▶ **GIANT FLOATING ICE SHELF** off the Antarctic Peninsula marks the end of a great flow of ice. The flow begins with snowfall in the continental interior, which compacts into ice and slowly makes its way to the edge of the continent and into the ocean. As climate change accelerates the breakup of ice shelves, it can speed the movement of the "upstream" ice across the land and into the sea.

The Unquiet Ice

KEY CONCEPTS

- The land-based ice sheets of Greenland and Antarctica hold enough water to raise global sea level by more than 200 feet.
- A complex "plumbing system" of rivers, lakes and meltwater lies under the ice sheets. That water "greases" the flow of vast streams of ice toward the ocean.
- For millennia, the outgoing discharge of ice has been balanced by incoming snowfall. But when warming air or surface meltwater further greases the flow or removes its natural impediments, huge quantities of ice lurch seaward.
- Models of potential sea-level rise from climate change have ignored the effects of subglacial water and the vast streams of ice on the flow of ice entering the sea.

—The Editors

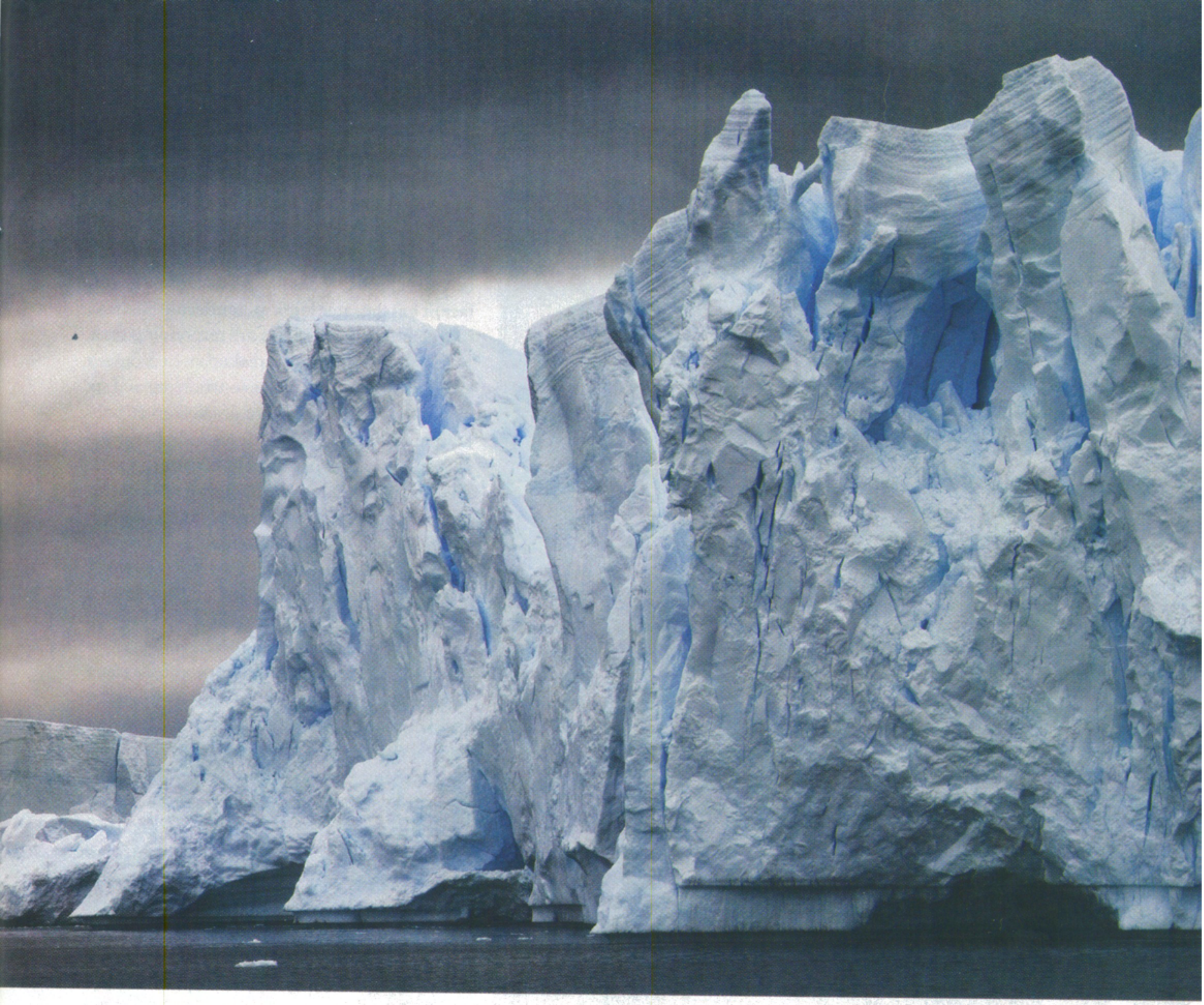
Abundant liquid water newly discovered underneath the world's great ice sheets could intensify the destabilizing effects of global warming on the sheets. Then, even without melting, the sheets may slide into the sea and raise sea level catastrophically

