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FEATURE ARTICLE

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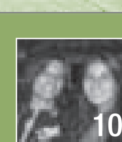

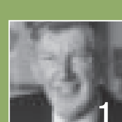

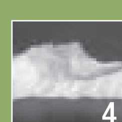

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Climate Change in Greenland: Past and Present

By Mohi Kumar

Meredith Kelly

Thawing earlier in spring, delayed fall freezing, shrinking sea ice, and disappearing mountain glaciers: as the atmosphere warms in response to increasing greenhouse gas emissions, climate scientists recognize that polar regions in the Northern Hemisphere will be vulnerable to ecosystem shifts, potentially causing changes in animal migration patterns, weather systems, and even oceanic circulation.

Predictions that can help Arctic peoples prepare for future changes rely heavily on both present observations and a solid understanding of past climate shifts. To help gather this information, two groups at Lamont are studying the effects of past and present Arctic climate change through research on Greenland's glaciers.

ICEQUAKE!

Bowed by the weight of glaciers and embedded with some of the oldest rocks on the North American Plate, the land beneath the Greenland ice cap is relatively stable, containing no major active subduction zones or rift valleys. Yet Lamont seismologists have recently discovered that Greenland is far from being seismically dead.

In 2003, Lamont-Doherty scientists Meredith Nettles, Göran Ekström (both then at Harvard University), and colleagues reanalyzed the last decade of world seismic data to look for earthquakes whose motions are too slow to be detected using traditional approaches. "We found, much to our surprise, that there were several earthquakes in Greenland," said Nettles. The earthquakes observed were


Meredith Kelly

between 4.6 and 5.1 on the moment magnitude scale, and all were clustered tightly along Greenland's coast.

Through analysis of seismic data, the team estimated the orientation of slippage planes and found that in each quake, material moved downhill toward the coast—a property shared by glaciers. They also noticed that many glaciers draining the icecap increasingly house large pools of meltwater on their surfaces, and that many more quakes were happening in the late summer—peak melting season—than in winter. Following the data, they hypothesized that perhaps meltwater underneath ice builds, reducing friction holding the glacier base stationary and allowing it to surge forward.

In total, Nettles and Ekström documented that more than 200 glacial earthquakes have occurred in Greenland since 1994. "People often think of glaciers as inert and slow-moving, but in fact they can also move rather quickly," explained Ekström. "Some of Greenland's glaciers, as large as Manhattan and as tall as the Empire State Building, can move 10 meters in less than a minute."

Instruments on ice

In the summer of 2006, Nettles led a team of researchers from the United States, Spain, and Denmark in a field expedition to eastern Greenland's Helheim Glacier with the goal of installing GPS instruments on the glacier's surface to monitor movement. By correlating abrupt movements seen through GPS receivers with far-field seismic data on glacial earthquakes, surges could be documented and characterized.

An outlet of the main icecap, the glacier is heavily crevassed, and Nettle's team was able to access it only by helicopter. Once on the glacier's surface, the scientists installed antennas and suitcase-sized receivers, anchoring them with poles. Two months later, they picked up the receivers and began their analysis.

"Did we find any earthquakes? Well, we went to this glacier because it generates a quarter of all large earthquakes in Greenland—it had 12 in 2005! But in 2006, there were no large earthquakes at all," Nettles explained. However, through further processing, two small earthquakes were identified, she added.

A remarkable finding

Nonetheless, the field study did reveal much about the dynamics of glaciers. Near the calving front, they recorded glacial advances of about 82 feet per day. Farther inland toward the ice sheet, speeds reduce to 20 feet per day. Because the glacier is advancing faster at the front than the back, it elongates. Further, the glacier's speed is modulated by the tide in the underlying fjord. "This is really remarkable," Nettles explained. "The glacier is more than half a mile thick, and the change in the tide is only a few feet at the front; yet we see a variation in the speed of the glacial flow even many miles up the glacier."

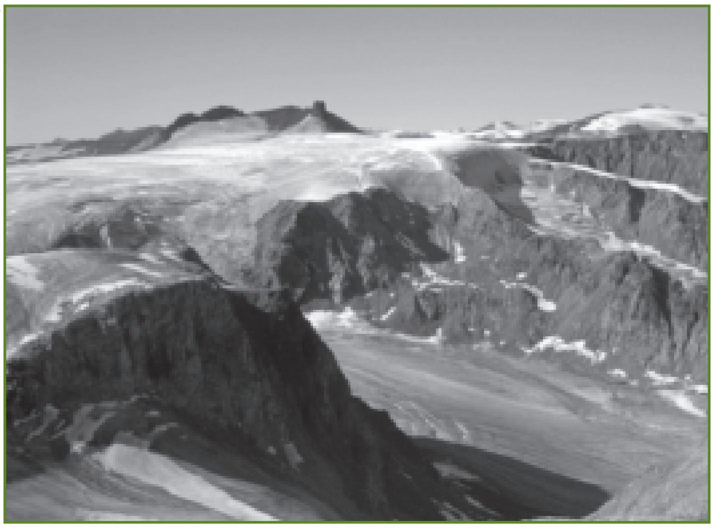
Nettles is visiting Helheim Glacier again this summer and is hopeful to see more earthquakes. Though many questions about glacial earthquakes remain unanswered, "we are observing that the response of ice sheets and the outlet glaciers that drain them can be very rapid, dynamic, and seasonal," Nettles said. "These glaciers deliver large quantities of freshwater to the oceans, so the implications for climate change are serious. We believe that further warming of the climate is likely to accelerate the behavior we've documented."


