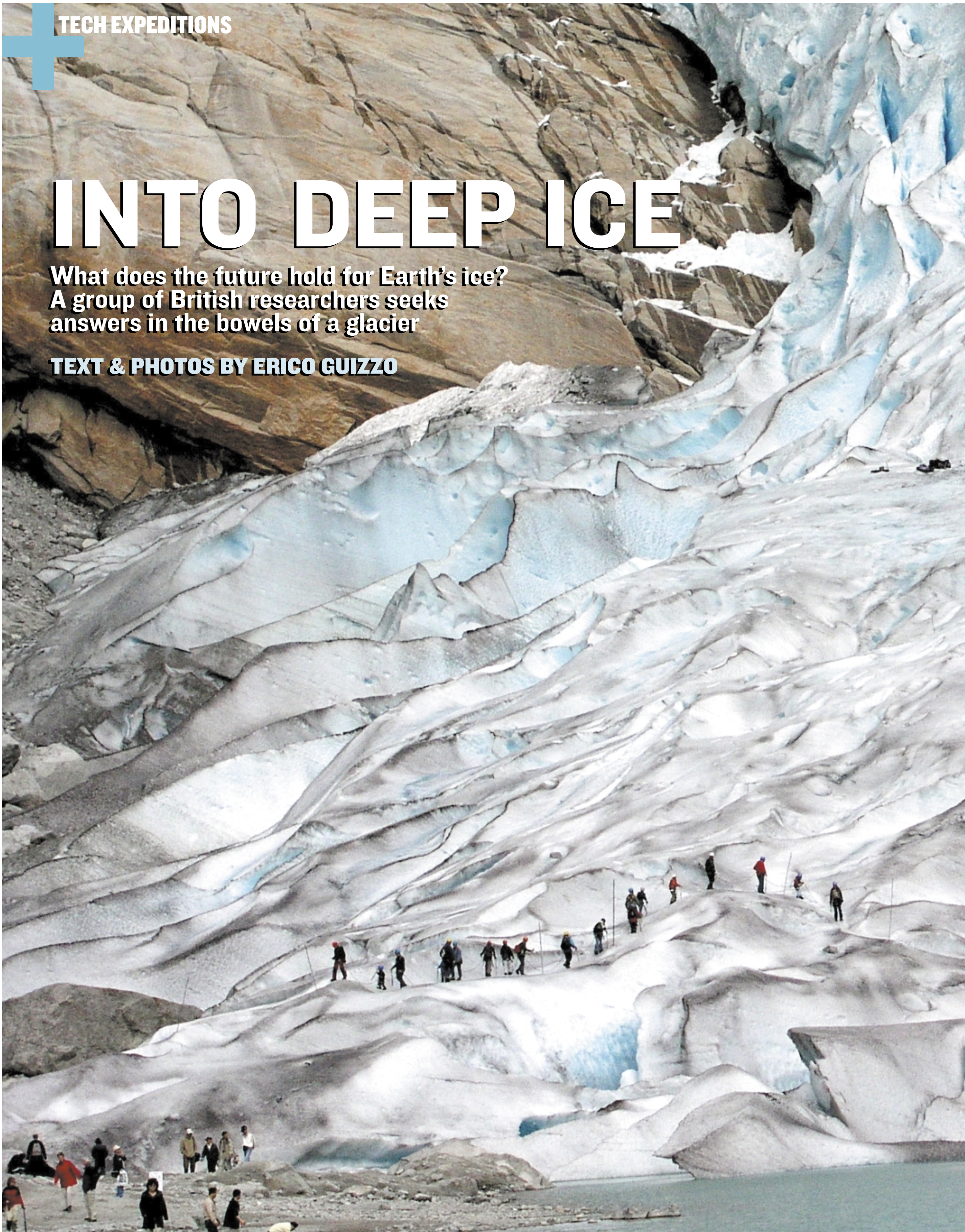
INTO DEEP ICE

What does the future hold for Earth's ice? A group of British researchers seeks answers in the bowels of a glacier

TEXT & PHOTOS BY ERICO GUIZZO



A COOL MISSION: A team of engineers and glaciologists [center] from the University of Southampton, in England, embeds capsules stuffed with environmental sensors deep within the Briksdalsbreen, a glacier in southwestern Norway that is particularly sensitive to climate variations.

