GLACIOLOGY

Water slide

Glaciologists have speculated that subglacial floods might lead to increased ice flow rates, altering Antarctica's mass balance and contribution to sea-level rise. Now, observations from Byrd Glacier in East Antarctica firmly link a subglacial flood to a 10% speed up of the glacier.

Helen Amanda Fricker
is at the Institute of Geophysics and Planetary Physics, Scripps Institution of Oceanography, La Jolla, California 92037, USA.
e-mail: hafricker@ucsd.edu

Subglacial floods in Antarctica were discovered only three years ago. Although it has long been accepted that lakes exist beneath the Antarctic ice sheet — the first subglacial lake was found in the 1950s[1] — the assumption that most lakes were stagnant persisted until 2005. Then a trio of studies using a variety of satellite data collectively showed that this was not the case[2–4]. In each instance, satellite data made it possible to identify the response of the ice surface to subglacial lake activity: lake filling caused the surface to rise and draining caused it to fall. Online on *Nature Geoscience* today, Leigh Stearns and colleagues[5] report a striking coincidence between both the beginning and end of a one-year acceleration in the ice velocity of Byrd Glacier and of a drainage event in two upstream subglacial lakes.

The subglacial environment is one of the least accessible places on Earth for data collection. The realization that satellite technology could provide information on subglacial hydrology by mapping the surface revolutionized a field that had traditionally relied on data from *in situ* and airborne radar sounding measurements. Surface deformation related to subglacial activity was first detected by satellite on Kamb Ice Stream, West Antarctica, using interferometric synthetic aperture radar (InSAR) data[2] and soon after using European remote-sensing (ERS) satellite radar altimeter (RA) data in Adventure Trench, East Antarctica[3]. But these techniques were limited by their temporal and spatial coverage, respectively. InSAR only provided a short time series and the ERS radar altimeter did not have the necessary coverage or performance: it only extends to 82.1° S and its performance is compromised over the rough surfaces of Antarctica's ice streams.

In January 2003, the Ice, Cloud and Land Elevation Satellite (ICESat) laser altimeter was launched, which was used to profile the ice stream surface and extended to 86° S. ICESat data showed an active subglacial system in Whillans, Mercer and MacAyeal ice streams, East Antarctica[4]. Together, these satellite studies reveal a complex, connected subglacial plumbing system in which water does not sit idle in one reservoir, but periodically cascades from one lake to the next one downstream in the chain, by means of outburst floods.

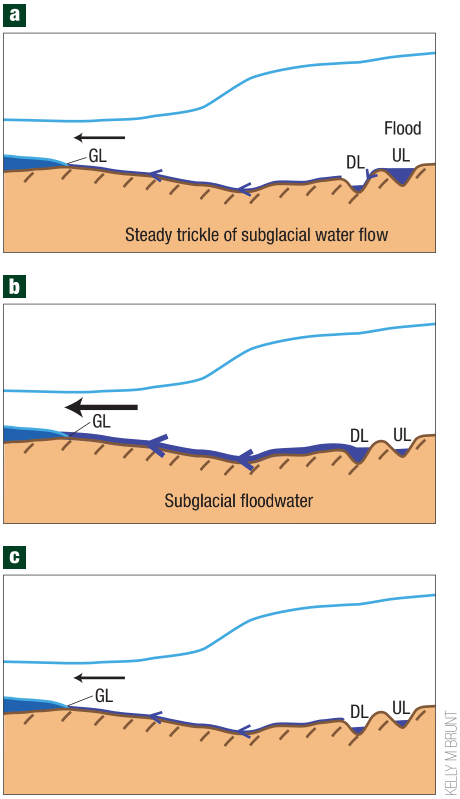

Figure 1 Subglacial flooding and ice dynamics at Byrd Glacier, East Antarctica. **a–c**, As shown by Stearns and colleagues[5], before December 2005 (**a**) a flood of subglacial water from the upstream lake (UL) to the downstream lake (DL) had started, but the only water under the glacier was a steady trickel of its own subglacially generated meltwater. Between December 2005 and February 2007 (**b**) the downstream lake expelled substantial amounts of water under the glacier, where it lubricated the bed and caused the glacier to speed up by 10%. After February 2007 (**c**) the flood ceased and the glacier speed returned to normal. GL is the grounding line where the glacier starts to float on the ocean.

