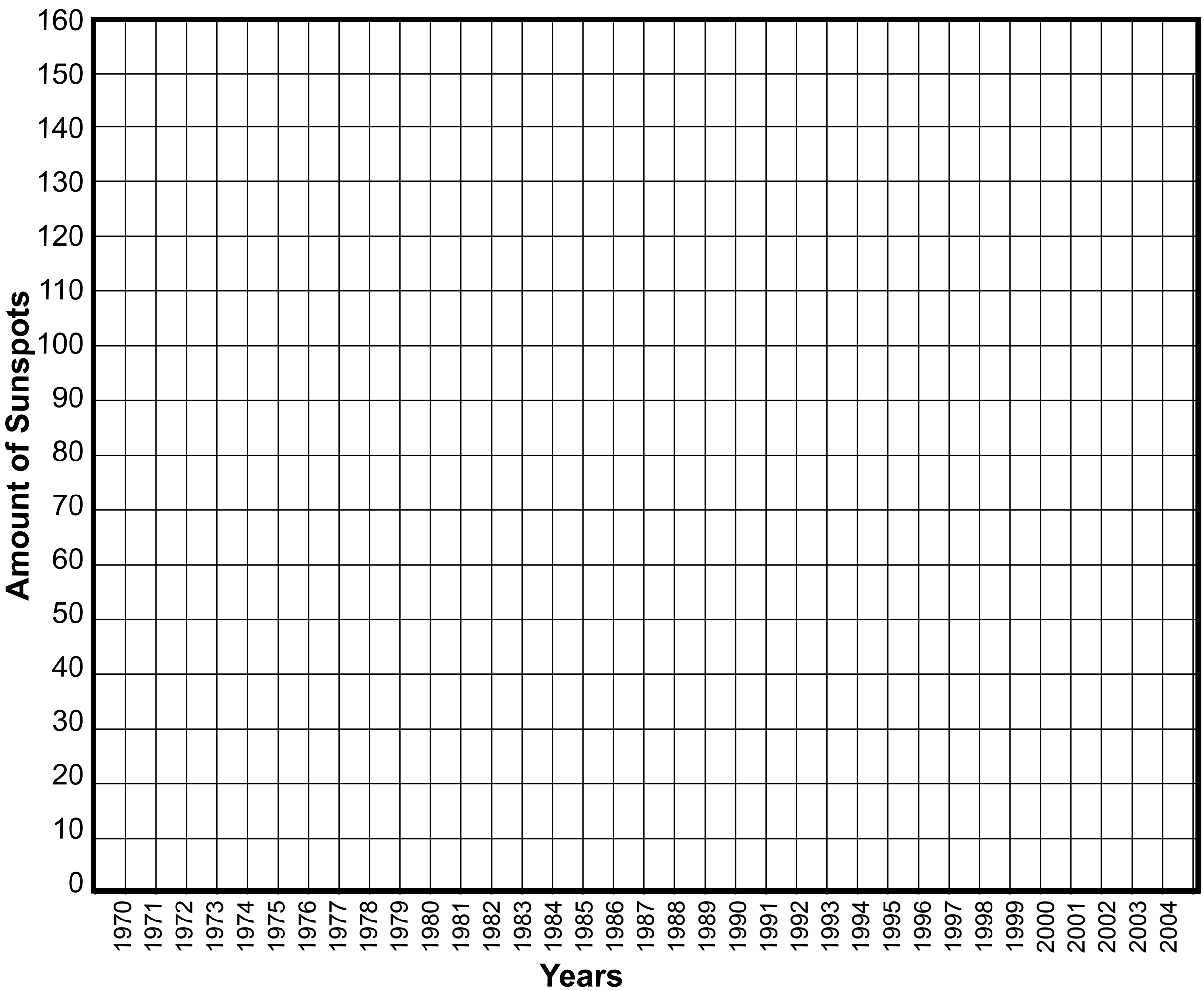
Name ______________________

Date __________ Class ______________

Make a graph of the number of sunspots over time:

- The data below indicate the average number of sunspots for each year. Use the data to make a graph of average number of sunspots as they change over time.
- Plot sunspot number against time by making a dot on your graph wherever the year and appropriate sunspot number intersect.
- Connect the points you've plotted with a line.

1970	109
1971	74
1972	72
1973	39
1974	34
1975	15
1976	14
1977	30
1978	103
1979	156
1980	141
1981	141
1982	116
1983	72
1984	44
1985	17
1986	12
1987	28
1988	89
1989	148
1990	149
1991	146
1992	96
1993	54
1994	36
1995	19
1996	9
1997	22
1998	65
1999	94
2000	120
2001	111
2002	104
2003	64
2004	41

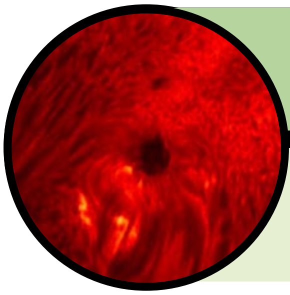


Answer these questions!

1. How many years are there between each time of abundant sunspots and each time of fewest sunspots? (In other words, how often does the pattern repeat?)

   ____

2. Make predictions! Will there be many or few sunspots during:
   - the year you graduate from high school? ______________
   - the year you were born? ________________
   - the year you turn 21 years old? ________________



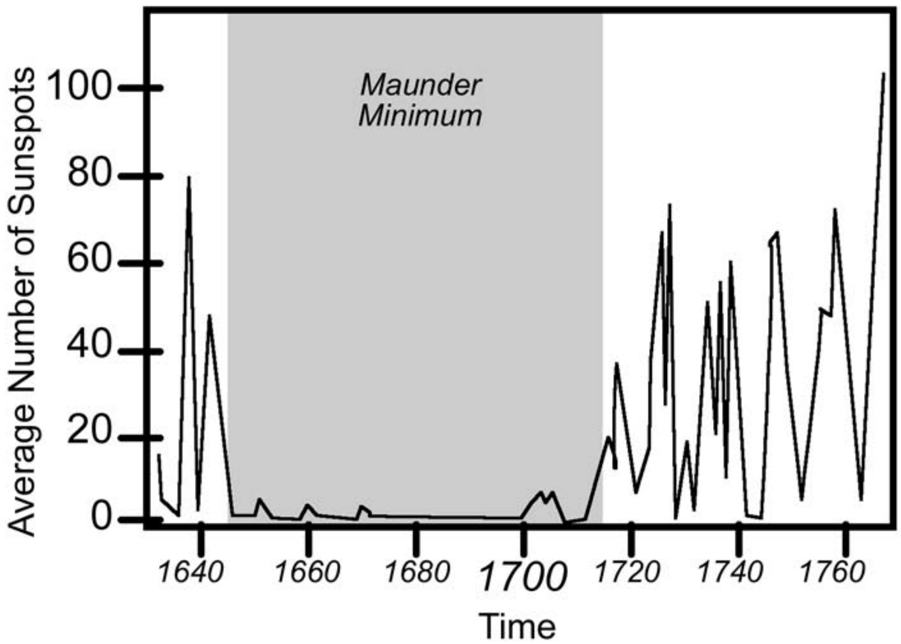
Climate Discovery Student Pages
National Center for Atmospheric Research

Page 2: Sunspots and Climate

Name ______________________

Date __________ Class __________

Directions:
- Examine the graph and answer the questions below.
- To begin, identify the axes. What is the horizontal (x) axis? What is the vertical (y) axis? What does each axis represent?



