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During recent ice ages, glaciers expanded from the poles and covered nearly a third of the continents. And in the distant past there were episodes known as Snowball Earth, when the entire planet froze over. At the other extreme, a warm period near the end of the age of dinosaurs may have left the earth ice-free. Today the amount of ice is modest — 10 percent of land areas, nearly all of that in Greenland and Antarctica.

Glaciers are, simply, rivers of ice formed from snow in regions that are frozen year-round. The snow compacts over time into granular, porous ice, which glaciologists call firn. When firn compacts even more, it becomes glacier ice, which flows, usually slowly, down mountainsides. Depending on how fast new snow accumulates at the top, or melts at the bottom, a glacier grows or shrinks in length and thickness.

Not long ago, the only way to measure glaciers was to put stakes in the ice. Using surveying tools, glaciologists would mark the location and return later to see how far the ice had moved. The method gave scientists a sense of only the areas measured during that study period. “We had these point measurements which were very labor-intensive,” said Tad Pfeffer, a glaciologist at the University of Colorado.

Today, satellites provide a global view. Images show where the glaciers are and how areas change over the years. Most useful has been NASA’s Gravity Recovery and Climate Experiment, or Grace. Two identical spacecraft have been measuring the earth’s gravity. When glaciers melt, the water flows elsewhere, and that part of the planet weighs less, slightly weakening its gravitational pull. Grace isn’t precise enough to measure the mass changes in an individual glacier, but it does provide data on regional shifts.

Another NASA satellite, IceSat, bounced lasers off the ice to precisely measure glaciers’ height. (In operation from 2003 through 2009, when the last of its lasers stopped working, it is scheduled to be replaced by IceSat-2 in 2017.)

In an analysis last year of the satellite and ground measurements, a team of scientists led by Alex S. Gardner, an earth scientist at Clark University in Worcester, Mass., who is moving to NASA’s Jet Propulsion Laboratory, concluded that, on average, glaciers in all regions were withering away, dumping 260 billion metric tons of water into the ocean every year.

"I can't think of any major glacier region that's growing right now," Dr. Scambos said. "Almost everywhere we look we're seeing mass loss."

The melting from the mountain glaciers alone raises sea level about 0.7 millimeters a year.

The ice sheets of Antarctica and Greenland together possess about 100 times as much ice as all of the mountain glaciers combined, but contribute only slightly more to the sea level rise: 310 billion tons a year, Dr. Scambos said. That is because most of the mountain glaciers lie in areas where temperatures are closer to the melting point than they are in Greenland or Antarctica, and so slight warming tips them to melting.

Greenland, with 10 percent of the world's ice, has enough to raise sea level by 23 feet. "I still think Greenland is the most important thing to watch for this century," Dr. Scambos said.

In 2012, when summer Arctic temperatures were particularly warm, surface melting was observed almost everywhere on Greenland's glaciers, even in the mountains. That had not happened for decades.

Researchers from Dartmouth found that another side effect from global warming, forest fires, made the melting even worse. Soot from fires elsewhere in the world landed on Greenland snow, making it darker, causing it to absorb more heat.

A new study of Greenland, published Sunday in the journal Nature Geoscience, paints an even bleaker picture. The melting is accelerated because many of the glaciers flow in the warming waters around Greenland. However, scientists had believed that the melting would slow once the bottom of the glaciers melted and they were no longer touching the water.

The new research indicates otherwise. Researchers at the University of California, Irvine, including Eric Rignot, the lead author of one of last week's papers concluding that the melt in West Antarctica is irreversible, discovered long, deep canyons below sea level and under the ice sheet. So even as the glaciers retreat, they will still be in contact with the encroaching warm water, and as a result, more ice will melt. "They will contribute more to sea level rise," said Mathieu Morlighem, lead author of the Nature Geoscience paper.

Antarctica is the largest frozen mass on the planet, accounting for about 90 percent of the earth's ice. Most of it is in East Antarctica, which is generally higher

and colder and less likely to melt. By some estimates global warming is leading to increased snowfall there, which is limiting the loss. But as in West Antarctica, some of the ice resides in bowl-shape depressions, which are similarly vulnerable to melting.

Over all, data from the European Space Agency's CryoSat satellite, published on Monday, indicates that the continent shed 160 billion tons a year from 2010 to 2013.

