Inquiry into High Resolution Ice Core and Marine Sediment Records

The Colorado fire season of 2020 was the largest in state history with 665,454 acres burning around the state. The next year, on December 30, 2021, grassland fires swept through the suburbs of Boulder, Colorado pushed by extreme winds and fueled by a 20+ year drought affecting the southwestern United States, forcing the evacuation of 30,000 people. By the time the fires were extinguished 1084 homes were destroyed and damages total half a billion dollars — all in under 6 hours.

Figure 1 Satellite view of a wildfire near Boulder, Colorado quickly spreading into nearby homes (Image credit: NASA/NASA Earth Observatory)

Today, events like this are happening more often and climate change is being pointed to as a cause more frequently. Climate change is impacting our planet, our lives, and our communities in a variety of ways. How rare is climate change? How quickly does climate change occur? To answer these questions (and others) we need to locate the fingerprints of past events in areas undisturbed for a long long time — we need to look deep under the oceans.

The Intergovernmental Panel on Climate Change's (IPCC) Workshop on Climate Sensitivity calls "climate sensitivity" one of the most important parameters in climate science. The term places the concept of how climate affects a region into a simple phrase so researchers can use it — and all its implications, feedbacks, and variabilities — as shorthand for the larger set of ideas. Humans have recorded the weather seemingly forever; the network of monitoring sites has multiplied rapidly in recent decades. Climate and weather monitoring groups around the world have installed a dense mesh composed of a myriad of instruments across the planet to record and monitor our planet. The recorded data has shown there are numerous climatically sensitive areas locations around the planet.

Within your group, discuss what would make an area more climatically sensitive than another? Are there climatically sensitive areas near you? Be prepared to share out with the larger group what you decided.

The oceans are different from the land though. The ability to place a dense network of climate monitoring sites is not feasible; placing long-term monitoring sites on the surface of the ocean and on the ocean floor has only recently become possible. In September 2004, the Integrated Ocean Drilling Program's [IODP] Expedition 303 departed for the North Atlantic with the stated climate objectives including:

Understanding the mechanisms and causes of abrupt climate change is one of the major challenges in global climate change research today and constitutes a vital initiative of the Initial Science Plan of IODP. Ideally, the best approach to this problem would be to collect records of climate variability from a dense geographic network of sites, but this is impractical in paleoceanographic research. In the absence of dense coverage, the most viable approach is to obtain long, continuous time series from key regions and compare the response and timing of climate change among sensitive regions.

- From Scientific and Operational Objectives of Expedition 303, Climate Objectives, 2005; http://iodp.tamu.edu/publications/PR/303PR/prel7.html#1007325

Given that there are not written or instrumental records of the varying conditions of climatically sensitive maritime areas, we need to look at the "fingerprints" of these conditions within the deep ocean sediments. With your group, make a list of characteristics of a marine depositional environment that are optimal in order to record climate changes (oscillations) in the sediments.

DSDP Leg 94 and Heinrich Events

Figure 2 Revised reconstruction of the North American ice sheets at 21.8 ka from C. Stokes (2017)

Heinrich Events are natural phenomena in which large groups of icebergs break off from the Laurentide Ice Sheet and traverse the Hudson Strait into the North Atlantic. First described by marine geologist Hartmut Heinrich, they have occurred multiple times over the past 640,000 years. The icebergs contained rock debris that had been eroded by the glaciers, and as they melted, this material was dropped to the sea floor as ice rafted debris (abbreviated to "IRD") forming deposits called Heinrich layers. Multiple mechanisms for a Heinrich Event have been proposed but most settle on rapid climatic oscillations which destabilized the Laurentide Ice Sheet and other northern hemisphere ice sheets.

In marine sediment cores, these events can be identified by recognizing large fractions of lithic fragments — portions of rocks of continental origin. Due to the large size of the lithic fragments, they cannot be transported by ocean currents and can be interpreted as having been carried by icebergs or sea ice which broke off glaciers or ice shelves, and dumped debris onto the sea floor as the icebergs melted. The presence of these lithic fragments in these sediment cores can be interpreted as indicating a Heinrich Event.

Procedure

1. Using the maps above as a guide, identify the following on the map at right:
    a. Hudson Strait
    b. Laurentide Ice Sheet margin
    c. Deep Sea Drilling Project Leg 94 Site 609/609B
    d. A possible path for icebergs to travel between Hudson

Strait and Site 609/609B

2. Retrieve the large images of Site 609 and 609B (either digital or printed).
    a. Looking at each core in order, identify lithic fragments (LF) present in the cores.
    b. Complete the table below. Measure the size in centimeters (cm) of the LF and its depth within the core. If you need more rows, add them as needed.