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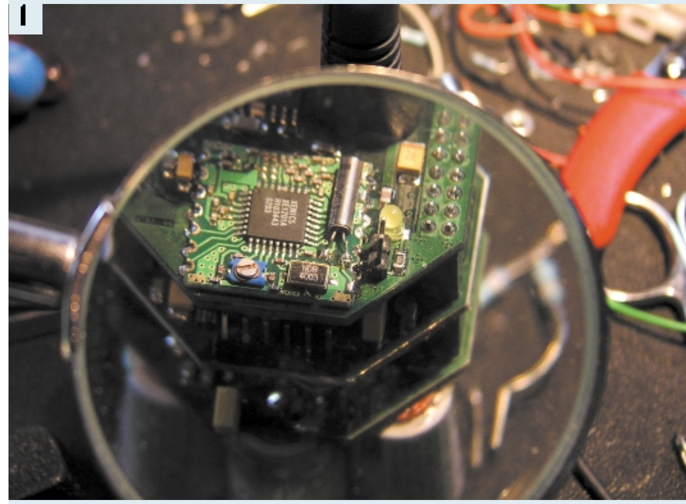

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"FOLLOW ME," Kirk Martinez says as he leaps from boulder to boulder, his shoulder-length brown hair trailing behind him. I try to keep pace, striding along the trail, a bitter wind against my face. We stop at the base of a wall of rock that rises more than a thousand meters. From behind that mountain, what looks like a huge river of snow snakes its way to where we stand. But as we move closer, one thing becomes clear: this enormous swath of bluish white is not snow—it's ice.

It's a bright August morning in the tiny bucolic town of Olden, in southwestern Norway, and I find myself about to clamber up the largest mass of frozen water I've ever seen. It's called the Briksdalsbreen. *Breen*, I am told, is Norwegian for glacier, and Briksdalen is the picturesque valley where it resides. Although it holds more than a billion tons of rock-hard ice—enough to fill up a thousand Empire State buildings—Briksdalsbreen is just a small arm of a much vaster glacier named the Jostedalsbreen, which, boasting an area of almost 500 square kilometers, is the largest ice field in continental Europe.

"Time to put on the gear," Martinez says, grabbing a helmet and an ice axe. He climbs onto the ice first, and again I try to follow him. "Keep your feet apart and walk with short, firm steps—and don't run," he cautions me. As we trudge onward, our crampons—spiky metal contraptions strapped to the bottoms of our boots—bite into the ice, making a satisfying sound: *crunch, crunch, crunch....*

Martinez, a professor of computer science at the University of Southampton, in England, is here, along with a squad of engineers and glaciologists, to field-test a wireless monitoring network specially designed to study glaciers. The system's key component is a capsule that the researchers have stuffed with environmental sensors. The plan is to embed dozens of these probes deep within this huge tongue of ice, where they will record temperature, pressure, and other variables for several months.

While Martinez is in charge of the group's electronics work, Jane K. Hart, a geography professor at Southampton, leads the glaciological investigations. This husband-and-wife team has been working on the project, called Glacsweb, for almost five years. They aim to tackle one of the most challenging problems faced by glaciologists today: understanding how Earth's ice masses will respond to the continued warming of the globe. Glaciers in the Alps, the Andes, Alaska, and central Asia have been rapidly shrinking, contributing to sea-level rise and often causing floods. But will others follow the same course? Will the glacial shrinkage accelerate? The Glacsweb system could shed light on these and other issues by allowing scientists to "see" with unprecedented detail what goes on deep inside glaciers.

Wireless sensor networks are spurring a revolution in environmental monitoring, with researchers using them to keep tabs on crops, rivers, volcanoes, and even birds [see "The Secret Life of Birds," April 2004]. The Southampton team is one of the few applying such networks to the study of glaciers. Their wireless probes could prove a good replacement for some of the conventional instruments used by glaciologists, like gauges that are also embedded in the ice but with wires running to the glacier's surface. The problem with these wired devices is that their cables are often broken as the ice around them deforms. The British researchers chose the Briksdalsbreen because it is relatively accessible and is particularly sensitive to climate fluctuations. During a previous research trip here, they deployed nine probes. Now they are back with more.