By Robin E. Bell

As our P-3 flying research laboratory skimmed above the icy surface of the Weddell Sea, I was glued to the floor. Lying flat on my stomach, I peered through the hatch on the bottom of the plane as seals, penguins and icebergs zoomed in and out of view. From 500 feet up everything appeared in miniature except the giant ice shelves—seemingly endless expanses of ice, as thick as the length of several football fields, that float in the Southern Ocean, fringing the ice sheets that virtually cover the Antarctic landmass. In the mid-1980s all our flights were survey flights: we had 12 hours in the air once we left our base in southern Chile, so we had plenty of time to chat with the pilots about making a forced landing on the ice shelves. It was no idle chatter. More than once we had lost one of our four engines, and in 1987 a giant crack became persistently visible along the edge of the Larsen B ice shelf, off the Antarctic Peninsula—making it abundantly clear that an emergency landing would be no gentle touchdown.

The crack also made us wonder: Could the ocean underlying these massive pieces of ice be warming enough to make them break up, even though they had been stable for more than 10,000 years?

Almost a decade later my colleague Ted Scambos of the National Snow and Ice Data Center in Boulder, Colo., began to notice a change in weather-satellite images of the same ice shelves that I had seen from the P-3. Dark spots, like freckles, began to appear on the monotonously white ice. Subsequent color images showed the dark spots to be areas of brilliant dark blue. Global climate change was warming the Antarctic Peninsula more rapidly than any other place on earth, and parts of the Larsen B ice surface were becoming blue ponds of meltwater. The late glaciologist Gordon de Q. Robin and Johannes Weertman, a glaciologist at



Northwestern University, had suggested several decades earlier that surface water could crack open an ice shelf. Scambos realized that the ponding water might do just that, chiseling its way through the ice shelf to the ocean waters below it, making the entire shelf break up. Still, nothing happened.

Nothing, that is, until early in the Antarctic summer of 2001–2002. In November 2001 Scambos got a message he remembers vividly from Pedro Skvarca, a glaciologist based at the Argentine Antarctic Institute in Buenos Aires who was trying to conduct fieldwork on Larsen B. Water was everywhere. Deep cracks were forming. Skvarca was finding it impossible to work, impossible to move. Then, in late February 2002, the ponds began disappearing, draining—the water was indeed chiseling its way through the ice shelf. By mid-March remarkable satellite images showed that some 1,300 square miles of Larsen B, a slab bigger than the state of Rhode Island, had fragmented. Nothing remained of it except an armada of ice chunks, ranging from the size of Manhattan to the size of a microwave oven. Our emergency landing site, stable for thousands of years, was gone. On March 20 Scambos's striking satellite images of the collapsing ice shelf appeared above the fold on the front page of the *New York Times* [*see sidebar at bottom of page 63*].

Suddenly the possibility that global warming might cause rapid change in the icy polar world was real. The following August, as if to underscore that possibility, the extent of sea ice on the other side of the globe reached a historic low, and summer melt on the surface of the Greenland ice sheet exceeded anything previously observed. The Greenland meltwaters, too, gushed into cracks and open holes in the ice known as moulins—and then, presumably, plunged to the base of the ice sheet, carrying the summer heat with them. There, instead of mix-

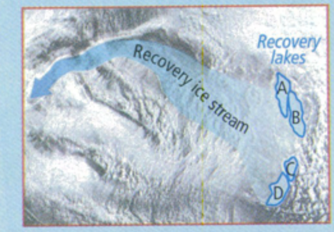
▲ JUST ADD ICE: No melting needed. Water level in the glass at the left rises when ice is added (*center*). When the ice melts, the water level remains unchanged (*right*). Global sea level rises the same way when ice slides off land and into the ocean.

SEBASTIAN COPELAND www.antarcticabook.com (*ice shelf*); BRIAN MARANAN PINEDA (*glasses*)

[THE THREAT]

World's Greatest Ice Sheets

Three ice sheets, one covering most of Greenland and two covering Antarctica (separated by the Transantarctic Mountains), hold 99 percent of the ice that would raise sea levels if global warming caused it to melt or go afloat (the other 1 percent is locked up in mountain glaciers). The Greenland ice sheet lies almost entirely on bedrock and flows into the ocean roughly half as meltwater and half as glacial ice. In Antarctica most of the ice flows into the ocean from regions of relatively fast-moving solid ice called ice streams that drain the ice from slower-moving regions.



◂ Under the ice in Antarctica investigators have discovered an extensive network of lakes and rivers; the map above shows the "subglacial" positions of several such features. The Recovery lakes (*inset at left*), four subglacial lakes discovered by the author and designated A, B, C and D, are the first lakes known to contribute to the start-up of a fast-moving stream of ice. The Recovery ice stream flows some 500 miles to the Filchner ice shelf.

