1987—is a better survey instrument than ALMA, as it has a wider field of view.

Among the optical and infrared telescopes, the four newest and biggest—Keck I and Keck II, Japan's 8.3-meter Subaru Telescope, and the international 8.1-meter Gemini North Telescope—are vital, says Paul Schechter, an astronomer at the Massachusetts Institute of Technology in Cambridge. He served on a recent National Research Council panel that examined how to optimize the U.S. optical and infrared science program and says that the four instruments "are things that the people on our committee would be horrified to see shut down."

In principle, some of the smaller optical telescopes could go without damaging scientific capabilities, says Robert Lupton, an astronomer at Princeton University. "They could get down to below 10 [telescopes] with no loss to U.S. astronomy," he says. But shuttering the smaller observatories may prove difficult for political reasons.

Canadian researchers, for example, hope to replace the 3.6-meter Canada-France-Hawaii Telescope, built in 1979, with a 10-meter telescope in the same dome. UH is already upgrading its 2.2-meter telescope, built in 1970, with state-of-the-art robotic optics. Even the 3.8-meter United Kingdom Infrared Telescope, which the decommissioning report suggested closing, has advocates. It's a better survey telescope than some of the bigger instruments, Caltech's Hillenbrand says.

How researchers will decide which telescopes to kill remains to be determined—as does how those decisions will be enforced on various funding agencies and foreign partners. But removing the instruments will be expensive. Currently only the Caltech Submillimeter Observatory, a 10.4-meter dish built in 1987, is slated for decommissioning—at a cost that's not yet known. "You can guess that it's bigger than a million dollars and smaller than 10 million," Caltech's Golwala says. Decommissioning costs fall to a telescope's owner. ■

Ilima Loomis is a freelance journalist in Maui, Hawaii.

A crowded summit

A 2010 report suggests that one of the nine optical and infrared telescopes and some combination of three of the four radio telescopes on Mauna Kea could be removed (*) by 2033.

TELESCOPE	MIRROR DIAMETER (METERS)	OWNER	BUILT
OPTICAL/INFRARED			
UH Hilo Educational Telescope	0.9	University of Hawaii	2008
UH 2.2-meter Telescope	2.2	University of Hawaii	1970
NASA Infrared Telescope Facility	3.0	NASA	1979
Canada-France-Hawaii Telescope	3.6	France, Canada, University of Hawaii	1979
United Kingdom Infrared Telescope *	3.8	University of Hawaii	1979
Keck I	10	California Institute of Technology and University of California	1993
Keck II	10	California Institute of Technology and University of California	1996
Subaru Telescope	8.3	Japan	1999
Gemini North Telescope	8.1	International	1999
RADIO/MICROWAVE			
Caltech Submillimeter Observatory *	10.4	California Institute of Technology	1987
James Clerk Maxwell Telescope *	15	East Asian Observatory	1987
Submillimeter Array *	8 x 6	Smithsonian Astrophysical Observatory, Taiwan	2002
Very Long Baseline Array *	25	U.S. National Science Foundation	1992

DATA: OFFICE OF MAUNA KEA MANAGEMENT, UNIVERSITY OF HAWAII, HILO

GEOPHYSICS

Polar scientists to peer beneath largest ice shelf

Seafloor map would offer clues to the fate of Antarctica's Ross Ice Shelf

By **Eric Hand**

The Ross Ice Shelf, a thick, floating tongue of solid ice the size of Spain, is the biggest of the many such barriers that ring Antarctica and keep its ice sheets from sliding into the sea. Yet the shape of the sea floor beneath—a critical factor in how fast the shelf might melt—is virtually unknown. The ice keeps sonar-carrying ships out, and the water beneath it blocks radar. "It's the least known piece of ocean floor on our planet," says Robin Bell, a geophysicist at Columbia University's Lamont-Doherty Earth Observatory in Palisades, New York.

Now, Bell and colleagues plan to fill in the giant blank spot. They have recently received a grant to survey the shelf with an ultrasensitive airborne gravity detector. The sensor detects tiny changes in gravity: the boosts caused by the extra mass of seafloor hills and the decreases from troughs. After a test flight over the mountains of Vermont next month, her team plans to crisscross the Ross shelf in 36 flights over two 3-week-long campaigns, one in November and a second in 2016. They hope to map features as small as 50 meters tall—dramatically better than the present map, which scientists pieced together in the 1970s by setting off small explosions on the ice every 50 kilometers and recording the echoes.

Knowing the shape of the sea floor could give climate scientists important clues about how warm ocean water could melt the ice from below—a process with repercussions that could extend far beyond Antarctica. Floating ice does not affect global sea levels when it melts. But a thinned—or worse, collapsed—ice shelf could clear the way for more of Antarctica's continent-covering ice sheets to enter the ocean and push up sea levels. "Remove that plug, and the ice starts to flow faster," says Helen Fricker, a co-principal investigator for the survey and a glaciologist at the Scripps Institution of Oceanography in San Diego, California.

The Ross shelf, roughly 600 meters thick and sitting over about 200 meters of water, has been relatively stable in recent decades. But ice shelves can be capricious: On the Antarctic Peninsula, an area of the Larsen B shelf the size of Rhode Island collapsed in a matter of months in 2002. Fricker wants to gather baseline parameters before Ross suddenly changes. "We don't know for sure that the Ross shelf won't change in the next 15 years," she says.