WITH ABOUT A TON OF EQUIPMENT, the British researchers figured it would be too expensive to fly in. So they packed their cargo into two large vans and drove from Southampton, on the English Channel, to Newcastle, in the northernmost part of the country, where they boarded a ferry and headed across the North Sea. A day later, they disembarked in Bergen, Norway's second largest city. From there, it was a 6-hour drive to the Melkevoll Bretun, a campsite near the Briksdalsbreen, where the group rented three cabins to serve as their base of operations.

When I arrive for my weeklong stay, the researchers have already been here for nine days. The cabin I'm bunking in has been transformed into an electronics laboratory. The dining table, pushed against a wall, serves as a workbench, equipped with an oscilloscope, spectrum analyzer, soldering iron, voltmeter, and computer.

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PREPARING THE PROBES: 1. Each probe carries a chunk of electronics that consists of three circuit boards packed with components, stacked atop six 3.6-volt lithium-ion batteries. **2.** A case made of polyester resin houses the circuitry and protects it from ice and water inside the glacier. **3.** The two-piece case is 14.8 centimeters long and 6.8 cm in diameter. It withstands extremely low temperatures and high pressures. **4.** Ahmed Elsaify brushes on superglue and epoxy to seal a probe's case. **5.** Kirk Martinez prepares the base station: a plastic box containing a Linux-based computer that will receive data from the probes at the glacier.

The windowsills are cluttered with small boxes of spare electronic components. And on the floor, dozens of batteries and transformers and a maze of cables are piled up near a power outlet.

That night, after dinner, I find Ahmed Elsaify, an Egyptian who has just joined the Glacsweb group as a postdoctoral student, hunching over the improvised lab bench. He holds a chunk of circuitry the size of a kiwifruit up before his eyes, examining it meticulously. It is a probe's electronic innards, he tells me, and it includes six lithium batteries, a bunch of sensors, a 64-kilobyte memory for data storage, a radio transceiver, and an antenna; it also has a 16-bit microcontroller—the brains of the device—and a real-time clock chip, which wakes up the normally dormant electronics at specific times [see photos, "Preparing the Probes"].

The circuits seem fine, so Elsaify calls Martinez, who sits nearby, and says that probe 10—slated for deployment the next day—is ready to be sealed. Martinez grabs the circuitry block and places it inside the special capsule that will protect the electronics from water and ice. But as he presses the two halves together, he notices that they don't quite close. "This is the kind of thing you design on the computer and it looks fine, but when you go to put it together..." Martinez says, pausing as he pops the case open to look inside. The problem, he concludes, is that the group replaced some of the sensors with slightly larger ones, and the case is now not closing perfectly, its halves separated by about 2 millimeters.

Martinez and Elsaify attempt to rearrange the electronics—to no good effect. They then discuss shaving the inside of the case but decide that they'd end up punching a hole in it. They also study the possibility of changing the antenna's position, but nothing works. After nearly 2 hours of frustrated attempts to close the troublesome capsule, Martinez makes an executive decision: "We'll have to trim the antenna."

With diagonal cutters he lops off a millimeter-thick slice of the antenna's plastic cap, revealing a coiled copper wire inside. He tries to close the case, but it still doesn't fit together. He goes ahead and trims one more piece—plastic and copper fragments flying meters away—and the two parts finally close.

The problem now is to determine how the shortened antenna will affect the probe's communications capabilities. Pure ice is not much of a problem for radio signals, Martinez tells me, but water strongly absorbs them, and the Briksdalsbreen is full of puddles and streams. To assess the situation, Martinez calls on Gang Zou, another postdoc in the group. The Chinese radio engineer sets the probe to broadcast some test data and reaches over to the spectrum analyzer. It shows a 433-megahertz signal at 2 milliwatts of power—the probe's transmission. It's not tremendously strong, but the researchers conclude it's enough for sending data through tens of meters of ice.