➡ ON THE WEB

Antarctica has never looked so good as it does in a new digital map that combines 1,100 satellite images into a seamless mosaic of the entire continent. Check out http://lima.usgs.gov

ing with seawater, as it did in the breakup of Larsen B, the water probably mixed with mud, forming a slurry that was smoothing the way across the bedrock—"greasing," or lubricating, the boundary between ice and rock. But by whatever mechanism, the giant Greenland ice sheet was accelerating across its rocky moorings and toward the sea.

More recently, as a part of the investigations of the ongoing International Polar Year (IPY) [*see sidebar on page 66*], my colleagues and I have been tracing the outlines of a watery "plumbing" system at the base of the great Antarctic ice sheets as well. Although much of the liquid water greasing the skids of the Antarctic sheets probably does not arrive from the surface, it has the same lubricating effect. And there, too, some of the ice sheets are responding with accelerated slippage and breakup.

Why are those processes so troubling and so vital to understand? A third of the world's population lives within about 300 feet above sea level, and most of the planet's largest cities are situated near the ocean. For every 150 cubic miles of ice that are transferred from land to the sea, the global sea level rises by about a 16th of an inch. That may not sound like a lot, but consider the volume of ice now locked up in the planet's three greatest ice sheets. If the West Antarctic ice sheet were to disappear, sea level would rise almost 19 feet; the ice in the Greenland ice sheet could add 24 feet to that; and the East Antarctic ice sheet could add yet another 170 feet to the level of the world's oceans: more than 213 feet in all [*see box at top of opposite page*]. (For comparison, the Statue of Liberty, from the top of the base to the top of the torch, is about 150 feet tall.) Liquid water plays a crucial and, until quite recently, underappreciated role in the internal movements and seaward flow of ice sheets. Determining how liquid water forms, where it occurs and how climate change can intensify its effects on the world's polar ice are paramount in predicting—and preparing for—the consequences of global warming on sea level.

Rumblings in the Ice

Glaciologists have long been aware that ice sheets do change; investigators simply assumed that such changes were gradual, the kind you infer from carbon 14 dating—not the kind, such as the breakup of the Larsen B ice shelf, that you can mark on an ordinary calendar. In the idealized view, an ice sheet accumulates snow—originating primarily in evaporated seawater—at its center and sheds a roughly equal mass to the ocean at its perimeter by melting and calving icebergs. In Antarctica, for instance, some 90 percent of the ice that reaches the sea is carried there by ice streams, giant conveyor belts of ice as thick as the surrounding sheet (between 3,500 and 6,500 feet) and 60 miles wide, extending more than 500 miles "upstream" from the sea. Ice streams moving through an ice sheet leave crevasses at their sides as they lurch forward. Near

MAPPING SPECIALISTS

the seaward margins of the ice sheet, ice streams typically move between 650 and 3,500 feet a year; the surrounding sheet hardly moves at all.

[THE CONSEQUENCES]

Inundation from the Ice Sheets

If today's ice sheets disappear, the resulting rise in global sea level would transform coastlines around the world; the effects on the Florida coastline are shown below. Actually, if climate change caused one ice sheet to disappear, parts of others would do so as well, and the effects on sea level would be even greater than what is depicted here.

▲ **West Antarctic ice sheet** holds enough ice to raise sea level globally by **19 feet.** Coastal and south Florida would be flooded.

▲ **Greenland ice sheet** is the equivalent of **24 feet** of global sea level. Flooding in Florida would be similar to the West Antarctic case.

▲ **East Antarctic ice sheet** could raise sea level globally by **170 feet.** Virtually the entire state of Florida would be underwater.

But long-term ice equilibrium is an idealization; real ice sheets are not permanent fixtures on our planet. For example, ice-core studies suggest the Greenland ice sheet was smaller in the distant past than it is today, particularly during the most recent interglacial period, 120,000 years ago, when global temperatures were warm. In 2007 Eske Willerslev of the University of Copenhagen led an international team to search for evidence of ancient ecosystems, preserved in DNA from the base of the ice sheet. His group's findings revealed a Greenland that was covered with conifers as recently as 400,000 years ago and alive with invertebrates such as beetles and butterflies. In short, when global temperatures have warmed, the Greenland ice sheet has shrunk.

Today the snowfall on top of the Greenland ice cap is actually increasing, presumably because of changing climatic patterns. Yet the mass losses at its edges are big enough to tip the scales to a net decline. The elevation of the edges of the ice sheet is rapidly declining, and satellite measurements of small variations in the force of gravity also confirm that the sheet margins are losing mass. Velocity measurements indicate that the major outlet glaciers—ice streams bounded by mountains—are accelerating rapidly toward the sea, particularly in the south. The rumblings of glacial earthquakes have become increasingly frequent along the ice sheet's outlet glaciers.

Like the Greenland ice sheet, the West Antarctic ice sheet is also losing mass. And like the Greenland ice sheet, it disappeared in the geologically recent past—and, presumably, could do so again. Reed P. Scherer of Northern Illinois University discovered marine microfossils at the base of a borehole in the West Antarctic ice sheet that only form in open marine conditions. The age of the fossils showed that open-water lifeforms might have lived there as recently as 400,000 years ago. Their presence implies that the West Antarctic ice sheet must have disappeared during that time.

