Teacher Resource

National Park Service
U.S. Department of the Interior

Fossil Butte National Monument
Kemmerer, Wyoming

Leafy Thermometers and Rain Gauges

Summary

This activity is a multi-day inquiry-based investigation of climate using Early Eocene fossil leaves from southwestern Wyoming and modern leaves in your area. The main objective is determining mean annual temperature (MAT) and precipitation (MAP) using leaf margin (LMA) and leaf area analysis (LAA).

Education Standards

This activity uses inquiry-based science and integrated learning principles. The Idaho, Utah, Wyoming and National education standards were consulted during its preparation. It is appropriate for middle school (5th–8th grade) and high school (9th–12th grade).

Learning Objectives

By the end of the activity, students will be able to:

- **classify** leaves.
- **measure** leaf surface area.
- **calculate** leaf proportions.
- **use** algebraic equations and graphs to estimate climate parameters.
- **explain** how leaves are used as thermometers and rain gauges.
- **compare and contrast** past and present climates.

Materials

- Photographs of fossil leaves from Fossil Basin, Wyoming (provided)
- Copies of *Seven Simple Steps to Binning Leaves* (provided)
- Copies of *Binning Chart* (provided)
- Copies of *Leaf Classification Worksheet* (provided)
- Copies of *Climate Analysis Worksheet* (provided)
- Copies of *Climate Change Worksheet* (provided)
- Modern leaves from your area
- Rulers with millimeter scale
- Calculators
- Scrap paper for leaf labels
- Paper clips
- Index cards (3”x5”)

Background for Teachers

One of the fundamental principles of geology is “the present is the key to the past.” This means the processes we observe happening on Earth today also happened in Earth’s past. This allows scientists to use knowledge of the present to make inferences about Earth’s history.

Rocks and fossils serve as indicators, called proxies, which open windows into deep time. For example, rock types and sedimentary features offer clues about depositional environments. Comparing fossils with their closest living relatives provides information about biological diversity, climate, and ecosystem.

Scientists studying flowering trees and shrubs noticed relationships between certain leaf characteristics and climate. In areas with higher average temperatures, more untoothed leaves were found. In places receiving abundant annual rainfall, more large leaves were present. Formulas to estimate mean annual temperature (MAT) and precipitation (MAP) were developed and tested on modern leaves. Today the same methods are applied to fossil leaves providing quantitative information about ancient climates.

Instructional Procedures

Day One

Classroom—Teacher-lead demonstrations of binning process, leaf surface area computation and size classification. Each student will need three fossil leaf photographs, *Seven Simple Steps to Binning Leaves, Binning Chart, Leaf Classification Worksheet,* ruler and calculator. Students begin work on *Leaf Classification Worksheet*.

Homework—Students complete *Leaf Classification Worksheet*.

Day Two

Classroom—Sort fossil leaves from homework into bins. Divide students into teams, assign each team 1-3 bins, provide each student with a copy of *Climate Analysis Worksheet* and have teams complete Part A for assigned bin. Teacher may wish to use projection equipment to display all student data collected in **Table 1**. Students begin work on *Climate Analysis Worksheet* Parts B thru D.

Homework—Students complete *Climate Analysis Worksheet*.

Day Three

Classroom—Students discuss findings from *Climate Analysis Worksheet*. Students begin work on *Climate Change Worksheet*.

Homework—Students complete *Climate Change Worksheet*.

Day Four

Classroom—Students discuss *Climate Change Worksheet*.

Day Five +

Assessment—Students demonstrate understanding by applying learned skills to modern leaves from your area.

Extension

Using the internet, students find examples of modern places with similar mean annual temperature and precipitation data as those estimated from the fossil leaves. Visit <http://www.nps.gov/fobu> and click on the *Photos & Multimedia* link to see what types of plants and animals lived in southwestern Wyoming during the Early Eocene. Do any modern places with similar temperature and precipitation have the same types of plants and animals? What are the implications for the Eocene climate based on evidence from Fossil Basin?

