Teacher Notes

Analysis of Data from a Multi-Decade Ice Core from West Central Greenland

Preparation

Determine whether you want to want to delivery this activity in person using handouts and transparencies or by computer using the online materials (https://byrd.osu.edu/educator/lessons/icecore).

If you are implementing the activity using handouts and transparencies…

- Print out the **Ice Core Plots** pages 1 to 3 on paper and tape them end-to-end. Print out the **Ice Core Plots** page 4 on a transparency. You will need one set of ice core plots one for each group. If you are going to reuse the materials, consider laminating the plots printed on paper.
- Print out the **Background Reading**. You will need one reading for each student.
- Determine whether you would like to present the **Ice Core Slides** with the three tasks yourself or show the **Video** of the slides with tasks being presented by Stacy Porter of the Byrd Center. If you are presenting the slides, download and test the slides on your computer. If you are showing the video, you may download it or view it on the website. Check that it works with your location's security settings. We recommend watching the video, even if you are going to present the slides yourself.

If you are implementing the activity on computer…

- Review the online materials (https://byrd.osu.edu/educator/lessons/icecore).
- Determine whether you want to present the **Ice Core Slides** with the three tasks yourself or have them view the **Video** of the slides with tasks being presented by Stacy Porter of the Byrd Center.
- Review the interactive graph. You are able to turn on and off data sets (clicking on the legend), view specific numeric values (trace along the plotted data), and zoom into a particular area (adjust the axes).
- Determine whether you would like students to examine the graph for a few minutes before presenting the slides or viewing the video. Having students examine the data and make observations/look for patterns beforehand sets up the activity more as a challenge to be solved.

Part 1

Distribute transparencies with 1) oxygen isotopic ratios ($\delta^{18}O$) and dust data. Also distribute transparency with 2) beta-activity data from 35 to 50 meters depth and 3) a sheet with background information.

Background information includes the 1-page information sheet and brief introductory presentation/introductory video.

Task 1

First ask students to make five or so observations about the data in front of them. Depending on the age and content knowledge of the group, this may be a more basic or more advanced discussion.

- **How do these data represent the climate?** The data are plotted against depth in the glacier. Since greater depths go further back in time, these data present what happened at this site in the past. Oxygen isotopes represent temperature. The more negative (or depleted) isotopes represent lower temperatures, while less negative (or enriched) isotopes indicate higher temperatures. These negative values are relative to Standard Mean Ocean Water (SMOW)*. The primary dust source for Greenland is likely North America, so higher dust could represent drier conditions in the source region. Beta-activity shows the radioactivity profile of the core. **Can the students recall why there is low-level radiation in the ice?** It is due to aboveground thermonuclear bomb testing performed in the 1950s and 1960s.
- **What core segment is represented?** The ice core oxygen isotope ratio and dust concentration data extend from the top of the core (0 m) to 50 m deep. The beta-activity data are provided for the 35 to 50 m section. **Where is the youngest and oldest ice?** The oldest ice is at the greatest depth (50 m) because the most recent snowfalls are recorded at the top of the core. This may seem obvious, but it helps students orient themselves to the ice core data. Also, it is important to see that the beta-activity data overlaps with the bottom portion of the oxygen and dust section.
- **What trends or patterns are observable in the data?** Students may notice the wave-like pattern in the oxygen isotope ratio. It is important to begin to have the students consider what these variations may represent but try not to explicitly point out that they are seasonal variations. Students also try to align the oxygen with the dust data, but you will see that this can be somewhat difficult. Students also tend to point out extreme peaks, such as the dust peak around 44.5 m.

Task 2

Next students will apply a timescale to the beta-activity data

- Students are given a timeline of thermonuclear bomb testing activity (see slides) which includes the moderate testing in the 1950s until a moratorium in 1958, then vigorous testing after the Soviets launched Tsar Bomba until the Test Ban Treaty in 1963. It is important to note that not only did testing activity increase as more nations developed the technology but also bombs were becoming bigger and more explosive.

- When looking at the beta activity, there is a slight delay between the times when radioactive materials are injected into the atmosphere and when they are deposited on the glaciers and ice sheets as the radioactive material is gradually distributed around the globe by wind. Have students focus on the increasing trend in beta activity that occurs as weapons testing builds (more tests, more powerful weapons), then drops off as a result of the testing moratorium that started in 1958, and then resumes when that moratorium is broken in 1961. Levels finally drop off when the testing ban goes into effect in 1963. (Testing continues but underground where material is not released into the atmosphere.) Individual testing events are not discernable from the data.
- Students might need assistance using the beta activity information as a key to assigning specific years to specific layers. Remind them, this is an imperfect process and there is always some margin of error, regardless of the person performing the task. It is REALISTIC if they are off by a few years either way.
- Students should be able to pinpoint a year to a specific depth based on the beta-activity plot. For instance, 38 m represents the year 1963. Since the oxygen isotope and dust information were collected from the same core, 38 m on that plot also represents the year 1963.

Task 3

Now that students have determined their reference horizon for the ice core timescale, they will discuss within their groups strategies to determine the year the ice core was drilled (i.e., the year at 0 m).