Only the ice sheet in East Antarctica has persisted through the earth's temperature fluctuations of the past 30 million years. That makes it by far the oldest and most stable of the ice sheets. It is also the largest. In many places its ice is more than two miles thick, and its volume is roughly 10 times that of the ice sheet in Greenland. It first formed as Antarctica drew apart from South America some 35 million years ago and global levels of carbon dioxide declined. The East Antarctic ice sheet appears to be growing slightly in the interior, but observers have detected some localized losses in ice mass along the margins.

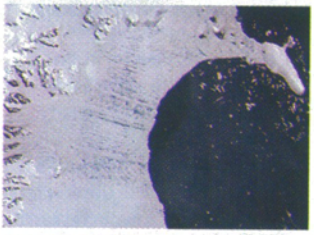
Accelerating Losses

What processes could lead to the net mass losses observed today in the ice sheets of Greenland and the West Antarctic? As one might expect, the losses in both ice sheets ultimately stem from a speedup of the ice streams and outlet glaciers that convey mass to the oceans. The extra water volume displaced by that extra ice mass, of course, is what causes global sea level to rise. (It is probably worth mentioning that the breakup or melting of floating ice shelves has no net effect on sea level. The reason is that floating ice displaces a volume of water equal to its own weight; when it melts, its weight does not change, but its new, smaller volume now fits exactly into the same volume that it displaced when it was ice.)

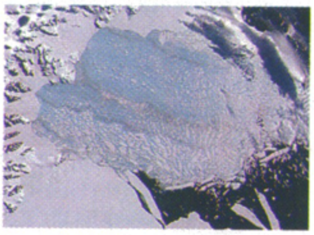
In the past five years investigators have developed two important new insights about the processes that can trigger accelerating flows. First, an ice stream can speed up quite suddenly as its base encounters mud, meltwater or even deep lakes that intermittently grease its way. Second, if seagoing ice shelves (floating in the Southern Ocean around Antarctica) or ice tongues (long but narrow ice shelves linked to single outlet glaciers, common in the fjords of Greenland) break up, their enormous masses no longer hold back the flow of ice streams. The glaciers feeding the Larsen B ice shelf, for instance, accelerated dra-

THE BREAKUP OF LARSEN B

Satellite images record the sudden breakup of a Rhode Island–size segment of an ice shelf off the Antarctic Peninsula known as Larsen B. The small dark regions on the ice surface in the upper image (*below*) are ponds of meltwater that formed in unusually warm air; the light-blue region in the bottom image is made up of the fragments of the original ice-shelf segment.



January 31, 2002

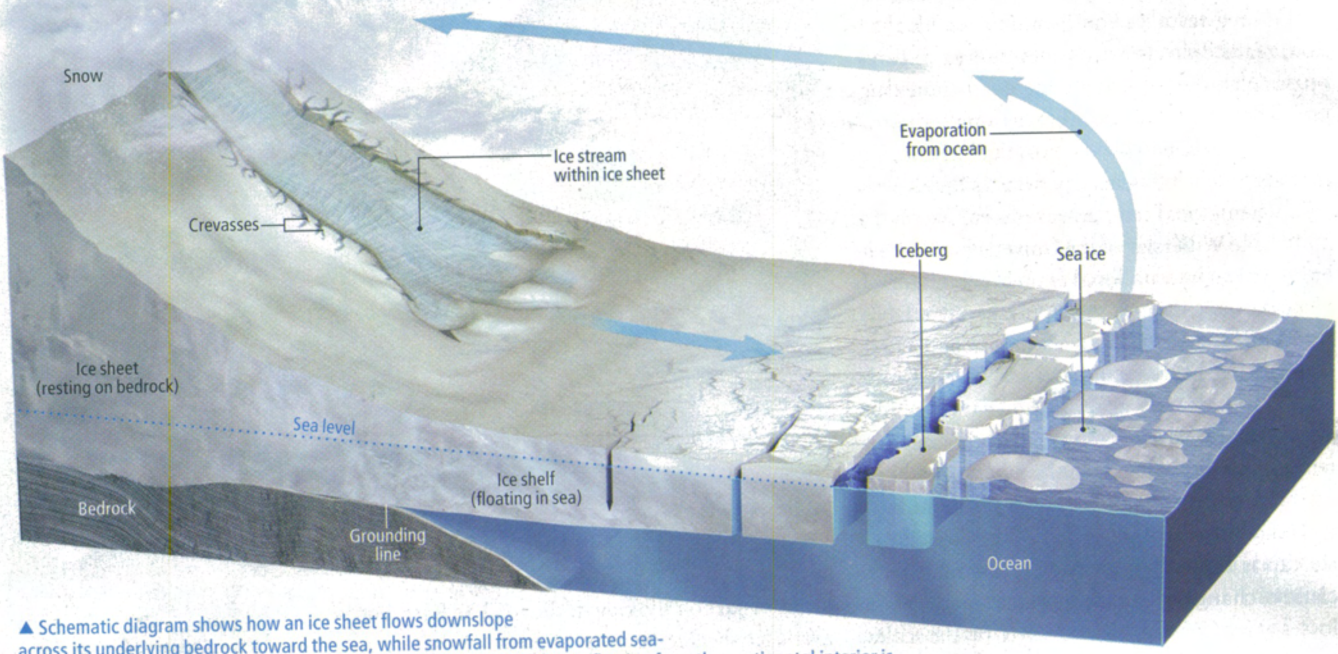


March 7, 2002

MAPPING SPECIALISTS (Florida maps); NASA/GODDARD SPACE FLIGHT CENTER SCIENTIFIC VISUALIZATION STUDIO (Larsen B images)