Assessment Plan

1. Students collect and classify (margin type and size class only) a suite of modern woody dicot leaves from your area.
2. Students use leaf margin (LMA) and leaf area analysis (LAA) to determine mean annual temperature (MAT) and mean annual precipitation (MAP) for the modern leaves.
3. Students compare the results of the analysis with an observation-based meteorological database. Find historical data summaries by visiting the National Climate Data Center web site at <http://www.ncdc.noaa.gov/oa/climate/regionalclimatecenters.html> and clicking on the appropriate regional climate center for your area.
4. Discuss student findings. If significant discrepancies exist between the analysis of modern leaves and the observation-based meteorological database brainstorm possible explanations.

Contact Information—e-mail: fobu_interpretation@nps.gov, phone: 307 877-4455, or mailing address: Fossil Butte National Monument, PO Box 592, Kemmerer, WY 83101. The activity and supporting materials are available at <www.nps.gov/fobu> under the quick-link tab *For Teachers*. All materials may be reproduced for educational use. Comments and suggestions are encouraged, and should be forwarded to the education specialist using contact information provided above.

Leaf Classification Worksheet

Part A. Binning Fossil Leaves

Classify fossil leaves using the *Seven Simple Steps to Binning Leaves* and a *Binning Chart*. For each leaf record the leaf ID number, leaf characteristics and bin number in **Table 1**. Bin numbers appear in the lower right corner of the shaded boxes on the *Binning Chart*. Once you assign a bin number binning is complete. However, all binned leaves should include margin type (Step 4).

Part B. Leaf Area and Size Class

1. Measure the length of the leaf in millimeters parallel to the midvein between petiole attachment and apex. Do not include the petiole. Record length in **Table 1**.
2. Measure the width of the leaf in millimeters perpendicular to the midvein where the leaf is at its widest. Record width in **Table 1**.
3. Using the formula, **Leaf area (mm^2) = Length (mm) x Width (mm) x 0.75**, calculate the leaf area in square millimeters. Show your work and record answer in **Table 1**.
4. Use *Raunkiaer-Webb Size Class Chart* below to assign a size class based on leaf area. Record size class in **Table 1**.

Raunkiaer-Webb Size Class Chart

Leaf area (mm^2)	Size class
Less than 25 mm^2	leptophyll
25-225 mm^2	nanophyll
225-2025 mm^2	microphyll
2025-4500 mm^2	notophyll
4500-18,225 mm^2	mesophyll
18,225-164,025 mm^2	macrophyll
Greater than 164,025 mm^2	megaphyll

Record Leaf Set Number in box. ☐

	Demo	Leaf 1	Leaf 2
Leaf ID Number			
Step 1			
Step 2			
Step 3			
Step 4			
Step 5			
Step 6			
Step 7			
Bin number			
Leaf length			
Leaf width			
Leaf area			
Size class			

Table 1 *(Leaf Classification Worksheet)*

Part C. Data Labels

Record the items in the shaded areas (leaf ID number, step 4, bin number and size class) of **Table 1** for Leaf 1 and 2 onto separate strips of scrap paper. Use paper clips to attach labels to fossil leaves.

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Climate Analysis Worksheet

Part A. Data Collection

1. Sort the leaves by bin number.
2. Divide into teams and begin data collection for assigned bins.
   a. Count the leaves in a bin and record the number in column A of **Table 1**.
   b. Remove any leaves from a bin that are not woody dicots. [Hint: To distinguish woody dicot leaves ask yourself the question, "does it have a network of veins and looks like it grew on a tree or a shrub?" If so, its a woody dicot.] Count the woody dicot leaves in a bin and record the number in column B of **Table 1**.
   c. Inspect the remaining leaves. If two or more leaves in a bin appear to be the same type of leaf, paper clip them together. Count the morphotypes (unique leaf types) in a bin and record the number in column C of **Table 1**.
   d. Count the untoothed morphotypes in a bin and record the number in column D of **Table 1**.
   e. If you have a morphotype represented by more than one leaf (the ones you paper-clipped together) average the surface area of the largest and smallest, and reclassify the morphotype using the *Raunkiaer-Webb Size Class Chart* in Part B of *Leaf Classification Worksheet*. Write the new size class on the note paper-clipped to the leaves.
   f. Sort the leaves in a bin by size class.
      1) For each bin count the mesophyll-sized morphotypes and record the number in column E of **Table 1**.
      2) For each bin count the macrophyll-sized morphotypes and record the number in column F of **Table 1**.
      3) For each bin count the megaphyll-sized morphotypes record the number in column G of **Table 1**.
3. Fill in **Table 1** for all bins 12-40 by sharing information with other teams.
4. Sum the columns in **Table 1**.