Answer these questions!

1. How is this graph similar to the graph that you made of sunspot data from 1970-2004? ____________

   ____

2. How is this graph different than sunspot data 1970-2004?______________________

   ____

3. The area shaded grey indicates a time of cool climate called the *Maunder Minimum*. Knowing this clue, you will be able to mark the following **true** or **false**.

   T F More sunspots mean more energy comes from the Sun.
   T F Less sunspots means that Earth has a warmer climate.
   T F Less sunspots means that Earth gets less energy from the Sun.
   T F More sunspots means that Earth has a warmer climate.

Dark Skies: Volcanic Contribution to Climate Change

Unit: Little Ice Age
Lesson: 8

Materials & Preparation

Time:
- Preparation: 30 minutes
- Teaching: Two, 45-minute, class periods

Materials for the Teacher:
- Dark Skies PowerPoint presentation (or overhead transparencies) (*see Advanced Preparation section, p.2)
- Computer projector (or overhead projector)

Materials for the Class:
- Colored pencils
- Flashlights
- Tracing paper

Materials for Individual Students:
- Pencil
- Student Page #1: *Changes in the Landscape, Changes in the Atmosphere*
- Student Page #2: *Volcanic Eruption, Climate Disruption*

National Science Standards
- Earth and Space Science: Content Standard D
- Science in Personal and Social Perspectives: Content Standard F

Colorado Science Standards
- Science: 4.1c, 4.2, 6e

Learning Goals
Students will
- Understand that climate change can result from natural events.
- Understand that volcanic eruptions contribute to the chemical composition of the atmosphere.
- Understand that large volcanic events impact local AND global environments as well as climate.
- Illustrate the effects of a volcanic eruption on the appearance and composition of the atmosphere.

What Students Do in this Lesson
In this activity students learn how volcanic eruptions affect global climate. To begin, students listen to first-hand accounts of the effects of a large volcanic eruption and then illustrate their understanding of the effects upon the landscape and the atmosphere. Next, students are introduced to the effects a major volcanic eruption had on the atmosphere through the use of recent and historical images. Students model the reduction in light to Earth's surface using simple tools. Student learning about atmospheric change due to eruptions. Climate impacts of erruptions are assessed with a simple graphing activity.

Key Concepts
- Natural events can change the climate.
- Small particles of debris produced by large volcanic eruptions collect in the atmosphere
- Some of this material can be distributed globally and remain in the atmosphere for up to several years.
- Volcanic debris in the atmosphere reduces the amount of sunlight reaching the surface of Earth.
- The reduction in light results in lower annual temperatures near Earth's surface.
- Low annual temperatures persist as long as the volcanic debris (aerosols) remain in the atmosphere.

Dark Skies: Volcanic Contribution to Climate Change

Advanced Preparation

- Review and practice the Dark Skies PowerPoint presentation available at: http://www.eo.ucar.edu/Dark_Skies_2.ppt
- Copy Student Page 1 (*Changes in the Landscape, Changes in the Atmosphere*) and Student Page 2 (*Volcanic Eruption, Climate Disruption*) for each student.
- Obtain drawing materials such as colored pencils and extra paper.

Introducing the Lesson

- Explain that in this lesson, students will explore the relationship between volcanoes, the atmosphere and climate.
- Show an image of a massive volcanic eruption (see examples on page 6 of this lesson or in the Dark Skies presentation). Ask students to identify the image. Is this process natural? (The answer is yes, however some students may confuse the eruption with a nuclear explosion.)
- Read the following quote describing what it was like to be in Olongapo City, relatively close to Mt. Pinatubo when it erupted in 1991.

  "I was only 14 when it happened. But I remember that there was no sun for several days. The sky was either red or black. The ground was shaking all the time for days from the aftershocks. It was raining ashes and we had to wear a mask when we go outside. We also stayed inside the base for three days." (http://forums.about.com/n/pfx/forum.aspx?nav=messages&tsn=3&tid=1491&webtag=ab-geography)
- Ask students to describe what occurs during a volcanic eruption and what materials are forced out of the volcano. Student's answers may include rocks, ash, and smoke.
- Draw student attention to the vast amounts of ash and gas that are forced into the atmosphere. Ask students to consider where that material goes and what effects it might have upon the planet.
- Read the following quote describing how the atmosphere appeared different in Baton Rouge, LA, a location very far from Mt. Pinatubo around the time of the eruption.

  "I was playing city little league baseball that summer, and I remember during our evening games, the sun would be so beautiful–more reddish than usual. During our playoffs, I can remember how the sky had a sort of wierd tint to it. That was maybe a few weeks after the eruption or so. If it was a partly cloudy day, the clouds would be a purplish-gray color." (http://forums.about.com/n/pfx/forum.aspx?nav=messages&tsn=2&tid=1491&webtag=ab-geography)
- Create a list of the various changes students predict for the landscape and atmosphere over time after an eruption.

Facilitating the Lesson

1. Distribute and review the Student Page, *Changes in the Landscape, Changes in the Atmosphere.*
2. Ask students to draw what they think the landscape near a volcano looks like during and after an eruption.
3. Explain to students that they should use their imaginations to draw what the atmosphere surrounding the Earth looks like before, during, and after an eruption.
4. Allow students to brainstorm their ideas at this stage of the lesson.
5. Ask volunteers to share their drawings with the class and explain what they believe happens to the landscape and atmosphere during and following a volcanic eruption. (Alternatively, have each student tape her/his drawing to the wall, and allow students to circulate around the room to view each picture as if in a museum.
6. Use student sharing to discuss the various predictions they made about the changes to the landscape and the

distribution of volcanic material throughout the atmosphere.