Antarctica is ringed by the circumpolar current, which carries a deep slug of warm water clockwise around the continent, generally at a safe distance from ice shelves. According to a study published in *Science* last December (*Science*, 5 December 2014, p. 1227), the current has been warming since the 1970s and rising closer to the shelves, especially along the western peninsula of Antarctica. A new map could reveal whether that water has ready access to the underside of the Ross shelf. "Is there a deep pathway, a canyon, a valley that the water can run up like a road?" Bell asks.

At a finer scale, knowing how rough or smooth the sea floor is will help ocean modelers gauge the threat from turbulent eddies that could bring that warm water up to the ice's underbelly. The rougher the bottom, the more vigorous the eddies. The 1970s-era map suggests that the sea floor is relatively smooth. But Bell says that a test flight with an older gravity sensor last November already revealed surprising roughness, suggesting that mixing is underestimated.

In May, Bell's team received a $2.2 million commitment from the Gordon and Betty Moore Foundation to fly the new gravity sensor aboard four-engine C-130 cargo planes, which fly longer distances in more types of weather than the Twin Otter, a workhorse of polar research. The gravity meter will be sensitive to changes as small as a milligal, which is the difference in gravity between the bottom and the top of a 3-meter stepladder. Bell is now waiting on an additional $3.4 million from the National Science Foundation that she needs to embark on the campaign.

Gravity sensor being loaded into a C-130 cargo plane for a November 2014 test on the Ross Ice Shelf.

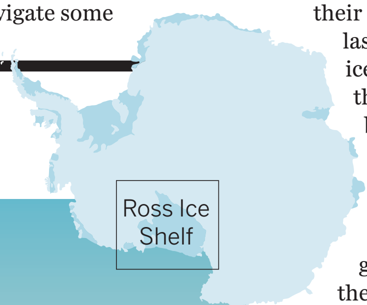
After demonstrating her instrument's capabilities at the Ross shelf, Bell hopes it will be used to probe the underpinnings of other shelves in Antarctica and Greenland. "The Ross is where I get people to go 'Wow,' " she says.

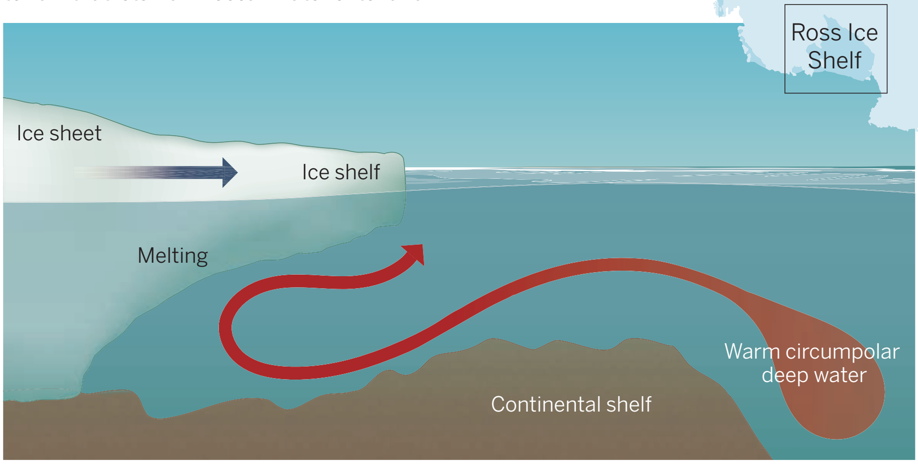
To wow her colleagues, however, she will have to navigate some pitfalls. The team has to compensate for any bumps during the flight, using GPS, an internal motion sensor, and a laser altimeter trained on the ice below. Even then, the variable density of seafloor rocks can make the gravity data hard to interpret. Keith Nicholls, a polar scientist at the British Antarctic Survey in Cambridge, U.K., says the soft sediments that cover the seafloor bedrock can change thickness drastically. "If you don't know your geology, you're stuffed," he says. Nicholls and his colleagues have used autonomous submersibles to map the seafloor geology beneath a few small ice shelves. But he says even their latest submersible, which could last for several months beneath the ice, would be hard-pressed to canvas the sea floor covered by a shelf as big as the Ross.

Douglas MacAyeal, a polar scientist at the University of Chicago in Illinois, is glad to see scientists returning to the Ross shelf. As a graduate student, he helped create the first map from 1972 to 1978. After hand-augering holes the width of a beer can and a few meters deep, he tamped down the explosive charges. He still recalls the whump of the ice-muffled detonations. In later decades, scientists concentrated on the land-based ice streams and ice sheets, he says, but now they're realizing that the fate of the land-based ice depends in large part on those floating fringes. "We have to go back," he says. "The limiting knowledge gap is no longer in the ice streams but is back again in the ice shelves." ■

Beneath the ice

By mapping the sea floor under ice shelves, scientists can identify terrain that lets warm ocean water enter and mix.





IMAGES: (TOP TO BOTTOM) ROBIN BELL; P. HUEY/*SCIENCE*