TALES FROM ICE TIME

Two holes through Greenland offer a glimpse of climates past and future

By RICHARD MONASTERSKY

The scene evokes images of surgeons performing a liver transplant in full football gear.

Moving quickly but gingerly, a crew of heavily outfitted drillers coaxes a long icicle from its container and hurries the glistening prize to a dumbwaiter. Room temperature here hovers at a dangerously warm level, only 10°C below freezing, and the crew must lower the ice as fast as possible into the safety of a cold snow cellar. They take care not to slip, though. The chunk of frozen water they hold is valued at more than $30,000.

This particular cylinder of ice represents one small step in a five-year effort to probe some of the hottest issues in climate-change research. The U.S. program, called the Greenland Ice Sheet Project 2 (GISP 2), aims to drill a 3,000-meter-deep hole straight through the thickest part of Greenland's glacial cap while collecting ice samples from every layer. At a nearby site, European scientists are drilling and sampling a similar core. Together, the two frozen records will give researchers their best look yet at how Earth's climate has behaved through some 2,000 centuries – a key to understanding what may lie ahead in an era of global warming.

Merely a hand's breadth across, the ice holes serve as tiny windows for gazing far back into the planet's history. Long before our ancestors invented the wheel, let alone the pollution-belching automobile, Earth passed through dramatic warm spells and ice ages. The natural forces that drove these climate shifts – including solar radiation, greenhouse gases and even tiny algae in the ocean – left subtle clues within the Greenland glacial cap. By looking for such evidence in the millennia-old ice, scientists hope to learn what controlled the variations of the ancient environment. Only by understanding the past can experts assess how rapidly Earth will warm as greenhouse pollutants build up in the atmosphere.

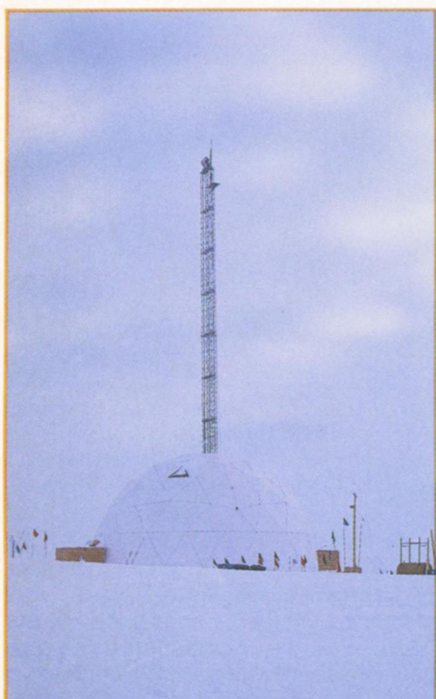
Paul Mayewski, GISP 2's chief scientist, sums up the value of the project in a single word: perspective.

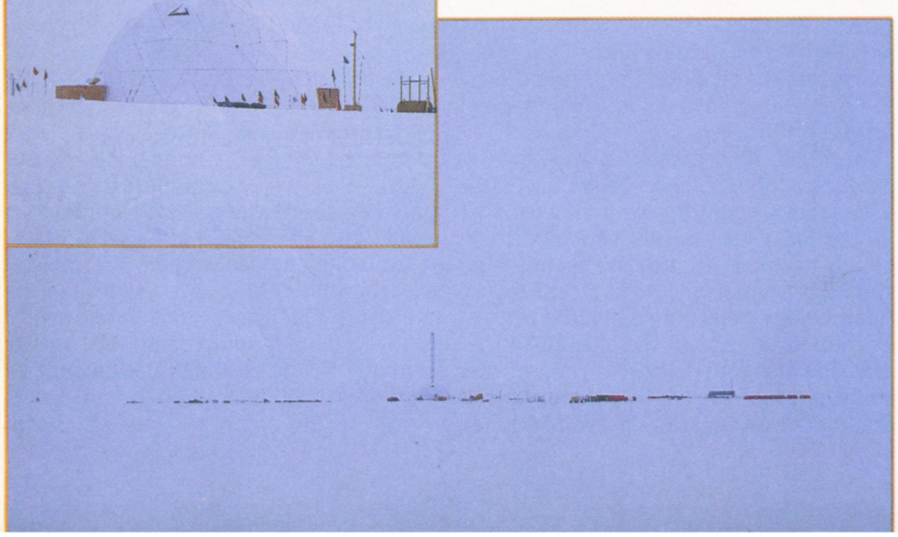
"Sitting in the middle of a forest, it's very hard to find out where you are," says Mayewski, a glacial geochemist with the University of New Hampshire in Durham. "If you really want to understand whether we're changing the climate or not, you need to understand [its] natural variability. If you don't have this perspective, you won't be able to understand the relationship between climate and civilization."