Bin Number	A leaves	B woody dicots	C morphotypes	D untoothed	E mesophyll	F macrophyll	G megaphyll
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							
31							
32							
33							
34							
35							
36							
37							
38							
39							
40							
Total							

Table 1 *(Climate Analysis Worksheet)*

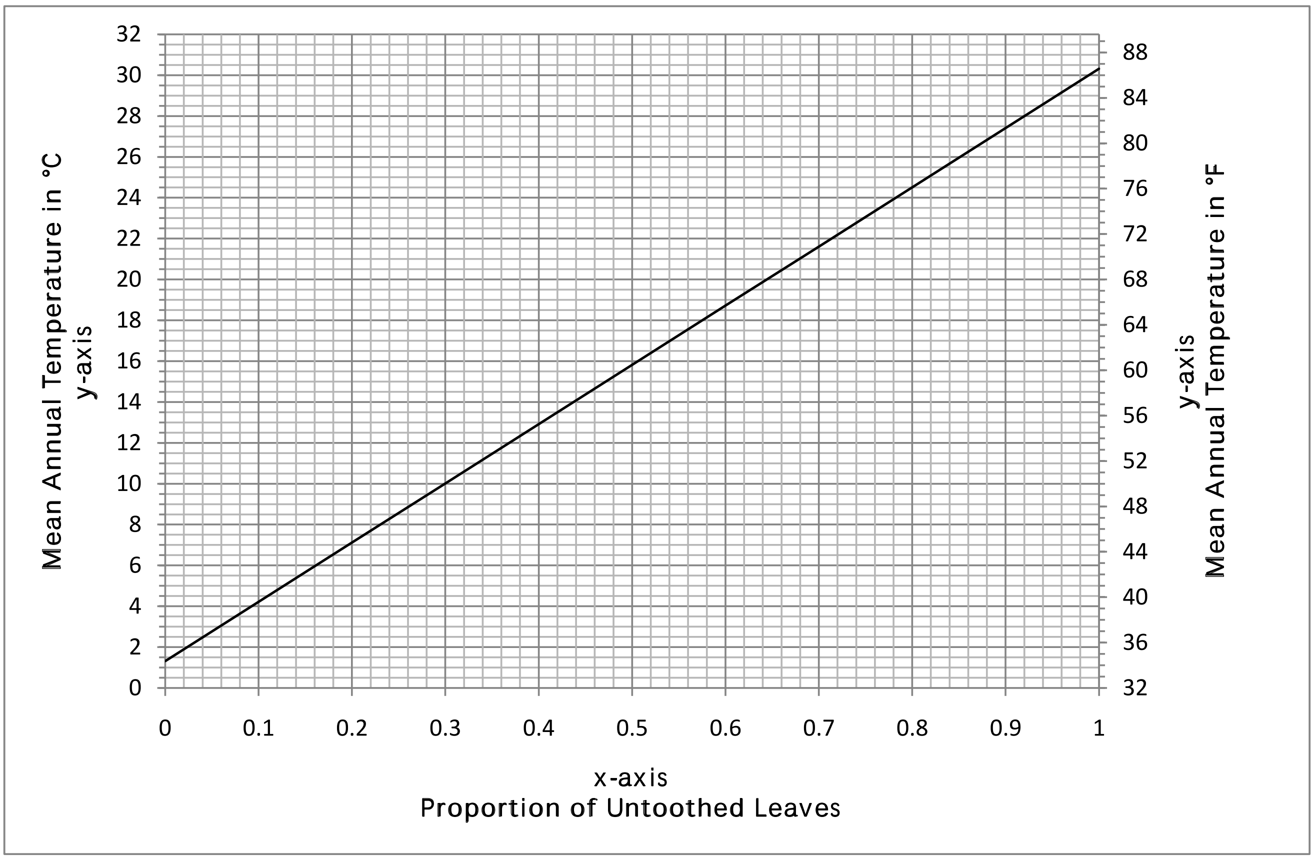
Part B. Leaf Margin Analysis and Mean Annual Temperature

1. Use the data from **Table 1** to determine the proportion of untoothed morphotypes (P_U) in the fossil leaf data set. Use the equation $\mathbf{P_U = \frac{Column\ D_{TOTAL}}{Column\ C_{TOTAL}}}$ to calculate the proportion. Show your work.