- A common strategy that students apply is determining the width of one year (e.g., ~1 meter) and then estimating the age at the top based on the depth between the top of the core and their reference year. For instance, students may determine the ratio of the depth between the peaks on the beta activity plot to the number of years that passed between the tests and extrapolate it on the other plot to arrive at a year for the top of the core. It is important to have the students understand what assumptions go into that strategy, the key assumption being a constant accumulation rate. Ask the students if they think it’s a fair assumption that this site receives the same amount of snowfall each year. What about the densification/compression of the deeper snow as more snow accumulates at the surface?

- It is important to remind the students what the oxygen isotope ratio data are indicating temperature and hence seasonal variations. Students can 1) mark the divisions between years (essentially December-January) and 2) determine the year that the core was drilled.

Note: Important considerations for students to make as they complete Task 3…

- Students might need help and it may be essential to be explicit about using oxygen isotope ratio minima with an accompanying dust peak. The dust tends to peak in the spring, but this signal is less consistent than the oxygen variations in this core. However, when the oxygen data are ambiguous (e.g., at ~6 m), an accompanying dust peak can aid in determining if there is an annual layer.
- Students will see the seasonal variation in proxy temperatures but may need some help for the years at more shallow depths (i.e., near the top of the core) because the data are more "choppy" and not as "smooth." If they ask about this you can mention that the processes that densify the snow and eventually convert it to ice naturally smooth the oxygen isotopic ratios over time.

A) **Have student groups briefly present their results and the basis on which they drew them.** What obstacles did they need to overcome and/or what assumptions did they need to make? If there is time, groups can use this session to gather information to improve their method and try again. Similarly, the class can determine an overall strategy and each group implement it to arrive at new results. Essentially, these presentations become an interim checkpoint in arriving at a final solution.

B) **Discuss the expert's conclusions.** Since Stacy analyzed this core, she can provide a brief overview of her analysis. The core was drilled in 2007; however, they only have data up to 2006 as you can see the data do not extend quite up to 0 m. There are copies of her divisions by year and a video explaining the results to show the class.

Part 2 (COMING SOON)

Distribute transparencies for the 120 to 130 meter section of the core including 1) oxygen isotopic ratios and dust concentration data and 2) sulfate measurements. The data from these depths represent the years 1805 to 1823 CE.

A) **Ask students to 1) identify similarities and differences in the data from lesser depths and greater depths and 2) develop explanations for what the differences represent.**

As they prepare to make comparisons, remind them that all of the sheets include depth on the y-axis.

Important differences and what they represent include…

- Have students count the number of years in the 120-130 m section, and for first 10 meters from Part 1. The annual layers are thinner in the 120 to 130 m sample. While the thickness of a layer is impacted by the amount of precipitation that occurs during that year, layers are also compressed over time by the weight of the overlying snow and ice. Layers at the greater depths are more compressed, and generally thinner, than those at more shallow depths.
- There are more frequent and larger breaks in the data at numerous places in the 120 to 130 m sample. Due to the brittleness of the ice, there are places where the core chipped and data could not be recovered for that depth.
- The annual pattern is more regular in the 120 to 130 m sample. In other words, there is a steady increase and decrease annually rather than irregular fluctuations due to individual storm events. This difference is due to diffusion that occurs in the ice over time. As diffusion occurs, individual storm events become difficult to identify in the record and eventually disappear which creates a smoother seasonal signal.
- Students might also notice two distinct spikes in sulfate concentrations in the 120 to 130 meter samples. These spikes have been identified as resulting from two volcanic eruptions. The spike in 1816 is due to the eruption in 1815 of Mount Tambora in Indonesia. This eruption released sulfates into the stratosphere that took about a year to reach Greenland before being deposited. The earlier sulfate peak is associated with emissions from an eruption in 1809 that, like those from Tambora, are found ice cores in both Polar Regions. These reference horizons aid in defining the date for the annual layers especially when large breaks are present in the data.
- Also, on the sulfate graph, there were lower levels in the 120 to 130 meter sample relative to some of the more recent samples in which concentrations are higher. This represents conditions before widespread industrialization. Note the most recent concentrations are lower than those during the period of rapid industrialization. This reflects the time period following pollution control legislation in North America (Clean Air Act).

B) Ask students 1) what global information is preserved in the core and what regional information is preserved in the core and 2) what post-depositional events could create artifacts (in other words, alter the information that would have been preserved in the core).

- Global information: volcanic activity (larger eruptions that release material into the stratosphere), sulfate emissions from industrialization, beta-radioactivity due to nuclear weapons testing in the atmosphere
- Regional information: volcanic activity (smaller, local eruptions), sulfate emissions more representative of North America due to prevailing winds, dust more representative of regional effects, temperature of the air from which the snow fell and major climatic phenomena that would impact temperature and precipitation (such as the North Atlantic Oscillation)
- Post-depositional events: wind scouring and deposition (looking at data from multiple cores can help eliminate these artifacts). Melting also disrupts the record.

Footnote

*Students may be confused by the units of oxygen isotopes and the negative values of the measurements. These units are relative to Standard Mean Ocean Water (SMOW), such that depleted (more negative) values of isotopes indicate less oxygen-18 compared to SMOW. The isotope maxima in the ice core are still depleted relative to SMOW, but less so. These variations are due to the fractionation of oxygen isotopes with temperature. The atmosphere gets its energy from heat. When it is warmer, the atmosphere has more energy to evaporate heavier molecules (oxygen-18) and transport them over longer distances. When it is colder, the atmosphere has less energy and transports fewer oxygen-18 molecules, thus ice core isotope values are much lower in winter.