[ICE MOVEMENT 101]

Steady State in a Frozen Country



▲ Schematic diagram shows how an ice sheet flows downslope across its underlying bedrock toward the sea, while snowfall from evaporated seawater replenishes part or all of the ice mass at its surface. Most of the ice flowing from the continental interior is carried to the sea by ice streams, relatively fast-moving conveyor belts of ice that break away from the surrounding sheet; the ice sheet travels seaward as well, albeit much more slowly. Once the base of the moving ice leaves its "grounding line," the floating ice is called an ice shelf, and it displaces a mass of water equal to its weight, raising the sea level accordingly. Throughout most of the past several millennia those processes did not raise sea level or shrink ice sheets because seawater evaporation and inland snowfall roughly balanced the discharge of ice into the sea.

matically after the ice shelf disintegrated in 2002. Thus "uncorked," the land-based ice streams and glaciers that were formerly held in check will likely speed their seaward migration, ultimately adding to the total volume of the sea.

Glaciologists have long recognized a third kind of trigger for accelerating ice-sheet flow, which is closely related to the second. Just as glaciers sped up when Larsen B disintegrated, an ice sheet accelerates if warm ocean currents thin an ice shelf into which the ice sheet flows. In the Amundsen Sea sector of West Antarctica, the surface of the ice sheet has dropped by as much as five feet a year and the sheet has sped up by 10 percent, both apparently in response to the thinning of the ice shelf.

"Greasing the Skids"

The breakup of the Larsen B ice shelf and the equally alarming association between the sudden drainage of surface water in Greenland and accelerating flows in the ice sheet have prompted a number of my colleagues and me to focus our studies on the role of liquid water within the ice sheets. We are finding that liquid water has helped the seaward ice movement keep pace with interior snowfall, maintaining the dynamic equilibrium of the ice sheets in some cases for millions of years. In West Antarctic ice streams, for instance, lubricating water melts out of the ice at the base of the ice sheet because of the heat from friction between moving ice and the underlying rock. In East Antarctica water melts at the base of the ice sheet primarily because of heat from the underlying continental crust. The ice is so thick in the East Antarctic that it acts as an insulating blanket, capturing the geothermal heat. All that subglacial water introduces enormous potential for instability in the ice movements. Events such as the breakup of Larsen B are far more likely than glaciologists ever thought possible to accelerate the flow rates of upstream ice.

The idea that the base of the ice sheets could melt first arose in 1955, when Gordon Robin suggested that geothermal heat could lead to extensive subglacial water, provided the overlying ice sheet was thick enough to insulate its base from its cold surface. But his suggestion was not confirmed until the 1970s and then in a startling way. By that time, ice-penetrating radar had been developed to the point that it could "see" through an ice sheet to the underlying surface. Robin organized an American, British and Danish team to collect such radar data from aircraft flown back and forth over the Antarctic conti-

[THE AUTHOR]

Robin E. Bell is director of the ADVANCE program at the Earth Institute at Columbia University. She is also a Doherty Senior Research Scientist at Columbia's Lamont-Doherty Earth Observatory, where she directs a major research program in Antarctica. Bell studies the mechanisms of ice-sheet collapse, as well as the chilly environments underneath the Antarctic ice sheet, and she has led seven expeditions to Antarctica. She is chair of the Polar Research Board of the National Academies and has served as vice chair of the International Planning Group for the International Polar Year.

nent. Most of the time the radar return signals on the onboard oscilloscope were irregular, as one would expect for signals bouncing off hills and valleys covered by thick ice. In some places, though, it looked as if someone had drawn a straight line across the oscilloscope. The radar energy was being reflected by a surface more like a mirror. Having begun his career as a sailor, Robin concluded that the mirrorlike surface must be water underneath the ice sheet. The radar data showed that some of the subglacial "mirrors" continued for almost 20 miles, but Robin had no sense of their true scale or depth.

Once more, Robin had to wait almost two decades for new technology. In the 1990s the European Space Agency completed the first comprehensive mapping of the ice surface. Looking at the image, one is instantly struck by a flat region in the center of the ice sheet. Some two miles above the water, Vostok Station, the Russian Antarctic base, looks onto an ice surface that outlines the flat contours of the lake. The size of Lake Vostok now became obvious; it is as big as Lake Ontario.