2. Calculate mean annual temperature (MAT) using the equation **MAT (°C) = (28.99 x P_U) + 1.32**. Show your work.

3. The diagonal line on graph below represents the relationship between the proportion of untoothed leaves (P_U) and mean annual temperature (MAT). It has a **negative slope** / **positive slope** (circle one) meaning the more untoothed leaves a place has the **cooler** / **warmer** (circle one) the average temperature is. Use the graph below to determine mean annual temperature (MAT) in °C and °F.

Step 1. Find the proportion of untoothed leaves (P_U) on the horizontal x-axis of the graph.
Step 2. Draw a vertical line using a ruler from P_U on the x-axis until it intersects the diagonal line.
Step 3. From the point of intersection with the diagonal line, draw a horizontal line using a ruler that intersects both vertical y-axes of the graph.



4. Read the mean annual temperature in °C from intersection of the horizontal line with the y-axis to the left. Record your answer below. Does the graphical solution agree with the algebraic solution in question 2? If they do not agree within 0.5°C you need to check both solutions.

5. Read the mean annual temperature in °F from intersection of the horizontal line with the y-axis to the right. Record your answer below.

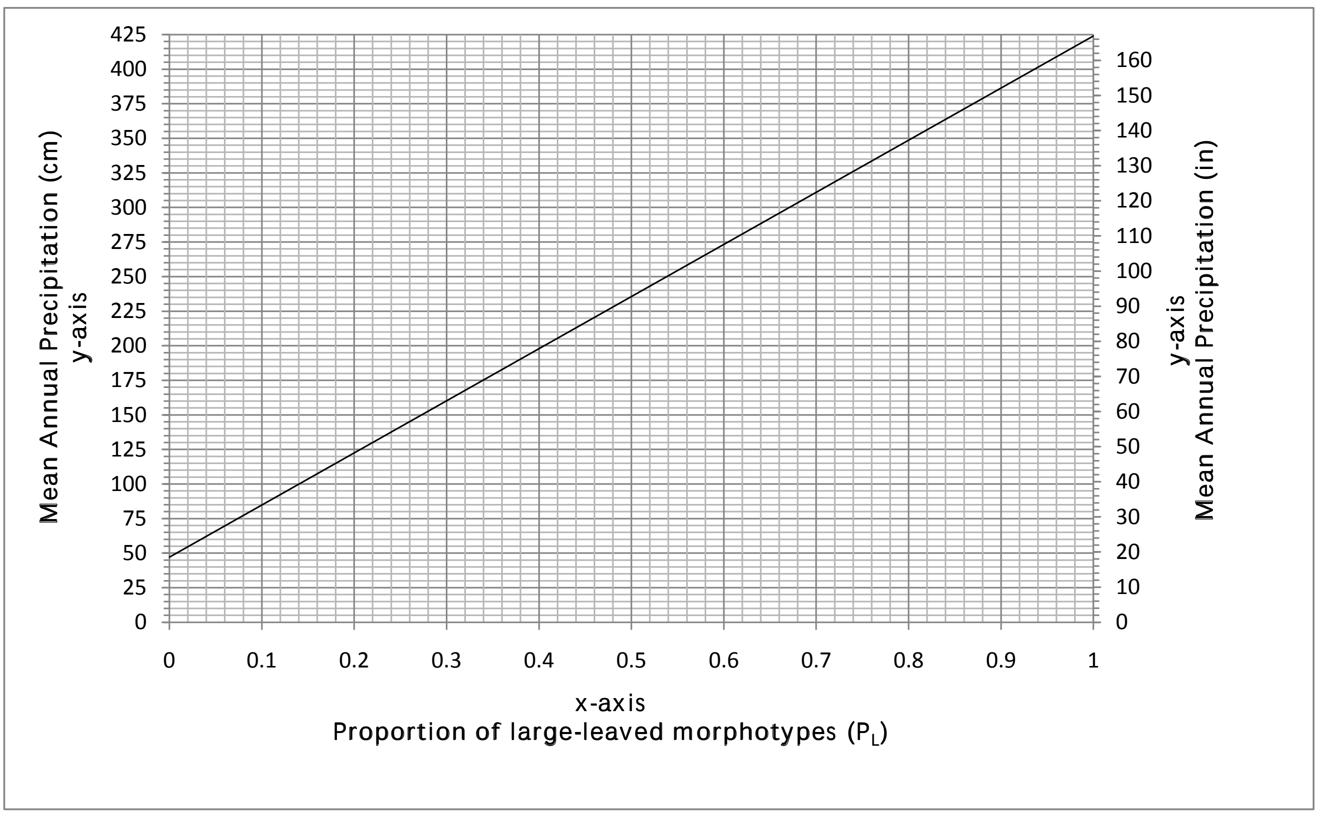
Part C. Leaf Area Analysis and Mean Annual Precipitation