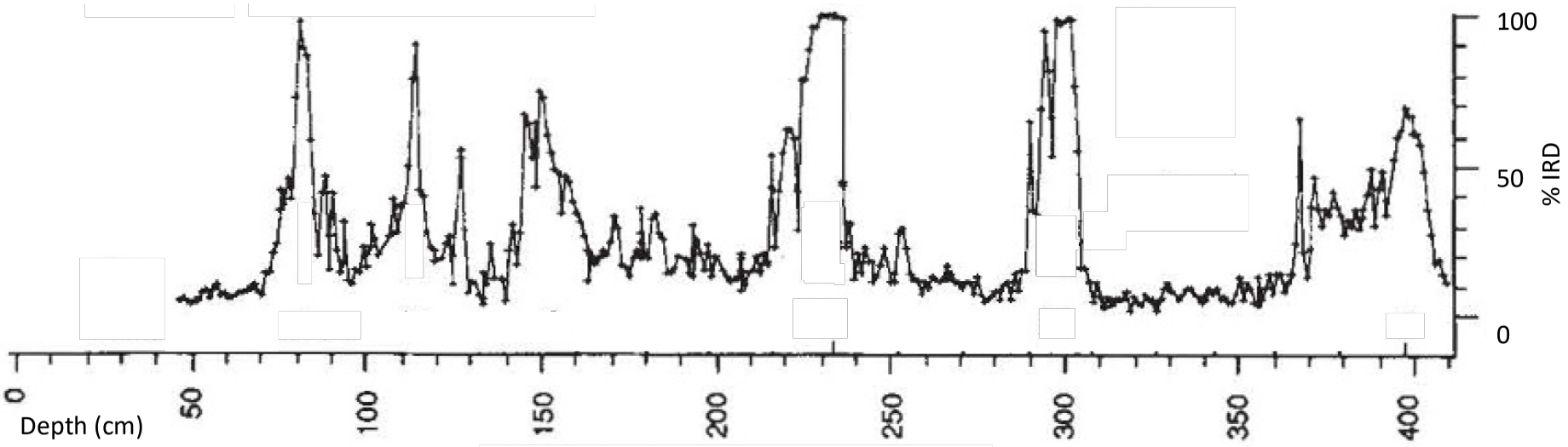
		Site 609	Site 609B
LF1	Size		
	Depth		
LF2	Size		
	Depth		
LF3	Size		
	Depth		
LF4	Size		
	Depth		
LF5	Size		
	Depth		

		Site 609	Site 609B
LF6	Size		
	Depth		
LF7	Size		
	Depth		
LF8	Size		
	Depth		
LF9	Size		
	Depth		
LF10	Size		
	Depth		

3. The next page has a larger graph of IRD as a percentage of the entire core; depth is displayed on the horizontal axis. Indicate on the graph, the depth of each of the items that you identified in your table above; use the abbreviations LF1, LF2, etc.
4. The table at right shows the accepted dates of Heinrich Events. Within Site 609, Heinrich Event H0 is not recorded. Create a time scale on the lower horizontal axis using this information and the previously identified lithic fragments. Since the Heinrich Events occur over a span of time, use a thicker highlighter to highlight the event with the middle being the Heinrich Event median age.

Heinrich Event	Age (x1000 years)
H0	9-13
H1	14-17
H2	21-24
H3	29-32
H4	35-39
H5	43-47
H6	~60

Figure 3 Heinrich Event ages (Hemming, 2004)



Age (x1000 years)

Greenland Ice Sheet Project 2 (GISP2)

The Greenland Ice Sheet Project was a major decades long project of the United States, Denmark, and Switzerland to drill ice cores in Greenland. The ice cores themselves provide a proxy record of temperature and atmospheric composition that helps to understand past climate variations. GISP2 was drilled at the summit of the ice sheet allowing for a deeper continuous record. Following 5 years of drilling, bedrock was struck on July 1, 1993 — with a depth of 3053.44 meters it was the deepest ice core recovered in the world at the time. The majority of the GISP2 ice core is stored at the National Ice Core Laboratory in Denver, Colorado.

