CRACKS IN THE ARMOR?

BY ROBERT MONROE

RULE NO. 1 FOR BEHAVIOR around "Loose Tooth": Maintain half a football field's distance from its rift zones at all times.

As the name of the soon-to-be iceberg suggests, there are some stability issues involved here. Loose Tooth is in the process of breaking away from Antarctica's Amery Ice Shelf as part of an occurrence known as iceberg calving. In many spots, the exposed portions of the rifts on either side of the tooth drop nearly 40 meters (130 feet) to the ocean surface, making for a long fall.

Jeremy Bassis, a fifth-year graduate student at Scripps Institution of Oceanography, is one of the few who has actually stepped up to Loose Tooth's rift and peered down into the chasm. He did it while tethered to a helicopter during a trip to set up GPS and seismic equipment to track the rift's progress. He describes Loose Tooth, credibly, as "a pretty spectacular place to be."

Loose Tooth is also proving to be a remarkable repository of information about a natural process that may be influenced by anthropogenic climate change. Almost three years after Bassis's first trip there, he and glaciologist Helen Amanda Fricker, his advisor at Scripps's Cecil H. and Ida M. Green Institute of Geophysics and Planetary Physics, are uncovering important details about ice shelf rifting while witnessing the birth of

Researchers from Australia's Commonwealth Scientific and Industrial Research Organisation observe an ice cave where the Amery Ice Shelf meets the Southern Ocean.

A Breakdown on Iceberg Calving from Antarctica's Cutting Edge

Left, *A solar-powered seismometer package and GPS antenna recorded movements of Loose Tooth over a 53-day stretch during the 2004–05 austral summer. Scripps seismologist Dennis Darnell (below) performed the installation.*

Helen Amanda Fricker

an iceberg. "Even though iceberg calving is such a huge component of the Antarctic ice sheet's mass budget, we don't really know much about the mechanisms involved," Fricker said. "We don't know what the major driving forces behind the rifting process are."

But two studies the pair recently published are starting to provide answers. Fricker and Bassis, working with Scripps's Bernard Minster, the University of Tasmania's Richard Coleman, and the Australian Antarctic Division's Neal Young, have discovered new information about the rifting process using a combination of well-established technologies.

SEASONAL BURSTS OF BREAKING

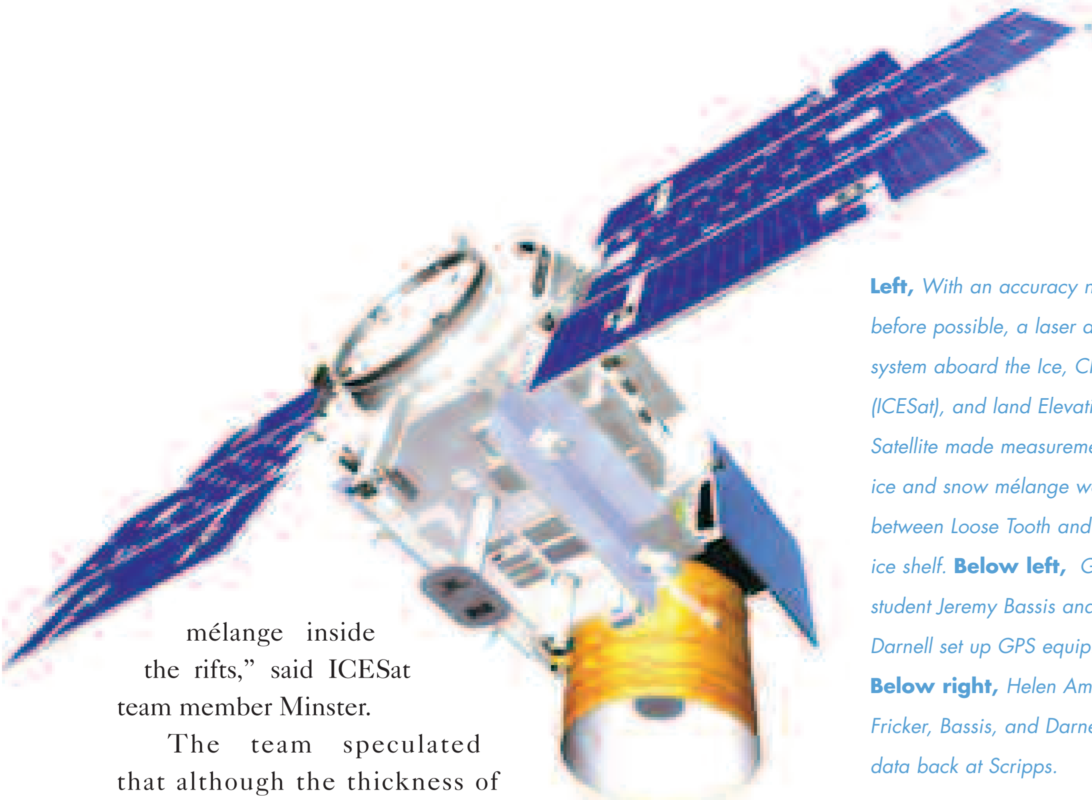
The GPS receivers and seismometers installed in December 2002 by Bassis and Coleman, and again two years later by Scripps seismologist Dennis Darnell and Australian colleagues, made the first second-by-second, millimeter-by-millimeter records of an iceberg slowly detaching from the main ice shelf. They revealed that Loose Tooth, a 30-square-kilometer (11.6-square-mile) block of ice in East Antarctica, is breaking away not in continuous fashion but in bursts of activity each lasting four hours and spaced anywhere from 10 days to three weeks apart.