Subglacial Plumbing

The discovery of subglacial lakes has fundamentally changed the way investigators think about water underneath the ice. It is not rare but rather both abundant and widespread. More than 160 subglacial Antarctic lakes have been located so far. Their combined volume is nearly 30 percent of the water in all the surface lakes elsewhere on the planet. My studies of East Antarctica's Lake Vostok in 2001 revealed a fairly stable system. In the past 50,000 years the lake water has slowly exchanged with the overlying ice sheet through melting and freezing. Of course, in the more distant past things might not have been so quiescent: geologic evidence shows that subglacial lakes can drain out suddenly, in a single belch, releasing tremendous amounts of water under the ice sheet or directly into the ocean. Immense valleys more than 800 feet deep (enough to swallow the Woolworth Building in New York City) encircle the entire Antarctic continent: the scars from giant floods.

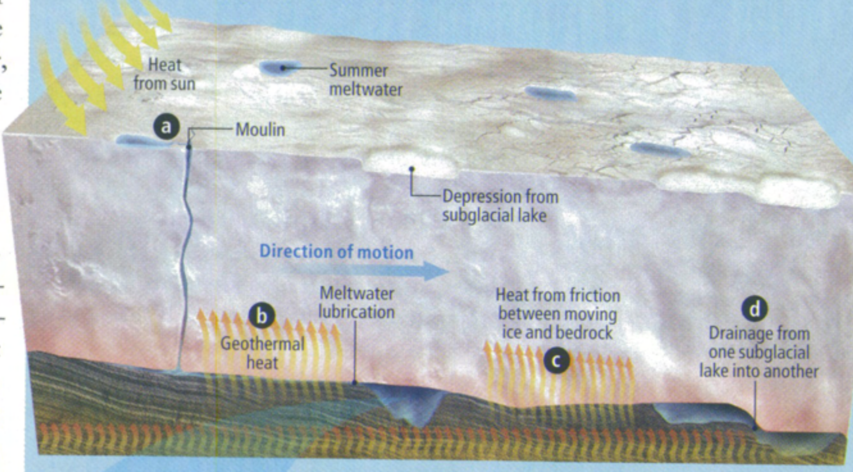
But Vostok and the other subglacial lakes were

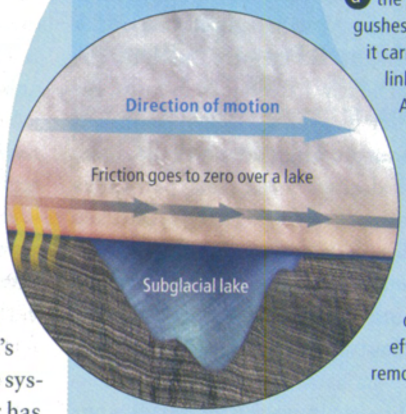
➡ For an animated movie of one subglacial lake draining into another, check out **http://svs.gsfc.nasa.gov/search/Scientist/HelenAmandaFricker.html**

[DISTURBING EQUILIBRIUM]

Not So Steady, Not So Frozen

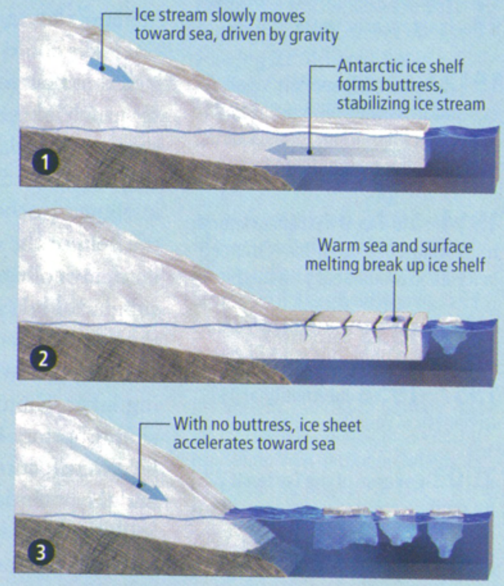
Newly discovered networks of liquid water in and under ice sheets may make the ice far less stable than investigators previously thought—and far more sensitive to the effects of global warming.





▲ Slippery Slope

Water under the ice, no matter how it gets there, can lubricate the contact between bedrock and the bottom of an ice sheet. In Greenland ⓐ the warming Arctic climate has led to surface meltwater that gushes into crevasses, or moulins, and drains along with the solar heat it carries to the base of the ice sheet. The drainage has been strongly linked to the acceleration of ice movement toward the sea. In Antarctica, drainage of surface meltwater is relatively unimportant to ice-sheet movement, but water accumulates at the base of the ice sheets in other ways. It melts out of the bottom of the ice from geothermal ⓑ or frictional heat ⓒ that is trapped by the insulating thickness of the ice itself. It is also present as an extensive system of subglacial rivers and lakes that drain into one another ⓓ. In Antarctica the water at the base of the ice sheets is almost entirely isolated from the direct, short-term effects of global warming, but its lubricating effect makes the sheets sensitive to any disturbance that could remove impediments, such as buttressing ice shelves, to their flow.



▸ Help! I'm Losing My Buttress!