7. Create a list of the various changes students predict for the landscape and atmosphere over time.

Presenting the Slide Show

- The PowerPoint presentation (available at: http://www.eo.ucar.edu/Dark_Skies_2.ppt) provides images, information, and anecdotes about changes in the landscape and atmosphere that can result from a massive volcanic eruption. While volcanic eruptions drastically change the local environment, the far reaching effects on the atmosphere and climate should be emphasized.
- Facilitate the presentation and encourage student questions and observations.
- Following the presentation, ask students what they would change if they were to revise their original drawings on the *Changes in the Landscape, Changes in the Atmosphere* Student Page.

Modeling the Reduction of Light

Explain to students that they will try to model the reduction of light reaching Earth following a volcanic eruption. Explain that the flashlight represents the Sun, the white surface represents the surface of the Earth, and the translucent sheet of paper represents the dust layer produced by a volcanic eruption that blocks incoming light. Alternatively, you may want to do this as a demonstration.

- Using the overhead projector or a flashlight, project a beam of light onto a white surface.
- Using a light meter (or visual assessment) record the amount of light reaching the surface.
- Next, place a sheet of translucent (tracing paper) between the light and the surface.
- Measure or note the change in the intensity of light reaching the white surface.

Assessment

- Hand out the Student Page *Volcanic Eruption, Climate Disruption* to each student.
- Explain the illustrations at the top that show what the Sun looked like before, during, and at several times after an eruption.
- Explain the axes of the graphs and the student directions.
- Ask students to draw a graph of the relative amount of ash in the atmosphere based on the illustrations of the Sun. (Answer: Large amount of ash right after the eruption and then amount of ash decreases gradually over time.)
- Ask students to predict how this amount of ash (and the change in ash through time) would affect temperature at the Earth's surface.
- Summarize results as a class. (Answer: Temperature curve should be the inverse of the ash curve - i.e., when the ash amount is greatest, temperature is lowest, when the ash amount is lower, the temperature is higher.)

Extensions or Homework

- Create a set of images that show the sequence of events, in the Earth's atmosphere during and after a volcanic eruption. Randomize the images and have students organize them into a correct sequence.
- Create a hypothesis about how volcanic eruptions impact the Earth system (biosphere, hydrosphere, geosphere).
- Students investigate what causes volcanoes and where volcanoes are located in their country or state.

Dark Skies: Volcanic Contribution to Climate Change

Background Information

Scientists who specialize in the study of climate (climatologists) have identified three major contributors to climate change: the solar cycle, extreme or persistent volcanic eruptions, and the release of gases into the atmosphere as by-products of human energy consumption. In this lesson, students learn about volcanic contributions to climate change.

Volcanoes have a significant long and short term effect on the global climate and environment. Over time, they influence the chemical composition of the atmosphere. Short term effects include local devastation and a measurable decrease in the global temperature. Ash and gas produced by volcanic eruptions may spread throughout the globe in a matter of weeks. Gases rich in sulfur combine with water vapor to form sulfuric aerosols that remain in the atmosphere for up to several years following an eruption. These small droplets form a cloud layer that blocks light from the Sun, reducing the amount of energy reaching Earth. In addition, the aerosols absorb energy radiated from the surface of Earth. This process, known as "radiative forcing," persists for several years and results in surface temperatures that are cooler in the summer and warmer in the winter.

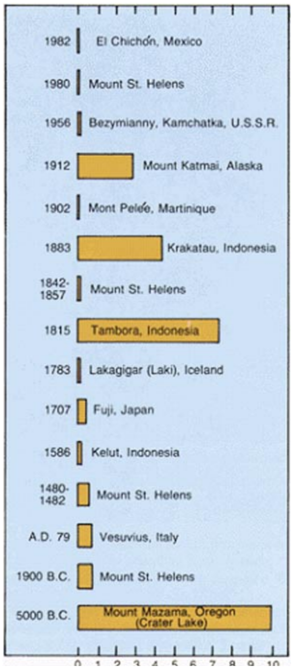
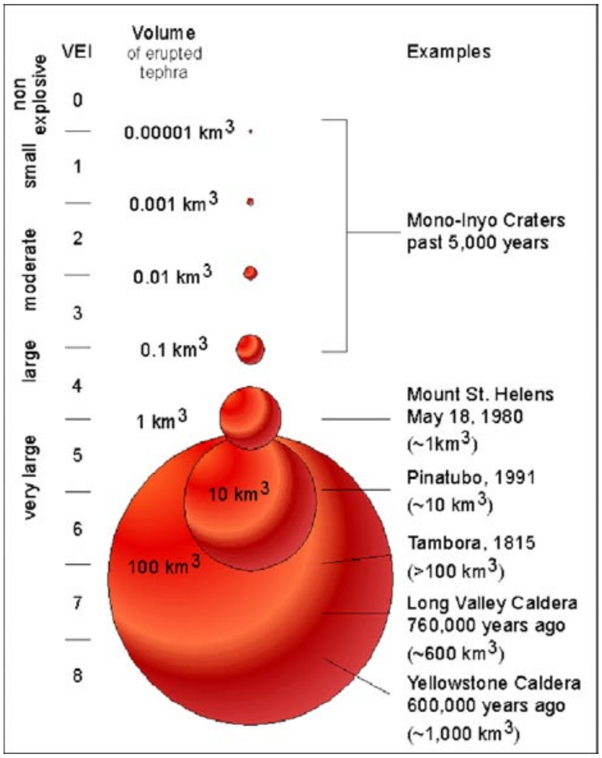


Figure 1: (above) Size of volcanic eruptions on a VEI scale of 0 to 10. Figure 2 (below) Volcanic eruptions on the VEI with volume emphasized.



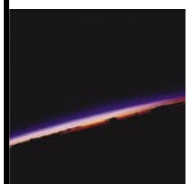
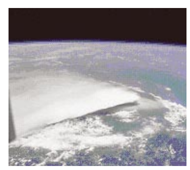
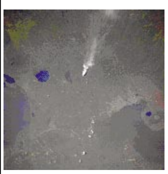
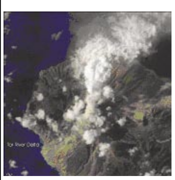
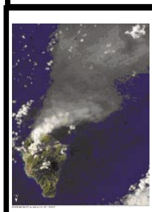
Once aerosols enter the stratosphere, they absorb energy radiating from the Earth, causing this layer of the atmosphere to warm. A warmer stratosphere leads to changes in winter conditions across the Northern Hemisphere. High pressure systems that form over the North Pole send cold air and storms to lower latitudes. This weather pattern is known as the "negative phase" of the Arctic Oscillation. From the early 1900's through the 1970's the Arctic Oscillation alternated between a negative and a positive phase; the positive phase having characteristics opposite of the negative phase. During the positive phase, high latitude locales such as Alaska, Scotland and Scandinavia have wetter weather while the western United States and the Mediterranean have drier weather, the eastern United States is warmer than usual while Greenland and Newfoundland are cooler than usual. Since approximately 1970, the positive phase has dominated, leading scientists to believe that human emissions of gases have changed the natural pattern of atmospheric circulation, and thus, the weather for the Northern Hemisphere.

