POLAR DETECTIVES:

USING ICE CORE DATA TO DECODE PAST CLIMATE MYSTERIES

ICE DRILLING PROGRAM OFFICE
CLIMATE EXPEDITIONS

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Using Ice Core Data to Decode Past Climate Mysteries

Teacher Notes: Students will investigate the formation and physical properties of ice cores. They will graph sulfur data from two ice core locations, draw conclusions about the impact of volcanic eruptions on weather at the time and compare the discrepant 1816 event to long term climate patterns.

Key Concepts: Physical properties of snowflakes vary depending on the temperature and humidity when the snow falls. Observable differences in ice core layers formed from the snow provide evidence of the climate at the time. Global circulation patterns impact the distribution of particulates and chemicals that get embedded in the ice. Scientists can analyze these indicators for more clues to climate history.

Target Grade Levels: Middle and High School

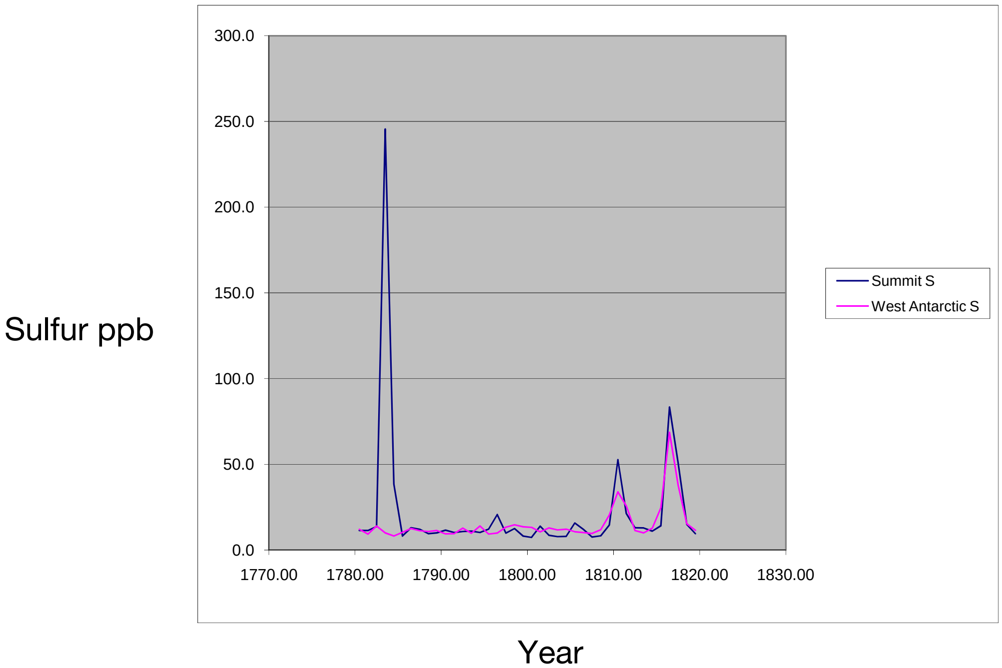
Background: This activity is based on known historic events, most probably caused by several volcanic eruptions, including 1783's Laki event in Iceland, an "unknown" in 1810 and the huge eruption at Mount Tambora in Indonesia in 1815. The repercussions on human behaviors and culture during this period of history were widespread and you may have fun following this activity with some reading on the impact of these past environmental conditions on society at the time. For discussion, point out to students the interactions among earth's systems. Events in the geosphere such as eruptions can affect the contents of the atmosphere, which may become archived in the ice of the cryosphere, and ultimately affect the hydrosphere through the raising or lowering of sea level under different temperature and climatic conditions.