1. Use the data from **Table 1** to determine the proportion of large-leaved morphotypes (P_L) in the fossil leaf data set. Use the equation $\mathbf{P_L = \dfrac{(Column\ E_{TOTAL} + Column\ F_{TOTAL} + Column\ G_{TOTAL})}{Column\ C_{TOTAL}}}$ to calculate the proportion. Show your work.

2. Calculate mean annual precipitation (MAP) using the equation $\mathbf{MAP\ (cm) = (377 \times P_L) + 47}$. Show your work.

3. The diagonal line on the graph below represents the relationship between the proportion of large-leaved morphotypes (P_L) and mean annual precipitation (MAP). It has a **negative slope / positive slope** (circle one) meaning the more large leaves a place has the **less precipitation / more precipitation** (circle one) it receives annually. Use the graph to estimate mean annual precipitation (MAP) in centimeters and inches.

Step 1. Locate the proportion of large-leaved morphotypes (P_L) on the horizontal x-axis of the graph.
Step 2. Draw a vertical line using a ruler from P_L on the x-axis until it intersects the diagonal line.
Step 3. From the point of intersection with the diagonal line, draw a horizontal line using a ruler that intersects both vertical y-axes of the graph.



4. Read the mean annual precipitation in centimeters (cm) from intersection of the horizontal line with the y-axis to the left. Record your answer below. Does the graphical solution agree with the algebraic solution in question 2? If they do not agree within 5 centimeters you need to check both solutions.

5. Read the mean annual precipitation in inches (in) from intersection of the horizontal line with the y-axis to the right. Record your answer below.

Part D. Modern Climatology Data

1. Convert the mean annual temperature (MAT) in °C from Part B question 2 to °F using the formula: $°F = \frac{(9 \times °C)}{5} + 32$. Show your work. Record answer in **Table 2**.

2. Convert the mean annual precipitation (MAP) in centimeters from Part C question 2 to inches using the formula: $in = \frac{cm}{2.54}$. Show your work. Record answer in **Table 2**.

3. Go to the Wyoming Climate Summaries web site at <www.wrcc.dri.edu/summary/climsmwy.html> and click on the links in the left margin for Fossil Butte, Kemmerer and Sage one station at a time. Record the *Annual Average Max. Temperature* (equivalent to T_{MAX} in **Table 2**), the *Annual Average Min. Temperature* (equivalent to T_{MIN} in **Table 2**) and *Annual Average Total Precipitation* (equivalent to MAP in **Table 2**) for each station.

4. To estimate mean annual temperature (MAT) for Fossil Butte, Kemmerer and Sage average T_{MAX} and T_{MIN}. Use the equation: $MAT = \frac{(T_{MAX} + T_{MIN})}{2}$. Show your work. Record answers in **Table 2**.

	Fossil Leaves	Fossil Butte	Kemmerer	Sage
T_{MAX}	Blank			
T_{MIN}	Blank			
MAT				
MAP				

Table 2

6. What general statement can be made about climate change over the last 52 million years in southwestern Wyoming based on the results in **Table 2**?