On longer time scales, Fricker and her colleagues also found that seasonal changes are more significant than scientists had previously believed. The team used imagery from a variety of satellites to track the growth of the rifts on either side of Loose Tooth. An eight-year run of observations indicated that rifting takes place faster in the austral spring and summer (between October and March) than in winter and fall.

The seasonality of the rift's propagation suggested that a variety of factors are at work. "Mélange" is the name given to the mixture of snow and ice that collects in the gap between the rift walls as the rifts widen and propagate. Scientists have thought for several years that mélange might "glue together" the sides of the rift, which has led to speculation that climate warming, whether anthropogenic or natural, could cause an acceleration in the iceberg detachment process if the "glue" begins to melt and loosen. A new tool to monitor the mélange has recently been provided by a new NASA mission—the Ice, Cloud, and land Elevation Satellite (ICESat)—launched in January 2003. A sophisticated instrument known as GLAS (Geoscience Laser Altimeter System) and borne on ICESat showed that the mélange is 85 meters (278 feet) thick and has remained so from season to season.

The observation is remarkable in itself considering the instrument flies 600 kilometers (370 miles) above Earth's surface at a speed of eight kilometers (five miles) per second. While doing so, GLAS fires laser pulses at Earth's surface, inferring elevations by measuring the round-trip travel times of these pulses to better than a fraction of a billionth of a second.

"The ICESat mission has provided us with much unprecedented information about the ice topography across rifts, and has given us first-time estimates of the thickness of the



Left, *With an accuracy never before possible, a laser altimeter system aboard the Ice, Cloud, (ICESat), and land Elevation Satellite made measurements of the ice and snow mélange wedged between Loose Tooth and its parent ice shelf.* **Below left,** *Graduate student Jeremy Bassis and Dennis Darnell set up GPS equipment.* **Below right,** *Helen Amanda Fricker, Bassis, and Darnell crunch data back at Scripps.*

mélange inside the rifts," said ICESat team member Minster.

The team speculated that although the thickness of the mélange doesn't change from winter to summer, its role in controlling the rifting process might. It may act as a glue in colder months as its mechanical strength increases through freezing and as a wedge in warmer months when conditions soften the icy combination, preventing the rift from closing up. Another possibility suggested by the researchers is that the rifting process might be sensitive to seasonal changes in ocean circulation and ocean temperature. A seasonal model of the Southern Ocean's circulation beneath Amery Ice Shelf is a "work in progress" by Australian colleagues, according to Fricker.

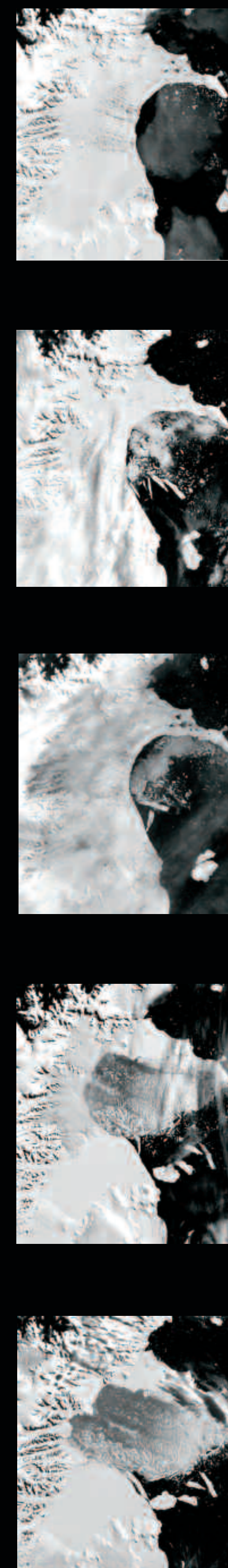
"It's improving our understanding of the seasonality of rifting, and creating better models of rifting processes will enable more realistic predictions to be made of ice shelf collapse under climate warming scenarios," Coleman said. "This contributes to reducing our uncertainty in making projections of sea-level change."

