



## **Land Ice: Why is it receding in some places but not in others and what are the projected impacts?**

### What is meant by land ice?

Land ice can be divided into two categories: (1) glaciers -- both mountain glaciers in the interior of landmasses, such as the glaciers of the Alps, Himalayas, Rocky Mountains, and Andes, and coastal or outlet glaciers, such as those along the coasts of Norway, Alaska, Greenland, and Antarctica -- and (2) the massive ice sheets that cover Greenland and Antarctica.

### Why should policymakers care about whether land ice is growing or retreating?

(1) Loss of land ice directly causes sea level to rise, which endangers coastal areas and their populations, development/infrastructure, and fisheries. (2) As land ice melts, the white surfaces of the Earth (which reflect much of the sun's energy back into space) decrease in area, exposing the darker surface of the land (which absorbs more energy) and leading to further increase in global temperatures. (3) The runoff from melting glaciers contributes water for drinking, agriculture, and hydropower, but as the glaciers recede, this source will disappear. (4) In some cases, permafrost (frozen soil) may be exposed and begin to thaw, releasing methane to the atmosphere. This increase would have a positive feedback through its contribution to warming of the atmosphere, and, thus, lead to even more melting of ice.

### How does melting land ice affect sea level?

There are two major contributors to sea-level change: (1) an increase in the mass of the ocean by the addition of water from the land and (2) a change in the volume of the ocean through the addition or subtraction (loss) of heat, making the ocean less or more dense.

Melting land ice (from all sources) that ends up in the ocean and/or ice breaking off (calving) from coastal glaciers contribute to an increase in ocean mass (and, thus, also to the volume). This is in contrast to floating sea ice that does not contribute additional mass to the ocean when it melts (Archimedes' principle).

### What causes mountain glaciers to melt or grow, and what are the impacts?

Glaciers melt or grow for three reasons: changes in the hydrological cycle (where, when, and how much rain/snow falls), soot pollution<sup>1</sup>, and atmospheric temperatures.

Glaciers diminish or grow based on the difference between the amount of snow that accumulates and the amount of ice that melts. If more snow falls in the winter than is offset by

ice melting in the summer, then glaciers grow. Changes in the hydrological cycle are observed, for example, in the Karakoram region of the Himalayas where, it is thought, added moisture (more snow) in the region has increased the size of the glaciers.<sup>2</sup> This is in contrast to most of the world's glaciers, which are shrinking. In a study of mountain glacier shrinkage using 10 climate models, the authors predict that atmospheric warming will cause a total glacier volume reduction of about 21% by 2100.<sup>3</sup>

Soot on the surface increases the amount of heat that can be absorbed by the-ice, causing an increase in melting over conditions with no soot. It is unknown how much melting is attributable to present-day soot.

Glacier melting contributed about 29% (~0.71 mm/yr) to the rise in sea level between 2003 and 2009 and may contribute 12 cm by 2100 (or ~1.2 mm/yr).<sup>4</sup> The 5<sup>th</sup> IPCC Assessment (September 2013) states: "Rate of ice loss of glaciers has *very likely* increased in the period 1993-2009," and "*Very high confidence* that the extent of Northern Hemisphere snow cover has decreased from 1967-2012".<sup>5</sup>

#### What causes melting or growth of coastal or outlet glaciers?

In addition to changes related to the hydrologic cycle and atmospheric warming, the melting and eroding of outlet glaciers surrounding coastal areas such as Antarctica, Greenland, and Alaska are thought to be caused by warm ocean water in contact with the coastal glaciers. An example is the Jakobshavn Glacier on Greenland.<sup>6</sup>

The warming of the ocean is caused by both natural multi-decadal variability and a long-term increase in the North Atlantic's upper ocean heat content.<sup>7</sup> The melting around Antarctica is due, in large part, to changing ocean circulation and a warmer ocean,<sup>8</sup> rather than a warming atmosphere.<sup>9</sup>

#### What about the ice sheets covering Antarctica and Greenland?

The combined contribution from Antarctic and Greenland ice sheets to the increase in sea level presently is on the same order as that from glaciers -- about 30%. Greenland is contributing about 70% (21% of total sea level rise) of the melt water coming from ice sheets, with the rest coming from West Antarctica and the Antarctic Peninsula (the area south of South America).<sup>10</sup> If all of the Greenland ice sheet were to melt, the sea would rise about 6 meters (20 feet), while melting all of the Antarctic ice sheet would result in a rise of sea level by about 60 meters (196 feet).