From the vantage point of the GISP 2 camp, it's not hard to imagine Earth as it was 18,000 years ago, during the coldest stage of the last ice age.

GISP 2 scientists spend their summers in a flat, frozen world some 650 kilometers north of the Arctic Circle, near the highest part of the immense ice sheet blanketing more than 80 percent of Greenland. Beyond the scattered buildings and tents, a white plain stretches in every direction toward unbroken horizons. On an overcast day, sky and snow wear the same dull hue, creating a featureless void that seems to go on forever.

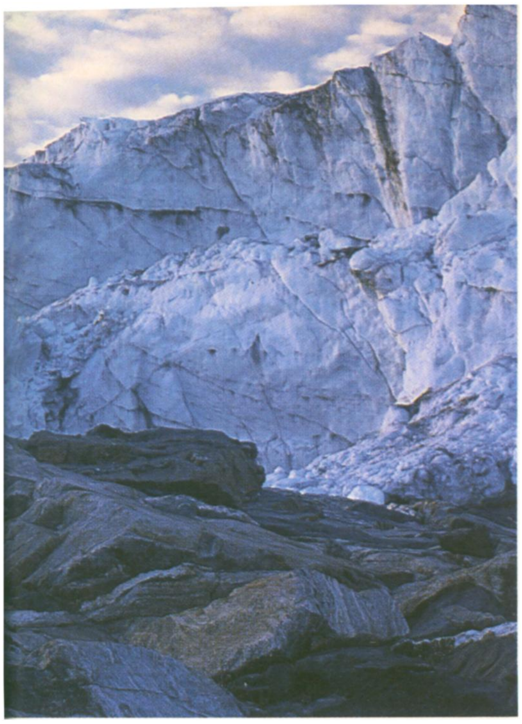
This is how Denmark or Detroit must





Photos: Monastersky

Snow and sky blend seamlessly on a cloudy day, with only the buildings of the GISP 2 camp to suggest a horizon. The centerpiece of the U.S. operation is a 52-foot-diameter dome (left), which houses the drill. The 50 crew members have a choice of sleeping quarters: heated barracks or their own, unheated tents.



An icy cliff looms over rocks at the edge of Greenland's glacial cap, which covers five-sixths of the huge island. Greenland measures almost one-quarter the size of the United States; its ice-free land area is slightly larger than New Mexico.

have looked during the last ice age, when thick glacial sheets covered much of Europe, Asia and North America. In the United States, the glaciers reached as far south as St. Louis in the heartland and Long Island in the east. Though the ice retreated from most parts of the globe by about 10,000 years ago, it still maintains a grip on Antarctica and Greenland.

Ice sheets form layer by layer, as each year's snow covers that of previous years. With time, the intense weight from overlying layers squeezes the buried snow, transforming it into solid ice filled with bubbles of trapped air. The ice sheet beneath the GISP 2 camp measures more than 3 kilometers deep — a load so heavy it has warped the bedrock on which it rests. Save for parts of Antarctica, Greenland's summit region has the world's thickest ice, offering scientists a chance to reconstruct the longest climate record to date. The European operation, called the Greenland Ice Core Project (GRIP), lies at the exact summit of the ice cap, about 30 kilometers from the U.S. camp.

Glacial ice has a thousand and one stories to tell about the past. Oxygen and hydrogen in the ice serve as atom-sized thermometers, recording atmospheric temperatures at the time the snow fell. From trapped air bubbles, scientists can extract minute samples of the ancient atmosphere to trace the natural waxing and waning of carbon dioxide and other greenhouse gases. Ions deposited in the ice chronicle volcanic eruptions and reveal how marine algae fared through the ages. Dust tells how stormy the atmosphere was, and ammonia may disclose the timing of particularly large forest fires in North America or Asia.