Armed with new knowledge of Antarctica's plumbing system, glaciologists began to speculate whether lake flooding events under ice streams and outlet glaciers could drive changes in ice velocity. Progress in the three years since the first observation of subglacial outburst floods was considerable. In East Antarctica, lakes were discovered at the head of Recovery Ice Stream, suggesting that their presence might initiate streaming flow[6]: water acts as a lubricant, reducing friction at the base of the ice and making the ice flow faster.

Ice velocity in the outlet glaciers of the three ice sheets — Greenland, East Antarctica and West Antarctica — crucially affects sea level, because discharge of grounded ice directly adds mass to the ocean. In Greenland, researchers using GPS[7,8] and SAR[8] demonstrated a link between faster ice flow and subglacial water that reaches the glacier bed from surface melt ponds through 'moulins', special types of crevasses. The race was on to find evidence of ice speed-up that occurred simultaneously with an Antarctic lake drainage event, but available velocity measurements did not sample the same period of time as the satellite data that detected elevation changes.

Leigh Stearns and colleagues[5] now combine a 48-year ice velocity record from Byrd Glacier, East Antarctica with ICESat data from the same system just 200 km upstream of the site of the velocity measurements. They find that a period of increased ice flow that started in 2005 and lasted for more than one year coincides (within uncertainties due to the resolution of the two records) with the timing of a lake drainage event recorded by ICESat.

The Byrd Glacier has one of the largest catchments in Antarctica. In the 2005 lake flooding event detected by ICESat, 1.7 km^3

of floodwater rushed downstream, where its effect on the overlying ice was captured in the velocity record. The timing of the onset of speed-up matched that of the lake drainage and the slow-down coincided with the flood cessation. During the event, the ice velocity increased by 10% compared with the glacier's average speed during previous decades, and the high flow speed lasted for an incredible 14 months. The link between floods and ice flow has serious implications for Antarctica's ice-sheet mass balance: floods can modify the rate of delivery of mass (of solid ice) to the Southern Ocean. During the 2005 event, Byrd Glacier discharged around 8% more mass than normal, which will affect estimates of mass loss using flux methods[9].

Predicting the future behaviour of the Antarctic ice sheet, and its contribution to sea-level rise requires an improved treatment of its subglacial system in ice-sheet models. Unfortunately, the ICESat record is short (2003–2008) and we therefore do not know how frequently floods and related speed-up events occur. In addition, the temporal resolution of Stearns and colleagues' velocity time series is not sufficient to determine whether a speed-up had occurred before their reported 2005 event. More observations are needed to quantify the frequency of such events. ICESat-II, scheduled to launch around 2015 into a similar type of orbit as ICESat, will extend the length of the laser altimeter time series over the lakes. These observations, combined with coincident velocity measurements from other satellite missions (such as InSAR), should provide much needed information in understanding the subglacial system and the ice sheet's response.

ICESat has provided glaciologists with a new tool for surveying and monitoring the nature of the subglacial system; coincident observations of ice velocity allow us to link these observations to the motion of the ice sheet. Leigh Stearns and Ben Smith, who discovered the exciting link between their separate data sets of ice velocity and the 2005 lake drainage event in a coffee break at the 2007 Fall Meeting of the American Geophysical Union, have made excellent use of the available data. Their pivotal paper provides the piece in the water–iceflow puzzle that had been missing so far: direct evidence for glacier acceleration as a result of subglacial floods.

Published online: 16 November 2008.

References

1. Robin, G de Q. *Int. Ass. Sci. Hydrolog.* 86–97 (1970).
2. Gray. L. *et al. Geophys. Res. Lett.* **32,** doi: 10.1029/2004GL021387 (2005).
3. Wingham, D., Siegert, M., Shepherd, A. & Muir, A. *Nature* **440,** 1033–1036 (2006).
4. Fricker, H. A., Scambos, T., Bindschadler, R. & Padman, L. *Science* **315,** 1544–1548 (2007).
5. Stearns, L., Smith, B. & Hamilton, G. *Nature Geosci.* doi:10.1038/ngeo356 (2008).
6. Bell, R. E., Studinger, M., Shuman, C. A., Fahnestock, M. A. & Joughin, I. *Nature* **445,** 904–907 (2007).
7. Zwally, H. J. *et al. Science* **297,** 5579 (2002).
8. Joughin, I. *et al. Science* **320,** 5877 (2008).
9. Rignot, E. *et al. Nature Geosci.* **2,** 106–110 (2008).