Arctic Land Ice is Decreasing

THE ISSUE. The Greenland Ice Sheet and the glacier-covered areas of Alaska and other Arctic lands are losing ice at an accelerating rate, contributing billions of tons to sea level rise.

WHY IT MATTERS. Ice loss from the ice sheets contributes directly to sea level rise. Moreover, these losses are likely to increase rapidly as warming in the Arctic continues. Surface melt is now increasing more quickly than all other factors driving Greenland's ice loss, although faster glacier flow remains important. Increased ice loss from Alaska's glaciers is also due mainly to surface melting[1]. Given these trends, and the trend toward rapid warming in the Arctic (at twice the global rate of warming), the Arctic is poised to lose more ice and add to sea level.

STATE OF THE SCIENCE. Since 2000, the net loss of ice from the Greenland ice sheet has increased five-fold, from 50 billion to nearly 270 billion tons per year[2-4] (362 billion tons is equal to 1 mm in sea level rise). Ice losses in the Gulf of Alaska region have risen from about 40 to 70 billion tons per year[5-6]. These trends are confirmed by three independent satellite methods, using gravitational changes, elevation changes, and changes in the mass budget (the net difference between snowfall and the combination of glacier outflow and runoff)[2].

In total, the Arctic currently contributes approximately 350 billion tons (approximately 1 mm) to sea level each year, primarily from Greenland, Alaska, and Arctic Canada. Recent measurements of the rate of sea level rise are 3.0 mm per year[7].

Slightly cooler summer seasons for Greenland in 2013 and 2014 reduced the rate of ice loss there[3], but strong melting in 2015, and the current trend of 2016 melting, are again contributing large amounts of runoff[8,9]. Because of its closer tie to seasonal weather conditions, surface melt is more variable than ice loss due to increased glacier outflow.

The trend over the past 10 years toward increased ice loss in Greenland is primarily due to increased surface melting[9]. As spring and summer temperatures have increased, net runoff of meltwater has grown dramatically. Ice loss due to faster glacier flow has remained stable overall and is unlikely to accelerate as rapidly as melting because of the stiffness of ice. The current surface melt runoff is two to three times the loss due to increased ice flow speed. As intense summer melt seasons like 2012, 2015, and 2016 become more common, further increases in melt runoff are inevitable.

WHERE THE SCIENCE IS HEADED. The major factor driving changes in surface melting of Arctic land ice, besides increasing temperatures, is a decrease in reflectivity of surface snow[8,10,11], which in turn is caused by the aging of snow under warm conditions and the concentration of impurities at the surface. Subtle variations in the reflectivity of snow have a very large impact on the energy absorbed by the surface. With clean dry snow having a reflectance of 90% or more, a 10% decrease in reflectivity doubles the amount of energy absorbed. Satellite monitoring of reflectivity in Greenland shows that the surface in summer is now several percent darker than at the beginning of the century[10,11]. This is thought to be due to concentration of the impurities such as soot and dust on the surface by melting, and by higher temperatures directly. A warmer summer and longer surface melt season darkens the Greenland ice sheet by coarsening the snow, and exposing old snow and bare ice. All these surface types are much darker than fresh powder. Large reflectivity changes in

Alaska, for example from volcanic ash, can lead to large one-year increases in ice mass loss[5], but in general the concentrations of contaminants in Alaskan snow are small, and the main cause of ice loss is warmer temperatures[1].

For glacier flow, the main driver is the effect of increased delivery of 'warm' ocean water (a few degrees above freezing) to glaciers that reach the ocean. Understanding interactions between a glacier ice front and the ocean are a major focus for predicting changes in flow rates for Greenland's glaciers. Ocean water temperatures at depths of a few hundred feet below the surface are rising. Pulses of this mid-level water reaching the glacier front, or the cavity beneath a floating glacier, have caused rapid glacier retreats and flow speed increases that have lasted a decade or more[12]. This environment is hard to observe, because the presence of large jostling blocks of ice is extremely destructive for instrumentation. Both NSF and NASA researchers are developing technologies to explore this environment and establish a monitoring program for the major glacier outlets.