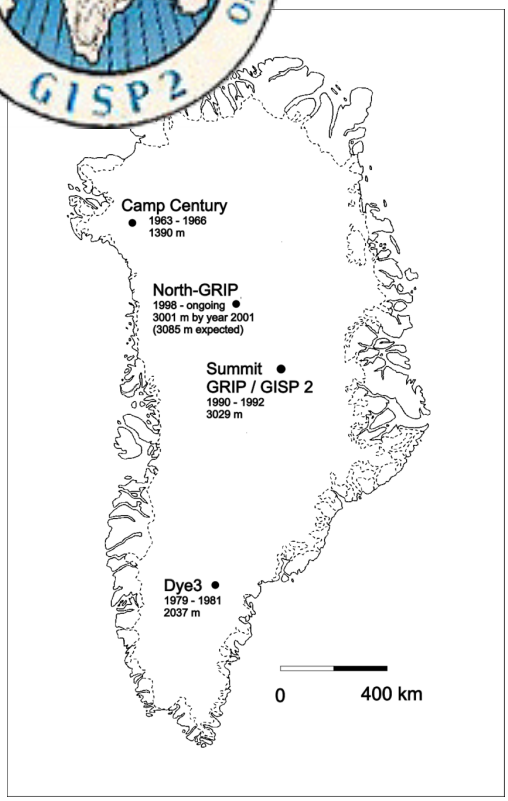
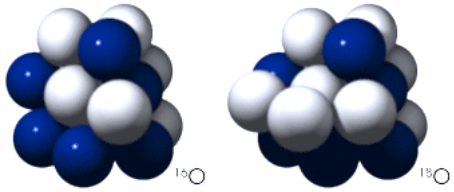


Figure 4 Map of Greenland showing the location of deep ice coring sites. Periods of active drilling and ice thicknesses are indicated. (Ruth, 2003).

One of the major items measured in nearly all ice cores is the ratio of two of the isotopes of oxygen — ^{16}O and ^{18}O.



All oxygen atoms have 8 protons, but the nucleus might contain 8, 9, or 10 neutrons. "Light" oxygen-16, with 8 protons and 8 neutrons, is the most common isotope found in nature, followed by much lesser amounts of "heavy" oxygen-18, with 8 protons and 10 neutrons. The ratio (relative amount) of these two types of oxygen in water changes with the climate. By determining how the ratio of heavy and light oxygen in marine sediments, ice cores, or fossils is different from a universally accepted standard, information regarding climate changes that have occurred in the past can be gleaned. The standard that is used for comparison is based on the ratio of oxygen isotopes in ocean water at a depth of 200-500 meters.

Simply put, high ^{18}O values indicate a warming climate and low ^{18}O values indicate a cooling climate.

So now that you have a little bit of grasp of GISP2, the data that can be retrieved from it, and what it means, let's put that to use.

The graph at right is the record of ^{18}O values from GISP2 with the agreed upon ages on the horizontal axis. Cut along the dotted line and attach this above your completed graph of IRD recorded from Site 609/609B. Make sure that you align the graph with the provided lines.

Procedure

1. Once aligned, continue the highlighted lines representing the Heinrich Events onto the GISP2 data.

   Consider the following:

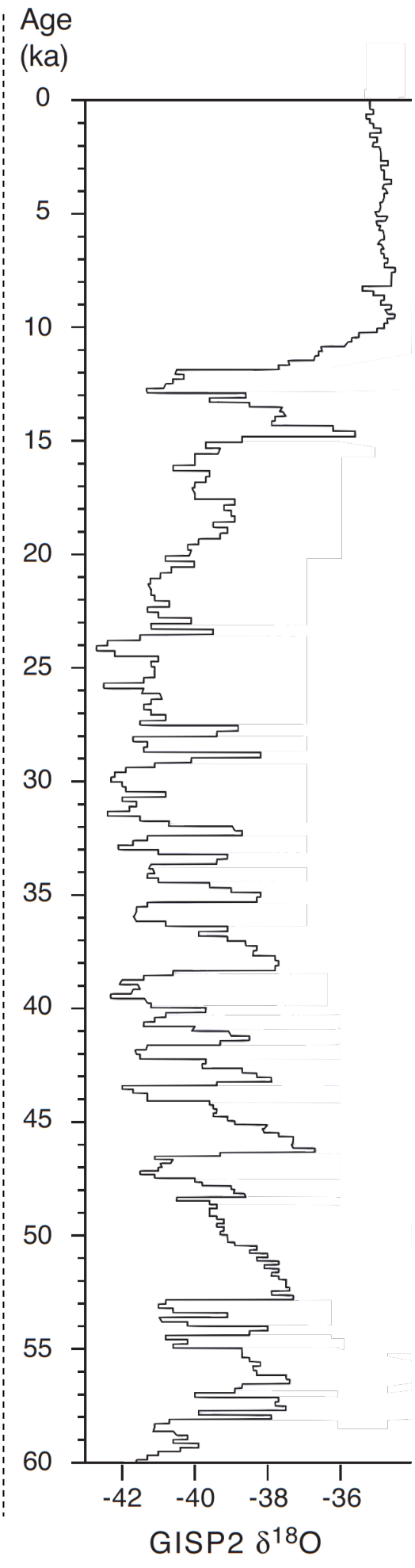
   The age scale on the GISP2 graph is correct. How does it compare to the age scale you created based on the ages of the Heinrich Events?