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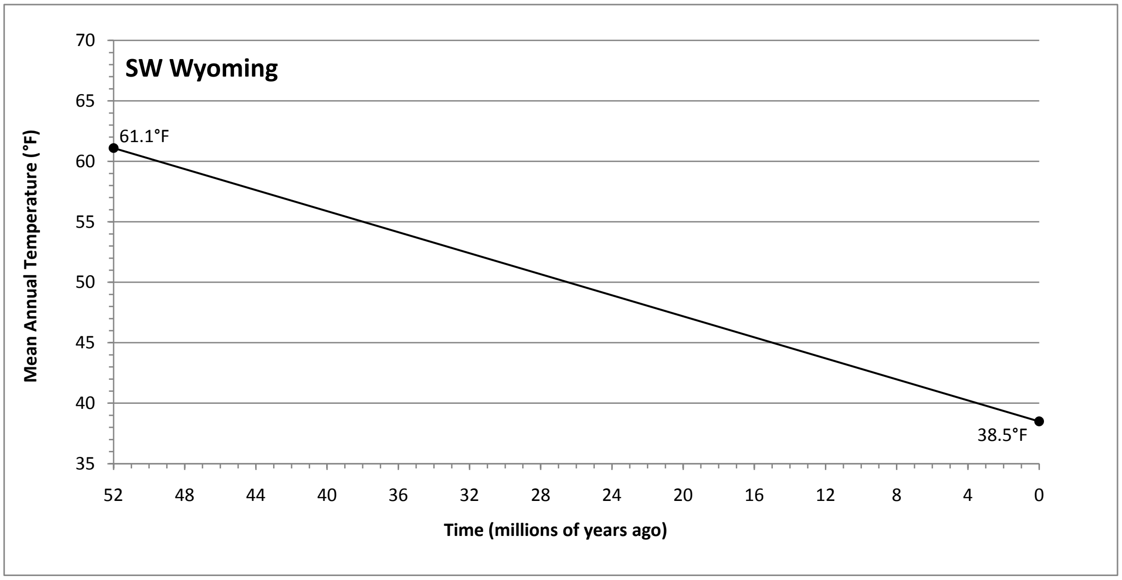
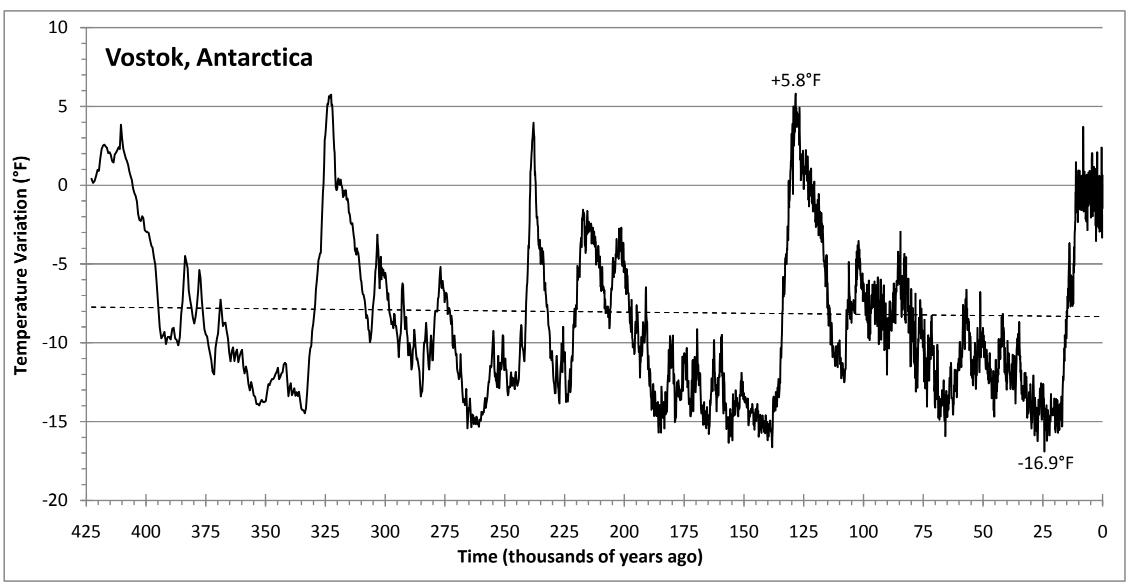
Climate Change Worksheet

1. **Graphs 1** and **2** show how temperature has changed over geologic time. Read the captions, compare the graphs and list three differences. [Bonus: List one similarity.]