With all the electronics tests completed, the probe is ready for the final touch: using superglue and epoxy, Martinez seals the case. It's 1 a.m., and probe 10 has finally been made whole.

EARTH HAS MORE THAN 160 000 GLACIERS. Scientists study them because they are an integral part of our climatic system, affecting and being affected by it. Today, with the rise of global surface temperatures, the overall trend is of "continuous if not accelerated glacier melting," according to the World Glacier Monitoring Service, in Zurich, Switzerland, which maintains the largest database on the subject.

By the end of this century, the U.N. Intergovernmental Panel on Climate Change projects that sea level will rise by 11 to 77 centimeters. Most of the increase will be due to thermal expansion of the water, but glacial melting is expected to contribute a significant portion—as much as 30 percent—of the total. The disappearance of ice masses may have a serious socioeconomic impact not only on low-lying coastal areas but also on regions whose hydrology and vegetation depend on glaciers.

But if the shrinkage is widespread, it's not universal. It turns out that the Briksdalsbreen and other glaciers in this part of Norway were not melting—they were growing. During the 1990s, the Briksdalsbreen and its neighbors the Bergsetbreen, the Bødalsbreen, and the Nigardsbreen have all experienced growth at speeds that surprised many researchers. In 1994 alone the front of the Briksdalsbreen charged ahead 80 meters, about four times its annual average. If you visited the glacier that year, you could actually see it slowly advancing, its front bulldozing plants, rocks, and everything else in front of it.

Why have these glaciers grown while so many others are melting? The answer: precipitation. During the early 1990s this region experienced consecutive winters with unusually high humidity, with some years registering almost double the usual precipitation, which, at the top of the glaciers, fell as snow. “Global warming means both temperature rise and increase of precipitation in coastal areas due to higher evaporation,” says Stefan Winkler, a geography professor at the University of Würzburg, in Germany, who has been tracking Norwegian glaciers. “And high winter precipitation means nothing else but high snow accumulation.” It was this extra dollop of snow that made the glaciers grow.

Scientists suspect, however, that this phenomenon alone is not enough to explain the Briksdalsbreen’s spectacular advances in years like 1994. Something else was also in action. The likely candidate is a large-scale fluctuation of atmospheric pressure that affects the climate of most of the Northern Hemisphere. “It’s called the North Atlantic Oscillation,” says Atle Nesje, a geology professor at the University of Bergen. One of its effects is that when pressure gets unusually low over Iceland and unusually high over the western part of the Mediterranean Sea, a mass of moist air flows into northwest Europe. “The result is a lot of precipitation in western Norway,” he says.

The North Atlantic Oscillation is a natural variation of the climate system, although it seemed somewhat off-balance during the 1990s, bringing more wetter winters than normal. Is global warming to blame? Scientists still don’t know, but they do know that this unbalance has brought detectable changes to the abundance of zooplankton in the oceans, the length of grape and olive harvests in Portugal and Spain, and the sex lives of Scandinavian ungulates. And in coastal Norway, it has made glaciers grow.

Now a reverse scenario seems to be taking shape. Over the past five years, winter precipitation in Norway’s coastal areas has decreased significantly, while summer temperatures have increased, with 2002’s being the warmest on record. This situation has caused more glacial ice to melt during summer than to form during winter, and the result is that the glacier has begun shrinking.

Will the Norwegian glaciers meet the same fate as other mountain glaciers in Europe that are likely to disappear by the end of the century? What can they tell us about how glaciers respond to climate change? What controls their sizes and rates of growth or melting? The Southampton team believes there are valuable lessons to be learned—and they may lie in the depths of the ice.

A GLACIER LIKE THE BRIKSDALSBREEN doesn’t just sit still. Because of its enormous weight, its mass is constantly moving downhill, the ice flowing like a river in slow motion. During the winter, new snow falls on its surface, especially on its highest areas. With time, that powder compacts, and air is expelled. If this dense snow lasts through the summer, it’s called firn. After many years, buried layers of firn turn into glacial ice, which has a characteristic bluish hue, because it absorbs light at the red end of the spectrum. Unlike ice at a skating rink, the surface of a glacier is not smooth or flat; it’s grainy and irregular, with plenty of craters and bumps [see photo, “Down It Goes”]. Nevertheless, it’s a slippery place to do science.