Like a movie run backward, the drill holes uncover the climate story in reverse. The top layers record the most recent episodes, while those beneath hold increasingly older information.

The two Greenland projects aim to reach both deeper and farther back in time than any other ice record unearthed so far. By the end of next summer, if they finish up as planned, both drilling groups will pull up an ice record dating back more than 200,000 years, containing clues to a time when, according to some anthropologists, our ancestors first ventured out of Africa and began to spread around the world. The Greenland cores will surpass by 40,000 years the world's longest ice record, drilled in the 1980s by a Soviet and French team at the USSR's Vostok base in Antarctica (SN: 9/17/88, p.184).

Perhaps even more important, the new record will provide a level of detail not available in the Antarctic ice core. Because Vostok lies in a virtual desert, receiving fewer than a dozen centimeters of snow each year, climate information there gets squeezed into extremely thin layers — an effect that smears out events over decades and even centuries. Reading the climate story in such a core is like following a soap opera by tuning in once a year. Greenland's summit region gets seven to eight times more snowfall, which spaces out the information into thicker layers. So far, the generous spacing has allowed GISP 2 scientists to analyze how climate factors changed from one year to the next.

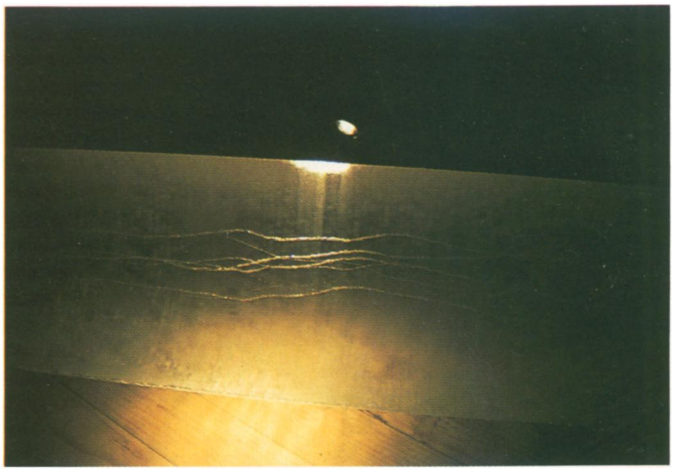
The GISP 2 crew has now completed four of its five summer field seasons on the ice. After spending the first three years performing reconnaissance and testing equipment, they began drilling in earnest this summer, cutting their way to 1,510 meters — just about halfway to the bottom of the ice sheet. The ice at this level dates back to about 8,500 years ago, near the beginning of the current warm period. The European drillers, progressing far more rapidly, have reached the 2,321-meter mark, where the ice is approximately 35,000 years old — firmly in the middle of the last ice age.

GISP 2 has moved more slowly because the crew is still working the kinks out of a new, U.S.-built drill, while the Europeans are using a well-seasoned Danish machine. In mid-July, the U.S. drill froze in the hole, shutting down operations until a supply plane brought glycol to free up the rig. The crew stopped drilling for a second time in early August while awaiting a new shipment of motors, which had been burning out much faster than anyone imagined possible.

Despite such problems, the new drill has some advantages. With a diameter of 5.2 inches, it collects almost twice as much ice for scientific analysis as its 4-inch-wide Danish counterpart. It also has an extremely deep range, allowing U.S. researchers to plan on drilling their next ice hole in Antarctica.