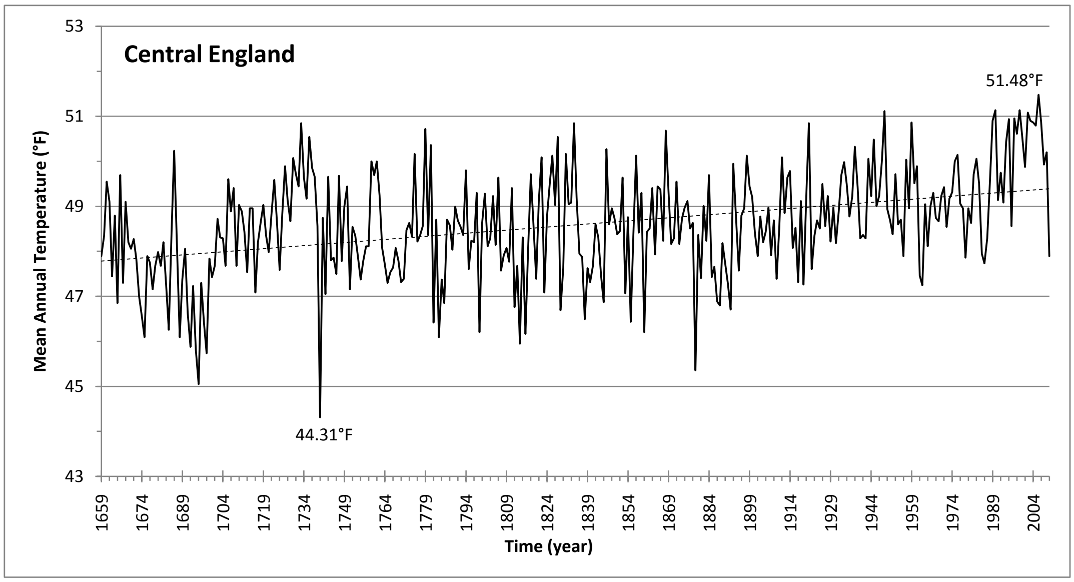


Graph 1—The graph shows the temperature change over the last 52 million years in southwestern Wyoming based on the analysis of fossil leaves (P. Kester and A. Aase, pers. com., 2011) and modern observational data. The mean annual temperature 52 million years ago was 61.1°F and today it is 38.5°F, a difference of 22.6°F.

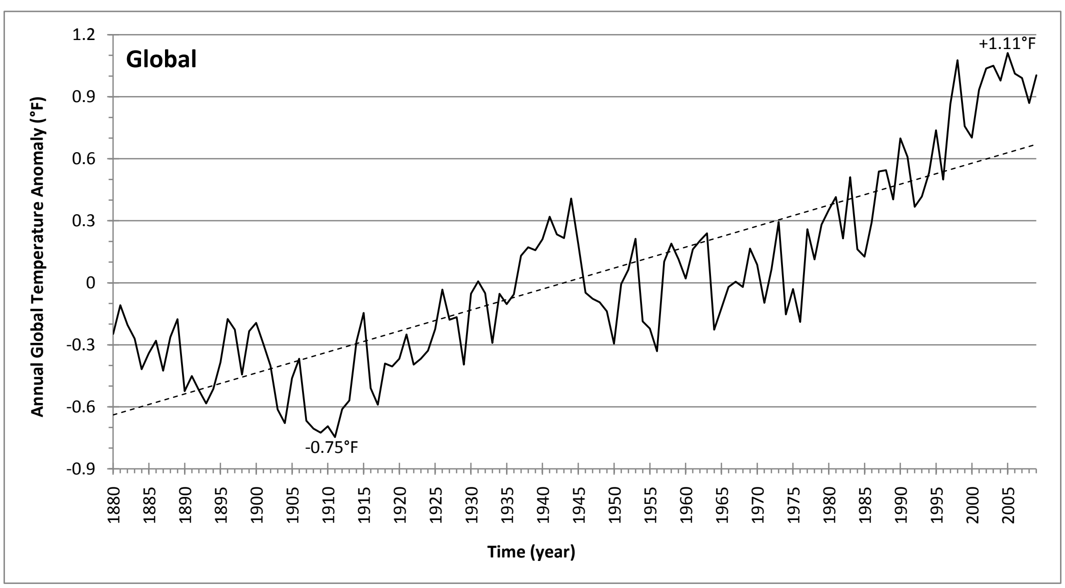


Graph 2—The graph (based on Petit, J.R. et al, 1999) shows the variation in temperature over the last 425,000 years at Vostok, Antarctica as determined from ice cores. The five tallest peaks represent short-lived warm periods that interrupted major glaciations. During the height of a warm period about 125,000 years ago, temperatures were 5.8°F warmer than today. At the last glacial extreme about 25,000 years ago they were 16.9°F cooler, a difference of 22.7°F.