Massive volcanic eruptions capable of changing global climate occur infrequently. In order to assess the relative size of eruptions, the Volcanic Eruptive Index (VEI) was developed in the early 1980's. The scale, like the Richter Scale used to measure earthquakes, is logarithmic. Thus, a volcanic event that measures 3 on the scale is ten times more explosive than an event measuring 2. Single volcanic explosions that change global climate generally measure greater than 5 on the VEI scale. These explosions generate millions of tons of debris that catapult into the upper tropopause and lower stratosphere. According to the USGS, "the record of volcanic eruptions in the past 10,000 years maintained by the Global Volcanism Program of the Smithsonian Institution shows that there have been 4 eruptions with a VEI of 7, 39 of VEI 6, and 84 of VEI 5..." More important to climate change than the ash and particulates produced by an explosion, is the amount of sulfur dioxide that is generated. Scientists have yet to determine the primary source of this sulfur. Also, each eruption releases varying amounts of sulfur depending upon the chemical composition of the magma.

The two figures on page 4 compare the relative sizes of several recent and historical eruptions. From these figures we learn that the 1980 eruption of Mt. St. Helen's was quite small in comparison to the massive eruptions of Krakatau in 1883 and Tambora in 1815. To estimate the size of historical explosions, geologists measure the depth of ash layers produced and their global distribution. Understanding and predicting the effects of eruptions help us to anticipate changes to the atmosphere, climate change, and the effects of human energy consumption which releases similar gas by-products into the atmosphere.

Additional Resources

- NASA Earth Observatory: http://earthobservatory.nasa.gov/
- Earth Observatory: Volcanoes & Climate Change: http://earthobservatory.nasa.gov/Study/Volcano/
- Mt. Pinatubo Eruption: http://www.gsfc.nasa.gov/gsfc/earth/pinatuboimages.htm
- Volcanoes and Climate Effects of Aerosols: http://eospso.gsfc.nasa.gov/science_plan/Ch8.pdf
- USGS Cascade Volcano Observatory: http://vulcan.wr.usgs.gov/
- National Snow and Ice Data Center, The Arctic Oscillation
  http://nsidc.org/arcticmet/patterns/arctic_oscillation.html

 Image of the atmosphere in pristine condition taken by NASA astronauts. Source: http://eol.jsc.nasa.gov/scripts/sseop/photo.pl?mission=STS41D&roll=32&frame=14	 Mt. St. Helen's, WA, photographed from the International Space Station following the 1980 eruption. Source: http://eol.jsc.nasa.gov/debrief/Iss005/topFiles/ISS005-E-18511.htm
 Image of the atmosphere following a volcanic eruption and the formation of an aerosol layer as photographed by NASA astronauts. Source: http://eol.jsc.nasa.gov/scripts/sseop/photo.pl?mission=STS41D&roll=32&frame=14	 The eruption of Mt. Etna, Sicily, as photographed from the International Space Station. Source: http://eol.jsc.nasa.gov/debrief/Iss005/topFiles/ISS005-E-19024.htm
 Photograph of a pristine atmosphere. Source: http://eol.jsc.nasa.gov/debrief/Sts109/topFiles/STS109-345-32.htm	 The Rabaul eruption plume, New Britain Island September 1994 photographed from the space shuttle. Source: http://eol.jsc.nasa.gov/sseop/EFS/photoinfo.pl?PHOTO=STS064-40-10
 A plume of volcanic ash from the volcano, Masaya, in Nicaragua, swept by the wind. Source: http://eol.jsc.nasa.gov/sseop/EFS/photoinfo.pl?PHOTO=STS51A-32-64	 Dormant volcano Augustine in Alaska. Source: http://vulcan.wr.usgs.gov/Volcanoes/Ecuador/images.html
 Ash and steam, Soufriere Hills Volcano, Montserrat photographed from the International Space Station. Source: http://eol.jsc.nasa.gov/debrief/Iss004/topFiles/ISS004-E-8972.htm	 Dormant volcano Cotopaxi located in Ecuador with a global positioning system in the foreground. Source: http://vulcan.wr.usgs.gov/Volcanoes/Ecuador/images.html
 Ash and steam, Soufriere Hills Volcano, Montserrat as photographed from the International Space Station. Source: http://eol.jsc.nasa.gov/debrief/Iss004/topFiles/ISS004-E-8973.htm	 Geologists monitoring gas emissions on Mt. St. Helen's, Washington Source: http://vulcan.wr.usgs.gov/Photo/Monitoring/Emissions/images.html

Information about images from Dark Skies presentation.

Dark Skies:
Student Page #1

Name ______________________

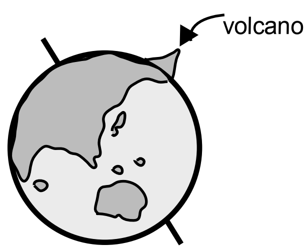
Date __________ Class ____________

Changes in the Landscape, Changes in the Atmosphere

Draw a view of the landscape near the volcano at different times after an eruption.

Before the eruption	During the eruption	Three weeks after the eruption	One year after the eruption

Draw a view of the Earth's atmosphere, as seen from space, before, during, and after the volcanic eruption. (Notes: Earth and volcano are not to scale. The rotation axis is shown with dark lines,)



Before the eruption	During the eruption	Three weeks after the eruption	One year after the eruption

Volcanic Eruption, Climate Disruption

How does a large volcanic eruption affect the atmosphere? How does debris in the atmosphere affect temperature on our planet? Create graphs below to estimate the change to the atmosphere and temperature. Use the illustrations of the Sun to estimate the amount of debris in the atmosphere.