Some accumulation facts: Ice coring research sites are chosen in cold regions, so that precipitation at the site will always fall as snow. At many locations, snow falls both in summer and in winter; the amount of snow that falls will depend both on the particular storm track and also on the atmospheric temperature. Warmer air can hold more moisture than colder air, so at some locations more snow might accumulate in the summer than in the winter. This is true even when the "warm" season is well below freezing, for example -20 C in the summer as compared to -40 C in the winter in the center of the Greenland ice sheet. There also may be multiple snow events contributing to the summer or winter accumulations each year. The answer to which season might have more accumulation may be, "It depends!" Summer in the northern hemisphere is June - August, while summer in the southern hemisphere is November - January.

Guidelines: Allow at least two fifty minute periods to complete the activity, depending on your students' knowledge of graphing skills and how much background information you would like to include. During period 1 set up the scenario, investigate simulated snow and create the model core column. During period 2 have students graph and analyze the data, followed by group discussions.

Materials: For each group of 6 students, you will need 6 copies of the activity packet, 1 (50 ml) graduated cylinder, 1 spoon, an index card or small funnel, 6 pieces of graph paper, 1-6 hand lenses, 3 small squares of black paper, two colored pencils per student, approximately ¼ c. of sugar, 3 T. of salt, and a small amount of pepper.

Task 3 Graph: Student outcomes should look similar to the finished example below.



National Science Education Content Standards

- Unifying Concepts and Processes
- A: Science as Inquiry
- D: Earth and Space Science
- F: Science in Personal and Social Perspectives
- G: History and Nature of Science

Climate Literacy: The Essential Principles of Climate Science

- 1: The sun is the primary source of energy for earth's climate system
- 2: Climate is regulated by complex interactions among components of the earth system
- 3: Life on earth depends on, is shaped by, and affects climate
- 4: Climate varies over space and time through both natural and man-made processes

- o 5: Our understanding of the climate system is improved through observations, theoretical studies and modeling
- o 7: Climate change will have consequences for the earth system and human lives.

Extensions: Information on ice core-related climate expeditions, people and tools can be found at http://www.icedrill.org, along with links to web sites for ice core drilling projects that are currently active.

For a look at some real world polar detectives and the issues they are addressing at a deep coring site in Antarctica, watch the online video called, "Climate Change: How Do We Know?" located at: http://www.waisdivide.unh.edu/outreach/video.html.

For an additional enrichment activity you might use Google Earth to investigate the volcanoes involved in these events.

Evaluation: The low latitude 1991 eruption of Mount Pinatubo in the Philippines offers a more recent major volcanic event and opportunity to assess student transfer of learning. See page 4 for some sample questions, with suggested answers below. You might also want have students analyze the 2010 eruptions of Eyjafjallajökull in Iceland, which caused major disruptions to European air travel for over a week, including delaying some ice scientists from reaching their Greenland research sites on time!

Potential Answers:

1) Scientists may date ice cores by finding evidence of a known volcanic event, counting annual layers or analyzing seasonal hydrogen peroxide data.

2a) Ash would be deposited in both polar regions due to the global atmospheric circulation patterns.

2b) Scientists might look for particulate matter, such as ash, or sulfur embedded in the ice.

3) There are good direct temperature records from this century, and indirect evidence such as the growth of crops, etc. might also be used.

For additional educational resources: Please visit www.climate-expeditions.org

Authors / Activity Credit: Linda Morris (Dartmouth), Mary Albert (Dartmouth), Joe McConnell (Desert Research Institute)

Student Name: ________________________________ **Class/Period:** ______________

From what you learned in the Polar Detectives activity, answer the following questions:

1) Describe one method by which scientists can date an ice core:

2) The arrow on the image below shows the location of Mt. Pinatubo, a volcano that erupted in the Philippines (June, 1991), sending ash high into the stratosphere.