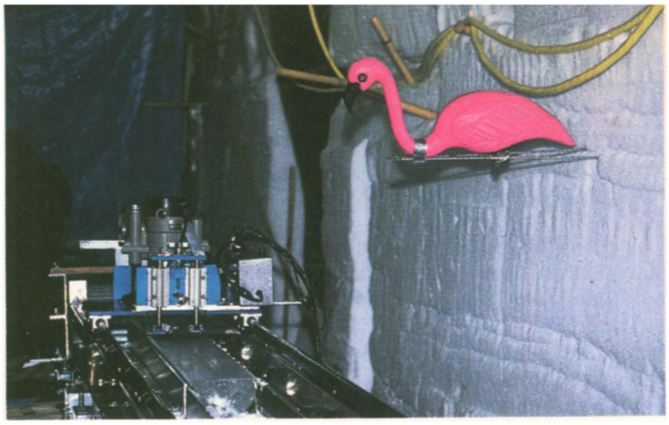
Aside from the different drilling rigs, GISP 2 and GRIP run very similar operations. Several times a day, crews lower a hollow drill bit into the ice hole, cut through several meters, and then retrieve the ice-filled drill. Gloved hands remove the ice core and lower it into a research tunnel carved out of the solid snow by chain saws. Down here, the air stays colder than it does on the surface, providing a safer environment for cutting the core segments and performing analyses. Although temperatures above ground almost always remain below freezing, the outdoor air often warms enough to jeopardize the cores. At temperatures above −15°C, microcracks can form in the ice, allowing trapped gases to escape.

Researchers working in the snow catacombs wear extra-thick clothing to combat the frigid conditions. Some must cover their Arctic garb with white "clean suits" to prevent stray dirt or fibers from



Prehistoric calendar: Light shining through a section of the GRIP ice core reveals faint bands, each corresponding to one year's accumulation of ice. Scientists can use the layering to determine the timing of ancient climatic events. Squiggly lines running along the length of the core are incidental scratches from a machine.

Richard Monastersky visited GISP 2 and GRIP in July with National Science Foundation officials and several other journalists.



Stuck into a wall of the snow trench, a lawn ornament overlooks a machine that measures the electrical conductivity of the ice core. The conductivity depends on acids (which can indicate volcanic eruptions) and bases (possibly from distant forest fires) trapped in the ice.

ruining sensitive measurements. Swaddled in all that bulk, they look like a convention of Michelin Men.

For mental protection against the cold, investigators in the GISP 2 trench have decorated the frozen walls with a plastic flamingo and Caribbean travel posters. In the European trench, a personal computer sits in a little alcove dug into the snow. On its screen, a blinking polar bear plays the role of a cursor.

The subterranean scientists conduct a half-dozen experiments, using lasers, electrical currents and a battery of chemical tests to determine what kind of climatic evidence the ice contains. Other tests measure the ice itself to assess its strength and ability to deform. Such information helps researchers understand how ice sheets grow and move — a critical factor in predicting whether global warming will have a catastrophic effect on Antarctic ice sheets. Some climate experts worry that the currently stable Antarctic glaciers could surge into the ocean, raising global sea levels and flooding many coastal cities.

Farther along in the trenches lie cavernous snow rooms, dug at a deeper level where temperatures stay even colder. Here, the bulk of the ice core sits in storage, waiting for transport to laboratories in the United States and Europe.

A few kilometers from the camp, beyond the view of any human settlement, the Greenland ice sheet assumes an air of timelessness. For hundreds of thousands of years, this region has remained essentially the same, cloaked in its mantle of ice.

Greenland's margins have had a far livelier past. During warm, interglacial periods — such as the present — the ice-free coast provides a home for numerous animals, including caribou, musk-ox, hares, foxes and people. During ice ages, the expanding glacial cap envelops the entire island, driving all life away.

Although the last ice age ended about 10,000 years ago, even minor climate shifts have dramatically affected the course of Greenland's history. In medieval times, unusually warm temperatures in the North Atlantic prompted Norse Vikings to establish the first European settlements on Greenland, following the island's discovery in 982 by Eric the Red. The infamous Viking explored the coastline of Greenland after authorities on Iceland banished him for his murderous habits. Because of the warmer climate back then, he would have found the island's shores more verdant than they are today, and this may have inspired the colorful name he gave it. But many historians take a dimmer view of Eric's motivation. The name Greenland, they say, was a ploy to lure other settlers — one of history's earliest examples of false advertising.