FULL-TIME OBSERVATION FOR LONG-TERM ANSWERS

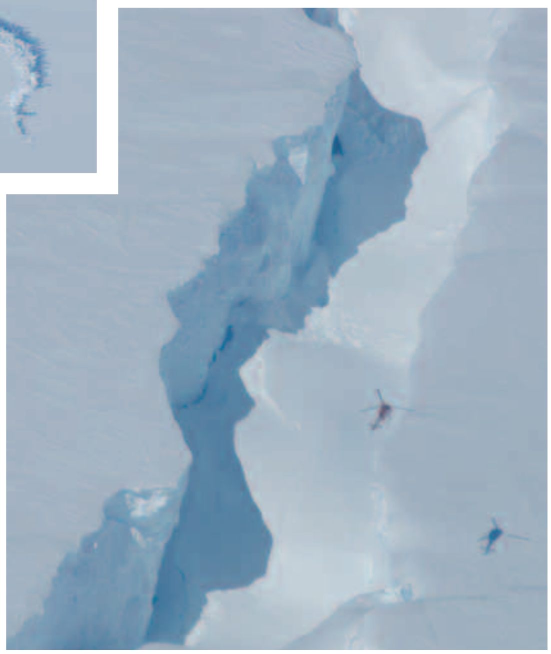
For several years, scientists have wondered whether there is a connection between iceberg calving and global warming. Is the production of large icebergs by ice shelves merely a cyclical event that counterbalances the constant addition of mass from snowfall? Will a rise in global temperatures result in an increase in the number of icebergs that detach from ice shelves—signaling that global warming has knocked the ice balance out of whack? If so, could the landlocked ice sheets currently held in place by ice shelves like Amery melt and discharge into the ocean in the foreseeable future, triggering a huge rise in sea level?

The speculation has accelerated in

Top to bottom, *The sudden collapse of the Larsen B Ice Shelf in 2002 caught the science world by surprise.*



Below, *A mere sliver clinging to the continent, the 30-square-kilometer (11.6-square-mile) Loose Tooth and its fissures dwarf a passing helicopter.* **Right,** *The midnight sun hovers over an Amery Ice Shelf encampment.*



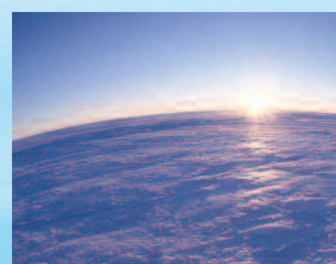
recent years, most publicly in 2002 when most of the Larsen B Ice Shelf on the other side of the Antarctic continent collapsed over a 35-day period. Approximately 3,250 square kilometers (1,255 square miles) of ice sheet, an area larger than Rhode Island, shattered into an armada of small icebergs bobbing in the ocean.

"You had an ice shelf there, and suddenly it was gone," Fricker said. "People then realized that these ice shelves can collapse on very short time scales."

This doesn't necessarily mean that the same thing is going to happen on the Amery. Many ice shelves have remained intact since the last glacial period 12,000 years ago while others have come and gone.