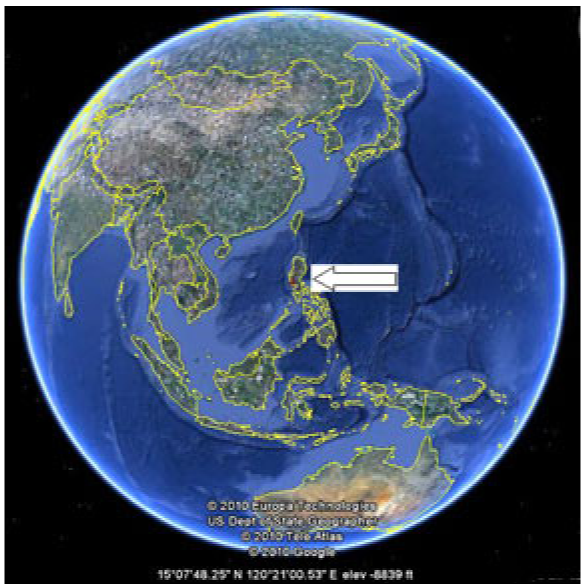


Photo Credit: Google Earth

a) On which ice sheet(s) (Greenland, Antarctica or both) would you expect the fall out from this event to be captured, and why?

b) What kind(s) of evidence could researchers look for in ice cores to indicate that this volcanic eruption occurred?

3) What different type(s) of data could you gather in order to see whether the 1991 event affected that year's climate?

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The Scenario: Can you imagine a “Year Without a Summer”[1]? Both historians and scientists have found that in 1816 environmental conditions caused temperatures to drop abnormally, more than half a degree Celsius. This was enough to kill animals and crops in the northern hemisphere, to reduce the amount of sunlight due to persistent fog, and to have ice and snow forming in Europe in July and August. Conditions were so grim that author Mary Shelley holed up inside her holiday hotel and competed with friends to see who could create the scariest story. The result? Frankenstein! Figuring out what caused these events and whether they were a random occurrence is the job of climate scientists. To discover an answer, they begin with a question.

The Question: For this activity we need to know, “What caused the extreme 1816 summer conditions and how did that year’s climate compare to long term patterns?” Climate indicators can include temperature, precipitation, sea level, and greenhouse gas concentrations in the atmosphere. This fits into key research scientists are doing today on how our current climate compares to climate conditions in the past.

A Hypothesis: One educated guess is that there may be evidence of a major event in ice cores, such as a volcanic eruption, that caused of the unusual climate in 1816.

What We Know: Layers of snow get compressed into ice over time in earth’s large ice sheets. Several people have studied snow formation extensively and created wonderful photo archives of snowflakes for us to see. A Vermonter named Wilson Bentley was the first to become famous doing this, and more recently a professor, Ken Libbrecht, built on Bentley’s work, creating images like those below from www.snowcrystals.com.

Task 1: Using your hand lens, examine the photos below. Are the snowflakes all the same shape and size?

It turns out that snow crystals form differently under different atmospheric conditions. The large branching (dendritic) flakes, such as the one on the left, form when the air is moist and warm (think “snow man” snow – fluffy and sticky enough to make great snowballs). Under very cold, drier conditions crystals are finer grained and more needle-like such as the third photo from the left (think “powder skiing”). In the center of the Greenland Ice Sheet, snow falls year round and does not melt. Layers of large, coarse crystals are evidence of snow that fell in summer, while layers with fine, smaller crystals indicate winter accumulations. These complex crystal shapes pile up over

[1]Evans, Robert. “Blast From the Past”. Smithsonian Magazine (July 2002).
Available online at: http://www.smithsonianmag.com/history-archaeology/blast.html

many decades to form a porous matrix many tens of yards thick, called “firn”. As the firn builds up, deeper layers become compressed into solid ice. The center of the Greenland ice sheet is roughly two miles thick! In addition to snow falling on the ice sheet, in some years a volcano located far away may erupt strongly enough that its emissions are carried by atmospheric circulation towards the poles, where tiny particles (aerosols) and ash fall out of the air onto the ice sheet.