Eruption Occurs

TIMELINE

Amount of volcanic debris in atmosphere

More Debris

Less Debris

Time

Temperature at the Earth surface

Warmer

Cooler

Time

The Little Ice Age – Understanding Climate and Climate Change

Unit: Little Ice Age
Lesson: 9

Materials & Preparation

Time:
- Preparation: 10 min
- Teaching: 45 min

Materials for the Teacher:
- Overhead projector
- Overhead transparencies of student pages 1 – 4
- Overhead transparency marker

Materials for Students:
- Pencil
- 1 per student of student pages 1 – 3,
- OR one of student pages 1, 2, or 3 for each group of 3-4 students

National Science Standards
- Science as Inquiry: Content Standard A
- Earth and Space Science: Content Standard D
- History and Nature of Science: Content Standard G

Colorado State Science Standards
- Science: 1, 4, 6

Learning Goals
Students will:
- Read and interpret graphs about natural events.
- Communicate their understanding of scientific data to peers.
- Describe climate and changes in climate during the Little Ice Age.

What Students Do In This Activity
Students receive data about tree ring records, solar activity, and volcanic eruptions during the Little Ice Age (1350-1850). By comparing and contrasting time intervals when tree growth was at a minimum, solar activity was low, and major volcanic eruptions occurred, they draw conclusions about possible natural causes of climate change.

Key Concepts
- Sunspots numbers increase and decrease on an 11-year cycle but were virtually absent during the Little Ice Age.
- Particles in the atmosphere from volcanic eruptions can reduce the amount of sunlight reaching Earth and cool the planet. At times when volcanic eruptions were more common through history, they caused global climate to cool.
- The amount of tree growth changes from year to year in response to long term climate changes. Less growth correlates with shorter growing seasons. Thus, tree rings can serve as a proxy for temperature records.

The Little Ice Age – Understanding Climate and Climate Change

Advanced Preparation

- Prepare overhead transparencies of all four Student Pages
- Copy Student Pages 1-3 for students either (1) to have one of each for each student if they will be working individually, (2) to have enough for student groups to share pages, or (3) to have each group interpret a different Student Page.

Introducing the Lesson

- *Note: This lesson is a nice summary after students have gained experience with the interpretation of data about the Little Ice Age from other activities within the Paleoclimatology section of this Teacher Guide. For other activities, visit: www.eo.ucar.edu/educators/ClimateDiscovery/LIA.htm*
- Explain to students that they will compile and interpret clues about the causes and effects of the Little Ice Age. The clues that they will use are data about past natural phenomena.
- As a class, brainstorm a list of natural events that could cause the Earth's climate to cool and a list of effects that climate cooling might have on Earth.

Facilitating the Lesson

- Arrange the students into groups of three or four.
- Provide each group with Student Page 1, 2, or 3. (Or, provide all three pages to each group or each student.)
- Ask the students to study the graph and participate in discussions with each other as they answer questions about the graph(s) on their student page(s). Have a student from each group be a scribe and record group answers.
- Place a transparency of the table/timeline from Student Page 4 on the projector. Describe to students that they will collectively use the table to summarize the solar, volcano, and tree ring data.
- Invite student groups to report their conclusions to the class as they show an overhead transparency of their student page about solar activity, volcanic ash in the atmosphere, and tree growth.
- Ask one student from each group to use the erasable pen to mark the time periods on the Student Page 4 timeline that best represents periods of lowest tree growth and highest volcanic ash in the atmosphere.
- Ask the students if they can see any relationships between the tree ring, solar, and volcanic activity. Review class brainstorms from introduction in the context of their data interpretation (for example, less sunspots correlates with cooling).
- Ask students to hypothesize when the coolest part of the Little Ice Age was, according to their data interpretation.
- Summarize by reviewing the lesson's key concepts listed on Page 1 of this lesson.

Science Background Information

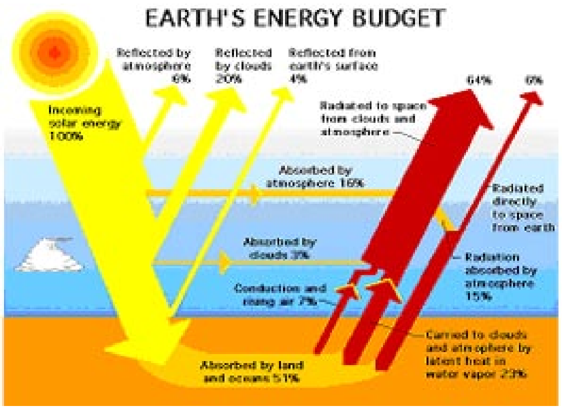
The Little Ice Age

The Little Ice Age (1350-1850) was a period of particularly harsh climate conditions around the Northern Hemisphere. A combination of decreased solar activity and numerous large volcanic eruptions cooled the Earth. Cooling caused glaciers to advance and stunted tree growth. Livestock died, harvests failed, and humans suffered from the increased frequency of famine and disease. The Little Ice Age illustrates changes to climate that occur when the Sun is less active and cooling of Earth is exacerbated by volcanic eruptions. Many other examples of climate change due to natural forces exist, including the "year without a summer" which followed the 1815 eruption of Tambora, Indonesia.

The Little Ice Age – Understanding Climate and Climate Change

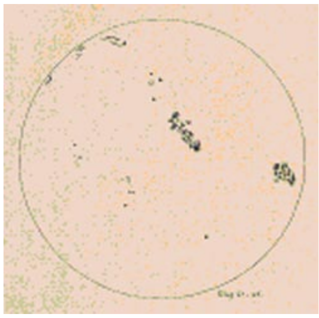
Solar and Volcanic Influences on Climate

Earth's climate is determined by the amount of energy it receives from the Sun, less the amount of energy that is reflected back into space. This is known as the "Earth's energy budget." The climate warms or cools depending upon the difference between energy absorbed and reflected.



(Source: NASA. Larger version suitable for classroom use available at http://asd-www.larc.nasa.gov/erbe/components2.gif)

Variations in the amount of solar radiation, due to variations in the number of sunspots, affect this balance. Volcanic eruptions produce clouds of dust, ash, and other tiny particles that encourage clouds to form, blocking incoming solar radiation and causing cooling. The combined effects of the solar cycle and volcanic eruptions naturally force changes in the climate. The Little Ice Age occurred at a time when the Sun's activity was at a minimum and volcanoes were very active. No sunspots were seen from 1645-1715, and volcanoes in South America and East Asia produced massive eruptions from 1600 through 1700.