Slippery ice streams, particularly in West Antarctica, would likely slide rapidly into the sea under gravity if it were not for the bracing effect of the floating ice shelves that surround the continent ❶. Relatively warm air and ocean water in recent years, however, have caused ice shelves to thin and, in the case of Larsen B, to break up ❷. With its buttress gone, a moving ice stream is no longer prevented from crashing into the sea and causing a rapid rise in sea level ❸.

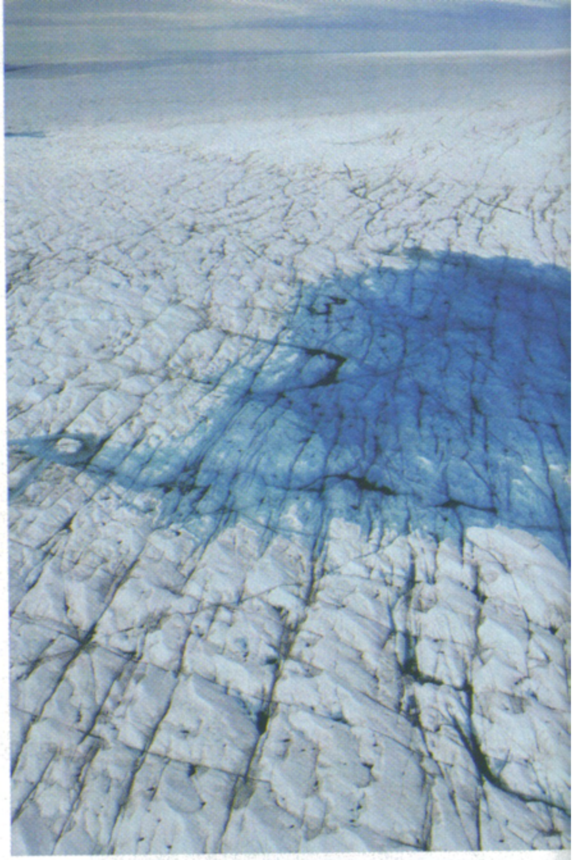
thought to be natural museums, isolated from the rest of the world millions of years ago. Then in 1997 the first hint that such subglacial flooding still takes place came from West Antarctica. The surface of the ice sheet sagged by more than 20 inches in three weeks. The only explanation that made any sense was that water was draining out of a subglacial lake, causing the overlying ice to sink. A group led by Duncan J. Wingham of University College London also measured elevations for that year over most of the East Antarctic ice. In one area the ice sheet sagged about 10 feet in 16 months, while 180 miles downslope two areas rose by about three feet. Once again, the explanation was obvious: a subglacial river had drained the water from one lake and filled two lakes downstream.

A little more than a year ago Helen A. Fricker of the Scripps Institution of Oceanography in La Jolla, Calif., was studying the precise measurements of surface elevations made by the ICESat spacecraft. Just before Fricker left for a Memorial Day weekend of sailing with her family, one of the profiles over the ice sheet diverged radically. A region along the margin of one of the largest West Antarctic ice streams had collapsed—a fall of nearly 30 feet in 24 months. Returning from her weekend, Fricker examined the ice surface surrounding her new lake, Lake Engelhardt—and quickly realized that it was only one in a series of cascading subglacial lakes. Large quantities of water draining through the plumbing system underneath major ice streams have turned out to be one more agent of rapid change in the flow of an ice stream.

Lake Effect

At about that same time, suspecting that subglacial lakes could affect ice-sheet stability, I realized that new satellite imagery made it easy to spot such lakes. Furthermore, models of the ice sheet predicted that one more set of large lakes might still remain to be discovered. I was intrigued by the chance to find them. So with the help of the new imagery and ICESat laser data, my colleagues and I discovered four new subglacial lakes, three of them larger than all the other lakes except Vostok.

Compared with subglacial rivers and collapsing lakes, though, "my" four new lakes were simply boring. All the exciting new results in my field were focusing on rapidly changing polar ice and the potential for ice sheets to raise sea level. Still, the lakes kept nagging me. They were far from the center of the ice sheet, where most large lakes occur. Crevasses and cracks in the ice formed along the edges of one lake; I could see the crevasse fields in satellite images.



JAMES BALOG *Aurora Photos*

Crevasses, as I mentioned earlier, form when an ice stream moves rapidly forward within an ice sheet. Looking at the imagery, I could see flow lines in the ice sheet, which connected the region of crevasses to a fast-flowing ice stream known as Recovery. Satellite interferometry showed that the Recovery ice stream begins accelerating at the lakes. Before the ice sheet crosses the lakes, its velocity is no more than about 10 feet a year. On the other side of the lakes the ice sheet accelerates to between 65 and 100 feet a year. So the lakes appear to be triggering the flow of an ice stream within the ice sheet. The finding is the first time subglacial lakes have been directly linked to accelerated surface flow.

My colleagues and I are still not certain exactly why the linkage occurs at all. Perhaps the lakes are slowly leaking out of their basins, thereby supplying water to lubricate the base of the ice sheet. Or the lake water might warm the base of the ice sheet as it crosses the lake, making it easier for the ice sheet to speed up on the far side of the lake.