Scientists say that the melting will continue as long as the heat-trapping carbon dioxide in the atmosphere increases. Even if carbon dioxide and temperatures stabilize, the melting and shifting of glaciers will continue for decades or centuries as they adjust to the new equilibrium.

But a vast majority of the ice is not yet destined to melt. "We have not committed to a lot more that could be committed if we keep turning up the thermostat," said Dr. Alley of Penn State.

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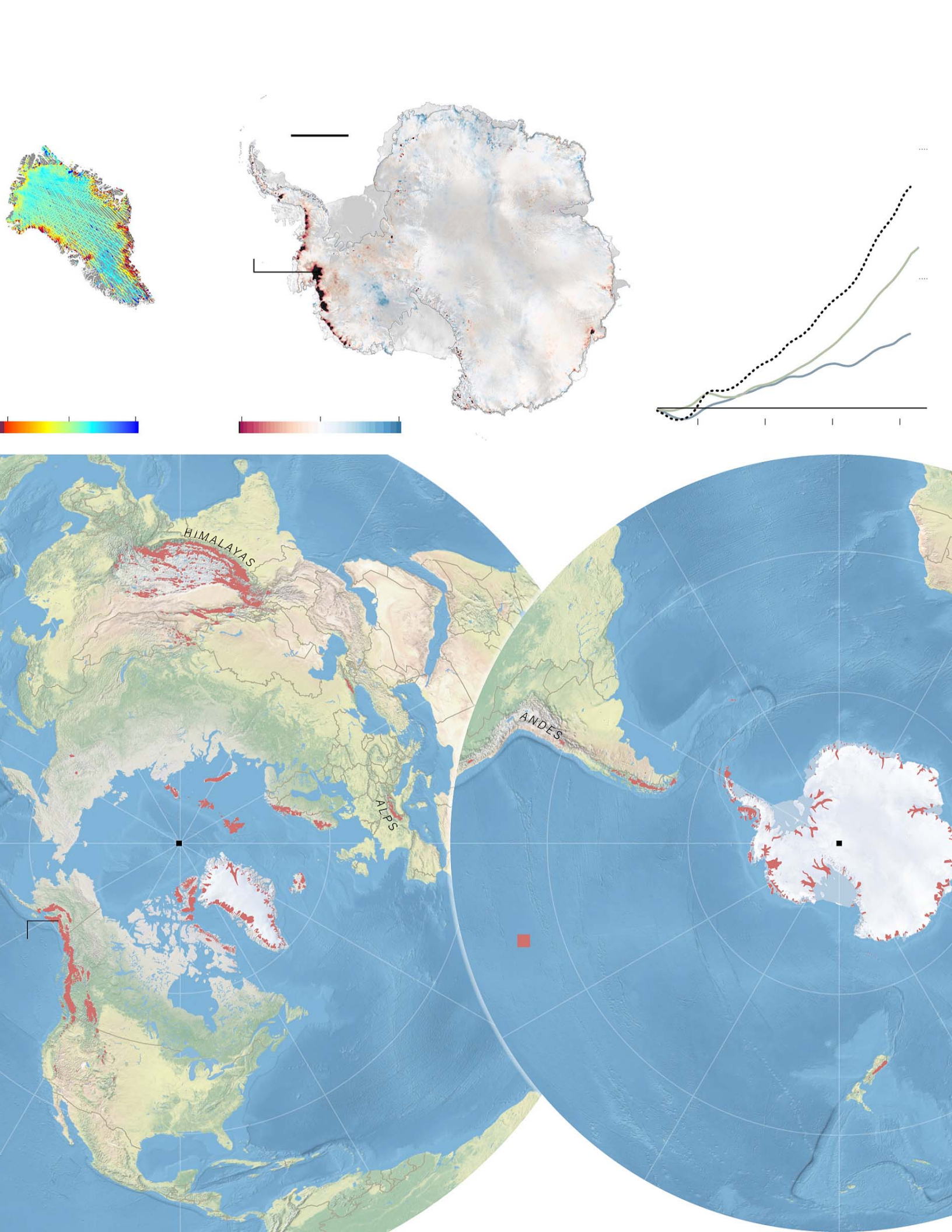
Muir Glacier at Glacier Bay National Park and Preserve in Alaska is among the many worldwide that are disappearing. Muir, left, as seen in August 1941, and photographed in August 2004. Credit W. Field; B. Molnia/ U.S.G.S., via Glacier Photograph Collection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