“If you fall,” Martinez instructs me on my first day at the glacier, “don’t try to swing the axe and stick it in the ice. Only Schwarzenegger can do that. Or was it Stallone?” As it happens, we’re on a portion of the Briksdalsbreen that is only slightly inclined, and if I fall here, Martinez says, I won’t slide very far. It’s at this part of the glacier, about half a kilometer from its terminus, that the group spends most of its time [see photo, “A Cool Mission”].

While we walk on the ice, Martinez explains how the Glacsweb system works. Embedded within the glacier, the probes—each costing

DATA FROM THE DEEP: 1. Ahmed Elsaify [left] and Kirk Martinez perform a communications test on a probe they are preparing to deploy. **2.** Using a fishing line taped to the probe, Martinez [left] lowers the capsule into a hole drilled in the ice as Jane Hart [center] and Kathryn Rose look on. **3.** Team members [from left] Martinez, Alistair Riddoch, Elsaify, and Hart analyze fresh data sent by several probes inside the glacier.

about US $400 to make—remain in sleep mode most of the time, reviving themselves six times a day to record environmental observations such as temperature, pressure, and electrical resistivity, which reveal whether they are immersed in snow, ice, or water. The probes also register strain, which shows how much they are squeezed by the surrounding environment, and tilt, which is measured by microelectromechanical system, or MEMS, accelerometers that keep track of the instruments' orientation.

Every day at noon Greenwich Mean Time, the probes transmit the data they have accumulated in their memories to a receiver that sits inside a deep crater on the glacier. From the receiver, the data flow through a wire into a plastic box, which the researchers call the base station. It contains a BitsyX, a Linux-based single-board computer that can withstand very low temperatures, powered by lead-acid batteries, which are recharged by a wind generator and solar panels mounted outside the box. The base station's computer verifies the integrity of the received data packets and relays them via a radio connection to another computer, 2.5 km away at our campsite, which like many vacation spots these days has Internet access. It's through this connection that the probes' data finally reach a server in Southampton.

Today, the researchers will deploy probe 10, the unit they sealed the night before. They plan to place the device not far from the ones already deployed, numbered 1 to 9, which have been here since last year. The first task is to make a hole in the glacier, and this morning Kathryn Rose, a Ph.D. student in the geography department, and Sarah Stafford, a geography undergrad, are charged with the drilling operation.

The students start a diesel-powered hot-jet pressure washer that pumps water through a long hose connected to a 1.5-meter-long hollow steel rod with a small aperture at the end. They lift the rod and push it against the ice, and a hole about 10 cm in diameter starts to form. Soon the rod disappears inside the ice, and Rose and Stafford keep pushing the hose downward. They need to drill until they reach the bottom of the glacier, where the ice meets the sediment layer underneath. It's at this interface, tens of meters deep, that the researchers want to place their probes. After about half an hour, Rose and Stafford notice the hose doesn't go down any farther: the steel rod has reached the bottom, and the hole is ready for the probe.

Martinez comes over and spools out some fishing line he has taped to probe 10, slowly lowering it into the hole [see photos, "Data From the Deep"]. All goes well as he pays out the first 17 meters, but suddenly the line goes slack. The probe is stuck, and Martinez shouts for someone to bring him the group's special borehole viewer: a small CCD camera with a bunch of white LEDs around it. He uses the attached wire to lower the device, which feeds images to a camcorder. Peering into the eyepiece, he sees that the probe is sitting on a ledge. Nothing that some maneuvering can't solve: Martinez jiggles the line, and the probe frees itself. When it bottoms out, some 38 meters down, the group declares victory. Probe 10 is in.