   Describe the relationship between the GISP2 core and the Heinrich Event / Site 609 IRD graph. Is there a relationship?

   Are all of the Heinrich Events correlate neatly? Are there some events that are better correlated than others? Which ones?

   Work with your group to come to a consensus — be prepared to share your work with the larger class.

2. What else would you require in order to build a better consensus?



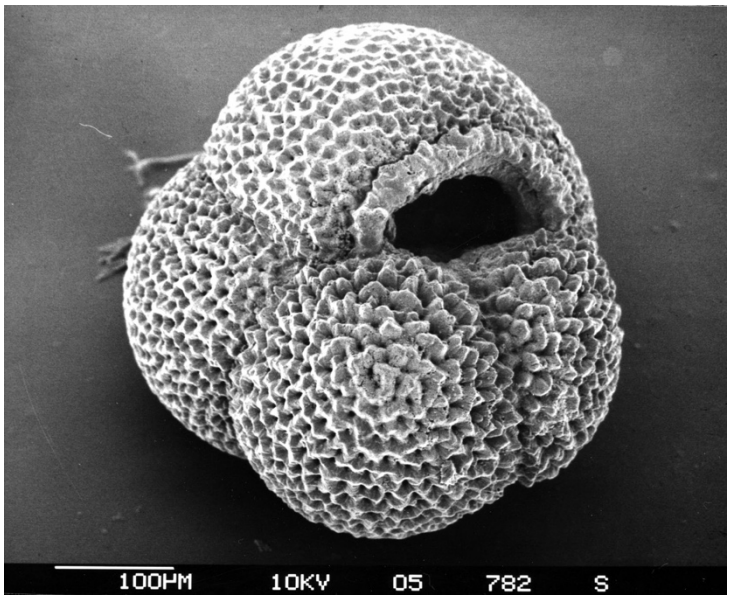
Bringing In More Data — Drill For More

Data does not always neatly fit with our ideas — sometimes our ideas are incorrect, sometimes they are in the right direction but they are just not well supported, and sometimes they are right on the spot.

Where else would we look? As a researcher, you'd want to again collect data from climatically sensitive maritime areas. Collecting data from areas that are more global might help to show if the events are regional or global in nature. Looking further afield, the Cariaco Basin off the coast of Venezuela and the Santa Barbara Basin off the coast of California are both options. In November 1992, the ODP drilled a number of cores in the Santa Barbara Basin as part of Leg 146; and in February 1996 the ODP drilled throughout the Caribbean Sea including the Cariaco Basin during Leg 165. This final portion of the investigation will be looking at the some of the tiniest of life forms and mineral deposits to help bolster our conclusions.

Iron (Fe) and Titanium (Ti) Concentrations: Cores from the Cariaco Basin are visibly laminated with some layers devoid of benthic organisms and others showing evidence of bioturbation conditions — which testify to past oscillations between oxic and anoxic conditions in the deep basin. These oscillations are reflected in sediment color, with laminated intervals appearing as dark green and bioturbated intervals appearing as a light green or yellowish brown. Sediment color variations in the Cariaco Basin are driven by changing surface productivity, with increased organic rain leading to darker sediments and, through remineralization reactions, periods of anoxic or near-anoxic conditions in the deep basin. Deposition of dark, generally laminated sediments preferentially occurs during warm periods, whereas deposition of light-colored bioturbated sediments are restricted to colder periods.