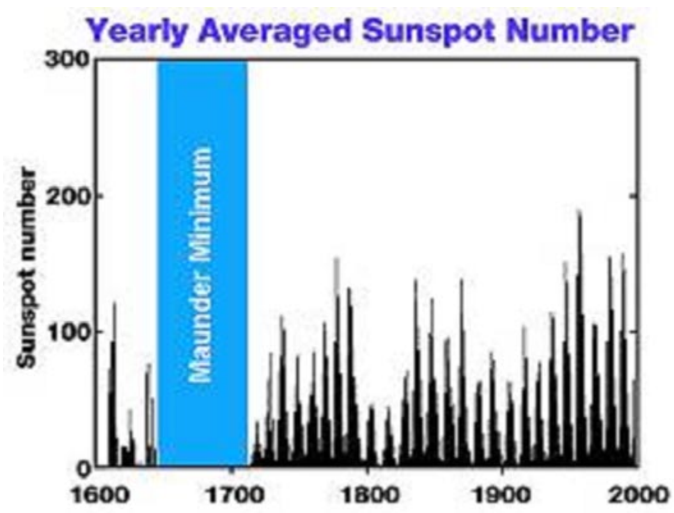


Sunspots as recorded by Galileo on June 26, 1613

Cycles of Solar Activity

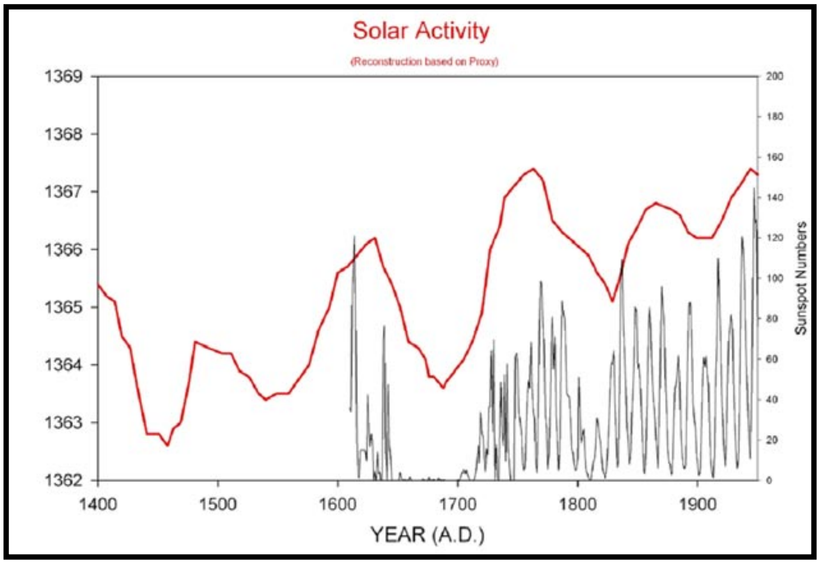
The energy output of the Sun, once thought to be constant, varies on an 11-year cycle in response to changes in the solar magnetic fields. Sunspots, areas of high magnetic activity, appear in greater or lesser numbers as the solar magnetic fields change. Cooler than their surroundings, sunspots occur along with heat producing events called faculae and flares. As a result, periods of intense sunspot activity correspond to increased energy from the Sun and warmer periods on Earth. The Earth cools when sunspot activity decreases.

The astronomer, Galileo Galilee observed and recorded sunspots in the early 1600's with the aid of one of the first telescopes. Since then, astronomers have kept a near-complete record of sunspot activity. These records show that the numbers of sunspots increase and decrease approximately every 11 years.



In 1890, astronomer E.W. Maunder reviewed centuries of sunspot data and identified a period (1645-1715) during which few or no sunspots formed. The period, known as the *Maunder Minimum*, coincides with years of hardship and harsh winter conditions in Europe. Scientists have used other methods to look for increases and decreases in solar activity, including examining the concentration of Beryllium-10, an isotope produced in abundance when the

The Little Ice Age - Understanding Climate and Climate Change



Solar activity (red upper line) related to Sun spot numbers (black lower line) 1400 – 2000 (Source: Ammann)

magnetic activity of the Sun increases.

Volcanic Eruptions Cool Earth

Volcanic activity affects the Earth's energy budget. Major volcanic activity produces a layer of ash and gas that scatters incoming sunlight, therefore causing Earth to cool. Sulfur gas, shot into the atmosphere by an eruption, combines with water vapor in the atmosphere to form a layer of sulfuric acid. This layer of very fine molecules increases the reflectivity of the atmosphere and Earth's albedo.

Albedo describes the ability of a surface to reflect light. Albedo is measured on a scale from 0 to 1 where zero represents no reflectivity and 1 represents 100% reflectivity. On average, Earth reflects 31% of the energy received from the Sun. But the Earth's surface does not reflect energy uniformly. Clouds, ice, and snow reflect up to 90% of the light from the Sun, whereas oceans reflect only about 10%. The eruption of Mt. Pinatubo in June of 1991, forced approximately 25 tons of material into the atmosphere, increasing the atmospheric sulfuric acid content 100 times. Following the Pinatubo eruption, Earth cooled by 0.5 degrees Centigrade.

Polar ice layers preserve the record of ancient volcanic activity. Eventually, precipitation cleanses the atmosphere of the volcanic ash and gas. The layer of sulfuric acid in the atmosphere forms a layer of acid-rich ice at the poles. Scientists measure the levels of sulfuric acid in ice cores to reconstruct the history of volcanic activity.