IN THIS PART OF NORWAY, everywhere you look you see the action of ice. It all began about 2 million years ago. At that time, shallow, open valleys and rounded mountains dominated the landscape. But then the Quaternary period brought the start of the ice ages, during which glaciers covered large parts of Earth's surface. Throughout this region, massive accumulations of ice repeatedly sculpted the land, leaving long, deep gouges in solid rock. The result is what we see today: deep, U-shaped valleys with flat bottoms and fjords that stretch for tens of kilometers inland.

The first person to suggest the idea of an ice age was Jean Louis Rodolphe Agassiz. Born in Switzerland, he received his degree in medical sciences in 1830, but his fascination for the natural world led him to a career as a zoologist and geologist. During trips to the Alps and other parts of Europe, Agassiz noticed that the flow of ice over the land had left plenty of telltale evidence, from small grooves in rocks to large boulders plucked from distant regions. What really surprised him, though, was that those same features were found in places with no glaciers nearby. He concluded that these huge bodies of ice had once been much larger, covering not just high plateaus but entire countries.

DELIVERY BY AIR: The group hired a helicopter service to haul heavy ice-drilling equipment up and down the glacier.

When he put forward his ice age theory in the late 1830s, people scoffed at the idea. At the time, the accepted explanation for the landscape features Agassiz was describing was that they resulted from Noah's Flood. Agassiz, who came to the United States in 1846 and became a professor at Harvard, proved his theory correct by finding ample geological evidence for it all over Europe and, later, in North America.

His work revolutionized geology and earned him recognition as the father of glaciology. (Even though he replaced the biblical Flood with huge ice masses, Agassiz didn't abandon his belief that glaciers had appeared instantaneously all over the world at God's command.)

Today, glaciologists aim to understand not only the past of Earth's glacial history but also its future. To make their predictions of how glaciers will respond to different climate scenarios, they rely on computer simulations that model ice-mass motion over time. Early models treated a glacier basically as a slab of ice sitting directly on a slope of bedrock. But during the 1980s, as researchers drilled boreholes in glaciers in Asia and Europe, they found not rock but a layer of sediment underneath the ice.

That discovery required glaciologists to reevaluate their models. Scientists are now learning that sometimes the weight of the ice is so great that the sediment layer gets squeezed to the point that it begins to flow downhill, with the glacier riding along. This previously undiscovered subglacial "sliding" effect, they believe, is in some cases responsible for most of the ice movement. Despite much investigation, though, this process remains poorly understood.

"Subglacial dynamics is an area with a gaping hole in knowledge," says Martin Truffer, a professor of geophysics at the University of Alaska, at Fairbanks, who has also conducted experiments with wireless sensors. "We understand some of the basic processes, but it is difficult to put this together into something like a predictive model." One of the problems, he says, is data scarcity. "If you can distribute cheap sensors widely, you're bound to learn new things and improve existing models."

It's this piece of the puzzle that the British team hopes to supply. The Glacsweb probes, Southampton's Hart tells me, will be able to track one of the key variables needed to study the sediment layer: water. When glaciers move over a water-soaked layer of sediment, they are able to go faster. That's the case of the Briksdalsbreen, which is likely flowing over a bed of muddy sediment about 10 meters thick.

And that might be the situation, too, in other parts of the globe. One of these places is the massive West Antarctica ice sheet, which is of particular concern because there is speculation about its possible collapse. It holds a volume of water equivalent to a sea-level rise of 6 meters, and even a partial meltdown could have catastrophic consequences. At the current rate of climate change, how will it react? Some scientists suspect that the flow of that ice sheet is controlled not by snowfall or atmospheric temperature but mainly by the dynamics of the sediment bed beneath it.

It's difficult, though, to confirm this hypothesis, because it's logistically difficult to study Antarctic glaciers. "So we're trying to do the same thing as you would in Antarctica, but to do it here—it's much easier," Hart says. One of the subglacial mysteries that the Glacsweb group hopes to solve is whether the sediment layer flows by viscous or plastic deformation. In other words, is it like a glob of molasses slithering downhill or more like a slab of clay getting squashed? The group doesn't have that particular answer yet, but the probes are already revealing interesting things.