Meredith Nettles


Meredith Kelley

Gordon S. Hamilton, University of Maine

Meredith Kelly



Andreas P. Ahlstrøm

PAST ABRUPT CLIMATE CHANGE: GREENLAND AND THE YOUNGER DRYAS

The key to understanding current climate change in Greenland might lie in the past, which paleoclimatologists know to be marked by episodes of abrupt climate change.

According to analyses of trapped gases in Greenland ice cores, around 13,000 years ago temperatures severely plummeted about 15°C over a span of just a decade, initiating a time period of freezing temperatures and high glacial volume known as the Younger Dryas.

Believed to have lasted only about 1,300 years, the Younger Dryas is heavily studied by climatologists, many of whom seek to understand what caused and ended it in order to build better climate models.

While Greenland ice cores gave mean *annual* temperatures, mountain glacier snowlines (determined by piles of glacial debris called moraines left behind after summer melting) could be matched to their elevation, allowing for a quick calculation of average *summer* temperatures necessary to sustain snow at those elevations.

Some results from Scoresby Sund

In the summer of 2003, the University of Maine's George Denton, Penn State's Richard Alley, and Gary Comer, a supporter of climate science at Lamont, conducted a survey of the Scoresby Sund region of East Greenland, an area near the Greenland ice core sites but dominated by mountain glaciers that have never been attached to the main ice sheet.

Denton, Alley, and Comer observed several pronounced moraines during their survey. "If dated to the Younger Dryas, these moraines indicate that summers were only about 4°C cooler than temperatures before this event," explained Lamont's Wally Broecker, a scientific adviser to Comer and a collaborator on the analysis of the survey's results. "Thus, winters during the Younger Dryas must have been much colder than previously thought."

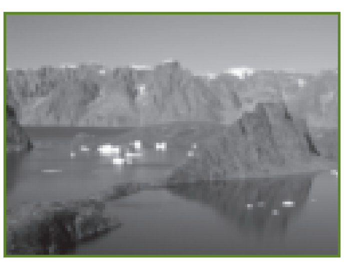
Meredith Kelly, a postdoctoral scientist at Lamont and a former student of Denton's, has spent the last three years verifying the ages of moraines in the Scoresby Sund region through studies in the field and detailed laboratory work. Guided by aerial photographs, Kelly and her team mapped lateral moraines and other ice-marginal deposits and collected samples from the surface of large boulders dropped off by the glaciers.

Dating exposure age—thanks to cosmic rays

Assuming that these boulders were completely scoured by glaciers, fresh rock surfaces are then exposed to the atmosphere after a glacier recedes. Galactic cosmic rays penetrate the skin of these boulders and hit oxygen atoms in quartz grains, causing the atoms to fragment. One of these fragments is an isotope of beryllium called beryllium-10 (^{10}Be).

Kelly measured the abundances of ^{10}Be in her samples and calibrated them to determine an exposure age—the more isotope present, the older the sample. She then calculated a statistical average of the samples and found that the moraines studied by Denton, Alley, Comer, and Broecker were indeed exposed during the Younger Dryas.

"If summer temperatures during the Younger Dryas were only a few degrees colder than present, winter temperatures must have been 26°–27°C colder than now to balance out what is seen in ice core records," explained Kelly. "What could have caused these extremely cold winters?



Meredith Kelly

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Perhaps variations in sea ice extent, driven by a slowdown of the global ocean conveyer, which transfers heat to the world oceans. We don't have all the answers yet."

SCIENCE IN A CHANGING LANDSCAPE

Both Nettles and Kelly see rapid changes and seasonal signals in the glaciers they study. But beyond science, the Greenland landscape tells its own story of profound change.

"Usually in a glacier, there is a place where the snow falls and contributes to the glacier's mass balance, and a place where snow melts," Kelly said. But in the mountain glaciers near her field site, snow accumulation no longer occurs. "All you see is blue ice and layers that are melting out. These glaciers will be gone in the next 20 or 30 years."

In Nettles' field area, the walls of the fjord are marked with a very clear trim line that shows where the level of ice used to be higher, about 70 or 100 meters above the current ice surface. "It looks like pictures I've seen of changes from the Last Glacial Maximum, but it's actually just a change in the ice level over the last five years or so," Nettles explained. "We're losing parts of the Artic environment, and to see it changing so fast is really sad."

While their individual research shows significant advances, "together Drs. Nettles and Kelly provide the potential for major new insights into the fundaments of modern-day loss of the Greenland ice sheet and the rate at which sea level will rise as a consequence of global warming," said Lamont Director Mike Purdy. "This problem happens to be one of the most societally significant issues of our time."

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