Looking for Patterns in Data

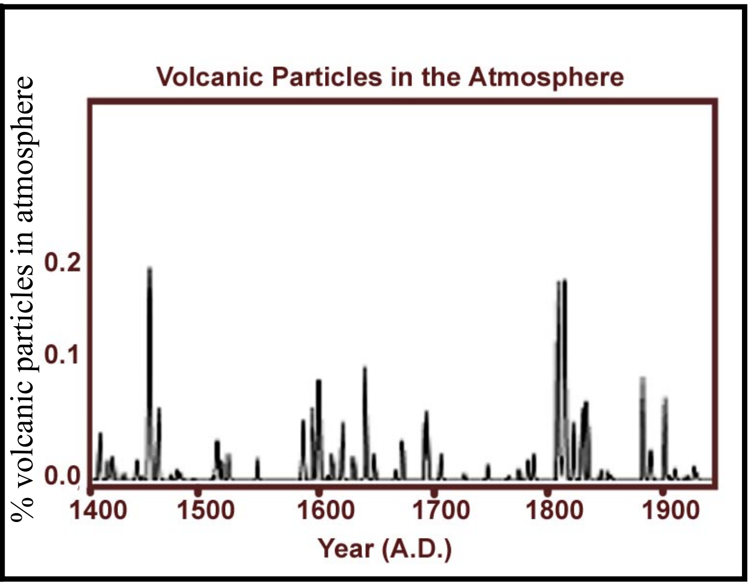
The British began the study of climate in the mid-1800s in an effort to predict the monsoon season and plan ocean travel to colonies in the Far East. One scientist, Charles Meldrum, found that monsoons increased as the number of sunspots increased. This study drew attention to the relationship between the Sun and Earth's climate. Scientists reasoned that the Sun's energy drove the climate and weather patterns on Earth and especially seasonal storms such as monsoons. A flurry of research activity produced numerous studies that related solar activity to observed events on Earth including wine production, rainfall, insect population, and more. Discrepancies in the research pointed out that the 11-year solar cycle explained only some of the changes in climate. Sometimes, when the activity of the Sun increased, the climate did not warm as predicted. At other times, cooling was extreme. Scientists began to look for other contributing factors to the Sun-climate change relationship. In 1960, Hubert Lamb proposed that volcanic activity accounted for the randomness of some climate data. Since then, studies have shown that volcanic activity cools the climate and exacerbates cooling or inhibits warming trends associated with the 11-year solar cycle.

Nature responds to short and long term cycles of climate change. Trees respond to both punctuated volcanic events and long term solar activity, which causes variations in the growing season. Other natural phenomena respond to changes in the climate as well. For example, the bloom date for a flower plant such as the cherry tree, varies annually with weather and over many years in response to climate change.

Additional Resources

- Windows to the Universe, http://www.windows.ucar.edu
- Project LEARN, http://www.ucar.edu/learn/
- The Galileo Project, http://galileo.rice.edu/index.html
- Climate Change Sites
  - http://www.ngdc.noaa.gov/paleo/education.html
  - http://www.exploratorium.edu/climate/

Date	Volcano
1452	Kuwae, Vanuatu, SW Pacific
1480	St. Helens, Washington, US
1482	St. Helens, Washington, US
1580	Billy Mitchell, Bouganiville, SW Pacific
1600	Huaynaputina, Peru
1641	Parker, Philippines
1660	Long Island, New Guinea
1680	Tongkoko, Sulawesi
1815	Tambora, Lesser Sunda Island
1883	Krakatau, west of Java
1902	Santa Maria, Guatemala
1912	Novaraupta (Katmal), Alaska
1980	St. Helens, Washington, US
1991	Pinatubo, Philippines



Left: A partial list of major volcanic eruptions from 1400 to the present, source: Ammann
Right: The amount of particulate matter generated by large volcanic eruptions between 1400 and the present. Source, Ammann

Page #1: The Little Ice Age - Understanding Climate

Name ____________________

Date __________ Class ____________

Solar Activity During the Little Ice Age

Directions:
In the graph below, the bottom jagged line indicates the number of sunspots counted during each of the solar cycles observed between 1400 and 1950 AD.

The upper line in the graph shows when solar activity increased and decreased during this time period, taking into account the sunspot cycles and other observations of the Sun.

Study the graph to answer the following questions:

- Do the highest numbers of observed sunspots coincide in any way with the line showing the highest levels of solar activity? If so, in about what years is this true?
- Do you think more solar activity would increase or decrease the amount of sunlight reaching the Earth's surface? Please explain.
- Write on the line below the years in which the sunspot cycle was entirely absent or the least number of sunspots were observed. Circle these locations on the graph.

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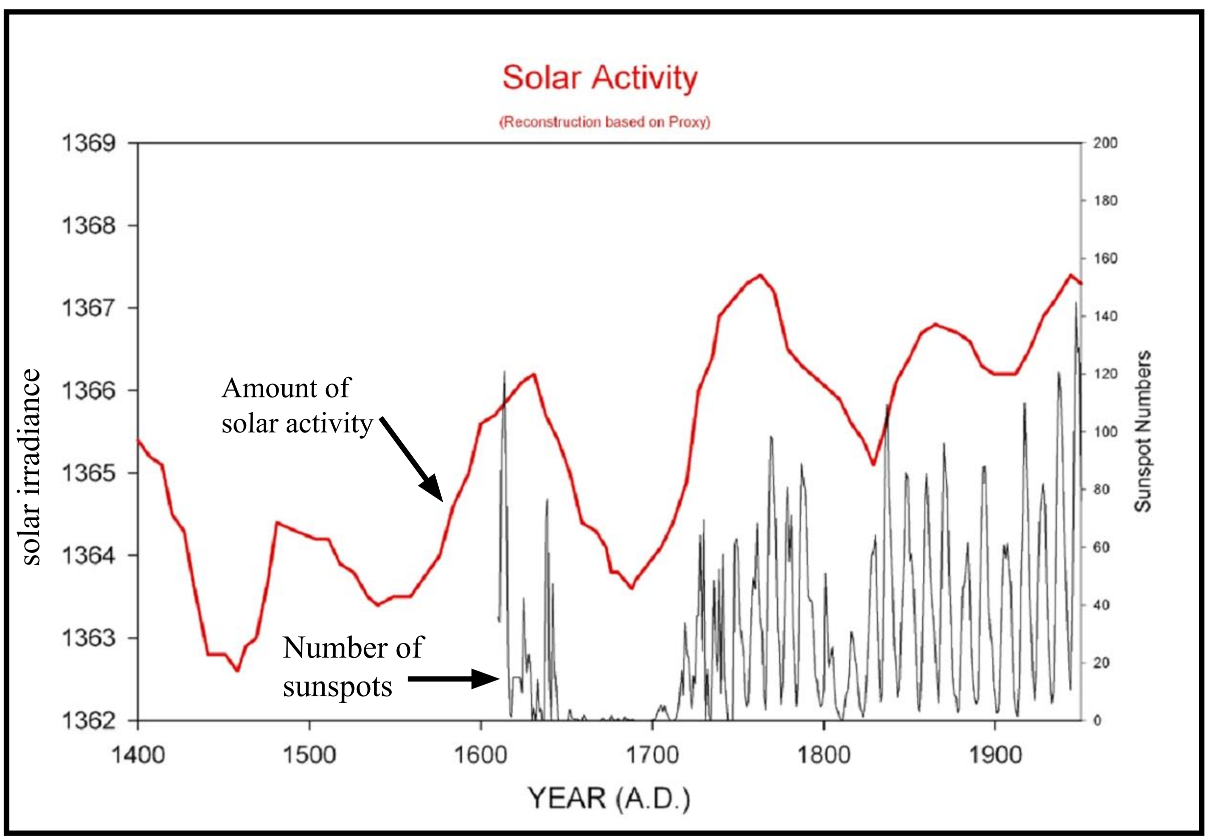

Page #2: The Little Ice Age – Understanding Climate

Name ______________________________

Date __________ Class ______________

Volcanic Activity During the Little Ice Age

Directions:
Study the graph shown below of volcanic particles in the atmosphere as you answer the following questions.