The Norse communities on Greenland thrived for several centuries, during a time now known as the medieval warm period. But the colonists suffered when the Atlantic region turned colder, ushering in a span called the little ice age. During this frigid era, which lasted roughly from the mid-1300s until the 1800s, the Greenland colonies mysteriously disappeared, perhaps because of the harsh environment.

In their ice core, GISP 2 scientists have traced the climatic shifts that exerted such a powerful influence on the history of human civilization on Greenland. The ratios of oxygen and hydrogen isotopes in the ice crystals reveal that the GISP 2 site had elevated temperatures during the medieval warm period. Summertime temperatures actually rose above freezing, an otherwise rare event at the top of

DIVIDED THEY DRILL

A pilot flying over the Greenland ice sheet could cruise for hours without seeing any sign of life on the desolate plains below. By those standards, the summit of the ice sheet seems a bustling metropolis. Two major scientific camps lie almost within sight of each other, separated by only 30 kilometers. In one camp, a European team attempts to drill the deepest ice hole on Earth. In the other, a U.S. team has set exactly the same goal.

With budgetary purse strings so tight these days, why are American and European researchers spending millions of dollars in what appears to be a duplication of effort?

Investigators at both camps maintain that appearances are deceiving in this case. Scientifically speaking, two nearby holes are much better than one — especially when they promise to yield the most important ice records ever drilled. But many participants also acknowledge that politics, rather than science, is what really drove the two groups to run separate but equivalent programs.

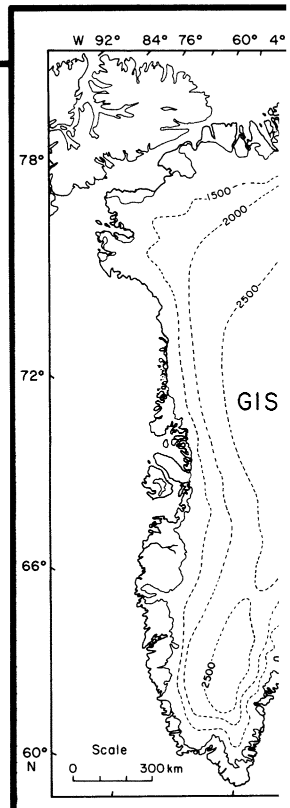
That's not the way it started out. Originally, ice core experts on opposite sides of the Atlantic planned to collaborate on a single drilling project in central Greenland. During 1979 through 1981, the United States, Denmark and Switzerland collectively drilled the GISP 1 hole in southeastern Greenland — an effort they viewed largely as a practice run for the real scientific goal of drilling in remote central Greenland. Following their success at GISP 1, the same international coalition began planning a similar cooperative effort for GISP 2, says the University of Copenhagen's Willi Dansgaard, leader of Denmark's portion of the GISP 1 project.

Ironically, though, the very success of the earlier venture came back to haunt the collaborators who pulled off the effort, says GISP 1's chief scientist, Chester C. Langway Jr.

"The ground rules started to change toward the end of the [GISP 1] operation when more and more U.S. investigators became interested and envious and wanted to be involved," explains Langway, an ice researcher with the State University of New York at Buffalo.

Though GISP 1 was an international project, the three involved countries did not provide equal financial support. While Denmark and Switzerland contributed funds, as well as the world's best ice core laboratories and researchers, the U.S. National Science Foundation (NSF) paid for the bulk of the program.

That system worked well in the late 1970s, but NSF



the ice cap. The isotopes also show evidence of the little ice age, although the cooling at the summit seems less intense than the one recorded in other parts of Greenland and in Iceland.

Playing the climate movie back a little farther, the GISP 2 ice will offer a portrait of the climatic optimum, a time about 7,000 years ago when civilization experienced its warmest period ever. Although scientists have yet to analyze the ice deposited during the climatic optimum, they believe Earth's average surface temperature may have been about 1.5°C warmer at that time. Mayewski suggests that this period of high temperatures will provide a model for studying the possible effects of a human-induced warming.

The Greenland ice cores will allow the first in-depth look at the climatic optimum and other events that occurred during the Holocene epoch, the period since the last ice age. "Up till now, ice cores have not told us that much about the Holocene," says Mayewski, because ice from this period is extremely brittle in most glacial sheets. At GISP 2 and GRIP, scientists have taken extreme care while drilling and sampling the brittle Holocene ice.

