



**Players.** These glaciers (*foreground*) are far smaller than the Greenland ice sheet (*background*) but they are wasting away relatively fast.

GLACIOLOGY

## Melting Glaciers, Not Just Ice Sheets, Stoking Sea-Level Rise

Glaciologists trekking onto remote, inhospitable streams of flowing ice year after year, decade after decade, brought back some especially bad news early in the last decade. The world's glaciers have been shrinking frighteningly fast, so fast that their melting was pushing up sea level far faster than the shrinking ice sheets of Greenland and Antarctica. But then 21st century monitoring from space began to show a much smaller role for glacial ice loss in sea-level rise. Which to believe?

A new study brings together both boots-on-the-ice and high-tech glaciologists. The study has found that, although the field measurements were painting an accurate picture of the few glaciers being monitored, they were not representative of the world's glaciers. All 19 glacierized regions of the world are losing ice, the study finds, but the iconic glaciers long-studied by field glaciologists are disappearing faster than most. Still, the world's glaciers are losing ice just as fast as the great ice sheets.

"I think there really was a consensus" among the diverse study authors, says J. Graham Cogley of Trent University in Peterborough, Canada, one of the 16 authors on the study. Even after he had spent 20 years compiling field observations that proved to be unrepresentative, Cogley thinks that the group managed to reconcile the conflicting estimates.

The trick to reconciling disparate gauges of ice loss proved to be comparing apples with apples. Before, it was mostly apples and oranges. Field glaciologists had driven poles

vertically into some 300 glaciers out of the world's 160,000 and returned year after year for decades to measure how much more of a pole had been exposed as warming removed ice. Then, they extrapolated the results to the globe as a whole by assuming that the unmeasured glaciers were behaving the same way.

In contrast, a satellite study, which started only in 2003, took a less detailed but global approach. Together, the two satellites of the Gravity Recovery and Climate Experiment (GRACE) measured the minuscule changes of gravity as ice melted away beneath them. GRACE couldn't "see" most individual glaciers, much less the detailed changes revealed by the widely scattered rod surveys, but it surveyed all 734,400 square kilometers of the 19 glacierized regions. And it found far less glacial ice being lost than the field glaciologists had.

To reconcile the difference between gravity-determined and field-determined ice losses, glaciologist Alex Gardner of Clark University in Worcester, Massachusetts, and colleagues put all the data on an equal footing. They compared the most refined versions of GRACE and field data for the same regions over the same period, 2003 to 2009. They then compared them with glacier changes gauged by the orbiting Ice, Cloud, and land Elevation Satellite, another global surveyor that uses a laser to measure changing ice height and therefore volume.

Within the uncertainties, the three gauging techniques agreed wherever they could be compared. Some glaciers might not be

reached a result so different from conclusions based on traditional field methods. Ground-based glaciologists may not agree at first, he adds, but "over time, I think there will be greater unanimity."

No one quite knows why fieldwork gave larger losses. "I'm inclined to attribute it to bad luck," Cogley says. The glaciers that were accessible and small enough to manage with the available resources turned out to be more vulnerable to warming, he says. Ivins speculates that the hardest glaciers for glaciologists to reach—the most remote, the highest, the coldest, the windiest, those in the roughest terrain—may be more stable in the face of warming.

Space-based ice monitoring may have scaled back the looming disaster among the world's glaciers, but it isn't making it go away. The closely watched glaciers visibly shrinking from year to year will not slow their retreat as the world warms further. Water supply problems—farmers losing meltwater in streams and rivers in the hot, dry summer months—will only get worse. And glaciers will be helping drive up sea level through the end of the century and a bit beyond. But with all glacierized regions losing ice in the present climate and more warming expected, Gardner says, all but the most resilient glaciers are likely to disappear within the millennium. Some glaciers in the Arctic and Antarctic might last that long, but particularly vulnerable regions like the Alps will likely see most of their glaciers disappear by the end of the century.

—RICHARD A. KERR