International Polar Year

The understanding of water in the ice sheets and subglacial lakes has changed dramatically in the past two years. But that understanding is by no means complete. One of the major goals of the International Polar Year is to gauge the status of

INTERNATIONAL POLAR YEAR

When the Larsen B ice shelf collapsed in March 2002, polar scientists realized that their timetable for action on global warming would be measured in months and years, not decades. Work began at once to organize the fourth International Polar Year (IPY), which runs through March 2009. More than 50,000 scientists from more than 60 nations have joined the effort to understand the polar environments. Here are some of the most important antecedents to the IPY:

1872–1874 Austro-Hungarian North Pole expedition, co-commanded by Karl Weyprecht

1882–1883 Weyprecht's dream of coordinated international cooperation in polar study is realized in the first International Polar Year (IPY)

1911 Roald Amundsen's expedition is the first to reach the South Pole

1912 Robert Falcon Scott's expedition reaches the South Pole just weeks after Amundsen's; Scott's party perishes on the return trip

1914–1916 Ernest Shackleton's trans-Antarctic expedition is trapped in ice, then dramatically rescued

1932–1933 Second IPY

1957–1958 International Geophysical Year (third IPY)

2002 Collapse of the Larsen B ice shelf

2007–2009 Fourth IPY

▲ **ABUNDANCE OF SURFACE WATER** melted by warm air above the Greenland ice sheet is dramatically portrayed in these two photographs. The summer ice surface has become dotted with lakes, such as the one above left—several hundred yards across—and riven with crevasses. A torrent of meltwater pours into a moulin, a deep opening in the ice (*above*), and drills its way to the bottom of the ice sheet, where it helps to speed the ice flow. The floating ice shelves of Antarctica are also accumulating surface meltwater.

the polar ice sheets and determine how they will change in the near future. The recent report by the Intergovernmental Panel on Climate Change (IPCC) emphasizes that the biggest question mark in predicting the effects of global warming is the uncertainty about the future of the polar ice sheets. None of the climate models used to date takes account of such major features as ice streams, and none of them incorporates an accurate representation of the bottom of an ice sheet.

For those reasons alone, predicting future sea-level change from the current climate models greatly underestimates the future contribution of the polar ice sheets to sea-level rise. But updating the models by quantifying the ice movements still demands intensive research efforts. Simply, if glaciologists do not know what goes on at the bottom of the ice sheets, no one can predict how ice sheets will change with time. And the key questions for making such predictions are: Just where is the subglacial water? How does it move? How does it affect the movement of the ice sheets?

The IPY offers an excellent opportunity to find out. By mobilizing international scientific teams and logistics, investigators will be able to deploy a new generation of airborne radar for mapping subglacial water. New gravity instrumentation, originally developed for the mining industry, will be adapted to estimate the volume of water in the subglacial lakes. Precise elevation measurements of the ice surface will enable water movement to be monitored. Newly installed seismometers will listen for glacial earthquakes.

In Greenland, glaciologists will install instruments to measure the movement of the ice sheet through the major outlet glaciers. The Center for Remote Sensing of Ice Sheets in Lawrence, Kan., will deploy an unmanned airborne vehicle to systematically map the water at the base of the ice sheet. In East Antarctica, my group will fly a Twin Otter (a two-engine, propeller-driven plane) over the Recovery lakes and the unexplored Gamburtsev Mountains to understand why the lakes form and how they are triggering the ice stream. At the same time, a U.S.-Norwegian team, including Ted Scambos, will cross the Recovery lakes, measuring the velocity of the ice sheet and its temperature gradient along the top. A Russian team will seek to sample Lake Vostok; an Italian team will study Lake Concordia, near the French-Italian station in East Antarctica; and a British team will survey a lake in the Ellsworth Mountains in West Antarctica.

All those efforts—in conditions that remain daunting to human work—reflect the consensus and urgency of the international scientific community: understanding the changing ice sheets and the water that governs their dynamism is crucial to the future of our society. ■

➡ MORE TO EXPLORE

Glaciology: Lubricating Lakes. Jack Kohler in *Nature*, Vol. 445, pages 830–831; February 22, 2007.

Large Subglacial Lakes in East Antarctica at the Onset of Fast-Flowing Ice Streams. Robin E. Bell, Michael Studinger, Christopher A. Shuman, Mark A. Fahnestock and Ian Joughin in *Nature*, Vol. 445, pages 904–907; February 22, 2007.

An Active Subglacial Water System in West Antarctica Mapped from Space. Helen Amanda Fricker, Ted Scambos, Robert Bindschadler and Laurie Padman in *Science*, Vol. 315, pages 1544–1548; March 16, 2007.

Ice Sheets. Charles R. Bentley, Robert H. Thomas and Isabella Velicogna. Section 6A in *Global Outlook for Ice and Snow*, pages 99–114; United Nations Environment Programme, 2007. Available at **www.unep.org/geo/geo_ice**