Venturing even deeper, the drills will cut through layers that formed during the last ice age, a time when human culture first flowered in the form of animal paintings on the walls of southern European caves. Even after a century of study, scientists don't understand what caused this and previous glacial periods, which have gripped the planet on and off for the last 2 million years. Evidence suggests that slight variations in Earth's orbit triggered the shifts and that greenhouse gases provided some of the force that cooled and warmed the planet; during the ice ages, carbon dioxide levels dropped by more than 30 percent. But many experts believe some other climate factor or factors must have played an even larger role. By revealing details of the glacial world, the Greenland cores will provide valuable clues for solving the ice age mystery, Mayewski says.

GISP 2 driller surveys a fresh length of ice core. Working in subfreezing temperatures, drillers must wear waterproof suits and gas masks to protect against the butyl acetate fluid used in drilling.

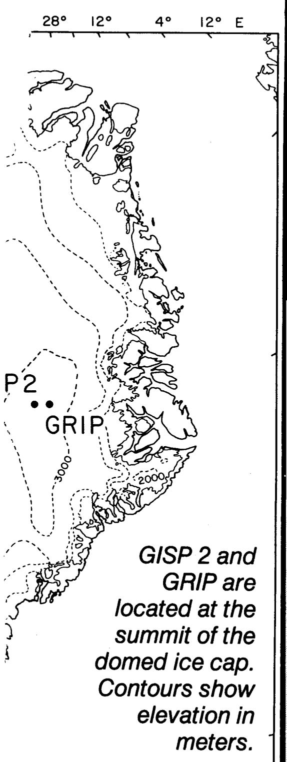
Designed to probe events of the past, ice core projects are by nature historical. But each researcher working in this area has one eye looking toward the future.

Most important, evidence culled from the ice can help scientists understand how quickly the world might warm in coming years. Climate experts generally believe greenhouse-gas pollution will raise Earth's surface temperature, but government leaders say agreement on that issue alone does not justify spending billions of dollars to remodel society. In order to assess the need for action, officials want to know the magnitude of the problem. Will the warming occur so slowly that people and natural ecosystems can adapt, or might conditions shift quite suddenly, wreaking unimaginable damage?

Ice records drilled previously indicate the climate can sometimes fluctuate with surprising speed. In particular, studies of the GISP 1 core, drilled from 1979 to 1981 in southeastern Greenland, suggest that the North Atlantic region warmed by a striking 7°C in a half-century (SN: 6/17/89, p.374). That drastic rate of warming about 10,500 years ago far outpaces what the world is currently experiencing.

"That really surprised us, that things could happen so quickly," says James White of the University of Colorado at

GISP 2 Science Management Office



GISP 2 and GRIP are located at the summit of the domed ice cap. Contours show elevation in meters.

officials thought it wouldn't serve the needs of the 1980s with U.S. investigators expressing growing interest in getting access to Greenland ice. So NSF decided the next hole would be strictly a U.S. operation, Langway says.

Aside from giving U.S. researchers the ice they wanted, that move has built a strong foundation for future U.S. ice core projects. "The United States did not have a deep-drilling capability three years ago," says GISP 2 researcher Richard Alley of Pennsylvania State University in University Park. Now it has a deep drill, a trained group of ice core analysts and a seasoned crew of drillers, he says.

When the U.S. decision to drill alone left European researchers out in the cold, Dansgaard and Hans Oeschger of the University of Bern set off to revive their decades-old plan to drill in central Greenland. The project that evolved – known as GRIP – draws its support from eight nations: Denmark, Switzerland, France, Germany, Italy, Iceland, Belgium and the United Kingdom.

While the drilling arrangement may have come about for political reasons, scientists involved in GRIP and GISP 2 agree that the ability to compare the two records provides an unprecedented opportunity for ice core researchers.

"It really is better to have two holes. There is no question about that," says Alley.

With only one hole, it is difficult to know whether compression and movement of the ice have skewed the climate evidence, say researchers. But with two nearby holes, investigators can cross-check to verify what they find. Given the importance of the record and the expense of drilling, "it's essential to know that the record is valid, that it is not physically deformed," says Mayewski. NSF will pay more than $20 million for GISP 2, while the Europeans are spending something less than $15 million on GRIP, says Dansgaard.