One afternoon at the campsite, Hart shows me a graph of the data from probe 8, which has collected more than a year's worth of measurements. She explains that in August 2004, pressure values were relatively low, which means the borehole was still open to the atmosphere at that point. Resistivity values confirm that supposition: they were also low, indicating the probe was surrounded by water. But in January, as winter set in, both pressure and resistivity values rose, reflecting the fact that the water around the probe had turned to ice. Then, a few months later, the pressure values went up even more, while resistivity values diminished. That's a sign that water was flowing again—that the glacier "woke up" after the cold winter and that a water stream appeared within the ice.

DOWN IT GOES: Hanging on a fishing line, the group's latest probe starts its descent into the depths of the glacier. There it will record environmental observations such as temperature, pressure, and electrical resistivity.

What's more, after examining data from its tilt sensors, Hart can now see how probe 8 moved inside the glacier. During the previous winter, the unit started rotating slowly from upright toward a more horizontal position. In the spring, it turned a bit faster. Then, during the summer, it tumbled even more.

Traditional wired instruments wouldn't have been able to show such detailed movement. But because the Glacsweb probes were designed to mimic how real stones move beneath the glacier, that's not a problem for them. "There are many models for how the sediment moves, and most of them say that the stones rotate," Hart says. "But that's actually a process that has never been seen before."

Later that day, Glacsweb team members gather in the living room of the cabin-laboratory to discuss the mission's progress. It's day 12 for the group, and at around 6:30 p.m. Martinez and Hart walk into the room. "We had a good day," Hart says. "Probe 10 spoke." The group peers at a notebook computer: rows of numbers scroll across the screen. It's fresh data from the probe, which, after all the banging and tweaking that had gone on, is now doing its job just as expected.

IT'S A RAINY AND COLD MORNING. The group gets up at 8:30 and starts getting ready for another day of work at the glacier. I prepare by putting waterproof on overalls and a Gore-Tex jacket over a fleece coat. I'm also wearing two pairs of socks, which I am told helps prevent blisters, and Italian leather boots with steel shanks, which help keep the crampons in place.

Our ride from the campsite to the glacier is a four-wheel-drive Toyota truck, and the researchers load it with ice-hiking gear, computers and other probe-debugging electronics, a $13 000 GPS receiver, sediment samplers, and weather-sensing instruments, plus an ample supply of Kit Kat bars and cheese sandwiches. After a tortuous drive along an unpaved road, it's just a short hike along an icy green lake up to the glacier.

Today the group is beginning a series of final tests to check whether the system will run smoothly when left by itself. Alistair Riddoch, a systems programmer who joined the project two years ago, is working on the base station's communications functions. He sits under a tent improvised with a blue tarp, tapping away at a notebook that he balances on his lap. "Come on!" he shouts, his eyes glued to the screen. "What's wrong with you?" Riddoch needs to make sure data are flowing properly: from the probes to the receiver to the base station to the campsite's computer and, finally, to the Southampton server. Somewhere along the way, though, the packets are getting stuck.

But such frustrations suddenly seem minor when Paritosh Padhy, a Ph.D. student in the group, radios to report that Elsaify, driving one of the vans back from the supermarket, was sideswiped by a truck. Out of control and heading straight for a lake bordering the road, Elsaify turned the van sharply, flipping it onto its side. Fortunately, the Egyptian postdoc is not hurt. As for the van, the rental company says it will send a replacement. Elsaify himself radios the group a while later, asking if they need him at the ice. Martinez responds: "Don't worry. Relax, have a cup of tea."

ABOUT A MONTH AFTER THE TRIP, I ask Martinez whether the system is running as planned. He says they have four probes sending data every day. The other units, however, have been out of communication for quite a while. But, he adds, the devices may be able to transmit their data later, during the winter, when the water surrounding them freezes and radio transmission gets better.

I also ask Martinez what he thinks will happen to these probes in the future. Will they end up at the lake in front of the glacier? Will they leak any toxic substances? "We may be picking them up with metal detectors one day," he wrote me in an e-mail. "Their impact on the environment would be pretty minimal, I think, because of the huge amounts of water around and the very slow decay of the integrated circuits and polyester."