- How do you think volcanic particles get into the atmosphere?
- What do you think volcanic particles are made of?
- Do you think volcanic particles in the atmosphere would increase or decrease the amount of sunlight reaching the Earth's surface? Please explain.
- Do you think that a major volcanic eruption might help bring about global warming, or global cooling? Explain your answer.
- Write on the line below the years in which there were especially high amounts of volcanic particles in the atmosphere. Circle these locations on the graph as well.

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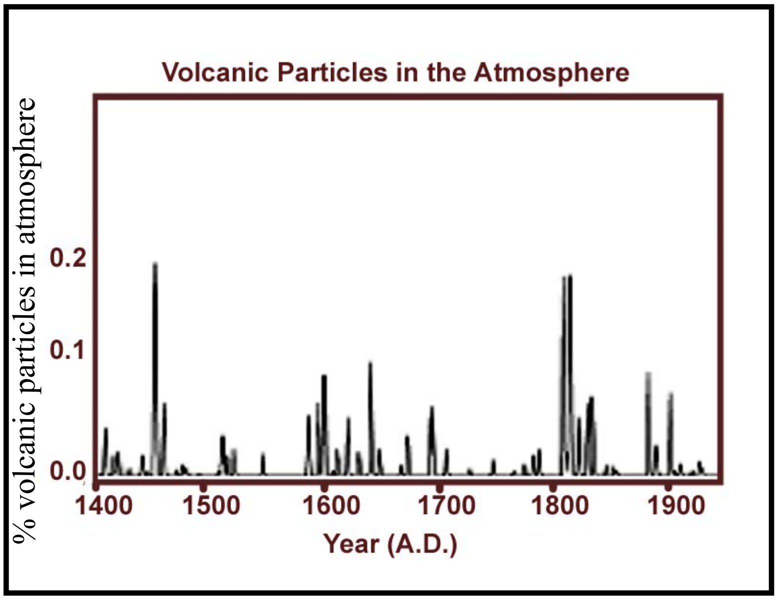

Name ______________________

Date __________ Class __________

Tree Growth in Northern Europe

Directions:

The graph represents the average growth of many different trees, not just one tree.
Study the graph below and answer the following questions:

- Does this graph indicate that the amount of tree growth tends to remain the same from year to year, or vary a lot over time?
- Does the pattern of tree growth indicate times when growth was slower? Circle places on the graph when tree growth was slower.
- What might slower growth mean about the climate?
- Write down the years on the line below when the amount of tree growth in Northern Europe was especially low.

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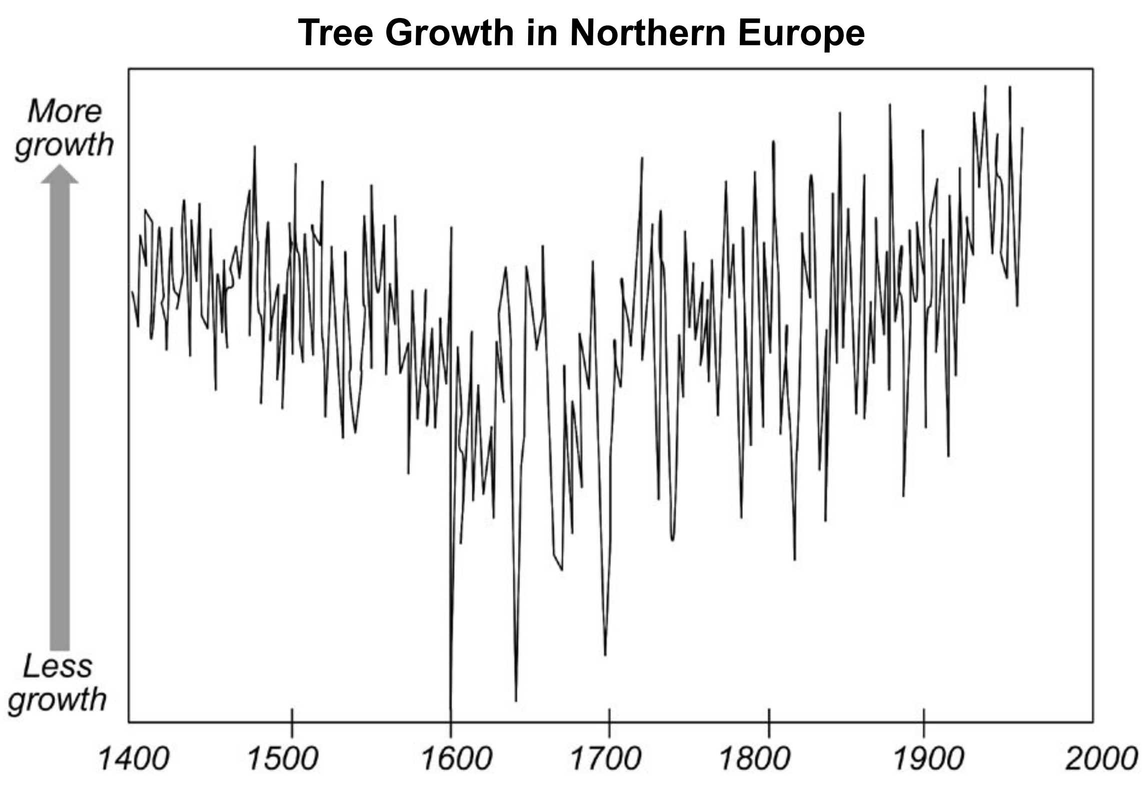

Page #4: The Little Ice Age - Understanding Climate

Name ______________________

Date __________ Class ______________

Finding the Causes of Global Climate Change

Directions:
In the table below, place an X or draw a vertical line that covers a time period that best represents the information requested.

YEAR	Least amount of tree grown in N Europe	Least amount of Sunspots	Highest amount of volcanic particles in atmosphere
2000			
1900			
1800			
1700			
1600			
1500			
1400			

Question:
If low tree growth, few sunspots, and many volcanic particles mean cooler climate, when do you hypothesize that Earth's climate would be coolest based on the information in the table above?