Two holes also provide a larger volume of ice, allowing more extensive measurements. And they offer a safety net in case drilling problems "trash" a particular section of ice core, as happened at GISP 2 earlier this season. When the U.S. drill inexplicably turned the ice core into mush, the crew lost a dozen meters of core, corresponding to about 50 years of ice record. The GISP 2 researchers plan to fill in their loss with European data.

But even while they tout the benefits of the current arrangement, some researchers privately say that such scientific advantages do not justify the cost of drilling separate holes in the same region. "If I controlled the money," comments one GISP 2 scientist, "I would not put [two nearby holes] as a high priority."

– R. Monastersky

Boulder, a participant in GISP 1 and 2.

To put the ancient warming in perspective, White imagines how it might have affected someone living in England at the time: "In less than a human lifetime, you would have gone from a very cold glacial climate to one which was not terribly different from that of today. That is very dramatic."

The GISP 1 core holds evidence of several other large temperature shifts during earlier periods of the last ice age, but such rapid jumps and dips don't show up in Antarctic cores. Some investigators read that discrepancy as a sign that the Greenland ice has recorded *regional* climate flips in the Northern Hemisphere, generated by changes in a sensitive system of North Atlantic ocean currents, says Wallace Broecker of Columbia University's Lamont-Doherty Geological Observatory in Palisades, N.Y.

Some of the GISP 1 findings, however, conflict with the Antarctic evidence against rapid worldwide changes. One puzzling clue from the Greenland ice core points to a climate shift about 10,500 years ago involving the entire planet. According to measurements of gas trapped in the GISP 1 ice, levels of carbon dioxide around the globe jumped by 50 parts per million in the space of 50 to 100 years. Such a huge surge would equal or perhaps surpass the amount of carbon dioxide spewed into the atmosphere during the last century by the burning of fossil fuels.

The carbon dioxide measurements astounded scientists, who remain unable to explain a natural change that large. However, many have questioned the findings' validity because the GISP 1 drilling site often warmed above freezing, an effect that could have altered the gas levels in the bubbles. Situated at a much higher elevation, the GISP 2 and GRIP camps don't face the same warm weather problem as GISP 1 did, so the ice from these holes should resolve whether the quick carbon dioxide rise actually occurred.

"If the [carbon dioxide jump] is there [in the new records], it's going to be extraordinarily hard to explain and very, very interesting. So we're all waiting to see," says Broecker.

He and other scientists view the evidence for quick changes in the past as a potential warning of what might lie ahead. They believe climate – especially in sensitive regions of the globe – may be stable only up to a point. If humans put enough pressure on the environment, they could knock the world's climate out of balance and send it reeling to a new and potentially very different form.

"It isn't a totally predictable system. It's somewhat like Russian roulette," Broecker warns. "We'll find out [eventually] what it will do, and maybe it will be very humble and do almost nothing. But on the other hand, maybe in 100 years it will undergo some big transition."

The issue of quick climate change motivates much of the research at GISP 2 and GRIP, as these holes are uniquely situated to uncover such events in the past. Antarctic cores do not record the rapid swings, and other Greenland cores have reached only into the last ice age. The current projects will pass through the last ice age, then into the warm interglacial period, about 120,000 years ago, and eventually into the second-to-last ice age.

That triumph must wait till next year, though, for the endless days of Arctic summer have passed and Greenland's summit grows more inhospitable with each nightfall. Temperatures now dip to –40°C as the sun spends almost half of its time beneath the horizon. The European camp, closed for a month already, has taken on the appearance of a ghost town.

At the U.S. site, crew members busily prepare to ship out in mid-September. They plant long bamboo poles around camp to help locate buildings and supplies come springtime, when snowdrifts will obscure almost everything around. Boarding the transport plane for the flight out, the scientists and drillers take seats in the cavernous cargo bay, next to stacks of long, insulated boxes. Inside lie lengths of the precious ice core – pieces of Greenland, pieces of time. □