Key References

1. Larsen, C.F., E. Burgess, A. Arendt, S. O'Neel, A. Johnson, C. Kienholz, 2015. Surface melt dominates Alaska glacier mass balance. Geophysical Research Letters, 42, 5902-5908, doi: 10.1002/2015GL064349.
2. Shepherd, A., E.R. Ivins, and 45 others, 2012. A reconciled estimate of ice-sheet mass balance. Science, 338(6111), pp.1183-1189, doi: 10. .1126/science.1228102.
3. Harig, C., and F. Simons, 2016. Ice mass loss in Greenland, the Gulf of Alaska, and the Canadian Archipelago: seasonal cycles and decadal trends. Geophys. Res. Lett., 43, 3150-3159, doi:10.1002/2016GL067759.
4. McMillan, M., A. Leeson, A. Shepherd, and 14 others, 2016 *in press*. A high resolution record of Greenland mass balance. Geophys. Res. Lett., doi: 10.1002/GRL.54619.
5. Arendt, A., S. Luthcke, A. Gardner, S. O'Neel, D. Hill, G. Moholdt, and W. Abdalati, 2013. Analysis of a GRACE global mascon solution for Gulf of Alaska glaciers, J. Glaciol., 59(217), 913–924, doi:10.3189/2013JoG12J197.
6. Gardner, A.S., G. Moholdt, and 9 others, 2013. A reconciled estimate of glacier contributions to sea level rise: 2003 to 2009. science, 340(6134), pp.852-857.
7. Hay, C.C., E. Morrow, R.E. Kopp, and J.X. Mitrovica, 2015. Probabilistic reanalysis of twentieth-century sea-level rise. Nature, 517(7535), pp.481-484, doi:10.1038/nature14093.
8. NSIDC, updated 2016. Greenland Today, http://nsidc.org/greenland-today/ and references therein.
9. van den Broeke, M., J. Bamber, J. Ettema, E. Rignot, E. Schrama, W.J. van de Berg, E. van Meijgaard, I. Velicogna, and B. Wouters, 2009. Partitioning recent Greenland mass loss. science, 326(5955), pp.984-986.
10. Tedesco, M., S. Doherty, X. Fettweis, P. Alexander, J. Jeyaratnam, and J. Stroeve, 2016. The darkening of the Greenland ice sheet: trends, drivers, and projections (1981–2100). The Cryosphere, 10, 477-496, doi: 10.5194/tcd-9-5595-2015.
11. Box, J.E., X. Fettweis, J.C. Stroeve, M. Tedesco, D.K. Hall, and K. Steffen, 2012. Greenland ice sheet albedo feedback: thermodynamics and atmospheric drivers. The Cryosphere, 821-839 doi: doi:10.5194/tc-6-821-2012
12. Straneo, F., G.S. Hamilton, D.A. Sutherland, L.A. Stearns, F. Davidson, M.O. Hammill, G.B. Stenson, and A. Rosing-Asvid, 2010. Rapid circulation of warm subtropical waters in a major glacial fjord in East Greenland. Nature Geoscience, 3(3), pp.182-186, doi:10.1038/ngeo764.

The Study of Environmental Arctic Change (SEARCH)
Advancing and communicating scientific understanding to help society respond to a rapidly changing Arctic.

https://www.arcus.org/search-program

Contacts for further information:

Ted Scambos, National Snow and Ice Data Center
teds@nsidc.org

Fiamma Straneo, Woods Hole Oceanographic Institution
fstraneo@whoi.edu

Marco Tedesco, Columbia University
mtedesco@ldeo.columbia.edu

SEARCH activities are supported by a collaborative grant from the National Science Foundation to the International Arctic Research Center (PLR-1331100) and the Arctic Research Consortium of the U.S. (PLR-1331083).