Task 2: Let’s see how these facts might provide a clue to past climates…

In this simulation, sugar will represent the coarser summer season snow, salt will represent finer, winter snow, pepper will stand for ash from the atmosphere and the graduated cylinder will represent the ice core in which these layers are found. Sprinkle a few grains of each substance onto separate squares of black paper and examine them with your hand lens. What do you observe about the particles?

Working as a team, create a model of an ice core with your materials, following the guidelines below. Use a spoon to remove the materials and a folded card as a funnel.

Layer 1: Form the base of your core by adding summer snow (sugar) to a thickness that you can clearly see, for example 10 ml.

Layer 2: Add winter snow (salt) on top of the summer snow. Should you assume more accumulation occurs in summer or winter? Put in enough so that you can clearly see the layer from the outside of the cylinder. These two layers represent evidence of one year of precipitation at your site.

Additional layers: Continue to alternate layers of summer and winter snow, gradually filling the cylinder. At several different times, put in evidence of a volcano (pepper) – this should be a thin layer but make it thick enough so that you can see the volcanic layers when you are finished.

Examine the finished “core” with your hand lens. What do you observe?

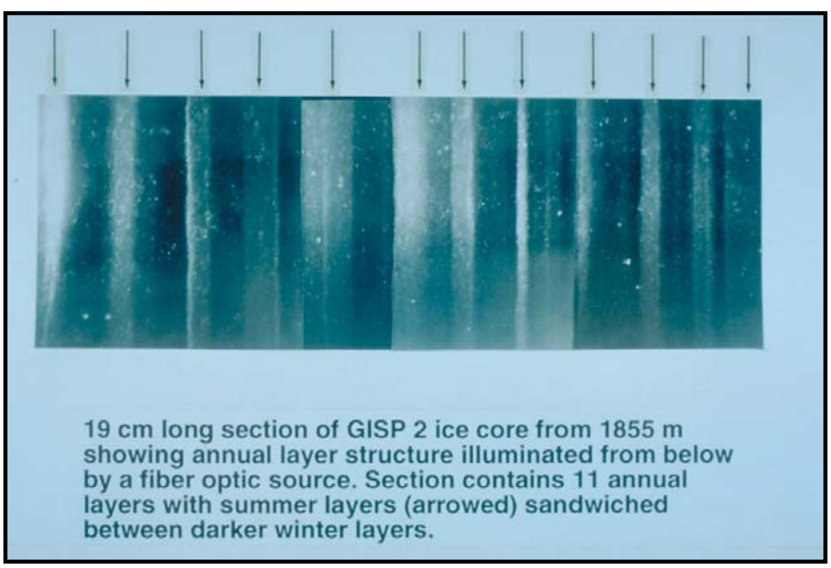


Photo credit: Tony Gow, Cold Regions Research and Engineering Laboratory

The difference in summer and winter snow crystals becomes more noticeable as the snow builds up in layers. How does the thickness of each layer relate to the weather at the time the snow fell? How does it relate to crystal size? In which layer(s) is there evidence of a volcanic event? How many years of accumulation are indicated in your model core? Which layer is the oldest?

Like counting annual rings of tree growth, observing physical differences in the layers of snow and ice is one method that scientists can use to figure out how old an ice core is at a particular depth. Evidence of known historic events, such as the eruption of Mt. Vesuvius in 79 AD, helps to pinpoint exact years within the core.

What We Need to Know: In addition to the physical properties which we can observe, the snow also contains chemical indicators that we can't see that give clues to the environment at the time the snow was deposited. We need to know about the chemicals in the core layers around 1816, and will investigate two in the next activity.

Designing an Investigation: We've looked at what scientists "know" and "need to know" in order to answer the question of what caused the conditions during the "Year of No Summer". With the hypothesis in mind – that there might be evidence of past events in ice cores, scientists designed two actual research investigations to search for evidence of a volcanic eruption and see if that might have contributed to the 1816 abnormal temperatures. The first expedition went to Summit Station, Greenland (at 72° 36'N, 38°W) and the second occurred in West Antarctica (at 79°S, 112°4' W). Can you find these locations on a map?