2. **Graphs 3** and **4** show how temperature has changed as advanced human civilization developed. Read the captions, compare the graphs and list three differences.



Graph 3—The graph (based on Parker, D.E. et al, 1992) shows mean annual temperature for Central England from 1659 to 2010. It is the longest continuous temperature record in existence. The lowest mean annual temperature over this period was 44.31°F in 1740 and the highest was 51.48°F in 2006, a difference of 7.17°F.



Graph 4—The graph (based on data from the National Climate Data Center) shows the annual global temperature anomaly for 1880-2009. A temperature anomaly is the difference between an observed temperature and a long-term average temperature. The largest negative anomaly over this period was -0.75°F in 1911 and the largest positive anomaly was 1.11°F in 2005, a difference of 1.86°F.

3. Why does **Graph 1** look so different from the other three? [Hint: Give a pointed answer.]

4. Why is a global average, as opposed to data from a single location, a more meaningful measure of climate change?

5. The methods used to produce the graphs are different, but what do they all show? [Hint: Look to axes]

6. The dashed line in the last three graphs are linear trendlines. Trendlines smooth the peaks and valleys using an averaging technique to reveal the direction and magnitude of change over a period of time.

Step 1. Calculate the change in temperature, ΔT(°F), for Vostok, Antarctica, Central England and Global using data in the table below and the equation: **ΔT(°F) = t_{min} - t_{max}**. Show your work.

	SW Wyoming		Vostok, Anarctica		Central England		Global	
	t_{min}	t_{max}	t_{min}	t_{max}	t_{min}	t_{max}	t_{min}	t_{max}
T (°F)	38.5	61.1	-8.3358	-7.7408	49.44	47.825	0.7688	-0.547

Example (SW Wyoming):
from table, t_{min} = 38.5°F
from table, t_{max} = 61.1°F
ΔT(°F) = 38.5°F - 61.1°F
= -22.6°F

Record your anwers here.

	SW Wyoming	Vostok, Anarctica	Central England	Global
ΔT(°F)	-22.6			

Step 2. Calculate the rate of temperature change per century, $\Delta T/t$(°F/100 yrs), for Vostok, Anarctica, Central England and Global using data from Step 1, the table below, and the following equation. Show your work and round answer to 5 decimal places.

$$\Delta \mathbf{T/t}(°F/100\ yrs) = \frac{\Delta T\ (°F)}{\Delta t\ (yrs)} \times 100$$

	SW Wyoming	Vostok, Anarctica	Central England	Global
Δt(yrs)	52,000,000	425,000	352	130

Example (SW Wyoming):
from Step 1, ΔT (°F) = -22.6°F
from table, Δt (yrs) = 52,000,000 yrs

$$\Delta T/t\ (°F/100\ yrs) = \frac{-22.6°F}{52{,}000{,}000\ yrs} \times 100$$
$$= -0.00005°F/100yrs$$

Record your answers here.

	SW Wyoming	Vostok, Anarctica	Central England	Global
$\Delta T/t$(°F/100 yrs)	-0.00005			

7. Compare the rates of temperature change per century. The short-term records (Central England and Global) suggest Earth's surface temperature is _______________ (**cooling**, or **warming)** significantly, while the long-term records (SW Wyoming and Vostok, Antarctica) suggest it has _______________ (**cooled**, or **warmed**) albeit very slowly.

8. In your opinion, why does, or doesn't the evidence presented support a conclusion that modern climate change is being influenced by humans (anthropogenic climate change)?

9. Use the internet to investigate three factors (one anthropogenic and two natural) that influence Earth's climate. On separate index cards list each factor, what its influence is and how that varies over time. Be prepared to discuss the relative contribution of each factor to modern climate change in class.