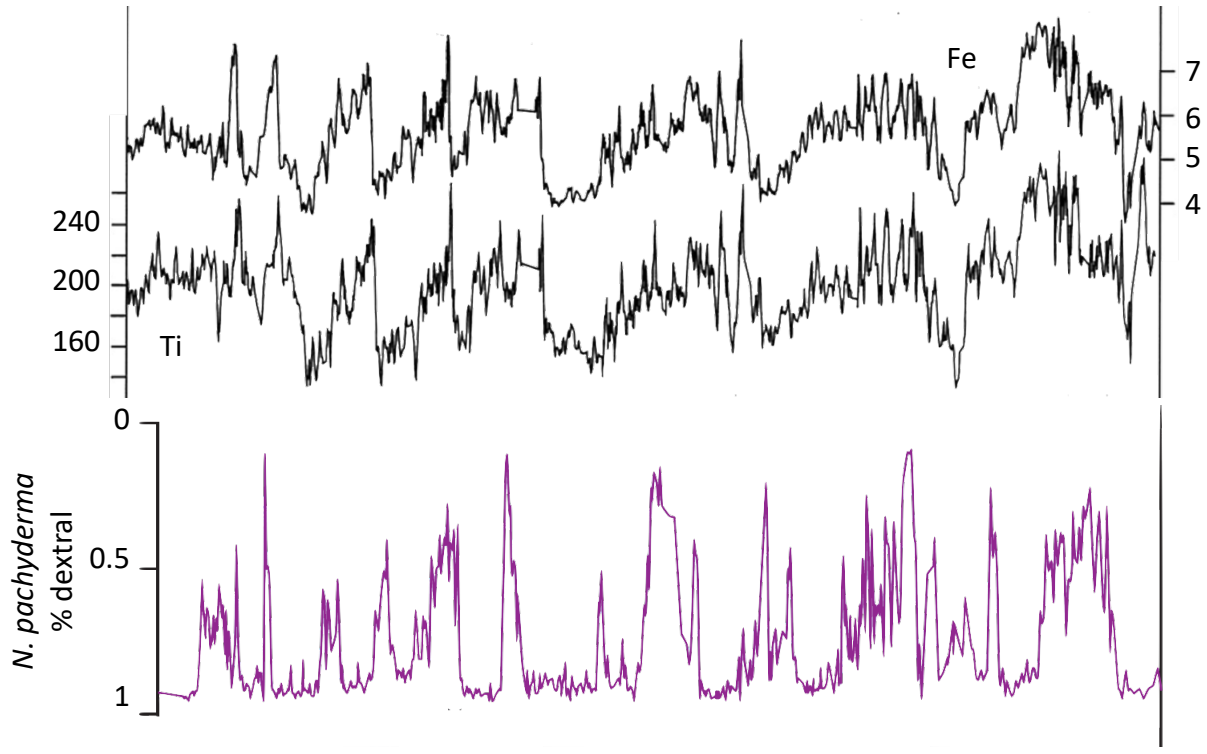
High-resolution elemental measurements were obtained with a profiling x-ray fluorescence (XRF) scanner at the University of Bremen (right). The XRF profiling scanner is a nondestructive analysis system for scanning the archive half of split sediment cores. High Fe and Ti values are closely associated with the dark laminated sediments deposited during warmer periods.



***Neogloboquadrina pachyderma*:** A planktonic foraminifera, *N. pachyderma* can be used as a proxy for water temperature. These foraminifera are found in two forms. When the ocean water is relatively warm, this organism tends to grow into a right-coiling form (dextral). When the water is relatively cold, *N. pachyderma* grows into a left-coiling form (sinistral).

Procedure

1. Place your existing graph of IRD and the GISP2 ice core and place it below the two additional graphs now provided below.
    a. Align the new graphs with the right side of the sheet (60,000 years)
2. With the new data aligned, adjust your lines for the Heinrich Events as needed to reflect your new thinking.



Wrap-Up

1. Regarding the Heinrich Events that were originally identified using Core 609/609B, are the climatic events that caused the Heinrich Events localized, regional, or global in nature? Support your claim with evidence from this investigation.

2. What leads you to decide if a Heinrich Event was caused by a localized, regional, or global oscillation in climate? Do you require additional information in order to draw a satisfactory conclusion? What specifically would you need? What sites would you consider as vital to your claim?

3. Within your group, speculate on what would cause such a rapid oscillation in global climate.

Millennial oscillations in climate have occurred in the past and there is nothing to indicate that they will not continue to occur. What implications do these millennial oscillations in climate have for modern society? Your community?