During major eruptions, volcanoes emit large amounts of sulfur and other elements into the stratosphere. Strong winds there distribute the sulfur broadly so it is deposited over much of the planet. The sulfur is captured in the ice in layers corresponding to the year it settled out of the atmosphere. **Clue:** *Global circulation patterns mean that sulfur from eruptions near the equator is distributed over both hemispheres, while sulfur from eruptions in the mid- and high latitudes is often deposited only over the hemisphere where the volcano is located.*

The amount of sulfur tells us about the size of the eruption, while the distribution tells us about both the size and location. The tools and techniques used to gather and analyze the data from eruptions involve ice coring drills engineered to meet the needs of each research team, and sophisticated equipment such as vacuum chambers and mass spectrometers, to analyze the samples after they are prepared for the research labs.

To prove or disprove the hypothesis, your team will need to think critically about the data on sulfur concentrations gathered during the two research investigations.

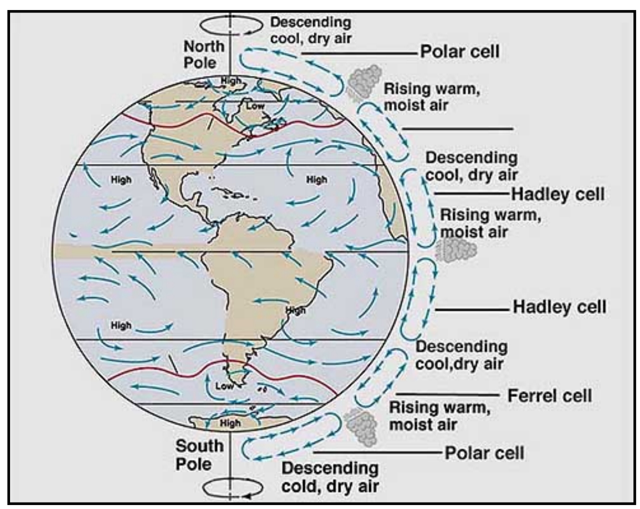
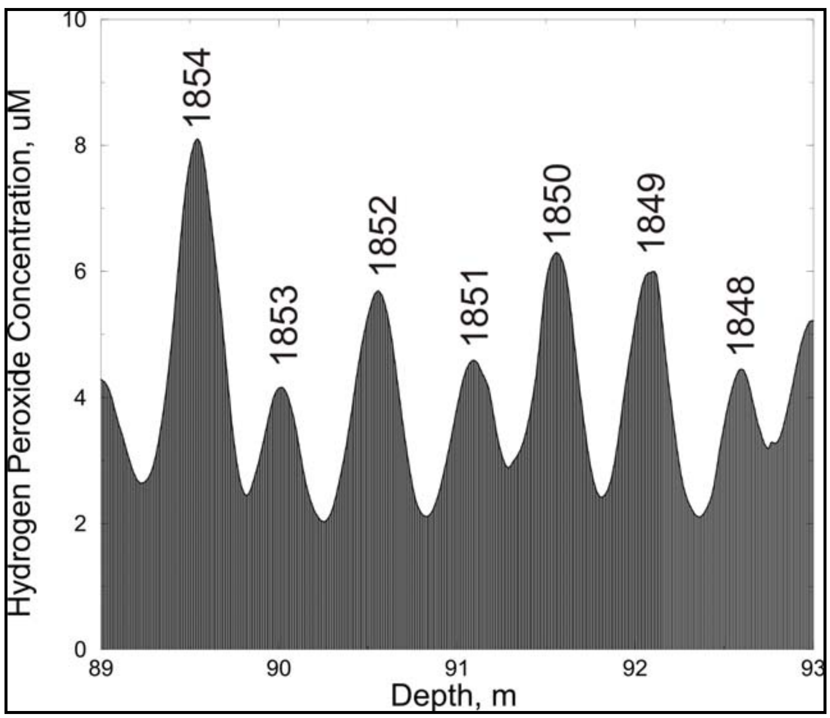