The Antarctic Peninsula is warming as a result of stronger winds whereas cooling occurs over Eastern Antarctica and the Antarctic plateau. Additionally, the bedrock of the western area of the continent is much lower than in the east. This results in more ice melting due to ocean currents. The Southern Ocean (the name of the circumpolar ocean south of about 60° S), through the absorption of heat from the atmosphere, is thought to have reduced the level of atmospheric warming in the Southern Hemisphere.<sup>11</sup>

The 5<sup>th</sup> IPCC Assessment (Sept. 2013) states: "Rate of ice loss from Greenland ice sheet has *very likely* substantially increased between 2002-2011," and "Rate of ice losses from Antarctic

ice sheet has come mainly from northern Antarctic Peninsula and Amundsen Sea Sector of West Antarctica (*very high confidence*).<sup>12</sup>

### Why are there differences in how the ice melts or grows in different areas?

Weather and climate are different in the Northern and Southern Hemispheres due to the differences in the distribution of land and ocean. In the Northern Hemisphere, the westerly winds are generally weakening (slower), while, in contrast, they are strengthening (stronger and faster) in the Southern Hemisphere. This leads to differences in how moisture is transported through the atmosphere.

Warming has thus far been mostly in the high-to-mid latitudes of the Northern Hemisphere, the interior of several continents, and the northernmost reaches of the Antarctic. The warming trend in the high latitudes of the Northern Hemisphere is greater than in the Southern Hemisphere.<sup>13</sup>

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<sup>1</sup> Painter, T. H., M. G. Flanner, G. Kaser, B. Marzeion, R. A. VanCuren, and W. Abdalati (2013), End of the Little Ice Age in the Alps forced by industrial black carbon, *Proc. Natl. Acad. Sci.*, doi: 10.1073/pnas.1302570110

<sup>2</sup> Gardelle, J., Berthier, E. and Arnaud, Y. 2012. Slight mass gain of Karakoram glaciers in the early twenty-first century. *Nature Geoscience* 5: 322-325

<sup>3</sup> Radić, V., and R. Hock. 2011. Regionally differentiated contribution of mountain glaciers and ice caps to future sea-level rise. *Nature Geoscience* 4(2):91–94, doi:10.1038/ngeo1052

<sup>4</sup> R., and Paul, F., A Reconciled Estimate of Glacier Contributions to Sea Level Rise: 2003 to 2009, *Science* 17 May 2013: 852-857.

<sup>5</sup> IPCC, 2013: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, in press.

<sup>6</sup> Joughin, I., Abdalati, W., Fahnestock, M. 2004., Large fluctuations in speed on Greenland's Jakobshavn Isbræ glacier *Nature* 432, 608-610, doi:10.1038/nature03130;

<sup>7</sup> Straneo, F. and Heimbach, P. 2013 North Atlantic warming and the retreat of Greenland's outlet glaciers, *Nature* 504, 36–43, doi:10.1038/nature12854

<sup>8</sup> Stanton, T.P., Shaw, W.J., Truffer, Corr, J.H.F., Peters, L.E., Riverman, K. L., Bindschadler, R., Holland, D. M., and Anandakrishnan, S. 2013, Channelized ice melting in the ocean boundary layer beneath Pine Island Glacier, Antarctica. *Science*, 341(6151):1236–1239, 2013.

<sup>9</sup> Thompson DWJ, Solomon S. 2002. Interpretation of recent Southern Hemisphere climate change. *Science* 296 5569: 895-899.

<sup>10</sup> Hanna, E., et al. (2011), Greenland Ice Sheet surface mass balance 1870 to 2010 based on Twentieth Century Reanalysis, and links with global climate forcing, *J. Geophys. Res.*, doi:10.1029/2011JD01638

<sup>11</sup> Ibid.[8]

<sup>12</sup> Ibid.[5]

<sup>13</sup> <http://earthobservatory.nasa.gov/Features/WorldOfChange/decadaltemp.php>