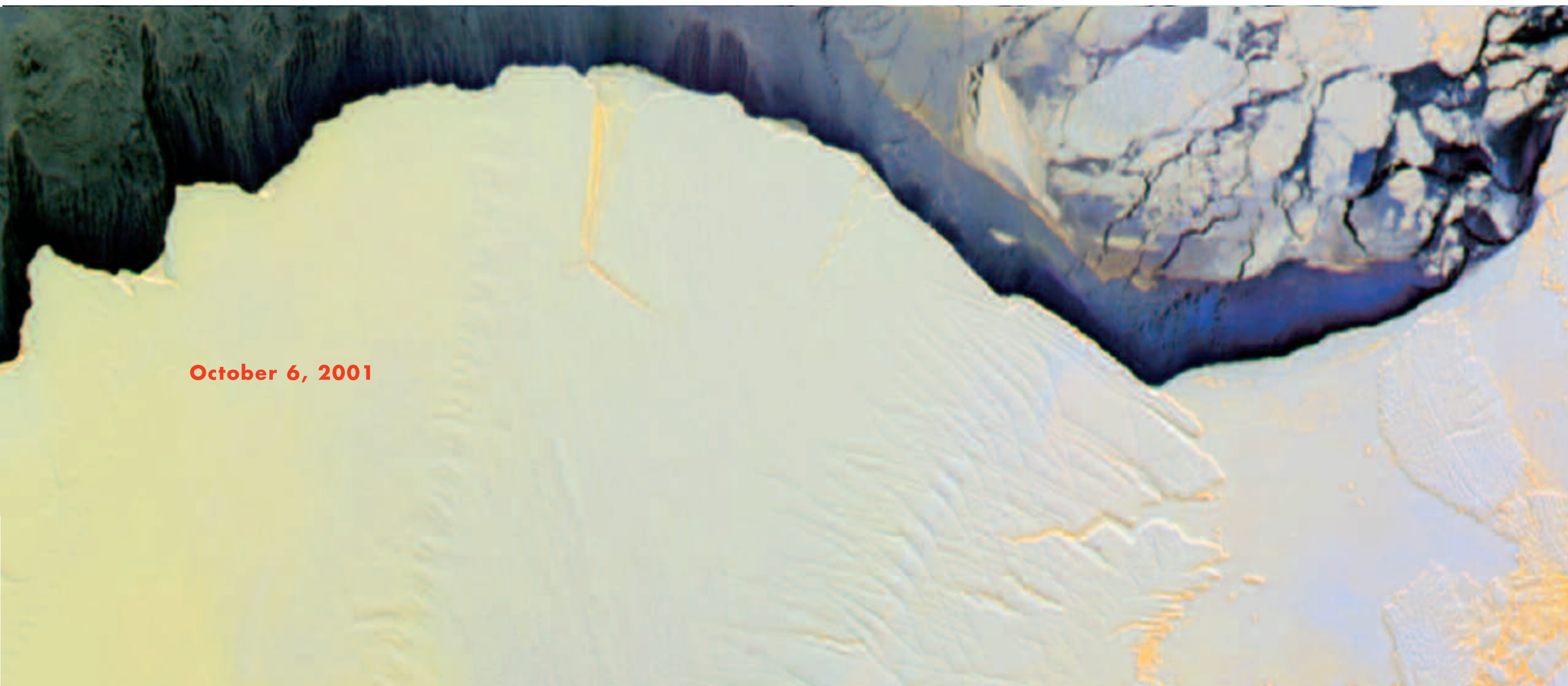
"The collapse of sections of the Larsen Ice Shelf is really a different phenomenon than what we are observing on the Amery Ice Shelf," Bassis said. "On the Larsen, researchers observed a whole series of cracks initiate and propagate over several summer seasons. The rifts on the Amery Ice Shelf have been propagating slowly for over a decade now. What we really don't know yet is if global warming can trigger the same kind of collapse on the Amery—or other ice shelves—as was observed on the Larsen."

Answers to unknowns like these will only come with time. The ground-based measurements made by the team on the 2002–03 and 2004–05 austral summer trips covered only 46- and 53-day periods, respectively. A long-term instrument presence at Loose Tooth remains an unmet need, but researchers consider it a worthy investment. Fricker and colleagues are proposing a coordinated international initiative establishing GPS and seismic stations at Loose



Tooth, with mirror campaigns on the larger Filchner–Ronne and Ross Ice Shelves, in 2007–08 to coincide with the International Polar Year, in a project they call "CRAC"—Collaborative Research into Antarctic Calving.

"Working out what happens in winter, when we currently have not had any observations, is really important," Fricker said. "We've been inferring what is happening during the winter months by interpolating what we observe during the austral summer. To be completely sure, we need to occupy the sites year-round."



October 6, 2001

September 30, 2004

Above, *Multiangle Imaging SpectroRadiometer satellite images show the progressing breakaway of the trapezoidal Loose Tooth from October 6, 2001 (top) to September 30, 2004 (bottom). The chunk could completely separate by the end of the decade, by which time researchers hope to have significantly improved their understanding of iceberg calving.*