Photo Credit: NASA Goddard Space Flight Center

Task 3: Gathering and Analyzing Data Using the graph paper provided in landscape layout and the data on the chart included on page 9, plot the concentration of sulfur in parts per billion (Y- axis) against the year (X-axis) for each core. Use different colored pencils for the Summit (Greenland) and Antarctic data sets. You can also use Excel software for graphing.

Review your graph to answer the following: How many major eruptions are indicated in the period of history represented by the cores, and during which year(s)? What are the sulfur levels that correspond to these peaks? In what way were the Greenland results similar to the W. Antarctic results? In what way were the two graphs different? Which volcanoes were located near the equator? Which were located in a mid- or high latitude location?

Scientists usually compare different kinds of data from the same time period while thinking about their results. In addition to using known volcanic markers and counting annual layers to identify the ice that corresponds with each year in the core, scientists can use chemical dating tools. When sunlight reacts with water vapor in the air, a photochemical reaction produces hydrogen peroxide (H_2O_2). Presence of this chemical in high amounts corresponds with summer sun (and peaks on the graph), while the troughs or low concentrations occur during the months when the sun is not visible at the site…winter in that region. An example of this highly seasonal data from a more recent core is shown below.



Drawing Conclusions and Communicating Results: After their ice core field research, scientists were able to pinpoint ice cores from the period around 1816 using physical and chemical means. Multiple historical records confirm unusually cold temperatures during that year. You have just discovered evidence of several major volcanic eruptions around the same time period. What do you think? Was ash in the atmosphere a major factor, blocking sunlight and leading to a "Year Without a Summer"? Could there be other influences?

To learn more, keep an eye out for climate scientists in the news; the last step researchers undertake is to help create new knowledge by publishing their results!

Ice Core Sulfur (S) Data:
Summit (Greenland) and West Antarctica Sites

In the left-hand column, the .5 added to each year indicates that it was half-way through the calendar year, or summer when the ice core data was recorded.

Concentrations are in parts per billion (ppb) and represent an average for the year (i.e., from summer 1780 to summer 1781 researchers found an average of 11.5 ppb of sulfur in the core taken at Summit Station, Greenland).

Data courtesy of Dr. Joe McConnell.

Year	Summit, S	W. Antarctic, S
1780.5	11.5	12.1
1781.5	11.5	9.4
1782.5	13.8	14.1
1783.5	245.6	10.0
1784.5	38.5	8.1
1785.5	8.2	10.4
1786.5	13.1	12.6
1787.5	12.2	11.2
1788.5	9.6	10.8
1789.5	10.1	11.4
1790.5	11.7	9.5
1791.5	10.3	9.6
1792.5	10.8	12.8
1793.5	11.1	9.8
1794.5	10.3	14.0
1795.5	12.2	9.3
1796.5	20.8	9.9
1797.5	9.9	13.3
1798.5	12.6	14.7
1799.5	8.2	13.6
1800.5	7.4	13.2
1801.5	14.0	10.6
1802.5	8.7	12.9
1803.5	7.9	11.7
1804.5	8.0	12.2
1805.5	15.8	10.7
1806.5	12.0	10.3
1807.5	7.6	9.7
1808.5	8.3	11.8
1809.5	14.7	20.4
1810.5	52.7	34.0
1811.5	21.3	25.6
1812.5	13.1	11.4
1813.5	13.0	10.0
1814.5	11.1	12.8
1815.5	14.2	24.8
1816.5	83.5	68.7
1817.5	50.8	37.8
1818.5	15.0	15.3
1819.5	9.5	11.5