And what's next on the agenda for Glacsweb? Martinez says his group hopes to spread probes over a more extensive area. One strategy for doing so—the subject of Padhy's Ph.D. thesis—is to improve communications by making the probes capable of exchanging data packets among themselves, forming what is known as an ad hoc mesh network. That way, a probe that is too far from the receiver could route its data through an intermediate probe. In addition,

"ICE TEAM, THIS IS GROUND TEAM." "THE GOATS ARE EATING THE WIRES OF THE WEATHER STATION"

Work continues largely uninterrupted until shortly after 5 p.m., when team members deploy their last probe. Now all the system's pieces are in place. Will it work?

Alas, no. Problems are still cropping up. The next day the group finds that the data sent by the base station on the glacier are not reaching the antenna and computer at the campsite. Martinez and Padhy talk on two-way radios, attempting to troubleshoot.

"We might have to adjust the antenna a little," Martinez, who is at the glacier, suggests.

"Okay—got it," Padhy replies from the campsite.

They send Elsaify, who has now earned something of a reputation as the team's stuntman, to adjust the antenna, which is on top of one of the cabins, along with a weather station that records data for the group. Elsaify climbs up the sloped roof, which is covered by a thick layer of grass. I am told this rather unconventional roofing material helps keep the cabin cooler during the summer. But there's something else atop the cabin—something I've never seen on a roof before: two goats, which belong to the campsite owners, live up there.

When Elsaify appears, the goats run in his direction and start biting his clothes and licking his hands. Up on the roof, he finds yet another surprise. "Ice team, this is ground team," Elsaify radios Martinez. "The goats are eating the wires of the weather station."

"Should we use another type of wire?" Martinez responds.

"I think it's better if we put the weather station on a taller pole," Elsaify suggests.

By the end of the day, with the antenna repositioned, data packets are flowing again. As everything seems to be working as expected, the group at the glacier prepares for a final task. They wrap a net around some 300 kilograms of equipment and wait for a helicopter to show up. The researchers hired it because their gear is too heavy to be hauled up and down the glacier. The helicopter lowers a cable, which Martinez hooks to the net, and then it flies away, carrying the equipment to the campsite [see photo, "Delivery by Air"].

Returning to the cabins, the group begins to pack and load the vehicles. The next day, after a major cabin cleanup, there's still time for a celebratory barbecue. "It was a good trip," Hart tells the group. Then it's time to go.

Martinez says, the group is also working on a system—this is Zou's main job now—to allow probes to report their locations. Each probe will emit brief radio pulses that a group of antennas on the glacier's surface will use to perform geometric calculations and determine the devices' locations. The position data may let the researchers understand how different portions of the glacier flow over time.

In terms of glaciological work, the group will also try to correlate the probe's measurements with other data about the Briksdalsbreen, such as GPS surveys of its surface, records of its position, and satellite imagery. The goal is to better understand how the ice and sediment interact to affect the motion of the glacier. That knowledge could help scientists improve their glacier models and simulations, perhaps giving us a better picture of what Earth's ice will do from now on.

As for the Briksdalsbreen, there's not much certainty about its future. If summer temperatures continue to increase in the region, the glacier is likely to shrink. Last year alone, it receded 96 meters, the largest annual retreat recorded since monitoring started in 1900. But things could revert yet again. This past winter, there was much more precipitation than in previous years, with about 12 meters of snow accumulating on top of the Jostedalsbreen. That means that the Briksdalsbreen may begin to charge ahead just as it's done before. Whatever happens, the Glacsweb group will be as close to the action as anyone can possibly get. ■

TO PROBE FURTHER

To see more photos of the Glacsweb team's fieldwork at Briksdalsbreen, visit http://www.spectrum.ieee.org.

For updates on the group's progress and real-time data from the glacier, see http://leo.ecs.soton.ac.uk/glacsweb.

More technical details on the Glacsweb system are available at http://eprints.ecs.soton.ac.uk/9997/01/martinez11.pdf.

For more on climate change and glaciers, see "As Climate Changes, So Do Glaciers," by Thomas V. Lowell, available at http://www.pnas.org/cgi/content/full/97/4/1351.